SEL-T4287 Traveling-Wave Test System Instruction Manual

Features, Benefits, and Applications

Traveling-wave fault locators and protective relays measure sharp changes in their input currents and voltages with rise times as fast as 1 microsecond. These fault locators and relays respond to relative polarities and the relative timing of the sharp signal changes. The SEL-T4287 Traveling-Wave Test System is a secondary pulse injection test set that generates current traveling waves (current steps) with a short rise time, adequately slow decay, and nanosecond precision necessary for testing standalone traveling-wave fault locators, traveling-wave protective relays, and traveling-wave fault locators embedded in line protective relays.

The SEL-T4287 provides the following features:

- **Current Pulses With Nanosecond Precision.** Use precise pulses for accurate testing of traveling-wave functions.
- **Two Three-Phase Current Channels With One Voltage Module for Converting to Voltage Channels.** Evaluate the performance of traveling-wave functions, such as traveling-wave differential (TW87) schemes, traveling-wave directional (TW32) elements, and single- and double-ended traveling-wave fault locators (TWFL).
- **Universal AC Power Supply Inputs.** Take advantage of the universal power supply for use of the SEL-T4287 in the laboratory and field.
- **Simple Multifunction Display.** Quickly read and select test parameters and settings.
- **Intuitive User Interface.** Expedite and simplify testing.
- **Front-Panel Controls.** Simplify entry of test configurations with an intuitive human-machine interface (HMI), no software required.

- **Configurable Test Triggering Options.** Inject traveling waves by using any one of these methods:
  - Pressing a front-panel pushbutton.
  - Configuring the SEL-T4287 to automatically trigger tests at a specific time when an IRIG-B signal is present.
  - Triggering tests from other test equipment.
- **Low-Level Inputs and Outputs.** Receive triggers from and send triggers to other devices to coordinate tests.
- **IRIG-B.** Synchronize multiple test sets to an absolute time signal.
- **Front-Panel USB Port.** Upgrade test set firmware from a computer.
- **Adjustable Carrying Handle.** Easily transport the test set for field test setups with this rugged and mobile design.

Product Overview

The SEL-T4287 is a compact test set that produces traveling-wave (TW) current step signals with microsecond rise time, adequately slow decay, and nanosecond precision for testing TW-based features of relays and fault locators. The SEL-T4287 is suitable for testing traveling-wave protection elements and schemes in SEL products, such as the SEL-T400L Time-Domain Line Protection. You can also use the SEL-T4287 to test traveling-wave fault locators embedded in SEL protective relays, such as the SEL-411L Advanced Line Differential Protection, Automation, and Control System, as well as other manufacturers' traveling-wave fault locators.

The SEL-T4287 simulates traveling waves that are generated by faults in the power system. All simulated faults applied by the SEL-T4287 represent bolted single-line-to-ground faults. The traveling waves are provided to the device(s) under test through two sets of three-phase current outputs. Use these current outputs to inject traveling waves into the local and remote relays applied to a two-terminal line, such as when testing the TW87 scheme or double-ended TWFL. Connect these two outputs to the current inputs of a single relay to test single-ended TWFL. You can also test the TW32 element in a relay by connecting one of the three-phase current outputs to the current inputs on the tested relay and the other three-phase current outputs to the voltage inputs by using the supplied voltage module (Part Number 915900503). Details regarding these applications are described in *Applications on page 16*.

The SEL-T4287 generates traveling waves based on user-specified parameters for the line length (LL), traveling-wave line propagation time (TWLPT), number of terminals (NTERM), fault type (FLTYPE), and fault location (FL). These parameters are configured through the front panel, which includes a multifunction display, a USB port, trigger source indication LEDs, and front-panel controls, as shown in *Figure 1*. Multiple triggering sources are available to suit your testing needs, including a front-panel pushbutton, a 48 V binary input from a traditional relay test set, and a 5 V TTL rising-edge input. You can also trigger a test at a specific time when connected to an IEEE C37.118-compliant IRIG-B signal. *Figure 2* shows the rear-panel inputs, outputs, and power supply. External trigger outputs are available to signal other test sets.

The SEL-T4287 comes equipped with an adjustable handle/kickstand that allows you to change the viewing angle of the display when it is placed on a flat surface.

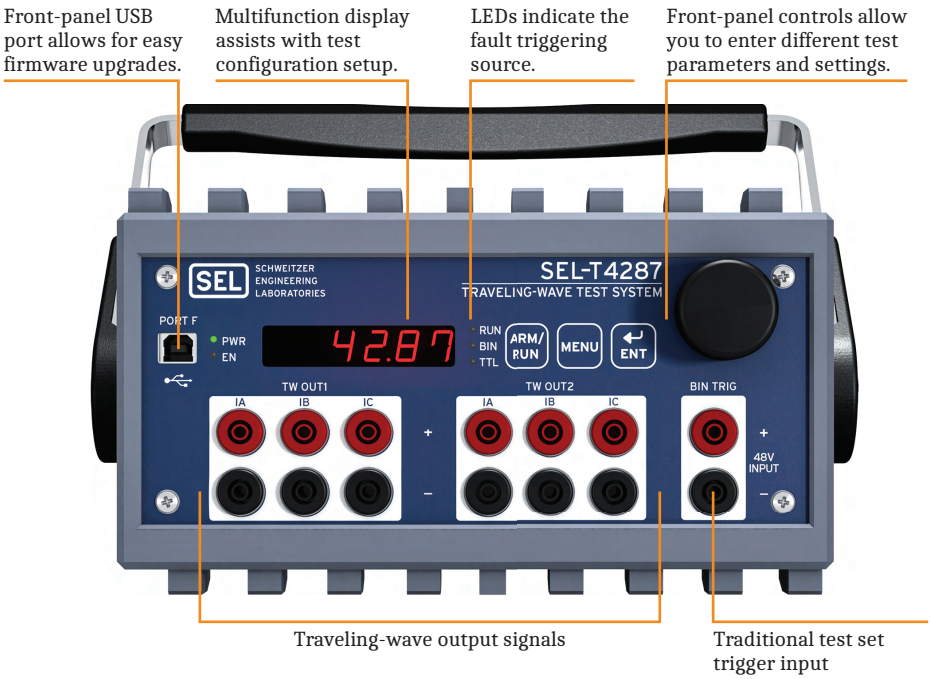


Figure 1 SEL-T4287 Front-Panel Features

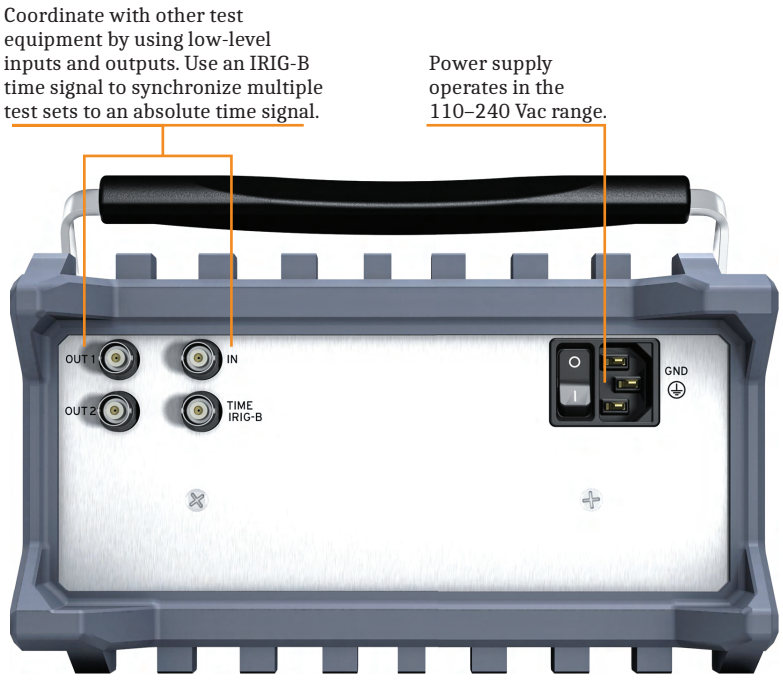


Figure 2 SEL-T4287 Rear-Panel Features

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 apply to this device.

	**⚠CAUTION** Refer to accompanying documents.	**⚠ATTENTION** Se reporter à la documentation.
	Protective earth (ground)	Terre de protection
	Instruction manual	Manuel d'instructions

Safety Marks

The following statements apply to this device.

⚠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 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.
⚠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.

Location

The SEL-T4287 is not designed for fixed installation. Use the SEL-T4287 in a protected environment inside a building and on a flat surface free of debris and liquids. As a safety measure, restrict access to the SEL-T4287 and its output ports. The rear rubber bumper protects the rear-panel ports so the SEL-T4287 can be placed upright. Do not position the test set such that it is difficult to operate the power switch.

Connections

Safety

⚠DANGER
Do not connect the SEL-T4287 traveling-wave outputs or digital inputs/outputs to live power system circuits. This can cause electrical shock that can result in injury or death.

There are important safety symbols on the rear of the SEL-T4287, shown in *Figure 3*. Observe proper safety precautions when you connect power to the rear panel of the SEL-T4287. In particular, 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*. Ensure that you limit access to these terminals.

