SEL-221D-7
SEL-121D-7

Phase Distance Relay
Ground Directional Overcurrent Relay
Fault Locator

Instruction Manual

19960119

SCHWEITZER ENGINEERING LABORATORIES, INC.

⚠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.

⚠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

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.

⚠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 blessuers ou la mort.

PM221D-02

SEL-121D-7 RELAY ADDENDUM

The fault locator in this version of the SEL-121D relay is designed for radial line applications. It minimizes the effects of loads connected to the feeder through delta-wye transformers.

The algorithm used by the SEL-121D-7 relay to determine ground fault distances is unique: the load current from the non-faulted feeders does not appreciably affect the result. Equation 1 shows an example for an A-phase ground fault. Note that only the residual current is used in calculating the distance to the fault:

$$Z1 = \frac{VA}{IR(1 + k)} \qquad \text{Equation 1}$$

Where:

$Z1 \equiv$ Positive-sequence impedance to the fault location
$VA \equiv$ A-phase voltage at the relay
$IR \equiv$ Residual current measured at the relay
$k \equiv (Z0 - Z1)/3(Z1)$
$Z1 \equiv$ Positive-sequence impedance modeled in the relay
$Z0 \equiv$ Zero-sequence impedance modeled in the relay

Note that, in the SEL-121D-7 relay, VA is calculated, not directly measured. VA is calculated from the sum of measured positive- and negative-sequence voltages, added to the calculated zero-sequence voltage, V0, where $V0 = I0 \times (R0S + jX0S)$. R0S and X0S are relay settings.

If this special fault locating algorithm is not employed for such applications and load currents are appreciable, errors in distance calculations for ground faults result. More details on this fault locating method are provided in the paper, "A Review of Impedance-based Fault Locating Experience," by Dr. Edmund O. Schweitzer, III.

(Patent Pending)

SEL-200 SERIES (SHALLOW) RELAY HARDWARE ADDENDUM

SEL introduces the shallow SEL-200 series hardware. This brings a reduction in unit depth and weight and provides a low-level signal testing option. The firmware remains unchanged. It compares to the original SEL-200 series relay hardware as follows:

ORIGINAL SEL-200 SERIES RELAY HARDWARE SPECIFICATIONS

3.47" x 19.00" x 11.66" (8.81 cm x 48.26 cm x 29.62 cm) (H x W x D)

16 pounds (7.3 kg)

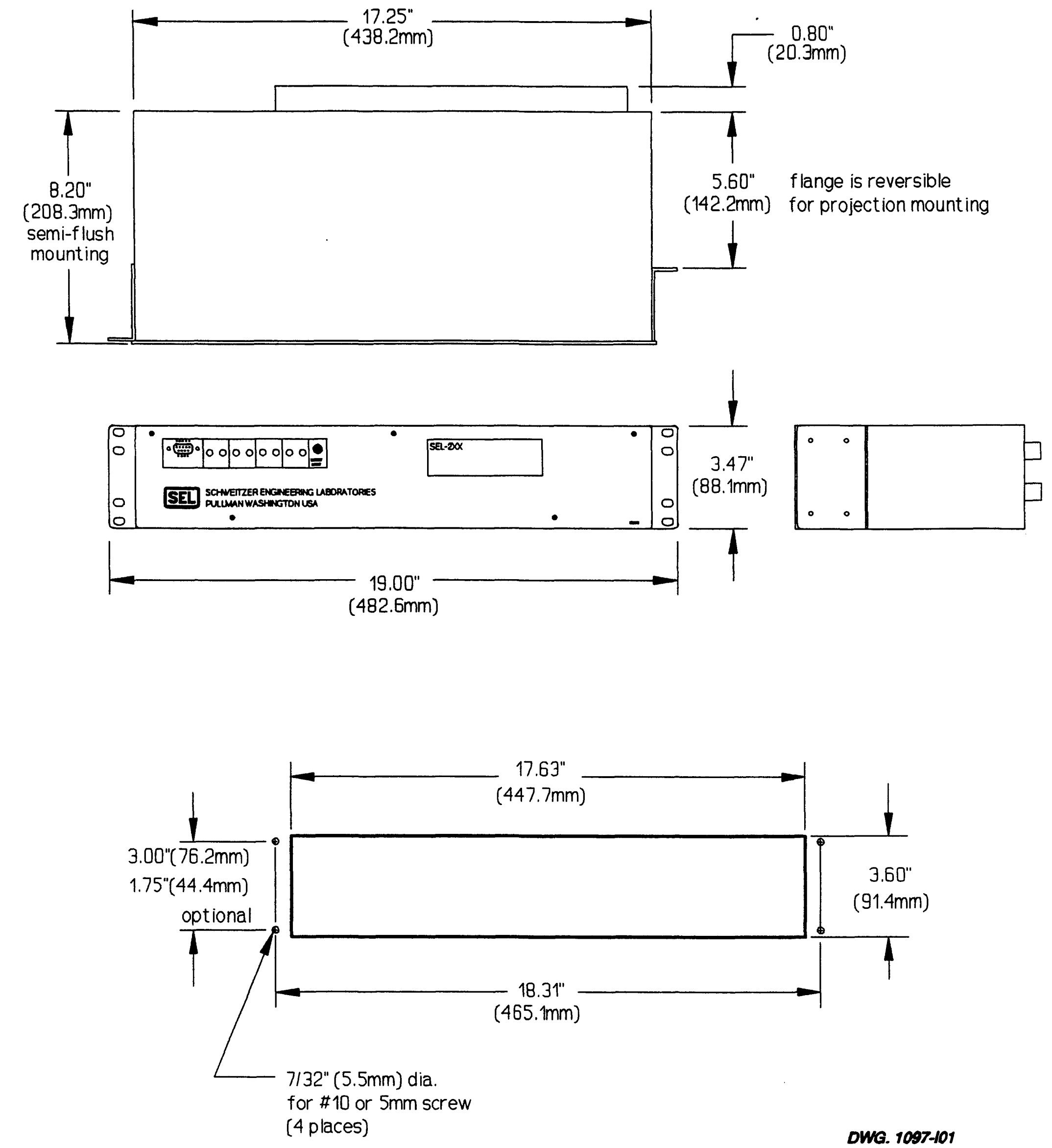
SEL-200 SERIES (SHALLOW) RELAY HARDWARE SPECIFICATIONS

3.47" x 19.00" x 9.00" (8.81 cm x 48.26 cm x 22.86 cm) (H x W x D)

12 pounds (5.5 kg)

Depth (dimension D) is to the end of the rear panel terminal blocks.

All other specifications remain the same. The shallow SEL-200 series relay dimensions, panel cutout, and drill diagrams are on the following page.



SEL-200 Series (Shallow) Relay Dimensions, Panel Cutout, and Drill Diagrams

SEL-200 SERIES RELAY ADDENDUM

The SEL-200 series relays provide the same reliable relaying, fault locating, and event reporting functions as the SEL-100 series relays in a simpler, more compact package. The new relays are software compatible with the SEL-100 series relays.

Smaller Package Conserves Panel Space

In horizontal configuration, the SEL-200 series relay fits in a standard 19 inch rack. However, it is only 3.5 inches tall and 10.5 inches deep. You can fit more equipment in each protection panel, or consolidate existing panels.

Improved Reliability Provides Higher Availability

The high reliability of the SEL-100 series relays is improved in the SEL-200 series relays. In the new hardware, all electronic components (excluding the power supply and instrument transformers) are contained on a single printed circuit board.

Specifications

While the relay protection specifications have not changed, a few of the hardware and power supply specifications are different.

Optical Isolator Logic Input Ratings	24 Vdc: 10 - 30 Vdc 48 Vdc: 25 - 60 Vdc 125 Vdc: 60 - 200 Vdc 250 Vdc: 200 - 280 Vdc Current = 4 mA at nominal voltage
Power Supply	24/48 Volt: 20 - 60 Vdc; 12 watts 125/250 Volt: 85 - 350 Vdc or 85 - 264 Vac; 12 watts
Communications	Two EIA RS-232-C serial communications ports, Port 2 has front and rear panel connectors. The serial ports use standard, 9-pin subminiature "D" connectors.
Dimensions	3.5" x 19" x 10.5" (8.89 cm x 48.2 cm x 26.7 cm) (H x W x D)
Unit Weight	16 pounds (7.3 kg)
Shipping Weight	Approximately 26 pounds (11.8 kg), including two instruction manuals.

Front Panel Serial Communications Port

The SEL-200 series relay is equipped with two EIA RS-232-C serial communications ports. Port 2 has 9-pin connectors on both the front and rear panels, designated Port 2F and Port 2R, respectively.

Port 2R, located on the relay rear panel, is typically used with an SEL-DTA display/transducer adapter, SEL-RD relay display, or local printer. Port 2F is always available for short term local communications with a portable computer or printing terminal. Simply plug the device into the front panel port. The relay automatically discontinues communications with Port 2R and addresses Port 2F. When testing or data retrieval is complete, unplug the temporary device from Port 2F. The relay automatically resumes communication with the device connected to Port 2R.

Serial communications Port 1 and the Auxiliary Input for demodulated IRIG-B time code input remain on the relay rear panel.

Communications port baud rate jumpers are located along the front edge of the circuit board. To select a baud rate for Port 1 or Ports 2, remove the relay front panel. The jumpers are visible near the center of the relay drawout assembly, to the right of the target LEDs. Carefully move the jumpers using needle-nosed pliers.

Caution: Do not select two baud rates for the same port as this can damage the relay baud rate generator. The relay is shipped with Port 1 set to 300 baud and Port 2F/2R set to 2400 baud.

Rear Panel Features

We have redesigned the relay rear panel to simplify the connections. Terminals for logic input and contact output connections are located in the upper bank of 6-32 screw terminals, numbered 1 through 28. The function of each terminal pair is clearly labelled. Make ac signal and relay power supply connections on the lower bank of terminals, numbered 29 through 45. AC and dc connection diagrams on the following pages show example connections and reference the new terminal numbers.

Rear panel communication port connectors are located in the upper right hand corner. Relay nameplate data and communication port pinout information is printed below the connectors. Communication connection diagrams on the following pages show examples of this SEL relay connected to various serial communication devices.

Drawout Assembly Removal Instructions

SEL may occasionally offer firmware upgrades to improve the performance of your relay. These instructions explain how to remove the relay drawout assembly to install new firmware.

The modifications require that you power down the relay, remove the relay front panel, pull out the drawout unit, exchange several integrated circuit chips, and reassemble the relay. If you do not wish to perform the modifications yourself, we can assist you. Simply return the relay and integrated circuit chips to us. We will install the new chips and return the unit to you within a few days.

WARNING: This procedure requires that you handle electrostatic discharge sensitive components. If your facility is not equipped to work with these components, we recommend that you return the relay to SEL for firmware installation.

Upgrade Instructions

1. If the relay is in service, disable its control functions. Turn off control power to the relay. Short the relaying CT secondary inputs to the relay using appropriate shorting switches.

2. Remove the relay front panel by unscrewing the five front panel screws. With the front panel removed, you can see the aluminum drawout chassis. The main board is attached to the top of the drawout chassis. The power supply and transformer assembly are attached to the bottom of the relay chassis.

3. Disconnect the power supply and transformer secondary cables from the underside of the drawout assembly.

4. Remove the drawout assembly by pulling the spacers on the bottom of the drawout chassis. You should be able to remove the assembly with your fingers. Because steps 5 and 6 involve handling electrostatic discharge (ESD) sensitive devices and assemblies, perform these steps at an ESD safe work station. This will help prevent possible damage by electrostatic discharge.

5. Note the orientation of the ICs to be replaced. Use a small screwdriver to pry the indicated ICs free from their sockets. Be careful not to bend the IC pins or damage adjacent components.

6. Carefully place the new ICs in the appropriate sockets. Check the orientation of the ICs. Be sure that each IC is in its corresponding socket. Look for IC pins that bent under or did not enter a socket hole.

7. Slide the drawout assembly into the relay chassis. Using your fingers, push the assembly in until the front of the assembly is flush with the front of the relay chassis. Reconnect the power supply and transformer secondary cables to the receivers on the underside of the drawout assembly. Replace the relay front panel.

8. With breaker control disabled, turn relay power on and enter your settings. Execute the STATUS, METER, and TRIGGER commands to ensure that all functions are operational. Set and record your Access Level 1 and 2 passwords and the date and time. The relay is now ready to resume protective functions.

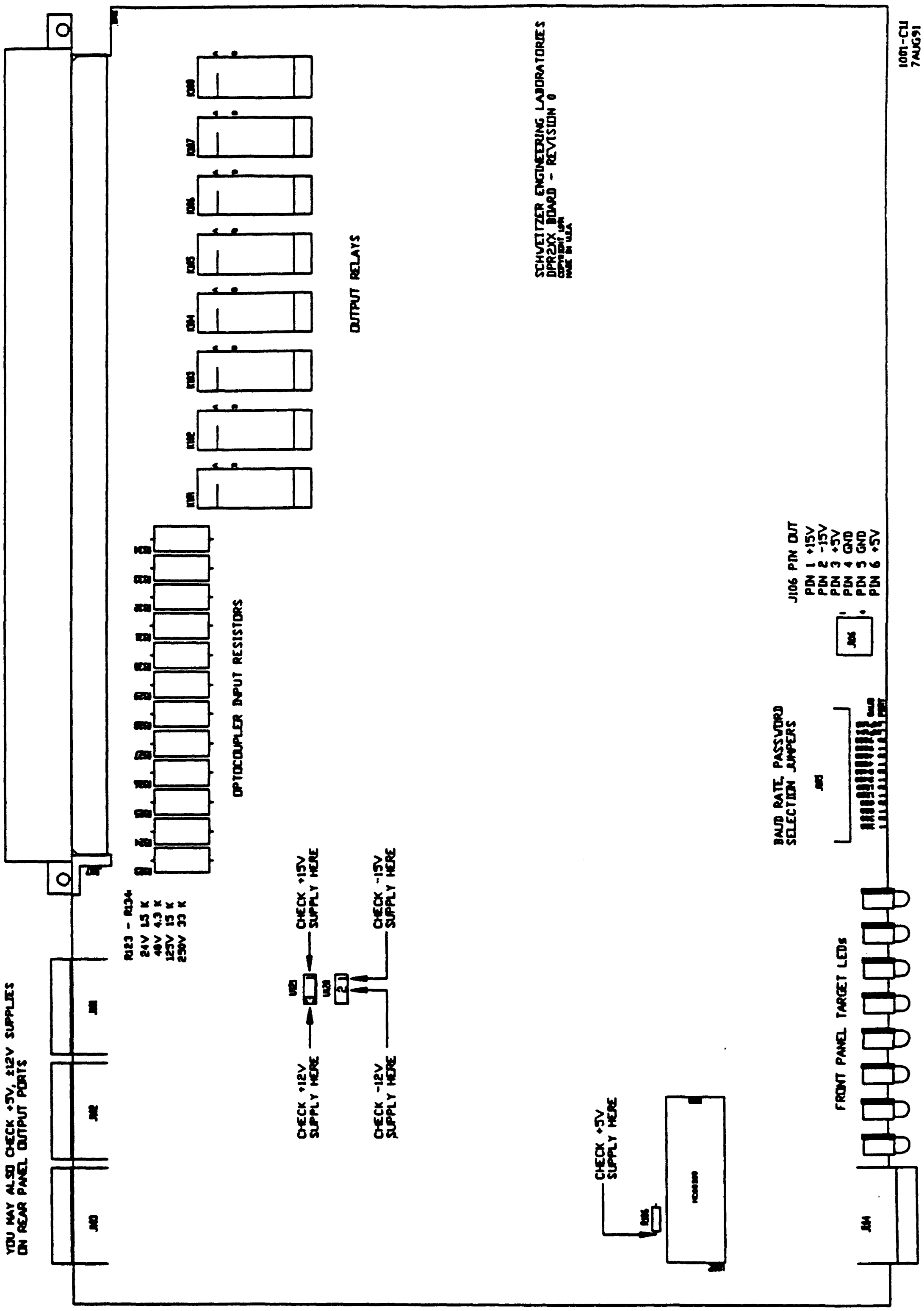


Figure 1: SEL-200 Series Relay Main Board Troubleshooting Test Points and Jumper Locations

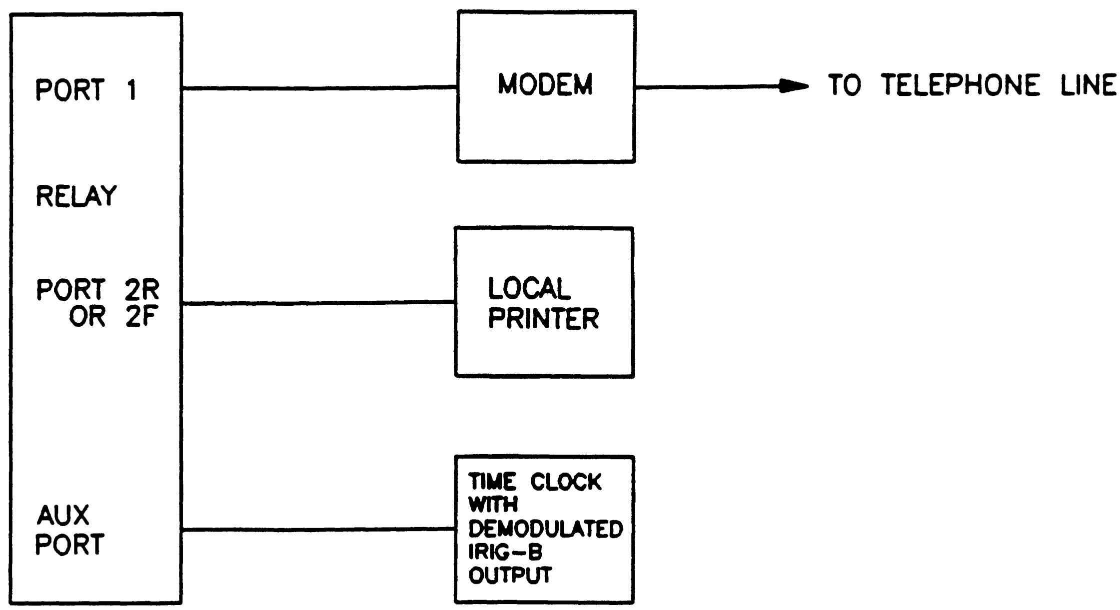


Figure 2: **200 Series Relay Communication and Clock Connections One Unit at One Location**

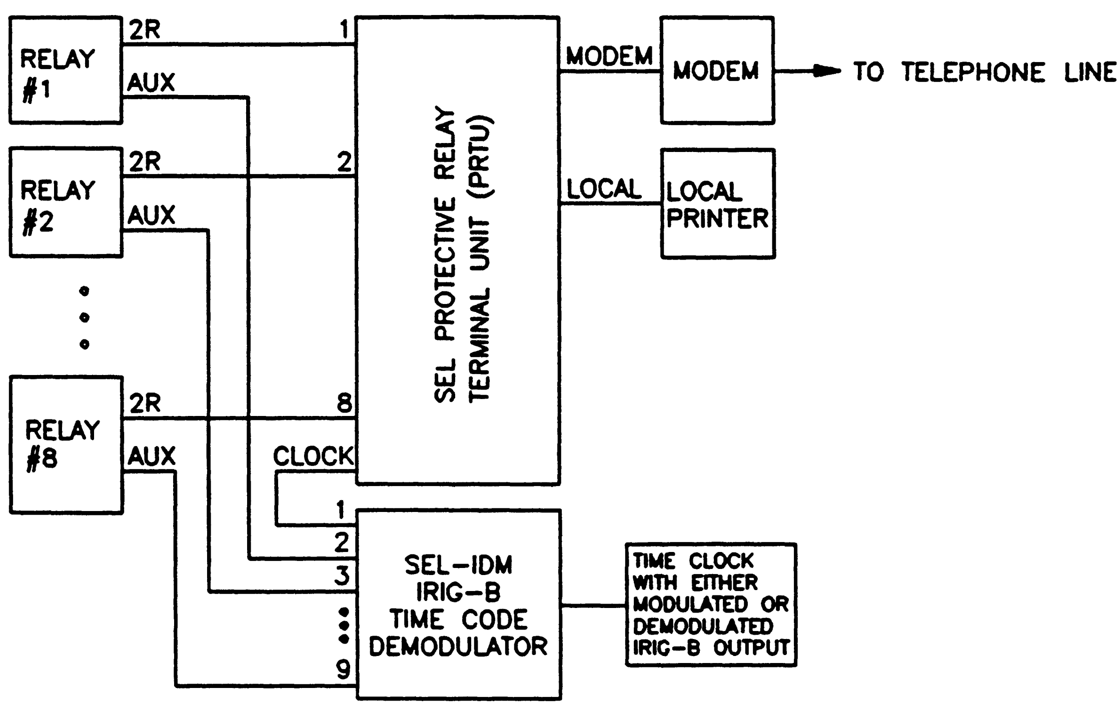
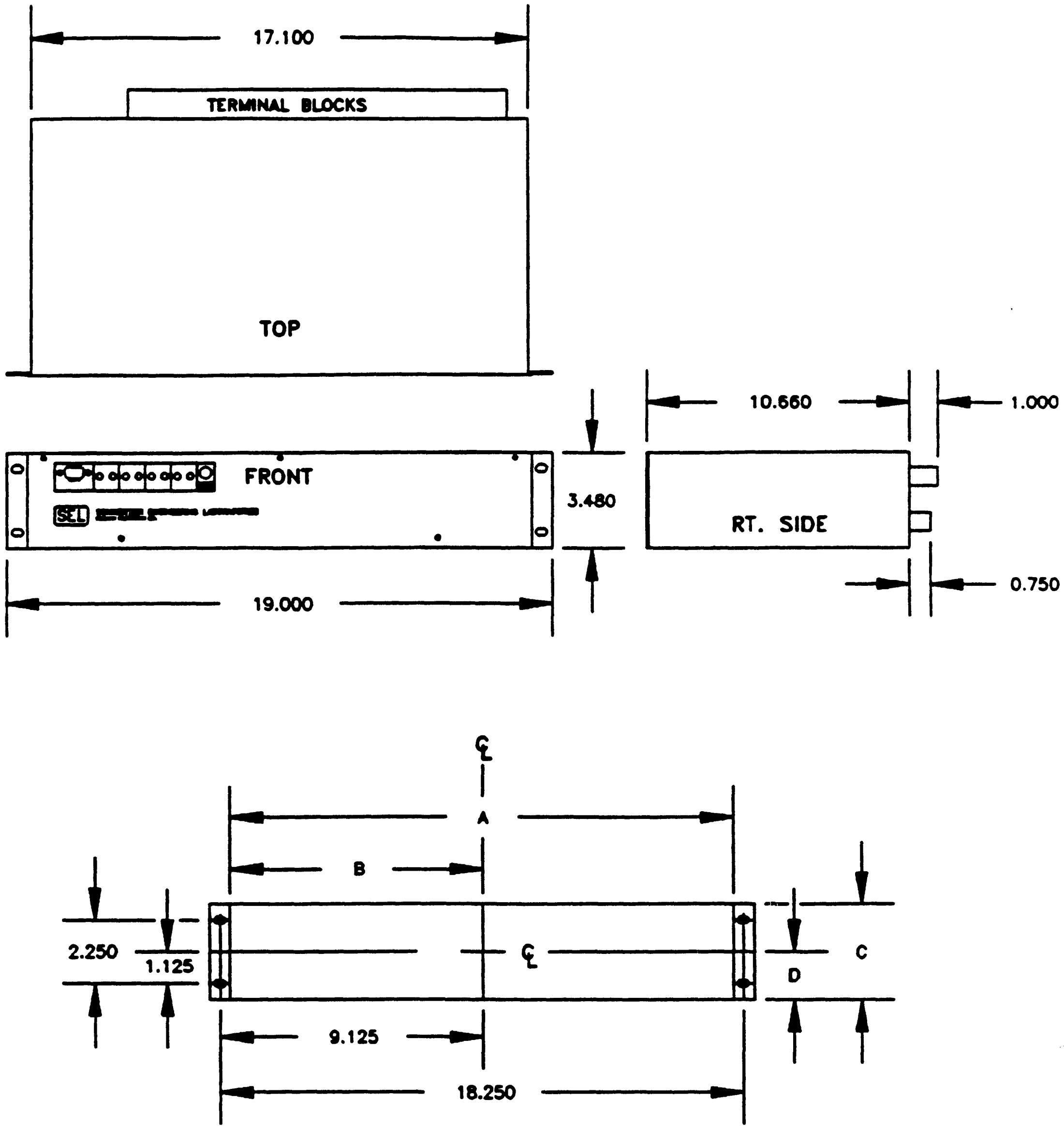


Figure 3: **200 Series Relay Communication and Clock Connections Multiple Units at One Location**



DIMENSION	CUTOUT	PREFERRED
A	17.20 - 17.80	17.30
B	8.60 - 8.90	8.65
C	3.52 - 3.60	3.56
D	1.76 - 1.80	1.78

NOTE: ALL INSTRUMENTS MAY BE MOUNTED HORIZONTALLY (AS SHOWN ABOVE) OR VERTICALLY

ALL DIMENSIONS ARE IN INCHES

Figure 4: Panel Cutout and Drill Patterns for SEL Low-Profile Instruments

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.

ATTENTION!

Cet équipement 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 accès non-autorisé à l'équipement pourrait être possible. SEL décline toute responsabilité pour tout dommage résultant de cet accès non-autorisé.

20001120

Standard Product Warranty – Ten Years

Definition of Terms

Product:	All items manufactured by SEL that are sold to a customer.
New Product:	A product manufactured by SEL that is sold for the first time.
Customer:	An end-user of the product.

New Product Warranty

All new products sold to customers are warranted against defects in design, materials, and workmanship for a period of ten (10) years from the date of first retail delivery to a customer. If it is determined that the new product defect is covered under this warranty, SEL will repair, replace, or substitute an identical unit at its own discretion to the customer at no charge.

SEL may, at its own discretion, require the customer to ship the unit back to the factory for diagnosis before making a determination as to whether it is covered by this warranty. In such event, SEL may, at its own discretion, decide to provide the customer with a substitute unit which may be sent to the customer either from the SEL factory or from an authorized representative or distributor from their inventory.

All expenses related to the shipment of defective units back to SEL or the provision of a substitute unit to the customer are the responsibility of the customer. This expense may include, but is not limited to, freight, insurance, Customs clearance, and duties. All expenses related to the shipment of repaired units back to customers (or the provision of a new unit to the customer) will be borne by SEL.

Product Upgrade Policy

From time to time, SEL makes product upgrades to add to or enhance the performance of the products. Customers of a particular product being issued an upgrade will be notified either by SEL directly or through its authorized representatives or distributors.

Customers who have purchased an annual upgrade policy will receive all upgrades during the calendar year free of charge. Customers who did not purchase the annual upgrade policy may purchase each unit upgrade individually. The annual upgrade policy can be purchased at any time. Regardless of whether the upgrade policy is purchased, SEL will make reasonable efforts to notify all customers of all available upgrades.

SCHWEITZER ENGINEERING LABORATORIES
2350 NE Hopkins Court • Pullman, WA • 99163-5603 • USA
Phone: (509) 332-1890 • Fax: (509) 332-7990
E-mail: info@selinc.com • Internet: www.selinc.com

EQUIPMENT REPAIR AND WARRANTY

Repair costs of products not covered under this warranty are paid for by customers. Customers are responsible for the cost of shipping the products to SEL located at: 2350 NE Hopkins Court, Pullman, Washington 99163 USA.

All products repaired by SEL will be warranted against defects in material and workmanship for a period of one year from the date the equipment is returned to the customer or the remainder of the new product warranty, whichever is longer.

LIMITATIONS

SEL's warranty does not extend to (A) SEL's products subject to (i) improper installation, connection, operation, maintenance, or storage; (ii) accident, damage, abuse, or misuse; (iii) abnormal or unusual operating conditions or applications outside the specifications for the product; (iv) a purpose or application in any way different from that for which the products were designed; or (v) repairs conducted by persons other than SEL employees or an authorized representative or distributor; (B) Equipment and products not manufactured by SEL. Such equipment and products may be covered by a warranty issued by the respective manufacturer.

This warranty is in lieu of any other warranties, express or implied, including without limitation, any warranty of merchantability or fitness for a particular purpose, and is in lieu of any and all other obligations or liability of SEL. Under no circumstances shall SEL be liable for any accidential or consequential damages or for any other loss, injury, damage, or expense of any kind including loss of profits arising hereunder.

To the extent any court, arbitration panel, or other governmental body of competent jurisdiction shall declare any provision of this warranty invalid or unenforceable by reason of a rule of law or public policy, all the other provisions hereof shall remain in full force and effect.

SEL RELAY INSTRUCTION MANUAL ADDENDUM

ACB PHASE ROTATION OPTION

The SEL relay instruction manuals are written for standard ABC phase rotation applications. If your SEL relay is ordered with the ACB phase rotation option, references made in the instruction manual to voltage and current phase angle should be noted accordingly. The firmware identification number (FID) may be used to verify whether your relay was ordered with ABC or ACB rotation.

All current and voltage inputs are connected to the SEL relay rear panel as shown in the instruction manual.

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INTRODUCTION

OVERVIEW

This instruction manual applies to SEL-121D and SEL-221D relays. The SEL-221D and SEL-121D relays have identical protection features, but use different hardware designs. Where there are differences between the two relay models, both relays are described.

The SEL-221D phase distance and ground directional overcurrent relay with fault locator may be applied to protect transmission, subtransmission and distribution lines. The SEL-221D is intended for use on grounded systems with delta-connected voltage transformers (use the SEL-221G relay where wye-connected voltage transformers are applied).

The features of the SEL-221D include:

Distance relaying for phase and three-phase faults

Directional overcurrent protection for ground faults

Overcurrent protection may be enabled or maintained on loss-of-potential

Switch-onto-fault protection

Loss-of-potential detection

Versatile user-programmable logic

Three-shot reclosing

Transmission line fault locating

Event recording

Automatic self testing

Metering

Target indicators for faults and testing

Time code input

Communication ports for local and remote access

Compact size and economical

GENERAL INFORMATION

This introduction gives the specifications for the SEL-221D relay, and describes its theory of operation. Although you should be familiar with the specifications and theory of operation, you may wish to first complete the INITIAL CHECKOUT procedure, which follows this introduction.

The SEL-221D relay is intended for application where three-phase four-wire voltage inputs are not available, such as when a pair of open-delta connected voltage transformers are applied.

Communications functions provide remote and local examination of a wide range of data, including the voltages and currents presented to the instrument, the system settings, and a history of the twelve most recent fault types and locations. System settings may be remotely entered and modified. Circuit breaker control via the communications channels is also provided. Settings and circuit breaker control are protected by a secure two-level password access scheme which is monitored for unauthorized access by an alarm contact output.

A fault locator is included which uses fault type, prefault and fault conditions to provide an accurate estimate of fault location, without the need for communications channels, or special instrument transformers, even during conditions of substantial load flow and fault resistance. The relay locates ground faults by estimating the zero-sequence voltage from the product of a setting for the zero-sequence source impedance (R0S,X0S) and the measured zero-sequence current.

A detailed event report is generated following every fault. It contains all information needed to quantitatively examine the prefault, fault, and postfault voltages and currents. Such parameters as fault current sensed by the relay, relay response time, and total fault clearing time are easily obtained. The event report includes the distance to the fault, the type of fault, and the state of all relay units during the event. The event is time-tagged by a self-contained clock. In addition to the automatic generation of this report for faults, the report may be generated upon command, or by assertion of any of several control inputs to the instrument. This allows triggering the report from other equipment, such as oscillographic starting units or other relaying systems. The relay retains the twelve most-recent event reports. Any of these reports may be recalled by command.

Phasor diagrams of the voltages and currents can be constructed from the fault report, showing the prefault conditions, the fault conditions and the postfault conditions. The accurate information is useful in verifying short circuit and load-flow calculations, verifying transmission line constants, and measuring voltage and current unbalance. It also has been used to check the input connections for proper phase-sequence rotation and polarity.

Long-term accuracy and availability are designed into the instrument. Amplitude-dependent measurements are made with respect to an internal stable and precise voltage reference, which is monitored as a part of the self-checking process. Long-term phase stability is guaranteed, since all phase-shifting operations are performed by precise time delays controlled from a quartz crystal oscillator.

