SEL-221B, -1
SEL-121B, -1

Phase Distance Relay
Ground Directional Overcurrent Relay
Selectable Settings Groups
Fault Locator

Instruction Manual

20000107

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.

PM221B-01

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.

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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.

MANUAL CHANGE INFORMATION

The date code at the bottom of each page of this manual reflects the creation or revision date. Date codes are changed only on pages that have been revised and any following pages affected by the revisions (i.e., pagination). If significant revisions are made to a section, the date code on all pages of the section will be changed to reflect the revision date.

Each time revisions are made, both the main table of contents and the affected individual section table of contents are regenerated and the date code is changed to reflect the revision date.

Changes in this manual to date are summarized below (most recent revisions listed at top).

Revision Date	Summary of Revisions
The ***Manual Change Information*** section has been created to begin a record of revisions to this manual. All changes will be recorded in this Summary of Revisions table.	
20000107	Clarify operation of settings group selection and ALARM contact when an invalid setting group is selected by contact inputs S1 - S5.
990308	Incorporated "***Kilometer Option***", "***ACB Phase Rotation Option***", and "***50 Hz Options***" addenda into ***Section 1: Introduction***. Incorporated "***Jumper Installation Instructions***" addendum into ***Section 6: Installation***. Updated "***Logic Input Ratings***" in the ***Specifications*** subsection in ***Section 1: Introduction***. Incorporated "***SEL-121-1 Relay With Trip Duration Setting***" addendum into ***Section 4: Commands and Serial Communications***. The title reads ***SEL-221B-1/121B-1 Relay With Trip Duration Setting***. Updated ***Figure 6.5: Relay Dimensions, Panel Cutout, and Drill Plan*** in ***Section 6: Installation.*** Changed the figure caption to read ***Relay Dimensions and Drill Plan***.

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OVERVIEW

The SEL-221B Phase Distance and Ground Directional Overcurrent Relay with selectable setting groups and fault locator may be applied to protect transmission, subtransmission, and distribution lines.

The features of the SEL-221B Relay include:

Eight Selectable Setting Groups

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

Transmission Line Fault Locating

Event Recording

Automatic Self-Testing

Metering

Target Indicators for Faults, Selected Setting Group Display, and Testing

Time-Code Input

Communications Ports for Local and Remote Access

Compact Size and Economical

GENERAL INFORMATION

This introduction gives the specifications for the SEL-221B Relay and describes its theory of operation. Although you should be familiar with the specifications and theory of operation, first you may wish to complete Section 2: INITIAL CHECKOUT. 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 entered, modified, and activated either remotely or locally. 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 with pre-fault and fault conditions to provide an accurate estimate of fault location. This eliminates the need for communications channels, special instrument transformers, or source impedances, even during conditions of substantial load flow and fault resistance.

A detailed event report is generated following every fault. It contains all information needed to quantitatively examine the pre-fault, fault, and post-fault 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 elements 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. The SEL-221B 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 event report, showing the pre-fault, fault, and post-fault conditions. This 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 because all phase-shifting operations are performed by precise time delays controlled from a quartz crystal oscillator.

Kilometer/50 Hz Options

The SEL-221B instruction manual is written for fault locations in terms of miles. If your SEL-221B Relay is ordered with the kilometer line length option, references made in the instruction manual to miles should be substituted with kilometers.

One exception to the straight substitution of kilometers for miles is the reference in the instruction manual to the effect of shunt capacitance on the fault location calculation. The line length equation and associated paragraphs, corrected for a 100-kilometer line, should read:

Shunt capacitance of the transmission line is not taken into account. The capacitance causes the fault location to appear less remote by approximately a factor of 1/cos(bL), where bL is the line length in radians at 50 Hz. One wavelength at 50 Hz is 5996 kilometers. For example, the line length of a 100-kilometer line in radians, is:

$$(100/5996) \times 2 \times 3.14159 = 0.1048 \text{ radians}$$

The indication neglecting capacitance is about cos(0.1048) = 0.9945 times the actual fault location, or about 0.55 kilometers short for a fault at the remote end of a 100-kilometer line.

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 ("B") or ACB ("C") rotation.

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

50 Hz Options

This manual is written for relays operating at a nominal system frequency of 60 Hz. For relays which specify a nominal frequency of 50 Hz, substitute 50 Hz for each reference to 60 Hz.

References made to a sampling time of 1/240 seconds should be replaced with a time of 1/200 seconds.

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 inverse-time element with selectable curve shapes

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

Zone 3 mhos and definite-time element may be reversed

High-set phase overcurrent elements

Medium-set phase overcurrent elements may be enabled on loss-of-potential.

Relay Elements

Phase overcurrent

50AL, 50BL, 50CL (phase fault detectors)
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

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

Maximum torque angle: 47 - 90° in one-degree 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: 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 or 0.5 < I < 2 A

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

Memory polarization:
  Zone 1, 2, and 3 three-phase mho elements are memory-polarized from a 4-cycle memory filter.