Grounding Terminal Symbol Danger

Figure 3 Rear-Panel Safety Symbols

Power and Ground Connections

⚠WARNING
Do not use a line cord that does not meet the listed power supply rating.

Power and ground are provided by the NEMA line cord. No additional connections are necessary. The serial-number label on the back of the unit lists the power supply voltage. Once you connect power, move the power switch to the on position. The **PWR** and **EN** LEDs will illuminate, and the HMI displays READY.

Input and Output Connections

Use only appropriate cables and connections on the inputs and outputs of the SEL-T4287. These include 50 Ω BNC cables on the rear ports, sheathed or unsheathed banana jacks on the front ports, a USB Type-B connector for **Port F**, and a C14 connector for power. Use standard insulated banana plug test leads when connecting the SEL-T4287 traveling-wave outputs to the terminals of the device(s) under test. Be sure that these leads have the same length and the same wire gauge to preserve adequate accuracy of the TW test signals.

For tests that require current TW signals be applied, use test leads to connect the traveling-wave outputs on the SEL-T4287 to the current inputs on the device under test. For example, to apply current TWs to the SEL-T400L, use the wiring diagram in *Figure 4* to connect the TW outputs on the SEL-T4287 to the IW current inputs on the SEL-T400L (the IX inputs on the SEL-T400L can be used in place of the IW inputs by using similar wiring with the respective terminals).

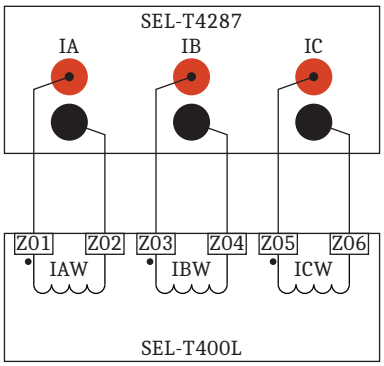


Figure 4 Wiring Diagram Used to Connect the Traveling-Wave Outputs on the SEL-T4287 to the IW Current Inputs on the SEL-T400L to Apply Current TW Signals

For tests that require voltage TW signals be applied to the device under test, connect the banana plugs of the provided voltage module directly to the banana jacks on the traveling-wave outputs, and use test leads to connect the banana jacks of the voltage module to the voltage inputs on the device under test. For example, to apply voltage TWs to the SEL-T400L, use the wiring diagrams in *Figure 12* and *Figure 13* to wire the voltage module (connected directly to the SEL-T4287 traveling-wave outputs) to the voltage inputs on the SEL-T400L.

Maintenance

⚠WARNING
Use of this equipment in a manner other than specified in this manual can impair operator safety safeguards provided by this equipment.

Follow these maintenance instructions for years of reliable, trouble-free service from the SEL-T4287.

Cleaning

Use care when cleaning the SEL-T4287. Use only a mild soap or detergent solution and a damp cloth to clean the chassis. Be careful cleaning the front and rear panels because a permanent plastic sheet covers each panel.

Do not use abrasive materials, polishing compounds, or harsh chemical solvents (such as xylene or acetone) on any surface.

Functional Description

Use the SEL-T4287 to verify the performance of single-ended and double-ended protection and fault-locating functions.

To produce traveling-wave test signals, the following test parameters and settings must be configured in the SEL-T4287 (see *Configuring the SEL-T4287 on page 14*):

- Line length (LL)
- Traveling-wave line propagation time (TWLPT)
- Number of terminals (NTERM)
- Fault type (FLTYPE)

- Fault location (FL)
- Trigger source (TRIG)

When triggered, TWs are produced on terminals **TW OUT1** and **TW OUT2**. To facilitate triggering external devices, the SEL-T4287 includes two 5 Vdc TTL outputs, **OUT 1** and **OUT 2**. When **TW OUT1** generates a TW, **OUT 1** is pulsed for 5 ms. Similarly, when **TW OUT2** generates a TW, **OUT 2** is pulsed for 5 ms. *Simulating Faults on page 8* explains the effects of NTERM and FLTYPE on the timing, magnitude, and polarity of the traveling waves produced by the SEL-T4287. See *Configuring the SEL-T4287 on page 14* for additional details on these and other configuration parameters.

Powering the Test Set

With the power switch in the off position, apply 110–240 Vac to the power supply by using the included power cable (or equivalent), and move the power switch to the on position. The **PWR** LED will illuminate and the front-panel HMI will display READY.

Front-Panel Indication and Controls

The LED display allows for six alphanumeric digits and features a menu system. Use the rotary dial and pushbuttons to navigate through the menu. To issue a lamp test, press and hold the rotary dial for four seconds; the LED display and all LEDs illuminate. Release the rotary dial to end the lamp test. The lamp test can only be performed while the front panel displays READY or a countdown timer.

Configure the SEL-T4287 by pressing **MENU** and navigating through each menu item with the rotary dial. To modify a test parameter or setting, press **ENT** or the rotary dial. For some entries, the cursor blinks to indicate what you can change; advance the cursor to the next field by pressing the rotary dial. Use the rotary dial to make modifications to a test parameter or setting. Once you have entered the desired value, press **ENT** to save the entry (the display blinks SAVED) or **MENU** to discard any changes and return to the previous menu. To exit the menu, press **MENU** until the display shows either READY or a countdown timer.

Figure 1 shows the front-panel **PWR** and **EN** LEDs. When power is applied to the test set and the power switch is in the on position, the **PWR** LED illuminates. The **PWR** LED remains illuminated while the SEL-T4287 is powered on and operating properly. The **EN** LED illuminates when the outputs (**TW OUT1**, **TW OUT2**, **OUT 1**, **OUT 2**) of the test set are enabled. The outputs are enabled when one of the following conditions is true and there are no internal diagnostic failures:

- TRIG is set to RUN PB, LOOP, TTL, or BIN and you are not accessing the front-panel menu. These triggering methods require manual initiation of the traveling-wave injections, which cannot be performed while the front-panel menu is active.
- TRIG is set to IRIG (SINGLE or LOOP). In this case, the test set is automatically armed and triggered at the appropriate time, as described in *IRIG (SINGLE or LOOP) Trigger on page 12*. When you enter the front-panel menu while TRIG is set to IRIG (SINGLE or LOOP), the test will not be interrupted, the test set outputs will remain enabled, and the **EN** LED will remain asserted.

If the **EN** LED is not illuminated and an internal diagnostic failure is suspected, establish communication to the front-panel USB port (see *Appendix C: Communications Setup on page 28*) and use the serial port **STATUS** command to check

the error status. If the response to the **STATUS** command indicates `ERR01`, the firmware and hardware are not compatible (see *Troubleshooting on page 26*). If the response indicates `ERR02`, the HMI board is missing or disconnected.

When TRIG is set to RUN PB, TTL, or BIN, the three trigger LEDs indicate which source is set to trigger an injection. The corresponding LED illuminates green when armed, and blinks red for 1 second when triggered. Otherwise, these LEDs are off.

Simulating Faults

Number of Terminals (NTERM)

Faults in power transmission lines cause transients that travel close to the speed of light and propagate along the line as TWs. TW functions are categorized into two methods: single-ended (use information from one terminal) and double-ended (require information from two terminals). Configure NTERM to ONE for testing single-ended applications or NTERM to TWO for testing double-ended applications. The NTERM test parameter affects the time of traveling-wave signals available via the **TW OUT1** and **TW OUT2** terminals. The magnitudes and polarities of the traveling-wave signals are determined by the FLTYPE setting (see *Fault Type (FLTYPE) on page 11*). All simulated faults applied by the SEL-T4287 represent bolted single-line-to-ground faults.

Single-Ended Applications

These include single-ended TWFL and, with proper modification, the TW32 element, as explained in *Applications on page 16*.

Internal Faults

To simulate an internal fault for testing single-ended applications, set NTERM = ONE and choose an internal fault type (see *Fault Type (FLTYPE) on page 11*).

Figure 5 shows a Bewley diagram for a fault at location F on a line of length LL. The fault is FL (mi or km) away from the local terminal (S) and LL – FL (mi or km) away from the remote terminal (R).

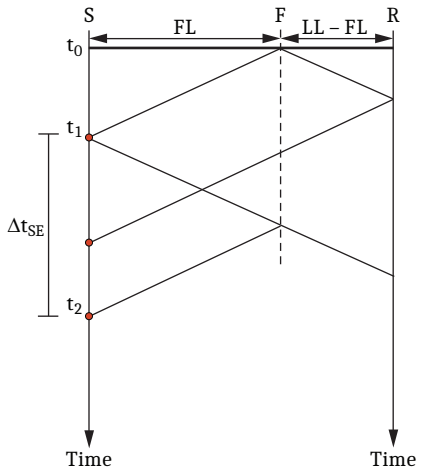


Figure 5 Bewley Diagram Explaining Single-Ended TWFL

A current traveling wave is launched from the fault point (F) at t_0 and arrives at the local terminal (S) at t_1, where t_1 is determined by *Equation 1*. Part of the wave reflects, travels back toward the fault, reflects back from the fault, and then returns to the local terminal (S) at t_2, which is calculated by *Equation 2*.

$$t_1 = \frac{FL}{LL} \bullet TWLPT + t_0$$

Equation 1

$$t_2 = 3 \bullet \frac{FL}{LL} \bullet TWLPT + t_0$$

Equation 2

where:

t_1, t_2, and TWLPT are in microseconds
FL and LL are in miles or kilometers

The single-ended traveling-wave-based fault-locating method uses the difference in arrival times, Δt_{SE}, to solve for the location of the fault in relation to the local relay, as given by *Equation 3* and *Equation 4*.

$$\Delta t_{SE} = (t_2 - t_1)$$

Equation 3

$$FL = \frac{LL}{2}\left(\frac{\Delta t_{SE}}{TWLPT}\right)$$

Equation 4

When NTERM is set to ONE and an internal fault is simulated at t_0, **TW OUT1** generates a traveling wave t_1 microseconds after the trigger, and **TW OUT2** generates a traveling wave t_2 microseconds after the trigger. The resulting time difference in microseconds between the **TW OUT1** and **TW OUT2** signals is Δt_{SE}. *Table 1* summarizes the timing relationship among the test trigger (t_0), **TW OUT1** injection (t_1), and **TW OUT2** injection (t_2) when NTERM is set to ONE and an internal FLTYPE (INT AG, INT BG, INT CG) is selected.

