SEL-TWFL

Dual Traveling-Wave Fault Locator and 12-Channel MHz Recorder

Instruction Manual

20240213
Firmware R100

SEL SCHWEITZER ENGINEERING LABORATORIES

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Preface

Overview

This instruction manual provides information and instructions for evaluating, applying, configuring, installing, testing, commissioning, and maintaining the SEL-TWFL device. It is intended for personnel responsible for evaluation and certification of fault locators, engineers designing utility-specific application standards, engineers applying an SEL-TWFL to specific lines, panel designers, technicians, and communications and integration engineers. Included are detailed technical descriptions of fault locating and line monitoring, supervisory and triggering elements, transient and sequential events recording, timekeeping, supervisory control and data acquisition (SCADA), and HMI protocols. The manual also provides settings guidelines, discusses application considerations, and includes recommendations for testing and commissioning of the traveling-wave-based functions.

An overview of each manual section follows.

Section 1: Introduction and Specifications. Introduces the SEL-TWFL and provides a high-level overview of its functions; summarizes fault-locating and line monitoring functions, applications, and benefits; and lists device specifications and ratings as well as type tests and standard compliance information. This section is intended for all users, including procurement and business personnel.

Section 2: Fault Locator and Line Monitor. Explains the fault-locating functionality of the SEL-TWFL including single- and multi-ended, traveling-wave- and impedance-based methods. This section provides information pertaining to configuring, testing, and understanding the results and accuracy of the SEL-TWFL fault-locating functions. This section also provides information related to the line monitor feature for detecting, tabulating, and alarming on low-energy disturbances and recurring faults on the line to improve line maintenance and reduce the number of line faults. This section is intended for utility personnel responsible for deploying fault locators and integrating fault-location results into SCADA/HMI software and databases.

Section 3: Digital I/O and Communications Ports. Explains contact and communications-based I/O capabilities of SEL-TWFL devices and provides information on how to configure, apply, test, and troubleshoot communications channels. The section includes application examples for two- and three-terminal lines that use MIRRORED BITS communications to trigger fault locating and recording. This section is intended for engineers responsible for evaluating and setting the devices, utility communications engineers responsible for configuring and maintaining analog and digital interstation communications channels, and for testing and commissioning personnel responsible for developing test plans and for testing these devices and communications channels in the field.

Section 4: Triggering and Supervisory Elements. Provides detailed descriptions of the elements used to trigger the recording functions and the elements used to supervise the fault-locating and line monitoring functions. The triggering elements include overcurrent, undervoltage, and overvoltage elements. The supervisory elements include disturbance detectors,

loss-of-potential logic, and fault-type identification logic. For each element, the section provides a brief overview; logic diagrams suitable for application engineers and for testing and commissioning personnel; a complete list of settings including their names, descriptions, ranges, and default values; and a complete list of binary outputs (Relay Word bits) that the elements drive. This section also describes user-programmable logic (SELOGIC). This section is intended for engineers responsible for evaluating and setting the SEL-TWFL and for testing and commissioning personnel responsible for developing test plans and testing the devices in the field.

Section 5: Transient and Sequential Events Recording. Explains the recording functionality of the SEL-TWFL including 1 Msps transient records of input currents and voltages, 10 ksps transient records of input currents and voltages and derived signals, the Sequential Events Recorder (SER) record, and various operational and diagnostic records. This section explains information contained in the records, how to configure SEL-TWFL recording functions, how to retrieve record files from the device, and how to interpret records. This section is intended for engineers responsible for configuring fault recordings in SEL-TWFL devices and analyzing fault records, asset management personnel using SEL-TWFL high-resolution recording functions, and integration engineers responsible for retrieving, parsing, and presenting various records from the device.

Section 6: Application Examples. Provides notes and examples related to applications of the SEL-TWFL, including two-terminal, three-terminal, and dual two-terminal overhead lines and two-terminal hybrid lines comprising overhead and cable sections. These applications use IEEE C37.94-compliant multiplexed channels for device-to-device communications and IEEE C37.118-compliant GPS clocks to obtain an absolute time reference via the IRIG-B input. The section also includes a two-terminal line application that uses the DNP3 protocol over Ethernet to send traveling-wave arrival times to a central location where a DNP3 client calculates the TW-based fault location.

Section 7: Engineering and Operator Access Interfaces and Tools. Provides information pertaining to human operators, including information on how to install and use ACSELERATOR QuickSet SEL-5030 Software and the SEL command line interface language to configure, manage, and test the device; how to prepare a PC for communication with the device; and how to configure it for communication over an Ethernet network. This section provides detailed information on how to interface with the device by using the front-panel HMI and how to interpret the front-panel indicators and target LEDs. This section is intended for engineers and technicians who create device settings files, configure and test devices in the field, or otherwise work with physical devices via communications ports or the front-panel HMI. This section is also helpful for integration engineers and product evaluation personnel because it explains how to establish communication with the device and how to use engineering access tools.

Section 8: SCADA and HMI Protocols. Describes the communications protocols of the device and how to integrate the SEL-TWFL into a SCADA/HMI system. It is intended for integration engineers and technicians.

Section 9: Installation. Provides information pertaining to physical device installation, including mounting the device chassis in a panel or rack, making rear-panel connections (including wiring to CTs, PTs, contact I/O, and an IRIG-B time source), connecting communications media to

the device, setting internal jumpers for emergency password override, and inspecting the device. This section is intended for panel designers, engineers responsible for designing ac and dc circuits, and technicians mounting, wiring, inspecting, and checking new SEL-TWFL devices.

Section 10: Testing and Commissioning. Provides recommendations on how to test and commission the SEL-TWFL traveling-wave-based functions, including measuring the traveling-wave line propagation time during commissioning. This section is intended for engineers responsible for developing test plans and technicians responsible for testing, commissioning, and troubleshooting fault locators in the field.

In addition, this instruction manual includes appendices containing reference information or step-by-step instructions, as follows.

Appendix A: Firmware and Manual Versions. Lists the current firmware versions and details differences between the current and previous versions.

Appendix B: Firmware Upgrade Instructions. Describes step-by-step instructions on how to upgrade SEL-TWFL firmware.

Appendix C: SEL ASCII Commands. Provides an overview of SEL ASCII commands. This appendix also includes a reference table associating the commands with typical engineering tasks.

Appendix D: Relay Word Bits. Lists all Relay Word bits in alphabetical order.

Appendix E: Analog Quantities. Contains a summary of analog quantities that are available in various SEL-TWFL records and accessible by using communications protocols.

Appendix F: Diagnostics. Explains device diagnostics and self-tests and offers troubleshooting guidelines and instructions.

Appendix G: Signal Processing and Operating Principles. Explains the device data acquisition and signal processing including sampling and processing rates, signal scaling, and measuring incremental quantities, traveling waves, phasors, and frequency. The appendix explains the line monitoring principle of operation and lists the signals included in the MHR and TDR IEEE COMTRADE records.

Appendix H: High-Accuracy Timekeeping. Explains SEL-TWFL time synchronization and external time source selection.

Appendix I: Distributed Network Protocol. Provides information on the SEL-TWFL implementation, configuration, and performance of the DNP3 server functionality (outstation protocol).

Appendix J: Cybersecurity Features. Describes cybersecurity features and best practices to assist users with meeting their cybersecurity requirements.

The SEL-TWFL applications often use other SEL products. Below is a list of instruction manuals and application guides for companion products:

- *ACSELERATOR QuickSet SEL-5030 Software Instruction Manual*
- *SEL-5601-2 SYNCHROWAVE Event Software Instruction Manual*
- *SEL-T4287 Traveling-Wave Test System Instruction Manual*
- *SEL-2507 High-Speed Remote I/O Module Instruction Manual*
- *SEL-T401L Ultra-High-Speed Line Relay Instruction Manual*
- *SEL ICON Integrated Communications Optical Network Instruction Manual*

- *SEL-RTAC Instruction Manual*
- SEL Application Guide, “Introduction to Fiber-Optic Communications Technology” (AG2014-33)
- SEL Application Guide, “Double-Ended Traveling-Wave Fault Locating Using the SEL RTAC as a DNP3 Client” (AG2022-03)

All of the previously listed documents are available at selinc.com.

Safety Information

Dangers, Warnings, and Cautions

This manual uses three kinds of hazard statements, defined as follows:

⚠DANGER
Indicates an imminently hazardous situation that, if not avoided, **will** result in death or serious injury.

⚠WARNING
Indicates a potentially hazardous situation that, if not avoided, **could** result in death or serious injury.

⚠CAUTION
Indicates a potentially hazardous situation that, if not avoided, **may** result in minor or moderate injury or equipment damage.

Safety Symbols

The following symbols are often marked on SEL products.

	⚠CAUTION Refer to accompanying documents.	**⚠ATTENTION** Se reporter à la documentation.
	Earth (ground)	Terre
	Protective earth (ground)	Terre de protection
	Direct current	Courant continu
	Alternating current	Courant alternatif
	Both direct and alternating current	Courant continu et alternatif
	Instruction manual	Manuel d’instructions

Safety Marks

The following statements apply to this device.

General Safety Marks

⚠CAUTION There is danger of explosion if the battery is incorrectly replaced. Replace only with Rayovac® no. BR2335 or equivalent recommended by manufacturer. See Owner's Manual for safety instructions. The battery used in this device may present a fire or chemical burn hazard if mistreated. Do not recharge, disassemble, heat above 100°C or incinerate. Dispose of used batteries according to the manufacturer's instructions. Keep battery out of reach of children.	⚠ATTENTION Une pile remplacée incorrectement pose des risques d'explosion. Remplacez seulement avec un Rayovac® no BR2335 ou un produit équivalent recommandé par le fabricant. Voir le guide d'utilisateur pour les instructions de sécurité. La pile utilisée dans cet appareil peut présenter un risque d'incendie ou de brûlure chimique si vous en faites mauvais usage. Ne pas recharger, démonter, chauffer à plus de 100°C ou incinérer. Éliminez les vieilles piles suivant les instructions du fabricant. Gardez la pile hors de la portée des enfants.
⚠CAUTION To ensure proper safety and operation, the equipment ratings, installation instructions, and operating instructions must be checked before commissioning or maintenance of the equipment. The integrity of any protective conductor connection must be checked before carrying out any other actions. It is the responsibility of the user to ensure that the equipment is installed, operated, and used for its intended function in the manner specified in this manual. If misused, any safety protection provided by the equipment may be impaired.	⚠ATTENTION Pour assurer la sécurité et le bon fonctionnement, il faut vérifier les classements d'équipement ainsi que les instructions d'installation et d'opération avant la mise en service ou l'entretien de l'équipement. Il faut vérifier l'intégrité de toute connexion de conducteur de protection avant de réaliser d'autres actions. L'utilisateur est responsable d'assurer l'installation, l'opération et l'utilisation de l'équipement pour la fonction prévue et de la manière indiquée dans ce manuel. Une mauvaise utilisation pourrait diminuer toute protection de sécurité fournie par l'équipement.
For use in Pollution Degree 2 environment.	Pour l'utilisation dans un environnement de Degré de Pollution 2.

Other Safety Marks (Sheet 1 of 2)

⚠DANGER Disconnect or de-energize all external connections before opening this device. Contact with hazardous voltages and currents inside this device can cause electrical shock resulting in injury or death.	⚠DANGER Débrancher tous les raccordements externes avant d'ouvrir cet appareil. Tout contact avec des tensions ou courants internes à l'appareil peut causer un choc électrique pouvant entraîner des blessures ou la mort.
⚠DANGER Contact with instrument terminals can cause electrical shock that can result in injury or death.	⚠DANGER Tout contact avec les bornes de l'appareil peut causer un choc électrique pouvant entraîner des blessures ou la mort.
⚠WARNING Use of this equipment in a manner other than specified in this manual can impair operator safety safeguards provided by this equipment.	⚠AVERTISSEMENT L'utilisation de cet appareil suivant des procédures différentes de celles indiquées dans ce manuel peut désarmer les dispositifs de protection d'opérateur normalement actifs sur cet équipement.
⚠WARNING Have only qualified personnel service this equipment. If you are not qualified to service this equipment, you can injure yourself or others, or cause equipment damage.	⚠AVERTISSEMENT Seules des personnes qualifiées peuvent travailler sur cet appareil. Si vous n'êtes pas qualifiés pour ce travail, vous pourriez vous blesser avec d'autres personnes ou endommager l'équipement.
⚠WARNING This device is shipped with default passwords. Default passwords should be changed to private passwords at installation. Failure to change each default password to a private password may allow unauthorized access. SEL shall not be responsible for any damage resulting from unauthorized access.	⚠AVERTISSEMENT Cet appareil est expédié avec des mots de passe par défaut. A l'installation, les mots de passe par défaut devront être changés pour des mots de passe confidentiels. Dans le cas contraire, un accés non-autorisé á l'équipement peut être possible. SEL décline toute responsabilité pour tout dommage résultant de cet accés non-autorisé.
⚠WARNING Do not look into the fiber ports/connectors.	⚠AVERTISSEMENT Ne pas regarder vers les ports ou connecteurs de fibres optiques.
⚠WARNING Do not look into the end of an optical cable connected to an optical output.	⚠AVERTISSEMENT Ne pas regarder vers l'extrémité d'un câble optique raccordé à une sortie optique.
⚠WARNING Do not perform any procedures or adjustments that this instruction manual does not describe.	⚠AVERTISSEMENT Ne pas appliquer une procédure ou un ajustement qui n'est pas décrit explicitement dans ce manuel d'instruction.
⚠WARNING During installation, maintenance, or testing of the optical ports, use only test equipment qualified for Class 1 LASER products.	⚠AVERTISSEMENT Durant l'installation, la maintenance ou le test des ports optiques, utilisez exclusivement des équipements de test homologués comme produits de type LASER de Classe 1.

Other Safety Marks (Sheet 2 of 2)

⚠WARNING Incorporated components, such as LEDs and transceivers are not user serviceable. Return units to SEL for repair or replacement.	⚠AVERTISSEMENT Les composants internes tels que les leds (diodes électroluminescentes) et émetteurs-récepteurs ne peuvent pas être entretenus par l'usager. Retourner les unités à SEL pour réparation ou remplacement.
⚠WARNING Before working on a CT circuit, first apply a short to the secondary winding of the CT.	⚠AVERTISSEMENT Avant de travailler sur un circuit TC, appliquez d'abord un court-circuit à l'enroulement secondaire du TC.
⚠WARNING Do not attempt to modify the SET_CA.TXT or SET_CM.TXT files. They contain device calibration data. Modifying these files may lead to device misoperation. Limit access to Access Level C (calibration access) passwords and ensure proper training of field personnel.	⚠AVERTISSEMENT N'essayez pas de modifier les fichiers SET_CA.TXT ou SET_CM.TXT. Ils contiennent des données d'étalonnage du dispositif. La modification de ces fichiers peut entraîner une erreur de fonctionnement du dispositif. Limitez l'accès aux mots de passe de niveau d'accès C (accès à l'étalonnage) et assurez une formation adéquate du personnel sur le terrain.
⚠CAUTION Equipment components are sensitive to electrostatic discharge (ESD). Undetectable permanent damage can result if you do not use proper ESD procedures. Ground yourself, your work surface, and this equipment before removing any cover from this equipment. If your facility is not equipped to work with these components, contact SEL about returning this device and related SEL equipment for service.	⚠ATTENTION Les composants de cet équipement sont sensibles aux décharges électrostatiques (DES). Des dommages permanents non-décelables peuvent résulter de l'absence de précautions contre les DES. Raccordez-vous correctement à la terre, ainsi que la surface de travail et l'appareil avant d'en retirer un panneau. Si vous n'êtes pas équipés pour travailler avec ce type de composants, contacter SEL afin de retourner l'appareil pour un service en usine.
⚠CAUTION Do not install a jumper on positions A or D of the top board J12 header. Device misoperation can result if you install jumpers on positions J12A and J12D.	⚠ATTENTION N'installez pas de cavalier sur les positions A ou D sur le connecteur J12 de la carte en haut. Une erreur de fonctionnement du dispositif peut résulter suite à l'installation d'un cavalier entre les positions J12A et J12D.
⚠CAUTION Insufficiently rated insulation can deteriorate under abnormal operating conditions and cause equipment damage. For external circuits, use wiring of sufficiently rated insulation that will not break down under abnormal operating conditions.	⚠ATTENTION Un niveau d'isolation insuffisant peut entraîner une détérioration sous des conditions anormales et causer des dommages à l'équipement. Pour les circuits externes, utiliser des conducteurs avec une isolation suffisante de façon à éviter les claquages durant les conditions anormales d'opération.
⚠CAUTION Device misoperation can result from applying other than specified secondary voltages and currents. Before making any secondary circuit connections, check the nominal voltage and nominal current specified on the rear-panel nameplate.	⚠ATTENTION Une erreur de fonctionnement du dispositif peut résulter par le branchement de tensions et courants secondaires non conformes aux spécifications. Avant de brancher un circuit secondaire, vérifiez la tension ou le courant nominal sur la plaque signalétique à l'arrière du panneau.
⚠CAUTION Do not connect power to the device until you have completed these procedures and receive instruction to apply power. Equipment damage can result otherwise.	⚠ATTENTION Ne mettez-pas le dispositif sous tension avant d'avoir complété ces procédures et d'avoir reçu l'instruction de brancher l'alimentation. Des dommages à l'équipement peuvent survenir autrement.
⚠CAUTION Use of controls or adjustments, or performance of procedures other than those specified herein, may result in hazardous radiation exposure.	⚠ATTENTION L'utilisation de commandes ou de réglages, ou l'application de tests de fonctionnement différents de ceux décrits ci-après peuvent entraîner l'exposition à des radiations dangereuses.
⚠CAUTION Class 1 LASER Product. This product uses visible or invisible LASERs based on model option. Looking into optical connections, fiber ends, or bulkhead connections can result in hazardous radiation exposure.	⚠ATTENTION Produit LASER de Classe 1. Ce produit utilise des LASERS visibles ou invisibles dépendant des options du modèle. Regarder vers les connecteurs optiques, les extrémités des fibres ou les connecteurs de cloison peut entraîner une exposition à des rayonnements dangereux.

General Information

Typographic Conventions

There are three ways to interface with the SEL-TWFL:

- Using ACSELERATOR QuickSet Software
- Using the front-panel menus and pushbuttons
- Using a command line interface on a PC terminal emulator

The instructions in this manual indicate these options with specific font and formatting attributes. The following table lists these conventions:

Example	Description
STATUS	Commands, command options, and command variables typed at a command line interface on a PC.
n **SUM *n***	Variables determined based on an application (in bold if part of a command).
<Enter>	Single keystroke on a PC keyboard.
<Ctrl+D>	Multiple/combination keystroke on a PC keyboard.
Start > Settings	PC software dialog boxes and menu selections. The > character indicates submenus.
ENABLED	Device front- or rear-panel labels and pushbuttons.
MAIN > METER	Device front-panel LCD menus and device responses visible on the PC screen. The > character indicates submenus.

Logic Diagrams

Logic diagrams in this manual follow the conventions and definitions shown below.

NAME	SYMBOL	FUNCTION
COMPARATOR	A, B, +, −, C	Input A is compared to input B. Output C asserts if A is greater than B.
OR	A, B, C	Either input A or input B asserted cause output C to assert.
NOR	A, B, C	If neither A nor B asserts, output C asserts.
AND	A, B, C	Input A and input B must assert to assert output C.
AND W/ INVERTED INPUT	A, B, C	If input A is asserted and input B is deasserted, output C asserts. Inverter "O" inverts any input or output on any gate.
NAND	A, B, C	If A and/or B are deasserted, output C is asserted.
TIME DELAYED PICK UP AND/OR TIME DELAYED DROP OUT	A, X, Y, B	X is a time-delay-pickup value; Y is a time-delay-dropout value. B asserts time X after input A asserts; B will not assert if A does not remain asserted for time X. If X is zero, B will assert when A asserts, and B will remain asserted for time Y after A deasserts. If Y is zero, B will deassert when A deasserts.
EDGE TRIGGER TIMER	A, X, Y, B	Rising edge of A starts timers. Output B will assert time X after the rising edge of A. B will remain asserted for time Y. If Y is zero, B will assert for a single processing interval. Input A is ignored while the timers are running.
SET RESET LATCH	S, Q, R	Input S asserts Output Q until Input R asserts. Output Q deasserts or resets when R asserts.
FALLING EDGE	A, B	B asserts at the falling edge of Input A.
RISING EDGE	A, B	B asserts at the rising edge of Input A.

Trademarks

Trademarks appearing in this manual are shown in the following table.

SEL Trademarks	
acSELerator QuickSet®	Mirrored Bits®
acSELerator Team®	SEL Blueframe®
Compass®	SELogic®
ICON®	synchroWAVe®

Technical Support

We appreciate your interest in SEL products and services. If you have questions or comments, please contact us at:

Schweitzer Engineering Laboratories, Inc.
2350 NE Hopkins Court
Pullman, WA 99163-5603 U.S.A.
Tel: +1.509.338.3838
Fax: +1.509.332.7990
Internet: selinc.com/support
Email: info@selinc.com

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SECTION 1

Introduction and Specifications

Overview

The SEL-TWFL is a standalone and economical traveling-wave-based fault locator. It uses SEL traveling-wave-based fault-locating technology, which has a field-proven accuracy of about one tower span. The SEL-TWFL does not include line protection functions; it is primarily developed for installations where the line protective relay does not include accurate fault-locating capability. The SEL-TWFL works in conjunction with existing line protective relays so you can obtain the benefit of highly accurate fault locating, in addition to line monitoring and ultra-high resolution transient recording, without redesigning your protection standard or changing your protection scheme. The SEL-TWFL interfaces with conventional CTs and PTs, and a single SEL-TWFL can be used to monitor two-line terminals at a substation (see *Figure 6.3*). It can be applied on multiterminal lines and on overhead, cable, and hybrid lines for fault locating and line monitoring.

Front- and Rear-Panel Overview

Figure 1.1 Front Panel

Figure 1.2 Rear Panel Includes Voltage and Current Terminals for Dual-Line Applications

Functional Overview

Figure 1.3 Functional Overview Diagram

Table 1.1 SEL-TWFL Functions

ANSI Number or Acronym	Description
ZFL	Impedance-Based Fault Locator
TWFL	Traveling-Wave-Based Fault Locator
LM	Line Monitor
27	Undervoltage (phase and positive-sequence)
50	Instantaneous Overcurrent (phase, zero-sequence, and negative-sequence)
59	Overvoltage (phase, positive-sequence, zero-sequence, and negative-sequence)
OP	Open-Pole Detection Logic
LOP	Loss-of-Potential Logic
85 RIO	SEL MIRRORED BITS I/O With Selectable SEL MB8 or IEEE C37.94 Encoding
MET	Metering
SELOGIC	Programmable Logic
SER	Sequential Events Recorder
DFR	Digital Fault Recorder
TWTEST	Traveling-Wave Test Mode
HMI	Local Operator Interface
DNP3	Distributed Network Protocol 3.0 (Ethernet)
FTP	File Transfer Protocol

Feature Highlights

The SEL-TWFL is suitable for fault locating and line monitoring applications on two- and three-terminal lines. The following are the SEL-TWFL feature highlights.

Fault Locator (FL). The SEL-TWFL incorporates a single-ended traveling-wave-based fault-locating method that works on local current traveling waves (TWs) and analyzes the first TW as well as several successive TW reflections. The SEL-TWFL also incorporates a multi-ended TW-based fault-locating method that uses only the first TWs at all line terminals. The TW-based fault-locating technology used in the SEL-TWFL has a field-proven accuracy of about one tower span (±300 m or ±1,000 ft), regardless of the line length. The multi-ended algorithm requires a 64 kbps IEEE C37.94-encoded channel to exchange the fault-locating data, and it requires the time stamps (clocks connected via IRIG-B inputs to the device) from all ends of the line to be aligned to the same time reference. The SEL-TWFL ensures dependable fault-locating results under a wide range of operating conditions by using the multi-ended and single-ended impedance-based fault-locating methods in addition to the TW-based methods.

Line Monitor (LM). Identify trouble spots along the line and prevent faults by using the SEL-TWFL line monitoring function. The line monitor triggers on current TWs launched by fault precursors, locates these events with high accuracy by using the multi-ended TW-based fault-locating method (an IEEE C37.94-encoded channel with clocks connected via IRIG-B inputs is required), tabulates these events for locations along the line, and alarms if the event count exceeds a user-settable threshold. Monitor the

line for dirty or cracked insulators, encroaching vegetation, marginal clearances, marginal lightning protection, incipient cable faults, conductor galloping, ice unloading, and similar conditions. Reset the event counters for the problem locations after addressing the underlying problem by performing adequate maintenance.

Digital Fault Recorder (DFR). The SEL-TWFL provides transient recording at a 1 MHz sampling rate, maximum duration of 1.2 s per record, total storage of about 60 s of recording, IEEE C37.111-2013 COMTRADE file format, and a user-configurable trigger. Back-to-back triggering is allowed with the total recording duration of 3.6 s. Analyze high-frequency power system events, including lightning strikes, breaker restrikes, and breaker transient recovery voltages with the exceptional 1 MHz, 18-bit recording capability of the SEL-TWFL. The 1 MHz IEEE COMTRADE record (MHR) contains voltages and currents sampled at 1 MHz with 18 bits of resolution, device settings, fault location, and event summary data. The 10 kHz IEEE COMTRADE record (TDR) contains currents and voltages sampled at 10 kHz with an effective resolution of 20 bits, selected analog quantities, Relay Word bits, device settings, fault location, and event summary data. When the device is connected to a high-accuracy clock, the transient record samples are time-stamped with a resolution of 1 μs and an accuracy of 100 ns.

Triggering Functions. Configure the fault locator trigger by programming a dedicated SELOGIC setting. Use a contact input or a MIRRORED BITS input to trigger on trip signals from the line protective relay. When you use the line monitor, the assertion of the fault locator trigger informs the line monitoring logic that the event is a fault and not a low-energy event. The SEL-TWFL includes two levels of phase, negative-sequence, and zero-sequence nondirectional overcurrent elements, two levels of phase and positive-sequence undervoltage elements, and two levels of phase, positive-sequence, negative-sequence, and zero-sequence overvoltage elements to trigger the transient recorder.

Models and Options

The SEL-TWFL allows you to simplify procurement, engineering, panel design and manufacturing, and spare part management by having only a few models with most characteristics and specifications being standard.

Mounting and Chassis:	3U horizontal rack mount
Connector Type:	Screw-terminal blocks
Number of Current Inputs:	2 three-phase sets
Number of Voltage Inputs:	2 three-phase sets
Voltage Rating:	$(100–250)/\sqrt{3}$ V phase-to-neutral
Frequency Rating (Setting):	50 Hz or 60 Hz
Number of Trip-Rated High-Speed Contact Outputs:	6 (rated voltage 48–250 Vdc)
Number of Standard Form A Contact Outputs:	8 (rated voltage 48–250 Vdc)
Number of Individually Isolated Contact Inputs:	8
Number of Contact Inputs With a Common Terminal:	5

Alarm Contact Output:	Form C (rated voltage 48–250 Vdc)
Number of Standard Signaling Ports:	3 (multimode fiber, 820 nm)
Signaling Ports Encoding Method (Setting):	SEL MB8 or IEEE C37.94
SCADA and Engineering Access Port:	Fiber Ethernet, 100 Mbps[a] or 1 Gbps
Front-Panel Engineering Access Port:	USB 2.0
Communications Protocols:	DNP3, SEL ASCII, SEL Fast Meter, SEL Fast SER, SEL Fast Operate, FTP, and Telnet
Firmware Options:	None

[a] Installed SFP transceiver is 1310 nm, 100BASE-FX, multimode. See *Fiber-Optic Ethernet Port 5 on page 1.9* in *Specifications*.

When ordering the SEL-TWFL, select the rated current, power supply rated voltage, and contact input rated voltage through the SEL-TWFL model number, as shown in *Table 1.2*.

Table 1.2 SEL-TWFL Models

Model	Current Rating	Power Supply Rating	Contact Input Rating
TWFL#0001	5 A	125–250 Vdc, 110–240 Vac	125 Vdc
TWFL#0002	1 A	125–250 Vdc, 110–240 Vac	125 Vdc
TWFL#0003	5 A	125–250 Vdc, 110–240 Vac	110 Vdc
TWFL#0004	1 A	125–250 Vdc, 110–240 Vac	110 Vdc
TWFL#0005	5 A	48–125 Vdc, 110–120 Vac	48 Vdc
TWFL#0006	1 A	48–125 Vdc, 110–120 Vac	48 Vdc
TWFL#0007	5 A	48–125 Vdc, 110–120 Vac	125 Vdc
TWFL#0008	1 A	48–125 Vdc, 110–120 Vac	125 Vdc
TWFL#0009	5 A	48–125 Vdc, 110–120 Vac	110 Vdc
TWFL#0010	1 A	48–125 Vdc, 110–120 Vac	110 Vdc
TWFL#0011	5 A	125–250 Vdc, 110–240 Vac	250 Vdc
TWFL#0012	1 A	125–250 Vdc, 110–240 Vac	220 Vdc
TWFL#0019	5 A	48–125 Vdc, 110–120 Vac	250 Vdc

Contact the SEL factory or your local Technical Service Center for additional ordering information (see *Technical Support* on page xxi in the *Preface*). Ordering information is also available on the SEL website at selinc.com.

Applications

You can use the SEL-TWFL in a wide range of applications. *Table 1.3* and *Table 1.4* list highlights for fault-locating and recording applications.

Table 1.3 Fault-Locating Application Highlights

Application	Key Features and Recommendations
Long Lines	➤ Benefit from TW-based fault-locating methods, which work best on long lines and have a high accuracy that is independent of the line length. ➤ Perform a line energization test and use the high-resolution DFR record (1 µs resolution) to set the TW line propagation time with maximum accuracy.
Short Lines	➤ Benefit from the multi-ended TW-based fault-locating method[a]; this is the best method available for short lines.
Multiterminal Lines	➤ For two- and three-terminal lines, apply the multi-ended TW-based fault-locating method to obtain the fault location. ➤ For applications with more than three terminals, use SCADA/HMI software to process TW time stamps from SEL-TWFL devices at all terminals of the line to identify the faulted line section and calculate the fault location on the faulted section.
Tapped Lines	➤ Apply the multi-ended TW-based fault-locating method between the two main terminals to obtain the fault location for an entire line.
Hybrid Lines Consisting of Overhead and Cable Sections	➤ Apply the multi-ended TW-based fault-locating method and benefit from its ability to calculate the fault location for two-terminal nonhomogeneous lines with as many as five different line sections.[b]
Series-Compensated Lines	➤ Confidently apply the TW-based fault-locating methods because they are inherently immune to the effects of series compensation.
Lines Terminating on Transformers or Series Reactors Only	➤ Rely on impedance-based fault-locating methods, especially the multi-ended method; transformer or series reactor terminations (high surge impedance) yield zero or very small current TWs and render the TW-based fault-locating methods ineffective. ➤ Similarly to how a high surge impedance prevents the device from measuring TW currents, auxiliary CTs connected in series with the SEL-TWFL will also prevent the SEL-TWFL from measuring current TWs and will render the TW-based fault-locating methods ineffective. Avoid auxiliary CTs in the SEL-TWFL current input circuits.
Wide-Area Fault Locating	➤ Deploy multiple SEL-TWFL devices and synchronize them by using standard IRIG-B inputs and obtain a wide-area fault-locating system with unprecedented accuracy. ➤ Obtain an absolute time reference for the TW time stamps by using a standard IRIG-B connection to a high-accuracy clock. ➤ Obtain accurate TW time stamps by using DNP3 or from the IEEE COMTRADE header files. ➤ Perform fault locating for complex multisection, multiterminal, and tapped lines by programming custom equations in SCADA/HMI software.

[a] See the technical paper "Line Length and Fault Distance Considerations in Traveling-Wave Protection and Fault-Locating Applications" by B. Kasztenny and V. Mynam, available at selinc.com.

[b] For three-terminal line applications, any of the sections can be a homogeneous overhead line or a homogeneous underground cable.

Table 1.4 Digital Fault Recording Application Highlights

Application	Key Features and Recommendations
Standalone High-Resolution DFR	➤ Use standard cabling to wire the SEL-TWFL to standard protection instrument transformers. ➤ Obtain an absolute time reference for your records by using a standard IRIG-B connection to a high-accuracy clock. ➤ Program the transient recorder trigger based on internal measurements or cross-triggers from protective relays (use contact I/O or MIRRORED BITS I/O). ➤ Record six current channels and six voltage channels for as long as 1.2 s with 1 µs time resolution, 100 ns accuracy, and 18 bits of signal resolution. ➤ Program the transient recorder trigger for back-to-back triggers and obtain a total of 3.6 s of continuous recording. Store as much as 60 s of recorded data before you have to retrieve the files in order to prevent losing the data. ➤ Benefit from the low-burden dc-coupled SEL-TWFL voltage input design and connect the voltage channels to high-accuracy low-burden voltage sources, such as compensated capacitive voltage dividers. ➤ Obtain metering data, perform fault locating, and program custom logic (SELOGIC) in addition to the primary function of digital fault recording.
Substation and Wide-Area DFR	➤ Deploy multiple SEL-TWFL devices and synchronize them by using standard IRIG-B inputs and obtain a wide-area recording system with unprecedented accuracy and resolution.

Specifications

Compliance

Designed and manufactured under an ISO 9001 certified quality management system

FCC Compliance Statement

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference in which case the user will be required to correct the interference at his own expense.

UL Listed to U.S. and Canadian safety standards (File E212775; NRGU, NRGU7)

CE Mark

UKCA Mark

RCM Mark

General

AC Analog Inputs

Sampling Rate:	1 MHz
A/D Resolution:	18 bits

AC Current Inputs

Rated Input Current:	1 A Model: 1 A 5 A Model: 5 A
Continuous Thermal Rating:	1 A Model: 3 A 5 A Model: 15 A
A/D Measurement Limit:	1 A Model: 50 A peak (17.67 Arms fully offset ac current) 5 A Model: 250 A peak (88.4 Arms fully offset ac current)
One-Second Thermal Withstand:	1 A Model: 100 Arms 5 A Model: 500 Arms
Burden:	1 A Model: <0.1 VA at 1 A, 60 Hz 5 A Model: <0.5 VA at 5 A, 60 Hz

AC Voltage Inputs

Connection:	Three-phase four-wire wye with a common neutral, dc coupled (Voltage Input VY) Three-phase six-wire individually isolated, dc coupled (Voltage Input VZ)
Rated Voltage Range:	57.7–144.3 V LN (100–250 V LL)
Continuous Thermal Rating:	175 Vrms LN
A/D Measurement Limit:	280 V peak LN
Ten-Second Thermal Withstand:	350 Vrms LN
Burden:	<0.1 VA at 120 V LN

Power Supply

High-Voltage Range (125–250 Vdc)

Rated Voltage:	125–250 Vdc 110–240 Vac
Operational Voltage Range:	85–300 Vdc 85–264 Vac
Rated Frequency:	50/60 Hz
Operational Frequency Range:	30–120 Hz
Vdc Input Ripple:	15% per IEC 60255-26:2013
Control Power Interruption Ride-Through:	46 ms @ 125 Vdc, 250 ms @ 250 Vdc per IEC 60255-26:2013
Burden:	<35 W, <90 VA

Medium-Voltage Range (48–125 Vdc)

Rated Voltage:	48–125 Vdc 110–120 Vac
Operational Voltage Range:	38–200 Vdc 85–140 Vac
Rated Frequency:	50/60 Hz
Operational Frequency Range:	30–120 Hz
Vdc Input Ripple:	15% per IEC 60255-26:2013
Control Power Interruption Ride-Through:	14 ms @ 48 Vdc, 160 ms @ 125 Vdc per IEC 60255-26:2013
Burden:	<35 W, <90 VA

Contact Outputs

Update Rate:	10 kHz
Mechanical Endurance:	10,000 operations

Fast Hybrid (High-Speed, High-Current Interrupting) Form A

Rated Voltage:	48–250 Vdc
Operational Voltage Range:	0–300 Vdc
Operating Time:	Pickup time ≤10 µs (resistive load) Dropout ≤8 ms (resistive load)
Make[1, 2] (Short Duration Contact Current):	30 Adc 2,000 operations
Limiting Making Capacity[2]:	1,000 W at 250 Vdc (L/R = 40 ms)
Short-Time Thermal Withstand:	50 Adc for 1 s
Continuous Contact Current:	6 Adc at 70°C (158°F) 4 Adc at 85°C (185°F)
Contact Protection:	MOV protection across open contacts 300 Vdc continuous voltage
Maximum Leakage Current:	<100 µA at 300 Vdc
Limiting Breaking Capacity/Electrical Endurance[1, 2]:	10,000 operations 4 operations in 1 s, followed by 2 min idle

[1] According to IEEE C37.90-2005.
[2] According to IEC 60255-27:2013.

Rated Voltage	Resistive Break	Inductive Break
48 Vdc	10 Adc	10 Adc (L/R = 40 ms)
125 Vdc	10 Adc	10 Adc (L/R = 40 ms)
250 Vdc	10 Adc	10 Adc (L/R = 20 ms)

Standard Form A

Rated Voltage:	48–250 Vdc
Operational Voltage Range:	0–300 Vdc
Operating Time:	Pickup time ≤6 ms (resistive load) Dropout ≤6 ms (resistive load)
Make[1, 2] (Short Duration Contact Current):	30 Adc 1,000 operations at 250 Vdc 2,000 operations at 125 Vdc

Limiting Making Capacity[2]: 1,000 W at 250 Vdc (L/R = 40 ms)

Short-Time Thermal Withstand: 50 Adc for 1 s

Continuous Contact Current: 6 Adc at 70°C (158°F)
4 Adc at 85°C (185°F)

Contact Protection: MOV protection across open contacts
300 Vdc continuous voltage

Limiting Breaking Capacity/Electrical Endurance[1, 2]: 10,000 operations
10 operations in 4 s, followed by 2 min idle

[1] According to IEEE C37.90-2005.
[2] According to IEC 60255-27:2013.

Rated Voltage	Resistive Break	Inductive Break
48 Vdc	0.63 Adc	0.63 Adc (L/R = 40 ms)
125 Vdc	0.30 Adc	0.30 Adc (L/R = 40 ms)
250 Vdc	0.20 Adc	0.20 Adc (L/R = 40 ms)

Alarm Output (Form C)

Rated Voltage: 48–250 Vdc

Operational Voltage Range: 0–300 Vdc

Operating Time: Pickup time ≤6 ms (resistive load)
Dropout ≤6 ms (resistive load)

Short-Time Thermal Withstand: 50 Adc for 1 s

Continuous Contact Current: 6 Adc at 70°C (158°F)
4 Adc at 85°C (185°F)

Contact Protection: MOV protection across open contacts
300 Vdc continuous voltage

Limiting Breaking Capacity/Electrical Endurance[1, 2]: 10,000 operations
10 operations in 4 s, followed by 2 min idle

[1] According to IEEE C37.90-2005.
[2] According to IEC 60255-27:2013.

Rated Voltage	Resistive Break	Inductive Break
48 Vdc	0.63 Adc	0.63 Adc (L/R = 40 ms)
125 Vdc	0.30 Adc	0.30 Adc (L/R = 40 ms)
250 Vdc	0.20 Adc	0.20 Adc (L/R = 40 ms)

Contact Inputs

Optoisolated (Bipolar Operation)

Connection: Terminal Block 100: 5 inputs with a shared common terminal
Terminal Block 200: 8 fully isolated inputs

Sampling Rate: 10 kHz

Input Voltage Options:

Rated Voltage	Maximum Voltage	Pickup Voltage	Dropout Voltage
48 Vdc	60 Vdc	38 Vdc	28 Vdc
110 Vdc	132 Vdc	88 Vdc	66 Vdc
125 Vdc	150 Vdc	100 Vdc	75 Vdc
220 Vdc	264 Vdc	176 Vdc	132 Vdc
250 Vdc	300 Vdc	200 Vdc	150 Vdc

Current Draw: ≤5 mA at rated voltage
≥1 mA required for assertion (220, 250 Vdc option)
≥2 mA required for assertion (48, 110, 125 Vdc option)

Communications Ports

Fiber-Optic Communications Ports 1, 2, and 3

Applications: Multi-ended traveling-wave-based fault locating[1], multi-ended impedance-based fault locating[1], line monitoring[1], and fault locator and event recorder triggering

[1] IEEE C37.94 encoding, 30 ms maximum channel latency

Data Rate: 19,200 to 115,200 bps (SEL MIRRORED BITS encoding)
64 kbps (IEEE C37.94 encoding)

Connector Type: ST

Fiber Type: Multimode

Wavelength: 820 nm

Fiber Size: 62.5/125 µm

Minimum Receiver Sensitivity: –24 dBm

Transmitter Power: –18.5 dBm (minimum)
–10.5 dBm (maximum)

Maximum Distance: 2 km (for typical continuous fiber-optic cable)

USB Front-Panel Port F

Connector Type: Type B

USB Type: 2.0

Fiber-Optic Ethernet Port 5

Applications: Remote engineering access and permanent connection to SCADA or HMI client

Installed SFP Transceiver: 2 km, 1,310 nm, multimode

Connector Type: LC

Port 5-Compliant SFP Transceivers

2 km, 1,310 nm, multimode
0.3/0.55 km, 850 nm, multimode
10 km, 1,310 nm, single-mode
20 km, 1,310 nm, single-mode
30 km, 1,310 nm, single-mode
40 km, 1,310 nm, single-mode
50 km, 1,550 nm, single-mode
80 km, 1,550 nm, single-mode
160 km, 1,550 nm, single-mode
200 km, 1,550 nm, single-mode

Time Input

IRIG-B Input

Applications: Precise time synchronization for digital fault recording, sequential events recording, multi-ended traveling-wave-based fault locating, multi-ended impedance-based fault locating, and line monitoring

Format: Demodulated IRIG-B

Rated I/O Voltage: 5 Vdc

Operating Voltage Range: 0–8 Vdc

Input Impedance: ≥1 kΩ

Time Accuracy: 100 ns when connected to a high-accuracy clock

Holdover Accuracy: <1 µs for 15 s

Clock Drift When Free Running: <5 min per year typical

Installation

According to IEC 60255-27:2013

Operating Temperature

Device: –40° to +85°C (–40° to +185°F)

Note: LCD contrast impaired for temperatures below –20°C (–4°F) and above +70°C (+158°F).

SFP Transceivers: –40° to +70°C (–40° to +158°F)

Humidity: 5% to 95% without condensation

Altitude: <2000 m

Overvoltage Category: Category III

Insulation Class: I

Pollution Degree: 2

Size and Weight

Size: 3U 19-in horizontal rack-mount

Weight: 7.54 kg (16.63 lb) (maximum)

Terminal Connections and Wire Sizes

Rear Screw-Terminal Tightening Torque, #8 Ring Lug

Minimum: 1.0 Nm (9 in-lb)

Maximum: 2.0 Nm (18 in-lb)

User terminals and stranded copper wire should have a minimum temperature rating of 105°C (221°F). Ring terminals are recommended.

Wire Sizes

Use the following table as a guide in selecting wire sizes. The grounding conductor should be as short as possible and sized equal to or greater than any other conductor in the same cable connected to the device, unless otherwise required by local or national wiring regulations.

Connection Type	Minimum Wire Size	Maximum Wire Size
Grounding (Earthing) Connection	14 AWG (2.5 mm^2)	N/A
Current Connection	16 AWG (1.5 mm^2)	10 AWG (5.3 mm^2)
Potential (Voltage) Connection	18 AWG (0.8 mm^2)	14 AWG (2.5 mm^2)
Power, Contact I/O	18 AWG (0.8 mm^2)	10 AWG (5.3 mm^2)

Type Tests

Electromagnetic Compatibility (EMC)

Emissions: IEC 60255-26:2013, Section 7.1
Class A
47 CFR Part 15B
Class A
Canada ICES-001 (A) / NMB-001 (A)

Electromagnetic Compatibility Immunity

Conducted RFI Immunity: IEC 60255-26:2013, Section 7.2.8
10 Vrms

Radiated RFI Immunity: IEC 60255-26:2013, Section 7.2.4
10 V/m (modulated)
IEEE C37.90.2-2004
20 V/m (modulated, >35 V/m peak)

Electrostatic Discharge Immunity: IEC 60255-26:2013, Section 7.2.3
IEEE C37.90.3-2001
2, 4, 6, and 8 kV contact discharge
2, 4, 8, and 15 kV air discharge

Electrical Fast Transient Burst Immunity: IEC 60255-26:2013, Section 7.2.5
Zone A
4 kV, 5 kHz repetition rate on power supply I/O, signal data, and control lines
2 kV, 5 kHz repetition rate on communications ports (IRIG-B)

Power Frequency Immunity: IEC 60255-26:2013, Section 7.2.9
Zone A

Power Frequency Magnetic Field Immunity: IEC 60255-26:2013, Section 7.2.10
Level 5
1,000 A/m for 3 s
100 A/m for 60 s

Pulse Magnetic Field Immunity: IEC 61000-4-9:2001
Level 5
1,000 A/m

Damped Oscillatory Magnetic Field: IEC 61000-4-10:2001
Level 5
100 A/m at 100 kHz and 1 MHz

Power Supply Immunity: IEC 60255-26:2013, Section 7.2.11, 7.2.12, and 7.2.13
IEC 60255-27:2013, Section 5.1.3, 10.6.6

Surge Immunity: IEC 60255-26:2013, Section 7.2.7
Zone A
Line-to-line: 0.5, 1.0, 2.0 kV
Line-to-earth: 0.5, 1.0, 2.0, 4.0 kV

Surge Withstand Capability Immunity and Damped Oscillatory Wave Immunity: IEC 60255-26:2013, Section 7.2.6
2.5 kV peak common mode
1.0 kV peak differential mode
1 MHz damped oscillatory
IEEE C37.90.1-2012
2.5 kV oscillatory
4.0 kV fast transient
2.5 kV, 1 MHz damped oscillatory

Environmental

Cold, Operational: IEC 60255-27:2013, Section 10.6.1.2
Test Ad: 16 hours at –40°C

Dry Heat, Operational: IEC 60255-27:2013, Section 10.6.1.1
Test Bd: 16 hours at +85°C

Damp Heat, Cyclic: IEC 60255-27:2013, Section 10.6.1.6
Test Db: +25° to +55°C, 6 cycles (12 + 12-hour cycle), 95% RH

Damp Heat, Steady State: IEC 60255-27:2013, Section 10.6.1.5
Test Cab: 93% RH, +40°C, 10 days

Object Penetration: IEC 60255-27:2013, Section 10.6.2.6
Protection Class: IP30

Vibration Resistance: IEC 60255-27:2013, Section 10.6.2.1
Class 2 Endurance, Class 2 Response

Shock Resistance: IEC 60255-27:2013, Section 10.6.2.2, 10.6.2.3
Class 1 Shock Withstand, Class 1 Bump Withstand, Class 2 Shock Response

Seismic: IEC 60255-27:2013, Section 10.6.2.4
Class 2 Quake Response

Safety

Dielectric Strength: IEC 60255-27:2013, Section 10.6.4.3
IEEE C37.90-2005, Section 8
2.5 kVrms: analog inputs, contact inputs, contact outputs, and IRIG-B input
3.6 kVdc: power supply

Impulse: IEC 60255-27:2013, Section 10.6.4.2
IEEE C37.90-2005, Impulse section
5.0 kV: analog inputs, digital inputs, digital outputs, power supply, and IRIG-B input

Product Safety Requirements: IEC 60255-27:2013

Laser Safety: 21 CFR 1040.10
IEC 60825-1:2014
Class 1

Fault Locator and Line Monitor

Fault Locator

Methods:	Multi-ended and single-ended traveling-wave-based; multi-ended and single-ended impedance-based
Communications Port for Multi-Ended Methods:	User-selectable, Port 1, 2, and/or 3
Time Synchronization Requirements:	None for single-ended methods High-accuracy IRIG-B when using Port 1, 2, or 3 for multi-ended methods
Data Presentation:	Summary report, transient record (IEEE COMTRADE[1] header file), front-panel HMI, SCADA protocols

[1] IEEE Std C37.111-2013 (IEC 60255-24:2013), *Measuring Relays and Protection Equipment – Part 24: Common Format for Transient Data Exchange (COMTRADE) for Power Systems*

Multi-Ended Traveling-Wave-Based Method

Channel Requirements:	IEEE C37.94 channel on user-selectable Port 1, 2, or 3 with a high-accuracy clock at all line terminals and channel latency less than 30 ms
Device Accuracy[1]:	20 m (90th percentile error) 10 m (median error)

[1] Device accuracy tested with a current step

Application Accuracy:	300 m typical See *Accuracy Analysis* on page 2.18
Number of Line Terminals:	As many as 3
Number of Nonhomogeneous Line Sections:	As many as 5 (only for two-terminal line applications)
CT Cable Length Compensation:	0.000 to 10.000 µs

Single-Ended Traveling-Wave-Based Method

Device Accuracy[1]:	20 m (90th percentile error) 10 m (median error)

[1] Device accuracy tested with a current step

Application Accuracy:	300 m typical See *Accuracy Analysis* on page 2.21
Number of Ranked Fault Location Alternatives Reported:	As many as 4
CT Cable Length Compensation:	Not required

Multi-Ended Impedance-Based Method

Channel Requirements:	IEEE C37.94 channel on user-selectable Port 1, 2, or 3 with a high-accuracy clock at all line terminals and channel latency less than 30 ms
Method:	Negative-sequence line voltage profile (unbalanced faults) or positive-sequence line voltage profile (three-phase faults)
Application Accuracy:	See *Accuracy Analysis* on page 2.24
Number of Line Terminals:	As many as 3
Number of Nonhomogeneous Line Sections:	As many as 5 (only for two-terminal line applications)

Single-Ended Impedance-Based Method

Method:	Apparent impedance polarized with negative-sequence current (unbalanced faults) or positive-sequence current (three-phase faults)
Application Accuracy:	See *Accuracy Analysis* on page 2.26
Number of Nonhomogeneous Line Sections:	As many as 5

Line Monitor

Operation:	Detects, locates, tabulates, and alarms on fault precursors. Provides blocking regions for line taps with load or generation, or in-line series capacitors. Tabulates and alarms for total line events outside the blocking regions and for daily event counts within the blocking regions
Channel Requirements:	IEEE C37.94 channel on user-selectable Port 1, 2, or 3 with a high-accuracy clock at each line terminal and channel latency less than 30 ms
Triggering Mechanism:	Low-energy events only, faults only, low-energy events and faults (user-selectable)
Sensitivity:	Current traveling waves at each line terminal greater than 2.5% of peak nominal current
Location Resolution:	0.25 mi or km
Counter Range per Location:	0–255 (counting stops at 255)
Number of Line Terminals:	As many as 3
Number of Line Monitoring Blocking Regions per Line:	2
Alarm Threshold:	1–200
Data Presentation:	A text file with tabulated event location and count, alarm bits, and alarm locations available over SCADA protocols

Transient Recording

Recording Rates:	1 MHz concurrently with 10 kHz
Maximum Duration:	3.6 s total in back-to-back recording
Output Format:	Binary 32-bit IEEE COMTRADE

Record Storage (Summary, History, Transient Records)

Total Storage:	No less than 60 s of total recording time 50 records at LER = 1.2 s 200 records at LER = 0.3 s

Sequential Events Recorder

Storage	10,000 entries
Number of Configurable Points:	100
Burst Mode:	1,000 entries
Resolution	100 µs

Supervisory and Triggering Elements and SELOGIC Equations

Processing Intervals

Calculations and Logic Processing for Supervisory and Triggering Elements:	500 µs
SELOGIC Processing:	100 µs

Steady-State Accuracy

Pickup Accuracy for Phase Current Elements:	±(1% of setting or 1% of nominal, whichever is greater)
Pickup Accuracy for Sequence Current Elements:	±(2% of the highest phase current or 1% of nominal, whichever is greater)

Pickup Accuracy for Phase Voltage Elements:	±(0.25% of setting or 0.1 V secondary, whichever is greater)
Pickup Accuracy for Sequence Voltage Elements:	±(0.5% of highest phase voltage or 0.2 V secondary, whichever is greater)
Accuracy of Timers for Definite-Time Elements:	±(1 ms or 0.1% of the setting, whichever is greater)

System Configuration

Nominal System Frequency:	50 Hz or 60 Hz
Frequency Tracking Range:	±10 Hz from nominal
Maximum Frequency Slew Rate:	±10 Hz/s
System Phase Rotation:	ABC or ACB
Current Transformer Ratio:	1 to 50,000 in steps of 1
Line Current Source:	IW, IX, or COMB (combined)
Line Voltage Source:	VY, VZ
Secondary CT Cable-Delay Compensation:	0.000 to 10.000 µs in steps of 0.001 µs
Potential Transformer Ratio:	1.00 to 10,000.00 in steps of 0.01
Nominal Voltage (LL):	100 to 250 V secondary in steps of 1 V

Line Configuration

Number of Lines:	As many as 2
Positive-Sequence Line Impedance Magnitude:	1 A Model: 0.25 to 1,275.00 Ω secondary in steps of 0.01 Ω 5 A Model: 0.05 to 255.00 Ω secondary in steps of 0.01 Ω
Positive-Sequence Line Impedance Angle:	50.00° to 90.00° in steps of 0.01°
Zero-Sequence Line Impedance Magnitude:	1 A Model: 0.25 to 1,275.00 Ω secondary in steps of 0.01 Ω 5 A Model: 0.05 to 255.00 Ω secondary in steps of 0.01 Ω
Zero-Sequence Line Impedance Angle:	50.00° to 90.00° in steps of 0.01°
Line Length:	0.01 to 500.00 in steps of 0.01
Line Length Unit:	km or mi
TW Line Propagation Time:	10.00 to 1,700.00 µs in steps of 0.01 µs

Instantaneous and Definite-Time Zero-Sequence Overcurrent Element (50G/67GT)

Number of Elements (Levels):	2
Operating Current:	3I0
Pickup:	1 A Model: 0.05 to 20.00 A secondary in steps of 0.01 A 5 A Model: 0.25 to 100.00 A secondary in steps of 0.01 A
Delay:	0.000 to 10.000 s in steps of 0.001 s
Timer Operation:	Integrating with reset time delay of 25 ms
Torque Control:	Configurable through a SELOGIC equation
Pickup Time:	<1.5 cycles
Transient Overreach:	<10%

Instantaneous and Definite-Time Negative-Sequence Overcurrent Element (50Q/67QT)

Number of Elements (Levels):	2
Operating Current:	3I2
Pickup:	1 A Model: 0.05 to 20.00 A secondary in steps of 0.01 A 5 A Model: 0.25 to 100.00 A secondary in steps of 0.01 A
Delay:	0.000 to 10.000 s in steps of 0.001 s
Timer Operation:	Integrating with reset time delay of 25 ms
Torque Control:	Configurable through a SELOGIC equation
Pickup Time:	<1.5 cycles
Transient Overreach:	<10%

Instantaneous and Definite-Time Phase Overcurrent Element (50P/67PT)

Number of Elements (Levels):	2
Operation:	Phase-segregated pickup with common torque control and timer
Pickup:	1 A Model: 0.05 to 20.00 A secondary in steps of 0.01 A 5 A Model: 0.25 to 100.00 A secondary in steps of 0.01 A
Delay:	0.000 to 10.000 s in steps of 0.001 s
Timer Operation:	Integrating with reset time delay of 25 ms
Torque Control:	Configurable through a SELOGIC equation
Pickup Time:	<1.5 cycles
Transient Overreach:	<10%

Instantaneous and Definite-Time Phase Undervoltage Element (27P/27PT)

Number of Elements (Levels):	2
Operation:	Phase-segregated pickup with common torque control and timer
Operating Voltage:	Phase-to-neutral
Pickup:	OFF, 2.00 to 175.00 V secondary in steps of 0.01 V
Delay:	0.000 to 10.000 s in steps of 0.001 s
Timer Operation:	Integrating with reset time delay of 25 ms
Torque Control:	Configurable through a SELOGIC equation
Pickup Time:	<1.5 cycles

Instantaneous and Definite-Time Positive-Sequence Undervoltage Element (27PS/27PST)

Number of Elements (Levels):	2
Operating Voltage:	Positive-sequence
Pickup:	OFF, 2.00 to 175.00 V secondary in steps of 0.01 V
Delay:	0.000 to 10.000 s in steps of 0.001 s
Timer Operation:	Integrating with reset time delay of 25 ms
Torque Control:	Configurable through a SELOGIC equation
Pickup Time:	<1.5 cycles

Instantaneous and Definite-Time Phase Overvoltage Element (59P/59PT)

Number of Elements (Levels):	2
Operation:	Phase-segregated pickup with common torque control and timer
Operating Voltage:	Phase-to-neutral
Pickup:	OFF, 2.00 to 175.00 V secondary in steps of 0.01 V
Delay:	0.000 to 10.000 s in steps of 0.001 s
Timer Operation:	Integrating with reset time delay of 25 ms

Torque Control:	Configurable through a SELOGIC equation
Pickup Time:	<1.5 cycles

Instantaneous and Definite-Time Positive-Sequence Overvoltage Element (59PS/59PST)

Number of Elements (Levels):	2
Operating Voltage:	Positive-sequence
Pickup:	OFF, 2.00 to 175.00 V secondary in steps of 0.01 V
Delay:	0.000 to 10.000 s in steps of 0.001 s
Timer Operation:	Integrating with reset time delay of 25 ms
Torque Control:	Configurable through a SELOGIC equation
Pickup Time:	<1.5 cycles

Instantaneous and Definite-Time Zero-Sequence Overvoltage Element (59G/59GT)

Number of Elements (Levels):	2
Operating Voltage:	3V0
Pickup:	OFF, 2.00 to 300.00 V secondary in steps of 0.01 V
Delay:	0.000 to 10.000 s in steps of 0.001 s
Timer Operation:	Integrating with reset time delay of 25 ms
Torque Control:	Configurable through a SELOGIC equation
Pickup Time:	<1.5 cycles

Instantaneous and Definite-Time Negative-Sequence Overvoltage Element (59Q/59QT)

Number of Elements (Levels):	2
Operating Voltage:	3V2
Pickup:	OFF, 2.00 to 300.00 V secondary in steps of 0.01 V
Delay:	0.000 to 10.000 s in steps of 0.001 s
Timer Operation:	Integrating with reset time delay of 25 ms
Torque Control:	Configurable through a SELOGIC equation
Pickup Time:	<1.5 cycles

Open-Pole Logic

Number of Breakers per Line:	1 or 2
Breaker Operation:	Single-pole or three-pole (per breaker)
Principle of Operation:	Current with 52a position (per breaker) or current with voltage supervision
52a Inputs:	Dedicated SELOGIC equations, including contact inputs and MIRRORED BITS inputs
Current Selection:	IW, IX, or COMB (combined)
Undervoltage Pickup:	1 to 200 V secondary in steps of 1 V
Security Dropout Timer:	0.000 to 1.000 s in steps of 0.001 s

SELOGIC Equations, Latches, and Timers

Equations

Number of Equations:	64

Note: Torque-control inputs, output actuation, timers, latches, and other relevant settings have their own separate equations.

Logical Operations:	AND, OR, NOT, rising edge, falling edge
Number of Inputs:	As many as 15
Parentheses:	As many as 14
Length Limit:	511 characters

Latches

Number of Latches:	16
Operation:	Reset-dominant, nonvolatile
Set and Reset Inputs:	Dedicated equations

Timers

Number of Timers:	16
Pickup Time:	0.0 to 60,000.0 ms in steps of 0.1 ms
Dropout Time:	0.0 to 60,000.0 ms in steps of 0.1 ms
Timing Accuracy:	±(0.2 ms or 1% of the setting, whichever is greater)
Inputs:	Dedicated equations

Metering Accuracy

All metering specifications apply at 20°C and nominal frequency unless otherwise noted.

Current (Local)

Phase Current Magnitude:	±0.2% plus ±0.001 • Inom (0.05 • Inom – 3 • Inom)
Phase Current Angle:	±1° (0.05 • Inom – 0.2 • Inom) ±0.2° (0.2 • Inom – 3 • Inom)
Sequence Current Magnitude:	±0.3% plus ±0.001• Inom (0.05 • Inom – 3 • Inom)
Sequence Current Angle:	±1.5° (0.05 • Inom – 0.2 • Inom) ±0.3° (0.2 • Inom – 3 • Inom)

Voltage

Phase Voltage Magnitude:	±0.2% (5–175 V_{LN})
Phase Voltage Angle:	±0.2° (5–175 V_{LN})
Sequence Voltage Magnitude:	±0.3% (5–175 V_{LN})
Sequence Voltage Angle:	±0.3° (5–175 V_{LN})

Frequency (Input 5—175 V_{LN}, 40—70 Hz)

Accuracy:	±0.001 Hz

Built-In Testing Functions

Loopback Mode for Communications Ports 1, 2, and 3

Purpose:	Troubleshoot a communications channel connected to Port 1, 2, or 3 by allowing the device to receive its own packets while passing the received bits to the downstream logic or substituting them with fail-safe values
Initiation:	SEL ASCII command
Annunciation:	Relay Word bit
Security:	Access Level 2 and time-out

Traveling-Wave Test Mode

Purpose:	Test the line monitoring logic by using only high-frequency signals, without the presence of fundamental-frequency components in currents or voltages
Initiation:	SEL ASCII command
Annunciation:	Relay Word bit
Security:	Access Level 2 and confirmation of the initiating command on the front panel; time-out

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SECTION 2

Fault Locator and Line Monitor

Introduction

The SEL-TWFL is suitable for fault-locating and line monitoring applications on radial, two-terminal, and three-terminal lines. It incorporates an accurate and dependable fault locator that uses the following four fault-locating methods:

- Single-ended TW-based method
- Multi-ended TW-based method
- Single-ended impedance-based method
- Multi-ended impedance-based method

The fault-locating logic makes the best use of data available to the SEL-TWFL for any given fault. If a suitable communications channel is available, the SEL-TWFL uses multi-ended fault-locating methods. Further, if the SEL-TWFL measures current traveling waves (TWs) that are suitable for fault locating, the fault-locating logic uses TW-based methods. The SEL-TWFL reports fault-locating results from all methods and selects the most accurate and reliable result based on the available data. The combination of single-ended and multi-ended methods, as well as TW-based and impedance-based methods, provides the best accuracy and dependability for any combination of operating conditions and fault types.

The TW-based fault-locating methods use current TWs and work well with standard protection CTs. In order to better identify TW reflections, the single-ended TW-based fault-locating method also uses voltage and current phasors and works well with standard protection PTs including CCVTs.

When connected to Port 1, 2, or 3 over the IEEE C37.94-compliant communications channel, the SEL-TWFL uses the multi-ended TW- and impedance-based fault-locating methods. This fault-locating application requires that the device at each line terminal be connected over the IRIG-B input to an external IEEE C37.118-compliant GPS clock with submicrosecond accuracy.

You can apply the SEL-TWFL to overhead lines, cable lines, and hybrid lines with a combination of overhead and cable sections. In applications to hybrid lines, use the multi-ended TW- and impedance-based methods. In applications to series-compensated lines, obtain the best results by using the multi-ended TW-based method. When device-to-device communications is not available, you can apply the SEL-TWFL to multiterminal lines and calculate the TW-based fault location by using custom calculations in your SCADA/HMI software. These calculations use TW time stamps that the SEL-TWFL at each line terminal captures and your SCADA/HMI software can acquire from these devices over a network (see *Example 6: Two-Terminal Overhead Line Without Device-to-Device Communications* on page 6.17 for more information).

The SEL-TWFL reports fault-location results through the following means:

- DNP3
- Header files of the TDR and MHR IEEE COMTRADE records

- Device responses to the SUMMARY and HISTORY commands
- Front-panel HMI

The SEL-TWFL uses the multi-ended TW-based fault-locating method for line monitoring. The line monitoring logic allows you to detect weak spots along the line such as dirty or cracked insulators, incipient cable faults, encroaching vegetation, marginal clearance, or marginal lightning protection (see *Line Monitoring Principle of Operation* on page G.7 for more details on the line monitor operating principle and *Line Monitor* on page 2.27 for information on how to apply and configure this feature). Use this feature to prevent line faults and allow condition-based line maintenance.

Table 2.1 summarizes connection requirements for the SEL-TWFL fault-locating methods. The multi-ended TW-based method over a multiplexed channel offers the best results at the cost of a low-bandwidth digital channel.

Table 2.1 SEL-TWFL Connection Requirements for Fault-Locating Methods and Data

Fault-Locating Method and Data	Instrument Transformers		IEEE C37.94 Communications Channel	External Time Source[a]
	CTs	PTs		
Single-Ended TW-Based Method	✓	✓[b]		
Multi-Ended TW-Based Method	✓		✓[c]	✓
Single-Ended Impedance-Based Method	✓	✓		
Multi-Ended Impedance-Based Method	✓	✓	✓	✓
TW Time Stamps for Multi-Ended TW-Based Offline Fault Locating	✓			✓
Voltage and Current Phasors[d] for Multi-Ended Impedance-Based Offline Fault Locating	✓	✓		

[a] IEEE C37.118-compliant.
[b] Recommended.
[c] One-way channel latency below 30 ms.
[d] Not time-aligned.

Table 2.2 summarizes the fault-locating applications for each of the fault-locating methods. Implement the multi-ended (ME) methods in your SCADA/HMI software by using data obtained from the SEL-TWFL devices over DNP3. Use *Table 2.2* when analyzing, refining, or prioritizing fault locations that you obtained from each of the SEL-TWFL methods before dispatching your line crew.

Table 2.2 SEL-TWFL Fault-Locating Applications (Sheet 1 of 2)

Application B — Best A — Accurate most of the time U — Useful N — Not applicable or returning poor results	Fault-Locating Method					
	SE TW-Based	ME TW-Based	SE Z-Based	ME Z-Based	ME Using TW Time Stamps	ME Using Phasors
Two- and Three-Terminal Overhead Lines	A	B	U	A	B	A
Two- and Three-Terminal Cable Lines	U	B	N	A	B	U
Two-Terminal Hybrid Lines	N	B	U	A	B	U
Two- and Three-Terminal Series-Compensated Lines	A	B	N	U	B	U

Table 2.2 SEL-TWFL Fault-Locating Applications (Sheet 2 of 2)

Application B – Best A – Accurate most of the time U – Useful N – Not applicable or returning poor results	Fault-Locating Method					
	SE TW-Based	ME TW-Based	SE Z-Based	ME Z-Based	ME Using TW Time Stamps	ME Using Phasors
Two- and Three-Terminal Lines With Taps[a]	N	B	N	U	B	U
Multiterminal Lines Without Device-to-Device Communications	U	N	U	N	B	A

[a] Assuming no measurements at the taps.

Configuration Settings Shared Among Multiple Device Functions

Device Configuration Settings

SEL-TWFL configuration includes settings associated primarily with the device itself rather than with any particular function that the device provides. Use general settings to identify the SEL-TWFL as an asset and to enable advanced settings if needed.

Table 2.3 lists the general device settings.

Table 2.3 General Settings

Setting	Description	Range	Default	Class
CONAM	Company Name	Text[a] string as long as 20 characters	CONM	Device
SID	Station Identifier	Text[a] string as long as 40 characters	StationA	Device
FLID	Fault Locator Identifier	Text[a] string as long as 40 characters	SEL-TWFL	Device
NLINE	Number of Lines	1, 2	1	Device
L*m*ID	Line *m* Identifier	Text[a] string as long as 40 characters	L1 230kV StationA – StationB (*m* = 1) L2 230kV StationA – StationB (*m* = 2)	Device
LLUNIT	Line Length Unit	mi, km	mi	Device
EADVS	Enable Access to Advanced Settings	Y, N	N	Device

[a] May include special characters and a space.

Follow these settings rules when configuring the general settings for Line *m* (*m* = 1–2).

CONAM

Follow your company asset-labeling practice and enter a designation for your organization or a region in your organization. The SEL-TWFL uses the CONAM text to identify itself in reports and records and when responding to some SEL ASCII commands.

SID

Follow your company asset-labeling practice and enter a station identifier for the device location. Use informative names for ease of event analysis and accuracy of recordkeeping. The device uses the SID text to identify itself in reports and records and when responding to some SEL ASCII commands. Consider replacing this setting with a generic name if you must anonymize your settings files before sending them to a third party (including SEL).

FLID

Follow your company asset-labeling practice and enter a unique fault locator identifier. Use informative names for ease of event analysis and accuracy of recordkeeping. Consider embedding designations of the monitored line, breaker or breakers, and protection system (main 1 or main 2) that triggers the fault locator in the FLID string. The device uses the FLID text to identify itself in reports and records and when responding to some SEL ASCII commands. Consider replacing this setting with a generic name if you must anonymize your settings files before sending them to a third party (including SEL).

NLINE

Use the NLINE setting to identify the number of lines that the SEL-TWFL is monitoring (1 or 2). If you set NLINE to 1, then the device settings are enabled only for Line 1. To enable Line 1 and Line 2, set NLINE to 2.

L*m*ID

Follow your company asset-labeling practice and enter a unique identifier for Line 1 (L1ID) and Line 2 (L2ID, available if NLINE = 2). Use informative names for ease of event analysis and accuracy of recordkeeping. The device uses the L*m*ID text to identify the line associated with the event summary report available in the header (HDR) files of the MHR and TDR IEEE COMTRADE records and in response to the **SUMMARY (SUM)** command. Consider replacing this setting with a generic name if you must anonymize your settings files before sending them to a third party (including SEL).

LLUNIT

Use the LLUNIT setting to specify your unit of choice for the physical line length as either miles or kilometers.

EADVS

Enable (EADVS = Y) or disable (EADVS = N) access to the advanced SEL-TWFL settings. Advanced settings are settings that apply to a small percentage of applications. The SEL-TWFL advanced settings include the following:

- Line *m* fault locator trigger maximum wait time (L*m*FLMWT)
- Line *m* traveling-wave mode used in the traveling-wave-based fault-locating methods (L*m*MODE)

After you set the advanced settings, you can set EADVS to N to prevent further edits to the advanced settings. When EADVS is set to N, the QuickSet settings software either hides the settings or shows them as noneditable fields (depending on the View/Settings Editor/Hide or Disabled Settings preference).

AC Input Configuration

The fault-locating, line monitoring, metering, and supervisory and triggering functions of the SEL-TWFL require common configuration data related to the ac voltages and currents connected to the device. *Table 2.4* lists the settings related to the ac inputs of the device. Obtain these nameplate values from project files and wiring diagrams.

Table 2.4 AC Input Configuration Settings

Setting	Description	Range	Default	Class
NFREQ	Nominal System Frequency	50, 60 Hz	60	Device
PHROT	System Phase Rotation	ABC, ACB	ABC	Device
CTRW	Current Transformer Ratio	1–50000	200	Device
CTRX	Current Transformer Ratio	1–50000	200	Device
PTRY	Potential Transformer Ratio	1.00–10000.00	2000.00	Device
VNOMY	PT Nominal Secondary Voltage (L-L)	100–250 V secondary	115	Device
PTRZ	Potential Transformer Ratio	1.00–10000.00	2000.00	Device
VNOMZ	PT Nominal Secondary Voltage (L-L)	100–250 V secondary	115	Device

Follow these settings rules when configuring the ac inputs for Line *m* (*m* = 1–2).

NFREQ

Use the NFREQ setting to configure the system nominal frequency (50 or 60 Hz). The device uses the nominal system frequency for phasor measurement when the present system frequency cannot be measured. It also applies various timers that are factory-configured in fractions or multiples of the nominal power system cycle, and it uses the NFREQ setting to calculate the nominal power system cycle duration.

PHROT

Use the PHROT setting to configure the system phase rotation (ABC or ACB). The SEL-TWFL uses this setting to calculate the positive- and negative-sequence voltage and current phasors. Ensure this setting is correct; if not, the positive- and negative-sequence values will be incorrect (swapped).

CTRW

When L*m*I is IW (see *LmI* on page 2.6), use the CTRW setting to specify the Line *m* CT ratio for the secondary current wired to the SEL-TWFL current input IW. Note that all current-dependent functions of the device require this setting. These include fault locating, line monitoring, recording, metering, and supervisory and triggering elements. Specify the CTRW setting, even if you only intend to use the IW current for monitoring or recording purposes (i.e., even when L*m*I = IX).

CTRX

When L*m*I is IX (see *LmI* on page 2.6), use the CTRX setting to specify the Line *m* CT ratio for the secondary current wired to the SEL-TWFL current input IX. Note that all current-dependent functions of the device for Line *m* require this setting. These include fault locating, line monitoring, recording,

metering, and supervisory and triggering elements. Specify the CTRX setting, even if you only intend to use the IX current for monitoring or recording purposes (i.e., even when L*m*I = IW).

PTRY

NOTE: Voltage input VY is a set of three channels with a common neutral (four-wire connection).

When L*m*V is VY (see *LmV* on page 2.7), use the PTRY setting to specify the Line *m* PT ratio for the secondary voltage wired to the SEL-TWFL voltage input VY. Make sure to use this setting value when converting impedance-based settings for Line *m* from primary ohms to secondary ohms.

VNOMY

When L*m*V is VY (see *LmV* on page 2.7), use the VNOMY setting to specify the Line *m* nominal secondary voltage for the PT wired to voltage input VY of the SEL-TWFL. VNOMY is the root-mean-square (rms) line-to-line voltage, even though the device accepts three line-to-neutral voltages through use of a four-wire connection with a common neutral.

PTRZ

NOTE: Voltage input VZ is a set of three isolated voltage channels (six-wire connection with no internal neutral)

When L*m*V is VZ (see *LmV* on page 2.7), use the PTRZ setting to specify the Line *m* PT ratio for the secondary voltage wired to the SEL-TWFL voltage input VZ. Make sure to use this setting value when converting impedance-based settings for Line *m* from primary ohms to secondary ohms.

VNOMZ

When L*m*V is VZ (see *LmV* on page 2.7), use the VNOMZ setting to specify the Line *m* nominal secondary voltage for the PT wired to voltage input VZ of the SEL-TWFL. VNOMZ is the root-mean-square (rms) line-to-line voltage, even though the device accepts three line-to-neutral voltages through use of a six-wire connection with no internal neutral.

Source Selection

L*m*I

Use the L*m*I setting to specify the Line *m* current for fault locating, line monitoring, metering, and supervisory and triggering elements. Typically, you measure the line current directly by using current input IW (L*m*I = IW) or current input IX (L*m*I = IX); see *Figure 9.23*. In dual-breaker applications, wire both breaker currents separately to the IW and IX current inputs, and set L*m*I to COMB to instruct the SEL-TWFL to match ratios and add the input IW and input IX currents for fault locating, line monitoring, and metering; see *Figure 9.24*.

Consider five line terminal configurations as shown in *Figure 2.1*.

The configuration of *Figure 2.1(a)* is a single-breaker application such as single-bus single-breaker or double-bus single-breaker. Connect the line CT to the IW current input of the SEL-TWFL and set the Line *m* current source to IW (L*m*I = IW).

The configuration of *Figure 2.1(b)* is a dual-breaker application such as a breaker-and-a-half, ring-bus, or double-bus double-breaker application. Connect the line CTs individually to the IW and IX current inputs of the SEL-TWFL, and set L*m*I to COMB. The device allows for different CT ratios for the IW and IX inputs, with a maximum mismatch of 1:15. When L*m*I is set to COMB, the effective CT ratio for calculating settings in secondary amperes and ohms is the CT

ratio of input IW or IX, whichever is higher. See *Secondary Current Scaling* on page G.3 for more information on scaling currents measured with CTs of different ratios.

The configuration of *Figure 2.1(c)* is a dual-breaker application with CTs of the same ratio paralleled for a single CT input (typically a retrofit application). Connect the paralleled CTs to the IW current input of the SEL-TWFL and set L*m*I to IW.

The configuration of *Figure 2.1(d)* is a single-breaker application with a line-side reactor. Connect the line CT to the IW current input, connect the reactor CT to the IX current input, and set L*m*I to COMB. Typically, the line and reactor CTs would have different ratios and the device compensates for the CT ratio difference.

The configuration of *Figure 2.1(e)* is similar to that of *Figure 2.1(d)*, except that the line is terminated with two breakers. In this case, parallel the two breaker CTs with the same ratio and connect them to the IW input of the device. Connect the reactor CT to the IX current input and set L*m*I to COMB. Typically, the line and reactor CTs would have different ratios and the device compensates for the CT ratio difference.

SEL strongly discourages using interposing CTs to match the breaker CT ratios, because the interposing CTs may interfere with the traveling-wave-based functions of the SEL-TWFL. Interposing CTs can be considered for matching the reactor CT ratio because the SEL-TWFL does not attempt to measure TWs in the reactor currents.

Figure 2.1 SEL-TWFL Line Terminal Configurations

L*m*V

Use the L*m*V setting to specify the Line *m* voltage for fault locating, line monitoring, metering, and supervisory and triggering elements. In configurations where Line *m* obtains voltages from line-side PTs, wire the PTs to the VY or VZ voltage input on the SEL-TWFL and set the Line *m* voltage source to the respective voltage input (e.g., L1V = VY and L2V = VZ).

Line Configuration

SEL-TWFL fault-locating and line monitoring functions require common configuration data related to the power line. *Table 2.5* lists the Line *m* configuration settings.

Table 2.5 Line Configuration Settings

Setting[a, b]	Description	Range	Default	Class
L*m*NTERM	Number of Terminals	2, 3	2	Device
L*m*NSEC	Number of Sections	1, 2, 3, 4, 5	1	Device
L*m*LL*n*	Section *n* Length	0.01–300.00[c]	40.00	Device
L*m*TWLPT*n*	Section *n* TW Line Propagation Time	10.00–1700.00 µs	219.00	Device
L*m*Z1MAG*n*	Section *n* Positive-Sequence Line Impedance Magnitude	0.05–255.00 Ω secondary[d]	7.80	Device
L*m*Z1ANG*n*	Section *n* Positive-Sequence Line Impedance Angle	30.00–90.00 degrees	84.00	Device
L*m*Z0MAG*n*	Section *n* Zero-Sequence Line Impedance Magnitude	0.05–255.00 Ω secondary[d]	24.80	Device
L*m*Z0ANG*n*	Section *n* Zero-Sequence Line Impedance Angle	30.00–90.00 degrees	81.50	Device
L*m*PORT*n*	Section *n* Fault Locator Data Port	P1, P2, P3, LOCAL, NA	P1 (*m* = 1, *n* = 1) P2 (*m* = 2, *n* = 1) NA (*m* = 1–2, *n* = 2–5)	Device
L*m*RSID*n*	Remote Station Identifier	Text[e] string as long as 40 characters	StationB (*n* = 1) NA (*n* = 2–5)	Device

[a] *m* = 1–2.
[b] *n* = 1–5.
[c] The range shown is in units of miles (LLUNIT = mi). For units of kilometers (LLUNIT = km), the range is 0.01–500.
[d] The ranges and defaults shown are for 5 A-rated CTs. Multiply by 5 for 1 A-rated CTs.
[e] May include special characters and a space.

Follow these settings rules when configuring the power line data for Line *m* (*m* = 1–2 and *n* = 1–5).

L*m*NTERM

NOTE: In dual-line applications, only one of the monitored lines may be a three-terminal line.

Use the L*m*NTERM setting to specify the number of line terminals (2 or 3) for fault locating and line monitoring on Line *m*. Set L*m*NTERM to 2 for radial and two-terminal lines, or set L*m*NTERM to 3 for three-terminal lines.

L*m*NSEC

Use the L*m*NSEC setting to specify the number of sections for Line *m*. For two-terminal lines, set L*m*NSEC to 1 if the line is homogeneous, or set L*m*NSEC to the number of nonhomogeneous sections (as many as five) if the line is a hybrid line comprising overhead and cable sections. For three-terminal lines, the L*m*NSEC setting value is forced to 3; in this case, any of the sections can be a homogeneous overhead line or a homogeneous underground cable.

L*m*LL*n* and L*m*TWLPT*n*

Use the L*m*LL*n* and L*m*TWLPT*n* settings to specify the physical line length (in units specified by the LLUNIT setting) and the TW line propagation time (in microseconds), respectively, of Section *n* on Line *m*.

For two-terminal homogeneous lines, set L*m*LL1 as the entire line length and L*m*TWLPT1 as the entire TW line propagation time between the line terminals.

For two-terminal hybrid lines, enter the line length (L*m*LL*n*) and TW line propagation time (L*m*TWLPT*n*) for each Section *n*. Apply the same Section *n* line length and TW line propagation time settings in the SEL-TWFL at each line terminal (see *Example 5: Two-Terminal Hybrid Line* on page 6.14).

For three-terminal lines, set L*m*LL*n* as the line length and L*m*TWLPT*n* as the TW line propagation time for each Section *n* between the respective line terminal and the tap point. Use the same Section *n* line length and TW line propagation time settings in the SEL-TWFL at each line terminal (see *Example 4: Three-Terminal Overhead Line* on page 6.10).

The SEL-TWFL allows a maximum of 300 miles or 500 kilometers (depending on the LLUNIT value) between any two Line *m* terminals. Additionally, the length between any two Line *m* terminals is limited to 1700 μs of TW line propagation time.

L*m*Z1MAG*n* and L*m*Z0MAG*n*

Use the L*m*Z1MAG*n* and L*m*Z0MAG*n* settings to specify the magnitudes of the positive- and zero-sequence line impedances for Section *n* on Line *m* in secondary ohms at the nominal system frequency. When converting primary ohms to secondary ohms, use the PT ratio based on the L*m*V setting (L*m*PTRY if L*m*V = VY or L*m*PTRZ if L*m*V = VZ) and the effective CT ratio based on the L*m*I setting (L*m*CTRW if L*m*I = IW, L*m*CTRX if L*m*I = IX, or max(L*m*CTRW, L*m*CTRX) if L*m*I = COMB).

For two-terminal homogeneous lines, set L*m*Z1MAG*n* as the entire positive-sequence impedance and L*m*Z0MAG*n* as the entire zero-sequence impedance between the line terminals.

For two-terminal hybrid lines, enter the positive- and zero-sequence impedance for each Section *n*. Use the same Section *n* positive- and zero-sequence impedance settings in the SEL-TWFL at each line terminal (see *Example 5: Two-Terminal Hybrid Line* on page 6.14).

For three-terminal lines, set L*m*Z1MAG*n* and L*m*Z0MAG*n* as the positive- and zero-sequence impedances, respectively, for Section *n* between each line terminal and the tap point. Use the same Section *n* positive- and zero-sequence impedance settings in the SEL-TWFL at each line terminal (see *Example 4: Three-Terminal Overhead Line* on page 6.10).

L*m*Z1ANG*n* and L*m*Z0ANG*n*

Use the L*m*Z1ANG*n* and L*m*Z0ANG*n* settings to specify the angles of the positive- and zero-sequence line impedances for Section *n* on Line *m* in electrical degrees at the nominal system frequency.

For two-terminal homogeneous lines, set L*m*Z1ANG*n* as the angle of the entire positive-sequence impedance and L*m*Z0ANG*n* as the angle of the entire zero-sequence impedance between the line terminals.

For two-terminal hybrid lines, enter the angle of the positive- and zero-sequence impedance for each Section *n*. Apply the same Section *n* positive- and zero-sequence impedance angle settings in the SEL-TWFL at each line terminal (see *Example 5: Two-Terminal Hybrid Line* on page 6.14).

For three-terminal lines, set L*m*Z1ANG*n* and L*m*Z0ANG*n* as the angle of the positive- and zero-sequence impedances, respectively, for Section *n* between each line terminal and the tap point. Use the same Section *n* positive- and zero-sequence impedance angle settings in the SEL-TWFL at each line terminal (see *Example 4: Three-Terminal Overhead Line* on page 6.10).

L*m*PORT*n*

NOTE: In radial-line applications, set L*m*PORT*n* to NA (*m* = 1–2, *n* = 1–5).

Select the communications port to receive the fault-locating data from the remote SEL-TWFL on Section *n* of Line *m*. Remember to enable the selected port and configure it for IEEE C37.94 encoding (ENCODING = C37.94). To use an IEEE C37.94-compliant multiplexed channel for fault locating, the one-way channel latency must be below 30 ms.

For two-terminal homogeneous lines, set L*m*PORT1 to P1, P2, or P3, depending on which port you provisioned to connect to the SEL-TWFL at the other line terminal (see *Example 1: Two-Terminal Overhead Line (Single Breaker)* on page 6.2).

For two-terminal hybrid lines, configure the SEL-TWFL associated with Section 1 to have L*m*PORT1 set to LOCAL and L*m*PORT*n* set to P1, P2, or P3 for Section *n*, where *n* is the value of the L*m*NSEC setting. Similarly, configure the SEL-TWFL associated with Section *n* to have L*m*PORT*n* set to LOCAL and L*m*PORT1 set to P1, P2, or P3 (see *Example 5: Two-Terminal Hybrid Line* on page 6.14).

For three-terminal lines, configure the SEL-TWFL associated with Section 1 to have L*m*PORT1 set to LOCAL and L*m*PORT2 and L*m*PORT3 set to P1, P2, or P3, depending on which port you provisioned to connect to each SEL-TWFL that is associated with Section 2 and Section 3, respectively. Similarly, configure the SEL-TWFL associated with Section 2 to have L*m*PORT2 set to LOCAL and L*m*PORT1 and L*m*PORT3 set to P1, P2, or P3, depending on which port you provisioned to connect to each SEL-TWFL associated with Section 1 and Section 3, respectively. Similarly, configure the SEL-TWFL associated with Section 3 to have L*m*PORT3 set to LOCAL and L*m*PORT1 and L*m*PORT2 set to P1, P2, or P3, depending on which port you provisioned to connect to each SEL-TWFL that is associated with Section 1 and Section 2, respectively (see *Example 4: Three-Terminal Overhead Line* on page 6.10).

L*m*RSID*n*

Use the L*m*RSID*n* setting to identify the remote station on Section *n* of Line *m*.

Breaker Monitor

Use the SEL-TWFL breaker monitor to configure parameters related to the breaker(s) at the local line terminal, including the number of breakers (one or two), type of breaker mechanism (operating each pole independently or operating all three poles together), and present breaker position (open or closed). The device requires this information to detect an open-pole condition (see *Open-Pole Detection* on page 2.12). The open-pole detection logic supervises fault locating and line monitoring, and therefore you must configure the breaker monitor and open-pole detection logic before using the fault locator.

Table 2.6 and *Table 2.7* list the settings and Relay Word bits associated with the SEL-TWFL breaker monitor.

Table 2.6 Breaker Monitor Settings (Sheet 1 of 2)

Setting[a, b]	Description	Range	Default	Class
L*m*BNUM	Number of Breakers	1, 2	1	Device
L*m*B*n*TYPE	Breaker *n* Mechanism Type	SINGLE-POLE, THREE-POLE	THREE-POLE	Device
L*m*B*n*A52A	Breaker *n* Phase A 52a Status Input SELogic Equation	SELogic Expression	IN201 (*n* = 1) 0 (*n* = 2)	Device

Table 2.6 Breaker Monitor Settings (Sheet 2 of 2)

Setting[a, b]	Description	Range	Default	Class
L*m*B*n*B52A	Breaker *n* Phase B 52a Status Input SELogic Equation	SELogic Expression	L*m*B*n*A52A	Device
L*m*B*n*C52A	Breaker *n* Phase C 52a Status Input SELogic Equation	SELogic Expression	L*m*B*n*A52A	Device

[a] *m* = 1–2.
[b] *n* = 1–2.

Table 2.7 Breaker Monitor Relay Word Bits

Relay Word Bit[a, b]	Description
L*m*B*n*A52A	Line *m* Breaker *n* Phase A 52a status
L*m*B*n*B52A	Line *m* Breaker *n* Phase B 52a status
L*m*B*n*C52A	Line *m* Breaker *n* Phase C 52a status

[a] *m* = 1–2.
[b] *n* = 1–2.

Follow these settings rules when configuring the breaker monitor for Line *m* (*m* = 1–2 and *n* = 1–2).

L*m*BNUM

Use the L*m*BNUM setting to identify the number of breakers on Line *m* at the local line terminal. Set L*m*BNUM to 1 if Line *m* is terminated with a single breaker, such as in single-bus single-breaker or double-bus single-breaker bus configurations. Set L*m*BNUM to 2 if Line *m* is terminated with two breakers, such as in breaker-and-a-half, ring-bus, or double-bus double-breaker bus configurations. If you set L*m*BNUM to 1, then you will need to provide the 52a auxiliary contact signal(s) for one breaker. If you set L*m*BNUM to 2, then you will need to provide the 52a auxiliary contact signals for two breakers. SEL recommends monitoring each breaker individually in dual-breaker applications for the benefit of event analysis and for the ease of accommodating the breaker out-of-service condition. If, however, you do not monitor each breaker individually, then you should set L*m*BNUM to 1 and provide the 52a auxiliary contact signal that represents the closed state of either of the two breakers (wire the 52a auxiliary contacts of the two breakers in parallel).

L*m*B*n*TYPE

Use the L*m*B1TYPE and L*m*B2TYPE (available if L*m*BNUM = 2) to select the breaker mechanism type for Breaker 1 and Breaker 2, respectively. Set L*m*B*n*TYPE to THREE-POLE if Breaker *n* on Line *m* has one mechanism operating all three poles. Set L*m*B*n*TYPE to SINGLE-POLE if Breaker *n* on Line *m* has three independent mechanisms each operating one pole of the breaker. If you set L*m*B*n*TYPE to THREE-POLE, then the SEL-TWFL expects you to provide one 52a auxiliary contact signal for Breaker *n*. The SEL-TWFL will use this signal as a position signal for Poles A, B, and C. If you set L*m*B*n*TYPE to SINGLE-POLE, then the SEL-TWFL expects you to provide three 52a auxiliary contact signals for Breaker *n*, each representing a position signal for one pole of the breaker.

L*m*B*n*A52A, L*m*B*n*B52A, and L*m*B*n*C52A

Use the L*m*B*n*A52A, L*m*B*n*B52A, and L*m*B*n*C52A SELOGIC equations to program the Line *m* Breaker *n* 52a auxiliary contact signals for Poles A, B, and C, respectively. If you set L*m*B*n*TYPE to THREE-POLE, you only need to config-

ure the L*m*B*n*A52A SELOGIC equation (the SEL-TWFL uses the L*m*B*n*A52A auxiliary contact signal as a shared position signal for all three poles of the breaker).

Use contact inputs or an SEL remote I/O module connected on Port 1, 2, or 3 to acquire the 52a auxiliary contact signals. Also, using the L*m*B*n*A52A, L*m*B*n*B52A, and L*m*B*n*C52A SELOGIC equations, you can force the Breaker *n* position signals to logical 0 (breaker open) during an out-of-service condition of one of the breakers in a dual-breaker application.

Open-Pole Detection

NOTE: When testing the device, make sure to apply coherent input signals (voltages, currents, and 52a auxiliary contact signals) that realistically represent breaker position. Otherwise, you may see unexpected test results because of interference from the open-pole logic.

Use the open-pole detection logic to determine if Line *m* (*m* = 1–2) is connected or disconnected from the local bus. The SEL-TWFL supervises fault locating and line monitoring on Line *m* with the open-pole bits for the respective line.

The open-pole detection logic (*Figure 2.2*) operates in one of two modes. When configured for L*m*OPMODE = 52, the logic declares an open-pole condition if the line current is below 2 percent of the nominal current (INOM) and the 52a auxiliary contact signal is deasserted. In dual-breaker applications, both breakers must be open for the open-pole detection logic to declare an open pole. When configured for L*m*OPMODE = V, the logic declares an open-pole condition if the line current is below 2 percent of INOM and the line voltage in a corresponding phase is below the L*m*OP27 threshold.

Figure 2.2 Open-Pole Detection Logic

The open-pole detection logic detects the undercurrent condition for the line current you specified by using the L*m*I setting (see *Figure 2.1* for examples). In applications with a line-side shunt reactor, you can exclude the reactor current from the line current by using the L*m*I setting, provided you wired the reactor current to the SEL-TWFL separately from the breaker current.

If configured for L*m*OPMODE = 52, the open-pole detection logic uses the 52a auxiliary contact signal as configured in the breaker monitor (see *Breaker Monitor* on page 2.10). If configured for L*m*OPMODE = V, the open-pole detection logic uses the magnitude of the line voltage you specified by using the L*m*V setting.

NOTE: SEL strongly recommends using the 52a auxiliary contact signals for open-pole detection (L*m*OPMODE = 52).

Remember that if L*m*OPMODE is configured to V, the open-pole Relay Word bits may deassert even if the breaker is open. If you used line-side PTs to obtain the voltages, the open-pole bits will deassert when the line is energized from the remote line terminal. If you used bus-side PTs to obtain the voltages, the open-pole bits will not assert at all if you set L*m*OPMODE to V.

For each line, the open-pole logic operates on a per-phase basis and asserts the L*m*OPA, L*m*OPB, and L*m*OPC Relay Word bits. The logic asserts the L*m*_3PO Relay Word bit to indicate that all three poles are open. The L*m*APO Relay Word bit signifies the any-pole-open condition. The SEL-TWFL uses the L*m*APO Relay Word bit to supervise line monitoring.

Table 2.8 and *Table 2.9* list the settings and Relay Word bits associated with the SEL-TWFL open-pole detection logic.

Table 2.8 Open-Pole Detection Settings

Setting[a]	Description	Range	Default	Class
L*m*OPMODE	Open-Pole Detection Mode	52, V	52	Device
L*m*OP27	Open-Pole Detection Undervoltage Threshold (L-N)	1–200 V secondary	40	Device

[a] *m* = 1–2.

Table 2.9 Open-Pole Relay Word Bits

Relay Word Bit[a]	Description
L*m*OPA	Pole A opened on Line *m*
L*m*OPB	Pole B opened on Line *m*
L*m*OPC	Pole C opened on Line *m*
L*m*_3PO	Three poles opened on Line *m*
L*m*APO	Any pole opened on Line *m*

[a] *m* = 1–2.

Follow these settings rules when configuring the open-pole detection logic for Line *m* (*m* = 1–2).

L*m*OPMODE

NOTE: SEL strongly recommends using the 52a auxiliary contact signals for open-pole detection (L*m*OPMODE = 52).

Use the L*m*OPMODE setting to select the supervisory condition for the undercurrent condition in the open-pole detection logic. Set L*m*OPMODE to 52 if you use the 52a auxiliary contact signals for supervising the undercurrent condition. Set L*m*OPMODE to V if you use line voltage for supervising the undercurrent condition.

L*m*OP27

NOTE: For consistency with all voltage settings, the L*m*OP27 setting is in secondary volts and not per unit of the nominal voltage. Make sure to set the L*m*OP27 setting considering the nominal voltage setting and PT ratio setting for Line *m*.

Use the L*m*OP27 setting to specify the undervoltage threshold when supervising the undercurrent condition with an undervoltage condition in the open-pole detection logic (L*m*OPMODE = V). The open-pole bits will deassert, declaring that the breaker is closed, if the voltage is above the L*m*OP27 threshold. Consider the impact of ring-down voltages that may occur after tripping the protected line, and avoid setting L*m*OPMODE to V, especially in single-pole tripping applications because of the line-side arc-suppressing reactors that cause a voltage ring-down effect.

Fault Locator

Fault Locator Application and Settings

You must configure the following settings in fault-locating applications. These settings are described in *Configuration Settings Shared Among Multiple Device Functions* on page 2.3:

- Number of lines and line length unit (NLINE, LLUNIT)
- Line current source selection and CT ratios (L*m*I, CTRW, CTRX)
- Line voltage source selection and PT ratios (L*m*V, PTRY, PTRZ)
- Nominal voltage, frequency, and system phase rotation (VNOMY, VNOMZ, NFREQ, PHROT)
- Number of terminals and sections (L*m*NTERM, L*m*NSEC)
- Section *n* length and TW line propagation time (L*m*LL*n*, L*m*TWLPT*n*)
- Section *n* positive- and zero-sequence impedances (L*m*Z1MAG*n*, L*m*Z1ANG*n*, L*m*Z0MAG*n*, L*m*Z0ANG*n*)
- Section *n* fault locator data port for multi-ended methods (L*m*PORT*n*)
- Remote station identifier (L*m*RSID*n*)

You must also configure the fault locator settings that are listed in *Table 2.10*.

Table 2.10 Fault Locator Settings

Setting[a]	Description	Range	Default	Class
L*m*FL	Line *m* Fault Locator Trigger SELogic Equation	SELogic Expression	0	Device
L*m*FLMWT	Line *m* Fault Locator Trigger Maximum Wait Time	50–100 ms	100	Device
L*m*TWCPT	Line *m* TW CT Cable Propagation Time	0.000–10.000 µs	0.000	Device
L*m*MODE[b]	Line *m* TW Mode	PHASE, CLARKE	CLARKE	Device

[a] *m* = 1–2.
[b] Advanced setting: set EADVS = Y to gain access to the advanced settings.

Follow these settings rules when configuring the fault locator for Line *m* (*m* = 1–2).

L*m*FL

Configure the Line *m* fault locator trigger by programming the L*m*FL SELOGIC equation. Use a contact input or a MIRRORED BITS input to trigger on trip signals from the line protective relays. When you use the line monitor, the fault locator trigger assertion signals the line monitoring logic that the event is a fault and not a low-energy event. Do not include the L*m*TWIDD or L*m*TWDD Relay Word bit in the L*m*FL SELOGIC equation when using the line monitor to detect low-energy events (L*m*ELM = YE).

L*m*FLMWT

Configure the Line *m* fault locator trigger maximum wait time (L*m*FLMWT) to the maximum duration the fault locator should wait to receive the trigger condition from the line protective relay. L*m*FLMWT is an advanced setting, and the factory default of 100 ms is suitable for most applications. Consider increasing

the value of the L*m*FLMWT setting in applications where the fault locator trigger signal may take longer than 100 ms, such as line protection that uses inverse-time overcurrent elements or step-distance protection.

L*m*TWCPT

Use the Line *m* TW CT cable propagation time setting (L*m*TWCPT) to increase the accuracy of the multi-ended TW-based fault-locating method by compensating for the time delay that the CT secondary cables introduce. Calculate the time delay by dividing the CT secondary cable length by the TW propagation velocity in your CT control cable (typically considerably slower than the speed of light in free space). You can use about 70 percent of the speed of light in free space to approximate the propagation velocity in control cables. For better results, consult your cable data sheet or contact the manufacturer to obtain the propagation velocity or measure the velocity for any given cable type by using time-domain reflectometry.

Only the multi-ended TW-based fault-locating method benefits from the CT secondary cable compensation. Further, the compensation is not needed if the SEL-TWFL at each line terminal uses CT cables with the same propagation time (i.e., similar cable types with similar lengths). Assuming the TW propagation velocity for cables to be 70 percent of the speed of light in free space, 50 m of difference in CT cable length between line terminals may result in 36 m of fault-location error for the multi-ended TW-based fault-locating method on an overhead line.

For best results in dual-breaker applications, use the same CT cable length for both CTs. If you have unequal CT cable lengths, use the average length of the two CT cables when calculating the TW CT cable propagation time setting value.

Fault-location results reported by the single-ended TW-based fault-locating method, the single-ended impedance-based fault-locating method, or the multi-ended impedance-based fault-locating method are unaffected by the CT cable delay.

L*m*MODE

Use the L*m*MODE setting to instruct the TW-based fault-locating methods on Line *m* to use either Clarke mode components, as is customary for overhead conductors that mutually couple, or phase components, as is customary for conductors that do not couple, such as some cables.

Follow these rules to determine the L*m*MODE setting for the TW-based fault-locating methods:

- Set L*m*MODE to CLARKE for overhead lines and for hybrid lines where the cable sections consist of three single-phase conductors in a common shield.
- Set L*m*MODE to PHASE for cable lines consisting of single-phase cables with individual shields.
- Contact SEL for recommendations and analysis on how to set L*m*MODE for hybrid lines with overhead and cable sections.