Ground Overcurrent

51N residual time-overcurrent element:
- Selectable curve shape (4 curves)
- Time dial: 0.50 to 15.00 in 0.01 steps
- Pickup: 0.25 to 6.3 A, ± 0.05 A ± 3% of setting
- Timing: ± 4% and ± 1 cycle for residual current magnitude between 2 and 20 multiples of pickup
- Directional or nondirectional

50N1, 50N2, 50N3 residual overcurrent elements:
- Pickup: 0.25 A to 48 times 51N pickup for 51N pickup < 3.15 A
  0.5 A to 48 times 51N pickup for 51N pickup ≥ 3.15 A
- Transient overreach: 5% of set pickup
- Timers are provided for 50N1, 50N2, and 50N3

Ground Directional Elements

Negative-sequence directional element:
- Angle: same as mho element setting
- Sensitivity: refer to the following table

Zero-sequence directional element:
- Voltage polarization
  - Angle: same as mho element setting
  - Sensitivity: refer to the following table

Voltage Polarization Sensitivities for 32Q and 32V

*Z1 (ohms)	**32Q Sens. (VA)	***32V Sens. (VA)
0.125 - 0.5	0.04 / Z1	0.14 · 51N
0.5 - 2.0	0.14 · Z1	0.28 · 51N · Z1
2.0 - 8.0	0.04 · Z1	0.07 · 51N · Z1
8.0 - 32.0	0.01 · Z1	0.02 · 51N · Z1

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

- Current polarization:
  - Angle: 0°
  - Sensitivity: (0.5 amps) · (51N pickup setting) in units of residual amps squared

Sequence-Component Elements

Zero-sequence overvoltage element (47NL)
Pickup: 14 volts V0
Zero-sequence overcurrent element (50NL)
Pickup: I0 = 0.083 amps for 51N pickup < 3.15 amps
I0 = (0.083 amps) · (51N pickup / 3.15 amps) for 51N pickup ≥ 3.15 amps
Positive-sequence overvoltage element (47P)
Pickup: 14 volts V1

Relay Settings

Eight selectable relay setting groups are set using the SET command followed by the group number (1-8). The setting groups are selected locally with a two-pole, multi-position switch or remotely using the GROUP command followed by the group number (1-8). Each position of the switch asserts a different pair of input contacts which, in turn, invokes a different setting group. The combinations of input contact pairs corresponding to the different setting groups are shown in Table 1.1.

Table 1.1: Setting Groups Invoked by Input Pairs

Setting Groups	Contact Inputs				
	S1	S2	S3	S4	S5
Setting #1	1	1	0	0	0
Setting #2	0	1	1	0	0
Setting #3	0	0	1	1	0
Setting #4	0	0	0	1	1
Setting #5	1	0	1	0	0
Setting #6	0	1	0	1	0
Setting #7	0	0	1	0	1
Setting #8	1	0	0	1	0
Remote	0	1	0	0	1

Note: The GROUP command only works when input contacts S2 and S5 are asserted, enabling the Remote function. If input contacts S1 through S5 are asserted in any pattern other than those shown in Table 1.1, the relay remains enabled in the previously selected setting group with the ALARM contact closed.

Setting Group

A front panel indication of the selected setting group is displayed by pressing the TARGET RESET button. Initially all the LEDs illuminate for 1 second as a lamp test; then the LED corresponding to the setting group number illuminates for 1 second. Finally, the targets return to their normal state.

Movement of the setting group selector switch causes the LED corresponding to the switch location to illuminate. If the switch is left in a location, the LED will stay lit for about 5 seconds. At that time the active setting group will be updated. If the selector switch is returned to the active setting group position before another setting group is activated, the LED will illuminate for about 1 second, then the targets will return to their normal state.

Fault Location

Fault location is computed from event reports stored following each fault. Algorithm compensates for pre-fault current to improve accuracy for high-resistance faults.

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. 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 Ac Input Voltage

115 volt nominal phase-to-phase, three-phase 4-wire connection

Rated Ac Input Current

5 amps per phase nominal
15 amps per phase continuous
500 amps for 1 second thermal rating

Output Contact Current Ratings

30 amps make per IEEE C37-90
6 amps carry continuously
MOV protection provided

Optoisolated Inputs SEL-221B Relay

The following optoisolated inputs draw 4 mA when nominal control voltage is applied:

24 Vdc: 15 - 30 Vdc
48 Vdc: 30 - 60 Vdc
250 Vdc: 150 - 300 Vdc

Fixed "Level-Sensitive" inputs are provided on relays with 125 Vdc opto-isolated inputs. The 125 Vdc optoisolated inputs each draw 6 mA when nominal control voltage is applied.

125 Vdc: on for 100 - 150 Vdc; off below 75 Vdc

Optoisolated Inputs SEL-121B Relay

The following optoisolated inputs draw 6 mA when nominal control voltage is applied:

24 Vdc:	10 - 30 Vdc
48 Vdc:	25 - 60 Vdc
125 Vdc:	60 - 200 Vdc
250 Vdc:	200 - 280 Vdc

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-232)

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 near 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

SEL-221B: Refer to Figure 6.5.
SEL-121B: 5.25" x 19" x 13" (13.3 cm x 48.2 cm x 33.0 cm) (H x W x D).

Mounting

Mounts in standard EIA 19" (48.2 cm) relay rack or panel cutout.