Table 1 Timing Relationship of TW OUT1 and TW OUT2 Injections When NTERM = ONE and FLTYPE Is Internal

Condition	Time
Trigger	t_0
TW OUT1 injection	t_1 (See *Equation 1*)
TW OUT2 injection	t_2 (See *Equation 2*)

External Faults

When an external fault behind one of the terminals launches a traveling wave, the relay at that end sees an initial wave and then sees the reflection from the remote end 2 • TWLPT microseconds later. When NTERM is set to ONE and an external FLTYPE (EXT AG, EXT BG, EXT CG) is selected, the timing relationship between **TW OUT1** and **TW OUT2** is as shown in *Table 2*. This replicates a traveling wave that initiates behind the local relay, travels across the transmission line to the remote end, and is reflected back to the local terminal.

Table 2 Timing Relationship of TW OUT1 and TW OUT2 Injections When NTERM = ONE and FLTYPE Is External

Condition	Time
Trigger	t_0
TW OUT1 injection	t_0
TW OUT2 injection	$t_0 + 2 \bullet \text{TWLPT}$

Double-Ended Applications

These include the TW87 protection scheme and double-ended TWFL. Refer to *Applications on page 16* for examples of each test configuration.

Internal Faults

To simulate an internal fault for testing double-ended applications, set NTERM = TWO and choose an internal fault type (see *Fault Type (FLTYPE) on page 11*).

Figure 6 shows a Bewley diagram for an internal fault at location F on a line of length LL. The fault is FL (mi or km) away from the local terminal (S) and $LL - FL$ (mi or km) away from the remote terminal (R).

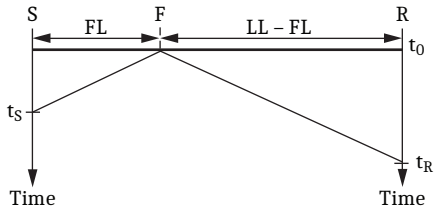


Figure 6 Bewley Diagram Explaining Double-Ended TWFL and TW87 Scheme

A current traveling wave is launched from the fault point (F) at t_0 and arrives at the local terminal (S) at t_S, where t_S is in microseconds and is determined by *Equation 5*.

$$t_S = \frac{FL}{LL} \bullet \text{TWLPT} + t_0$$

Equation 5

The first traveling wave to arrive at the remote relay arrives at time t_R after the fault inception. *Equation 6* defines t_R in microseconds.

$$t_R = \left(1 - \frac{FL}{LL}\right)\text{TWLPT} + t_0$$

Equation 6

The double-ended traveling-wave-based fault-locating method uses the difference in arrival times, Δt_{DE}, to solve for the location of the fault in relation to the local relay, as given by *Equation 7* and *Equation 8*.

$$\Delta t_{DE} = t_S - t_R$$

Equation 7

$$FL = \frac{LL}{2}\left(1 + \frac{\Delta t_{DE}}{\text{TWLPT}}\right)$$

Equation 8

When NTERM is set to TWO and an internal fault is simulated at t_0, **TW OUT1** generates a traveling wave for the local relay t_S microseconds after the trigger, and **TW OUT2** generates a traveling wave for the remote relay t_R microseconds after the trigger. The resulting time difference in microseconds between traveling waves is Δt_{DE}. *Table 3* summarizes the timing relationship among the test trigger (t_0), **TW OUT1** injection (t_S), and **TW OUT2** injection (t_R) when NTERM is set to TWO and an internal FLTYPE (INT AG, INT BG, INT CG) is selected.

Table 3 Timing Relationship of TW OUT1 and TW OUT2 Injections When NTERM = TWO and FLTYPE Is Internal

Condition	Time
Trigger	t_0
TW OUT1 injection	t_S (See *Equation 5*)
TW OUT2 injection	t_R (See *Equation 6*)

External Faults

When an external fault behind one of the terminals launches a traveling wave, the relay at that end sees an initial wave with either positive or negative polarity and the relay at the other end sees the same initial wave TWLPT microseconds later with opposite polarity. When NTERM is set to TWO and an external FLTYPE (EXT AG, EXT BG, EXT CG) is selected, the timing relationship between **TW OUT1** and **TW OUT2** is as shown in *Table 4*. This replicates a traveling wave that initiates behind the local relay and travels across the transmission line to the remote end.

Table 4 Timing Relationship of TW OUT1 and TW OUT2 Injections When NTERM = TWO and FLTYPE Is External

Condition	Time
Trigger	t_0
TW OUT1 injection	t_0
TW OUT2 injection	t_0 + TWLPT

Fault Type (FLTYPE)

NOTE: When an external FLTYPE is selected, only TWLPT affects the timing between the traveling waves produced by **TW OUT1** and **TW OUT2**. See *Table 2* and *Table 4*.

The SEL-T4287 supports simulation of internal and external single-line-to-ground faults. The FLTYPE selection inherently controls the magnitude and polarity of each **TW OUT1** and **TW OUT2** output. Selecting an internal versus an external FLTYPE also affects the timing of the outputs, as described in *Number of Terminals (NTERM) on page 8*. *Table 5* indicates the polarity and per-unit magnitude of each output for all available FLTYPE settings, which include internal or external phase-to-ground fault options. The magnitudes and polarities of *Table 5* mimic the current TW patterns that occur on a transmission line following the indicated phase-to-ground fault. The magnitudes are normalized to 5 A.

Table 5 Polarity and Per-Unit Magnitude of TW OUT1 and TW OUT2 Based on FLTYPE (Sheet 1 of 2)

FLTYPE	TW OUT1			TW OUT2		
	A	B	C	A	B	C
INT AG	1	–0.5	–0.5	1	–0.5	–0.5
INT BG	–0.5	1	–0.5	–0.5	1	–0.5
INT CG	–0.5	–0.5	1	–0.5	–0.5	1
EXT AG	–1	0.5	0.5	1	–0.5	–0.5

Table 5 Polarity and Per-Unit Magnitude of TW OUT1 and TW OUT2 Based on FLTYPE (Sheet 2 of 2)

FLTYPE	TW OUT1			TW OUT2		
	A	B	C	A	B	C
EXT BG	0.5	–1	0.5	–0.5	1	–0.5
EXT CG	0.5	0.5	–1	–0.5	–0.5	1

Triggering Tests

Arming

The SEL-T4287 must be armed prior to a traveling-wave injection. Arming the unit primes the internal circuitry for accurate signal injections. Once armed, an injection can be triggered through one of the trigger methods (see *RUN Pushbutton Trigger on page 12* through *Binary (48 V) Trigger on page 14*). Arming must be done manually unless TRIG is set to IRIG (SINGLE or LOOP) or LOOP. To manually arm the SEL-T4287 after all test parameters and settings have been configured, perform the following steps:

Step 1. If the display does not show READY, press **MENU** until the display shows READY.

Step 2. Press the **ARM/RUN** pushbutton. The display then shows ARM'D and the LED corresponding to the selected trigger illuminates green.

The SEL-T4287 stays armed for 30 seconds. If no trigger occurs within this period or the **MENU** pushbutton is pressed, the unit disarms and all trigger sources are ignored until the SEL-T4287 is rearmed.

RUN Pushbutton Trigger

To set up the **ARM/RUN** pushbutton as the injection trigger, navigate through the front-panel menu to the TRIG setting and select RUN PB. After arming the unit, press **ARM/RUN** again to trigger an injection. The **RUN** LED then illuminates red for 1 second, during which TRIG'D appears on the display. After 1 second, the LED turns off and the display shows READY.

IRIG (SINGLE or LOOP) Trigger

To perform time-synchronized testing, navigate through the front-panel menu to the TRIG setting and select IRIG. To initiate a single test at the top of the second for a specific time, select SINGLE; to initiate consecutive tests periodically at the top of every 5 minutes, select LOOP. Then select the time in 24-hour format to initiate the next test. Once the time is saved, a countdown begins. You can view the countdown timer at any time by navigating out of the menu (press **MENU** until the display shows the countdown). During the last 10 seconds, the test set automatically exits the menu and displays the countdown timer. At this point, access to the menu is prohibited and no changes can be made. The SEL-T4287 automatically arms itself 5 seconds prior to the specified initiation time and triggers a test when the countdown reaches 0. If IRIG LOOP mode is selected, FLTYPE is set to an internal fault type, and LL ≥ 0.08, the FL starts at 0 and increments after every injection with a resolution of LL/8 until FL equals LL, and then it changes back to 0 and continues incrementing.