SPECIFICATIONS

Relay Functions

Mho characteristics for phase-phase and three-phase faults
Three phase-to-phase zones
Three three-phase zones

Residual-overcurrent protection for ground faults
Three definite-time elements
One time element with four selectable curve shapes

Negative- and zero-sequence directional elements for ground faults
Zero-sequence element is current polarized

Zone 3 mhos and one residual overcurrent element may be reversed
Provides backup protection
Supports communication - based protection schemes

Automatic reclosing for selectable fault types (3 shots)
Settable open interval and reset timers
Selectable reclose initate and cancel conditions

Relay Elements

Phase Overcurrent Element Specifications (Secondary Quantities)

50AL, 50BL, 50CL (phase fault detectors)
50AG, 50BG, 50CG (REJO Logic)
50AM, 50BM, 50CM (Loss-of-Potential scheme)
50AH, 50BH, 50CH (high-set elements)
Pickup: 0.5 to 40 A, ±0.1 A ±2% of setting
Transient overreach: 5% of set pickup

Distance Element Specifications (Secondary Quantities)

Phase Distance:
21P1: 0.125 to 32 ohms
21P2: 0.125 to 128 ohms
21P3: 0.125 to 128 ohms

Three-Phase Distance:
21ABC1: 0.125 to 32 ohms
21ABC2: 0.125 to 128 ohms
21ABC3: 0.125 to 128 ohms

Angle setting (MTA): 47° - 90° in 1° steps.

Timers are provided for Zones 2 and 3:
Zone 2 Timer: 0-2000 cycles in quarter-cycle steps
Zone 3 Timer: 0-2000 cycles in quarter-cycle steps

Zone 2 and 3 settings are limited as follows:
For Zone 1 < 8 ohms: 1 - 16 times Zone 1
For Zone 1 > 8 ohms: 1 - 4 times Zone 1
Zone 2 may not be set greater than 4 times
Zone 1 when Zone 3 is less than 4 times Zone 1.

Operating time: Mho elements operate in 10 - 45 ms (25 ms typical), including output relay delay.

Steady-state error:
5% of set reach ±0.01 ohm at angle of maximum torque for V > 5 V and I > 2 A.
10% of set reach ±0.01 ohm at angle of maximum torque for 5 > V > 1 V and 0.5 < I < 2 A.

Transient overreach:
5% of set reach, plus steady-state error.

Memory polarization:
Zone 1, 2 and 3 three-phase elements are memory polarized using voltage from a four-cycle memory.

Ground Overcurrent Elements (Secondary Quantities)

51N residual time-overcurrent element:
Selectable curve shape (4 curves)
Time dial: 0.50 to 15.00 in steps of 0.01
Pickup: 0.25 to 6.3 A, 0.05 A ±2% of setting

50N1, 50N2, 50N3 residual-overcurrent elements:
Pickup: 0.25 A to 48 times 51N pickup
Transient overreach: 5% of set pickup
Timers are provided for 50N2 and 50N3:
Zone 2 Timer: 0-2000 cycles in quarter-cycle steps
Zone 3 Timer: 0-2000 cycles in quarter-cycle steps

Ground Directional Elements

Negative-sequence directional element:
Angle: same as mho element setting.

<u>Voltage Polarization Sensitivities for 32Q</u>

*Z1 (ohms)	**32Q Sens. (VA)
0.125 - 0.5	0.04 / Z1
0.5 - 2.0	0.14 x Z1
2.0 - 8.0	0.04 x Z1
8.0 - 32.0	0.01 x Z1

* Z1 is the Zone 1 reach setting, in secondary ohms.
** 32Q sensitivity is in units of (neg. seq. amps) * (neg. seq. volts).

Zero-sequence current polarized directional element:
Angle: 0°.
Sensitivity: (0.5 amps) x (51N pickup setting) at 0° in units of residual amps squared, and Ipol > 0.5 amps.

Sequence-Component Elements (Secondary Quantities)

Negative-sequence overvoltage element (47QL)
Pickup: 14 volts V2
Negative-sequence overvoltage element (47QH)
Pickup: 30 volts V2
Negative-sequence overcurrent element (46QL)
Pickup: 0.083 amps I2
Positive-sequence overvoltage element (47P)
Pickup: 14 volts
Three-shot Reclosing Relay:
79OI1, 79OI2, and 79OI3 open intervals:
Timer ranges: 0-10,000 cycles in quarter-cycle steps. A setting of 0 disables that shot and successive shots.
79RS reset interval:
Timer range: 60-10,000 cycles in quarter-cycle steps

Fault Location

Fault location is computed from event reports stored following each fault. Algorithm compensates for prefault current for improved accuracy for high-resistance faults. Zero-sequence voltage component is estimated from zero-sequence source impedance setting and zero-sequence current, to calculate estimates of VA, VB, and VC from VAB, VBC, and VCA. Thus, the fault locator can locate ground faults, even though line-to-line voltage transformers are used.

Fault Reporting

A data record is retained for each of the 12 most-recent faults, which includes current, voltage, relay element, input contact and output contact information. The report may also be triggered by command or contact closure. When tripping occurs after the end of the event report, a second report is triggered at tripping.

Self Testing

Analog ac channel offset errors
Stall timer monitors processor
Power supply voltage checks
Setting checks
RAM, ROM, and A/D converter tests

Rated Input

115 volt nominal phase-to-phase, three-phase three-wire connection

Rated Input Current

5 amps per phase nominal
15 amps per phase continuous
500 amps for one second thermal rating

Output Contact Current	30 amp make per IEEE C37-90 para 6.7.2 6 amp carry continuously MOV protection provided
Logic Input Ratings	24 Vdc: 10 - 30 Vdc 48 Vdc: 25 - 60 Vdc 125 Vdc: 60 - 200 Vdc 250 Vdc: 200 - 280 Vdc Current = 4 mA at nominal voltage
Power Supply	24/48 Volt: 20 - 60 Vdc; 12 watts 125/250 Volt: 85 - 350 Vdc or 85 - 264 Vac; 12 watts
Dielectric Strength	Routine tested: V, I inputs: 2500 Vac for 10 seconds Other: 3000 Vdc for 10 seconds (excludes EIA RS-232-C and IRIG-B input)
Interference Tests	IEEE C37-90 SWC test (type tested) IEC 255-6 interference test (type tested)
Impulse Tests	IEC 255-5 0.5 joule 5000 volt test (type tested)
RFI Tests	Type-tested in field from a quarter-wave antenna driven by 20 watts at 150 MHz and 450 MHz, randomly keyed on and off, at a distance of 1 meter from relay.
Dimensions	3.5" x 19" x 10.5" (8.89 cm x 48.2 cm x 26.7 cm) (H x W x D), SEL-221D 5.25" x 19" x 13" (13.3 cm x 48.2 cm x 33.0 cm) (H x W x D), SEL-121D Mounts in EIA 19" rack, or panel cutout.
Unit Weight	16 pounds (7.3 kg), SEL-221D 21 pounds (9.5 kg), SEL-121D
Shipping Weight	26 pounds (11.8 kg), including two instruction manuals, SEL-221D 32 pounds (14.5 kg), including two instruction manuals, SEL-121D
Operating Temp.	-40°F to 158°F (-40°C to 70°C)
Burn-in Temp.	Each relay is burned in at 60° C for 100 hours.

BASIC PROTECTIVE CAPABILITIES

The SEL-221D relay provides complete protection for transmission line faults of all types.

Figure 1.1 illustrates the basic configuration of the protective capabilities. (Exact descriptions of the logic are in the FUNCTIONAL DESCRIPTION section of this manual.)

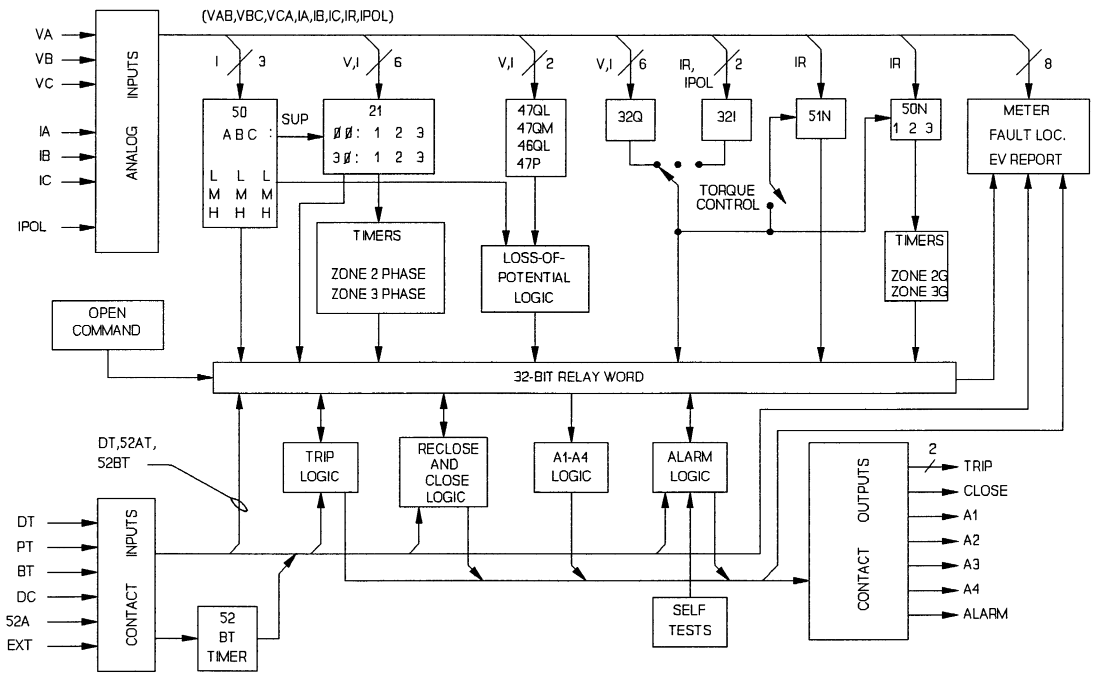

Figure 1.1: Relay Function Block Diagram

Analog inputs from current and voltage transformers are delivered to the protective relaying elements and saved for additional features, such as metering and fault locating.

The relay elements process the analog data. Some intermediate logic is performed, such as overcurrent supervision of the mho elements, directional supervision of the residual-overcurrent elements, and grouping of certain elements into zones.

The states of the intermediate results and some other information are recorded in the Relay Word.

Logic for tripping, closing and other purposes uses the Relay Word data. Most of that logic is programmable by logic masks.

Below, the basic protective capabilities are grouped and explained by fault type.

Three-Phase and Phase-Phase Faults:

Three zones are provided. The elements have a circular mho characteristic. Zone 3 may be reversed.

The three-phase elements are supervised by three overcurrent elements. Four cycle memory polarization is provided for all three zones.

The phase-phase mho elements are based on the compensator-distance principle. They have no response for three-phase faults. The phase-phase elements are supervised by three overcurrent elements. At least one overcurrent element must pick up.

All six mho elements are supervised by the loss-of-potential logic, when it is enabled.

Three medium-set overcurrent elements are selectable whenever a loss-of-potential condition is detected, so that nondirectional phase and three-phase protection is provided until the potential problem can be remedied.

Ground Faults

Ground fault protection consists of three instantaneous/definite-time, residual-overcurrent elements, and a residual time-overcurrent element. One instantaneous element is normally high-set for a Zone 1 ground function. Another is intended for Zone 2 operation. The third instantaneous element is intended for Zone 3 (forward or reverse) application. Timers are provided for Zones 2 and 3. The timed and instantaneous outputs of Zones 2 and 3 are available for communications schemes and other applications.

Direction is determined by a negative-sequence directional element, and a current polarized zero-sequence element. Settings are provided to select either the negative-sequence element or the current polarized zero-sequence element. When voltages are lost, the direction is assumed forward if the negative-sequence element is enabled. To securely discriminate between forward and reverse-direction faults, the directional elements have a torque threshold which must be exceeded in either direction before the fault direction is declared.

The direction of the residual-overcurrent element associated with Zone 3 may be reversed, to assist in blocking schemes and in weak-infeed schemes.

The curve shape of the time-overcurrent element (51N) is user-selectable. This element is either non-directional or forward-reaching, as enabled.

Switch-Onto-Fault Protection

The high-set overcurrent elements should be set to respond to a zero-voltage three-phase fault at any time. In addition, the medium-set overcurrent elements may be enabled whenever the 52A contact input is not asserted (breaker open), and during the interval following breaker closure.

The flexible trip logic allows for other combinations.

Reclosing

A three-shot reclosing relay is provided. Reclosing may be initiated or cancelled for any or all of the following:

Zone 1 ground faults
Zone 1 phase faults
Zone 1 three-phase faults
Zone 2 ground faults cleared after a time delay

Zone 2 phase faults cleared after a time delay
Zone 2 three-phase faults cleared after a time delay
Zone 2 ground faults cleared by permissive transfer tripping
Zone 2 phase faults cleared by permissive transfer tripping

SIGNAL PROCESSING

Phasor representations of the input quantities are desired, i.e., each input signal is represented by a Cartesian coordinate pair of numbers, which is updated every one-fourth power system cycle. The phasor quantities are subsequently processed by relaying and fault-locating algorithms.

The digital filters eliminate dc offsets introduced by the analog electronics, reduce the decaying exponential offset present on the current data following a fault, and passing the power system frequency information. The digital filters are simple, so that a minimum burden of computation is placed on the microprocessor.

A very simple and effective digital filter which has the properties of a double-differentiator smoother, and which requires only addition and subtraction of data samples is employed. Let the latest four samples of one channel of information be X1, X2, X3, and X4. Then the filter is defined by:

$$P = X1 - X2 - X3 + X4.$$

This filter has the desired property of eliminating dc offsets, as can be seen by setting all the samples to the same value and noting that the filter output is zero. It also eliminates ramps, as can be seen by setting the samples equal to, say, 1, 2, 3, 4, and again noting that the resulting output is zero.

A new value of P for each input is computed every one-fourth cycle. The latest value of P and the value of P one-fourth cycle earlier (renamed Q) form a Cartesian-coordinate pair representing the input signal as a phasor (P, Q). The phasor representations of the input signals are processed in the relay and fault-locating algorithms. In addition, they are available as part of the system output in response to an event. The data can be used to construct phasor diagrams of the voltages and currents.

INITIAL CHECKOUT
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INITIAL CHECKOUT

The initial checkout of the SEL-221D relay is intended to familiarize you with the instrument, and to ensure that it is operational.

EQUIPMENT REQUIRED

The equipment listed below is necessary for initial checkout of the relay.

1. Computer terminal with EIA RS-232-C serial interface.
2. Interconnecting cable between terminal and relay.
3. Source of control power.
4. Source of three-phase voltages and at least two currents.

CHECKOUT PROCEDURE

In the procedure below, you will use several of the relay commands. These commands are described in detail in the COMMANDS AND SERIAL COMMUNICATIONS Section. The detail given below should allow you to complete the checkout without referring to the detailed descriptions, however.

1. Inspect the instrument for physical damage such as dents or rattles.

2. Connect a computer terminal to PORT 2 on the relay front or rear panel. The terminal should be configured to 2400 baud, eight data bits, two stop bits, and no parity. Be sure your terminal is compatibly configured. Additional details on the port configurations are given in the FUNCTIONAL DESCRIPTION Section. Baud rate selection is described in the EIA RS-232-C JUMPERS Subsection of the JUMPER SELECTION Section of the INSTALLATION chapter of this manual.

3. Connect a frame ground to terminal marked GND on the rear panel, and connect control power to terminals marked + and -.

4. Turn on the power. The enable target (EN) should illuminate. (If not, be sure that power is present and check the fuse or fuses.) The message:

```
Example 230 kV Line             Date: 6/1/92    Time: 01:01:01

SEL-121D
=
```

should appear on the terminal, and the ALARM relay should pull in, holding its B contacts open. Also, output relay A4 (set to follow reclose cancel) should stay closed until the loss-of-potential problem is rectified, since the LOP bit of the MRC mask is set. (If the relay pulls in, but no message is received, then check the configuration of the terminal. If neither occurs, turn off the power and refer to the TROUBLESHOOTING Guide.)

The equal sign is a prompt which indicates that communications with the relay are at Access Level 0, the lowest of the three relay access levels. The only allowable command at this level is ACCESS, which gains access to Access Level 1, as described below.

5. Type **ACCESS <ENTER>**. In response to the prompt, enter the password **OTTER** and press **<ENTER>**. The prompt => should appear, indicating communications at Access Level 1 are established.

6. The relay is shipped with demonstration settings which can be inspected using the SHOWSET command. Type **SHOWSET <ENTER>** to inspect these settings. The following should be obtained:

```
=>SHOWSET <ENTER>

Settings for:  Example 230 kV Line

R1   =13.90   X1   =79.96    R0   =41.50   X0   =248.57    LL=100.00
R0S  =8.30    X0S  =49.71
CTR  =200.00  PTR  =2000.00  MTA  =80.80   LOCAT=Y
79OI1=40.00   79OI2=60.00    79OI3=80.00   79RS =240.00
Z1%  =80.00   Z2%  =120.00   Z3%  =150.00
Z2DP =30.00   Z3DP =60.00
50L  =100.00  50M  =200.00   50MFD=20.00   50H  =3000.00
51NP =100.00  51NTD=3.00     51NC =2       51NTC=Y
50N1P=1000.00 50N2P=700.00   50N3P=600.00
Z2DG =20.00   Z3DG =40.00    50G  =100.00  REJO =N
52BT =30.00   ZONE3=F        32QE =Y       32IE =N       LOPE=Y
TIME1=5       TIME2=0        AUTO =2       RINGS=3

Logic settings:

MTU  MPT  MTB  MTO  MA1  MA2  MA3  MA4  MRI  MRC
84   C4   00   E4   C4   00   00   00   00   EC
C4   E6   00   E7   E6   80   00   00   44   80
C8   C8   00   C8   88   00   02   04   00   C8
33   03   00   33   02   00   00   00   00   33
```

A brief line-by-line description of the relay settings follows:

Line 1:	Positive- and zero-sequence impedances of the transmission line (primary ohms), and the line length (miles) for which the impedances are given.
Line 2:	Zero-sequence source impedance (used only by fault locator for ground faults).
Line 3:	Current and voltage transformer ratios, maximum torque angle, and fault locator enable.
Line 4:	Three reclosing open interval delays and one reset delay.
Line 5:	Zones 1, 2, and 3 reach as a percent of the line.
Line 6:	Zones 2 and 3 time delays for phase faults.
Line 7:	Instantaneous phase overcurrent element low, medium, and high pickups, and the delay for 50M to trip after loss-of-potential (50MFD).
Line 8:	Residual time-overcurrent pickup, time dial, curve, and torque control enable.
Line 9:	Zones 1, 2, and 3 instantaneous residual-overcurrent element pickup thresholds.
Line 10:	Zones 2 and 3 time delays for ground faults, 50G phase overcurrent element setting, and REJO enable.
Line 11:	52B time delay, Zone 3 direction selection, and the enables for the negative-sequence directional element, the current polarized zero-sequence directional elements, and the loss-of-potential logic.
Line 12:	Port 1 and 2 timeouts, the autoport for automatically transmitted messages, and the number of rings after which the modem will automatically answer.

A complete description of the relay settings is given under the SET command description.

A detailed explanation of the logic settings is given in the description of the LOGIC command. Each column in the logic settings display shows the masks for the four Relay Words as follows:

Row 1, of any column:	1ABC	2ABC	3ABC	REJO	LOP	50H	50M	50L
Row 2, of any column:	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Row 3, of any column:	Z2PT	Z3PT	50G	3P50	50MF	RC	RI	DF
Row 4, of any column:	ALRM	TRIP	TC	DT	52BT	52AT	Z2GT	Z3GT

The logic settings are shown in hexadecimal format. A table and example of hexadecimal to binary conversion is shown in the COMMAND DESCRIPTIONS Section under the "SHOWSET" command description.

7. Turn the power off and connect a source of three-phase voltages to the relay at terminals marked VAB, VBC, and VCA. Apply 67 volts per phase (line-to-neutral) in positive-sequence. Wye-connect the two current sources to generate balanced positive-sequence currents. Connect A and B current sources to the dotted A and B current input terminals of the SEL-221D. Connect the undotted A and B current input terminals both to the undotted C current input terminal. Connect the dotted C current input terminal to both the A and B current source returns. Set the A-phase current source to 2 amperes, at the same angle as the A-phase voltage. Set the B-phase current source to 2 amperes, at the same angle as the B-phase voltage.

8. Turn the relay power back on, execute the ACCESS command, and enter the password **OTTER** again. Now with potentials applied to the relay, the A4 relay should open.

9. The voltages and currents can now be measured with the METER command. With applied voltages of 67 volts per phase, and a potential transformer ratio of 2000, the displayed voltages should be 232.1 kV. With applied currents of 2.0 amperes per phase, and a current transformer ratio of 200, the displayed currents should be 400 amperes.

10. Test the digital relay/fault locator with the voltages and currents listed below. They were obtained assuming a source impedance of 0.2 times the total 100-mile line impedance, and single-end feed, for faults at the indicated locations and types. A BASIC program is included at the end of the manual, which you may find useful when computing the test set settings.

Table 2.1: Fault Locator Test Values

LOCATION	TYPE	VA	VB	VC	IA	IB	IC	UNITS
75 miles	AG	52.89	70.12	70.06	5.11	0.00	0.00	V or A
		0.00	-124	124	-80	0.00	0.00	Degrees
	BC	67.00	56.75	56.75	0.00	7.53	7.53	V or A
		0.00	-126	126	0.00	-170	10	Degrees
85 miles	AG	54.24	69.81	69.76	4.62	0.00	0.00	V or A
		0.00	-124	124	-80	0.00	0.00	Degrees
	BC	67.00	57.69	57.69	0.00	6.81	6.81	V or A
		0.	-125	125	0.00	-170	10	Degrees
125 miles	AG	57.76	69.00	68.97	3.35	0.00	0.00	V or A
		0.00	-123	123	-80	0.00	0.00	Degrees
	BC	67.00	60.20	60.20	0.00	4.93	4.93	V or A
		0.00	-124	124	0.00	-170	10	Degrees

The faults at 75 miles are within Zone 1, since Zone 1 reach is set to 80.0% of a 100-mile line. (See Z1% in the settings above.) The faults at 85 miles are beyond Zone 1, but within the 120-mile setting of Zone 2. (See Z2% in the settings.) The faults at 125 miles are beyond Zone 1 and Zone 2, but within Zone 3, set to 150 miles. (See Z3% in the settings.)

The faults listed above should cause certain combinations of output relays to remain closed and front panel LED's to remain illuminated as long as the fault condition persists. These results are shown in the following table.

Table 2.2: Output Contact and Target LED Results

LOCATION	TYPE	OUTPUT RELAYS	TARGET LED
75 mi	AG	TRIP, A1, A2, A3, A4	**G1**
75 mi	BC	TRIP, A1, A2, A3	**ϕ1**
85 mi	AG	TRIP, A2, A3, A4	**G2**
85 mi	BC	TRIP, A2, A3	**ϕ2**
125 mi	AG	TRIP, A3, A4	**G3**
125 mi	BC	TRIP, A3	**ϕ3**

The output relay A1 at terminals is set to key permissive trip for any Zone 1 fault, Zone 2 fault, and residual time-overcurrent trip (51NT). From the table, output relay A1 should close for all faults except the Zone 3 phase fault.

The residual time-overcurrent trip is monitored with the A2 output relay on terminals. The output relay A2 operates on any of the ground faults shown in the first table since the fault condition persists longer than the 51N time delay, determined by the settings. However, the 51N fault target does not illuminate since the 51N is not the element which caused the trip. If the fault clears before the 51N time is elapsed, then the 51N should not trip.

Reclose initiate and cancel are monitored with the output relays A3 on terminals and A4 on terminals, respectively. The output relay A3 should close for Zone 1 faults only, since the logic mask MRI is set to reclose initiate for Zone 1 ground and phase-to-phase faults.

If any of the faults listed in the first table persist, then relay A4 should close to show that reclose is cancelled. Refer to the Zone 1 faults, if the fault is cleared before the open interval time is elapsed, then the reclose occurs successfully. The reclose cancel (A4) closes only if the reclosure is unsuccessful.

The programming of the output relays A1-A4 and six other logic masks (MRC, MRI, etc.) is explained in detail under the description of the LOGIC command.

For the Zone 1 ground fault, the Zone 1 ground fault target (G1) should illuminate. In general, the displayed targets are selected from the picked-up relay elements at the quarter-cycle at which the TRIP output is first asserted. In this sense, the targets show which elements actually caused the TRIP, even though other elements may also time out after that. The Zone 2 ground fault should illuminate target G2, but not target G1 or G3, and the Zone 3 ground fault should illuminate target G3 only.

For the Zone 1 phase fault, the Zone 1 phase target (01) should illuminate. From the table, only the 02 LED should illuminate for Zone 2 phase-to-phase faults, and the 03 LED should illuminate for a phase fault in Zone 3.

Faults generate a short event report. To see the full event report for the last fault, type **EVENT 1 <ENTER>**. The report provides an eleven-cycle record of the currents, voltages, relay element states, and the states of all contact inputs and outputs. The twelve newest reports are saved.

The relay includes a check for loss-of-potential, such as might occur when a secondary-circuit potential fuse blows. To demonstrate the response of the instrument, be sure the currents are zero or balanced, and turn off one of the three-phase potentials. The relay should respond by closing the A4 relay. (The A4 relay is programmed to follow reclose cancel, which follows LOP, in the example settings.)

This checkout procedure demonstrates only a few of the relay features. Study the Functional Description, Command, and Event Report Sections of this manual to obtain a complete understanding of the relay capabilities. For more test procedures see Section 7: MAINTENANCE AND TESTING.

FUNCTIONAL DESCRIPTION
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FUNCTIONAL DESCRIPTION

INTRODUCTION

This section describes all relay inputs and outputs, relay elements, and the logic equations which relate the inputs, outputs and relay elements.

It also describes the self tests and their effects on system operation.

INPUTS AND OUTPUTS

Serial Interfaces

The SEL-221D relay is equipped with two EIA RS-232-C serial communication ports. PORT 2 has 9-pin connectors on both the front and rear panels, designated PORT 2F and PORT 2R, respectively.

PORT 2R, located on the relay rear panel, is typically used with an SEL-DTA Display/ Transducer Adapter, SEL-RD Relay Display, or local printer. PORT 2F is always available for short term local communications with a portable computer or printing terminal. Simply plug the device into the front panel port. The relay automatically discontinues communications with PORT 2R and addresses PORT 2F. When testing or data retrieval is complete, unplug the temporary device from PORT 2F. The relay automatically resumes communication with the device connected to PORT 2R.

Serial communications PORT 1 and the Auxiliary Input for demodulated IRIG-B time code input remain on the relay rear panel.

The baud rate for each port is set by jumpers near the front of the main board. You can access these jumpers by removing either the top cover or front panel. Available baud rates are 300, 600, 1200, 2400, 4800, or 9600.

Caution: Do not select two baud rates for the same port as this can damage the relay baud rate generator. The relay is shipped with PORT 1 set to 300 baud and PORT 2 set to 2400 baud.

The serial data format is:

Eight data bits
Two stop bits
No parity

This format may not be changed. The serial communications protocol appears in Section 4.

The SEL-121D relay does not include a front panel serial data interface.

Input Power

Terminals marked + and - should be connected to a source of control voltage. Polarity of dc power is unimportant. Power requirement is about 12 watts. Terminal marked GND should be wired to the relay rack ground reference. It connects to the instrument frame.

Contact Inputs

Six input circuits are provided. They are listed below:

Direct Trip	Direct Close
Permissive Trip	52A Monitor
Block Trip	External Trigger

To assert an input, nominal control voltage is applied to the appropriate terminal pair. Polarity is unimportant. The table below shows input parameters:

Rated Control Voltage	Contact Input Range
24 Vdc	10 - 30 Vdc
48 Vdc	25 - 60 Vdc
125 Vdc	60 - 200 Vdc
250 Vdc	200 - 280 Vdc

The functions of the inputs are explained below.

Direct Trip (DT):

Assertion of the DT input causes the TRIP output to close immediately and unconditionally if so enabled (See LOGIC MTU command). It also cancels any reclose initiation or reclose sequence if so enabled in the MRC mask (see LOGIC MRC command), and triggers an event report. The TRIP output remains closed as long as the DT input is asserted, and drops out about 0.5 cycle after the DT input deasserts or about 60 ms after the TRIP output first closed, whichever is later. Applications include reclose cancel, test trip, and DUTT schemes. (The OPEN command has the same effect as the DT input.)

Direct Close (DC):

The DC input causes the CLOSE output to close, as long as no fault is detected, and the 52A input is not asserted. The CLOSE output stays closed until the 52A input asserts, or until the reclosing relay reset interval expires, whichever occurs first. No event report is triggered. (The CLOSE command has the same effect as the DC input.)

Permissive Trip (PT):

The PT input is normally used in permissive transfer tripping schemes. When it asserts, an event is triggered and additional tripping conditions are allowed, as selected in the logic setting procedure (See the LOGIC MPT command).

Block Trip (BT):

The BT input is normally used in blocking schemes. When it is not asserted, selected tripping conditions are allowed (See the LOGIC MTB command). This input also triggers an event report.

Circuit Breaker Monitor (52A):

The 52A input indicates the state of the breaker, is used by the tripping and closing functions, and is used in the reclosing relay.

External Trigger for Event Report (ET):

An event report is triggered whenever the external trigger input is asserted. Asserting this input does not influence the protective functions in any way.

Relay Outputs

Seven output relays are provided. They are listed below with their contact types.

Output Relay	Contact Type
TRIP	a
CLOSE	a or b
A1	a or b
A2	a or b
A3	a or b
A4	a or b
ALARM	a or b

All relay contacts are rated for circuit breaker tripping duty.

Of the seven output relays, three perform fixed functions, and four are programmable using the LOGIC command.

TRIP Output:

This output closes for any number of conditions selectable by the user. The conditions are grouped as follows: unconditional, subject to PT input assertion, subject to the absence of BT input, subject to the breaker being open. The TRIP output never closes for less than 60 ms. After this interval, it opens when the fault condition vanishes, and the breaker appears open, as judged by the 52A input, or when the TARGET RESET button is pressed, which facilitates relay testing without the use of a breaker simulator.

CLOSE Output:

This output closes for reclose operations, assertion of the DC input, and in response to the CLOSE command. It opens when the 52A input is asserted, or after the reclosing relay reset interval, whichever occurs first.

ALARM Output:

The ALARM output closes for the following conditions:

Three unsuccessful Level 1 access attempts: 1 second pulse
Any Level 2 access attempt: 1 second pulse
Self test failures: permanent contact closure or 1 second pulse depending on which self test fails

The ALARM output also closes for about eight seconds when settings are changed.

Programmable Outputs (A1, A2, A3, A4):

These four outputs may be assigned to any combination of the bits in the Relay Word. These include the following:

Zone 1 three-phase faults
Zone 2 three-phase faults
Zone 3 three-phase faults

Zone 1 phase-phase faults
Zone 2 phase-phase faults
Zone 3 phase-phase faults

Zone 1 ground faults
Zone 2 ground faults
Zone 3 ground faults

Time-overcurrent element trip
Time-overcurrent element pickup

Main trip output
Main close output
Reclose initiate
Reclose cancel

Potential Inputs

The potential inputs should be driven from a set of two potential transformers connected in an open-delta configuration. Inside the relay is a set of three input transformers connected in a three-phase, three-wire, delta connection. Note the relay estimates the zero-sequence voltage for ground fault locating from the product of a setting for the zero-sequence source impedance and the measured zero-sequence current. The nominal voltage rating is 115 volts line-to-line.

Current Inputs

The rating of the input transformers in the relay is 15 amperes continuous, and 500 amperes for one second.

IRIG-B Input Description

The port labelled J201/AUX INPUT is for the demodulated IRIG-B time code input.

The actual IRIG-B input circuit is a 56 ohm resistor in series with a opto-coupler input diode. The input diode has a forward drop of about 1.5 volts. Driver circuits should be designed to put approximately 10 mA through the diode when "on".

The IRIG-B serial format consists of a one second long, 100 pulse code divided into fields. The relay decodes the second, minute, hour and day fields.

When IRIG-B data acquisition is activated, either manually with the IRIG command or automatically, two consecutive frames are taken. The older frame is updated by one second, then the frames are compared. If the frames do not agree, the data are considered erroneous and discarded.

Automatic execution is invoked about once every five minutes, except about midnight on New Year's Eve. At this time IRIG-B data acquisition is halted so the system clock may implement the year change without interference from the IRIG-B clock.

DEFINITION OF LOGIC VARIABLES

The relay output relay states depend on the following:

Relay elements
Contact-monitoring inputs
Setting parameters
Logic programming
Commands received over communications link
Status of self-tests

Since so many binary variables are involved, we define the functioning using Boolean logic equations. The logic variables involved are defined below.