Fault-Locating Methods

Multi-Ended Traveling-Wave-Based Method

Principle of Operation

The SEL-TWFL provides multi-ended TW-based fault locating for two- and three-terminal lines. This section first describes the method used for two-terminal lines and then explains how it is applied to three-terminal lines.

Figure 2.3 shows a Bewley diagram for a fault at location F on a two-terminal homogeneous line of length LL. The fault is M distance (mi or km) away from the local terminal (S) and $LL - M$ distance (mi or km) away from the remote terminal (R). The TW propagation velocity (PV) for the line is $LL/TWLPT$ (LL and TWLPT are the total line length and the TW line propagation time, respectively).

NOTE: The multi-ended TW-based method works with an IEEE C37.94-compliant multiplexed channel on Port 1, 2, or 3, according to the L*m*PORT*n* setting (*m* = 1–2, *n* = 1–5). You must connect each SEL-TWFL via the IRIG-B input to an IEEE C37.118-compliant GPS clock with submicrosecond accuracy to obtain an absolute time reference.

Figure 2.3 Bewley Diagram Explaining Multi-Ended TW-Based Fault-Locating Method

The first TW arrives at the local terminal (S) at $t_S = M/PV$ time. The first TW arrives at the remote terminal (R) at $t_R = (LL - M)/PV$ time. Solving these two equations for fault location M, we obtain the multi-ended TW-based fault-locating method for two-terminal lines:

$$M = \frac{LL}{2}\left(1 + \frac{t_S - t_R}{TWLPT}\right) \qquad \textbf{Equation 2.1}$$

The SEL-TWFL multi-ended TW-based fault-locating method compensates for the CT cable delay between the CTs and the SEL-TWFL by backdating the TW time stamps through use of the TWCPT local and remote settings as follows:

$$\begin{aligned} M &= \frac{LL}{2}\left(1 + \frac{(t_S - TWCPT_S) - (t_R - TWCPT_R)}{TWLPT}\right) \\ &= \frac{LL}{2}\left(1 + \frac{(t_S - t_R) - (TWCPT_S - TWCPT_R)}{TWLPT}\right) \end{aligned} \qquad \textbf{Equation 2.2}$$

Equation 2.2 teaches that the multi-ended TW-based fault-location result is affected not by the individual CT cable delays but by the difference in the CT cable delays at both line terminals. The CT cable compensation becomes marginally important if the two CT cable delays are similar.

The multi-ended TW-based fault-locating method for two-terminal lines uses *Equation 2.2*, which uses the following parameters and measurements:

LL = line length in mi or km, provided as a line configuration setting, L*m*LL1.

TWLPT = TW line propagation time provided as a line configuration setting, L*m*TWLPT1 (SEL recommends measuring this value rather than calculating it. See *Section 10: Testing and Commissioning* for more information).

TWCPT = TW CT cable propagation time provided as a fault locator setting, L*m*TWCPT. The remote SEL-TWFL communicates its TW CT cable propagation time setting over the communications channel.

$t_S - t_R$ = difference between the arrival time of the first current TW at the local and remote line terminals, respectively. This time difference calculation is accurate as long as the two SEL-TWFL devices are synchronized to the common time reference by using satellite clocks connected through the IRIG-B inputs.

When applied to two-terminal nonhomogeneous lines, the multi-ended TW-based fault-locating method accurately locates faults along the line. The method first uses the total line length, the total TW line propagation time, and the relative arrival time for the TWs at the local and remote terminals to calculate the fault location by using *Equation 2.2*. The method then compensates for line nonhomogeneity by using the resulting location and the values you configured for the L*m*LL*n* and L*m*TWLPT*n* settings to calculate the actual fault location[1].

The following description explains how the multi-ended TW-based method for two-terminal lines is applied to three-terminal lines. *Figure 2.4* shows a three-terminal line with Terminals R, S, and T and Tap Point P. The figure lists the lengths and TW line propagation times for each section of the line. The time stamps of the first current TWs at each terminal are t_R, t_S, and t_T, respectively.

Figure 2.4 Multi-Ended TW-Based Fault-Locating Method Explanation for Three-Terminal Lines

The multi-ended TW-based fault-locating method for three-terminal lines identifies the faulted line segment and reports the fault location from the terminal associated with the faulted line segment. It uses the multi-ended method for two-terminal lines to calculate the fault location between each pair of terminals (M'). This calculation uses the TW arrival times at each line terminal, along with the sum of line section lengths and the sum of TW propagation times for the line sections between the two respective terminals, in *Equation 2.2*. The method performs the calculation for all six combinations of local and remote terminals: M'_{RS}, M'_{RT}, M'_{TR}, M'_{TS}, M'_{SR}, and M'_{ST}. The following equations show the fault-location calculations with respect to Terminal R as the local terminal. The equations with respect to Terminal S and Terminal T as the local terminal are similar.

$$M'_{RS} = \frac{LLR + LLS}{2}\left(1 + \frac{t_R - t_S}{TWLPTR + TWLPTS}\right)$$

$$M'_{RT} = \frac{LLR + LLT}{2}\left(1 + \frac{t_R - t_T}{TWLPTR + TWLPTT}\right)$$

[1] B. Kasztenny, A. Guzmán, M. V. Mynam, and T. Joshi, "Locating Faults Before the Breaker Opens – Adaptive Autoreclosing Based on the Location of the Fault," proceedings of the 71st Annual Conference for Protective Relay Engineers (CPRE), College Station, TX, March 2018. Available at selinc.com.

Note that lengths LLR, LLS, and LLT are provided to the SEL-TWFL as settings, L*m*LL1, L*m*LL2, and L*m*LL3, respectively. Similarly, TW propagation times TWLPTR, TWLPTS, and TWLPTT are provided as settings, L*m*TWLPT1, L*m*TWLPT2, and L*m*TWLPT3, respectively.

The method then identifies which two of the six fault-location values are the same. If $M'_{RS} \approx M'_{RT}$, then the fault is on the RP line segment and the fault location (M) from Terminal R is the average value as follows:

$$M = \frac{1}{2}(M'_{RS} + M'_{RT})$$

If $M'_{TR} \approx M'_{TS}$, then the fault is on the TP line segment and the fault location (M) from Terminal T is the average value as follows:

$$M = \frac{1}{2}(M'_{TR} + M'_{TS})$$

If $M'_{SR} \approx M'_{ST}$, then the fault is on the SP line segment and the fault location (M) from Terminal S is the average value as follows:

$$M = \frac{1}{2}(M'_{SR} + M'_{ST})$$

The SEL-TWFL measures current TWs by using a differentiator-smoother filter (see *Signal Processing* on page G.4). The TW-based fault-locating methods work with TW samples taken every microsecond and apply a time-stamping algorithm that uses interpolation to achieve time-stamping resolution of approximately 0.1 µs.

The multi-ended TW-based fault-locating method works with either the Clarke mode components (L*m*MODE = CLARKE) or phase components (L*m*MODE = PHASE). In applications that use Clarke mode components, the fault-locating logic selects the mode with the greatest TW magnitude for time-stamping. In applications that use phase components, the fault-locating logic selects the phase with the greatest TW magnitude for time-stamping.

The multi-ended TW-based method uses the first current TWs. The logic defines the first TWs as those that precede the L*m*TWDD Relay Word bit assertion and have a magnitude that is greater than half of the maximum magnitude of all TWs captured for Line *m* within the TW data collection period of approximately twice the L*m*TWLPT*n* setting value. For two-terminal homogeneous lines, L*m*TWLPT*n* is the entire TW line propagation time; for two-terminal nonhomogeneous and three-terminal lines, L*m*TWLPT*n* is the TW line propagation time of Section *n* associated with the local SEL-TWFL.

Accuracy Analysis

Use *Equation 2.2* to determine the sensitivity of the multi-ended TW-based fault-locating method to settings and time-stamping errors. Expect the following sensitivities to errors:

- A 1 percent error in the LL setting results in a 1 percent error in the fault location.
- A 1 µs error in the TWLPT setting results in a fault-locating error of as much as 150 m (500 ft) for overhead lines and as much as 75 m (250 ft) for cable lines.

- A 0.1 µs error in the TWCPT setting results in about a 15 m (50 ft) error in the fault location on overhead lines and about a 7.5 m (25 ft) error on cable lines.
- A 0.1 µs error in SEL-TWFL time-stamping results in about a 15 m (50 ft) error in the fault location on overhead lines and about a 7.5 m (25 ft) error on cable lines.

Expect the line sag to be about 0.3 percent of the line length. The sag changes with ambient temperature and line loading, resulting in line length changes of a fraction of 0.3 percent. As a result of line sag, you may expect an extra fault-locating error of a fraction of 0.3 percent.

Minimize errors in the L*m*TWLPT*n* settings by measuring the propagation time during the SEL-TWFL commissioning (see *Section 10: Testing and Commissioning*). Improve line length data (L*m*LL*n* setting) accuracy by correlating reported fault locations with confirmation of locations by your line crews. Approximate the CT cable lengths and enter expected L*m*TWCPT settings to account for TW propagation time between the CTs and the SEL-TWFL.

The SEL multi-ended TW-based fault-locating method for two-terminal lines has a field-proven track record obtained through the use of the SEL-411L Advanced Line Differential Protection, Automation, and Control System, the SEL-T400L Time-Domain Line Protection, and the SEL-T401L Ultra-High-Speed Line Relay with reported errors within one tower span (300 m; 1,000 ft) on average.

When tested under ideal conditions of accurate settings and steep current signals representing TWs, the SEL-TWFL multi-ended TW-based fault-locating method yields a 90th percentile error of less than 20 m (66 ft) and a median error of less than 10 m (33 ft).

Single-Ended Traveling-Wave-Based Method

Principle of Operation

Figure 2.5 shows a Bewley diagram for a fault at location F on a line of length LL. The fault is M distance (mi or km) away from the local terminal (S) and $LL - M$ distance (mi or km) away from the remote terminal (R). Consider the bus (B) behind the local terminal (S) to be a bus terminating a line connected to the local terminal.

A current TW launched at the fault point (F) arrives at the local terminal (S) at t_1. Part of it reflects, travels back toward the fault, reflects back from the fault, and then returns to the local terminal (S) at t_4. During the $t_4 - t_1$ time interval, the TW traveled a distance of $2 \bullet M$.

Figure 2.5 Bewley Diagram Explaining Single-Ended TW-Based Fault-Locating Method

We write the distance-velocity-time equation as follows:

$$2 \bullet M = (t_4 - t_1) \bullet PV \qquad \textbf{Equation 2.3}$$

where the propagation velocity, PV, is:

$$PV = \frac{LL}{TWLPT} \qquad \textbf{Equation 2.4}$$

Substituting *Equation 2.4* into *Equation 2.3*, and solving for M, we obtain the single-ended TW-based fault-locating method:

$$M = \frac{(t_4 - t_1)}{2 \bullet TWLPT} \bullet LL \qquad \textbf{Equation 2.5}$$

Note that LL and TWLPT are provided to the SEL-TWFL as settings, L*m*LL1 and L*m*TWLPT1, respectively. The method shown in *Equation 2.5* uses only local time stamps and is therefore immune to errors in time alignment between the local and the remote SEL-TWFL.

The method works well if it correctly identifies the first return from the fault (TW at time t_4). *Figure 2.5* shows that the first TW that arrived at time t_1 continued toward the bus (B), reflected from the bus, and then returned to the local terminal at time t_2. If the method mistook the arrival at time t_2 for the time of the first return from the fault, the fault-location result would be entirely incorrect. Similarly, the first TW that arrived at the remote terminal (R) reflects from the bus and returns to the local terminal (S), propagating through the fault point (F). This TW arrives at the local terminal at time t_3. If the method mistook the arrival at time t_3 for the time of the first return from the fault, the fault-location result would similarly be entirely incorrect.

The SEL-TWFL single-ended TW-based fault-locating method solves this challenge by applying the following techniques:

- The single-ended TW-based fault-locating method uses available fault-location results from the other three fault-locating methods to narrow down the fault location and calculate the expected time of the first return from the fault.
- The method considers several alternatives for the fault location and evaluates them for plausibility. For example, with reference to *Figure 2.5*, the method assumes that arrivals at times t_2, t_3, and t_4 are possible first returns from the fault and calculates three possible fault locations.
- The method generates time stamps of expected TWs for any given plausible fault location. For example, with reference to *Figure 2.5*, when evaluating the alternative of time t_4 as the first return from the fault, the method expects to measure TWs at time t_3 (first return from the remote terminal) and time t_5 (reflection of the first TW from the local bus traveling to the remote terminal and returning).
- The method ranks the alternative fault locations based on how well they fit the actual TW pattern that the SEL-TWFL measures. The method reports both the best alternative and the three highest-ranking alternatives, if they are available.

The single-ended TW-based fault-locating method uses identical signal processing to the multi-ended TW-based fault-locating method, including selecting the mode and precise time-stamping via interpolation. The single-ended TW-based fault-locating method is not affected by the CT cable TW propagation time because these delays mutually cancel in the time difference used in *Equation 2.5*.

When applied to two-terminal nonhomogeneous lines and three-terminal lines, the single-ended TW-based fault-locating method locates faults only in the first line section that is associated with the SEL-TWFL.

Accuracy Analysis

Use *Equation 2.5* to determine the sensitivity of the single-ended TW-based fault-locating method to settings and time-stamping errors. Expect the following sensitivities to errors:

- A 1 percent error in the LL setting results in a 1 percent error in the fault location.
- A 1 µs error in the TWLPT setting results in a fault-locating error of as much as 300 m (1,000 ft) for overhead lines and as much as 150 m (500 ft) for cable lines.

When tested under ideal conditions with accurate settings and steep current signals representing TWs, the single-ended TW-based fault-locating method yields a 90th percentile error of less than 20 m (66 ft) and a median error of less than 10 m (33 ft).

Multi-Ended Impedance-Based Method

Principle of Operation

The SEL-TWFL provides multi-ended impedance-based fault locating for two- and three-terminal lines. This section first describes the method used for two-terminal lines and then explains how it is applied to three-terminal lines.

NOTE: The multi-ended impedance-based method works with IEEE C37.94-compliant multiplexed channels on Port 1, 2, or 3, according to the L*m*PORT*n* setting (*m* = 1–2, *n* = 1–5). You must connect each SEL-TWFL via the IRIG-B input to an IEEE C37.118-compliant GPS clock with submicrosecond accuracy to obtain an absolute time reference.

The SEL-TWFL multi-ended impedance-based fault-locating method for two-terminal lines is based on the principle of the negative-sequence voltage profile along the faulted line. For three-phase balanced faults, the method uses the positive-sequence voltage profile. This method is used in ACSELERATOR TEAM SEL-5045 Software for fault locating on two-terminal transmission lines and has good field results.

Figure 2.6 shows a negative-sequence voltage profile for a fault at location F on a line of length LL. The fault is M distance (mi or km) away from the local terminal (S) and LL – M distance (mi or km) away from the remote terminal (R).

Figure 2.6 Negative-Sequence Voltage Profile Explaining Multi-Ended Impedance-Based Fault-Locating Method

The negative-sequence voltage at the fault location (V_{2F}) in terms of the Terminal S voltage and current is:

$$V_{2F} = V_{2S} - \frac{M}{LL} \bullet Z_1 \bullet I_{2S} \qquad \textbf{Equation 2.6}$$

The negative-sequence voltage at the fault location (V_{2F}) in terms of the Terminal R voltage and current is:

$$V_{2F} = V_{2R} - \frac{LL - M}{LL} \bullet Z_1 \bullet I_{2R} \qquad \textbf{Equation 2.7}$$

Comparing *Equation 2.6* and *Equation 2.7* and solving for M, we obtain the following equation:

$$M = LL \bullet \mathrm{Re}\left(\frac{(V_{2S} - V_{2R}) + Z_1 \bullet I_{2R}}{Z_1 \bullet (I_{2S} + I_{2R})}\right) \qquad \textbf{Equation 2.8}$$

The multi-ended impedance-based fault-locating method uses negative-sequence phasors for all unbalanced faults and positive-sequence phasors for three-phase balanced faults. Furthermore, the method uses both local and remote voltage and current phasors and therefore requires time-alignment of local and remote data. As a result, you must connect each SEL-TWFL via the IRIG-B input to an IEEE C37.118-compliant GPS clock with submicrosecond accuracy to obtain an absolute time reference.

The SEL-TWFL captures local phasor data based on the rising edge of L*m*TD50DH, aligns the data to the top of the millisecond, and exchanges the data over the communications channel. Upon receiving data from the remote SEL-TWFL, the local device executes *Equation 2.8* on the time-aligned phasors captured in the fault-data capture window and averages the calculated fault-location values.

When applied to two-terminal nonhomogeneous lines, the multi-ended impedance-based fault-locating method accurately locates faults along the entire line. This method first calculates the negative-sequence voltage at all the transition points by using the measured voltages and currents along with the line section impedances. It performs the calculations with respect to both the local and

remote terminals. The method identifies the faulted line section by determining where the negative-sequence voltage profile from the local terminal intersects with the negative-sequence voltage profile from the remote terminal. With the faulted section identified, the method compensates for line nonhomogeneity by using the calculated negative-sequence voltage for both ends of the faulted line section along with the values you configured for the L*m*Z1MAG*n*, L*m*Z1ANG*n*, L*m*Z0MAG*n*, and L*m*Z0ANG*n* settings in *Equation 2.8* to calculate the actual fault location.

The following description explains how the multi-ended impedance-based method for two-terminal lines is applied to three-terminal lines. *Figure 2.7* shows a three-terminal line with Terminals R, S, and T and Tap Point P. The figure lists the lengths and impedances for each section of the line. The measured negative-sequence voltage and current at each terminal are V_{2R}, I_{2R}, V_{2S}, I_{2S}, V_{2T}, and I_{2T}, respectively.

Figure 2.7 Multi-Ended TW-Based Fault-Locating Method Explanation for Three-Terminal Lines

The multi-ended impedance-based fault-locating method for three-terminal lines identifies the faulted line segment and reports the fault location from the terminal associated with the faulted segment. It calculates the negative-sequence voltage at the tap (P) by using the measured negative-sequence voltage and current from each line terminal, along with the respective line section impedance, as follows:

$$V_{2P@R} = V_{2R} - Z_{1R} \bullet I_{2R}$$
$$V_{2P@S} = V_{2S} - Z_{1S} \bullet I_{2S}$$
$$V_{2P@T} = V_{2T} - Z_{1T} \bullet I_{2T}$$

where:

$$Z_{1R} = \text{L}m\text{Z1MAG1} \angle \text{L}m\text{Z1ANG1}$$
$$Z_{1S} = \text{L}m\text{Z1MAG2} \angle \text{L}m\text{Z1ANG2}$$
$$Z_{1T} = \text{L}m\text{Z1MAG3} \angle \text{L}m\text{Z1ANG3}$$

Note that lengths LLR, LLS, and LLT are provided to the SEL-TWFL as settings L*m*LL1, L*m*LL2, and L*m*LL3, respectively. Similarly, the magnitudes and angles of impedances Z_{1R}, Z_{1S}, and Z_{1T} are provided as settings L*m*Z1MAG1, L*m*Z1ANG1, L*m*Z1MAG2, L*m*Z1ANG2, L*m*Z1MAG3, and L*m*Z1ANG3, respectively.

The method identifies which two of the three voltage estimates are equal; if $V_{2P@S} \approx V_{2P@T}$, then the fault is on the RP line segment. The method calculates the average of the negative-sequence voltage at the tap as follows:

$$V_{2P} = \frac{1}{2}(V_{2P@S} + V_{2P@T})$$

It calculates the negative-sequence current at the tap by applying Kirchhoff's Current Law as follows:

$$I_{2P} = I_{2S} + I_{2T}$$

and it calculates the fault location (M) from Terminal R by using *Equation 2.8* as follows:

$$M = \frac{LmLL1}{2} \bullet \mathrm{Re}\left(\frac{(V_{2R} - V_{2P}) + Z_{1R} \bullet I_{2P}}{Z_{1R} \bullet (I_{2R} + I_{2P})}\right)$$

If $V_{2P@S} \approx V_{2P@R}$, then the fault is on the TP line segment. The method calculates the average of the negative-sequence voltage at the tap as follows:

$$V_{2P} = \frac{1}{2}(V_{2P@S} + V_{2P@R})$$

It calculates the negative-sequence current at the tap by applying Kirchhoff's Current Law as follows:

$$I_{2P} = I_{2S} + I_{2R}$$

and it calculates the fault location (M) from Terminal T by using *Equation 2.8* as follows:

$$M = \frac{LmLL3}{2} \bullet \mathrm{Re}\left(\frac{(V_{2T} - V_{2P}) + Z_{1T} \bullet I_{2P}}{Z_{1T} \bullet (I_{2T} + I_{2P})}\right)$$

If $V_{2P@R} \approx V_{2P@T}$, then the fault is on the SP line segment. The method calculates the average of the negative-sequence voltage at the tap as follows:

$$V_{2P} = \frac{1}{2}(V_{2P@R} + V_{2P@T})$$

It calculates the negative-sequence current at the tap by applying Kirchhoff's Current Law as follows:

$$I_{2P} = I_{2R} + I_{2T}$$

and it calculates the fault location (M) from Terminal S by using *Equation 2.8* as follows:

$$M = \frac{LmLL2}{2} \bullet \mathrm{Re}\left(\frac{(V_{2S} - V_{2P}) + Z_{1S} \bullet I_{2P}}{Z_{1S} \bullet (I_{2S} + I_{2P})}\right)$$

Accuracy Analysis

Use *Equation 2.8* to determine the sensitivity of the multi-ended impedance-based fault-locating method to settings and phasor measurement errors. Expect better accuracy than for the single-ended impedance-based fault-locating method. Specifically, the SEL-TWFL multi-ended impedance-based fault-locating method is immune to the remote infeed effect, and it works well for resistive faults in nonhomogeneous systems. Line nonhomogeneity (transposition) affects this method but to a lesser degree than it affects the single-ended impedance-based fault-locating method. Also, this method is not affected by mutual zero-sequence coupling or errors in the zero-sequence line impedance data. However, do not expect accuracy better than about 1–2 percent of the line length for ground faults.

Single-Ended Impedance-Based Method

Principle of Operation

The SEL-TWFL uses a single-ended impedance-based fault-locating method with negative-sequence current polarization for unbalanced faults and positive-sequence polarization for three-phase symmetrical faults. SEL relays and software have used this method for decades with good field results.

The impedance-based fault-locating method selects one of six protection measurement loops for further calculations based on the fault-type identification logic that uses local voltages and currents. For double-phase-to-ground faults, the method favors the phase loop over the two ground loops. For three-phase symmetrical faults, the method uses positive-sequence voltages and currents.

Once the impedance-based fault-locating method selects the faulted loop (LP = AG, BG, CG, AB, BC, CA, positive-sequence), the method calculates the loop voltage and current phasors (VLP and ILP, respectively).

Next, the single-ended impedance-based fault-locating method calculates the polarizing current, IPOL. The polarizing current is the shifted negative-sequence current angle for the selected loop. In applications that use the positive-sequence loop, the method polarizes the calculations with the positive-sequence current.

The single-ended impedance-based method calculates the fault location M (mi or km) as follows:

$$M = LL \bullet \frac{\mathrm{Im}(V_{LP} \bullet I_{POL}^{*})}{\mathrm{Im}(Z_1 \bullet I_{LP} \bullet I_{POL}^{*})} \qquad \textbf{Equation 2.9}$$

where:

Z_1 is the positive-sequence impedance of the line defined by the Z1MAG and Z1ANG settings;

Im stands for the imaginary part of a complex number; and

* denotes a complex conjugate.

The method calculates the loop current for the ground loops in *Equation 2.9* by using the line Z_0/Z_1 complex impedance ratio derived from the L*m*Z1MAG, L*m*Z1ANG, L*m*Z0MAG, and L*m*Z0ANG settings. Therefore, both the positive- and zero-sequence line impedance data are involved in the fault-locating calculations for the ground loops.

The SEL-TWFL fault-locating method executes *Equation 2.9* on fault phasors captured following assertion of L*m*TD50DH. The method averages the fault-location (M) values captured in the fault-data capture window.

When applied to radial or two-terminal nonhomogeneous lines, the single-ended impedance-based fault-locating method accurately locates faults along the entire line. This method first calculates the loop voltage and current at the transition points by using the measurements of voltage and current at the local terminal along with the line section impedances. Starting with the local terminal, the method uses these calculated values in *Equation 2.9* to determine the per-unit fault location with respect to each transition point. The faulted section is the first line section for which the calculated fault location is less than 1.0 per unit. With the faulted section identified, the method compensates for line nonhomogeneity by using the values you configured for the L*m*Z1MAG*n*, L*m*Z1ANG*n*, L*m*Z0MAG*n*, L*m*Z0ANG*n*, and L*m*LL*n* settings to calculate the actual fault location with respect to the local terminal.

When applied to three-terminal lines, the single-ended impedance-based fault-locating method in the SEL-TWFL locates faults only in the first line section associated with the SEL-TWFL.

Accuracy Analysis

The accuracy of the single-ended impedance-based fault-locating method depends on a number of well-known factors including the accuracy of the line impedance data, fault resistance, system nonhomogeneity, and mutual coupling. Use *Equation 2.9* to determine the sensitivity of the fault locator to errors in settings and phasor measurements. Do not expect accuracy better than about 2–5 percent of the line length unless the fault resistance is small, the line parameters are very accurate, and the line is not mutually coupled. For single-line-to-ground faults with high resistance and in a nonhomogeneous system, expect fault-location errors much greater than 5 percent.

Selecting and Reporting Best Fault-Location Results

The Line *m* fault locator executes all four fault-locating methods as long as it has valid data for each. It provides the fault-location results if the L*m*FL SELOGIC equation asserts within the L*m*FLMWT time setting following the detection of the disturbance. The fault-locating logic selects the most accurate and reliable fault-location result based on outputs from all methods available for a given application and present operating condition. It also provides the reference terminal associated with the selected fault-locating method. The SEL-TWFL applies the following general selection criteria:

- The multi-ended TW-based method has the highest priority.
- The single-ended TW-based method has the second highest priority as long as it is corroborated by the multi-ended TW-based method, multi-ended impedance-based method, or single-ended impedance-based method (in that order, depending on availability). If the result from the single-ended TW-based method is corroborated by one of the other fault-locating methods, the L*m*TWFLCL Relay Word bit is asserted to indicate a high level of confidence in the calculated fault location.
- The multi-ended impedance-based method has the third highest priority.
- The single-ended impedance-based method has the lowest priority.

The SEL-TWFL reports results from all fault-locating methods. To minimize the search time in the field, SEL recommends comparing all the results before dispatching the line crew.

Also, if you retrieved the MHR IEEE COMTRADE record from the SEL-TWFL, consider plotting the Bewley diagram in SEL-5601-2 SYNCHROWAVE Event Software for the reported fault location(s) to gain even more confidence regarding the fault location. When estimating the expected search span, consider the method that the SEL-TWFL used to obtain the fault-location result as well as the optional verification through a Bewley diagram. In many cases, your line crew will have to inspect only one or two tower spans on each side of the fault location that the SEL-TWFL reported.

See *Section 8: SCADA and HMI Protocols* for more information on how to access the fault data for your SCADA/HMI applications.

Line Monitor

The line monitor is suitable for two- and three-terminal line applications. It is operational only if the SEL-TWFL uses the multi-ended TW-based fault-locating method. Therefore, it requires an IEEE C37.94-compliant multiplexed channel between the SEL-TWFL devices, and you must connect each SEL-TWFL via the IRIG-B input to an IEEE C37.118-compliant GPS clock with submicrosecond accuracy to obtain an absolute time reference. Refer to *Line Monitoring Principle of Operation* on page G.7 for more information.

Line Monitor Settings

Table 2.11 lists the line monitor settings, and *Table 2.12* lists the line monitor Relay Word bits. To use the line monitor, you must first configure the fault locator (see *Fault Locator Application and Settings* on page 2.14).

Table 2.11 Line Monitor Settings

Setting[a, b]	Description	Range	Default	Class
L*m*ELM	Enable Line Monitoring for Line *m*	Y, YE, YF, N	Y	Device
L*m*LMALM	Line Monitoring Alarm Threshold	1–200	3	Device
L*m*LMBL*n*	Line Monitoring Blocking Location *n*	OFF, 0.00–[L*m*LL][c]	OFF	Device
L*m*LMBR*n*	Line Monitoring Blocking Location *n* Radius	0.00–10.00	0.20	Device
L*m*LMALM*n*	Line Monitoring Blocking Region *n* Alarm Threshold	1–200	10	Device

[a] *m* = 1–2.
[b] *n* = 1–2.
[c] For two-terminal lines, L*m*LL is the entire line length; for three-terminal lines, L*m*LL is the length of Section *n* associated with the local SEL-TWFL.

Table 2.12 Line Monitor Relay Word Bits

Relay Word Bit[a, b]	Description
L*m*LMEVE	Line monitoring new event detected on Line *m*[c]
L*m*LMA	Line monitoring alarm on Line *m*
L*m*LMAB*n*	Line monitoring Blocking Region *n* alarm on Line *m*

[a] *m* = 1–2.
[b] *n* = 1–2.
[c] 20 ms pulse.

Use the following settings recommendations when selecting the line monitor settings for Line *m* (*m* = 1–2 and *n* = 1–2).

L*m*ELM

Use the L*m*ELM setting to enable the line monitor for Line *m* and specify the type of events you want to monitor.

Set L*m*ELM to YE to monitor the power line for low-energy events. The line monitor will detect, locate, tabulate, and alarm for discharge across dirty or damaged insulators, incipient cable faults, discharge from encroaching vegetation, and other events not accompanied by protection operation. For the line monitor to function, you do not have to program disturbance detectors in the L*m*FL SELOGIC equation. Moreover, triggering the fault locator on non-fault events prevents the line monitor from classifying these low-energy events as non-fault events. The line monitor uses the absence of the fault locator trigger to distin-

guish non-fault events on the line from line faults. Set L*m*ELM to YE if you intend to monitor the line for fault precursors and you do not want the monitoring data to include faults.

Set L*m*ELM to YF to monitor the power line for faults. In this mode, the line monitor locates, tabulates, and alarms for faults on the line. Program the L*m*FL SELOGIC equation to monitor the trip signal to the line circuit breaker. The line monitor uses the presence of the fault locator trigger to distinguish line faults from non-fault events. Set L*m*ELM to YF if you intend to monitor historical distribution of line faults in order to detect systemic problems on the line, such as insufficient clearance, mechanical resonance of conductors due to in-sufficient damping, and so on. Monitoring the line for faults allows you to detect weak spots on the line that cause transient faults, which are often left unreported and not analyzed because of successful autoreclosing.

Set L*m*ELM to Y to monitor both low-energy events and faults. The line monitor works independently in each SEL-TWFL of the scheme. Consider setting L*m*ELM to YE in one of the devices and setting L*m*ELM to YF in another device. The line monitor data set from the device with L*m*ELM set to YE will tabulate low-energy events related to potential faults, and the data set from the device with L*m*ELM set to YF will provide historical fault distribution along the line.

L*m*LMALM

Use the L*m*LMALM setting to specify the alarm threshold for the line. If you do not have any historical data to guide you, consider setting L*m*LMALM to 3. There is a very low probability that three unrelated events would occur at the same location. The line monitor alarms if the event counter in one, two, or three adjacent 0.25 mi or km bins exceeds the alarm threshold. For a 100 mi line, the probability of a single event falling within three adjacent bins is $3 \bullet 0.25 / 100 = 0.0075$. The probability of three unrelated events with a uniform distribution of occurrence falling in the same three bins is therefore $(0.0075)^3 = 4.2 \bullet 10^{-7}$. Such a low probability of a false alarm warrants setting L*m*LMALM to 3 and initiating an inspection if the SEL-TWFL line monitor sets off an alarm.

Consider setting the L*m*LMALM threshold to 1 or 2 for cable lines. These lines are not expected to experience any low-energy events. Instead, they may experience incipient faults. Therefore, consider investigating the case, even if the line monitor detects a single event, just as you would for a protection operation.

L*m*LMBL1 and L*m*LMBL2

Use the L*m*LMBL1 and L*m*LMBL2 settings to specify locations for which you do not want to alarm. Tapped lines may experience low-energy events due to switching operations associated with tapped loads or generators. These events may include switching events, restriking of the switching device, or commutation errors in power electronics associated with the tapped load or generator. Also, switching of in-line series capacitors will trigger the line monitor. Use as many as two blocking regions to prevent tap or series capacitor locations from alarming for line events. Use L*m*LMBL1 to specify the location of the first tap or series capacitor (distance from the device in mi or km as per the LLUNIT setting). Use L*m*LMBL2 to specify the location of the second tap or capacitor. You can also use the blocking regions to apply a different alarm threshold for cable sections on hybrid lines (see settings *LmLMALM1 and LmLMALM2* on page 2.29).

L*m*LMBR1 and L*m*LMBR2

Use the L*m*LMBR1 and L*m*LMBR2 settings to specify the radius (in mi or km according to the LLUNIT setting) of the first and second blocking regions, respectively. The first blocking region spans from (L*m*LMBL1 – L*m*LMBR1) to (L*m*LMBL1 + L*m*LMBR1), and the second blocking region spans from (L*m*LMBL2 – L*m*LMBR2) to (L*m*LMBL2 + L*m*LMBR2). The multi-ended TW-based fault-locating method is typically accurate to within a tower span. A good practice is to set the radius to two or three tower spans to account for the locating error plus an additional 0.25 (mi or km) to account for rounding up the event location to the nearest line monitor bin.

L*m*LMALM1 and L*m*LMALM2

The line monitor counts events located within the blocking regions. Routine switching or other noise associated with the tapped load or generator would cause these counters to quickly reach their upper limit. Therefore, the line monitor resets all counters within the blocking regions at midnight on the device clock, and by doing so, it monitors the daily total event counts for these locations. Use the L*m*LMALM1 and L*m*LMALM2 thresholds to set alarms for excessive daily event counts within the blocking regions. Use your operational data to select the alarm thresholds. For example, if your tapped transformer is equipped with an on-load tap changer that switches no more than 6 times a day, you can set the alarm threshold to 6, plus a margin. You can also inspect the line monitor data in the LINEMONL*m*.TXT file for actual event counts within the blocking regions that you set for the line taps and use the historical data as the basis for setting the alarm thresholds.

You can also use the L*m*LMALM1 and L*m*LMALM2 thresholds to alarm for cable sections on hybrid lines. For example, you can use the first blocking region to span a cable section and set L*m*LMALM1 to 1 to alarm on any event within that cable section, such as for an incipient cable fault. Setting L*m*LMALM1 higher than 1 can limit the usefulness of monitoring because counters within the blocking regions reset daily. You can use a counter in your SCADA/HMI software to obtain a total count for cable events before taking action.

Line Monitor Outputs and Data

The line monitor provides the following user feedback and records the following data:

- For testing purposes, the front-panel LCD screen displays a message each time the line monitor triggers or asserts an alarm. The event trigger message displays the event location and the total event count. The alarm message displays the alarm location. The messages self-clear in 15 s (see *Figure 7.11*).
- The L*m*LMEVE Relay Word bit pulses for 20 ms each time the line monitor triggers. You can use this bit to trigger transient recording to capture the high-resolution voltages and currents for inspection and validation. The L*m*LMEVE Relay Word bit has a latency no greater than 100 ms plus the value of the L*m*FLMWT setting. The L*m*FLMWT setting is an advanced setting with a default value of 100 ms, which is suitable for most applications. Therefore, unless your application requires you to modify the L*m*FLMWT value, you

should set the pre-fault record duration, PRE, in the transient recorder to at least 200 ms when you use the L*m*LMEVE Relay Word bit to trigger transient recording. For three-terminal lines, L*m*LMEVE will assert only in the SEL-TWFL associated with the line section on which the event occurred.

- Assertion of the L*m*LMA, L*m*LMAB1, and L*m*LMAB2 Relay Word bits signifies an alarm for the line (L*m*LMA) and the two blocking regions (L*m*LMAB1 and L*m*LMAB2). Monitor these bits in your SCADA/HMI software to alert your line maintenance department. Remember that the event counters within the blocking regions autoreset at midnight, which deasserts the L*m*LMAB1 and L*m*LMAB2 Relay Word bits, if they were asserted. Latch these bits in your SCADA/HMI software or in the device by using SELOGIC latches. Reset the latched bits after understanding and attending to the problem at the alarm location. You can use the L*m*LMA, L*m*LMAB1, and L*m*LMAB2 Relay Word bits to trigger a transient recording to capture the high-resolution voltage and current data for inspection and validation. These bits have a latency no greater than 100 ms plus the value of the L*m*FLMWT setting. The L*m*FLMWT setting is an advanced setting with a default value of 100 ms, which is suitable for most applications. Therefore, unless your application requires you to modify the L*m*FLMWT setting, you should set the pre-fault record duration, PRE, in the transient recorder to at least 200 ms.
- The L*m*LMLOC, L*m*LMLOCB1, and L*m*LMLOCB2 analog values show the locations associated with the L*m*LMA, L*m*LMAB1, and L*m*LMAB2 alarms (see *Table 2.13*). Use these values when alerting your line maintenance department. Remember that with multiple alarm locations present on the line, the L*m*LMLOC, L*m*LMLOCB1, and L*m*LMLOCB2 analog values indicate the locations with the highest event count. Inspect counter values for the entire line before dispatching a line crew. You can use the device HMI to view the analog values associated with line monitoring (see *Table 7.7*).
- The L*m*LMETOT analog value is the total number of events logged for the entire line (see *Table 2.13*).
- The **LIMO** command allows you to inspect the values of counters and the line monitor alarm status and clear selected counters after rectifying a problem on the line, such as after washing a dirty insulator or trimming encroaching vegetation.
- The LINEMONL*m*.TXT file contains all the line monitor counter values and information regarding the most recent line monitor events for Line *m*. For two-terminal lines, the LINEMONL*m*.TXT file includes all line monitoring events between the local and the remote terminal. For three-terminal lines, the LINEMONL*m*.TXT file contains only line monitoring events between the local terminal and the tap point. See the LINEMONL*m*.CSV file for information about events located between the tap and each remote terminal. You can import the LINEMONL*m*.TXT file into Microsoft Excel or similar software for plotting and analysis. The LINEMONL*m*.TXT file is located in the REPORTS directory of the SEL-TWFL.

➤ The LINEMONL*m*.CSV file contains information regarding the most recent line monitor events for Line *m*. The LINEMONL*m*.CSV file includes all line monitoring events, including events located between the tap and each remote terminal on three-terminal lines. You can view the LINEMONL*m*.CSV file directly in Microsoft Excel or similar software for plotting and analysis without importing the file. The LINEMONL*m*.CSV file is located in the REPORTS directory of the SEL-TWFL.

Table 2.13 Line Monitor Analog Values

Analog Value[a, b]	Description	Unit
L*m*LMLOC	Line monitoring alarm location[c]	mi or km[d]
L*m*LMLOCB*n*	Line monitoring Blocking Region *n* alarm location	mi or km[d]
L*m*LMETOT	Line monitoring total event count[e]	count

[a] *m* = 1–2.
[b] *n* = 1–2.
[c] Location with the highest event count if the alarm condition is satisfied at multiple locations.
[d] Per LLUNIT setting.
[e] This counter may decrease at midnight when counters within the blocking regions autoreset.

Attending to Line Monitor Alarms and Inspecting Data

When the line monitor asserts an alarm (L*m*LMA, L*m*LMAB1, or L*m*LMAB2 Relay Word bit), retrieve and archive the LINEMONL*m*.TXT and LINEMONL*m*.CSV files (see *SEL-TWFL File Directories* on page 8.15) and use the line monitor command (see *LIMO* on page C.10) to inspect and clear the counters at the alarm location.

The Line Monitoring History section of the LINEMONL*m*.TXT file in the REPORTS directory of the SEL-TWFL contains the line monitor counter values and other relevant information for Line *m* (see *Figure 2.8* for an example of the LINEMONL1.TXT file for a two-terminal line). The report in *Figure 2.8* shows a total of 15 events and lists bin locations (first column) and associated counters (second column). The line in *Figure 2.8* has a weak spot at about 30.00 mi with 7 events at 30.00 mi, 2 events at 29.75 mi, and 1 event at 30.25 mi. The third column shows the locations of Blocking Regions 1 and 2 marked as B1 and B2, respectively. In the example of *Figure 2.8*, Blocking Region 1 spans from 34.50 mi to 36.00 mi and has 1 event at 35.75 mi. For three-terminal lines, the LINEMONL*m*.TXT file contains only line monitoring events between the local terminal and the tap point.

To facilitate analysis, the Line Monitoring Event Data section of the LINEMONL*m*.TXT file shows details related to the latest line monitoring events recorded by the device, as shown in *Figure 2.8*. The information includes the event record number containing the TW signals that triggered the line monitor event, the time the disturbance was detected, the calculated location, the incremented event counter, the event type (“E” indicates a low-energy event and “F” indicates a fault event), the phase(s) involved in the event, the first TW arrival time stamps for the local and remote devices (time stamp includes seconds, milliseconds, microseconds, and nanoseconds), and the ratio of ground mode TWs to phase TWs (“H” indicates the ratio is high and “L” indicates the ratio is low). Any event that occurs in Blocking Region 1 is marked as B1, and any event that occurs in Blocking Region 2 is marked as B2. An event occurring in both regions is marked with B1 B2. The Line Monitoring Event Data section displays the 50 most recent events for the line and 50 most recent events for the blocking regions.

The information in the Line Monitoring Event Data section is also provided in a comma-separated values (CSV) file, LINEMONL*m*.CSV. This file is located in the REPORTS directory of the SEL-TWFL (see *Figure 2.9* for an example of the LINEMONL1.CSV file). The LINEMONL*m*.CSV file includes all line monitoring events, including events located between the tap and each remote terminal on three-terminal lines. Furthermore, the LINEMONL*m*.CSV file includes the fault location reference terminal (LOCAL, P1, P2, or P3) and the first TW arrival time stamps for the local and remote device (time stamp includes hours, minutes, seconds, milliseconds, microseconds, and nanoseconds). The LINEMONL*m*.CSV file displays the 50 most recent events for the line and the 50 most recent events for the blocking regions. On three-terminal lines, the LINEMONL*m*.CSV file also displays the 50 most recent events located between the tap point and the remote terminals.

For analysis and plotting, you can import the LINEMONL*m*.TXT file into Microsoft Excel or you can view the LINEMONL*m*.CSV file directly in Microsoft Excel without importing the file. You can choose to archive the files to keep track of the line history.

You can access the LINEMONL*m*.TXT and LINEMONL*m*.CSV files by using several methods:

- Use an FTP client, such as File Explorer, over an Ethernet connection and copy the file from the REPORTS directory.
- Use the FILE READ REPORTS LINEMONL*m*.TXT or FILE READ REPORTS LINEMONL*m*.CSV command to retrieve the respective file over the front-panel port.
- View the file and copy selected portions of it from the terminal window by using the FILE SHOW REPORTS LINEMONL*m*.TXT or FILE SHOW REPORTS LINEMONL*m*.CSV command, respectively.

```
SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

Line 1: L1 230kV StationA - StationB
Line Monitoring History
Total number of events:     15
Location [mi]   Event Count
    0.25          0
    0.50          0
    0.75          0
    ...
   29.50          0
   29.75          2
   30.00          7
   30.25          1
   30.50          0
   30.75          0
   ...
   34.25          0
   34.50          0     B1
   34.75          0     B1
   35.00          0     B1
   35.25          0     B1
   35.50          0     B1
   35.75          1     B1
   36.00          0     B1
   36.25          0
   36.50          0
   ...

Line Monitoring Event Data
ER     DATE       TIME            LOCATION EVENT_COUNT BLK_REGION F/E PHASE TW_TIME_LOCAL TW_TIME_P1   TWIO
10027  2024/01/30 16:25:20.7150   30.014   7                      F   B     20.715016040  20.715235000 L
10026  2024/01/30 16:23:31.6883   30.014   6                      E   B     31.688329026  31.688547976 L
10025  2024/01/30 16:22:50.8110   30.073   5                      E   B     50.810971129  50.811189432 L
10024  2024/01/30 16:20:28.9325   30.050   4                      E   B     28.932519487  28.932738047 L
10023  2024/01/30 16:19:36.7394   30.084   3                      E   B     36.739451451  36.739669641 L
10022  2024/01/30 16:18:52.6651   30.084   2                      E   B     52.665113283  52.665331475 L
10021  2024/01/30 16:17:43.4831   30.055   1                      E   B     43.483117699  43.483336204 L
10020  2024/01/30 16:16:16.4874   29.750   2                      E   B     16.487370127  16.487591975 L
10019  2024/01/30 16:15:17.4744   29.763   1                      E   B     17.474421291  17.474643000 L
10017  2024/01/30 16:13:06.5591   30.266   1                      E   B     06.559131368  06.559347567 L
10015  2024/01/30 16:09:49.7448   35.719   1           B1         E   C     49.744851850  49.745008305 L
10012  2024/01/30 16:05:02.2668   72.605   1                      E   A     02.266813137  02.266565494 L
10011  2024/01/30 16:03:32.9470   72.922   1                      E   A     32.947003224  32.946752105 L
10009  2024/01/30 16:01:30.1231   72.201   2                      E   C     30.123111189  30.122867973 L
10008  2024/01/30 16:00:43.6998   72.211   1                      E   C     43.699803907  43.699560582 L
```

Figure 2.8 LINEMONL1.TXT File Example

```
SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

Line 1: L1 230kV StationA - StationB
Line 1: LOCAL station is StationA
Line 1: P1 station is StationB

Line Monitoring Event Data
ER,DATE,TIME,LOCATION,REF_TERM,EVENT_COUNT,BLK_REGION,F/E,PHASE,TW_TIME_LOCAL,TW_TIME_LOCAL(NS),TW_TIME_P1,TW_TIME_P1(NS),
   TW_TIME_P2,TW_TIME_P2(NS),TW_TIME_P3,TW_TIME_P3(NS),TWIO
10027,2024/01/30,16:25:20.7150,30.014,LOCAL,7,"",F,B,16:25:20,715016040,16:25:20,715235000,,,,,L
10026,2024/01/30,16:23:31.6883,30.014,LOCAL,6,"",E,B,16:23:31,688329026,16:23:31,688547976,,,,,L
10025,2024/01/30,16:22:50.8110,30.073,LOCAL,5,"",E,B,16:22:50,810971129,16:22:50,811189432,,,,,L
10024,2024/01/30,16:20:28.9325,30.050,LOCAL,4,"",E,B,16:20:28,932519487,16:20:28,932738047,,,,,L
10023,2024/01/30,16:19:36.7394,30.084,LOCAL,3,"",E,B,16:19:36,739451451,16:19:36,739669641,,,,,L
10022,2024/01/30,16:18:52.6651,30.084,LOCAL,2,"",E,B,16:18:52,665113283,16:18:52,665331475,,,,,L
10021,2024/01/30,16:17:43.4831,30.055,LOCAL,1,"",E,B,16:17:43,483117699,16:17:43,483336204,,,,,L
10020,2024/01/30,16:16:16.4874,29.750,LOCAL,2,"",E,B,16:16:16,487370127,16:16:16,487591975,,,,,L
10019,2024/01/30,16:15:17.4744,29.763,LOCAL,1,"",E,B,16:15:17,474421291,16:15:17,474643000,,,,,L
10017,2024/01/30,16:13:06.5591,30.266,LOCAL,1,"",E,B,16:13:06,559131368,16:13:06,559347567,,,,,L
10015,2024/01/30,16:09:49.7448,35.719,LOCAL,1,"B1",E,C,16:09:49,744851850,16:09:49,745008305,,,,,L
10012,2024/01/30,16:05:02.2668,72.605,LOCAL,1,"",E,A,16:05:02,266813137,16:05:02,266565494,,,,,L
10011,2024/01/30,16:03:32.9470,72.922,LOCAL,1,"",E,A,16:03:32,947003224,16:03:32,946752105,,,,,L
10009,2024/01/30,16:01:30.1231,72.201,LOCAL,2,"",E,C,16:01:30,123111189,16:01:30,122867973,,,,,L
10008,2024/01/30,16:00:43.6998,72.211,LOCAL,1,"",E,C,16:00:43,699803907,16:00:43,699560582,,,,,L
```

Figure 2.9 LINEMONL1.CSV File Example

When a line monitor alarm is asserted on Line *m*, issue the **LIMO L*m*** command and you will receive the following response:

```
=>LIMO L1 <Enter>

SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

Line 1: L1 230kV StationA - StationB
Line Monitoring Alarm
Total number of events:     15

Alarm at location:  30.00 mi
Location [mi]   Event Count
   29.75          2
   30.00          7
   30.25          1
```

For the previous example, issue the **LIMO L*m* 29 31** command to inspect more counters adjacent to the alarm location and you will receive the following response:

```
=>LIMO L1 29 31 <Enter>

SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

Line 1: L1 230kV StationA - StationB
Line Monitoring Event Count
Total number of events:     15
Location [mi]   Event Count
   29.00          0
   29.25          0
   29.50          0
   29.75          2
   30.00          7
   30.25          1
   30.50          0
   30.75          0
   31.00          0
```

Dispatch your line crew to the location of 30.00 mi. Assume your crew found insulators covered with salt residue deposited by wind from a nearby highway overpass. Assume the insulators have been washed at a convenient time. After the underlying problem has been rectified, you should reset the counters corresponding to the alarm location by issuing the **LIMO L*m* 29.75 30.25 C** command from Access Level 2:

```
=>>LIMO L1 29.75 30.25 C <Enter>
Clear Line Monitoring event counters on Line 1 between 29.75 mi and 30.25 mi.
Are you sure (Y/N)? y

Clearing Complete

=>>LIMO L1 29 31

SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

Line 1: L1 230kV StationA - StationB
Line Monitoring Event Count
Total number of events:      5
Location [mi]   Event Count
   29.00          0
   29.25          0
   29.50          0
   29.75          0
   30.00          0
   30.25          0
   30.50          0
   30.75          0
   31.00          0
```

Note that you cleared 10 events, and therefore the total event count went from 15 to 5. Clearing the counters at the alarm location resulted in the L*m*LMA Relay Word bit deasserting (check using the **TAR L*m*LMA** command). If the L*m*LMA Relay Word bit stays asserted, it means an alarm is set for another location. Issue the **LIMO L*m*** command to confirm. If no alarm is present, you will receive the following response:

```
=>>LIMO L1 <Enter>

SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

Line 1: L1 230kV StationA - StationB
No line monitoring alarms.
```

Use the **LIMO L*m* C** command to reset the counters and clear the Line Monitoring Event Data section in both the LINEMONL*m*.TXT and LINEMONL*m*.CSV files. When you change the L*m*LL*n*, L*m*NTERM, L*m*NSEC, or L*m*PORT*n* settings while the line monitor is enabled (L*m*ELM = Y, YE, or YF), the SEL-TWFL clears the line monitor counters and Line Monitoring Event Data section for Line *m*.

The **LIMO L*m*** command provides you with visibility into all three alarms: the line and the two blocking regions. For example, if all three alarms are asserted, you will receive the following response:

```
=>>LIMO L1 <Enter>

SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

Line 1: L1 230kV StationA - StationB
Line Monitoring Alarm
Total number of events:     38

Alarm at location:  90.00 mi
Location [mi]   Event Count
   89.75          0
   90.00          3
   90.25          1

Blocking region 1
Alarm at location:  35.00 mi
Location [mi]   Event Count
   34.75          1
   35.00         10
   35.25          0

Blocking region 2
Alarm at location:  60.00 mi
Location [mi]   Event Count
   59.75          2
   60.00         15
   60.25          1
```

When no line monitoring alarms are present, you have finished attending to the line monitoring alarms.

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SECTION 3

Digital I/O and Communications Ports

NOTE: See *Section 7: Engineering and Operator Access Interfaces and Tools* and *Section 8: SCADA and HMI Protocols* for information on using communications Ports F and 5 for engineering access and SCADA.

This section provides details on the digital inputs and outputs and the communications Ports 1, 2, and 3 of the SEL-TWFL. The section is organized as follows:

- *Overview* on page 3.1 provides a general overview of the digital inputs and outputs and explains their intended use.
- *Programming Digital Inputs and Outputs* on page 3.2 describes the configuration and use of contact inputs and outputs and MIRRORED BITS inputs and outputs.
- *Configuring and Troubleshooting MIRRORED BITS Communications* on page 3.5 describes the configuration and use of communications Ports 1, 2, and 3, including data transmission and reception, error messages, loopback testing, interfacing with SEL remote I/O modules, and establishing communications via multiplexers.
- *Digital Communications Examples* on page 3.17 provides examples of using the digital inputs and outputs on the SEL-TWFL for fault-locating applications.

Overview

Typical SEL-TWFL digital communications applications include:

- Monitoring the position of the line breaker(s) and disconnect switch(es).
- Sending and receiving cross-triggers for fault locating and digital fault recording.
- Sending and receiving fault-locating and line monitoring data.

The SEL-TWFL includes the following digital input and output means:

- Six trip-rated outputs that use a hybrid (solid-state and electromechanical) design and close in 10 µs.
- Eight Form A contact outputs for general signaling applications, including signaling local relays.
- Eight contact inputs for general signaling applications, including breaker and disconnect switch position monitoring and signaling from local relays.
- Five contact inputs for general signaling applications. This group of contact inputs shares a common terminal.
- Three fiber-optic communications ports (Ports 1, 2, and 3), each with setting-selectable SEL MIRRORED BITS (MB8) or IEEE C37.94 encoding, for communicating with remote devices via multiplexers as well as communicating with local devices and SEL remote I/O modules.

Ports 1, 2, and 3 provide the following functionality:

- When configured for SEL MB8 encoding, the port receives eight MIRRORED BITS inputs from and sends eight programmable MIRRORED BITS outputs to MIRRORED BITS-compatible devices, including SEL devices, controllers, and remote I/O modules.
- When configured for IEEE C37.94 encoding, the port receives and sends eight MIRRORED BITS inputs and outputs and enables multi-ended impedance- and traveling-wave-based fault locating and line monitoring.
- When configured for IEEE C37.94 encoding, the port can only be connected to an IEEE C37.94 port of another SEL-TWFL over an IEEE C37.94-compliant multiplexer.

Use the SEL-TWFL model number to specify the rated voltage for the contact inputs (see *Models and Options* on page 1.4). The contact outputs are rated for 48–250 Vdc.

You can use SELOGIC equations to drive the digital outputs and decide how the device uses the digital inputs. All contact inputs include a security debounce time of 2.0 ms. Digital communications protocols on the communications ports protect data by using strong data integrity algorithms and prevent accidental cross-connection by using transmit and receive addresses.

You can view the state (asserted or deasserted) of all digital inputs and outputs of the SEL-TWFL without connecting to the device (navigate to the `Metering & IO` screen on the front-panel HMI).

Programming Digital Inputs and Outputs

Contact Inputs

The SEL-TWFL provides eight fully isolated inputs labeled IN201 through IN208 and five inputs that share a common terminal labeled IN101 through IN105. See *Specifications* on page 1.8 for performance and withstand characteristics of the inputs and *AC/DC Connection Diagrams* on page 9.14 for details on wiring the inputs. If your application requires more contact inputs, consider using an SEL remote I/O module, such as the SEL-2507 High-Speed Remote I/O Module, over Port 1, 2, or 3 to acquire eight additional contact inputs per port and to control eight additional contact outputs per port.

The SEL-TWFL acquires the state of the contact inputs every 0.1 ms and applies a fixed debounce time delay of 2.0 ms for security.

Table 3.1 lists the Relay Word bits that represent the state of the contact inputs. Use these Relay Word bits in SELOGIC equations to connect elements that trigger fault locating and event recording with the digital inputs they require. Configure these Relay Word bits for selected contact inputs in the Sequential Events Recorder (SER) to record their state changes with time stamps.

Table 3.1 Contact Inputs Relay Word Bits

Relay Word Bit[a]	Description
IN10*n*	IN10*n* input asserted
IN20*m*	IN20*m* input asserted

[a] *n* = 1–5, *m* = 1–8.

MIRRORED BITS Inputs

The SEL-TWFL provides 8 MIRRORED BITS inputs per port on Ports 1, 2, and 3. To use the MIRRORED BITS inputs on a given port, you must first enable and configure that port (see *Ports 1, 2, and 3 Configuration* on page 3.5). Note the following when applying the MIRRORED BITS inputs:

- The SEL-TWFL communications protocols apply data integrity protection algorithms, as well as short and fixed debounce time delays, to secure the transmitted bits against noise. See *Specifications* on page 1.8 for information on the data protection strength (bit error rate immunity) of the SEL-TWFL communications ports.
- For additional security, you can use SELOGIC timers to program an additional debounce time delay for the MIRRORED BITS inputs. You can also use multiple MIRRORED BITS inputs to communicate one digital signal.
- When a port loses connection, all MIRRORED BITS inputs on that port simultaneously default to logical 0. If needed, use the port status Relay Word bits (ROKP1, ROKP2, and ROKP3) in SELOGIC equations to program custom fail-safe logic.
- When a port is disabled, all MIRRORED BITS inputs on that port default to logical 0.
- The **COMM PORTS** multicolor status LED indicates the health of the enabled communications Ports 1, 2, and 3 (see *Status and Target LEDs* on page 7.13 for details).

Table 3.2 lists the Relay Word bits that represent the state of the MIRRORED BITS inputs. Use these Relay Word bits in SELOGIC equations to connect protection elements and schemes with the digital inputs they require. Configure these Relay Word bits for selected MIRRORED BITS inputs in the SER to record their state changes with time stamps.

Table 3.2 MIRRORED BITS Inputs Relay Word Bits

Relay Word Bit[a]	Description
RMB*n*P1	Received Mirrored Bit *n* on Port 1
RMB*n*P2	Received Mirrored Bit *n* on Port 2
RMB*n*P3	Received Mirrored Bit *n* on Port 3

[a] *n* = 1–8.

Contact Outputs

The SEL-TWFL provides six trip-rated Form A contact outputs (OUT101 through OUT106) and eight generic Form A outputs (OUT201 through OUT208). See *Specifications* on page 1.8 for performance and withstand characteristics of the outputs and *AC/DC Connection Diagrams* on page 9.14 for details on wiring the outputs. If your application requires more contact outputs, consider using an SEL remote I/O module, such as the SEL-2507 High-Speed Remote I/O Module, over Port 1, 2, or 3 to control eight additional contact outputs per port and to acquire eight additional contact inputs per port.

The SEL-TWFL actuates the contact outputs every 0.1 ms. Drive each output with a dedicated SELOGIC equation (see *Table 3.3*). The state of the SELOGIC equation that drives an output is available as a Relay Word bit with the same name (see *Table 3.4*). The Relay Word bit indicates the state of the driver for the output and not the state of the contacts of the outputs. There is a short delay

between assertion (deassertion) of the output driver and the closing (opening) of contacts of the output (see the operating time specifications in *Specifications* on page 1.8).

Table 3.3 Contact Outputs Settings

Setting[a]	Description	Range	Default	Class
OUT10*n*	Output OUT10*n* Close Signal SELogic Equation	SELogic Expression	TRIP (*n* = 1) 0 (*n* = 2–6)	Device
OUT20*m*	Output OUT20*m* Close Signal SELogic Equation	SELogic Expression	0	Device

[a] *n* = 1–6, *m* = 1–8.

Table 3.4 Contact Outputs Relay Word Bits

Relay Word Bit[a]	Description
OUT10*n*	OUT10*n* output close signal
OUT20*m*	OUT20*m* output close signal

[a] *n* = 1–6, *m* = 1–8.

Mirrored Bits Outputs

The SEL-TWFL provides 8 Mirrored Bits outputs per port on Ports 1, 2, and 3. To use the Mirrored Bits outputs on a given port, you must enable and configure that port first (see *Ports 1, 2, and 3 Configuration* on page 3.5).

The device actuates the Mirrored Bits outputs every 0.1 ms, but it sends the data at the rate specified by the port encoding and baud rate settings (see *Table 3.8*). Drive each Mirrored Bits output with a dedicated SELogic equation (see *Table 3.5*). The state of the SELogic equation that drives a Mirrored Bits output is available as a Relay Word bit with the same name (see *Table 3.6*).

Table 3.5 Mirrored Bits Outputs Settings

Setting[a]	Description	Range	Default	Class
TMB*n*P1	Mirrored Bit Output *n* SELogic Equation	SELogic Expression	0	Device
TMB*n*P2	Mirrored Bit Output *n* SELogic Equation	SELogic Expression	0	Device
TMB*n*P3	Mirrored Bit Output *n* SELogic Equation	SELogic Expression	0	Device

[a] *n* = 1–8.

Table 3.6 Mirrored Bits Outputs Relay Word Bits

Relay Word Bit[a]	Description
TMB*n*P1	Transmitted Mirrored Bit *n* asserted on Port 1
TMB*n*P2	Transmitted Mirrored Bit *n* asserted on Port 2
TMB*n*P3	Transmitted Mirrored Bit *n* asserted on Port 3

[a] *n* = 1–8.

Configuring and Troubleshooting MIRRORED BITS Communications

Ports 1, 2, and 3 Configuration

Table 3.7 shows the settings for communications Ports 1, 2, and 3.

Table 3.7 Communications Ports 1, 2, and 3 Settings

Setting	Description	Range	Default	Class
EPORT	Enable Port	Y, N	N	Ports 1, 2, 3
ENCODING	Data Encoding	MB8, C37.94	MB8	Ports 1, 2, 3
DATACLK[a]	Data Clock (I - Internal, E - External)	I, E	E	Ports 1, 2, 3
SPEED[b]	Baud Rate	19200, 38400, 57600, 115200	38400	Ports 1, 2, 3
TXID	Transmit Identifier	1, 2, 3, 4	1	Ports 1, 2, 3
RXID	Receive Identifier	1, 2, 3, 4	2	Ports 1, 2, 3

[a] Applicable when ENCODING = C37.94.
[b] Applicable when ENCODING = MB8.

Follow these settings rules when configuring communications Ports 1, 2, and 3.

EPORT

Use the EPORT setting corresponding to the respective port to enable (EPORT = Y) or disable (EPORT = N) all communications on that port.

ENCODING

Use the ENCODING setting corresponding to the respective port to set the data encoding for either SEL MIRRORED BITS MB8 (ENCODING = MB8) or IEEE C37.94 (ENCODING = C37.94). Select SEL MB8 encoding for signaling local SEL relays and SEL remote I/O modules. Select IEEE C37.94 encoding for signaling the remote SEL-TWFL over compliant multiplexers. See *Digital Communications Examples* on page 3.17 for examples of when the port in use is configured for either SEL MB8 or IEEE C37.94 encoding.

SEL MB8 Encoding

SEL products, such as protective relays, remote I/O modules, and logic processors, use several variations of the MIRRORED BITS communications protocol. When the SEL-TWFL Port 1, 2, or 3 is configured for SEL MB8 encoding, that port operates as follows:

- SEL MB8 Format. Set the connected SEL device for the SEL MB8 format (STOPBIT = 2).
- Paced-Mode Operation. Set the connected SEL device for paced mode (TXMODE = P).

NOTE: When using MIRRORED BITS communications between the SEL-TWFL and SEL-400 series relays, be sure to set the SEL-400 series relay settings to TXMODE = P (because the SEL-TWFL operates only in paced mode) and STOPBIT = 2 (because the SEL-TWFL uses only the SEL MB8 format).

IEEE C37.94 Encoding

When Port 1, 2, or 3 is configured for IEEE C37.94 encoding, that port is compliant with the IEEE C37.94-2017 standard for direct device-to-multiplexer communication. The IEEE C37.94 standard defines the data structure and encoding. It also defines the physical interface (ST connector, 850 nm light wavelength, 50 or 62.5 micron multimode fiber), ensuring that IEEE C37.94-compliant devices interface with IEEE C37.94-compliant multiplexers.

DATACLK

When data encoding is set to IEEE C37.94, use the DATACLK setting to select the communications timing source. Select either internal (DATACLK = I) or external (DATACLK = E). When connecting the SEL-TWFL to a multiplexer, set DATACLK to E in the SEL-TWFL to align the data transfer with the timing set by the multiplexer. For back-to-back connections, set DATACLK to E in one SEL-TWFL and set DATACLK to I in the other SEL-TWFL. The device with the setting DATACLK = E aligns its data transfer with the timing set by the device with the setting DATACLK = I.

SPEED

When data encoding is set for SEL MB8, use the SPEED setting to match the data rate of the device connected on that port. The SEL-TWFL transmits MIRRORED BITS outputs at fixed intervals (referred to as paced-mode operation). When possible, use the 115,200 bps data rate to accelerate signaling over SEL MB8-encoded communications. See *Table 3.8* for MIRRORED BITS outputs transmission intervals for different data rates and encoding methods.

Table 3.8 MIRRORED BITS Outputs Transmission Intervals and Debounce Timer

Encoding Setting	Data Rate (bps)	Transmission Interval (ms)	Debounce Timer (ms)
MB8	115,200	0.50	0.50
	57,600	2	2
	38,400	2	2
	19,200	2	2
C37.94	64,000	0.50	1

TXID and RXID

Use the TXID setting to assign a unique identifier to the messages sent on a given port. Use the RXID setting to identify the valid transmitting device for messages received on a given port. Set RXID in one device equal to the TXID in the connected device, and vice versa. Message addressing prevents unexpected operations when two devices communicating over Port 1, 2, or 3 are accidentally cross-connected via fiber-optic cables or in a SONET/SDH/MPLS multiplexer configuration. You can override address checking by using the **LOOP** command when troubleshooting MIRRORED BITS communications (see *Loopback Testing* on page 3.14 for more information).

Message Transmission, Reception, and Data Integrity Protection

When a port is configured for SEL MB8 encoding, the SEL-TWFL continuously transmits on that port an attention message containing the TXID value until it receives an attention message that includes an RXID value matching the RXID setting. If the attention message is successful, the device has properly synchronized and it begins transmitting data.

Each transmitted message contains the most recent values of the MIRRORED BITS outputs.

The SEL-TWFL decodes and verifies each received message from the MIRRORED BITS inputs. When SEL MB8 encoding is used, the SEL-TWFL requires two consecutive messages to be received and validated to change the value of the MIRRORED BITS input. When IEEE C37.94 encoding is used, the SEL-TWFL

requires three consecutive messages to be received and validated to change the value of the MIRRORED BITS input. The SEL-TWFL meets the IEC 60834-1, *Teleprotection Equipment of Power Systems – Performance and Testing – Part 1: Command Systems* transmission time, bit error rate security, and bit error rate dependability recommendations for direct tripping and teleprotection applications over digital channels.

Channel Alarming

The SEL-TWFL asserts the ROKP*n* Relay Word bit (Receive OK on Port *n*; *n* = 1, 2, or 3) to signify normal operating conditions. ROKP*n* asserts only after the port receives a successful attention message and after two consecutive messages exhibit none of the possible errors described in *Table 3.9*. Once ROKP*n* asserts, the received bits are passed to the security debounce timers of the MIRRORED BITS inputs.

Table 3.9 Error Conditions Monitored in MIRRORED BITS Communications

Error Type	Description	Encoding	
		MB8	C37.94
Parity Error	Data failed UART parity check.	×	
Re-Sync	Device at the other end of the link requested a resynchronization.	×	
Bad Re-Sync	Transmit and receive addresses between the local and remote devices do not match.	×	
Data Error	Received data failed a data integrity check, or the transmit and receive addresses do not match.	×	
Device Disabled	Device disabled, such as during a device power-up sequence or a settings change.	×	×
Loopback	Loopback test mode is in progress.	×	×
Framing Error	UART did not detect a stop bit.	×	
	IEEE C37.94 frame bit sequence is not detected.		×
Format Error	Payload data failed data integrity check or the transmit and receive addresses do not match.		×
Loss of Signal	Two or more frames in the recent eight frames failed the IEEE C37.94 frame bit sequence. The transmit logic asserts the Yellow Path bit in the outgoing frame if the Loss of Signal bit is asserted.		×
Yellow Path	Three or more consecutive frames received with the Yellow Path bit asserted while the Loss of Signal bit is not asserted.		×

If the ROKP*n* Relay Word bit deasserts because of any of the errors listed in *Table 3.9*, MIRRORED BITS communications on Port *n* enters a channel fail state. While in this channel fail state, the SEL-TWFL forces the MIRRORED BITS inputs on that port to a fail-safe value of logical 0.

The device counts the number of communications errors that have occurred on each enabled port since you last cleared the channel statistics by issuing the **COM P *n* C** (*n* = 1, 2, or 3) command. Use the **COM P *n*** command to obtain a report of the communications errors, including the latest count of each error. See *Communications Report for Ports 1, 2, and 3* for additional information.

Communications Report for Ports 1, 2, and 3

The **COM** command (see *COMMUNICATIONS* on page C.7) provides a present status and a history report for Ports 1, 2, and 3. *Figure 3.1* shows the format of the report when the selected port is configured for SEL MB8 encoding, and *Figure 3.2* shows a sample report. Similarly, *Figure 3.3* shows the format of the report when the selected port is configured for IEEE C37.94 encoding, and *Figure 3.4* shows an example. *Table 3.10* explains the individual data items reported for each encoding method and provides comments and troubleshooting guidelines. To simplify troubleshooting, use the **COM P *n* C** command to clear the COM report after resolving each communications issue.

```
COMMON REPORT HEADER

Summary for Port n
    Encoding MB8

Channel status
    ROKP1 = b    LBOKP1 = b

For Date and Time 1 to Date and Time 2

    Last Error          xxxxxxxxxx
    Total Errors              c
    Device Disabled           c
    Data Error                c
    Re-Sync                   c
    Parity Error              c
    Framing Error             c
    Bad Re-Sync               c
    Loopback                  c
    Longest Error (s)     aaaaa.aaa
    Unavailability            0.xxxxxx
```

Figure 3.1 COM Report Data Items for a Port Configured for SEL MB8 Encoding

```
=>>COM P 1 <Enter>

SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

Summary for Port 1
    Encoding MB8

Channel Status
    ROKP1 = 1    LBOKP1 = 0

For 2024/01/30 16:59:30.000 to 2024/01/30 17:00:00.000

    Last Error          Re-Sync
    Total Errors              6
    Device Disabled           1
    Data Error                2
    Re-Sync                   1
    Parity Error              1
    Framing Error             1
    Bad Re-Sync               0
    Loopback                  0
    Longest Error (s)        19.842
    Unavailability            0.000111
```

Figure 3.2 Sample COM Report for a Port Configured for SEL MB8 Encoding

```
COMMON REPORT HEADER

Summary for Port n
    Encoding C37.94

Channel status
    ROKP1 = b    LBOKP1 = b    Yellow Path = b    Loss of Signal = b

For Date and Time 1 to Date and Time 2

    Last Error          xxxxxxxxxx
    Total Errors              0
    Device Disabled           0
    Loss of Signal            0
    Yellow Path               0
    Framing Error             0
    Format Error              0
    Loopback                  0
    Longest Error (s)     aaaaa.aaa
    Unavailability            0.xxxxxx
```

Figure 3.3 COM Report Data Items for a Port Configured for IEEE C37.94 Encoding

```
=>>COM P 1 <Enter>

SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

Summary for Port 1
    Encoding C37.94

Channel Status
    ROKP1 = 1    LBOKP1 = 0    Yellow Path = 0    Loss of Signal = 0

For 2024/01/30 16:59:30.000 to 2024/01/30 17:00:00.000

    Last Error          Yellow Path
    Total Errors             12
    Device Disabled           2
    Loss of Signal            1
    Yellow Path               1
    Framing Error             1
    Format Error              7
    Loopback                  0
    Longest Error (s)        19.842
    Unavailability            0.000194
```

Figure 3.4 Sample COM Report for a Port Configured for IEEE C37.94 Encoding

Table 3.10 refers to a link as a direct connection between two devices (the SEL-TWFL to a MIRRORED BITS communications-compatible SEL device when using SEL MB8 encoding, the SEL-TWFL to a multiplexer when using IEEE C37.94 encoding, and a back-to-back SEL-TWFL connection when bench-testing the SEL-TWFL in the laboratory setting). *Table 3.10* refers to a channel as the end-to-end connection over a network between a local SEL-TWFL and a remote SEL-TWFL or other MIRRORED BITS communications-compatible SEL device. The SEL-TWFL Ports 1, 2, and 3 are fiber-optic ports, and therefore when using SEL MB8 encoding, the term link includes both the fiber-optic cable and a media converter (SEL-2814 Fiber-Optic Transceiver With Hardware Flow Control and SEL-2812 Fiber-Optic Transceiver With IRIG-B).

Table 3.10 Information Included in the COM P *n* Report[a] (Sheet 1 of 5)

Report Item	Description	Comments and Troubleshooting	Encoding	
			MB8	C37.94
Channel Status				
ROKP*n*	Receive OK status for the Port *n* connection. When ROKP*n* is asserted, the connection is operating normally and the device is receiving valid data. The MIRRORED BITS inputs are operational and the analog payload exchanged when using the IEEE C37.94 encoding is received. When ROKP*n* is deasserted, the Port *n* connection is not operating normally. The device forces the MIRRORED BITS inputs on that port to the fail-safe value of logical 0.	Inspect the COM P *n* report for errors (see *Table 3.9*). Follow the troubleshooting steps for each error, as outlined in this table. The ROKP*n* deasserts when you put Port *n* in the loopback mode. Disregard the ROKP*n* status in the loopback mode and pay attention to the LBOKP*n* status instead.	×	×
LBOKP*n*	Receive OK status for the Port *n* connection while in the loopback mode. When LBOKP*n* is asserted, the looped-back connection is operating normally, receiving valid data. The MIRRORED BITS inputs are operational or forced to logical 0 depending on the parameters of the loopback mode (see *LOOP* on page C.10 and *LOOP P n DATA* on page C.11 for more information). The analog payload exchanged when using the IEEE C37.94 encoding is received on the looped-back connection. When LBOKP*n* is deasserted, the Port *n* looped-back connection is not operating normally.	Inspect the COM P *n* report for errors (see *Table 3.9*). Follow the troubleshooting steps for each error, as outlined in this table. Alternatively, you can move the loopback point in your link or channel until you see LBOKP*n* asserting, signifying that no errors are present. Move the loopback point by one demarcation point and troubleshoot the specific error you see at that time. Repeat the same procedure, moving the loopback point farther from the SEL-TWFL until you reach the SEL-TWFL at the end of the link or channel and no errors are present. LBOKP*n* deasserts when you terminate the loopback mode for Port *n*. Apply care when using the loopback feature built into some multiplexers. Such software-based loopback functions can loop the connection back, but at the same time, they can send the data to the other device. Ensure you isolate both devices for security when using the software-based loopback feature available in some multiplexers.	×	×
Yellow Path	The Yellow Path status indicates that the remote device is not receiving data (see Loss of Signal). To assert the Yellow Path status, the device must be receiving data. Therefore, Yellow Path indicates the link is broken in one direction only (transmit direction for the device with Yellow Path asserted).	Troubleshoot the channel in the direction from the local device toward the remote device (fiber-optic cables and multiplexers). Inspect the COM P *n* report in the remote device for errors (see *Table 3.9*). Follow the troubleshooting steps for each error in the remote device, as outlined in this table.		×
Loss of Signal	The Loss of Signal status indicates that the device is not receiving data. The device sends the Yellow Path bit in the outgoing frame if the Loss of Signal bit is asserted.	Inspect the COM P *n* report for errors (see *Table 3.9*). Follow the troubleshooting steps for each error, as outlined in this table. Inspect the remote device COM report for the Yellow Path status. If asserted at the remote device, the Yellow Path status indicates the channel has a problem in one direction only.		×

Table 3.10 Information Included in the COM P *n* Report[a] (Sheet 2 of 5)

Report Item	Description	Comments and Troubleshooting	Encoding	
			MB8	C37.94
Channel Statistics				
Date and Time 1 and Date and Time 2	The report shows connection statistics beginning on Date and Time 1 (the time the report was last cleared) and ending on Date and Time 2 (the time the **COM** command was issued).	Ensure you analyze the connection statistics for the intended time period (commissioning-to-date, last 24 hours, since rectifying an issue, and so on). Use this date and time information to correlate channel problems with any activities at the locations of the local and remote devices or any work on fiber patch panels and cables. It is good practice to clear the statistics after troubleshooting (use the **COM P *n* C** command).	×	×
Last Error	This item lists the type of error that the port diagnostics last detected (Device Disabled, Data Error, Re-Sync, Parity Error, Loss of Signal, Yellow Path, Framing Error, Bad Re-Sync, Format Error).	If the connection is not operating normally (ROKP*n* is deasserted), the Last Error occurred when the link or channel experienced a major problem, and you should prioritize troubleshooting the Last Error. If the connection works intermittently (ROKP*n* status chatters and errors accumulate), consider issuing the **COM P *n*** command several times to see if the Last Error is reported consistently or if it changes. If the same error is reported as the Last Error, prioritize troubleshooting that error.	×	×
Total Errors	This counter tallies all occurrences of all communications errors that the port diagnostics detected since you cleared the report by using the **COM P *n* C** command (Device Disabled, Data Error, Re-Sync, Parity Error, Loss of Signal, Yellow Path, Framing Error, Bad Re-Sync, Format Error).	Use this data item as a measure of channel quality. Compare with historical values for this particular link or channel or with typical values for this link or channel type in your organization (making measurements on a 24-hour basis, for example). Initiate remedial actions if the measured value does not meet your expectations or specifications.	×	×
Device Disabled	This counter tallies the instances of the device removed from service (disabled as signified by the deassertion of the EN Relay Word bit). When out of service, the device does not send data on Ports 1, 2, and 3, which triggers communications errors in the remote device(s). When the device intentionally stops communicating during the out-of-service condition, it does not update the unavailability calculations.	Compare this data item with the expected number of device out-of-service conditions. The device intentionally enters an out-of-service condition when you change settings. If you suspect other reasons for going out of service, issue the **STA** command to obtain more information about the device diagnostics (see *Appendix F*). Use this item to explain communications outages in devices connected to the local device.	×	×

Table 3.10 Information Included in the COM P *n* Report[a] (Sheet 3 of 5)

Report Item	Description	Comments and Troubleshooting	Encoding	
			MB8	C37.94
Data Error	This counter tallies the number of times the SEL MB8 message has not conformed to the SEL MB8 message format or that the message has timed out.	Disturbances in the communications network, such as ring switching or network synchronization, can cause a burst of Data Errors. Effectively, the network can corrupt a few messages each time when reconfiguring itself and self-healing after a problem. Inquire about any network activity and inspect network equipment logs if you suspect the device detects Data Errors because of activity in the communications network. When troubleshooting device-to-device or device-to-multiplexer links, Data Errors can be caused by cable issues, fiber pinching or bending, dirty or defective fiber connectors, issues with the SEL-2814 or SEL-2812, improper shielding, and other media problems.	×	
Re-Sync	This counter tallies the number of SEL MB8 resynchronization messages the local device receives from the remote device.	Re-Sync errors indicate communications issues that the remote device experiences. When the remote device detects errors in the received SEL MB8 data, it requests a Re-Sync from the local device. Re-Sync errors indicate a connection problem in the direction from the device with Re-Sync errors to the other device.	×	
Parity Error	This counter tallies the number of times the calculated parity has not matched the parity bit in the received SEL MB8 message.	Parity Errors occur when the data rates between the communicating devices do not match. Inspect the data rate settings in each pair of devices that communicate (device-to-device, device-to-multiplexer) and ensure the data rates match. Parity Errors accompanied by the ROKP*n* status deassertion indicate an incorrect data format setting in the communications network. When using an SEL ICON network for the communications channel, configure the communications port on the SEL-TWFL for SEL MB8 encoding and apply the 6,O,2 setting (6 data bits, odd parity, and 2 stop bits) to the ICON asynchronous data module. Parity Errors accompanied by Data Errors or Framing Errors indicate data corruption issues in the link or channel.	×	
Loss of Signal	This counter tallies the number of times the Loss of Signal bit asserted.	If this counter is incrementing continuously, then most likely the frame is incorrect. Verify that the multiplexer IEEE C37.94 module is configured for N = 1. Loss of Signal errors accompanied by Data Errors indicate problems with the link between the device and the multiplexer.		×
Yellow Path	This counter tallies the number of times the Yellow Path bit asserted (remote device not receiving data).	Inspect the remote device for errors and troubleshoot accordingly. High counts of the Yellow Path counter indicate an intermittent link problem between the device and the multiplexer.		×

Table 3.10 Information Included in the COM P *n* Report[a] (Sheet 4 of 5)

Report Item	Description	Comments and Troubleshooting	Encoding	
			MB8	C37.94
Framing Errors	This counter tallies the number of invalid "start" or "stop" bits detected.	Framing Errors occur when the data rates between the communicating devices do not match. Inspect the data rate settings in each pair of devices that communicate (device-to-device, device-to-multiplexer) and ensure the data rates match. Framing Errors accompanied by Format Errors indicate problems with the link between the device and the multiplexer. Disturbances in the communications network, such as ring switching or network synchronization, can cause a burst of Framing Errors. Effectively, the network can corrupt a few messages each time when reconfiguring itself and self-healing after a problem. Inquire about any network activity and inspect network equipment logs if you suspect the device detects Framing Errors because of activity in the communications network.	×	
	This counter tallies the number of IEEE C37.94 messages with Framing Errors.	Verify that the multiplexer IEEE C37.94 module is configured for N = 1. Framing Errors accompanied by Data Errors indicate an intermittent link issue between the device and the multiplexer.		×
Bad Re-Sync	This counter tallies the number of invalid SEL MB8 resynchronization messages the local device received.	A Bad Re-Sync message occurs when the transmit and receive addresses between the local and remote devices do not match. Verify that the TXID setting in the local device matches the RXID setting in the remote device, and vice versa. Inspect the network logs to verify the SEL-TWFL was not accidentally cross-connected to the wrong device.	×	
Format Error	This counter tallies the number of frames containing data that failed the data integrity check (corrupt packets) and the number of times the frame is received from the wrong device (the receive address does not match).	An accumulation of Format Errors with no other errors indicates data corruption in the network. If Format Errors occur periodically in a repeating pattern, verify the DATACLK settings in both devices. (DATACLK must be set to external when using multiplexers). If Format Errors occur permanently, verify that the TXID setting in the local device matches the RXID setting in the remote device, and vice versa. Disturbances in the communications network, such as ring switching or network synchronization, can cause a burst of Format Errors. Effectively, the network can corrupt a few frames each time when reconfiguring itself and self-healing after a problem. Inquire about any network activity and inspect network equipment logs if you suspect the device detects Format Errors. Format Errors accompanied by Framing Errors indicate problems with the link between the device and the multiplexer.		×

Table 3.10 Information Included in the COM P *n* Report[a] (Sheet 5 of 5)

Report Item	Description	Comments and Troubleshooting	Encoding	
			MB8	C37.94
Loopback	This counter tallies the number of times the loopback mode has been initiated.	Inspect this counter to correlate high values of any other error counters with loopback testing. It is good practice to clear the report before initiating the loopback mode (use the **COM P *n* C** command). Use the **LOOP P *n* X** command to terminate the loopback mode.	×	×
Longest Error (s)	Duration of the longest error.	Use this measurement to better understand the reported unavailability and distinguish between sporadic but repetitive loss of connection outages and longer-term link or channel outages. If the Longest Error is close to the total unavailability time, then the device experienced a longer-term link or channel outage.	×	×
Unavailability	Connection unavailability in per unit of the total time. Unavailability is defined as a state when the ROKP*n* status is deasserted. A device out-of-service condition (device disabled) does not constitute unavailability (the device stopped transmitting rather than the link or channel failed).	Use this measurement to evaluate link and channel availability. Compare with historical values for this link or channel and with typical values for this link or channel type in your organization. Compare with the formal specification you issued to your channel provider. Calculate the total unavailability time as a product of unavailability and the time of the report (time between Date and Time 1 and Date and Time 2). Compare with the Longest Error to determine if the connection experiences sporadic and repetitive issues or a single longer-term outage.	×	×

[a] *n* = 1–3.

Loopback Testing

Loopback testing is a commonly used method for troubleshooting digital communications channels. In order to isolate the problem, you may loop back the communications link by connecting the transmit output to the receive input at various points in the communications path between the two communicating devices. If the equipment between the device and the loopback point is healthy and configured properly, the device will receive its own data and show no errors. If you see errors for a given loopback location, you know where the problem is. It is good practice to clear the channel statistics before starting a loopback test. By examining communications errors, you can identify the nature of the problem as well. For example, you can troubleshoot a SONET/SDH/MPLS connection between two SEL-TWFL devices by performing a loopback test while gradually moving the loopback position away from the device (apply loopback to the device port; apply loopback to the fiber-optic cable at a media converter, such as the SEL-2814 Fiber-Optic Transceiver With Hardware Flow Control or the SEL-2812 Fiber-Optic Transceiver With IRIG-B; issue a command to loop back data in the local SONET/SDH/MPLS multiplexer; issue a command to loop back data in the remote SONET/SDH/MPLS multiplexer; and so on).

Apply care when using the loopback feature built into some multiplexers. Such software-based loopback functions can loop the connection back, but at the same time, they can send the data to the other device. Ensure you isolate both devices for security when using the software-based loopback feature available in some multiplexers.

When you loop back a communications channel connected to Port 1, 2, or 3, the SEL-TWFL rejects the data based on the transmit and receive addresses (TXID and RXID settings). To perform a meaningful loopback test, put the communications port in a loopback test mode prior to looping back the communications link. You can use one of two loopback test modes:

- Initiate a loopback test mode by issuing the **LOOP *n*** (*n* = 1, 2, or 3) command to allow the device to receive its own data while keeping the received MIRRORED BITS inputs on Port *n* at the fail-safe value of logical 0.
- Initiate a loopback test mode by issuing the **LOOP DATA *n*** (*n* = 1, 2, or 3) command to allow the device to receive its own data while accepting MIRRORED BITS inputs received data on Port *n*.

By default, the **LOOP** command enables the loopback test mode with a 5 min time-out. You can initiate the test for a longer duration by specifying the time-out period as a command attribute. For example, initiate a loopback test on Port 2 for 30 min by issuing the **LOOP 2 30** command. Use **LOOP R** to terminate the loopback test mode before it times out on its own. See *Appendix C: SEL ASCII Commands* for more information on the **LOOP** command.

In the loopback test mode, the ROKP*n* Relay Word bit deasserts and the device uses the LBOKP*n* Relay Word bit to indicate the communications status. Logic identical to that of ROKP*n* drives LBOKP*n*. In the loopback mode, the device collects communications port statistics for Ports 1, 2, and 3. Inspect LBOKP*n* and the received MIRRORED BITS inputs (RMB1P*n* through RMB8P*n* Relay Word bits) as well as the COM report when troubleshooting communications on Port *n* (use the **COM P *n*** command to obtain the port report with communications statistics). *Figure 3.5* shows an example COM report for Port 1 when the loopback test mode is enabled and ENCODING is set to SEL MB8.

```
=>>COM P 1 <Enter>

SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

Summary for Port 1
    Encoding MB8

Channel Status
   ROKP1 = 0    LBOKP1 = 1

For 2024/01/30 16:59:30.000 to 2024/01/30 17:00:00.000

    Last Error          Data Error
    Total Errors            12
    Device Disabled          3
    Data Error               4
    Re-Sync                  1
    Parity Error             2
    Framing Error            2
    Bad Re-Sync              0
    Loopback                 1
    Longest Error (s)       19.842
    Unavailability           0.000245
```

Figure 3.5 Sample COM Report for a Communications Channel on Port 1 During a Loopback Test With ENCODING Set to SEL MB8

Figure 3.6 shows an example of the COM report for Port 1 when the loopback test mode is enabled and ENCODING is set to IEEE C37.94.

```
=>>COM P 1 <Enter>

SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

Summary for Port 1
    Encoding C37.94

Channel Status
    ROKP1 = 0    LBOKP1 = 1    Yellow Path = 0    Loss of Signal = 0

For 2024/01/30 16:59:30.000 to 2024/01/30 17:00:00.000

    Last Error          Loss of Signal
    Total Errors             11
    Device Disabled           2
    Loss of Signal            3
    Yellow Path               1
    Framing Error             3
    Format Error              2
    Loopback                  1
    Longest Error (s)       141.491
    Unavailability            0.000880
```

Figure 3.6 Sample COM Report for a Communications Channel on Port 1 During a Loopback Test With ENCODING Set to IEEE C37.94

Configuring an SEL-2507 Connection

Use an ST-terminated fiber-optic cable to make a direct connection between the SEL-TWFL and the SEL-2507 High-Speed Remote I/O Module.

Configure the connection by using the Port settings on the SEL-TWFL and by using the rear-panel control (DIP) switches on the SEL-2507. Ensure the SEL-TWFL port is configured for SEL MB8 data encoding (ENCODING = MB8). *Table 3.11* shows the suggested SEL-TWFL and SEL-2507 settings. For example, to communicate at 115,200 bps with an SEL-TWFL configured for RXID = 1 and TXID = 3, you need to set the SEL-2507 control (DIP) switches as follows: 0001****11.

Table 3.11 Suggested Settings for SEL-TWFL and SEL-2507 MIRRORED BITS Communications (Sheet 1 of 2)

SEL-TWFL Port Settings		SEL-2507 Control (DIP) Switches[a]
Name	**Value**	
EPORT	Y	Not applicable
ENCODING	MB8	
SPEED (bps)	115200	********11
	57600 (not allowed with SEL-2507)	Not allowed
	38400	********00
	19200	********10
TXID	1	**00******
	2	**10******
	3	**01******
	4	**11******

Table 3.11 Suggested Settings for SEL-TWFL and SEL-2507 MIRRORED BITS Communications (Sheet 2 of 2)

SEL-TWFL Port Settings		SEL-2507 Control (DIP) Switches[a]
Name	Value	
RXID	1	00********
	2	10********
	3	01********
	4	11********

[a] 0 means OFF (upper switch position); 1 means ON (lower switch position).

Refer to the *SEL-2507 High-Speed Remote I/O Module Instruction Manual*, available at selinc.com, for more information about the SEL-2507.

Digital Communications Examples

You can use contact inputs and outputs and MIRRORED BITS inputs and outputs on communications Ports 1, 2, and 3 in any combination for digital signaling. When possible, use digital signaling to gain the benefits of speed, security, and standardization. This subsection presents two examples of all-digital signaling. All-digital signaling allows you to standardize panel design, wiring, input-output lists, and equipment model numbers (bill of material and spare devices). It also allows faster data exchange by avoiding security debounce time delays to address noise when using contact inputs and outputs. Refer to *Section 9: Installation* for information on the connectors, cables, and media converters that are required for all-digital SEL-TWFL signaling.

Example 1: Two-Terminal Line Application With MIRRORED BITS-Compatible Protective Relays (Main 1) and Contact I/O-Based Protective Relays (Main 2)

Refer to *Figure 3.7*, and program the SEL-TWFL to accomplish the following functionality (Ports 1, 2, and 3 are interchangeable and their functional allocation in *Figure 3.7* is only an example):

- Configure Port 1 for IEEE C37.94 encoding, and connect it directly to an IEEE C37.94-compliant multiplexer by using a multimode fiber-optic cable. Use eight MIRRORED BITS outputs and inputs to cross-trigger digital fault recording and fault locating between the SEL-TWFL devices.
- Configure Port 2 for SEL MB8 encoding and use a media converter, such as the SEL-2814 Fiber-Optic Transceiver With Hardware Flow Control, to connect the Port 2 fiber-optic channel to the EIA-232 interface of a MIRRORED BITS-compatible primary protective relay (Main 1), such as the SEL-421 Protection, Automation, and Control System. Receive the protection trip signal for triggering the fault locator and event recorder by using eight MIRRORED BITS inputs.

- Configure Port 3 for SEL MB8 encoding and use a multimode fiber-optic cable to connect it to the SEL-2507 High-Speed Remote I/O Module that is wired to contact I/O of the backup protective relay (Main 2). Receive the protection trip signal for triggering the fault locator and event recorder.
- By using spare MIRRORED BITS inputs and outputs, cross-trigger digital fault recording and fault locating between the devices.

Figure 3.7 Two-Terminal Line Application With MIRRORED BITS-Compatible Protective Relays (Main 1) and Contact I/O-Based Protective Relays (Main 2)

Example 2: Three-Terminal Line Application With MIRRORED BITS-Compatible Protective Relays

Refer to *Figure 3.8*, and program the SEL-TWFL to accomplish the following functionality (Ports 1, 2, and 3 are interchangeable and their functional allocation in *Figure 3.8* is only an example):

- Configure Port 1 and Port 2 for IEEE C37.94 encoding and connect them directly to an IEEE C37.94-compliant multiplexer by using multimode fiber-optic cables. Use eight MIRRORED BITS outputs and inputs per port to cross-trigger digital fault recording and fault locating with the remote SEL-TWFL that is connected on that port.
- Configure Port 3 for SEL MB8 encoding and use a media converter, such as the SEL-2814 Fiber-Optic Transceiver With Hardware Flow Control, to connect the fiber-optic Port 3 to the EIA-232 interface of a MIRRORED BITS-compatible protective relay, such as the SEL-421 Protection, Automation, and Control System. Receive the protection trip signal for triggering the fault locator and event recorder by using eight MIRRORED BITS inputs.
- By using spare MIRRORED BITS inputs and outputs, cross-trigger digital fault recording and fault locating between the devices.

Figure 3.8 Three-Terminal Line Application With Mirrored Bits-Compatible Protective Relays

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SECTION 4

Triggering and Supervisory Elements

Introduction

This section describes the elements used to trigger the recording functions and the elements used to supervise the fault locating and line monitoring functions. Each subsection provides an explanation of a function along with a list of corresponding Relay Word bits, settings, and general settings guidelines. When necessary, it explains the principle of operation before describing implementation details. For more information related to signal processing and operating principles, refer to *Appendix G: Signal Processing and Operating Principles*.

This section is organized as follows:

- *Overcurrent Elements* on page 4.1
- *Voltage Elements* on page 4.8
- *Supervisory Elements* on page 4.17
- *SELOGIC Custom Programming* on page 4.22

Overcurrent Elements

The SEL-TWFL includes two levels (instances) of phase, zero-sequence, and negative-sequence instantaneous and definite-time overcurrent elements. These nondirectional elements (ANSI device numbers 50P, 50G, and 50Q for the phase, zero-sequence, and negative-sequence elements, respectively) allow selection of operating current (Line 1 or Line 2) and provide a programmable torque-control input for custom applications. Use the torque-controlled SELOGIC setting to supervise the overcurrent element. The torque-controlled outputs (67P, 67G, 67Q) can be configured with a time delay to provide a definite-time overcurrent function (67PT, 67GT, and 67QT). The definite-time overcurrent logic uses integrating timers, which have an instantaneous type of reset with a fixed reset delay of 25 ms (refer to *Definite-Time Integrating Timer Logic* on page G.11 for more information).

The two levels of phase, zero-sequence, and negative-sequence overcurrent elements have independent enable, operating quantity, pickup, torque-control, and time-delay settings. All the overcurrent elements use full-cycle phasors. This section enumerates the Level *n* (*n* = 1–2) element settings and Relay Word bits with *n* following the element type (P, G, or Q). For example, 67Q2 refers to Level 2 of the torque-controlled (67) element operating on the negative-sequence (Q) current.

The phase, zero-sequence, and negative-sequence overcurrent elements all follow the same logic and naming conventions for settings and Relay Word bits. *Figure 4.1* is a high-level overview of the instantaneous and definite-time overcurrent logic, showing three element types with the symbol *X* representing P (phase), G (zero-sequence), or Q (negative-sequence). You control the logic with

the enable, operating quantity, pickup, torque-control SELOGIC equation, and time-delay settings. The logic responds with the instantaneous nondirectional, instantaneous torque-controlled, and time-delayed torque-controlled output Relay Word bits.

Figure 4.1 High-Level Overview of the Instantaneous and Definite-Time Overcurrent Element Logic

Phase Overcurrent Elements

The SEL-TWFL includes two levels (instances) of the phase instantaneous and definite-time overcurrent (50/67P) element. Both levels respond to the phase current in the selected operating quantity (Line *m* current, where *m* = 1–2) and have individual pickup, torque-control, and time-delay settings to fulfill different applications.

The SEL-TWFL 50/67P element logic is similar to the 50/67G and 50/67Q element logic. You may only need to give this section a brief read if you are already familiar with either the 50/67G element or the 50/67Q element.

When the 50/67P element in *Figure 4.2* is enabled (E50P*n* = Y), it uses the 50P*n*P pickup setting and applies it to the phase line currents (IA, IB, and IC) for the selected operating quantity, configured by the 50P*n*O setting.

The 50P*n* Relay Word bit signifies the instantaneous nondirectional overcurrent condition in any phase. The 67P*n*A, 67P*n*B, and 67P*n*C Relay Word bits signify the instantaneous torque-controlled operation on a per-phase basis, and the 67P*n* Relay Word bit signifies the instantaneous torque-controlled operation in any phase. The 67P*n*TC torque-control SELOGIC equation always applies to the 67P logic, and therefore you can use this equation to supervise the nondirectional output.

The 67P logic uses an integrating timer for time-delayed operation (see *Definite-Time Integrating Timer Logic* on page G.11). The 67P*n*T Relay Word bit signifies the torque-controlled definite-time overcurrent condition. Use the 67P*n*D time-delay setting to specify the delay.

Figure 4.2 Phase Instantaneous and Definite-Time Overcurrent Element Logic

Table 4.1 and *Table 4.2* list the settings and Relay Word bits associated with the SEL-TWFL 50/67P elements.

Table 4.1 Phase Instantaneous and Definite-Time Overcurrent Level *n* Element Settings

Setting[a]	Description	Range	Default	Class
E50P*n*	Enable 50P and 67PT Overcurrent	Y, N	N	Device
50P*n*O	Phase Overcurrent Operating Quantity	L1I, L2I	L1I	Device
50P*n*P	Phase Overcurrent Pickup	0.25–100.00 A secondary[b]	10.00	Device
67P*n*TC	Phase Overcurrent Torque-Control SELogic Equation	SELogic Expression	1	Device
67P*n*D	Phase Overcurrent Time Delay	0.000–10.000 s	0.000	Device

[a] *n* = 1–2.
[b] The ranges and defaults shown are for 5 A-rated CTs. Divide by 5 for 1 A-rated CTs.

Table 4.2 Phase Instantaneous and Definite-Time Overcurrent Element Relay Word Bits

Relay Word Bit[a]	Description
50P*n*	50P instantaneous overcurrent Level *n* operated
50A*n*	50P instantaneous overcurrent Level *n* Phase A operated
50B*n*	50P instantaneous overcurrent Level *n* Phase B operated
50C*n*	50P instantaneous overcurrent Level *n* Phase C operated
67P*n*	67P torque-controlled overcurrent Level *n* operated
67P*n*A	67P torque-controlled overcurrent Level *n* Phase A operated
67P*n*B	67P torque-controlled overcurrent Level *n* Phase B operated
67P*n*C	67P torque-controlled overcurrent Level *n* Phase C operated
67P*n*T	67PT time-delayed torque-controlled overcurrent Level *n* operated
67P*n*TC	67P Level *n* torque-control condition asserted

[a] *n* = 1–2.

Follow these settings rules when configuring the phase instantaneous and definite-time elements (*n* = 1–2).

E50P*n*

Set the E50P*n* setting to Y to enable the 50/67P Level *n* element.

50P*n*O

Select the operating quantity for the phase overcurrent element. Use the 50P*n*O setting to select either the Line 1 or Line 2 current.

50P*n*P

Use the 50P*n*P setting to set the overcurrent threshold for the 50/67P Level *n* element. The setting is in secondary amperes, considering the *effective* CT ratio. The effective CT ratio depends on the CT ratio of the current input IW (CTRW setting), the current input IX (CTRX setting), or both, according to the current source selection (L*m*I setting). Note that the instantaneous nondirectional (50P*n* output Relay Word bit), the instantaneous torque-controlled (67P*n* output Relay Word bit), and the definite-time torque-controlled (67P*n*T output Relay Word bit) functions all share the same pickup threshold.