You can access the front-panel menu to view all test parameters and settings when IRIG LOOP mode is active, but you can only change FLTYPE and TRIG. Injections continue to occur every 5 minutes until you change the TRIG setting. If IRIG SINGLE mode is active, you can view or change all test parameters and

NOTE: The SEL-T4287 must be provided with a demodulated IRIG-B signal with IEEE C37.118 control function bits (e.g., IRIG-B000 or IRIG-B004) for IRIG-based triggering.

NOTE: IRIG-B004 is a time format that replaces and is backward compatible with IRIG-B000.

NOTE: If TRIG is set to IRIG LOOP, FLTYPE is set to an internal fault type, and LL<0.08, FL will increment by 0.01 for every injection. Upon reaching 100 percent of the LL, the FL rolls over to 0 and continues until you change the trigger mode.

settings, but changing the TRIG setting cancels the existing test. When TRIG is set to IRIG (SINGLE or LOOP), the **EN** LED remains illuminated when you enter the front-panel menu because arming and triggering are still performed automatically.

A high-accuracy IRIG-B signal must be applied to the **TIME IRIG-B** input on the rear of the SEL-T4287 to use IRIG (SINGLE or LOOP) mode for triggering time-synchronized tests. The IRIG-B signal must use the IEEE C37.118 control function extensions, including the Time Quality field (e.g., IRIG-B000). The IRIG-B signal may also contain the Continuous Time Quality field (e.g., IRIG-B004). These fields are defined in IEEE C37.118.1-2011 Annex D.2, and they are used by the SEL-T4287 to verify the accuracy of the connected time source.

To trigger time-synchronized tests in IRIG (SINGLE or LOOP) mode when the continuous time quality estimate is provided, the Continuous Time Quality (CTQ) bits must indicate that the estimated maximum time error is less than 1 µs. If the continuous time quality estimate is not provided, the Time Quality (TQ) bits must indicate that the source clock has accuracy to within 1 µs of a UTC traceable source. The response from the **STATUS** command displays the time quality and continuous time quality information decoded by the SEL-T4287. *Table 6* shows the related LED display messages and corresponding cause.

Table 6 LED Display Messages

Display	Cause
NOIRIG	An IEEE C37.118-compliant IRIG-B signal is not detected.
BADCTQ[a]	The CTQ bits, if available, indicate that the estimated maximum time error is greater than or equal to 1 µs.
BADTQ[a]	The TQ bits, if available, indicate that the source clock does not have accuracy to within 1 µs of a UTC traceable source.

[a] Message alternates with NOIRIG.

NOTE: Time-based triggering with IRIG (LOOP or SINGLE) mode is only allowed when the selected trigger time is 10 seconds or more in advance. If the selected trigger time is less than 10 seconds in advance, the front panel will display ERR03.

The IRIG (SINGLE or LOOP) trigger has an internal delay of ±20 ns. For example, if you configure the SEL-T4287 with TRIG = IRIG (SINGLE or LOOP) and FL = 0, then a traveling wave will be injected on the **TW OUT1** terminals at the top of the second ±20 ns for the selected trigger time.

LOOP Trigger

The availability of this trigger mode is independent of an IRIG-B signal. To select the LOOP trigger mode, navigate through the front-panel menu to the TRIG setting and select LOOP. In this mode, tests are automatically triggered every five minutes after the countdown timer is manually started. You can start the countdown by navigating out of the menu (press **MENU** until the display shows the timer) and pressing the **ARM/RUN** pushbutton. The SEL-T4287 automatically arms 5 seconds prior to the injection time and triggers a test when the countdown reaches 0. If FLTYPE is set to an internal fault and LL ≥ 0.08, the FL starts at 0 and increments after every injection with a resolution of LL/8 until FL equals LL, and then it changes back to 0 and continues incrementing. You can view all settings, but you can only change the FLTYPE and TRIG settings. Entering the menu pauses the countdown timer. To resume, navigate out of the menu and press the **ARM/RUN** pushbutton. Injections continue to occur until you change the TRIG setting. This trigger mode is not recommended for end-to-end testing.

NOTE: If TRIG is set to LOOP, FLTYPE is set to an internal fault type, and LL < 0.08, FL will increment by 0.01 for every injection. Upon reaching 100 percent of the LL, the FL rolls over to 0 and continues until you change the trigger mode.

TTL (5 V) Trigger

To select the TTL 5 V input as the injection trigger, navigate through the front-panel menu to the TRIG setting and select TTL. After arming the unit, a rising edge detected on the **IN** BNC connector on the rear panel of the SEL-T4287 triggers an injection. The TTL LED then illuminates red for 1 second, during which TRIG'D appears on the display. After 1 second, the LED turns off and the display shows READY.

NOTE: The TTL 5 V pulse on the **IN** BNC connector must be longer than 4 ms to trigger a test.

The TTL 5 V trigger has an internal delay of 3.98 ms ±0.5 µs. For example, if you configure the SEL-T4287 with TRIG = TTL and FL = 0, arm the test set, and apply a TTL 5 V pulse to the **IN** BNC connector, then a traveling wave will be injected on the **TW OUT1** terminals 3.98 ms ±0.5 µs after the rising edge of the applied TTL 5 V pulse.

Binary (48 V) Trigger

To select the binary 48 V input as the injection trigger, navigate through the front-panel menu to the TRIG setting and select BIN. After arming the unit, a rising edge detected on the **BIN TRIG** input triggers an injection. The **BIN** LED then illuminates red for 1 second, during which TRIG'D appears on the display. After 1 second, the LED turns off and the display shows READY.

NOTE: The binary 48 V pulse on the **BIN TRIG** input must be longer than 4 ms to trigger a test.

The Binary 48 V trigger has an internal delay of 3.98 ms ±0.2 ms. For example, if you configure the SEL-T4287 with TRIG = BIN and FL = 0, arm the test set, and apply a binary 48 V pulse to the **BIN TRIG** input, then a traveling wave will be injected on the **TW OUT1** terminals 3.98 ms ±0.5 ms after the rising edge of the applied binary 48 V pulse.

NOTE: The **BIN TRIG** input is bipolar. Trigger testing with this input by applying either +48 Vdc or −48 Vdc.

Configuring the SEL-T4287

Configure the SEL-T4287 by pressing **MENU** and navigating through each menu item with the rotary dial. To modify a test parameter or setting, press **ENT** or the rotary dial. For some entries, the cursor blinks to indicate what you can change; advance the cursor to the next field by pressing the rotary dial. Use the rotary dial to make modifications to a test parameter or setting. Once you have entered the desired value, press **ENT** to save the entry (the display blinks SAVED) or **MENU** to discard any changes and return to the previous menu. To exit the menu, press **MENU** until the display shows either READY or a countdown timer.

NOTE: The units of the FL and LL test parameters should be consistent with the units of the line length setting in the device under test.

Line Length (LL)

Set the length of the protected transmission line between 0.01 and 500.00. The default value for LL is 100.00. LL must match the LL setting in the device under test.

Traveling-Wave Line Propagation Time (TWLPT)

Enter the amount of time, in microseconds, that it takes a traveling wave to traverse the entire length of the line. The acceptable range is 10.00 to 1700.00 µs. The default value for TWLPT is 537.00. TWLPT must match the TWLPT setting in the device under test.

When testing protective relays and fault-locating devices that use TWLPT, such as the SEL-T400L, apply the same TWLPT value to the SEL-T4287 that is used in the device under test. When testing relays and fault-locating devices that use the line propagation velocity (LPVEL) instead of TWLPT, such as the SEL-411L, calculate TWLPT in microseconds, according to *Equation 9*.

$$TWLPT = \frac{LL}{LPVEL \bullet C} \bullet 1E6$$

Equation 9

where:

LL = line length, as defined in *Line Length (LL) on page 14*

LPVEL = the propagation velocity in pu of the speed of light

C = 186282.397 mi/sec if the LL units are in miles (mi) or 299792.458 km/sec if the LL units are in kilometers (km)

Number of Terminals (NTERM)

Set the number of terminals involved in the test setup. Set NTERM = ONE when testing single-ended TWFL or the TW32 element in a single device. Set NTERM = TWO for testing double-ended TWFL or the TW87 protection scheme with two relays. The default value for NTERM is ONE. See *Number of Terminals (NTERM) on page 8* for an explanation of how the NTERM setting affects the timing of traveling-wave injections.

Fault Type (FLTYPE)

Select the desired fault type to simulate during testing. Simulated fault types are phase-to-ground and can be either internal or external. Internal fault-type options are INT AG, INT BG, and INT CG. Similarly, external fault-type options are EXT AG, EXT BG, and EXT CG. The FLTYPE determines the magnitude and polarity of each output phase (see *Fault Type (FLTYPE) on page 11*). The default value for FLTYPE is INT AG. The selection of either an internal or external FLTYPE also impacts the timing of the traveling-wave outputs (see *Simulating Faults on page 8*). See *Table 5* for the magnitude and polarity of each phase based on the fault type.