Relay Elements

Single-phase overcurrent relays	50AL 50BL 50CL	(Phase fault detectors)
Single-phase overcurrent relays	50AG 50BG 50CG	(Used in REJO logic)
Medium-set single phase OC relays	50AM 50BM 50CM	(Selectable for loss-of-pot)
High-set single phase OC relays	50AH 50BH 50CH	(Always available)

Zone 3 three-phase mho distance	21ABC3	(Reversible)
Zone 3 line-line mho distance	21P3	(Reversible)
Zone 2 three-phase mho distance	21ABC2	
Zone 2 line-line mho distance	21P2	
Zone 1 three-phase mho distance	21ABC1	(Includes delay if Z1DG not 0.00)
Zone 1 line-line mho distance	21P1	(Includes delay if Z1DG not 0.00)
Residual time-overcurrent pickup	**51NP**	T.C. or nondirectional
Residual time-overcurrent trip	**51NT**	T.C. or nondirectional
Residual inst-overcurrent	50N1	Nondirectional
Residual inst-overcurrent	50N2	Nondirectional
Residual inst-overcurrent	50N3	Nondirectional
Negative-sequence directional	32Q	32QF=forward; 32QR=reverse
Zero-sequence directional	32I	32IF=forward; 32IR=reverse
Negative-sequence overvoltage	47QL	Used for loss-of-potential detection
Negative-sequence overvoltage	47QH	Used for loss-of-potential detection
Negative-sequence overcurrent	46QL	Used for loss-of-potential detection
Positive-sequence overvoltage	47P	Used for loss-of-potential detection

Timers

Z2DG	Zone 2 ground timer timeout operated by **67N2**	
Z3DG	Zone 3 ground timer timeout operated by **67N3**	
Z2DP	Zone 2 phase timer timeout operated by **Z2P** or **2ABC**	
Z3DP	Zone 3 phase timer timeout operated by **Z3P** or **3ABC**	
52AT	Time delayed 52A (pickup and dropout)	(52BT setting)
52BT	Inverse of 52AT	(52BT setting)

Note: 52AT follows the 52A input after a settable time delay given by the 52BT setting.

79OI1	Reclosing relay first open interval expired
79OI2	Reclosing relay second open interval expired
79OI3	Reclosing relay third open interval expired
79RS	Reclosing relay reset interval timer expired

Enables from setting procedures

ZONE3	Zone 3 reach direction (F=Forward, R=Reverse)
32QE	Enables 32Q
32IE	Enables 32I
51NTC	Selects directional torque control for 51N
LOPE	Loss-of-potential enable
REJOE	Remote-end-just-opened enable

Contact Inputs

DT	Direct trip
PT	Permissive trip
BT	Block trip
DC	Direct close
52A	Circuit breaker monitor
EXT	External trigger for event report

Contact Outputs

TRIP	Circuit breaker trip
CLOSE	Circuit breaker close
A1	Programmable output 1
A2	Programmable output 2
A3	Programmable output 3
A4	Programmable output 4
ALARM	System alarm

INTERMEDIATE LOGIC

The logic equations developed below represent combinations of the relay elements and other conditions. In the following equations the "*" indicates logical "and," and the "+" indicates logical "or."

Set LOP	=	47QL * NOT (46QL)	(negative-sequence set condition includes a three cycle pickup delay)
		+ NOT (47P) * NOT (**50M**)	
Clear LOP	=	NOT (47QL) * 47P	

(The different set and clear conditions ensure LOP stays latched during subsequent faults, but is cleared when balanced voltages and currents return.)

50L	=	50AL + 50BL + 50CL	Phase fault current supervision
3P50	=	50AL * 50BL * 50CL	Three-phase fault current supervision
50G	=	50AG + 50BG + 50CG	REJO Phase overcurrent element
3G50	=	50AG * 50BG * 50CG	Three-phase overcurrent element
3G50D	=	3G50 * (2 cycle TDDO)	
50M	=	50AM + 50BM + 50CM	Medium-level overcurrent condition
50MF	=	50M * (**LOP** + NOT(LOPE)) * 50MFD	Asserts a settable delay after LOP and 50M overcurrent
50H	=	50AH + 50BH + 50CH	High-level overcurrent condition
3ABC	=	21ABC3 * **3P50** * NOT (**LOP** * LOPE)	(3ABC in Relay Word)
2ABC	=	21ABC2 * **3P50** * NOT (**LOP** * LOPE)	(2ABC in Relay Word)
1ABC	=	21ABC1 * **3P50** * NOT (**LOP** * LOPE)	(1ABC in Relay Word)
Z3P	=	21P3 * **50L** * NOT (**LOP** * LOPE)	(Reversible)
Z2P	=	21P2 * **50L** * NOT (**LOP** * LOPE)	
Z1P	=	21P1 * **50L** * NOT (**LOP** * LOPE)	
DF	=	[32QF + **LOP** * LOPE] * 32QE + 32IF * 32IE + NOT(32QE + 32IE)	Forward direction
DR	=	32QR * 32QE + 32IR * 32IE	Reverse direction
D3	=	**DF** if Zone 3 is forward	
D3	=	DR if Zone 3 is reverse	
67N1	=	50N1 * **DF**	
67N2	=	50N2 * **DF**	
67N3	=	50N3 * D3	(Reversible)

Note: When directional elements are both disabled (32QE = 32IE = N), the **DF** (directional forward) bit defaults forward. The Zone 3 ground element will not operate under this condition, when Zone 3 is reversed.

Z3PT	=	(**Z3P** + **3ABC**) * Z3DP	Zone 3 timeout-phase
Z2PT	=	(**Z2P** + **2ABC**) * Z2DP	Zone 2 timeout-phase
Z3GT	=	**67N3** * Z3DG	Zone 3 timeout-ground
Z2GT	=	**67N2** * Z2DG	Zone 2 timeout-ground

RELAY WORD

Relay elements and intermediate logic results are represented in a 32-bit Relay Word (grouped into four 8-bit words). The user selects bits in this word to perform his desired functions for controlling outputs and for initiating or cancelling reclose. The selected bits are stored in masks for each function. The user programs the bits in these masks with the LOGIC command.

Table 3.1: Relay Word

1ABC	2ABC	3ABC	REJO	LOP	50H	50M	50L
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Z2PT	Z3PT	50G	3P50	50MF	RC	RI	DF
ALRM	TRIP	TC	DT	52BT	52AT	Z2GT	Z3GT

The meaning of each bit in the Relay Word is explained in the Relay Word Bit Summary Table below:

Table 3.2: Relay Word Bit Summary Table

1ABC	-	Zone 1 three-phase element (set by Z1%)
2ABC	-	Zone 2 three-phase element (set by Z2%)
3ABC	-	Zone 3 three-phase element (set by Z3%)
REJO	-	Remote-end-just-opened
LOP	-	Loss-of-potential condition
50H	-	High-level overcurrent element (set by 50H)
50M	-	Medium-level overcurrent element (set by 50M)
50L	-	Phase fault current supervision (set by 50L)
51NT	-	Residual time-overcurrent trip
67N1	-	Residual instantaneous-overcurrent (directional or nondirectional)
67N2	-	Residual instantaneous-overcurrent (directional or nondirectional)
67N3	-	Residual instantaneous-overcurrent (directional or nondirectional)
51NP	-	Residual time-overcurrent pickup
Z1P	-	Zone 1 line-line element (set by Z1%)
Z2P	-	Zone 2 line-line element (set by Z2%)
Z3P	-	Zone 3 line-line element (set by Z3%)
Z2PT	-	Zone 2 timeout-phase
Z3PT	-	Zone 3 timeout-phase
50G	-	REJO phase overcurrent element
3P50	-	Three-phase fault current supervision
50MF	-	Asserts a settable delay after LOP and 50M pickup
RC	-	Reclose cancel
RI	-	Reclose initiate
DF	-	Direction forward
ALRM	-	System alarm
TRIP	-	Circuit breaker trip
TC	-	Trip (open) command
DT	-	Direct trip from DT input
52BT	-	Inverse of 52AT
52AT	-	Time delayed 52A
Z2GT	-	Zone 2 timeout-ground
Z3GT	-	Zone 3 timeout-ground

The use of the Relay Word and programmable masks provides the user with great flexibility in applying the SEL-221D, without rewiring panels or changing jumpers on circuit boards.

OUTPUT EQUATIONS

The logic for controlling the TRIP, A1, A2, A3 and A4 output relays is programmable for flexibility and for testing. The logic is programmed by setting masks for various conditions, which are applied to the general Relay Word.

The general forms for each of the output equations follow:

Let R	=	Relay Word
MTU	=	mask for trip (unconditional)
MPT	=	mask for trip (permissive trip)
MTB	=	mask for trip (with no blocking)
MTO	=	mask for trip (with breaker open)

Then:

TRIP = R * MTU
+ R * MPT * (PT + **REJO** * REJOE)
+ R * MTB * NOT (BT)
+ R * MTO * **52BT**

Close TRIP = **TRIP**
Open TRIP = NOT (**TRIP**) * NOT(52A + TARGET RESET button pushed) * (60 ms minimum TRIP)
close CLOSE = (DC + 79OI1 + 79OI2 + 79OI3 + CLOSE command) * 52BT
open CLOSE = NOT (CLOSE) + 79RS

A1 = R * MA1
A2 = R * MA2
A3 = R * MA3
A4 = R * MA4

The "*" symbol indicates logical "and," and the "+" indicates logical "or."

PILOTLESS ACCELERATED TRIP SCHEMES

The following discussion provides an overview of pilotless accelerated trip schemes. This description is followed by a detailed explanation of the scheme implementation in the SEL-221D relay.

In many lower voltage transmission applications, the cost of communication equipment for line protection is not justifiable. In these installations, it is still possible to achieve accelerated trip times. We can do this because certain system conditions indicate in-section faults.

Viewing the system shown in Figure 3.1, we know that after Breaker 2 clears its contribution to the fault, only fault current through the B-phase breaker pole can flow through Breaker 1.

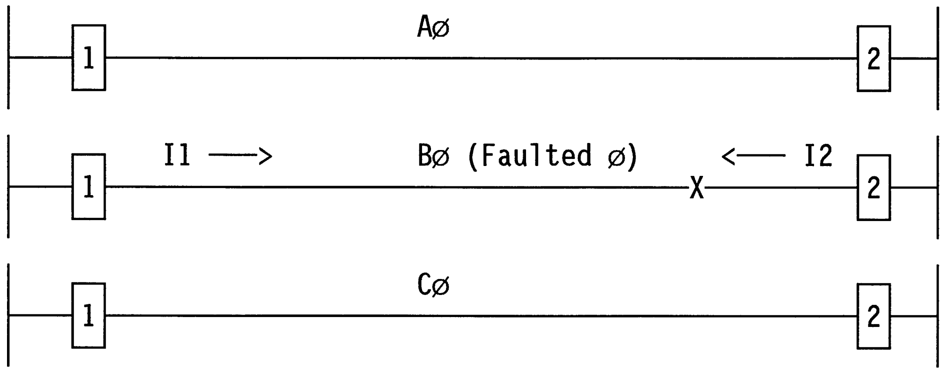


Figure 3.1: Faulted System with Breakers 1 and 2 Closed

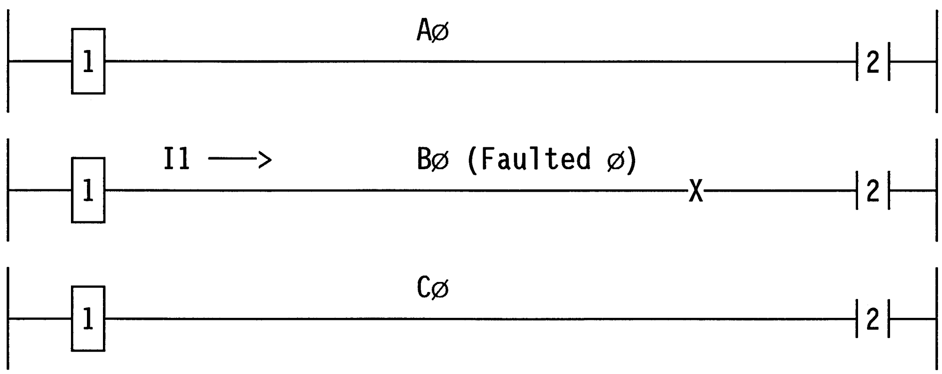


Figure 3.2: Faulted System with Breaker 2 Open

If the following conditions are met, they may be used in the same way as a received permissive signal from the remote end without requiring a communications channel:

1. Three-phase load was present before the fault, so the remote end of the transmission line was closed.

2. Three-phase current was lost, which shows that the remote end of the transmission line opened its breaker.

3. Current above a certain threshold is detected in at least one of the three phases, indicating a possible fault.

When all these conditions are met and an overreaching protective element asserts, the relay can issue an accelerated trip.

PILOTLESS TRIPPING WITH THE SEL-221D RELAY

Overcurrent elements used by the REJO function are defined using "+" as logical OR and "*" as logical AND:

50G = 50AG + 50BG + 50CG	50G asserts when any phase current is above the 50G setting.
3G50 = 50AG * 50BG * 50CG	3G50 asserts when all three phase currents are above the 50G setting.
3G50D = 3G50 * (2 cycle TDDO)	3G50D is an instantaneous pickup, two-cycle time delayed dropout 3G50 element.

TDDO ≡ Time delayed dropout

The relay sets or clears the overcurrent elements based on the following conditions:

1. The 3G50 element is set by three-phase load current.
2. The 3G50D element indicates that load current was present until at least two cycles ago.
3. If the 50G element is picked up, current is still flowing in at least one-phase.
4. The REJO element is defined by the following logic equation:

REJO = NOT(3G50) * 3G50D * 50G * (½ cyc pu/inst do)

Three-phase load is no longer present, but was at least two cycles ago, current is still flowing in at least one phase, and these conditions are maintained for at least half-cycle.

The relay uses the REJO bit in two places: as a qualifier for permissive tripping and as an indicator in the Relay Word.

If the REJO function is enabled (REJOE = Y in the relay settings), the REJO condition is used as a qualifier for permissive tripping.

Thus, when REJOE=Y and a REJO condition is detected, elements set in the MPT logic mask are enabled. You can set the MPT mask as if the relay were being used in a permissive tripping scheme, including instantaneous Zone 2 phase distance (Z2P and 2ABC) and ground directional overcurrent (67N2) elements.

The REJO bit need not be set in any of the tripping logic masks to enable this function.

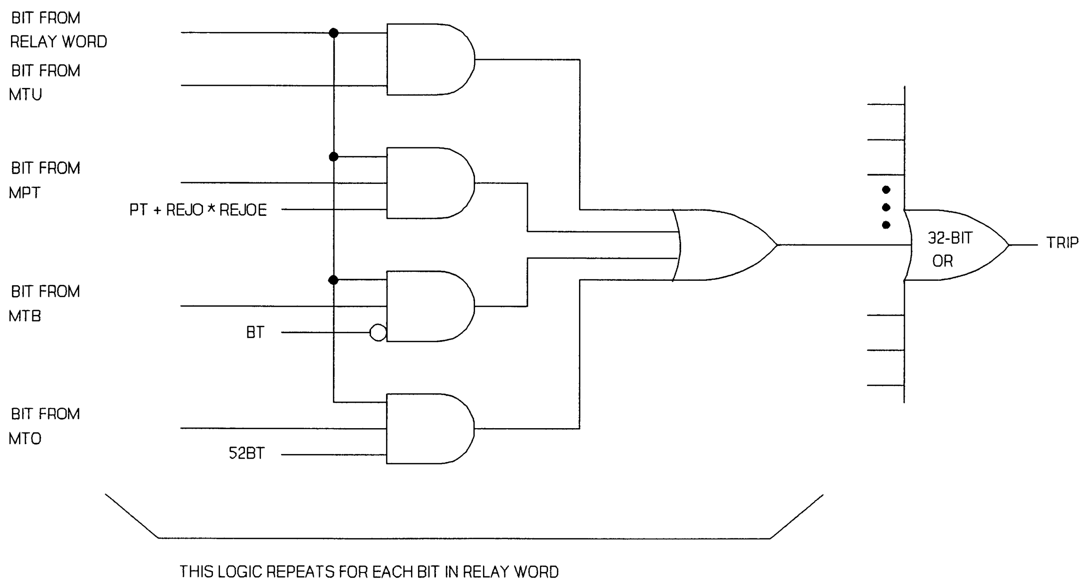


Figure 3.3: SEL-221D Programmable Trip Logic Diagram

RECLOSING RELAY

The reclosing relay provides up to three shots of automatic reclosing for selectable fault types and relay elements contained in the 32-bit Relay Word. The programmable logic provides access to the internally derived reclose initiate and cancel signals. It also allows for external initiation and cancellation of reclosing. The three open intervals and the reset timer are individually settable using the SET command.

To provide flexibility in applying the relay to various reclosing schemes, the conditions for reclose initiation and cancellation are selected in a similar way to the programming of the output relays:

RI = R * MRI
RC = R * MRC

where MRI is the mask for reclose initiation, and MRC is the mask for reclose cancellation.

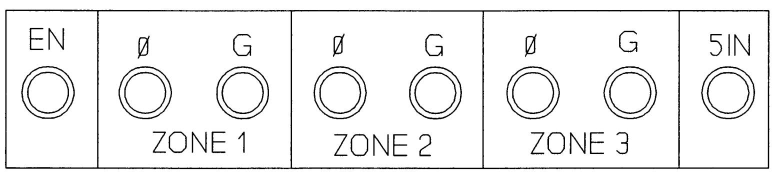
The open intervals do not begin until the TRIP output deasserts. Since the TRIP output never asserts for less than 60 ms, the open interval may start several milliseconds after the fault has actually cleared and the breaker opened.

Reclose is automatically cancelled when the circuit breaker is observed to trip when a fault condition is not present.

Reclose is automatically cancelled for faults during the open interval of any shot. For this reason, care must be taken to coordinate the 52BT delay with the open interval settings. If the 52BT timer expires before the open interval, then the reclose sequence could be prematurely cancelled, the relay being overly sensitive due to possible MTO logic settings.

TARGETS

The front panel targets are shown below.



The enable light (EN) indicates normal operation.

The next six indicators show the phase and ground element status for all three zones. The last light shows the status of the residual time-overcurrent element.

The relay targets display the latest relay element condition at the time of tripping. For example, the Zone 1 ground fault indicator illuminates for a Zone 1 ground fault if the fault caused a trip to occur. The other five fault targets illuminate for appropriate faults when their time delays expire at the time that tripping occurs.

To clear the targets, press the TARGET RESET button. All eight indicators illuminate for about one second, as a lamp test. After that, the fault targets are cleared, and the enable light shows the operational state of the relay again. Also, the targets are cleared after a new fault occurs, but before the new fault targets are presented, so that the targets show the most recent fault. Furthermore, pressing the TARGET RESET button unlatches the TRIP output from the 52A input. This feature is useful during testing, and it minimizes the risk of re-installing the relay with the TRIP output asserted.

Other types of targeting options are available from SEL. For more information refer to the FIRMWARE IDENTIFICATION Section in the EVENT REPORTING Chapter of this manual.

SELF TESTS

The SEL-221D runs a variety of self tests that ensures reliable operation. This section describes each test and what steps are taken if the test fails. Some tests have warning and failure states, while others, such as the A/D test, only have failure states. Any change in self test status results in the generation of a status report.

Failure of any test causes the relay to deenergize the coil of the ALARM output relay. Failures that disable the control functions also place the output relay driver port in an input mode so that no A-contact outputs may be asserted. All self tests are run on power up before the relay is enabled, or prior to enabling the relay after using the setting procedure. Afterwards all self tests are run at least every few minutes.

Offset

The offset voltage of each channel of the analog input electronics is measured and compared against fixed limits. A warning is issued when the offset is measured to be greater than 50 millivolts in any channel. A failure is declared when the offset exceeds 75 millivolts. The STATUS command format is used to display the levels of the offsets of all channels.

Power Supply

The power supply voltages are limit-checked. The table on the next page summarizes the voltage limits.

Table 3.3: Power Supply Self Test Limits

Supply	Warning Thresholds		Failure Thresholds	
+5 V	+5.3 V	+4.7 V	+5.4 V	+4.6 V
+15 V	+15.8 V	+14.2 V	+16.2 V	+13.8 V
-15 V	-15.8 V	-14.2 V	-16.2 V	-13.8 V

The STATUS command response is transmitted for any failure or warning. A failure of the +5 volt supply causes all output relays to be de-energized and blocked from operation. A failure of the ±15 volt supplies disables protective relay functions, but does not disable control functions. The ALARM relay remains closed for a power supply failure.

Random-Access Memory

The random-access memory (RAM) is periodically checked to ensure that each byte can be written to and read from correctly. There is no warning state for this test. If a problem is detected, the STATUS command message is transmitted. It contains the socket designation of the affected RAM IC. Protective and control functions are disabled for a RAM failure, and the ALARM output relay contacts close.

Read-Only Memory

The read-only memory (ROM) is periodically tested by computing a checksum. If the computed value does not agree with the stored value, a ROM failure is declared. The STATUS command response is transmitted, all protection and control functions are disabled, and the ALARM relay contacts close.

Analog-to-Digital Converter

The analog-to-digital converter (ADC) changes voltage signals derived from the power system voltages and currents into numbers for processing by the microcomputer. The ADC test determines if the converter is functioning by checking its conversion time. If the conversion time is excessive, or if a conversion is started and never finishes, then the test fails. There is no warning state for this test. Failure of the ADC causes the protective functions to be disabled, but the control functions are retained. The STATUS command response is transmitted and the ALARM relay contacts close for a failure of this test.

Settings

Two images of the system settings are stored in nonvolatile memory. These are compared when the relay is initially set, and periodically thereafter. Should the images ever disagree, the setting test fails, and all protection and control functions are disabled. The STATUS message is transmitted to indicate the failed test. The ALARM relay remains closed for a setting failure.

SETTING PROCEDURE

Relay settings are entered using the SET and LOGIC commands, via either of the serial interface ports. The settings are stored in nonvolatile memory, so that they are retained when the power is off.

The SET and LOGIC command descriptions explain how to enter settings.

EVENT REPORT

The relay records an eleven-cycle event report following any of these events:

Zone 1 fault	Zone 2 fault	Zone 3 fault
51N pickup	50H pickup	Direct trip
External trigger	Block trip	Permissive trip
TRIGGER command	OPEN command	

A second report is triggered for the same fault if the trip occurs after the first report expires, so the beginning and end of each fault for which the relay trips is recorded. (Note that reports are triggered at the 16th quarter-cycle of data.) Another event report can be triggered by assertion of the input contacts listed above, even though a fault condition is still present.

Timing of the triggering instant is recorded to the nearest quarter-cycle, so that the duration of long faults can be computed from the time the first report is triggered by the fault, and the time the second report is triggered by the trip. The reported event time corresponds to the 16th quarter-cycle of the event report, in all cases. The event report contains voltages, currents, system settings, and other information. It is described in detail in the EVENT REPORTING Section.

Execution of the CLOSE command does not trigger an event. Direct close, by asserting the DIRECT CLOSE input, does not trigger an event.

The twelve most-recent event reports are stored in memory, and may be retrieved using the EVENT command. A short history of the twelve most-recent events is available using the HISTORY command.

FAULT LOCATOR

The relay fault locator is automatically triggered by any of several events. These events include pickup of certain relay elements, assertion of certain contact inputs or outputs, and user entered commands. However, the fault locator can be either enabled or disabled with LOCAT setting in the setting procedure.

Specifically, the triggering events are:

(1) RELAY ELEMENTS (high level trigger)
Three-phase distance Zones 1, 2, or 3
Two-phase distance Zones 1, 2, or 3
Ground overcurrent Zones 1, 2, or 3, and 51N pickup
Phase overcurrent element 50H

(2) CONTACT INPUTS (rising edge trigger)
External Trigger
Direct Trip
Permissive Trip
Block Trip

(3) CONTACT OUTPUTS (rising edge trigger)
TRIP

(4) USER ENTERED COMMANDS (rising edge trigger)
Trigger

Note that the fault locator is triggered by the relay elements in a level sensitive manner. That is, additional event reports are not generated when additional relay elements pick up. Only the first relay element of any contiguous sequence triggers an event report.

Furthermore, all triggering relay elements must drop out for at least four cycles before they may initiate another event report. (This helps eliminate triggering multiple records for boundary faults.)

All other triggering events are rising edge sensitive, meaning that for these events, additional reports are generated even while any or all relay elements remain picked up. This strategy permits the recording of fault clearing even when it occurs long after the initial event report is completed.

The fault location is always determined for event records in which any triggering relay elements are picked up, providing that midfault does not occur within the first seven rows or the last three rows of the event report. (Midfault is defined as the middle of the first contiguous segment where at least one triggering relay element remains picked up.) Furthermore, whenever the locator is able to determine the fault location, the corresponding record is labeled according to fault type, regardless of what actually triggered the event report. On the other hand, event records taken when no triggering relay elements are picked up are labeled as follows:

"EXT" for reports triggered externally via input contacts, or by the "TRIGGER" command.

or

"TRIP" for reports triggered by the assertion of the "TRIP" output contact.

The actual fault location algorithm is composed of two steps. First the fault type must be determined, and then the location calculated.

For the event reports, the fault type is determined largely independently of the relay element operations. Only the indicated zone is determined by relay elements, whereas the involved phases are determined by fault current comparison. (This is different from the TARGET data, which is completely derived from relay element operations.)

The compared currents are taken from the two rows at the middle of the stored fault data. If the uncompensated current magnitudes are in large ratios between phases (4:1 or more), then the fault type becomes immediately apparent as single- or two-phase. If not, the same current is load compensated by the two corresponding prefault current rows in the first cycle of the event report. If these fault current component magnitudes are in moderate ratios (1.5:1 or more), then the fault type is taken as single- or two-phase, or if the ratios are all less than 1.5, then the fault type is taken as three-phase. The explicit fault classification logic is as follows, where I values are uncompensated midfault currents, and IF values are midfault currents compensated for load, yielding true fault current components:

```
      IF  ( Imax  >   4 x Imed  )  THEN Single-phase
 ELSE IF  ( Imed  >   4 x Imin  )  THEN Two-phase
 ELSE IF  ( Ifmax > 1.5 x Ifmed )  THEN Single-phase
 ELSE IF  ( Ifmed > 1.5 x Ifmin )  THEN Two-phase
 ELSE IF  (  none of the above  )  THEN Three-phase
```

This algorithm is largely immune to load and system grounding variations.

Once the fault type is determined, the fault locator employs the Takagi algorithm to locate the fault. Using both prefault and fault data, it compensates for the errors introduced by fault resistance in the presence of load flow. On the other hand, if no prefault data are provided by the event record, the relay gives a location based on a simple reactance measurement.

The fault locator depends on accurate transmission line parameters and instrument transformer ratios. Pay special attention to these potential sources of difficulty:

1. Instrument transformer ratio errors due to overburden by other devices.
2. Capacitive potential transformer capacitor value.
3. Transmission line parameter errors.

Although the fault-location computation takes several seconds, faults in quick succession, such as occur in a reclosing sequence, are handled. This is because the fault data are stored, and subsequently processed in turn. As an example, suppose three faults occur within a few seconds. The data from these faults are stored as they occur. The fault-location computations begin with the first (oldest) fault and proceed until all three faults are processed. Each of the summary event reports is transmitted as soon as the corresponding fault location is available.

The relay locates phase-to-ground faults even though it measures phase voltages. It uses an estimate of the zero-sequence voltage, since no measurement is available from the measured line-to-line voltages. It does this from the product of the zero-sequence source impedance and the measured zero-sequence current.

The voltage VA is determined for an A-phase to ground fault as follows:

$$VA = V1 + V2 + V0 \text{ and } V1 + V2 = 1/3\ [\ VAB - VCA\ ]$$
$$VA = 1/3\ [\ VAB - VCA\ ] + V0$$

where V1 is the positive-sequence voltage, V2 is the negative-sequence, and V0 is the zero-sequence voltage. This is easily shown by rewriting the equation:

$$VA = 1/3 [VA - VB + VA - VC] + 1/3 [VA + VB + VC]$$

The zero-sequence voltage is therefore the component needed to reconstruct VA, given only the line-to-line input voltages. Although it is unavailable in the line-to-line voltage measurements, it may be computed as follows:

$$V0 = - [Z0S \times I0]$$

where Z0S is the zero-sequence source impedance, and I0 is the zero-sequence current.

Therefore, the computed value for A-phase voltage is:

$$VA = 1/3 [VAB - VCA] - [Z0S \times I0]$$

The constant Z0S is a complex number that is entered in the SET command as R0S and X0S.

Shunt capacitance of the transmission line is not taken into account. The capacitance causes the fault location to appear more remote by, approximately, a factor of 1/cos(bL), where bL is the line length in radians at 60 Hz. One wavelength at 60 Hz is 3100 miles. For example, the line length of a 100-mile line in radians is:

$$(100/3100) \times 2 \times 3.14159 = 0.2027 \text{ radians}$$

The indication neglecting capacitance is about cos (0.2027) = 0.98 times the actual location, or about 2 miles short for a fault at the far end of a 100-mile line.

When compensation using shunt reactors is employed, and when the measured current equals the reactor current plus the line current, the shunt reactors reduce the errors due to neglecting the shunt capacitance of the transmission line.

When series capacitor compensation is used, accurate performance is obtained for faults between the relay and the capacitors, and beyond the capacitors if the capacitor protective gaps flash. If the gaps do not flash, the measured impedance includes the line impedance and the capacitance impedance, and the errors can be substantial. This problem is aggravated by high-speed clearing and the excitation of eigenmodes or resonances of the line-capacitor system, which may not be much removed from 60 Hz. On the other hand, we have had success in cases where series capacitor gaps did not flash, by recomputing the fault location from the event-report data, using a voltage equal to the measured voltage minus the capacitor voltage drop. The latter is computed from the capacitance value and the measured current.

MHO UNITS

The mho circles are affected by these settings: maximum torque angle, set reach, and transmission line (positive-sequence) angle and length. The circles pass through the impedance-plane origin, and the diameter passing through the origin is at an angle of MTA (maximum torque angle) with respect to the resistance axis. The chord passing through the origin at the positive-sequence impedance (Z1) angle of the transmission line has a length equal to the set reach. Therefore the mho circle diameter is:

DIAMETER = [SET REACH]/[cos(T. L. ANGLE - MTA)]

The Zone 3 direction setting determines if the phase and three-phase mho elements of Zone 3 are forward or reverse reaching.

The mho elements are based on the general principles of operation reported by W. K. Sonnemann and H. W. Lensner in the AIEE Transactions, Part III, vol. 77, pp 372-382, June 1958 in their paper entitled "Compensator Distance Relaying." The general principles have been applied successfully in many electromechanical and solid-state designs of several manufacturers. Electromechanical versions use induction cylinders for a product-type phase comparison between the measurands. In the solid-state analog designs, coincident-timing phase comparators are used. In the SEL-221D, the phase comparison is performed by phasor multiplication in the microprocessor.

The inputs for the phase comparators for the various distance functions are listed below:

Function	Input A	Input B
Phase-phase	Vab - Z1 x Iab	Vbc - Z1 x Ibc
Three-phase	Vab - Z1 x Iab	-jVab - 3/8 x Vc (memory)

The constant Z1 is the reach of the relay element in positive-sequence ohms.

DIRECTIONAL ELEMENTS

Either the negative-sequence or the current polarized zero-sequence directional element may be enabled to provide for directional supervision of the residual-overcurrent elements. The Zone 3 direction setting determines if the 67N3 is enabled for forward or reverse faults.

When no directional elements are enabled, the DF bit is always set.

The directional elements are also phasor-product derived. For the negative-sequence element the product is the negative-sequence voltage times the negative-sequence current, adjusted by the maximum torque angle setting.

For the zero-sequence element, the product is the residual current times the polarizing current.

TIME-OVERCURRENT ELEMENT

The 51N time-overcurrent element provides directional-forward or nondirectional protection. Its pickup (51NP) and trip (51NT) states are both available in the Relay Word for programming into any masks.

The time dial and the curve shape are selected in the setting procedure. Four curve shapes are available. The curves are given in this section.

The 51N characteristic is formed by a simple delay (modeling the inertia of an overcurrent relay disk) followed by a recursive sum of the magnitude or magnitude-squared of the residual current, adjusted by the pickup setting.

The time dial setting determines the limit the recursive sum must reach for a trip. The pickup setting is taken care of by scaling the current.