67P*n*TC

NOTE: The SEL-TWFL does not include directional elements. Use the communications ports or contact inputs to provide directional input, via the torque-control SELOGIC equation, from a protective relay to the SEL-TWFL.

Use the 67P*n*TC torque-control SELOGIC equation for supervising or blocking the 50/67P Level *n* element (67P*n* and 67P*n*T Relay Word bits). Typical applications include directional control, dynamic supervision or blocking, and advanced applications, such as directional control involving complex logical conditions and timers.

Program the 67P*n*TC torque-control SELOGIC equation to logical 1 if you do not want any supervision or blocking.

67P*n*D

NOTE: The SEL-TWFL accepts time-delay settings expressed in seconds, not in power system cycles.

Use the 67P*n*D setting to set the time delay for the 67P Level *n* element. The element uses an integrating timer. This timer uses an instantaneous type of reset with a fixed reset delay of 25 ms (see *Definite-Time Integrating Timer Logic* on page G.11).

The SEL-TWFL processes the timer logic at fixed time intervals and accepts time-delay settings expressed in seconds. The resulting time delay is accurate and independent of the power system frequency.

Zero-Sequence Overcurrent Elements

The SEL-TWFL includes two levels (instances) of the zero-sequence instantaneous and definite-time overcurrent (50/67G) element. Both levels respond to the zero-sequence component in the selected operating quantity (Line *m* current, where *m* = 1–2) and have individual pickup, torque-control, and time-delay settings to fulfill different applications.

The SEL-TWFL 50/67G element logic is similar to the 50/67P and 50/67Q element logic. You may only need to give this section a brief read if you are already familiar with either the 50/67P element or the 50/67Q element.

When the 50/67G element in *Figure 4.3* is enabled (E50G*n* = Y), it uses the 50G*n*P pickup setting and applies it to the zero-sequence component (3I0) for the selected operating quantity, configured by the 50G*n*O setting.

The 50G*n* Relay Word bit signifies the instantaneous nondirectional overcurrent condition. The 67G*n* Relay Word bit signifies the instantaneous torque-controlled operation. The 67G*n*TC torque-control SELOGIC equation always applies to the 67G logic, and therefore you can use this equation to supervise the nondirectional output.

The 67G logic uses an integrating timer for time-delayed operation (see *Definite-Time Integrating Timer Logic* on page G.11). The 67G*n*T Relay Word bit signifies the torque-controlled definite-time overcurrent condition. Use the 67G*n*D time-delay setting to specify the delay.

Figure 4.3 Zero-Sequence Instantaneous and Definite-Time Overcurrent Element Logic

Table 4.3 and *Table 4.4* list the settings and Relay Word bits associated with the SEL-TWFL 50/67G elements.

Table 4.3 Zero-Sequence Instantaneous and Definite-Time Overcurrent Level *n* Element Settings

Setting[a]	Description	Range	Default	Class
E50G*n*	Enable 50G and 67GT Overcurrent	Y, N	N	Device
50G*n*O	Zero-Sequence Overcurrent Operating Quantity	L1I, L2I	L1I	Device
50G*n*P	Zero-Sequence Overcurrent Pickup	0.25–100.00 A secondary[b]	10.00	Device
67G*n*TC	Zero-Sequence Overcurrent Torque-Control SELogic Equation	SELogic Expression	1	Device
67G*n*D	Zero-Sequence Overcurrent Time Delay	0.000–10.000 s	0.000	Device

[a] *n* = 1–2.
[b] The ranges and defaults shown are for 5 A-rated CTs. Divide by 5 for 1 A-rated CTs.

Table 4.4 Zero-Sequence Instantaneous and Definite-Time Overcurrent Element Relay Word Bits

Relay Word Bit[a]	Description
50G*n*	50G instantaneous overcurrent Level *n* operated
67G*n*	67G instantaneous torque-controlled overcurrent Level *n* operated
67G*n*T	67GT time-delayed torque-controlled overcurrent Level *n* operated
67G*n*TC	67G Level *n* torque-control condition asserted

[a] *n* = 1–2.

Follow these settings rules when configuring the zero-sequence instantaneous and definite-time elements (*n* = 1–2).

E50G*n*

Set the E50G*n* setting to Y to enable the 50/67G Level *n* element.

50G*n*O

Select the operating quantity for the zero-sequence overcurrent element. Use the 50G*n*O setting to select either the Line 1 or Line 2 current.

50G*n*P

Use the 50G*n*P setting to set the overcurrent threshold for the 50/67G Level *n* element. The threshold applies to the tripled zero-sequence current (3I0). The setting is in secondary amperes, considering the *effective* CT ratio. The effective CT ratio depends on the CT ratio of the current input IW (CTRW setting), the current input IX (CTRX setting), or both, according to the line current source selection (L*n*I setting). Note that the instantaneous nondirectional (50G*n* output Relay Word bit), the instantaneous torque-controlled nondirectional (67G*n* output Relay Word bit), and the definite-time torque-controlled (67G*n*T output Relay Word bit) functions all share the same pickup threshold.

67G*n*TC

NOTE: The SEL-TWFL does not include directional elements. Use the communications ports or contact inputs to provide directional input, via the torque-control SELOGIC equation, from a protective relay to the SEL-TWFL.

Use the 67G*n*TC torque-control SELOGIC equation for supervising or blocking the 50/67G Level *n* element (67G*n* and 67G*n*T Relay Word bits). Typical applications include directional control, dynamic supervision or blocking, and advanced applications, such as directional control involving complex logical conditions and timers.

Program the 67G*n*TC torque-control SELOGIC equation to logical 1 if you do not want any supervision or blocking.

67G*n*D

NOTE: The SEL-TWFL accepts time-delay settings expressed in seconds, not in power system cycles.

Use the 67G*n*D setting to set the time delay for the 67G Level *n* element. The element uses an integrating timer. This timer uses an instantaneous type of reset with a fixed reset delay of 25 ms (see *Definite-Time Integrating Timer Logic* on page G.11 for more information).

The SEL-TWFL processes the timer logic at fixed time intervals and accepts time-delay settings expressed in seconds. The resulting time delay is accurate and independent of the power system frequency.

Negative-Sequence Overcurrent Elements

The SEL-TWFL includes two levels (instances) of the negative-sequence instantaneous and definite-time overcurrent (50/67Q) element. Both levels respond to the negative-sequence component in the selected operating quantity (Line *m* current, where *m* = 1–2) and have individual pickup, torque-control, and time-delay settings to fulfill different applications.

The SEL-TWFL 50/67Q element logic is similar to the 50/67P and 50/67G element logic. You may only need to give this section a brief read if you are already familiar with either the 50/67P element or the 50/67G element.

When the 50/67Q element in *Figure 4.4* is enabled (E50Q*n* = Y), it uses the 50Q*n*P pickup setting and applies it to the negative-sequence component (3I2) for the selected operating quantity, configured by the 50Q*n*O setting.

The 50Q*n* Relay Word bit signifies the instantaneous nondirectional overcurrent condition. The 67Q*n* Relay Word bit signifies the instantaneous torque-controlled operation. The 67Q*n*TC torque-control SELOGIC equation always applies to the 67Q logic, and therefore you can use this equation to supervise the nondirectional output.

The 67Q logic uses an integrating timer for time-delayed operation (see *Definite-Time Integrating Timer Logic* on page G.11). The 67Q*n*T Relay Word bit signifies the torque-controlled definite-time overcurrent condition. Use the 67Q*n*D time-delay setting to specify the delay.

Figure 4.4 Negative-Sequence Instantaneous and Definite-Time Overcurrent Element Logic

Table 4.5 and *Table 4.6* list the settings and Relay Word bits associated with the SEL-TWFL 50/67Q elements.

Table 4.5 Negative-Sequence Instantaneous and Definite-Time Overcurrent Level *n* Element Settings

Setting[a]	Description	Range	Default	Class
E50Q*n*	Enable 50Q and 67QT Overcurrent	Y, N	N	Device
50Q*n*O	Negative-Sequence Overcurrent Operating Quantity	L1I, L2I	L1I	Device
50Q*n*P	Negative-Sequence Overcurrent Pickup	0.25–100.00 A secondary[b]	10.00	Device
67Q*n*TC	Negative-Sequence Overcurrent Torque-Control SELogic Equation	SELogic Expression	1	Device
67Q*n*D	Negative-Sequence Overcurrent Time Delay	0.000–10.000 s	0.000	Device

[a] *n* = 1–2.
[b] The ranges and defaults shown are for 5 A-rated CTs. Divide by 5 for 1 A-rated CTs.

Table 4.6 Negative-Sequence Instantaneous and Definite-Time Overcurrent Element Relay Word Bits

Relay Word Bit[a]	Description
50Q*n*	50Q instantaneous overcurrent Level *n* operated
67Q*n*	67Q instantaneous torque-controlled overcurrent Level *n* operated
67Q*n*T	67QT time-delayed torque-controlled overcurrent Level *n* operated
67Q*n*TC	67Q Level *n* torque-control condition asserted

[a] *n* = 1–2.

Follow these settings rules when configuring the negative-sequence instantaneous and definite-time elements (*n* = 1–2).

E50Q*n*

Set the E50Q*n* setting to Y to enable the 50/67Q Level *n* element.

50Q*n*O

Select the operating quantity for the negative-sequence overcurrent element. Use the 50Q*n*O setting to select either the Line 1 or Line 2 current.

50Q*n*P

Use the 50Q*n*P setting to set the overcurrent threshold for the 50/67Q Level *n* element. The threshold applies to the tripled negative-sequence current (3I2). The setting is in secondary amperes, considering the *effective* CT ratio. The effective CT ratio depends on the CT ratio of the current input IW (CTRW setting), the current input IX (CTRX setting), or both, according to the line current source

selection (L*n*I setting). Note that the instantaneous nondirectional (50Q*n* output Relay Word bit), the instantaneous torque-controlled (67Q*n* output Relay Word bit), and the definite-time torque-controlled (67Q*n*T output Relay Word bit) functions all share the same pickup threshold.

67Q*n*TC

NOTE: The SEL-TWFL does not include directional elements. Use the communications ports or contact inputs to provide directional input, via the torque-control SELOGIC equation, from a protective relay to the SEL-TWFL.

Use the 67Q*n*TC torque-control SELOGIC equation for supervising or blocking the 50/67Q Level *n* element (67Q*n* and 67Q*n*T Relay Word bits). Typical applications include directional control, dynamic supervision or blocking, and advanced applications, such as directional control involving complex logical conditions and timers.

Program the 67Q*n*TC torque-control SELOGIC equation to logical 1 if you do not want any supervision or blocking.

67Q*n*D

NOTE: The SEL-TWFL accepts time-delay settings expressed in seconds, not in power system cycles.

Use the 67Q*n*D setting to set the time delay for the 67Q Level *n* element. The element uses an integrating timer. This timer uses an instantaneous type of reset with a fixed reset delay of 25 ms (see *Definite-Time Integrating Timer Logic* on page G.11 for more information).

The SEL-TWFL processes the timer logic at fixed time intervals and accepts time-delay settings expressed in seconds. The resulting time delay is accurate and independent of the power system frequency.

Voltage Elements

The SEL-TWFL includes two levels (instances) of definite-time undervoltage and overvoltage elements. The undervoltage elements respond to phase-to-ground voltages (ANSI device number 27P) and positive-sequence voltage (27PS). The overvoltage elements respond to phase-to-ground voltages (59P), positive-sequence voltage (59PS), zero-sequence voltage (59G), and negative-sequence voltage (59Q). All the voltage elements respond to the selected operating voltage (Line 1 or Line 2) and have independent pickup, torque-control, and time-delay settings. The definite-time voltage elements use integrating timers, which have an instantaneous type of reset with a fixed reset delay of 25 ms (refer to *Definite-Time Integrating Timer Logic* on page G.11 for more information).

This section enumerates the settings and Relay Word bits of the Level *n* (*n* = 1–2) voltage element with *n* following the element type (P, PS, G, or Q). For example, 27P2 refers to Level 2 of the undervoltage (27) element operating on the phase (P) voltage. All the voltage elements follow a nearly identical logic. If you are already familiar with the phase undervoltage (27P) element logic, then you may only need to give the other subsections a brief read.

Phase Undervoltage Elements

The SEL-TWFL includes two levels (instances) of the phase undervoltage (27P) element. When the 27P element in *Figure 4.5* is enabled (E27P*n* = Y), it uses the 27P*n*P pickup setting and applies it to the phase-to-ground voltages (VA, VB, and VC) for the selected operating quantity (Line *m* voltages, where *m* = 1–2), configured by the 27P*n*O setting. The logic applies the 27P*n*TC torque-control SELOGIC equation to supervise the voltage comparator. The 27P*n*A, 27P*n*B, and 27P*n*C Relay Word bits signify the instantaneous undervoltage condition on a

per-phase basis, and the 27P*n* Relay Word bit signifies the instantaneous undervoltage condition in any phase. The 27P logic uses an integrating timer for time-delayed operation (see *Definite-Time Integrating Timer Logic* on page G.11). Use the 27P*n*D time-delay setting to specify the delay. The 27P*n*T Relay Word bit signifies the definite-time undervoltage operation.

Figure 4.5 Phase Undervoltage Element Logic

Table 4.7 and *Table 4.8* list the settings and Relay Word bits associated with the SEL-TWFL 27P elements.

Table 4.7 Phase Undervoltage Level *n* Element Settings

Setting[a]	Description	Range	Default	Class
E27P*n*	Enable 27P Undervoltage	Y, N	N	Device
27P*n*O	Phase Undervoltage Operating Quantity	L1V, L2V	L1V	Device
27P*n*P	Phase Undervoltage Pickup	OFF, 2.00–175.00 V secondary	OFF	Device
27P*n*TC	Phase Undervoltage Torque-Control SELogic Equation	SELogic Expression	1	Device
27P*n*D	Phase Undervoltage Time Delay	0.000–10.000 s	0.000	Device

[a] *n* = 1–2.

Table 4.8 Phase Undervoltage Element Relay Word Bits

Relay Word Bit[a]	Description
27A*n*	27P undervoltage Level *n* Phase A asserted
27B*n*	27P undervoltage Level *n* Phase B asserted
27C*n*	27P undervoltage Level *n* Phase C asserted
27P*n*	27P undervoltage Level *n* asserted
27P*n*TC	27P Level *n* torque-control condition asserted
27P*n*T	27P time-delayed undervoltage Level *n* asserted
27ABC*n*	27P undervoltage Level *n* all phases asserted

[a] *n* = 1–2.

Follow these settings rules when configuring the phase undervoltage elements (*n* = 1–2).

E27P*n*

Set the E27P*n* setting to Y to enable the 27P Level *n* undervoltage element.

27P*n*O

Select the operating quantity for the phase undervoltage element. Use the 27P*n*O setting to select either the Line 1 or Line 2 voltage.

27P*n*P

Use the 27P*n*P setting to set the pickup threshold of the 27P Level *n* element. The 27P*n* element is operational if you enabled the undervoltage element (E27P*n* = Y) and set the 27P*n*P pickup threshold to a value other than OFF.

Note that the undervoltage elements do not apply a voltage cutoff threshold or an open-pole supervision, and therefore they will assert if the line is de-energized or the device voltage inputs are disconnected.

27P*n*TC

Use the 27P*n*TC torque-control SELOGIC equation for supervising or blocking the 27P*n* element. Program the 27P*n*TC torque-control SELOGIC equation to logical 1 if you want the element to operate all the time. Typical applications include any pole open (L*m*APO), three poles open (L*m*_3PO), and loss-of-potential (L*m*LOP) conditions.

27P*n*D

NOTE: The SEL-TWFL accepts time-delay settings expressed in seconds, not in power system cycles.

Use the 27P*n*D setting to set the time delay for the 27P Level *n* element. The element uses an integrating timer. This timer uses an instantaneous type of reset with a fixed reset delay of 25 ms (see *Definite-Time Integrating Timer Logic* on page G.11 for more information).

The SEL-TWFL processes the timer logic at fixed time intervals and accepts time-delay settings expressed in seconds. The resulting time delay is accurate and independent of the power system frequency.

Positive-Sequence Undervoltage Elements

The SEL-TWFL includes two levels (instances) of the positive-sequence undervoltage (27PS) element. When the 27PS element in *Figure 4.6* is enabled (E27PS*n* = Y), it uses the 27PS*n*P pickup setting and applies it to the positive-sequence voltage (V1) for the selected operating quantity (Line *m* voltage, where *m* = 1–2), configured by the 27PS*n*O setting. The logic applies the 27PS*n*TC torque-control SELOGIC equation to supervise the voltage comparator. The 27PS*n* Relay Word bit signifies the instantaneous positive-sequence undervoltage condition. The 27PS logic uses an integrating timer for time-delayed operation (see *Definite-Time Integrating Timer Logic* on page G.11 for more information). Use the 27PS*n*D time-delay setting to specify the delay. The 27PS*n*T Relay Word bit signifies the definite-time undervoltage operation.

Figure 4.6 Positive-Sequence Undervoltage Element Logic

Table 4.9 and *Table 4.10* list the settings and Relay Word bits associated with the SEL-TWFL 27PS elements.

Table 4.9 Positive-Sequence Undervoltage Level *n* Element Settings

Setting[a]	Description	Range	Default	Class
E27PS*n*	Enable 27PS Undervoltage	Y, N	N	Device
27PS*n*O	Positive-Sequence Undervoltage Operating Quantity	L1V, L2V	L1V	Device
27PS*n*P	Positive-Sequence Undervoltage Pickup	OFF, 2.00–175.00 V secondary	OFF	Device
27PS*n*TC	Positive-Sequence Undervoltage Torque-Control SELogic Equation	SELogic Expression	1	Device
27PS*n*D	Positive-Sequence Undervoltage Time Delay	0.000–10.000 s	0.000	Device

[a] *n* = 1–2.

Table 4.10 Positive-Sequence Undervoltage Element Relay Word Bits

Relay Word Bit[a]	Description
27PS*n*	27PS undervoltage Level *n* asserted
27PS*n*TC	27PS Level *n* torque-control condition asserted
27PS*n*T	27PS time-delayed undervoltage Level *n* asserted

[a] *n* = 1–2.

Follow these settings rules when configuring the positive-sequence undervoltage elements (*n* = 1–2).

E27PS*n*

Set the E27PS*n* setting to Y to enable the 27PS Level *n* undervoltage element.

27PS*n*O

Select the operating quantity for the positive-sequence undervoltage element. Use the 27PS*n*O setting to select either the Line 1 or Line 2 voltage.

27PS*n*P

Use the 27PS*n*P setting to set the pickup threshold of the 27PS Level *n* element. The 27PS*n* element is operational if you enabled the undervoltage element (E27PS*n* = Y) and set the 27PS*n*P pickup threshold to a value other than OFF.

Note that the undervoltage elements do not apply a voltage cutoff threshold or an open-pole supervision, and therefore they will assert if the line is de-energized or the device voltage inputs are disconnected.

27PS*n*TC

Use the 27PS*n*TC torque-control SELOGIC equation for supervising or blocking the 27PS*n* element. Program the 27PS*n*TC torque-control SELOGIC equation to logical 1 if you want the element to operate all the time. Typical applications include any pole open (APO), three poles open (3PO), and loss-of-potential (LOP) conditions.

27PS*n*D

NOTE: The SEL-TWFL accepts time-delay settings expressed in seconds, not in power system cycles.

Use the 27PS*n*D setting to set the time delay for the 27PS Level *n* element. The element uses an integrating timer. This timer uses an instantaneous type of reset with a fixed reset delay of 25 ms (see *Definite-Time Integrating Timer Logic* on page G.11 for more information).

The SEL-TWFL processes the timer logic at fixed time intervals and accepts time-delay settings expressed in seconds. The resulting time delay is accurate and independent of the power system frequency.

Phase Overvoltage Elements

The SEL-TWFL includes two levels (instances) of the phase overvoltage (59P) element. When the 59P element in *Figure 4.7* is enabled (E59P*n* = Y), it uses the 59P*n*P pickup setting and applies it to the phase-to-ground voltages (VA, VB, and VC) for the selected operating quantity (Line *m* voltages, where *m* = 1–2), configured by the 59P*n*O setting. The logic applies the 59P*n*TC torque-control SELOGIC equation to supervise the voltage comparator. The 59A*n*, 59B*n*, and 59C*n* Relay Word bits signify the instantaneous overvoltage condition on a per-phase basis, and the 59P*n* Relay Word bit signifies the instantaneous overvoltage condition in any phase. The 59P logic uses an integrating timer for time-delayed operation (see *Definite-Time Integrating Timer Logic* on page G.11 for more information). Use the 59P*n*D time-delay setting to specify the delay. The 59P*n*T Relay Word bit signifies the definite-time overvoltage operation.

Figure 4.7 Phase Overvoltage Element Logic

Table 4.11 and *Table 4.12* list the settings and Relay Word bits associated with the SEL-TWFL 59P elements.

Table 4.11 Phase Overvoltage Level *n* Element Settings

Setting[a]	Description	Range	Default	Class
E59P*n*	Enable 59P Overvoltage	Y, N	N	Device
59P*n*O	Phase Overvoltage Operating Quantity	L1V, L2V	L1V	Device
59P*n*P	Phase Overvoltage Pickup	OFF, 2.00–175.00 V secondary	OFF	Device
59P*n*TC	Phase Overvoltage Torque-Control SELogic Equation	SELogic Expression	1	Device
59P*n*D	Phase Overvoltage Time Delay	0.000–10.000 s	0.000	Device

[a] *n* = 1–2.

Table 4.12 Phase Overvoltage Element Relay Word Bits

Relay Word Bit[a]	Description
59A*n*	59P overvoltage Level *n* Phase A asserted
59B*n*	59P overvoltage Level *n* Phase B asserted
59C*n*	59P overvoltage Level *n* Phase C asserted
59P*n*	59P overvoltage Level *n* asserted
59P*n*TC	59P Level *n* torque-control condition asserted
59P*n*T	59P time-delayed overvoltage Level *n* asserted

[a] *n* = 1–2.

Follow these settings rules when configuring the phase overvoltage elements (n = 1–2).

E59P*n*

Set the E59P*n* setting to Y to enable the 59P Level *n* overvoltage element.

59P*n*O

Select the operating quantity for the phase overvoltage element. Use the 59P*n*O setting to select either the Line 1 or Line 2 voltage.

59P*n*P

Use the 59P*n*P setting to set the pickup threshold of the 59P Level *n* element. The 59P*n* element is operational if you enabled the overvoltage element (E59P*n* = Y) and set the 59P*n*P pickup threshold to a value other than OFF.

59P*n*TC

Use the 59P*n*TC torque-control SELOGIC equation for supervising or blocking the 59P*n* element. Program the 59P*n*TC torque-control SELOGIC equation to logical 1 if you want the element to operate all the time.

59P*n*D

NOTE: The SEL-TWFL accepts time-delay settings expressed in seconds, not in power system cycles.

Use the 59P*n*D setting to set the time delay for the 59P Level *n* element. The element uses an integrating timer. This timer uses an instantaneous type of reset with a fixed reset delay of 25 ms (see *Definite-Time Integrating Timer Logic* on page G.11 for more information).

The SEL-TWFL processes the timer logic at fixed time intervals and accepts time-delay settings expressed in seconds. The resulting time delay is accurate and independent of the power system frequency.

Positive-Sequence Overvoltage Elements

The SEL-TWFL includes two levels (instances) of the positive-sequence overvoltage (59PS) element. When the 59PS element in *Figure 4.8* is enabled (E59PS*n* = Y), it uses the 59PS*n*P pickup setting and applies it to the positive-sequence voltage (V1) for the selected operating quantity (Line *m* voltage, where m = 1–2), configured by the 59PS*n*O setting. The logic applies the 59PS*n*TC torque-control SELOGIC equation to supervise the voltage comparator. The 59PS*n* Relay Word bit signifies the instantaneous positive-sequence overvoltage condition. The 59PS logic uses an integrating timer for time-delayed operation (see *Definite-Time Integrating Timer Logic* on page G.11 for more information). Use the 59PS*n*D time-delay setting to specify the delay. The 59PS*n*T Relay Word bit signifies the definite-time overvoltage operation.

Figure 4.8 Positive-Sequence Overvoltage Element Logic

Table 4.13 and *Table 4.14* list the settings and Relay Word bits associated with the SEL-TWFL 59PS elements.

Table 4.13 Positive-Sequence Overvoltage Level *n* Element Settings

Setting[a]	Description	Range	Default	Class
E59PS*n*	Enable 59PS Overvoltage	Y, N	N	Device
59PS*n*O	Positive-Sequence Overvoltage Operating Quantity	L1V, L2V	L1V	Device
59PS*n*P	Positive-Sequence Overvoltage Pickup	OFF, 2.00–175.00 V secondary	OFF	Device
59PS*n*TC	Positive-Sequence Overvoltage Torque-Control SELogic Equation	SELogic Expression	1	Device
59PS*n*D	Positive-Sequence Overvoltage Time Delay	0.000–10.000 s	0.000	Device

[a] *n* = 1–2.

Table 4.14 Positive-Sequence Overvoltage Element Relay Word Bits

Relay Word Bit[a]	Description
59PS*n*	59PS overvoltage Level *n* asserted
59PS*n*TC	59PS Level *n* torque-control condition asserted
59PS*n*T	59PS time-delayed overvoltage Level *n* asserted

[a] *n* = 1–2.

Follow these settings rules when configuring the positive-sequence overvoltage elements (*n* = 1–2).

E59PS*n*

Set the E59PS*n* setting to Y to enable the 59PS Level *n* overvoltage element.

59PS*n*O

Select the operating quantity for the positive-sequence overvoltage element. Use the 59PS*n*O setting to select either the Line 1 or Line 2 voltage.

59PS*n*P

Use the 59PS*n*P setting to set the pickup threshold of the 59PS Level *n* element. The 59PS*n* element is operational if you enabled the overvoltage element (E59PS*n* = Y) and set the 59PS*n*P pickup threshold to a value other than OFF.

59PS*n*TC

Use the 59PS*n*TC torque-control SELOGIC equation for supervising or blocking the 59PS*n* element. Program the 59PS*n*TC torque-control SELOGIC equation to logical 1 if you want the element to operate all the time.

59PS*n*D

NOTE: The SEL-TWFL accepts time-delay settings expressed in seconds, not in power system cycles.

Use the 59PS*n*D setting to set the time delay for the 59PS Level *n* element. The element uses an integrating timer. This timer uses an instantaneous type of reset with a fixed reset delay of 25 ms (see *Definite-Time Integrating Timer Logic* on page G.11 for more information).

The SEL-TWFL processes the timer logic at fixed time intervals and accepts time-delay settings expressed in seconds. The resulting time delay is accurate and independent of the power system frequency.

Zero-Sequence Overvoltage Elements

The SEL-TWFL includes two levels (instances) of the zero-sequence overvoltage (59G) element. When the 59G element in *Figure 4.9* is enabled (E59G*n* = Y), it uses the 59G*n*P pickup setting and applies it to the zero-sequence voltage (3V0) for the selected operating quantity (Line *m* voltages, where *m* = 1–2), configured by the 59G*n*O setting. The logic applies the 59G*n*TC torque-control SELOGIC equation to supervise the voltage comparator. The 59G*n* Relay Word bit signifies the instantaneous zero-sequence overvoltage condition. The 59G logic uses an integrating timer for time-delayed operation (see *Definite-Time Integrating Timer Logic* on page G.11 for more information). Use the 59G*n*D time-delay setting to specify the delay. The 59G*n*T Relay Word bit signifies the definite-time overvoltage operation.

Figure 4.9 Zero-Sequence Overvoltage Element Logic

Table 4.15 and *Table 4.16* list the settings and Relay Word bits associated with the SEL-TWFL 59G elements.

Table 4.15 Zero-Sequence Overvoltage Level *n* Element Settings

Setting[a]	Description	Range	Default	Class
E59G*n*	Enable 59G Overvoltage	Y, N	N	Device
59G*n*O	Zero-Sequence Overvoltage Operating Quantity	L1V, L2V	L1V	Device
59G*n*P	Zero-Sequence Overvoltage Pickup	OFF, 2.00–300.00 V secondary	OFF	Device
59G*n*TC	Zero-Sequence Overvoltage Torque-Control SELogic Equation	SELogic Expression	1	Device
59G*n*D	Zero-Sequence Overvoltage Time Delay	0.000–10.000 s	0.000	Device

[a] *n* = 1–2.

Table 4.16 Zero-Sequence Overvoltage Element Relay Word Bits

Relay Word Bit[a]	Description
59G*n*	59G overvoltage Level *n* asserted
59G*n*TC	59G Level *n* torque-control condition asserted
59G*n*T	59G time-delayed overvoltage Level *n* asserted

[a] *n* = 1–2.

Follow these settings rules when configuring the zero-sequence overvoltage elements (*n* = 1–2).

E59G*n*

Set the E59G*n* setting to Y to enable the 59G Level *n* overvoltage element.

59G*n*O

Select the operating quantity for the zero-sequence overvoltage element. Use the 59G*n*O setting to select either the Line 1 or Line 2 voltage.

59G*n*P

Use the 59G*n*P setting to set the pickup threshold of the 59G Level *n* element. The 59G*n* element is operational if you enabled the overvoltage element (E59G*n* = Y) and set the 59G*n*P pickup threshold to a value other than OFF.

59G*n*TC

Use the 59G*n*TC torque-control SELOGIC equation for supervising or blocking the 59G*n* element. Program the 59G*n*TC torque-control SELOGIC equation to logical 1 if you want the element to operate all the time.

59G*n*D

NOTE: The SEL-TWFL accepts time-delay settings expressed in seconds, not in power system cycles.

Use the 59G*n*D setting to set the time delay for the 59G Level *n* element. The element uses an integrating timer. This timer uses an instantaneous type of reset with a fixed reset delay of 25 ms (see *Definite-Time Integrating Timer Logic* on page G.11 for more information).

The SEL-TWFL processes the timer logic at fixed time intervals and accepts time-delay settings expressed in seconds. The resulting time delay is accurate and independent of the power system frequency.

Negative-Sequence Overvoltage Elements

The SEL-TWFL includes two levels (instances) of the negative-sequence overvoltage (59Q) element. When the 59Q element in *Figure 4.10* is enabled (E59Q*n* = Y), it uses the 59Q*n*P pickup setting and applies it to the negative-sequence voltage (3V2) for the selected operating quantity (Line *m* voltages, where *m* = 1–2), configured by the 59G*n*O setting. The logic applies the 59Q*n*TC torque-control SELOGIC equation to supervise the voltage comparator. The 59Q*n* Relay Word bit signifies the instantaneous negative-sequence overvoltage condition. The 59Q logic uses an integrating timer for time-delayed operation (see *Definite-Time Integrating Timer Logic* on page G.11 for more information). Use the 59Q*n*D time-delay setting to specify the delay. The 59Q*n*T Relay Word bit signifies the definite-time overvoltage operation.

Figure 4.10 Negative-Sequence Overvoltage Element Logic

Table 4.17 and *Table 4.18* list the settings and Relay Word bits associated with the SEL-TWFL 59Q elements.

Table 4.17 Negative-Sequence Overvoltage Level *n* Element Settings (Sheet 1 of 2)

Setting[a]	Description	Range	Default	Class
E59Q*n*	Enable 59Q Overvoltage	Y, N	N	Device
59Q*n*O	Negative-Sequence Overvoltage Operating Quantity	L1V, L2V	L1V	Device
59Q*n*P	Negative-Sequence Overvoltage Pickup	OFF, 2.00–300.00 V secondary	OFF	Device

Table 4.17 Negative-Sequence Overvoltage Level *n* Element Settings (Sheet 2 of 2)

Setting[a]	Description	Range	Default	Class
59Q*n*TC	Negative-Sequence Overvoltage Torque-Control SELogic Equation	SELogic Expression	1	Device
59Q*n*D	Negative-Sequence Overvoltage Time Delay	0.000–10.000 s	0.000	Device

[a] *n* = 1–2.

Table 4.18 Negative-Sequence Overvoltage Element Relay Word Bits

Relay Word Bit[a]	Description
59Q*n*	59Q overvoltage Level *n* asserted
59Q*n*TC	59Q Level *n* torque-control condition asserted
59Q*n*T	59Q time-delayed overvoltage Level *n* asserted

[a] *n* = 1–2.

Follow these settings rules when configuring the negative-sequence overvoltage elements (*n* = 1–2).

E59Q*n*

Set the E59Q*n* setting to Y to enable the 59Q Level *n* overvoltage element.

59Q*n*O

Select the operating quantity for the negative-sequence overvoltage element. Use the 59Q*n*O setting to select either the Line 1 or Line 2 voltage.

59Q*n*P

Use the 59Q*n*P setting to set the pickup threshold of the 59Q Level *n* element. The 59Q*n* element is operational if you enabled the overvoltage element (E59Q*n* = Y) and set the 59Q*n*P pickup threshold to a value other than OFF.

59Q*n*TC

Use the 59Q*n*TC torque-control SELOGIC equation for supervising or blocking the 59Q*n* element. Program the 59Q*n*TC torque-control SELOGIC equation to logical 1 if you want the element to operate all the time.

59Q*n*D

NOTE: The SEL-TWFL accepts time-delay settings expressed in seconds, not in power system cycles.

Use the 59Q*n*D setting to set the time delay for the 59Q Level *n* element. The element uses an integrating timer. This timer uses an instantaneous type of reset with a fixed reset delay of 25 ms (see *Definite-Time Integrating Timer Logic* on page G.11 for more information).

The SEL-TWFL processes the timer logic at fixed time intervals and accepts time-delay settings expressed in seconds. The resulting time delay is accurate and independent of the power system frequency. You can disregard the SEL-TWFL timing error when calculating time-coordination margins.

Supervisory Elements

This section describes the elements and logic that supervise the fault-locating and line monitoring functions. These include disturbance detectors, loss-of-potential logic, and fault-type identification logic.

Disturbance Detectors

The SEL-TWFL includes TW- and incremental-quantity-based disturbance detectors that operate on a per-line basis. The disturbance detectors require no dedicated settings, and therefore you do not need to configure them to apply the SEL-TWFL.

Traveling-Wave-Based Disturbance Detectors

TW disturbance detectors are very sensitive TW-based elements that trigger on voltage or current changes. The TW functions use disturbance detectors to trigger the collection of TW information associated with the fault or low-energy events.

Figure 4.11 illustrates a simplified logic diagram of the TW disturbance detection logic. This logic is identical for Line 1 and Line 2. The logic responds to the sum of the TW signals from all three phases. The background noise estimator monitors the standing noise and establishes an adaptive threshold for the comparator.

Identical logic monitors line currents (L*m*TWIDD outputs) and line voltages (L*m*TWVDD outputs).

The SEL-TWFL processes TW disturbance detection logic on a per-line basis every microsecond and consumes the disturbance detection outputs every microsecond. Every 0.1 ms, the device also drives the Relay Word bits that signify disturbance detection.

Figure 4.11 TW Disturbance Detection Simplified Diagram

Table 4.19 TW Disturbance Detection Relay Word Bits

Relay Word Bit[a]	Description
L*m*TWDD	Traveling-wave disturbance detector asserted on Line *m*
L*m*TWIDD	Traveling-wave current disturbance detector asserted on Line *m*
L*m*TWVDD	Traveling-wave voltage disturbance detector asserted on Line *m*

[a] *m* = 1–2.

Incremental-Quantity-Based Disturbance Detectors

The SEL-TWFL includes a sensitive current-only incremental-quantity-based disturbance detector. This output is used in loss-of-potential logic and detection of the fault time for pre-fault and fault data capture for fault reporting and fault locating. *Figure 4.12* shows the incremental-quantity disturbance detection logic.

This logic is identical for Line 1 and Line 2. The output L*m*TD50DH Relay Word bit asserts if the incremental current in any phase exceeds a factory-selected threshold.

Figure 4.12 L*m*TD50DH Disturbance Detection Logic

Table 4.20 Incremental-Quantity Disturbance Detection Relay Word Bits

Relay Word Bit[a]	Description
L*m*TD50DH	Incremental-quantity disturbance detector asserted on Line *m*

[a] *m* = 1–2.

Loss-of-Potential Logic

NOTE: The LOP logic secures all voltage-dependent elements, including fault-type identification logic and the line monitor function. The LOP logic does not block the over- and undervoltage elements by default. Use torque-control SELOGIC equations to block these voltage elements as desired.

The loss-of-potential (LOP) logic monitors the health of the voltage input source (including PTs, fuses, wiring, and test switches) to prevent unexpected operation because of low or unbalanced voltages at the SEL-TWFL input terminals. The device processes LOP logic on a per-line basis. This logic is identical for Line 1 and Line 2.

The LOP logic uses no dedicated settings, and therefore you do not need to configure it to apply the SEL-TWFL.

The SEL-TWFL LOP logic monitors the line incremental voltages and currents (see *Figure 4.13*). A change in voltage in any phase determines the voltage change condition. A change in current in any phase determines the current change condition. If a voltage change condition exists without a current change condition for one-quarter of a power system cycle while the breakers are closed, the L*m*LOP Relay Word bit asserts. Low positive-sequence voltage magnitude or high negative-sequence voltage magnitude seals in the L*m*LOP Relay Word bit. The voltage must return to normal (near-nominal positive-sequence voltage and no negative-sequence voltage unbalance) in order for the L*m*LOP Relay Word bit to deassert.

The LOP logic is allowed to operate if the positive-sequence current is higher than twice the current disturbance threshold. This condition ensures the current disturbance will assert and prevent a spurious LOP declaration when the voltage changes and there is no current flow, such as during certain test conditions or during line faults if there is no current path from the line terminal to the power system (line breaker closed but external breakers opened). The LOP logic is allowed to operate if the voltage has been normal prior to the disturbance. This condition also simplifies testing by avoiding spurious LOP assertion during certain test conditions.

The L*m*LOP Relay Word bit also asserts when the voltage is low for 5 s during the first 10 s after the breaker has closed (after the L*m*_3PO Relay Word bit has deasserted). This part of the LOP logic covers a scenario in which the line has been energized while the PT fuses are blown or removed or when voltage test switches are left open. When energizing the protected line, the voltage may be

abnormal if the line has had a short-circuit prior to closing the circuit breaker or if it develops one immediately after closing the circuit breaker. The LOP logic resets the 10 s timer if the voltage is healthy. As a result of this design, the SEL-TWFL LOP logic will not detect an LOP condition that developed when the line was de-energized if the line also develops a fault when de-energized. The LOP logic will assert when energizing the line again after repairing it.

When checking incremental voltages and currents, the SEL-TWFL uses thresholds optimized for the expected noise level in the incremental signals during no-fault conditions. Low positive-sequence voltage and negative-sequence unbalance conditions also use factory-set thresholds.

Figure 4.13 LOP Logic Diagram

Table 4.21 Loss-of-Potential Relay Word Bit

Relay Word Bit[a]	Description
L*m*LOP	Loss-of-potential condition detected on Line *m*

[a] *m* = 1–2.

Fault-Type Identification Logic

The SEL-TWFL incorporates a fault-type identification logic based on phasors (FID). The fault-type information is used by the impedance-based fault-locating methods to identify the appropriate faulted loop. The device executes this logic on a per-line basis. The FID logic is blocked during open-pole conditions. The L*m*APO Relay Word bit (any pole open) must deassert for 25 ms before the FID logic becomes operational. The logic outputs are used to identify the appropriate faulted loop for impedance-based fault-locating methods.

The FID logic requires no dedicated settings, and therefore you do not need to configure it to apply the SEL-TWFL.

The FID logic uses an angle difference between sequence quantities to identify unbalanced faults. The FID logic uses the zero-sequence quantity (S0), which combines the zero-sequence current and the zero-sequence voltage. Similarly, the FID logic uses the negative-sequence quantity (S2), which combines the

negative-sequence current and the negative-sequence voltage. The use of sequence voltages allows the FID logic to operate dependably during weak-infeed conditions or when the zero- and negative-sequence currents are small and unreliable, such as in the vicinity of wind generators or inverter-based generators.

The logic derives two operating signals: negative-sequence 3I2 • 1∠Z1ANG – H2 • 3V2 and zero-sequence 3I0 • 1∠Z1ANG – H0 • 3V0. The FID logic applies the H2 constant to increase the S2 signal for forward faults by as much as three times the nominal current when the 3V2 voltage is as high as the nominal phase-to-ground voltage. Similarly, the FID logic applies the H0 constant to increase the S0 signal for forward faults by as much as three times the nominal current when the 3V0 voltage is as high as the nominal phase-to-ground voltage. The FID logic also uses the positive-sequence voltage, V1.

During a loss-of-potential condition, the FID logic uses only the zero- and negative-sequence currents (assertion of the L*m*LOP Relay Word bit forces the H2 and H0 constants to zero and makes the downstream logic ignore the positive-sequence voltage).

The FID logic operates by comparing the angle between the S0 and S2 signals (*Figure 4.14(a)*) and the angle between the V1 and S2 signals (*Figure 4.14(b)*). *Figure 4.14* applies to systems with an ABC phase rotation. The FID logic for the ACB phase rotation is similar, except the Phase B and C indices in the involved signals are swapped.

The ∠(S0, S2) relationship in *Figure 4.14(a)* allows the logic to narrow down the fault type to two possibilities (AG or BCG, for example). The ∠(V1, S2) relationship in *Figure 4.14(b)* allows the logic to resolve the two possibilities. For example, the case in *Figure 4.14* is a BCG fault.

During a loss-of-potential condition, the ∠(V1, S2) relationship is not available because the voltage signal is not available. In such cases, the FID logic operates using the ∠(3I0, 3I2) relationship only (during the loss-of-potential condition, S0 = 3I0 and S2 = 3I2). Under these conditions, the FID logic favors single-phase faults over two-phase faults. For example, if the L*m*LOP Relay Word bit is asserted, the current-only FID logic declares an AG fault for the case in *Figure 4.14(a)*.

Figure 4.14 Angle Between (a) S0 and S2 and (b) V1 and S2 During Unbalanced Faults (ABC Phase Rotation)

SELOGIC Custom Programming

The SEL-TWFL includes user-programmable logic (SELOGIC for short) for customizing inputs to the fault locator and event recorder and for driving device outputs.

The SEL-TWFL SELOGIC programming capabilities include equations, timers, and latches as follows:

- *Dedicated* SELOGIC equations for customizing inputs to the fault locator and event recorder and for driving device outputs. In most applications, you can program them by using a single input Relay Word bit or a simple AND or OR combination of two or more Relay Word bits. The device provides 119 dedicated SELOGIC equations: 14 contact outputs, 24 MIRRORED BITS outputs, 16 timer inputs, 32 latch inputs, and 33 inputs to the fault locator, breaker monitor, triggering elements, and event recorder.
- *Timers* for delaying pickup and dropout of logical variables. Timer inputs are dedicated SELOGIC equations. The device provides a total of 16 timers.
- *Latches* for implementing memory logic by explicitly setting and resetting a logical variable. Set and reset inputs of a latch are dedicated SELOGIC equations. The device provides a total of 16 reset-dominant nonvolatile latches.
- *Generic* SELOGIC equations (SELOGIC variables) for programming custom logic that may or may not be directly related to the fault locator, breaker monitor, triggering elements, event recorder, or device outputs. The device provides a total of 64 generic SELOGIC equations. The generic SELOGIC equations are instantaneous and do not have timers associated with their outputs.

SELOGIC Processing Rate and Sequence

The SEL-TWFL evaluates SELOGIC equations, timers, and latches every 0.1 ms in a single processing interval in the following sequence:

1. Generic SELOGIC equations SV01 through SV64.
2. SELOGIC timers T01IN through T16IN.
3. SELOGIC latches LT01S and LT01R through LT16S and LT16R.
4. Dedicated SELOGIC equations.

The SEL-TWFL uses the following three processing rates:

- 0.1 ms processing interval for acquiring device inputs; evaluating SELOGIC equations, latches, and timers; and executing the incremental-quantity- and traveling-wave-based disturbance detectors.
- 0.5 ms processing interval for phasor-based functions.
- 1 µs processing interval for analog data acquisition and traveling-wave calculations. This process outputs Relay Word bits through the 0.1 ms process.

In addition, when asserting Relay Word bits related to device or channel diagnostics, line monitoring, the front-panel **TARGET RESET** pushbutton, and other similar functions, the device uses slower processing intervals or operates in response to events, such as a local operator pressing a pushbutton or a line event triggering the line monitor function.

SELogic Equations

Observe the following syntax rules when programming all SELogic equations (generic SELogic equations and dedicated SELogic equations including fault-locator inputs, breaker monitor inputs, torque-control inputs, event recorder inputs, device outputs, SELogic timer inputs, and SELogic latch set and reset inputs).

Operands (Inputs)

All Relay Word bits (see *Appendix D: Relay Word Bits* for a complete list) and logical constants (0 and 1). Relay Word bits include contact inputs and Mirrored Bits inputs.

Maximum Number of Operands (Inputs) per Equation

15

Operators in the Sequence of Priority

Single-operand operators:

NOT
R_TRIG (rising-edge trigger/detector)
F_TRIG (falling-edge trigger/detector)

Two-operand operators:

AND
OR

Processing Direction

Right-to-left for single-operand operators
(from the operand progressing to the left).

Left-to-right for two-operand operators.

Parentheses ()

Maximum of 14 pairs of parentheses per equation.

Maximum Equation Length

511 characters (applies to the equation and the comment, if included).

SELogic Equation Output

Relay Word bit with the same name as the equation.

Recursive Usage

Permitted (the equation output can be included as its own input; the SELogic engine uses the previous value of the equation when evaluating the equation).

Comments

Permitted at the end of the equation following the # sign.

Table 4.22 shows the settings for the generic SELogic equations, and *Table 4.23* shows the Relay Word bits associated with the generic SELogic equations. The SEL-TWFL outputs, fault-locator trigger inputs, breaker monitor inputs, torque-control inputs, and event recorder trigger inputs that are dedicated SELogic equations are listed in their respective subsections of this instruction manual.

Table 4.22 SELogic Equation Settings

Setting	Description	Range	Default	Class
SV*nn*[a]	SELogic Variable *nn* Equation	SELogic Expression	0	Device

[a] *nn* = 01–64.

Table 4.23 SELogic Equation Relay Word Bits

Relay Word Bit	Description
SV*nn*[a]	SELogic Variable *nn* condition asserted

[a] *nn* = 01–64.

Refer to *SELogic Programming Notes* on page 4.27 for guidance.

SELOGIC Timers

The SEL-TWFL includes 16 SELOGIC timers with the following characteristics (see *Figure 4.15*):

- When deasserted, the timer output asserts after the input is continuously asserted for the T*nn*PU (*nn* = 01–16) time interval. When asserted, the timer output deasserts after the input is continuously deasserted for the T*nn*DO time interval. Refer to *SELOGIC Programming Notes* on page 4.27 for guidance.
- The timer input signal is a dedicated SELOGIC equation, T*nn*IN. The input value is available as the T*nn*IN Relay Word bit for troubleshooting, testing, and applications with no intentional delay.
- The timer output is available as the T*nn* Relay Word bit.
- The T*nn*PU and T*nn*DO pickup and dropout time-delay settings have a 0.1 ms resolution. Refer to *Specifications* on page 1.8 for information on the timing accuracy of SELOGIC timers.

Figure 4.15 SELOGIC Timer Input, Output, and Settings

NOTE: The SEL-TWFL SELOGIC timers accept time-delay settings expressed in milliseconds, not in power system cycles.

Table 4.24 shows the settings for SELOGIC timers, and *Table 4.25* shows the Relay Word bits associated with SELOGIC timers.

Table 4.24 SELOGIC Timer Settings

Setting	Description	Range	Default	Class
T*nn*IN[a]	Timer *nn* Input SELogic Equation	SELogic Expression	0	Device
T*nn*PU	Timer *nn* Pickup	0.0–60000.0 ms	0.0	Device
T*nn*DO	Timer *nn* Dropout	0.0–60000.0 ms	0.0	Device

[a] *nn* = 01–16.

Table 4.25 SELOGIC Timer Relay Word Bits

Relay Word Bit	Description
T*nn*IN[a]	Timer *nn* input condition asserted
T*nn*	Timer *nn* output asserted

[a] *nn* = 01–16.

Refer to *SELOGIC Programming Notes* on page 4.27 for guidance.

SELOGIC Latches

The SEL-TWFL includes 16 reset-dominant nonvolatile SELOGIC latches with the following characteristics (see *Figure 4.16*):

- The SELOGIC latches are reset-dominant (when both set and reset inputs are asserted, the latch output resets). The SELOGIC latches are nonvolatile: the device stores the latch state in the permanent (nonvolatile) memory within 1 s following the state change; when the device starts up, it restores the latch state from the memory. Avoid using nonvolatile latches if you expect frequent state changes. The operation of writing to nonvolatile memory is specified for as many as 70 writes a day, on average, for 25 years. Refer to *SELOGIC Programming Notes* on page 4.27 for guidance.
- The set and reset signals are dedicated SELOGIC equations, LT*nn*S and LT*nn*R, respectively (*nn* = 01–16). The set and reset values are available as the LT*nn*S and LT*nn*R Relay Word bits for troubleshooting, testing, and applications without latching.
- The latch output is available as the LT*nn* Relay Word bit.

Figure 4.16 SELOGIC Latch Inputs, Outputs, and Settings

NOTE: The SEL-TWFL SELOGIC latches are reset-dominant and nonvolatile. The device restores their last known state from permanent memory when powering up.

Table 4.26 shows the settings for SELOGIC latches, and *Table 4.27* shows the Relay Word bits associated with SELOGIC latches.

Table 4.26 SELOGIC Latch Settings

Setting	Description	Range	Default	Class
LT*nn*S[a]	Latch *nn* Set SELogic Equation	SELogic Expression	0	Device
LT*nn*R	Latch *nn* Reset SELogic Equation	SELogic Expression	0	Device

[a] *nn* = 01–16.

Table 4.27 SELOGIC Latch Relay Word Bits

Relay Word Bit	Description
LT*nn*S[a]	Latch *nn* set condition asserted
LT*nn*R	Latch *nn* reset condition asserted
LT*nn*	Latch *nn* output asserted

[a] *nn* = 01–16.

Refer to *SELOGIC Programming Notes* on page 4.27 for guidance.

SELOGIC Availability

The SEL-TWFL includes over 100 SELOGIC equations. When fully utilized (511-character length limit per equation), a SELOGIC equation can include 50 or more operators (gates and triggers), making the total number of operators in the device greater than 5,000. The device evaluates these equations every 0.1 ms. The device allows practical amounts of SELOGIC programming and uses a percentage of the SELOGIC utilization to ensure the programmed SELOGIC equations can be executed within the 0.1 ms interval. If you program all SELOGIC equations to a constant of logical 0 or logical 1, the percentage of SELOGIC utilization is at 0 percent; when the utilization is at 100 percent, you cannot program any more SELOGIC equations. With default SEL-TWFL settings, the percentage of SELOGIC utilization is not zero but about 2 percent because some SELOGIC equations are programmed by default.

Use the **STA S** SEL ASCII command to verify the available SELOGIC capacity in the device. Also, QuickSet displays the available SELOGIC capacity when you work with a settings file without access to the device (see *Figure 4.17*).

(a)

```
=>>STA S <Enter>

SEL-TWFL                                  Date: 2024/01/30  Time: 17:00:00.000
StationA                                  Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129        Serial Number: 1240300001

SELogic Execution Availability:  98%
```

(b)

Figure 4.17 Obtaining the Available SELOGIC Capacity by Using (a) the STA S SEL ASCII Command and (b) QuickSet

You can approximate the SEL-TWFL percentage of SELOGIC utilization as follows:

- SELOGIC Equation percentage utilization =
  0.422% • number of edge detectors + 0.167% • number of operands (Relay Word bit inputs) + 0.159% • number of pairs of parentheses
- SELOGIC Timer percentage utilization =
  Timer Input SELOGIC equation percentage utilization (the timer itself does not increase the utilization)
- SELOGIC Latch percentage utilization =
  Latch Set and Reset Input SELOGIC equations percentage utilization (the latch itself does not increase the utilization)

Capacity Examples

Capacity Example 1. Consider the following generic SELogic equation:

SV01 = (50Q2 AND NOT L1LOP) AND R_TRIG IN201

The SV01 SELogic equation contains 1 edge detector (R_TRIG), 3 operands (50Q2, L1LOP, and IN201), and 1 pair of parentheses. Therefore, the SV01 SELogic equation uses 0.422% • 1 + 0.167% • 3 + 0.159% • 1 = 1.08% of the total SELogic capacity of the device.

Capacity Example 2. Consider the following dedicated SELogic equation:

L1B1A52A = IN201

The L1B1A52A SELogic equation contains 1 operand (IN201) and no edge detectors or parentheses. Therefore, the L1B1A52A SELogic equation uses 0.167% • 1 = 0.167% of the total SELogic capacity of the device.

SELogic Programming Notes

Understanding Operator Precedence

The following example explains the sequence priority when evaluating SELogic equations.

Consider the following SELogic equation:

SV01 = (A AND B OR NOT F_TRIG C) OR D AND E OR NOT F AND G

The example uses the generic variable names A through G as inputs, SV01 as the output, and seven intermediate variables (Y_k) to explain the processing sequence.

The device evaluates the expression in the parentheses first. The single-operand operators take precedence. When two or more single-operand operators are programmed in sequence, the device evaluates them right-to-left (the operator next to the operand is evaluated first):

Y_1 = F_TRIG C
Y_2 = NOT Y_1

The AND operator takes precedence over the OR operator, and therefore:

Y_3 = A AND B
Y_4 = Y_3 OR Y_2

In the remaining expression outside of the parentheses, the single-operand operator takes precedence, and therefore:

Y_5 = NOT F

The AND operator takes precedence over the OR operator, and therefore:

Y_6 = Y_5 AND G
Y_7 = D AND E

Finally, the device evaluates:

SV01 = Y_4 OR Y_6 OR Y_7

Figure 4.18 shows the logic diagram for the SV01 SELogic equation according to the SEL-TWFL operator precedence rules.

Figure 4.18 SV01 Logic in the Processing Priority Example

When in doubt, use parentheses to ensure the desired sequence of calculations.

Understanding Relative Timing Ambiguity

As a result of sequential processing, multiple processing tasks, multiple processing rates, and the need to move data between these tasks, a relative timing ambiguity may occur between various Relay Word bits. This relative timing ambiguity does not exceed 1 ms. This phenomenon is common to all sequential logic engines (relays, fault locators, programmable logic controllers, and computers). The following example explains and illustrates this phenomenon.

Consider the following SELOGIC program:

SV01 = SV02 OR IN201
SV02 = IN202

Assume IN202 just asserted while IN201 is deasserted. At the end of the processing interval, the logical values are:

IN201 = 0
IN202 = 1
SV01 = 0
SV02 = 1

Note that the value of SV01 contradicts the value of SV02 (SV01 is 0, but it should be SV02 OR IN201 = 1 OR 0 = 1). This discrepancy exists for one processing interval and occurs because SV01 depends on SV02 but SV02 is processed after SV01 (see *Figure 4.19*).

Figure 4.19 Timing Diagram Illustrating the Impact of the Processing Sequence

The SEL-TWFL provides all Relay Word bits, including values of all SELOGIC equations, as digital channels in the TDR IEEE COMTRADE record. The device also time-stamps Relay Word bits in the Sequential Events Recorder (SER). When analyzing the device records, remember that the assertion or deassertion of Relay Word bits related to each other through SELOGIC equations or through the logic of triggering elements may show a timing ambiguity between 0.1 ms and 1 ms for Relay Word bits that the device evaluates in different processing tasks. Refer to *Figure G.1* for more information on device processing.

If you expect race conditions between the inputs to your logic, remember to consider the timing ambiguity of as much as 1 ms in the inputs to the logic that drives the edge detectors (triggers), latches, or zero-pickup timers. Address the race conditions by adding 1 ms timers to delay selected conditions depending on how you prefer to bias the logic under race conditions.

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SECTION 5

Transient and Sequential Events Recording

The SEL-TWFL provides you with unprecedented transient recording capabilities. This section describes this functionality as follows:

- *Transient Recording* on page 5.1 describes the content and characteristics of the SEL-TWFL transient records, their format, file naming convention, and retrieval methods. This material also explains the transient recorder settings and triggering logic and provides details on other items, including back-to-back triggering, the time required to free up temporary storage after back-to-back triggers, and the time it takes to archive and retrieve records.
- *Summary Report* on page 5.15 describes the summary report that the device creates for each transient record, including the report content and details on data items in the report.
- *History Record* on page 5.18 describes the history record that the device updates for each transient record, including the record content and details on the data items in the record.
- *Sequential Events Recording* on page 5.20 describes the SER record content, characteristics, settings, and retrieval methods.

Transient Recording

When triggered to perform transient recording, the SEL-TWFL creates the following records:

- An ultra-high-resolution IEEE COMTRADE record containing device voltages and currents (MHR record, 1 MHz sampling rate).
- A high-resolution IEEE COMTRADE record containing device voltages and currents, derived analog quantities, and all Relay Word bits (TDR record, 10 kHz sampling rate).
- A summary report containing static data, such as the trigger time stamp and record (event) number. If the device has been triggered for fault locating, the summary report also contains a fault summary, including pre-fault and fault voltage and current phasors; frequency; fault locator targets; fault time, fault location, and fault-locating method; and other information that summarizes both the fault and device operation.

NOTE: SEL recommends using SEL-5601-2 SYNCHROWAVE Event Software to view and analyze SEL-TWFL transient records.

The SEL-TWFL generates a unique record number for each trigger to associate the transient records and summary reports with each other. When the device triggers transient recording, it also appends a one-line summary to the history record. The history record is a catalog of all records created by the device (see *History Record* on page 5.18); the summary report is an overview of a specific record (see *Summary Report* on page 5.15); and the IEEE COMTRADE records are transient records containing the device input voltages and currents and, in the TDR record

only, the derived analog quantities and Relay Word bits. For convenience, the SEL-TWFL embeds the device settings and summary report in the header files of the corresponding IEEE COMTRADE records.

IEEE COMTRADE Records

Record Types and Format

The MHR IEEE COMTRADE record (ultra-high-resolution record) contains voltage and current signals that the SEL-TWFL acquired at 1 Msps (megasamples per second). By using the MHRCH setting, you can decide to record all local channels (six voltages and six currents) or only those voltages and currents that the device uses for fault locating. The MHRCH setting allows you to maximize the device memory storage capability and minimize the record file size and transfer time. The MHR IEEE COMTRADE record does not contain calculated traveling-wave (TW) signals or Relay Word bits. If included, these derived quantities would make the MHR IEEE COMTRADE files very large. Refer to *TW and Phasor Signals in the IEEE COMTRADE Records* on page G.12 for information on how to calculate the TW signals from the MHR IEEE COMTRADE record. Analyze event records by using SYNCHROWAVE Event Software.

The TDR IEEE COMTRADE record (high-resolution record) contains voltage and current signals that the SEL-TWFL downsampled from 1 Msps to 10 ksps (kilosamples per second). The record contains all local voltage and current channels. The TDR IEEE COMTRADE record includes a selected set of derived analog quantities and all Relay Word bits in the device. The derived quantities include line voltage and current signals, phasors, and frequency based on the NLINE, L*m*I, and L*m*V device settings.

The header files of both the MHR and TDR IEEE COMTRADE records contain all the device settings and other data that are convenient for analysis (see *Header File Content* on page 5.5).

When the SEL-TWFL triggers transient recording, it always creates both the MHR and TDR IEEE COMTRADE records. These records share the same pretrigger length and total length settings, and the device references their time stamps to the same time base. Therefore, you can superimpose signals from the MHR and TDR IEEE COMTRADE records to better understand the power system and device operation.

The SEL-TWFL synchronizes the sampling process with the top of the second from the internal clock and compensates for the analog filter group delays of both records when time-stamping the samples. When an IEEE C37.118-compliant clock is connected to the device over the IRIG-B input, the internal device clock synchronizes the sampling instant to absolute time. See *Appendix H: High-Accuracy Timekeeping* for more information.

The SEL-TWFL provides the MHR and TDR IEEE COMTRADE records according to IEEE Std C37.111-2013, *Measuring Relays and Protection Equipment – Part 24: Common Format for Transient Data Exchange (COMTRADE) for Power Systems*. Each IEEE COMTRADE record consists of the configuration (CFG), data (DAT), and header (HDR) files. The data file uses the 32-bit binary encoding. The MHR and TDR IEEE COMTRADE records comprise their own configuration, data, and header files.

The SEL-TWFL allows at least 60 s of total transient recording time. The longest record length is 1.2 s, and the device stores as many as 50 records that are 1.2 s long. The shortest record length is 0.3 s, and the device stores as many as 200

records that are 0.3 s long. The device allows triggering in quick succession (back-to-back recording) for as long as 3.6 s of recording time before ignoring further triggers while processing the captured records.

Record Content

Table 5.1 lists analog channels in the MHR IEEE COMTRADE record. The signals included in the record have a bandwidth of about 400 kHz and are presented in primary units with an 18-bit resolution of the device analog-to-digital converter.

Table 5.2 lists analog channels in the TDR IEEE COMTRADE record. The signals included in the record have a bandwidth of about 3 kHz with an effective 20-bit resolution. The increased resolution is a byproduct of downsampling from the 1 Msps device sampling rate to the 10 ksps recording rate of the TDR IEEE COMTRADE record. The input voltages and currents are presented in primary units. The derived quantities are presented in secondary units for ease of comparison with settings. The TDR IEEE COMTRADE record also contains all Relay Word bits in the device.

Use a viewing and analysis software compatible with the IEEE C37.111-2013 version of the standard to open, visualize, and analyze the record content. You can inspect the configuration file (CFG) by using any text file viewer to obtain the scaling factors and other data you may need in custom software applications or to verify the operation of your IEEE COMTRADE viewer. When using SYNCHROWAVE Event Software, you can view and analyze TW signals derived from the MHR IEEE COMTRADE record (see *Table G.1* for more information). SYNCHROWAVE Event Software also calculates the magnitudes and angles of the phasors that the SEL-TWFL stored in the TDR IEEE COMTRADE record (see *Table G.2* for more information).

NOTE: When you open the MHR IEEE COMTRADE record, SYNCHROWAVE Event Software calculates voltage and current phase and modal TWs for each configured line (see *Table G.1*). These SYNCHROWAVE Event Software-derived quantities are in primary units for ease of analysis of power system events.

Table 5.1 Analog Channels in the MHR IEEE COMTRADE Record (1 Msps)

Name[a]	Description	Unit
IAW IBW ICW	Terminal W Phase A, B, and C currents	A primary
IAX IBX ICX	Terminal X Phase A, B, and C currents	A primary
VAY VBY VCY	Terminal Y Phase A, B, and C voltages	kV primary
VAZ VBZ VCZ	Terminal Z Phase A, B, and C voltages	kV primary

[a] Not all local channels may be included, depending on the MHRCH setting (ALL, USED).

Table 5.2 Analog Channels in the TDR IEEE COMTRADE Record (10 ksps) (Sheet 1 of 2)

Name	Description	Unit
IAW IBW ICW	Terminal W Phase A, B, and C currents	A primary
IAX IBX ICX	Terminal X Phase A, B, and C currents	A primary
L1IA L1IB L1IC	Line 1 Phase A, B, and C currents	A primary
L2IA L2IB L2IC	Line 2 Phase A, B, and C currents	A primary
VAY VBY VCY	Terminal Y Phase A, B, and C voltages	kV primary
VAZ VBZ VCZ	Terminal Z Phase A, B, and C voltages	kV primary
L1VA L1VB L1VC	Line 1 Phase A, B, and C voltages	kV primary
L2VA L2VB L2VC	Line 2 Phase A, B, and C voltages	kV primary
L1IA.Re L1IB.Re L1IC.Re	Line 1 Phase A, B, and C currents, real	A secondary peak
L1IA.Im L1IB.Im L1IC.Im	Line 1 Phase A, B, and C currents, imaginary	A secondary peak
L2IA.Re L2IB.Re L2IC.Re	Line 2 Phase A, B, and C currents, real	A secondary peak
L2IA.Im L2IB.Im L2IC.Im	Line 2 Phase A, B, and C currents, imaginary	A secondary peak
L1VA.Re L1VB.Re L1VC.Re	Line 1 Phase A, B, and C voltages, real	V secondary peak
L1VA.Im L1VB.Im L1VC.Im	Line 1 Phase A, B, and C voltages, imaginary	V secondary peak
L2VA.Re L2VB.Re L2VC.Re	Line 2 Phase A, B, and C voltages, real	V secondary peak

Table 5.2 Analog Channels in the TDR IEEE COMTRADE Record (10 ksps) (Sheet 2 of 2)

Name	Description	Unit
L2VA.Im L2VB.Im L2VC.Im	Line 2 Phase A, B, and C voltages, imaginary	V secondary peak
L1FREQ	Line 1 frequency	Hz
L2FREQ	Line 2 frequency	Hz

See *Data Acquisition and Processing* on page G.1 for more information.

Header File Content

The header files of both the MHR and TDR IEEE COMTRADE records contain the summary report, version report, device settings, and other data helpful in analyzing power system events and fault locator operation. *Figure 5.1* shows the header file structure and *Table 5.3* provides more information on the data items included in the header file. The data item values in the header file appear in quotation marks and follow the data item names after a separating comma (for example, CTRW,"400").

FID	A
Event_Report_Type	B
[SUMMARY] Summary Report Content [Line 1 SUMMARY] Summary Report Content for Line 1 [Line 2 SUMMARY] Summary Report Content for Line 2	C
[VERSION] Version Report Content	D
[1] Settings — Device Class	E
[R] Settings — Report Class	F
[P1] Settings — Port 1 Class	G
[P2] Settings — Port 2 Class	H
[P3] Settings — Port 3 Class	I

Figure 5.1 Header File Structure

```
[Line 1 Fault Location]
L1_SE_TW_Location1
L1_SE_TW_Location2
L1_SE_TW_Location3
L1_SE_TW_Location4
L1_ME_TW_Location
L1_ME_TW_Location_Reference_Terminal
L1_SE_Z-Based_Location
L1_ME_Z-Based_Location
L1_ME_Z-Based_Reference_Terminal
L1_First_TW_Time_Local
L1_First_TW_Time_Received_P1
L1_First_TW_Time_Received_P2
L1_First_TW_Time_Received_P3
L1_TWIDD_Timestamp
L1_TWVDD_Timestamp
L1_Fault_Type_ZFL
                                                                    J
[Line 2 Fault Location]
L2_SE_TW_Location1
L2_SE_TW_Location2
L2_SE_TW_Location3
L2_SE_TW_Location4
L2_ME_TW_Location
L2_ME_TW_Location_Reference_Terminal
L2_SE_Z-Based_Location
L2_ME_Z-Based_Location
L2_ME_Z-Based_Reference_Terminal
L2_First_TW_Time_Local
L2_First_TW_Time_Received_P1
L2_First_TW_Time_Received_P2
L2_First_TW_Time_Received_P3
L2_TWIDD_Timestamp
L2_TWVDD_Timestamp
L2_Fault_Type_ZFL
[Additional_Parameters]
INOM                                                                K
TWDSW
```

Figure 5.1 Header File Structure (Continued)

Table 5.3 Header File Content (Sheet 1 of 2)

Item	Content	Comments
A	Firmware identification string.	See *SEL-TWFL Firmware Revision Convention* on page B.1. To fully identify the device that created the record, obtain the company name and the station and fault locator identifiers from the device settings listed under the [1] heading in the header file.
B	Record type (MHR or TDR).	This field is the only difference between the header files of the MHR and TDR records. The file name also contains the record type (see *File Naming Convention* on page 5.11).
C	Following the [SUMMARY], [Line 1 SUMMARY], and [Line 2 SUMMARY] headings, this section is the summary report.	See *Summary Report* on page 5.15. The summary report contains the record number (listed as Event_Number), which you need in order to associate transient records and summary reports with each other. The IEEE COMTRADE file name also contains the record number (see *File Naming Convention* on page 5.11). You can also obtain the summary report by using the **SUMMARY** command.
D	Following the [VERSION] heading, this section is the version report.	The version report allows you to obtain device configuration information, such as the nominal secondary current or type of communications transceivers that were installed in the SEL-TWFL at the time of the trigger. See *Checking Device Status and Installed Hardware and Firmware* on page 9.19. You can also obtain the version report by using the **VERSION** command.

Table 5.3 Header File Content (Sheet 2 of 2)

Item	Content	Comments
E	Following the [1] heading, this section lists all Device-class settings (referred to as Group 1).	See *Section 7: Engineering and Operator Access Interfaces and Tools* and *Section 8: SCADA and HMI Protocols* for more information on settings and setting tools. For cybersecurity reasons, the header file does not include the settings of the Port F and Port 5 engineering access and SCADA/HMI ports. For brevity, the header file does not contain DNP3 map settings. The header file only contains settings that may be relevant for transient record analysis concerning fault locating and also supervisory and triggering elements.
F	Following the [R] heading, this section lists all Report-class settings.	
G	Following the [P1] heading, this section lists all Port 1-class settings.	
H	Following the [P2] heading, this section lists all Port 2-class settings.	
I	Following the [P3] heading, this section lists all Port 3-class settings.	
J	Following the [Line 1 Fault Location] and [Line 2 Fault Location] headings, this section lists fault-location results from all the fault-locating methods of the device on a per-line basis.	See *Section 2: Fault Locator and Line Monitor* for more information. This section also lists the time stamps of the first current TWs used by the TW-based fault-locating methods. The remote current TW time stamp is available if Port 1, 2, or 3 is used over an IEEE C37.94 channel for fault locating. This section also includes the reference terminal used by the multi-ended fault-locating methods and the fault type used by the impedance-based fault-locating methods. Use these time stamps for multi-ended TW fault locating when device-to-device communications is not available.
K	Following the [Additional_Parameters] heading, this section lists additional parameters useful for analyzing transient records.	INOM is the device nominal current (5 A or 1 A). TWDSW is a parameter of the differentiator-smoother filter that the device uses to measure TWs (see *Signal Processing* on page G.4).

Triggering, Recording, and Archiving

The SEL-TWFL triggers transient recording when instructed to do so by the rising edge of the programmable trigger condition. You can program the ER SELOGIC equation to specify your desired triggering condition. The device also triggers transient recording for the following events to ensure you always have data for analysis, regardless of how you programmed the ER SELOGIC equation:

- **Fault locator trigger** (see *Fault Locator Application and Settings* on page 2.14). This triggering ensures that you have an available recording of the device voltages and currents, including the ultra-high-resolution MHR IEEE COMTRADE record that contains TW information, to analyze and verify the fault-location results. It also ensures the fault-locating logic has a record available in which to store the detailed fault-location results.
- **PULSE command** (see *PULSE* on page C.13). This triggering is for testing purposes and creates a record when you test the device contact outputs by using the **PULSE** command. This triggering also ensures that you have evidence of when a **PULSE** command was issued and operated device outputs in case these outputs were not iso-

lated or were operated by mistake and caused an undesired effect on the power system. Note that the device will not accept the **PULSE** command unless the BREAKER jumper (only used for testing) that is inside the device chassis is applied to allow the **PULSE** command (see *Accessing and Configuring Device Jumpers* on page 9.15).

➤ **TRIGGER command** (see *TRIGGER* on page C.20). This triggering records device voltages and currents for analysis of steady-state conditions, such as during commissioning or when troubleshooting unexpected metering values or an LOP condition.

Figure 5.2 shows a simplified triggering, recording, and archiving logic. The logic responds to rising edges of the triggering inputs, and therefore a standing input will not trigger or retrigger the recording. Once the recording starts, the SEL-TWFL transient recorder ignores all triggers until the recording is complete.

Figure 5.2 Simplified Triggering, Recording, and Archiving Logic

While recording, the transient recorder stores the data in temporary memory that is capable of holding 3.6 s of data. When that temporary storage space is used up, the recorder rejects new triggers until the temporary memory is freed up through archiving the data to a micro SD card. The 3.6 s of temporary memory allows for 3 back-to-back triggers for transient records that are 1.2 s long and for proportionally more triggers for shorter records. For example, the recorder accepts 12 back-to-back triggers for records that are 0.3 s long. After the recorder completes recording, it requires approximately 21 s to archive 0.1 s of data and free up the temporary memory for a new record. For example, if you triggered a single 0.5 s long record, the recorder finishes archiving the record in 105 s and you will regain full temporary memory storage after 105 s. While storing the record on the micro SD card, the recorder accepts new triggers until the temporary memory is full. The recorder accepts 7 back-to-back triggers for records that are 0.5 s long, and therefore you can trigger 6 more times during the 105 s time interval that it takes to archive the first record. If you used up all 3.6 s of temporary memory, it takes approximately 13 min to fully regain the temporary storage. While the recorder archives the data, it frees up the temporary memory. After a record has been archived, the temporary memory that the record occupied is freed up and the recorder accepts a new trigger and creates a new record. The above examples use a worst-case archiving speed applicable when MHRCH is set to ALL.

The recorder processes a transient record stored in the temporary memory immediately after it finishes recording unless a previous record is being archived. If the previous record is being archived, the recorder waits until the archiving is finished and only then inspects the temporary memory for new records. If a new

NOTE: To download the MHR IEEE COMTRADE files after transient records have been triggered, you must wait for the data in temporary memory to be archived to the micro SD card.

record is present, the SEL-TWFL assigns a record number to it, calculates the summary report data (see *Summary Report* on page 5.15), updates the history record to show the new record, and proceeds to archive that record. You can start downloading the TDR IEEE COMTRADE files as soon as the history record shows the new record. However, to download the MHR IEEE COMTRADE files, you must wait for the data in temporary memory to be archived to the micro SD card.

NOTE: The SEL-TWFL notifies the user about a new transient record by updating the history record only after archiving the previous record. When during testing you have triggered a maximum number of records back-to-back, you may need to wait up to 13 min for the device to update the history record with the last record triggered in the back-to-back sequence.

If several back-to-back transient records have been triggered, the recorder archives the records stored in the temporary memory one record at a time. For example, if you triggered 4 back-to-back records, each 0.5 s long, the device notifies you about the first record right away. The recorder takes 105 s to archive the first record and the device notifies you about the second record only at that time (i.e., in 1 min and 45 s). The process continues until the device updates the history record to show all records and all records have been archived. When you trigger 4 back-to-back records, each 0.5 s long, the device notifies you about the last record approximately 315 s (5 min 15 s) after capturing the records.

For each triggered record, the SEL-TWFL assigns a unique record number between 10,000 and 65,535, incrementing for each new transient record and restarting at 10,000 after record number 65,535. Note that upon deletion of the records from the device memory (see *Transient Record Deletion* on page 5.20), the record numbering does not reset but continues to increment sequentially. For example, if the largest record number stored in the device is 10,120 and you deleted the records in the device, the device assigns 10,121 to the next new transient record, and the history record shows only the single 10,121 record stored in the device.

Use the LER setting to specify the length of a transient record; use the pre-trigger length setting, PRE, to specify the length of the record before the trigger assertion. When a new record is triggered later than PRE time after the previous record finished (see *Figure 5.3(a)*), the new record has a pre-trigger duration equal to the PRE setting and there will be a gap between the two records. When a new record is triggered sooner than PRE time after the previous record finished (see *Figure 5.3(b)*), the new record has a pre-trigger duration shorter than the PRE setting (T0) and the two records will have no gap between them. A record is always the length specified by the LER setting, and when the pre-trigger length is shortened as a result of back-to-back recording, the post-trigger length is longer compared with the nominal length of a single record.

Figure 5.3 Back-to-Back Recording: (a) Separated and (b) Overlapping Records

Configuration

Table 5.4 lists the settings associated with the SEL-TWFL transient recorder.

Table 5.4 Transient Recording Settings

Setting	Description	Range	Default	Class
ER	Event Report Trigger SELogic Equation	SELogic Expression	R_TRIG L1LOP OR F_TRIG L1_3PO OR R_TRIG L1LMA	Report
LER	Event Report Duration	0.3–1.2 s	0.4	Report
PRE	Pre-Trigger Duration	0.05–(LER–0.2) s	0.2	Report
MHRCH	MHz Record Channel Selection	ALL, USED	USED	Report

Follow these setting recommendations when configuring transient recording, keeping in mind that the ER SELOGIC equation and the transient record length settings, LER and PRE, are common to the MHR and TDR IEEE COMTRADE records.

ER

NOTE: The triggering logic responds to the rising edges of the ER Relay Word bit. It is good practice to program edge detectors (typically R_TRIG) for individual conditions in the ER SELOGIC equation. Otherwise, a permanent assertion of one condition will mask state changes in all other conditions and prevent the transient recorder from triggering if these conditions change.

Use the ER SELOGIC equation to program conditions for triggering SEL-TWFL transient recording. The fault locator triggers bypass the ER SELOGIC equation and trigger transient recording even if they are not programmed in the ER SELOGIC equation.

The triggering logic responds to the rising edges of the ER Relay Word bit. Therefore, it is good practice to apply edge detectors (typically R_TRIG) to individual conditions in the ER SELOGIC equation. Otherwise, a permanent assertion of one condition will mask state changes in all other conditions and prevent the transient recorder from triggering if any of these conditions change. In standalone DFR applications, program a digital input in the ER SELOGIC equation to trigger transient recording. In order to ensure you obtain a transient record even if the SEL-TWFL has not triggered transient recording on its own, you should also trigger transient recording by using outputs from relays, such as outputs that signal a protection trip.

You can consider using one of the TW-based Relay Word bits, such as L*m*TWDD, as a trigger when investigating switching events that result in very small changes in the measured currents and voltages. Consider, however, that these Relay Word bits are very sensitive and may result in frequent triggering, which can fill the device memory very quickly.

LER

Use the LER setting to specify the transient record length in seconds. The record length comprises the pre-trigger and post-trigger intervals. Longer records require more memory, resulting in fewer records stored (see *Storage Capacity* on page 5.11). Also, longer records take more time to retrieve (see *IEEE COMTRADE File Retrieval* on page 5.12). When configuring the LER setting, balance your recording needs with the device storage capability and expected retrieval time.

PRE

Use the PRE setting to specify the pre-trigger length of the transient record in seconds. The minimum value of the PRE setting is 50 ms (i.e., 3 cycles at 60 Hz or 2.5 cycles at 50 Hz). With two or more cycles of pre-trigger data, you can calculate pre-trigger current and voltage magnitudes and angles. Typically, you will

configure recording for a few cycles of pre-trigger data (PRE) and reserve most of the event length (LER) to record the fault, fault clearing, and reclosing (assuming triggering from fast elements). If you attempt to record fault precursors, consider setting the pre-trigger length to a larger value.

MHRCH

Use the MHRCH setting to specify if you want the MHR IEEE COMTRADE record to include all device voltages and currents (MHRCH = ALL) or only those voltages and currents that the device uses given the settings you have applied (MHRCH = USED). Selecting USED allows you to reduce the file size and shorten the file retrieval time. By selecting USED, you exclude unused currents and voltages based on the NLINE, L*m*I, and L*m*V device settings.

The MHRCH setting only applies to the MHR IEEE COMTRADE record. The TDR IEEE COMTRADE record always contains all device voltages and currents.

Storage Capacity

The SEL-TWFL permanent storage capacity is at least 60 s of total recording time. For example, it can store 200 transient records that are 0.3 s long (i.e., 200 pairs of TDR and MHR IEEE COMTRADE records), 120 records that are 0.5 s long, 60 records that are 1 s long, or 50 records that are 1.2 s long. If you change the LER setting value but keep old records, the device will hold records of two or more different lengths. As a result of this unequal record length, the storage space may be slightly less than the 60 s of total recording time.

NOTE: The SEL-TWFL overwrites the oldest transient records after the permanent storage reaches its capacity. You cannot set the device to preserve old records at the expense of not storing new records.

Once the permanent storage reaches its capacity, each new transient record overwrites the oldest record in the device. You can implement an event-driven (automated) file retrieval system or retrieve records promptly to avoid losing records because of overwriting with new records.

The SEL-TWFL stores the transient records in nonvolatile memory on an 8 GB Micro SD card. The device uses a proprietary format for the SD card. Do not attempt to use a standard micro SD card in the device, and do not attempt to read the SEL-TWFL card on a standard computer system. If you encounter the SD card warning in the device diagnostic messages, contact SEL for a replacement SD card (see *Replacing the SD Card* on page 9.21).

The transient record becomes nonvolatile when the transient recorder moves the captured data from the temporary memory to permanent storage on the micro SD card. This operation takes approximately 21 s per each 0.1 s of record length. For example, a 0.5 s long record becomes nonvolatile 105 s after the device captured it. You will lose the record if the device loses power while archiving the record data to the SD card.

File Naming Convention

The SEL-TWFL IEEE COMTRADE files follow the file naming convention in IEEE Std C37.232-2011, *IEEE Standard for Common Format for Naming Time Sequence Data Files (COMNAME)* except that the device applies the IEEE C37.232-2011 standard in an asset-centric way, giving priority to asset identification (station identifier, device make and model, and fault locator identifier) rather than the trigger date and time. The total length of the file name does not exceed 75 characters, including the three-character file name extension (CFG, DAT, HDR).

The file name consists of eight comma-delimited segments followed by the .ext segment, as shown in *Figure 5.4*.

SID10	,	SEL-TWFL	,	FLID10	,	YYMMDD	,	HHMMSS.DDDD	,	0t	,	No.NNNNN	,	RES	.	ext

Figure 5.4 File Name Segments in the SEL-TWFL IEEE COMTRADE File Naming Convention

The file name segments in *Figure 5.4* are as follows:

SID10[a]	First 10 characters of the Station Identifier (SID) setting
SEL-TWFL	Fixed string conveying the device make and model
FLID10[a]	First 10 characters of the Fault Locator Identifier (FLID) setting
YYMMDD	Trigger UTC date
HHMMSS.DDDD	Trigger UTC time
0t	Indicates that the time stamp is the trigger time with a UTC offset of 0
No.NNNNN	Record number (five digits following the “No.” string)
RES	Three-character record resolution (MHR or TDR)
ext	File name extension (CFG, DAT, HDR)

[a] The device removes characters that are not permitted in file names.

For example, a record with the following file name:

WEST_CREEK,SEL-TWFL,TL2306PRI,240130,065309.2076,0t,No.10021,TDR.CFG

is a **configuration** file of a **TDR** IEEE COMTRADE record from an **SEL-TWFL** identified as **TL2306PRI**, installed in a substation identified as **WEST_CREEK**, and triggered on **January 30, 2024** at **06:53:09.2076** UTC time. The device labeled the record as record number **10021**.

When you sort by name a folder containing SEL-TWFL IEEE COMTRADE files, you will group the files alphabetically by location (station identifier), alphabetically by asset (fault locator identifier), chronologically (date and time of trigger and record number), and by the record resolution. This method of sorting is helpful when selecting files for copying and transmitting between engineering teams. You can program machine clients to parse the file names and sort them by using different criteria, such as time, record number, or resolution.

IEEE COMTRADE File Retrieval

NOTE: The SEL-TWFL transient record files are large. SEL recommends using FTP to download those files from the device.

At a minimum, you will need to download the CFG and DAT files of an IEEE COMTRADE record in order for your viewing and analysis software (such as SYNCHROWAVE Event Software) to open the record. The header file is not required for viewing the waveforms, but it provides additional information (see *Header File Content* on page 5.5) and allows for several convenient features in SYNCHROWAVE Event Software.

You can use the following file transfer protocols to download IEEE COMTRADE files from the SEL-TWFL:

- File Transfer Protocol (FTP) by using an FTP client over an FTP session on Port 5 (see *File Transfer Protocol* on page 8.4)
- Ymodem protocol by using a terminal emulator over a Telnet session on Port 5 (see *Telnet Protocol* on page 8.5)
- Ymodem protocol by using a terminal emulator on Port F (see *Communications Setup* on page 7.40)

The IEEE COMTRADE files can be retrieved from the device by a human operator (ad hoc file download) or a machine client (event-driven or automated file archiving).

The most common ad hoc retrieval tools are as follows:

- An FTP client (e.g., Microsoft Windows File Explorer, FileZilla, FireFTP)
- ACSELERATOR QuickSet SEL-5030 Software (see *PC Software* on page 7.19)
- A terminal emulator (e.g., HyperACCESS, PuTTY, Tera Term).

For event-driven file retrieval and archiving, use the SEL-3530 Real-Time Automation Controller (RTAC) (see selinc.com/products/3530). For polling file retrieval and archiving, use the SEL Blueframe Data Management and Automation (DMA) Disturbance Monitoring package. For event-driven and polling file retrieval and archiving, integrate the SEL RTAC with DMA Disturbance Monitoring (see selinc.com/products/DMA).

FTP Client

NOTE: Some FTP clients may not execute the directory refresh command properly for the SEL-TWFL. You may need to close and open a session to ensure the directory is refreshed. Also, you can download an IEEE COMTRADE record only after the history record lists it.

Use any FTP client such as File Explorer to conveniently browse and copy files from the SEL-TWFL to a selected folder on your Ethernet network. Remember to copy all three files comprising an IEEE COMTRADE record (CFG, DAT, and HDR). Select the TDR IEEE COMTRADE record files, the MHR IEEE COMTRADE record files, or both based on your analysis needs. This method of file retrieval is most convenient because it allows you to browse the device memory similarly to a standard memory drive. SEL strongly recommends using this method when testing the device. To use FTP for file transfer, you must enable and configure the FTP server functionality in the device (see *File Transfer Protocol* on page 8.4). See *SEL-TWFL File Directories* on page 8.15 for an explanation of the device directory structure and the device files location.

QuickSet

The most efficient way to download files in QuickSet is by using FTP over Port 5. To use this method, perform the following steps (these steps assume the SEL-TWFL has already been properly set for basic Ethernet communications; if not, refer to *Communications Setup* on page 7.40):

Step 1. Enable and configure the FTP server functionality in the device (see *File Transfer Protocol* on page 8.4).

Step 2. Follow the steps in *Establishing Communication Over Ethernet Port 5* on page 7.46, but when choosing the QuickSet File Transfer Option, select FTP (see *Figure 7.34*).

Step 3. To view, select, and save files, follow the steps outlined in QuickSet *Tools > Events* on page 7.31.

If an Ethernet connection between the SEL-TWFL and QuickSet is not available, download the files through Port F. To use this method, perform the following steps (these steps assume that the proper USB drivers have already been installed on your machine; if not, refer to *Communications Setup* on page 7.40):

Step 1. Follow the steps in *Establishing Communication Over Front-Panel Port F* on page 7.42 to enable a USB connection with QuickSet.

Step 2. To view, select, and save files, follow the steps outlined in QuickSet *Tools > Events* on page 7.31.

Terminal Emulator

This method is relatively elaborate because it requires you to issue SEL ASCII commands to the SEL-TWFL and operate the file transfer function of the terminal emulator software at the same time. Use this method only if you cannot use FTP or QuickSet. Perform the following steps to use SEL ASCII commands in a terminal emulator to download files (these steps assume that the proper USB drivers have already been installed if you are using USB communications and the device has been properly set for basic Ethernet communications if you are using Telnet communications; if not, refer to *Communications Setup* on page 7.40):

Step 1. Establish a connection between the SEL-TWFL and the terminal software.

a. For USB communications, follow the steps on *Using a Terminal Emulator* on page 7.43.

b. For Telnet communications, follow the steps on *Using a Terminal Emulator* on page 7.47.

Step 2. Issue the **FILE DIR EVENTS** command to display the contents of the EVENTS directory. The contents will match that of the history record but will show all six files associated with each unique record number (i.e., the CFG, DAT, and HDR files for both the TDR and MHR records).

Step 3. Issue the **FILE READ EVENTS** ***filename.ext*** command (where filename is the name of the file, and ext is CFG, DAT, or HDR) to prepare the SEL-TWFL to send the specified file. Use the terminal emulator receive file functionality with the transfer protocol set to Ymodem to initiate the file transfer from the device to the selected folder on your machine.

Step 4. Repeat *Step 3* to download all three files (CFG, DAT, HDR) for the transient record of interest.

Retrieval Time

Table 5.5 lists the approximate time it takes to download a single TDR or MHR IEEE COMTRADE record for the default record length of 0.4 s for each of the three file transfer methods. As shown in *Table 5.5*, FTP downloads are much faster than both Ymodem file transfer options. Additionally, TDR IEEE COMTRADE record downloads are much faster than MHR IEEE COMTRADE record downloads. Note that download times increase proportionally for longer record lengths and are significant for the maximum record length of 1.2 s when using Ymodem.

SEL recommends using FTP for file retrieval. *Table 5.6* lists the time it takes to download a single TDR or MHR IEEE COMTRADE record when using FTP for three different record lengths: the minimum length (0.3 s), a mid-range length (0.7 s), and the maximum length (1.2 s).

Table 5.5 IEEE COMTRADE File Download Times for TDR and MHR Records for LER = 0.4 s

Method	TDR	MHR
FTP	6 s	1 min
Ymodem over TELNET	1 min 15 s	22 min 45 s
Ymodem over USB	1 min 45 s	31 min 15 s

Table 5.6 IEEE COMTRADE File Download Times for TDR and MHR Records of Various Lengths When Using FTP

Record Length	TDR	MHR
LER = 0.3 s	4 s	45 s
LER = 0.7 s	7 s	2 min
LER = 1.2 s	12 s	3 min 15 s

Summary Report

When the SEL-TWFL triggers transient recording, it also creates a summary report that contains summary information about the event captured in the transient record, including the record number, time stamp, fault summary if a fault locator trigger asserted, and other data items helpful when analyzing the fault locator operation. When the SEL-TWFL overwrites the oldest transient record with a new record, the device removes the summary report corresponding to the overwritten record.

Summary Report Content

Figure 5.5 shows a sample summary report for when the fault locator on Line 1 is triggered. *Table 5.7* explains the individual data items in the report. If the SEL-TWFL is configured for two lines (NLINE = 2) and fault and pre-fault data are available for both Line 1 and Line 2, then the summary report contains data for both lines.

```
=>>SUM <Enter>

SEL-TWFL                                    Date: 2024/01/30  Time: 16:12:55.149
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

Event Number: 10017
Event Type: FL
Targets: L1FL

                                                                          ROK LBOK
MB:8->1     RMBP1     TMBP1     RMBP2     TMBP2     RMBP3     TMBP3  123  123
TRIG     00000000  00000000  00000000  00000000  00000000  00000000  110  000
L1FL     00000000  00000000  00000000  00000000  00000000  00000000  110  000

Line 1: L1 230kV StationA - StationB
Fault Time: 16:12:55.1496         Frequency: 59.975
Fault Location: 23.075(mi) from StationA
Fault Location Method: ME TW

              Line Currents                        Line Voltages
PreFault:     IA     IB     IC    3I0    3I2       VA       VB       VC
MAG(A/kV)    571    540    551     16     58  205.329  205.631  203.430
ANG(DEG)     6.0 -112.8  129.8  -67.0  -28.9      0.1   -120.1    120.0

Fault:
MAG(A/kV)   5117    460    514   5027   5130   97.591  204.784  201.907
ANG(DEG)    93.8   48.3  -56.4   87.1   89.6    169.5     48.6    -69.8
```

Figure 5.5 Sample Summary Report

Table 5.7 Summary Report Content (Sheet 1 of 2)

Data Item	Description	Comments
Date and Time	Date and time of the transient record trigger according to the device clock in UTC time	This time stamp correlates with the trigger time in the TDR and MHR IEEE COMTRADE records and with the event time stamp in the history record. Because of the rising edge detectors that you typically program in the ER SELOGIC equation, this time stamp can be 0.1 ms behind the time stamp in the SER entry for the Relay Word bit that triggered the entry. Unlike the date and time in a standard command response header, this time stamp does not correspond to the date and time of issuing the **SUMMARY** command but corresponds to the transient record itself.
Event Number	Consecutive record number starting at 10,000 and wrapping around at 65,535	This number is a unique transient record identifier that allows you to correlate IEEE COMTRADE records, history record entries, and summary reports.
Event Type	Record trigger source	See *Figure 5.2* for details on triggering logic. The trigger sources are displayed in the Event Type field in the following order of priority: ➤ TRIG (**TRIGGER** command) ➤ PULSE (**PULSE** command) ➤ FL (fault locator trigger) ➤ ER (record trigger condition that the ER SELOGIC equation specifies)
Targets	Fault locator trigger and line monitor alarm indications	This field indicates if the fault locator is triggered and if the line monitor alarm asserted (on a per-line basis).
Frequency	System frequency	The device captures frequency as a pre-trigger value.
Fault Time	Time of the fault according to the device clock in UTC time	The device captures this data item as the time associated with the assertion of the L*m*TD50DH Relay Word bit, preceding assertion of the L*m*FL Relay Word bit. The fault time data item is therefore independent of the trigger time. The fault time is only available for the FL event type.
Fault Location and Method	Most reliable fault-location result based on all fault-locating methods available at the time of the fault	See *Selecting and Reporting Best Fault-Location Results* on page 2.26 for more details. If the fault-location result is not available, the device displays a string of $ signs. The fault location is only available for the FL event type.

Table 5.7 Summary Report Content (Sheet 2 of 2)

Data Item	Description	Comments
Pre-Fault	Pre-fault voltage and current phasors	The pre-fault quantities are only available for the FL event type and when there is a disturbance preceding the trigger (a rising edge of the L*m*TD50DH Relay Word bit). The device captures the pre-fault quantities 20 ms prior to assertion of the L*m*TD50DH Relay Word bit.
Fault	Fault voltage and current phasors	The fault quantities are only available for the FL event type. The device captures the fault quantities for a duration of 1 cycle, starting at 1.25 cycles after the disturbance (L*m*TD50DH Relay Word bit assertion). For better accuracy, the device averages the phasors captured in that window.
MB (8->1) TRIG	The status (logical 0 or 1) of the MIRRORED BITS inputs (RMB) and outputs (TMB) for Ports 1, 2, and 3 at the time the event recorder and fault locator were triggered, respectively	These data items also display the receive OK status (ROK Relay Word bit) and receive OK while in loopback test status (LBOK Relay Word bit) for the MIRRORED BITS inputs and outputs.
MB (8->1) L1FL MB (8->1) L2FL		

The summary report includes a fault report, i.e., provides pre-fault and fault quantities and fault location, only if the SEL-TWFL detects a fault sequence as follows:

1. The power system is in a quiescent state for at least 100 ms. The device declares a quiescent state if it does not detect a disturbance (the L*m*TD50DH Relay Word bit is deasserted) and the elements configured in the L*m*FL SELOGIC equation are not picked up.
2. The L*m*TD50DH Relay Word bit asserts, signifying a disturbance. The device captures the pre-fault quantities and the fault time based on the rising edge of the L*m*TD50DH Relay Word bit; at this time, the device also captures TW data for performing TW-based fault locating.
3. A fault locator trigger asserts within the FL trigger maximum wait time (L*m*FLMWT setting) after the disturbance. The device captures the fault locator targets and fault quantities at this time; the device also captures fault voltage and current phasor data for reporting and performing impedance-based fault locating.

The fault-related data (fault time, pre-fault quantities, fault location) are only available if the SEL-TWFL detects a disturbance (the L*m*TD50DH Relay Word bit asserts) followed by the assertion of the fault locator trigger within the L*m*FLMWT setting value. If the fault locator trigger asserts at or later than the L*m*FLMWT setting value, the device does not report fault quantities.

The line positive-sequence pre-fault voltage is the angle reference for the phasor angles in the summary report. The angle reference itself is secondary. It is crucial that pre-fault and fault phasors are all referenced to the same base. This common angle reference allows you to calculate angle differences and incremental changes in phasors if you need them for event analysis or in custom SCADA/HMI calculations. You can also use, in common calculations, the summary report phasors from multiple SEL-TWFL devices (and SEL relays) that are connected to the same bus because normally they share the same angle reference.

Summary Report Retrieval

As with most other SEL-TWFL reports, the summary report is not available as a file in the format shown in *Figure 5.4* but as a device response to an SEL ASCII command. Issue the **SUMMARY** (or **SUM**) command (see *SUMMARY* on page C.17) to obtain the summary report as text printed in the terminal emulator window. You can capture that text and save it in a file if required. Issue the **SUM** command to obtain the summary report for the most recent record. Issue the **SUM *n*** command to obtain the summary report for the *n*-th record (*n* = 10,000 – 65,535).

Additionally, whenever the device creates a new summary report, it transmits it to any open Telnet session if the Port 5 Telnet Configuration AUTO setting is set to Y (see *Telnet Protocol* on page 8.5 for additional information).

The device also includes the summary report data in the header file of the IEEE COMTRADE records (see *Header File Content* on page 5.5). The version included in the header file is formatted to have one data item per line for ease of parsing by machine clients.

The individual data items comprising the summary report are also available as analog quantities over DNP3 (see *Appendix E: Analog Quantities* for more details).

History Record

The history record is a catalog of all transient records present in the SEL-TWFL. When the device triggers transient recording, it updates the history record by adding a new line to the record. This update takes place when the transient recorder is ready to move the transient record from temporary storage to permanent storage on the micro SD card (see *Triggering, Recording, and Archiving* on page 5.7 for more information). You can start downloading the IEEE COMTRADE files and access the summary report as soon as the history record shows the new entry (enter the **HIS** command to view the history record). When you delete transient records from the device memory (see *Transient Record Deletion* on page 5.20), the history record is updated to show only the remaining records still present in the device memory. When the SEL-TWFL overwrites the oldest record with a new record, the device removes the entry corresponding to the overwritten record from the history record.

History Record Format and Content

Figure 5.6 shows a sample history record. *Table 5.8* explains the individual data items in the record.

```
=>>HIS <Enter>

SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

#     DATE       TIME         EVENT L1_FLOC L2_FLOC TARGETS
10023 2024/01/30 16:48:37.314 FL      21.40 $$$$$$$ L1FL L1LMA
10022 2024/01/30 16:24:13.150 FL    $$$$$$$   40.09 L2FL L2LMA
10021 2024/01/30 16:18:55.320 FL      23.07 $$$$$$$ L1FL
10020 2024/01/30 16:13:31.392 FL    $$$$$$$   40.08 L2FL
10019 2024/01/30 16:09:12.345 FL    $$$$$$$   26.17 L2FL
10018 2024/01/30 16:00:15.022 FL    $$$$$$$   40.11 L2FL
10017 2024/01/30 15:23:14.986 FL    $$$$$$$   18.49 L2FL
10016 2024/01/30 15:20:02.458 FL      21.41 $$$$$$$ L1FL
10015 2024/01/30 15:17:48.078 FL      45.33 $$$$$$$ L1FL
```

Figure 5.6 Sample History Record

Table 5.8 History Record Content

Data Item	Description	Comments
#	Consecutive transient record number; begins at 10,000 and wraps around at 65,535; referred to as Event Number in the summary report	This number is a unique transient record identifier that allows you to correlate IEEE COMTRADE records, history record entries, and summary reports. The history record lists the newest entries at the top (the entries with the highest record number). When you delete the transient records from the device, the record number does not return to 10,000 but continues to increment to the next record number.
DATE and TIME	Date and time of the record trigger according to the device clock in UTC time	This time stamp correlates with the trigger time in the TDR and MHR IEEE COMTRADE records and with the event time stamp in the summary report. Because of the rising edge detectors that you typically program in the ER SELOGIC equation, this time stamp can be 0.1 ms behind the time stamp in the SER entry for the Relay Word bit that triggered the entry.
EVENT	Record trigger source; referred to as Event Type in the summary report	See *Figure 5.2* for details on triggering logic. The trigger sources are displayed in the EVENT field in the following order of priority: ➤ TRIG (**TRIGGER** command) ➤ PULSE (**PULSE** command) ➤ FL (fault locator trigger) ➤ ER (record trigger condition that the ER SELOGIC equation specifies)
L1_FLOC	Most reliable fault-location result based on all fault-locating methods available at the time of the fault (on a per-line basis); referred to as Fault Location in the summary report	See *Selecting and Reporting Best Fault-Location Results* on page 2.26 for more details. If the fault-location result is not available, the device displays a string of $ signs. The fault-location result is only available for the FL event type.
L2_FLOC		
TARGETS	Fault locator trigger and line monitor alarm indications	This field indicates if the fault locator is triggered and if the line monitor alarm asserted (on a per-line basis).