Fault Location (FL)

Set the location for the simulated fault as a number between 0.00 and the LL value in increments of 0.01. If an external fault type was chosen for FLTYPE, the FL parameter is not applicable and `N/A` is displayed. The default value for FL is 50.00.

Trigger Source (TRIG)

Choose the trigger source from either RUN PB, IRIG, LOOP, TTL, or BIN. If IRIG is selected, choose between SINGLE mode and LOOP mode. See *Triggering Tests on page 12* for more details on each method of triggering tests. The default value for TRIG is RUN PB.

The SEL-T4287 only enables the trigger source selected by the TRIG setting. For example, if TRIG is set to RUN PB, the assertion of the **BIN TRIG** input will be ignored.

Table 7 Test Parameters and Settings for Configuring the SEL-T4287

Name	Range	Increment	Default Value
LL	0.01–500.00 (km or mi)	0.01	100.00
TWLPT	10.00–1700.00 ms	0.01 ms	537.00
NTERM	ONE, TWO	N/A	ONE
FLTYPE	INT AG, INT BG, INT CG, EXT AG, EXT BG, EXT CG	N/A	INT AG
FL	0.00–LL (km or mi)	0.01	50.00
TRIG	RUN PB, IRIG, LOOP, TTL, BIN	N/A	RUN PB

Applications

⚠DANGER
Do not connect the SEL-T4287 traveling-wave outputs or digital inputs/outputs to live power system circuits. This can cause electrical shock that can result in injury or death.

⚠WARNING
Do not connect the SEL-T4287 in parallel with a traditional test set during testing. Use the SEL-T4287 as a standalone test set only.

⚠WARNING
Use standard insulated banana plug test leads when connecting the SEL-T4287 traveling-wave outputs to the terminals of the device(s) under test. Be sure that these leads have the same length and the same wire gauge to preserve adequate accuracy of the TW test signals.

Use the SEL-T4287 as a standalone test set for testing applications based on traveling-wave principles, such as the TW87 scheme, TW32 element, and single- and double-ended TWFL found in the SEL-T400L Time-Domain Line Protection. You can also find double-ended TWFL in the SEL-411L Advanced Line Differential Protection, Automation, and Control System. The SEL-T4287 can also be used to test other manufacturers' traveling-wave fault locators.

You can perform end-to-end testing with two SEL-T4287 test sets that are time-synchronized with an IRIG-B signal. This section provides an overview of how to apply the SEL-T4287 for testing these features. For additional testing details, refer to the appropriate instruction manual for the device being tested.

Testing Double-Ended TW-Based Fault Locators

When a fault occurs, it launches traveling waves in both directions. If the fault is on the protected line (internal fault), the waves arrive at each end with the same polarity because of the orientation of CTs at each location. *Figure 6* illustrates the arrival of the waves at the local and remote terminals. The arrival time of the initial waves depends on the FL, LL, and TWLPT test parameters, as shown in *Equation 5* and *Equation 6*. If the fault is on an adjacent line (external fault), the traveling waves arrive at each end with opposite polarity. In the external fault case, the arrival times differ by TWLPT microseconds.

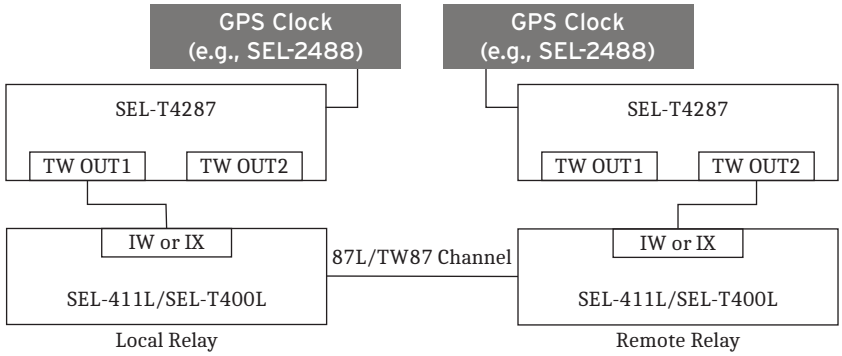
End-to-End Field Testing

NOTE: When performing end-to-end testing with two SEL-T4287 devices, use the latest version of the hardware (serial number greater than 1180170000) and firmware to achieve the Injection Timing Accuracy in Traveling-Wave Outputs and Test Trigger Delay in Time Input stated in *Specifications on page 21*.

Use two SEL-T4287 Test Systems in conjunction with GPS satellite clocks, such as the SEL-2488 Satellite-Synchronized Network Clock, to perform end-to-end testing of double-ended TW-based fault locators, as shown in *Figure 7*. The connected clock must report time quality via the TQ bits embedded in the IRIG-B signal, in compliance with IEEE C37.118. When performing this test, wire **TW OUT1** of the local test set and **TW OUT2** of the remote test set to the current terminals of the corresponding relay. Set NTERM = TWO, TRIG = IRIG (SINGLE or LOOP), and use the same LL, TWLPT, FLTYPE, and FL test parameters in both

NOTE: The SEL-T4287 does not adjust for local time with a UTC offset. It uses the time provided to it by the satellite clock, whether it is in local time or UTC. Either is acceptable, but consistency must be used at the local and remote terminals when performing end-to-end testing in order to trigger the tests simultaneously.

test sets. It is important to note that FL in the local and remote test sets should be set the same during this end-to-end test. This configuration enables proper timing of the traveling waves at each end for both internal and external fault types. For example, if you configure LL = 100 and FL = 30 in both test sets and simulate an internal fault, the local and remote relays determine a fault location of 30 (km or mi) and 70 (km or mi), respectively. You can use this same setup for end-to-end testing of the TW87 scheme that is available in the SEL-T400L.

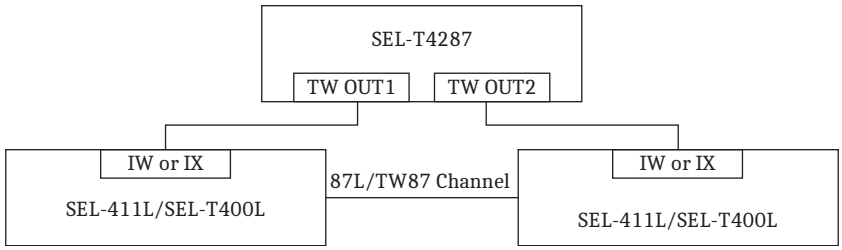


The SEL-411L Relays require an IRIG-B signal for this configuration.

Figure 7 System Configuration for End-to-End Testing of the TW87 Scheme (SEL-T400L) and the Double-Ended TW-Based Fault Locator (SEL-T400L or SEL-411L)

Laboratory Bench-Testing

Test this application in a laboratory environment by connecting a single SEL-T4287 to two relays capable of double-ended TW-based fault locating, as shown in *Figure 8*. In this configuration, set NTERM = TWO, connect **TW OUT1** to the current terminals of one relay, and wire **TW OUT2** to the current terminals of the other relay. You can use this same setup for laboratory testing of the TW87 scheme that is available in the SEL-T400L.



The SEL-411L Relays require an IRIG-B signal for this configuration.

Figure 8 System Configuration for Bench-Testing the TW87 Scheme (SEL-T400L) and the Double-Ended TW-Based Fault Locator (SEL-T400L or SEL-411L)

Testing TW87 Schemes

TW87 schemes, as found in the SEL-T400L, provide ultra-high-speed and sensitive line protection. The TW87 scheme in the SEL-T400L works with a point-to-point fiber-optic channel between a local relay and a remote relay and does not depend on external time sources for time alignment. *Figure 8* illustrates how to connect the SEL-T4287 to two relays that are capable of performing TW87 protection, such as the SEL-T400L. You can also use the setup shown in *Figure 7* to perform end-to-end testing of the TW87 scheme. Set NTERM = TWO for this test.

Testing Single-Ended TW-Based Fault Locators

NOTE: When testing the single-ended TW-based fault-locating method in the SEL-T400L, ensure that $\Delta t_{SE} > 20$ µs, where Δt_{SE} is calculated in *Equation 3*. Failure to do so may produce incorrect test results.

The single-ended TW-based fault locator in the SEL-T400L captures data from the initial traveling wave and subsequent reflections to calculate the fault location without requiring any information from the relay at the remote terminal. Test the single-ended TW-based fault-locating method by using the setup shown in *Figure 9*. An SEL-T4287 is connected to an SEL-T400L such that **TW OUT1** and **TW OUT2** are connected to the IW and IX current inputs, respectively. For this application, set NTERM = ONE in the SEL-T4287, and set LINEI = COMB and CTRX = CTRW in the SEL-T400L.