TIME-OVERCURRENT CURVE EQUATIONS

These time curve equations are valid for the phase and residual time-overcurrent elements. Plots showing operating time versus multiples of pickup current are shown on the following pages.

Let t = operating time in seconds,
TD = time dial setting,
M = multiples of pickup.

Curve 1 -- Moderately Inverse

$$t_M = TD \left[0.157 + \frac{0.668}{M-1} \right]$$

Curve 2 -- Inverse

$$t_M = TD \left[0.180 + \frac{5.95}{M^2-1} \right]$$

Curve 3 -- Very Inverse

$$t_M = TD \left[0.0963 + \frac{3.88}{M^2-1} \right]$$

Curve 4 -- Extremely Inverse

$$t_M = TD \left[0.0352 + \frac{5.67}{M^2-1} \right]$$

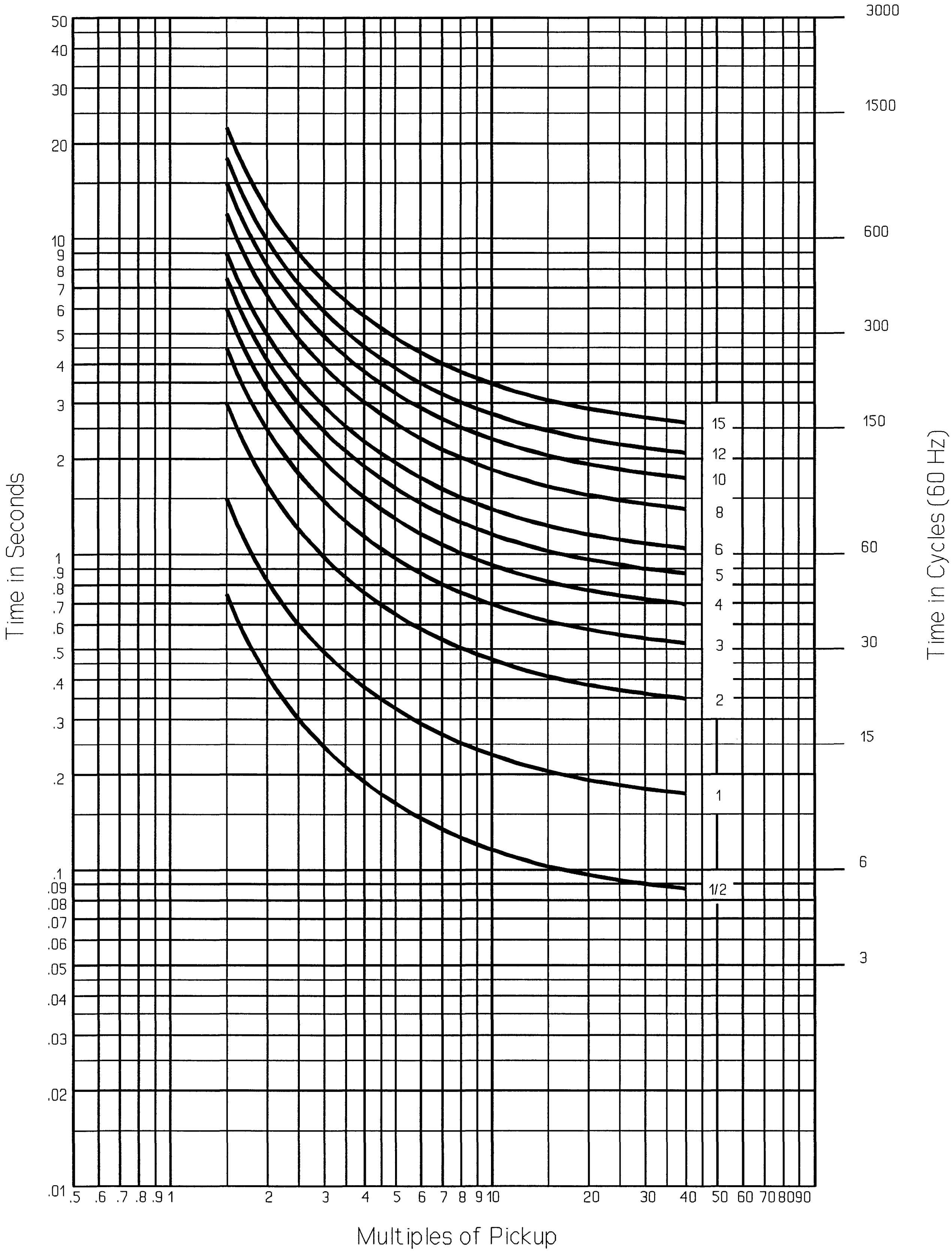


Figure 3.4: Residual Time-Overcurrent Element Moderately Inverse Time Characteristic (Curve 1)

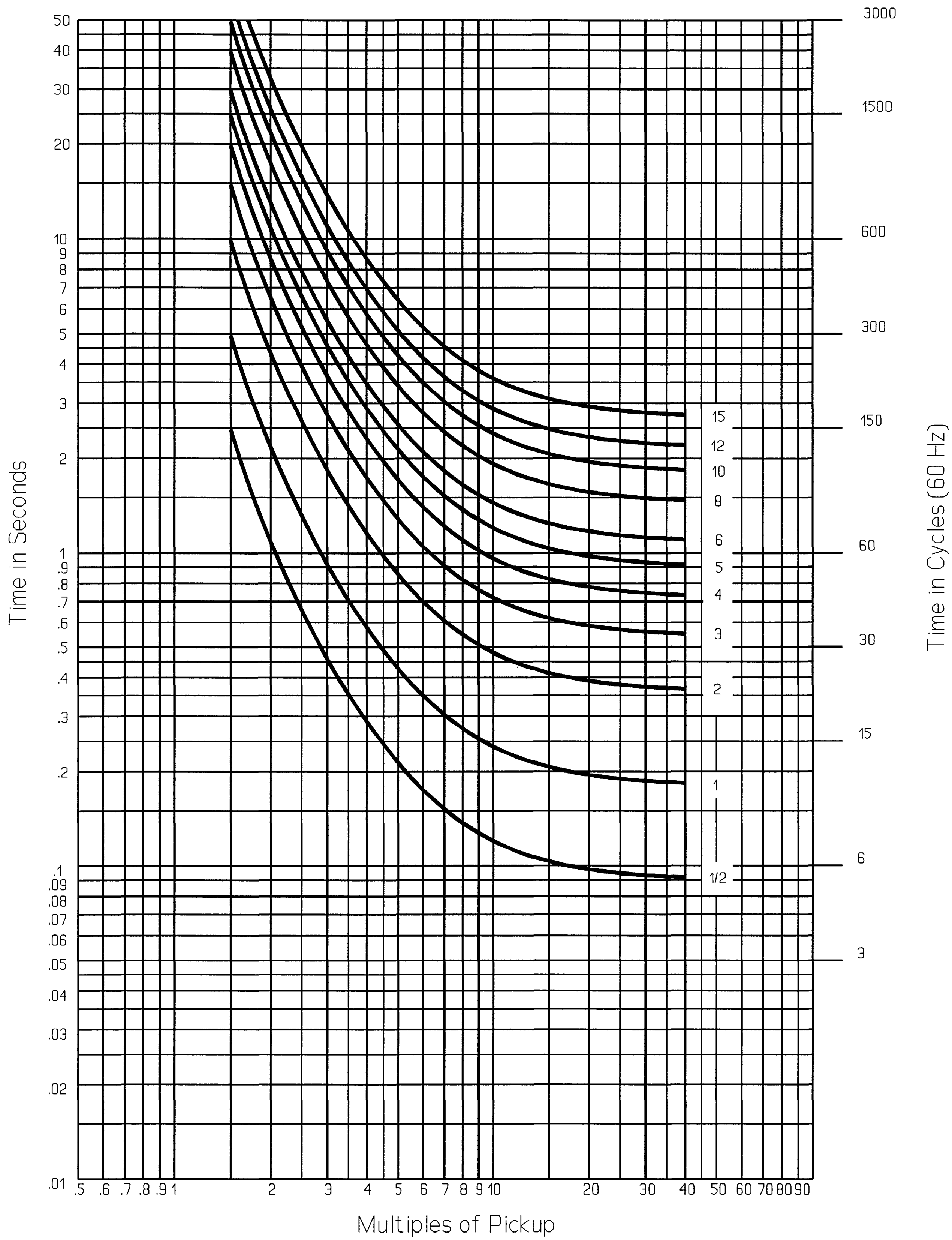


Figure 3.5: Residual Time-Overcurrent Element Inverse Time Characteristic (Curve 2)

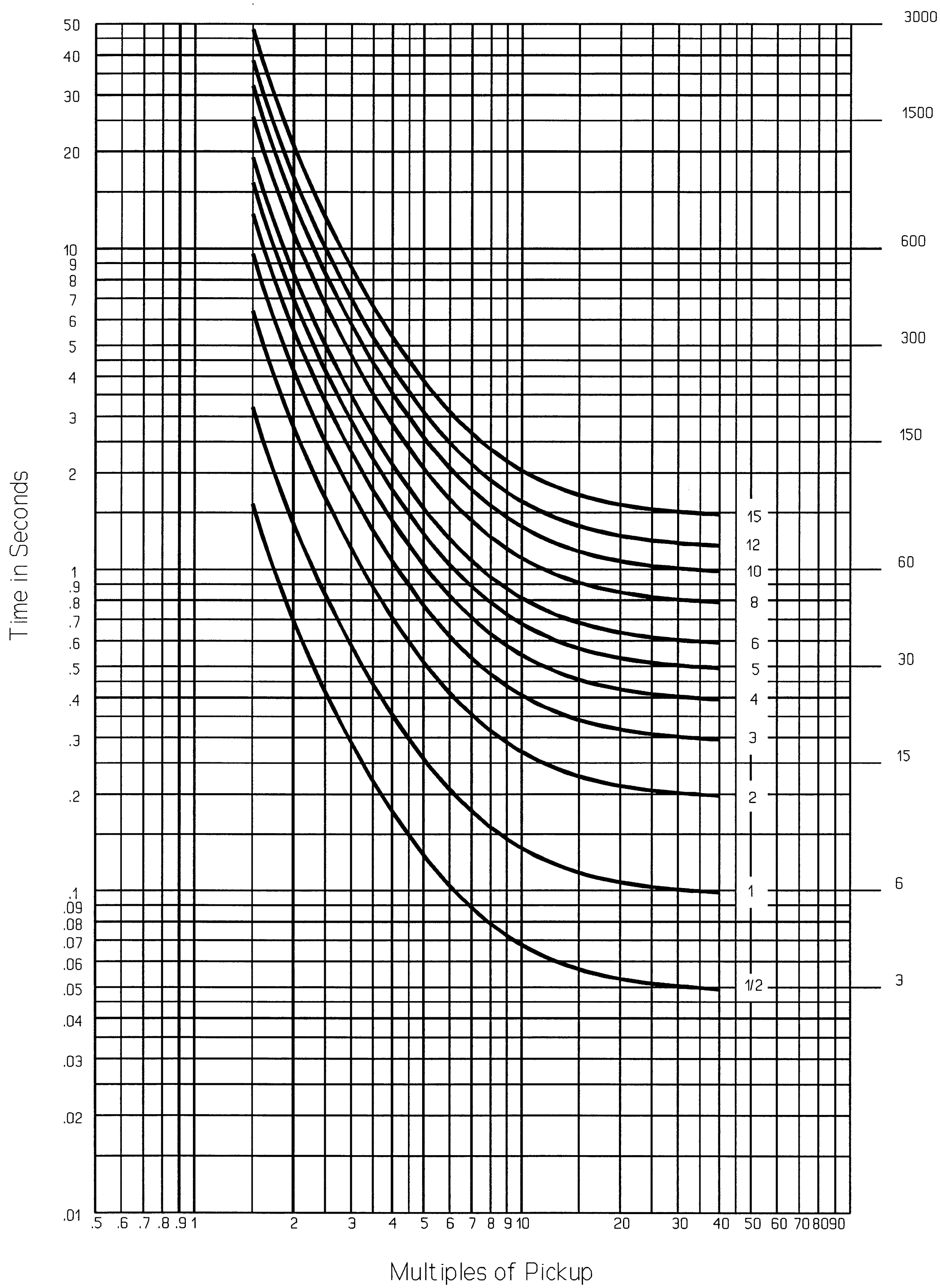


Figure 3.6: Residual Time-Overcurrent Element Very Inverse Time Characteristic (Curve 3)

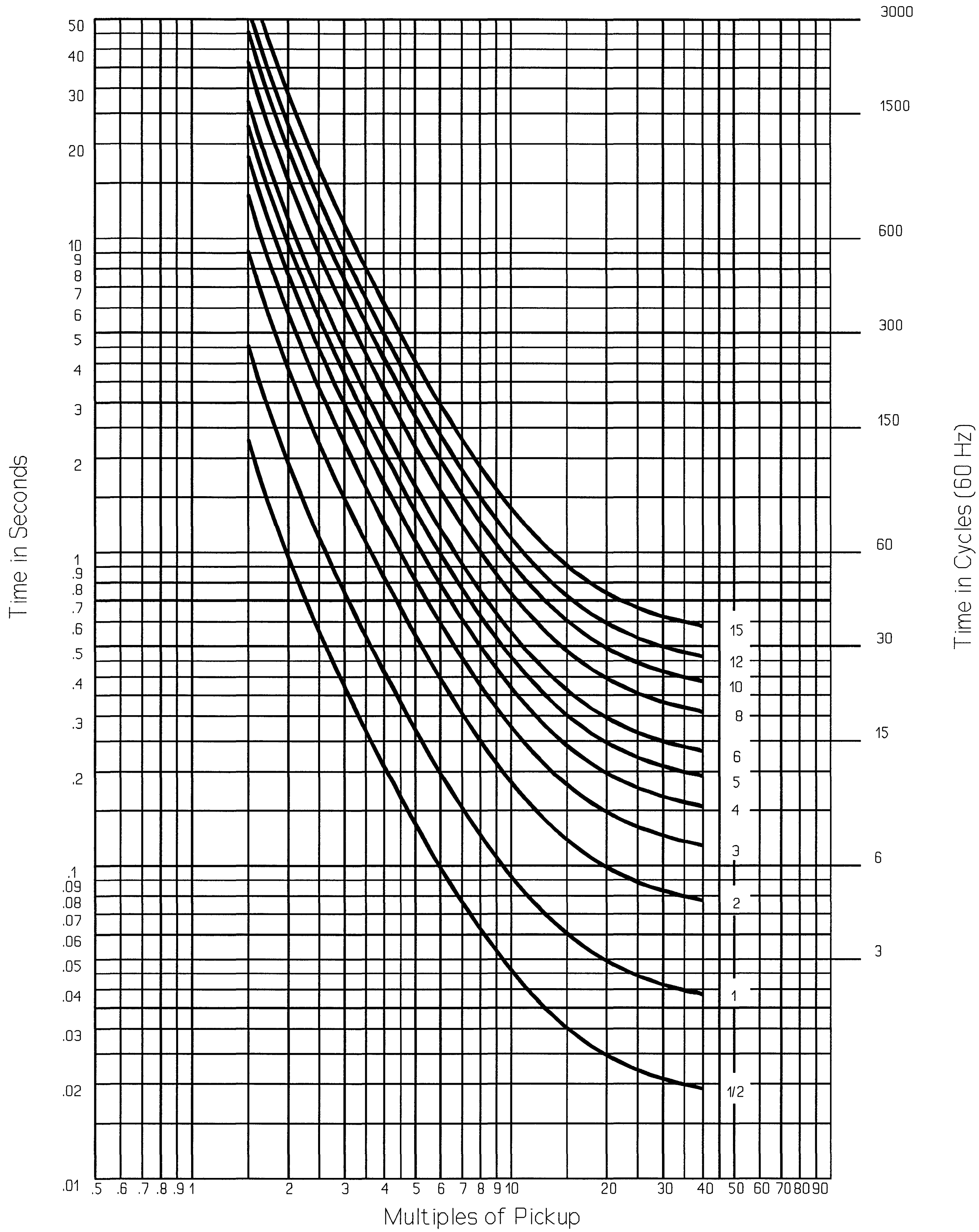
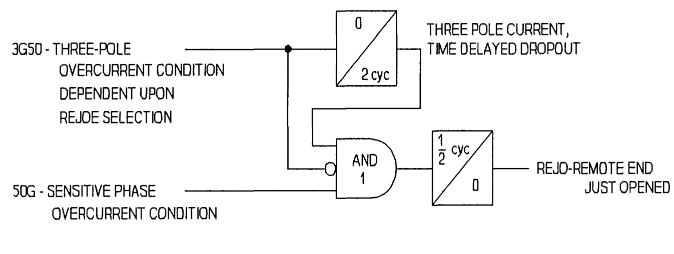
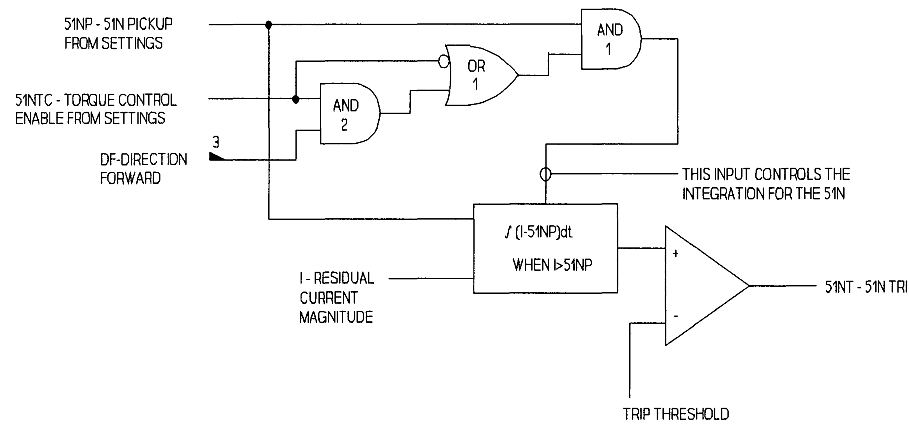


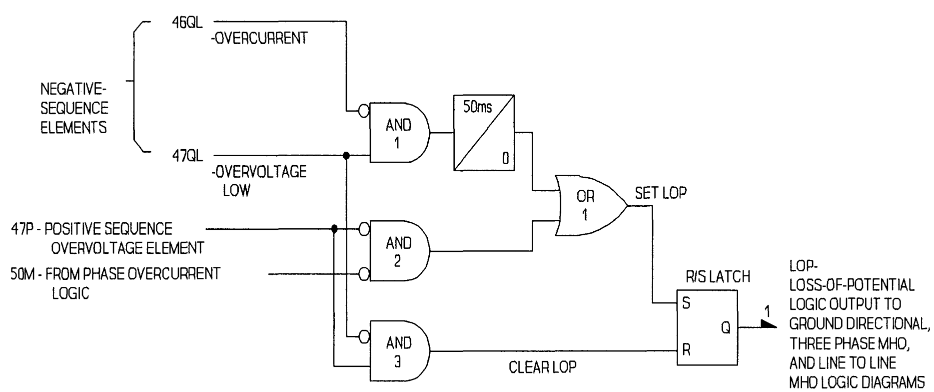
Figure 3.7: Residual Time-Overcurrent Element Extremely Inverse Time Characteristic (Curve 4)



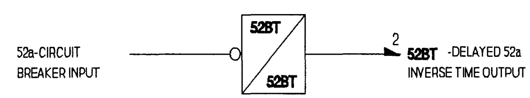
REMOTE-END-JUST-OPENED LOGIC DIAGRAM



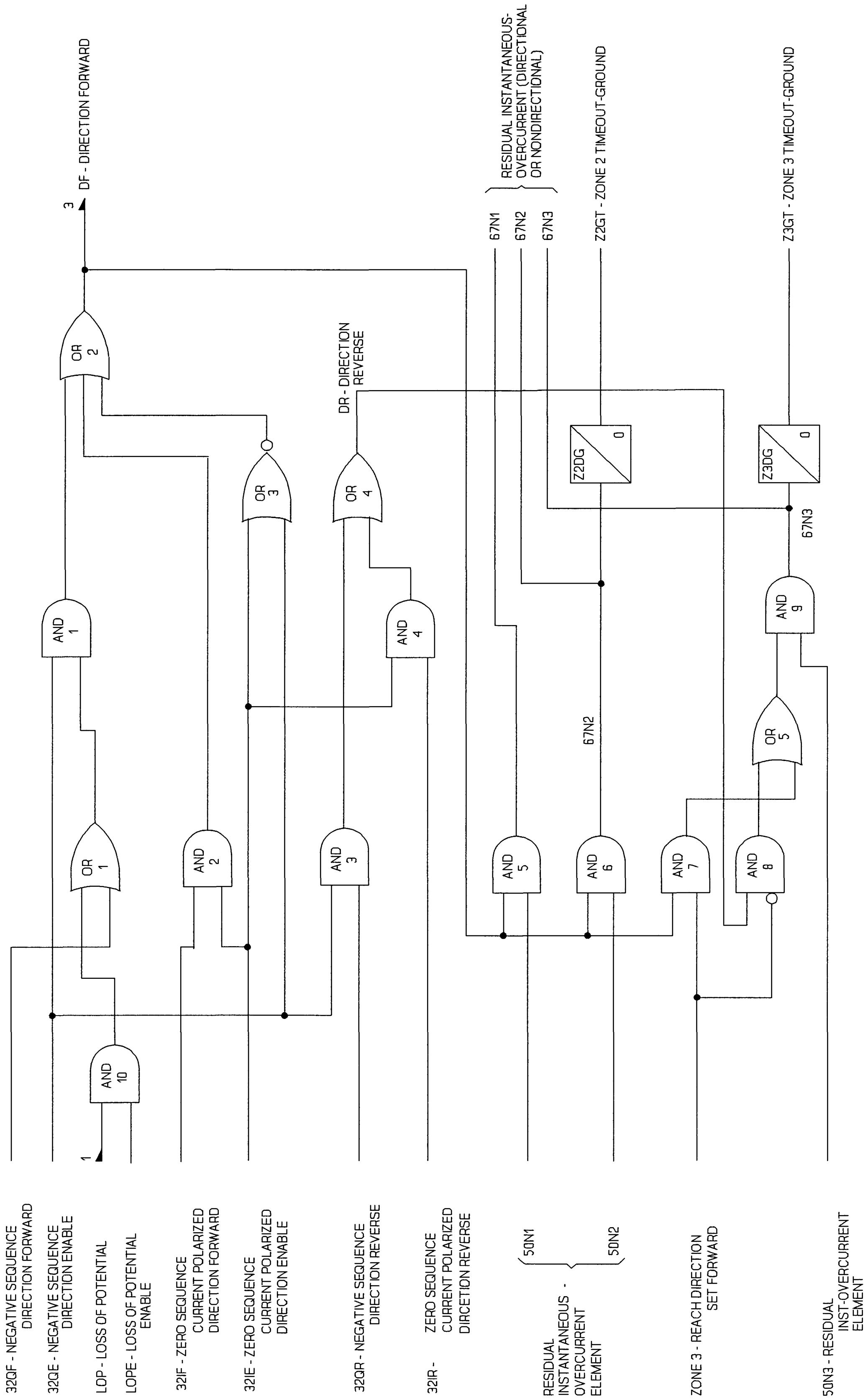
RESIDUAL TIME OVERCURRENT (51N) LOGIC DIAGRAM



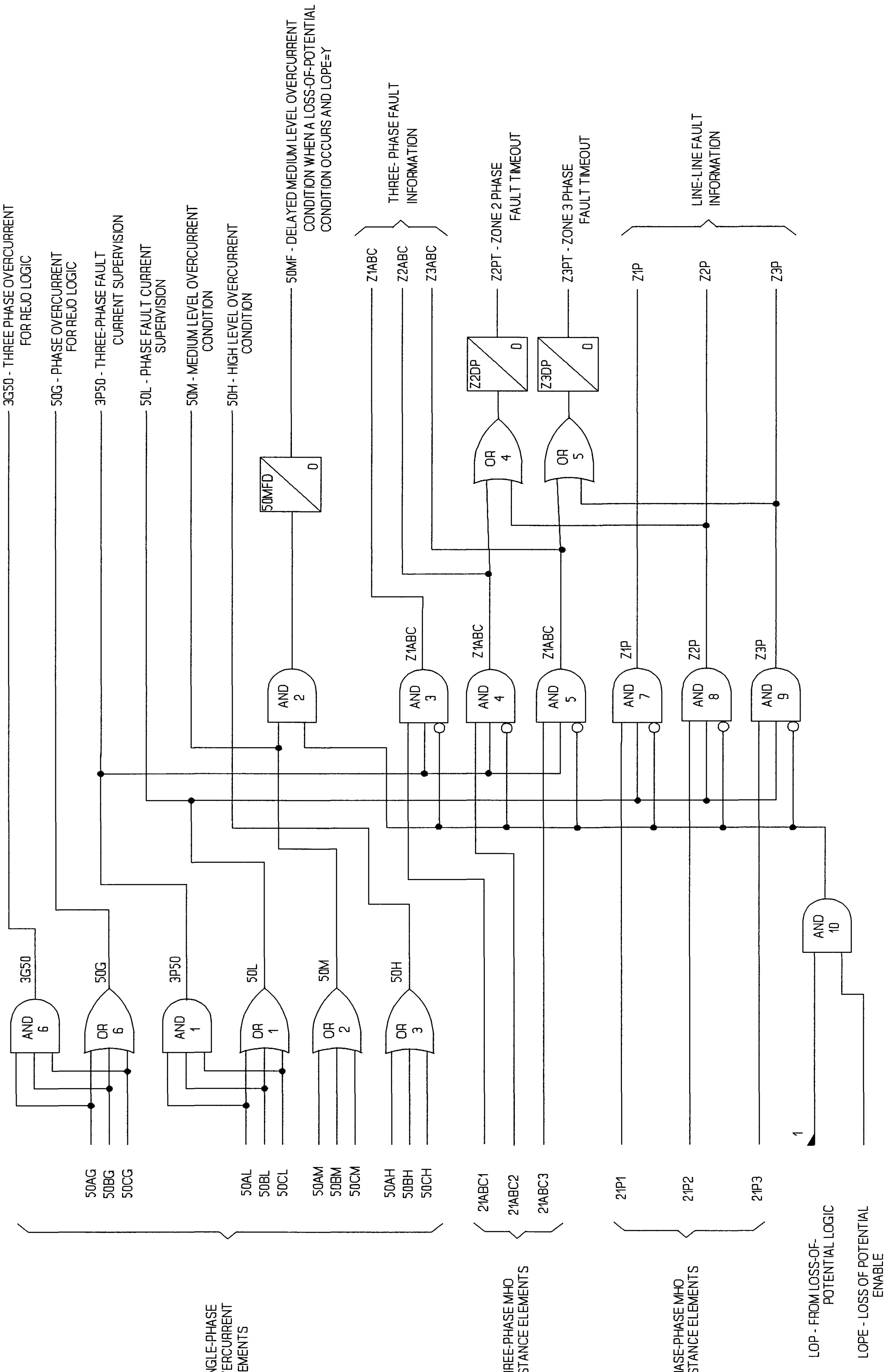
LOSS-OF-POTENTIAL LOGIC DIAGRAM



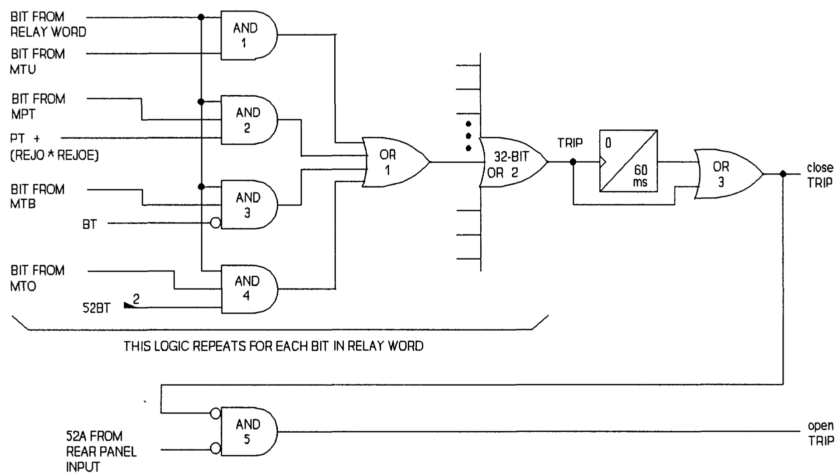
52BT LOGIC DIAGRAM



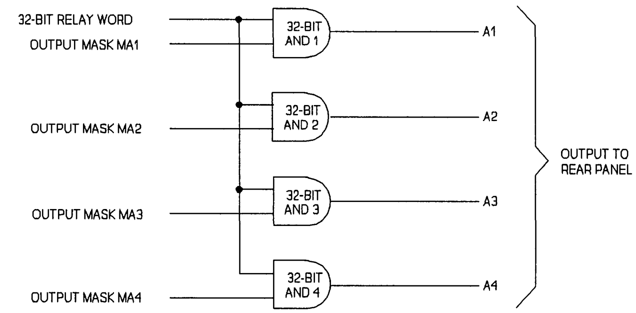
GROUND DIRECTIONAL AND GROUND OVERCURRENT LOGIC DIAGRAM



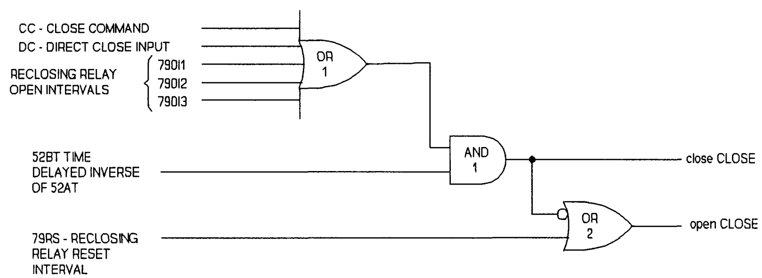
THREE-PHASE MHO, LINE-LINE MHO AND PHASE OVERCURRENT LOGIC DIAGRAM



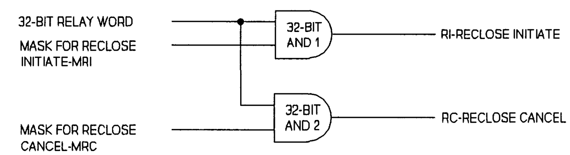
PROGRAMMABLE TRIP LOGIC DIAGRAM



PROGRAMMABLE OUTPUT LOGIC DIAGRAM



CLOSE LOGIC DIAGRAMS



PROGRAMMABLE RECLOSE INITIATE
AND CANCEL LOGIC DIAGRAM

MTU - MASK FOR UNCONDITIONAL TRIP
MPT - MASK FOR TRIP WITH PERMISSIVE-TRIP ASSERTED
MTB - MASK FOR TRIP WITH BLOCK-TRIP UNASSERTED
MTO - MASK FOR TRIP WITH BREAKER OPEN
PT - PERMISSIVE TRANSFER TRIP
BT - BLOCK TRIP
52BT - 52A INPUT TIMER INVERTED OUTPUT

COMMANDS AND SERIAL COMMUNICATIONS
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COMMANDS AND SERIAL COMMUNICATIONS

INTRODUCTION

The SEL-221D relay is set and operated via serial communications interfaces, which connect to a computer terminal and/or a modem, or the SEL Protective Relay Terminal Unit. Communications serve these purposes:

1. The relay responds to commands spanning all functions of the instrument, such as setting, metering, setting the clock, and control operations.

2. The relay transmits messages in response to changes in system status, such as, self test warning.

3. The relay generates an event record for any of the following conditions:

    a) A fault
    b) Assertion of the EXTERNAL TRIGGER input
    c) Assertion of the DIRECT TRIP input
    d) Assertion of the PERMISSIVE TRIP input
    e) Assertion of the BLOCK TRIP input
    f) In response to the TRIGGER command
    g) Assertion of the TRIP output

    (No event record is made for assertion of the CLOSE input, assertion of the 52A input or execution of the CLOSE commands.)

Two levels of access (Access Levels 1 and 2) through the communications ports are protected against unauthorized access via passwords.

It is impossible to disable any relaying or control functions via communications, except by entering unintended or improper settings, using the SET or LOGIC command.

SERIAL PORT CONNECTIONS AND CONFIGURATIONS

The SEL-221D relay is equipped with two EIA RS-232-C serial communications ports. PORT 2 has 9-pin connectors on both the front and rear panels, designated PORT 2F and PORT 2R, respectively.