Unit Weight

SEL-221B: 12 pounds (5.5 kg)
SEL-121B: 21 pounds (9.5 kg)

Shipping Weight

SEL-221B: 17 pounds (7.7 kg)
SEL-121B: 26 pounds (11.8 kg)

Operating Temp.

-40° to 158°F (-40° to 70°C)

BASIC PROTECTIVE CAPABILITIES

The SEL-221B Relay provides complete protection for transmission line faults of all types.

The SEL-221B Relay Function Block Diagram (Figure 1.1) illustrates the basic configuration of the protective capabilities. (Exact descriptions of the logic are in the Section 3: FUNCTIONAL DESCRIPTION.)

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 Faults

Three zones are provided. Zones 1, 2, and 3 are mho circles passing through the origin. Zone 3 may be reversed.

The three-phase elements are supervised by three overcurrent elements, which must all pick up. They are also supervised by a loss-of-potential scheme, when enabled. A minimum of six cycles of memory polarization is provided for Zones 1, 2, and 3.

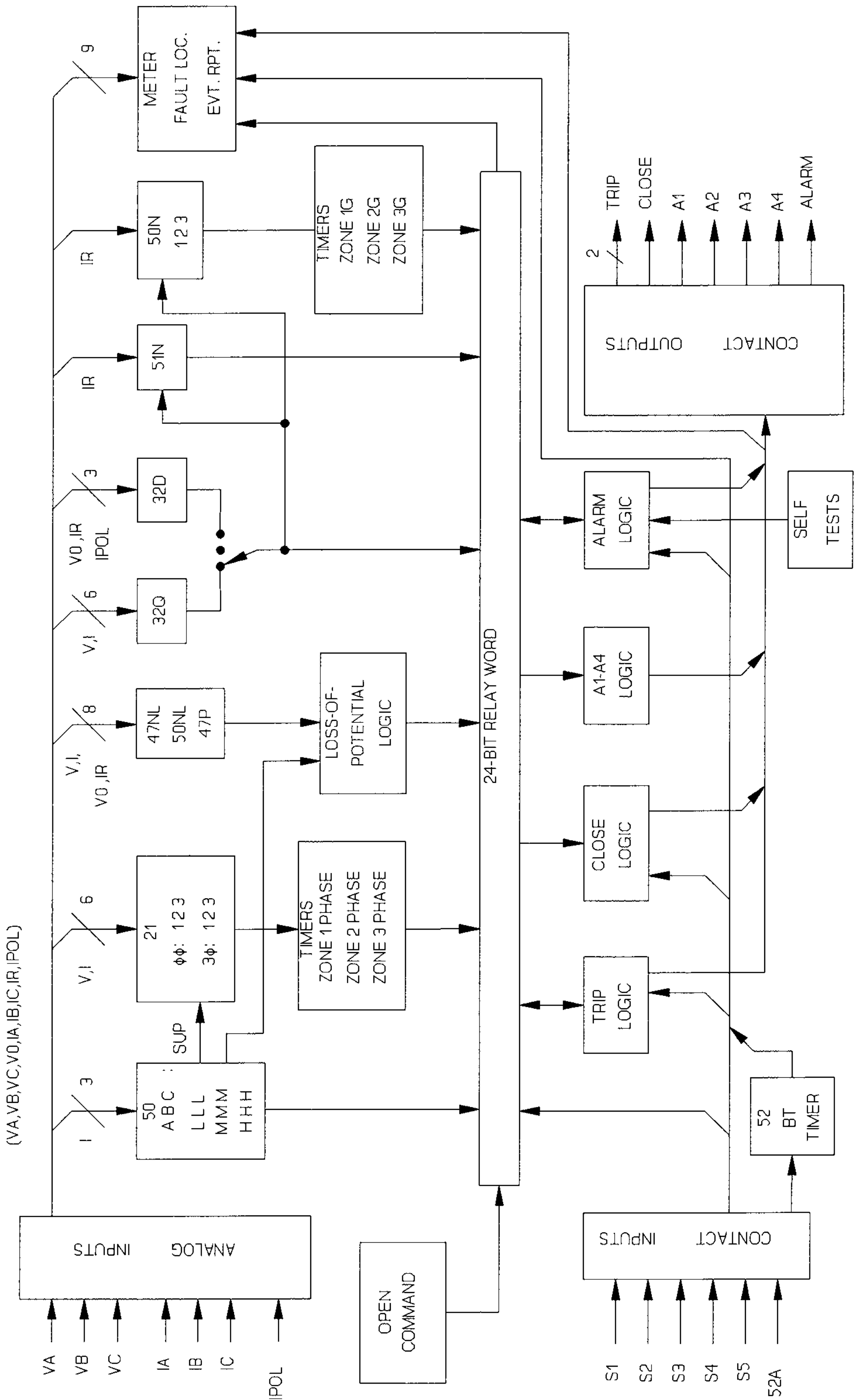

Figure 1.1: Relay Function Block Diagram

Phase-Phase Faults

Three zones are provided. Zones 1, 2, and 3 have the same reach as the three-phase zones. The characteristics are mho based on the compensator-distance principle. They have no response for three-phase faults.