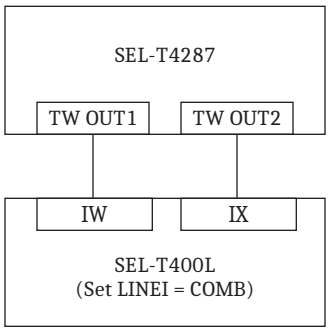


Figure 9 System Configuration for Testing the Single-Ended TW-Based Fault Locator (SEL-T400L)

Testing the TW32 Element

When a fault occurs on a transmission line, both voltage and current traveling waves are produced and they arrive simultaneously at each terminal of the line. The SEL-T400L can make an extremely fast directional decision based on the polarity relationship between the first voltage and current traveling waves. For a fault on the transmission line in the forward direction, the voltage and current traveling waves observed by the relay have opposite polarity. For a fault on the transmission line in the reverse direction, the voltage and current traveling waves observed by the relay have the same polarity.

NOTE: When using one SEL-T4287 with the voltage module to test the TW32 element for a forward or reverse fault condition, configure the test set for NTERM = ONE, FL = 0, and an internal FLTYPE.

Connect the voltage module directly to the TW outputs of the SEL-T4287 to obtain voltage TWs. When attached to the SEL-T4287, the voltage module connects internal resistors (noninductive, 1 ohm, 0.25 watts, and 1 percent tolerance) in parallel with the TW outputs. This results in voltage TWs applied to the device under test when a test is triggered. *Figure 10* is an illustration of the front side of the voltage module that shows the location of external connection points for test leads (solid red and black terminals) and a wiring diagram of internal resistors (dotted lines).

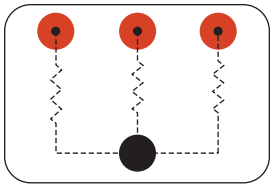


Figure 10 Voltage Module Internal Connections of Resistors and External Connection Points for Test Leads

Figure 11 shows the system configuration for using one SEL-T4287 and a voltage module to test the TW32 element. This test requires that **TW OUT1** and **TW OUT2** send traveling waves to the relay at the same time. Therefore, set NTERM = ONE, FL = 0, and choose an internal FLTYPE when performing this test to ensure the

current TWs and the voltage TWs are generated at exactly the same time. With this configuration, the evaluation of *Equation 1* and *Equation 2* shows that **TW OUT1** and **TW OUT2** will each inject a TW signal at exactly the same time, with no delay, when the test is triggered.

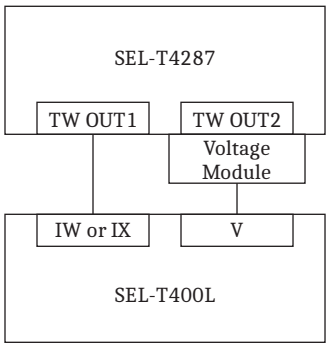


Figure 11 Testing Configuration for TW32 Applications

With this setup, triggering a test with standard wiring (standard polarity) simulates a reverse fault because the traveling waves produced by **TW OUT1** and **TW OUT2** have the same polarity. To simulate a forward fault, reverse the polarity of cables on one of the TW outputs. *Figure 12* and *Figure 13* show the voltage module and relay connections for generating voltage TWs for simulating forward and reverse faults, respectively.

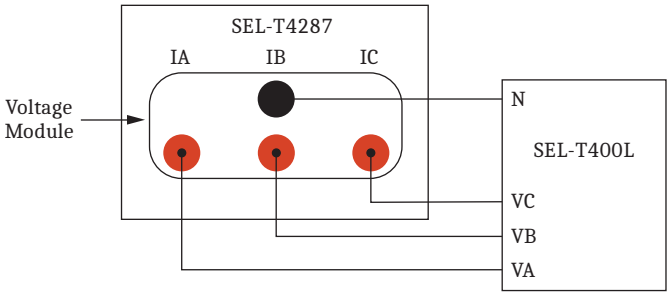


Figure 12 Voltage Module and Relay Connections for Generating Voltage TWs for Forward Faults

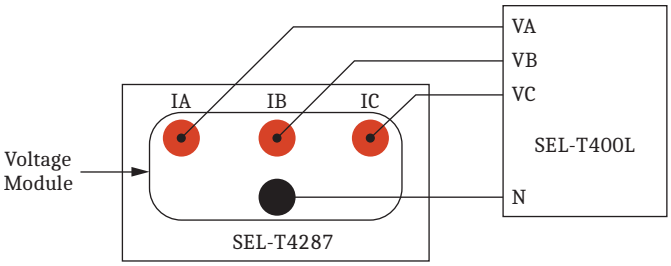


Figure 13 Voltage Module and Relay Connections for Generating Voltage TWs for Reverse Faults

Mechanical Diagram

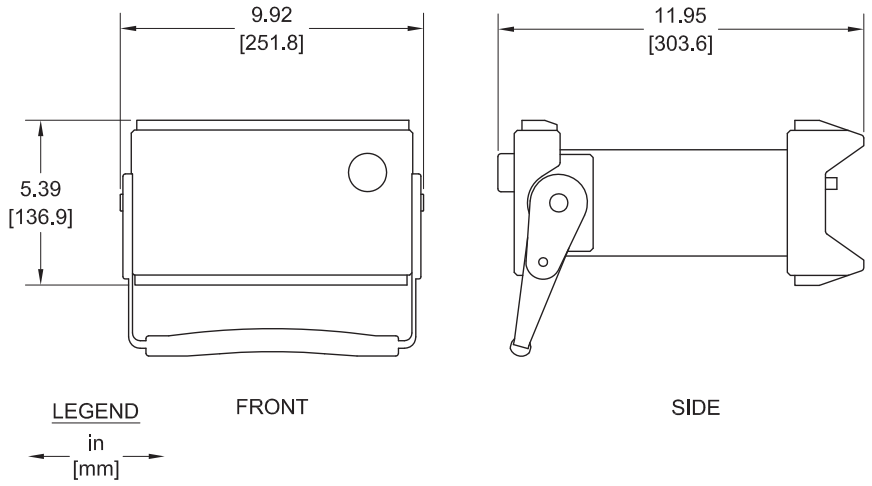


Figure 14 SEL-T4287 Dimensions

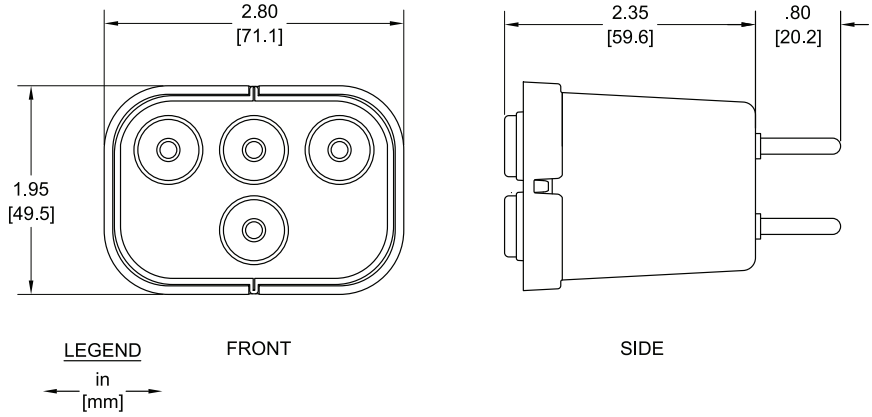


Figure 15 Voltage Module Dimensions

Specifications

Compliance

Designed and manufactured under an ISO 9001 certified quality management system

47 CFR 15B, Class A

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 E218267; PICQ, PICQ7)

CE Mark

RCM

Power Supply

Rated Voltage:	110–240 Vac
Operational Voltage Range:	85–264 Vac
Rated Frequency:	50/60 Hz
Operational Frequency Range:	30–120 Hz
Burden:	<50 VA

Digital Inputs

IN BNC

Rated Voltage:	5 Vdc
Operational Voltage Range:	0–6 Vdc
Logic Low Threshold:	≤ 0.8 Vdc
Logic High Threshold:	≥ 2.8 Vdc
Minimum Pulse Width:	4 ms
Input Impedance:	2.5 kΩ
Test Triggering Delay:	3.98 ms ±0.5 µs

BIN TRIG

Rated Voltage:	48 Vdc
Operational Voltage Range:	0–60 Vdc
Assertion Voltage Range:	38.4–60 Vdc
Deassertion Voltage Range:	0–28.8 Vdc
Minimum Pulse Width:	4 ms
Input Impedance:	> 13 kΩ
Test Triggering Delay:	3.98 ms ±0.2 ms

Digital Outputs (TTL)

Rated Voltage:	5 Vdc
Output Impedance:	50 Ω ±5%
Pulse Width:	5 ms ±10 ns

Traveling-Wave Outputs

Rated Current:	5 A peak
Rated Voltage:	11 V peak
Absolute Operating Current:	10 A peak
Absolute Operating Voltage:	20 V peak
Rated Current Rise Time:	<1 µs with output connection shorted through 4-inch loop
Halfway Decay Time:	389 µs ±20% with output connection shorted through 4-inch loop[a] 631 µs ±20% with only the voltage module attached[a]
Injection Timing Accuracy:	<16 ns[a]

Time Input

Input:	Demodulated IRIG-B
Rated Voltage:	5 Vdc
Operational Voltage Range:	0–6 Vdc
Logic Low Threshold:	≤0.8 Vdc
Logic High Threshold:	≥2.2 Vdc
Input Impedance:	2.5 kΩ
Test Triggering Delay:	±20 ns[a]

Protocols

ASCII:	Plain-language commands for human and simple machine communication. Use for firmware upgrades.
Xmodem:	Support for upgrading firmware files

General

Operating Temperature

0°–70°C (32°–158°F)

Storage Temperature

0°–70°C (32°–158°F)

Humidity

5% to 95% without condensation

Altitude

2000 m maximum

Overvoltage Category

II

Measurement Category

O

Pollution Degree

2

Electromagnetic Environment

Industrial

Unit Weight (Maximum)

9.07 kg (20 lb)

Product Standards

Safety, Electrical Equipment for Measurement, Control, and Laboratory Use:	IEC 61010-1:2010 UL 61010-1 CAN/CSA-C22.2 No. 61010-1, 3rd Edition
EMC, Electrical Equipment for Measurement, Control, and Laboratory Use:	IEC 61326-1:2013 IEC 61000-3-2/3 FCC 47 CFR Part 15.107 & 15.109, Subpart B

[a] Applies only to units with serial numbers greater than 1180170000.