PORT 2R, located on the relay rear panel, is typically used with an SEL-DTA Display/ Transducer Adapter, SEL-RD Relay Display, or local printer. PORT 2F is always available for short term local communications with a portable computer or printing terminal. Simply plug the device into the front panel port. The relay automatically discontinues communications with PORT 2R and addresses PORT 2F. When testing or data retrieval is complete, unplug the temporary device from PORT 2F. The relay automatically resumes communication with the device connected to PORT 2R.

Serial communications PORT 1 and the Auxiliary Input for demodulated IRIG-B time code input remain on the relay rear panel.

Communications port baud rate jumpers are located along the front edge of the circuit board. To select a baud rate for PORT 1 or PORTs 2, remove the relay front panel. The jumpers are visible near the center of the relay drawout assembly, to the right of the target LEDs. Carefully move the jumpers using needle-nosed pliers. Available rates are 300, 600, 1200, 2400, 4800, and 9600 baud.

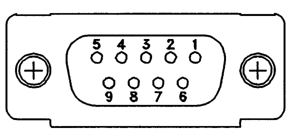
Caution: Do not select two baud rates for the same port as this can damage the relay baud rate generator. The relay is shipped with PORT 1 set to 300 baud and PORT 2 set to 2400 baud.

The serial data format is:

Eight data bits
Two stop bits
No parity bit

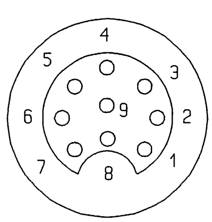
This format cannot be altered.

The SEL-121D relay does not include a front panel serial interface port.



(female chassis connector, as viewed from outside panel)

Figure 4.1: SEL-221D Relay Nine-Pin Connector Pin Number Convention



(female chassis connector, as viewed from outside rear panel)

Figure 4.2: SEL-121D Relay Nine-Pin Connector Pin Number Convention

Table 4.1 lists port pin assignments and signal definitions.

Table 4.1: SEL-221D Relay Serial Port Connector Pin Assignments

Pin	PORT 1, PORT 2R	PORT 2F	Description
1	+5 Vdc	N/C	
2	RXD	RXD	Receive data input.
3	TXD	TXD	Transmit data output.
4	+12 Vdc	N/C	
5	GND	GND	
6	-12 Vdc	N/C	
7	RTS	RTS	The relay asserts this line under normal conditions. When its received-data buffer is full, the line is deasserted, and asserts again when the buffer has sufficient room to receive more data. Connected devices should monitor RTS (usually with their CTS input) and stop transmission whenever the line deasserts. If transmission continues, data may be lost.
8	CTS	CTS	The relay monitors CTS, and transmits characters only if CTS is asserted.
9	GND	GND	Ground for ground wires and shields

Table 4.2 lists port pin assignments and signal definitions.

Table 4.2: SEL-121D Relay Serial Port Connector Pin Assignments

Pin	Name	Description
2	TXD	Transmit data output.
3	RTS	The relay asserts this line under normal conditions. When its received-data buffer is full, the line deasserts until the buffer has room to receive more data. Connected devices should monitor RTS (usually with their CTS input) and stop transmitting characters whenever the line deasserts. If transmission continues, data may be lost.
4	RXD	Receive data input.
5	CTS	The relay monitors CTS and transmits characters only when CTS is asserted.
6	+5 volts	
7	+12 volts	
8	-12 volts	
1,9	GND	Ground for ground wires and shields.

COMMUNICATIONS PROTOCOL

The communications protocol consists of hardware and software features. The hardware protocol consists of the control line functions described above. A software protocol designed for manual and automatic communications is provided, and described here.

1. All commands received by the relay must be of the form:

   <command><CR> or <command><CRLF>

   Thus a command transmitted to the relay should consist of the command name, followed by either a carriage return, or a carriage return and a line feed. (To use any command, only the first three characters need be typed. Upper or lower cases are irrelevant.)

2. All messages transmitted by the relay are of the following format:

<STX><MESSAGE LINE 1><CRLF>
<MESSAGE LINE 2><CRLF>
.
.
<LAST MESSAGE LINE><CRLF><PROMPT><ETX>

That is, each message begins with the start-of-transmission character (ASCII 02), and ends with the end-of-transmission character (ASCII 03), and each line of the message includes a carriage return and line feed at its end.

3. The relay indicates the volume of data in its received-data buffer by an XON/XOFF protocol.

XON (ASCII hex 11) is transmitted by the relay when the buffer drops below one-quarter full. The relay also asserts the RTS output.

XOFF (ASCII hex 13) is transmitted when the buffer fills above three-fourths full. The relay deasserts the RTS output, when the buffer is approximately 95% full. Automatic transmitting sources should monitor for the XOFF character so as not to overwrite the relay received-data buffer. Transmission should terminate at the end of the message being transmitted when XOFF is received, and may be resumed when the XON character is received.

4. An XON/XOFF procedure may be used to control data transmission by the relay. When the relay receives XOFF while it is transmitting, it responds by pausing until an XON character is received. If no message is being transmitted when XOFF is received, the relay blocks transmission of any message that may be presented to its transmitting buffer. The message will be transmitted once XON is received.

The CAN character (ASCII hex 18) received at any time aborts a pending transmission. This is useful in terminating an unwanted transmission.

5. The control characters can be sent from most keyboards using the following keystrokes:

XON: **<CTRL> Q** (hold down the control key, and press Q)
XOFF: **<CTRL> S** (hold down the control key, and press S)
CAN: **<CTRL> X** (hold down the control key, and press X)

COMMAND CHARACTERISTICS

The relay responds to commands received by either of its serial communications interfaces. A two-level password system provides security against unauthorized access.

When the power is first turned on, the instrument is in Access Level 0, and honors only the ACCESS command. "Invalid command" or "Invalid access level" are the responses to any other entries.

Most commands are available from Access Level 1, which is entered using the ACCESS command and a password. The password is factory-set to OTTER, and may be changed via the PASSWORD command (Access Level 2).

Critical commands, such as for circuit breaker control and changing settings, are available only from Access Level 2 which is entered from Access Level 1 using the 2ACCESS command and a different password. The Level 2 password is factory-set to TAIL, and may be changed via the PASSWORD command.

Startup

When power is first applied, the instrument transmits the following message to the port designated as the "automatic" port:

```
Example 230 kV Line                  Date: 6/1/92     Time: 01:01:01

SEL-121D
=
```

You should also hear the ALARM relay pull in, opening its B contact. Also, output relay A4 (set to follow reclose cancel) should stay closed until the loss-of-potential problem is rectified, since the LOP bit of the MRC mask is set.

The instruments are shipped with PORT 2 designated as the automatic port; however, a setting called AUTO exists for selecting either PORT 1 or 2 for the transmission of automatic responses from the relay (see the SET command).

To enter Level 1, type the following on a terminal connected to PORT 2:

```
=ACCESS <ENTER>
```

The response is:

```
Password: ? @@@@@@
```

Respond by entering the Level 1 password, e.g., OTTER, followed by a carriage return. The response is:

```
Example 230 kV Line                  Date: 6/1/92     Time: 01:01:44

Level 1
=>
```

The equals sign and greater-than sign form the Access Level 1 prompt. Now, any Level 1 command can be executed.

To enter Access Level 2, a similar procedure is used:

Enter the command 2ACCESS, and listen for the ALARM relay to drop out and pull in. This action pulses the ALARM relay contact closed for about one second, indicating that Level 2 Access is being attempted. Provide the proper password, e.g., TAIL, in response to the prompt for password. In response to the correct password, access to Level 2 is attained, as indicated by the following message and the Level 2 prompt:

```
Example 230 kV Line                  Date: 6/1/92     Time: 01:01:50

Level 2
=>>
```

Any Level 2 or Level 1 command can now be executed.

Command Format

Commands consist of three or more characters; only the first three characters of any command need be entered.

Upper or lower case characters may be used without distinction. (**Note:** Case is important for passwords.)

Arguments must be separated from the command by spaces, commas, semicolons, colons, or slashes.

Commands may be entered any time after an appropriate prompt is received.

COMMAND DESCRIPTIONS

Access Level 0 Command

ACCESS

Use ACCESS to gain access to the system from the Level 0 prompt (=). After typing **ACCESS <ENTER>**, a prompt for the Level 1 password appears. Enter the password, and press return. The factory set Level 1 password is "OTTER," but should ultimately be changed by the end-user using the PASSWORD command.

Successful access is indicated by the typical response shown below:

```
=ACCESS <ENTER>
Password: ? @@@@@@

Example 230 kV Line                  Date: 6/1/92     Time: 01:02:05

Level 1
=>
```

The => prompt indicates you have reached Access Level 1.

If three unsuccessful access attempts are made in a row, the alarm contact is pulsed closed for one second. This feature can be used to alert operations personnel that possible unauthorized access is being attempted, if the alarm contact is connected to a monitoring system, such as SCADA.

Access Level 1 Commands

2ACCESS

Use 2ACCESS to gain access to Level 2 from Level 1. After typing **2ACCESS <ENTER>**, a prompt for the Level 2 password appears. Enter the password in the same manner as for the ACCESS command, and press return. The factory set Level 2 password is "TAIL," but should ultimately be changed by the end-user using the PASSWORD command.

Successful access is indicated by the typical response shown below:

```
=>2ACCESS <ENTER>
Password: ? @@@@@@

Example 230 kV Line                    Date: 6/1/92      Time: 01:02:13

Level 2
=>>
```

The =>> prompt signifies that Access Level 1 and 2 commands may now be used. The alarm contact is pulsed closed for one second (if no alarm condition exists, such as self test failure) for any Level 2 access attempt, successful or otherwise.

DATE mm/dd/yy

To read the date kept by the internal calendar/clock, type **DATE <ENTER>**. To set the date, type **DATE mm/dd/yy <ENTER>**.

For example, to set the date to February 3, 1992, enter:

```
=>DATE 2/3/92 <ENTER>
```

The relay responds by setting the date, pulsing closed the alarm relay as the year is stored in EEPROM (only if the year input is different from the presently stored year), and displaying the set date.

EVENT n

Event records may be reviewed via an event report. To review the event report for the nth event, enter **EVENT n <ENTER>**. The parameter n is 1 for the most recent event, through 12 for the oldest event stored in the relay memory. If n is not specified, then it defaults to one.

For example, to inspect the newest report enter **EVENT 1 <ENTER>**, or just **EVE <ENTER>**.

The report provides the relay identifier string, and the date and time the event occurred. The next part of the report displays eleven cycles of data for the five current channels (IPOL, IR, IA, IB, and IC), three voltage channels (VAB, VBC, and VCA), and the states of the internal relay elements, outputs and inputs during the event. Next, the report shows the type of event, and for faults, the location, duration, and current. At the end of the report the relay and logic settings are displayed.

Recall (from the COMMUNICATIONS PROTOCOL description) that you can terminate any transmission from the relay using the CTL-X (cancel) sequence, you can pause using CTL-S, and you can continue using CTL-Q. These are useful in reviewing or terminating an event report.

When the event buffers are cleared by a control power interruption, all the event data are lost. Asking for an event from an empty buffer results in this message:

```
Invalid Event
```

A sample event report and explanation are given in the EVENT REPORTING Section.

HISTORY

The date, time, type of event, and (if the event is a fault) distance, duration and current are shown for each of the twelve most recent events. An example of the display is shown below:

```
Example 230 kV Line                     Date: 6/1/92     Time: 01:45:40

#    DATE          TIME       TYPE  DIST   DUR   CURR

1   4/26/88   09:03:01.092  3AG   100.2  7.25  798
2   4/26/88   09:02:13.041  3AG   74.9   7.00  1016
3   4/26/88   09:00:39.962  1AG   25.3   7.25  2162
4   4/26/88   09:00:13.345  1BC   25.5   7.25  3167
5
6
7
8
9
10
11
12
```

Note that only four events have occurred since the relay was set or powered on.

The time is saved to the nearest quarter-cycle (4.17 ms), and is referenced to the 16th row of data in the report. All reports trigger at row 16. Thus the duration of a long fault which triggers a report when the fault occurs, and a second report when TRIP occurs, may be determined from the difference between the two report times.

The following TYPE indicators exist:

The TYPE column provides an abbreviated indication of the type of event found in the event report. This is the same data presented as EVENT in the event summary automatically generated for each fault.

For faults, the indication includes zone and phase involvement information. The zone is determined from the relay elements picked up at the middle of the first contiguous sequence of picked-up relay elements in the report. For example, if relay elements are contiguously picked up from the 16th to the 24th rows, the zone will be determined from the 20th row. The zone is indicated by the left-most character of the TYPE string, and is one of:

1	:	For faults in which a Zone 1 element picked up
2	:	For Zone 2, but not Zone 1
3	:	For Zone 3, but not Zone 2 or 1
5	:	For 51N pickup, but not Zones 3, 2, or 1
H	:	For 50H pickup, but not 51N or Zones 3, 2, or 1
?	:	For none of the above picked up at mid-fault

The phase involvement is shown by the characters subsequent to the zone indication, and is determined independently from relay elements. Phase involvement is determined solely from uncompensated and load compensated current magnitudes at the midpoint of the first contiguous relay pickup sequence in the event report. (See the FAULT LOCATOR in Section 3 for algorithmic details.) The phase involvement is indicated as one of:

AG	:	For A-phase to ground faults
BG	:	For B-phase to ground faults
CG	:	For C-phase to ground faults
AB	:	For A-B two-phase faults
BC	:	For B-C two-phase faults
CA	:	For C-A two-phase faults
ABG	:	For A-B two-phase to ground faults
BCG	:	For B-C two-phase to ground faults
CAG	:	For C-A two-phase to ground faults
ABC	:	For three-phase faults

The zone and phase involvement data are concatenated into a single string, completing the TYPE designation, as in "3BG", for a Zone 3 B-to-ground fault, for example. For event reports triggered by the assertion of the TRIP output, the TYPE designation is further appended with a "T". This aids the determination of clearing times for faults which persist beyond the end of the first event report. For example, if the relay trips for a 3BG fault after the initial report was completed, the second report shows "3BGT" for TYPE.

For events other than faults, the TYPE indication is either "TRIP" or "EXT." The TYPE shows "TRIP" when the relay generates an event report in response to the assertion of the TRIP output, say by execution of the OPEN command during no-fault conditions. For all other events, TYPE shows "EXT," indicating the report was generated in response to some external stimulus, such as the assertion of the ET (External Trigger), PT (Permissive Trip), BT (Block Trip), or DT (Direct Trip) inputs, or by execution of the TRIGGER command.

The DIST column presents the equivalent distance to a fault in miles. This is calculated using either the Takagi algorithm or a reactance measurement, depending on whether prefault data are available in the event report. For some boundary faults of long duration, when relay operation is sporadic, the fault-locator may not be able to locate the fault for every report generated. The DIST column may contain "999999" in such cases. (While this behavior can be contrived under test conditions, it is extremely rare in actual practice.)

The column headed DUR gives a measure of the fault duration. This is measured from the first pickup of the 51N, 50H, or a Zones 1, 2, or 3 relay element, until the first dropout of all said relay elements. In other words, it is the duration of the first contiguous pickup of relay elements found in the long event report, converted to units of cycles.

The CURR column shows the magnitude of the maximum phase-current measured at the middle of the fault, in primary amperes.

IRIG

Executing the IRIG command causes the relay to read the demodulated IRIG-B time code input at J201 on the rear panel, if present.

If the time code is successfully read, then the interval clock/calendar time and date are updated to the time code reading, and a message consisting of the relay ID string and the date and time is output.

If no time code signal is present or if the time code cannot be successfully decoded, the error message "IRIGB DATA ERROR" is produced.

Note: It is normally unnecessary to synchronize using this command, as the relay performs it automatically every few minutes. The command is provided as a test and setup feature, to avoid waiting for automatic synchronization during test and installation.

METER n

The voltages, currents, and real and reactive power are displayed in primary quantities of amperes, kilovolts, megawatts and megavars. An example is shown below:

```
Example 230 kV Line                     Date: 6/1/92     Time: 13:27:05

                 A          B          C
I (A)          997       1001        999
                AB         BC         CA
V (kV)       232.1      232.4      232.0

P (MW)      402.37
Q (MVAR)     -3.83
```

P and Q are positive when the power flow is in the direction of the reach of the relay, i.e., out from the bus and into the line. They are computed as follows:

$$P + jQ = Vab \times (Ia^*) - Vbc \times (Ic^*)$$

The optional command parameter n selects the number of times the meter data are displayed. For example, to see a series of eight meter readings, type **METER 8 <ENTER>**.

QUIT

Executing the QUIT command returns control to Access Level 0 from either Access Level 1 or 2, and displays the relay I.D., date, and time. Use this command when you are done communicating with the relay, so that unauthorized access is avoided. (Note that control returns to Access Level 0 automatically after a settable interval of no activity. See the TIME1 and TIME2 settings of the SET command.)

SHOWSET

Enter SHOWSET to inspect the settings of the relay. The command shows the relay settings and logic settings presently set. The settings cannot be modified with this command. The settings are entered using the SET and LOGIC commands under Access Level 2.

An example of the output from executing SHOWSET is shown below:

```
Settings for:  Example 230 kV Line

R1   =13.90     X1   =79.96     R0   =41.50     X0   =248.57     LL=100.00
R0S  =8.30      X0S  =49.71
CTR  =200.00    PTR  =2000.00   MTA  =80.80     LOCAT=Y
79OI1=40.00     79OI2=60.00     79OI3=80.00     79RS =240.00
Z1%  =80.00     Z2%  =120.00    Z3%  =150.00
Z2DP =30.00     Z3DP =60.00
50L  =100.00    50M  =200.00    50MFD=20.00     50H  =3000.00
51NP =100.00    51NTD=3.00      51NC =2         51NTC=Y
50N1P=1000.00   50N2P=700.00    50N3P=600.00
Z2DG =20.00     Z3DG =40.00     50G  =100.00    REJOE=N
52BT =30.00     ZONE3=F         32QE =Y         32IE =N         LOPE=Y
TIME1=5         TIME2=0         AUTO =2         RINGS=3

Logic settings:

MTU  MPT  MTB  MTO  MA1  MA2  MA3  MA4  MRI  MRC
84   C4   00   E4   C4   00   00   00   00   EC
C4   E6   00   E7   E6   80   00   00   44   80
C8   C8   00   C8   C8   00   02   04   00   C8
33   03   00   33   02   00   00   00   00   33
```

A brief line-by-line description of the relay settings follows:

Line 1:	Positive- and zero-sequence impedances of the transmission line (primary ohms), and the line length (miles) for which the impedances are given.
Line 2:	Zero-sequence source impedance (used only by fault locator for ground faults).
Line 3:	Current and voltage transformer ratios, maximum torque angle, and fault locator enable.
Line 4:	Three reclosing open interval delays and one reset delay.
Line 5:	Zones 1, 2, and 3 reach as a percent of the line.
Line 6:	Zones 2 and 3 time delays for phase faults.
Line 7:	Instantaneous phase overcurrent element low, medium, and high pickups, and the delay for 50M to trip after loss-of-potential (50MFD).
Line 8:	Residual time-overcurrent pickup, time dial, curve, and torque control enable.
Line 9:	Zones 1, 2, and 3 instantaneous residual-overcurrent element pickup thresholds.
Line 10:	Zones 2 and 3 time delays for ground faults, 50G element pickup setting, REJO enable.
Line 11:	52B time delay, Zone 3 direction selection, and the enables for the negative-sequence directional element, the current polarized zero-sequence directional element, and the loss-of-potential logic.
Line 12:	PORT 1 and 2 timeouts, the autoport for automatically transmitted messages, and the number of rings after which the modem will automatically answer.

A complete description of the relay settings is given under the SET command description.

A detailed explanation of the logic settings is given in the description of the LOGIC command. Each column in the logic settings display shows the masks for the four Relay Words as follows:

Row 1, of any column:	1ABC	2ABC	3ABC	REJO	LOP	50H	50M	50L
Row 2, of any column:	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Row 3, of any column:	Z2PT	Z3PT	50G	3P50	50MF	RC	RI	DF
Row 4, of any column:	ALRM	TRIP	TC	DT	52BT	52AT	Z2GT	Z3GT

The logic settings are shown in hexadecimal format. The following table shows the equivalencies between hexadecimal (hex) and binary numbers to assist you in examining the logic settings display.

Table 4.3: Hexadecimal/Binary Conversion

Hexadecimal	Binary	Hexadecimal	Binary
0	0000	8	1000
1	0001	9	1001
2	0010	A	1010
3	0011	B	1011
4	0100	C	1100
5	0101	D	1101
6	0110	E	1110
7	0111	F	1111

For example, consider row 2 of mask MA1, which is set to E6 hex format. Using the table to convert E6 to binary gives:

E6 -> 1110 0110.

Now, build the Relay Word for row 2 of mask MA1 as follows:

```
51NT   67N1   67N2   67N3   51NP  Z1P   Z2P   Z3P
 1      1      1      0      0     1     1     0
 _________  E  _________     _______  6  _______
```

STATUS

Inspect the relay self test status using the STATUS command. The instrument also automatically executes the STATUS command whenever a self test enters a warning or a failure state, causing the STATUS report to be transmitted out of the port selected for automatic transmissions. (See AUTO setting of the SET procedure.)

The format of the STATUS report is shown below:

```
Example 230 kV Line                    Date: 6/1/92      Time: 01:04:56

SELF-TESTS

W=Warn   F=Fail

      IP   IR   IA   IB   IC   VAB  VBC  VCA

OS    0    0    2    2    4    -2   -2   -2
PS     4.99      15.14       -14.85
RAM    ROM     A/D     MOF     SET
OK     OK      OK      OK      OK
```

The OS row indicates the measured offset voltages of the eight analog channels. They are expressed in millivolts at the point in the system immediately ahead of the programmable-gain amplifier. Warning and failure thresholds are 50 and 75 millivolt deviations from zero, respectively.

An out-of-tolerance offset is indicated by a W (warning) or F (failure) following the displayed gain or offset value.

The PS row indicates the voltages of the three power supplies. Suffixes of W or F are added to indicate warning or failure states of the power supply voltage tests. Warning and failure levels are deviations by 0.3 and 0.4 volt for the five-volt supply, and 0.8 and 1.2 volts for the 15-volt supplies.

The status of five tests is reported in the last two rows. If a RAM or ROM test fails, the IC socket number of the defective part is indicated, in place of OK.

The A/D self test checks the A/D conversion time. If it exceeds a threshold, the test fails, and the protection functions are disabled. The MOF test is a check of the offset in the MUX-PGA-A/D circuit when a grounded input is selected. It has warning and failure thresholds the same as the offset tests. SET indicates the state of the self test which compares two copies of the settings stored in nonvolatile memory. Failure of this test disables relay and control functions.

The following table shows the actions which the relay takes in response to any anomalous self-test condition, where F=Failure, W=Warning:

SELF TEST	STATUS MESSAGE	PROTECTION DISABLED	CONTROL DISABLED	ALARM OUTPUT
CHANNEL	W	no	no	no
OFFSET	F	no	no	1 second contact pulse
+5V	W	no	no	no
	F	YES	YES	permanent contact closure
±15V	W	no	no	no
	F	YES	no	permanent contact closure
RAM	F	YES	YES	permanent contact closure
ROM	F	YES	YES	permanent contact closure
A/D	F	YES	no	permanent contact closure
MASTER	W	no	no	no
OFFSET	F	no	no	1 second contact pulse
SETTINGS	F	YES	YES	permanent contact closure

TARGETS n k

This command selects the information to be displayed on the front-panel target LEDs, and also communicates the state of the selected LEDs.

When the relay power is turned on, the LED display indicates the functions marked on the front panel. That is, the LEDs default to displaying fault information shown in the row labeled RELAY TARGETS in the table on the following page.

Using the TARGET command, you may select any one of seven sets of data, as listed below, to be printed and to be displayed on the LEDs.

Table 4.4: Target LED Assignment									
LED: n	1	2	3	4	5	6	7	8	
0	EN	$\phi 1$	G1	$\phi 2$	G2	$\phi 3$	G3	51N	Relay Targets
1	1ABC	2ABC	3ABC	REJO	LOP	50H	50M	50L	Relay Word Row 1
2	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	Relay Word Row 2
3	Z2PT	Z3PT	50G	3P50	50MF	RC	RI	DF	Relay Word Row 3
4	ALRM	TRIP	TC	DT	52BT	52AT	Z2GT	Z3GT	Relay Word Row 4
5	52AT		ET	52A	DC	BT	PT	DT	Contact Inputs
6		TRIP	CLOSE	A1	A2	A3	A4	ALRM	Contact Inputs

These selections are useful in testing, in checking contact states, and in remotely reading the targets. A "1" indicates an asserted element; a "0" indicates an deasserted element.

The optional command parameter k selects the number of times the target data are repeatedly displayed for a certain choice of parameter n. For example, to see a series of ten readings of Relay Word #4, type **TARGET 4 10 <ENTER>**.

Be sure to return the function of the targets to display the fault targets, so that field personnel do not misinterpret the displayed data. Do this by typing TAR 0. Use TAR R to reset the fault targets and to return the function of the targets display to the fault targets (TAR O data).

Pressing the TARGET RESET button on the front panel clears the TAR 0 data, and lights up all target LED's for about one second, as a lamp test, and unlatches the TRIP output from the 52A input.

TIME hh:mm:ss

To read the internal clock, type **TIME <ENTER>**. To set the clock, enter TIME followed by the desired setting. Separate the hours, minutes and seconds with colons, semicolons, spaces, commas or slashes. For examples, to set the clock to 23:30:00 type:
TIME 23 30 00 <ENTER> or **TIME 23:30:00 <ENTER>**, etc.

A quartz crystal oscillator provides the time base for the internal clock, and the relay time code input can be used to synchronize this clock to an external clock having a demodulated IRIG-B time code output.

TRIGGER

Enter **TRIGGER <ENTER>** to generate an event record. A response of "Triggered" is transmitted. After a short delay, during which the computer is formatting the just-triggered record, a summary of the record is displayed.

The TRIGGER command is useful in inspecting the phasor voltages and currents at any time. For example, when the relay is first installed, execute the TRIGGER command, draw the phasors (the EVENT REPORTING section explains how to do this), and check for the proper polarity and phase-sequence of the inputs.

Event records may also be generated without control action by asserting the EXTERNAL TRIGGER input.

Access Level 2 Commands

All commands are available from Access Level 2; however, the commands listed below are available ONLY from Access Level 2. Recall that any attempt, successful or otherwise, at entering Access Level 2 causes the alarm relay to pulse closed for one second.

CLOSE

The CLOSE output relay can be closed by execution of the CLOSE command or by asserting the DIRECT CLOSE input, as long as the 52A input is not asserted. The CLOSE output relay then remains closed until the 52A input is asserted, (indicating that the circuit breaker is closed), or until the reclose reset internal time (79RS) expires.

To close the circuit breaker using this command, type **CLOSE <ENTER>**. The prompting message "Close BREAKER (Y/N) ?" is displayed. Answering **Y <ENTER>** yields a second prompting string: "Are you sure (Y/N) ?" Typing **Y <ENTER>** then closes the CLOSE output relay, as long as 52A is not asserted. The message "Breaker CLOSED" is transmitted once the breaker closes, or if it is already closed (as determined by the state of the 52A input). Typing **N <ENTER>** to either of the above prompts aborts the closing operation, with transmission of the message "Aborted."

The CLOSE command aborts unless the remote open/close jumper (JMP104) is in place on the main circuit board.

The logic command programs a series of masks used for controlling the relay outputs and reclosing operations.

LOGIC n

The parameter n specifies which mask to program. The n can be any of the following:

MTU - Mask for unconditional trip
MPT - Mask for trip with permissive-trip asserted
MTB - Mask for trip with block-trip deasserted
MTO - Mask for trip with breaker open
MA1 - Mask for A1 relay control
MA2 - Mask for A2 relay control
MA3 - Mask for A3 relay control
MA4 - Mask for A4 relay control
MRI - Mask for reclose initiate
MRC - Mask for reclose cancel

The logic programming procedure consists of typing in changes for the mask, or by typing **<ENTER>**, indicating no change. Each of the masks, listed above, is split into sections corresponding to the four Relay Words as follows:

Relay Word 1:	1ABC	2ABC	3ABC	REJO	LOP	50H	50M	50L
Relay Word 2:	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Relay Word 3:	Z2PT	Z3PT	50NG	3P50	50MF	RC	RI	DF
Relay Word 4:	ALRM	TRIP	TC	DT	52BT	52AT	Z2GT	Z3GT

Once all data are provided for each Relay Word, the new logic settings are displayed, and a prompt is issued requesting your approval to enable the SEL-221D with the new logic settings. Answering **Y <ENTER>** enters the new data. It also clears the event buffers. Answering **N <ENTER>** retains the old settings.

The logic command, when executed, displays a header for each Relay Word (as shown above), and the present logic mask for that particular Relay Word. Then, a question mark prompt displays, and the relay waits for input. Enter only ones and zeros as input, where one selects and zero de-selects a member of a Relay Word. Press the carriage return if the group is satisfactory. If it is desired to change any member of a group, then all eight members of a Relay Word must be input at the same time, even if no change is desired for some members. If an error occurs during input of new data, the existing settings and question mark prompt are redisplayed, so a correction can be entered.

An example below shows a change to the MTU logic mask. **The masks must be properly configured for your application.**

LOGIC command example for the MTU mask:

```
=>>LOGIC MTU <ENTER>

1 selects, 0 deselects.

1ABC 2ABC 3ABC REJO LOP  50H  50M  50L
 0    0    0    0    0    0    0    0
 ? 10000000 <ENTER>
 1    0    0    0    0    0    0    0
 ? <ENTER>
51NT 67N1 67N2 67N3 51NP Z1P  Z2P  Z3P
 0    0    0    0    0    0    0    0
 ? 11000100 <ENTER>
 1    1    0    0    0    1    0    0
 ? <ENTER>
Z2PT Z3PT 50NG 3P50 50MF RC   RI   DF
 0    0    0    0    0    0    0    0
 ? 11001000 <ENTER>
 1    1    0    0    1    0    0    0
 ? <ENTER>
ALRM TRIP TC   DT   52BT 52AT Z2GT Z3GT
 0    0    0    0    0    0    0    0
 ? 00110011 <ENTER>
 0    0    1    1    0    0    1    1
 ? <ENTER>

New MTU :

1ABC 2ABC 3ABC REJO LOP  50H  50M  50L
 1    0    0    0    0    0    0    0
51NT 67N1 67N2 67N3 51NP Z1P  Z2P  Z3P
 1    1    0    0    0    1    0    0
Z2PT Z3PT 50NG 3P50 50MF RC   RI   DF
 1    1    0    0    1    0    0    0
ALRM TRIP TC   DT   52BT 52AT Z2GT Z3GT
 0    0    1    1    0    0    1    1

OK (Y/N) ? Y <ENTER>
Enabled

Example 230 kV Line                Date: 6/1/92      Time: 23:35:40


=>>
```

The mask for unconditional trip (MTU) selects tripping by the Zone 1 three-phase, phase and ground elements, by the high-set overcurrent elements, by timeout of the 51N element, and the Zones 2 and 3 phase and ground timers. The 50MF selection enables unconditional tripping for loss-of-potential (LOP) and 50M overcurrent conditions which persist for a settable time delay (5OMFD).

OPEN

The TRIP output relay closes in response to the OPEN command, as long as the TC (trip command) bit is selected in an appropriate TRIP MASK, (one or more of MTU, MPT, MTB, or MTO). The TRIP relay remains closed until the 52A input is not asserted. Thus, the TRIP output relay seals in. In all cases the TRIP output remains asserted at least 60 ms.

When the 52A contact is not asserted and the OPEN command is executed, the TRIP output relay pulses closed for about 1/2 second.

To open the power circuit breaker by command, type **OPEN <ENTER>**. A prompt "Open BREAKER (Y/N) ?" is transmitted. Answering **Y <ENTER>** yields a second prompt: "Are you Sure (Y/N) ?". Answering **Y <ENTER>** causes the TRIP output relay to close as described above. Answering **N <ENTER>** to either prompt aborts the OPEN command with the message "Aborted."

The OPEN command aborts unless the remote open/close jumper (JMP104) is in place on the main circuit board.

PASSWORD (1 or 2) password

To inspect the passwords, enter **PASSWORD <ENTER>**.

To change the password for Access Level 1 to BIKE enter:

```
=>PASSWORD 1 BIKE <ENTER>
```

The relay responds by setting the password, pulsing closed the alarm relay, and transmitting the response "Set."