Zone 3 may be reversed and used for local backup.

The phase-to-phase elements are supervised by three overcurrent elements. At least one overcurrent element must pick up to allow the phase-to-phase elements to operate. When enabled, they are also supervised by a loss-of-potential scheme.

Three high-set nondirectional overcurrent elements provide backup to the three-phase and phase-to-phase mho elements.

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

Ground Faults

Ground fault protection consists of three instantaneous residual overcurrent elements and a residual time-overcurrent element. One high-set instantaneous element is normally reserved 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 all three zones. Both the instantaneous and time delayed outputs of Zones 2 and 3 are available in the Relay Word.

Direction is determined by a negative-sequence directional element or a dual-polarized zero-sequence element. Settings are provided to select the negative-sequence element, or neither, either, or both sources of zero-sequence polarization. When voltages are lost, the direction is assumed forward. 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 local backup schemes.

The curve shape of the time-overcurrent element is user-selectable. This element is either nondirectional or forward-reaching, as enabled.

Switch-Onto-Fault Protection

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

The memory polarization of the distance elements guarantees positive action for a minimum of four cycles when bus-side voltages are used.

The flexible trip logic allows for other combinations.

HARDWARE DESCRIPTION

The SEL-221B Hardware Block Diagram (Figure 1.2) illustrates the major parts of the relay. Current and voltage inputs are isolated by magnetic input transformers. The signals are low-pass filtered, sampled by sample/hold amplifiers, and then multiplexed to a programmable-gain amplifier. Its output drives an analog-to-digital converter. This analog-input network gives the microcomputer measurements of the measurands four times per power-system cycle.

The microcomputer consists of an eight-bit microprocessor, ROM (read-only memory) for program storage, RAM (random-access memory) for data storage, and EEPROM (electrically-erasable programmable ROM) for storing the relay settings. The EEPROM saves settings even during power loss. Input/output (I/O) devices connected to the microcomputer bus provide for the control of the output relays and targets and for monitoring inputs, such as the state of the breaker 52A contact. Other I/O devices provide communications for setting, reporting fault location, and other purposes. An input for time code is also provided, so that the internal time clock of the relay may be synchronized to an external source of time code.

SIGNAL PROCESSING

The relay derives phasor representations of voltage and current from samples taken four times a cycle. The relay updates the phasors every quarter-cycle. The relaying and fault-locating algorithms subsequently process the phasor quantities.