History Record Retrieval

The SEL-TWFL provides the history record as a file in the REPORTS and EVENTS directories and as a report in response to the **HISTORY** (or **HIS**) command. The device provides separate history file versions of the history record: formatted (HISTORY.TXT) for human operators, see *Figure 5.6*, and comma-delimited (CHISTORY.TXT) for ease of parsing by machine clients.

Issue the **HIS** command (see *HISTORY* on page C.9) to obtain a report of the history record as text printed in the terminal emulator window. You can capture that text and save it in a file if required. Issue the **HIS** command to obtain the complete history report and issue **HIS *k*** to obtain the *k* newest entries in the history report.

Download the HISTORY.TXT file from the REPORTS directory (see *SEL-TWFL File Directories* on page 8.15) to obtain the history record as a formatted text file. The device refreshes the file content before transmitting the file.

NOTE: When you trigger several transient records back-to-back, the SEL-TWFL will refresh the history record only when archiving each new transient record (moving it from temporary storage to permanent storage on the micro SD card), one record at a time. This process may take up to several minutes. See *Triggering, Recording, and Archiving* on page 5.7 for more information.

When you program machine clients to access the history record, you can use the **CHISTORY** command (see *CHISTORY* on page C.22) or you can download the CHISTORY.TXT file from the REPORTS directory. The device refreshes the file content before transmitting the file.

You can also view data items from the history record for FL event types on the SEL-TWFL HMI (see *HMI Content* on page 7.6).

Transient Record Deletion

The SEL-TWFL transient recorder overwrites the oldest transient records when the archived records reach the permanent storage capacity of at least 60 s of total recording time. You do not need to delete records to ensure the device captures records for new events.

It is good practice to delete all transient records from the device as a last step in commissioning the device (to avoid confusion when analyzing in-service devices and to prevent your record archiving system from storing records triggered when testing the device). Issue the **HIS C** command to clear all transient records from the device memory (see *HISTORY* on page C.9). Record deletion removes all the IEEE COMTRADE files from the EVENTS directory and all entries from the history record. The **SUM** command returns null data if no records are present.

Sequential Events Recording

The SEL-TWFL provides a Sequential Events Recorder (SER) that logs state changes of factory-selected conditions and binary points that you can freely program. The factory-selected events include device power up, settings changes, and other significant conditions. The programmable binary points are Relay Word bits in the device. The SER logs both changes of state (assertion and deassertion) and time-stamps them with a resolution of 0.1 ms. When the device is connected to an IEEE C37.118-compatible clock, the SER time stamps correlate to absolute time with accuracy better than 1 µs. The time stamps of the SER entries align with the transition time of the binary channels in the TDR IEEE COMTRADE record. Because the TDR IEEE COMTRADE record contains all Relay Word bits in the device, it also acts as an SER record for the time period covered by the transient record.

The device stores 10,000 entries in the SER record. When the SER storage is full, the newest entry will overwrite the oldest entry.

The SER includes a deletion and reinsertion function for binary points that oscillate (chatter). Based on your settings that control the auto-deletion function, the device deletes oscillating SER binary points from the SER. This function prevents filling in the SER with entries created by chattering SER binary points.

The SER keeps up with typical bursts of state changes. Capable of logging a total of 100 binary points, with each point capable of changing state in 0.1 ms, 0.5 ms, or 1 ms, the SER can be exposed to significant bursts of state changes. The SER uses a temporary buffer, capable of holding more than 1,000 entries to address the SER log burst scenario. The SER moves the data from the buffer to the permanent memory at a typical pace of 1 entry per 10 ms. In the unlikely case that the SER buffer becomes full, the SER logic stops accepting new entries and logs the `SER data loss begin` entry. Subsequently, it proceeds to move all entries from the buffer to the permanent memory, which typically takes less than 10 s for all entries. When all entries are stored and the buffer is empty, the SER recovers from the burst and logs the `SER data loss end` entry. Note that the TDR IEEE COMTRADE record includes all Relay Word bits in the device, so you do not need to rely on the SER record when analyzing transient records that may create bursts of state changes in some Relay Word bits.

SER Record Format and Content

Figure 5.7 shows a sample SER record. *Table 5.9* explains the individual data items in the record.

```
=>>SER <Enter>

SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

#       DATE        TIME           ELEMENT              STATE
18    2024/01/30  16:22:48.0571   SER archive cleared
17    2024/01/30  16:23:49.2794   L1OPA                Deasserted
16    2024/01/30  16:23:49.2799   L1OPC                Deasserted
15    2024/01/30  16:23:49.2799   L1OPB                Deasserted
14    2024/01/30  16:24:50.1498   L1TWDD               Asserted
13    2024/01/30  16:24:50.1499   L1TD5ODH             Asserted
12    2024/01/30  16:24:50.1500   L1FL                 Asserted
11    2024/01/30  16:24:50.1501   L1FL                 Deasserted
10    2024/01/30  16:24:50.1650   L1LMEVE              Asserted
9     2024/01/30  16:24:50.1660   L1LMA                Asserted
8     2024/01/30  16:24:50.1708   L1TWDD               Deasserted
7     2024/01/30  16:24:50.1849   L1LMEVE              Deasserted
6     2024/01/30  16:24:50.2017   L1TWDD               Asserted
5     2024/01/30  16:24:50.2194   L1TD5ODH             Deasserted
4     2024/01/30  16:24:50.2288   L1OPA                Asserted
3     2024/01/30  16:24:50.2367   L1OPC                Asserted
2     2024/01/30  16:24:50.2388   L1OPB                Asserted
1     2024/01/30  16:24:50.2794   L1TWDD               Deasserted
```

Figure 5.7 Sample SER Record

Table 5.9 SER Record Content

Data Item	Description	Comments
#	SER entry number; the newest SER entry is always numbered as 1	The SER presents the entries from oldest to newest with the oldest at the top of the record. Therefore, the SER entry number appears in descending order even though the time flows from the top of the record to the bottom. The SER entry number is therefore a row number in the SER record, rather than a number corresponding to an SER entry. See *SER* on page C.14 for information on how to control the display by using the **SER** command.
DATE and TIME	Date and time of the entry according to the device clock in UTC time	For Relay Word bits, this time stamp correlates with the state change of the corresponding binary channel in the TDR IEEE COMTRADE record.
ELEMENT	Factory-set SER entry or Relay Word bit programmed in the SER	See *Appendix D: Relay Word Bits* for a complete list of all Relay Word bits with descriptions. See *Table 5.10* for factory-set SER entries.
STATE	Designation of state change	"Asserted" (transition from logical 0 to 1) and "Deasserted" (transition from logical 1 to 0) for Relay Word bits; event-specific text for factory-set SER record entries (see *Table 5.10*).

Table 5.10 shows factory-set SER record entries and the event-specific text displayed for each. For example, if you turn the power off and then back on, the SER record displays `Device restarted`.

Table 5.10 Factory-Set SER Record Entries

Event	SER Record Entry
Device turning on	`Device restarted`
Device settings change	`Settings changed`
SER archive cleared	`SER archive cleared`
SER buffer overflow	`SER data loss begin`
SER buffer overflow end	`SER data loss end`
Diagnostic restart of device (see *Appendix F: Diagnostics*)	`Diagnostic restart`
Auto-removed chattering SER element	`Auto-Removed`
Auto-reinstated ceased-chattering SER element	`Auto-Reinstated`
Device clock is free running	`Time Source: Free Running`
Device clock locked to local high-quality IRIG-B source	`Time Source: HIRIG`

SER Configuration

Table 5.11 shows the SER settings.

Table 5.11 SER Settings

Setting	Description	Range	Default	Class
SER1	SER Points List 1, Up to 25 RWBs		L1FL	Report
SER2	SER Points List 2, Up to 25 RWBs		L1LMA, L1LMEVE	Report
SER3	SER Points List 3, Up to 25 RWBs		L1_3PO, L1APO, L1LOP	Report
SER4	SER Points List 4, Up to 25 RWBs		ROKP1, ROKP2, ROKP3, TSOK, SALARM, HALARM	Report
ESERDEL	Enable Auto-Removal of Chattering SER Points	Y, N	N	Report
SRDLCNT	Number of Counts Before Auto-Removal	2–20	5	Report
SRDLTIM	Auto-Removal Time Interval	0.1–30.0 s	0.5	Report

Follow these settings recommendations when configuring the SER.

SER*n*

Use the SER*n* (*n* = 1–4) setting to list as many as 100 Relay Word bits for recording with the SER. Use the 4 SER lists, each capable of holding 25 Relay Word bits, to standardize your settings for various applications. The device logs state changes for the binary points from all SER*n* lists in the same common SER record.

ESERDEL, SRDLCNT, and SRDLTIM

Use the ESERDEL setting to enable (ESERDEL = Y) or disable (ESERDEL = N) the anti-chatter filter in the SER scanning logic. The anti-chatter filter monitors each binary point configured in the SER for repeated assertions and deassertion (chattering). The anti-chatter filter suspends logging state changes for the binary point that met the chattering criteria. The SER logs the suspension of a binary point by recording `Auto-Removed` as the binary point transition in the SER entry (see *Table 5.10*). You can see the list of binary points that are temporarily suspended from the SER scanning logic by issuing the **SER D** command. Once the suspended point stops chattering, the anti-chatter filter allows the binary point to be scanned for state changes and logged in the SER. The SER logs the end of suspension of a binary point by recording `Auto-Reinstated` as the binary point transition in the SER entry (see *Table 5.10*). When a binary point is suspended, the SER scanning logic does not log its state changes and these state changes are permanently lost in the SER and will not be reinstated.

Use the SRDLCNT and SRDLTIM settings to define the chattering condition for all binary points configured in the SER. Once a binary point has changed state more than the value of the SRDLCNT setting in a time period equal to the SRDLTIM setting, the SER scanning logic declares the binary point as chattering for the time duration of 10 • SRDLTIM and removes it from the SER scanning logic. At the end of this period, the SER scanning logic repeats the chattering test. If the binary point meets the chattering criteria, the SER anti-chatter filter continues to suspend the binary point. If the binary point does not meet the chattering criteria (stopped chattering), the SER anti-chatter filter reinstates the binary point to the SER scanning logic.

SER Record Retrieval and Deletion

The SEL-TWFL provides the SER record as a file in the REPORTS directory and as a report in response to the **SER** command.

Issue the **SER** command (see *SER* on page C.14) to obtain a report of the SER record as text printed in the terminal emulator window. You can capture that text and save it in a file if required. Issue the **SER** command to obtain a report of the complete SER record. Use the **SER** command parameters to request a specified number of most recent SER entries and to request SER entries between any two SER row numbers or between any two time stamps. You can use the parameters of the **SER** command to display the entries from oldest to newest or from newest to oldest.

When you issue the **SER** command, the device retrieves SER entries from non-volatile memory. If the checksum on that entry fails, the device displays the `Invalid Data` message for that entry. If the SER triggers a new entry when the **SER** command is being processed, the device will abort the command if the newly triggered entry violates the format of the SER report being generated (for example, when you display SER entries from newest to oldest). In such a case, the device displays the `Command aborted, data overwrite occurred` message in the terminal emulator window.

Issue the **SER C** command to clear the SER record. When you clear the SER record, the record shows a single entry `SER Archive Cleared`.

Download the SER.TXT file from the REPORTS directory (see *SEL-TWFL File Directories* on page 8.15) to obtain the SER record as a text file. The device refreshes the file content before transmitting the file.

An alternative SER report format is available by using SEL Fast SER, a protocol that allows machine clients to obtain unsolicited SER data from the device. See *SEL Fast Binary Protocols* on page 8.13 for more information.

SECTION 6

Application Examples

The SEL-TWFL is capable of locating faults on and monitoring two lines, and it is suited for applications involving radial lines, two- or three-terminal lines, lines with unmeasured taps, and hybrid lines.

This section provides examples that describe how to apply the SEL-TWFL on two- and three-terminal lines. The first five examples are for locating faults by using IEEE C37.94-compliant multiplexed channels. The sixth example uses DNP3 protocol over Ethernet and calculates the fault location in a central DNP3 client computer. These examples use either MIRRORED BITS communications or contact inputs on the SEL-TWFL to trigger the fault locator. The examples that use MIRRORED BITS communications include a media converter to connect the fiber-optic communications port of the SEL-TWFL to the EIA-232 interface of the SEL protective relay. The SEL-2814 Fiber-Optic Transceiver With Hardware Flow Control and the SEL-2812 Fiber-Optic Transceiver With IRIG-B are media converters suitable for these applications. In all the examples, each SEL-TWFL is connected via the IRIG-B input to an IEEE C37.118-compliant GPS clock with submicrosecond accuracy to obtain an absolute time reference.

This section is organized as follows:

- *IEEE C37.94-Compliant Multiplexed Channel Applications* on page 6.1
  - *Example 1: Two-Terminal Overhead Line (Single Breaker)* on page 6.2
  - *Example 2: Two-Terminal Overhead Line (Dual Breaker)* on page 6.4
  - *Example 3: Dual Two-Terminal Overhead Lines* on page 6.6
  - *Example 4: Three-Terminal Overhead Line* on page 6.10
  - *Example 5: Two-Terminal Hybrid Line* on page 6.14
- *DNP3 Over Ethernet Application* on page 6.17
  - *Example 6: Two-Terminal Overhead Line Without Device-to-Device Communications* on page 6.17

IEEE C37.94-Compliant Multiplexed Channel Applications

Apply the multi-ended fault-locating methods by using an IEEE C37.94-compliant multiplexed channel. The following examples include fault locator and communications settings that follow the settings order in ACSELERATOR Quick-Set® SEL-5030 Software.

Example 1: Two-Terminal Overhead Line (Single Breaker)

Figure 6.1 shows two SEL-TWFL devices monitoring an overhead transmission line with a three-pole mechanism breaker at each line terminal. Each SEL-TWFL obtains currents from line CTs and voltages from line-side VTs. At each line terminal, the breaker auxiliary contact is wired to one of the corresponding SEL-TWFL contact inputs and provides breaker position status to reliably detect open-pole conditions. The devices use IRIG-B signals from IEEE C37.118-compliant GPS clocks with submicrosecond accuracy to obtain an absolute time reference. Each SEL protective relay sends fault locator (FL) trigger signals to Port 1 of the corresponding SEL-TWFL by using MIRRORED BITS communications via an SEL-2814. To calculate fault locations by using the multi-ended traveling-wave- and impedance-based fault-locating methods, the two SEL-TWFL devices exchange data via Port 2 over IEEE C37.94-compliant multiplexed channels.

Figure 6.1 Single-Breaker, Two-Terminal Overhead Line Application That Uses SEL-2814 Transceivers, IEEE C37.94-Compliant Multiplexed Channels, and MIRRORED BITS Communications

Table 6.1 through *Table 6.6* summarize the required settings for this application.

Fault Locator Settings

Table 6.1 General Settings

Setting Name	Setting Value		Unit	Comment
	Station S	Station R		
SID	StationS	StationR	N/A	Set the station identifier for each line terminal.
NLINE	1	1	N/A	Set the number of lines to 1.
LLUNIT	mi or km	mi or km	N/A	Set the preferred units for the line length.

Table 6.2 Line 1 Source Selection

Setting Name	Setting Value		Unit	Comment
	Station S	Station R		
L1I	IW	IW	N/A	Wire the line CTs to the IW current inputs of the device.
L1V	VY	VY	N/A	Wire the line PTs to the VY voltage inputs of the device.

Table 6.3 Line 1 Configuration

Setting Name	Setting Value		Unit	Comment
	Station S	Station R		
L1NTERM	2	2	N/A	Set the number of line terminals to 2.
L1NSEC	1	1	N/A	Because this is a homogeneous line, set the number of line sections to 1.
L1LL1	100.00 or 160.93	100.00 or 160.93	N/A	Set the line length according to the units specified in the LLUNIT setting. For this example, enter 100.00 if you set LLUNIT to mi or enter 160.93 if you set LLUNIT to km.
L1TWLPT1	547.76	547.76	µs	Set the traveling-wave line propagation time. Expect the following value, assuming a propagation velocity of 98 percent of the speed of light in free space: 160.93 km / (0.98 • 299792.458 km/s) = 547.76 µs. SEL recommends updating this value based on the commissioning test results (see *Measuring TW Line Propagation Time During a Line Energization Test* on page 10.14).
L1Z1MAG1	4.87	4.87	Ω secondary	Positive-sequence line impedance magnitude.
L1Z1ANG1	84.00	84.00	deg	Positive-sequence line impedance angle.
L1Z0MAG1	15.50	15.50	Ω secondary	Zero-sequence line impedance magnitude.
L1Z0ANG1	81.50	81.50	deg	Zero-sequence line impedance angle.
L1PORT1	P2	P2	N/A	Select communications Port 2 to receive the fault-locating data from the remote SEL-TWFL.
L1RSID1	StationR	StationS	N/A	Enter the identifier for the remote station.

Table 6.4 Line 1 Circuit Breaker

Setting Name	Setting Value		Unit	Comment
	Station S	Station R		
Breaker Monitor				
L1BNUM	1	1	N/A	Because each end of the line has a single breaker, set the number of breakers to 1 in each device.
L1B1TYPE	THREE-POLE	THREE-POLE	N/A	Set the Breaker 1 mechanism type to three-pole.
L1B1A52A	IN201	IN201	N/A	Wire the 52A contact that indicates Breaker 1 status to IN201.
Open-Pole Detection				
L1OPMODE	52	52	N/A	Set the open-pole detection mode to use the breaker status.

Table 6.5 Line 1 Fault Locator

Setting Name	Setting Value		Unit	Comment
	Station S	Station R		
L1FL	RMB1P1	RMB1P1	N/A	Connect communications Port 1 on each SEL-TWFL to the respective SEL relay. Use Received Mirrored Bit 1 on Port 1 to trigger the fault locator for Line 1.
L1TWCPT	0.000	0.000	µs	The TWCPT setting improves accuracy of the double-ended TW-based method; however, you may decide not to use this setting if you have difficulties obtaining the secondary CT cable data or you know that the CT cables have a similar length at both line terminals.

Communications

Table 6.6 Port 1 and Port 2

Setting Name	Setting Value		Unit	Comment
	Station S	Station R		
Port 1				
EPORT	Y	Y	N/A	Connect communications Port 1 on each SEL-TWFL to the respective SEL relay, and configure Port 1 for MB8 encoding.
ENCODING	MB8	MB8	N/A	
SPEED	38400	38400	bps	
TXID	1	1	N/A	Set RXID in each SEL-TWFL equal to the TXID in the connected SEL relay, and vice versa.
RXID	2	2	N/A	
Port 2				
EPORT	Y	Y	N/A	Connect communications Port 2 on each SEL-TWFL to the respective multiplexer, and configure Port 2 for IEEE C37.94 encoding.
ENCODING	C37.94	C37.94	N/A	
DATACLK	E	E	N/A	Use the DATACLK setting to select the communications timing source. When connecting the device to a multiplexer, set DATACLK to E in the SEL-TWFL to align the data transfer with the timing set by the multiplexer.
TXID	3	4	N/A	Set RXID in one device equal to the TXID in the connected device, and vice versa.
RXID	4	3	N/A	

Example 2: Two-Terminal Overhead Line (Dual Breaker)

Figure 6.2 shows two SEL-TWFL devices monitoring an overhead transmission line with dual single-pole mechanism breakers at each line terminal. This example is similar to *Example 1: Two-Terminal Overhead Line (Single Breaker)* on page 6.2 with the following differences:

- Each device obtains currents from the Breaker 1 and Breaker 2 CTs that are wired to the corresponding SEL-TWFL current inputs.
- At each line terminal, the breaker auxiliary contacts of both single-pole breakers are wired to the corresponding SEL-TWFL contact inputs and provide breaker position status to reliably detect open-pole conditions.

Figure 6.2 Dual-Breaker, Two-Terminal Overhead Line Application That Uses SEL-2814 Transceivers, IEEE C37.94-Compliant Multiplexed Channels, and MIRRORED BITS Communications

This example uses the settings shown in *Table 6.1*, *Table 6.3*, *Table 6.5*, and *Table 6.6*. Use the settings shown in *Table 6.7* and *Table 6.8* to replace those shown in *Table 6.2* and *Table 6.4*, respectively.

Fault Locator Settings

Table 6.7 Line 1 Source Selection

Setting Name	Setting Value		Unit	Comment
	Station S	Station R		
L1I	COMB	COMB	N/A	Wire the Breaker 1 CTs to the IW current inputs and the Breaker 2 CTs to the IX current inputs of each SEL-TWFL. Set L1I to COMB to instruct the device to match ratios, and add the IW and IX currents for metering and fault-locating functions.
L1V	VY	VY	N/A	Wire the line PTs to the VY voltage inputs of the device.

Table 6.8 Line 1 Circuit Breaker (Sheet 1 of 2)

Setting Name	Setting Value		Unit	Comment
	Station S	Station R		
Breaker Monitor				
L1BNUM	2	2	N/A	Because each end of the line has dual breakers, set the number of breakers to 2 in each device.
L1B1TYPE	SINGLE-POLE	SINGLE-POLE	N/A	Set the Breaker 1 mechanism type to single-pole.
L1B1A52A	IN201	IN201	N/A	Wire the 52A contact that indicates Breaker 1 Phase A status to IN201 on the SEL-TWFL.
L1B1B52A	IN202	IN202	N/A	Wire the 52A contact that indicates Breaker 1 Phase B status to IN202 on the SEL-TWFL.
L1B1C52A	IN203	IN203	N/A	Wire the 52A contact that indicates Breaker 1 Phase C status to IN203 on the SEL-TWFL.

Table 6.8 Line 1 Circuit Breaker (Sheet 2 of 2)

Setting Name	Setting Value		Unit	Comment
	Station S	Station R		
L1B2TYPE	SINGLE-POLE	SINGLE-POLE	N/A	Set the Breaker 2 mechanism type to single-pole.
L1B2A52A	IN204	IN204	N/A	Wire the 52A contact that indicates Breaker 2 Phase A status to IN204 on the SEL-TWFL.
L1B2B52A	IN205	IN205	N/A	Wire the 52A contact that indicates Breaker 2 Phase B status to IN205 on the SEL-TWFL.
L1B2C52A	IN206	IN206	N/A	Wire the 52A contact that indicates Breaker 2 Phase C status to IN206 on the SEL-TWFL.
Open-Pole Detection				
L1OPMODE	52	52	N/A	Set the open-pole detection mode to use the breaker status.

Example 3: Dual Two-Terminal Overhead Lines

Figure 6.3 shows three SEL-TWFL devices monitoring two overhead transmission lines. Each device obtains currents from line CTs and voltages from line-side VTs. The device at Station S obtains currents and voltages from both lines. Breaker auxiliary contacts wired to one of the contact inputs on the corresponding device provide breaker position status information to reliably detect open-pole conditions. The devices use IRIG-B signals from IEEE C37.118-compliant GPS clocks with submicrosecond accuracy to obtain an absolute time reference. Protective relays send FL trigger signals to the SEL-TWFL devices by using the corresponding SEL-TWFL contact inputs. To calculate the location of faults on both lines by using the multi-ended traveling-wave- and impedance-based fault-locating methods, the Station S and Station R SEL-TWFL devices exchange data via Port 1 and the Station S and Station T devices exchange data via Port 2 over IEEE C37.94-compliant multiplexed channels.

Figure 6.3 Application for Dual Two-Terminal Overhead Lines That Uses IEEE C37.94-Compliant Multiplexed Channels and Protective Relays With Contact Inputs

Table 6.9 through *Table 6.15* show the settings used for this example. For settings related to circuit breakers and communications Ports 1 and 2, review *Example 1: Two-Terminal Overhead Line (Single Breaker)* on page 6.2.

Fault Locator Settings

Table 6.9 General Settings

Setting Name	Setting Value			Unit	Comment
	Station S	Station R	Station T		
SID	StationS	StationR	StationT	N/A	Set the station identifier for each line terminal.
NLINE	2	1	2	N/A	Set the number of lines to 2 at Station S and the number of lines to 1 at Station R to indicate the number of lines being monitored by the SEL-TWFL at each station. At Station T, set the number of lines to 2 to enable the use of Line 2 for consistency with the SEL-TWFL at Station S.
L1ID	Line1 230 kV StationS – StationR	Line1 230 kV StationR – StationS	N/A	N/A	Set the Line 1 identifier in each device. At Station S and Station R, configure Line 1 in each SEL-TWFL as the line between Station S and Station R (Line 1 shown in *Figure 6.3*).
L2ID	Line2 230 kV StationS – StationT	N/A	Line2 230 kV StationT – StationS	N/A	Set the Line 2 identifier in each device. At Station S and Station T, configure Line 2 in each SEL-TWFL as the line between Station S and Station T (Line 2 shown in *Figure 6.3*).

Table 6.10 Line 1 Source Selection

Setting Name	Setting Value		Unit	Comment
	Station S	Station R		
L1I	IW	IW	N/A	Wire the Line 1 CTs to the IW current inputs.
L1V	VY	VY	N/A	Wire the Line 1 PTs to the VY voltage inputs.

Table 6.11 Line 1 Configuration (Sheet 1 of 2)

Setting Name	Setting Value		Unit	Comment
	Station S	Station R		
L1NTERM	2	2	N/A	Set the number of line terminals to 2.
L1NSEC	1	1	N/A	Because Line 1 is a homogeneous line, set the number of line sections to 1 in each device.
L1LL1	100.00 or 160.93	100.00 or 160.93	N/A	Set the line length for Line 1 according to the units specified in the LLUNIT setting. For this example, enter 100.00 if you set LLUNIT to mi or enter 160.93 if you set LLUNIT to km.
L1TWLPT1	547.76	547.76	µs	Set the traveling-wave line propagation time. Expect the following value for Line 1, assuming a propagation velocity of 98 percent of the speed of light in free space: 160.93 km / (0.98 • 299792.458 km/s) = 547.76 µs. SEL recommends updating this value based on the commissioning test results (see *Measuring TW Line Propagation Time During a Line Energization Test* on page 10.14).
L1Z1MAG1	4.87	4.87	Ω secondary	Positive-sequence line impedance magnitude.
L1Z1ANG1	84.00	84.00	deg	Positive-sequence line impedance angle.
L1Z0MAG1	15.50	15.50	Ω secondary	Zero-sequence line impedance magnitude.

Table 6.11 Line 1 Configuration (Sheet 2 of 2)

Setting Name	Setting Value		Unit	Comment
	Station S	Station R		
L1Z0ANG1	81.50	81.50	deg	Zero-sequence line impedance angle.
L1PORT1	P1	P1	N/A	Select the communications port to receive the fault-locating data from the remote SEL-TWFL.
L1RSID1	StationR	StationS	N/A	Enter the identifier for the remote station.

Table 6.12 Line 1 Fault Locator

Setting Name	Setting Value		Unit	Comment
	Station S	Station R		
L1FL	IN101	IN101	N/A	Connect IN101 on each SEL-TWFL to the respective line relay to trigger the fault locator for Line 1.

Table 6.13 Line 2 Source Selection

Setting Name	Setting Value		Unit	Comment
	Station S	Station T		
L2I	IX	IX	N/A	Wire the Line 2 CTs to the IX current inputs.
L2V	VZ	VZ	N/A	Wire the Line 2 PTs to the VZ voltage inputs.

Table 6.14 Line 2 Configuration

Setting Name	Setting Value		Unit	Comment
	Station S	Station T		
L2NTERM	2	2	N/A	Set the number of line terminals to 2.
L2NSEC	1	1	N/A	Because Line 2 is a homogeneous line, set the number of line sections to 1 in each device.
L2LL1	120.00 or 193.12	120.00 or 193.12	N/A	Set the line length for Line 2 according to the units specified in the LLUNIT setting. For this example, enter 120.00 if you set LLUNIT to mi or enter 193.12 if you set LLUNIT to km.
L2TWLPT1	657.33	657.33	µs	Set the traveling-wave line propagation time. Expect the following value for Line 2, assuming a propagation velocity of 98 percent of the speed of light in free space: 193.12 km / (0.98 • 299792.458 km/s) = 657.33 µs. SEL recommends updating this value based on the commissioning test results (see *Measuring TW Line Propagation Time During a Line Energization Test* on page 10.14).
L2Z1MAG1	5.84	5.84	Ω secondary	Positive-sequence line impedance magnitude.
L2Z1ANG1	84.00	84.00	deg	Positive-sequence line impedance angle.
L2Z0MAG1	18.60	18.60	Ω secondary	Zero-sequence line impedance magnitude.
L2Z0ANG1	81.50	81.50	deg	Zero-sequence line impedance angle.
L2PORT1	P2	P2	N/A	Select the communications port to receive the fault-locating data from the remote SEL-TWFL.
L2RSID1	StationT	StationS	N/A	Enter the identifier for the remote station.

Table 6.15 Line 2 Fault Locator

Setting Name	Setting Value		Unit	Comment
	Station S	Station T		
L2FL	IN102	IN102	N/A	Connect IN102 on each SEL-TWFL to the respective line relay to trigger the fault locator for Line 2.

The QuickSet settings screens shown in *Figure 6.4* through *Figure 6.7* provide additional clarification for configuring the SEL-TWFL at each station. *Figure 6.4* and *Figure 6.5* show the settings for the device at Station S, *Figure 6.6* shows the settings for the device at Station R, and *Figure 6.7* shows the settings for the device at Station T.

Line 1 Configuration

		Section 1	Section 2	Section 3	Section 4	Section 5
L1NTERM	Number of Terminals	2				
L1NSEC	Number of Sections	1				
L1LLn	Section n Length (mi)	100.00	40.00	40.00	40.00	40.00
L1TWLPTn	Section n TW Line Propagation Time (microseconds)	547.76	219.00	219.00	219.00	219.00
L1Z1MAGn	Section n Positive-Sequence Impedance Mag (ohms, sec)	4.87	1.95	1.95	1.95	1.95
L1Z1ANGn	Section n Positive-Sequence Impedance Angle (deg)	84.00	84.00	84.00	84.00	84.00
L1Z0MAGn	Section n Zero-Sequence Impedance Mag (ohms, sec)	15.50	6.20	6.20	6.20	6.20
L1Z0ANGn	Section n Zero-Sequence Impedance Angle (deg)	81.50	81.50	81.50	81.50	81.50
L1PORTn	Section n Fault Locator Data Port	P1	NA	NA	NA	NA
L1RSIDn	Remote Station Identifier (40 characters)	StationR	NA	NA	NA	NA

Figure 6.4 Settings for Line 1 at Station S for the Dual Two-Terminal Overhead Line Application in *Figure 6.3*

Line 2 Configuration

		Section 1	Section 2	Section 3	Section 4	Section 5
L2NTERM	Number of Terminals	2				
L2NSEC	Number of Sections	1				
L2LLn	Section n Length (mi)	120.00	40.00	40.00	40.00	40.00
L2TWLPTn	Section n TW Line Propagation Time (microseconds)	657.33	219.00	219.00	219.00	219.00
L2Z1MAGn	Section n Positive-Sequence Impedance Mag (ohms, sec)	5.84	1.95	1.95	1.95	1.95
L2Z1ANGn	Section n Positive-Sequence Impedance Angle (deg)	84.00	84.00	84.00	84.00	84.00
L2Z0MAGn	Section n Zero-Sequence Impedance Mag (ohms, sec)	18.60	6.20	6.20	6.20	6.20
L2Z0ANGn	Section n Zero-Sequence Impedance Angle (deg)	81.50	81.50	81.50	81.50	81.50
L2PORTn	Section n Fault Locator Data Port	P2	NA	NA	NA	NA
L2RSIDn	Remote Station Identifier (40 characters)	StationT	NA	NA	NA	NA

Figure 6.5 Settings for Line 2 at Station S for the Dual Two-Terminal Overhead Line Application in *Figure 6.3*

Line 1 Configuration

L1NTERM Number of Terminals	2				
L1NSEC Number of Sections	1				
	Section 1	**Section 2**	**Section 3**	**Section 4**	**Section 5**
L1LLn Section n Length (mi)	100.00	40.00	40.00	40.00	40.00
L1TWLPTn Section n TW Line Propagation Time (microseconds)	547.76	219.00	219.00	219.00	219.00
L1Z1MAGn Section n Positive-Sequence Impedance Mag (ohms, sec)	4.87	1.95	1.95	1.95	1.95
L1Z1ANGn Section n Positive-Sequence Impedance Angle (deg)	84.00	84.00	84.00	84.00	84.00
L1Z0MAGn Section n Zero-Sequence Impedance Mag (ohms, sec)	15.50	6.20	6.20	6.20	6.20
L1Z0ANGn Section n Zero-Sequence Impedance Angle (deg)	81.50	81.50	81.50	81.50	81.50
L1PORTn Section n Fault Locator Data Port	P1	NA	NA	NA	NA
L1RSIDn Remote Station Identifier (40 characters)	StationS	NA	NA	NA	NA

Figure 6.6 Settings at Station R for the Dual Two-Terminal Overhead Line Application in *Figure 6.3*

Line 2 Configuration

L2NTERM Number of Terminals	2				
L2NSEC Number of Sections	1				
	Section 1	**Section 2**	**Section 3**	**Section 4**	**Section 5**
L2LLn Section n Length (mi)	120.00	40.00	40.00	40.00	40.00
L2TWLPTn Section n TW Line Propagation Time (microseconds)	657.33	219.00	219.00	219.00	219.00
L2Z1MAGn Section n Positive-Sequence Impedance Mag (ohms, sec)	5.84	1.95	1.95	1.95	1.95
L2Z1ANGn Section n Positive-Sequence Impedance Angle (deg)	84.00	84.00	84.00	84.00	84.00
L2Z0MAGn Section n Zero-Sequence Impedance Mag (ohms, sec)	18.60	6.20	6.20	6.20	6.20
L2Z0ANGn Section n Zero-Sequence Impedance Angle (deg)	81.50	81.50	81.50	81.50	81.50
L2PORTn Section n Fault Locator Data Port	P2	NA	NA	NA	NA
L2RSIDn Remote Station Identifier (40 characters)	StationS	NA	NA	NA	NA

Figure 6.7 Settings at Station T for the Dual Two-Terminal Overhead Line Application in *Figure 6.3*

Example 4: Three-Terminal Overhead Line

Figure 6.8 shows three SEL-TWFL devices monitoring a three-terminal overhead transmission line. Each device obtains currents from line CTs and voltages from line-side VTs. At each line terminal, the breaker auxiliary contact is wired to one of the corresponding SEL-TWFL contact inputs and provides breaker position status to reliably detect open-pole conditions. The devices use IRIG-B signals from IEEE C37.118-compliant GPS clocks with submicrosecond accuracy to obtain an absolute time reference. Protective relays send FL trigger signals to the SEL-TWFL devices by using the corresponding SEL-TWFL contact inputs. To calculate fault locations by using the multi-ended traveling-wave- and impedance-based fault-locating methods, the devices exchange data for the three-terminal line over IEEE C37.94-compliant multiplexed channels. The Station S device exchanges data with the Station R and Station T devices via Port 1 and Port 2, respectively. The Station R device exchanges data with the Station S and

Station T devices via Port 1 and Port 3, respectively. The Station T device exchanges data with the Station S and Station R devices via Port 2 and Port 3, respectively.

Figure 6.8 Three-Terminal Line Application That Uses IEEE C37.94-Compliant Multiplexed Channels and Protective Relays With Contact Inputs

Table 6.16 shows the settings used for this example that are common to the devices at Station S, Station R, and Station T. Note that in all devices, Section 1 is the section of line between Station S and the tap point, Section 2 is the section of line between Station R and the tap point, and Section 3 is the section of line between Station T and the tap point. *Table 6.17* shows the settings used for this example that are unique to the devices at Station S, Station R, and Station T. To determine settings not shown, such as settings related to source selection, circuit breakers, and communications Ports 1, 2, and 3, review *Example 1: Two-Terminal Overhead Line (Single Breaker)* on page 6.2 and *Example 3: Dual Two-Terminal Overhead Lines* on page 6.6.

The QuickSet settings screens shown in *Figure 6.9*, *Figure 6.10*, and *Figure 6.11* provide additional clarification for configuring the SEL-TWFL at Station S, Station R, and Station T, respectively. Note that in this example, each SEL-TWFL reports the fault location by using the station with the faulted section as a reference. If the fault location is at the tap, all the devices report the fault location by using the corresponding local line terminal as a reference.

Fault Locator Settings

Table 6.16 Line 1 Configuration Settings Common to the Devices at Station S, Station R, and Station T (Sheet 1 of 2)

Setting Name	Setting Value	Unit	Comment
L1NTERM	3	N/A	Set the number of line terminals to 3. Note that the device forces the L1NSEC setting to a value of 3 when L1NTERM is set to 3.

Table 6.16 Line 1 Configuration Settings Common to the Devices at Station S, Station R, and Station T (Sheet 2 of 2)

Setting Name	Setting Value			Unit	Comment
	Section 1	Section 2	Section 3		
L1LL*n*	40.00 or 64.37	60.00 or 96.56	20.00 or 32.19	N/A	Set the line length for each section according to the units specified in the LLUNIT setting. For Section 1 (Station S to the tap point), enter 40.00 if you set LLUNIT to mi or enter 64.37 if you set LLUNIT to km. Similarly, for Section 2 (Station R to the tap point), enter 60.00 (mi) or 96.56 (km). For Section 3 (Station T to the tap point), enter 20.00 (mi) or 32.19 (km).
L1TWLPT*n*	219.11	328.66	109.55	µs	Set the traveling-wave line propagation time for each section. Expect the following value for Section 1, assuming a propagation velocity of 98 percent of the speed of light in free space: 40.00 mi / (0.98 • 186282.397 mi/s) = 219.11 µs. Expect the following value for Section 2: 60.00 mi / (0.98 • 186282.397 mi/s) = 328.66 µs. Expect the following value for Section 3: 20.00 mi / (0.98 • 186282.397 mi/s) = 109.55 µs.
L1Z1MAG*n*	1.95	2.92	0.97	Ω secondary	Positive-sequence line impedance magnitude for each section.
L1Z1ANG*n*	84.00	84.00	84.00	deg	Positive-sequence line impedance angle for each section.
L1Z0MAG*n*	6.20	9.30	3.10	Ω secondary	Zero-sequence line impedance magnitude for each section.
L1Z0ANG*n*	81.50	81.50	81.50	deg	Zero-sequence line impedance angle for each section.

Table 6.17 Line 1 Configuration Settings Unique to the Devices at Station S, Station R, and Station T (Sheet 1 of 2)

Setting Name	Setting Value			Unit	Comment
	Section 1	Section 2	Section 3		
Station S					
L1PORT*n*	LOCAL	P1	P2	N/A	Set Section 1 Fault Locator Data Port (L1PORT1) to LOCAL to associate Section 1 to the local device at Station S. Set Section 2 Fault Locator Data Port (L1PORT2) to P1 to receive data from the remote device associated with Section 2 via the IEEE C37.94 communications channel connected to Port 1. Set Section 3 Fault Locator Data Port (L1PORT3) to P2 to receive data from the remote device associated with Section 3 via the IEEE C37.94 communications channel connected to Port 2.
L1RSID*n*	StationS[a]	StationR	StationT	N/A	Enter the identifier for each remote station.
Station R					
L1PORT*n*	P1	LOCAL	P3	N/A	Set L1PORT1 to P1 to receive data from the remote device associated with Section 1 via the IEEE C37.94 communications channel connected to Port 1. Set L1PORT2 to LOCAL to associate Section 2 to the local device at Station R. Set L1PORT3 to P3 to receive data from the remote device associated with Section 3 via the IEEE C37.94 communications channel connected to Port 3.
L1RSID*n*	StationS	StationR[a]	StationT	N/A	Enter the identifier for each remote station.

Table 6.17 Line 1 Configuration Settings Unique to the Devices at Station S, Station R, and Station T (Sheet 2 of 2)

Setting Name	Setting Value			Unit	Comment
	Section 1	Section 2	Section 3		
Station T					
L1PORT*n*	P2	P3	LOCAL	N/A	Set L1PORT1 to P2 to receive data from the remote device associated with Section 1 via the IEEE C37.94 communications channel connected to Port 2. Set Section 2 Fault Locator Data Port (L1PORT2) to P3 to receive data from the remote device associated with Section 2 via the IEEE C37.94 communications channel connected to Port 3. Set L1PORT3 to LOCAL to associate Section 3 to the local device at Station T.
L1RSID*n*	StationS	StationR	StationT[a]	N/A	Enter the identifier for each remote station.

[a] The L1RSID*n* value is forced to the SID setting in the local device when L1PORT*n* is set to LOCAL.

Line 1 Configuration

L1NTERM Number of Terminals	3				
L1NSEC Number of Sections	3				
	Section 1	Section 2	Section 3	Section 4	Section 5
L1LLn Section n Length (mi)	40.00	60.00	20.00	40.00	40.00
L1TWLPTn Section n TW Line Propagation Time (microseconds)	219.11	328.66	109.55	219.00	219.00
L1Z1MAGn Section n Positive-Sequence Impedance Mag (ohms, sec)	1.95	2.92	0.97	1.95	1.95
L1Z1ANGn Section n Positive-Sequence Impedance Angle (deg)	84.00	84.00	84.00	84.00	84.00
L1Z0MAGn Section n Zero-Sequence Impedance Mag (ohms, sec)	6.20	9.30	3.10	6.20	6.20
L1Z0ANGn Section n Zero-Sequence Impedance Angle (deg)	81.50	81.50	81.50	81.50	81.50
L1PORTn Section n Fault Locator Data Port	LOCAL	P1	P2	NA	NA
L1RSIDn Remote Station Identifier (40 characters)	StationS	StationR	StationT	NA	NA

Figure 6.9 Settings at Station S for the Three-Terminal Line in *Figure 6.8*

Line 1 Configuration

L1NTERM Number of Terminals	3				
L1NSEC Number of Sections	3				
	Section 1	Section 2	Section 3	Section 4	Section 5
L1LLn Section n Length (mi)	40.00	60.00	20.00	40.00	40.00
L1TWLPTn Section n TW Line Propagation Time (microseconds)	219.11	328.66	109.55	219.00	219.00
L1Z1MAGn Section n Positive-Sequence Impedance Mag (ohms, sec)	1.95	2.92	0.97	1.95	1.95
L1Z1ANGn Section n Positive-Sequence Impedance Angle (deg)	84.00	84.00	84.00	84.00	84.00
L1Z0MAGn Section n Zero-Sequence Impedance Mag (ohms, sec)	6.20	9.30	3.10	6.20	6.20
L1Z0ANGn Section n Zero-Sequence Impedance Angle (deg)	81.50	81.50	81.50	81.50	81.50
L1PORTn Section n Fault Locator Data Port	P1	LOCAL	P3	NA	NA
L1RSIDn Remote Station Identifier (40 characters)	StationS	StationR	StationT	NA	NA

Figure 6.10 Settings at Station R for the Three-Terminal Line in *Figure 6.8*

Line 1 Configuration

L1NTERM Number of Terminals	3				
L1NSEC Number of Sections	3				
	Section 1	Section 2	Section 3	Section 4	Section 5
L1LLn Section n Length (mi)	40.00	60.00	20.00	40.00	40.00
L1TWLPTn Section n TW Line Propagation Time (microseconds)	219.11	328.66	109.55	219.00	219.00
L1Z1MAGn Section n Positive-Sequence Impedance Mag (ohms, sec)	1.95	2.92	0.97	1.95	1.95
L1Z1ANGn Section n Positive-Sequence Impedance Angle (deg)	84.00	84.00	84.00	84.00	84.00
L1Z0MAGn Section n Zero-Sequence Impedance Mag (ohms, sec)	6.20	9.30	3.10	6.20	6.20
L1Z0ANGn Section n Zero-Sequence Impedance Angle (deg)	81.50	81.50	81.50	81.50	81.50
L1PORTn Section n Fault Locator Data Port	P2	P3	LOCAL	NA	NA
L1RSIDn Remote Station Identifier (40 characters)	StationS	StationR	StationT	NA	NA

Figure 6.11 Settings at Station T for the Three-Terminal Line in *Figure 6.8*

Example 5: Two-Terminal Hybrid Line

Figure 6.12 shows two SEL-TWFL devices monitoring one hybrid line with three sections. Section 1 and Section 3 are overhead lines (OHLs), and Section 2 is an underground cable (UGC). Each device obtains currents from line CTs and voltages from line-side VTs. At each line terminal, the breaker auxiliary contact is wired to one of the corresponding SEL-TWFL contact inputs and provides breaker position status to reliably detect open-pole conditions. The devices use IRIG-B signals from IEEE C37.118-compliant GPS clocks with submicrosecond accuracy to obtain an absolute time reference. Each SEL protective relay sends FL trigger signals to Port 1 of the corresponding SEL-TWFL by using MIRRORED BITS communications via an SEL-2814. To calculate fault locations by using the multi-ended traveling-wave- and impedance-based fault-locating methods, the two SEL-TWFL devices exchange data via Port 2 over IEEE C37.94-compliant multiplexed channels.

Figure 6.12 Two-Terminal Hybrid Line Application That Uses SEL-2814 Transceivers, IEEE C37.94-Compliant Multiplexed Channels, and MIRRORED BITS Communications

Table 6.18 shows the settings used for this example that are common to the devices at Station S and Station R. Note that in all devices, Section 1 is the OHL adjacent to Station S, Section 2 is the UGC, and Section 3 is the OHL adjacent to

Station R. *Table 6.19* shows the settings used for this example that are unique to the devices at Station S and Station R. To determine settings not shown, such as settings related to source selection, circuit breakers, and communications Ports 1, 2, and 3, review *Example 1: Two-Terminal Overhead Line (Single Breaker)* on page 6.2 and *Example 3: Dual Two-Terminal Overhead Lines* on page 6.6.

The QuickSet settings screens shown in *Figure 6.13* and *Figure 6.14* provide additional clarification for configuring the SEL-TWFL at Station S and Station R, respectively.

Fault Locator Settings

Table 6.18 Line 1 Configuration Settings Common to the Devices at Station S and Station R

Setting Name	Setting Value			Unit	Comment
L1NTERM	2			N/A	Set the number of line terminals to 2.
L1NSEC	3			N/A	Because this is a nonhomogeneous line with two overhead sections and one underground section, set the number of line sections to 3.
	Section 1	Section 2	Section 3		
L1LL*n*	31.07 or 50.00	6.21 or 10.00	12.43 or 20.00	N/A	Set the line length for each section according to the units specified in the LLUNIT setting. For Section 1 (overhead line adjacent to Station S), enter 31.07 if you set LLUNIT to mi or enter 50.00 if you set LLUNIT to km. Similarly, for Section 2 (underground cable), enter 6.21 (mi) or 10.00 (km). For Section 3 (overhead line adjacent to Station R), enter 12.43 (mi) or 20.00 (km).
L1TWLPT*n*	170.19	60.65	68.07	µs	Set the traveling-wave line propagation time for each section. Expect the following value for Section 1, assuming a propagation velocity of 98 percent of the speed of light in free space: 50.00 km / (0.98 • 299792.458 km/s) = 170.19 µs. Expect the following value for Section 2, assuming a propagation velocity of 55 percent of the speed of the light in free space: 10.00 km / (0.55 • 299792.458 km/s) = 60.65 µs. Expect the following value for Section 3, assuming a propagation velocity of 98 percent of the speed of light in free space: 20.00 km / (0.98 • 299792.458 km/s) = 68.07 µs.
L1Z1MAG*n*	20.03	1.34	8.01	Ω secondary	Positive-sequence line impedance magnitude for each section.
L1Z1ANG*n*	79.43	76.25	79.43	deg	Positive-sequence line impedance angle for each section.
L1Z0MAG*n*	57.58	1.44	23.03	Ω secondary	Zero-sequence line impedance magnitude for each section.
L1Z0ANG*n*	74.95	33.69	74.95	deg	Zero-sequence line impedance angle for each section.

Table 6.19 Line 1 Configuration Settings Unique to the Devices at Station S and Station R

Setting Name	Setting Value			Unit	Comment
	Section 1	Section 2	Section 3		
Station S					
L1PORT*n*	LOCAL	NA[a]	P2	N/A	Set Section 1 Fault Locator Data Port (L1PORT1) to LOCAL to associate Section 1 with the local device at Station S. Set Section 3 Fault Locator Data Port (L1PORT3) to P2 to receive data from the remote device associated with Section 3 via the IEEE C37.94 communications channel connected to Port 2.
L1RSID*n*	StationS[b]	NA[a]	StationR	N/A	Enter the identifier for the remote station.
Station R					
L1PORT*n*	P2	NA[a]	LOCAL	N/A	Set L1PORT1 to P2 to receive data from the remote device associated with Section 1 via the IEEE C37.94 communications channel connected to Port 2. Set L1PORT3 to LOCAL to associate Section 3 with the local device at Station R.
L1RSID*n*	StationS	NA[a]	StationR[b]	N/A	Enter the identifier for the remote station.

[a] The setting is hidden and the value is forced to NA.
[b] The L1RSID*n* value is forced to the SID setting in the local device when L1PORT*n* is set to LOCAL.

Figure 6.13 Settings at Station S for the Two-Terminal Hybrid Line in *Figure 6.12*

Line 1 Configuration

L1NTERM Number of Terminals	2				
L1NSEC Number of Sections	3				
	Section 1	**Section 2**	**Section 3**	**Section 4**	**Section 5**
L1LLn Section n Length (km)	50.00	10.00	20.00	40.00	40.00
L1TWLPTn Section n TW Line Propagation Time (microseconds)	170.19	60.65	68.07	219.00	219.00
L1Z1MAGn Section n Positive-Sequence Impedance Mag (ohms, sec)	20.03	1.34	8.01	1.95	1.95
L1Z1ANGn Section n Positive-Sequence Impedance Angle (deg)	79.43	76.25	79.43	84.00	84.00
L1Z0MAGn Section n Zero-Sequence Impedance Mag (ohms, sec)	57.58	1.44	23.03	6.20	6.20
L1Z0ANGn Section n Zero-Sequence Impedance Angle (deg)	74.95	33.69	74.95	81.50	81.50
L1PORTn Section n Fault Locator Data Port	P2	NA	LOCAL	NA	NA
L1RSIDn Remote Station Identifier (40 characters)	StationS	NA	StationR	NA	NA

Figure 6.14 Settings at Station R for the Two-Terminal Hybrid Line in *Figure 6.12*

DNP3 Over Ethernet Application

Example 6: Two-Terminal Overhead Line Without Device-to-Device Communications

When device-to-device communications is not available, you can use DNP3 protocol over Ethernet to send traveling-wave arrival times to a central location where the DNP3 client calculates the TW-based fault location. *Figure 6.15* shows two SEL-TWFL devices monitoring one transmission line. Each device obtains currents from line CTs and voltages from line-side VTs. At each line terminal, the breaker auxiliary contact is wired to one of the corresponding SEL-TWFL contact inputs and provides breaker position status to reliably detect open-pole conditions. The devices use IRIG-B signals from IEEE C37.118-compliant GPS clocks with submicrosecond accuracy to obtain their corresponding absolute time reference. Each SEL protective relay sends FL trigger signals to Port 1 of the corresponding SEL-TWFL by using MIRRORED BITS communications via an SEL-2814. Each SEL-TWFL sends data via Port 5 to the corresponding Real-Time Automation Controller (RTAC) by using DNP3 protocol over Ethernet, and the RTACs send data over a SCADA network to the RTAC DNP3 client computer at the control center. The control center RTAC calculates the fault location by using the double-ended traveling-wave-based fault-locating method. Refer to SEL application guide "Double-Ended Traveling-Wave Fault Locating Using the SEL RTAC as a DNP3 Client" (AG2022-03) for additional application details.

Figure 6.15 Two-Terminal Overhead Line Application That Uses SEL-2814 Transceivers, DNP3 Protocol, and Mirrored Bits Communications

SECTION 7

Engineering and Operator Access Interfaces and Tools

This section describes engineering and operator access interfaces and tools for configuring the SEL-TWFL, viewing and retrieving data from the device, and performing specific operations such as triggering a record or closing a contact output. This section is organized as follows:

- *Introduction* on page 7.1 provides a high-level overview of the engineering and operator interfaces and tools.
- *Front-Panel Operations* on page 7.4 describes the front-panel functionality, including status and target indicators and the HMI.
- *PC Software* on page 7.19 provides information about ACSELERATOR QuickSet SEL-5030 Software, a Windows-based primary engineering interface for the SEL-TWFL.
- *SEL ASCII Command Language* on page 7.34 describes the supplementary engineering interface for the SEL-TWFL.
- *Access Control and Passwords* on page 7.36 describes the access control scheme of the device for managing access for human operators and machine clients.
- *Settings Structure* on page 7.39 describes the organization of the device settings and how to view and edit settings.
- *Communications Setup* on page 7.40 provides step-by-step instructions for configuring the SEL-TWFL communications ports and your PC for engineering access communications.

Introduction

Perform engineering and operator tasks for the SEL-TWFL by using any of the following three methods:

- Front-panel HMI
- ACSELERATOR QuickSet SEL-5030 Software
- SEL ASCII command language

The front-panel HMI includes LED indicators for signaling device information such as device health, fault locator targets, status of communications ports, and status of a connected external timing source. You can print and use your own custom labels for the LED targets.

The front-panel HMI includes an LCD screen and navigation keys to view device identification information, status, and metering data. You do not need to enter a password to access the LCD screen. Use the front-panel HMI as an information source for operators in the field and when inspecting a new device before you

NOTE: You cannot view or change settings by using the SEL-TWFL front-panel HMI. Use the communications ports for engineering access.

NOTE: The SEL-TWFL ships with Port F enabled and Port 5 disabled. You must first connect over Port F to gain access to settings and to configure Port 5 before you can use Port 5 for access over Ethernet.

establish access over a communications port for engineering or testing tasks. For security of in-service devices, the SEL-TWFL requires you to use the front-panel HMI to acknowledge your intent to enter the TW test mode.

QuickSet is a dedicated Windows-based application for performing common engineering tasks for SEL devices. These tasks include, but are not limited to, creating a new settings file, downloading or uploading settings files to a device, managing device settings files, retrieving device records, and viewing device status and other data. QuickSet is free of charge and you can obtain it from selinc.com by using your mySEL account.

You can use QuickSet over a direct cable connection to the front-panel USB Port F or over an Ethernet LAN connected to Port 5 (see *Communications Setup* on page 7.40 for step-by-step instructions).

The SEL ASCII command language is a dialog language for human-machine communications, with the human operator (or a machine client) issuing commands to the device (SEL-TWFL) and the device responding with a dialog or a report. Use a computer with a USB port and terminal emulator to issue SEL ASCII commands to the SEL-TWFL. You can also use a Telnet client to issue SEL ASCII commands to the SEL-TWFL over an Ethernet LAN. QuickSet includes both a terminal emulator and a Telnet client, but you can use any compliant terminal emulator or Telnet client.

Table 7.1 lists common engineering tasks and provides information on how to accomplish the tasks by using the front-panel HMI, QuickSet, or SEL ASCII commands.

Table 7.1 Typical Engineering and Operator Tasks and How to Accomplish Them With the SEL-TWFL (Sheet 1 of 2)

Task	QuickSet	Front-Panel HMI	SEL ASCII Commands
Identify the device	Tools > HMI > HMI > Device Status	`Fault Locator > Identificaton`	**VER, ID**
Change access level	N/A	N/A	**ACC, 2AC, BAC, CAL**
Change Port F settings	Settings Editor	N/A	**SET P F**
Change Port 5 settings	Settings Editor	N/A	**SET P 5**
Change password	Device Manager Plug-In Module	N/A	**PAS *level***
View settings	Settings Editor	N/A	**SHO *class name***
Change settings	Settings Editor	N/A	**SET *class name***
Save settings files from the device	File > Read	N/A	**FILE READ SETTINGS *name*.TXT**
Download settings files to the device	File > Send	N/A	**FILE WRITE SETTINGS *name*.TXT**
Reset all settings to factory defaults	N/A	N/A	**R_S F**
View metering for Line *m*	Tools > HMI > HMI > Metering	`Metering & IO > V & I Line m`	**MET L*m***
View state of contact inputs and MIRRORED BITS inputs	Tools > HMI > HMI > Device Overview (Contact Inputs) Tools > HMI > HMI > Relay Word Bits	`Metering & IO > Inputs`	**TAR *Relay Word bit name*** or ***row***
View state of contact outputs and MIRRORED BITS outputs	Tools > HMI > HMI > Device Overview (Contact Outputs) Tools > HMI > HMI > Relay Word Bits	`Metering & IO > Outputs`	**TAR *Relay Word bit name*** or ***row***
View fault locator targets and status indicators	Tools > HMI > HMI > Device Overview Tools > HMI > HMI > Relay Word Bits	Target and Status LEDs	**TAR *Relay Word bit name*** or ***row***

Table 7.1 Typical Engineering and Operator Tasks and How to Accomplish Them With the SEL-TWFL (Sheet 2 of 2)

Task	QuickSet	Front-Panel HMI	SEL ASCII Commands
Reset fault locator targets	Tools > HMI > HMI > Device Overview Tools > HMI > HMI > Device Control	Press and release **TARGET RESET** pushbutton	**TAR C or TAR R**
View past fault locator event summaries	Tools > Events > Get Event Files	`FL Events`	**HIS, SUM**
Select and download transient records	Tools > Events > Get Event Files	N/A	**FILE READ EVENTS *name*.ext (CFG, DAT, HDR)**
Delete transient records	Tools > HMI > HMI > Device Control	N/A	**HIS C**
View SER record	Tools > HMI > HMI > Sequential Events Recorder	N/A	**SER**
Download SER record	Tools > HMI > HMI > Sequential Events Recorder	N/A	**FILE READ REPORTS SER.TXT**
Delete SER record	Tools > HMI > HMI > Device Control	N/A	**SER C**
Trigger transient record	Tools > HMI > HMI > Device Control Tools > Events > Get Event Files	N/A	**TRI**
View state of IRIG-B input	Tools > HMI > HMI > IRIG Status	`RWBs` **TIME SYNC** status LED	**TIM Q**
View date and time	Tools > HMI > HMI > Device Status	`Fault Locator > Date & Time`	**TIM, DAT**
Set date and time	Tools > HMI > HMI > Device Control	N/A	**TIM *time*, DAT *date***
View device diagnostics	Tools > HMI > HMI > Device Status	`Fault Locator > Diagnostics`	**STA**
View port statistics	Tools > HMI > HMI > Communications Status	`RWBs`	**COM P *n***
Clear port statistics	Tools > HMI > HMI > Communications Status	N/A	**COM P *n* C**
Initiate Port 1 to 3 loopback	N/A	N/A	**LOOP P *n***
Force contact outputs	Tools > HMI > HMI > Device Control	N/A	**PULSE *name***
Test target and status LEDs	N/A	Press and hold **TARGET RESET** pushbutton	N/A
Initiate traveling-wave test mode	Tools > HMI > HMI > Device Control	Cannot initiate but must acknowledge TW test mode	**TWTEST**
View line monitor counters for Line *m*	N/A	`Line Monitor > Line m`	**LIMO L*m***
Clear line monitor counters for Line *m*	N/A	N/A	**LIMO L*m* C**
Download line monitor record for Line *m*	N/A	N/A	**FILE READ REPORTS LINEMONL*m*.TXT**
Upgrade device firmware	Tools > Firmware Loader (see *Appendix B: Firmware Upgrade Instructions*)	N/A	**L_D**
Downgrade device firmware	Contact SEL		

Upgrading the firmware in the SEL-TWFL is an infrequent but critical task. See *Appendix B: Firmware Upgrade Instructions* for step-by-step instructions for upgrading firmware. The SEL-TWFL only allows you to upgrade firmware over the front-panel USB Port F.

Front-Panel Operations

Front-Panel Layout

Figure 7.1 shows the layout of the SEL-TWFL front panel. The front-panel LCD and LED targets provide an overview of the operating status of the SEL-TWFL and the monitored line.

The LCD and associated navigation pushbuttons form the HMI, which allows direct access to metering, event data, and device identification and status information. Multicolor LEDs provide visual indication of device status and fault locator targets.

The SEL-TWFL front panel includes a **TARGET RESET** pushbutton, which you can use to reset the latched targets as well as to perform a lamp test to verify that the LED indicators are operational. The SEL-TWFL front panel includes two transparent pockets for slide-in custom labels. Use these labels to rename the LEDs or to show diagrams or other useful information (see *Figure 7.13* for more information).

Figure 7.1 SEL-TWFL Front Panel

The SEL-TWFL front panel includes a USB 2.0 Type B serial port (**PORT F**). Use Port F for temporary engineering access to the device, such as for commissioning and testing in the field. The SEL-TWFL ships with Port F enabled and all other ports disabled. Therefore, you must connect to Port F first in order to configure other ports before you can use them. You can upgrade device firmware only over Port F. Refer to *Communications Setup* on page 7.40 for step-by-step instructions on how to configure the SEL-TWFL ports and your PC to communicate with one another.

Front-Panel HMI

The alphanumeric LCD and six navigation pushbuttons comprise the SEL-TWFL front-panel HMI. Use the front-panel HMI to perform the following tasks:

- Identify the device by viewing fault locator name, station name, serial number, part number, firmware revision, IP address, and Telnet port.
- View device status and diagnostics warning and failure messages.
- Check for changes in settings by viewing settings checksums for all settings classes and comparing them with their expected values.

- Inspect voltage and current signals at the device terminals by viewing metering values.
- Inspect the state (logical 0 or 1) of all device contact inputs and MIRRORED BITS inputs received on enabled communications Ports 1, 2, and 3.
- Inspect the state (logical 0 or 1) of all device contact outputs and MIRRORED BITS outputs transmitted on enabled communications Ports 1, 2, and 3.
- Inspect the state (logical 0 or 1) of the selected Relay Word bits.
- Inspect the device date and time.
- View fault locator event summaries including targets and fault location.
- Acknowledge traveling-wave test mode issued over communications Ports F and 5.

NOTE: The SEL-TWFL does not allow you to make settings changes by using the front-panel HMI. To make settings changes, use a computer and connect to the front-panel USB Port F or Ethernet Port 5.

The LCD displays two lines, each containing 16 characters. You can scroll to the right to view messages longer than 16 characters. Six navigation pushbuttons below the LCD window control the LCD menus.

Data for Line 2 are available via the front-panel HMI only if Line 2 is enabled (NLINE = 2).

Basic HMI Operation

Use the six-button keypad to navigate the HMI menu. *Table 7.2* describes the function of each pushbutton.

Table 7.2 Navigation Pushbutton Functions

Pushbutton	Function
Up Arrow	Move up within a menu or data list.
Down Arrow	Move down within a menu or data list.
Left Arrow	Move the cursor to the left.
Right Arrow	Move the cursor to the right.
ESC	Escape from the current menu or display. Hold for 2 s to adjust contrast (`Contrast` screen).
ENT	Select the menu item at the cursor.

When you navigate the HMI screens, the top line of the LCD displays the present menu in capital letters and the bottom line of the LCD displays a submenu item in sentence-case letters. The ↓, ↓↑, and ↑ characters in the bottom LCD line help you navigate and inform you if there are items below, below and above, or above the present submenu item. Press the **ENT** pushbutton to proceed to the selected submenu item. The HMI allows you to continually scroll through the menu: pressing the **Down Arrow** pushbutton when in the last item of the menu selects the first item on the menu, and pressing the **Up Arrow** pushbutton when in the first item of the menu selects the last item on the menu. When viewing data, the first LCD line typically displays the data label and the bottom LCD line typically displays the data value and unit.

You can adjust the LCD screen contrast to suit your viewing angle and lighting conditions. To change the screen contrast, press and hold the **ESC** pushbutton for 2 s. The device displays a contrast adjustment box similar to that shown in *Figure 7.2*.

Press the **Right Arrow** or **Left Arrow** pushbutton to increase or decrease the contrast, respectively. When finished, press **ENT** to save the selected contrast. Press **ESC** once at any time to discard the changes and exit the adjustment function.

Figure 7.2 LCD Contrast Adjustment Screen

Default Display Messages

After 15 minutes of inactivity (i.e., the navigation buttons are unused and there are no new event-driven LCD messages), the backlight turns off and the LCD shows either the default display screens, fault location, or internal diagnostics message. *Figure 7.3* shows the default display screens when one line is enabled (NLINE = 1). These screens advance every 2 s and provide basic information related to the device identification, metering, and date and time. Use the **Up Arrow** or **Down Arrow** pushbutton to pause the automatic advancing of the default display screens, and manually navigate through the default screens. Press **ESC** or **ENT** to interrupt the default display screens and start menu navigation.

Figure 7.3 Default Display Messages

HMI Content

The SEL-TWFL front-panel HMI organizes access to preselected data in a menu-driven system. Use the LCD and the six pushbuttons below the LCD to navigate these menus. *Figure 7.4* shows the main HMI menu. Press **ENT** or **ESC** to interrupt the default display messages and enter the main HMI menu; use the **Up Arrow** and **Down Arrow** pushbuttons to navigate, and press **ENT** to select the desired menu item.

Figure 7.4 Main HMI Menu

Figure 7.5 shows the `Fault Locator` menu. Use this menu to obtain information related to the device as a secondary system asset (name, serial number, part number, version of firmware and settings, IP address, Telnet port, diagnostics information, date and time, etc.).

Figure 7.5 Fault Locator HMI Menu

When no failures or warnings are detected by the device, it displays the HMI message shown in *Figure 7.6*. If the device detects a failure or needs to issue a warning, it replaces this message with the specific failure or warning message (see *Appendix F: Diagnostics* for information on device diagnostics).

```
No Failures or
Warnings
```

Figure 7.6 Fault Locator HMI Failures and Warnings Message

Figure 7.7 shows the `Metering & IO` menu. Use this menu to obtain information about the signals present at the device terminals, such as line voltage and current metering and the state (logical 0 or 1) of the binary inputs and outputs, including the MIRRORED BITS inputs and outputs.

```
MAIN MENU
↓ Fault Locator
MAIN MENU
↓↑ Metering & IO
  METERING & I/O
  ↓ V & I Line 1
    VAB (kV)     [L1]
     500.000  +30.0°
        ...
    3I0 (A)      [L1]
      21.009 -176.3°
  METERING & I/O
  ↓↑ V & I Line 2
    VAB (kV)     [L2]
     500.000  +10.0°
        ...
    3I0 (A)      [L2]
      21.009 -176.3°
  METERING & I/O
  ↓↑ Inputs
    100 Inputs (1>5)
    01001
    200 Inputs (1>8)
    00100110
    P1 RX MBs  (1>8)
    00011010   ROK:1
    P2 RX MBs  (1>8)
    00000010   ROK:1
    P3 RX MBs  (1>8)
    01001100   ROK:1
  METERING & I/O
  ↑ Outputs
    100 Outputs(1>6)
    000000   ALARM:0
        ...
    P3 TX MBs  (1>8)
    010000     ROK:1
MAIN MENU
↓↑ FL Events
MAIN MENU
↓↑ Line Monitor
MAIN MENU
↑ RWBs
```

Metering for Line 1

- ①
- Primary units
- Phase angles referenced to V1 (first preference) or I1 (if V1 is below 2 V secondary)

Metering for Line 2

Present I/O values are displayed

MIRRORED BITS I/O displayed only if the corresponding port is enabled

ALARM is the state of the Alarm contact output

① See *Table E.1* for more information.

Figure 7.7 Metering & IO HMI Menu

Refer to *Table E.1* for more information related to metering.

Figure 7.8 shows the `FL Events` menu. Use this menu to obtain information about the most recent and past events triggered by the fault locator, including the fault-location results for the most recent trigger (see *Table 7.3*). The `FL Events`

menu shows information similar to the history record (see *Section 5: Transient and Sequential Events Recording* for more information). The HMI displays the events from newest to oldest. If there are no entries in the event buffer, the `FL Events` menu displays the following message: `No FL Event Data`.

① See *Table 7.3* for more information.

Figure 7.8 Fault Locator Events HMI Menu

Table 7.3 Most Recent Fault-Location Results Available on the LCD Screen

Analog Quantity	Description	Example Display
L*m*_SE_TW_Location1	Line *m* fault location, single-ended TW-based method Result 1	`FL:StationA SETW1 155.879 mi`
L*m*_SE_TW_Location2	Line *m* fault location, single-ended TW-based method Result 2	`FL:StationA SETW2 155.879 mi`
L*m*_SE_TW_Location3	Line *m* fault location, single-ended TW-based method Result 3	`FL:StationA SETW3 155.879 mi`
L*m*_SE_TW_Location4	Line *m* fault location, single-ended TW-based method Result 4	`FL:StationA SETW4 155.879 mi`
L*m*_ME_TW_Location	Line *m* fault location, multi-ended TW-based method	`FL:StationA ME TW 149.692 mi`
L*m*_SE_Z-Based_Location	Line *m* fault location, single-ended impedance-based method	`FL:StationA SE Z 121.002 mi`
L*m*_ME_Z-Based_Location	Line *m* fault location, multi-ended impedance-based method	`FL:StationA ME Z 149.312 mi`

Figure 7.9 shows the `Line Monitor` menu. Use this menu to view the line monitoring information for each line. If the line monitoring logic is enabled, then the `Line Monitor` menu will display the analog quantities in *Table 7.4*.

① See *Table 7.4* for more information.

Figure 7.9 Line Monitor HMI Menu

Table 7.4 Line Monitor Analog Quantities Available on the LCD Screen (Sheet 1 of 2)

Analog Quantity	Description	Example Display
L*m*LMLOC	Line *m* line monitoring alarm location[a]	`LM LAST LOC 34.25 mi [L1]`
L*m*LMLOCB1	Line *m* line monitoring Blocking Region 1 alarm location[a]	`LM LAST B1 LOC 12.50 mi [L1]`

Table 7.4 Line Monitor Analog Quantities Available on the LCD Screen (Sheet 2 of 2)

Analog Quantity	Description	Example Display
L*m*LMLOCB2	Line *m* line monitoring Blocking Region 2 alarm location[a]	LM LAST B2 LOC 37.75 mi [L1]
L*m*LMETOT	Line *m* line monitoring total event count[b]	LM TOT EVE COUNT 17 [L1]

[a] Location with highest event count if the alarm condition is satisfied at multiple locations.
[b] This counter may decrease at midnight when counters within the blocking regions autoreset.

Figure 7.10 shows the RWBs menu. Use this menu to view the state of selected Relay Word bits (*Table 7.5*). Refer to *Appendix D: Relay Word Bits* for the list of all Relay Word bits. The HMI displays only those Relay Word bits that may be useful when inspecting an in-service device without connecting to the device and using a computer.

① See *Table 7.5* for more information.

Figure 7.10 Relay Word Bits HMI Menu

Table 7.5 Relay Word Bits Available Through the Front-Panel HMI (Sheet 1 of 2)

Relay Word Bit	Description
ACCESS	Device in Access Level B or higher
ALARM	OR combination of HALARM and SALARM
BNC_OK	High-accuracy IRIG-B signal from BNC port available
L1APO	Any pole opened on Line 1
L1LMA	Line monitoring alarm on Line 1
L1LMAB1	Line monitoring Blocking Region 1 alarm on Line 1
L1LMAB2	Line monitoring Blocking Region 2 alarm on Line 1
L2APO	Any pole opened on Line 2
L2LMA	Line monitoring alarm on Line 2
L2LMAB1	Line monitoring Blocking Region 1 alarm on Line 2
L2LMAB2	Line monitoring Blocking Region 2 alarm on Line 2
LINK5	Port 5 valid link detected
ROKP1	Port 1 operating correctly
ROKP2	Port 2 operating correctly
ROKP3	Port 3 operating correctly
TESTDB2	TEST DB2 command is overriding data

Table 7.5 Relay Word Bits Available Through the Front-Panel HMI (Sheet 2 of 2)

Relay Word Bit	Description
TIRIG	Device receives a valid IRIG-B signal
TSOK	Device clock is synchronized with high accuracy to the absolute time
TWTEST	Traveling-wave test mode in progress

Event-Driven LCD Messages

The SEL-TWFL HMI interrupts the currently displayed screen to display messages and prompts (see *Figure 7.11*) that are driven by the following events:

- **Fault Location.** When the fault locator triggers for an event, the LCD displays the fault location (in mi or km), the method used to calculate the fault location, and the reference station ID for the associated line (`[L1]` or `[L2]`). The fault-location message is displayed until any pushbutton is pressed.
- **Line Monitoring Event.** When the line monitor triggers for an event (see *Line Monitor* on page 2.27), the LCD displays the event location (in mi or km), the total event count for the bin, and the associated line (`[L1]` or `[L2]`). This message is for testing purposes and self-clears in 15 s.
- **Line Monitoring Alarm.** When the line monitor asserts an alarm, the LCD displays the associated line (`[L1]` or `[L2]`) and the bin location of the event that caused the alarm. This message is for testing purposes and self-clears in 15 s.
- **Diagnostics Warning or Failure.** When the device diagnostics subsystem detects a failure or asserts a warning, the LCD displays the warning/failure message(s). The diagnostics warning messages clear when any pushbutton is pressed. The diagnostics failure messages clear when the failure condition is reset and device power is cycled.
- **TW Test Mode Acknowledgment.** When you issue the **TWTEST** command (see *Testing With TWs* on page 10.3) to put the SEL-TWFL into the TW test mode, the LCD displays an acknowledgment message and waits 60 s for you to confirm (press **ENT**) or abort (press **ESC**). If you do not respond within 60 s, the device will abort the TW test mode attempt. The front-panel acknowledgment prevents inadvertently putting an in-service device into the TW test mode.
- **SELBOOT.** When you issue the **L_D** command to halt the device program and exit to the flash boot program (SELBOOT) with the purpose of sending new firmware to the device, the LCD displays `SELboot` (see *Upgrading Firmware by Using SEL Commands* on page B.13). When the LCD displays this message, you cannot navigate the HMI screens and you will not see any other messages until the firmware upgrade process completes.

Fault-Location Message Example

```
FL:StationA [L1]
ME TW  45.389 mi
```

Line Monitoring Event Message Example

```
LINE EVENT: [L1]
15.232 mi,    2
```

Line Monitoring Alarm Message Example

```
LINE ALARM: [L1]
67.75 mi
```

Diagnostics Message Example

```
MB Power Supply
Warning
```

TW Test Mode Acknowledgment Message

```
CONFIRM TWTEST?
ESC=N, ENT=Y
```

SELBOOT Message

```
     SELboot
```

Figure 7.11 Event-Driven LCD Messages

The event-driven LCD messages follow a built-in priority. For example, a warning message overrides the fault-location message and a failure message overrides the warning message. Expect to see the most relevant and important message on the LCD.

Status and Target LEDs

The SEL-TWFL front panel provides an at-a-glance overview of device operating conditions with multicolor factory-programmed status and target LEDs. The LEDs provide health status for the device; trigger indication; health status for communications Ports 1, 2, and 3; and status of time synchronization. Additionally, the LEDs provide the following on a per-line basis:

- Fault locator and trigger indication
- Fault-locating methods that provided the fault location
- Line monitoring alarm indication
- Health status for voltage

Figure 7.12 shows the arrangement of the status and target LEDs. When the fault locator is triggered, the device latches the TRIGGERED, FL TRIG, and fault-locating method targets and stores their state in nonvolatile memory. You can reset these latched targets by using one of the following methods:

- Press and immediately release the TARGET RESET pushbutton.
- Assert the DRST_TAR control point from your DNP3 SCADA client.
- Issue the **TAR C** or **TAR R** command.
- Click the **Target Reset** button in the QuickSet Control Window branch of the HMI tree view.

Figure 7.12 Front-Panel Status and Target LED Layout

Table 7.6 describes the ENABLED and TRIGGERED targets, and *Table 7.7* describes the TARGET RESET pushbutton operation.

Table 7.6 ENABLED and TRIGGERED Targets

Target	LED	Description and Usage Notes
ENABLED	G	➤ The device is operational and all functions are available. ➤ While the device is operational, the device may experience issues that do not affect the main functions of the device. In such instances, the device displays a warning on the HMI screen. If a warning appears, check the device status (use the HMI and navigate to `Fault Locator > Diagnostics`, or use the **STA** command). See *Appendix F: Diagnostics* for more information.
		➤ The main functions of the device are not available for one of the following reasons: ➢ The device has lost control power. ➢ A setting change is in progress. ➢ A firmware or SELBOOT upgrade is in progress. ➢ A critical device failure has occurred. See *SEL-TWFL Diagnostic Details and Remediation Steps* on page F.3 for more information. ➤ Check the device status to gain insights into the nature of the problem (use the HMI if operational and navigate to `Fault Locator > Diagnostics`, or use the **STA** command).
TRIGGERED	R	➤ The fault locator is triggered on Line 1 or Line 2. The TRIGGERED target latches the fault locator targets (*Table 7.8*). ➤ If you did not clear the targets from a previous fault locator trigger event, the new trigger event will override the old targets. The SEL-TWFL targets, fault locator trigger, fault-locating methods, line monitoring alarm, and LOP are on a per-line basis. You can get information about previous trip events by using the HMI and navigating to `FL Events`. ➤ Reset the TRIGGERED, FL TRIG, and fault-locating method targets by using the TARGET RESET pushbutton, DNP3, **TAR C** or **TAR R** command, or QuickSet.
		No trigger occurred or all triggered events have been acknowledged (reset).

Table 7.7 TARGET RESET Pushbutton Operation

Pushbutton	Operation	Description and Usage Notes
TARGET RESET	Press and Release	Press and release the pushbutton to clear (reset) the latched **TRIGGERED**, **FL TRIG**, and fault-locating method targets, and fault-location LCD screen.
	Press and Hold	➤ Press and hold the pushbutton for 1 s to initiate the lamp test. The target and status LEDs cycle through all three colors and the turned-off state every second as long as the pushbutton is held. The lamp test does not apply to the **ENABLED** LED. ➤ Initiating the lamp test does not reset the latched targets, and you can still see them when you release the pushbutton. Press and quickly release the pushbutton to reset the targets.

Table 7.8 describes the targets associated with the fault locator trigger, fault-locating methods, and line monitoring alarm. These targets latch red when the fault locator is triggered.

Table 7.8 Fault Locator Targets

Target[a]	LED	Description
FL TRIG	R	Fault locator triggered
ME TW	R	Multi-ended traveling-wave-based fault location result is available
ME Z	R	Multi-ended impedance-based fault location result is available
SE TW	R	Single-ended traveling-wave-based fault location result is available
SE Z	R	Single-ended impedance-based fault location result is available
LM ALARM	R	Line monitoring alarm

[a] Available on a per-line basis.

Table 7.9 describes the health status indicators for voltage; communications Ports 1, 2, and 3; and time. These indicators are self-resetting and show the present status of the monitored condition.

Table 7.9 Health Status Indicators (Sheet 1 of 3)

Target	LED	Description	Usage Notes and Troubleshooting Steps
LOP[a]		Line *m* voltage is normal, or the line is disconnected (open-pole condition).	Normal condition. No action needed.
	R	Loss-of-potential (LOP) condition is asserted, and voltage-dependent functions are blocked.	➤ Examine voltage metering (use the HMI and navigate to `Metering & IO`). Compare with voltage metering from other sources, if available. ➤ Apply safety precautions and visually inspect wiring for the Line *m* voltage input; ensure the voltage test switches are closed. Consider using a handheld meter to measure the voltage at the device terminals. ➤ Follow safety procedures and check the secondary and primary PT fuses. ➤ When testing the device, avoid applying test patterns that inadvertently model an LOP condition. Apply balanced nominal voltage to the Line *m* voltage input to reset the LOP logic.

Table 7.9 Health Status Indicators (Sheet 2 of 3)

Target	LED	Description	Usage Notes and Troubleshooting Steps
COMM PORTS		Communications Ports 1, 2, and 3 are disabled.	Normal condition if you did not enable communications Ports 1, 2, and 3.
	G	All of the enabled communications ports (P1, P2, and P3) operate without errors.	Normal condition if you enabled any or all of the communications Ports 1, 2, and 3.
	Y	Some of the enabled communications ports (P1, P2, and P3) do not communicate at all or operate with errors.	➤ Inspect the ROKP1, ROKP2, and ROKP3 Relay Word bits to identify which port is reporting a problem (use the HMI and navigate to `Metering & IO > Inputs` to view the MIRRORED BITS I/O and channel status). ➤ If an unused (not connected) port is enabled, disable it to eliminate the alarm. ➤ Visually inspect the connectors of the affected port, and ensure the connection is not loose or damaged; follow best practices and eye-safety precautions, and clean the fiber terminations if needed. ➤ Visually inspect the fiber-optic cables for damage and excessive bending or pinching. ➤ Issue the **COM P *n*** (*n* = 1–3) commands to gain more insight into the problem, and select the proper troubleshooting steps, including the loopback test. See *Communications Report for Ports 1, 2, and 3* on page 3.8 for more information.
	R	None of the enabled communications ports (P1, P2, and P3) operate correctly.	Follow the steps outlined above.

Table 7.9 Health Status Indicators (Sheet 3 of 3)

Target	LED	Description	Usage Notes and Troubleshooting Steps
TIME SYNC	G	Device time is accurate.	➤ The device clock is synchronized to the IRIG-B input. See *Appendix H: High-Accuracy Timekeeping* for more information. ➤ Note that if the device was synchronized to a high-accuracy time source prior to any problem with the time input, the device will use its own clock when the time input becomes unavailable or inaccurate. Until the device estimates that it has drifted too much and may be inaccurate, it will continue to rely on its internal clock. In such a case, the green status LED will deassert seconds after the time input becomes unavailable or inaccurate.
		Device time may be inaccurate.	➤ A typical satellite clock inspects the satellite signal for several seconds after powering up or re-acquiring the satellite signal. During that time, the clock does not output accurate time and the TIME SYNC status LED will not illuminate green. Troubleshoot the TIME SYNC status LED only after confirming that the clock has locked and outputs a valid timing signal. ➤ Inspect the TIRIG, BNC_OK, and TSOK Relay Word bits (use the HMI and navigate to `RWBs & Analog`), and use the **TIME Q** command to gain more insight into the problem and troubleshoot accordingly. ➤ Visually inspect the IRIG-B connection to the device.

[a] Available on a per-line basis.

The SEL-TWFL provides Relay Word bits that drive the front-panel target and status LEDs. *Table 7.10* lists these Relay Word bits, and you can use them in SELOGIC programming if needed.

Table 7.10 Target and Status LED Relay Word Bits (Sheet 1 of 2)

Relay Word Bit	Description
EN	Device is enabled
TARFLTR	TRIGGERED target is asserted
TAR1FLTR	Line 1 FLTRIG target is asserted
TAR2FLTR	Line 2 FLTRIG target is asserted
TAR1LMA	Line 1 LM ALARM status is asserted
TAR2LMA	Line 2 LM ALARM status is asserted
TAR1METW	Line 1 ME TW target is asserted
TAR2METW	Line 2 ME TW target is asserted
TAR1MEZ	Line 1 ME Z target is asserted
TAR2MEZ	Line 2 ME Z target is asserted
TAR1SETW	Line 1 SE TW target is asserted

Table 7.10 Target and Status LED Relay Word Bits (Sheet 2 of 2)

Relay Word Bit	Description
TAR2SETW	Line 2 SE TW target is asserted
TAR1SEZ	Line 1 SE Z target is asserted
TAR2SEZ	Line 2 SE Z target is asserted
TAR1LOP	Line 1 LOP status is asserted
TAR2LOP	Line 2 LOP status is asserted
TRGTR	TARGET RESET pushbutton pressed or command issued
TARCPG	Communications Ports 1, 2, and 3 status is asserted green (all enabled ports OK)
TARCPY	Communications Ports 1, 2, and 3 status is asserted yellow (some but not all enabled ports OK)
TARCPR	Communications Ports 1, 2, and 3 status is asserted red (all enabled ports not OK)
TARTSYN	TIME SYNC status is asserted

Custom Labels

The SEL-TWFL comes with permanent labels for the front panel (Area 1 and Area 2 shown in *Figure 7.13*). If you prefer different labels, you can insert your own. Either design your own labels or download a label template at selinc.com/products/TWFL/. *Figure 7.13* shows the two openings that allow you to insert and remove custom labels.

Figure 7.13 Openings for Front-Panel Custom Labels

PC Software

QuickSet is a free PC software program for the SEL-TWFL. By using this software, you can perform the following for the SEL-TWFL:

- Create and manage settings
- Communicate with the device by using SEL ASCII commands
- Upload and download settings
- Upgrade firmware
- Download records for event analysis
- View the virtual device HMI
- Perform event playback tests

Refer to selinc.com for PC requirements, installation, licensing, and additional information regarding configuring the software. Within QuickSet, click **Help > Contents** to view the *ACSELERATOR QuickSet SEL-5030 Software Instruction Manual*.

Obtaining and Installing QuickSet

Obtain QuickSet from the SEL website at selinc.com/products/5030/. QuickSet is also available on CD upon request. Follow the installation instructions that can be found on the SEL website or the CD, and install QuickSet.

When the installation program prompts you to select drivers, be sure to check the SEL-TWFL checkbox. Ignore the prompts to install add-ons – there are no software add-ons for the SEL-TWFL.

QuickSet Welcome Screen

When you launch QuickSet, the initial window (shown in *Figure 7.14*) appears. This consists of a welcome screen and a menu. The welcome screen consists of the Settings and Setup categories.

Figure 7.14 Initial QuickSet Window

The welcome screen provides the following options.

Settings

New	Create new settings.
Read	Read settings from a connected device and display the settings in the QuickSet window.
Open	Open settings stored in a Relay Database file.
Device Manager	Open Device Manager (asset management tool for SEL devices). See the *ACSELERATOR QuickSet SEL-5030 Software Instruction Manual* for more information.

Setup

Communication	Configure communications between QuickSet and the device.
Manage	Manage offline settings and databases.
Update	Install and update QuickSet software and drivers.

QuickSet Functions

QuickSet provides the following functions.

File

New	Create new settings.
Open	Open settings stored in a Relay Database file.
Close	Close settings instance that is open in the QuickSet window.
Save/Save As	Save settings instance that is open in the QuickSet window to the active Relay Database file.
Print Device Settings	Print settings reports.
Read	Read settings from a connected device and display the settings in the QuickSet window.
Send	Send settings instance that is open in the QuickSet window to a connected device.
Database Manager	Open Database Manager to create a new Relay Database file, copy settings within the active Relay Database file, add descriptions to settings within the database, and copy and move settings between different databases.
Exit	Close QuickSet.

Edit

Copy	Copy settings.
Search	Search for a text string within the open settings.
Compare	Compare the open settings to another settings instance in the Relay Database file.
Merge	Merge the open settings with another settings instance in the Relay Database file.
Part Number	Change the device part number in the open settings.

Communications	
Connect	Connect to a device.
Parameters	Modify the communications parameters, including connection type (serial [including USB], network, or modem); PC port numbers, speed, and settings; device passwords, IP addresses, ports, and file transfer options; and modem phone numbers and speeds.
Network Address Book	Select from a list of Ethernet-connected devices. Add or modify devices by specifying the connection name, IP address, Telnet port number, user ID, and password.
Terminal	Connect to a device and open a terminal window to issue SEL ASCII commands.
Logging	Initiate terminal logging to record terminal communications. View and clear the connection log.
Tools	
Settings	Convert settings between settings versions. Import and export settings to and from text files.
HMI	Open HMI for the connected device.
Events	Collect transient records from the connected device.
Options	Select QuickSet options, including settings comments, transient record viewer, and terminal options.
Firmware Loader	Upgrade device firmware.
Device Manager	Open Device Manager (asset management tool for SEL devices). See the *ACSELERATOR QuickSet SEL-5030 Software Instruction Manual* for more information (click **Help > Contents** to view this manual).
Help	Access program help.

For more detailed descriptions of the submenu functions, refer to the *ACSELERATOR QuickSet SEL-5030 Software Instruction Manual*.

Working With Settings Files

QuickSet provides the ability to create settings for SEL devices without the need for a connection to a physical device. After creating the settings, you can upload them from the Relay Database file to a device.

File > New

To begin creating SEL-TWFL settings, click **File > New** from the menu to cause QuickSet to display the **Settings Editor Selection** window (as shown in *Figure 7.15*). The **Device Family** column indicates the device family, the **Device Model** column shows the specific device type, and the **Version** column specifies the settings version. Select SEL-TWFL from the **Device Family** menu, the appropriate model (SEL-TWFL) from the **Device Model** menu, and the settings version number (SVN; 001 in this example) from the **Version** menu. Click **OK**.

Figure 7.15 Settings Editor Selection

Locate the Z-number in the FID string (as shown in *Figure 7.16*).

Figure 7.16 QuickSet Driver Information in the SEL-TWFL FID String

The first portion of the Z-number (002 in *Figure 7.16*) denotes the QuickSet Device Setting Version Number (SVN) you use when creating or editing device settings files. The latter portion of the Z-number (003 in *Figure 7.16*) denotes the HMI version number.

If you create settings offline, the SVN of the device may be unknown at the time you create the settings. If the SVN is unknown, select the largest SVN in the **Version** box in the QuickSet **Settings Editor Selection** window. Once you know the correct SVN, you can convert the settings to the correct version by using the SVN convert utility in QuickSet. (See *Tools* > *Settings* > *Convert* on page 7.30 for more information.)

Figure 7.17 shows the **Settings Editor** window. The settings tree (on the left side) shows the three settings categories in the SEL-TWFL.

The bottom section of the QuickSet window provides the SEL-TWFL part number, settings class currently being worked on, remaining availability for SELOGIC programming, settings database file name, and PC-to-device connection status and parameters.

Figure 7.17 Settings Editor Screen

Click each arrow (>) and button in the settings tree as necessary to expand and select the settings that you want to work on. *Figure 7.18* shows an expanded view of the settings tree.

Figure 7.18 Expanded Settings Tree

Entering Settings

To select a setting, either click on it in the settings tree or press **<Tab>** until that setting is highlighted. You can press **<F1>** to obtain context-sensitive help for the setting that is currently selected (see *Figure 7.19*). To restore the previous value for a setting, right-click the setting and select **Previous Value**. To restore the factory-default settings value, select the setting, right-click the setting, and select **Default Value**. If you enter a setting that is out of range or has an error, QuickSet shows the error at the bottom of the **Settings Editor** window. Double-click the error listing to go to the setting to enter a valid input.

Figure 7.19 Context-Sensitive Help for SEL-TWFL Settings in QuickSet

Expression Builder

Some device settings, including SELOGIC equations, the Sequential Events Recorder (SER) lists, and DNP3 binary point lists, involve Relay Word bits. QuickSet provides the Expression Builder utility in which to organize these lists, making it easy to find, select, and use these Relay Word bits.

The Expression Builder is only available for settings with an ellipsis button (...) to the right of the corresponding setting box. *Figure 7.20* shows an example of programming the L1FL SELOGIC equation by using the Expression Builder.

Figure 7.20 Using Expression Builder to Program the L1FL SELOGIC Equation

The SEL-TWFL Relay Word bits are organized in the Expression Builder in logical categories as shown in the left pane of *Figure 7.20*.

File > Save

NOTE: You can also use Device Manager to manage database files (see the ACSELERATOR QuickSet SEL-5030 Software Instruction Manual for more information [click **Help > Contents** to view this manual]).

When you finish making settings changes, click **File > Save** from the menu to save the modified device settings files to a settings database file (with an .rdb extension).

File > Open

Click **File > Open** from the menu to open device settings files previously saved in a settings database.

File > Read

Click **File > Read** from the menu to load all settings from an SEL-TWFL to your PC. If you want the ability to select just certain settings classes to load, navigate to **Tools > Options > Settings** and make sure that the **Specify Groups** checkbox is selected (you will be able to specify settings classes to read), as shown in *Figure 7.21*.

Figure 7.21 Specify Groups Checkbox

When you select the **Read** function (with the **Specify Groups** option selected), QuickSet displays the **Settings Group/Class Select** window (shown in *Figure 7.22(a)*). Specify which settings classes you want to read from the SEL-TWFL by selecting the appropriate checkboxes, and click **OK**. When you select only a subset of the available settings classes, QuickSet populates those classes you do not select with default settings, as shown in *Figure 7.22(b)*. As QuickSet reads the device settings, a **Transfer Status** window appears, as shown in *Figure 7.22(c)*.

Figure 7.22 Selecting Settings Classes to Read: (a) Reading All Settings, (b) Reading Port 1 Settings Only, and (c) Transfer Status Window

File > Send

Click **File > Send** from the menu to send settings from your PC to an SEL-TWFL. Select which settings you want to send and click **OK**. *Figure 7.23(a)* shows an example of sending all settings, and *Figure 7.23(b)* shows an example of sending only the Fault Locator settings.

Figure 7.23 Sending Settings: (a) All Settings and (b) Only the Fault Locator Settings

Communications Menu

Communicate with the SEL-TWFL over the front-panel USB Port F or over an Ethernet LAN by using Port 5.

See *Preparing a PC for Front-Panel Port F Communications* on page 7.41 for instructions on how to prepare your PC for communication with the SEL-TWFL over Port F, and *Establishing Communication Over Front-Panel Port F* on page 7.42 for information on how to establish communication between QuickSet and an SEL-TWFL over Port F.

See *Configuring Port 5 for an Ethernet Local-Area Network* on page 7.45 for instructions on how to configure Port 5 for communication over an Ethernet LAN, and *Establishing Communication Over Ethernet Port 5* on page 7.46 for information on how to establish communication between QuickSet and an SEL-TWFL over Port 5.

Terminal Emulator Window

The terminal window provides an SEL ASCII command language interface to the device. This terminal emulator provides Ymodem and 1K Xmodem file transfer capabilities.

Open the terminal window by clicking **Communications > Terminal** from the menu (*Figure 7.24(a)*), clicking the terminal ( ) icon on the toolbar, or by pressing **<Ctrl+T>**. Verify proper communication with the device by opening a terminal window, pressing **<Enter>** a few times, and verifying that you receive an = (equal sign) Access Level 0 prompt for each press of the **<Enter>** key, as shown in *Figure 7.24(b)*. If you receive no prompt, verify correct communications setup. Be sure to select the **Send Ctrl Characters** checkbox to enable the software to process control characters such as **<Ctrl+X>**.

Figure 7.24 Terminal Emulator Window: (a) Open From the Menu and (b) Open Window Showing Prompt

QuickSet can log any terminal session and save it to a text file for future reference. To enable terminal logging, click **Communications > Logging > Terminal Logging**, as shown in *Figure 7.25*. From the window that appears, you can specify a name and save location for the text file that records all activity in the terminal window. In addition, a check mark appears next to the menu option to indicate that logging is currently enabled. To disable terminal logging, click **Communications > Logging > Terminal Logging** again (the check mark disappears, indicating that logging is disabled).

Figure 7.25 Enabling Terminal Logging

Tools Menu

The **Tools** menu provides access to the HMI (see *Tools > HMI* on page 7.31), transient records (see *Tools > Events* on page 7.31), and settings menus.

Tools > Settings > Convert

When you need to update settings from an older SVN to a newer SVN, you can convert the older settings to the new SVN by using the settings conversion utility. To convert settings, click **Tools > Settings > Convert** from the menu. Select **Settings to Convert**, and then select the new SVN to convert, specify the device type (**Device Family**, **Device Model**, and **Version**), and click **Convert** to convert the selected settings. This function is typically used to upgrade a settings file to a newer version that is required by a newer device firmware version. In all settings conversions, new settings in the latest settings version are populated with default settings unless QuickSet indicates otherwise. QuickSet provides a **Convert Settings** report (see *Figure B.1*) that shows missed, changed, and invalid settings resulting from the conversion. Review this report to determine whether you need to modify any settings. See *Evaluating Settings Changes and Preparing Settings Files for New Firmware* on page B.4 for additional information.

Import Settings From Text Files

To import settings from text files, such as the files you read from the device SETTINGS directory, navigate to **Tools > Settings > Import**. Use this option when there are multiple saved settings text files for a particular device. Instead of having to import all of the settings, you can select each text file to be imported into the present device settings. QuickSet will only import files with names corresponding to those files you selected.

Export Settings to Text Files

To export settings to text files, navigate to **Tools > Settings > Export** and then select the settings groups/classes that you want to export. This option will export the present settings into separate text files corresponding to the settings classes. This can be useful when you must store the settings in a different format or import them into a different database. The **Export Selection** window provides a list of available **Device Groups** (classes) as well as four additional options for exporting settings. You can export all visible, valid settings by selecting all the settings groups/classes in the **Device Groups** pane and clearing the four options, as shown in *Figure 7.26*. The options allow you to customize and export the data to a text file.

NOTE: SEL devices and QuickSet do not display or allow editing settings that are not applicable, given the values of other settings. These not applicable settings are referred to as hidden or disabled. You can suppress or allow the display of these settings in QuickSet under the View menu.

Figure 7.26 Export Settings to Text

Tools > HMI

Click **Tools > HMI** from the menu to view device metering and the status of inputs and outputs and to perform selected control functions. Viewing device information requires Access Level 1 or higher. Control operations require Access Level 2 or higher. The HMI function provides the following features:

- **Device Overview.** View the status of contact inputs, contact outputs, and the virtual target pane
- **Phasors.** View values and vector representation of phase and sequence voltages, currents, and frequency
- **Metering.** View metering data (response to the **MET** command)
- **Relay Word Bits.** View the status (logical 0 or 1) of the Relay Word bits (response to the **TAR** command)
- **Device Status.** View the device status (response to the **STA** command)
- **Communications Status.** View the status of communications Ports 1, 2, and 3
- **IRIG Status.** View the status of the IRIG-B time input
- **Sequential Events Recorder.** View the instructions on how to view and download SER data
- **Device Control.** Clear transient records and SER data, trigger transient records, reset front-panel targets, set the date and time, pulse contact outputs, and initiate/cancel the TW test mode

To open the virtual HMI, click **Tools > HMI** in the QuickSet menu bar. You can also click the Human-Machine Interface icon ( ) to access the HMI.

You can customize the appearance of many of the virtual HMI screens by clicking the data items and objects displayed. You can save customized **Device Overviews** as HMI configurations. To save the current configuration under the current name, click **Tools > HMI > Save Configuration**; to specify a different configuration name, click **Tools > HMI > Save Configuration As**.

HMI configurations are identified by configuration name and device type. To use a preprogrammed configuration, click **Tools > HMI > Select Configuration**. To view available configurations, click **Tools > HMI > Manage Configurations**. To make the present configuration the default configuration for a given device type, select the configuration in the **Manage Configurations** window, click **Edit**, and select the **Default** checkbox.

Tools > Events

To retrieve transient records from the SEL-TWFL, click **Tools > Events > Get Event Files**, as shown in *Figure 7.27*. See *Section 5: Transient and Sequential Events Recording* for more information on event analysis.

Figure 7.27 Retrieve Transient Records by Using the Events Menu

The window shown in *Figure 7.28* appears. QuickSet downloads the 10 kHz and 1 MHz transient records separately.

Figure 7.28 Available IEEE COMTRADE Records

The **Event History** shows the stored transient records. Check the record you want to download and click **Get Selected Events**, as shown in *Figure 7.28*.

The window in *Figure 7.29* appears. Either enter the location where you want to store the transient records or click the ellipsis button and navigate to the location. To download all the selected IEEE COMTRADE files into a zip folder, leave the **Save As Zip File** checkbox selected and enter a name for the zip file when prompted.

Figure 7.29 Get Event Reports Options

Selecting **Custom Naming** allows you to modify the file name for the IEEE COMTRADE files.

Tools > Firmware Loader

The Firmware Loader is a built-in tool that guides you through the process of upgrading the firmware in the device. See *Appendix B: Firmware Upgrade Instructions* for a detailed description of how to use the Firmware Loader.

Help Menu

If you need more information about a particular setting while using QuickSet, click the setting and press **<F1>**. QuickSet opens the *SEL-TWFL Instruction Manual* to the location with information relevant to the selected setting.

If you need more information about QuickSet in general, click **Help > Contents** from the menu to launch the *ACSELERATOR QuickSet SEL-5030 Software Instruction Manual*.

Updating QuickSet

NOTE: An internet connection is required to add new drivers in QuickSet and to receive update notifications.