After entering new passwords, execute "PASS" to inspect the new passwords. Make sure they are what you intended. Be sure to write down the passwords after you change them.

Passwords consist of up to six numbers, letters, or any other printable character, except the delimiters (space, comma, semicolon, colon, slash). Upper and lower case letters are treated as different letters. Examples of valid, distinct passwords include:

OTTER otter Ot3456 +TAIL+ !@#$%^ SEL-221D 123456 12345. 12345 ab1CDE

Should the passwords be lost, or should you wish to operate the SEL-221D without password protection, install Jumper JMP103 on the main circuit board. (NO password protection). With no password protection, you may gain access without knowing the passwords, and then execute the PASSWORD command to discover or change the "forgotten" passwords.

SET

SET allows entry of relay settings. At the setting procedure prompts, enter new data or press **<ENTER>** to indicate no change.

The SET command prompts you for each setting. The relay checks new settings against established limits. If the setting is within range, the relay prompts you for the next setting. Press **<ENTER>** to retain an existing setting.

When you finish entering setting changes, it is not necessary to scroll through the remaining settings. Type **END <ENTER>** after your last change to display the new settings and enable prompt. Do not use the END statement at the Relay ID setting; use **<CTRL>X** to abort the SET procedure from this point.

After you enter all data, the relay displays the new settings and prompts for approval to enable them. Answer **Y <ENTER>** to approve the new settings. Error messages notify you when combinations of entries result in a secondary out-of-range setting. If all settings are acceptable, the relay enables them, closes the ALARM contact momentarily, and clears the event buffer.

A list of relay settings and the primary limit checks follow. Please note that each setting must be within the secondary setting limit of the relay.

R1, X1	Positive-sequence impedance of line (0-9999 ohms primary)
R0, X0	Zero-sequence impedance of line (0-9999 ohms primary)
LL	Line length (0.1-999 miles)
R0S,X0S	Zero-sequence source impedance (0-5000 ohms primary) (used only by the fault locator for ground faults)
CTR	CT ratio (e.g., for 600:5, enter 120) (1-5000)
PTR	PT ratio (e.g., 1200:1, enter 1200) (1-10,000)
MTA	Maximum torque angle for mho elements (47°- 90°)
LOCAT	Do you want the fault locator enabled? (Y or N)
79OI1	Reclosing relay open interval 1 (¼ to 10,000 cycles; 0 disables reclosing)
79OI2	Reclosing relay open interval 2 (¼ to 10,000 cycles; 0 disables reclosing)
79OI3	Reclosing relay open interval 3 (¼ to 10,000 cycles; 0 disables reclosing)
79RS	Reclosing relay reset time (60 to 8,000 cycles)

Z1%	Zone 1 reach (percent of line length: 0 to 2000%)
Z2%	Zone 2 reach (percent of line length: 0 to 3200%)
Z3%	Zone 3 reach (percent of line length: 0 to 3200%)
Z2DP	Zone 2 delay for phase and three-phase faults (0-2000 cycles in quarter-cycle steps)
Z3DP	Zone 3 delay for phase and three-phase faults (0-2000 cycles in quarter-cycle steps)
50L	Phase overcurrent element low pickup (0.25-50,000 primary amperes)
50M	Phase overcurrent element medium pickup (0.25-50,000 primary amperes)
50MFD	Phase overcurrent delay on loss-of-potential (0 to 60 cycles in quarter-cycle steps)
50H	Phase overcurrent element high pickup (0.25-50,000 primary amperes)
51NP	Residual time-overcurrent pickup (0.25-50,000 primary amperes)
51NTD	Residual time-overcurrent time dial (0.5-15)
51NC	Residual time-overcurrent curve index. Choices are as follows: Use 1 to select a moderately inverse curve Use 2 to select an inverse curve Use 3 to select a very inverse curve Use 4 to select an extremely inverse curve
51NTC	Do you want residual time-overcurrent torque control? (Y or N)
50N1P	Zone 1 residual instantaneous-overcurrent (0.25-50,000 primary amperes)
50N2P	Zone 2 residual instantaneous-overcurrent (0.25-50,000 primary amperes)
50N3P	Zone 3 residual instantaneous-overcurrent (0.25-50,000 primary amperes)
Z2DG	Zone 2 delay for ground faults (0-2000 cycles in quarter-cycle steps)
Z3DG	Zone 3 delay for ground faults (0-2000 cycles in quarter-cycle steps)
50G	Phase overcurrent element (0.25-50,000 primary amperes)
REJOE	REJO logic enable (Y or N)
52BT	52B time delay (0 to 10,000 cycles)
ZONE3	Zone 3 direction (F = forward or R = reverse)
32QE	Do you want negative-sequence directional supervision of the ground-overcurrent elements? (Y or N)
32IE	Do you want current polarized zero-sequence directional element enabled? (Y or N)
LOPE	Should tripping be blocked when loss-of-potential is detected? (Y or N)
TIME1	Timeout for PORT 1 (0-30 minutes)
TIME2	Timeout for PORT 2 (0-30 minutes)
AUTO	Select Port for automatically generated messages (1, 2, or 3 both)
RINGS	The number of rings after which the modem answers (1-30 rings)

Refer to the FUNCTIONAL DESCRIPTION and be sure the settings you choose result in relay performance appropriate to your application.

As you enter the settings, they are checked against the setting limits given above. Then the relay computes internal settings from your entries, and checks them to ensure they are within the range of the relay.

For example, let CTR=1000 and 50N1P = 1. Each of these settings is admissible alone, but together they result in a secondary pickup setting of 1 mA, which is out of range. Internal setting error messages indicate such conditions after you select to enable the new settings. (Refer to the Specifications for the secondary ranges of the relay elements.)

The Zones 1, 2 and 3 reach values are the reaches of the mho units for a zero-resistance fault on the transmission line. The maximum torque angle (MTA) for the mho circles is independently set, and the diameter of the circle is expanded to keep the reach setting in the direction of the transmission line impedance constant as the maximum torque angle is separated from the transmission line angle. Thus the maximum torque angle setting does not affect the reach in the direction of the transmission line, and the mho circle diameter relates to the set reach and the difference between the transmission line angle and the MTA by the expression below.

$$\text{DIAMETER} = [\text{ SET REACH }] / [\cos(\text{ T. L. ANGLE} - \text{MTA })]$$

SEL-221D RELAY/FAULT LOCATOR COMMAND SUMMARY

Access Level 0

ACCESS	Answer password prompt (if password protection enabled) to gain access to Level 1. Three unsuccessful attempts pulses ALARM relay.

Access Level 1

2ACCESS	Answer password prompt (if password protection enabled) to gain access to Level 2. This command always pulses the ALARM relay.
DATE m/d/y	Show or set date. DAT 2/3/92 sets date to Feb. 3, 1992. This setting is overridden when IRIG-B synchronization occurs.
EVENT	Show event record. EVE 1 shows long form of most-recent event.
HISTORY	Show DATE, TIME, EVENT TYPE, FAULT LOCATION, DURATION, and CURRENT for the twelve most recent faults.
IRIG	Force immediate execution of time code synchronization task.
METER n	Show primary current, voltage, real and reactive power. METER runs once. METER n runs n times.
QUIT	Return to Access Level 0 and reset targets to target 0.
SHOWSET	Show the relay settings and logic settings. This command does not affect the settings. The logic settings are shown in hexadecimal format for each.
STATUS	Show self test status.
TARGET n	Show data and set target lights as follows: TAR 0: Relay Targets — TAR 1: Relay Word #1 TAR 2: Relay Word #2 — TAR 3: Relay Word #3 TAR 4: Relay Word #4 — TAR 5: Contact Inputs TAR 6: Contact Outputs — TAR R: Clears targets and returns to TAR 0 Be sure to return to TAR 0 when done, so LEDs display fault targets.
TIME h/m/s	Show or set time. TIM 13/32/00 sets clock to 1:32:00 PM. This setting is overridden when IRIG-B synchronization occurs.
TRIGGER	Trigger and save an event record. (Type of event is EXT).

Access Level 2

CLOSE	Close circuit breaker, if allowed by jumper setting.
LOGIC n	Show or set logic masks MTU, MPT, MTO, MTB, MRI, MRC, MA1-MA4.
OPEN	Open circuit breaker, if allowed by jumper setting.
PASSWORD	Show or set passwords. PAS 1 OTTER sets Level 1 password to OTTER. PAS 2 TAIL sets Level 2 password to TAIL.
SET	Initiate setting procedure. ALARM relay closes while new settings are being computed, and event data buffers are cleared. SET n initiates the setting procedure with setting n.

Use the following to separate commands and their parameters: space, comma, semicolon, colon, or slash.

SCHWEITZER ENGINEERING LABORATORIES, INC.
2350 NE Hopkins Court
Pullman, WA 99163-5603
Tel: (509) 332-1890 Fax: (509) 332-7990

Rev. 4

Patents Pending

EVENT REPORTING
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EVENT REPORTING

INTRODUCTION

The relay transmits a summary event report in response to several events, and saves a full event report in its memory. The summary report includes the identifier message entered at the beginning of the setting procedure, date, time, and type of event. If it is a fault, then the distance to the fault and the impedance to the fault (along the line) in secondary ohms, the fault duration, and a fault current measurement are also displayed. (A setting permits disabling the fault locator.)

The summary report is automatically transmitted out the designated AUTOMATIC port (refer to AUTO setting), regardless of access level, as long as that port has not timed out. If the automatic transmissions are to be monitored by a dedicated channel or to be printed on a dedicated printer, be sure to enter a setting of zero for the port timeout interval of the appropriate port (refer to TIME1, TIME2 settings).

The full report contains current and voltage information from which phasor diagrams of the prefault, fault, and postfault conditions may be constructed. It also contains many status points, spanning the states of all relay elements, inputs and outputs. These are useful in reviewing fault duration, relay element responses, time of arrival of transfer-trip signalling with respect to local relay response, etc.

The full report is not automatically transmitted, owing to its length (about one page). Its transmission is requested by using the EVENT command, e.g., EVENT 1.

The most-recent twelve events are stored in the relay volatile memory. These data are retained as long as the control power remains on. (This differs from the relay settings, which are retained in nonvolatile memory. The settings are retained until changed by the SET command, regardless of control power cycling.) You may quickly review the stored events using the HISTORY command.

Event reporting is triggered by any of the following:

Fault in any zone
Assertion of DIRECT TRIP Input
Assertion of BLOCK TRIP Input
Assertion of PERMISSIVE TRIP Input
Assertion of EXTERNAL TRIGGER Input
Execution of OPEN command, if a trip results
Execution of TRIGGER command

Another event report is triggered for the same fault, if the trip occurs after the end of the first report.

Event reporting is NOT triggered by any of the following:

Assertion of DIRECT CLOSE Input
Execution of the CLOSE command
Changes to the 52A Input

See the FAULT LOCATOR subsection in the FUNCTIONAL DESCRIPTION section for more explicit information on event report triggering.

EXAMPLE EVENT REPORT

A full report is provided at the end of this section. The report was generated in response to a simulated fault on the Example 230 kV Line described in the INITIAL CHECKOUT section of this manual. An A-to-ground fault 50 miles away was used. The test set settings were computed using the BASIC program in the appendices, and assuming a source impedance of 0.2 of the total line impedance. A latching relay was used to simulate the circuit breaker action and to provide a contact whose state is sensed by the relay 52A input.

The actual settings for the test set are given below:

VA	VB	VC	IA	
47.86	71.31	71.24	6.93	volts or amps
0	-125.5	125.5	-80.4	degrees

In primary units of kilovolts and amperes, the voltages and currents are:

VAB	VBC	VCA	IA	
213.4	232.1	213.4	1386	kilovolts or amperes

These were obtained using the potential and current transformer ratios assumed in the Example 230 kV Line. Note that these ratios are displayed at the end of the report:

PTR = 2000 CTR = 200.

The paragraphs following describe the relay response to this simulated fault, using information taken from the full event report.

INTERPRETATION OF VOLTAGE AND CURRENT DATA

The voltage and current data provided in the event report are determined from the secondary quantities presented to the relay rear panel, by the processing steps outlined below:

1. The input analog signals are filtered by two-pole low-pass filters with cutoff frequencies of about 85 Hz.

2. The filtered analog signals are sampled four times per power system cycle, and converted into numerical values.

3. The sampled data are processed by digital filters which remove dc and ramp components. The unit sample response of these filters is:

   $$1, -1, -1, 1$$

   This filter has the property of a double differentiator-smoother.

4. The digital filter output data are scaled into primary quantities using the current and potential transformer ratios entered in the setting procedure. Since the samples are taken four times per power-system cycle, and since the four most-recent samples are processed through the digital filter every quarter-cycle, successive outputs of the filter arrive every 90°. That is, with respect to the present value of the filter output, the previous value was taken one-quarter cycle earlier, and appears to be LEADING the present value by 90°.

These filter output values can be used to represent the signals as phasors:

> The PRESENT value of the output is the X-component of the phasor.
> The PREVIOUS value of the output is the Y-component of the phasor.

It may seem confusing to refer to the older data as the leading component of the phasor. The following example may help. Consider a sinewave with zero-phase shift with respect to t=0, and having a peak amplitude of 1. Now consider two samples, one taken at t=0, and the other taken 90° later. They have values 0 and 1, respectively. By the above rules, the phasor components are (X,Y) = (1,0). Now consider a cosine function. Its samples taken at the same time instants are 1 and 0, and its phasor representation is (0,1). The phasor (0,1) leads the phasor (1,0) by 90°, and this agrees with the 90° lead that the cosine function has with respect to the sine function.

To construct a phasor diagram of voltages and currents, select a pair of adjacent rows in the event report, in the region of interest, e.g., prefault, fault, or postfault. On Cartesian coordinates, plot the lower row (more-recent data) as the X-components, and the upper row (older data) as the Y-components. The complete phasor diagram may be rotated to any preferred angle of reference. The effective value of any of the phasors equals the square root of the sum of the squares of the components.

Note that moving forward one quarter-cycle causes the phasors all to rotate 90°, as can be seen by plotting the phasor diagram using rows 1 and 2, then rows 2 and 3.

As an example, refer to the second and third rows of cycle 6 of data in the full report:

	Currents				Voltages			
IPOL	IR	IA	IB	IC	VAB	VBC	VCA	
0	-994	-991	0	0	196.4	-191.9	-4.9	(Y-component)
0	966	966	0	0	81.8	130.2	-213.1	(X-component)

These were taken near the "middle" of the fault, as can be judged from the action of residual overcurrent elements.

Convert these to polar form (magnitude and angle):

	Currents				Voltages			
IPOL	IR	IA	IB	IC	VAB	VBC	VCA	
0	1386	1384	0	0	212.8	231.9	213.2	(magnitude)
*	-46	-46	*	*	67	-56	-179	(angle)
*	-80	-80	*	*	33	-90	-213	(angle - 34)

In the third row, 34° are subtracted from all angles of the second row, so as to assign the Phase-A voltage phasor as the 0° reference. The magnitude and shifted angles can be compared to the settings of the test set given earlier. The angle measurement errors are 1° or less, and the magnitude errors are less than 1%.

The event report indicates a fault current of 1383.8 amperes primary, which agrees well with the 1386-ampere test set current referred to the primary.

The indicated fault location is 50.29 miles. The actual fault location is 50.00 miles. The error is 50.29 - 50.00, or 0.29 miles, which is about 0.6% of the set reach for this example.

RELAY ELEMENTS STATUS INDICATORS

The states of all relay elements are indicated in the six columns headed "Relays." Active states of the various relay elements are indicated by designator symbols which correspond with the relay element names. Inactive states are indicated by periods placed in the corresponding columns. The contents of the columns for active relay elements are:

50P: Phase overcurrent elements:	H = 50H	High-set picked up
	M = 50M	Medium-set
	L = 50L	Low-set

V213: Three-phase distance units:	1	= Z1	Zone 1 picked up
	2	= Z2	Zone 2
	3	= Z3	Zone 3
21P: Two-phase distance units:	1	= Z1	Zone 1 picked up
	2	= Z2	Zone 2
	3	= Z3	Zone 3
67N: Residual overcurrent units:	1	= 67N1	High-set picked up
	2	= 67N2	Medium-set
	3	= 67N3	Low-set
51N: Residual time-overcurrent:	P	= 51NP	51N element picked up
	T	= Trip	51N trip threshold reached
LOP: Loss-of-Potential detect:	*	= LOP	

The states of all output and input contacts are shown in the next two groups of columns, headed "Outputs" and "Inputs." Assertion of any output or input contact is indicated by an asterisk (*) in the corresponding column, while non-assertion is indicated by a period. The contents of the columns are:

Outputs

TP : TRIP output
CL : CLOSE output
A1 : PROGRAMMABLE output #1
A2 : PROGRAMMABLE output #2
A3 : PROGRAMMABLE output #3
A4 : PROGRAMMABLE output #4
AL : ALARM output

Inputs

DT : DIRECT TRIP input
PT : PERMISSIVE TRIP input
BT : BLOCK TRIP input
DC : DIRECT CLOSE input
52A : BREAKER AUXILIARY 52A SWITCH input
ET : EXTERNAL TRIGGER (for event report) input

In the example event report, the medium-set phase overcurrent element (50M) is picked up for load current as indicated by the "M" in the 50P column.

The Zone 2 residual-overcurrent element (67N2) and residual time-overcurrent element (51N) are the first elements to pick up for the fault. This is indicated by the "2" in the 67N column and the "P" in the 51N column in the last quarter-cycle of the fourth cycle of the event report. For almost every actual fault, the first element(s) to pick up will be found in this, the sixteenth row of data. In the same quarter-cycle, the programmable output A1 asserts, as indicated by the "*" in the A1 column. The A1 output is programmed to generate an overreaching permissive signal for a POTT scheme for the example settings, and thus asserts as soon as any Zones 1 or 2 elements pick up.

In the 17th quarter-cycle of the report, the Zone 1 residual-overcurrent element (67N1) picks up. In response, the TRIP output and programmable output A3 asserts. The TRIP output asserts because the 67N1 element was incorporated into the UNCONDITIONAL TRIP MASK (MTU) of the LOGIC settings. The A3 output asserted because the 67N1 element was incorporated into the RECLOSE INITIATE MASK (MRI) of the logic settings, which means that the RECLOSE function will be initiated for Zone 1 ground faults. Furthermore, the programmable output A3 was set to follow the RECLOSE INITIATE condition via the A3 MASK (MA3) of the logic settings.

The 52A contact input monitored the latching relay (circuit breaker simulator) state. This input deasserts in row 21 of the report, indicating that the latching relay had changed to the "open" state about one cycle after tripping had been initiated.

The duration of the fault can be estimated from the total time the relay elements are picked up. They were picked up for a total of 17 quarter-cycles, or 4.25 cycles. This value is reported near the bottom of the report as: Duration: 4.25.

For further description of information in this report, see the HISTORY command description.

FIRMWARE IDENTIFICATION

A means of determining relay Firmware Identification (FID) data is now provided. The FID string is printed near the top of each long event report.

The string format is as follows:

FID = [PN] - R[RN] - V[VS] - D[RD]

Where:

[PN] =	Product Name	(e.g., SEL-221D)
[RN] =	Revision Number	(e.g., 100)
[VS] =	Version Specifications	(e.g., 656mptrer2)
[RD] =	Release Date	(e.g., YYMMDD = 880425)

An example of the FID string is:

FID=SEL-121D-R100-V656mptrer2-D880425

For the SEL-221D family of relays, the version specifications are interpreted as follows:

V[VS] = V[ABCDEFGHIJ]

Option	Specifier	Specifier Meaning	Option Description
A	5, 6	50 Hz, 60 Hz	Power System Frequency
B	1, 5	1 amp, 5 amps	Nominal Amps per Phase
C	1, 6	120 volts, 67 volts	Nominal Volts per Phase
D	m, k	miles, kilometers	Fault Locator Distance Units
E	p, n	positive, negative	Phase-Sequence of Power System
F	a, t	all, trip only	Zones Reported on Target LED's
G	c, r	cumulative, recent	Target LED Update Logic
H	c, e	control, event	Inputs
I	c, r	compensated, radial	Fault Locator Option
J	1, 2	old, rev. 4	Main Board Configuration

SAMPLE EVENT REPORT

Example 230 kV Line   Date: 6/1/92   Time: 11:02:21.150

FID=SEL-121D-R100-V656mptr-D880425

	Currents (amps)				Voltages (kV)			Relays	Outputs	Inputs
IPOL	IR	IA	IB	IC	VAB	VBC	VCA	52265L 011710 P3PNNP	TCAAAAA PL1234L	DPBD5E TTTC2T A
0	4	-661	-53	717	-102.4	-128.4	231.4	M.....	....	....*.
0	-4	453	-796	346	208.6	-193.3	-16.1	M.....	....	....*.
0	-4	661	53	-717	102.4	128.4	-231.4	M.....	....	....*.
0	3	-453	796	-346	-208.6	193.3	16.1	M.....	....	....*.
0	5	-661	-53	717	-102.4	-128.4	231.4	M.....	....	....*.
0	-3	453	-796	346	208.6	-193.3	-16.1	M.....	....	....*.
0	-5	661	53	-717	102.4	128.4	-231.6	M.....	....	....*.
0	4	-453	796	-346	-208.8	193.3	16.3	M.....	....	....*.
0	4	-661	-53	717	-102.2	-128.6	231.6	M.....	....	....*.
0	-5	453	-799	346	209.0	-193.1	-16.3	M.....	....	....*.
0	-3	661	57	-717	101.6	128.6	-231.2	M.....	....	....*.
0	187	-211	670	-274	-207.6	193.1	15.1	M.....	....	....*.
0	-199	-676	-79	551	-95.2	-129.0	225.5	M.....	....	....*.
0	-616	-431	-311	129	201.7	-192.9	-10.0	M.....	....	....*.
0	648	815	53	-217	86.3	130.0	-216.7	M.....	....	....*.
0	920	900	47	-31	-196.8	192.1	5.3	M..2P.	..*....	....*.
0	-927	-950	-3	28	-82.6	-130.2	213.5	M..1P.	*.*.*..	....*.
0	-983	-978	-9	3	196.2	-191.9	-4.9	M..1P.	*.*.*..	....*.
0	961	963	0	-3	82.0	130.2	-213.1	M..1P.	*.*.*..	....*.
0	992	991	3	0	-196.0	191.9	4.9	M..1P.	*.*.*..	....*.
0	-965	-966	0	0	-82.0	-130.2	213.1	M..1P.	*.*.*..	......
0	-994	-991	0	0	196.4	-191.9	-4.9	M..1P.	*.*.*..	......
0	966	966	0	0	81.8	130.2	-213.1	M..1P.	*.*.*..	......
0	994	991	0	0	-196.4	191.9	4.9	M..1P.	*.*.*..	......
0	-967	-966	0	0	-81.8	-130.2	213.1	M..1P.	*.*.*..	......
0	-993	-991	0	0	196.4	-191.9	-4.9	M..1P.	*.*.*..	......
0	967	969	0	0	82.2	130.2	-213.5	M..1P.	*.*.*..	......
0	809	805	0	0	-197.8	192.1	6.3	M..1P.	*.*.*..	......
0	-764	-768	0	0	-88.1	-129.8	219.2	M..1P.	*.*.*..	......
0	-377	-374	0	0	203.5	-192.5	-11.6	M..2P.	*.*....	......
0	315	318	0	0	97.1	129.4	-227.5	M...P.	*......	......
0	75	69	0	0	-208.4	192.7	16.3	M...P.	*......	......
0	-38	-38	0	0	-100.7	-129.4	231.0	......	....	......
0	-11	-6	0	0	208.8	-192.7	-16.9	......	....	......
0	6	3	0	0	101.4	129.4	-231.4	......	....	......
0	1	0	0	0	-209.0	192.5	16.9	......	....	......
0	-2	0	0	0	-101.4	-129.2	231.4	......	....	......
0	1	0	0	0	209.0	-192.5	-16.9	......	....	......
0	1	0	0	0	101.4	129.2	-231.4	......	....	......
0	-1	0	0	0	-209.0	192.5	16.9	......	....	......
0	0	0	0	0	-101.4	-129.2	231.4	......	....	......
0	0	0	0	0	209.0	-192.5	-16.7	......	....	......
0	0	0	0	0	101.4	129.2	-231.8	......	....	......
0	0	0	0	0	-209.0	192.5	16.9	......	....	......

```
Event   : 1AG    Location   : 50.29  mi  4.08   ohms sec
Duration: 4.25   Flt Current: 1383.8

R1   =13.90     X1   =79.96     R0   =41.50     X0   =248.57    LL   =100.00
R0S  =8.30      X0S  =49.71
CTR  =200.00    PTR  =2000.00   MTA  =80.80     LOCAT=Y
79OI1=40.00     79OI2=60.00     79OI3=80.00     79RS =240.00
Z1%  =80.00     Z2%  =120.00    Z3%  =150.00
Z2DP =30.00     Z3DP =60.00
50L  =100.00    50M  =200.00    50MFD=20.00     50H  =3000.00
51NP =100.00    51NTD=3.00      51NC =2         51NTC=Y
50N1P=1000.00   50N2P=700.00    50N3P=600.00
Z2DG =20.00     Z3DG =40.00     50G  =100.00    REJOE=N
52BT =30.00     ZONE3=F         32QE =Y         32IE =N         LOPE =Y
TIME1=5         TIME2=0         AUTO =2         RINGS=3
```

Logic settings:

MTU	MPT	MTB	MTO	MA1	MA2	MA3	MA4	MRI	MRC
84	C4	00	E4	C4	00	00	00	00	EC
C4	E6	00	E7	E6	80	00	00	44	80
C8	C8	00	C8	88	00	02	04	00	C8
33	03	00	33	02	00	00	00	00	33

INSTALLATION
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FIGURES

INSTALLATION

MOUNTING

The SEL-221D relay is intended for mounting by its front vertical flanges, in a 19-inch vertical relay rack. It may also be mounted semi-flush in a switchboard panel. Four #10 screws should be used for this purpose. Front and rear panel drawings are included at the rear of this manual.

FRAME GROUND CONNECTION

Terminal 46 on the rear panel must be connected to frame ground for safety and performance. These terminals connect directly to the chassis ground of the instrument.

POWER CONNECTIONS

Terminals 44 and 45 on the rear panel must be connected to a source of control voltage. Control power passes through these terminals to the fuse or fuses and toggle switch, if installed. It then passes through a surge filter, and connects to the switching power supply and to the output relay control circuits. The control power circuitry is isolated from the frame ground.

SECONDARY CIRCUITS

The relay presents a very low burden to the secondary current and potential circuits. Each current circuit is independent of the other circuits. That is, there is no interconnection of current circuits inside the instrument. When current polarization is not desired or required, terminals 4 and 10 may be left open-circuited.

Three-wire delta potentials are required for the SEL-221D relay voltage inputs.

CONTROL CIRCUITS

The control inputs are dry. For example, to assert the 52A input, control voltage must be applied to the 52A input terminals. Each input is individually isolated, and a terminal pair is brought out for each input. There are no internal connections between control inputs.

Control outputs are dry relay contacts rated for tripping duty. Each contact is protected by a metal-oxide varistor. These devices have an energy rating of 80 joules, a maximum clamping voltage of 395 volts, and a minimum varistor voltage (for 1 mA dc current) of 212 volts.

COMMUNICATIONS CIRCUITS

Connections to the two EIA RS-232-C serial communications ports are made via the two nine-pin connectors, labeled PORT 1 and PORT 2R on the rear panel and PORT 2F on the front panel. Pins 5 and 9 connect directly to frame (chassis) ground. These connections should not be relied upon for safety grounding, since their current-carrying capacity is less than control-power short circuit current and protection levels.

The communications circuits are protected by low-energy, low-voltage MOVs and passive RC filters. Communications-circuit difficulties can be minimized by keeping the length of the EIA RS-232-C cables as short as possible. Lengths of twelve feet or less are recommended, however, in no case, should the cable length exceed 100 feet. The use of shielded communications cable for lengths in excess of ten feet is recommended. For communications over long distances, modems are required.

Route the communications cables well away from the secondary and control circuits. Do not bundle the communications wiring with secondary or control circuit wiring. If these wires are bundled, switching spikes and surges can cause noise in the communications wiring. This noise may exceed the communications logic thresholds and introduce errors. The IRIG-B clock cable should also be routed away from the control wiring and secondary circuits.

JUMPER SELECTION

All jumpers are on the front edge of the main board. They are easily accessed by removing the front panel.

EIA RS-232-C Jumpers

Jumper P105 provides for EIA RS-232-C baud rate selection. Baud rates available are 300, 600, 1200, 2400, 4800 and 9600. To select a baud rate for a particular port, place the jumper so it connects a pin labeled with the desired port to a pin labeled with the desired baud rate.

Caution: Do not select two baud rates for the same port. This can damage the baud rate generator.

Password Protection Jumpers

When Jumper JMP103 is in place the password protection is disabled. This feature is useful if passwords are not required, or if they are forgotten.

Remote Trip/Close Enable Jumper

When Jumper JMP104 is in place remote trip/close commands may be executed. If Jumper JMP104 is removed attempts to use the OPEN or CLOSE commands result in an "Aborted" message.

SETTING PROCEDURE

Settings for the relay are entered using the SET and LOGIC commands, via either of the serial interface ports. The settings are stored in nonvolatile memory, so that they are retained when the power is off.

The SET and LOGIC command descriptions explain how to enter settings.

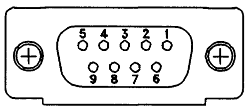
EIA RS-232-C AND IRIG-B INSTALLATION

This section contains specific information concerning pinouts of the communications ports.

The current drive for an IRIG-B "one" is 10 to 20 mA. The input circuit consists of a 56-ohm resistor in series with the photodiode input of an optical isolator. The photodiode has a forward voltage drop of about 1.8 volts. The input may be driven directly by the output of a TTL-level driver having sufficient current capability. The inputs may also be driven in a current loop from a higher-voltage driver.

A pin definition of the nine-pin port connectors and cabling information for the EIA RS-232-C ports is given below. Several types of EIA RS-232-C cables are given. These and other cables are available from SEL. Cable configuration sheets are also available for a large number of devices, upon request at no charge.

Nine-Pin Connector Pin Number Convention



(female chassis connector, as viewed from outside panel)

Figure 6.1: SEL-221D Relay Nine-Pin Connector Pin Number Convention

EIA RS-232-C Cables

```
SEL-221D                  9-Pin *DTE DEVICE

GND  5 ------------------ 5   GND
TXD  3 ------------------ 2   RXD
RXD  2 ------------------ 3   TXD        (SEL  CABLE 234)
RTS  7-┐
       │ Jumper
CTS  8-┘
                      ┌- 1   DCD
                      ├- 4   DTR
               Jumper ├- 6   DSR
                      └- 8   CTS
                         9   RI

SEL-221D                  **DCE DEVICE

GND   5 ----------------- 7   GND
TXD   3 ----------------- 2   RXD
RTS   7 ----------------- 20  DTR        (SEL  CABLE 222)
RXD   2 ----------------- 3   TXD
CTS   8 ----------------- 8   CD
GND   9 ----------------- 1   GND
```

```
PRTU                          SEL-221D

GND   1 ———————————————————— 5   GND
TXD   2 ———————————————————— 2   RXD
RXD   4 ———————————————————— 3   TXD          (SEL  CABLE 231)
CTS   5 ———————————————————— 7   RTS
+12   7 ———————————————————— 8   CTS
GND   9 ———————————————————— 9   GND
```

* DTE = Data Terminal Equipment
** DCE = Data Communication Equipment

INITIAL CHECKOUT

The suggestions outlined below may be followed or combined with your normal practice. In no case should a recommendation below be followed unless it is allowed under the rules of your normal practice.

A portable terminal or computer is a convenient tool for providing local communications with the relay during checkout in the field. Such a device should be connected to PORT 2F or PORT 2R for checkout, and PORT 2 should be designated as the automatic port, using the AUTO setting in the SET command, during checkout.

1. Apply control power, and verify that the startup message is received on the terminal. If it is not then set AUTO = 2, using the SET command, from Access Level 2. Using the ACCESS command and the SHOWSET command, check the settings. Set the clock. Note that the A4 relay is closed due to the loss-of-potential scheme.

2. Apply three-phase voltages. Execute the METER command, and verify that the readings are accurate. If they are not, be sure that the correct PT ratio was entered, and recall that the displayed values are in primary line-to-line kV.

3. Using the TRIGGER command, save an event record. Type the EVENT 1 command, and examine the triggered event record. Referring to the top row of data as the "Y" components, and the next row as the "X" components, plot the three voltage phasors, and ensure that they are 120° apart, of reasonable magnitudes, and rotating in the positive-sequence direction. The sum of the voltage data in any one row should be near zero, since the relay measures VAB, VBC, and VCA.