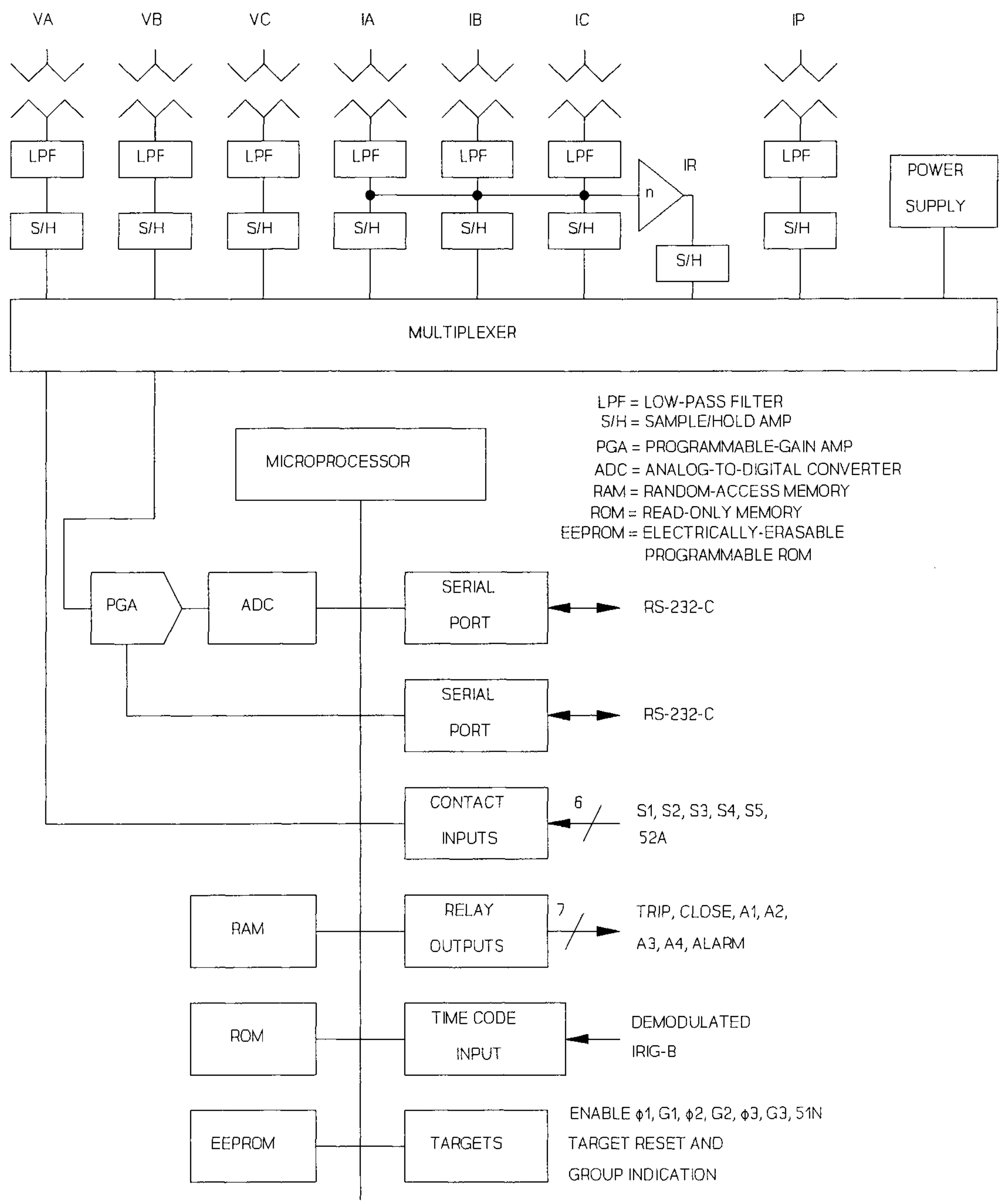

Figure 1.2: Hardware Block Diagram

Digital Filters

The requirements for the digital filters include elimination of dc offsets introduced by the analog electronics, reduction of 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, 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, and 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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TABLES

INITIAL CHECKOUT

The initial checkout of the SEL-221B 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 SEL-221B Relay.

1. Computer terminal with EIA-232 serial interface.
2. Interconnecting cable between terminal and SEL-221B 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 SEL-221B Relay commands. These commands are described in detail in Section 4: COMMANDS AND SERIAL COMMUNICATIONS. However, the detail given below should allow you to complete the checkout without referring to the detailed descriptions.

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

2. Connect a computer terminal to Port 2 on the front or rear panel of the relay. Configure the terminal to 2400 baud, eight data bits, two stop bits, and no parity. Additional details on the port configurations are given in the Section 3: FUNCTIONAL DESCRIPTION. Baud rate selection is described in the EIA-232 Jumpers subsection of the Jumper Selection in Section 6: INSTALLATION.

3. Connect a frame ground to the marked GND terminal 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: 1/1/91
Time: 01:01:44

SEL-121B
=>
```

should appear on the terminal, and the ALARM relay should pull in, holding its "b" contact open. (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 Trouble-Shooting Guide in Section 7: SERVICE AND CALIBRATION.)

The "=" prompt indicates that communications with the SEL-221B Relay are at Access Level 0, the lowest of the three levels of access to the relay. The only allowable command at this level is ACCESS, which gains access to Access Level 1, as described below.

5. Enter the command "ACCESS" and press the **<ENTER>** key. 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 eight identical demonstration setting groups which can be inspected using the SHOWSET command. Type **SHOWSET <ENTER>**, where n=1-8, to inspect these settings. The relay should respond:

```
=>SHOWSET 1 <ENTER>

Settings for group 1:  Example 230 kV Line

R1   =13.90     X1   =79.96     R0   =41.50     X0   =248.57 LL
=100.00
CTP  =N         CTR  =200.00    PTR  =2000.00   MTA  =80.80   LOCAT=Y
Z1%  =80.00     Z2%  =120.00    Z3%  =150.00
Z1DP =0.00      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
50N1P=1000.00   50N2P=700.00    50N3P=600.00
Z1DG =0.00      Z2DG =20.00     Z3DG =40.00
52BT =30.00     ZONE3=F         32QE =N         32VE =Y       32IE =Y
LOPE =Y         TIME1=5         TIME2=0         AUTO =2       RINGS=3

Logic settings:

MTU   MTO   MA1   MA2   MA3   MA4
8A    EA    80    40    20    00
C4    F7    44    22    11    80
```

A brief line-by-line description of the settings follow:

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: Current transformer polarity, current and voltage transformer ratios, maximum torque angle, and fault locator enable.

Line 3: Zone 1, 2, and 3 reach as a percent of the line length.

Line 4: Zone 1, 2, and 3 time delays for phase faults.

Line 5: Phase overcurrent element low, medium, and high pickups, and the delay for 50M to trip after loss-of-potential (50MFD).

Line 6: Residual time-overcurrent pickup, time dial, and curve index.

Line 7: Zone 1, 2, and 3 residual instantaneous overcurrent element pickup thresholds.

Line 8: Zone 1, 2, and 3 time delays for ground faults.

Line 9: 52B time delay, Zone 3 directional elements, and the enables for the negative-sequence directional, voltage polarized zero-sequence directional, and current polarized zero-sequence directional elements.

Line 10: Loss-of-potential enable, PORT 1 and 2 timeouts, the autoport(s) for automatically transmitted messages, and the number of rings after which the modem will automatically answer.

A complete description of the settings appears 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 three Relay Words as follows:

Row 1, of any column:	1ABC	2ABC	3ABC	LOP	50H	50M	50MF	50L
Row 2, of any column:	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Row 3, of any column:	Z2PT	Z3PT	Z2GT	Z3GT	ALARM	TRIP	TC	DF

The logic settings are shown in hexadecimal format. A table and example of hexadecimal to binary conversion is shown in the Command Descriptions of Section 4: COMMANDS AND SERIAL COMMUNICATIONS.

7. Turn the power off and connect a source of three-phase voltages to the relay at terminals marked VA, VB, VC, and VN. 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 relay. 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.

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 134 kV. With applied currents of 2.0 amperes per phase and a current transformer ratio of 200, the displayed currents should be 400 amperes. Furthermore, all line-to-line quantities should be balanced, differing from the line-to-neutral measurements by a factor of 1.73.

10. Test the digital relay/fault locator with the voltages and currents listed in Table 2.1. 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.

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 because Zone 1 reach is set to 80.0% of a 100-mile line. (See Z1% in the settings shown in Step 6.) 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 close and front panel LEDs (TARGET 0) to illuminate as long as the breaker is closed before applying the fault. The output relays will remain closed as long as the fault condition persists. These results are shown in Table 2.2.

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 is set to operate for any Zone 1 fault.

The residual time-overcurrent trip is monitored with the A4 output relay. The output relay A4 operates for any of the ground faults shown in the first table if the fault condition persisted 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 will not trip.

The programming of the output relays A1-A4 and the other logic masks (MTU and MTO) are 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 if the fault persists for the Zone 1 time (Z1DG set to zero or instantaneous trip). 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 element(s) actually caused the TRIP, even though other elements' timers may subsequently expire. The Zone 2 ground fault should illuminate target G2 and the Zone 3 ground fault should illuminate target G3.

For the Zone 1 phase fault, the Zone 1 phase target (ϕ1) should illuminate if the fault persists for the Zone 1 time (Z1DP). From the table, only the ϕ2 LED should illuminate for Zone 2 phase-phase faults, and only the ϕ3 LED should illuminate for a phase fault in Zone 3.

Faults generate a short event report that is transmitted to the designated autoport. To see the full event report for the most recent 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.

11. 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.

Trigger an event with the TRIGGER command and examine the event report. An asterisk (*) in the LOP column of the event report indicates that a loss-of-potential is detected. These steps are shown as follows.