QuickSet consists of the main software program and separate driver files for individual SEL devices. As new device firmware versions are released, you may need to update QuickSet to add new driver files. This can be accomplished by one of the following methods:

- When **Enable Update Notifications** is selected in the **Tools > Options** menu of SEL Compass, the Compass software periodically checks for updates on a specified schedule and facilitates the update process.
- The **Update** icon on the QuickSet initial screen starts SEL Compass and checks for updates.

- The **Install Devices** button on the Settings Editor Selection window starts SEL Compass and presents a menu of available drivers.
- The **Check for updates** option in the Help menu starts SEL Compass and checks for updates.

SEL ASCII Command Language

You can use the SEL ASCII command language to set the device, interrogate the device for data, download device settings and records, and command the device, such as to request and obtain a report for a communications port (present status and performance statistics). When using SEL ASCII commands for engineering access, apply a terminal emulator software to type commands and view and copy device responses. QuickSet includes a simple terminal emulator.

You can use the SEL ASCII command language over the front-panel USB Port F. Port F is intended for temporary engineering access such as commissioning or testing the device. You will need a terminal emulator to issue SEL ASCII commands over Port F.

You can also use the SEL ASCII command language over Ethernet Port 5 connected to an Ethernet LAN. You will need a Telnet client to issue SEL ASCII commands over Port 5.

An SEL ASCII command consists of the command, including optional parameters, followed by either a CR character (carriage return) or CR and LF characters (carriage return and line feed) as follows:

<command> <Enter> or **<command> <Enter> <CR>**

Pressing **<Enter>** on standard computer keyboards sends the ASCII character CR for a carriage return. Press **<Enter>** after commands to send the proper ASCII code to the device.

You may truncate commands to the first three characters. For example, **HISTORY <Enter>** is equivalent to **HIS <Enter>**. You may use upper- and lowercase characters without distinction, except when typing passwords. In response to a command, the device may respond with an additional dialog line or message. The device transmits dialog lines in the following format:

<DIALOG LINE ><CR><LF>

The device transmits messages in the following format:

<STX><MESSAGE LINE 1><CR><LF>
<MESSAGE LINE 2><CR><LF>
…
<LAST MESSAGE LINE><CR><LF>< ETX>

For example, a **COM P 1** command interrogates the SEL-TWFL for the status and performance statistics of the communications Port 1. To use the command, type:

```
=>>COM P 1 <Enter>
```

The SEL-TWFL responds as follows:

```
=>>COM P 1 <Enter>

SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

Summary for Port 1
    Encoding MB8

Channel Status
    ROKP1 = 1    LBOKP1 = 0

For 2024/01/30 16:59:30.000 to 2024/01/30 17:00:00.000

    Last Error          Re-Sync
    Total Errors              6
    Device Disabled           1
    Data Error                2
    Re-Sync                   1
    Parity Error              1
    Framing Error             1
    Bad Re-Sync               0
    Loopback                  0
    Longest Error (s)        19.842
    Unavailability            0.000111
```

Table 7.1 lists the most frequently used commands for the frequent engineering tasks. *Appendix C: SEL ASCII Commands* provides a reference table and an alphabetical list of all SEL-TWFL SEL ASCII commands.

Machine clients can use the SEL ASCII command language to interrogate the device for data and for other SCADA/HMI functions. When programming or configuring a machine client for integration applications, you must observe the printing characters and control characters that the SEL ASCII command syntax uses.

The ASCII character set specifies numeric codes that represent printing characters and control characters. See *Table 7.11* for selected control characters of the SEL ASCII command language.

Table 7.11 Selected ASCII Control Characters

Decimal Code	Name	Usage	Keystroke(s)
13	CR	Carriage return	**<Enter>** or **<RETURN>** or **<Ctrl+M>**
10	LF	Line feed	**<Ctrl+J>**
02	STX	Start of transmission	**<Ctrl+B>**
03	ETX	End of transmission	**<Ctrl+C>**
24	CAN	Cancel	**<Ctrl+X>**
17	XON	Flow control on	**<Ctrl+Q>**
19	XOFF	Flow control off	**<Ctrl+S>**

Each ASCII message begins with the start-of-transmission character, STX, and ends with the end-of-transmission character, ETX. Each line of the message ends with a carriage return, CR, and line feed, LF.

Send the CAN character to the device to abort a transmission in progress. For example, if you request a long report and want to terminate transmission of this report, press **<Ctrl+X>** to terminate the report.

Access Control and Passwords

Access Levels

Access levels restrict operations a user can perform on the SEL-TWFL. Each access level is protected by a unique password. Use access level passwords to restrict access for human operators and machine clients. The SEL-TWFL access levels are 0, 1, B, 2, and C. Refer to the following SEL-TWFL access level rules when deciding on access privileges:

- Access Level 0 is the most basic and default level. Its only purpose is to allow a login to Access Level 1.
- Access Level 1 allows you read-only access to device data such as settings or metering information.
- Access Level B has all Access Level 1 privileges and additionally it allows you to actuate the contact outputs of the device (such as for testing) as long as the BREAKER jumper inside the device chassis is set to enable contact output testing (see *Accessing and Configuring Device Jumpers* on page 9.15).
- Access Level 2 allows you to read and write data (such as to modify settings).
- Access Level C allows you access to calibration and other data related to internal device circuits and computer code. You should perform Access Level C tasks only under direct supervision of SEL personnel. Consider not releasing Level C passwords to your field staff.
- The front-panel HMI effectively operates at Access Level 1 because it provides read-only access to the basic device identification, status, and metering data (see *Front-Panel Operations* on page 7.4). However, the front-panel HMI does not prompt for a password because the HMI requires a physical presence, and therefore it is protected by the physical security perimeter.

Table 7.12 summarizes the SEL-TWFL access levels.

Table 7.12 SEL-TWFL Access Levels

Access Level	Prompt	Allowed Operations
0	=	Log in to Access Level 1
1	=>	View data and status information
B	==>	Access Level 2 functions except settings changes and deleting records
2	=>>	Perform all user functions
C	==>>	Calibration-related functions and deep diagnostics functions (**Note:** Use only under direct supervision of SEL personnel)

Figure 7.30 Access Level Navigation Diagram

As *Figure 7.30* shows, you can move between access levels by using the SEL ASCII commands summarized in *Table 7.13*. See *Appendix C: SEL ASCII Commands* for a full list of SEL ASCII commands, including the access levels at which any given command is available. The SEL-TWFL performs command interpretation and execution according to your current access level. Each access level has a password that you must enter before you can work with the device at that level.

Table 7.13 Access Level Commands and Default Passwords

Access Level	SEL ASCII Command	Factory-Default Password
0	QUIT	(None)
1	ACC	OTTER
B	BAC	EDITH
2	2AC	TAIL
C	CAL	CLARKE

The device prompts for a password in response to **ACC**, **BAC**, **2AC**, and **CAL** commands. You must enter the correct password to enter Access Levels 1, B, 2, and C. Passwords are case-sensitive; you must enter a password exactly as set. If you enter the password correctly, the SEL-TWFL moves to the target access level and displays a level-specific prompt as shown in *Table 7.12*.

To aid audits of your field work, the device asserts the alarm Relay Word bit ACCESS when entering Access Level B or 2 from a lower access level.

After the third failed password attempt, the SEL-TWFL asserts the BADPASS and PASNVAL Relay Word bits for 1 s, operates the Alarm contact output, and displays the following error message:

```
WARNING: ACCESS BY UNAUTHORIZED PERSONS STRICTLY PROHIBITED
```

You will not be able to make further access level entry attempts for 30 s. If you attempted to enter a password over a Telnet session, the device will also terminate the session after a 30 s time-out.

The BADPASS and SALARM Relay Word bits pulse the Alarm output of the device (see *Appendix F: Diagnostics*). Monitor the Alarm output to detect failed password entry attempts.

When a connection with the SEL-TWFL times out after 15 min of inactivity, the device closes the communications connection for that communications port and reverts to Access Level 0.

Passwords

NOTE: This device is shipped with default passwords. Default passwords should be changed to private passwords at installation. Failure to change each default password to a private password may allow unauthorized access. SEL shall not be responsible for any damage resulting from unauthorized access.

It is important that you change all of the passwords from their default values. This helps protect the device from unauthorized access. Valid passwords are character sequences of as many as 12 characters and are case-sensitive. Valid password characters are any printable ASCII character. Use strong passwords. Strong passwords contain a mix of the valid password characters in a combination that does not spell common words in any portion of the password.

See *Cybersecurity Features* on page J.1 for more information about electronic and physical security features of the SEL-TWFL.

Changing the Passwords

Perform the following steps to change passwords:

Step 1. Establish communication with the SEL-TWFL.

Step 2. Make sure the Port setting MAXACC = 2, and enter Access Level 2 (Level 2 is sufficient to change passwords, except when changing the Level C password).

a. Type **ACC <Enter>**.

b. Type the Access Level 1 password and press **<Enter>**. The factory-default password is **OTTER**.

c. Type **2AC <Enter>**.

d. At the password prompt, type the Access Level 2 password and press **<Enter>**. The factory-default password is **TAIL**.

e. You will see the Access Level 2 prompt, =>>.

Step 3. To set a new password for Access Level 2, use the **PAS 2** command; when prompted, enter the old password, the new password, and a confirmation of the new password, as follows:

```
=>>PAS 2 <Enter>
Old PW: ? **** <Enter>
New PW: ? **** <Enter>
Confirm PW: ? **** <Enter>
Password Changed
```

Step 4. In a similar manner as in *Step 3*, create new, strong passwords for Access Levels 1 and B by using the **PAS 1** and **PAS B** commands. To change the Access Level C password, use the **PAS C** command from Access Level C.

Step 5. Following your company procedures and best practices, record your new passwords and store this record in a secure location.

If you forget a password, or encounter difficulty changing the default passwords, you can temporarily disable password verification by means of a jumper on the top printed circuit board. See *Accessing and Configuring Device Jumpers* on page 9.15 for information on the PASSWORD jumper.

Settings Structure

Settings Menu Tree and Classes

The SEL-TWFL settings are organized in classes for ease of use in QuickSet and when using SEL ASCII commands.

When using QuickSet, note that the settings are organized into a five-level-deep structure with three main areas of engineering (fault locating, reporting, and communications), as shown in *Figure 7.18*. Each menu item of the settings tree corresponds to a settings screen you use to view and edit settings and to invoke context-sensitive help for each of the settings.

When you use the SEL ASCII command language, the settings are organized into a single-level structure with three menu items, as shown in *Table 7.14*. QuickSet also uses the settings classes and instances when transferring settings to and from the SEL-TWFL and when printing or comparing settings.

Table 7.14 View and Set SEL-TWFL Settings Classes and Instances

Settings Class	Instance	SEL ASCII Command to View Settings	SEL ASCII Command to Set Settings	QuickSet Menu Item
Fault Locator	N/A	SHO	SET	Fault Locator Settings
Reports	N/A	SHO R	SET R	Reports
Port	Port F	SHO P F	SET P F	Communications
	Port 1	SHO P 1	SET P 1	
	Port 2	SHO P 2	SET P 2	
	Port 3	SHO P 3	SET P 3	
	Port 5	SHO P 5	SET P 5	
DNP	DNP Map Settings *n*[a]	SHO D *n*	SET D *n*	

[a] *n* = 1–5.

Viewing Settings

NOTE: SEL devices and QuickSet do not display or allow editing settings that are not applicable, given the values of other settings. These not applicable settings are referred to as hidden or disabled. You can suppress or allow the display of these settings in QuickSet under the View menu.

In QuickSet, click **View > Settings Editor** from the menu and navigate directly to the setting of interest to view the setting, its description, units, ranges, and a context-sensitive help.

When using the SEL ASCII command language, view settings by using the **SHO** command, as shown in *Table 7.14*. The **SHO** command shows the Fault Locator settings. The device responds similarly to **SHO R** (Report Settings), **SHO P *n*** (Port *n* settings), and **SHO D** (DNP settings).

Editing Settings

When using QuickSet, navigate to the setting of interest and edit the settings value. Periodically save your edits.

When using the SEL ASCII command language, use the **SET** command, as shown in *Table 7.14*. When you issue the **SET** command, the device presents a list of settings one at a time. Enter a new setting value, or press **<Enter>** to accept the present setting value. *Table 7.15* lists keystrokes that you can use to efficiently access and change settings of interest.

Table 7.15 Actions at Settings Prompts

Action	Device Response
<Enter>	Accept present setting value and move to the next setting; if at the last setting, exit settings.
[value] <Enter>	Enter the value and move to the next setting if valid; if at the last setting, exit settings.
^ <Enter>	Move to the previous setting; if at the top of settings, stay at the present setting.
< <Enter>	Move to the top of the previous settings category; if in the first category, stay at the present setting.
> <Enter>	Move to the next settings category; if in the last category, exit settings.
END <Enter>	Go to the end of the present settings session, select whether to save your settings, and exit the editing session.
<Ctrl+X>	Abort the editing session without saving changes.

As you enter device settings, the device verifies the settings entered against the valid ranges for the settings shown in the setting prompt. If you enter a value that is outside the corresponding range for that setting, the device responds `Out of Range` and prompts you to reenter the setting.

When you exit from the **SET** command, the device responds, `Save Changes (Y/N)?`. If you answer **Y <Enter>**, the device writes the new settings to nonvolatile memory. If you answer **N <Enter>**, the device discards any settings changes you have made.

At the end of the settings class/instance, the device provides a summary of all the settings from the current SET dialog before prompting to accept the changes. You can waive the summary by appending the **TE** (TERSE) parameter to the **SET** command.

Refer to *PC Software* on page 7.19 for information on how to store, compare, and print device settings by using QuickSet.

Communications Setup

The SEL-TWFL does not allow settings changes through the front-panel HMI. You must use one of two communications ports – Port F or Port 5 – to configure the device and perform other engineering tasks. The SEL-TWFL ships with Port 5 disabled and Port F enabled. Therefore, when working with a new SEL-TWFL, you must first use a PC to access the device on Port F. Upon establishing communication with the device, either continue working over Port F or enable and configure Port 5 to perform engineering tasks over an Ethernet network.

Preparing a PC for Front-Panel Port F Communications

Before using a PC to communicate for the first time with the SEL-TWFL, you must prepare that PC as explained in the following text.

Background

You must install a USB 2.0 driver (SEL Fast CDC USB Device) on your Windows PC before you can communicate with the SEL-TWFL by means of the front-panel USB 2.0 Port F. The USB driver creates a virtual communications port on your PC suitable for communication with the SEL-TWFL over Port F (by using such settings as baud rate and parity). Each time you connect a device to the USB port on your PC, Windows determines if the required driver has already been installed and is ready for use.

When you connect a PC to Port F, you will encounter one of three possibilities:

1. Reconnecting the device over Port F to a USB port (on the PC) that has been previously connected to the device causes Windows to recognize that the driver is already installed and that there is a connection to the same virtual COM port created the first time the device was connected to that particular USB port (e.g., COM 13). No action is required on your part.
2. Connecting the device over Port F to a USB port on the PC (in which the USB driver is installed) that has not been previously connected to the device causes Windows to launch the **Found New Hardware Wizard**. Use the wizard and select **Install the software automatically (Recommended)** and click **Next**. Windows locates the required driver and creates a new virtual COM port (e.g., COM 13). Windows creates a new virtual COM port on your PC each time you connect a device to a physical USB port that has not previously been connected to that device. The virtual COM port number remains associated with the same physical USB port on your PC until you uninstall the driver.
3. Connecting a PC for the first time to a device USB port causes Windows to launch the **Found New Hardware Wizard**. Do not use the wizard; instead, follow the manual installation process described in *Installing the SEL Fast CDC USB Device Driver* on page 7.41.

The USB port uses a connection-based protocol. Under certain circumstances, such as device reboot, the USB connection may be terminated. If this occurs, either use your Windows application software (such as QuickSet) to reconnect to the device or disconnect and then reconnect the USB connector at either the computer or the device.

Installing the SEL Fast CDC USB Device Driver

Retrieve the SEL Fast CDC USB Driver Package folder from the SEL-TWFL product page on the SEL website (selinc.com/products/TWFL/), from the corresponding Product Literature CD, or from the ACSELERATOR QuickSet SEL-5030 Installation CD. Copy the folder to any convenient directory, such as C:\SEL\Drivers\Relay_USB\. Follow the installation instructions available at selinc.com/products/TWFL/.

Establishing Communication Over Front-Panel Port F

Connect an SEL-C664 cable, or any standard A-to-B USB cable, between Port F on the SEL-TWFL and your PC.

Using QuickSet

Launch QuickSet and select **Communications > Parameters** from the menu or click the **Communication** icon from the welcome screen (See *PC Software* on page 7.19 for more information on QuickSet). Your PC should display a communications menu such as that shown in *Figure 7.31*.

Figure 7.31 QuickSet Communications Parameters for Port F Access

NOTE: If you do not see **COM*x*: SEL Fast CDC USB Device** as listed in *Figure 7.31*, make sure that the driver is installed properly. If you are unable to install the driver, contact your system administrator for assistance.

To use the USB front-panel Port F, select **Serial** from the Active Connection Type menu. Select **COM*x*: SEL Fast CDC USB Device** from the available drivers in the **Device** list (in the example of *Figure 7.31*). Make sure DTR is turned on and enter the correct Level One and Level Two passwords. Ignore other settings such as Parity and Data Speed.

Click **OK** to complete the settings. Click the icon in QuickSet to launch the built-in terminal emulator. If a window such as that shown in *Figure 7.32* appears, the PC and the SEL-TWFL are communicating properly. Press **<Enter>** to establish communication with the device at Access Level 0. Type **ACC <Enter>** at the Access Level 0 prompt (=) to enter Access Level 1.

Figure 7.32 Terminal Emulator Communicating With the Device and Showing Level 0 Prompt

If the driver is properly installed, but you still have difficulty communicating with the device, perform the following steps:

Step 1. Close the Communication Parameters window (*Figure 7.31*).

Step 2. Disconnect the USB cable.

Step 3. Wait 10 seconds.

Step 4. Reconnect the USB cable.

Step 5. Click **Communications > Parameters** from the menu to open the Communication Parameters window.

Step 6. On the Serial tab, select **COM*x*: SEL Fast CDC USB Device** from the available drivers in the Device list.

Step 7. Click **OK**.

Using a Terminal Emulator

Open Device Manager in Windows to determine which virtual port has been assigned to the SEL Fast CDC USB driver. Make sure to specify that assigned port in your terminal emulator, as shown in *Figure 7.33*.

Figure 7.33 Selecting the USB Communications Port in the Terminal Emulator

You can ignore the Speed setting. If you do not see the assigned communications port listed (COM8 in the example shown in *Figure 7.33*), make sure that the driver is installed properly. If you are unable to install the driver, contact your system administrator for assistance.

Launch your terminal emulator. If a window similar to the one shown in *Figure 7.32* appears, the terminal emulator and the SEL-TWFL are communicating properly. Press **<Enter>** to establish communication with the device at Access Level 0.

If the driver is properly installed, but you still have difficulty communicating with the device, perform the following steps:

Step 1. Close your terminal emulator.

Step 2. Disconnect the USB cable.

Step 3. Wait 10 seconds.

Step 4. Reconnect the USB cable.

Step 5. Open your terminal emulator.

Step 6. Select the assigned port in your terminal emulator.

Port F Settings

Front-panel Port F is enabled by default and you must use it to communicate with the device for the first time. You must use Port F to enable and configure Ethernet engineering access and SCADA/HMI on Port 5 before you can use Port 5.

Use the Port F settings shown in *Table 7.16* to control Port F access.

Table 7.16 Port F Settings

Setting	Description	Range	Default	Class
EPORT	Enable Port	Y, N	Y	Port F
MAXACC	Maximum Access Level	1, B, 2, C	C	Port F

Follow these setting rules when configuring Port F.

EPORT

NOTE: If you disable both Port F and Port 5, you will not be able to access the device and will have to use the PASSWORD jumper to regain access.

Use the EPORT setting to enable and disable Port F. The SEL-TWFL does not allow settings changes through the front-panel HMI, and it has two engineering access ports – Port F and Port 5. If you disable both Port F and Port 5, you will not be able to access the device. Should this happen, use the PASSWORD jumper inside the device chassis to regain access to the device over Port F (see *Accessing and Configuring Device Jumpers* on page 9.15).

MAXACC

Use the MAXACC setting to restrict access levels for Port F. When you set the MAXACC setting, users will be able to access levels below and up to the MAXACC setting value. The maximum access level restriction does not remove authentication, and users still need to enter passwords to access the device. When you attempt to access a level above the maximum access level, the device refuses and replies with the `Command Unavailable` message. The device does not assert the ALARM Relay Word bit if the user attempts to access a level above the MAXACC setting value. The PASSWORD jumper overrides the maximum access level restriction.

It is good practice to restrict access levels for Port F to Access Level 2 (set MAXACC to 2). This allows a full-range of typical engineering tasks, yet it prevents unintentional access to the calibration level, Access Level C. If needed, the user with Access Level 2 privileges can change the MAXACC setting to grant access to Access Level C.

Configuring Port 5 for an Ethernet Local-Area Network

Before connecting the SEL-TWFL to your substation Ethernet LAN and using Port 5 for engineering access and SCADA/HMI functions, you must configure Port 5 to match your LAN configuration. The SEL-TWFL does not allow settings changes through the front-panel HMI, and therefore you need to use the front-panel USB Port F to configure Ethernet Port 5 (see *Preparing a PC for Front-Panel Port F Communications* on page 7.41).

Table 7.17 shows Port 5 settings. Contact your Information Technology or Substation Communications group responsible for network configuration and request network settings for a specific SEL-TWFL asset (network device).

Table 7.17 Ethernet Port 5 Settings

Setting	Description	Range	Default	Class
EPORT	Enable Port	Y, N	N	Port 5
MAXACC	Maximum Access Level	0, 1, B, 2, C	1	Port 5
IPADDR	IP Address	*w.x.y.z* (*w*: 1–126, 128–233, *x*: 0–255, *y*: 0–255, *z*: 0–255)	192.168.1.2	Port 5
SUBNETM	Subnet Mask	*w.x.y.z* (*w*: 128, 192, 224, 240, 248, 252, 254, 255, *x*: 0, 128, 192, 224, 240, 248, 252, 254, 255, *y*: 0, 128, 192, 224, 240, 248, 252, 254, 255, *z*: 0, 128, 192, 224, 240, 248, 252, 254)	255.255.255.0	Port 5
DEFRTR	Default Router	*w.x.y.z* (*w*: 1–126, 128–233, *x*: 0–255, *y*: 0–255, *z*: 0–255)	192.168.1.1	Port 5
ETCPKA	Enable TCP Keep-Alive	Y, N	Y	Port 5
KAIDLE	TCP Keep-Alive Idle Range	1–20 s	10	Port 5
KAINTV	TCP Keep-Alive Interval Range	1–20 s	10	Port 5
KACNT	TCP Keep-Alive Count Range	1–20	5	Port 5

The SEL-TWFL ships with Port 5 disabled (EPORT = N).

Except the MAXACC setting, Port 5 settings are well-established Ethernet standard settings. This instruction manual does not provide any specific recommendations for these settings. Follow your company policies and the recommendations of your Information Technology or Substation Communications group when selecting Ethernet Port 5 settings. See *Section 8: SCADA and HMI Protocols* for more information on Port 5 applications including the DNP3, Telnet, and FTP protocols.

MAXACC

Use the MAXACC setting to restrict access levels for Port 5. The MAXACC setting applies to SEL ASCII commands in a terminal window session over Telnet and the FTP file transfer session.

When you set the MAXACC setting, users will be able to access levels below and up to the MAXACC setting value. The maximum access level restriction does not remove authentication, and users still need to enter passwords to access the device. When you attempt to access a level above the maximum access level, the device refuses and replies with the `Command Unavailable` message. The device does not assert the ALARM Relay Word bit if the user attempts to access a level above the MAXACC setting value. The PASSWORD jumper overrides the maximum access level restriction.

It is good practice to restrict access levels for Port 5 to Access Level 1 (set MAXACC to 1). This allows access to device data and records, yet it prevents unintentional or malicious deletion of data or changes to device settings.

Configuring Port 5 by Using SEL ASCII Commands

You can use QuickSet when configuring Port 5 as a part of a complete SEL-TWFL settings file. You can also configure Port 5 settings by using the SEL ASCII command language interface on Port F. From Access Level 2, execute the **SET P 5** command to enable and set Ethernet Port 5.

Establishing Communication Over Ethernet Port 5

Make sure your PC is connected to the same LAN as, and has access to, the target SEL-TWFL. Issue a **PING** command from your PC to verify that the SEL-TWFL is present on the network as expected. If the device is not present on the network, apply standard Ethernet testing and troubleshooting methods. Seek help from your Information Technology or Substation Communications group, if you encounter LAN connectivity problems with your SEL-TWFL.

Using QuickSet

Launch QuickSet, select **Communications > Parameters**, and choose **Network** for the connection type, as shown in *Figure 7.34*.

Enter the following parameters in the QuickSet Communication Parameters window:

- IP address for the target SEL-TWFL (Host IP address).
- File transfer option. The default logical port numbers for Telnet and FTP are 23 and 21, respectively.
- Level One and Level Two passwords.

Figure 7.34 QuickSet Communications Parameters for Port 5 Access

Click **OK** to complete the settings. To verify your Port 5 connectivity, start a Telnet session. Telnet communication is equivalent to serial communication in that both methods of communication use a terminal emulator. The only difference is that Telnet communication is over Ethernet on Port 5 and serial communication is over the front-panel USB Port F.

Using a Terminal Emulator

To start the Telnet session, click the icon in QuickSet to launch the built-in terminal emulator. If a window such as that shown in *Figure 7.32* appears, the PC and the SEL-TWFL are communicating properly. Press **<Enter>** to establish communication with the device at Access Level 0. Type **ACC <Enter>** at the Access Level 0 prompt (=) to enter Access Level 1.

If you do not see the window in *Figure 7.32*, perform the following actions:

- Verify that the IP addresses of both the SEL-TWFL and your PC are correct
- Verify that Telnet is enabled in the SEL-TWFL (ETELNET = Y)
- Verify that the switch/router configurations are correct

ETHERNET Report

You can use the **ETH** command (see *ETHERNET* on page C.8) to troubleshoot Port 5 Ethernet connections. When the Port 5 transceiver is installed and the port is enabled (EPORT = Y), the **ETH** command displays link status, speed, and other related Port 5 information. *Figure 7.35* shows the report format, and *Figure 7.36* shows an example report.

```
[common header]

MAC: xx-xx-xx-xx-xx-xx
IP ADDRESS: www.xxx.yyy.zzz
SUBNET MASK: www.xxx.yyy.zzz
DEFAULT GATEWAY: www.xxx.yyy.zzz

             LINK   SPEED  DUPLEX  MEDIA
PORT 5       xxxx   xxxxx  xxxx    xx

        PACKETS                 BYTES              ERRORS
      SENT     RCVD         SENT       RCVD     SENT    RCVD
      xxxx     xxxx      xxxxxxx    xxxxxxx     xxxx    xxxx
```

Figure 7.35 Data Items in the ETHERNET Report

```
=>>ETH <Enter>

SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

MAC: 00-30-A7-4C-43-55
IP ADDRESS: 192.168.1.2
SUBNET MASK: 255.255.255.0
DEFAULT GATEWAY: 192.168.1.1

             LINK   SPEED  DUPLEX  MEDIA
PORT 5       Up     100M   Full    FX

        PACKETS                 BYTES              ERRORS
      SENT     RCVD         SENT       RCVD     SENT    RCVD
        79      906        11004      58189        0       0
```

Figure 7.36 Sample ETHERNET Report

Table 7.18 explains the ETHERNET report fields.

Table 7.18 Information Included in the ETHERNET Report (Sheet 1 of 2)

Data Item	Description	Comments and Troubleshooting
MAC	Port 5 Media Access Control Address	The MAC address is assigned at the factory and should not be modified. Use the displayed MAC address to identify network traffic originating at this device when troubleshooting network problems using a third-party analyzer.
IP ADDRESS	IP address defined in the Port 5 IPADDR setting	The IP address is typically assigned by your network administrator. If you encounter communications issues, consult your network administrator to verify if the displayed address is allowed on your network.
SUBNET MASK	Subnet mask defined in the Port 5 SUBNETM setting	The subnet mask divides the IP address into the subnet part, common to all devices on the local IP segment, and a unique part, identifying this device. Consult your network administrator to verify if the displayed mask matches the local network configuration rules.
DEFAULT GATEWAY	Default IP gateway (router) address defined in the Port 5 DEFRTR setting	Consult your network administrator to obtain the default gateway address. The default gateway address cannot be the same as the IP Address, Network Address, or Broadcast Address.
LINK	Port 5 status	This field displays the current link status (Up or Down). If the link is down, check the Port 5 fiber connections, the Port 5 SFP transceiver (verify that it is inserted and locked into place; see *Installing and Replacing SFP Transceivers* on page 9.10), and the link activity light located below the port.

Table 7.18 Information Included in the ETHERNET Report (Sheet 2 of 2)

Data Item	Description	Comments and Troubleshooting
SPEED	Port 5 link speed	With SEL-supplied SFP transceivers, the Port 5 link speed is either 100M (one hundred megabits per second) or 1G (one gigabit per second), depending on the installed transceiver.
DUPLEX	Port 5 link operating mode	With SEL-supplied SFP transceivers, Port 5 communications are always operating in full duplex mode.
MEDIA	Port 5 communications media designation (100BASE-*xx* or 1000BASE-*xx*)	Where *xx* indicates the type of the Port 5 SFP transceiver. Options include: ➤ FX for 1310 nm short-range multimode fiber ➤ SX for 850 nm short-range multimode fiber ➤ LX for 1310 nm 10–40 km single-mode fiber ➤ XD for 1550 nm 50 km single-mode fiber ➤ ZX for 1550 nm >50 km single-mode fiber

Additional counter fields PACKETS SENT, PACKETS RCVD, BYTES SENT, BYTES RCVD, ERRORS SENT, and ERRORS RCVD are self-explanatory. Use these fields to detect a broken fiber and to monitor the amount of traffic flowing over Port 5. ERRORS SENT and ERRORS RECEIVED fields count the number of packet errors and should remain at or close to zero. Increased count in these fields indicates noisy communications with insufficient link margin. Counters that are incremented until they are full are indicated by $$$$$$$.

Use the **ETH C** or **ETH R** command to clear the Ethernet connection statistics.

MAC Report

Use the **MAC** command (see *MAC* on page C.11) to inspect the Media Access Control (MAC) address for Port 5 (Ethernet). *Figure 7.37* shows a sample **MAC** command response. The MAC address is set at the factory and cannot be modified by the user. Contact SEL on the rare occasion that such a change may be necessary.

```
Port 5-1 MAC Address:  00-30-A7-4C-43-55
```

Figure 7.37 Sample MAC Command Response

Use the displayed MAC address to identify network traffic originating at this device when troubleshooting network problems with a third-party analyzer.

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SECTION 8

SCADA and HMI Protocols

Introduction

SCADA systems and other machine clients can communicate with the SEL-TWFL through use of the following protocols:

- **Distributed Network Protocol Version 3 (DNP3).** Use DNP3 to retrieve metering data, Relay Word bit status, and fault summary data, including fault location, fault type, and traveling-wave arrival times. Optimize data collection by using as many as five configurable data maps that allow you to select and organize the data you need in as many as six concurrent DNP sessions over Ethernet.
- **SEL ASCII commands.** SEL ASCII commands enable communication between a human operator and the device via any standard terminal emulator or Telnet client. A machine client can also use the SEL ASCII protocol to communicate with the device, collect data, and issue commands. *Section 7: Engineering and Operator Access Interfaces and Tools* provides information on how to use SEL ASCII commands for engineering access, and *Appendix C: SEL ASCII Commands* describes SEL-TWFL commands.
- **SEL Compressed ASCII commands.** SEL Compressed ASCII commands are a subset of SEL ASCII commands to which the SEL-TWFL responds with comma-delimited messages formatted for ease of parsing by machine clients. Use SEL Compressed ASCII commands to obtain data contained in device reports. Refer to *SEL Compressed ASCII Commands* on page 8.7 for detailed information on how to use the SEL Compressed ASCII protocol. As many as three machine clients can interact concurrently with the SEL-TWFL through use of SEL Compressed ASCII commands over Ethernet. Consider using an RTAC, such as the SEL-3530, as the SEL Compressed ASCII protocol client and SCADA gateway.
- **SEL Binary Protocols (Fast Meter and Fast SER).** These are binary machine-to-machine protocols for obtaining time-variant data (metering and status) and Sequential Events Recorder (SER) data. SEL binary communications transactions can be used concurrently with the SEL ASCII protocol session. SEL Fast Meter and SEL Fast SER protocols complement the SEL Compressed ASCII commands. Use the SEL Fast Meter protocol to solicit time-variant data. Use the SEL Fast SER protocol to obtain data contained in SEL-TWFL SER records. As many as three machine clients can concurrently interact with the SEL-TWFL through use of these protocols over Ethernet. Consider using an RTAC, such as the SEL-3530, as the SEL Fast Meter and SEL Fast SER protocol client and SCADA gateway.

- **File Transfer Protocol.** File Transfer Protocol (FTP) is a standard TCP/IP protocol for exchanging files. Use FTP to access the SEL-TWFL files including settings, reports, and transient records. Use any standard FTP client such as File Explorer or an internet browser.

Table 8.1 summarizes the SEL-TWFL protocols and their applications.

Table 8.1 SEL-TWFL Ports, Protocols, and Applications

Port	Protocols	Application Description
Port F; USB	SEL ASCII commands SEL Compressed ASCII commands SEL Fast Meter and SEL Fast SER	Temporary local engineering access for maintenance, testing and commissioning, and upgrading firmware.
Port 5; Ethernet	DNP3 LAN/WAN[a] SEL ASCII commands[b] SEL Compressed ASCII commands[b] SEL Fast Meter and SEL Fast SER FTP[c]	Remote engineering access and permanent connection to SCADA or HMI client.

[a] As many as six concurrent sessions.
[b] Via Telnet; as many as three concurrent sessions.
[c] Single session.

This section is organized as follows:

- *DNP3 LAN/WAN Protocol* on page 8.2 explains how to enable DNP3 LAN/WAN communications and describes the basic DNP configuration settings necessary for communicating with the SCADA system. For additional information on DNP3 in the SEL-TWFL, see *Appendix I: Distributed Network Protocol*.
- *File Transfer Protocol* on page 8.4 explains how to enable and configure FTP and how to use an FTP client to browse and copy device files.
- *Telnet Protocol* on page 8.5 explains how to enable and configure Telnet to allow the use of SEL ASCII commands, SEL Compressed ASCII commands, and SEL Fast Meter and SEL Fast SER protocols.
- *SEL Compressed ASCII Commands* on page 8.7 explains how to use SEL Compressed ASCII commands to communicate with the SEL-TWFL.
- *SEL Fast Binary Protocols* on page 8.13 explains how to use SEL Fast Meter and SEL Fast SER protocols for data collection and reporting metering and other information.
- *SEL-TWFL File Directories* on page 8.15 provides information on the device files and directories. These files include settings files, various reports, and transient records.

Appendix J: Cybersecurity Features summarizes the cybersecurity features of the SEL-TWFL and provides guidelines for secure application of the device.

DNP3 LAN/WAN Protocol

The SEL-TWFL allows as many as six concurrent DNP3 LAN/WAN sessions on Ethernet Port 5 for communicating with the SCADA system. Use DNP3 to retrieve metering data, Relay Word bit status, fault summary information (includ-

ing fault location, fault type, pre-fault and fault currents and voltages, and traveling-wave arrival times), and line monitoring data. Additionally, you can use DNP3 to reset latched targets. See *Appendix I: Distributed Network Protocol* for more information on DNP3 LAN/WAN in the SEL-TWFL.

Table I.2 shows the DNP3 settings. The following section describes SEL-TWFL DNP3 communication settings required to establish DNP3 LAN/WAN communications with the SCADA system.

DNP3 Communications Settings

Table 8.2 lists the DNP3 communications settings. These settings apply to all DNP3 sessions.

Table 8.2 DNP Communications Settings

Setting	Description	Range	Default	Class
EDNP	Enable DNP Sessions	0–6	0	Port 5
DNPADR	Device DNP Address	0–65519	0	Port 5
DNPPNUM	DNP TCP and UDP Port	1025–65534	20000	Port 5
EVELOCK	Event Summary Lock Period	0–1000 s	0	Port 5
DNPID	DNP ID for Object 0, Var 246	20 characters	TWFL1-DNP	Port 5

Follow these settings rules when configuring the DNP3 settings.

EDNP

Use the EDNP setting to enable as many as six DNP3 sessions (EDNP = 1–6) on Ethernet Port 5. Set EDNP to 0 to disable DNP. Make sure that the port is enabled (EPORT = Y) and configured properly for use on the Ethernet LAN before entering the DNP3 communications settings. See *Establishing Communication Over Ethernet Port 5* on page 7.46 for instructions on how to configure Port 5.

DNPADR

Use the DNPADR setting to specify the SEL-TWFL DNP3 address.

DNPPNUM

Use the DNPPNUM setting to specify the TCP or UDP port for DNP3 LAN/WAN communications. If Telnet is enabled (ETELNET = Y), the DNP TCP or UDP port setting must be different than the Telnet port setting.

EVELOCK

Use the EVELOCK setting to specify the event summary lock period to ensure the DNP3 master has enough time to retrieve all the intended fault summary data.

When DNP3 session *n* (*n* = 1–6) is in the single-event mode, any new fault summary data generate a DNP3 event. The device will not update the DNP3 event registers for subsequent fault summary data for EVELOCK time. See *Reading Device Fault Summary Data* on page I.13 for additional information on EVELOCK, RPEVTYP*n*, and related settings.

DNPID

Set the DNP3 ID that will be returned for reads of Object 0, Variation 246.

File Transfer Protocol

FTP is a standard application-level protocol for exchanging files over a TCP/IP network. The SEL-TWFL operates as an FTP server presenting files to an FTP client. Use FTP to move files from the SEL-TWFL to the SCADA/HMI computer. Typical applications include retrieval of transient record (IEEE COMTRADE) files.

You need Access Level 1 privileges to use FTP with the SEL-TWFL. The device serves one FTP session and denies any subsequent requests to establish multiple FTP sessions. You can use Telnet and FTP concurrently on Ethernet Port 5.

Table 8.3 shows the FTP settings.

Table 8.3 FTP Settings

Setting	Description	Range	Default	Class
EFTPSERV	Enable FTP	Y, N	N	Port 5
FTPCBAN	FTP Connect Banner	ASCII string with a maximum length of 254 characters	FTP SERVER	Port 5
FTPIDLE	FTP Idle Time-Out	5–255 min	5	Port 5

Follow these settings rules when configuring the FTP settings.

EFTPSERV

NOTE: Use the MAXACC Port 5 setting to restrict access levels for FTP, as required. It is good practice to restrict access levels for Port 5 to Access Level 1 (set MAXACC to 1). This allows access to device data and records, yet it prevents unintentional or malicious deletion of data or changes to device settings. The SEL-TWFL allows FTP login at Access Levels 1 and 2 (FTP usernames ACC and 2AC, respectively).

Enable (EFTPSERV = Y) or disable (EFTPSERV = N) FTP. Ensure Port 5 is enabled (EPORT = Y) and configured properly for use on the Ethernet LAN before entering FTP settings. See *Establishing Communication Over Ethernet Port 5* on page 7.46 for instructions on how to configure Port 5. Issue the **PING** command from the computer to verify that the FTP client computer is connected to the target device. If you experience problems with FTP, troubleshoot communications settings between the PC and the device, the FTP client configuration, and the network configuration.

FTPCBAN

Use the FTPCBAN setting to specify the connect banner. The SEL-TWFL responds with this banner during the FTP session. Consider using unique banners to ensure the FTP client has accessed the correct device.

FTPIDLE

Use the FTPIDLE setting to specify the time-out period for an inactive session. The SEL-TWFL terminates an FTP session after the client is inactive for a period of time equal to the value of the FTPIDLE setting.

You can use any compliant FTP client with the SEL-TWFL over a TCP/IP Ethernet network. Note that internet browsers often provide FTP functionality and that File Explorer also acts as an FTP client.

NOTE: Enter the three-character access level name and password for that access level as the FTP client username and password.

To initiate an FTP session through use of File Explorer or an internet browser, type **ftp://** followed by the IP address of the target device. You will see a prompt similar to that shown in *Figure 8.1*. Enter the three-character access level name as the username, and enter the access level password for the username. For example, with default passwords, if you use the username of 2AC and password of TAIL, you will connect with Access Level 2 privileges. After you have successfully logged on, you will see the SEL-TWFL file directory, as shown in *Figure 8.2*, which you can browse, copy files from, and copy files to.

Figure 8.1 File Explorer FTP Client Logon Window

Figure 8.2 SEL-TWFL Root Directory

SEL-TWFL File Directories on page 8.15 describes the SEL-TWFL directories and their content and it applies to an FTP session.

Telnet Protocol

Telnet is a terminal emulation protocol that works over a TCP/IP Ethernet network. You can use SEL ASCII and SEL Compressed ASCII commands over Telnet (see *Appendix C: SEL ASCII Commands*).

The SEL-TWFL allows as many as three Telnet sessions and will deny any subsequent requests for additional sessions. Telnet and FTP will run concurrently on Ethernet Port 5. You can use any compliant Telnet client with the SEL-TWFL. To initiate a Telnet session from QuickSet, click **Communications > Parameters**, select **Network** from the **Active Connection Type** box, and enter the appropriate settings. Access the terminal window via the terminal icon on the menu bar or select the **QuickSet** window and press **<CTRL+T>**. To terminate a Telnet session, use the **EXI** command from any access level.

Table 8.4 shows the Telnet settings.

Table 8.4 Telnet Settings

Setting	Description	Range	Default	Class
ETELNET	Enable Telnet	Y, N	N	Port 5
TPORT	Telnet Port	1025–65534, 23	23	Port 5
TCBAN	Telnet Connect Banner	ASCII string with a maximum length of 254 characters	TERMINAL SERVER	Port 5
TIDLE	Telnet Port Time-Out	1–30 min	15	Port 5
AUTO	Send Auto Messages to Port	Y, N	N	Port 5

Follow these settings rules when configuring the Telnet settings.

ETELNET

NOTE: Use the MAXACC Port 5 setting to restrict access levels for SEL ASCII commands over Ethernet/Telnet, as required. It is good practice to restrict access levels for Port 5 to Access Level 1 (set MAXACC to 1). This allows access to device data and records, yet it prevents unintentional or malicious deletion of data or changes to device settings.

Enable (ETELNET = Y) or disable (ETELNET = N) the Telnet protocol. Verify that the port is enabled (EPORT = Y) and configured properly for use on the Ethernet LAN before entering Telnet settings. See *Establishing Communication Over Ethernet Port 5* on page 7.46 for instructions on how to configure Port 5. Issue the **PING** command from the computer to verify connection between the Telnet client computer and the target SEL-TWFL. If you experience problems with the Telnet protocol, troubleshoot communications settings between the PC and the device, the Telnet client configuration, and the network configuration.

TPORT

Set the Telnet port for the Telnet sessions. Port 23 is typically used for this purpose.

TCBAN

Use the TCBAN setting to specify the connect banner. The SEL-TWFL responds with this banner upon initiation of the Telnet session. Consider using unique banners to ensure the Telnet client has accessed the correct device.

TIDLE

Use the TIDLE setting to specify the time-out period for an inactive session. The SEL-TWFL terminates a Telnet session after the client is inactive for a period of time equal to the value of the TIDLE setting.

AUTO

Use the AUTO setting to enable automatic messages on Port 5. With AUTO set to Y, the SEL-TWFL reports a message upon initiating a Telnet session, a diagnostic (self-test) failure, or a transient record trigger. For virtual (Telnet) ports/sessions, the device issues automatic messages only if the connection is active. Automatic messages contain the following information:

- **Session Initiation:** When a Telnet session starts, the SEL-TWFL transmits a message providing common header information (including the fault locator, station, and firmware ID; serial number; time source information; and the present date and time).
- **Diagnostic:** When the SEL-TWFL detects an internal problem, the device responds with the status report.
- **Event:** When the SEL-TWFL triggers a transient record, the device responds with the summary report.

You can use Telnet to work with files. See *FILE* on page C.8 and *SEL-TWFL File Directories* on page 8.15 for more information on how to use SEL ASCII commands to work with files.

SEL Compressed ASCII Commands

SEL Compressed ASCII commands are a subset of SEL ASCII commands to which the SEL-TWFL responds in a comma-delimited format for ease of parsing by machine clients (rather than messages formatted for human readability). SEL Compressed ASCII commands help machine clients in SCADA and HMI applications access device data quickly and efficiently because SCADA and HMI software can parse and interpret comma-delimited messages without expending the customization and maintenance labor needed to interpret non-delimited messages formatted for human readability. Most spreadsheet and database programs can directly import comma-delimited files.

Responses to SEL Compressed ASCII commands include a checksum field. The SEL-TWFL calculates a checksum for each line by numerically summing all of the bytes that precede the checksum field in the message. The client software that uses the data can detect transmission errors in the message by summing the characters of the received message and comparing this sum to the received checksum.

Responses to SEL Compressed ASCII commands generally have fewer characters than conventional reports because the compressed reports reduce blanks, tabs, and other white space between data fields (typically used to ensure human readability) to a single comma. Hence the name *Compressed* ASCII commands.

Table 8.5 lists the SEL Compressed ASCII commands and contents of the command responses. These commands are described in detail in *Commands for Machine Clients* on page C.21.

Table 8.5 SEL Compressed ASCII Commands

Command	Response	Minimum Access Level
BNAME	ASCII names of Fast Meter status bits	0
CASCII	Configuration data of all Compressed ASCII commands available at Access Level 1 and above	0
CHISTORY	Compressed version of the history report	1
CSTATUS	Compressed version of the status report	1
DNAME	ASCII names of digital I/O reported in Fast Meter	0
ID	Device identification	0
SNS	ASCII names for SER data reported in Fast Meter	0

Device Message Format in Response to SEL Compressed ASCII Commands

Each message begins with the start-of-transmission character, STX, and ends with the end-of-transmission character, ETX:

```
<STX><MESSAGE LINE 1><CR><LF>
<MESSAGE LINE 2><CR><LF>
...
<LAST MESSAGE LINE><CR><LF><ETX>
```

Each line in the message consists of one or more data fields, a checksum field, and a new line indication (<CR><LF>; carriage return and line feed). Commas separate adjacent fields. Each field is either a number or a string. Number fields contain base-10 numbers using the ASCII characters 0–9, plus (+), minus (–), and period (.). String fields begin and end with quote marks and contain standard ASCII characters. Hexadecimal numbers are contained in string fields.

The checksum consists of four ASCII characters that are the hexadecimal representation of the two-byte binary checksum. The checksum value is the sum of the first byte on a line (first byte following <STX>, <CR>, or <CR><LF>) through the comma preceding the checksum.

If you request data by issuing an SEL Compressed ASCII command and these data are not available (such as in the case of an empty history record), the SEL-TWFL responds with the following SEL Compressed ASCII format message:

```
<STX>"No Data Available","0668"<CR><LF><ETX>
```

where:

No Data Available is a text string field.

0668 is the checksum field, which is a hexadecimal number represented by a character string.

CASCII Configuration Message for SEL Compressed ASCII Commands

The SEL-TWFL allows the configuration **CASCII** command (see *CASCII* on page C.22) to simplify machine data extraction from SEL-TWFL responses (reports) to SEL Compressed ASCII commands. The device responds to the **CASCII** command with a block of data for each of the Compressed ASCII commands it allows (**CHISTORY** and **CSTATUS** commands). The block of data for each command provides information allowing machine data extraction from the message the SEL-TWFL sends in response to the command. The SCADA and HMI client can use SEL ASCII commands to issue the **CASCII** command to perform the following:

1. Identify or confirm the set of SEL Compressed ASCII commands that the SEL-TWFL allows.
2. Learn how to parse and decode the SEL-TWFL response to each of the SEL Compressed ASCII commands.

The SEL-TWFL arranges items in the SEL Compressed ASCII configuration message in a predefined order. For the purpose of improving products and services, SEL sometimes changes the items and item order. The information presented below explains the message and serves as a guide to the items in SEL Compressed ASCII configuration messages.

An SEL Compressed ASCII command can require multiple header and data configuration lines. The following is an example of the general format of an SEL Compressed ASCII configuration message:

```
<STX>"CAS",n,"yyyy"<CR><LF>
"COMMAND 1",ll,"yyyy"<CR><LF>
"#H","xxxxx","xxxxx",......,"xxxxx","yyyy"<CR><LF>
"#D","ddd","ddd","ddd","ddd",......,"ddd","yyyy"<CR><LF>
.
.
.
.
"COMMAND n",ll,"yyyy"<CR><LF>
"#H","xxxxx","xxxxx",......,"xxxxx","yyyy"<CR><LF>
"#D","ddd","ddd","ddd","ddd",......,"ddd","yyyy"<CR><LF><ETX>
```

where:

n is the number of SEL Compressed ASCII command descriptions to follow.

COMMAND is the ASCII name for the SEL Compressed ASCII command that the device allows. The naming convention for the Compressed ASCII commands is a C character preceding the typical command. For example, **CSTATUS**, abbreviated to **CST**, is the SEL Compressed ASCII **STATUS** command.

#H identifies a header line to precede one or more data lines in the device response message; the # character represents the number of subsequent ASCII names. For example, 21H identifies a header line with 21 ASCII labels.

#D identifies a data line.

xxxxx is an ASCII name for corresponding data on following data lines in the device response message. The maximum ASCII name length is 10 characters.

ddd identifies a format field containing one of the following type designators:

- I – Integer data
- F – Floating-point data
- *z*S – String of maximum *z* characters (for example, 10S indicates a string with a maximum of 10 characters)

yyyy is the 4-byte hexadecimal ASCII representation of the checksum. A new line indication (<CR><LF>) follows every checksum.

Similar to the **CASCII** command, the **ID** command (see *IDENTIFICATION* on page C.23) is used to extract identification information from the SEL-TWFL in SEL Compressed ASCII format. The following is an example of the general format of an SEL Compressed ID message:

```
"FID=SEL-TWFL-Rnnn-Vx-Zssspp-Dyyyymmdd","yyyy"
"BFID=SLBT-TWFL-Rxxx-Vx-Zxxxxxx-Dxxxxxxxx","yyyy"
"CID=nnnn","yyyy"
"DEVID=CONAM, SID, FLID","yyyy"
"DEVCODE=mm","yyyy"
"PARTNO=TWFL#xxxx","yyyy"
"SERIALNO=xxxxxxxxxx","yyyy"
"CONFIG=abcdefgh","yyyy"
```

where:

FID is the firmware identification string.

BFID is the SELBOOT firmware identification string (see *SELBOOT Firmware Revision History* on page A.1 for further information).

CID is the firmware file checksum.

DEVID is the device identifier comprising the CONAM, SID, and FLID settings.

DEVCODE is a unique SEL device code used for identification purposes.

PARTNO is the device part number.

SERIALNO is the device serial number.

CONFIG identifies a format field in which the designator positions (abcdefgh) indicate a specific device configuration as follows:

- a represents the nominal frequency, where 1 = 60 Hz and 2 = 50 Hz.
- b represents the phase rotation, where 1 = ABC and 2 = ACB.
- c represents the phase input current scaling, where 1 = 5 A and 2 = 1 A.
- d is reserved; always shows as 0.
- e represents the VY voltage input connection, where 2 = Wye.
- f represents the current input connection, where 2 = Wye.
- g represents the date format, where 1 = YMD.
- h is reserved; always shows as 0.

Compressed Reports

The SEL-TWFL provides a compressed history report and a compressed status report.

Compressed History Report

The device responds to the compressed history command, **CHISTORY** (see *CHISTORY* on page C.22), with a compressed report containing the same information as the history record (see *History Record* on page 5.18). *Figure 8.3* shows a sample compressed history report, and *Table 8.6* describes the individual data items.

```
==>>CHI <Enter>
"FLID","SID","FID","0422"
"SEL-TWFL","StationA","FID=SEL-TWFL-R100-V0-Z001001-D20240129","0F90"
"REF_NUM","YEAR","MONTH","DAY","HOUR","MIN","SEC","MSEC","USEC","EVENT","L1_FLOC",
   "L2_FLOC","TARGETS","1863"
11150,2024,1,30,16,49,7,149,864,"FL",23.07,$$$$$$$,"L1FL","0AFA"
11149,2024,1,30,16,41,52,149,964,"FL",$$$$$$$,26.17,"L2FL L2LMA","0CA8"
11148,2024,1,30,16,38,41,149,764,"FL",21.41,$$$$$$$,"L1FL L1LMA","0C9F"
11147,2024,1,30,16,35,30,149,764,"FL",21.41,$$$$$$$,"L1FL","0B22"
11146,2024,1,30,16,32,30,149,964,"FL",$$$$$$$,26.17,"L2FL","0B29"
11145,2024,1,30,16,29,30,149,964,"FL",$$$$$$$,40.09,"L2FL","0B2B"
11144,2024,1,30,16,25,0,149,764,"FL",45.33,$$$$$$$,"L1FL","0AF2"
```

Figure 8.3 Sample Compressed History Report

Table 8.6 Information included in the Compressed History Report

Data Item	Description	Comments
FLID	Fault locator identifier specified by the FLID setting	Refer to *Table C.2* for further information on each of these fields
SID	Station identifier specified by the SID setting	
FID	Firmware identification string for SEL devices	
REF_NUM	Unique transient (event) record number	Refer to *Table 5.8* for further information on each of these fields
YEAR	Date and time of transient record capture in UTC time	
MONTH		
DAY		
HOUR		
MIN		
SEC		
MSEC		
USEC		
EVENT	Indicates the mechanism that generated the transient record	
L1_FLOC	Fault-location result for Line *m* in units determined by the LLUNIT setting	
L2_FLOC		
TARGETS	Fault locator and line monitor trigger status	

Compressed Status Report

The device responds to the compressed status command, **CSTATUS** (see *CSTATUS* on page C.22), with a compressed status report containing information from extended diagnostic self-checks for detecting failures and out-of-tolerance conditions (see *Appendix F: Diagnostics* for additional information). *Figure 8.4* shows a sample CSTATUS report, and *Table 8.7* describes the individual diagnostic data items. The **Self-Test Description** column in *Table 8.7* references the column in *Table F.2* of the same name. Refer to *Table F.2* for recommended actions if one of the CSTATUS report self-test fields displays a warning or failure condition. Note that the CSTATUS report also contains the FID field, containing the firmware identification string of the device (see *Table C.2* for additional information on the FID string), as well as the date and time that the CSTATUS report was generated (i.e., the MONTH, DAY, YEAR, HOUR, MIN, SEC, and MSEC fields).

```
=>>CST <Enter>
"FID","0143"
"FID=SEL-TWFL-R100-V0-Z001001-D20240129","093F"
"MONTH","DAY","YEAR","HOUR","MIN","SEC","MSEC","0ACA"
1,30,2024,17,0,43,699,"0437"
"MB_PS","AI_PS","DC_OFFSET","SETTINGS","EEPROM","USB","SD_CARD","RAM","FLASH","DATA
    _ACQ","MB_PROC","MB_SOC","AI_FPGA","TEMP","RTC","HMI","IO_BOARD","2461"
"OK","OK","OK","OK","OK","OK","OK","OK","OK","OK","OK","OK","44.3","OK","OK","
    OK","11D9"

=>>
```

Figure 8.4 Sample Compressed Status Report

Table 8.7 Diagnostic Information Included in the Compressed Status Report

Data Item	Possible Field Values	Self-Test Description
MB_PS	OK, WARN, FAIL	Top Printed Circuit Board Power Supply Out of Tolerance (WARN); Top Printed Circuit Board Power Supply Failure (FAIL)
AI_PS	OK, WARN, FAIL	Analog Input Board Power Supply Out of Tolerance (WARN); Analog Input Board Power Supply Failure (FAIL)
DC_OFFSET	OK, WARN	Current/Voltage Channel DC Offset Out of Tolerance (WARN)
SETTINGS	OK, FAIL	Settings Failure (FAIL)
EEPROM	OK, WARN, FAIL	EEPROM Warning (Invalid MAC address) (WARN); EEPROM Failure (FAIL)
USB	OK, FAIL	USB Failure (FAIL)
SD_CARD	OK, WARN	SD Card Warning (WARN)
RAM	OK, FAIL	Random-Access Memory Failure (FAIL)
FLASH	OK, WARN, FAIL	SELBOOT Firmware Verification Failure (WARN); Firmware Verification Failure (FAIL)
DATA_ACQ	OK, FAIL	Analog Input Board ADC Subsystem Failure (FAIL)
MB_PROC	OK, FAIL	Central Processor Failure (FAIL)
MB_SOC	OK, FAIL	Top Printed Circuit Board Critical Error Detected (FAIL)
AI_FPGA	OK, FAIL	Analog Input Board Critical Error Detected (FAIL)
TEMP	Degrees Celsius (“W” appended if outside acceptable temperature range)	Top Printed Circuit Board Temperature Warning
RTC	OK, WARN	Real-Time Clock Warning (WARN)
HMI	OK, WARN	HMI Board Missing Warning (WARN)
IO BOARD	OK, FAIL	I/O Board Missing (FAIL)

Software Flow Control

Software handshaking is a form of flow control that two communicating devices use to prevent input buffer overflow and loss of characters. The device uses XON and XOFF control characters to implement software flow control for SEL ASCII commands.

The SEL-TWFL transmits the XOFF character when the device input buffer is more than 75 percent full. The connected device should monitor the data it receives for the XOFF character to prevent device input buffer overflow. The

external device should suspend transmission at the end of a message in progress when it receives the XOFF character. When the SEL-TWFL has processed the input buffer so that the buffer is less than 25 percent full, the device transmits an XON character. The external device should resume normal transmission after receiving the XON character.

The SEL-TWFL also uses XON/XOFF flow control to pause data transmission to avoid overflow of the input buffer in a connected device. When the SEL-TWFL receives an XOFF character during transmission, it pauses transmission at the end of the message in progress. If there is no message in progress when the device receives the XOFF character, it blocks transmission of any subsequent message. Normal transmission resumes after the device receives an XON character.

SEL Fast Binary Protocols

SEL Fast Meter is a communications protocol in the SEL-TWFL that uses binary messages to provide responses to solicitations for metering information. In addition to solicited metering information, the device can also send unsolicited SER data through use of the SEL Fast SER protocol with binary messages.

The SEL-TWFL interleaves SEL Fast Meter and SEL Fast SER messages with SEL ASCII command messages. The device serves separate data streams over the same port. Data communications with the SEL-TWFL consist of SEL ASCII commands and reports through use of a terminal or a terminal emulator with a human operator or a machine client sending commands and receiving device responses. The binary data streams can interrupt the SEL ASCII data stream to obtain such time-sensitive information as metering or status data, and then allow the ASCII data stream to continue.

This mechanism allows use of a single communications channel for SEL ASCII command communications interleaved with short bursts of binary data to allow fast acquisition of metering or status data (SEL Fast Meter and SEL Fast SER). The client software must allow two separate data streams in order to use this feature. The binary commands and ASCII commands can also be accessed by a device that does not interleave the data streams. Real-time automation controllers, such as the SEL-3530 Real-Time Automation Controller (RTAC), use both binary messages and SEL ASCII commands to collect data from SEL devices for SCADA and HMI functions. SEL recommends using an SEL RTAC to collect SEL Fast Meter and SEL Fast SER data on Ethernet Port 5 over Telnet.

SEL Application Guide, *Configuration and Fast Meter Messages* (AG95-10), available at selinc.com, provides a comprehensive description of the SEL Fast Meter messages.

This section summarizes the binary commands and messages that the SEL-TWFL allows. SEL recommends using SEL Fast Meter and SEL Fast SER Commands and Compressed ASCII configuration information to communicate with the SEL-TWFL. This information is necessary to develop or specify the software that an external device uses to communicate with the SEL-TWFL through use of the SEL Fast Message protocol. To develop your own SEL Fast Protocol client, you will also need to contact SEL for SEL Fast protocol details.

Table 8.8 lists the two-byte SEL Fast Meter commands and the actions the SEL-TWFL takes in response to each command.

Table 8.8 SEL Fast Meter Binary Messages and Device Actions

Command (Hex)	Message Name	Device Action
A5B9	Status Bits Clear Command	Device clears SEL Fast Meter status byte.
A5C0	Fast Meter Definition	Device responds with available SEL Fast Meter messages and general configuration information.
A5C1	Fast Meter Configuration	Device responds with configuration of SEL Fast Meter data message.
A5D1	Fast Meter Data	Device responds with present values of analog and digital data.

General Fast Messages have a two-byte identifier (A546h) and a function code. SEL Fast SER messages are general Fast Messages that transport SER record information. The SEL Fast SER messages include function codes to accomplish different tasks. *Table 8.9* lists the SEL Fast SER function codes and the actions the SEL-TWFL takes in response to each command.

Table 8.9 Fast Message Command Function Codes Used With Fast Messages (A546 Message) Actions

Function Code (Hex)	Function	Device Action
00h	Request Fast Message definition block	Device transmits SEL Fast Message definition request acknowledged message (Function Code 80h).
01h	Enable unsolicited transfers	Device transmits SEL Fast SER command acknowledged message (Function Code 81h). Device will transmit subsequent SER events (Unsolicited SER broadcast, Function Code 18).
02h	Disable unsolicited transfers	Device sends SEL Fast SER command acknowledged message (Function Code 82h). Device will not transmit subsequent SER messages.
05h	Ping (determines if channel is operable)	Device aborts unsolicited message in progress and transmits ping acknowledged message (Function Code 85h).
98h	Acknowledge Fast SER message	Device completes dialog processing for unsolicited message sequence.

Recommended Use of SEL Compressed ASCII and Fast Message Commands

Compressed ASCII and Fast Message commands provide information that allows a machine client to adapt to the SEL-TWFL messages (listed in *Table 8.10*). The SEL RTAC uses the self-description messages to configure a database and name the elements in that database.

Table 8.10 lists commands and command usage in the recommended order of execution for self-configuration. See *Commands for Machine Clients* on page C.21 for more information on the ASCII commands listed in *Table 8.10*.

Table 8.10 Commands in Recommended Sequence for Self-Configuration

Command (ASCII or Hexadecimal [h suffix])	Response	Usage
ID	Device identification	ID and FID
A5C0h	Device Fast Meter definition block	Defines available Fast Meter messages and general device configuration information
A5C1h	Fast Meter configuration blocks	Defines contents of Fast Meter data messages
BNA	Binary names	ASCII names of status bits
DNA X or **T**	Digital I/O names	ASCII names of digital I/O points
SNS	SER names	ASCII names for SER data points
CASCII	Compressed ASCII configuration block (works for **CHISTORY** and **CSTATUS**)	Configuration data for Compressed ASCII commands

SEL-TWFL File Directories

The SEL-TWFL works with a number of files organized in directories. These files include settings files, history and diagnostic records, the SER record, and transient record (event) files. You can browse and access these files through use of FTP or by using SEL ASCII commands in a terminal emulator on Port F or a Telnet client on Ethernet Port 5.

The SEL-TWFL root directory contains a CFG.TXT file and four directories: SETTINGS, EVENTS, REPORTS, and DIAGNOSTICS.

The settings files and the CFG.TXT file use the System Data Format (SDF) file system unless otherwise specified. The files may contain keywords to aid file parsing. A keyword is a string surrounded by the open and close bracket characters ([ ]) followed by a carriage return (<CR>) and line feed (<LF>). There can be only one keyword per line in the file. For example, the file would display the keyword INFO as follows: [INFO]<CR><LF>.

CFG.TXT File

The CFG.TXT file is a read-only file that contains general configuration information about the SEL-TWFL and each settings class. You may consider configuring SCADA/HMI software to retrieve the CFG.TXT file to determine the device configuration before performing other operations.

Figure 8.5 shows a sample CFG.TXT file. Each line containing information on settings classes includes checksums for the data contained in that line.

```
=>>FILE SHO CFG.TXT <Enter>
[INFO]
RELAYTYPE=TWFL
FID=SEL-TWFL-R100-V0-Z001001-D20240129
BFID=SLBT-TWFL-R100-V0-Z001001-D20231211
PARTNO=TWFL#0001
[CLASSES]
"1","Fault Locator Settings","\SETTINGS\SET_1.TXT","4B3A103A"
"R","Reports","\SETTINGS\SET_R.TXT","1A70FDF9"
"PF","Front Panel Port F","\SETTINGS\SET_PF.TXT","52FD101C"
"P1","Port 1","\SETTINGS\SET_P1.TXT","60235B4A"
"P2","Port 2","\SETTINGS\SET_P2.TXT","5D92B796"
"P3","Port 3","\SETTINGS\SET_P3.TXT","1B4082F2"
"P5","Ethernet Port 5","\SETTINGS\SET_P5.TXT","FD75FE7A"
"D1","DNP Map Settings 1","\SETTINGS\SET_D1.TXT","55597D52"
"D2","DNP Map Settings 2","\SETTINGS\SET_D2.TXT","55597D52"
"D3","DNP Map Settings 3","\SETTINGS\SET_D3.TXT","55597D52"
"D4","DNP Map Settings 4","\SETTINGS\SET_D4.TXT","55597D52"
"D5","DNP Map Settings 5","\SETTINGS\SET_D5.TXT","55597D52"
```

Figure 8.5 FILE SHO CFG.TXT Command Response

SETTINGS Directory

You can access SEL-TWFL settings through a number of files in the SETTINGS directory. SEL strongly recommends that you use software specifically designed to manipulate SEL settings files (such as ACSELERATOR QuickSet SEL-5030 Software) rather than directly accessing or editing these text files. The device only allows you to write to the individual SET_*cn* files, where *c* is the settings class code and *n* is the settings instance. Changing settings with software involves a number of steps, which you can have QuickSet perform for you. If, however, you choose to use the SCADA/HMI software to access settings, note that the settings files are organized as shown in *Table 8.11*.

The SETTINGS directory contains the settings files shown in *Table 8.11*.

Table 8.11 SETTINGS Directory Files (Sheet 1 of 2)

File	Description
ERR.TXT (read-only)	Report of the last settings write operation
SET_ALL.TXT (read-only)	All settings
SET_1.TXT	Device/Fault Locator settings
SET_D1.TXT	DNP Map Settings 1
SET_D2.TXT	DNP Map Settings 2
SET_D3.TXT	DNP Map Settings 3
SET_D4.TXT	DNP Map Settings 4
SET_D5.TXT	DNP Map Settings 5
SET_R.TXT	Recording settings (SER and transient recorder)
SET_P1.TXT	Port 1 settings
SET_P2.TXT	Port 2 settings

Table 8.11 SETTINGS Directory Files (Sheet 2 of 2)

File	Description
SET_P3.TXT	Port 3 settings
SET_P5.TXT	Ethernet Port 5 settings
SET_PF.TXT	Front-panel USB Port F settings
SET_CA.TXT	Calibration data for device hardware
SET_CM.TXT	Calibration data for device firmware

See *Settings Structure* on page 7.39 for more information on the organization of the SEL-TWFL settings.

SET_ALL.TXT File

The SET_ALL.TXT file contains all SEL-TWFL settings. You can only read this file. Extract SET_ALL.TXT if you want to archive device settings or inspect the device settings. Do not modify the extracted SET_ALL.TXT file. You will not be able to save it back to the SEL-TWFL.

SET_*cn*.TXT Files

The SETTINGS directory contains a file for each instance of each settings class. The settings class is designated by *c*, and the settings instance number by *n*. Read a file to archive and edit a given settings class and instance. Write back the file to modify device settings for that class and instance. The SEL-TWFL processes the settings file immediately after it saves it; you do not need to issue any commands to prompt the device to accept new settings.

ERR.TXT File

When you write a settings file, the SEL-TWFL checks the file format, settings ranges, and other settings rules. The ERR.TXT file reports errors (if any) for the last write operation for the settings file in the SETTINGS directory. If there were no errors, the ERR.TXT file will still be in the SETTINGS directory, but it will be empty.

SET_CA.TXT File (Access Level C – Calibration)

⚠WARNING
Do not attempt to modify the SET_CA.TXT or SET_CM.TXT files. They contain device calibration data. Modifying these files may lead to device misoperation. Limit access to Access Level C (calibration access) passwords and ensure proper training of field personnel.

The SET_CA.TXT file contains calibration data for device hardware. SEL Manufacturing creates this file individually for each specific SEL-TWFL article (serial number). The file must not be altered or else the device may incorrectly measure voltages and currents. The SEL-TWFL firmware upgrade process preserves this file. If you suspect that the SET_CA.TXT file has been inadvertently altered, contact SEL. SEL archives the SET_CA.TXT files for all SEL-TWFL devices shipped, and you can obtain a copy of the file if needed. It is also good practice to archive the SET_CA.TXT file for all new SEL-TWFL devices that you receive. A convenient time to archive the SET_CA.TXT file is when you set passwords for the device or when you commission the device for the first time. Save the file under the name SET_CA_serial_number.TXT for convenience.

SET_CM.TXT File (Access Level C – Calibration)

The SET_CM.TXT file contains calibration data for device firmware. This file is independent of hardware but may change when the firmware version changes (the R or V number in the FID string); see *Appendix B: Firmware Upgrade Instructions*. You do not need to maintain a copy of the SET_CM.TXT file. The SEL-TWFL firmware upgrade process overrides the old SET_CM.TXT file to guarantee the new firmware has matching calibration data. You must not alter this file without SEL supervision. SEL is not responsible for any damage resulting from modifying the SET_CM.TXT file without SEL knowledge and supervision.

EVENTS Directory

The SEL-TWFL stores history and compressed history records, as well as transient record files, in the EVENTS directory.

The HISTORY.TXT file contains the log of transient records in an ASCII format (see *HISTORY* on page C.9 and *Section 5: Transient and Sequential Events Recording* for more information). The CHISTORY.TXT file contains a log of transient records in an SEL Compressed ASCII format (see *CHISTORY* on page C.22 and *SEL Compressed ASCII Commands* on page 8.7 for more information).

The device stores the transient records in the binary IEEE C37.111-2013 COMTRADE format. The high-resolution 10 ksps records are labeled as TDR, and the ultra-high-resolution 1 Msps records are labeled as MHR. See *Section 5: Transient and Sequential Events Recording* for more information about device records.

When using an FTP client, browse the EVENTS directory and copy files in which you are interested. When using SEL ASCII commands to interface with the SEL-TWFL, use the **FILE DIR EVENTS** command to display the contents of the EVENTS directory and the **FILE READ EVENTS *filename.**** command to initiate a file transfer that uses the Ymodem protocol.

You cannot delete files in the EVENTS directory. You can, however, clear transient records by using the **HIS C** command. This command clears the history archive and deletes transient records in the device.

REPORTS Directory

Table 8.12 lists the files contained in the REPORTS directory. These files contain device responses to the corresponding SEL ASCII commands. See *Section 2: Fault Locator and Line Monitor* and *Section 5: Transient and Sequential Events Recording* for more information about the contents of these files. See *Appendix C: SEL ASCII Commands* for more information about the commands that produce REPORTS directory files.

When you retrieve a file, the SEL-TWFL executes the corresponding command to produce the most recent report data, writes these data to the file, and provides the file to you.

When using an FTP client, browse the REPORTS directory and copy the files in which you are interested. When interfacing with the SEL-TWFL through use of SEL ASCII commands, use the **FILE DIR REPORTS** command to display the contents of the REPORTS directory and the **FILE READ REPORTS *filename.**** command to initiate a file transfer that uses the Ymodem protocol.

You cannot delete files in the REPORTS directory.

Table 8.12 REPORTS Directory Files

File	Description
HISTORY.TXT	History record (created in response to the **HIS** command)
LINEMONL1.TXT	Line monitoring record for Line 1
LINEMONL1.CSV	
LINEMONL2.TXT	Line monitoring record for Line 2
LINEMONL2.CSV	
MET.TXT	Meter report (created in response to the **MET** command)
SER.TXT	Sequential Events Recorder record (created in response to the **SER** command)
TAR.TXT	Status of all the Relay Word bits (created in response to the **TAR ROW LIST** command)
CHISTORY.TXT	Compressed history record (created in response to the **CHI** command)

DIAGNOSTICS Directory

The DIAGNOSTICS directory contains those files that are listed in *Table 8.13*. These files contain device responses to the corresponding SEL ASCII commands. See *Appendix C: SEL ASCII Commands* for more information about the commands that produce reports (available as files) in the DIAGNOSTICS directory.

When you retrieve a file, the SEL-TWFL executes the corresponding command to produce the most recent report data, writes these data to the file, and provides the file to you.

When using an FTP client, browse the DIAGNOSTICS directory and copy the files of interest. When interfacing with the SEL-TWFL through use of SEL ASCII commands, use the **FILE DIR DIAGNOSTICS** command to display the contents of the DIAGNOSTICS directory and the **FILE READ DIAGNOSTICS *filename.**** command to initiate a file transfer that uses the Ymodem protocol.

You cannot delete files in the DIAGNOSTICS directory.

Table 8.13 DIAGNOSTICS Directory Files

File	Description
STATUS.TXT	Status record (created in response to the **STA** command)
VEC_D.TXT	Diagnostics vector (created in response to the **VEC D** command)
VEC_E.TXT	Exceptions vector (created in response to the **VEC E** command)

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SECTION 9

Installation

This section describes installation features and installation requirements for the SEL-TWFL.

Consider the following when installing the SEL-TWFL:

- *Environment and Mounting* on page 9.1
- *Electrical Connections* on page 9.3
- *Communications Ports* on page 9.7
- *AC/DC Connection Diagrams* on page 9.14
- *Accessing and Configuring Device Jumpers* on page 9.15

This section also provides recommendations for *Inspecting the Device* on page 9.18, *Replacing the SD Card* on page 9.21, *Replacing the Lithium Battery* on page 9.22, and *Cleaning Recommendations* on page 9.23.

Environment and Mounting

Device Size

The SEL-TWFL uses a horizontal, rack-mount 3U chassis, where one U is approximately 44.45 mm (1.75 in) high.

Physical Location

The SEL-TWFL is suitable for installation in Overvoltage Category III and Pollution Degree 2 environments according to IEC 60255-27:2013, *Measuring Relays and Protection Equipment – Part 27: Product Safety Requirements*. This rating allows mounting of the device indoors or in an outdoor enclosure where environmental conditions meet the ratings of the device and the device is protected from exposure to direct sunlight, precipitation, and full wind pressure.

The device is rated for operating temperatures from –40° to +85°C (–40° to +185°F) and a maximum altitude of 2,000 m (6,560 ft) above mean sea level. For detailed environmental specifications, see *Environmental* on page 1.10.

Mounting

See *Figure 9.1* for exact mounting dimensions for the device.

Use the reversible front flanges for either semiflush or projection mounting of the device. Semiflush mounting results in a small panel protrusion from the device rack rails of approximately 23.9 mm (0.94 in). Projection mounting places the device front panel approximately 84.8 mm (3.34 in) past the device rack rails. Use four screws of the appropriate size for your rack.

Figure 9.1 Chassis Dimensions

Figure 9.2 shows the front panel of the SEL-TWFL. For more information about front-panel operations, see *Front-Panel Operations* on page 7.4.

Figure 9.2 Front Panel

Rear-Panel Layout

Figure 9.3 shows the rear panel of the SEL-TWFL. The device provides terminals for the power supply, secondary CT and PT connections, contact I/O, and safety grounding of the chassis, as well as, a BNC connector for the IRIG-B signal. It also includes the following fiber-optic communications ports: Ports 1, 2, and 3 (for exchanging fault-locating data and receiving fault locator trigger commands) and Ethernet Port 5 (for engineering access and SCADA).

Figure 9.3 Rear Panel

Electrical Connections

Safety

NOTE: The danger symbol located on the rear panel corresponds to the following: *Contact with instrument terminals can cause electrical shock that can result in injury or death.*

Observe proper safety precautions when you connect the device at terminals marked by the safety symbols shown in *Figure 9.4*. Ensure that you limit access to these device terminals.

Figure 9.4 Rear-Panel Safety Symbols

Grounding

Connect the grounding (earthing) Terminal 31 (labeled **GND**; see *Figure 9.3*) to a rack frame ground or main station ground for proper safety and performance. Use 12–10 AWG (4–6 mm^2) wire less than 2 m (6.6 ft) long crimped to a green #8 hexagonal-head ground lug screw for this connection. This terminal connects directly to the internal chassis ground of the SEL-TWFL.

Power Supply

Connect Terminals 29 and 30, labeled **POWER**, to a dc or ac power source that matches the power supply range and ratings specified on the SEL-TWFL rear-panel serial number label (see *Figure 9.27*). *Figure 9.5* shows the terminals for the power supply connections. Note that only Terminals 29 and 30 are used for connecting power to the device. Although Terminals 29 (hot; **+/H**) and 30 (neutral; **−/N**) indicate polarity for convenience of troubleshooting wiring problems, the power supply is not polarity-sensitive. Both **POWER** terminals are isolated from the chassis ground.

Figure 9.5 Terminals for the Power Supply Connections

Connection to external power must comply with IEC 60947-1 and IEC 60947-3 (see *Wire Sizes* on page 1.10 for information on recommended wire size). Place an external switch, circuit breaker, or overcurrent device in the SEL-TWFL **POWER** circuit to allow interruption of both the hot (**+/H**) and neutral (**–/N**) leads. The current rating for the power-disconnect circuit breaker or fuse must be 20 A maximum. *Table 9.1* shows the SEL-TWFL internal power supply fuse information. Before wiring the **POWER** terminals, inspect the serial number label and verify that the power supply rating of the device matches your application.

Table 9.1 Internal Power Supply Fuse Information

Rated Voltage	Operational Voltage Range	Fuse F1	Fuse Description
48–125 Vdc or 110–120 Vac	38–140 Vdc or 85–140 Vac (30–120 Hz)	T3.15AH250V	5x20 mm, time-lag, 3.15 A, high-break capacity, 250 V
125–250 Vdc or 110–240 Vac	85–300 Vdc or 85–264 Vac (30–120 Hz)		

Secondary CT and PT Connections

The SEL-TWFL has two sets of three-phase current inputs labeled IW and IX (*Figure 9.6(a)*) and two sets of voltage inputs labeled VY and VZ (*Figure 9.6(b)*).

Figure 9.6 Terminal Blocks for Current and Voltage Inputs

Use the L1I and L2I current source selection settings to specify the currents associated with each line. In two-line applications, wire the CT currents to the corresponding IW and IX current inputs. In one-line applications, set L1I to IW, IX, or COMB and wire the CT currents to the selected current inputs. When using the COMB option, the SEL-TWFL adds the IW and IX currents. All current inputs are isolated from each other and the chassis, and you must ground selected terminals (current return terminals) by following the safety and grounding practices for secondary circuits. Before wiring the current inputs, inspect the serial number label and verify that the current rating of the device (5 A or 1 A) matches your application.

Use the VY and VZ voltage inputs to wire line voltages. Use the L1V and L2V voltage source selection settings to specify the voltages associated with each line. The VY voltage input is a four-wire input with a common neutral connection, and you can use it only with wye-connected PTs. The neutral terminal (Z16) of the VY voltage input is isolated from the other terminals and the chassis, and you must ground it following safety and grounding practices for secondary circuits. Terminals Z17 and Z18 are not used, and they are not connected to Terminal Z16.

The VAZ, VBZ, and VCZ voltage inputs are isolated from each other and the chassis, and you must ground selected terminals by following the safety and grounding practice for secondary circuits. Before wiring the voltage inputs, inspect the serial number label and verify that the voltage rating of the voltage input (144 Vrms terminal-to-terminal maximum rated voltage) is sufficient for your application.

⚠DANGER
Contact with instrument terminals can cause electrical shock that can result in injury or death.

⚠WARNING
Before working on a CT circuit, first apply a short to the secondary winding of the CT.

The alert symbol (⚠) on the rear panel indicates the need for proper safety precautions when working on secondary circuits connected to these terminals.

Connect the CT and PT wiring to the terminal blocks in the bottom row of the device rear panel (see *Wire Sizes* on page 1.10 for information on recommended wire size).

Contact Inputs

The SEL-TWFL has two sets of fixed-threshold optoisolated contact inputs. The Terminal 100 inputs, IN101 through IN105, are five contact inputs with a common terminal (*Figure 9.7(a)*). The Terminal 200 inputs, IN201 through IN208, are eight fully isolated contact inputs (*Figure 9.7(b)*). You can set the debounce timers individually for each of the contact inputs, and you can use SELOGIC equations to program how the device uses the contact inputs.

Figure 9.7 Terminal Blocks for Contact Inputs

All contact inputs share the same rated voltage, depending on the SEL-TWFL model. Before wiring the contact inputs, inspect the serial number label and verify that the contact input voltage rating of the device (48 V, 110 V, 125 V, 220 V, or 250 V) matches your application.

You must apply dc voltage to wet the contact inputs. The contact inputs are polarity-insensitive (bipolar operation), and the device will detect input changes with voltage applied at either polarity. However, inputs IN101 through IN105 share Terminal A22. Therefore, connections on Terminals A17 through A21 must have the same polarity.

Refer to *Contact Inputs* on page 1.9 for details on pickup and dropout thresholds and current draw for a specific rated contact input voltage. The contact input impedance is predominantly resistive, allowing a wide variety of contact outputs to drive the inputs.

Connect the contact outputs of the sending devices to the SEL-TWFL contact input terminal blocks in the top and middle rows of the device rear panel (see *Wire Sizes* on page 1.10 for information on recommended wire size).

Contact Outputs

The SEL-TWFL has two sets of contact outputs. The Terminal 100 outputs, OUT101 through OUT106, are six Form A high-speed trip-rated contact outputs that are intended for driving the circuit breaker trip coils directly, without interposing devices (*Figure 9.8(a)*). The Terminal 200 outputs, OUT201 through OUT208, are eight Form A contact outputs (*Figure 9.8(b)*). Additionally, the device provides a Form C Alarm output (*Figure 9.8(a)*).

Figure 9.8 Terminal Blocks for Contact Outputs

NOTE: Avoid using high-speed outputs to drive highly sensitive, high input-resistance electronic inputs (e.g., <2 mA electronic circuits) unless such inputs are connected in parallel with a low-resistance load (e.g., a breaker trip coil).

All contact outputs of all SEL-TWFL models are rated for 48–250 V and are polarity-insensitive. The device actuates all contact outputs every 0.1 ms. You can use SELOGIC equations to program how the device uses the contact outputs.

Alarm Output

The Alarm contact output uses a Form C configuration. Form C outputs share a common connection between normally closed (b) and normally open (a) contacts. *Figure 9.9* shows the configuration of the a and b contacts in the Alarm output.

The SEL-TWFL performs self-tests to monitor internal functions and hardware for out-of-tolerance conditions. If the device detects an internal out-of-tolerance condition, the device declares Status Warning or Status Failure and asserts the ALARM Relay Word bit (see *Appendix F: Diagnostics* for more information). The Alarm output operates when the ALARM Relay Word bit asserts. To provide a remote alarm for the device status that is independent of control power, connect the b contact of the Alarm output to your control system input. The device also operates the Alarm output for non-failure conditions, such as when it enters a temporary state that warrants operator awareness, including TW test mode, or upon a failed password entry attempt.

Figure 9.9 Alarm Contact Output and Terminal Assignments

Communications Ports

The SEL-TWFL has communications ports you can use for device signaling, SCADA, and engineering access. *Table 9.2* summarizes the communications ports and their applications.

Table 9.2 Communications Ports and Their Applications[a]

Port	Application	Medium	Connectors
PORT 1	Device signaling (8 inputs and 8 outputs per port) using SEL MB8 encoding and IEEE C37.94 encoding. Multi-ended TW-based fault locating and line monitoring when configured for IEEE C37.94 encoding.	Fiber, multimode	ST, 62.5/125 µm, 820 nm
PORT 2			
PORT 3			
PORT F	Front port, local engineering access[b]	Copper	USB, Type B
PORT 5	Engineering access	Fiber (100 Mbps[c]), multimode or single-mode	LC (SFP)

[a] Port 6 cannot be configured and is intended for future use.
[b] Port F also allows SEL ASCII (with Fast Meter) and Telnet protocols.
[c] The device ships with a 100 Mbps SFP transceiver. You can replace it with a 1 Gbps SFP transceiver from SEL.

Communications Ports 1, 2, and 3

NOTE: On a per port basis, select either SEL MB8 encoding for signaling local SEL relays and SEL I/O devices or IEEE C37.94 encoding for signaling the remote SEL-TWFL over compliant multiplexers. When using SEL MB8 encoding, select the baud rate on a per port basis. When using IEEE C37.94 encoding, the data rate is 64 kbps.

As shown in *Figure 9.10*, the device provides three multimode rear-panel fiber-optic communications ports (PORT 1, PORT 2, and PORT 3) with ST receptacles.

Figure 9.10 Multimode Fiber-Optic Communications Ports

Figure 9.11 shows a fiber-optic cable with ST connectors. Carefully insert the ST connector into the ST receptacle; push in and twist clockwise until the connector latches.

Figure 9.11 Fiber-Optic Cable With ST Connectors

Fault locating is the primary application for the SEL-TWFL fiber-optic ports (PORT 1, PORT 2, and PORT 3). For multi-ended fault-locating applications, configure these communications ports to IEEE C37.94 encoding to exchange fault-locating data over SONET/SDH/MPLS networks. Additionally, you may configure your protection system to send the fault locator trigger by using these communications ports. See *Section 3: Digital I/O and Communications Ports* for more information.

Figure 9.12 shows an application example using multiplexers that are compliant with IEEE C37.94. For this application, connect the SEL-TWFL directly to the fiber-optic interface on the multiplexer. Configure a communications port on each SEL-TWFL for IEEE C37.94 encoding and set the data clock to external. Program the ENCODING setting to use the IEEE C37.94-encoded connection for double-ended fault locating.

The multiplexer interface module should be set for a port data rate of N = 1 (1 x 64 kbps circuit).

Figure 9.12 Multi-Ended Fault-Locating Application for a Two-Terminal Line That Uses IEEE C37.94-Compliant Multiplexers

SEL-TWFL Connection With Local Protection Devices Over Fiber-Optic Ports 1, 2, and 3

SEL recommends using direct MIRRORED BITS communications when connecting with local protection devices. Connect an SEL-TWFL to a MIRRORED BITS-compatible device to trigger the fault locator and transient recorder functions in the SEL-TWFL. When connecting an SEL-TWFL to another SEL device with an EIA-232 port, use the SEL-2814 Fiber-Optic Transceiver With Hardware Flow Control (male connection) to convert the communications medium from fiber to copper, as shown in *Figure 9.13*. Set the DCE/DTE switch on the SEL-2814 to DCE. The other SEL device usually provides power to the SEL-2814 via the connector. If this is not the case, connect an external power supply to the power input of the SEL-2814.

The SEL-TWFL allows SEL MB8 encoding (see *Configuring and Troubleshooting MIRRORED BITS Communications* on page 3.5 for more information) to ensure compatibility with all other MIRRORED BITS-capable SEL products. Because SEL devices do not detect the MIRRORED BITS communications data rate, be sure to match the SPEED settings in both devices. The maximum MIRRORED BITS communications data rate differs among SEL products. For fast operation, set the MIRRORED BITS communications data rate to the maximum rate available between the two devices.

Figure 9.13 Communication With a MIRRORED BITS-Compatible Protection Device

SEL-TWFL Connection With Local Protection Devices Over Remote I/O Modules and Contact I/O

Figure 9.14 shows the case where the SEL-TWFL connects to a local device that is incompatible with the MIRRORED BITS communications protocol over an SEL remote I/O module. You can convert the MIRRORED BITS I/O into contact inputs and outputs through use of SEL remote I/O modules, such as the SEL-2507 High-Speed Remote I/O Module, and hardwire the appropriate I/O contacts between the end device and the SEL-2507. For this application, configure a fiber-optic port (PORT 1, PORT 2, or PORT 3) on the SEL-TWFL for SEL MB8 encoding.

Follow both the SEL-2507 and the local device wiring recommendations. Apply best practices for wiring the electrical connections between the SEL-2507 and the device. For the highest noise immunity, place the SEL-2507 in the immediate vicinity of the other protection device. Ensure that overly sensitive inputs (i.e., <2 mA) have additional load (e.g., a 33 kΩ, 5 W resistor) connected in parallel and avoid driving a single contact input with multiple high-speed hybrid contact outputs connected in parallel.

You must also set a number of SEL-2507 settings depending on the application. The SEL-2507 uses a ten-position control (DIP) switch to set the TX and RX addresses to match the SEL-TWFL port addresses, to match the port communications data rate, and to set the message security count setting. See *Configuring an SEL-2507 Connection* on page 3.16 for more information.

Figure 9.14 Communication With a Generic Protection Device by Using Contact I/O and an SEL Remote I/O Module

Fiber-Optic Small Form-Factor Pluggable Port

PORT 5 is a fiber-optic small form-factor pluggable (SFP) port with an LC connector, as shown in *Figure 9.15*. Use PORT 5 for access to Ethernet networking functions including TCP/IP, FTP, and Telnet over local-area and wide-area networks.

NOTE: PORT 6 is intended for future use and cannot be configured or used.

Figure 9.15 PORT 5 With SFP Transceiver Installed

When you order your SEL-TWFL, PORT 5 includes a 1310 nm 100BASE-FX SFP transceiver (SEL part number 8109-01) for local multimode fiber-optic Ethernet links within the control house building. The maximum distance achievable with this type of transceiver is 2 km (1.24 mi), as shown in *Table 9.3*. If your application requires longer distances or single-mode fiber, order the appropriate SFP transceiver separately, and install the SFP transceiver following SEL-recommended steps in *Installing and Replacing SFP Transceivers* on page 9.10.

Table 9.3 SFP Transceivers Distance and Cable Type

Transceiver Part Number	Standard	Fiber	Max. Distance	Wavelength	Link Budget	TX Power (dBm)	RX Sens. Max. (dBm)	RX Sens. Min. (dBm)
8103-01	100BASE-FX	MMF[a]	2 km (62.5/125 µm)	1310 nm	17 dB	–14 to –24	–12	–31
8109-01[b]								
8140-01	100BASE-FX	MMF	550 m (62.5/125 µm) 2 km (50/125 µm)	1310 nm	10 dB	–14 to –20	–8	–30
8131-01	1000BASE-SX	MMF	300 m (62.5/125 µm) 550 m (50/125 µm)	850 nm	9 dB	–2.5 to –9	0	–18
8130-01	1000BASE-LX	SMF[c]	10 km	1310 nm	11.5 dB	–3 to –9.5	–3	–21
8130-02	1000BASE-LX	SMF	20 km	1310 nm	16 dB	–1 to –6	–3	–22
8130-03	1000BASE-LX	SMF	30 km	1310 nm	19 dB	0 to –5	–3	–24
8130-04	1000BASE-LX	SMF	40 km	1310 nm	22 dB	3 to –2	–3	–24
8130-05	1000BASE-XD	SMF	50 km	1550 nm	19 dB	0 to –5	–3	–24
8130-06	1000BASE-ZX	SMF	80 km	1550 nm	24 dB	5 to 0	–3	–24
8130-08	1000BASE-ZX	SMF	160 km	1550 nm	37 dB	5 to 1	–10	–36
8130-10	1000BASE-ZX	SMF	200 km	1550 nm	41 dB	8 to 5	–10	–36

[a] MMF = multimode fiber.
[b] The device ships with this transceiver installed.
[c] SMF = single-mode fiber.

Installing and Replacing SFP Transceivers

Although SFP transceivers are hot-swappable, consider taking the device out of service before installing or changing the SFP transceiver.

SFP transceivers include a rubber plug to protect the electronics inside the port, as shown in *Figure 9.16(a)*. Ensure that the plug is present whenever the port is not in use. Attempting to clean the port may result in damage to the transceiver. For the same reason, be sure to first clean the LC cable connector before inserting the connector into the SFP receptacle. *Figure 9.16(b)* shows an SFP transceiver with the plug inserted to properly cover the port.

Figure 9.16 SFP Transceiver (a) Without Plug and (b) With Plug Inserted

Figure 9.16(a) also shows a lever that provides a mechanism by which you can hold the SFP transceiver when removing it from the device. Removing the SFP transceiver from the device without using this lever may result in damage to the SFP transceiver.

Figure 9.17(a) shows an SFP transceiver that is about to be inserted into the Port 5 receptacle. To install the SFP transceiver, gently push the SFP transceiver into the receptacle until fully inserted, as *Figure 9.17(b)* shows. When fully inserted, the SFP transceiver latches into position. Move the lever up to lock it in place (closed position).

Figure 9.17(b) shows the installed SFP transceiver with the lever in the closed position (up) and the rubber plug inserted. To insert the fiber-optic cable, leave the lever in the closed position but remove the rubber plug, as shown in *Figure 9.17(c)*.

Figure 9.17 SFP Transceiver (a) About to be Inserted, (b) Installed, and (c) Ready for Cable

Figure 9.18 shows a fiber-optic cable with LC connectors. Carefully insert the LC connectors into the SFP receptacles and gently push until the connectors latch, as shown in *Figure 9.19(a)*.

Figure 9.18 Fiber-Optic Cable With LC Connectors

To remove the SFP transceiver, first remove the fiber-optic cable and then move the lever to the open position (down), as shown in *Figure 9.19(b)*. Grip the lever and gently pull the SFP transceiver from the receptacle.

Figure 9.19 SFP Transceiver With (a) Properly Inserted Cable and (b) Lever Down for Removal

Working With Fiber-Optic Ports

⚠WARNING
Do not look into the fiber ports/connectors.

⚠WARNING
Do not look into the end of an optical cable connected to an optical output.

⚠CAUTION
Class 1 LASER Product. This product uses visible or invisible LASERs based on model option. Looking into optical connections, fiber ends, or bulkhead connections can result in hazardous radiation exposure.

All SEL-TWFL ports, except the front-panel Port F, are fiber-optic ports. Observe the following safety precautions when working with fiber-optic transceivers, patch cords, patch panels, and cables:

- Do not look into the fiber (laser) ports/connectors.
- Do not look into the end of an optical cable connected to an optical output.
- During installation, maintenance, or testing of the optical ports, use only test equipment qualified for Class 1 LASER products.
- Incorporated components, such as transceivers and laser emitters, are not user-serviceable. Return units (SEL-TWFL or SFP transceiver) to SEL for repair or replacement.
- Do not perform any procedures or adjustments that this instruction manual does not describe.

When selecting and installing fiber-optic cables, pay attention to the recommendation from the fiber-optic cable manufacturer for installation details, such as operating temperature, bend radius, mechanical strain, cable attenuation, and cable terminations.

IRIG-B Input Connection

NOTE: IRIG-B004 is a time format that replaces and is backward compatible with IRIG-B000.

Figure 9.20 shows the BNC connector for the IRIG-B timing input of the device. The SEL-TWFL IRIG-B input works with demodulated, high-accuracy signals with either odd or even parity that are compatible with IEEE C37.118 with time code extensions (IRIG-B004).

Figure 9.20 BNC Connector for the IRIG-B Timing Input

Figure 9.21 shows a coaxial cable with a BNC connector. Carefully insert the BNC connector into the BNC receptacle; push in and twist clockwise until the connector latches.

Figure 9.21 Coaxial Cable With BNC Connector

For the best SER report and transient recording time-stamp accuracy, use an IRIG-B source with a 10 ms edge time and jitter less than ±0.5 µs, such as a GPS satellite clock.

Figure 9.22 shows a typical IRIG-B signal distribution chain, including an SEL-2488 Satellite-Synchronized Network Clock and a recommended 50-ohm terminating resistor.

Figure 9.22 Typical IRIG-B Application Example

Note that the coaxial cable connecting signal distribution chain components causes a delay of 5.05 ns/m (1.54 ns/ft). Therefore, for the maximum length of 152 m (500 ft), the coaxial cable causes a delay of 0.77 µs between the clock and the last device in the chain. Furthermore, the cable between the GPS antenna and the clock also adds to the IRIG-B signal delay (unless the clock compensates for this delay).

For best results, place the SEL-TWFL close to the clock and make proper use of the cable-delay compensation settings available in most clocks. Whenever possible, use a direct IRIG-B connection or minimize the number of devices sharing the SEL-TWFL coaxial cable feed. Always use high-quality 50-ohm impedance coaxial cable (e.g., RG-58 or better).

For safety purposes, ground the shield of the coaxial cable at a single location (preferably at or in the immediate vicinity of the clock).

AC/DC Connection Diagrams

You can apply the SEL-TWFL to a variety of typical line terminations and bus arrangements.

Figure 9.23 shows the wiring for monitoring one line with the SEL-TWFL. *Figure 9.24* depicts the wiring for monitoring two lines with the SEL-TWFL.

(1) Optional contact outputs
(2) Installations where the breaker mechanism allows operating each pole independently (B and C 52A auxiliary contacts)
(3) Additional contact inputs with a common terminal

Figure 9.23 Typical AC/DC Connections: Single Circuit Breaker Line Termination

(1) Optional contact outputs
(2) Installations where the breaker mechanism allows operating each pole independently (B and C 52A auxiliary contacts)

Figure 9.24 Typical AC/DC Connections: Double Circuit Breaker Line Termination

Accessing and Configuring Device Jumpers

The SEL-TWFL provides two jumpers located inside the chassis on the top printed circuit board that perform the following functions when the pins are shorted:

- Disable password protection (all access levels)
- Allow testing device outputs with the **PULSE** command

SEL device documentation refers to these two jumpers as PASSWORD and BREAKER, respectively.

You can access the two jumpers without removing the device from the device cabinet or the top printed circuit board from the chassis. Refer to *Figure 9.2* and loosen the four screws that secure the front panel to the chassis. Follow your company's electrostatic discharge (ESD) precautions for working with electronic equipment and remove the SEL-TWFL front panel to access the jumpers. Keep in mind, the front-panel assembly is connected to the top printed circuit board with a cable, and use care when you detach the front-panel assembly so that you do not stress the connectors of that cable. *Figure 9.25* shows the location of the jumper header on the SEL-TWFL top printed circuit board.

Figure 9.25 Location of the Jumper Header on the SEL-TWFL Top Printed Circuit Board (Top View)

The jumper header is located on the front of the board, immediately to the right of the power connector when looking at the front of the device with the front cover removed (see *Figure 9.26*). The jumper header has four sets of pin pairs. The upper pin and the lower pin make up a control point or position. Each position can be left open or shorted with a jumper. The positions on the left and right (labeled D and A, respectively) are for SEL use only. These should remain open at all times. The second position from the left is the BREAKER position. The third position from the left is the PASSWORD position.

The device ships with two jumpers that you can use to allow testing of the contact outputs with the **PULSE** command and to disable password protection. When shipped, the jumpers are attached to the upper pins in the BREAKER and PASSWORD positions of the header (the upper pin acts as a jumper storage means). Attached only to the upper pin, the jumper does not short the two pins (pins are open). You can pull the jumper toward you and insert it back to short the two pins.

The device ships with the BREAKER and PASSWORD pins open. Should the shorting jumpers be removed or lost, the device will fail safe, preventing the use of the **PULSE** command to test the device contact outputs and requiring passwords for access.

Refer to *Table 9.4* for jumper functions and to *Figure 9.26* for jumper header position designations.

Table 9.4 BREAKER and PASSWORD Jumpers

Position	Jumper Placement	Function
A	None[a] (pins open)	Reserved for SEL use only
BREAKER	Upper[a] (pins open)	PULSE command disabled
	Lower (pins shorted)	PULSE command allowed (testing)
PASSWORD	Upper[a] (pins open)	Password required
	Lower (pins shorted)	Password protection disabled (temporary or emergency use)
D	None[a] (pins open)	Reserved for SEL use only

[a] Default shipping placement.

Figure 9.26 Jumper Header Location on the Top Printed Circuit Board (Front View) and BREAKER and PASSWORD Jumper Positions in the Jumper Header

NOTE: If you leave the BREAKER jumper shorting the pins in your in-service devices, ensure your testing and commissioning procedure requires your field personnel to isolate the contact outputs before testing.