4. Using the TARGETS command, check the state of all contact inputs and outputs. For example, if the connections to the circuit breaker 52A contact are made, and if the circuit breaker is closed, the TARGET command with option 5 should show a one (1) under the 52A heading (type TARGET 5 <ENTER>).

5. Gain access to Access Level 2 using the 2ACCESS command and the appropriate password. Be sure that the ALARM relay contacts close and open when the 2ACCESS command is executed. (The ALARM pulse will not be detectable if the ALARM contacts are permanently closed due to any other alarm condition.)

6. The tripping function should be tested three ways. First, be sure the circuit breaker can be tripped by the relay by executing the OPEN command. Be sure the TC bit is set in the MTU mask. Second, the circuit breaker may be tripped by asserting the DIRECT TRIP input, assuming that the DT bit is selected in the MTU mask. The TRIP output relay opens in both of these cases after the 52A input is deasserted, indicating that the circuit breaker has indeed opened. This function of monitoring the 52A contact ensures that the output relay does not inadvertently open while trip coil current is flowing in response to a control operation. Third, the circuit breaker may be tripped by applying voltages and currents representing a fault condition for which the relay should respond. Here, the TRIP relay closes, regardless of the state of the 52A contact, and opens when the 52A input is deasserted AND fault conditions no longer exist. The TRIP output always remains closed for at least 60 ms.

7. The circuit breaker may be closed two ways, by executing the CLOSE command, or by assertion of the DIRECT CLOSE input. The CLOSE output relay closes for either of these conditions, as long as the 52A input is deasserted (indicating that the circuit breaker is indeed open). The CLOSE relay opens when the 52A input is asserted, or when the reclosing relay reset interval expires, whichever occurs first.

8. If the PERMISSIVE TRIP and BLOCK TRIP inputs are used, these should also be checked for proper operation. (See the LOGIC MPT and LOGIC MTB settings). An event report should be generated for assertion of either the PT or BT inputs.

9. Asserting the EXTERNAL TRIGGER input should trigger the recording of an event record. It does not affect the protective relaying functions in any way.

10. Use the STATUS command to inspect the self-test status. You may wish to save the reading as part of an "as-left" record. When local checkout is complete, communications with the instrument via a remote interface (if used) should be tested. Be sure, in particular, that the automatic port is properly assigned, and that the desired timeout intervals are selected for each port. Also, be sure to record password settings.

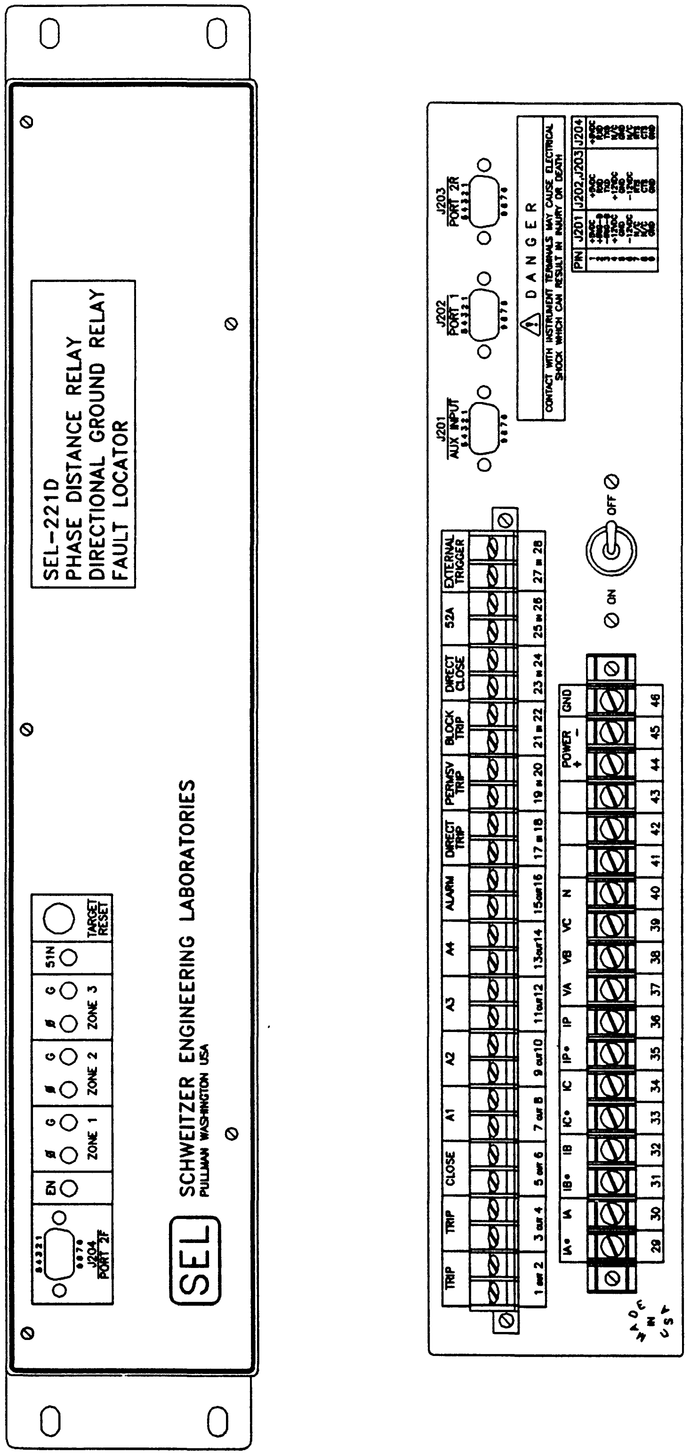
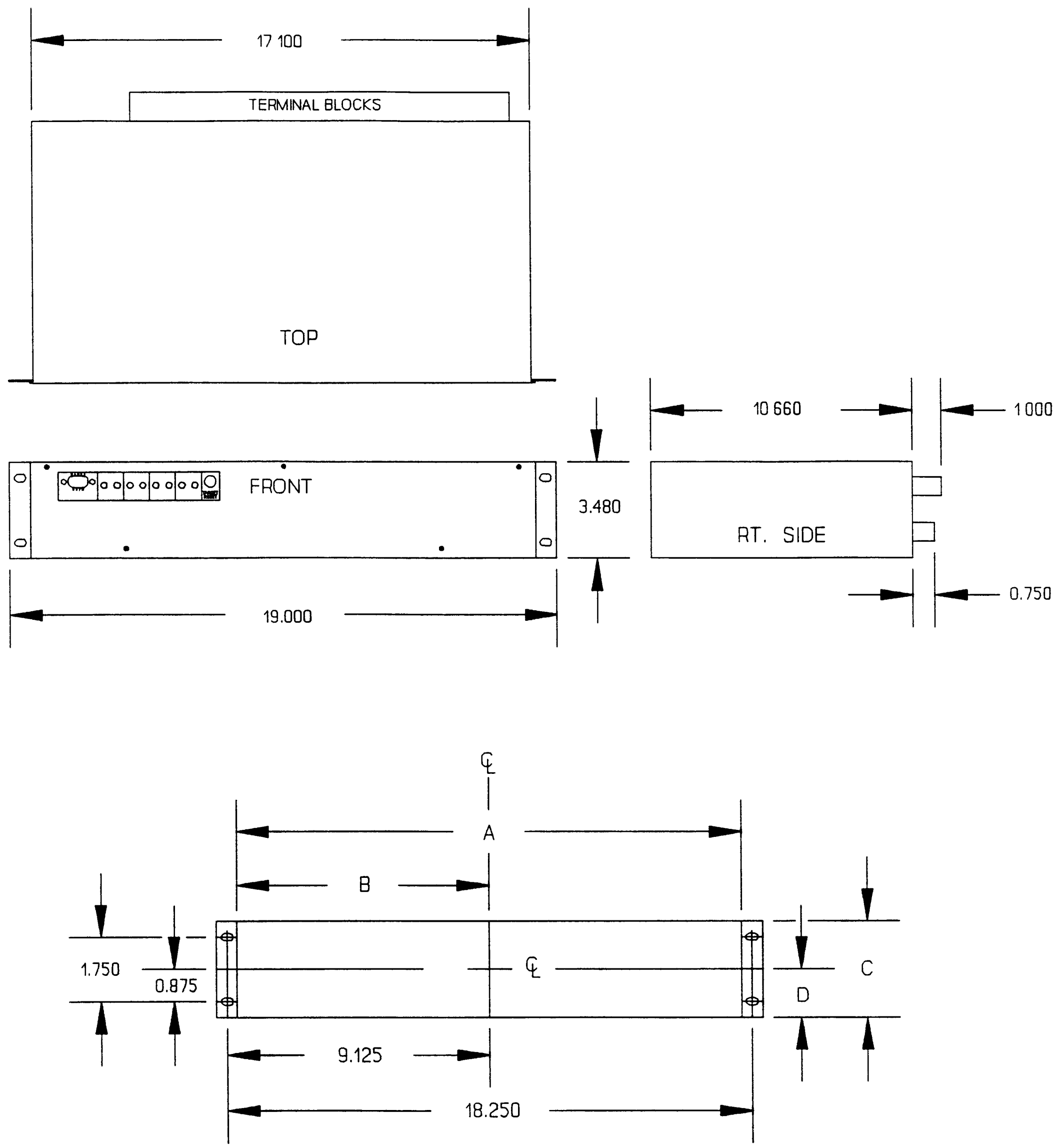


Figure 6.2: Horizontal Front and Rear Panel Drawings



DIMENSION	CUTOUT	PREFERRED
A	17.20— 17.80	17.30
B	8.60— 8.90	8.65
C	3 52— 3 60	3.56
D	1.76— 1.80	1.78

NOTE: ALL INSTRUMENTS MAY BE MOUNTED HORIZONTALLY (AS SHOWN ABOVE) OR VERTICALLY

ALL DIMENSIONS ARE IN INCHES

Figure 6.3: Relay Dimensions, Panel Cutout, and Drill Plan

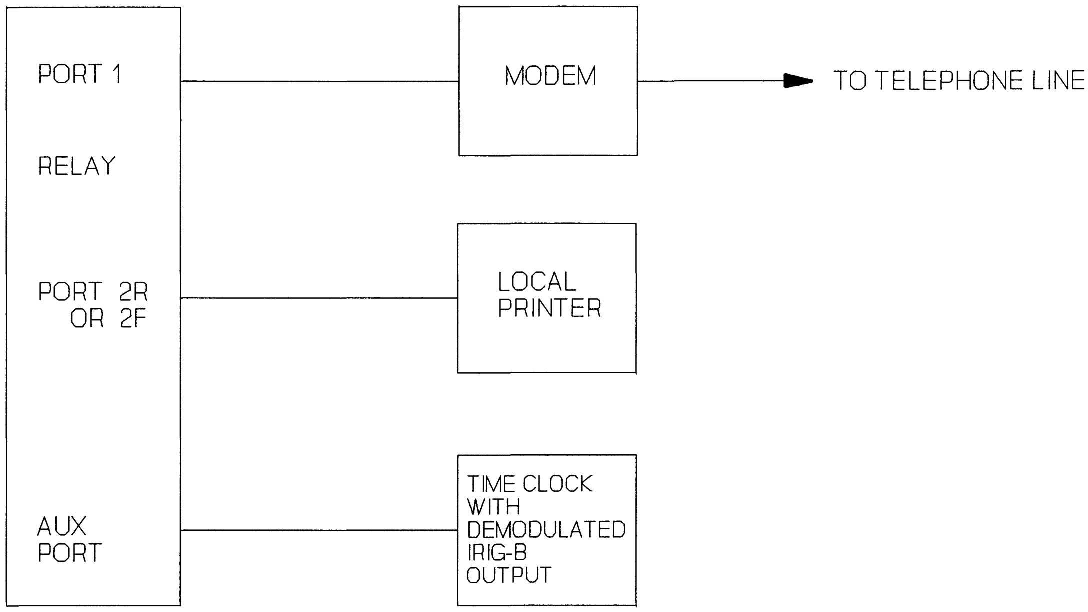


Figure 6.4: Communications and Clock Connections - One Unit at One Location

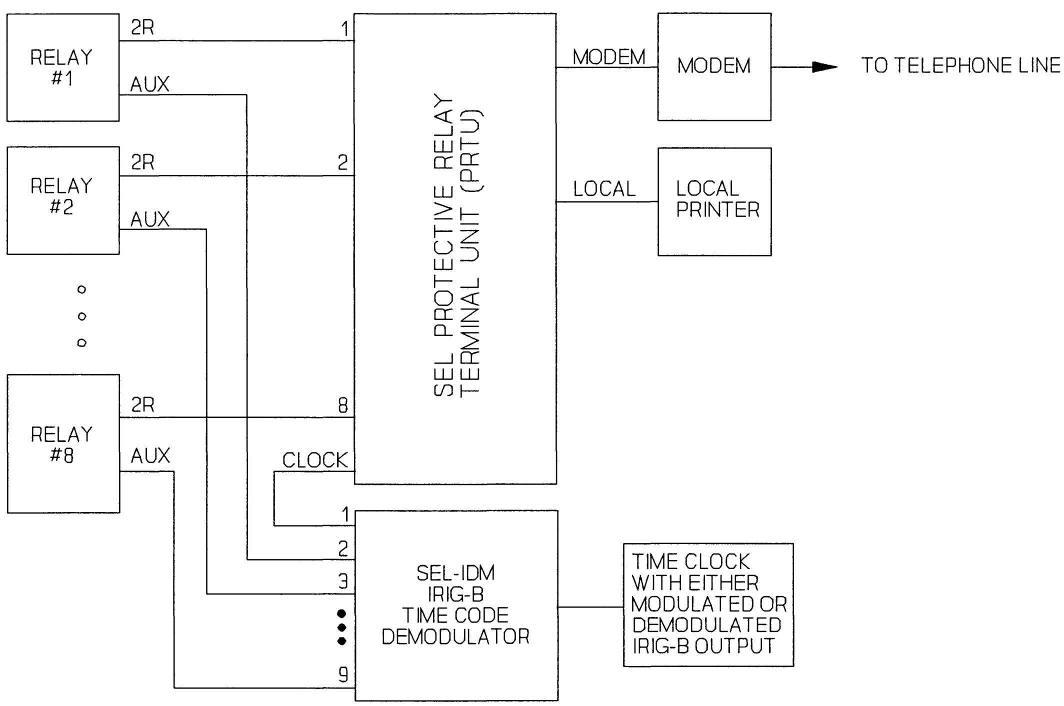


Figure 6.5: Communications and Clock Connections - Multiple Units at One Location

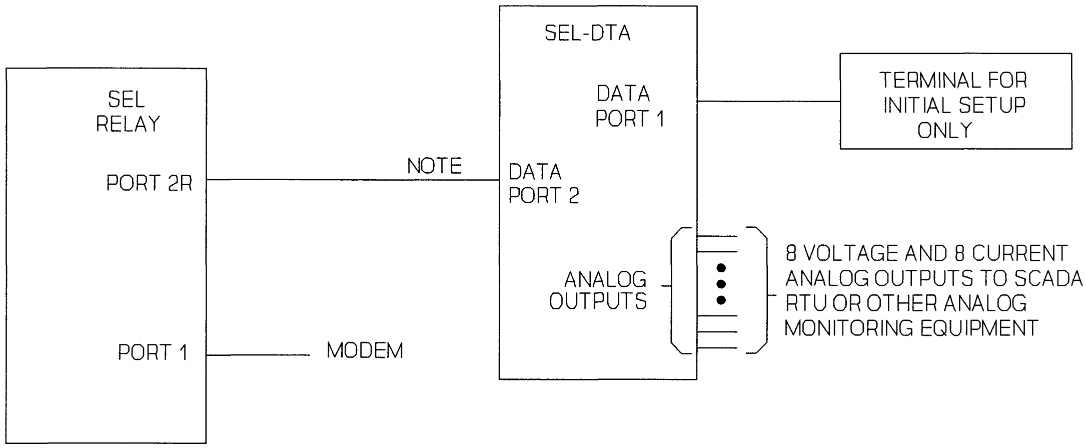


Figure 6.6: SEL Relay Communications Diagram for Connection to the SEL-DTA

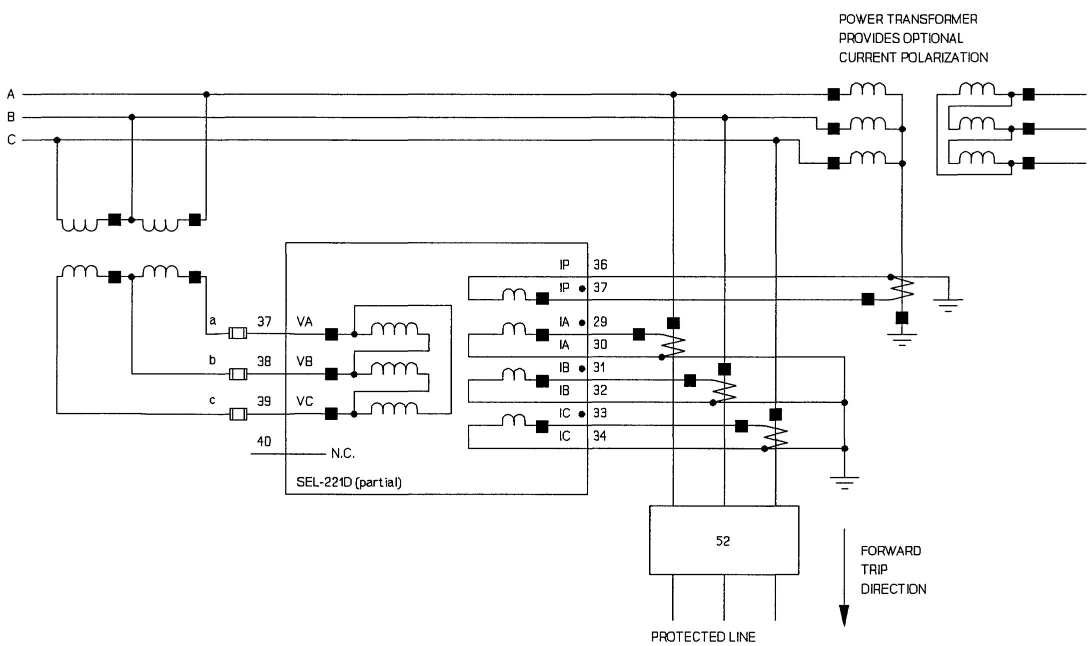


Figure 6.7: External Ac Current and Voltage Connections

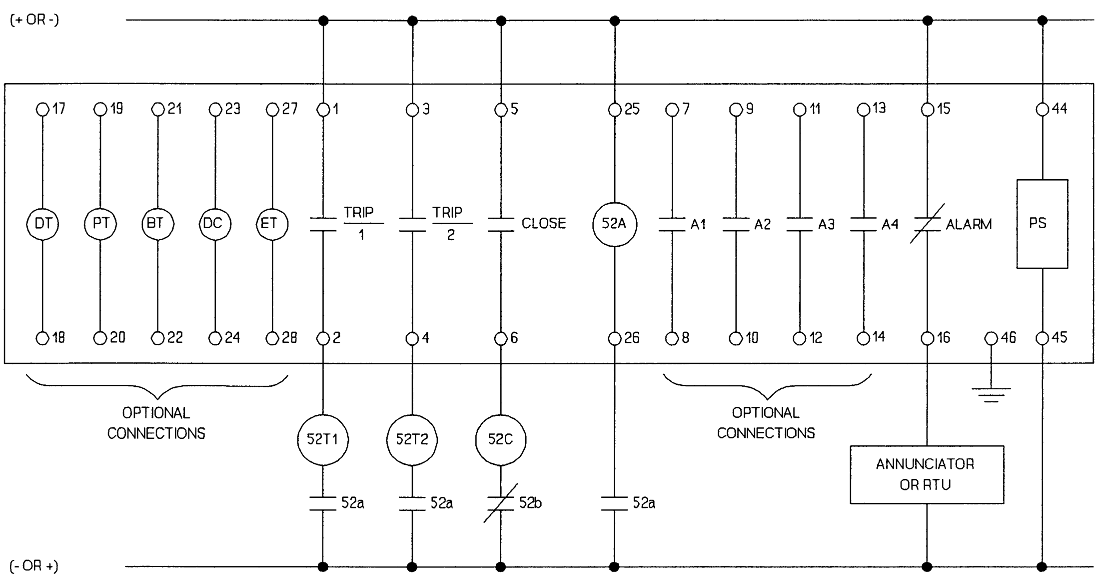


Figure 6.8: External Dc Connection Diagram (Typical)

SEL DIRECTION AND POLARITY CHECK FORM

STATION ____________________ DATE: ___/___/___ TESTED BY ____________________

SWITCH NO. ____________________ EQUIPMENT ____________________

INSTALLATION ________ ROUTINE ________ OTHER ____________________

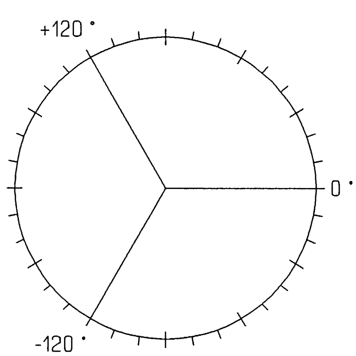
LOAD CONDITIONS:

STATION READINGS: ________ MW (OUT)(IN) ________ MVAR (OUT)(IN) ________ VOLTS ________ AMPS

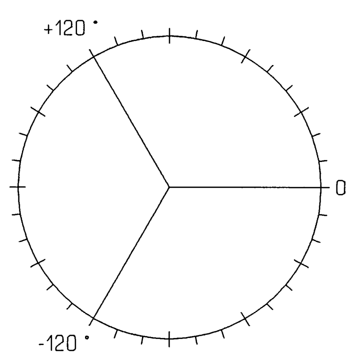
SEL READINGS: ________ MW (+)(-) ________ MVAR (+)(-)

AS SEEN ON SCREEN	Ia	Ib	Ic	Va	Vb	Vc	
COMPANY NOTATION	I( )	I( )	I( )	V( )	V( )	V( )	
1st LINE CHOSEN (Y COMPONENT)							
2nd LINE CHOSEN (X COMPONENT)							
CALCULATED MAGNITUDE $\sqrt{X^2 + Y^2}$							ROW 1
ANGLE IN DEGREES ARCTAN Y/X							
VALUE OF Va DEGREES TO SUBTRACT TO OBTAIN Va DEGREES = 0							
@ Va DEGREES = 0, ANGLE USED TO DRAW PHASOR DIAGRAM							ROW 2

USE THE VALUES IN ROWS 1 AND 2 ABOVE TO DRAW PHASOR DIAGRAMS BELOW



CURRENTS



VOLTAGES

SEL DIRECTION AND POLARITY CHECK FORM

STATION ______________________ DATE: ___/___/___ TESTED BY ______________

SWITCH NO. ______________ EQUIPMENT ______________________________

INSTALLATION ______ ROUTINE ______ OTHER ______________________________

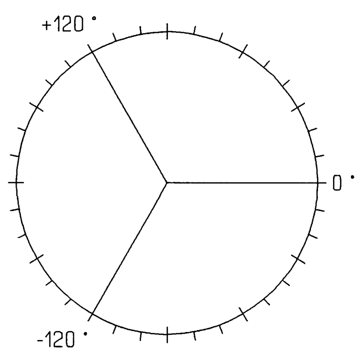
LOAD CONDITIONS:

STATION READINGS: ______ MW (OUT)(IN) ______ MVAR (OUT)(IN) ______ VOLTS ______ AMPS

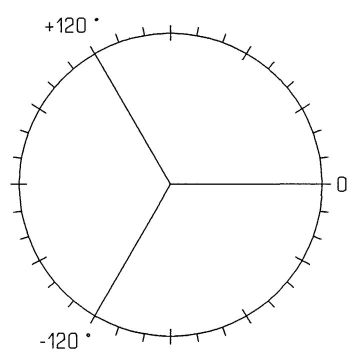
SEL READINGS: ______ MW (+)(-) ______ MVAR (+)(-)

AS SEEN ON SCREEN	Ia	Ib	Ic	Va	Vb	Vc	
COMPANY NOTATION	I( )	I( )	I( )	V( )	V( )	V( )	
1st LINE CHOSEN (Y COMPONENT)							
2nd LINE CHOSEN (X COMPONENT)							
CALCULATED MAGNITUDE $\sqrt{X^2 + Y^2}$							ROW 1
ANGLE IN DEGREES ARCTAN Y/X							
VALUE OF Va DEGREES TO SUBTRACT TO OBTAIN Va DEGREES = 0							
@ Va DEGREES = 0, ANGLE USED TO DRAW PHASOR DIAGRAM							ROW 2

USE THE VALUES IN ROWS 1 AND 2 ABOVE TO DRAW PHASOR DIAGRAMS BELOW



CURRENTS



VOLTAGES

MAINTENANCE AND TESTING
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MAINTENANCE AND TESTING

SEL-221D TEST PROCEDURE

Testing the relay consists of performing the Initial Checkout, described near the beginning of the Instruction Manual, and following some additional steps described here.

Initial Checkout

Please follow the steps listed in the Initial Checkout section of the Instruction Manual. The Initial Checkout procedure makes it easy to set up the relay for testing, and to ensure that it is generally functional.

Setting Test

To ensure the relay accepts settings, perform the following steps:

1. Gain Level 2 Access. (See ACCESS and 2ACCESS commands.)

2. Type SET.

3. Change one setting. For example change Zone 1 reach from 80% to 82%.

4. Type **END <ENTER>** to complete the setting procedure. Type in **YES <ENTER>** to the prompt: "OK (Y or N) ?". The ALARM contact should close for several seconds while the relay computes internal settings, if no alarm condition presently exists (such as self test failure).

5. Use the SHOWSET command to inspect the settings, and ensure that your change was accepted.

6. Use the SET and SHOWSET commands again to restore and check the settings.

7. Type **LOG MTU <ENTER>**.

8. Change one bit.

9. Complete the logic setting procedure.

10. Type **LOG MTU <ENTER>** again, and observe that the bit change is present. Restore the setting, and use the command again to check the restored setting.

METER Test

This test checks the magnitude accuracy of the relay. It is a three-phase test.

1. Connect the voltage input terminals VA, VB, and VC to the terminals of a three-phase voltage source. Apply 50 Vac $_{l\text{-}n}$ or 86.6 Vac $_{l\text{-}l}$.

2. Connect the current inputs and apply balanced three-phase current of five amperes (at the same angle as applied voltage) through the three inputs.

3. Using the METER command, inspect the measured voltages, currents, and power. Voltages VAB, VBC, and VCA should equal the applied line-neutral voltage times the potential transformer ratio setting times a square root of three. With the Example 230 kV Line settings, you should obtain:

   $$VAB = VBC = VCA = 50 \times 2000 \times 1.732 = 173.2 \text{ kV}. \ (\pm 0.5\%)$$

   Similarly, currents IA, IB, and IC should equal the applied current times the current transformer ratio. With the Example 230 kV Line settings, you should obtain:

   $$IA = IB = IC = 5 \times 200 = 1000 \text{ A}. \ (\pm 1\%)$$

   The power reading should be:

   $$VAB \times IA \times 1.732 = 300 \text{ MW}.$$

   The reactive power reading should be less than 5 MVAR.

Mho Relay Testing

The three-phase test described below is recommended. The status of any mho element may be observed using the TARGETS command. The total output of any zone may be observed using a programmable output relay, and setting the logic mask for that relay to observe the selected element.

The steps below apply to any of the three zones.

1. Connect a relay test set capable of providing three-wire voltages and at least one current to the relay. To connect the set for testing a phase element, connect the current source so that the current enters the dotted end of one-phase and exits the dotted end of the other phase. (For example, for a BC test, inject the current into B-dot, connect the undotted B and C current terminals together, and connect C-dot to the current source return terminal.)

2. Determine the voltages and currents required for a fault on the boundary at the maximum-reach point of the relay. An easy and convenient way to do this is to use the BASIC program given in the appendices. Using zero source impedance further simplifies the test. (Entering Z0=Z1 allows you to use the single-phase fault current calculation for phase-A as the three-phase fault current calculation.)

   For example, using the Example 230 kV Line settings, we see the CT/PT ratio is 0.1, so the secondary-ohm line data to enter into the BASIC program are:

   $$Z1 = 1.39 + j\ 7.996 \text{ ohms}$$
   $$Z0 = 1.39 + j\ 7.996 \text{ ohms}$$

   Enter 0 for ground fault resistance.

   Enter 0 source-to-bus impedance.

   To test Zone 1, which is set to 80% of the line, enter 0.8 for the per-unit distance from the bus to the fault. The program will compute the test set voltages and currents for AG and BC faults 0.8 pu or 80 miles away from the bus. Since the 80.8° MTA setting places the mho circle diameter on the transmission line positive-sequence impedance characteristic, the computed voltages and currents test the mho characteristic at its point of maximum reach along its maximum torque angle.

   The computer screen shows the voltages and current for a phase-A-ground fault, on a system with Z0=Z1. For a three-phase fault IA is the same, and IB and IC are equal in magnitude to IA, but at angles of ±120° from IA.

   The screen also shows the voltages and currents for a BC fault.

   For the example settings, the BASIC program display for the Zone 1 boundary conditions is:

```
VA      VB      VC      IA      IB      IC
67      67      67    10.3       0       0      A-G
 0    -120    +120     -80       0       0

67      67      67       0     8.9     8.9      B-C
 0    -120    +120       0    -170     +10
```

   Thus, for a Zone 1 boundary three-phase fault, the test set would be set for 67 volts per phase, and 10.3 amps per phase, with the currents lagging the voltages by 80°.

3. To obtain two other convenient test points, consider a square inscribed in the mho circle with one diagonal being the diameter along the MTA. The two corners of that square on the other diagonal are reached by increasing the current by a factor of 1.414, at angles of ±45° away from the angle obtained from the BASIC program.

   For our three-phase example, the required currents are 10.3 x 1.414 = 14.6 amperes, at the angles listed on the next page:

IA	IB	IC		
-35	-155	85	degrees	(MTA + 45°)
-125	115	-5	degrees	(MTA - 45°)

4. Test the relay at the three current settings (MTA, MTA + 45, MTA - 45). Using the TARGET 1 command, observe that the Zone 1 ABC (1ABC) bit should blink showing the boundary of the Zone 1 element. If the LED doesn't blink, adjust the angles of the three currents slightly until the LED begins to blink.

Directional Element Checking

Use the TARGETS command to observe the Relay Word with the DF bit (r3), by typing **TAR 3 <ENTER>**. The DF bit status is now displayed on the right-most LED of the relay targets. (Use the SET command to disable the LOP scheme, to prevent test-condition voltages from setting the loss-of-potential condition.)

The negative-sequence element may be checked, as follows.

Apply VA= 30 volts, VB = 0, VC = 0. This results in an applied V2 = 10 volts.

Apply IA = 3 amperes, corresponding to a negative-sequence current of 1 ampere.

Move the phase of the current with respect to the voltage, and observe the boundary of the directional element at MTA ± 90°.

The current polarization may be checked by turning off the voltage and applying a second current source to the polarizing current input (IP). Use an amplitude of 3 amperes, and move the phase of IA with respect to IP. Maximum torque is at 0°, so you should observe the boundary of the characteristic at ±90°.

Overcurrent Element Checking

Pickup of the 67N1, 67N2, 67N3, and 51N residual overcurrent elements is easily checked by first typing TARGET 2, so that Relay Word 2, with the overcurrent element bits, is displayed on the target LEDs. Disable all directional functions for this test. (Set 51NTC = N, and likewise for 32QE and 32IE.)

Apply current to one-phase, and observe the pickup and dropout of each element.

In a similar manner check the pickup and dropout of the phase overcurrent elements, by first typing TARGET 1, to display the 50H, 50M, and 50L bits on the LEDs. Apply current to one-phase, and observe the pickup and dropout of each element.

Testing the Input Circuits

1. Use the TARGETS command to set the LEDs to follow the contact inputs, by typing **TAR 5 <ENTER>**.

2. Apply control voltage to each input, and observe that the corresponding target LED turns on. Event reports should be triggered whenever you energize the DT, PT, BT, and ET inputs.

Testing the Serial Ports

The Initial Checkout procedure assumes you connect a terminal to PORT 2. Set the baud rate of PORT 1 to the same value as that of PORT 2, and switch your terminal from PORT 2 to PORT 1. Ensure that you can communicate through this port. If your relay is equipped with front and rear panel PORT 2 connectors, ensure that both operate properly.