```
=> TRIGGER <ENTER>
Triggered

=>

=> EVENT <ENTER>
```

This checkout procedure demonstrates only a few of the relay features. Study Section 2: FUNCTIONAL DESCRIPTION, Section 4: COMMANDS AND SERIAL COMMUNICATION, and Section 5: EVENT REPORTING to obtain a complete understanding of the relay capabilities. For more test procedures see Test Procedures in Section 7: SERVICE AND CALIBRATION.

FUNCTIONAL DESCRIPTION
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FIGURES

FUNCTIONAL DESCRIPTION

INTRODUCTION

This section describes all SEL-221B 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-221B Relay is equipped with two EIA-232 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 (-E2 model) or One stop bit (-E1 model)
No parity

This format may not be changed. The serial communications protocol appears in Section 4: COMMANDS AND SERIAL COMMUNICATIONS.

The SEL-121B 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. The terminal marked GND should be wired to the relay rack ground reference for grounding the instrument frame.

Contact Inputs

Six input circuits are provided. They are listed below.

Setting Group Selector S1	Setting Group Selector S4
Setting Group Selector S2	Setting Group Selector S5
Setting Group Selector S3	52A Monitor

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
48 Vdc	25 - 60 Vdc
125 Vdc	60 - 200 Vdc
250 Vdc	200 - 280 Vdc

The functions of the inputs are explained below.

Setting group selector inputs (S1-S5):
The setting group selector inputs are used to select the active setting group for the relay. Each setting group is activated by a different combination pair of these inputs. A two-deck multi-position selector switch is used to assert the input pairs to activate each of the eight different setting groups. If a valid group is not selected by the S1-S5 contact inputs, the relay remains enabled with the previously selected setting group and the ALARM contact closes.

Circuit Breaker Monitor (52A):
The 52A input indicates the state of the breaker and is used by the tripping and closing functions.

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 subject to the breaker being open. The TRIP output never closes for less than 60 msec. After this interval, it opens when the fault condition vanishes and the breaker appears open, as judged by the 52A input.

CLOSE Output:

This output closes in response to the CLOSE command. It opens when the 52A input is asserted.

ALARM Output:

The ALARM output closes for the following conditions:

Three unsuccessful Level 1 access attempts: 1 second pulse
Any Level 2 attempt: 1 second pulse
Self-test failures: permanent contact closure or 1 second pulse depending on which self-test fails
Invalid contact input assertion pattern: permanent contact closure for any permanent contact input assertion pattern other than the patterns shown in Table 1.1

The ALARM output also closes momentarily when settings are changed or activated, when passwords are changed, or when a date is entered (see Date command), if the present year stored in EEPROM is different than the year input.

The ALARM output closes while the relay detects a loss-of-potential condition if you select LOPE = 2, 3, or 4.

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

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

Potential Inputs

The potential inputs should be driven from a set of three line-potential transformers with their primaries connected in a grounded-wye configuration and with their secondaries connected in four-wire wye. Inside the relay is a set of three input transformers connected in four-wire wye. Because the relay includes zero-sequence voltage polarization, it is necessary to connect the neutral input terminal to the star point of the PT secondaries. The relay determines the zero-sequence voltage from the three voltage inputs VA, VB, and VC, so a separate V0 input is not needed. The nominal voltage rating is 115 volts line-to-line, or 67 volts line-to-neutral.

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 labeled J201 / AUX INPUT is for the demodulated IRIG-B input.

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 SEL-221B Relay logic consists of relay elements, timers, and combinations of conditions. Many of these are recorded in the Relay Word, which forms the heart of the programmable mask logic of this relay. Elements and other quantities available in the Relay Word are indicated in boldface type throughout this manual.

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)
Medium-set single-phase OC relays	50AM 50BM 50CM		(Selectable for LOP)
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 Z1DP not 0.00)	
Zone 1 line-line mho distance	21P1	(Includes delay if Z1DP not 0.00)	
Residual time-overcurrent pickup	**51NP**	Directional	
Residual time-overcurrent trip	**51NT**	Directional	
Residual overcurrent	50N1	Nondirectional	(Includes delay if Z1DG not 0.00)
Residual inst-overcurrent	50N2	Nondirectional	
Residual inst-overcurrent	50N3	Nondirectional	
Negative-sequence directional	32Q	32QF=forward; 32QR=reverse	
Zero-sequence dual pole directional	32D	32DF=forward; 32DR=reverse	
Zero-sequence overvoltage	47NL	Used for LOP detection	
Zero-sequence overcurrent	50NL	Used for LOP detection	
Positive-sequence overvoltage	47P	Used for LOP detection	

Contact Inputs

Setting group selector	S1
Setting group selector	S2
Setting group selector	S3
Setting group selector	S4
Setting group selector	S5
Circuit breaker monitor	52A

Contact Outputs

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

Timers

Z1GTMR	Zone 1 ground timer timeout operated by 50N1*DF	(Z1DG setting)
Z2GTMR	Zone 2 ground timer timeout operated by **67N2**	(Z2DG setting)
Z3GTMR	Zone 3 ground timer timeout operated by **67N3**	(Z3DG setting)
Z1PTMR	Zone 1 phase timer timeout operated by **Z1P** and Z1ABC	(Z1DP setting)
Z2PTMR	Zone 2 phase timer timeout operated by **Z2P** and Z2ABC	(Z2DP setting)
Z3PTMR	Zone 3 phase timer timeout operated by **Z3P** and Z3ABC	(Z3DP setting)
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

50MFD Loss-of-potential enabling delay, operated by
50M * [**LOP** + (LOPE = N or 4)]

Enables from Setting Procedure

ZONE3 = F	Zone 3 reach is forward
ZONE3 = R	Zone 3 reach is reverse
32VE	Enables voltage polarization of 32D
32IE	Enables current polarization of 32D
32QE	Enables 32Q

LOPE = loss-of-potential enable (from settings)

INTERMEDIATE LOGIC

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