NOTE: Under no circumstance should you put the PASSWORD jumper in place to short the pins for an in-service device on a long-term basis.

The SEL-TWFL ships with the BREAKER jumper placed to leave the pins open (PULSE command disabled). With the pins open, you will not be able to close the contact outputs with the **PULSE** command. For commissioning and testing the SEL-TWFL contact outputs, put the BREAKER jumper in the pins shorted position, as shown in *Figure 9.26*. See *Appendix C: SEL ASCII Commands* for more information about the **PULSE** command.

The SEL-TWFL ships with the PASSWORD jumper placed to leave the pins open, as shown in *Figure 9.26* (password required). Use default passwords when first accessing the device, and change the passwords following your company security policy and procedures before putting the device in service. For devices permanently installed in your test laboratory, you can put the PASSWORD jumper in place to short the pins, for convenience (no password required).

Inspecting the Device

Visual Inspection

The following items are included in your SEL-TWFL shipment from SEL:

- SEL-TWFL with an SFP transceiver installed in Port 5
- CD containing the electronic version of the *SEL-TWFL Instruction Manual*, USB driver for a Microsoft Windows-based computer, and a printable label template
- Custom Label Kit
- SEL-C664 USB A-Type to USB B-Type Cable
- Printed volume of the *SEL-TWFL Instruction Manual* in its own packaging (if ordered)
- SEL-C5300 AC Line Cord for 125/250 V Power Supply in its own packaging (if ordered)

If any item is missing or damaged, contact your distributor or SEL for a replacement. If you ordered accessories with your SEL-TWFL, SEL will ship them separately.

ACSELERATOR QuickSet SEL-5030 Software is not included on the CD – use your mySEL account to download the newest version from selinc.com (QuickSet is free of charge).

The SEL-TWFL ships with an 8109-01 SFP transceiver installed in Ethernet Port 5 and a plastic dust cover installed in Port 6. Do not remove this cover. Port 6 is intended for future use and cannot be configured or used.

Perform the following when you remove the device from the shipping packaging:

- Remove the protective wrapping from the SEL-TWFL.
- Inspect the front and rear panels of the SEL-TWFL chassis.
- Check that no significant scratches or dents are evident on any outer surface.
- Confirm that all terminal strips and communications ports receptacles on the rear panel are intact.

Examine the serial number label on the rear panel and confirm that the device power supply input ratings, contact I/O voltage ratings, and ac voltage and current ratings match your application. *Figure 9.27* shows a sample rear-panel serial number label.

Figure 9.27 SEL-TWFL Serial Number Label

The serial number label does not list power system phase rotation and frequency ratings because you use device settings to configure these parameters. The default settings are ABC phase rotation and 60 Hz nominal frequency.

You can use the serial number (S/N) to find the manufacturing date of spare or in-service SEL-TWFL devices. Digits 2 through 6 encode the manufacturing year and day in the YYDDD format. YY denotes the last two digits of the year, and DDD denotes the sequential day of the year. For example, S/N 1240300001 denotes a manufacturing date of January 30, 2024.

If any serial number label specification is other than what you expected, contact your distributor or SEL immediately.

Connecting and Applying Control Power

Connect control power to the SEL-TWFL to continue initial setup of the device. *Figure 9.5* shows the power supply connections.

Always attach a safety ground as the first connection you make to the SEL-TWFL. Connect the grounding terminal on the rear panel (Terminal 31; labeled **GND**) to a rack frame ground or main station ground for proper safety and performance. The bottom right of *Figure 9.3* shows the ground terminal.

Upon connecting control power, the device turns on the LCD backlight and performs an internal self-test. When it completes this check, the device displays default LCD screens, or a warning or failure message if applicable, and illuminates the **ENABLED** status LED (see *Front-Panel Operations* on page 7.4).

Checking Device Status and Installed Hardware and Firmware

Use the device front-panel HMI to view the device status without the need for any software, cables, or accessories (press **ENT** twice and scroll to an item of interest: time, identification, diagnostics). If you established communication with the device via Port F or Port 5, you can use a terminal emulator or QuickSet to view the device status (see *Communications Setup* on page 7.40 for details on how to establish communication with the device).

Figure 9.28 shows the SEL-TWFL status report in response to the **STATUS** command (see *STATUS* on page C.17) for a healthy device.

```
=>>STA <Enter>

SEL-TWFL                                  Date: 2024/01/30  Time: 17:00:00.000
StationA                                  Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129        Serial Number: 1240300001

Failures
  No Failures

Warnings
  No Warnings

Temperature
  44.0 degrees Celsius

Device Enabled
```

Figure 9.28 Status Report for a Healthy Relay (Response to the STATUS Command)

For more information on device status, see *Appendix F: Diagnostics*. If the device reports errors or warnings, follow the instructions provided in *Appendix F: Diagnostics* to rectify the problem, collect information to help SEL troubleshoot the issue, or contact SEL for more assistance as needed (see *Technical Support* on page xxi in the *Preface*).

Use the **VERSION** command (see *VERSION* on page C.21) to display the device hardware and firmware configuration. The resulting version report shows the part number, serial number, checksums, firmware release numbers, and other important device configuration information. Confirm that all installed components are as expected. *Figure 9.29* shows the format of the report, and *Figure 9.30* shows a sample report. *Table 9.5* explains the individual data items and provides comments for each.

```
=>VER <Enter>

Part Number:                      TWFL#xxxx
Serial Number:                    nnnnnnnnnn
Firmware ID:                      SEL-TWFL-Rnnn-Vx-Zssspppp-Dyyyymmdd
Firmware Checksum:                nnnn
SELboot Firmware ID:              SLBT-TWFL-Rxxx-Vx-Zxxxxxx-Dxxxxxxxx
SELboot Firmware Checksum:        nnnn
Current Inputs Nominal Current:   x A
Contact Inputs Rated Voltage:     x Vdc
Power Supply Rated Voltage:       x-y Vdc, m-n Vac
Port 5 SFP:                       SFP information
SD Card Size:                     c GB

If the above information is not as expected, contact SEL for assistance.
```

Figure 9.29 Data Items in the Version Report

```
=>VER <Enter>

Part Number:                      TWFL#0001
Serial Number:                    1240300001
Firmware ID:                      SEL-TWFL-R100-V0-Z001001-D20240129
Firmware Checksum:                F2E2
SELboot Firmware ID:              SLBT-TWFL-R100-V0-Z001001-D20231211
SELboot Firmware Checksum:        0738
Current Inputs Nominal Current:   5 A
Contact Inputs Rated Voltage:     125 Vdc
Power Supply Rated Voltage:       125-250 Vdc, 110-240 Vac
Port 5 SFP:                       100BASE-FX (1310nm, 2km)
SD Card Size:                     8 GB

If the above information is not as expected, contact SEL for assistance.
```

Figure 9.30 Sample Version Report

Table 9.5 Information Included in the Version Report (Sheet 1 of 2)

Data Item	Description	Comments
Part Number	Device part number	See *Models and Options* on page 1.4. Contact SEL if the part number is not what you expected (see *Technical Support* on page xxi in the *Preface*).
Serial Number	Device serial number	Ensure the device serial number is as expected and matches the number on the serial number label on the device rear panel (see *Figure 9.27*).
Firmware ID	Firmware identification string for SEL devices	Inspect the FID string to ensure the device is using the expected firmware version. See *Firmware* on page A.1 for more information.

Table 9.5 Information Included in the Version Report (Sheet 2 of 2)

Data Item	Description	Comments
Firmware Checksum	Firmware file checksum	Use the firmware checksum as an independent check of the firmware version. Use the firmware verification tool available at selinc.com to verify authenticity of firmware files. See *Appendix B: Firmware Upgrade Instructions* for more information.
SELBOOT Firmware ID	SELBOOT firmware identification string	See *SELBOOT Firmware Revision History* on page A.1 for further information.
SELBOOT Firmware Checksum	SELBOOT firmware file checksum	Use the firmware checksum as an independent check of the firmware version. Use the firmware verification tool available at selinc.com to verify authenticity of firmware files. See *Appendix B: Firmware Upgrade Instructions* for more information.
Current Inputs Nominal Current	Rated secondary current	Ensure that the ratings are as expected and match those on the serial number label on the device rear panel (see *Figure 9.27*).
Contact Inputs Rated Voltage	Rated contact input voltage	
Power Supply Rated Voltage	Rated power supply voltage	
Port 5 SFP	Specification of the transceiver installed in Port 5	Verify that the installed transceiver is as expected and meets the wavelength and power budget requirements of your application.
SD Card Size	SD card capacity	Confirm that the SD card capacity is as expected.

Replacing the SD Card

NOTE: A faulty SD card prevents the SEL-TWFL from saving transient records. Settings, SER record, and other nonvolatile data items are stored separately and are not affected by an SD card failure. Fault locating and other functions operate normally.

The SEL-TWFL stores transient records (TDR and MHR IEEE COMTRADE files) on an 8 GB Micro SD card. *Figure 9.25* shows the location of the SD card on the device top printed circuit board. If you see the SD card warning in the device diagnostic messages, contact SEL for a replacement SD card. To replace the card, remove the SEL-TWFL front panel and gently push the SD card in. This releases the card from the card socket. Pull the old card out. Install the new card received from SEL by gently pushing it into the open slot of the card socket. The SEL-TWFL uses a proprietary format for the SD card. Do not attempt to use a standard micro SD card in the device, and do not attempt to read the SEL-TWFL card on a standard computer system.

Replacing the Lithium Battery

The SEL-TWFL uses a battery as backup power for the real-time clock that keeps calendar time during extended loss of power conditions. The device battery has a 10-year life span and does not discharge while the device is powered (i.e., battery life will typically be much longer than 10 years). Use the device serial number to find the manufacturing date for spare devices and to estimate how long a spare device has been powered down. Because the SEL-TWFL is typically used with a high-accuracy external clock connected to the IRIG-B device input, the battery is not critical and its replacement is unnecessary in most applications. If you need to replace the real-time clock battery, perform the following steps.

⚠CAUTION
There is danger of explosion if the battery is incorrectly replaced. Replace only with Rayovac No. BR2335 or equivalent recommended by manufacturer. See Owner's Manual for safety instructions. The battery used in this device may present a fire or chemical burn hazard if mistreated. Do not recharge, disassemble, heat above 100°C or incinerate. Dispose of used batteries according to the manufacturer's instructions. Keep battery out of reach of children.

⚠CAUTION
Equipment components are sensitive to electrostatic discharge (ESD). Undetectable permanent damage can result if you do not use proper ESD procedures. Ground yourself, your work surface, and this equipment before removing any cover from this equipment. If your facility is not equipped to work with these components, contact SEL about returning this device and related SEL equipment for service.

Step 1. Remove the device from service.

a. Follow the standard procedure of your company for removing a device from service.

b. Disconnect power from the device.

c. Remove the device from the rack or panel if necessary to access the top cover.

d. Retain the chassis **GND** connection, if possible, and apply your company ESD precautions.

Step 2. Disconnect the cable that connects the front-panel with the top printed circuit board.

Step 3. Remove the front panel from the device.

Step 4. Remove the top cover to access the battery.

Step 5. Locate the lithium battery.

The lithium battery is at the front of the top printed circuit board (see *Figure 9.25*).

Step 6. Remove the battery from beneath the clip of the battery holder.

Step 7. Replace the battery with an exact replacement.

Use a 3 V lithium coin cell, Rayovac No. BR2335 or equivalent. The positive side (+) of the battery faces up.

Step 8. Reinstall the device top cover.

Step 9. Reconnect the front-panel cable to the front panel.

Step 10. Reattach the front panel.

Step 11. Set the device date and time by using QuickSet or by issuing the **TIM** command, or let the device obtain the date and time information from the clock connected on the IRIG-B input.

Step 12. Follow your standard company procedure to return the device to service.

Cleaning Recommendations

Perform the following steps and use care when cleaning the SEL-TWFL:

Step 1. Use a mild soap or detergent solution and a damp cloth to clean the device chassis.

Be careful cleaning the front and rear panels; do not use abrasive materials, polishing compounds, or harsh chemical solvents (such as xylene or acetone) on any device surface. Be careful when cleaning areas in proximity to the ports, including the Port 5 and Port 6 SFP receptacles, to avoid entry of any substance into the receptacles.

Step 2. Allow the device to air dry, or wipe dry with a soft dry cloth.

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SECTION 10

Testing and Commissioning

The SEL-TWFL includes traveling-wave-based fault locating, impedance-based fault locating, and line monitoring. To test these functions, use one of the following two approaches. Either ensure that the input signals realistically represent power system events or use synthesized test signals that take the design of the SEL-TWFL into account. The former approach is more suited for testing the SEL-TWFL to validate the fault locator specifications and functionality, such as when certifying the device make and model for use. The latter approach is suited for commissioning testing of devices in the field. Because traveling waves (TWs) are sharp changes in currents and voltages, you must use test signals that contain transition times on the order of several microseconds when testing the TW-based functions in the device.

NOTE: When testing the SEL-TWFL TW-based fault-locating methods, you must use either voltage and current signals that represent power system events or synthesized signals that take into account the SEL-TWFL operating principles. Applying arbitrary test signals may yield unexpected test results.

This section provides recommendations for commissioning testing of the SEL-TWFL TW-based functions in the field by using synthesized TW test signals. Apply standard testing and commissioning practices when testing the phasor-based supervisory and triggering elements of the device. Commissioning testing is concerned with verifying that the application of a specific device is correct (i.e., a specific SEL-TWFL is wired correctly, runs the correct firmware version, applies settings as intended, and responds to line faults within the limits of its performance and the settings philosophy applied). Commissioning testing is not concerned with design or performance of the device make and model; it only verifies the health of the specific SEL-TWFL and associated equipment, as well as the workmanship involved in applying and installing that device.

This section explains the requirements for a TW test set and the synthetic TW signals it produces. The section also provides specific tests for TW functions in the SEL-TWFL. For these tests, use a test set like the SEL-T4287 Traveling-Wave Test System that is suitable for testing TW-based fault locators.

This section is organized as follows:

- *Testing TW-Based Functions* on page 10.2 includes the following subsections:
  - *Introduction* on page 10.2 provides the general commissioning testing philosophy SEL recommends for the SEL-TWFL TW-based functions and specifies the scope, required equipment, and personnel skill set necessary for testing.
  - *Testing With TWs* on page 10.3 provides step-by-step procedures for using an SEL-T4287 to test the TW-based functions.
- *Basic SEL-TWFL Inspection and Tests* on page 10.12 reviews basic checks for voltage and current metering, contact inputs and outputs, and communications ports.
- *Measuring TW Line Propagation Time During a Line Energization Test* on page 10.14 describes a step-by-step procedure for measuring the TW line propagation time, which is required as one of the key SEL-TWFL settings.

Testing TW-Based Functions

Introduction

General Testing Philosophy

This section describes test procedures suitable for commissioning testing of the following TW-based functions of the SEL-TWFL:

- Multi-ended[a] TW-based fault-locating method (laboratory bench test and end-to-end test)
- Single-ended TW-based fault-locating method
- Line monitoring logic[b]

[a] Two-terminal lines only.
[b] This test is the same as the test for the multi-ended TW-based fault-locating method. See *Line Monitoring Principle of Operation* on page G.7.

The test procedures this section describes focus on verifying that the SEL-TWFL TW-based functions are operational and are using settings as intended. These procedures are not meant to prove the fault locator design and performance. Use known methods to verify wiring, communications channels, and device inputs and outputs prior to testing the device (see *Basic SEL-TWFL Inspection and Tests* on page 10.12 for more information).

Use a TW test set that meets the requirements listed in *Secondary Injection Test Set Requirements* on page 10.3 to verify the TW-based functions. Use the TW test mode in the SEL-TWFL (see *TWTEST* on page C.20) to facilitate this testing. In the TW test mode, you do not need to apply the associated low-frequency (50/60 Hz) signals, and therefore, you can test the TW-based functions by using only a TW test set that meets the necessary requirements.

Scope of Testing

Follow your company's practices for testing fault locators and event recorders. The test procedures in this section assume that the test personnel are proficient in testing fault locators and event recorders in general. This includes, but is not limited to, the following tasks and steps:

- Removing the device from service and restoring it back into service
- Testing wiring, device input circuitry, and associated settings, such as CT or PT ratios
- Verifying versions of device firmware and settings files
- Testing digital and analog communications circuits
- Testing outputs and associated circuitry
- Performing an on-load metering test before enabling the communications schemes and outputs

This section focuses on testing TW-based functions through the use of secondary injection from a TW test set.

Secondary Injection Test Set Requirements

The TW test set must allow the following (the SEL-T4287 meets or exceeds these requirements):

- Applying sharp changes in currents from a pre-fault value of 0 to a test value of several amperes secondary, with a rise time shorter than about 5 µs and a half-way decay time longer than about 0.3 ms
- Applying the sharp changes in all three phases simultaneously, with scatter below 1 µs, and with TW current present in all three phases
- Applying a second sharp change in currents to simulate a through-fault or internal fault condition, with a delay of as long as 1.7 ms with respect to the first change and timing accuracy better than about 5 µs
- For end-to-end testing, synchronizing the time of the first TWs between two test sets with accuracy better than about 1 µs (satellite-synchronized testing option)

Personnel and General Equipment Requirements

This section assumes that the personnel using or modifying the described test procedures are proficient in the following tasks:

- Testing fault locators and event recorders in general
- Operating a TW test set and associated software
- Operating and interfacing with the SEL-TWFL
- Performing end-to-end testing with multiple test crews, if end-to-end testing is included in the commissioning test plans

You will need the following equipment to perform the tests this section describes:

- A portable computer with associated software to interface with the SEL-TWFL
- A TW test set capable of generating current waves, such as the SEL-T4287
- For end-to-end testing, satellite-synchronized IEEE C37.118-compliant clocks at each end of the line to provide an absolute time reference for each SEL-TWFL and each TW test set; often, these clocks are already installed and you will only need access to their BNC-terminated IRIG-B outputs
- For laboratory bench testing, a satellite-synchronized IEEE C37.118-compliant clock to provide an absolute time reference for each SEL-TWFL

NOTE: Obtain the fault-location value from the summary report, front-panel HMI reading, or header file of the IEEE COMTRADE record.

Testing With TWs

SEL-T4287 Traveling-Wave Test System

The SEL-T4287 (see *Figure 10.1*) is a compact test set that generates current TWs (current steps) for testing TW functions, such as fault locating. Specify line length, TW line propagation time, fault location, and fault type to simulate TWs launched by a fault. Configure these basic parameters as well as the triggering mode by using the SEL-T4287 front-panel HMI to simulate TWs at either one or two line terminals. You can use one SEL-T4287 to test the SEL-TWFL in the laboratory or two SEL-T4287 test systems with an absolute time reference to perform end-to-end testing on a transmission line.

You can use the SEL-T4287 to test the following functions of the SEL-TWFL:

- Multi-ended TW-based fault-locating methods
- Single-ended TW-based fault-locating methods
- Line monitoring logic

Figure 10.1 SEL-T4287 Traveling-Wave Test System

TEST 1. Testing the Multi-Ended TW-Based Fault-Locating Method for Two-Terminal Lines

The multi-ended TW-based fault-locating method responds to current TWs measured at the local and remote terminals. As a result, you only need to apply step-current signals to test this method. Therefore, you can use a step-current generating source with two sets of three-phase outputs, such as the SEL-T4287. The SEL-TWFL settings and Relay Word bits used in this section are referenced to Line 1.

Test Procedure for Laboratory Bench Testing

You can use a single SEL-T4287 to test both SEL-TWFL devices when bench-testing the multi-ended TW-based fault-locating method for two-terminal lines in a laboratory, as shown in *Figure 10.2*. You must connect each SEL-TWFL via the IRIG-B input to an IEEE C37.118-compliant GPS clock with submicrosecond accuracy. However, you do not need to connect the GPS clock to the SEL-T4287 to perform these tests.

Ensure that all the cables connecting the SEL-T4287 current outputs to the SEL-TWFL current inputs have the same length and the same wire gauge to preserve the accuracy of the output current TW test signals.

Figure 10.2 Configuration for Bench-Testing the Multi-Ended TW-Based Fault-Locating Method for Two-Terminal Lines

Perform the following steps for bench-testing the multi-ended TW-based fault-locating method for two-terminal lines by using one SEL-T4287:

Step 1. Prepare the SEL-TWFL devices for testing as follows:

a. Configure each device for your two-terminal line application. See *Section 2: Fault Locator and Line Monitor* for guidance on configuring device settings.

b. Program the L1TWDD Relay Word bit in the L1FL SELOGIC equation. (Remove it after testing to avoid extremely sensitive triggering of transient recordings.)

c. Verify that communications Port 1 is enabled and configured (EPORT, ENCODING, DATACLK, TXID, and RXID settings) in both devices. Set ENCODING to C37.94, and set DATACLK to E (external) in one SEL-TWFL and I (internal) in the other SEL-TWFL.

d. Connect the two devices by using a fiber-optic patch cord.

e. Set L1PORT1 to P1 in each device.

f. Verify that the ROKP1 Relay Word bit is asserted on each device (indicating that the communications channel is operating correctly). The **COMM PORTS** status LED should be illuminated green.

g. Connect the demodulated IRIG-B output of the satellite-synchronized clock to the IRIG-B input of each SEL-TWFL.

h. Verify that the **TIME SYNC** LED is illuminated green on each device (indicating that the devices are time-synchronized to an absolute time reference).

i. Connect the IW or IX terminals on the SEL-TWFL 1 to the **TW OUT1** outputs of the SEL-T4287, and connect the IW or IX terminals on the SEL-TWFL 2 to the **TW OUT2** outputs of the SEL-T4287. Select the IW or IX terminals according to the corresponding L1I setting in each SEL-TWFL.

Step 2. Configure the SEL-T4287 by performing the following:

a. Press the **MENU** pushbutton.

b. Set the line length, LL, equal to the L1LL1 setting in the SEL-TWFL devices.

c. Set the TW line propagation time, TWLPT, equal to the L1TWLPT1 setting in the SEL-TWFL devices.

d. Set the number of terminals, NTERM, to TWO.

e. Select the desired fault type, FLTYPE, for applying internal faults (e.g., INT AG for internal AG faults). The SEL-T4287 applies internal fault current TWs according to *Table 10.1*.

f. Select the desired fault location, FL, where the value is in the units specified by the LLUNIT setting in each SEL-TWFL.

g. Navigate to the `TRIG` menu on the LED display and select `RUN PB` to set the **ARM/RUN** pushbutton as the test trigger.

h. Press the **MENU** pushbutton; the display should indicate that the SEL-T4287 is `READY`.

i. Press the **ARM/RUN** pushbutton twice to trigger the test signals (the first press arms the SEL-T4287, and the second press triggers the test).

Table 10.1 Recommended Current TW Magnitudes for Testing Internal Faults[a]

Fault Type	TW OUT1			TW OUT2		
	IA	IB	IC	IA	IB	IC
INT AG	I_{TEST}	$-\frac{1}{2}I_{TEST}$	$-\frac{1}{2}I_{TEST}$	I_{TEST}	$-\frac{1}{2}I_{TEST}$	$-\frac{1}{2}I_{TEST}$
INT BG	$-\frac{1}{2}I_{TEST}$	I_{TEST}	$-\frac{1}{2}I_{TEST}$	$-\frac{1}{2}I_{TEST}$	I_{TEST}	$-\frac{1}{2}I_{TEST}$
INT CG	$-\frac{1}{2}I_{TEST}$	$-\frac{1}{2}I_{TEST}$	I_{TEST}	$-\frac{1}{2}I_{TEST}$	$-\frac{1}{2}I_{TEST}$	I_{TEST}

[a] Where $0.5 \cdot I_{NOM} \leq I_{TEST} \leq 2 \cdot I_{NOM}$ is recommended; the SEL-T4287 uses I_{TEST} = 5 A.

Step 3. Verify that the following conditions are true for the SEL-TWFL devices:

➢ The **FL TRIG** LED for Line 1 is illuminated red on each device (indicating a trigger operation).

➢ The fault-location result is within 0.1 km (0.06 mi) of the programmed fault location, FL, in the SEL-T4287 (the fault location is reported on the SEL-TWFL LCD and can also be accessed by issuing the **SUM** command).

➢ Monitor the L1FL and L1TWDD Relay Word bits in each SEL-TWFL when applying TW test signals. Use SYNCHROWAVE Event Software to visualize the phase and TW currents in the MHR IEEE COMTRADE record and Relay Word bits in the TDR IEEE COMTRADE record.

Figure 10.3 shows the plots of the signals used to test the multi-ended TW-based fault-locating method for two-terminal lines by simulating an internal AG fault at 50 km from Terminal 1 (the black and blue signals correspond to SEL-TWFL 1 and SEL-TWFL 2, respectively). The devices were set with the L1TWLPT1 and L1LL1 parameters of 681 µs and 200 km, respectively. As expected, the multi-ended TW-based fault-locating method estimated the fault at 49.9 km from Terminal 1, which corresponds to a time difference of approximately 341 µs between the TW arrival times at each line terminal.

Figure 10.3 Test Currents and Relay Word Bits Associated With Testing the Multi-Ended Traveling-Wave-Based Fault-Locating Method for Two-Terminal Lines for an Internal AG Fault at 50 km

Test Procedure for End-to-End Testing

For end-to-end testing, you need two SEL-T4287 test systems, as shown in *Figure 10.4*. At the two line terminals, connect each SEL-TWFL and each SEL-T4287 via the IRIG-B input to an IEEE C37.118-compliant GPS clock with submicrosecond accuracy. Ensure that all the cables connecting the SEL-T4287 current outputs to the SEL-TWFL current inputs have the same length and the same wire gauge to preserve the accuracy of the output current TW test signals.

Figure 10.4 Configuration for End-to-End Testing of the Multi-Ended TW-Based Fault-Locating Method for Two-Terminal Lines

Perform the following steps for end-to-end testing of the multi-ended TW-based fault-locating method for two-terminal lines by using two SEL-T4287 test systems:

Step 1. Prepare the SEL-TWFL devices for testing as follows:

a. Configure each device for your two-terminal line application. See *Section 2: Fault Locator and Line Monitor* for guidance on configuring device settings.

b. Program the L1TWDD Relay Word bit in the L1FL SELOGIC equation. (Remove it after testing to avoid extremely sensitive triggering of transient recordings.)

c. Verify that communications Port 1 is enabled and configured (EPORT, ENCODING, DATACLK, TXID, and RXID settings) in both devices. Set ENCODING to C37.94, and set DATACLK to E (external) in each device.

d. Connect the two devices by using the IEEE C37.94 multiplexed channel.

e. Set L1PORT1 to P1 in each device.

f. Verify that the ROKP1 Relay Word bit is asserted on each device (indicating that the communications channel is operating correctly). The **COMM PORTS** status LED should be illuminated green.

g. Connect the demodulated IRIG-B output of each satellite-synchronized clock to the IRIG-B input of the corresponding SEL-TWFL.

h. Verify that the **TIME SYNC** LED is illuminated green on each device (indicating that the devices are time-synchronized to an absolute time reference).

i. Connect the IW or IX terminals on the SEL-TWFL 1 to the **TW OUT1** outputs of Test System 1, and connect the IW or IX terminals on the SEL-TWFL 2 to the **TW OUT2** outputs of Test System 2. Select the IW or IX terminals according to the corresponding L1I setting in each SEL-TWFL.

Step 2. Configure the SEL-T4287 (both test sets accordingly) and establish necessary connections by performing the following:

a. Connect the demodulated IRIG-B output of each satellite-synchronized clock to the IRIG-B input of the corresponding SEL-T4287.

b. Press the **MENU** pushbutton.

c. Set the line length, LL, equal to the L1LL1 setting in the SEL-TWFL devices.

d. Set the TW line propagation time, TWLPT, equal to the L1TWLPT1 setting in the SEL-TWFL devices.

e. Set the number of terminals, NTERM, to TWO.

f. Select the desired fault type, FLTYPE, for applying internal faults (e.g., INT AG for internal AG faults). The SEL-T4287 applies internal fault current TWs according to *Table 10.1*.

g. Select the desired fault location, FL, where the value is in the units specified by the LLUNIT setting in each SEL-TWFL. Apply the same FL value in both test sets.

h. Navigate to the `TRIG` menu on the LED display and select the `IRIG` option to select automatic triggering of the test signals by using the absolute time reference.

i. In the `IRIG` menu, select the `SINGLE` option for applying a single fault.

j. Press the **ENT** pushbutton and set the fault time at least three minutes ahead of time for coordinating the fault injection at the two terminals. The trigger (fault) time should be set the same in both SEL-T4287 test systems.

k. Press the **ENT** pushbutton to save the fault time, and then press the **MENU** pushbutton until the display shows the countdown for applying the test signals. The test will be triggered at the time you specified.

Step 3. Verify that the following conditions are true for the SEL-TWFL devices:

➢ The **FL TRIG** LED for Line 1 is illuminated red on each device (indicating a trigger operation).

➢ The fault-location result is within 0.1 km (0.06 mi) of the programmed fault location, FL, in the SEL-T4287 (the fault location is reported on the SEL-TWFL LCD and can also be accessed by issuing the **SUM** command).

➢ Monitor the L1FL and L1TWDD Relay Word bits in each SEL-TWFL when applying TW test signals. Use SYNCHROWAVE Event Software to visualize the phase and TW currents in the MHR IEEE COMTRADE record and Relay Word bits in the TDR IEEE COMTRADE record.

TEST 2. Testing the Single-Ended TW-Based Fault-Locating Method

The single-ended TW-based fault-locating method uses the TW reflection from the fault to estimate the fault location (see *Single-Ended Traveling-Wave-Based Method* on page 2.19). The SEL-TWFL reports the single-ended TW-based fault location if all of the following conditions are met:

1. The multi-ended TW-based fault-locating method estimation is not available.
2. The local terminal detects at least one reflected TW from the fault.
3. After detecting a TW reflected from the fault, the local terminal detects a corresponding reflection from the remote terminal, or none of the impedance-based fault-locating methods were able to estimate the fault location.

To test the single-ended TW-based fault-locating method, configure the SEL-T4287 for single-ended testing. Under this configuration, the SEL-T4287 generates two sets of current TWs with a time difference between them corresponding to the TW round-trip time for the TW reflection from the local terminal to travel back to the fault location, reflect, and then return back to the local terminal. The SEL-TWFL settings and Relay Word bits used in this section are referenced to Line 1.

Figure 10.5 shows the configuration for testing the single-ended TW-based fault-locating method by using one SEL-T4287. This configuration is adequate for applications where L1I is set to COMB. In applications in which L1I is set to IW or IX, temporarily change L1I to COMB and remember to restore the original L1I setting value after testing. When emulating a single terminal (SEL-T4287 setting NTERM is set to ONE), the SEL-T4287 injects two sets of TWs. The **TW OUT1** outputs test signals that simulate the first TWs launched by a fault, and the **TW OUT2** outputs test signals that simulate the TWs reflected back from the fault. The fault location setting, FL, in the SEL-T4287 determines the time difference between the first TWs and the reflected TWs. When L1I is set to COMB, the SEL-TWFL uses both currents and the line current includes both TWs.

Ensure that all the cables connecting the SEL-T4287 current outputs to the SEL-TWFL current inputs have the same length and the same wire gauge to preserve the accuracy of the output current TW test signals.

Figure 10.5 Configuration for Testing the Single-Ended TW-Based Fault-Locating Method

Test Procedure

Perform the following steps when testing the single-ended TW-based fault-locating method by using one SEL-T4287:

Step 1. Prepare the SEL-TWFL for testing as follows:

a. Set CTRX equal to CTRW. (If the CTRX and CTRW settings are different prior to testing, remember to restore the true values after testing.)

b. Set L1I to COMB; with this setting, the device responds to the sum of the IW and IX signals, and therefore, it measures both TWs generated by the test set. (If the L1I setting value prior to testing was not COMB, remember to restore the original L1I setting value after testing.)

c. Configure the device for your application. See *Section 2: Fault Locator and Line Monitor* for guidance on configuring device settings.

d. Program the L1TWDD Relay Word bit in the L1FL SELOGIC equation. (Remove it after testing to avoid extremely sensitive triggering of transient recordings.)

e. Connect the IW terminals on the SEL-TWFL to the **TW OUT1** outputs of the SEL-T4287, and connect the IX terminals on the SEL-TWFL to the **TW OUT2** outputs of the SEL-T4287.

Step 2. Configure the SEL-T4287 by performing the following:

a. Press the **MENU** pushbutton.

b. Set the line length, LL, equal to the L1LL1 setting in the SEL-TWFL.

c. Set the TW line propagation time, TWLPT, equal to the L1TWLPT1 setting in the SEL-TWFL.

d. Set the number of terminals, NTERM, to ONE.

e. Select the desired fault type, FLTYPE, for applying internal faults (e.g., INT AG for internal AG faults). The SEL-T4287 applies internal fault current TWs according to *Table 10.1*.

f. Select the desired fault location, FL, where the value is in the units specified by the LLUNIT setting in the SEL-TWFL.

g. Navigate to the `TRIG` menu on the LED display and select `RUN PB` to set the **ARM/RUN** pushbutton as the test trigger.

h. Press the **MENU** pushbutton; the display should indicate that the SEL-T4287 is `READY`.

i. Press the **ARM/RUN** pushbutton twice to trigger the test signals (the first press arms the SEL-T4287, and the second press triggers the test).

Step 3. Obtain the fault-location result from the SEL-TWFL and compare with the simulated value (in the SEL-TWFL, use the **SUM** command, the device front-panel HMI, or the header file of the IEEE COMTRADE record).

Step 4. Monitor the currents received at the SEL-TWFL when applying TW test signals. Use SYNCHROWAVE Event Software to visualize the phase and TW currents in the MHR IEEE COMTRADE record. *Figure 10.6* shows the Phase A line current and Phase A differentiator-smoother output signal. Determine the time difference between the two differentiator-smoother peaks to verify that you injected the TWs

with a timing of double the travel time from the bus to the intended fault location. In this example, the time difference is approximately 341 µs, which is the round-trip travel time for a 100 km distance (2 • 50 km) with the TWLPT and LL parameters of 681 µs and 200 km, respectively.

Figure 10.6 Test Currents and Relay Word Bits Associated With Testing the Single-Ended Traveling-Wave-Based Fault-Locating Method for an Internal AG Fault at 50 km

Basic SEL-TWFL Inspection and Tests

Verifying Voltage and Current Inputs

Use the **MET** command to verify SEL-TWFL wiring; ac input circuitries; CT and PT ratio settings; and L*m*I, L*m*V, VNOMY, VNOMZ, and NFREQ settings. This command can also be used for troubleshooting your test setup and for performing on-load testing after restoring ac voltage and current connections to the device and before restoring the trip and other outputs.

The **MET** command (see *METER* on page C.12) displays device metering values. *Figure 10.7* shows a sample MET report (see *Metering Quantities* on page E.1 for more information). The phasor angles are referenced to the local positive-sequence voltage for the respective line. The phasor magnitudes are provided in rms values.

```
=>MET <Enter>

SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001


Line 1
                   Line Phase Currents
                 IA         IB         IC
I MAG (A)       493.898    514.642    506.222
I ANG (DEG)       -9.4     -127.4      111.6

                   Line Phase Voltages              Line Phase-Phase Voltages
                 VA         VB         VC           VAB        VBC        VCA
V MAG (kV)      133.585    133.653    138.260      227.850    235.511    238.905
V ANG (DEG)       -2.0     -119.0      121.0         29.5      -88.5      148.9

                  Line Sequence Currents
                 I1         3I2        3I0
I MAG (A)       504.867     25.280     22.328
I ANG (DEG)       -8.4     -174.3     -121.1

                  Line Sequence Voltages
                 V1         3V2        3V0
V MAG (kV)      135.125     11.280      3.922
V ANG (DEG)       0.0     -102.2     -129.1

               Three Phase Power
P (MW)             202.525
Q (MVAR)            29.978

FREQ (Hz)      60.001


Line 2
                   Line Phase Currents
                 IA         IB         IC
I MAG (A)       358.345    369.900    377.173
I ANG (DEG)      -14.4     -129.4      110.6

                   Line Phase Voltages              Line Phase-Phase Voltages
                 VA         VB         VC           VAB        VBC        VCA
V MAG (kV)      138.261    138.229    138.233      235.492    239.420    243.222
V ANG (DEG)       -2.1     -118.9      121.1         29.5      -88.9      149.5

                  Line Sequence Currents
                 I1         3I2        3I0
I MAG (A)       368.168     40.845     29.875
I ANG (DEG)      -11.0     -123.1     -133.3

                  Line Sequence Voltages
                 V1         3V2        3V0
V MAG (kV)      138.193      7.730      7.723
V ANG (DEG)       0.0      -90.3      -90.3

               Three Phase Power
P (MW)             149.972
Q (MVAR)            29.249

FREQ (Hz)      60.001

=>>
```

Figure 10.7 Metering Data (Response to the METER Command)

Compare the values the SEL-TWFL reports with the values you inject.

Additionally, you can trigger a transient recording by issuing the **TRIGGER** command. Compare the reported voltage and current traces in the transient record with the signals you inject.

Verifying Contact Inputs

If you established communication with the SEL-TWFL via Port F or Port 5 (see *Communications Setup* on page 7.40 for details on how to establish communication with the device), you can use a terminal emulator or QuickSet to view the status (asserted/deasserted) of the contact inputs. Regardless of whether or not you established communication with the device, you can also use the front-panel HMI to view the status of the contact inputs.

Verifying Contact Outputs

If you established communication with the SEL-TWFL via Port F or Port 5 (see *Communications Setup* on page 7.40 for details on how to establish communication with the device), you can use a terminal emulator or QuickSet to pulse the contact outputs. Note that the BREAKER jumper enables and disables the **PULSE** command (see *Accessing and Configuring Device Jumpers* on page 9.15 for details). You can use the front-panel HMI to verify the status (open or closed) of the contact outputs.

Verifying Communications Ports and IRIG-B Input

Verify communications Ports 1, 2, and 3 and the IRIG-B timing input by connecting a compliant device, configuring the ports accordingly, and exercising supported applications. Use communications statistics to inspect for problems. See *Communications Report for Ports 1, 2, and 3* on page 3.8 for communications ports statistics and *TIME Q Report* on page H.4 for IRIG-B inputs statistics.

Measuring TW Line Propagation Time During a Line Energization Test

The SEL-TWFL TW-based fault-locating methods use the TW line propagation time setting, L*m*TWLPT*n* (where *m* = 1–2 and *n* = 1–5). For every 1 µs of error in the TW line propagation time setting, the fault-location result could be off by about 300 m or 1,000 ft (single-ended method) or by about 150 m or 500 ft (multi-ended method) on overhead lines. Therefore, it is critical to configure the device with an accurate TW line propagation time. This section provides the procedure for measuring the TW line propagation time on a two-terminal homogeneous line, L*m*TWLPT1.

SEL recommends measuring the TW line propagation time by using the TW recordings captured while performing a line energization test. After you have the authorization of the power system operator, follow these steps to measure the TW line propagation time:

Step 1. Verify that the PT secondary voltages and CT secondary currents are properly connected to the SEL-TWFL.

Step 2. Verify that the SEL-TWFL has the proper settings. Particularly ensure the accuracy of these settings:

- NFREQ (nominal system frequency)
- PHROT (system phase rotation)
- L*m*I (line current source)
- Current transformer ratio:
  - CTRW if L*m*I = IW
  - CTRX if L*m*I = IX
  - CTRW and CTRX if L*m*I = COMB
- Potential transformer ratio
  - PTRY if L*m*V = VY
  - PTRZ if L*m*V = VZ

Step 3. Program the L*m*TWDD Relay Word bit in the ER SELOGIC equation. (Remove it after testing to avoid extremely sensitive triggering of transient recordings.)

Step 4. With the line energized, verify that the SEL-TWFL measures the expected voltages and currents.

Step 5. Request opening of the circuit breakers at the local and remote terminals to de-energize the power line.

NOTE: For best results, when measuring the TW line propagation time, you must close the local circuit breaker while the remote circuit breaker is open.

Step 6. Request closing of the local line circuit breaker to energize the line.

Step 7. Verify that the SEL-TWFL captured the energization event by either refreshing the **Event History** in QuickSet or issuing the **HIS** command in the terminal emulator.

Step 8. Retrieve the MHR IEEE COMTRADE record for the line energization by using QuickSet or via FTP by using File Explorer or a web browser.

Step 9. Launch SYNCHROWAVE Event Software and view the L*m*IA, L*m*IB, and L*m*IC currents.

Step 10. Following the pole closure, identify the pole that closed last and the corresponding phase current that has a visible change at approximately $\Delta t \cong (2 \bullet LL)/(0.98 \bullet c)$ after the pole closure (where c is the speed of light and LL is the line length, c = 186,282 mi/s and 299,792 km/s). This change corresponds to the TW reflection from the remote end of the line. The 0.98 value is the typical TW propagation velocity for an overhead power line relative to the speed of light in free space, c. For cables, use half the speed of light in free space when approximating the time of the reflection from the remote end of the line.

NOTE: Use half of the TW round-trip time as the L*m*TWLPT1 setting.

Step 11. Plot the phase current for the phase identified in *Step 10* together with the corresponding alpha current TW and measure Δt; use half of this time in microseconds to set L*m*TWLPT1.

Example

The SEL-TWFL settings and analog signals used in this example are referenced to Line 1. *Figure 10.8* shows the phase currents captured with the SEL-TWFL during energization of a two-terminal 345 kV, 53.3 km (33.1 mi) overhead transmission line. As shown in the figure, Pole A is the last pole to close. Estimate the approximate round-trip travel time as follows:

$$\text{RoundTripTime}_{\text{APPROX}} = \frac{2 \bullet \text{LL}}{0.98 \bullet \text{c}} = \frac{2 \bullet 53.3\ \text{km}}{0.98 \bullet 0.3\ \text{km}/\mu\text{s}} = 363\ \mu\text{s}$$

Observing the Phase A current, you can see a visible change at approximately 363 µs after Pole A closes (as shown in *Figure 10.8*). For overhead lines, the TW Mode setting, L1MODE, is set to CLARKE; therefore, use the Alpha A current TW for measuring the L1TWLPT1 setting value.

Figure 10.8 Identify the Last Pole to Close to Determine the L1TWLPT1 Value

Use SYNCHROWAVE Event Software and set Cursor Snap Mode to **Peaks**. Plot the Phase A current (L1IA) and the Alpha A current TW (L1TWIA.ALPHA), as shown in *Figure 10.9*. Inspect the current TW trace and identify the peak that corresponds to the pole closing and the peak that corresponds to the reflection from the remote terminal.

Figure 10.9 Line Current and Alpha Current TW in the Selected Phase

Zoom in around the TW launched when the last pole closes and around the reflected TW, and accurately place the cursors at the current TW peaks, as shown in *Figure 10.10*.

Figure 10.10 Place Cursor at Peaks for (a) Current TW Launched at Breaker Closing and (b) Current TW Reflected From the Remote Terminal

NOTE: To obtain accurate TW arrival times when using SYNCHROWAVE Event Software, set Cursor Snap Mode to **Peaks**.

Measure the time difference between the two peaks by using the software time cursors. Use half of the measured round-trip time as the L1TWLPT1 setting value as follows:

$$\text{L1TWLPT1} = \frac{373.7\ \mu\text{s}}{2} = 186.9\ \mu\text{s}$$

APPENDIX A

Firmware and Manual Versions

Firmware

The firmware identification (FID) string describes the version of the main firmware, and the SELBOOT firmware identification (BFID) string describes the version of the SELBOOT firmware. See *SEL-TWFL Firmware Revision Convention* on page B.1 for more information on the FID and BFID strings. To obtain the FID and BFID strings, issue the **VER** command. You can also view the FID string on the device HMI by navigating to **Fault Locator > Identificaton > FID**.

Main Firmware Revision History

Table A.1 lists the SEL-TWFL firmware versions, summary of changes, and corresponding instruction manual date codes. The most recent firmware revision is listed first. The Compatible SELBOOT Versions column of *Table A.1* lists the versions of SELBOOT firmware that are compatible with each version of the main firmware. SEL recommends that the latest compatible SELBOOT firmware be used for each version of the main firmware.

Changes that address security vulnerabilities are marked with "[Cybersecurity]". Other improvements to cybersecurity functionality that should be evaluated for potential cybersecurity importance are marked with "[Cybersecurity Enhancement]".

Table A.1 Main Firmware Revision History

Firmware Identification (FID) Number	Summary of Changes	Compatible SELBOOT Versions	Manual Date Code
SEL-TWFL-R100-V0-Z001001-D20240129	➤ Initial version.	R100-V0	20240213

SELBOOT Firmware Revision History

Table A.2 lists the SELBOOT firmware revisions and summary of changes. The most recent SELBOOT firmware is listed first.

Table A.2 SELBOOT Firmware Revision History

SELBOOT Firmware Identification (BFID)	Summary of Changes
SLBT-TWFL-R100-V0-Z001001-D20231211	➤ Initial version.

Instruction Manual

The date code at the bottom of each page of this manual reflects the revision date. The bottom of the cover page lists the R-number of the FID string of the firmware for which the instruction manual is adequate. You can use the instruction manual for firmware with any V-number in the FID string. However, it is best practice to use the newest instruction manual for any given firmware revision.

Table A.3 lists the instruction manual versions and summary of changes. The most recent manual revision is listed first.

Table A.3 Instruction Manual Revision History

Date Code	Summary of Revisions
20240213	➤ Initial version.

APPENDIX B

Firmware Upgrade Instructions

This appendix provides guidelines and step-by-step instructions for upgrading the SEL-TWFL firmware. Before deciding to perform the upgrade, carefully read firmware release notes (*Table A.1*) and any SEL service bulletin prompting consideration of a firmware upgrade. Also consider the scope of the settings review and the extent of device recommissioning. When relying on the SEL-TWFL multi-ended fault-locating methods, upgrade all devices in your fault-locating application to the same firmware revision. This is important to ensure compatibility in logic and peer-to-peer communications among the individual devices in the scheme.

These instructions are only intended for upgrading firmware from an earlier version to a later version. Attempting to downgrade firmware (i.e., reverting back to an earlier firmware version) may result in loss of device calibration and other critical information in the device memory and may render the device nonoperational. Contact SEL if you need to downgrade the firmware in a device.

SEL allows upgrading the SEL-TWFL firmware only over the front-panel USB Port F by using a local computer. You cannot upgrade firmware over Port 5 through the Ethernet network.

This appendix does not describe procedures for removing an operational device from service to upgrade firmware, restoring the device back to service, and recommissioning or otherwise checking the device after the upgrade. Follow your company policies and procedures, and industry best practices, when planning for and executing these important steps.

This appendix contains the following information:

- *SEL-TWFL Firmware Revision Convention* on page B.1
- *Preparing to Upgrade Firmware Prior to Working on Site* on page B.2
- *Preparing to Upgrade Firmware on Site* on page B.6
- *Upgrading Firmware by Using ACSELERATOR QuickSet Firmware Loader* on page B.7
- *Upgrading Firmware by Using SEL Commands* on page B.13
- *Troubleshooting Firmware Upgrade Problems* on page B.19

SEL-TWFL Firmware Revision Convention

The SEL-TWFL firmware is either a *standard* release or a *point* release. A standard release adds new functionality to a prior firmware revision beyond specifications of that prior revision. A point release modifies functionality of the prior firmware revision to conform to the original specifications of that firmware revision or for internal optimization without any other changes. Use the distinction between a standard release and a point release to decide how closely you want to

evaluate the new firmware, if you want to review your application, if you need to review and modify your settings, and how much recommissioning you want to perform following the firmware upgrade.

A standard release is identified by the R-number of the firmware identification (FID) string. For example:

Present firmware:

FID=SEL-TWFL-R100-V0-Zxxxxxx-Dxxxxxxxx

New standard release firmware:

FID=SEL-TWFL-R101-V0-Zxxxxxx-Dxxxxxxxx

A point release is identified by the V-number of the FID string. For example:

Present firmware:

FID=SEL-TWFL-R100-V0-Zxxxxxx-Dxxxxxxxx

New point release firmware:

FID=SEL-TWFL-R100-V1-Zxxxxxx-Dxxxxxxxx

Assume you originally installed an R100-V0 firmware revision. If SEL discovers a deficiency in this firmware, SEL may issue R100-V1 firmware to address the deficiency. Because the R-number is unchanged in the new firmware, you can be certain that only deficiencies are addressed and the device functionality has not been altered beyond that originally intended for the R100 revision. In this scenario, you should not expect any settings changes (the Z number in the FID string will remain unchanged) or need for re-engineering the application, documentation changes, or extensive recommissioning after the firmware upgrade.

Subsequently, SEL may issue R101-V0 firmware to bring new functionality or better performance to the SEL-TWFL. Because the R-number changed, you may expect added functionality, added settings, new settings ranges, and so on. You should review your application and settings, and you may expect a larger recommissioning effort when upgrading from R100 to R101 as compared with upgrading from R100-V0 to R100-V1.

Note that SEL-TWFL firmware files may be intended for specific devices (for a range of device serial numbers). Do not attempt to upgrade devices that have serial numbers that are not listed in the firmware upgrade kit you received from SEL.

Preparing to Upgrade Firmware Prior to Working on Site

NOTE: Upgrade your QuickSet SEL-TWFL driver, if necessary, before traveling to the work site.

You will need the following items to perform the firmware upgrade:

- PC with a CDC USB Device driver installed (see *Preparing a PC for Front-Panel Port F Communications* on page 7.41 for information on how to install the driver) and ACSELERATOR QuickSet SEL-5030 Software installed (see *Obtaining and Installing QuickSet* on page 7.20 for information on how to install QuickSet)
- Access Level 1 and 2 passwords for the device(s) you will work on. In special cases, you may also need the Access Level C password
- A terminal emulator installed that includes Xmodem/CRC and Ymodem protocols (QuickSet includes a compliant terminal emulator software)
- USB A-to-B cable (such as an SEL-C664 USB cable)

- New firmware file. This file contains the main program to be loaded onto the device
- New settings files, if issued as a part of the firmware upgrade process
- SELBOOT firmware file, if applicable. This file contains code that enables the main program to load and execute on the SEL-TWFL hardware. (New SELBOOT firmware is released rarely, and you will only occasionally need to upgrade the SELBOOT firmware.)

Table B.1 identifies which firmware files you received in the upgrade kit.

Table B.1 Firmware Upgrade Files

File Name	File Type
SLBT-TWFL-R*nnn*-V*x*.zds[a]	SEL-TWFL SELBOOT firmware
SEL-TWFL-R*nnn*-V*x*.zds[ab]	SEL-TWFL device firmware

[a] *nnn* in the file name represents the firmware revision number.
[b] *x* represents the point release version number.

You should decide at the planning stage which of the following two firmware upgrade methods you want to use.

- *Upgrading Firmware by Using ACSELERATOR QuickSet Firmware Loader*. The Firmware Loader feature of QuickSet automates the firmware upgrade process and is more appropriate for new users. You can use the Firmware Loader to upgrade only device firmware (SEL-TWFL-R*nnn*-V*x*.zds file). If you must upgrade SELBOOT firmware (SLBT-TWFL-R*nnn*-V*x*.zds file), use the method below.
- *Upgrading Firmware by Using SEL Commands*. Connect to the device in a terminal emulator session and perform a sequence of steps to upgrade the firmware. This method is efficient for experienced users who are familiar with and prefer using SEL ASCII commands. This method is simple and fast if you do not need to archive device settings and records as a part of the firmware upgrade or if you have archived the device settings and records already.

Saving and Verifying Firmware Files

NOTE: Firmware is designed to be used with specific devices. A list of device serial numbers is provided as part of the firmware upgrade package. The firmware provided is for use with the listed devices only. Attempts to upgrade unlisted devices might not be successful and can result in device failure.

The firmware files are provided either on a Firmware Upgrade CD included in the firmware upgrade kit or in an email you receive from SEL. Copy the firmware files to an easily accessible location on your PC.

SEL provides firmware hashes as an additional tool to verify the integrity of SEL firmware upgrade files. This helps ensure that the firmware received from the factory is complete and unaltered prior to sending the firmware to the SEL device. Verify that the firmware file in your possession is a known valid SEL firmware release by comparing the calculated hash value of the firmware in your possession with the hash value provided at selinc.com/products/firmware/.

To obtain the hash value for the firmware file you intend to use, obtain a file integrity checker tool (FSUM by SlavaSoft, Inc., for example) and use it to analyze the firmware by using the SHA-1 and SHA-256 checksum algorithms. For example, if using FSUM, open the Microsoft Windows command line interface by clicking the **Start** button, selecting **Run**, and typing **cmd <Enter>**. Enter the following at the command prompt:

fsum –jnc –sha1 –sha256 *firmware file name*

where *firmware file name* is the full path and file name of the SEL firmware file you plan to upgrade.

The FSUM tool lists the SHA-1 hash value first, followed by the SHA-256 hash value.

Go to selinc.com/products/firmware/ to obtain the SHA-1 and SHA-256 hash values for the revision (R-number) and version (V-number) of the firmware you plan to upgrade. The hash values from the output of FSUM should match the SHA-1 and SHA-256 hash values from the selinc.com hash verification tool. If the values do not match, either you are comparing different firmware files or the firmware file you planned to upload has been altered and should not be used. Contact SEL immediately if you suspect your firmware file has been altered.

Evaluating Settings Changes and Preparing Settings Files for New Firmware

Depending on whether you upgrade firmware to a new standard release or a new point release, and on the extent and nature of the changes, you may be able to continue using the present settings files. Otherwise, you may need to prepare new settings files and have them ready when you upgrade the firmware.

You may also combine a firmware upgrade with noncritical settings changes. In such a case, prepare new settings files and have them ready before you start working on site.

It is good practice to store in-service settings files in a central depository. Obtain the present in-service settings files from your central depository and convert them to a new revision before starting work on site. SEL recommends using the QuickSet settings conversion feature (shown in *Figure B.1*) to convert the in-service settings files to the settings file for the new firmware revision and to flag differences.

Figure B.1 Converting Settings

To evaluate new settings and changes to values of old settings, carefully read the SEL service bulletin that prompted you to upgrade the firmware. In general, if the new firmware is a point release (see *SEL-TWFL Firmware Revision Convention* on page B.1), there will be no new settings added to the device and a settings comparison can be performed after the upgrade process to confirm that settings properly transferred across the upgrade. If the new firmware is a standard release, compare the settings version number (SVN), see *Figure 7.16*, of the new firmware with the SVN of the previous firmware. If these numbers match, no new settings have been introduced, and as before, a settings comparison can be performed after the upgrade process to confirm that the settings properly transferred across the upgrade. If the new firmware has a new SVN, then the settings changed in some manner between the firmware versions. In this case, SEL recommends that before working on site, you convert the previous settings to a new settings file that contains the latest settings changes and load a new settings file on site after upgrading the firmware. The following text describes the QuickSet settings conversion feature, which should be used prior to the onsite work.

To compare and convert settings differences between previous and new firmware, use the settings conversion utility (see *Tools > Settings > Convert* on page 7.30). After the utility runs, it displays a comparison report (shown in *Figure B.1*) that indicates new settings as Missing (i.e., not in the previous firmware version). These settings are now in the device, but because they are new, their values are defaults and may be incorrect for your application. Be certain to enter values for the new settings to suit your application.

If the report indicates different (Changed) settings, compare the settings you saved previously with the new settings in the device. A changed settings value may result from a setting in the new firmware version providing greater resolution than the setting in the previous firmware. For example, the previous firmware version setting may only allow two decimal points (ABC = 0.01), but the new firmware version may allow three decimal points (ABC = 0.010). Verify that the settings values in the device match the saved settings values.

You can print or save the comparison report per your archiving and documentation standards. If there are changes between the previous file and the converted file, there will be an **Accept Changes** button to the right of the **Settings Comparison Report** heading shown in *Figure B.1*. Accepting the changes causes the newly converted settings to appear, and they can be saved as necessary. Follow your company's procedures to issue a pending settings file to be loaded onto the device after the firmware upgrade.

Refer to the *ACSELERATOR QuickSet SEL-5030 Software Instruction Manual* available at selinc.com/products/5030/ for more information on the settings conversion utility.

Testing the Firmware Upgrade Procedure Prior to Working on Site

It is good practice to perform the firmware upgrade on a test device in the laboratory before working on site. This extra step ensures accuracy and security of the process, especially when you need to upgrade many devices at multiple locations with multiple personnel. You may consider skipping this step if your field personnel are familiar with SEL devices and perform firmware upgrades on a regular basis.

Preparing to Upgrade Firmware on Site

When on site, carefully identify devices you want to upgrade by checking serial numbers, faceplate labels, device identification information, and station name and device name settings.

Before starting the firmware upgrade, take steps to prevent accidental loss of control power to the device or to your PC. If you lose control power during the firmware upgrade, you will need to start over. Such recovery from an aborted firmware upgrade attempt may require additional steps. Some steps may require you to restart the device by removing and reapplying control power to the device. Identify the correct breaker or switch that powers the device on which you intend to work and make sure you do not accidentally remove control power from an in-service device.

Taking the Device Out of Service

Before starting the firmware upgrade for an in-service device, ensure the device is removed from service according to your company's procedures and best practices. Specifically, ensure that the device digital outputs (both contact outputs and communications-based outputs) are isolated to prevent unintended signaling to the connected equipment.

The SCADA/HMI system may alarm when the device disables itself and operates the Alarm contact output during the firmware upgrade process. Make sure you notify your system operators about your onsite work.

Connecting to the Device

Connect an SEL-C664 communications cable (or equivalent USB A-to-B cable) to your PC and the front-panel USB Port F of the device. Set the communications parameters in a terminal emulator software such as QuickSet as follows:

- RTS/CTS = Off
- DTR = On
- Data Bits = 8
- Stop Bits = 1
- Parity = None
- XON/XOFF = Off

There is no need to set the data speed (baud rate).

Saving Device Records (Optional)

SEL recommends saving both device settings and device records before upgrading firmware. Depending on the nature of the changes in the new firmware release, loading new firmware and performing some troubleshooting operations may delete device settings and records. Refer to *Section 7: Engineering and Operator Access Interfaces and Tools* and *Section 5: Transient and Sequential Events Recording* for information on saving device files, including settings and records. You can save these files by using Port 5 over an Ethernet LAN prior to the onsite work. This can be performed remotely by using a machine client rather than as an ad hoc task on site. QuickSet Firmware Loader automates the steps of saving settings and transient records prior to performing the firmware upgrade, but because this occurs over Ymodem through the front-panel USB Port F of the

NOTE: SEL recommends using FTP over Port 5 for retrieving transient records. To save time and simplify on-site work, consider saving transient records and settings before starting the process of upgrading firmware.

device, it may take a long time to retrieve transient records (see *IEEE COMTRADE File Retrieval* on page 5.12). Consider downloading transient records remotely by using FTP over Port 5.

Upgrading Firmware by Using ACSELERATOR QuickSet Firmware Loader

Connect to the device, launch QuickSet, navigate to **Tools > Firmware Loader**, and follow the onscreen prompts.

Step 1. In the **Prepare the Device (Step 1 of 4)** window (*Figure B.2*), click the ellipsis button and browse to the location of the new firmware file. Select the file you saved and verified prior to the onsite work and click **Open**. The file location, file name, device model, and version information appear in the window. Verify that this information is correct, and that the **SELBOOT Max Baud** setting is 115200. QuickSet refers to the setting version number (SVN) as "Version" in *Figure B.2*.

NOTE: Upgrade your QuickSet SEL-TWFL driver, if necessary, before starting the firmware upgrade. You will not be able to use QuickSet with the device after the firmware upgrade if QuickSet does not have the driver for that version installed.

Figure B.2 Prepare the Device (Step 1 of 4) Dialog Window

Step 2. Decide whether you want to save the calibration settings, device settings, and transient records present in the device before upgrading the firmware.

NOTE: The SEL-TWFL firmware upgrade process preserves the calibration settings, so you do not need to save them. In the extremely unlikely event they are erased during the firmware upgrade, you can obtain a copy of these calibration constants from SEL and save them to the affected device.

Calibration settings in *Figure B.2* are factory constants, necessary for proper device operation. The SEL-TWFL firmware upgrade process preserves these factory constants and you do not need to save them. In the extremely unlikely event that they are erased during the firmware upgrade, you can obtain a copy of these calibration constants from SEL and save them to the affected device. If you select the **Save calibration settings** checkbox, the Firmware Loader saves these settings in a separate text file at a location you specify. You will need to enter the Access Level C password to save the calibration settings.

Device settings in *Figure B.2* are settings the user controls. If you select the **Save device settings** checkbox, the Firmware Loader saves these settings in a relay database (.rdb file) at a file location you specify.

NOTE: SEL-TWFL transient records are large IEEE COMTRADE files that can take tens of minutes each to download over the front-panel Port F. If these records must be archived, consider downloading them by using FTP over Port 5, preferably prior to the scheduled firmware upgrade work.

The events referred to in *Figure B.2* are the transient records that the device stores in the IEEE COMTRADE format. If you select the **Save events** checkbox, the Firmware Loader opens a window similar to that shown in *Figure B.4*. Click **Get Selected Events** to save the IEEE COMTRADE records.

Click **Next** to continue. The following example assumes that you have selected only the device settings.

First, the Firmware Loader prompts you for an appropriate name and location on your PC to which you want to save the settings file.

If you have created a relay database, save the settings in that relay database. If not, click **New** to create and name a new database (see *Figure B.3*). In this example, we use a previously created database called Apollo Station, and we name the file to be saved **Line 1**.

Figure B.3 Save Device Settings Dialog Window

Figure B.4 Selecting IEEE COMTRADE Records

When the Firmware Loader finishes downloading the items you have selected, the window shown in *Figure B.5* appears, confirming that all the data items you have selected were saved and that the Firmware Loader is ready to load the firmware onto the device.

Figure B.5 Load Firmware (Step 2 of 4) Dialog Window

Before you proceed, you may optionally consider saving communications reports and the SER record from the device. See *Step 4* on page B.15 in *Upgrading Firmware by Using SEL Commands* for instructions.

Step 3. In the dialog box of *Figure B.5*, click **Next** to begin the firmware upgrade.

Figure B.6 shows the **Load Firmware (Step 3 of 4)** window, in which the Firmware Loader enters SELBOOT, maximizes the data rate of the port, erases the present firmware, and initiates the transfer of the new firmware file (which may take as long as 25 minutes).

Figure B.6 Load Firmware (Step 3 of 4) Dialog Window

During the firmware file upload, the device LCD displays the following message: `SELboot`. When the firmware file upload from the PC to the device is complete, the device restarts and temporarily loses communication with your PC. The Firmware Loader reestablishes communication and issues the **STA** command to the device. Inspect the status report for irregularities, and then click **Next** to continue. If you see status failures, go to *Resolving Device Status Failures* on page B.19.

In some cases, the device may fail to reconnect to the PC, causing the Firmware Loader to display the message shown in *Figure B.7(a)*. Click **No**, and when the message in *Figure B.7(b)* appears, click **OK**.

(a)

(b)

Figure B.7 Failure to Reconnect Prompts

Disconnect the USB cable, wait 10 s, and then reconnect the cable. You should see a window similar to *Figure B.6*. Click **Next** to continue.

If the device does not restart within 2 min of firmware file upload completion, and the device HMI displays no error messages, switch the control power off and back on. The Firmware Loader application should resume. Click **Yes** if the Firmware Loader prompts you to continue.

If there are no failures, the firmware is installed and the device is enabled (the **ENABLED** front-panel target LED illuminates green).

Compare settings in the device with an archived copy of the settings. To compare the settings in the device with saved settings, click the **Begin** button to the right of **Compare device settings** in the prompt shown in *Figure B.8*.

Figure B.8 Verify Device Settings (Step 4 of 4) Dialog Window

The Firmware Loader reads all device settings from the device and asks you to identify the location of the database containing the saved files. In this example, select the **Line 1** file in the Apollo Station database (as shown in *Figure B.9*) and click **OK**.

Figure B.9 Selection of the Saved Device Settings File

The Firmware Loader compares the settings in the device with the settings in the file you just selected and produces a report such as that shown in *Figure B.10*.

Figure B.10 Sample Settings Comparison Report

If there are no changed or missing settings, as shown in *Figure B.10*, close the window. This concludes the firmware upgrade process. You should see a window similar to *Figure B.8*. Click **Exit**.

If you must change settings because of the firmware upgrade, strongly consider issuing a new settings file, bringing it with you onsite, and loading it onto the device. You can then use the settings compare feature to verify the loaded settings against the file containing the as-issued settings, and save the settings from the device to a file marked as-commissioned. The next step describes this optional procedure.

Step 4. Load new settings onto the device (optional). In the **Verify Device Settings (Step 4 of 4)** window, shown in *Figure B.8*, you can use the **Restore device settings** option to load any settings file onto the device.

Click the **Begin** button to the right of **Restore device settings** (shown in *Figure B.8*), and in the window shown in *Figure B.11*, select the settings file you want to load and click **OK**.

Figure B.11 Selecting Settings File to Load Onto the Device

In the resulting prompt, shown in *Figure B.12*, select the specific settings class within the settings files and click **OK** again.

Figure B.12 Selecting Settings Class to Load Onto the Device

The Firmware Loader sends the selected settings to the device. Once the new settings have been loaded onto the device, compare the device settings with the as-issued copy, see *Evaluating Settings Changes and Preparing Settings Files for New Firmware* on page B.4 for instructions on comparing the newly loaded settings against the original settings copy. This concludes loading settings; click **Exit** in the **Verify Device Settings (Step 4 of 4)** window (shown in *Figure B.8*) to exit the Firmware Loader.

Upgrading Firmware by Using SEL Commands

These instructions assume you have a working knowledge of your terminal emulator. In particular, you must be able to select a transfer protocol (1K Xmodem and Ymodem) and transfer files (send and receive files). This method is fast and simple if you use it to upgrade the device firmware and use other methods to save and upload setting files and device records.

Connect to the device and launch terminal emulator software on your PC.

Step 1. Go to Access Level 2 as follows.

Type **ACC <Enter>**, type the Access Level 1 password, and press **<Enter>**. Type **2AC <Enter>**, type the Access Level 2 password, and press **<Enter>**. You will see the Access Level 2 prompt (=>>). If you do not intend to save any information from the device, proceed to *Step 5*.

Step 2. Decide whether you want to save device settings, transient records, or communications logs. If so and you have access to the device over the Ethernet network on Port 5, use FTP to collect files of interest from the device. If you do not have Ethernet access and want to save device data, use the **FILE READ** command to transfer files of interest from the device to your PC.

Step 3. The following example shows how to use the **FILE READ** command to download the settings files from the device to your PC.

NOTE: The SEL-TWFL firmware upgrade process preserves the calibration settings, so you do not need to save them. In the extremely unlikely event that they are erased during the firmware upgrade, you can obtain a copy of these calibration constants from SEL and save them to the affected device.

To see the folders in the device, type **FILE DIR <Enter>**. The device responds as follows:

```
==>>FILE DIR <Enter>

CFG.TXT                                                R   2024/01/30 17:00:10
SETTINGS                                               R D 2024/01/29 00:00:00
EVENTS                                                 R D 2024/01/30 17:00:10
DIAGNOSTICS                                            R D 2024/01/30 17:00:10
REPORTS                                                R D 2024/01/30 17:00:10

=>>
```

To see all settings files, type **FILE DIR SETTINGS <Enter>**. The device responds as follows:

```
==>>FILE DIR SETTINGS <Enter>

ERR.TXT                                                R   2024/01/30 17:00:25
SET_ALL.TXT                                            R   2024/01/30 17:00:25
SET_1.TXT                                              RW  2024/01/30 09:18:04
SET_R.TXT                                              RW  2024/01/30 10:31:05
SET_PF.TXT                                             RW  2024/01/30 08:06:32
SET_P1.TXT                                             RW  2024/01/30 12:46:32
SET_P2.TXT                                             RW  2024/01/30 12:44:25
SET_P3.TXT                                             RW  2024/01/30 12:36:32
SET_P5.TXT                                             RW  2024/01/30 08:19:14
SET_P6.TXT                                             RW  2024/01/30 11:42:46
SET_D1.TXT                                             RW  2024/01/30 14:07:53
SET_D2.TXT                                             RW  2024/01/30 14:46:32
SET_D3.TXT                                             RW  2024/01/30 15:26:32
SET_D4.TXT                                             RW  2024/01/30 16:06:33
SET_D5.TXT                                             RW  2024/01/30 16:40:33

=>>
```

Although the SET_ALL.TXT file contains all settings, this file is read-only and you cannot use it later to restore settings. To be able later to download all the settings to the device from your PC, you must first individually download from the device to the PC all files corresponding to the settings classes. Following is an example of how to download the SET_1.TXT file. Follow the same procedure for the remaining files:

From Access Level 2, type **FILE READ SETTINGS SET_1.TXT <Enter>**. The device responds with the following message:

```
==>>FILE READ SETTINGS SET_1.TXT <Enter>
#000 Ready to send file
#001 Transfer Complete

==>>
```

At the `#000 Ready to send file` response, use the appropriate file transfer function of your terminal emulator to download the settings file from the device and store it in a location of choice on your PC.

When the transfer completes, the device responds as follows:

```
#001 Transfer Complete

==>>
```

After collecting all the files and records that you want, continue to the next step to start the firmware upgrade process.

Step 4. Decide what other device information you want to save and save it by using SEL ASCII commands. Save or copy the device responses to store the information in a text file.

To capture reports that the device prints in the terminal window, enable logging or use the copy and paste function if your terminal emulator has that capability. If using the QuickSet terminal emulator, enable terminal logging by navigating to **Communications > Logging > Terminal Logging**; see *PC Software* on page 7.19 for more information. QuickSet prompts you for the file name and location to which you want to store the terminal session. After specifying the file and location, issue SEL ASCII commands as necessary to collect the desired information. The following list shows the SEL-TWFL commands that allow you to gather various reports relevant to the state of the device, the monitored line(s), and the communications channels.

- **COM P *n*** (*n* = 1–3) to capture communications reports for Port 1, Port 2, or Port 3
- **ETH** to capture the Ethernet Port 5 communications report
- **SER** to capture the SER record (you can also download it as a file)
- **STA** to capture device status information

QuickSet saves the device responses to the commands you enter to the file you specified when enabling logging. Upon completing this optional task, disable terminal logging (**Communications > Logging > Terminal Logging**).

Step 5. From Access Level 2, issue the **L_D** command. The **L_D** command stops the main device program, and by doing so, it takes the device out of service (disables the device). When the main program is stopped, the device executes the SELBOOT code that allows you to upgrade the firmware.

When you type **L_D <Enter>**, the device responds as follows:

```
Ready to take the device out of service for firmware upgrade.

You can only upgrade firmware. To downgrade firmware, abort this procedure and
contact SEL.

Ensure you have a reliable control power connection and reliable device-to-PC
communications during the firmware upgrade process.

Do you want to proceed (Y/N)?
```

Acknowledge by typing **Y <Enter>**. In response, the device becomes disabled (the front-panel **ENABLED** LED turns off and the Alarm contact output asserts), the front-panel LCD screen displays `SELboot`, and the terminal window displays the following message at the SELBOOT prompt (!>):

```
Device disabled.

Issue the REC command to start the main firmware upgrade; issue the REC BOOT
command to start the SELboot firmware upgrade; issue the EXIT command to abort
and enable the device.

!>
```

Type **HELP <Enter>** if you need information on commands available at the SELBOOT prompt. Type **FID <Enter>** if you want to verify the present revisions of the main and SELBOOT firmware in the device before proceeding.

Step 6. Upgrade the SELBOOT firmware in the device (rarely required).

Upgrading SELBOOT firmware is rarely required. Skip this step if you do not upgrade SELBOOT firmware. Upgrading SELBOOT firmware is analogous to upgrading the main firmware.

Issue the **REC BOOT** command to initiate the SELBOOT firmware upgrade process. When you issue the **REC BOOT** command, the device executes a series of steps including receiving the new SELBOOT firmware file, validating it, erasing the old SELBOOT firmware, and writing the new SELBOOT firmware into the permanent memory.

When you type **REC BOOT <Enter>**, the device responds as follows:

```
Ready to receive new SELboot firmware by using the Xmodem protocol.

CAUTION: This operation erases the present firmware. If the control power is
interrupted during this process, you may need to return the unit to the factory
for reprogramming.

Do you want to proceed (Y/N)?
```

The command uses a double-acknowledgment to avoid accidental firmware deletion, and when you type **Y <Enter>**, the device responds:

```
Are you sure (Y/N)?
```

Acknowledge by typing **Y <Enter>**, and the device will proceed with the SELBOOT firmware upgrade process and display the following message:

NOTE: Use the Xmodem protocol, preferably with the 1K option, to transfer firmware files. Use the Ymodem protocol to transfer device records, settings files, and other files. If you fail to initiate file transfer within 20 s, issue the **REC BOOT** command again.

```
To start uploading new firmware, press any key first, and then initiate file
transfer at the terminal by using the Xmodem protocol.
```

At this time, use the file transfer feature of the terminal emulator and start transferring the new SELBOOT firmware file by using the Xmodem protocol. Select the **1K** option for the file transfer, if available. If you fail to initiate the file transfer within 20 s, issue the **REC BOOT** command again. When you have successfully started the file transfer, the device responds as follows:

```
Receiving SELboot firmware... SELboot firmware received.

Validating SELboot firmware... SELboot firmware validated.

Erasing SELboot firmware... SELboot firmware erased.

Writing SELboot firmware...

SELboot firmware upgrade completed. The device is restarting.

Press <Enter> to re-establish a terminal session after the device restarts. Issue
the REC command to start the main firmware upgrade; issue the REC BOOT command
to start the SELboot firmware upgrade; issue the EXIT command to abort and
enable the device.

!>
```

After upgrading the SELBOOT firmware, the device restarts and begins running the SELBOOT program. Type **EXIT <Enter>** to complete the process and enable the device. Type **REC <Enter>** to upgrade the main firmware (see *Step 7*).

Step 7. Upgrade the main firmware in the device.

Typically, you will need to upgrade only the main firmware. If you also need to upgrade the SELBOOT firmware, proceed to *Step 6* to upgrade the SELBOOT firmware first, and then come back to *Step 7* to upgrade the main firmware.

Issue the **REC** command to initiate the upgrade process. When you issue the **REC** command, the device executes a series of steps, including erasing the present firmware, receiving the new firmware file, validating it, and applying it.

When you type **REC <Enter>**, the device responds as follows:

```
Ready to receive new firmware by using the Xmodem protocol.

CAUTION: This operation erases the present firmware before receiving new
firmware. If you proceed, you will erase the present firmware and need to upload
new firmware, and possibly update settings, before returning the device to
service. You may need a new QuickSet (PC setup program) driver after upgrading
the firmware.

Do you want to proceed (Y/N)?
```

The **REC** command uses a double-acknowledgment to avoid accidental firmware deletion, and when you type **Y <Enter>**, the device responds:

```
Are you sure (Y/N)?
```

Acknowledge by typing **Y <Enter>**, and the device will proceed with the main firmware upgrade process and display the following message:

NOTE: Use the Xmodem protocol, preferably with the 1K option, to transfer firmware files. Use the Ymodem protocol to transfer device records, settings files, and other files. If you fail to initiate the file transfer within 20 s, issue the **REC** command again.

```
Erasing firmware... Firmware erased.

To start uploading new firmware, press any key first, and then initiate file
transfer at the terminal by using the Xmodem protocol.
```

At this time, use the file transfer feature of the terminal emulator and start transferring the new firmware file by using the Xmodem protocol. Select the **1K** option for the file transfer, if available. If you fail to initiate the file transfer within 20 s, issue the **REC** command again. When you have successfully started the file transfer, the device responds as follows:

```
Receiving firmware... Firmware received.

Validating firmware... Firmware validated.

Firmware upgrade completed. The device is restarting. This may take several
minutes.

Press <Enter> to re-establish a terminal session after the device restarts.
```

Wait for the device to restart, and press **<Enter>**. The device responds with the Level 0 prompt (=).

Step 8. Verify the firmware version and device status.

From Access Level 2, check the firmware version by typing **VER <Enter>**. Confirm the device uses the intended versions of the SELBOOT firmware and the main firmware.

From Access Level 2, issue the status command by typing **STA <Enter>**. Review the device status report for failures and warnings. Normally, the device shows no errors and the **ENABLED** target LED illuminates green. Resolve any failures according to the instructions at *Resolving Device Status Failures* on page B.19.

If the device does not illuminate the **ENABLED** LED within two minutes after it displays the `Press <Enter> to re-establish a terminal session after the device restarts.` message, contact your Technical Service Center or the SEL factory for assistance.

Step 9. Compare settings in the device with the intended settings.

SEL recommends using QuickSet to compare settings. Launch QuickSet and use the **Read** option from the welcome screen (see *QuickSet Welcome Screen* on page 7.20) to download the settings from the device. Next, use the QuickSet compare utility found in the **Edit** menu to compare settings in the device with the intended settings. A comparison report like that in *Figure B.10* will appear. Use this report to check for differences between the present device settings and the settings file. You can print and save this report.

You can also use the **SHO** command to view settings, but it is good practice to work with settings files rather than viewing individual settings and comparing them one by one with expected values.

If you need to change settings because of a firmware upgrade, strongly consider issuing a new settings file, bringing it with you on site, and loading it onto the device (see *Evaluating Settings Changes and Preparing Settings Files for New Firmware* on page B.4 for additional information). You can use the QuickSet compare utility to verify the loaded settings against the file containing the issued settings, and then save the settings from the device to a file marked as-commissioned. The next optional step describes this procedure.

Step 10. Load new settings to the device (Optional).

You can also use QuickSet to load the settings onto the device (see *Step 9*). If you prefer to use SEL ASCII commands, use this procedure.

NOTE: Use the Xmodem protocol, preferably with the 1K option, to transfer firmware files. Use the Ymodem protocol to transfer device records, settings files, and other files. If you fail to initiate the file transfer within 20 s, issue the **REC** command again.

Use the **FILE WRITE** command to save settings to the device. The following example shows how to use the **FILE WRITE** command from your terminal emulator to upload the Port 1 settings file from your PC to the device by using the Ymodem protocol. To upload other files with the **FILE WRITE** command, use the same command and folder (**FILE WRITE SETTINGS**) but enter the appropriate file name.

At the Access Level 2 prompt, type the following:

```
=>>FILE WRITE SETTINGS SET_P1.TXT <Enter>
```

The device responds as follows:

```
FILE WRITE SETTINGS SET_P1.TXT
CC
```

In your terminal emulator, select **Send file** and select the SET_P1.TXT file from where you saved it on your PC. Click the appropriate command in the terminal emulator to send the file to the device. When the device receives the file, it responds as follows:

```
=>>FILE WRITE SETTINGS SET_P1.TXT
CCCC#001 Transfer Complete
=>>
```

After saving all settings classes to the device, issue the **STA** command and verify that the device operates normally and that the **ENABLED** target LED is illuminated green.

Troubleshooting Firmware Upgrade Problems

Resolving Device Status Failures

If the device returns a status failure message in response to the **STA** command, perform the following steps:

Step 1. From Access Level 2, issue the **STA C** command to clear the status and restart the device, and type **Y <Enter>** when prompted for confirmation. The device responds with the `Clearing warnings and failures. Restarting the device.` message. Wait for approximately 30 s, and then press **<Enter>** until you see the Access Level 0 prompt (=).

Step 2. Issue the **STA** command again to display the status report. Check the report for failures.

Step 3. If there are no failure messages, proceed with the next steps in your on-site work procedure.

Step 4. If the device reports status failures, continue with *Step 5* and *Step 6*.

Step 5. From Access Level 2, issue the **R_S** command to restore factory-default settings in the device. The device prompts whether to restore default settings. Acknowledge by typing **Y <Enter>**.

If the device does not accept the **R_S** command, contact SEL for assistance.

The device can take as long as two minutes to erase present settings and restore default settings. The device then restarts and the **ENABLED** target LED illuminates green.

The **R_S** command resets device passwords to default values. Remember to set unique passwords by following your company procedures. Use the **PAS *n*** (*level* = 1, B, 2, and C) command to set the device passwords.

The **R_S** command resets device settings to default values. Remember to restore device settings for your device by using either QuickSet (refer to *Working With Settings Files* on page 7.22) or the **FILE WRITE** command (refer to *Step 10* on page B.18).

Step 6. From Access Level 2, issue the **STA** command again and check the status report for failures. If any failure status messages persist, see *Appendix F: Diagnostics*, or contact SEL for assistance.

NOTE: Issuing the **R_S** command erases settings and other important data. Be sure to retain device settings and other data downloaded from the device at the start of the firmware upgrade process. Device calibration level settings will not be erased when you issue the **R_S** command.

If the recommissioning tests make you suspect that the device lost its calibration data (extremely unlikely), contact SEL for help and to obtain calibration data for the affected unit. Take note of the unit serial number before contacting SEL.

Technical Support

We appreciate your interest in SEL products and services. If you have questions or comments, please contact us at:

Schweitzer Engineering Laboratories, Inc.
2350 NE Hopkins Court
Pullman, WA 99163-5603 U.S.A.
Tel: +1.509.338.3838
Fax: +1.509.332.7990
Internet: selinc.com/support
Email: info@selinc.com

APPENDIX C

SEL ASCII Commands

Introduction

This appendix lists and describes the SEL ASCII commands of the SEL-TWFL. Use SEL ASCII commands to view and modify settings, obtain status and metering data from the device, or instruct the device to perform an operation such as triggering a transient record.

Commands, command options, and command variables are shown in bold. Lowercase italic letters and words in a command represent command variables that you determine based on the application (for example, communications Port *n* [*n* = F, 1, 2, 3, or 5]).

You can shorten any SEL ASCII command to the first three characters; for example, you can use **ACC** for **ACCESS**. Always press the **<Enter>** key to instruct the device to process the command. For example, to issue the **ACCESS** command, type **ACC** and press **<Enter>**. When programing a machine client to issue commands, send a carriage return **<CR>** character, or a carriage return character followed by a line feed character **<CR><LF>**, to instruct the device to process the command.

Tables in this section show the access level(s) where the command or command option is active. Some commands display a different level of information or perform a different function when issued at different access levels. The device responds with the `Invalid Access Level` message if you enter a command from an access level lower than the specified access level for the command.

You can issue SEL ASCII commands locally over the front-panel Port F and remotely through the Telnet protocol over Ethernet Port 5. Allow SEL ASCII commands over Port F by enabling the port (EPORT = Y). Allow SEL ASCII commands over Port 5 by enabling the port (EPORT = Y), configuring it properly for connection to the WAN/LAN network, and enabling (ETELNET = Y) and configuring the Telnet protocol. You can apply access level restrictions for Port F and Port 5. Specifically, for additional security, you can set lower access level restrictions when allowing remote access to the device. Use the MAXACC Port F and Port 5 settings to restrict the access level on a per-port basis. For example, you can set MAXACC to 2 for Port F to allow the full-range of typically used commands on Port F, and you can set MAXACC to 1 for Port 5 to confine the users to commands that access information but do not delete or change any information.

SEL ASCII Command Reference

Table C.1 summarizes the SEL ASCII commands available in the SEL-TWFL for engineering, maintenance, and testing tasks (categorized by function). *Description of Commands* on page C.6 provides additional details about each SEL ASCII command.

Table C.1 SEL ASCII Command Reference (Sheet 1 of 3)

SEL ASCII Command	Description	Access Level	Examples
Access Control and Security			
ACCESS	Use **ACC** to go to Access Level 1 to view device data.	0, 1, B, 2	**ACC <Enter>**
BACCESS	Use **BAC** to go to Access Level B.	1, B, 2	**BAC <Enter>**
2ACCESS	Use **2AC** to go to Access Level 2 for full user privileges, including settings changes and clearing records.	1, B, 2	**2AC <Enter>**
QUIT	Use **QUI** to exit for security to Access Level 0 after working at higher access levels.	0, 1, B, 2	**QUI <Enter>**
EXIT	Use **EXI** to terminate a Telnet session or the firmware update process.	0, 1, B, 2	**EXI <Enter>**
PASSWORD	Use **PAS *n*** to change the Access Level *n* (*n* = 1, B, 2, or C) password.	2	**PAS 1 <Enter>** **PAS 2 <Enter>**
CALIBRATION	Use **CAL** to go to Access Level C. Use this command only under SEL supervision.	2	**CAL <Enter>**
Device Identification			
IDENTIFICATION	Use **ID** to view the device identification (serial number, firmware revision, etc.).	0, 1, B, 2	**ID <Enter>**
VERSION	Use **VER** to view the device version.	1, B, 2	**VER <Enter>**
MAC	Use **MAC** to view the Media Access Control address for the SFP transceiver in Port 5.	1, B, 2	**MAC <Enter>**
ETHERNET	Use **ETH** to view configuration, status, and performance statistics, and use **ETH C** to clear performance statistics for Ethernet Port 5.	1, B, 2	**ETH <Enter>** **ETH C <Enter>**
Configuring the Device			
HELP	Use **HELP** to list the SEL-TWFL SEL ASCII commands and their descriptions.	0, 1, B, 2	**HELP <Enter>**
SET	Use **SET** to edit settings: **SET** for fault locator, **SET P *p*** for communications Port *p* (*p* = F, 1, 2, 3, or 5), **SET R** for report, **SET D *n*** for DNP Map *n* (*n* = 1–5).	2	**SET <Enter>** **SET L1Z1MAG1 <Enter>** **SET P 5 <Enter>**
SHOW	Use **SHO** to view settings: **SHO** for fault locator, **SHO P *p*** for communications Port *p* (*p* = F, 1, 2, 3, or 5), **SHO R** for report, **SHO D *n*** for DNP Map *n* (*n* = 1–5).	1, B, 2	**SHO <Enter>** **SHO D 1 <Enter>** **SHO P 5 <Enter>**
TIME	Use **TIM** to view and **TIM *hh:mm:ss*** to set the time.	1, B, 2	**TIM <Enter>** **TIM 09:00:00 <Enter>**
DATE	Use **DAT** to view and **DAT *yyyy/mm/dd*** to set the date.	1, B, 2	**DAT <Enter>** **DAT 2024/01/30 <Enter>**

Table C.1 SEL ASCII Command Reference (Sheet 2 of 3)

SEL ASCII Command	Description	Access Level	Examples
Viewing Records, Historical Data, and Other Static Data			
HISTORY	Use **HIS** to view and **HIS C** to clear the transient records (events) history.	1, B, 2	**HIS <Enter>** **HIS 10 <Enter>** **HIS C <Enter>**
SUMMARY	Use **SUM** to view the transient record (event) summary.	1, B, 2	**SUM <Enter>** **SUM N <Enter>**
SER	Use **SER** to view and **SER C** to clear the SER record. Use **SER D** to view the SER entries that the device is suspending from the SER record based on the anti-chatter settings.	1, B, 2	**SER <Enter>** **SER 23 28 <Enter>** **SER 2024/01/30 2024/02/06<Enter>**
LIMO	Use **LIMO** to view the line monitoring data for all lines on which you use the line monitor. Use **LIMO L*m*** to view the line monitoring data for Line *m* and **LIMO L*m* C** to clear the line monitoring event counters for Line *m*. Use **LIMO L*m location*** and **LIMO L*m location1 location2*** to view the event counters at a specific location(s) on Line *m*. Use **LIMO L*m location* C** and **LIMO L*m location1 location2* C** to clear the event counters at a specific location(s) on Line *m* (*m* = 1 or 2).	1, B, 2	**LIMO <Enter>** **LIMO L1 <Enter>** **LIMO L2 9.51 <Enter>** **LIMO L2 9.50 C <Enter>** **LIMO L1 9 10 <Enter>** **LIMO L1 9 10 C <Enter>** **LIMO L1 C <Enter>**
SHOW	Use **SHO** to view settings: **SHO** for fault locator, **SHO P *p*** for communications Port *p* (*p* = F, 1, 2, 3, or 5), **SHO R** for report, **SHO D *n*** for DNP Map *n* (*n* = 1–5).	1, B, 2	**SHO <Enter>** **SHO D 1 <Enter>** **SHO P 5 <Enter>**
TRIGGER	Use **TRI** to trigger a transient record.	1, B, 2	**TRI <Enter>**
FILE	Use **FILE DIR** to view the file directory, **FILE READ** to transfer settings from the device to the PC, and **FILE WRITE** to transfer files from the PC to the device. Use Ymodem to transfer device records.	1, B, 2	**FIL DIR <Enter>** **FIL READ SETTINGS SET_P1.TXT <Enter>**
Communications			
COMMUNICATIONS	Use **COM P *n*** to view and **COM P *n* C** to clear performance statistics for communications Port *n* (*n* = 1, 2, or 3).	1, B, 2	**COM P 1 <Enter>** **COM P 1 C <Enter>**
LOOP	Use **LOOP P *n*** to start the loopback mode for communications Port *n* with SEL MB8/IEEE C37.94 encoding while forcing the received bits to logical 0, **LOOP P *n* DATA** to pass the actual sent bits back as received bits, and **LOOP P *n* X** to terminate the loopback test mode (*n* = 1, 2, or 3).	2	**LOO P 2 <Enter>** **LOO P 2 DATA <Enter>** **LOO P 2 X <Enter>**
ETHERNET	Use **ETH** to view configuration, status, and performance statistics, and use **ETH C** to clear performance statistics for Ethernet Port 5.	1, B, 2	**ETH <Enter>** **ETH C <Enter>**
MAC	Use **MAC** to view the Media Access Control address for the SFP transceiver in Port 5.	1, B, 2	**MAC <Enter>**
STATUS	Use **STA** to view the device status including internal diagnostics, **STA S** to view SELOGIC execution availability.	1, B, 2	**STA <Enter>**

Table C.1 SEL ASCII Command Reference (Sheet 3 of 3)

SEL ASCII Command	Description	Access Level	Examples
Testing and Commissioning			
METER	Use **MET** to view the metering data.	1, B, 2	**MET <Enter>** **MET 10 <Enter>**
TWTEST	Use **TWT** to start and **TWT X** to terminate the traveling-wave test mode.	2	**TWT <Enter>**
PULSE	Use **PUL OUT*nnn s*** to pulse output OUT*nnn* for *s* seconds (requires the BREAKER jumper to be in the enable position).	B, 2	**PUL OUT101 <Enter>**
TEST DB2	Use **TEST DB2** to force digital and analog DNP3 inputs for testing (**TEST DB2 D|A *name value***) and **TEST DB2 OFF** to clear all test values.	B, 2	**TEST DB2 D IN101 1 <Enter>** **TEST DB2 A IA 100 <Enter>**
TARGET	Use **TAR** to view the Relay Word bit status and **TAR C** to clear all latched device targets.	1, B, 2	**TAR LIST <Enter>** **TAR LOP <Enter>**
TRIGGER	Use **TRI** to trigger a transient record.	1, B, 2	**TRI <Enter>**
STATUS	Use **STA** to view the device status including internal diagnostics and **STA S** to view the SELOGIC execution availability.	1, B, 2	**STA <Enter>**
Firmware Upgrade and Advanced Tasks			
L_D	Use **L_D** to take the device out of service and go to SELBOOT in preparation for receiving new firmware.	2	**L_D <Enter>**
R_S	Use **R_S** to perform a factory reset (restore factory configuration except calibration data, clear records, and restart the device). Use **R_S F** at Access Level C to also reset the firmware calibration data.	2	**R_S <Enter>**
VECTOR	Use **VEC** to view internal device diagnostics data. At Access Level C, use this command exclusively under SEL supervision.	2	**VEC <Enter>**

Common Header in Reports Generated by SEL ASCII Commands

The SEL-TWFL responds to some SEL ASCII commands with information formatted as a report. These commands include **COM**, **HIS**, **SUM**, **SER**, **MAC**, **ETH**, **STA**, **MET**, and **TIM Q**. The reports include common header lines, which provide basic information about the device and the report itself. Briefly inspect the header lines to ensure you are viewing or saving a report for the correct device. When saving a report for your internal documentation or forwarding it to others (including SEL), always include the header lines to ensure your report data are clearly associated with the device identification information and that the body of the report is dated and time-stamped.

Figure C.1 defines the items in the header, and *Figure C.2* shows a sample header. *Table C.2* explains the individual data items and includes comments and troubleshooting guidelines.

```
FLID                                      Date: yyyy/mm/dd  Time: hh:mm:ss.xxx
SID                                       Time Source: X
[FID] SEL-TWFL-Rnnn-Vx-Zssspp-Dyyyymmdd   Serial Number: nnnnnnnnnn
```

Figure C.1 Data Items in the Common Header of SEL ASCII Command Reports

```
SEL-TWFL                                  Date: 2024/01/30  Time: 17:00:00.000
StationA                                  Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129        Serial Number: 1240300001
```

Figure C.2 Sample Common Header of SEL ASCII Command Reports

Table C.2 Information Included in the SEL ASCII Report Header Lines

Data Item	Description	Comments and Troubleshooting
FLID	Fault locator identifier specified by the FLID setting	Verify that the fault locator and station identifier match the expected values to ensure you are viewing a report from the correct device, especially when you do not receive the report directly from the device on site.
SID	Station identifier specified by the SID setting	
Date	Date of the report based on the device calendar: *yyyy/mm/dd* is the date[a]	Verify that the report date and time are as expected to ensure you are viewing the correct report, especially when you do not receive the report directly from the device on site. The device time is UTC time.
Time	Time of the report based on the device clock: *hh:mm:ss.xxx* is the time[a]	
Time Source	Time synchronization mode. Possible sources are the following: Free Running, HIRIG, Remote Free Running, and Remote HIRIG.	If Time Source is HIRIG or Remote HIRIG, the device clock is locked to a high-accuracy time source. If Time Source is Free Running, the device is relying on its internal oscillator and is likely to drift away from the absolute time. Consider making a note of the time when you capture a report. This will allow you to estimate the drift and understand time stamps that may be included in the report. If the Time Source is not HIRIG while a functioning time source is connected to the IRIG-B input (i.e., the device does not consider the time source to be a high-accuracy source), inspect your IRIG-B connection and time source and use the **TIM Q** command to learn more about the time source problem. Consider using a DNP master or the **TIM** command to set the device clock when a high-accuracy time source is not available. See *Appendix H: High-Accuracy Timekeeping* for more information.
Serial Number	Device serial number	Verify that the device serial number matches the expected value to ensure you are viewing the report from the correct device.
FID	Firmware identification string for SEL devices	Inspect the FID string to ensure the device is running the expected firmware revision and version. See *Appendix B: Firmware Upgrade Instructions* for more information.
SEL-TWFL	Product name	
R	Firmware revision: *nnn* is the revision number	
V	Firmware version: *x* is the version number	
Z	Settings and HMI version numbers: *sss* is the settings version number (SVN), and *ppp* is the HMI version number	
D	Firmware date code: *yyyymmdd* is the date	

[a] For the summary report (SUM), Date and Time are the date and time that the device triggered the transient record.

Description of Commands

The list of SEL ASCII commands is divided into two parts. *Commands for Engineering Tasks* on page C.6 describes commands typically – but not exclusively – used by human operators performing engineering, testing, or commissioning tasks. *Commands for Machine Clients* on page C.21 describes commands typically issued by machine clients in integration applications, such as supervisory control and data acquisition (SCADA) or a human-machine interface (HMI).

Commands for Engineering Tasks

ACCESS

Use the **ACC** command to go to Access Level 1. Access Level 1 allows you to read data, but not write data. The device prompts for a password in response to the **ACC** command (see *Access Control and Passwords* on page 7.36 for more information). The default password for Access Level 1 is OTTER.

Table C.3 ACC Command

Command	Description	Access Level
ACC	Use **ACC** to go to Access Level 1 to view device data.	0, 1, B, 2

2ACCESS

NOTE: You will only be able to access a level below or equal to the maximum access level restriction set for the port. The MAXACC Port F and Port 5 settings specify the highest level you can access on each port, respectively.

Use the **2AC** command to go to Access Level 2. Access Level 2 allows you to both read and write data, such as when changing device settings. The device prompts for a password in response to the **2AC** command (see *Access Control and Passwords* on page 7.36 for more information). The default password for Access Level 2 is TAIL.

Table C.4 2AC Command

Command	Description	Access Level
2AC	Use **2AC** to go to Access Level 2 for full user privileges, including settings changes and clearing records.	1, B, 2

BACCESS

Use the **BAC** command to go to Access Level B. Access Level B allows you to control device outputs (via the **PULSE** command) in addition to providing all Access Level 1 privileges and many other functions. Access Level B is similar to Access Level 2 with the exception of some critical operations, such as changing the device settings. Refer to the access levels in *Table C.4* to *Table C.44* to identify the commands available at Access Level B. The device prompts for a password in response to the **BAC** command (see *Access Control and Passwords* on page 7.36 for more information). The default password for Access Level B is EDITH.

Table C.5 BAC Command

Command	Description	Access Level
BAC	Use **BAC** to go to Access Level B.	1, B, 2

CALIBRATION

Use the **CAL** command to go to Access Level C (calibration). Access Level C is intended for use by the SEL factory and by SEL field service personnel. Do not enter Access Level C except when directed by SEL. (See *Access Control and Passwords* on page 7.36 for more information). The default password for Access Level C is CLARKE. You will need to enter Access Level C if you want to save the device calibration files (see *Appendix B: Firmware Upgrade Instructions*).

Table C.6 CAL Command

Command	Description	Access Level
CAL	Use **CAL** to go to Access Level C. Use this command only under SEL supervision.	2

COMMUNICATIONS

Use the **COM P *n*** (or **COM P*n***) command to obtain communications statistics for communications channels on Port 1, 2, or 3. See *Communications Report for Ports 1, 2, and 3* on page 3.8.

Table C.7 COM Command

Command[a]	Description	Access Level
COM P *n*	Use **COM P *n*** to view and **COM P *n* C** to clear performance statistics for communications Port *n*.	1, B, 2
COM P *n* C		B, 2

[a] *n* = 1, 2, or 3.

DATE

Use the **DAT** command to view and set the device date. The device can use other time sources, such as IRIG-B, to overwrite the date you enter. Enter the **DAT** command with a date to set the internal clock date. The **DAT** format is yyyy/mm/dd. You can separate the month, day, and year parameters with spaces, commas, slashes, colons, or semicolons.

If you enter a valid date and the device time synchronization source is listed as Free Running (see *Table C.2* and *Appendix H: High-Accuracy Timekeeping*), the device saves the date and updates the real-time clock. If any other time synchronization source is listed (i.e., the device is receiving time from other time sources), the device rejects the **DAT** command set request and instead displays the current internal clock date.

Table C.8 DAT Command

Command	Description	Access Level
DAT	Use **DAT** to view and **DAT *yyyy/mm/dd*** to set the date.	1, B, 2
DAT *yyyy/mm/dd*[a]		

[a] Where: *yyyy* = year (2000–2199), *mm* = month of year (1–12), *dd* = day of month (1–31).

ETHERNET

Use the **ETH** command to obtain the Ethernet Port 5 configuration and status. The **ETH C** (or **ETH R**) command clears the Ethernet connection statistics. See *ETHERNET Report* on page 7.48 for more information.

Table C.9 ETH Command

Command	Description	Access Level
ETH	Use **ETH** to view configuration, status, and performance statistics, and use **ETH C** to clear performance statistics for Ethernet Port 5.	1, B, 2
ETH C		

EXIT

Use the **EXI** command to terminate a Telnet session and go to Access Level 0 or to terminate the firmware upgrade process that you initiated by using the **L_D** command.

Table C.10 EXI Command

Command	Description	Access Level
EXI	Use **EXI** to terminate a Telnet session.	0, 1, B, 2

FILE

Use the **FILE** command to transfer files between the device and PC. Use the Ymodem protocol to transfer device files.