Testing the IRIG-B Time Code Input

1. Connect a source of demodulated IRIG-B time code to the relay Auxiliary Port with a series resistor to monitor the current. Adjust the source to obtain an "ON" current of about 10 mA.

2. Execute the IRIG command, and ensure that the relay clock is set to the correct time, and that the indicated date is correct.

Note: A convenient, inexpensive way to test the IRIG-B port is to use a recording of the IRIG-B time code signal, passed through a simple demodulator. Please contact the factory for further details.

Testing the Power Supply Voltages

1. Execute the STATUS command, and inspect the voltage readings for the +5 and ±15 volt supplies.

2. At the Auxiliary Port, use a voltmeter to read the +5 and ±12 volt outputs. The 12-volt outputs are derived from the 15-volt supplies using three-terminal regulators.

3. Compare the +5 volt readings from the status report and the voltmeter. The voltage difference should be less than 50 mV, and both readings should be within 0.15 volts of five volts.

4. The 12 volt supplies should be within 0.5 volt of their nominal values.

REMOVAL OF FRONT PANEL AND DRAWOUT ASSEMBLY

To prevent shock hazard, power to the relay must be interrupted before removing the front panel assembly.

1. Disconnect external power source.

2. Remove the outermost front panel screws.

3. Front panel may be hinged forward and left alone, or removed by disconnecting the display board ribbon cable and the power switch/fuse connector (if installed).

4. Remove the two hex head screws from under the forward outside edges of the SEL-121D relay drawout assembly. The SEL-221D relay does not have the screws.

5. Disconnect the SEL-121D relay analog input connector from the main board (P 104). It is the right-most connector. Disconnect the SEL-221D relay power supply and analog signal connectors beneath the drawout assembly.

6. Remove drawout assembly by pulling on spacers located on bottom of tray with index fingers.

CALIBRATION

The SEL-221D Relay is factory calibrated. If you suspect that the relay is out of calibration, please contact the factory.

TROUBLE SHOOTING GUIDE

Inspection Procedure

The inspection procedure given below should be followed before the system is disturbed. After completing the inspection procedure, proceed to the troubleshooting table.

1. Measure and record control power voltage present at terminals marked + and -.

2. Check to see that the power is on, but do NOT turn system off if it is on.

3. Measure and record the voltage present at all control inputs.

4. Measure and record the state of all output relays.

5. Inspect the cabling to the serial communications ports, and be sure that a communications device is connected to at least one communications port.

Troubleshooting Table

All Front Panel LED'S Dark

1. Power is off
2. Blown fuse
3. Input power not present
4. Self test failure
5. Target command improperly set

Note: For 1, 2, 3, and 4, the ALARM relay contacts should be closed.

System Does Not Respond to Commands

1. Communications device not connected to system.
2. Relay or communications device at incorrect baud rate or other communication parameter incompatibility, including cabling error.
3. Internal ribbon cable connector loose or disconnected.
4. System is processing event record. (Wait several seconds.)
5. System is attempting to transmit information, but cannot due to handshake line conflict. (Check communications cabling.)
6. System is in the XOFF state, halting communications. (Type control-Q to put system in XON state.)

Tripping Output Relay Remains Closed Following Fault

1. 52A input remains asserted (i.e., CB auxiliary contact did not open with breaker.)
2. Auxiliary contact inputs improperly wired.
3. Output relay contacts burned closed.
4. Failure of interface board.

No Prompting Message Issued to Terminal upon Power-Up

1. Terminal not connected to system.

2. Wrong baud rate.

3. Improper connection of terminal to system.

4. Other port designated as the AUTOMATIC port (see AUTO setting in the SET command).

5. Port timeout interval set to a value other than zero.

6. Failure of main board or interface board.

System Does Not Respond to Faults

1. Relay improperly set. Review your settings using the SET and LOGIC commands.

2. Test set improperly set.

3. CT or PT input cable wiring error.

4. Analog input cable between transformer-termination and main board loose or defective.

5. Check built-in-test status with STATUS command.

6. Check input voltages and currents with METER command; and with TRIGGER and EVENT sequence.

Terminal Displays Meaningless Characters

1. Baud rate incorrectly set.

2. Check terminal configuration: see Commands and Serial Communications section of manual.

Self-Test Failure: +5 Volts

1. Power supply +5 volt output out of tolerance: see STATUS command.

2. A/D converter failure.

Self-Test Failure: +15 Volts

1. Power supply +15 volt output out of tolerance: see STATUS command.

2. A/D converter failure.

Self-Test Failure: -15 Volts

1. Power supply -15 volt output out of tolerance: see STATUS command.

2. A/D converter failure.

Self-Test Failure: Offset

1. Offset drift. (Adjust offsets)

2. A/D converter drift.

3. Loose ribbon cable from transformers to main board.

Self-Test Failure: ROM Checksum

1. EPROM failure. (Replace EPROMS)

Self-Test Failure: RAM

1. Failure of static RAM IC. (Replace RAM)

Self-Test Failure: A/D Converter

1. A/D converter failure.

2. RAM error not detected by RAM test.

Stall Relay Closed (Alarm)

1. Power is off.

2. Blown fuse.

3. Power supply failure.

4. Improper EPROMS or EPROM failure.

5. Main board or interface board failure.

Firmware Upgrade Instructions, SEL-121D Relay

SEL may occasionally offer firmware upgrades to improve the performance of your relay. These instructions explain how to install new firmware.

The modifications require that you power down the relay, remove its front panel, pull out the drawout unit, exchange several integrated circuit chips, and reassemble the relay. If you do not wish to perform the modifications yourself, we can assist you. Simply return the relay and integrated circuit chips to us. We will install the new chips and return the unit to you within a few days.

Warning: This procedure requires that you handle electrostatic discharge sensitive components. If your facility is not equipped to work with these components, we recommend that you return the relay to SEL for firmware installation.

Upgrade Instructions

1. If the relay is in service, disable its control functions.

2. Turn off control power to the relay.

3. Remove the front panel by unscrewing the four front panel screws (one in each corner).

4. With the front panel leaning forward, you can see the aluminum drawout chassis. The main board is attached to the top of the drawout chassis. The power supply and interface board are attached to the bottom of the drawout chassis. Several ribbon cables connect the boards to each other and to other portions of the relay.

5. Disconnect the analog input ribbon cable (the right-most cable) from the main board.

6. The front panel display cable connects the relay interface board to the front panel display board. It is located on the left side of the front panel. Disconnect this cable from the display board.

7. Two hex head screws hold the drawout chassis in place. These screws are on the bottom of the chassis in each front corner. Remove both screws.

8. Remove the drawout assembly by pulling the spacers on the bottom of the drawout chassis. You should be able to remove the assembly with your fingers.

9. Because steps 10 through 12 involve handling electrostatic discharge (ESD) sensitive devices and assemblies, perform these steps at an ESD safe work station. This will help prevent possible damage by electrostatic discharge.

10. Note the orientation of the ICs to be replaced. Use a small screwdriver to pry the indicated ICs free from their sockets. Be careful not to bend the IC pins or damage adjacent components.

11. Carefully place the new ICs in the appropriate sockets.

12. Check the orientation of the ICs. Be sure that each IC is in its corresponding socket. Look for IC pins that bent under or did not enter a socket hole.

13. Slide the drawout assembly back into the relay chassis. Using your fingers, push the assembly in until the retaining screw holes in the drawout assembly align with corresponding holes in the relay chassis.

14. Install the retaining screws and reconnect the two ribbon cables.

15. With breaker control disabled, turn relay power back on and enter your settings. Execute the STATUS, METER, and TRIGGER commands to ensure that all functions are operational. Set and record your Access Levels 1 and 2 passwords and the date and time. The relay is now ready to resume protective functions.

16. Please return the old ICs to Schweitzer Engineering Laboratories, Inc. in the same packing materials. New chips are shipped with a mailing label to simplify this process. When we receive the old parts, we will record a firmware upgrade for each of your relays.

Firmware Upgrade Instructions, SEL-221D Relay

1. If the relay is in service, disable its control functions. Turn off control power to the relay.

2. Remove the relay front panel by unscrewing the five front panel screws. With the front panel removed, you can see the aluminum drawout chassis. The main board is attached to the top of the drawout chassis. The power supply and transformer assembly are attached to the bottom of the relay chassis.

3. Disconnect the power supply and transformer secondary cables from the underside of the drawout assembly.

4. Remove the drawout assembly by pulling the spacers on the bottom of the drawout chassis. You should be able to remove the assembly with your fingers. Because steps 5 and 6 involve handling electrostatic discharge (ESD) sensitive devices and assemblies, perform these steps at an ESD safe work station. This will help prevent possible damage by electrostatic discharge.

5. Note the orientation of the ICs to be replaced. Use a small screwdriver to pry the indicated ICs free from their sockets. Be careful not to bend the IC pins or damage adjacent components.

6. Carefully place the new ICs in the appropriate sockets. Check the orientation of the ICs. Be sure that each IC is in its corresponding socket. Look for IC pins that bent under or did not enter a socket hole.

7. Slide the drawout assembly into the relay chassis. Using your fingers, push the assembly in until the front of the assembly is flush with the front of the relay chassis. Reconnect the power supply and transformer secondary cables to the receivers on the underside of the drawout assembly. Replace the relay front panel.

8. With breaker control disabled, turn relay power on and enter your settings. Execute the STATUS, METER, and TRIGGER commands to ensure that all functions are operational. Set and record your Access Levels 1 and 2 passwords and the date and time. The relay is now ready to resume protective functions.

Factory Assistance

If you have any questions regarding the performance, application, or repair of this or any other SEL product, do not hesitate to contact the factory. Our staff is happy to assist you.

Schweitzer Engineering Laboratories, Inc.
2350 NE Hopkins Court
Pullman, WA 99163-5603
Tel: (509) 332-1890
FAX: (509) 332-7990

SEL SCHWEITZER ENGINEERING LABORATORIES, INC.
2350 NE HOPKINS COURT • PULLMAN, WA 99163-5603 • TEL: (509) 332-1890

PROGRAM TO COMPUTE TEST SET SETTINGS FOR TESTING DISTANCE RELAYS

The BASIC program in this note determines voltages and currents which would appear on distance relay terminals for ground and phase faults on a radial system with source impedance at the same angle as line impedance. It is useful in determining test settings for SEL distance relays and fault locating equipment.

The program was initially designed to run on a TRS-80 Model 100 briefcase computer but may be installed on virtually any personal computer or laptop.

It first prompts you for the positive and zero-sequence impedances of the transmission line. Enter the data in secondary ohms for the entire length of the protected line.

Next, you may enter fault resistance, which is used in the ground-fault computations.

Enter source impedance as a per-unit value with a base of the previously-entered transmission line data. For example, if the radial system has a source impedance of about ten percent of the entered line impedance, enter 0.1 for the per-unit distance from the source to the bus.

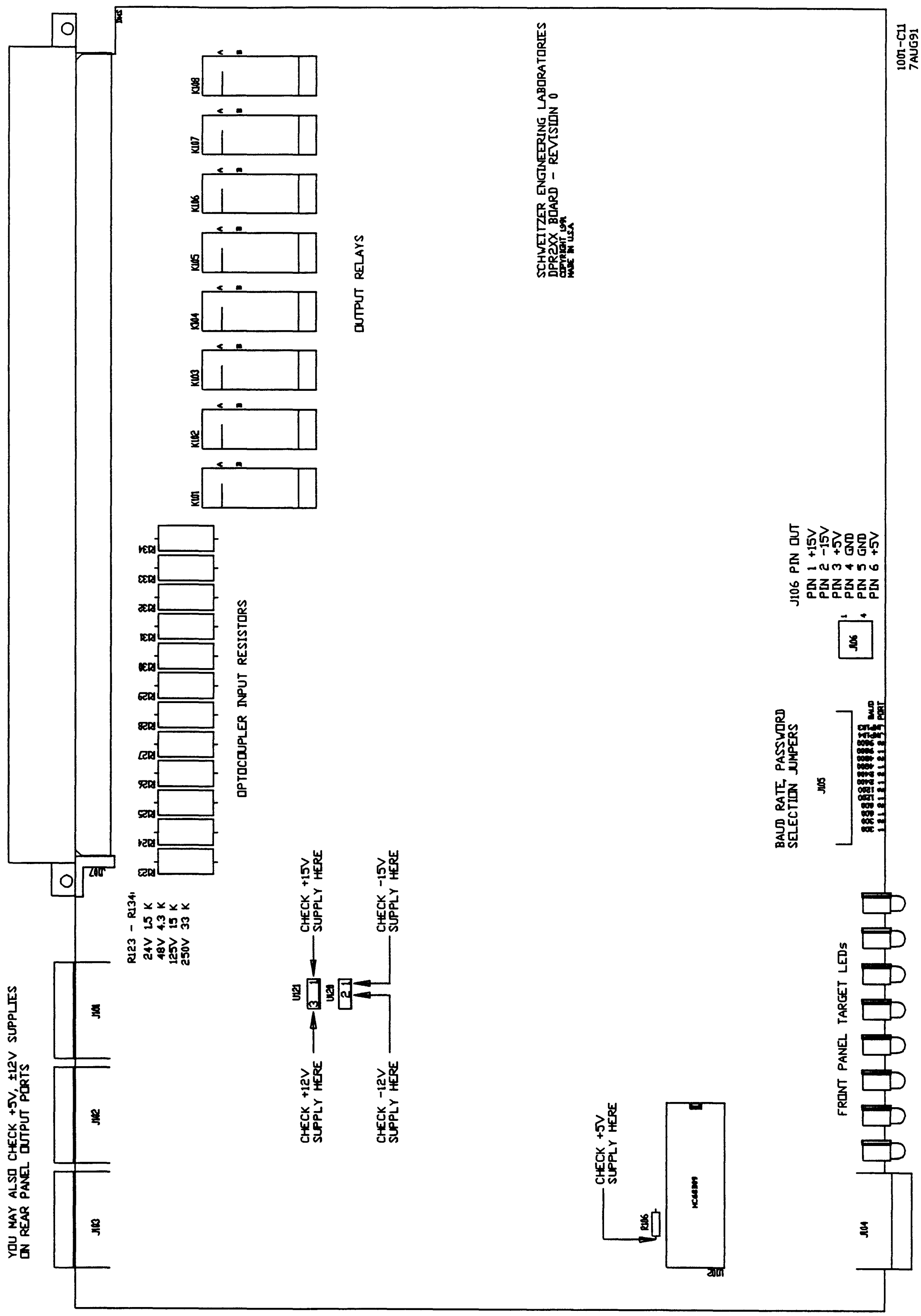
Specify the distance from the bus to the fault as a fraction of the total line length. To obtain the voltages and currents for a fault one-half the way down the line from the bus, enter 0.5 for the distance from the bus to the fault.

After you enter this data, the program begins computations. The display then shows voltages and currents for both an AG and BC fault. These data can be entered into any active test source.

The bottom line of the display offers you a choice of entering a new impedance data (I), changing the distance from the source to the bus (B), specifying a new fault location (F), or quitting (Q).

```
1       REM SCHWEITZER ENGINEERING LABORATORIES, INC.
2       REM 2350 NE Hopkins Court
3       REM Pullman, WA  99163-5603
4       REM
10      REM COMPUTE DOBLE SETTINGS FOR A ONE-BUS SYSTEM
20      REM HOMOGENEOUS SYSTEM
30      REM SOURCE VOLTS= 67 L-N
40      REM
50      REM ENTER IMPEDANCES FOR 100% OF LINE
60      INPUT "ENTER Z1: R,X";R1,S1
70      INPUT "ENTER Z0: R,X";R0,S0
75      INPUT "ENTER RF FOR GND FLTS";RF
80      REM
90      REM ENTER BUS LOC. FROM SOURCE
100     INPUT "DIST SOURCE TO BUS (PU OF LINE)";S
120     INPUT "DIST BUS TO FAULT (PU OF LINE)";F
130     REM
140     REM  PHASE A TO GROUND
150     REM COMPUTE POS SEQ CURRENT
160     X = R0+2*R1: Y = S0+2*S1
170     R3 = R1-R0:   S3 = S1-S0
180     AR=1/(S+F):  AI=0
190     BR=X      :  BI=Y
195     BR=BR+3*RF/(S+F)
200     GOSUB 2000
210     I = RR    :   J = RI
220     IA = 3*67*I:  JA=3*67*J
225     IB=0:JB=0:IC=0:JC=0
230     AR=X:AI=Y:BR=I:BI=J
232     GOSUB 1000
234     UA=67*(1-S*RR):VA=67*(-S*RI)
240     AR=R3      :AI=S3
250     BR=I       :BI=J
260     GOSUB 1000
270     TR=S*RR    :TS=S*RI
280     UB=67*(-0.5+TR)
290     VB=67*(-SQR(3)/2+TS)
300     UC=67*(-0.5+TR)
310     VC=67*(SQR(3)/2+TS)
315     FF$="A-G"
320     GOSUB 4041
500     REM  B-C FAULT
510     AR=1: AI=0
520     BR=2*R1*(S+F):BI=2*S1*(S+F)
530     GOSUB 2000
540     I=RR:J=RI
550     IA=0:JA=0
560     AR=I:AI=J:BR=0:BI=-67*SQR(3)
570     GOSUB 1000
580     IB=RR:JB=RI:IC=-IB:JC=-JB
590     UA=67:VA=0
600     AR=I:AI=J:BR=S*RI:BI=S*S1
610     GOSUB 1000
620     AR=RR:AI=RI:BR=0:BI=SQR(3)
630     GOSUB 1000
635     TR=RR:TS=RI
640     UB=67*(-0.5+TR)
650     VB=67*(-SQR(3)/2+TS)
660     UC=67*(-0.5-TR)
670     VC=67*(0.5*SQR(3)-TS)
675     FF$="B-C"
680     GOSUB 4041
900     INPUT "IMP BUS FAULT OR QUIT (I,B,F,Q)";A$
910     IF A$ = "I" THEN GOTO 50
920     IF A$ = "B" THEN GOTO  75
930     IF A$ = "F" THEN GOTO 120 ELSE GOTO 999
999     END
1000    REM MULT SUBROUTINE
1010    REM AR,AI * BR,BI = RR,RI
1020    RR=AR*BR-AI*BI
1030    RI=AI*BR+AR*BI
1040    RETURN
2000    REM DIVISION SUBROUTINE
2010    REM AR,AI / BR,BI = RR,RI
2020    D = BR*BR + BI*BI
2030    RR = AR*BR + AI*BI
2040    RR = RR/D
2050    RI = BR*AI - AR*BI
2060    RI = RI/D
2070    RETURN
3000    REM RECT TO POLAR CONV
3010    REM AR,AI, TO RH, TH
3020    PI = 3.14159265358
3030    IF (AR=0 AND AI=0) THEN    RH=0: TH=0: RETURN
3040    IF (AR=0 AND AI>0) THEN    RH=AI: TH=90:RETURN
3050    IF (AR=0 AND AI<0) THEN RH=-AI: TH=-90: RETURN
3060    IF (AR>0) THEN TH=(180/PI)*ATN(AI/AR)
3070    IF (AR<0) THEN TH=(180/PI)*ATN(AI/AR)+180
3080    IF TH>180 THEN TH = TH-360
3090    RH=SQR(AR*AR+AI*AI)
3100    RETURN
4041    AR=UA:AI=VA:GOSUB 3000
4042    UA=RH:VA=TH
4043    AR=UB:AI=VB:GOSUB 3000
4044    UB=RH:VB=TH-VA
4045    AR=UC:AI=VC:GOSUB 3000
4046    UC=RH:VC=TH-VA
4047    AR=IA:AI=JA:GOSUB 3000
4048    IA=RH:JA=TH-VA
4049    AR=IB:AI=JB:GOSUB 3000
4050    IB=RH:JB=TH-VA
4055    AR=IC:AI=JC:GOSUB 3000
4060    IC=RH:JC=TH-VA
4061    VA=0
4100    PRINT " VA    VB    VC    IA    IB    IC"
4130    PRINT USING"##.# ";UA;UB;UC;IA;IB;IC,
4132    PRINT FF$
4140    PRINT USING"#### ";VA;VB;VC;JA;JB;JC
4150    RETURN
```

INTERNAL DIAGRAMS
TABLE OF CONTENTS



SEL-200 Series Relay Main Board Troubleshooting Test Points and Jumper Locations

SEL-221D RELAY/FAULT LOCATOR COMMAND SUMMARY

Access Level 0

ACCESS	Answer password prompt (if password protection enabled) to gain access to Level 1. Three unsuccessful attempts pulses ALARM relay.

Access Level 1

2ACCESS	Answer password prompt (if password protection enabled) to gain access to Level 2. This command always pulses the ALARM relay.
DATE m/d/y	Show or set date. DAT 2/3/92 sets date to Feb. 3, 1992. This setting is overridden when IRIG-B synchronization occurs.
EVENT	Show event record. EVE 1 shows long form of most-recent event.
HISTORY	Show DATE, TIME, EVENT TYPE, FAULT LOCATION, DURATION, and CURRENT for the twelve most recent faults.
IRIG	Force immediate execution of time code synchronization task.
METER n	Show primary current, voltage, real and reactive power. METER runs once. METER n runs n times.
QUIT	Return to Access Level 0 and reset targets to target 0.
SHOWSET	Show the relay settings and logic settings. This command does not affect the settings. The logic settings are shown in hexadecimal format for each.
STATUS	Show self test status.
TARGET n	Show data and set target lights as follows: TAR 0: Relay Targets — TAR 1: Relay Word #1 TAR 2: Relay Word #2 — TAR 3: Relay Word #3 TAR 4: Relay Word #4 — TAR 5: Contact Inputs TAR 6: Contact Outputs — TAR R: Clears targets and returns to TAR 0 Be sure to return to TAR 0 when done, so LEDs display fault targets.
TIME h/m/s	Show or set time. TIM 13/32/00 sets clock to 1:32:00 PM. This setting is overridden when IRIG-B synchronization occurs.
TRIGGER	Trigger and save an event record. (Type of event is EXT).

Access Level 2

CLOSE	Close circuit breaker, if allowed by jumper setting.
LOGIC n	Show or set logic masks MTU, MPT, MTO, MTB, MRI, MRC, MA1-MA4.
OPEN	Open circuit breaker, if allowed by jumper setting.
PASSWORD	Show or set passwords. PAS 1 OTTER sets Level 1 password to OTTER. PAS 2 TAIL sets Level 2 password to TAIL.
SET	Initiate setting procedure. ALARM relay closes while new settings are being computed, and event data buffers are cleared.

Use the following to separate commands and their parameters: space, comma, semicolon, colon, or slash.

SCHWEITZER ENGINEERING LABORATORIES, INC.
2350 NE Hopkins Court
Pullman, WA 99163-5603
Tel: (509) 332-1890 Fax: (509) 332-7990

Rev. 4

Patents Pending

EXPLANATION OF EVENT REPORT

```
Example 230 kV Line                             Date: 6/1/92     Time: 11:02:21.150

FID=SEL-121D-R100-V656mptr-D880425

               Currents                       Voltages       Relays Outputs Inputs
                (amps)                          (kV)
                                                             52265L TCAAAAA DPBD5E
  IPOL     IR      IA      IB      IC     VAB     VBC     VCA 011710 PL1234L TTTC2T
                                                             P3PNNP              A

     0    648     815      53    -217    86.3   130.0  -216.7 M..... ....... ....*.
     0    920     900      47     -31  -196.8   192.1     5.3 M..2P. ..*.... ....*.

     0   -927    -950      -3      28   -82.6  -130.2   213.5 M..1P. *.*.*.. ....*.
     0   -983    -978      -9       3   196.2  -191.9    -4.9 M..1P. *.*.*.. ....*.
     0    961     963       0      -3    82.0   130.2  -213.1 M..1P. *.*.*.. ....*.
     0    992     991       3       0  -196.0   191.9     4.9 M..1P. *.*.*.. ....*.

Event   : 1AG    Location   : 50.29  mi  4.08   ohms sec
Duration: 4.25   Flt Current: 1383.8

R1   =13.90     X1   =79.96     R0   =41.50     X0   =248.57   LL   =100.00
R0S  =8.30      X0S  =49.71
CTR  =200.00    PTR  =2000.00   MTA  =80.80     LOCAT=Y
79OI1=40.00     79OI2=60.00     79OI3=80.00     79RS =240.00
Z1%  =80.00     Z2%  =120.00    Z3%  =150.00
Z2DP =30.00     Z3DP =60.00
50L  =100.00    50M  =200.00    50MFD=20.00     50H  =3000.00
51NP =100.00    51NTD=3.00      51NC =2         51NTC=Y
50N1P=1000.00   50N2P=700.00    50N3P=600.00
Z2DG =20.00     Z3DG =40.00     50G  =100.00    REJOE=N
52BT =30.00     ZONE3=F         32QE =Y         32IE =N        LOPE =Y
TIME1=5         TIME2=0         AUTO =2         RINGS=3
```

Currents and voltages are in primary Amps and kV. Rows are 1/4 cycle apart. Time runs down page. Obtain phasor RMS value and angle using any entry as Y-component, and the entry immediately underneath as the X-component. For example, from bottom rows, IAY = 963, IAX = 991. Therefore, IA = 1382 amps RMS primary, at an angle of ATAN(963/991) = 44°, with respect to the sampling clock.

```
FID>      Firmware Identification Data
<Relays>  columns show states of internal relay elements ---> Designators
  50P : phase overcurrent ..... : 50H,  50M,  50L        ---> H,M,L
  213 : 3-phase distance ...... : Z1,   Z2,   Z3         ---> 1,2,3
  21P : 2-phase distance ...... : Z1,   Z2,   Z3         ---> 1,2,3
  67N : inst ground-overcurrent : 67N1, 67N2, 67N3       ---> 1,2,3
  51N : ground time-overcurrent                          ---> P,T
  LOP : loss-of-potential logic                          ---> *
<Outputs>     columns show states of output contacts:  ON = "*" , OFF = "."
              TP=TRIP, CL=CLOSE, A1-A4=PROGRAMMABLE, AL=ALARM
<Inputs>      columns show states of input contacts:
              DT=DIRECT TRIP, PT=PERMISSIVE TRIP, BT=BLOCK TRIP,DC=DIRECT
              CLOSE, 52A=PCB A-CONTACT, ET=EXTERNAL TRIGGER (event report)
<Event>       Fault indications are "ZT" where Z indicates zone and T type
              Z is one of 1=Zone 1, 2=Zone 2, 3=Zone 3, 5=51N
                H=50H, "?" = indeterminate zone
              T is one of AG,BG,CG = single-phase, AB,BC,CA = 2-phase
                ABG,BCG,CAG = 2-phase to ground, ABC = 3-phase
                followed by a "T" if a TRIP triggered the report
              Other indications are TRIP = triggered by TRIP output
                    and EXT = externally or otherwise triggered
<Location>    Distance to fault in miles.  999999 is indeterminate distance
<ohms sec>    Distance to fault in secondary ohms.  999999 is indeterminate
<Duration>    Fault duration determined from relay element(s) pickup time
<Flt Current> Max phase current (primary amps) taken near middle of fault
R1,X1,R0,X0   Primary series impedance settings for transmission line
LL            Line length corresponding to specified line impedances
R0S,X0S       Zero-seq source impedance (used by fault locator only)
CTR, PTR      Current and potential transformer ratios (XTR:1)
LOCAT         Enable or disable fault locator (Y/N)
79OI1,2,3,RS  Three-shot recloser open and reset intervals
Z1%,Z2%,Z3%   Reaches of 3- and 2-phase mhos, percent of line length (LL)
Z2DP, 3       Zones 1, 2, and 3 timer settings for 3- and 2-phase faults
50L,M,H,MFD   Overcurrent settings and coordinating delay for 50M & LOP Trip
51NP,TD,C,TC  GND time-overcurrent pickup, time dial, curve, torque control
50N1P,2,3     Ground inst-overcurrent pickup settings Zones 1, 2, and 3
Z2DG, 3       Zone timers for ground faults
50G           Phase overcurrent for REJO
REJOE         REJO logic enable
52BT          52B delay setting (for switch-onto-fault coordination)
ZONE3         Directional orientation of ALL Zone 3 elements (Fwd/Rvs)
32QE,IE       Ground fault directionality from (V2,I2), or (IP,I0)
LOPE          Enable for loss-of-potential supervision (Y/N)
TIME1,2       Communications port timeout intervals (automatic log-off)
AUTO          Port assignment for automatic message transmissions
RINGS         Number of rings to wait before modem answers telephone
<Logic settings>  See LOGIC command for a description of mask settings
```

SEL-221D RELAY/FAULT LOCATOR COMMAND SUMMARY

Access Level 0

ACCESS	Answer password prompt (if password protection enabled) to gain access to Level 1. Three unsuccessful attempts pulses ALARM relay.

Access Level 1

2ACCESS	Answer password prompt (if password protection enabled) to gain access to Level 2. This command always pulses the ALARM relay.
DATE m/d/y	Show or set date. DAT 2/3/92 sets date to Feb. 3, 1992. This setting is overridden when IRIG-B synchronization occurs.
EVENT	Show event record. EVE 1 shows long form of most-recent event.
HISTORY	Show DATE, TIME, EVENT TYPE, FAULT LOCATION, DURATION, and CURRENT for the twelve most recent faults.
IRIG	Force immediate execution of time code synchronization task.
METER n	Show primary current, voltage, real and reactive power. METER runs once. METER n runs n times.
QUIT	Return to Access Level 0 and reset targets to target 0.
SHOWSET	Show the relay settings and logic settings. This command does not affect the settings. The logic settings are shown in hexadecimal format for each.
STATUS	Show self test status.
TARGET n	Show data and set target lights as follows: TAR 0: Relay Targets — TAR 1: Relay Word #1 TAR 2: Relay Word #2 — TAR 3: Relay Word #3 TAR 4: Relay Word #4 — TAR 5: Contact Inputs TAR 6: Contact Outputs — TAR R: Clears targets and returns to TAR 0 Be sure to return to TAR 0 when done, so LEDs display fault targets.
TIME h/m/s	Show or set time. TIM 13/32/00 sets clock to 1:32:00 PM. This setting is overridden when IRIG-B synchronization occurs.
TRIGGER	Trigger and save an event record. (Type of event is EXT).

Access Level 2

CLOSE	Close circuit breaker, if allowed by jumper setting.
LOGIC n	Show or set logic masks MTU, MPT, MTO, MTB, MRI, MRC, MA1-MA4.
OPEN	Open circuit breaker, if allowed by jumper setting.
PASSWORD	Show or set passwords. PAS 1 OTTER sets Level 1 password to OTTER. PAS 2 TAIL sets Level 2 password to TAIL.
SET	Initiate setting procedure. ALARM relay closes while new settings are being computed, and event data buffers are cleared.

Use the following to separate commands and their parameters: space, comma, semicolon, colon, or slash.

SCHWEITZER ENGINEERING LABORATORIES, INC.
2350 NE Hopkins Court
Pullman, WA 99163-5603
Tel: (509) 332-1890 Fax: (509) 332-7990

Printed in USA
Rev. 4

Patents Pending

EXPLANATION OF EVENT REPORT

```
Example 230 kV Line                           Date: 6/1/92     Time: 11:02:21.150

FID=SEL-121D-R100-V656mptr-D880425

              Currents                        Voltages         Relays Outputs Inputs
               (amps)                           (kV)
                                                               52265L TCAAAAA DPBD5E
  IPOL     IR      IA      IB      IC     VAB     VBC     VCA  011710 PL1234L TTTC2T
                                                               P3PNNP              A

     0    648     815      53    -217    86.3   130.0  -216.7  M..... ....... ....*.
     0    920     900      47     -31  -196.8   192.1     5.3  M..2P. ..*.... ....*.

     0   -927    -950      -3      28   -82.6  -130.2   213.5  M..1P. *.*.*.. ....*.
     0   -983    -978      -9       3   196.2  -191.9    -4.9  M..1P. *.*.*.. ....*.
     0    961     963       0      -3    82.0   130.2  -213.1  M..1P. *.*.*.. ....*.
     0    992     991       3       0  -196.0   191.9     4.9  M..1P. *.*.*.. ....*.

Event    : 1AG    Location   : 50.29  mi  4.08   ohms sec
Duration: 4.25    Flt Current: 1383.8

R1   =13.90    X1   =79.96     R0   =41.50    X0   =248.57   LL   =100.00
R0S  =8.30     X0S  =49.71
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Z2DG =20.00    Z3DG =40.00     50G  =100.00   REJOE=N
52BT =30.00    ZONE3=F         32QE =Y        32IE =N        LOPE =Y
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