Appendix A: Firmware and Manual Versions

Firmware

Determining the Firmware Version

To determine the firmware version, view the status information by using the serial port **STATUS** command. The status information includes the Firmware Identification (FID) number.

The firmware version number is after the R, and the release date is after the D. For example, the following is firmware version number R100, release date March 14, 2017.

FID=SEL-T4287-R100-V0-Z001001-D20170314

Revision History

Table 8 lists the firmware versions, revision descriptions, and corresponding instruction manual date codes. The most recent firmware version is listed first.

Table 8 Firmware Revision History

Firmware Identification (FID) Number	Summary of Revisions	Manual Date Code
SEL-T4287-R101-V0-Z001001-D20180131 **NOTE:** Units with serial number greater than 1180170000 are only compatible with firmware version R101-V0 and higher.	➤ Improved the accuracy of the internal clock and the signal characteristics of the three-phase current outputs. This applies only to units with serial number greater than 1180170000. ➤ Resolved an issue with the time-based triggering modes (IRIG LOOP and IRIG SINGLE) where test initiation was incorrectly delayed. ➤ Modified the time-based triggering modes (IRIG LOOP and IRIG SINGLE) to only be allowed when the selected trigger time is 10 seconds or more in advance. ➤ Modified the external time source accuracy logic by using the Continuous Time Quality (CTQ) bits if available and changing the accuracy requirement for the Time Quality (TQ) bits in the C37.118 IRIG-B message to 1 microsecond. ➤ Added front-panel error messages BADTQ and BADCTQ when the accuracy of the external clock fails the TQ or CTQ requirements, respectively. ➤ Changed the pulse width duration of OUT1 and OUT2 to ensure other test sets can be triggered from these outputs. ➤ Modified the **EN** LED to remain illuminated when the front-panel menu is accessed while TRIG is set to IRIG LOOP or IRIG SINGLE. ➤ Replaced the **VERSION** command with the **STATUS** command, and added information about the test set status in the command response.	20180131
SEL-T4287-R100-V0-Z001001-D20170314	➤ Initial version.	20170314

Instruction Manual

The date code at the bottom of each page of this manual reflects the creation or revision date.

Table 9 lists the instruction manual versions and revision descriptions. The most recent instruction manual version is listed first.

Table 9 Instruction Manual Revision

Date Code	Summary of Revisions
20181206	➤ Updated *Product Overview.* ➤ Updated *Input and Output Connections* in *Connections*. ➤ Updated *Number of Terminals (NTERM)* in *Functional Description*. ➤ Updated *Testing the TW32 Element* in *Applications*. ➤ Added *Figure 15: Voltage Module Dimensions*. ➤ Updated *Halfway Decay Time* in *Specifications*. ➤ Added *Figure 16: Tera Term (Version 4.84) Window Where the Firmware File to Send Is Chosen and the Checksum Xmodem Protocol Is Selected*. ➤ Added *Appendix D: SEL ASCII Commands* and *SEL-T4287 Test Set Command Summary.*
20180131	➤ Reorganized information. ➤ Updated all sections of this manual.
20170314	➤ Initial version.

Appendix B: Firmware Upgrade Instructions

Overview

These instructions guide you through the process of upgrading the SEL-T4287 firmware. These instructions assume you have a working knowledge of your PC terminal emulation software. In particular, you must be able to modify the serial communications parameters (data speed, data bits, parity, and similar parameters), disable any hardware or software flow control in the computer terminal emulation software, select a transfer protocol (1K Xmodem or Checksum Xmodem, for example), and transfer files (send and receive binary files).

Perform firmware upgrades through the front-panel USB Port F. To successfully upgrade firmware, it is recommended you become familiar with *Appendix C: Communications Setup on page 28*. You must perform the following procedures exactly as described to avoid putting the test set into an unusable state, which would require factory repair.

Required Equipment

You will need the following items before beginning the firmware upgrade process:

- Personal computer (PC)
- Terminal emulation software that supports Checksum Xmodem protocol, such as Tera Term (version 4.84).
- SEL-C664 cable or any standard A-to-B USB cable
- Firmware upgrade file (.rpd file name extension)
- SEL-T4287 firmware upgrade instructions

NOTE: Not all terminal emulation software and not all versions of Tera Term support Checksum Xmodem protocol.

Upgrade Procedure

Obtain Firmware File

The firmware file is usually provided on CD-ROM. Locate the firmware file on the disc and copy the firmware file to an easily accessible location on the PC.

Establish Communication With the SEL-T4287

See *Appendix C: Communications Setup on page 28* for instructions on preparing the test set for a firmware upgrade.

Start SELBOOT

Step 1. Type **L_D <Enter>**.

The test set responds in the terminal window with the following:

Disable test set to receive firmware (Y/N)?

Step 2. Type **Y <Enter>**.

The test set responds in the terminal window with the following:

Are you sure (Y/N)?

Step 3. Type **Y <Enter>**.

The test set responds in the terminal window with the following:

Test Set Disabled

Wait for the SELBOOT program to load.

The front-panel displays SELBT and the **EN** LED turns off. When finished loading the SELBOOT program, the test set responds in the terminal with the SELBOOT !> prompt.

Step 4. Press **<Enter>** to confirm that the test set is in SELBOOT; another SELBOOT !> prompt will display.

Upload New Test Set Firmware

Step 1. From the SELBOOT !> prompt, type **REC <Enter>**.

The test set responds in the terminal window with the following message:

Caution! – This command erases the device firmware. If you erase the firmware, new firmware must be loaded into the device before it can be put back into service. Are you sure you want to erase the existing firmware? (Y/N)

Step 2. Type **Y <Enter>**.

The test set responds in the terminal window, **Erasing**, and erases the existing firmware. The front panel displays ERASE. When finished erasing, the test set responds in the terminal window, **Erase successful**, and prompts you to press any key to begin transferring the new firmware.

Step 3. Press **<Enter>** to begin uploading the new firmware. The front panel displays UPDATE.

Step 4. Start the send process in your terminal emulation program.

Step 5. Browse in the terminal program to the location of the new firmware file. Use the Checksum Xmodem protocol, as shown in *Figure 16*, for fast transfer of the new firmware to the test set.

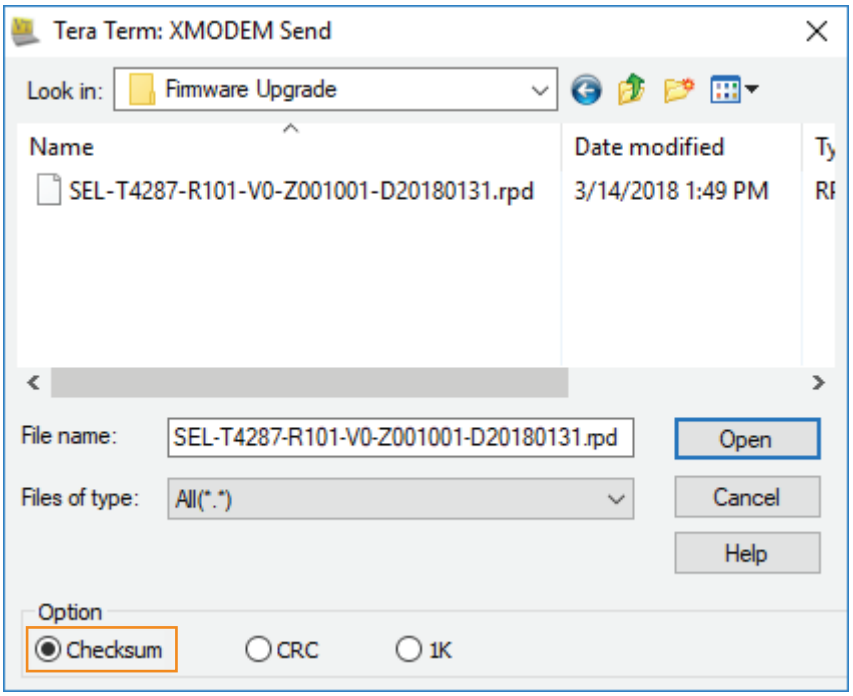


Figure 16 Tera Term (Version 4.84) Window Where the Firmware File to Send Is Chosen and the Checksum Xmodem Protocol Is Selected

Step 6. Begin the file transfer.