Table C.11 FILE Command

Command	Description	Access Level
FILE DIR ***[directory]***	Use **FILE DIR** to view the file directory and a list of file names in a specified directory (*directory*). If a directory is not specified, then the list of files and directories in the root directory is displayed.	1, B, 2
FILE READ ***[directory] filename***	Use **FILE READ** to initiate a file transfer of the file *filename* (in the folder *directory*) from the device to the terminal emulator software. The *filename* parameter is required.	
FILE WRITE SETTINGS ***filename***	Use **FILE WRITE** to initiate a file transfer of the file *filename* in the folder SETTINGS from the terminal emulator software to the device. If the *filename* parameter is not specified, the file name must be given in the Ymodem header.	2

All text enclosed in [brackets] indicates optional command line parameters. File directories in the SEL-TWFL are EVENTS, REPORTS, SETTINGS, and DIAGNOSTICS. For **FILE READ** operations, specify the directory parameters as needed. The **FILE WRITE** command is available only for the SETTINGS directory. See *Section 8: SCADA and HMI Protocols* for more information about the SEL-TWFL directories and files.

HELP

Use the **HELP** command to list the SEL-TWFL SEL ASCII commands and their descriptions.

Table C.12 HELP Command

Command	Description	Access Level
HELP	Use **HELP** to list the SEL-TWFL SEL ASCII commands and their descriptions.	0, 1, B, 2

HISTORY

Use the **HIS** command to display the history record that lists transient records that the device has recorded. The rows in the history record include the record (event) number, date, time, event type, fault location, maximum current, frequency, and targets (see *History Record* on page 5.18 for more information). Use the **HIS** command to obtain one-line descriptions of transient records. The **HIS C** command clears the history record. You can start downloading a transient record file when that record appears in the history record.

Table C.13 HIS Command

Command	Description	Access Level
HIS	Use **HIS** to view the transient records (events) history.	1, B, 2
HIS *k*	Use **HIS *k*** to display the *k* most recent transient records stored in the device with the oldest at the bottom of the list and the most recent at the top of the list.	
HIS C	Use **HIS C** to clear the transient records (events) history.	2

L_D

Use the **L_D** command to stop the device main program (takes the device out of service) and start the SELBOOT program for the purpose of receiving device firmware, either the main firmware or the SELBOOT firmware. See *Upgrading Firmware by Using SEL Commands* on page B.13 for a usage example.

Table C.14 L_D Command

Command	Description	Access Level
L_D	Use **L_D** to take the device out of service and go to SELBOOT in preparation for receiving new firmware.	2

LIMO

Use the **LIMO** command to obtain line monitoring information including total event count, alarm status, and event counters for all lines on which you use the line monitor. Use the **LIMO L*m*** command to obtain line monitoring information for Line *m* only. Use the **LIMO L*m a b* C** command to clear the event counters for Line *m* for a selected range of locations after remediation of the root cause of the alarm.

Table C.15 LIMO Command

Command[a]	Description	Access Level
LIMO	Use **LIMO** to view the line monitoring alarm(s) including alarm location(s) and event counts for all lines on which you use the line monitor.	1, B, 2
LIMO L*m*	Use **LIMO L*m*** to view the line monitoring alarm for Line *m* including alarm location and event counts.	
LIMO L*m a*	Use **LIMO L*m a*** to view the event counter for location *a* on Line *m*.	
LIMO L*m a b*	Use **LIMO L*m a b*** to view event counters for locations between *a* and *b* on Line *m* (the first 20 locations are displayed).	
LIMO L*m a* C	Use **LIMO L*m a* C** to clear the event counter for location *a* on Line *m*.	2
LIMO L*m a b* C	Use **LIMO L*m a b* C** to clear the event counters for locations between *a* and *b* on Line *m*.	
LIMO L*m* C	Use **LIMO L*m* C** to clear the event counters for Line *m*.	

[a] *m* = 1 or 2.

LOOP

Use the **LOOP P *n*** or (**LOOP *n***) command to instruct the device to receive the transmitted communications data and IEEE C37.94 encoding for troubleshooting purposes.

If you have enabled multiple communications ports (1, 2, or 3), then you must specify the port parameter for the **LOOP** command. If you have only one of the ports enabled, the device assumes that port if no port is otherwise specified. If you do not specify a time-out period, the loopback mode times out in 5 min (see *Loopback Testing* on page 3.14 for more information).

Table C.16 LOOP Command

Command[a]	Description	Access Level
LOOP	Use **LOOP** to initiate loopback mode of the active communications port (available only when a single port is enabled) for 5 min; ignore input data and force the received bits (RMB*m*P*n*) to logical 0.	2
LOOP P *n*	Use **LOOP P *n*** to initiate loopback mode of the active communications Port *n* for 5 min; ignore input data and force the received bits (RMB*m*P*n*) to logical 0.	
LOOP P *n t*	Use **LOOP P *n t*** to initiate loopback mode of the active communications Port *n* and end loopback mode after *t* min; ignore input data and force the received bits (RMB*m*P*n*) to logical 0.	

[a] *n* = 1, 2, or 3; *m* = 1–8; *t* = 1–5000 min, with 1 min resolution.

In the loopback mode, the ROKP*n* Relay Word bit deasserts and the device uses the LBOKP*n* Relay Word bit to indicate whether the data transmissions are satisfactory. The device collects communications statistics as usual.

LOOP P *n* DATA

Use the **LOOP P *n* DATA** (or **LOOP *n* DATA**) command to instruct the device to receive the transmitted MIRRORED BITS outputs (TMB*m*P*n*) as inputs (RMB*m*P*n*) for troubleshooting purposes. See *Loopback Testing* on page 3.14 for more information.

Table C.17 LOOP P *n* DATA Command

Command[a]	Description	Access Level
LOOP DATA	Use **LOOP DATA** to initiate the loopback mode of the active communications port (available only when a single port is enabled) for 5 min; MIRRORED BITS outputs are passed to MIRRORED BITS inputs.	2
LOOP P *n* DATA	Use **LOOP P *n* DATA** to initiate the loopback mode of communications Port *n* for 5 min; MIRRORED BITS outputs are passed to MIRRORED BITS inputs.	
LOOP P *n* DATA *t*	Use **LOOP P *n* DATA *t*** to initiate the loopback mode of communications Port *n* for *t* min; MIRRORED BITS outputs are passed to MIRRORED BITS inputs.	

[a] *n* = 1, 2, or 3; *t* = 1–5000 min, with 1 min resolution.

LOOP P *n* X

Use the **LOOP P *n* X** (or **LOOP *n* X**, **LOOP P *n* R**, or **LOOP *n* R**) command to terminate the loopback mode on communications ports (1, 2, or 3). If you do not specify a port (**LOOP X** or **LOOP R**), the device terminates the loopback mode on all ports (see *Loopback Testing* on page 3.14 for more information).

Table C.18 LOOP P *n* X Command

Command[a]	Description	Access Level
LOOP P *n* X	Use **LOOP P *n* X** to terminate loopback mode on communications Port *n*. (Reset Port *n* to normal use.)	2
LOOP X	Use **LOOP X** to terminate loopback mode on all communications ports. (Reset the ports to normal use.)	

[a] *n* = 1, 2, or 3.

MAC

Use the **MAC** command to obtain the Media Access Control (MAC) address of the SFP transceiver for Port 5. For more information, see *MAC Report* on page 7.49.

Table C.19 MAC Command

Command	Description	Access Level
MAC	Use **MAC** to view the Media Access Control address for the SFP transceiver in Port 5.	1, B, 2

METER

Use the **MET** command to display local and remote fundamental frequency voltages, currents, and the power system frequency (see *Verifying Voltage and Current Inputs* on page 10.12 for more information).

Table C.20 MET Command

Command[a]	Description	Access Level
MET	Use **MET** to view the metering data.	1, B, 2
MET *n*	Use **MET *n*** to view the metering data *n* times.	

[a] *n* = 1–32767.

PASSWORD

Use the **PAS** command to set password protection for device access levels.

PAS *n*

Use the **PAS *n*** command to change the password for the specified access level.

⚠WARNING
The SEL-TWFL is shipped with default passwords. Default passwords should be changed to private passwords at installation. Failure to change each default password to a private password may allow unauthorized access. SEL shall not be responsible for any damage resulting from unauthorized access.

Table C.21 PAS Command

Command[a]	Description	Access Level
PAS *n*	Use **PAS *n*** to change the Access Level *n* password.	2

[a] *n* = 1, B, 2, and C (C is only available at Access Level C).

Valid passwords are character sequences of as many as 12 printable ASCII characters. All passwords are case-sensitive.

Password Changes

When you issue the **PAS** command, you will be prompted first to enter the old password (the default passwords for Access Levels 1, B, 2, and C are OTTER, EDITH, TAIL, and CLARKE, respectively) and then twice to enter the new password. You may disable a prompt for the old password by using the PASSWORD jumper (see *Accessing and Configuring Device Jumpers* on page 9.15 for more information). After you set the new passwords, remember to disable password bypass by removing the PASSWORD jumper.

The following is an example of changing the password for Access Level 1.

```
==>>PAS 1 <Enter>
Old PW: ? ***** <Enter>
New PW: ? ***** <Enter>
Confirm PW: ? ***** <Enter>
Password Changed
```

When you enter an incorrect password in response to the `Old PW` prompt, the device displays the `Invalid Password` message and pulses the PASNVAL Relay Word bit for 1 s. Entry of three incorrect passwords within one minute causes the device to pulse the PASNVAL and BADPASS Relay Word bits for 1 s and to display the following message, where x is the password level that you attempted to change:

```
Level x Denied

WARNING: ACCESS BY UNAUTHORIZED PERSONS STRICTLY PROHIBITED

Access Temporarily Denied.
```

You will not be able to make another access level entry attempt for 30 s. When you successfully enter a new password, the device pulses the CHGPASS Relay Word bit for 1 s.

PULSE

Use the **PUL *m*** command to close a device contact output for a specified time. This function can aid you in device testing and commissioning.

Table C.22 PUL *m* Command

Command[a]	Description	Access Level
PUL *m*	Use **PUL *m*** to pulse output *m* for 1 second.	B, 2
PUL *m s*	Use **PUL *m s*** to pulse output *m* for *s* seconds.	

[a] *m* = OUT101–OUT106, OUT201–OUT208, and ALARM; *s* = 1–30 s, with 1 s resolution.

For example, if you issue the **PUL OUT101** command, Contact Output OUT101 closes for 1 s, and the PULSE Relay Word bit asserts for 1 s. If you issue the **PUL ALARM** command, the Alarm contact output closes for 1 s and the PULSE and ALARM Relay Word bits assert for 1 s.

If the BREAKER jumper is not in place, the device rejects the command and responds with the `Command Aborted: No Breaker Jumper` message. For more information on the password jumper, see *Accessing and Configuring Device Jumpers* on page 9.15.

QUIT

Use the **QUIT** command to go to Access Level 0.

NOTE: Issuing the **QUIT** command does NOT terminate connections for either Telnet or FTP sessions.

Table C.23 QUIT Command

Command	Description	Access Level
QUIT	Use **QUI** to exit for security to Access Level 0 after working at higher access levels.	0, 1, B, 2

R_S

Use the **R_S** command to restore the factory-default settings except calibration data and clear all other nonvolatile data (SER record, transient records (TDR and MHR IEEE COMTRADE records), and diagnostic report files). Use this command when decommissioning the device.

NOTE: If you are returning the device to SEL for service, do not erase data with this command.

Use **R_S F** at Access Level C to perform the same task as **R_S** and also reset the firmware calibration data. The hardware calibration data is never reset. Upgrading the firmware resets the firmware calibration data to make sure they match the new firmware.

Table C.24 R_S Command

Command	Description	Access Level
R_S	Use **R_S** to restore the factory-default settings except calibration data and passwords, clear all private data, and reboot the system.	2[a]

[a] The R_S command is only available at Access Level 2 following a settings failure or a RAM failure.

SER

Use the **SER** commands to view and clear the SER record. You can view the SER entries in numerical or chronological order (see *SER Record Format and Content* on page 5.21 for more information).

Table C.25 SER Command

Command	Description	Access Level
SER	Use **SER** to display all entries from the SER, with the oldest (highest number) at the top of the list and the most recent (lowest number) at the bottom of the list.	1, B, 2
SER *k*	Use **SER *k*** to display the *k* most recent entries from the SER, with the oldest (highest number) at the top of the list and the most recent (lowest number) at the bottom of the list (where *k* = 1–10000).	
SER *m n*	Use **SER *m n*** to display the SER entries from *m* to *n*. If *m* is greater than *n*, entries appear with the oldest (highest number) at the top of the list and the most recent (lowest number) at the bottom of the list. If *m* is less than *n*, entries appear with the most recent (lowest number) at the top of the list and the oldest (highest number) at the bottom of the list.	
SER *date1*	Use **SER *date1*** to display all SER entries on *date1*.	
SER *date1 date2*	Use **SER *date1 date2*** to display the SER entries from *date1* at the top of the list to *date2* at the bottom of the list.	
SER D	Use **SER D** to view the SER entries that the device is suspending from the SER record based on the anti-chatter settings.	
SER C	Use **SER C** to clear the SER record.	2

See *Table 5.10* for a list of factory-set SER record entries.

SET

Use the **SET** command to change settings in the device. The SEL-TWFL settings structure contains items in the following hierarchy: classes, instances, categories, and individual settings. The following is an outline of the device settings structure:

Classes (Device/Fault Locator, Port, Reports, and DNP Map)

Instances (Examples: Port = F, 1, 2, 3, and 5 and DNP Map = 1–5)

Categories (collections of settings within a class)

Settings (individual device settings with values)

The **SET** commands contain these settings structure items, which you must specify in the proper order from class to instance (if applicable) to setting. Use **SET** to edit Device/Fault Locator settings, use **SET P** to edit communications port settings, use **SET R** to edit recording settings, and use **SET D** to edit DNP Map settings.

Table C.26 SET Command

Command[a]	Description	Access Level
SET	Use **SET** to set the Device/Fault Locator settings, beginning at the first setting.	2
SET *label*	Use **SET *label*** to set the Device/Fault Locator settings, beginning at setting *label*.	
SET P	Use **SET P** to set the Port settings of the active communications port (from which you issue the command), beginning at the first setting for this port.	
SET P *label*	Use **SET P *label*** to set the Port settings of the active communications port (from which you issue the command), beginning at setting *label*.	
SET P *p*	Use **SET P *p*** to set the Port settings for communications Port *p*, beginning at the first setting for this port.	
SET P *p label*	Use **SET P *p label*** to set the Port settings for communications Port *p*, beginning at setting *label*.	
SET R	Use **SET R** to set the Report settings, beginning at the first setting in this class.	
SET R *label*	Use **SET R *label*** to set the Report settings, beginning at setting *label*.	
SET D *n*	Use **SET D *n*** to set the DNP Map *n* settings.	
SET D *n label*	Use **SET D *n label*** to set the DNP Map *n* settings, beginning at setting label.	

[a] *label* = setting name such as CTRW in Device/Fault Locator settings.
p = F, 1, 2, 3, or 5; *n* = 1–5.

The device validates your settings entries as you enter each setting. At the end of a settings instance session, the device responds by displaying all the settings in the settings instance and then prompts, `Save changes (Y,N)?` If you answer **Y <Enter>**, the device pulses the SETCHG and SALARM Relay Word bits, saves the new settings and responds with the `Settings saved` message. If you answer **N <Enter>** to the save settings prompt, the device responds with the `Settings aborted` message.

Use the **TE** (terse) option in the **SET** command to inhibit the device from displaying the settings readback information prior to prompting you to save the settings changes. SEL recommends that you use the **TE** option sparingly; you should review the settings readback information to confirm that you have entered the settings that you intended.

Table C.27 TE Option Examples

Command[a]	Description	Access Level
SET TE	Use **SET TE** to set Device/Fault Locator settings, beginning at the first setting in this instance; omit settings readback.	2
SET *label* TE	Use **SET *label* TE** to set Device/Fault Locator settings, beginning at setting *label*; omit settings readback.	
SET P *p label* TE	Use **SET P *p label* TE** to set the Port settings for communications Port *p*, beginning at setting *label*; omit settings readback.	

[a] *label* = setting name such as CTRW in Device/Fault Locator settings. *p* = F, 1, 2, 3, or 5.

SET C

This command allows changing factory constants. Never use this command without SEL supervision. This command is available on Access Level C only and listed only for completeness and disclosure.

SHOW

Use the **SHO** command to display settings in the device (name and value; use **SET** to see the range and unit, if needed). Options for the **SHO** command are the same as the **SET** command.

Table C.28 SHO Command

Command[a]	Description	Access Level
SHO	Use **SHO** to show the Device/Fault Locator settings, beginning at the first setting.	1, B, 2
SHO *label*	Use **SHO *label*** to show the Device/Fault Locator settings, beginning at setting *label*.	
SHO P	Use **SHO P** to show the Port settings for the communications port that you use when issuing the command, beginning at the first setting.	
SHO P *label*	Use **SHO P *label*** to show the Port settings for the communications port that you use when issuing the command, beginning at setting *label*.	
SHO P *p*	Use **SHO P *p*** to show the Port settings for communications Port *p*, beginning at the first setting for this port.	
SHO P *p label*	Use **SHO P *p label*** to show the Port settings for communications Port *p*, beginning at setting *label*.	
SHO R	Use **SHO R** to show the Report settings, beginning at the first setting for this class.	
SHO R *label*	Use **SHO R *label*** to show the Report settings, beginning at setting *label*.	

[a] *label* = setting name such as CTRW; *p* = F, 1, 2, 3, or 5.

STATUS

Use the **STA** command to obtain the device status (internal diagnostics information). See *Appendix F: Diagnostics* for information on device diagnostics and the status report.

Table C.29 STA Command

Command	Description	Access Level
STA	Use **STA** to display the status report.	1, B, 2
STA C	Use **STA C** or **STA R** to clear device status information and restart device.	2
STA S	Use **STA S** to display SELOGIC programming availability.	1, B, 2

SUMMARY

Use the **SUM** command to view the summary reports. For more information, see *Summary Report* on page 5.15. The **SUM** command without any parameters displays the summary report for the most recent transient record (event).

Table C.30 SUM Command

Command	Description	Access Level
SUM	Use **SUM** to display the most recent transient record summary.	1, B, 2
SUM *n*[a]	Use **SUM *n*** to display a transient record summary for Event (record) Number *n*.	
SUM N	Use **SUM N** to view the oldest unacknowledged transient record summary.	
SUM A	Use **SUM A** to acknowledge the oldest unacknowledged transient record summary after issuing a **SUM N** command.	

[a] Parameter *n* indicates the transient record number; see the event history report (*HISTORY* on page C.9).

Transient records have absolute numbers between 10,000 and 65,535. Parameter *n* is the number of a specific record and has a range of 10,000 through 65,535. See *History Record* on page 5.18 for more information.

TARGET

Use the **TAR** command to view logical values of Relay Word bits. When using the **TAR** command, you can specify the row number or Relay Word bit name (see *Appendix D: Relay Word Bits*).

Table C.31 TAR Command

Command	Description	Access Level
TAR	Use **TAR** to display target Row 0 or display the most recently viewed target row.	1, B, 2
TAR *n*	Use **TAR *n*** to display target Row *n*.	
TAR *n k*[a]	Use **TAR *n k*** to display target Row *n* and repeat for *k* times; the repeat count *k* must follow the row number.	
TAR *name*	Use **TAR *name*** to display the target row containing *name* Relay Word bit.	
TAR *name k*[a]	Use **TAR *name k*** to display the target row containing *name* Relay Word bit and repeat for *k* times; the repeat count *k* can be before or after the *name* option.	
TAR LIST	Use **TAR LIST** to display all target rows.	
TAR C or **TAR R**	Use **TAR C** or **TAR R** to reset latched targets and reset the memorized target row to Row 0.	
TAR ROW LIST	Use **TAR ROW LIST** to display all target rows, including the row number.	
TAR ROW *name*	Use **TAR ROW *name*** to display the target row, including the row number, where the *name* Relay Word bit is located.	

[a] *k* = 1–32767.

If you do not specify the Relay Word bit name or row number, the **TAR** command will use the last row number. The device displays Row 0 if you have not specified a row since the device turned on, the access level timed out, a terminal session closed, or you issued the **QUIT** command.

The **TAR C** or **TAR R** command has two functions: to reset any latched device targets resulting from a tripping event (asserts TRGTR for one SELOGIC processing interval) and to reset the target row to Row 0, which the device reports when you issue the **TAR** command without specifying the Relay Word bit name or row number.

TEST DB2

Use the **TEST DB2** command to test the mapping of digital and analog DNP3 inputs. The command overrides values in the DNP3 communications interface only. The values that the device uses for fault locating and control are not changed. However, remote devices may use these analog and digital inputs to make control decisions. Ensure that remote DNP3 clients are properly configured to receive the overridden DNP3 inputs before using the **TEST DB2** command in the device.

When the **TEST DB2** command forces the DNP3 inputs to test values, the TESTDB2 Relay Word bit is asserted to indicate that the DNP3 test mode is active. Issue the **TEST DB2** command to see the present status of all analog and digital values that are currently being overridden.

Use the **TEST DB2 OFF** command to end the testing session and remove the override values. The device resumes communicating the true values over DNP3.

Table C.32 TEST DB2 Command

Command	Description	Access Level
TEST DB2	Use **TEST DB2** to display current digital and analog override names and values.	B, 2
TEST DB2 D *name*[a] *value*[b]	Use **TEST DB2 D *name value*** to write the specified override *value* into the digital input *name*.	
TEST DB2 A *name*[c] *value*[d]	Use **TEST DB2 A *name value*** to write the specified override *value* into the analog input *name*.	
TEST DB2 OFF	Use **TEST DB2 OFF** to clear all digital and analog override test values.	
TEST DB2 D *name*[a] OFF	Use **TEST DB2 D *name* OFF** to terminate the test mode for the digital value specified, and reset the variable to the current value.	
TEST DB2 A *name*[c] OFF	Use **TEST DB2 A *name* OFF** to terminate the test mode for the analog value specified, and reset the variable to the current value.	

[a] Digital *name* can be selected from the Binary Inputs (except UNRDEV and NUNREV) in *Table I.5*.
[b] The override *value* for digital quantities can be logical 0 or logical 1.
[c] The analog *name* can be selected from the Analog Inputs (excluding the Event Summary Analog Inputs) in *Table I.5*.
[d] The override *value* for analog quantities can be an integer or a floating-point number.

TIME

Use the **TIM** command to view and set the device internal clock time. The device works with Coordinated Universal Time (UTC) only, and only IRIG-B version IEEE C37.118. The IEEE C37.118 version includes UTC offset information that the device uses to display UTC. If you use the **TIM** command to set the clock in the device, the device accepts this time as UTC. Separate the hours, minutes, and seconds with colons, semicolons, spaces, commas, or slashes. The **TIM Q** command displays the time you set as UTC and shows the UTC offset as zero.

If a valid IRIG-B time signal is connected to the device, the **TIM** command cannot be used to set the device time. In this case, the device does not update the time (i.e., it rejects the **TIM** command set request) and instead displays the current device time.

Table C.33 TIM Command

Command	Description	Access Level
TIM	Use **TIM** to display the present device internal clock time.	1, B, 2
TIM *hh:mm*	Use **TIM *hh:mm*** to set the device internal clock to *hh:mm*.	
TIM *hh:mm:ss*	Use **TIM *hh:mm:ss*** to set the device internal clock to *hh:mm:ss*.	
TIM Q	Use **TIM Q** to display detailed information about the internal device clock.	

The value *hh* is for hours from 0–23; the value *mm* is for minutes from 0–59; the value *ss* is for seconds from 0–59. If you enter a valid time, the device updates the clock and displays the entered time. If you enter an invalid time, the device responds with the `Invalid Time` message.

The **TIM Q** command displays detailed information on the device internal clock. Use this command to obtain the status of high-accuracy time source inputs and the present clock time mode. See *Appendix H: High-Accuracy Timekeeping* for more information about device time.

TRIGGER

Use the **TRI** command to capture high-resolution (TDR) and ultra-high-resolution (MHR) transient records (see *Section 5: Transient and Sequential Events Recording* for more information).

Table C.34 TRI Command

Command	Description	Access Level
TRI	Use **TRI** to trigger a transient record.	1, B, 2

When you issue the **TRI** command, the device asserts the TRIG Relay Word bit for one processing interval and responds with the `Triggered` message. The device ignores all triggers if the device is disabled, another recording is in progress, or if the memory is full. For any of these conditions, the device responds with the `Did not trigger` message.

TWTEST

Use the **TWT** command to test the TW-based functions. This command requires front-panel acknowledgment. When you acknowledge the **TWT** command, the device asserts the TWTEST Relay Word bit. The TWTEST bit overrides supervision of the TW-based functions with phasors. The TW-based functions therefore respond directly to TWs and you can use TW injections to test them, without any need to inject signals in the lower frequency spectrum. See *Section 10: Testing and Commissioning* for more information.

Enable the TW test mode by issuing the **TWT** command. The device confirms the command by displaying the `Traveling-wave test mode in progress` message. The TW test mode expires in 30 min, but you can extend a TW test by issuing the **TWT** command again to restart the time-out period. When the TW test mode expires, the device deasserts the TWTEST bit. Issue the **TWT X** command to cancel the TW test mode at any time. The device responds with the `Traveling-wave test mode canceled` message and deasserts the TWTEST bit. Always cancel the TW test mode before putting the device in service.

The **TWT** command temporarily alters how the device operates, and therefore for security, it is only accessible at Access Level 2.

Table C.35 TWT Command

Command	Description	Access Level
TWT	Use **TWT** to initiate the TW test mode or restart the TW test mode time-out.	2
TWT X	Use **TWT X** to cancel the TW test mode.	

VECTOR

Use the **VEC** command to capture device diagnostics data. The information contained in a vector report is formatted for SEL in-house use only. Your SEL application engineer or the factory may request a **VEC** and **VEC D** command capture to help diagnose a device or system problem. When in Access Level C, issue the **VEC** command only under SEL supervision.

Table C.36 VEC Command

Command	Description	Access Level
VEC	Use **VEC** to display exception records only.	2
VEC D	Use **VEC D** to display diagnostic records only.	
VEC D *n*	Use **VEC D *n*** to display *n* diagnostic records only.	
VEC E	Use **VEC E** to display exception records only.	
VEC E *n*	Use **VEC E *n*** to display *n* exception records only.	
VEC C	Use **VEC C** to clear all diagnostics and exception vector records.	

VERSION

Use the **VER** command to obtain the device hardware and firmware configuration. The **VER** command lists the part number, serial number, firmware and SELBOOT firmware checksums, firmware and SELBOOT firmware ID, and device configuration information, which includes current inputs nominal current, contact inputs and power supply rated voltage, Port 5 SFP transceiver information, and the size of the SD card (see *Checking Device Status and Installed Hardware and Firmware* on page 9.19 for more information).

Table C.37 VER Command

Command	Description	Access Level
VER	Use **VER** to view the device version.	1, B, 2

Commands for Machine Clients

BNAMES

The **BNA** command displays ASCII names of bits indicating device power-up and settings change for SEL Fast Meter protocol in SEL Compressed ASCII format. See *SEL Compressed ASCII Commands* on page 8.7 and *SEL Fast Binary Protocols* on page 8.13 for more information.

Table C.38 BNA Command

Command	Description	Access Level
BNA	Use **BNA** to display ASCII names of bits indicating device power-up and settings changes.	0, 1, B, 2

CASCII

The **CAS** command displays the SEL Compressed ASCII configuration message. This configuration instructs a machine client about the method for extracting data from other SEL Compressed ASCII commands. See *CASCII Configuration Message for SEL Compressed ASCII Commands* on page 8.8 for more information.

Table C.39 CAS Command

Command	Description	Access Level
CAS	Use **CAS** to display the SEL Compressed ASCII configuration message.	0, 1, B, 2

CHISTORY

The **CHI** command is the **HISTORY** command for the SEL Compressed ASCII command set. The device outputs an SEL Compressed ASCII history report for SCADA and other automation applications. Issue the **CHI** command to view the SEL Compressed ASCII history record. See *Compressed History Report* on page 8.10 for more information.

Table C.40 CHI Command

Command	Description	Access Level
CHI	Use **CHI** to view the entries in the history record in SEL Compressed ASCII format.	1, B, 2
CHI *n*	Use **CHI *n*** to view the *n* most recent entries in the history record in SEL Compressed ASCII format.	

CSTATUS

The **CST** command is the **STATUS** command for the SEL Compressed ASCII command set. See *Compressed Status Report* on page 8.11 for more information.

Table C.41 CST Command

Command	Description	Access Level
CST	Use **CST** to view the device status in SEL Compressed ASCII format.	1, B, 2

DNAME

The **DNA** command displays the ASCII names of Relay Word bits reported in an SEL Fast Meter message in SEL Compressed ASCII format. See *SEL Compressed ASCII Commands* on page 8.7 and *SEL Fast Binary Protocols* on page 8.13 for more information.

Table C.42 DNA Command

Command	Description	Access Level
DNA	Use **DNA** and **DNA X** to display ASCII names of Relay Word bits reported in an SEL Fast Meter message in SEL Compressed ASCII format.	0, 1, B, 2
DNA T	Use **DNA T** to display ASCII names of all Relay Word bits.	

IDENTIFICATION

The **ID** command displays device identification information. See *CASCII Configuration Message for SEL Compressed ASCII Commands* on page 8.8 for more information.

Table C.43 ID Command

Command	Description	Access Level
ID	Use **ID** to display a list of device identification information.	0, 1, B, 2

SNS

The **SNS** command displays the names of the Relay Word bits configured in the SER *n* lists, where *n* = 1–8. This is a comma-delimited string used in conjunction with the SEL Fast SER. See *Section 8: SCADA and HMI Protocols*, *SEL Compressed ASCII Commands* on page 8.7, and *SEL Fast Binary Protocols* on page 8.13 for more information.

Table C.44 SNS Command

Command	Description	Access Level
SNS	Use **SNS** to obtain the names of Relay Word bits configured in the SER.	0, 1, B, 2

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APPENDIX D

Relay Word Bits

Relay Word bits are Boolean variables generated and consumed by fault locator logic and overcurrent and voltage elements. Relay Word bits represent binary inputs of the device, are used for driving binary outputs of the device and in SELOGIC equations, are subject to SER logging, and are available to SCADA/HMI clients over communications protocols. The Relay Word bit names follow a consistent naming convention with the most significant attributes appearing first. The Relay Word bit names are closely aligned with the names of settings that affect the logic that drives these Relay Word bits.

Table D.1 lists the SEL-TWFL Relay Word bits in alphabetical order. Individual sections of this instruction manual provide additional information in the context of the SEL-TWFL functions that generate or consume specific Relay Word bits.

Table D.1 Relay Word Bits (Sheet 1 of 11)

Name	Description	Row
27A1	27P undervoltage Level 1 Phase A asserted	35
27A2	27P undervoltage Level 2 Phase A asserted	35
27ABC1	27P undervoltage Level 1 all phases asserted	35
27ABC2	27P undervoltage Level 2 all phases asserted	35
27B1	27P undervoltage Level 1 Phase B asserted	35
27B2	27P undervoltage Level 2 Phase B asserted	35
27C1	27P undervoltage Level 1 Phase C asserted	35
27C2	27P undervoltage Level 2 Phase C asserted	35
27P1	27P undervoltage Level 1 asserted	33
27P1T	27P time-delayed undervoltage Level 1 asserted	33
27P1TC	27P Level 1 torque-control condition asserted	33
27P2	27P undervoltage Level 2 asserted	33
27P2T	27P time-delayed undervoltage Level 2 asserted	33
27P2TC	27P Level 2 torque-control condition asserted	33
27PS1	27PS undervoltage Level 1 asserted	34
27PS1T	27PS time-delayed undervoltage Level 1 asserted	34
27PS1TC	27PS Level 1 torque-control condition asserted	34
27PS2	27PS undervoltage Level 2 asserted	34
27PS2T	27PS time-delayed undervoltage Level 2 asserted	34
27PS2TC	27PS Level 2 torque-control condition asserted	34
50A1	50P instantaneous overcurrent Level 1 Phase A operated	30
50A2	50P instantaneous overcurrent Level 2 Phase A operated	30
50B1	50P instantaneous overcurrent Level 1 Phase B operated	30
50B2	50P instantaneous overcurrent Level 2 Phase B operated	30
50C1	50P instantaneous overcurrent Level 1 Phase C operated	30

Table D.1 Relay Word Bits (Sheet 2 of 11)

Name	Description	Row
50C2	50P instantaneous overcurrent Level 2 Phase C operated	30
50G1	50G instantaneous overcurrent Level 1 operated	28
50G2	50G instantaneous overcurrent Level 2 operated	28
50P1	50P instantaneous overcurrent Level 1 operated	27
50P2	50P instantaneous overcurrent Level 2 operated	27
50Q1	50Q instantaneous overcurrent Level 1 operated	29
50Q2	50Q instantaneous overcurrent Level 2 operated	29
59A1	59P overvoltage Level 1 Phase A asserted	41
59A2	59P overvoltage Level 2 Phase A asserted	41
59B1	59P overvoltage Level 1 Phase B asserted	41
59B2	59P overvoltage Level 2 Phase B asserted	41
59C1	59P overvoltage Level 1 Phase C asserted	41
59C2	59P overvoltage Level 2 Phase C asserted	41
59G1	59G overvoltage Level 1 asserted	39
59G1T	59G time-delayed overvoltage Level 1 asserted	39
59G1TC	59G Level 1 torque-control condition asserted	39
59G2	59G overvoltage Level 2 asserted	39
59G2T	59G time-delayed overvoltage Level 2 asserted	39
59G2TC	59G Level 2 torque-control condition asserted	39
59P1	59P overvoltage Level 1 asserted	37
59P1T	59P time-delayed overvoltage Level 1 asserted	37
59P1TC	59P Level 1 torque-control condition asserted	37
59P2	59P overvoltage Level 2 asserted	37
59P2T	59P time-delayed overvoltage Level 2 asserted	37
59P2TC	59P Level 2 torque-control condition asserted	37
59PS1	59PS overvoltage Level 1 asserted	38
59PS1T	59PS time-delayed overvoltage Level 1 asserted	38
59PS1TC	59PS Level 1 torque-control condition asserted	38
59PS2	59PS overvoltage Level 2 asserted	38
59PS2T	59PS time-delayed overvoltage Level 2 asserted	38
59PS2TC	59PS Level 2 torque-control condition asserted	38
59Q1	59Q overvoltage Level 1 asserted	40
59Q1T	59Q time-delayed overvoltage Level 1 asserted	40
59Q1TC	59Q Level 1 torque-control condition asserted	40
59Q2	59Q overvoltage Level 2 asserted	40
59Q2T	59Q time-delayed overvoltage Level 2 asserted	40
59Q2TC	59Q Level 2 torque-control condition asserted	40
67G1	67G instantaneous torque-controlled overcurrent Level 1 operated	28
67G1T	67GT time-delayed torque-controlled overcurrent Level 1 operated	28
67G1TC	67G Level 1 torque-control condition asserted	28
67G2	67G instantaneous torque-controlled overcurrent Level 2 operated	28

Table D.1 Relay Word Bits (Sheet 3 of 11)

Name	Description	Row
67G2T	67GT time-delayed torque-controlled overcurrent Level 2 operated	28
67G2TC	67G Level 2 torque-control condition asserted	28
67P1	67P instantaneous torque-controlled overcurrent Level 1 operated	27
67P1A	67P torque-controlled overcurrent Level 1 Phase A operated	31
67P1B	67P torque-controlled overcurrent Level 1 Phase B operated	31
67P1C	67P torque-controlled overcurrent Level 1 Phase C operated	31
67P1T	67PT time-delayed torque-controlled overcurrent Level 1 operated	27
67P1TC	67P Level 1 torque-control condition asserted	27
67P2	67P instantaneous torque-controlled overcurrent Level 2 operated	27
67P2A	67P torque-controlled overcurrent Level 2 Phase A operated	31
67P2B	67P torque-controlled overcurrent Level 2 Phase B operated	31
67P2C	67P torque-controlled overcurrent Level 2 Phase C operated	31
67P2T	67PT time-delayed torque-controlled overcurrent Level 2 operated	27
67P2TC	67P Level 2 torque-control condition asserted	27
67Q1	67Q instantaneous torque-controlled overcurrent Level 1 operated	29
67Q1T	67QT time-delayed torque-controlled overcurrent Level 1 operated	29
67Q1TC	67Q Level 1 torque-control condition asserted	29
67Q2	67Q instantaneous torque-controlled overcurrent Level 2 operated	29
67Q2T	67QT time-delayed torque-controlled overcurrent Level 2 operated	29
67Q2TC	67Q Level 2 torque-control condition asserted	29
ACCESS	Device in Access Level B or higher	9
ACCESSP	One-second pulse when access level is increased to B or higher	9
ALARM	OR combination of HALARM and SALARM	18
BADPASS	One-second pulse after three consecutive bad password entries	9
BNC_OK	High-accuracy IRIG-B signal from BNC port available	5
CHGPASS	One-second pulse whenever a password is changed	9
DST	Daylight-saving time is active	6
DSTP	Daylight-saving time change is pending	6
EN	Device is enabled	0
ER	Event report trigger condition asserted	8
HALARM	OR combination of HALARMP and HALARML	8
HALARML	Latches for any device failures	8
HALARMP	Pulses for five seconds when a warning condition occurs	8
IN101	IN101 input asserted	16
IN102	IN102 input asserted	16
IN103	IN103 input asserted	16
IN104	IN104 input asserted	16
IN105	IN105 input asserted	16
IN201	IN201 input asserted	17
IN202	IN202 input asserted	17
IN203	IN203 input asserted	17

Table D.1 Relay Word Bits (Sheet 4 of 11)

Name	Description	Row
IN204	IN204 input asserted	17
IN205	IN205 input asserted	17
IN206	IN206 input asserted	17
IN207	IN207 input asserted	17
IN208	IN208 input asserted	17
L1_3PO	Three poles opened on Line 1	10
L1APO	Any pole opened on Line 1	10
L1B1A52A	Line 1 Breaker 1 Phase A 52a status	46
L1B1B52A	Line 1 Breaker 1 Phase B 52a status	46
L1B1C52A	Line 1 Breaker 1 Phase C 52a status	46
L1B2A52A	Line 1 Breaker 2 Phase A 52a status	46
L1B2B52A	Line 1 Breaker 2 Phase B 52a status	46
L1B2C52A	Line 1 Breaker 2 Phase C 52a status	46
L1FL	Fault locator trigger condition asserted on Line 1	7
L1FREQOK	Frequency measurement is locked and accurate on Line 1	10
L1LMA	Line monitoring alarm on Line 1	44
L1LMAB1	Line monitoring Blocking Region 1 alarm on Line 1	44
L1LMAB2	Line monitoring Blocking Region 2 alarm on Line 1	44
L1LMEVE	Line monitoring new event detected on Line 1	44
L1LOP	Loss-of-potential condition detected on Line 1	10
L1OPA	Pole A opened on Line 1	10
L1OPB	Pole B opened on Line 1	10
L1OPC	Pole C opened on Line 1	10
L1TD50DH	Incremental-quantity disturbance detector asserted on Line 1	10
L1TWDD	Traveling-wave disturbance detector asserted on Line 1	43
L1TWFLCL	TW fault location confidence level on Line 1	42
L1TWIDD	Traveling-wave current disturbance detector asserted on Line 1	43
L1TWVDD	Traveling-wave voltage disturbance detector asserted on Line 1	43
L2_3PO	Three poles opened on Line 2	11
L2APO	Any pole opened on Line 2	11
L2B1A52A	Line 2 Breaker 1 Phase A 52a status	47
L2B1B52A	Line 2 Breaker 1 Phase B 52a status	47
L2B1C52A	Line 2 Breaker 1 Phase C 52a status	47
L2B2A52A	Line 2 Breaker 2 Phase A 52a status	47
L2B2B52A	Line 2 Breaker 2 Phase B 52a status	47
L2B2C52A	Line 2 Breaker 2 Phase C 52a status	47
L2FL	Fault locator trigger condition asserted on Line 2	7
L2FREQOK	Frequency measurement is locked and accurate on Line 2	11
L2LMA	Line monitoring alarm on Line 2	44
L2LMAB1	Line monitoring Blocking Region 1 alarm on Line 2	44
L2LMAB2	Line monitoring Blocking Region 2 alarm on Line 2	44

Table D.1 Relay Word Bits (Sheet 5 of 11)

Name	Description	Row
L2LMEVE	Line monitoring new event detected on Line 2	44
L2LOP	Loss-of-potential condition detected on Line 2	11
L2OPA	Pole A opened on Line 2	11
L2OPB	Pole B opened on Line 2	11
L2OPC	Pole C opened on Line 2	11
L2TD50DH	Incremental-quantity disturbance detector asserted on Line 2	11
L2TWDD	Traveling-wave disturbance detector asserted on Line 2	43
L2TWFLCL	TW fault location confidence level on Line 2	42
L2TWIDD	Traveling-wave current disturbance detector asserted on Line 2	43
L2TWVDD	Traveling-wave voltage disturbance detector asserted on Line 2	43
LBOKP1	Port 1 operating correctly in loopback mode	13
LBOKP2	Port 2 operating correctly in loopback mode	13
LBOKP3	Port 3 operating correctly in loopback mode	13
LINK5	Port 5 valid link detected	13
LPSEC	Leap second retard direction	6
LPSECP	Leap second is pending	6
LT01	Latch 1 output asserted	63
LT01R	Latch 1 reset condition asserted	65
LT01S	Latch 1 set condition asserted	65
LT02	Latch 2 output asserted	63
LT02R	Latch 2 reset condition asserted	65
LT02S	Latch 2 set condition asserted	65
LT03	Latch 3 output asserted	63
LT03R	Latch 3 reset condition asserted	65
LT03S	Latch 3 set condition asserted	65
LT04	Latch 4 output asserted	63
LT04R	Latch 4 reset condition asserted	65
LT04S	Latch 4 set condition asserted	65
LT05	Latch 5 output asserted	63
LT05R	Latch 5 reset condition asserted	66
LT05S	Latch 5 set condition asserted	66
LT06	Latch 6 output asserted	63
LT06R	Latch 6 reset condition asserted	66
LT06S	Latch 6 set condition asserted	66
LT07	Latch 7 output asserted	63
LT07R	Latch 7 reset condition asserted	66
LT07S	Latch 7 set condition asserted	66
LT08	Latch 8 output asserted	63
LT08R	Latch 8 reset condition asserted	66
LT08S	Latch 8 set condition asserted	66
LT09	Latch 9 output asserted	64

Table D.1 Relay Word Bits (Sheet 6 of 11)

Name	Description	Row
LT09R	Latch 9 reset condition asserted	67
LT09S	Latch 9 set condition asserted	67
LT10	Latch 10 output asserted	64
LT10R	Latch 10 reset condition asserted	67
LT10S	Latch 10 set condition asserted	67
LT11	Latch 11 output asserted	64
LT11R	Latch 11 reset condition asserted	67
LT11S	Latch 11 set condition asserted	67
LT12	Latch 12 output asserted	64
LT12R	Latch 12 reset condition asserted	67
LT12S	Latch 12 set condition asserted	67
LT13	Latch 13 output asserted	64
LT13R	Latch 13 reset condition asserted	68
LT13S	Latch 13 set condition asserted	68
LT14	Latch 14 output asserted	64
LT14R	Latch 14 reset condition asserted	68
LT14S	Latch 14 set condition asserted	68
LT15	Latch 15 output asserted	64
LT15R	Latch 15 reset condition asserted	68
LT15S	Latch 15 set condition asserted	68
LT16	Latch 16 output asserted	64
LT16R	Latch 16 reset condition asserted	68
LT16S	Latch 16 set condition asserted	68
OUT101	OUT101 output close signal	18
OUT102	OUT102 output close signal	18
OUT103	OUT103 output close signal	18
OUT104	OUT104 output close signal	18
OUT105	OUT105 output close signal	18
OUT106	OUT106 output close signal	18
OUT201	OUT201 output close signal	19
OUT202	OUT202 output close signal	19
OUT203	OUT203 output close signal	19
OUT204	OUT204 output close signal	19
OUT205	OUT205 output close signal	19
OUT206	OUT206 output close signal	19
OUT207	OUT207 output close signal	19
OUT208	OUT208 output close signal	19
PASNVAL	One-second pulse when an incorrect password is entered at Access Level B or higher	9
PULSE	PULSE command issued	8
RMB1P1	Received Mirrored Bit 1 on Port 1	21
RMB1P2	Received Mirrored Bit 1 on Port 2	23

Table D.1 Relay Word Bits (Sheet 7 of 11)

Name	Description	Row
RMB1P3	Received Mirrored Bit 1 on Port 3	25
RMB2P1	Received Mirrored Bit 2 on Port 1	21
RMB2P2	Received Mirrored Bit 2 on Port 2	23
RMB2P3	Received Mirrored Bit 2 on Port 3	25
RMB3P1	Received Mirrored Bit 3 on Port 1	21
RMB3P2	Received Mirrored Bit 3 on Port 2	23
RMB3P3	Received Mirrored Bit 3 on Port 3	25
RMB4P1	Received Mirrored Bit 4 on Port 1	21
RMB4P2	Received Mirrored Bit 4 on Port 2	23
RMB4P3	Received Mirrored Bit 4 on Port 3	25
RMB5P1	Received Mirrored Bit 5 on Port 1	21
RMB5P2	Received Mirrored Bit 5 on Port 2	23
RMB5P3	Received Mirrored Bit 5 on Port 3	25
RMB6P1	Received Mirrored Bit 6 on Port 1	21
RMB6P2	Received Mirrored Bit 6 on Port 2	23
RMB6P3	Received Mirrored Bit 6 on Port 3	25
RMB7P1	Received Mirrored Bit 7 on Port 1	21
RMB7P2	Received Mirrored Bit 7 on Port 2	23
RMB7P3	Received Mirrored Bit 7 on Port 3	25
RMB8P1	Received Mirrored Bit 8 on Port 1	21
RMB8P2	Received Mirrored Bit 8 on Port 2	23
RMB8P3	Received Mirrored Bit 8 on Port 3	25
ROKP1	Port 1 operating correctly	13
ROKP2	Port 2 operating correctly	13
ROKP3	Port 3 operating correctly	13
SALARM	OR combination of BADPASS, SETCHG, and TWTEST	9
SETCHG	One-second pulse whenever settings are changed	9
SV01	SELogic Variable 1 condition asserted	51
SV02	SELogic Variable 2 condition asserted	51
SV03	SELogic Variable 3 condition asserted	51
SV04	SELogic Variable 4 condition asserted	51
SV05	SELogic Variable 5 condition asserted	51
SV06	SELogic Variable 6 condition asserted	51
SV07	SELogic Variable 7 condition asserted	51
SV08	SELogic Variable 8 condition asserted	51
SV09	SELogic Variable 9 condition asserted	52
SV10	SELogic Variable 10 condition asserted	52
SV11	SELogic Variable 11 condition asserted	52
SV12	SELogic Variable 12 condition asserted	52
SV13	SELogic Variable 13 condition asserted	52
SV14	SELogic Variable 14 condition asserted	52

Table D.1 Relay Word Bits (Sheet 8 of 11)

Name	Description	Row
SV15	SELogic Variable 15 condition asserted	52
SV16	SELogic Variable 16 condition asserted	52
SV17	SELogic Variable 17 condition asserted	53
SV18	SELogic Variable 18 condition asserted	53
SV19	SELogic Variable 19 condition asserted	53
SV20	SELogic Variable 20 condition asserted	53
SV21	SELogic Variable 21 condition asserted	53
SV22	SELogic Variable 22 condition asserted	53
SV23	SELogic Variable 23 condition asserted	53
SV24	SELogic Variable 24 condition asserted	53
SV25	SELogic Variable 25 condition asserted	54
SV26	SELogic Variable 26 condition asserted	54
SV27	SELogic Variable 27 condition asserted	54
SV28	SELogic Variable 28 condition asserted	54
SV29	SELogic Variable 29 condition asserted	54
SV30	SELogic Variable 30 condition asserted	54
SV31	SELogic Variable 31 condition asserted	54
SV32	SELogic Variable 32 condition asserted	54
SV33	SELogic Variable 33 condition asserted	55
SV34	SELogic Variable 34 condition asserted	55
SV35	SELogic Variable 35 condition asserted	55
SV36	SELogic Variable 36 condition asserted	55
SV37	SELogic Variable 37 condition asserted	55
SV38	SELogic Variable 38 condition asserted	55
SV39	SELogic Variable 39 condition asserted	55
SV40	SELogic Variable 40 condition asserted	55
SV41	SELogic Variable 41 condition asserted	56
SV42	SELogic Variable 42 condition asserted	56
SV43	SELogic Variable 43 condition asserted	56
SV44	SELogic Variable 44 condition asserted	56
SV45	SELogic Variable 45 condition asserted	56
SV46	SELogic Variable 46 condition asserted	56
SV47	SELogic Variable 47 condition asserted	56
SV48	SELogic Variable 48 condition asserted	56
SV49	SELogic Variable 49 condition asserted	57
SV50	SELogic Variable 50 condition asserted	57
SV51	SELogic Variable 51 condition asserted	57
SV52	SELogic Variable 52 condition asserted	57
SV53	SELogic Variable 53 condition asserted	57
SV54	SELogic Variable 54 condition asserted	57
SV55	SELogic Variable 55 condition asserted	57

Table D.1 Relay Word Bits (Sheet 9 of 11)

Name	Description	Row
SV56	SELogic Variable 56 condition asserted	57
SV57	SELogic Variable 57 condition asserted	58
SV58	SELogic Variable 58 condition asserted	58
SV59	SELogic Variable 59 condition asserted	58
SV60	SELogic Variable 60 condition asserted	58
SV61	SELogic Variable 61 condition asserted	58
SV62	SELogic Variable 62 condition asserted	58
SV63	SELogic Variable 63 condition asserted	58
SV64	SELogic Variable 64 condition asserted	58
T01	Timer 1 output asserted	61
T01IN	Timer 1 input condition asserted	59
T02	Timer 2 output asserted	61
T02IN	Timer 2 input condition asserted	59
T03	Timer 3 output asserted	61
T03IN	Timer 3 input condition asserted	59
T04	Timer 4 output asserted	61
T04IN	Timer 4 input condition asserted	59
T05	Timer 5 output asserted	61
T05IN	Timer 5 input condition asserted	59
T06	Timer 6 output asserted	61
T06IN	Timer 6 input condition asserted	59
T07	Timer 7 output asserted	61
T07IN	Timer 7 input condition asserted	59
T08	Timer 8 output asserted	61
T08IN	Timer 8 input condition asserted	59
T09	Timer 9 output asserted	62
T09IN	Timer 9 input condition asserted	60
T10	Timer 10 output asserted	62
T10IN	Timer 10 input condition asserted	60
T11	Timer 11 output asserted	62
T11IN	Timer 11 input condition asserted	60
T12	Timer 12 output asserted	62
T12IN	Timer 12 input condition asserted	60
T13	Timer 13 output asserted	62
T13IN	Timer 13 input condition asserted	60
T14	Timer 14 output asserted	62
T14IN	Timer 14 input condition asserted	60
T15	Timer 15 output asserted	62
T15IN	Timer 15 input condition asserted	60
T16	Timer 16 output asserted	62
T16IN	Timer 16 input condition asserted	60

Table D.1 Relay Word Bits (Sheet 10 of 11)

Name	Description	Row
TAR1FLTR	Line 1 FLTRIG target is asserted	0
TAR1LMA	Line 1 LM ALARM status is asserted	1
TAR1LOP	Line 1 LOP status is asserted	3
TAR1METW	Line 1 ME TW target is asserted	1
TAR1MEZ	Line 1 ME Z target is asserted	1
TAR1SETW	Line 1 SE TW target is asserted	1
TAR1SEZ	Line 1 SE Z target is asserted	1
TAR2FLTR	Line 2 FLTRIG target is asserted	0
TAR2LMA	Line 2 LM ALARM status is asserted	2
TAR2LOP	Line 2 LOP status is asserted	3
TAR2METW	Line 2 ME TW target is asserted	2
TAR2MEZ	Line 2 ME Z target is asserted	2
TAR2SETW	Line 2 SE TW target is asserted	2
TAR2SEZ	Line 2 SE Z target is asserted	2
TARCPG	Communications Ports 1, 2, and 3 status is asserted green (all enabled ports OK)	4
TARCPR	Communications Ports 1, 2, and 3 status is asserted red (all enabled ports not OK)	4
TARCPY	Communications Ports 1, 2, and 3 status is asserted yellow (some but not all enabled ports OK)	4
TARFLTR	TRIGGERED target is asserted	0
TARTSYN	TIME SYNC status is asserted	4
TESTDB2	TEST DB2 command is overriding data	12
TIRIG	Device receives a valid IRIG-B signal	5
TMB1P1	Transmitted Mirrored Bit 1 asserted on Port 1	20
TMB1P2	Transmitted Mirrored Bit 1 asserted on Port 2	22
TMB1P3	Transmitted Mirrored Bit 1 asserted on Port 3	24
TMB2P1	Transmitted Mirrored Bit 2 asserted on Port 1	20
TMB2P2	Transmitted Mirrored Bit 2 asserted on Port 2	22
TMB2P3	Transmitted Mirrored Bit 2 asserted on Port 3	24
TMB3P1	Transmitted Mirrored Bit 3 asserted on Port 1	20
TMB3P2	Transmitted Mirrored Bit 3 asserted on Port 2	22
TMB3P3	Transmitted Mirrored Bit 3 asserted on Port 3	24
TMB4P1	Transmitted Mirrored Bit 4 asserted on Port 1	20
TMB4P2	Transmitted Mirrored Bit 4 asserted on Port 2	22
TMB4P3	Transmitted Mirrored Bit 4 asserted on Port 3	24
TMB5P1	Transmitted Mirrored Bit 5 asserted on Port 1	20
TMB5P2	Transmitted Mirrored Bit 5 asserted on Port 2	22
TMB5P3	Transmitted Mirrored Bit 5 asserted on Port 3	24
TMB6P1	Transmitted Mirrored Bit 6 asserted on Port 1	20
TMB6P2	Transmitted Mirrored Bit 6 asserted on Port 2	22
TMB6P3	Transmitted Mirrored Bit 6 asserted on Port 3	24
TMB7P1	Transmitted Mirrored Bit 7 asserted on Port 1	20
TMB7P2	Transmitted Mirrored Bit 7 asserted on Port 2	22

Table D.1 Relay Word Bits (Sheet 11 of 11)

Name	Description	Row
TMB7P3	Transmitted Mirrored Bit 7 asserted on Port 3	24
TMB8P1	Transmitted Mirrored Bit 8 asserted on Port 1	20
TMB8P2	Transmitted Mirrored Bit 8 asserted on Port 2	22
TMB8P3	Transmitted Mirrored Bit 8 asserted on Port 3	24
TQUAL1	IRIG-B Time Quality Bit 1	6
TQUAL2	IRIG-B Time Quality Bit 2	6
TQUAL3	IRIG-B Time Quality Bit 3	6
TQUAL4	IRIG-B Time Quality Bit 4	6
TRGTR	TARGET RESET pushbutton pressed or command issued	4
TSOK	Device clock is synchronized with high accuracy to the absolute time	5
TWTEST	Traveling-wave test mode in progress	12

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APPENDIX E

Analog Quantities

Introduction

The SEL-TWFL acquires, calculates, records, and makes available to the user a wide range of analog quantities. The device uses the means appropriate for each type of data to store these different analog data and to make them available to human operators and machine clients. This appendix itemizes the analog quantities of the SEL-TWFL as follows:

- *Metering Quantities* on page E.1 lists the device metering quantities available on the device front-panel HMI, in the ACSELERATOR QuickSet SEL-5030 Software virtual HMI, and by using the DNP3 LAN/WAN protocol and the **METER** command.
- *Analog Quantities Available Over SEL Fast Meter Protocol* on page E.2 lists data available by using the SEL Fast Meter protocol for SCADA and HMI applications.
- *Analog Quantities Related to Events and Faults* on page E.3 lists event-related quantities, such as pre-fault and fault voltages and currents and the fault location, as well as miscellaneous quantities that aid in analysis of device operation.

Metering Quantities

Table E.1 lists SEL-TWFL metering quantities available on the device front-panel HMI, in the QuickSet HMI, and by using the DNP3 LAN/WAN protocol and the **METER** (**MET**) command. These voltages and currents are frequency-compensated phasors scaled to root-mean-square (rms) and referenced to the positive-sequence voltage angle or if the voltage is zero, the positive-sequence current angle (see *Phasors and Frequency Estimation* on page G.10 for more information on frequency and phasor measurement).

Table E.1 Metering Quantities Available on the Front-Panel HMI, in the QuickSet HMI, and by Using DNP3 and the MET Command (Sheet 1 of 2)

Label[a, b, c]	Description[d]	Units[e]	DNP3 Label
L*m*Iϕ	Line *m* Phase ϕ current, magnitude	A	L*m*Iϕ
	Line *m* Phase ϕ current, angle	deg	L*m*IϕFA
L*m*I1	Line *m* positive-sequence current, magnitude	A	L*m*I1
	Line *m* positive-sequence current, angle	deg	L*m*I1FA
L*m*3I2	Line *m* negative-sequence current, magnitude	A	L*m*_3I2
	Line *m* negative-sequence current, angle	deg	L*m*_3I2FA

Table E.1 Metering Quantities Available on the Front-Panel HMI, in the QuickSet HMI, and by Using DNP3 and the MET Command (Sheet 2 of 2)

Label[a, b, c]	Description[d]	Units[e]	DNP3 Label
L*m*3I0	Line *m* zero-sequence current, magnitude	A	L*m*_3I0
	Line *m* zero-sequence current, angle	deg	L*m*_3I0FA
L*m*Vϕ	Line *m* Phase ϕ voltage, magnitude	kV	L*m*Vϕ
	Line *m* Phase ϕ voltage, angle	deg	L*m*VϕFA
L*m*Vϕϕ	Line *m* Phase ϕ-to-Phase ϕ voltage, magnitude	kV	L*m*Vϕϕ
	Line *m* Phase ϕ-to-Phase ϕ voltage, angle	deg	L*m*VϕϕFA
L*m*V1	Line *m* positive-sequence voltage, magnitude	kV	L*m*V1
	Line *m* positive-sequence voltage, angle	deg	L*m*V1FA
L*m*3V2	Line *m* negative-sequence voltage, magnitude	kV	L*m*_3V2
	Line *m* negative-sequence voltage, angle	deg	L*m*_3V2FA
L*m*3V0	Line *m* zero-sequence voltage, magnitude	kV	L*m*_3V0
	Line *m* zero-sequence voltage, angle	deg	L*m*_3V0FA
L*m*P	Line *m* three-phase power, active	MW	L*m*P3
L*m*Q	Line *m* three-phase power, reactive	MVAR	L*m*Q3
L*m*FREQ	Line *m* frequency	Hz	L*m*FREQ

[a] *m* = 1–2.
[b] ϕ = A, B, or C.
[c] ϕϕ = AB, BC, or CA.
[d] All voltages and currents are fundamental frequency phasors scaled to rms and with their angles referenced to V1 or if V1 is zero, I1.
[e] Primary kV and A.

Analog Quantities Available Over SEL Fast Meter Protocol

Table E.2 lists the analog quantities available from the SEL-TWFL over SEL Fast Meter protocol (see *Section 8: SCADA and HMI Protocols* for more information). These voltages and currents are frequency-compensated phasors scaled to rms and referenced to the positive-sequence voltage angle or if the voltage is zero, the positive-sequence current angle (see *Phasors and Frequency Estimation* on page G.10 for more information on frequency and phasor measurement).

Table E.2 Analog Quantities Available Over SEL Fast Meter Protocol

Label[a, b]	Description[c]	Units[d]
L*m*IϕRE_P	Line *m* Phase ϕ current, real	A
L*m*IϕIM_P	Line *m* Phase ϕ current, imaginary	A
L*m*VϕRE_P	Line *m* Phase ϕ voltage, real	V
L*m*VϕIM_P	Line *m* Phase ϕ voltage, imaginary	V
L*m*FREQ	Line *m* frequency	Hz

[a] *m* = 1–2.
[b] ϕ = A, B, or C.
[c] All voltages and currents are fundamental frequency phasors scaled to rms and with their angles referenced to V1 or if V1 is zero, I1.
[d] Primary V and A.

Analog Quantities Related to Events and Faults

Table E.3 lists analog quantities related to events or to the SEL-TWFL operation in general. Different subsets of these data are available on the device front-panel HMI, by using the **HISTORY** (**HIS**) and **SUMMARY** (**SUM**) commands, by using the DNP3 LAN/WAN protocol, and in the header (HDR) files of the MHR and TDR IEEE COMTRADE records.

Section 5: Transient and Sequential Events Recording provides more information on these analog quantities.

Table E.3 Event-Related Analog Quantities Available on the Front-Panel HMI, by Using the HIS and SUM Commands and DNP3, and in the IEEE COMTRADE HDR Files (Sheet 1 of 5)

Label[a, b, c]	DNP3 Label	Description[d]	Format or Units[e]	Device HMI	HIS	SUM	DNP3	HDR File
Basic Event Data								
Event_Date	N/A	Event record trigger date	yyyy/mm/dd	×	×	×		×
Event_Time	N/A	Event record trigger time	hh:mm:ss.sss	×	×	×		×
ETIMEH	ETIMEH	Event record trigger time in DNP format	high word				×	
ETIMEM	ETIMEM	Event record trigger time in DNP format	middle word				×	
ETIMEL	ETIMEL	Event record trigger time in DNP format	low word				×	
ETIMEH16	ETIMEH16	Event record trigger time in DNP format	high 16 bits signed				×	
ETIMEM16	ETIMEM16	Event record trigger time in DNP format	middle 16 bits signed				×	
ETIMEL16	ETIMEL16	Event record trigger time in DNP format	low 16 bits signed				×	
Event_Number	N/A	Event record number	#####	×	×	×		×
FUNR	FUNR	Number of event records unread by DNP client	integer				×	
ETYPE[f]	ETYPE	Event type			×	×	×	×
Fault Information								
L*m*FTIME[g]	N/A	Line *m* fault time	hh:mm:ss.ssss			×		×
L*m*FTIMH	L*m*FTIMH	Line *m* fault time in DNP format	high word				×	
L*m*FTIMM	L*m*FTIMM	Line *m* fault time in DNP format	middle word				×	
L*m*FTIML	L*m*FTIML	Line *m* fault time in DNP format	low word				×	
L*m*FTIMH16	L*m*FTIMH16	Line *m* fault time in DNP format	high 16 bits signed				×	
L*m*FTIMM16	L*m*FTIMM16	Line *m* fault time in DNP format	middle 16 bits signed				×	
L*m*FTIML16	L*m*FTIML16	Line *m* fault time in DNP format	low 16 bits signed				×	
L*m*FTYPE	L*m*FTYPE	Line *m* fault type					×	×

Table E.3 Event-Related Analog Quantities Available on the Front-Panel HMI, by Using the HIS and SUM Commands and DNP3, and in the IEEE COMTRADE HDR Files (Sheet 2 of 5)

Label[a, b, c]	DNP3 Label	Description[d]	Format or Units[e]	Device HMI	HIS	SUM	DNP3	HDR File
L*m*FLOC	L*m*FLOC	Line *m* fault location	km/mi	×	×	×	×	×
L*m*FLRT	L*m*FLRT	Line *m* fault location reference terminal		×		×	×	×
L*m*IM_FLT	L*m*FIM	Line *m* fault current, maximum phase magnitude	A	×			×	
Fault Currents, Voltages, and Frequency								
L*m*FREQ	L*m*FFREQ	Line *m* pre-fault frequency	Hz			×	×	×
L*m*Iϕ	L*m*FIϕMP	Line *m* Phase ϕ pre-fault current, magnitude	A			×	×	×
	L*m*FIϕAP	Line *m* Phase ϕ pre-fault current, angle	deg			×	×	×
L*m*3I2	L*m*F3I2MP	Line *m* negative-sequence pre-fault current, magnitude	A			×	×	×
	L*m*F3I2AP	Line *m* negative-sequence pre-fault current, angle	deg			×	×	×
L*m*3I0	L*m*F3I0MP	Line *m* zero-sequence pre-fault current, magnitude	A			×	×	×
	L*m*F3I0AP	Line *m* zero-sequence pre-fault current, angle	deg			×	×	×
L*m*Vϕ	L*m*FVϕMP	Line *m* Phase ϕ pre-fault voltage, magnitude	kV			×	×	×
	L*m*FVϕAP	Line *m* Phase ϕ pre-fault voltage, angle	deg			×	×	×
L*m*Iϕ	L*m*FIϕM	Line *m* Phase ϕ fault current, magnitude	A			×	×	×
	L*m*FIϕA	Line *m* Phase ϕ fault current, angle	deg			×	×	×
L*m*3I2	L*m*F3I2M	Line *m* negative-sequence fault current, magnitude	A			×	×	×
	L*m*F3I2A	Line *m* negative-sequence fault current, angle	deg			×	×	×
L*m*3I0	L*m*F3I0M	Line *m* zero-sequence fault current, magnitude	A			×	×	×
	L*m*F3I0A	Line *m* zero-sequence fault current, angle	deg			×	×	×
L*m*Vϕ	L*m*FVϕM	Line *m* Phase ϕ fault voltage, magnitude	kV			×	×	×
	L*m*FVϕA	Line *m* Phase ϕ fault voltage, angle	deg			×	×	×
Additional Information About Fault Locating								
L*m*_SE_TW_Location1	L*m*SETWFL1	Line *m* fault location, single-ended TW-based method Result 1	km/mi	×			×	×
L*m*_SE_TW_Location2	L*m*SETWFL2	Line *m* fault location, single-ended TW-based method Result 2	km/mi	×			×	×

Table E.3 Event-Related Analog Quantities Available on the Front-Panel HMI, by Using the HIS and SUM Commands and DNP3, and in the IEEE COMTRADE HDR Files (Sheet 3 of 5)

Label[a, b, c]	DNP3 Label	Description[d]	Format or Units[e]	Device HMI	HIS	SUM	DNP3	HDR File
L*m*_SE_TW_Location3	L*m*SETWFL3	Line *m* fault location, single-ended TW-based method Result 3	km/mi	×			×	×
L*m*_SE_TW_Location4	L*m*SETWFL4	Line *m* fault location, single-ended TW-based method Result 4	km/mi	×			×	×
L*m*_ME_TW_Location	L*m*METWFL	Line *m* fault location, multi-ended TW-based method	km/mi	×			×	×
L*m*_ME_TW_Location_Reference_Terminal	L*m*METWRT	Line *m* METWFL fault location reference terminal		×			×	×
L*m*_SE_Z-Based_Location	L*m*SEZFL	Line *m* fault location, single-ended impedance-based method	km/mi	×			×	×
L*m*_ME_Z-Based_Location	L*m*MEZFL	Line *m* fault location, multi-ended impedance-based method	km/mi	×			×	×
L*m*_ME_Z-Based_Location_Reference_Terminal	L*m*MEZRT	Line *m* MEZFL fault location reference terminal		×			×	×
L*m*_First_TW_Time_Local	N/A	Time stamp of the first local TW compensated for the CT cable delay.	yyyy/mm/dd hh:mm:ss.XX XXXXXX					×
	L*m*FILTWMS	Line *m* local first TW arrival time	ms				×	
	L*m*FILTWUS	Line *m* local first TW arrival time	µs				×	
	L*m*FILTWNS	Line *m* local first TW arrival time	ns				×	
	L*m*FILTWH	Line *m* local first TW arrival time seconds in DNP format	high word				×	
	L*m*FILTWM	Line *m* local first TW arrival time seconds in DNP format	middle word				×	
	L*m*FILTWL	Line *m* local first TW arrival time seconds in DNP format	low word				×	
	L*m*FILTWH16	Line *m* local first TW arrival time seconds in DNP format	high 16 bits signed				×	
	L*m*FILTWM16	Line *m* local first TW arrival time seconds in DNP format	middle 16 bits signed				×	
	L*m*FILTWL16	Line *m* local first TW arrival time seconds in DNP format	low 16 bits signed				×	

Table E.3 Event-Related Analog Quantities Available on the Front-Panel HMI, by Using the HIS and SUM Commands and DNP3, and in the IEEE COMTRADE HDR Files (Sheet 4 of 5)

Label[a, b, c]	DNP3 Label	Description[d]	Format or Units[e]	Device HMI	HIS	SUM	DNP3	HDR File
L*m*_First_TW_Time_Received_P*n*	N/A	Time stamp of the first remote TW compensated for the CT cable delay, received on Port *n*	yyyy/mm/dd hh:mm:ss.XX XXXXXX					×
	FIRTWP*n*MS	Remote first TW arrival time received on Port *n*	ms				×	
	FIRTWP*n*US	Remote first TW arrival time received on Port *n*	µs				×	
	FIRTWP*n*NS	Remote first TW arrival time received on Port *n*	ns				×	
	FIRTWP*n*H	Remote first TW arrival time seconds received on Port *n* in DNP format	high word				×	
	FIRTWP*n*M	Remote first TW arrival time seconds received on Port *n* in DNP format	middle word				×	
	FIRTWP*n*L	Remote first TW arrival time seconds received on Port *n* in DNP format	low word				×	
	FIRTWP*n*H16	Remote first TW arrival time seconds received on Port *n* in DNP format	high 16 bits signed				×	
	FIRTWP*n*M16	Remote first TW arrival time seconds received on Port *n* in DNP format	middle 16 bits signed				×	
	FIRTWP*n*L16	Remote first TW arrival time seconds received on Port *n* in DNP format	low 16 bits signed				×	
Line Monitor Data								
L*m*LMLOC	L*m*LMLOC	Line *m* line monitoring alarm location[h]	km/mi	×			×	
L*m*LMLOCB1	L*m*LMLOCB1	Line *m* line monitoring Blocking Region 1 alarm location[h]	km/mi	×			×	
L*m*LMLOCB2	L*m*LMLOCB2	Line *m* line monitoring Blocking Region 2 alarm location[h]	km/mi	×			×	
L*m*LMETOT	L*m*LMETOT	Line *m* line monitoring total event count[i]		×			×	
Calibration Settings Helpful When Analyzing Device Operation (Complete List of Device Settings Is Provided in the HDR File)								
TWDSW	N/A	Parameter of the differentiator-smoother filter the SEL-TWFL uses to measure traveling waves	1 MHz samples count					×

Table E.3 Event-Related Analog Quantities Available on the Front-Panel HMI, by Using the HIS and SUM Commands and DNP3, and in the IEEE COMTRADE HDR Files (Sheet 5 of 5)

Label[a, b, c]	DNP3 Label	Description[d]	Format or Units[e]	Device HMI	HIS	SUM	DNP3	HDR File
Device Temperatures								
MB_TEMP	MBTEMP	Temperature, main board	deg C				×	
SFP_P5_TEMP	SFP5TEMP	Temperature, Port 5 SFP transceiver	deg C				×	

[a] m = 1–2.
[b] n = 1–3.
[c] ϕ = A, B, or C.
[d] All voltages and currents are fundamental frequency phasors scaled to rms and with their angles referenced to V1 or if V1 is zero, I1.
[e] Primary kV and A.
[f] Event Type. For definition, see *Table 5.7*.
[g] Fault Time. For definition, see *Table 5.7*.
[h] Location with highest event count if the alarm condition is satisfied at multiple locations.
[i] This counter may decrease at midnight when counters within the blocking regions autoreset.

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APPENDIX F

Diagnostics

The SEL-TWFL continuously performs diagnostic self-checks on the hardware to detect failures and out-of-tolerance conditions. The device diagnostics implementation maximizes both sensitivity and coverage of failures and prevents unintended device operation due to internal device problems.

Diagnostic Overview

The device reports out-of-tolerance conditions as a *status warning* or as a *status failure*. The device issues a status warning for conditions that do not compromise device functionality but which are beyond expected limits. The device continues operation during status warning conditions. The device declares a status failure and enters a disabled state for severe out-of-tolerance conditions. During the disabled state, the device de-energizes all contact outputs and it does not execute fault locating, monitoring, and recording functions. When the device is disabled, the **ENABLED** front-panel LED is not illuminated.

The SEL-TWFL continuously monitors all memory chips and restarts upon detecting errors in internal memory. The device performs and logs in the SER as many as three diagnostic restarts in a seven-day period. After this limit is exceeded, the device refrains from further restarts and disables recording until you restart the device (fault locating and line monitoring remain enabled). Be sure to first collect all information related to abnormal device behavior before restarting the device (see *Table F.2* for more information). You can correct transitory failure conditions (such as soft memory errors caused by high-energy cosmic particles) by restarting the device.

Table F.1 summarizes the alarm Relay Word bits and the different conditions that cause them to assert.

Table F.1 Alarm Relay Word Bits

Alarm Relay Word Bit	Description
HALARML	Latches for any device failures
HALARMP	Pulses for five seconds when a warning condition occurs
HALARM	OR combination of HALARMP and HALARML
SETCHG	One-second pulse whenever settings are changed
ACCESSP	One-second pulse when access level is increased to B or higher
ACCESS	Device in Access Level B or higher
SALARM	OR combination of BADPASS, SETCHG, and TWTEST
PASNVAL	One-second pulse when an incorrect password is entered at Access Level B or higher
CHGPASS	One-second pulse whenever a password is changed
BADPASS	One-second pulse after three consecutive bad password entries

Depending on device status, the diagnostic self-checks either cause the HALARMP Relay Word bit to pulse for 5 s or permanently latch the HALARML Relay Word bit. The HALARM Relay Word bit is the OR combination of the HALARMP and HALARML bits. Use *Table F.2* to understand how the HALARMP and HALARML bits respond to any particular self-test outcome.

In addition to performing hardware diagnostics, the device monitors settings changes and password entry attempts. The device asserts the SETCHG Relay Word bit for a settings change and the BADPASS Relay Word bit after three unsuccessful password entry attempts. The SALARM Relay Word bit is the OR combination of the BADPASS, SETCHG, and TWTEST bits. The BADPASS and SETCHG bits assert for approximately one second. Monitor the BADPASS and SETCHG bits remotely to detect unintentional or malicious attempts to gain access to the device (including attempts to change settings).

The ALARM Relay Word bit remains asserted when the HALARM or SALARM Relay Word bit is asserted. Monitor the ALARM bit to detect unintentional or malicious attempts to test the device.

The SEL-TWFL monitors communications Port 5 for the presence and compatibility of the installed SFP transceiver. For example, if EPORT is set to Y for Port 5 and a transceiver is not installed, the device asserts the `PORT 5 SFP NOT INSTALLED` warning message.

Diagnostic Reporting

The SEL-TWFL provides local indication of device health and status via the **ENABLED** target LED and front-panel display messages. See *Table F.2* for a complete list of the diagnostic messages.

The SEL-TWFL provides a Form C Alarm contact output (*Figure F.1*) for fail-safe reporting of the diagnostic status to the SCADA/HMI system. When the device is operating normally, the contact between Terminals 13 and 14 is open and the contact between Terminals 15 and 14 is closed. Use the normally closed contact (b contact) provided between Terminals 13 and 14 to monitor device problems or suspicious activities. The b contact closes by itself if internal failures prevent the device from keeping it open.

The Alarm output is factory-set and closes for hardware failures, settings changes, three unsuccessful password entry attempts, and when device power is off (ALARM = NOT (HALARM OR SALARM)). Depending on the cause of the alarm, the output either asserts permanently or pulses.

Figure F.1 Alarm Contact Output and Terminal Assignments

You can configure the SEL-TWFL to report failures via Telnet on Port 5 (see *Table F.2*). Enable Telnet and set the Port 5 AUTO setting to Y to use this diagnostic reporting method. Refer to *Telnet Protocol* on page 8.5 for more information.

When investigating diagnostic alarms, use the status command (**STA**) to obtain the device status. *Figure F.2* shows an example of a status report for a device with an SD card warning, and the Temperature field showing the internal device temperature of 43.5 degrees Celsius.

```
=>>STA <Enter>

SEL-TWFL                                    Date: 2024/01/30 Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

Failures
  No Failures

Warnings
  SD CARD WARNING

Temperature
  43.8 degrees Celsius

Relay Enabled
```

Figure F.2 Status Report With an SD Card Warning (Example)

A version of the status report, suitable for machine parsing, which also contains additional device self-test information, is available in a comma-delimited format via the SEL Compressed ASCII **CSTATUS** command. See *SEL Compressed ASCII Commands* on page 8.7 for additional information.

SEL-TWFL Diagnostic Details and Remediation Steps

Table F.2 lists diagnostic messages that the device issues and steps SEL recommends for each message. In particular, these steps indicate whether you can leave the device in service or if you need to remove the device from service.

Table F.2 Diagnostic Messages and Action Items (Sheet 1 of 4)

Self-Test Description	HMI and Status Report Message	Relay Word Bits	Automessage via Telnet	Device Disabled	Recommended Action
Top Printed Circuit Board Temperature Warning	TEMPERATURE WARNING	HALARMP, HALARM (Pulsed)	Yes	No	Issue the **STA** command to see the Top Printed Circuit Board temperature. Ensure that the device is operating in an environment so that the Top Printed Circuit Board temperature value is between –45°C and 100°C. If the device is operating within the stated operating temperature range (–40° to +85°C ambient) when this message is displayed, remove the device from service and return it to SEL.
Top Printed Circuit Board Power Supply Out of Tolerance	MB POWER SUPPLY WARNING	HALARMP, HALARM (Pulsed)	Yes	No	Do not switch the device control power off or perform other testing that can overwrite transient records and SER data. From Access Level C, issue the **STA**, **VEC**, and **VEC D** commands and save the reports. Remove the device from service and return it to SEL.
Analog Input Board Power Supply Out of Tolerance	AI POWER SUPPLY WARNING	HALARMP, HALARM (Pulsed)	Yes	No	
Current Channel DC Offset Out of Tolerance	DC OFFSET WARNING	HALARMP, HALARM (Pulsed)	No	No	
Voltage Channel DC Offset Out of Tolerance	DC OFFSET WARNING	No alarms	No	No	

Table F.2 Diagnostic Messages and Action Items (Sheet 2 of 4)

Self-Test Description	HMI and Status Report Message	Relay Word Bits	Automessage via Telnet	Device Disabled	Recommended Action
Settings Failure	SETTINGS FAILURE	HALARML, HALARM (Latched)	Yes	Yes	Issue the **STA C** command from Access Level 2. If the message displays a second time, attempt to restore the default device settings by using the **R_S** command from Access Level 2. If the problem resolves, restore the settings in the device from the archive and recommission the device. If the attempt fails, issue the **VEC** and **VEC D** commands from Access Level 2, and save the report. Do not perform other testing that can overwrite transient records and SER data. Remove the device from service and return it to SEL.
HMI Board Missing Warning	HMI WARNING	HALARMP, HALARM (Pulsed)	No	No	Do not switch the device control power off or perform other testing that can overwrite transient records and SER data. From Access Level 2, issue the **VEC** and **VEC D** commands and save the reports. Remove the device from service and return it to SEL. **Note:** Following standard ESD safe working practices, verify that the connectors of the flat cable linking the HMI to the top printed circuit board are properly seated and fully latched. Access the HMI cable assembly by removing the device front panel (see *Replacing the Lithium Battery* on page 9.22 for information about accessing the inside of the device chassis, and follow applicable steps).
EEPROM Warning	EEPROM WARNING	HALARMP, HALARM (Pulsed)	Yes	No	Do not switch the device control power off or perform other testing that can overwrite transient records and SER data. From Access Level 2, issue the **VEC** and **VEC D** commands and save the reports. Remove the device from service and return it to SEL.
EEPROM Failure	EEPROM FAILURE	HALARML, HALARM (Latched)	Yes	Yes	
USB Failure	USB FAILURE	HALARMP, HALARM (Pulsed)	Yes	No	
Firmware Verification Failure	FLASH FAILURE	HALARML, HALARM (Latched)	Yes	Yes	
Top Printed Circuit Board Power Supply Failure	MB POWER SUPPLY FAILURE	HALARML, HALARM (Latched)	Yes	Yes	
Analog Input Board Power Supply Failure	AI POWER SUPPLY FAILURE	HALARML, HALARM (Latched)	Yes	Yes	
I/O Board Missing Failure	IO FAILURE	HALARML, HALARM (Latched)	Yes	Yes	

Table F.2 Diagnostic Messages and Action Items (Sheet 3 of 4)

Self-Test Description	HMI and Status Report Message	Relay Word Bits	Automessage via Telnet	Device Disabled	Recommended Action
SD Card Warning	SD CARD WARNING	HALARMP, HALARM (Pulsed)	Yes	No	Contact SEL for a replacement SD card (see *Replacing the SD Card* on page 9.21). Alternatively, return the device to SEL. **Note:** A faulty SD card results in the loss of transient records. Protection is still functional and SER data are still available, but no transient records will be saved.
Real-Time Clock Warning	RTC WARNING	No alarms	Yes	No	Issue the **STA C** command from Access Level 2. If the message displays a second time, issue the **VEC** and **VEC D** commands from Access Level 2 and save the reports. Do not perform other testing that can overwrite transient records and SER data. Consider replacing the battery (see *Replacing the Lithium Battery* on page 9.22). If the problem persists, remove the device from service and return it to SEL.
Random-Access Memory Failure	RAM FAILURE	HALARML, HALARM (Latched)	Yes	Yes	Issue the **STA C** command from Access Level 2. If the message displays a second time, issue the **VEC** and **VEC D** commands from Access Level 2 and save the reports. Do not perform other testing that can overwrite transient records and SER data. Remove the device from service and return it to SEL.
SELBOOT Firmware Verification Failure	FLASH WARNING	HALARMP, HALARM (Pulsed)	Yes	No	Do not switch the device control power off. From Access Level 2, issue the **VEC** and **VEC D** commands and save the reports. Remove the device from service and return it to SEL.
Central Processor Failure	CPU FAILURE	HALARML, HALARM (Latched)	No	Yes	Switch the device control power off and back on. If the device starts up successfully, enter Access Level 2, issue the **VEC** and **VEC D** commands, and save the reports. Remove the device from service and return it to SEL.
Analog Input Board ADC Subsystem Failure	DATA ACQ FAILURE	HALARML, HALARM (Latched)	No	Yes	Switch the device control power off and back on. If the message displays a second time, issue the **VEC** and **VEC D** commands from Access Level 2 and save the reports. Do not perform other testing that can override transient records and SER data. Remove the device from service and return it to SEL.
Analog Input Board Critical Error Detected	AI FPGA FAILURE	HALARML, HALARM (Latched)	Yes	Yes	Switch the device control power off and back on. If the message displays a second time, issue the **VEC** and **VEC D** commands from Access Level 2 and save the reports. Remove the device from service and return it to SEL.

Table F.2 Diagnostic Messages and Action Items (Sheet 4 of 4)

Self-Test Description	HMI and Status Report Message	Relay Word Bits	Automessage via Telnet	Device Disabled	Recommended Action
Top Printed Circuit Board Critical Error Detected	MB SOC FAILURE	HALARML, HALARM (Latched)	Yes	Yes	Switch the device control power off and back on. If the message displays a second time, issue the **VEC** and **VEC D** commands from Access Level 2 and save the reports. Do not perform other testing that can overwrite transient records and SER data. Remove the device from service and return it to SEL.
Top Printed Circuit Board Processor Overburden Condition Detected	MB PROC FAILURE	HALARML, HALARM (Latched)	Yes	Yes	Do not switch the device control power off or perform other testing that can overwrite transient records and SER data. From Access Level 2, issue the **VEC** and **VEC D** commands and save the reports. Contact SEL for further instructions.
Port 5 SFP Not Installed Warning	PORT 5 SFP NOT INSTALLED	HALARMP, HALARM (Pulsed)	Yes	No	Install an SEL-supplied SFP transceiver in Port 5 or disable the port by using the EPORT setting.
Port 5 SFP Not Compliant Warning	PORT 5 SFP NOT COMPLIANT	HALARMP, HALARM (Pulsed)	Yes	No	The SEL-TWFL requires an SFP transceiver that is supplied by SEL. See *Table 9.3* for a list of available SFP transceivers. Install an SEL-supplied SFP transceiver in Port 5 or disable the port by using the EPORT setting.

APPENDIX G

Signal Processing and Operating Principles

This appendix explains the signal processing and operating principles associated with the functions available in the SEL-TWFL.

Data Acquisition and Processing

Overall Block Diagram

Figure G.1 is a simplified block diagram of the SEL-TWFL. The following text explains the diagram and provides relevant context for better understanding.

The SEL-TWFL acquires the input currents and voltages at a sampling rate of 1 MHz (1 million samples per second). It prefilters the input currents and voltages with an analog low-pass filter to avoid aliasing. The effective measurement bandwidth of the SEL-TWFL is about 400 kHz. The device samples six currents (IW and IX three-phase current sets) and six voltages (VY and VZ three-phase voltage sets). Use the L*m*I and L*m*V settings (where *m* = 1–2) to associate each three-phase current and voltage with the monitored line.

Every microsecond, the device calculates current and voltage traveling waves (TWs) by using 1 MHz samples (see *Traveling Waves* on page G.13). The device processes these TWs and extracts TW features, such as magnitudes and time stamps used for disturbance detection, fault locating, and line monitoring.

Every 0.1 ms, the SEL-TWFL applies digital anti-aliasing filtering and downsamples the 1 MHz samples to a 10 kHz rate, applies additional low-pass filtering, and calculates the instantaneous voltages and currents and their incremental quantities.

The device uses the 10 kHz samples to calculate phasors for supervisory functions, metering, triggering elements (such as overcurrent, undervoltage, and overvoltage elements), and fault-type identification logic (see *Phasors and Frequency Estimation* on page G.10). The device runs these functions every 0.5 ms.

The device acquires the digital inputs and drives digital outputs every 0.1 ms, including both contact inputs and outputs and MIRRORED BITS inputs and outputs.

The SEL-TWFL samples currents and voltages synchronously with the internal clock. The device compensates time stamps of the samples for the group delay of the anti-aliasing filter. The device phase-locks its internal clock to the external time source when a high-accuracy IRIG-B signal is connected to the device. The device time-stamps the voltage and current samples with an accuracy better than 100 ns when a high-accuracy clock is connected to the device. The voltage and current samples are traceable to the Coordinated Universal Time (UTC) microsecond at which they were acquired. This functionality allows for the reliable comparison of events recorded by multiple SEL-TWFL devices. The 1 MHz sampling frequency and 18-bit resolution of individual ADC channels offer the ability to capture and analyze power system transients.

The SEL-TWFL provides data recording at two resolution levels. The MHR IEEE COMTRADE record has a 1 µs resolution and includes the input voltages and currents. You have an option to record all available signals or only signals that the device uses according to the applied settings. The TDR IEEE COMTRADE record has a 0.1 ms resolution and includes voltages and currents as well as a selected set of derived quantities (see *Table 5.2*). The TDR IEEE COMTRADE record also includes all the Relay Word bits in the device. The header files of both the MHR and TDR IEEE COMTRADE records include all the setting values in the device except for some communications port settings that are not included for cybersecurity reasons. See *Section 5: Transient and Sequential Events Recording* for more details on the recording capabilities of the device. See *TW and Phasor Signals in the IEEE COMTRADE Records* on page G.12 for more information on the derived quantities included in the device records.

Figure G.1 Simplified Signal Processing Diagram of the SEL-TWFL

Secondary Current Scaling

The SEL-TWFL uses settings in secondary amperes and volts. The PT ratio settings (PTRY and PTRZ) define the secondary voltage base. Use the PT ratio settings when selecting the voltage and impedance settings of the device in

secondary units. The *effective* CT ratio defines the secondary current base. In single CT input applications (L*m*I = IW or L*m*I = IX, where *m* = 1–2), the effective CT ratio is the CT ratio of the used current input (CTRW or CTRX). In dual CT input applications (L*m*I = COMB), the effective CT ratio is the greater of the two CT ratios [max(CTRW, CTRX)]. Use the effective CT ratio when calculating the current and impedance settings of the device in secondary units.

Figure G.2 illustrates the SEL-TWFL current scaling in dual CT input applications. One of the two taps is always precisely 1, and the other tap is always less than or equal to 1.

Figure G.2 Scaling Secondary Currents in Dual CT Input Applications (L*m*I = COMB)

The SEL-TWFL allows for a maximum mismatch between the CTRW and CTRX ratios, as high as 1:15.

Signal Processing

Traveling Waves

The SEL-TWFL uses TWs in the TW disturbance detection logic and the TW-based fault-locating methods. The device uses current TWs because CTs and current secondary wiring adequately reproduce the high-frequency signal components.

A fault current, if we consider it over a period of a few hundred microseconds, is a series of quasi steady-state intervals. It changes very slowly during the quasi steady-state intervals but very sharply between any two quasi steady-state intervals. From the signal processing point of view, a TW is a sharp change between two quasi steady-state signal levels. The SEL-TWFL uses a finite impulse response filter to extract TWs from the input signals sampled at the 1 MHz rate. The filter combines the operations of numerical differentiation and low-pass filtering (or smoothing) and is therefore what we call the differentiator-smoother.

Figure G.3 shows the data window of the differentiator-smoother filter; ΔT denotes half the length of the differentiator-smoother window, and *Equation G.1* (shown in *Table G.1*) provides the filter equation. *Figure G.4* illustrates the operation of the filter. The differentiator-smoother filter responds to an ideal step change in the input signal with a triangle-shaped output, and it responds to a ramp transition between two levels with a parabola-shaped output. The gain of the differentiator-smoother filter is such that the peak of the triangle-shaped response of the filter to an ideal step change in the input represents the value of the step in the input. As a result, the TW signals measured by the SEL-TWFL retain information about the magnitude and polarity of the TWs measured at the device inputs.

Figure G.3 Data Window of the Differentiator-Smoother Filter

Figure G.4 TW Measurement: (a) an Ideal Step and (b) a Ramp in the Input Signal

We refer to the output from the differentiator-smoother as a TW signal. Specifically, we use the following definitions:

- The peak of the differentiator-smoother output is the TW *instantaneous* magnitude, encoding the TW level and polarity.
- The time of the peak in the differentiator-smoother output is the TW arrival time.

The SEL-TWFL calculates TW arrival times by interpolating the time-of-peak in the differentiator-smoother output between the 1 MHz samples. The device fits a curve to the TW data points near the peak of the differentiator-smoother output. The interpolated arrival time is the time of the maximum (for positive TWs) or minimum (for negative TWs) of this best-fit curve. This interpolation improves the time-stamp resolution from 1 µs of the sampling interval to approximately 0.1 µs. The TW-based fault-locating methods use interpolated time stamps.

The SEL-TWFL differentiator-smoother filter has a total window length of 20 µs ($2 \cdot \Delta T = 20$ µs) for all TW functions. This window is long enough to allow the device to identify TWs that ramp relatively slowly because of dispersion (i.e.,

when TWs are ramp transitions rather than step changes). At the same time, this window is short enough to allow the device to separate two successive TWs spaced as little as about 30 µs apart.

The SEL-TWFL obtains the phase TWs (TWA, TWB, and TWC), obtains the modal TWs (zero, alpha, and beta), and applies both accordingly in various functions.

- The device calculates the *ground* mode as $TW0 = (TWA + TWB + TWC)/3$.
- The device calculates the *alpha* aerial mode referenced to Phase A as TWA – TW0. This mode is typically the highest and most reliable for Phase A-to-ground (AG) faults on overhead transmission lines. The device uses similar equations to calculate the Phase B- and Phase C-referenced alpha modes.
- The device calculates the *beta* aerial mode referenced to Phases A and B as $(TWA - TWB)/\sqrt{3}$. This mode is typically the highest and most reliable for Phase A-to-Phase B (AB) faults on overhead transmission lines. The device uses similar equations to calculate the BC- and CA-referenced beta modes.

The header file of the MHR IEEE COMTRADE record of the SEL-TWFL contains 1 MHz currents and voltages as well as the differentiator-smoother filter length to allow you to calculate the voltage and current TWs (the window length is 2 • TWDSW). Use SEL-5601-2 SYNCHROWAVE Event Software to calculate and plot the current and voltage TWs in both phase and modal reference frames (see *TW and Phasor Signals in the IEEE COMTRADE Records* on page G.12).

The SEL-TWFL qualifies current TWs before using them in the TW fault-locating methods. The device considers a peak in the output from the differentiator-smoother to be valid if the input signal exhibits a sharp change, with the time of change and the magnitude of change consistent with the time and magnitude of the output from the differentiator-smoother. *Figure G.5* illustrates the concept of TW qualification. For the SEL-TWFL to qualify a TW as valid, the error (the hatched area in *Figure G.5*) between the ideal step (defined by the TW magnitude and arrival time) and the step in the input must be small relative to the TW magnitude.

Figure G.5 Principle of Qualifying Current TWs for Use in the TW-Based Fault-Locating Methods

Incremental Quantities

Incremental quantities are the difference between the present values of the signals and their one-cycle-old values. The SEL-TWFL includes a sensitive current-only incremental-quantity-based disturbance detector (see *Incremental-Quantity-Based Disturbance Detectors* on page 4.18).

Figure G.6 illustrates the method of deriving incremental quantities. The delay in *Figure G.6* is exactly one power cycle. To follow a changing power system frequency and maintain accuracy of incremental quantities, the SEL-TWFL continuously measures the power system frequency and adjusts the delay accordingly.

Figure G.6 Logic for Deriving Incremental Quantities

Line Monitoring Principle of Operation

This section describes the line monitoring principle of operation by showing how it is applied to a two-terminal line. With reference to *Figure G.7*, the SEL-TWFL line monitor represents a two-terminal power line with 0.25 mi intervals (or 0.25 km intervals depending on the LLUNIT setting). The line monitor assigns a bin to each of the intervals and marks each bin with the midpoint location of the corresponding interval, such as 0.25, 0.50, 0.75, and so on. Except for the first bin and the last bin, a bin marked as L stretches across event locations from (L – 0.125) to (L + 0.125). Each bin has a counter associated with it to count events located within that bin. The counter range is from 0 to 255. When the counter reaches its upper limit, it is not incremented anymore but will remain at 255 until it is cleared by the user.

Figure G.7 Power Line Divided Into Bins for Counting Line Events

When the line monitor detects an event on the line and obtains a valid event location M (mi or km) from the multi-ended TW-based fault-locating method, it determines the bin for location M and increments the counter associated with that bin.

Figure G.8 shows the simplified diagram of the triggering and supervisory logic for the line monitor on Line *m* (where *m* = 1–2). The logic is identical for Line 1 and Line 2 and operates on a per-line basis. For the line monitor on Line *m* to operate, it must be armed, which requires the following conditions:

- All phase-to-ground voltage magnitudes are greater than 80 percent of their nominal value.
- An open-pole condition does not exist (L*m*APO is deasserted).
- A loss-of-potential condition does not exist (L*m*LOP is deasserted).
- The device correctly estimates frequency (L*m*FREQOK is asserted).

Figure G.8 Supervisory Conditions of the Line Monitor Trigger for Line *m*

The line monitor triggers for two types of events: low-energy and fault events. The line monitor defines a low-energy event as an event that meets the Local Supervision conditions shown in *Figure G.8* and receives Remote Supervision from each line terminal but is not accompanied by the fault locator trigger (from a protective relay trip command programmed in the fault locator trigger, L*m*FL SELOGIC equation; see *Fault Locator Application and Settings* on page 2.14). The absence of the fault locator trigger signifies that the line protection system did not operate for that event, and therefore the event is not a fault but a low-energy transient event. Expect low-energy events to be fault precursors, such as discharge across a dirty or defective insulator, incipient cable faults, discharge as a result of encroaching vegetation, ionized air with airborne soot from a fire underneath the line conductors, coupling from a lightning strike to the ground wires, and similar events.

The line monitor defines a fault event as an event that meets the Local Supervision conditions shown in *Figure G.8* and receives Remote Supervision from each line terminal and is followed by a fault locator trigger, L*m*FL SELOGIC equation (see *Fault Locator Application and Settings* on page 2.14).

To refrain from tabulating external events when calculating the event location for both low-energy and fault events, the line monitor logic determines if the polarities of the TWs at all line terminals are the same (all positive or all negative) and consistent with the pre-fault voltage polarity.

Using the line monitor enable setting, you can set the line monitor to trigger on low-energy events only, on faults only, or on both faults and low-energy events. Triggering on low-energy events focuses the line monitor on fault precursors, and therefore it concentrates the application on potential future faults. Triggering on faults focuses the line monitor on fault-caused line outages and provides a line fault history for the duration of the installation. Triggering on both low-energy events and faults provides a composite picture of the weak spots on the line: potential future faults and faults that have already occurred.

The line monitor compares the values of all the counters with the user-defined alarm threshold. It performs the comparison starting from the first bin adjacent to the local terminal. The first bin that exceeds the alarm threshold sets the alarm. The assertion of the L*m*LMA Relay Word bit signifies the alarm, and the L*m*LMLOC analog value contains the alarm location (in LLUNITs). You should examine the event counters for the entire line by using the **LIMO L*m*** command or by reviewing the LINEMONL*m*.TXT file to better understand the alarm and determine if other weak spots are present on the line.

An event repeating at the same location may yield event location results with an error on the order of one line monitoring bin. Therefore, it is possible that a recurring event at a single location will increment counters in three adjacent bins. *Figure G.9* illustrates this phenomenon. To address the spread in the event location results for a recurring event at the same location, the line monitor alarms for bin n if the sum of counters in bins $n - 1$, n, and $n + 1$ exceeds the threshold, and if the value of the counter in bin n is the highest among the $n - 1$, n, and $n + 1$ counters.

Figure G.9 Event Location Spread Causes Event Counting in Three Adjacent Bins

A tapped line can connect loads that are routinely switched, such as a tapped transformer that is periodically connected or disconnected, or a transformer with an on-load tap changer. Switching operations can generate TWs. To the SEL-TWFL devices installed at the line terminals, TWs launched from the tapped load appear as if they originated from the tap. Routine switching would therefore drive up the counter for the tap location leading to a spurious alarm. Similarly, switching in-line series capacitors generates TWs. The line monitor provides two blocking regions to prevent spurious alarms for tap and series capacitor locations or other locations that routinely generate TWs. *Figure G.10* shows the blocking regions of the line monitor.

Figure G.10 Blocking Regions of the Line Monitor

The logic increments the counters within a blocking region as described earlier, but it resets them to zero at midnight on the device clock. As a result, the counters monitor daily event totals for bins within the blocking regions. The line monitor provides separate alarm thresholds for the blocking regions. Use the blocking region alarm to detect excessive switching or restriking of a switching device at the tap location. The assertion of L*m*LMAB1 and L*m*LMAB2 Relay Word bits signifies the alarm for Blocking Regions 1 and 2, respectively, and the L*m*LMLOCB1 and L*m*LMLOCB2 analog values contain the alarm locations (in LLUNITs). You should examine the counters for the entire line by using the **LIMO L*m*** command or by reviewing the LINEMONL*m*.TXT file to better understand the alarm and determine if other weak spots are present on the line.

When testing the line monitor, you must either apply the voltage and current signals that result in the line monitoring logic being armed or use the TW test mode for testing with current TWs only. Refer to the **TWTEST** command description in *Appendix C: SEL ASCII Commands* for information on how to initiate and terminate the TW test mode.

Refer to *Line Monitor* on page 2.27 for more information on the application of the line monitor.

Phasors and Frequency Estimation

The SEL-TWFL uses a full-cycle frequency-compensated Cosine filter (see *Figure G.11*) to calculate phasors from the 10 kHz samples. The SEL-TWFL uses these phasors for supervisory logic, metering, triggering elements (such as overcurrent, undervoltage, and overvoltage elements), and fault-type identification logic. The device calculates these phasors once every millisecond.

Figure G.11 Full-Cycle Phasor Estimation Principle That Uses Frequency-Compensated Cosine Filtering

The SEL-TWFL includes these phasors in the TDR IEEE COMTRADE record for event analysis and troubleshooting.

The SEL-TWFL calculates the waveform frequency from the 10 kHz samples of the phase voltage signals by using a method that autocorrelates the measured waveform to find its repetition rate, i.e., the waveform period[1]. The SEL-TWFL uses frequency to compensate the phasors under off-nominal frequency conditions (see *Figure G.11*). The device processes the frequency estimation algorithm once every millisecond, and the frequency is available as the L*m*FREQ analog (where *m* = 1–2) in the TDR IEEE COMTRADE record.