The typical transfer time at 57600 bps with Checksum Xmodem protocol is about 2 minutes. The front panel displays LOAD while the test set loads the new firmware.

Step 7. Wait for the firmware to load.

If the test set responds in the terminal window with a message indicating transfer failure, please refer to *Troubleshooting on page 26*.

When finished loading the new firmware, the test set responds in the terminal window, **Transfer completed successfully. Please power cycle the test set to finish loading new firmware.** The front panel displays PCYCLE, indicating that it is okay to power cycle the test set.

Power Cycle the Test Set

NOTE: After erasing firmware with the **REC** terminal command, do not power cycle the test set until new firmware has been successfully loaded.

Step 1. Move the power switch to the off position.

Wait until the **PWR** LED on the front panel turns off.

Step 2. Move the power switch to the on position.

If the test set does not power on correctly, contact your Technical Service Center or the SEL factory for assistance (see *Technical Support on page 27*).

Troubleshooting

Once the firmware has been erased, new firmware must be loaded successfully before removing power from the test set, otherwise you will need to return the test set to the factory for re-imaging.

If you did not select a file to upload within 100 seconds of beginning the Xmodem file transfer, begin again at *Step 1* of *Upload New Test Set Firmware on page 25*.

If the file transfer is not completed successfully, the terminal window displays **Transfer not completed. Please make sure your terminal is using Checksum XMODEM for firmware upgrades.** Ensure that Checksum Xmodem has been selected as the file transfer protocol and begin again at *Step 1* of *Upload New Test Set Firmware on page 25*.

If the file transfer is canceled in the middle of the transfer, the terminal window will display **Transfer canceled**. Begin again at *Step 1* of *Upload New Test Set Firmware on page 25*.

If the Xmodem file transfer fails, attempt the transfer again. If failures continue to occur, contact your Technical Service Center or the SEL factory for assistance (see *Technical Support*).

If the LED display or serial port **STATUS** command indicate ERR01 after the transfer is complete, the loaded firmware is not compatible with the existing hardware. Perform the transfer again using the latest firmware version compatible with the hardware. If the error continues to occur, contact your Technical Service Center or the SEL factory for assistance (see *Technical Support*).

If the unit powers on correctly, and the **PWR** LED illuminates, but the front-panel controls and display are unresponsive, contact your Technical Service Center or the SEL factory for assistance (see *Technical Support*).

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: Communications Setup

Introduction

The only communications port on the SEL-T4287 is Port F, a USB port on the front panel used for upgrading firmware (see *Appendix B: Firmware Upgrade Instructions on page 24* for the necessary steps). This port does not allow you to make settings changes or trigger tests.

Once the USB driver is installed, your PC can communicate with the SEL-T4287 over the front-panel **PORT F**.

Required Equipment

You will need the following items before beginning the communications-setup process:

- Personal Computer (PC)
- A terminal emulator that supports Checksum Xmodem protocol (examples shown use Tera Term, which can be downloaded for free).
- SEL-C664 cable, or any standard A-to-B USB cable
- SEL-T4287 communications setup instructions

Communications Setup Procedure

Step 1. Ensure that the SEL USB to UART Device Driver is installed on your computer. The driver and installation instructions are available at selinc.com/products/usb-serial.

Step 2. Connect the SEL-C664 cable (or equivalent) between **PORT F** on the SEL-T4287 and your PC.

Step 3. Open the terminal emulation software. Select the **Serial** protocol and the appropriate COM port attached to the SEL-T4287.

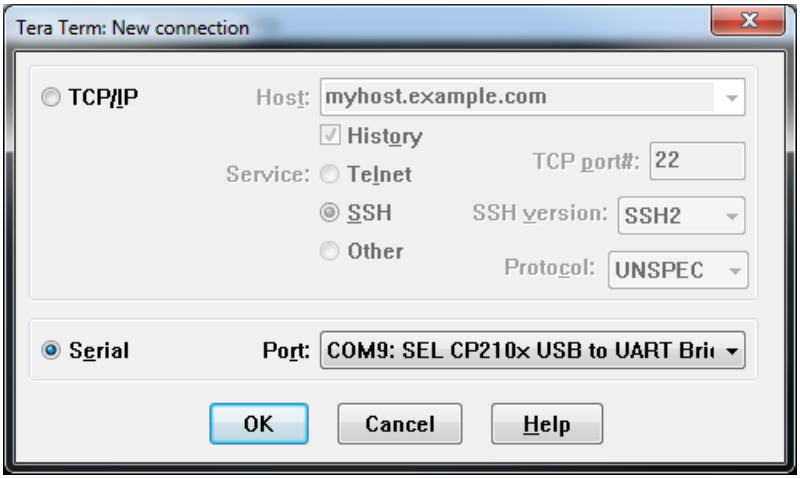


Figure 17 Tera Term Serial Connection

Step 4. In the Setup menu, select **Serial Port**. Apply the settings shown in *Figure 18* (with the appropriate COM port selected) and click **OK**.

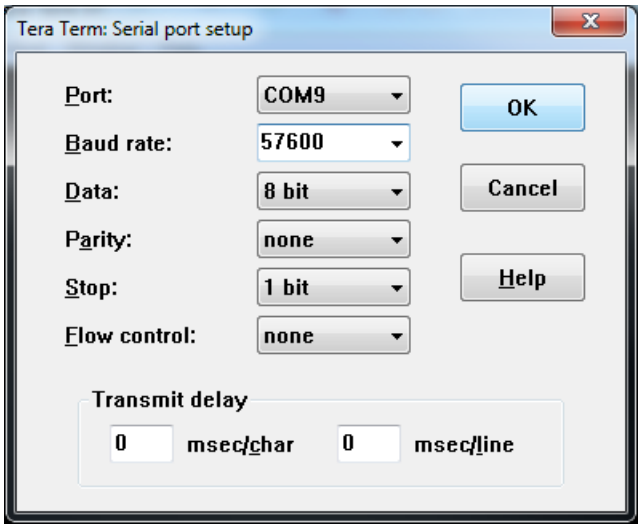


Figure 18 Serial Port Settings

Step 5. Press **<Enter>** and observe the = prompt. You will continue to get a new = prompt every time you press **<Enter>**.

Appendix D: SEL ASCII Commands

Introduction

You can use a communications terminal or terminal emulation program to upgrade firmware and to view device status information, such as the part number, serial number (only displayed for units with a serial number greater than 1180170000), firmware identification (FID) number, time and date information, and error status. You cannot use SEL ASCII commands to view or modify settings, trigger tests, or control device outputs. This appendix lists and explains the SEL ASCII commands supported by the SEL-T4287.

You can shorten any SEL ASCII command to the first three characters; for example, **STATUS** becomes **STA**. Always send a carriage return (<CR>) character, or a carriage return character followed by a line feed character (<CR><LF>), to instruct the relay to process the command. Most terminal programs interpret the Enter key as a <CR>. For example, to send the **STATUS** command, type **STA <Enter>**.

The SEL-T4287 contains one access level (Access Level 0, indicated by an = prompt); it does not support additional access levels, such as Access Level 1, Access Level B, and Access Level 2. Therefore, commands such as **ACCESS**, **BACCESS**, and **2ACCESS**, which are applicable to many other SEL products, are not valid for the SEL-T4287. All commands described in this appendix are issued from Access Level 0.

SEL ASCII Command Reference

Table 10 lists (alphabetically) the SEL ASCII commands available in the SEL-T4287.

Table 10 SEL ASCII Command Reference

SEL ASCII Command	Description	Examples
L_D	Prepare the test set to receive new firmware.	**L_D <Enter>**
STATUS	Reports the device part number, serial number[a], FID, time and date information, and error status.	**STA <Enter>**

[a] Only displayed for units with a serial number greater than 1180170000. Units with a serial number less than 1180170000 that are upgraded to R101-V0 or higher will not display the serial number in response to the **STATUS** command.

Description of Commands

L_D

Use the **L_D** command to prepare the test set to receive new firmware, as described in *Appendix B: Firmware Upgrade Instructions on page 24*.

Table 11 L_D Command

Command	Description
L_D	Prepare the test set to receive new firmware.

STATUS

The **STA** command reports device status information, such as the part number, serial number (only displayed for units with a serial number greater than 1180170000), FID number, time and date information, and error status. See *Front-Panel Indication and Controls on page 7* for additional error status information, and see *IRIG (SINGLE or LOOP) Trigger on page 12* for information regarding time quality and continuous time quality displayed in the response of the **STA** command.

Table 12 STA Command

Command	Description
STA	Display status report, including device part number, serial number[a], FID, time and date information, and error status.

[a] Only displayed for units with a serial number greater than 1180170000. Units with a serial number less than 1180170000 that are upgraded to R101-V0 or higher will not display the serial number in response to the **STATUS** command.

SEL-T4287 Test Set Command Summary

SEL ASCII Command	Description	Examples
L_D	Prepare the test set to receive new firmware.	**L_D <Enter>**
STATUS	Display status report.	**STA <Enter>**

SCHWEITZER ENGINEERING LABORATORIES, INC.
2350 NE Hopkins Court • Pullman, WA 99163-5603 U.S.A.
Tel: +1.509.332.1890 • Fax: +1.509.332.7990
selinc.com • info@selinc.com

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