The L*m*FREQOK Relay Word bit, when asserted, signifies that the device is using the system frequency from a valid measurement. When L*m*FREQOK is deasserted, the device does not measure the frequency because the voltage signal is missing or is non-periodic. When no frequency measurement is available, the device uses the nominal frequency that the L*m*NFREQ setting specifies.

Both the L*m*FREQ analog and the L*m*FREQOK Relay Word bit are included in the TDR IEEE COMTRADE record for ease and accuracy of event analysis and troubleshooting (see *TW and Phasor Signals in the IEEE COMTRADE Records* on page G.12).

Definite-Time Integrating Timer Logic

All definite-time elements of the SEL-TWFL use the same integrating timer logic (definite-time overcurrent, overvoltage, and undervoltage elements). *Figure G.12* illustrates and explains the operation of the SEL-TWFL definite-time integrating timers.

[1] B. Kasztenny, "A New Method for Fast Frequency Measurement for Protection Applications," proceedings of the 13th International Conference on Developments in Power System Protection, Edinburgh, UK, March 2016. Available at selinc.com.

Figure G.12 Definite-Time Integrating Timer Operation (Instantaneous Reset)

The definite-time integrating timers follow the IEC 60255-151 standard, *Measuring Relays and Protection Equipment – Part 151: Functional Requirements for Over/Under Current Protection*, and operate as follows:

- When the input is asserted, the timer logic increments an internal pickup counter.
- When the input deasserts while the internal pickup counter is above zero but below the operating threshold, the timer logic holds the pickup counter constant; it neither increments nor decrements it.
- When the input is deasserted, the timer logic increments a separate internal reset counter. When the reset counter reaches the reset threshold, the timer logic resets the internal pickup counter to zero. The SEL-TWFL uses a fixed reset delay of 25 ms.
- If the input reasserts when the reset counter is incrementing, the logic resets the reset counter to zero.
- When the pickup timer reaches the operate level that the delay setting specifies, the timer output asserts and the pickup counter does not increment anymore.
- When the input deasserts while the timer has timed-out and the logic is in the operate state, the output deasserts immediately; see *Figure G.12*.

TW and Phasor Signals in the IEEE COMTRADE Records

The SEL-TWFL records power system events to facilitate power system analysis as well as SEL-TWFL operation analysis and troubleshooting. See *Section 5: Transient and Sequential Events Recording* for more information.

The MHR IEEE COMTRADE record (ultra-high-resolution record) contains voltage and current signals acquired at 1 Msps (megasamples per second). By using the MHRCH setting, you can decide to record all local channels (six voltages and six currents) or only those voltages and currents that the device uses for triggering elements and fault locating. The MHRCH setting allows you to maximize the device memory storage and minimize the record file size and transfer time. The MHR IEEE COMTRADE record does not contain calculated TW signals or Relay Word bits. If included, these derived quantities would make the IEEE COMTRADE files very large. This section explains how to derive TW signals from the MHR IEEE COMTRADE record for analysis and troubleshooting of TW-based functions.

The TDR IEEE COMTRADE record (high-resolution record) contains voltage and current signals downsampled to 10 ksps (kilosamples per second). The TDR IEEE COMTRADE record contains selected derived phasor signals and all Relay Word bits in the device. The derived signals include full-cycle phasors for analysis and troubleshooting of phasor-based elements and fault-locating methods, as well as for general event analysis (see *Phasors and Frequency Estimation* on page G.10).

The SEL-TWFL creates both the MHR and TDR IEEE COMTRADE records for each event. These records share the same pre-fault length and duration settings, and their time stamps are referenced to the same time base. The device compensates the time stamps for the group delay of the analog anti-aliasing filter and the digital anti-aliasing filter the device uses when downsampling the 1 Msps samples to the 10 ksps samples. Therefore, you can superimpose signals from the MHR and TDR IEEE COMTRADE records for better understanding of the power system and the SEL-TWFL operation.

Traveling Waves

Table 5.1 lists analog channels in the MHR IEEE COMTRADE record. *Table G.1* lists signals that you can use to analyze power system events and the SEL-TWFL operation based on TWs.

Table G.1 Derived Signals for Event Analysis Based on the MHR IEEE COMTRADE Record (Sheet 1 of 2)

Name[a, b]	Description	Expression
TWIAW TWIBW TWICW	Terminal W Phase A, B, and C current TWs	N/A
TWIAX TWIBX TWICX	Terminal X Phase A, B, and C current TWs	N/A
L*m*IA L*m*IB L*m*IC	Line *m* Phase A, B, and C currents	L*m*IAW, L*m*IAX, or L*m*IAW + L*m*IAX L*m*IBW, L*m*IBX, or L*m*IBW + L*m*IBX (Depending on the L*m*I setting.) L*m*ICW, L*m*ICX, or L*m*ICW + L*m*ICX
TWVAY TWVBY TWVCY	Terminal Y Phase A, B, and C voltage TWs	N/A
TWVAZ TWVBZ TWVCZ	Terminal Z Phase A, B, and C voltage TWs	N/A
L*m*VA L*m*VB L*m*VC	Line *m* Phase A, B, and C voltages	L*m*VAY or L*m*VAZ L*m*VBY or L*m*VBZ (Depending on the L*m*V setting.) L*m*VCY or L*m*VCZ

Table G.1 Derived Signals for Event Analysis Based on the MHR IEEE COMTRADE Record (Sheet 2 of 2)

Name[a, b]	Description	Expression
L*m*TWIA L*m*TWIB L*m*TWIC	Line *m* Phase A, B, and C current TWs	$LmTWX_{(k)} = \frac{1}{N}\left(\sum_{j=0}^{N-1} x_{(k-j)} - \sum_{j=1}^{N} x_{(k-j-N)}\right)$ **Equation G.1** where: x is the input signal (e.g., L*m*IA) L*m*TWX is the TW signal (e.g., L*m*TWIA) k is the present sample index N is the differentiator smoother half-window length (TWDSW) you can find in the HDR file of the MHR IEEE COMTRADE record (TWDSW = 10); see *Figure G.3*
L*m*TWVA L*m*TWVB L*m*TWVC	Line *m* Phase A, B, and C voltage TWs	
L*m*TWIA.alpha L*m*TWIB.alpha L*m*TWIC.alpha	Line *m* Phase A, B, and C current TWs, alpha mode	$LmTWIA.alpha = (2 \cdot LmTWIA - LmTWIB - LmTWIC)/3 = LmTWIA - LmTWI0.zero$ $LmTWIB.alpha = (2 \cdot LmTWIB - LmTWIC - LmTWIA)/3 = LmTWIB - LmTWI0.zero$ $LmTWIC.alpha = (2 \cdot LmTWIC - LmTWIA - LmTWIB)/3 = LmTWIC - LmTWI0.zero$
L*m*TWIAB.beta L*m*TWIBC.beta L*m*TWICA.beta	Line *m* Phase A, B, and C current TWs, beta mode	$LmTWIAB.beta = (LmTWIA - LmTWIB)/\sqrt{3}$ $LmTWIBC.beta = (LmTWIB - LmTWIC)/\sqrt{3}$ $LmTWICA.beta = (LmTWIC - LmTWIA)/\sqrt{3}$
L*m*TWI0.zero	Line *m* current TW, ground mode	$LmTWI0.zero = (LmTWIA + LmTWIB + LmTWIC)/3$
L*m*TWVA.alpha L*m*TWVB.alpha L*m*TWVC.alpha	Line *m* Phase A, B, and C voltage TWs, alpha mode	$LmTWVA.alpha = (2 \cdot LmTWVA - LmTWVB - LmTWVC)/3 = LmTWVA - LmTWV0.zero$ $LmTWVB.alpha = (2 \cdot LmTWVB - LmTWVC - LmTWVA)/3 = LmTWVB - LmTWV0.zero$ $LmTWVC.alpha = (2 \cdot LmTWVC - LmTWVA - LmTWVB)/3 = LmTWVC - LmTWV0.zero$
L*m*TWVAB.beta L*m*TWVBC.beta L*m*TWVCA.beta	Line *m* Phase A, B, and C voltage TWs, beta mode	$LmTWVAB.beta = (LmTWVA - LmTWVB)/\sqrt{3}$ $LmTWVBC.beta = (LmTWVB - LmTWVC)/\sqrt{3}$ $LmTWVCA.beta = (LmTWVC - LmTWVA)/\sqrt{3}$
L*m*TWV0.zero	Line *m* voltage TW, ground mode	$LmTWV0.zero = (LmTWVA + LmTWVB + LmTWVC)/3$

[a] *m* = 1–2.
[b] Not all current and voltage TW signals may be included, depending on the MHRCH setting (ALL, USED).

When you open an MHR IEEE COMTRADE file in SYNCHROWAVE Event Software, the software calculates and plots the signals listed in *Table G.1*. The software uses the L*m*I setting to calculate the Line *m* current and it uses the TWDSW parameter to calculate TWs by using the exact same algorithm as the SEL-TWFL. The SEL-TWFL embeds both of these parameters in the HDR file of the MHR IEEE COMTRADE record.

Figure G.13 shows an example of the Line 1 current signal acquired at 1 Msps (L1IB) and the TW component contained in this signal (L1TWIB).

Figure G.13 MHR IEEE COMTRADE Record Example: (a) L1IB Current, (b) L1IB Current During the First Millisecond of the Fault, and (c) the L1TWIB Traveling-Wave Component

Use the signals from *Table G.1* when analyzing the following events:

- Accuracy of TW-based fault-locating methods
- Operation of line monitoring logic
- Line energization records when using them to measure the TW line propagation time setting
- Power system operation in general

Full-Cycle Phasors

The TDR IEEE COMTRADE record (*Table 5.2*) includes phasors (real and imaginary parts in secondary peak units) for the line currents and voltages. The TDR IEEE COMTRADE record also includes frequency on a per-line basis.

Table G.2 lists signals you can use to analyze power system events and elements based on phasors.

NOTE: The real and imaginary parts of the phasor are in secondary peak units. The phasor magnitude is in secondary rms units, and you can compare it directly with device settings.

NOTE: The phasor angles are rotating angles. You can stabilize them by using a reference signal such as V1POL.Phasor.

Table G.2 Derived Signals for Analysis of Phasor-Based Elements Based on the TDR IEEE COMTRADE Record

Name[a]	Description	Expression
L*m*IA.Phasor L*m*IB.Phasor L*m*IC.Phasor	Line *m* Phase A, B, and C currents, phasor	$\mathrm{L}m\mathrm{IA.Phasor} = \mathrm{L}m\mathrm{IA.Re} + \mathrm{j}\mathrm{L}m\mathrm{IA.Im}$ $\mathrm{L}m\mathrm{IB.Phasor} = \mathrm{L}m\mathrm{IB.Re} + \mathrm{j}\mathrm{L}m\mathrm{IB.Im}$ $\mathrm{L}m\mathrm{IC.Phasor} = \mathrm{L}m\mathrm{IC.Re} + \mathrm{j}\mathrm{L}m\mathrm{IC.Im}$
L*m*IA.Mag L*m*IB.Mag L*m*IC.Mag	Line *m* Phase A, B, and C currents, magnitude	$\mathrm{L}m\mathrm{IA.Mag} = \frac{1}{\sqrt{2}}\sqrt{\mathrm{L}m\mathrm{IA.Re}^2 + \mathrm{L}m\mathrm{IA.Im}^2}$ $\mathrm{L}m\mathrm{IB.Mag} = \frac{1}{\sqrt{2}}\sqrt{\mathrm{L}m\mathrm{IB.Re}^2 + \mathrm{L}m\mathrm{IB.Im}^2}$ $\mathrm{L}m\mathrm{IC.Mag} = \frac{1}{\sqrt{2}}\sqrt{\mathrm{L}m\mathrm{IC.Re}^2 + \mathrm{L}m\mathrm{IC.Im}^2}$
L*m*IA.Ang L*m*IB.Ang L*m*IC.Ang	Line *m* Phase A, B, and C currents, angle	$\mathrm{L}m\mathrm{IA.Ang} = \angle(\mathrm{L}m\mathrm{IA.Phasor})$ $\mathrm{L}m\mathrm{IB.Ang} = \angle(\mathrm{L}m\mathrm{IB.Phasor})$ $\mathrm{L}m\mathrm{IC.Ang} = \angle(\mathrm{L}m\mathrm{IC.Phasor})$
L*m*VA.Phasor L*m*VB.Phasor L*m*VC.Phasor	Line *m* Phase A, B, and C voltages, phasor	$\mathrm{L}m\mathrm{VA.Phasor} = \mathrm{L}m\mathrm{VA.Re} + \mathrm{j}\mathrm{L}m\mathrm{VA.Im}$ $\mathrm{L}m\mathrm{VB.Phasor} = \mathrm{L}m\mathrm{VB.Re} + \mathrm{j}\mathrm{L}m\mathrm{VB.Im}$ $\mathrm{L}m\mathrm{VC.Phasor} = \mathrm{L}m\mathrm{VC.Re} + \mathrm{j}\mathrm{L}m\mathrm{VC.Im}$
L*m*VA.Mag L*m*VB.Mag L*m*VC.Mag	Line *m* Phase A, B, and C voltages, magnitude	$\mathrm{L}m\mathrm{VA.Mag} = \frac{1}{\sqrt{2}}\sqrt{\mathrm{L}m\mathrm{VA.Re}^2 + \mathrm{L}m\mathrm{VA.Im}^2}$ $\mathrm{L}m\mathrm{VB.Mag} = \frac{1}{\sqrt{2}}\sqrt{\mathrm{L}m\mathrm{VB.Re}^2 + \mathrm{L}m\mathrm{VB.Im}^2}$ $\mathrm{L}m\mathrm{VC.Mag} = \frac{1}{\sqrt{2}}\sqrt{\mathrm{L}m\mathrm{VC.Re}^2 + \mathrm{L}m\mathrm{VC.Im}^2}$
L*m*VA.Ang L*m*VB.Ang L*m*VC.Ang	Line *m* Phase A, B, and C voltages, angle	$\mathrm{L}m\mathrm{VA.Ang} = \angle(\mathrm{L}m\mathrm{VA.Phasor})$ $\mathrm{L}m\mathrm{VB.Ang} = \angle(\mathrm{L}m\mathrm{VB.Phasor})$ $\mathrm{L}m\mathrm{VC.Ang} = \angle(\mathrm{L}m\mathrm{VC.Phasor})$

[a] m = 1–2.

When you open a TDR IEEE COMTRADE file in SYNCHROWAVE Event Software, the software plots signals listed in *Table 5.2* and calculates the signals listed in *Table G.2* so they can also be plotted.

APPENDIX H

High-Accuracy Timekeeping

The SEL-TWFL determines time from several sources: IRIG-B, the battery-backed real-time clock, a DNP3 master connected over Ethernet, and the **TIME** and **DATE** commands. Some of these sources provide only an approximate measure of time. For high-accuracy time synchronization, which is needed when using an IEEE C37.94-encoded multiplexed channel for multi-ended TW-based fault locating and to allow analysis of system-wide events, you must connect the device to an accurate time source, such as an IEEE C37.118-2005-compliant satellite clock. The SEL-TWFL only accepts high-accuracy IRIG-B signals with IEEE C37.118 time code extensions and performs all timekeeping functions following the Coordinated Universal Time (UTC). Using the UTC allows aggregation and analysis of system-wide events without the need to know the time zone or local daylight-saving time conventions.

The SEL-TWFL maintains time based on the following time sources:

- IRIG-B input
- DNP3 LAN/WAN protocol
- Local oscillator (Free Running mode)
- Battery-backed real-time clock when powered down

IRIG-B Time Input

In order to provide for submicrosecond time accuracy, you must connect the SEL-TWFL IRIG-B input to a high-accuracy time source.

The SEL-TWFL determines the preliminary suitability of the IRIG-B signal by applying the following tests. It asserts the TIRIG Relay Word bit only when these conditions are met:

- The seconds, minutes, and days fields are in range.
- The time from two consecutive messages differs by 1 s, except for leap second or daylight-saving time transitions.
- The IRIG-B signal contains the IEEE C37.118 time code extensions.
- The IRIG-B signal contains the correct parity bit.

If the SEL-TWFL deems the IRIG-B signal suitable, it then determines the suitability of the IRIG-B signal for high-accuracy timekeeping by applying additional tests and asserts the BNC_OK Relay Word bit only when these tests are met:

- The jitter between positive transitions (rising edges) of the clock signal is less than 500 ns.
- The time-error information contained in the time quality code of the IRIG-B IEEE C37.118 time code extensions indicates that the source (clock) time error is less than 10 µs.

If the device is in high-accuracy mode and either of the two tests fails, the device enters a holdover mode. When in holdover mode, the device keeps the TSOK and BNC_OK bits asserted and deasserts TIRIG. The device remains in holdover mode for as long as 15 s, and it then reverts to using either the high-accuracy IRIG-B input or the internal clock in the Free Running mode, depending on the conditions.

The device accepts an IEEE C37.118 IRIG-B signal with either odd or even parity. When an IRIG-B signal is connected, the device detects whether the signal has odd or even parity and continues to check the received IRIG-B signal for that parity. If a message is received with the opposite parity or no parity, the signal fails the parity test. If the clock has programmable parity and the parity is changed, the device disqualifies the IRIG-B signal for a few seconds until it can confirm that the parity change did not result from a corrupt message.

See *Table H.1* for SEL-TWFL timekeeping mode details.

Table H.1 SEL-TWFL Timekeeping Modes and Sources

Clock Source	Timekeeping Mode	SEL-TWFL Clock Accuracy	Relay Word Bits
No External Source	Free Running	Depends on last method of setting or synchronization[a]	TIRIG = 0 BNC_OK = 0 TSOK = 0
Low-Accuracy IRIG-B (With IEEE C37.118 Time Code Extensions)	Free Running	Time source not used[b] Accuracy depends on last method of setting or synchronization[a]	TIRIG = 1 BNC_OK = 0 TSOK = 0
High-Accuracy IRIG-B (With IEEE C37.118 Time Code Extensions)	HIRIG	<100 ns plus external clock error[b]	TIRIG = 1 BNC_OK = 1 TSOK = 1

[a] The SEL-TWFL internal clock is either synchronized via a direct IRIG-B connection or set using the TIM command or a DNP master.

[b] The IRIG-B time source must include the IEEE C37.118 time code extensions to provide the time-error estimate for the clock and must report an accuracy of <10 μs.

The IRIG-B signal carries the time-source error bound encoded on the four-bit time quality code defined in the IEEE C37.118 time code extensions. The device places the time quality information from the IRIG-B signal into the TQUAL1, TQUAL2, TQUAL3, and TQUAL4 Relay Word bits. See *Table H.2* for time quality Relay Word bit decoding. The SEL-TWFL rejects (does not use) time sources with a reported accuracy worse than 10 μs. Issue the **TIM Q** command to see the local device IRIG-B source time quality.

Table H.2 IRIG-B Signal Time Quality Encoding Per IEEE C37.118 (Sheet 1 of 2)

IRIG-B Clock Accuracy	TQUAL4	TQUAL3	TQUAL2	TQUAL1	TIM Q Command Response
Clock failure, time not reliable	1	1	1	1	>99,999 μs
Within 10 s	1	0	1	1	>99,999 μs
Within 1 s	1	0	1	0	>99,999 μs
Within 100 ms	1	0	0	1	>99,999 μs
Within 10 ms	1	0	0	0	10,000 μs
Within 1 ms	0	1	1	1	1,000 μs

Table H.2 IRIG-B Signal Time Quality Encoding Per IEEE C37.118 (Sheet 2 of 2)

IRIG-B Clock Accuracy	TQUAL4	TQUAL3	TQUAL2	TQUAL1	TIM Q Command Response
Within 100 µs	0	1	1	0	100 µs
Within 10 µs	0	1	0	1	10 µs
Within 1 µs	0	1	0	0	1 µs
Within 100 ns	0	0	1	1	0.1 µs
Within 10 ns	0	0	1	0	0.01 µs
Within 1 ns	0	0	0	1	0.001 µs
Clock synchronized	0	0	0	0	0.000 µs

The SEL-TWFL also decodes the nonsequential changes bits in the IEEE C37.118 time code extensions, including Leap Second Pending, Leap Second Direction, Daylight-Saving Time Pending, and Daylight-Saving Time. The status of these bits is reflected in the LPSECP, LPSEC, DSTP, and DST Relay Word bits, respectively. *Table H.3* shows the full list of Relay Word bits related to the SEL-TWFL timekeeping system.

Table H.3 Time and Date Management Relay Word Bits

RWB Name	Description
TIRIG	Device receives a valid IRIG-B signal
BNC_OK	High-accuracy IRIG-B signal from BNC port available
TSOK	Device clock is synchronized with high accuracy to the absolute time
DST	Daylight-saving time is active[a]
DSTP	Daylight-saving time change is pending[a]
LPSEC	Leap second retard direction
LPSECP	Leap second is pending
TQUAL4	IRIG-B Time Quality Bit 4
TQUAL3	IRIG-B Time Quality Bit 3
TQUAL2	IRIG-B Time Quality Bit 2
TQUAL1	IRIG-B Time Quality Bit 1

[a] The SEL-TWFL uses UTC and does not follow daylight-saving time or local time offset.

Use the **TAR** command to inspect the timekeeping Relay Word bits. Connect a high-accuracy IRIG-B signal to the device, wait at least 20 s for the SEL-TWFL to acquire the clock signal, and then issue the **TAR TIRIG** command. The device will display the row that includes the Relay Word bit that you placed as a parameter of the **TAR** command, as shown in *Figure H.1*.

```
=>>TAR TIRIG <Enter>

TIRIG    BNC_OK   TSOK     *        *        *        *        *
1        1        1        0        0        0        0        0
```

Figure H.1 Confirming the High-Accuracy Timekeeping Relay Word Bits

Use the same method to inspect the TQUAL bits by issuing the **TAR TQUAL1** command.

When the TIRIG, BNC_OK, and TSOK Relay Word bits are asserted, the local device is in high-accuracy IRIG-B timekeeping mode. If BNC_OK is not asserted, but TIRIG is asserted, the device is receiving a substandard IRIG-B signal. The following are possible reasons for not enabling the high-accuracy timekeeping mode:

- The IRIG-B clock does not provide the IEEE C37.118 time code extensions.
- The IRIG-B signal 100 Hz edge jitter is too large (>500 ns).
- The termination resistor, required by some IRIG-B clocks, is not installed (see *IRIG-B Input Connection* on page 9.12 for more information).
- The time source is reporting a time error ≥10 µs.
- The time source (if it is a satellite-synchronized clock) is not connected to an antenna.

If neither BNC_OK nor TIRIG is asserted, the device is unable to use the IRIG-B time source. The following are possible reasons for not recognizing the IRIG-B signal:

- The IRIG-B signal is not connected to the device.
- The IRIG-B clock signal is not of sufficient strength or is improperly configured.
- The termination resistor required by some IRIG-B clocks is not installed.

Inspecting the Timekeeping System

The TSOK Relay Word bit indicates that the device is locked to a high-accuracy IRIG-B source.

The **TIME SYNC** front-panel status LED illuminates green to indicate the status of device time synchronization with respect to the absolute time provided by an external time source (see *Table 7.9* for more information on the **TIME SYNC** status LED).

TIME Q Report

Issue the **TIM Q** command to determine which time source is in use and to display its time quality, as shown in *Figure H.2*.

```
COMMON REPORT HEADER

UTC: xx:xx:xx
UTC Offset:  x.xx hrs

Time Source: b
Last Update Source: b

Last Update Time: xx:xx:xx  xxxx/xx/xx

IRIG Time Quality: x.xxx us
```

Figure H.2 Data Items in the TIM Q Report

```
=>>TIM Q <Enter>

SEL-TWFL                                    Date: 2024/01/30  Time: 17:00:00.000
StationA                                    Time Source: HIRIG
SEL-TWFL-R100-V0-Z001001-D20240129          Serial Number: 1240300001

UTC: 17:00:00
UTC Offset:  0.00 hrs

Time Source: HIRIG
Last Update Source: HIRIG

Last Update Time: 17:00:00  2024/01/30

IRIG Time Quality: 0.000 us
```

Figure H.3 Sample TIME Q Report

In the example shown in *Figure H.3*, the local device is connected to a high-accuracy IRIG-B time source (HIRIG); the last updated time source is also HIRIG; the UTC offset (necessary to convert the SEL-TWFL UTC time stamps to local time) is 0; and the IRIG-B signal time quality is better than 0.1 µs (typical of high-accuracy time reported by a satellite-synchronized clock). *Table H.4* explains the TIME Q report data items and provides applicable troubleshooting guidelines.

Table H.4 Information Included in the TIME Q Report

Data Item	Description	Comments and Troubleshooting
UTC	Time (in UTC) captured when the command was processed	The SEL-TWFL uses Coordinated Universal Time (UTC) only. Time information is obtained using the IRIG-B IEEE C37.118 time code extensions. UTC allows for easy correlation of system-wide events without the need to know time zone or local daylight-saving time conventions.
UTC Offset	UTC offset captured when the command was processed	This is the offset between UTC and the local time. Offset is supplied by the IRIG-B source and contained in the IEEE C37.118 time code extensions. Add this offset to the UTC time stamp to obtain the local time.
Time Source	Time synchronization mode: Free Running, HIRIG	If Time Source is HIRIG, the device clock is locked to a high-accuracy time source. If Time Source is Free Running, the device is relying on its internal oscillator and is likely to drift away from the accurate absolute value. Consider making a note of the true time when you capture a report. If the Time Source is not HIRIG while a time source is connected to the IRIG-B input (i.e., the device does not consider the time source to be a high-accuracy source), inspect the Time Quality field to learn more about the time source problem. Consider using a DNP master or the **TIM** command to set the device clock when an IRIG-B time source is not available.
Last Updated Source	Name of the last time synchronization source	This field displays the last synchronization time source. *Table H.5* lists possible sources.
Last Updated Time	Time of the last time synchronization	This field displays the time when the internal time system was last referenced to a particular source.
IRIG-B Time Quality	Time quality reported by the IRIG-B source	This field displays local IRIG-B source time quality extracted from the IEEE C37.118 time code extensions. If the IRIG-B Time Quality value is 10 µs, it would mean the time accuracy is within 10 µs. *Table H.2* describes Field encoding. **Note:** IRIG-B Time Quality is displayed only if the Time Source is HIRIG.

Table H.5 Last Updated Sources (Sheet 1 of 2)

Source Name	Time Source Description
HIRIG	High-accuracy IRIG-B input signal.
ASCII DATE	Date set using the **DAT** command.
ASCII TIME	Time set using the **TIM** command.
DNP	Time set using the DNP master.

Table H.5 Last Updated Sources (Sheet 2 of 2)

Source Name	Time Source Description
NONV CLK	Nonvolatile clock, set in the past. Accuracy and origin of the time is unknown since the time that the device turned on.
NEVER SET	Applies in cases of a nonfunctioning real-time clock (typically because of an expired battery or a clock chip failure). If the real-time clock was never set, the date reverts to the year 2000.

APPENDIX I

Distributed Network Protocol

The SEL-TWFL is a Distributed Network Protocol (DNP3) Level 2 server (outstation device). This allows a DNP3-compliant SCADA master to access Relay Word bit status, diagnostics, and metering, fault locating, line monitoring, and fault summary data. The SEL-TWFL allows six DNP3 sessions, each with custom data mapping, analog deadbands, and other characteristics. *Table I.1* summarizes the SEL-TWFL DNP3 capabilities.

The DNP3 binary output control allows resetting device targets, resetting DNP3 event data, and loading DNP3 event data.

This appendix uses the terms inputs and outputs from the DNP3 master perspective, not from the SEL-TWFL server perspective.

Table I.1 Summary of the SEL-TWFL DNP3 Capabilities

Feature	Application
Event data	Report data: either unsolicited or when requested
Deadbands	Apply analog deadbands independently for each DNP session on a per-point basis
Sequence-of-events data	Log binary input state changes with time stamps of occurrence
Custom mapping	Select data for each session
Acknowledgment and reset	Reset front-panel targets; reset DNP event summary data and load event summary information
Time synchronization	Set the device time from the master or request time synchronization from the master
Object 0 device attributes	Provide device attributes (Device ID, number of binary and analog points, manufacturer information, etc.) for the active session
TEST DB2 command	Test the DNP3 protocol interface by forcing analog and binary points

The DNP3 Device Profile document (available on the supplied CD or as a download from https://selinc.com/products/TWFL/docs/) contains the standard device profile information for the SEL-TWFL. Refer to this document for complete information on DNP3 implementation in the SEL-TWFL.

DNP3 Configuration

DNP3 Connection Settings

Table 8.2 shows the Port 5 settings required to establish a DNP3 connection to the SEL-TWFL. These settings are common to all DNP3 sessions.

This section provides the DNP3 protocol settings and shows the data items available for mapping.

DNP3 Protocol Settings

The SEL-TWFL allows six DNP3 sessions to communicate with six separate DNP3 masters. Each session defines the SEL-TWFL DNP3 server operation for the connected DNP3 master. *Table I.2* lists the DNP3 settings for programming each session. These settings must match the configuration of the DNP3 master. You can set each session to use one of the five available maps, each of which has a default data set and is also customizable.

Table I.2 DNP Master Settings

Setting[a]	Description	Range	Default	Class
DNPIP*n*	DNP Session Master IP Address	*w.x.y.z* (*w*: 1–126, 128–233, *x*: 0–255, *y*: 0–255, *z*: 0–255)	192.168.1.(*n* + 2)	Port 5
DNPTR*n*	DNP Session Transport Protocol	UDP, TCP	TCP	Port 5
DNPUDP*n*	DNP UDP Response Port	REQ, 1 to 65534	20000	Port 5
REPADR*n*	DNP Address to Report to	0 to 65519	1	Port 5
DNPMAP*n*	DNP Session Map	1 to 5	1	Port 5
CLASSB*n*	Class for Binary Event Data	OFF, 1–3	1	Port 5
CLASSA*n*	Class for Analog Event Data	OFF, 1–3	2	Port 5
TIMERQ*n*	Minutes for Request Interval	I, M, 1–32767	I	Port 5
DECPLA*n*	Currents Scaling Decimal Places	0–3	1	Port 5
DECPLV*n*	Voltages Scaling Decimal Places	0–3	1	Port 5
DECPLM*n*	Misc Data Scaling Decimal Places	0–3	1	Port 5
STIMEO*n*	Select/Operate Time-Out	0.0–30.0 s	1.0	Port 5
DNPINA*n*	Seconds to Send Data Link Heartbeat	0–120 s	20	Port 5
DNPCL*n*	Enable Control Operations	Y, N	N	Port 5
AIVAR*n*	Analog Input Default Variation	1–6	2	Port 5
ANADBA*n*	Amps Reporting Deadband Counts	0–32767	100	Port 5
ANADBV*n*	Volts Reporting Deadband Counts	0–32767	100	Port 5
ANADBM*n*	Misc Data Reporting Deadband Counts	0–32767	100	Port 5
ETIMEO*n*	Event Message Confirm Time-Out	1–50 s	2	Port 5
UNSOL*n*	Enable Unsolicited Reporting	Y, N	N	Port 5
PUNSOL*n*	Enable Unsolicited Reporting at Power-Up	Y, N	N	Port 5
NUMEVE*n*	Number of Events to Transmit On	1–200	10	Port 5
AGEEVE*n*	Age of Oldest Event to Transmit On	0–99999 s	2	Port 5
URETRY*n*	Unsolicited Message Max Retry Attempts	2–10	3	Port 5
UTIMEO*n*	Unsolicited Message Offline Time-Out	2 to 5000 s	60	Port 5
EVEMOD*n*	Event Mode	SINGLE, MULTI	SINGLE	Port 5
RPEVTYP*n*	Event Report Type	FL, ALL	ALL	Port 5

[a] *n* = 1–6.

Data Maps

Default Data Map

NOTE: If the deadband value is changed via Object 34 write, this value is stored in the volatile memory of the device. A device restart will reset this value.

Table I.3 shows the SEL-TWFL DNP3 data map settings. *Table I.4* shows the default data map. Use the custom DNP3 mapping to create the map required for your application.

Table I.3 DNP Map Settings

Setting	Description	Range	Default	Class[a]
Binary Input Map				
BI_*xxx*[b]	BI_*xxx*[b] DNP Binary Input	Relay Word bits (see *Appendix D*) and dedicated DNP3 inputs (DEVDIS, STFAIL, STWARN, STSET, UNRDEV, NUNREV)	see *Table I.4*	D*n*
Binary Output Map				
BO_0*xx*[c]	BO_0*xx*[c] DNP Binary Output	Dedicated DNP3 outputs (DRST_TAR, DRSTDNPE, NOOP, NXTEVE)	see *Table I.4*	D*n*
Analog Input Map				
AI_*xxx*[d]	AI_*xxx*[d] DNP Analog Input	DNP3 analog quantities (see *Table E.1* and *Table E.3*)	see *Table I.4*	D*n*

[a] *n* = 1–5.
[b] *xxx* = 000–199.
[c] *xx* = 00–10.
[d] *xxx* = 000–119.

Table I.4 DNP3 Default Data Map (Sheet 1 of 3)

Object	Default Index	DNP3 Label	Description
Binary Inputs			
01, 02	0	DEVDIS	Device Disabled
01, 02	1	TARFLTR	TRIGGERED target is asserted
01, 02	2	STFAIL	Device Diagnostic Failure
01, 02	3	STWARN	Device Diagnostic Warning
01, 02	4	STSET	Settings have changed or device restarted
01, 02	5	SALARM	OR combination of BADPASS, SETCHG, and TWTEST
01, 02	6	HALARM	OR combination of HALARMP and HALARML
01, 02	7	BADPASS	One-second pulse after three consecutive bad password entries
01, 02	8	UNRDEV	An event, as yet unread by DNP, exists
01, 02	9	L1OPA	Pole A opened on Line 1
01, 02	10	L1OPB	Pole B opened on Line 1
01, 02	11	L1OPC	Pole C opened on Line 1
01, 02	12	L1_3PO	Three poles opened on Line 1
01, 02	13	L1B1A52A	Line 1 Breaker 1 Phase A 52a status
01, 02	14	L1B1B52A	Line 1 Breaker 1 Phase B 52a status
01, 02	15	L1B1C52A	Line 1 Breaker 1 Phase C 52a status
01, 02	16	TAR1FLTR	Line 1 FLTRIG target is asserted
01, 02	17	TAR1LMA	Line 1 LM ALARM status is asserted

Table I.4 DNP3 Default Data Map (Sheet 2 of 3)

Object	Default Index	DNP3 Label	Description
01, 02	18	TAR1METW	Line 1 ME TW target is asserted
01, 02	19	TAR1MEZ	Line 1 ME Z target is asserted
01, 02	20	TAR1SETW	Line 1 SE TW target is asserted
01, 02	21	TAR1SEZ	Line 1 SE Z target is asserted
01, 02	22	ROKP1	Port 1 operating correctly
01, 02	23	ROKP2	Port 2 operating correctly
01, 02	24	ROKP3	Port 3 operating correctly
01, 02	25	TARTSYN	TIME SYNC status is asserted
01, 02	26	IN101	IN101 input asserted
01, 02	27	IN102	IN102 input asserted
01, 02	28	IN103	IN103 input asserted
01, 02	29	IN104	IN104 input asserted
01, 02	30	IN105	IN105 input asserted
01, 02	31	OUT101	OUT101 output close signal
01, 02	32	OUT102	OUT102 output close signal
01, 02	33	OUT103	OUT103 output close signal
01, 02	34	OUT104	OUT104 output close signal
01, 02	35	OUT105	OUT105 output close signal
01, 02	36	OUT106	OUT106 output close signal
01, 02	37	SV01	SELogic Variable 1 condition asserted
01, 02	38	SV02	SELogic Variable 2 condition asserted
01, 02	39	SV03	SELogic Variable 3 condition asserted
01, 02	40	SV04	SELogic Variable 4 condition asserted
01, 02	41	SV05	SELogic Variable 5 condition asserted
01, 02	42	SV06	SELogic Variable 6 condition asserted
01, 02	43	SV07	SELogic Variable 7 condition asserted
01, 02	44	SV08	SELogic Variable 8 condition asserted
Binary Outputs			
10, 12	0	DRSTDNPE	Reset (clear) DNP Event Summary registers
Analog Inputs			
30, 32	0	L1IA	Line 1 Phase A current, magnitude (A, pri)
30, 32	1	L1IAFA	Line 1 Phase A current, angle (deg)
30, 32	2	L1IB	Line 1 Phase B current, magnitude (A, pri)
30, 32	3	L1IBFA	Line 1 Phase B current, angle (deg)
30, 32	4	L1IC	Line 1 Phase C current, magnitude (A, pri)
30, 32	5	L1ICFA	Line 1 Phase C current, angle (deg)
30, 32	6	L1VA	Line 1 Phase A voltage, magnitude (kV, pri)
30, 32	7	L1VAFA	Line 1 Phase A voltage, angle (deg)
30, 32	8	L1VB	Line 1 Phase B voltage, magnitude (kV, pri)
30, 32	9	L1VBFA	Line 1 Phase B voltage, angle (deg)

Table I.4 DNP3 Default Data Map (Sheet 3 of 3)

Object	Default Index	DNP3 Label	Description
30, 32	10	L1VC	Line 1 Phase C voltage, magnitude (kV, pri)
30, 32	11	L1VCFA	Line 1 Phase C voltage, angle (deg)
30, 32	12	L1_3I0	Line 1 zero-sequence current, magnitude (A, pri)
30, 32	13	L1_3I0FA	Line 1 zero-sequence current, angle (deg)
30, 32	14	L1I1	Line 1 positive-sequence current, magnitude (A, pri)
30, 32	15	L1I1FA	Line 1 positive-sequence current, angle (deg)
30, 32	16	L1_3I2	Line 1 negative-sequence current, magnitude (A, pri)
30, 32	17	L1_3I2FA	Line 1 negative-sequence current, angle (deg)
30, 32	18	L1_3V0	Line 1 zero-sequence voltage, magnitude (kV, pri)
30, 32	19	L1_3V0FA	Line 1 zero-sequence voltage, angle (deg)
30, 32	20	L1V1	Line 1 positive-sequence voltage, magnitude (kV, pri)
30, 32	21	L1V1FA	Line 1 positive-sequence voltage, angle (deg)
30, 32	22	L1_3V2	Line 1 negative-sequence voltage, magnitude (kV, pri)
30, 32	23	L1_3V2FA	Line 1 negative-sequence voltage, angle (deg)
30, 32	24	L1FREQ	Line 1 frequency (Hz)
30, 32	25	L1P3	Line 1 three-phase power, active (MW, pri)
30, 32	26	L1Q3	Line 1 three-phase power, reactive (MVAR, pri)
30, 32	27	ETYPE	Event type
30, 32	28	ETIMEH	Event record trigger time in DNP format, high word
30, 32	29	ETIMEM	Event record trigger time in DNP format, middle word
30, 32	30	ETIMEL	Event record trigger time in DNP format, low word
30, 32	31	L1FLOC	Line 1 fault location (km/mi)
30, 32	32	L1FLRT	Line 1 fault location reference terminal
30, 32	33	L1FIM	Line 1 fault current, maximum phase magnitude (A, pri)
30, 32	34	L1FFREQ	Line 1 pre-fault frequency (Hz)
30, 32	35	FUNR	Number of event records unread by DNP client
30, 32	36	MBTEMP	Temperature, main board (deg C)

Configurable Data Maps

The SEL-TWFL DNP3 implementation allows you to remap DNP3 data and, for analog values, specify per-point scaling, deadbands, and event class. For binary inputs, you can specify event class on a per-point basis. Use custom memory maps to organize data into a data subset optimized for your application. It is important to note that metering values from within the same memory map are time-coherent. The SEL-TWFL uses object and point labels, rather than point indices, to streamline the remapping process. This enables you to quickly create a custom map without having to search for each point index in a reference map. *Table I.5* shows the SEL-TWFL DNP reference data map. The SEL-TWFL scales analog values by the indicated settings or fixed scaling values. Per-point scaling and deadband settings specified in a custom DNP3 map override defaults.

Table I.5 DNP3 Reference Data Map (Sheet 1 of 4)

Object	Label	Description
Binary Inputs		
01, 02	DEVDIS	Device Disabled
01, 02	STFAIL	Device Diagnostic Failure
01, 02	STWARN	Device Diagnostic Warning
01, 02	STSET	Settings have changed or device restarted
01, 02	UNRDEV	An event, as yet unread by DNP, exists
01, 02	NUNREV	An unread event exists, newer than the event in the Event summary AIs
Binary Outputs		
10, 12	DRST_TAR	Reset targets
10, 12	DRSTDNPE	Reset (clear) DNP Event Summary registers
10, 12	NOOP	Perform no operation
10, 12	NXTEVE	Load next event into DNP Event Summary registers
Analog Inputs[a, b]		
30, 32	FWREV[c]	Device firmware version
30, 32	SNUMBH[c]	Device serial number, highest 4 digits
30, 32	SNUMBM[c]	Device serial number, middle 4 digits
30, 32	SNUMBL[c]	Device serial number, lowest 4 digits
30, 32	L*m*Iϕ[d]	Line *m* Phase ϕ current, magnitude (A, pri)
30, 32	L*m*IϕFA[e]	Line *m* Phase ϕ current, angle (deg)
30, 32	L*m*I1[d]	Line *m* positive-sequence current, magnitude (A, pri)
30, 32	L*m*I1FA[e]	Line *m* positive-sequence current, angle (deg)
30, 32	L*m*_3I2[d]	Line *m* negative-sequence current, magnitude (A, pri)
30, 32	L*m*_3I2FA[e]	Line *m* negative-sequence current, angle (deg)
30, 32	L*m*_3I0[d]	Line *m* zero-sequence current, magnitude (A, pri)
30, 32	L*m*_3I0FA[e]	Line *m* zero-sequence current, angle (deg)
30, 32	L*m*Vϕ[f]	Line *m* Phase ϕ voltage, magnitude (kV, pri)
30, 32	L*m*VϕFA[e]	Line *m* Phase ϕ voltage, angle (deg)
30, 32	L*m*VAB[f]	Line *m* Phase A-to-Phase B voltage, magnitude (kV, pri)
30, 32	L*m*VABFA[e]	Line *m* Phase A-to-Phase B voltage, angle (deg)
30, 32	L*m*VBC[f]	Line *m* Phase B-to-Phase C voltage, magnitude (kV, pri)
30, 32	L*m*VBCFA[e]	Line *m* Phase B-to-Phase C voltage, angle (deg)
30, 32	L*m*VCA[f]	Line *m* Phase C-to-Phase A voltage, magnitude (kV, pri)
30, 32	L*m*VCAFA[e]	Line *m* Phase C-to-Phase A voltage, angle (deg)
30, 32	L*m*V1[f]	Line *m* positive-sequence voltage, magnitude (kV, pri)
30, 32	L*m*V1FA[e]	Line *m* positive-sequence voltage, angle (deg)
30, 32	L*m*_3V2[f]	Line *m* negative-sequence voltage, magnitude (kV, pri)
30, 32	L*m*_3V2FA[e]	Line *m* negative-sequence voltage, angle (deg)
30, 32	L*m*_3V0[f]	Line *m* zero-sequence voltage, magnitude (kV, pri)
30, 32	L*m*_3V0FA[e]	Line *m* zero-sequence voltage, angle (deg)
30, 32	L*m*P3[g]	Line *m* three-phase power, active (MW, pri)

Table I.5 DNP3 Reference Data Map (Sheet 2 of 4)

Object	Label	Description
30, 32	L*m*Q3[g]	Line *m* three-phase power, reactive (MVAR, pri)
30, 32	L*m*FREQ[e]	Line *m* frequency (Hz)
30, 32	L*m*LMLOC[g]	Line *m* line monitoring alarm location (km/mi)
30, 32	L*m*LMLOCB1[g]	Line *m* line monitoring Blocking Region 1 alarm location (km/mi)
30, 32	L*m*LMLOCB2[g]	Line *m* line monitoring Blocking Region 2 alarm location (km/mi)
30, 32	L*m*LMETOT[c]	Line *m* line monitoring total event count
30, 32	MBTEMP[h]	Temperature, main board (deg C)
30, 32	SFP5TEMP[h]	Temperature, Port 5 SFP transceiver (deg C)
Event Summary Analog Inputs[a, b, i]		
30, 32	ETIMEH[c]	Event record trigger time in DNP format, high word
30, 32	ETIMEM[c]	Event record trigger time in DNP format, middle word
30, 32	ETIMEL[c]	Event record trigger time in DNP format, low word
30, 32	ETIMEH16[c]	Event record trigger time in DNP format, high 16 bits signed
30, 32	ETIMEM16[c]	Event record trigger time in DNP format, middle 16 bits signed
30, 32	ETIMEL16[c]	Event record trigger time in DNP format, low 16 bits signed
30, 32	ETYPE[c]	Event type
30, 32	L*m*FTIMH[c]	Line *m* fault time in DNP format, high word
30, 32	L*m*FTIMM[c]	Line *m* fault time in DNP format, middle word
30, 32	L*m*FTIML[c]	Line *m* fault time in DNP format, low word
30, 32	L*m*FTIMH16[c]	Line *m* fault time in DNP format, high 16 bits signed
30, 32	L*m*FTIMM16[c]	Line *m* fault time in DNP format, middle 16 bits signed
30, 32	L*m*FTIML16[c]	Line *m* fault time in DNP format, low 16 bits signed
30, 32	L*m*FTYPE[c]	Line *m* fault type
30, 32	L*m*FLOC[g]	Line *m* fault location (km/mi)
30, 32	L*m*FLRT[c]	Line *m* fault location reference terminal
30, 32	L*m*FIϕMP[d]	Line *m* Phase ϕ pre-fault current, magnitude (A, pri)
30, 32	L*m*FIϕAP[e]	Line *m* Phase ϕ pre-fault current, angle (deg)
30, 32	L*m*F3I2MP[d]	Line *m* negative-sequence pre-fault current, magnitude (A, pri)
30, 32	L*m*F3I2AP[e]	Line *m* negative-sequence pre-fault current, angle (deg)
30, 32	L*m*F3I0MP[d]	Line *m* zero-sequence pre-fault current, magnitude (A, pri)
30, 32	L*m*F3I0AP[e]	Line *m* zero-sequence pre-fault current, angle (deg)
30, 32	L*m*FVϕMP[f]	Line *m* Phase ϕ pre-fault voltage, magnitude (kV, pri)
30, 32	L*m*FVϕAP[e]	Line *m* Phase ϕ pre-fault voltage, angle (deg)
30, 32	L*m*FFREQ[e]	Line *m* pre-fault frequency (Hz)
30, 32	L*m*FIϕM[d]	Line *m* Phase ϕ fault current, magnitude (A, pri)
30, 32	L*m*FIϕA[e]	Line *m* Phase ϕ fault current, angle (deg)
30, 32	L*m*FIM[d]	Line *m* fault current, maximum phase magnitude (A, pri)
30, 32	L*m*F3I2M[d]	Line *m* negative-sequence fault current, magnitude (A, pri)
30, 32	L*m*F3I2A[e]	Line *m* negative-sequence fault current, angle (deg)
30, 32	L*m*F3I0M[d]	Line *m* zero-sequence fault current, magnitude (A, pri)

NOTE: Time stamps (date and time) are in UTC time.

Table I.5 DNP3 Reference Data Map (Sheet 3 of 4)

Object	Label	Description
30, 32	L*m*F3I0A[e]	Line *m* zero-sequence fault current, angle (deg)
30, 32	L*m*FVϕM[f]	Line *m* Phase ϕ fault voltage, magnitude (kV, pri)
30, 32	L*m*FVϕA[e]	Line *m* Phase ϕ fault voltage, angle (deg)
30, 32	L*m*MEZFL[g]	Line *m* fault location, multi-ended impedance-based method (km/mi)
30, 32	L*m*MEZRT[c]	Line *m* MEZFL fault location reference terminal
30, 32	L*m*METWFL[g]	Line *m* fault location, multi-ended TW-based method (km/mi)
30, 32	L*m*METWRT[c]	Line *m* METWFL fault location reference terminal
30, 32	L*m*SETWFL1[g]	Line *m* fault location, single-ended TW-based method Result 1 (km/mi)
30, 32	L*m*SETWFL2[g]	Line *m* fault location, single-ended TW-based method Result 2 (km/mi)
30, 32	L*m*SETWFL3[g]	Line *m* fault location, single-ended TW-based method Result 3 (km/mi)
30, 32	L*m*SETWFL4[g]	Line *m* fault location, single-ended TW-based method Result 4 (km/mi)
30, 32	L*m*SEZFL[g]	Line *m* fault location, single-ended impedance-based method (km/mi)
30, 32	L*m*FILTWH[c]	Line *m* local first TW arrival time seconds in DNP format, high word
30, 32	L*m*FILTWM[c]	Line *m* local first TW arrival time seconds in DNP format, middle word
30, 32	L*m*FILTWL[c]	Line *m* local first TW arrival time seconds in DNP format, low word
30, 32	L*m*FILTWH16[c]	Line *m* local first TW arrival time seconds in DNP format, high 16 bits signed
30, 32	L*m*FILTWM16[c]	Line *m* local first TW arrival time seconds in DNP format, middle 16 bits signed
30, 32	L*m*FILTWL16[c]	Line *m* local first TW arrival time seconds in DNP format, low 16 bits signed
30, 32	L*m*FILTWMS[c]	Line *m* local first TW arrival time, milliseconds
30, 32	L*m*FILTWUS[c]	Line *m* local first TW arrival time, microseconds
30, 32	L*m*FILTWNS[c]	Line *m* local first TW arrival time, nanoseconds
30, 32	FIRTWP*n*H[c]	Remote first TW arrival time seconds received on Port *n* in DNP format, high word
30, 32	FIRTWP*n*M[c]	Remote first TW arrival time seconds received on Port *n* in DNP format, middle word
30, 32	FIRTWP*n*L[c]	Remote first TW arrival time seconds received on Port *n* in DNP format, low word
30, 32	FIRTWP*n*H16[c]	Remote first TW arrival time seconds received on Port *n* in DNP format, high 16 bits signed
30, 32	FIRTWP*n*M16[c]	Remote first TW arrival time seconds received on Port *n* in DNP format, middle 16 bits signed
30, 32	FIRTWP*n*L16[c]	Remote first TW arrival time seconds received on Port *n* in DNP format, low 16 bits signed
30, 32	FIRTWP*n*MS[c]	Remote first TW arrival time received on Port *n*, milliseconds
30, 32	FIRTWP*n*US[c]	Remote first TW arrival time received on Port *n*, microseconds

Table I.5 DNP3 Reference Data Map (Sheet 4 of 4)

Object	Label	Description
30, 32	FIRTWP*n*NS[c]	Remote first TW arrival time received on Port *n*, nanoseconds
30, 32	FUNR[c]	Number of event records unread by DNP client

[a] ϕ = A, B, or C.
[b] *m* = 1 or 2.
[c] Default scaling = 1 and miscellaneous deadband ANADBM.
[d] Default current scaling DECPLA and deadband ANADBA.
[e] Default scaling = 100 and miscellaneous deadband ANADBM.
[f] Default voltage scaling DECPLV and deadband ANADBV.
[g] Default miscellaneous scaling DECPLM and deadband ANADBM.
[h] Default scaling = 10 and miscellaneous deadband ANADBM.
[i] *n* = 1, 2, or 3.

You can use any of the five available DNP3 maps to exchange data with any DNP3 master. The SEL-TWFL initially populates each map with default data points from the reference data map in *Table I.5*. You may remap the points in a default map to create a custom map from the points available in *Table I.5* with as many as:

- 200 binary inputs
- 11 binary outputs
- 120 analog inputs

Use ACSELERATOR QuickSet SEL-5030 Software to conveniently browse and map binary inputs, binary outputs, and analog inputs. *Figure I.1* shows the QuickSet interface for mapping analog inputs. Double-click the mapped point to launch the interface shown in *Figure I.2* to assign scaling, deadband, and class for the selected point.

Using a terminal interface, the SEL ASCII **SET D *n*** and **SHOW D *n*** commands are also available to edit or view the n-th map in your application.

Figure I.1 Analog Input Map Entry Window in QuickSet

Figure I.2 Analog Input Scaling, Deadband, and Class Settings Window in QuickSet

DNP3 Capabilities Overview

Data Access

Table I.6 summarizes methods of retrieving data via DNP3 from the least to most efficient and lists the associated DNP3 settings. The device uses separate settings for each session. The settings names in this section include the session number *n* as a suffix ranging from 1 to 6 (for example, CLASSB1, UNSOL1, and PUNSOL1 are settings for Session 1). All settings with the same numerical suffix comprise the complete DNP3 session configuration.

Table I.6 DNP3 Access Methods

Access Method	Master Polling	Device Settings[a]
Polled static	Class 0	Set CLASSB*n* and CLASSA*n* to OFF; set UNSOL*n* to N.
Polled report-by-exception	Class 0 occasionally; Class 1, 2, 3 frequently	Set CLASSB*n* and CLASSA*n* to the desired event class; set UNSOL*n* to N.
Unsolicited report-by-exception	Class 0 occasionally; optional Class 1, 2, 3 less frequently; mainly relies on unsolicited messages	Set CLASSB*n* and CLASSA*n* to the desired event class; set UNSOL*n* to Y and PUNSOL*n* to Y or N; set NUMEVE*n* and AGEEVE*n* to adjust the response rate.
Quiescent	Class 0, 1, 2, 3 never; relies completely on unsolicited messages	Set CLASSB*n* and CLASSA*n* to the desired event class; set UNSOL*n* and PUNSOL*n* to Y; set NUMEVE*n* and AGEEVE*n* to adjust the response rate.

[a] *n* = 1–6.

The SEL-TWFL uses the NUMEVE*n* and AGEEVE*n* settings to decide when to send unsolicited data to the DNP3 master. The device sends an unsolicited report when the total number of events accumulated in the event buffer reaches NUMEVE*n* or if the age of the oldest event in the buffer exceeds AGEEVE*n*. *Table I.7* lists the SEL-TWFL DNP3 buffer capacities.

Table I.7 DNP3 Event Buffer Capacity

Type	Maximum Number of Events
Binary	1024
Analog	One event per analog input in the DNP3 Map

Binary Inputs

Table I.11 defines the binary inputs (Objects 1 and 2) that the SEL-TWFL serves. The SEL-TWFL allows only the Read function code (1) with these objects. The default variation for both static and event inputs is 2. All the Relay Word bits are available as binary inputs (see *Appendix D: Relay Word Bits*).

NOTE: Time stamps (date and time) are in UTC time.

The SEL-TWFL DNP3 scanner checks for changes to the binary inputs approximately twice per second to detect a change. When DNP3 reports the time with these event objects, it is the time at which the scanner observed the bit change. This time value may be significantly delayed from when the Relay Word bit changed and should not be used for sequence-of-events determination. Binary inputs registered with SER are derived from the SER process and carry the true time stamp. Make sure to include a Relay Word bit in the SER*n* list settings (where *n* = 1–4) if you need the true time stamp for that bit transition. Some binary inputs such as DEVDIS, STWARN, and STFAIL are available to DNP3 without SER time stamps. For example, DEVDIS is derived from the device status variable; STWARN and STFAIL are derived from the diagnostic task data; and UNRDEV and NUNREV are derived from the event queue. Binary input STSET is derived from the SER and carries the true time stamp.

Binary Outputs

Table I.11 defines the binary outputs (Objects 10 and 12, Variation 2) that the SEL-TWFL accepts. See *Table I.8* for the Object 12 controls available in the SEL-TWFL. Pulse operations provide a pulse with duration of 1 ms. You must set the port setting DNPCL*n* to Y to enable binary controls for the DNP3 session.

Table I.8 Object 12 Acknowledgment and Data Housekeeping (Control) Operations

Control Point Label	DNP3 Control Operations						
	Close/Any	Trip/Any	NUL/Latch On	NUL/Latch Off	NUL/Pulse On	NUL/Pulse Off	NUL/NUL
NOOP	No action	No action	No action	No action	No action	No action	Not supported
DRST_TAR	Reset front-panel targets	Reset front-panel targets	Reset front-panel targets	No action	Reset front-panel targets	No action	Not supported
DRSTDNPE	Reset DNP event summary	Reset DNP event summary	Reset DNP event summary	No action	Reset DNP event summary	No action	Not supported
NXTEVE	Load oldest unread event summary (FIFO)[a]	Load oldest unread event summary (FIFO[a])	Load oldest unread event summary (FIFO[a])	Load newest event summary (LIFO[b])	Load oldest unread event summary (FIFO[a])	Load newest event summary (LIFO[b])	Not supported
Label1:Label2[c]	Label2 Close/Any action	Label1 Close/Any action	Label2 Close/Any action	Label1 Close/Any action	Label2 Close/Any action	Label1 Close/Any action	Not supported

[a] FIFO — First in first out.
[b] LIFO — Last in first out.
[c] "Label1" and "Label2" can be any Control Point Label.

Analog Inputs

Table I.11 defines the analog inputs (Objects 30 and 32) that the SEL-TWFL serves. The SEL-TWFL allows only the Read function code (1) with these objects. The AIVAR*n* setting defines the default variation for both static and event analog inputs. See the reference data map (*Table I.5*) for default scaling and deadband values. Per-point scaling and deadband settings specified in a custom DNP3 map override defaults.

Fault Summary Data

The fault summary (e.g., fault type, location, frequency, fault time, and trigger time) is available through a variety of analog inputs. When RPEVTYP*n* is set to FL, the SEL-TWFL only reports events in the DNP fault summary data that are associated with the rising edge of the L*m*FL Relay Word bit, where *m* = 1 or 2. When RPEVTYP*n* is set to ALL, the SEL-TWFL reports events that are triggered by the rising edge of the L*m*FL Relay Word bit or transient recording trigger. Additionally, when RPEVTYP*n* is set to ALL, the SEL-TWFL reports events in the DNP fault summary data that are triggered by using the SEL ASCII **TRIG** or **PULSE** command. To clear the event registers, the DNP3 master should send a close, trip, latch-on, or pulse-on control to the DRSTDNPE binary output.

The SEL-TWFL DNP3 event scanner checks for changes to device operations approximately twice per second.

In addition to the customary fault summary data, the SEL-TWFL also provides the fault-location values from the impedance and traveling-wave methods, traveling-wave arrival time, and fault time.

Event and Fault Type

See *Table I.9* and *Table I.10* for components of the event type (ETYPE) and fault type (L*m*FTYPE) analog inputs.

Table I.9 Object 30, 32, ETYPE Lower Byte-Event Cause

Bit Position								Event Cause
7	6	5	4	3	2	1	0	
								No fault summary loaded
							×	**TRIG** command
						×		**PULSE** command
				×				Event report (transient recorder) trigger
			×					Fault locator trigger

Table I.10 Object 30, 32, L*m*FTYPE[a] Lower Byte-Affected Phase(s)

Bit Position								Affected Phase
7	6	5	4	3	2	1	0	
								Indeterminate
							×	Phase A
						×		Phase B
					×			Phase C
				×				Ground

[a] *m* = 1 or 2.

Multi-Ended Traveling-Wave Fault Locating

To allow multi-ended traveling-wave fault locating in the SCADA/HMI environment, the SEL-TWFL makes the arrival time of the first traveling wave available via DNP3. Refer to *Multi-Ended Traveling-Wave-Based Method* on page 2.16 for details on how to calculate fault location for multiterminal lines. Traveling-wave arrival time with nanosecond resolution can be constructed using the following 16-bit analog input values, where *m* = 1 or 2:

- Millisecond digits (L*m*FILTWMS)
- Microsecond digits (L*m*FILTWUS)
- Nanosecond digits (L*m*FILTWNS)

The SEL-TWFL also makes the arrival time of the first traveling wave received from remote devices available via DNP3. Traveling-wave arrival time with nanosecond resolution can be constructed using the following 16-bit analog input values, where *n* = 1, 2, or 3:

- Millisecond digits (FIRTWP*n*MS)
- Microsecond digits (FIRTWP*n*US)
- Nanosecond digits (FIRTWP*n*NS)

Reading Device Fault Summary Data

If any fault summary data item configured in the DNP3 map changes beyond its set deadband, the SEL-TWFL generates a DNP3 event. The SEL-TWFL DNP3 event scanner checks for changes to DNP3 events approximately twice per second. When the scanner detects a DNP3 event, the SEL-TWFL provides the fault summary data to a DNP3 master in one of two modes: a single-event mode or a multiple-event mode. When the device is first enabled, there is a DNP3 settings change, a DNP3 map settings change, or a report settings change, then the SEL-TWFL DNP3 session defaults to the mode that the EVEMOD*n* setting specifies (EVEMOD*n* = SINGLE or EVEMOD*n* = MULTI). A DNP3 session switches to multiple-event mode if the DNP3 master sends a control (see *Table I.8*) to the NXTEVE binary output. The SEL-TWFL resets the fault summary analog inputs for an individual DNP3 session on a rising edge of the DRSTDNPE binary output.

Single-Event Mode

The single-event mode provides the most recent fault summary data. When the fault summary data are available, the SEL-TWFL copies the fault summary data to the DNP3 analog inputs, generating a DNP3 event. The DNP3 session then

ignores any subsequent fault summary data for a time equal to the EVELOCK setting value. The FUNR analog input is always set to zero while the DNP3 session is in the single-event mode.

Multiple-Event Mode

The multiple-event mode provides buffered fault summary data that may be read by issuing a control (see *Table I.8*) to the NXTEVE binary output. Any time there is a fault summary data item that is not read, the SEL-TWFL asserts the UNRDEV binary input. The FUNR analog input represents the number of transient records that have not been read by the DNP3 master on a per session basis. The DNP3 master can read the multiple-transient records summary data by using either the FIFO or LIFO mode. The DNP3 master must control the NXTEVE binary output such that the SEL-TWFL loads the new fault summary data into the DNP3 analog inputs no faster than once every two seconds. If the DNP3 master controls the NXTEVE binary output at a faster rate, the DNP3 event scanner may not recognize or process some DNP3 events.

FIFO

The SEL-TWFL initiates the multiple-event FIFO mode if the DNP3 master issues a close, trip, latch-on, or pulse-on control request to the NXTEVE binary output. The DNP3 master should monitor the UNRDEV binary input, which the SEL-TWFL asserts when there are fault summary data. The SEL-TWFL also asserts the NUNREV binary input when there are unread fault summary data. To read the oldest unread fault summary data, the DNP3 master issues a control to the NXTEVE binary output to trigger the SEL-TWFL to load the analog inputs with information from the oldest fault summary. After reading the analog inputs, the DNP3 master again checks the UNRDEV binary input, which will be asserted if there is another unread fault summary. The DNP3 master continues this process until the UNRDEV binary input deasserts. If the DNP3 master attempts to load values by controlling the NXTEVE binary output when the UNRDEV binary input is deasserted, the SEL-TWFL sets the ETYPE analog input to 0. With the FIFO mode, the DNP3 master always collects the fault summary data in chronological order.

LIFO

The multiple-event LIFO mode fault summary data retrieval is similar to the FIFO mode retrieval, with the following difference: to read the newest unread device record summary, the DNP3 master sends a latch-off or pulse-off control to the NXTEVE binary output. As with the FIFO mode retrieval, the DNP3 master monitors the UNRDEV binary input for any unread fault summary data. Note that if fault summary data are available while the DNP3 master is in the process of reading the newest fault summary, DNP3 event retrieval no longer continues in reverse chronological order. The DNP3 master reads the newest fault summary first and proceeds with the next newest fault summary. It skips any fault summary data that have already been read. The SEL-TWFL asserts the NUNREV binary input if this happens, signifying that the currently loaded fault summary is no longer the newest.

Object List

Table I.11 lists the SEL-TWFL DNP3 objects and variations with function codes and qualifier codes. *Table I.11* conforms to the format in the DNP3 specifications and therefore also includes objects that the SEL-TWFL does not allow. For these objects, *Table I.11* does not list the function and qualifier codes.

Table I.11 DNP3 Object List (Sheet 1 of 5)

Object	Variance	Description	Request[a]		Response[a]	
			Function Codes	Qualifier Codes	Function Codes	Qualifier Codes
0	211	Device attributes – User-specific sets of attributes	1	0, 6, 17	129	0, 17
0	212	Device attributes – Master data set prototypes	1	0, 6, 17	129	0, 17
0	213	Device attributes – Outstation data set prototypes	1	0, 6, 17	129	0, 17
0	214	Device attributes – Master data sets	1	0, 6, 17	129	0, 17
0	215	Device attributes – Outstation data sets	1	0, 6, 17	129	0, 17
0	216	Device attributes – Max. binary outputs per request	1	0, 6, 17	129	0, 17
0	219	Device attributes – Support for analog output events	1	0, 6, 17	129	0, 17
0	220	Device attributes – Max. analog output index	1	0, 6, 17	129	0, 17
0	221	Device attributes – Number of analog outputs	1	0, 6, 17	129	0, 17
0	222	Device attributes – Support for binary output events	1	0, 6, 17	129	0, 17
0	223	Device attributes – Max. binary output index	1	0, 6, 17	129	0, 17
0	224	Device attributes – Number of binary outputs	1	0, 6, 17	129	0, 17
0	225	Device attributes – Support for frozen counter events	1	0, 6, 17	129	0, 17
0	226	Device attributes – Support for frozen counters	1	0, 6, 17	129	0, 17
0	227	Device attributes – Support for counter events	1	0, 6, 17	129	0, 17
0	228	Device attributes – Max. counter index	1	0, 6, 17	129	0, 17
0	229	Device attributes – Number of counters	1	0, 6, 17	129	0, 17
0	230	Device attributes – Support for frozen analog inputs	1	0, 6, 17	129	0, 17
0	231	Device attributes – Support for analog input events	1	0, 6, 17	129	0, 17
0	232	Device attributes – Max. analog input index	1	0, 6, 17	129	0, 17
0	233	Device attributes – Number of analog inputs	1	0, 6, 17	129	0, 17
0	234	Device attributes – Support for double-bit events	1	0, 6, 17	129	0, 17
0	235	Device attributes – Max. double-bit binary index	1	0, 6, 17	129	0, 17
0	236	Device attributes – Number of double-bit binaries	1	0, 6, 17	129	0, 17
0	237	Device attributes – Support for binary input events	1	0, 6, 17	129	0, 17
0	238	Device attributes – Max. binary input index	1	0, 6, 17	129	0, 17
0	239	Device attributes – Number of binary inputs	1	0, 6, 17	129	0, 17
0	240	Device attributes – Max. transmit fragment size	1	0, 6, 17	129	0, 17
0	241	Device attributes – Max. receive fragment size	1	0, 6, 17	129	0, 17
0	242	Device attributes – Device manufacturer's software version	1	0, 6, 17	129	0, 17
0	243	Device attributes – Device manufacturer's hardware version	1	0, 6, 17	129	0, 17
0	245	Device attributes – User-assigned location name	1	0, 6, 17	129	0, 17
0	246	Device attributes – User-assigned ID code/number	1	0, 6, 17	129	0, 17
0	247	Device attributes – User-assigned device name	1	0, 6, 17	129	0, 17
0	248	Device attributes – Device serial number	1	0, 6, 17	129	0, 17
0	249	Device attributes – DNP3 subset and conformance	1	0, 6, 17	129	0, 17
0	250	Device attributes – Device manufacturer's product name and model	1	0, 6, 17	129	0, 17

Table I.11 DNP3 Object List (Sheet 2 of 5)

Object	Variance	Description	Request[a]		Response[a]	
			Function Codes	Qualifier Codes	Function Codes	Qualifier Codes
0	252	Device attributes – Device manufacturer's name	1	0, 6, 17	129	0, 17
0	254	Device attributes – Non-specific all attributes request	1	0, 6, 17	129	0, 17
0	255	Device attributes – List of attribute variations	1	0, 6, 17	129	0, 17
1	0	Binary input – All variations	1, 22	0, 1, 6, 7, 8, 17, 28		
1	1	Binary input	1	0, 1, 6, 7, 8, 17, 28	129	0, 1, 17, 28
1	2[a]	Binary input with status	1	0, 1, 6, 7, 8, 17, 28	129	0, 1, 17, 28
2	0	Binary input change – All variations	1	6, 7, 8		
2	1	Binary input change without time	1	6, 7, 8	129	17, 28
2	2[a]	Binary input change with time	1	6, 7, 8	129, 130	17, 28
2	3	Binary input change with relative time	1	6, 7, 8	129	17, 28
10	0	Binary output – All variations	1	0, 1, 6, 7, 8, 17, 28		
10	1	Binary output				
10	2[a]	Binary output status	1	0, 1, 6, 7, 8, 17, 28	129	0, 1, 17, 28
12	0	Control block – All variations				
12	1	Control device output block	3, 4, 5, 6	17, 28	129	echo of request
12	2	Pattern control block	3, 4, 5, 6	7	129	echo of request
12	3	Pattern mask	3, 4, 5, 6	0, 1	129	echo of request
20	0	Binary counter – All variations				
20	1	32-Bit binary counter				
20	2	16-Bit binary counter				
20	3	32-Bit delta counter				
20	4	16-Bit delta counter				
20	5	32-Bit binary counter without flag				
20	6[a]	16-Bit binary counter without flag				
20	7	32-Bit delta counter without flag				
20	8	16-Bit delta counter without flag				
21	0	Frozen counter – All variations				
21	1	32-Bit frozen counter				
21	2	16-Bit frozen counter				
21	3	32-Bit frozen delta counter				
21	4	16-Bit frozen delta counter				
21	5	32-Bit frozen counter with time of freeze				
21	6	16-Bit frozen counter with time of freeze				
21	7	32-Bit frozen delta counter with time of freeze				

Table I.11 DNP3 Object List (Sheet 3 of 5)

Object	Variance	Description	Request[a]		Response[a]	
			Function Codes	Qualifier Codes	Function Codes	Qualifier Codes
21	8	16-Bit frozen delta counter with time of freeze				
21	9	32-Bit frozen counter without flag				
21	10	16-Bit frozen counter without flag				
21	11	32-Bit frozen delta counter without flag				
21	12	16-Bit frozen delta counter without flag				
22	0	Counter change event – All variations				
22	1	32-Bit counter change event without time				
22	2[a]	16-Bit counter change event without time				
22	3	32-Bit delta counter change event without time				
22	4	16-Bit delta counter change event without time				
22	5	32-Bit counter change event with time				
22	6	16-Bit counter change event with time				
22	7	32-Bit delta counter change event with time				
22	8	16-Bit delta counter change event with time				
23	0	Frozen counter event – All variations				
23	1	32-Bit frozen counter event without time				
23	2	16-Bit frozen counter event without time				
23	3	32-Bit frozen delta counter event without time				
23	4	16-Bit frozen delta counter event without time				
23	5	32-Bit frozen counter event with time				
23	6	16-Bit frozen counter event with time				
23	7	32-Bit frozen delta counter event with time				
23	8	16-Bit frozen delta counter event with time				
30	0	Analog input – All variations	1, 22	0, 1, 6, 7, 8, 17, 28		
30	1[b]	32-Bit analog input with flag	1	0, 1, 6, 7, 8, 17, 28	129	0, 1, 17, 28
30	2[b]	16-Bit analog input with flag	1	0, 1, 6, 7, 8, 17, 28	129	0, 1, 17, 28
30	3[b]	32-Bit analog input without flag	1	0, 1, 6, 7, 8, 17, 28	129	0, 1, 17, 28
30	4[b]	16-Bit analog input without flag	1	0, 1, 6, 7, 8, 17, 28	129	0, 1, 17, 28
30	5[b]	Single-precision floating-point analog input with flag	1	0, 1, 6, 7, 8, 17, 28	129	0, 1, 17, 28
30	6[b]	Double-precision floating-point analog input with flag	1	0, 1, 6, 7, 8, 17, 28	129	0, 1, 17, 28
31	0	Frozen analog input – All variations				
31	1	32-Bit frozen analog input				
31	2	16-Bit frozen analog input				
31	3	32-Bit frozen analog input with time of freeze				
31	4	16-Bit frozen analog input with time of freeze				

Table I.11 DNP3 Object List (Sheet 4 of 5)

Object	Variance	Description	Request[a]		Response[a]	
			Function Codes	Qualifier Codes	Function Codes	Qualifier Codes
31	5	32-Bit frozen analog input without flag				
31	6	16-Bit frozen analog input without flag				
32	0	Analog change event – All variations	1	6, 7, 8		
32	1[b]	32-Bit analog change event without time	1	6, 7, 8	129	17, 28
32	2[b]	16-Bit analog change event without time	1	6, 7, 8	129, 130	17, 28
32	3	32-Bit analog change event with time	1	6, 7, 8	129	17, 28
32	4	16-Bit analog change event with time	1	6, 7, 8	129	17, 28
32	5[b]	Single-precision floating-point analog change event without time	1	6, 7, 8	129	17, 28
32	6[b]	Double-precision floating-point analog change event without time	1	6, 7, 8	129	17, 28
32	7[b]	Single-precision floating-point analog change event with time	1	6, 7, 8	129	17, 28
32	8[b]	Double-precision floating-point analog change event with time	1	6, 7, 8	129	17, 28
33	0	Frozen analog event – All variations				
33	1	32-Bit frozen analog event without time				
33	2	16-Bit frozen analog event without time				
33	3	32-Bit frozen analog event with time				
33	4	16-Bit frozen analog event with time				
34	0	Analog input deadband – All variations	1	0, 1, 6, 7, 8, 17, 28		
34	1[a]	16-Bit analog input deadband	1, 2	0, 1, 6, 7, 8, 17, 28	129	0, 1, 17, 28
34	2	32-Bit analog input deadband	1, 2	0, 1, 6, 7, 8, 17, 28	129	0, 1, 17, 28
34	3	Single-precision floating-point analog input deadband	1, 2	0, 1, 6, 7, 8, 17, 28	129	0, 1, 17, 28
40	0	Analog output status – All variations	1	6, 7, 8	129	
40	1	32-Bit analog output status				
40	2[a]	16-Bit analog output status				
40	3	Single-precision floating-point analog output status				
40	4	Double-precision floating-point analog output status				
41	0	Analog output block – All variations	3, 4, 5, 6	17, 28	129	echo of request
41	1	32-Bit analog output block				
41	2	16-Bit analog output block				
41	3	Single-precision floating-point analog output block				
41	4	Double-precision floating-point analog output block				
50	0	Time and date – All variations				
50	1	Time and date	1, 2	7, 8 index = 0	129	7, quantity = 1
50	2	Time and date with interval				

Table I.11 DNP3 Object List (Sheet 5 of 5)

Object	Variance	Description	Request[a]		Response[a]	
			Function Codes	Qualifier Codes	Function Codes	Qualifier Codes
50	3	Time and date at last recorded time	2	7, quantity = 1	129	
51	0	Time and date CTO – All variations				
51	1	Time and date CTO			129	7, quantity = 1
51	2	Unsynchronized time and date CTO			129	7, quantity = 1
52	0	Time delay – All variations				
52	1	Time delay, coarse				
52	2	Time delay, fine			129	7, quantity = 1
60	1	Class 0 data	1, 22	6, 7, 8		
60	2	Class 1 data	1, 20, 21, 22	6, 7, 8		
60	3	Class 2 data	1, 20, 21, 22	6, 7, 8		
60	4	Class 3 data	1, 20, 21, 22	6, 7, 8		
70	1	File identifier				
70	2	Authentication object				
70	3	File command object				
70	4	File command status object				
70	5	File transport object				
70	6	File transport status object				
70	7	File descriptor object				
80	1	Internal indications	2	0, 1 index = 4, 7		
81	1	Storage object				
82	1	Device profile				
83	1	Private registration object				
83	2	Private registration object descriptor				
90	1	Application identifier				
100	1	Short floating point				
100	2	Long floating point				
100	3	Extended floating point				
101	1	Small packed binary – Coded decimal				
101	2	Medium packed binary – Coded decimal				
101	3	Large packed binary – Coded decimal				
110	All	Octet string				
111	All	Octet string event				
112	All	Virtual terminal output block				
113	All	Virtual terminal event data				
N/A		No object required for the following function codes: 20 Enable unsolicited 22 Assign class 21 Disable unsolicited 23 delay measurement	20, 21, 22, 23			

[a] Default variation.
[b] Setting AIVAR*n* determines default variation.

Device Attributes (Object 0)

In response to Object 0 requests, the SEL-TWFL sends attributes that apply to that particular DNP3 session, such as the number of each data type. Because the device allows custom DNP3 maps, these values will likely be different for each session.

The SEL-TWFL uses its internal settings for the following variations:

- Variation 245 – SID setting
- Variation 246 – DNPID setting
- Variation 247 – FLID setting

Time Synchronization

NOTE: The accuracy of DNP3 time synchronization is insufficient for most fault recording needs. Use a high-accuracy time source connected via the IRIG-B input of the device. See *Appendix H: High-Accuracy Timekeeping* for information about timekeeping.

If the device is not connected to an accurate clock over the IRIG-B input, you can use DNP3 to periodically set the SEL-TWFL clock and calendar in order to keep the device time relatively accurate. Use setting TIMERQ*n* and use Object 50, Variation 3 to set the date and time via a DNP3 master.

You can set TIMERQ*n* in one of three ways:

- Use a numeric setting of 1–32767 minutes to specify the rate at which the device requests time.
- Use a setting of M to prevent the device from requesting time but still allow it to accept and apply time from the master.
- Use a setting of I to prevent the device from requesting time and cause it to ignore time from the master.

The device treats all incoming DNP3 time-set messages as UTC time. All DNP3 event time stamps (binary input changes with time, analog input changes with time, etc.) are in UTC time.

Testing

Use the SEL ASCII **TEST DB2** command to test the data mapping from the SEL-TWFL to the DNP3 master. You can use the **TEST DB2** command to force DNP3 analog or binary values. Forcing the DNP3 values does not change the values that the device uses for fault locating and metering. The **TEST DB2** command operates by object type and label, so it works equally well with custom mapping and the default DNP3 maps. See *TEST DB2* on page C.18 for more information.

APPENDIX J

Cybersecurity Features

Cybersecurity Features

The SEL-TWFL contains a number of features to assist users with meeting their cybersecurity requirements. These features are as follows.

Electronic Access Control

The SEL-TWFL has a number of mechanisms for managing electronic access. These include ways to limit access, provide user authentication, and monitor electronic and physical access.

Port Restrictions

The SEL-TWFL has two engineering access ports: the front-panel Port F for local engineering access and Ethernet Port 5 for remote engineering access. SEL recommends disabling ports that are not in use (set EPORT to N for each unused port). By default, only Port F is enabled.

You can increase security by recognizing differences in typical tasks performed when preparing a new device for field installation, commissioning and maintaining the device in the field, and occasionally accessing the device remotely. For example, after setting unique passwords, including the calibration Access Level C passwords, you can restrict the access level for the front-panel Port F to Access Level 2. This prevents entering Access Level C by mistake. Similarly, you can restrict the access level for Ethernet Port 5 to Access Level 1. This prevents accidentally erasing data or changing settings. Restricting port access allows you to operate under the principle of "least privilege" – restricting ports to only the levels needed for the engineering tasks performed on those ports.

Use the MAXACC settings for Port F and Port 5 to set access level restrictions for the two engineering access ports. The Port 5 maximum access level restriction applies to both the terminal window session with SEL ASCII commands over Telnet and the FTP session for file transfers.

When you attempt to access a level above the maximum access level, the device refuses and replies with the `Command Unavailable` message.

The PASSWORD jumper overrides the maximum access level restrictions for both ports.

Authentication and Authorization

The SEL-TWFL allows five levels of access. Refer to *Access Levels* on page 7.36 to learn which functions are allowed at each level, how each level is accessed, and what the default passwords are for each level. SEL recommends changing the default password of each access level to a unique password. The SEL-TWFL allows passwords of as many as 12 characters, using any printable character,

⚠WARNING
This device is shipped with default passwords. Default passwords should be changed to private passwords at installation. Failure to change each default password to a private password may allow unauthorized access. SEL shall not be responsible for any damage resulting from unauthorized access.

allowing users to select complex passwords if they choose. SEL recommends that passwords contain a minimum of 8 characters containing at least one of each of the following: lowercase letter, uppercase letter, number, and special character. The **PAS** command issues a warning if you do not follow this strong password rule.

TW test mode maintains security of in-service devices by requiring your testing and commissioning personnel to acknowledge the testing intent issued over the engineering port, thus preventing an unintentional or malicious initiation of the test.

Monitoring and Logging

The SEL-TWFL provides Relay Word bits that are useful for monitoring device access, as shown in *Table J.1*.

Table J.1 Relay Word Bits for Monitoring Potential Cybersecurity Threats

Relay Word Bit	Description
ACCESS	Device in Access Level B or higher
ACCESSP	One-second pulse when access level is increased to 2 or higher
BADPASS	One-second pulse after three consecutive bad password entries
PASNVAL	One-second pulse when an incorrect password is entered at Access Level B or higher
CHGPASS	One-second pulse whenever a password is changed
SETCHG	One-second pulse whenever settings are changed
SALARM	OR combination of BADPASS, SETCHG, and TWTEST
LINK5	Port 5 valid link detected

Physical Access Control

Typically, SEL-TWFL devices are installed within a control house that provides physical security. Other times, they are installed in cabinets within the switchyard. For applications in the switchyard, you can monitor physical ingress by wiring a door sensor to one of the SEL-TWFL contact inputs. This input can then be mapped for SCADA monitoring or added to the SER log so that you can monitor when physical access to the enclosure occurs.

Configuration Management

The SEL-TWFL provides mechanisms for assisting users with the management of configuration data. As stated previously, all settings changes are logged to the SER log. Analysis of this log will let you determine if any unauthorized settings changes occurred.

The SEL-TWFL also stores a checksum for each settings class in the CFG.TXT file. After configuring the device, you can read the CFG.TXT file and store it for future reference. The SEL-TWFL front-panel HMI also allows you to view the settings checksum values. You can then periodically read this file from the device, extract the checksum, and compare it to the stored reference. If any checksum has changed, you know that a settings class has been modified. Use the **FILE READ CFG.TXT** command to initiate the CFG.TXT file transfer that uses the Ymodem protocol (see *FILE* on page C.8 for more information).

Figure 8.5 shows the contents of a sample CFG.TXT file. The checksum is the last eight digits on each line; for example, 4B3A103A is the checksum for the fault locator settings.

Firmware Checksum Verification

SEL provides firmware checksum (CID) as an additional tool to verify the integrity of SEL firmware upgrade files. This helps ensure that the firmware you receive from the factory is complete and unaltered prior to sending the firmware to the SEL device. Verify that the firmware file in your possession is a known good SEL firmware release by comparing the calculated checksum of the firmware in your possession with the checksum provided at selinc.com/products/firmware/. See *Saving and Verifying Firmware Files* on page B.3 for more information on how to verify firmware authenticity.

Malware Protection

The SEL-TWFL has inherent and continuous monitoring for malware detection. For a full description, see selinc.com/mitigating_malware/.

Security Vulnerabilities

If SEL finds a security vulnerability with the SEL-TWFL, users will receive disclosure of the issue through the standard SEL security notification process. For a full description of this process, see selinc.com/support/security-notifications/.

Erasing Private Data

IMPORTANT: Do not erase device configuration or records when returning the SEL-TWFL to SEL for investigation.

SEL recommends erasing private device data including passwords, settings, event history, SER data, and diagnostics when the device is decommissioned unless you are returning it to SEL for investigation or service. Perform the following procedure to erase all private data in the SEL-TWFL:

Step 1. Go to Access Level C.

Step 2. Execute the **R_S** command.

Step 3. Allow the device to restart.

Once you complete these steps, all private data including passwords, event history, SER data, targets, settings, transient records, and diagnostics are erased. The settings are restored to factory-default values. Do not erase data before sending the SEL-TWFL to SEL for service. SEL needs to see how the device was configured in order to properly diagnose problems.

Contact SEL

For further questions or concerns about product security, contact SEL at security@selinc.com or +1.509.332.1890.

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SEL-TWFL Command Summary

SEL ASCII Command	Description	Access Level	Examples
Access Control and Security			
ACCESS	Use **ACC** to go to Access Level 1 to view device data.	0, 1, B, 2	**ACC <Enter>**
BACCESS	Use **BAC** to go to Access Level B.	1, B, 2	**BAC <Enter>**
2ACCESS	Use **2AC** to go to Access Level 2 for full user privileges, including settings changes and clearing records.	1, B, 2	**2AC <Enter>**
QUIT	Use **QUI** to exit for security to Access Level 0 after working at higher access levels.	0, 1, B, 2	**QUI <Enter>**
EXIT	Use **EXI** to terminate a Telnet session or the firmware update process.	0, 1, B, 2	**EXI <Enter>**
PASSWORD	Use **PAS *n*** to change the Access Level *n* (*n* = 1, B, 2, or C) password.	2	**PAS 1 <Enter>** **PAS 2 <Enter>**
CALIBRATION	Use **CAL** to go to Access Level C. Use this command only under SEL supervision.	2	**CAL <Enter>**
Device Identification			
IDENTIFICATION	Use **ID** to view the device identification (serial number, firmware revision, etc.).	0, 1, B, 2	**ID <Enter>**
VERSION	Use **VER** to view the device version.	1, B, 2	**VER <Enter>**
MAC	Use **MAC** to view the Media Access Control address for the SFP transceiver in Port 5.	1, B, 2	**MAC <Enter>**
ETHERNET	Use **ETH** to view configuration, status, and performance statistics, and use **ETH C** to clear performance statistics for Ethernet Port 5.	1, B, 2	**ETH <Enter>** **ETH C <Enter>**
Configuring the Device			
HELP	Use **HELP** to list the SEL-TWFL SEL ASCII commands and their descriptions.	0, 1, B, 2	**HELP <Enter>**
SET	Use **SET** to edit settings: **SET** for fault locator, **SET P *p*** for communications Port *p* (*p* = F, 1, 2, 3, or 5), **SET R** for report, **SET D *n*** for DNP Map *n* (*n* = 1–5).	2	**SET <Enter>** **SET L1Z1MAG1 <Enter>** **SET P 5 <Enter>**
SHOW	Use **SHO** to view settings: **SHO** for fault locator, **SHO P *p*** for communications Port *p* (*p* = F, 1, 2, 3, or 5), **SHO R** for report, **SHO D *n*** for DNP Map *n* (*n* = 1–5).	1, B, 2	**SHO <Enter>** **SHO D 1 <Enter>** **SHO P 5 <Enter>**
TIME	Use **TIM** to view and **TIM *hh:mm:ss*** to set the time.	1, B, 2	**TIM <Enter>** **TIM 09:00:00 <Enter>**
DATE	Use **DAT** to view and **DAT *yyyy/mm/dd*** to set the date.	1, B, 2	**DAT <Enter>** **DAT 2024/01/30 <Enter>**
Viewing Records, Historical Data, and Other Static Data			
HISTORY	Use **HIS** to view and **HIS C** to clear the transient records (events) history.	1, B, 2	**HIS <Enter>** **HIS 10 <Enter>** **HIS C <Enter>**
SUMMARY	Use **SUM** to view the transient record (event) summary.	1, B, 2	**SUM <Enter>** **SUM N <Enter>**

SEL ASCII Command	Description	Access Level	Examples
SER	Use **SER** to view and **SER C** to clear the SER record. Use **SER D** to view the SER entries that the device is suspending from the SER record based on the anti-chatter settings.	1, B, 2	**SER <Enter>** **SER 23 28 <Enter>** **SER 2024/01/30 2024/02/06<Enter>**
LIMO	Use **LIMO** to view the line monitoring data for all lines on which you use the line monitor. Use **LIMO L*m*** to view the line monitoring data for Line *m* and **LIMO L*m* C** to clear the line monitoring event counters for Line *m*. Use **LIMO L*m location*** and **LIMO L*m location1 location2*** to view the event counters at a specific location(s) on Line *m*. Use **LIMO L*m location* C** and **LIMO L*m location1 location2* C** to clear the event counters at a specific location(s) on Line *m* (*m* = 1 or 2).	1, B, 2	**LIMO <Enter>** **LIMO L1 <Enter>** **LIMO L2 9.51 <Enter>** **LIMO L2 9.50 C <Enter>** **LIMO L1 9 10 <Enter>** **LIMO L1 9 10 C <Enter>** **LIMO L1 C <Enter>**
SHOW	Use **SHO** to view settings: **SHO** for fault locator, **SHO P *p*** for communications Port *p* (*p* = F, 1, 2, 3, or 5), **SHO R** for report, **SHO D *n*** for DNP Map *n* (*n* = 1–5).	1, B, 2	**SHO <Enter>** **SHO D 1 <Enter>** **SHO P 5 <Enter>**
TRIGGER	Use **TRI** to trigger a transient record.	1, B, 2	**TRI <Enter>**
FILE	Use **FILE DIR** to view the file directory, **FILE READ** to transfer settings from the device to the PC, and **FILE WRITE** to transfer files from the PC to the device. Use Ymodem to transfer device records.	1, B, 2	**FIL DIR <Enter>** **FIL READ SETTINGS SET_P1.TXT <Enter>**
Communications			
COMMUNICATIONS	Use **COM P *n*** to view and **COM P *n* C** to clear performance statistics for communications Port *n* (*n* = 1, 2, or 3).	1, B, 2	**COM P 1 <Enter>** **COM P 1 C <Enter>**
LOOP	Use **LOOP P *n*** to start the loopback mode for communications Port *n* with SEL MB8/IEEE C37.94 encoding while forcing the received bits to logical 0, **LOOP P *n* DATA** to pass the actual sent bits back as received bits, and **LOOP P *n* X** to terminate the loopback test mode (*n* = 1, 2, or 3).	2	**LOO P 2 <Enter>** **LOO P 2 DATA <Enter>** **LOO P 2 X <Enter>**
ETHERNET	Use **ETH** to view configuration, status, and performance statistics, and use **ETH C** to clear performance statistics for Ethernet Port 5.	1, B, 2	**ETH <Enter>** **ETH C <Enter>**
MAC	Use **MAC** to view the Media Access Control address for the SFP transceiver in Port 5.	1, B, 2	**MAC <Enter>**
STATUS	Use **STA** to view the device status including internal diagnostics, **STA S** to view SELOGIC execution availability.	1, B, 2	**STA <Enter>**
Testing and Commissioning			
METER	Use **MET** to view the metering data.	1, B, 2	**MET <Enter>** **MET 10 <Enter>**
TWTEST	Use **TWT** to start and **TWT X** to terminate the traveling-wave test mode.	2	**TWT <Enter>**
PULSE	Use **PUL OUT*nnn* *s*** to pulse output OUT*nnn* for *s* seconds (requires the BREAKER jumper to be in the enable position).	B, 2	**PUL OUT101 <Enter>**

SEL ASCII Command	Description	Access Level	Examples
TEST DB2	Use **TEST DB2** to force digital and analog DNP3 inputs for testing (**TEST DB2 D|A *name value***) and **TEST DB2 OFF** to clear all test values.	B, 2	**TEST DB2 D IN101 1 <Enter>** **TEST DB2 A IA 100 <Enter>**
TARGET	Use **TAR** to view the Relay Word bit status and **TAR C** to clear all latched device targets.	1, B, 2	**TAR LIST <Enter>** **TAR LOP <Enter>**
TRIGGER	Use **TRI** to trigger a transient record.	1, B, 2	**TRI <Enter>**
STATUS	Use **STA** to view the device status including internal diagnostics and **STA S** to view the SELOGIC execution availability.	1, B, 2	**STA <Enter>**
Firmware Upgrade and Advanced Tasks			
L_D	Use **L_D** to take the device out of service and go to SELBOOT in preparation for receiving new firmware.	2	**L_D <Enter>**
R_S	Use **R_S** to perform a factory reset (restore factory configuration except calibration data, clear records, and restart the device). Use **R_S F** at Access Level C to also reset the firmware calibration data.	2	**R_S <Enter>**
VECTOR	Use **VEC** to view internal device diagnostics data. At Access Level C, use this command exclusively under SEL supervision.	2	**VEC <Enter>**

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SEL-TWFL Command Summary

SEL ASCII Command	Description	Access Level	Examples
Access Control and Security			
ACCESS	Use **ACC** to go to Access Level 1 to view device data.	0, 1, B, 2	**ACC <Enter>**
BACCESS	Use **BAC** to go to Access Level B.	1, B, 2	**BAC <Enter>**
2ACCESS	Use **2AC** to go to Access Level 2 for full user privileges, including settings changes and clearing records.	1, B, 2	**2AC <Enter>**
QUIT	Use **QUI** to exit for security to Access Level 0 after working at higher access levels.	0, 1, B, 2	**QUI <Enter>**
EXIT	Use **EXI** to terminate a Telnet session or the firmware update process.	0, 1, B, 2	**EXI <Enter>**
PASSWORD	Use **PAS *n*** to change the Access Level *n* (*n* = 1, B, 2, or C) password.	2	**PAS 1 <Enter>** **PAS 2 <Enter>**
CALIBRATION	Use **CAL** to go to Access Level C. Use this command only under SEL supervision.	2	**CAL <Enter>**
Device Identification			
IDENTIFICATION	Use **ID** to view the device identification (serial number, firmware revision, etc.).	0, 1, B, 2	**ID <Enter>**
VERSION	Use **VER** to view the device version.	1, B, 2	**VER <Enter>**
MAC	Use **MAC** to view the Media Access Control address for the SFP transceiver in Port 5.	1, B, 2	**MAC <Enter>**
ETHERNET	Use **ETH** to view configuration, status, and performance statistics, and use **ETH C** to clear performance statistics for Ethernet Port 5.	1, B, 2	**ETH <Enter>** **ETH C <Enter>**
Configuring the Device			
HELP	Use **HELP** to list the SEL-TWFL SEL ASCII commands and their descriptions.	0, 1, B, 2	**HELP <Enter>**
SET	Use **SET** to edit settings: **SET** for fault locator, **SET P *p*** for communications Port *p* (*p* = F, 1, 2, 3, or 5), **SET R** for report, **SET D *n*** for DNP Map *n* (*n* = 1–5).	2	**SET <Enter>** **SET L1Z1MAG1 <Enter>** **SET P 5 <Enter>**
SHOW	Use **SHO** to view settings: **SHO** for fault locator, **SHO P *p*** for communications Port *p* (*p* = F, 1, 2, 3, or 5), **SHO R** for report, **SHO D *n*** for DNP Map *n* (*n* = 1–5).	1, B, 2	**SHO <Enter>** **SHO D 1 <Enter>** **SHO P 5 <Enter>**
TIME	Use **TIM** to view and **TIM *hh:mm:ss*** to set the time.	1, B, 2	**TIM <Enter>** **TIM 09:00:00 <Enter>**
DATE	Use **DAT** to view and **DAT *yyyy/mm/dd*** to set the date.	1, B, 2	**DAT <Enter>** **DAT 2024/01/30 <Enter>**
Viewing Records, Historical Data, and Other Static Data			
HISTORY	Use **HIS** to view and **HIS C** to clear the transient records (events) history.	1, B, 2	**HIS <Enter>** **HIS 10 <Enter>** **HIS C <Enter>**
SUMMARY	Use **SUM** to view the transient record (event) summary.	1, B, 2	**SUM <Enter>** **SUM N <Enter>**

SEL ASCII Command	Description	Access Level	Examples
SER	Use **SER** to view and **SER C** to clear the SER record. Use **SER D** to view the SER entries that the device is suspending from the SER record based on the anti-chatter settings.	1, B, 2	**SER <Enter>** **SER 23 28 <Enter>** **SER 2024/01/30 2024/02/06<Enter>**
LIMO	Use **LIMO** to view the line monitoring data for all lines on which you use the line monitor. Use **LIMO L*m*** to view the line monitoring data for Line *m* and **LIMO L*m* C** to clear the line monitoring event counters for Line *m*. Use **LIMO L*m location*** and **LIMO L*m location1 location2*** to view the event counters at a specific location(s) on Line *m*. Use **LIMO L*m location* C** and **LIMO L*m location1 location2* C** to clear the event counters at a specific location(s) on Line *m* (*m* = 1 or 2).	1, B, 2	**LIMO <Enter>** **LIMO L1 <Enter>** **LIMO L2 9.51 <Enter>** **LIMO L2 9.50 C <Enter>** **LIMO L1 9 10 <Enter>** **LIMO L1 9 10 C <Enter>** **LIMO L1 C <Enter>**
SHOW	Use **SHO** to view settings: **SHO** for fault locator, **SHO P *p*** for communications Port *p* (*p* = F, 1, 2, 3, or 5), **SHO R** for report, **SHO D *n*** for DNP Map *n* (*n* = 1–5).	1, B, 2	**SHO <Enter>** **SHO D 1 <Enter>** **SHO P 5 <Enter>**
TRIGGER	Use **TRI** to trigger a transient record.	1, B, 2	**TRI <Enter>**
FILE	Use **FILE DIR** to view the file directory, **FILE READ** to transfer settings from the device to the PC, and **FILE WRITE** to transfer files from the PC to the device. Use Ymodem to transfer device records.	1, B, 2	**FIL DIR <Enter>** **FIL READ SETTINGS SET_P1.TXT <Enter>**
Communications			
COMMUNICATIONS	Use **COM P *n*** to view and **COM P *n* C** to clear performance statistics for communications Port *n* (*n* = 1, 2, or 3).	1, B, 2	**COM P 1 <Enter>** **COM P 1 C <Enter>**
LOOP	Use **LOOP P *n*** to start the loopback mode for communications Port *n* with SEL MB8/IEEE C37.94 encoding while forcing the received bits to logical 0, **LOOP P *n* DATA** to pass the actual sent bits back as received bits, and **LOOP P *n* X** to terminate the loopback test mode (*n* = 1, 2, or 3).	2	**LOO P 2 <Enter>** **LOO P 2 DATA <Enter>** **LOO P 2 X <Enter>**
ETHERNET	Use **ETH** to view configuration, status, and performance statistics, and use **ETH C** to clear performance statistics for Ethernet Port 5.	1, B, 2	**ETH <Enter>** **ETH C <Enter>**
MAC	Use **MAC** to view the Media Access Control address for the SFP transceiver in Port 5.	1, B, 2	**MAC <Enter>**
STATUS	Use **STA** to view the device status including internal diagnostics, **STA S** to view SELOGIC execution availability.	1, B, 2	**STA <Enter>**
Testing and Commissioning			
METER	Use **MET** to view the metering data.	1, B, 2	**MET <Enter>** **MET 10 <Enter>**
TWTEST	Use **TWT** to start and **TWT X** to terminate the traveling-wave test mode.	2	**TWT <Enter>**
PULSE	Use **PUL OUT*nnn* *s*** to pulse output OUT*nnn* for *s* seconds (requires the BREAKER jumper to be in the enable position).	B, 2	**PUL OUT101 <Enter>**

SEL ASCII Command	Description	Access Level	Examples
TEST DB2	Use **TEST DB2** to force digital and analog DNP3 inputs for testing (**TEST DB2 D|A *name value***) and **TEST DB2 OFF** to clear all test values.	B, 2	**TEST DB2 D IN101 1 <Enter>** **TEST DB2 A IA 100 <Enter>**
TARGET	Use **TAR** to view the Relay Word bit status and **TAR C** to clear all latched device targets.	1, B, 2	**TAR LIST <Enter>** **TAR LOP <Enter>**
TRIGGER	Use **TRI** to trigger a transient record.	1, B, 2	**TRI <Enter>**
STATUS	Use **STA** to view the device status including internal diagnostics and **STA S** to view the SELOGIC execution availability.	1, B, 2	**STA <Enter>**
Firmware Upgrade and Advanced Tasks			
L_D	Use **L_D** to take the device out of service and go to SELBOOT in preparation for receiving new firmware.	2	**L_D <Enter>**
R_S	Use **R_S** to perform a factory reset (restore factory configuration except calibration data, clear records, and restart the device). Use **R_S F** at Access Level C to also reset the firmware calibration data.	2	**R_S <Enter>**
VECTOR	Use **VEC** to view internal device diagnostics data. At Access Level C, use this command exclusively under SEL supervision.	2	**VEC <Enter>**

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