Loss-of-Potential Logic

Set **LOP** = [47NL * NOT(50NL)]
+ NOT(47P) * NOT(**50M**)

(Zero-sequence set condition includes a three-cycle pickup delay)

Clear **LOP** = NOT(47NL) * 47P

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

You determine how the relay uses loss-of-potential detection by selecting the LOPE setting. The LOPE setting choices and their associated results are:

- N Relay sets LOP bit when loss-of-potential condition is detected.
  Distance and directional elements are not blocked.
  Set the LOP bit in a programmable logic mask to indicate condition, if desired.

- Y Relay sets LOP bit when loss-of-potential condition is detected.
  Distance elements are blocked and directional elements default forward.
  Set the LOP bit in a programmable logic mask to indicate condition, if desired.

- 1 Relay blocks distance elements and directional elements default forward when LOP condition is detected.
  If the 52A input is asserted while LOP is detected, the Relay Word LOP bit is asserted.
  If the 52A input is not asserted while LOP is detected, the Relay Word LOP bit is not asserted.
  Set the LOP bit in a programmable logic mask to indicate that a loss-of-potential has occurred while the breaker is closed, if desired.

- 2 Relay sets LOP bit when loss-of-potential condition is detected.
  Distance elements are blocked and directional elements default forward.
  Relay asserts ALARM contact to indicate the LOP condition.

- 3 Relay blocks distance elements and directional elements default forward when LOP condition is detected.
  If the 52A input is asserted while LOP is detected, the Relay Word LOP bit is asserted.
  If the 52A input is not asserted while LOP is detected, the Relay Word LOP bit is not asserted.
  Relay asserts ALARM contact while the Relay Word LOP bit is asserted.

- 4 Relay sets LOP bit when loss-of-potential condition is detected.
  Distance and directional elements are not blocked.
  Relay asserts ALARM contact to indicate the LOP condition.

Table 3.1 summarizes the available LOPE settings and their results.

Table 3.1: LOPE Settings

LOPE Setting	Block 21 on LOP	52A Supervises LOP Relay Word Bit	Close ALARM Contact on LOP Bit Assertion
N	No	No	No
Y	Yes	No	No
1	Yes	Yes	No
2	Yes	No	Yes
3	Yes	Yes	Yes
4	No	No	Yes

Phase Overcurrent Conditions

50L	= 50AL + 50BL + 50CL	Phase fault current supervision
3P50	= 50AL * 50BL * 50CL	Three-phase fault current supervision
50M	= 50AM + 50BM + 50CM	Medium-level overcurrent condition
50MF	= **50M** * [**LOP** + NOT (LOPE)] * (50MFD)	Asserts a settable delay after **LOP** and **50M** overcurrent, or just **50M** overcurrent if **LOP** is disabled
50H	= 50AH + 50BH + 50CH	High-level overcurrent condition

Distance Relay Logic

Z3ABC	= 21ABC3 * 3P50 * NOT(**LOP** * LOPE = Y, 1, 2, or 3)	(**3ABC** in Relay Word)
Z2ABC	= 21ABC2 * 3P50 * NOT(**LOP** * LOPE = Y, 1, 2, or 3)	(**2ABC** in Relay Word)
Z1ABC	= 21ABC1 * 3P50 * NOT(**LOP** * LOPE = Y, 1, 2, or 3) * Z1PTMR	(**1ABC** in Relay Word)
Z3P	= 21P3 * 50L * NOT(**LOP** * LOPE = Y, 1, 2, or 3)	
Z2P	= 21P2 * 50L * NOT(**LOP** * LOPE = Y, 1, 2, or 3)	
Z1P	= 21P1 * 50L * NOT(**LOP** * LOPE = Y, 1, 2, or 3) * Z1PTMR	(Includes delay if Z1DP not 0.00)
Z3PT	= (**Z3P** + Z3ABC) * Z3PTMR	Zone 3 timeout-phase
Z2PT	= (**Z2P** + Z2ABC) * Z2PTMR	Zone 2 timeout-phase

Ground Overcurrent Conditions

DF = [(32QF + [**LOP** * LOPE = Y, 1, 2, or 3]) * 32QE] + [32DF * 32IE] + [(32DF + [**LOP** * LOPE = Y, 1, 2, or 3]) * 32VE] + NOT(32QE + 32VE + 32IE) — Forward direction

DR = 32QR * 32QE + 32DR * (32IE + 32VE) — Reverse direction

D3 = **DF** if Zone 3 is forward
D3 = DR if Zone 3 is reverse

67N1	= 50N1 * **DF** * Z1GTMR	(Includes delay if Z1DG not 0.00)
67N2	= 50N2 * **DF**	
67N3	= 50N3 * D3	(Reversible)

Note: When directional elements are all disabled (32QE = 32VE = 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.

Z3GT	= **67N3** * Z3GTMR	Zone 3 timeout-ground
Z2GT	= **67N2** * Z2GTMR	Zone 2 timeout-ground

RELAY WORD

Relay elements and intermediate logic results are represented in a 24-bit Relay Word, which is grouped into three 8-bit words. The user selects bits in this word to control outputs and tripping. The selected bits are stored in masks for each function. The user programs the bits in these masks with the LOGIC command.

Table 3.2: Relay Word

1ABC	2ABC	3ABC	LOP	50H	50M	50MF	50L
51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Z2PT	Z3PT	Z2GT	Z3GT	ALRM	TRIP	TC	DF

Table 3.3 explains the meaning of each bit in the Relay Word.

Table 3.3: 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%)
LOP	-	Loss-of-potential condition
50H	-	High-level overcurrent element (set by 50H)
50M	-	Medium-level overcurrent element (set by 50M)
50MF	-	Asserts a settable delay after LOP and 50M pickup (delay set by 50MFD)
50L	-	Phase fault current supervision (set by 50L)
51NT	-	Residual time-overcurrent trip (set by 51NP, 51NTD, and 51NC)
67N1	-	Residual instantaneous-overcurrent (directional or nondirectional) (set by 50N1P)
67N2	-	Residual instantaneous-overcurrent (directional or nondirectional) (set by 50N2P)
67N3	-	Residual instantaneous-overcurrent (directional or nondirectional) (set by 50N3P)
51NP	-	Residual time-overcurrent pickup (set by 51NP)
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 phase fault, time delayed (set by Z2DP)
Z3PT	-	Zone 3 phase fault, time delayed (set by Z3DP)
Z2GT	-	Zone 2 ground fault, time delayed (set by Z2DG)
Z3GT	-	Zone 3 ground fault, time delayed (set by Z3DG)
ALRM	-	System alarm
TRIP	-	Circuit breaker trip
TC	-	Trip (open) command
DF	-	Direction forward

The Relay Word and programmable masks provide the user with great flexibility in applying the relay, without having to rewire panels or change jumpers on circuit boards.

OUTPUT EQUATIONS

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

The general forms for each of the output equations are shown below:

Let R = Relay Word

MTU = mask for trip (unconditional)
MTO = mask for trip (with breaker open)

Then: **TRIP** = [R * MTU
+ R * MTO * 52BT]
* NOT(TS) (trip suspicion not detected)
close TRIP contact = **TRIP**
open TRIP contact = NOT(**TRIP**) * [NOT(50L) * NOT 50NL + TARGET RESET button pushed] * (60 ms minimum TRIP)

close CLOSE contact = (CLOSE Command) * NOT(52A) * NOT(**TRIP**)
open CLOSE contact = NOT(CLOSE)

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

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

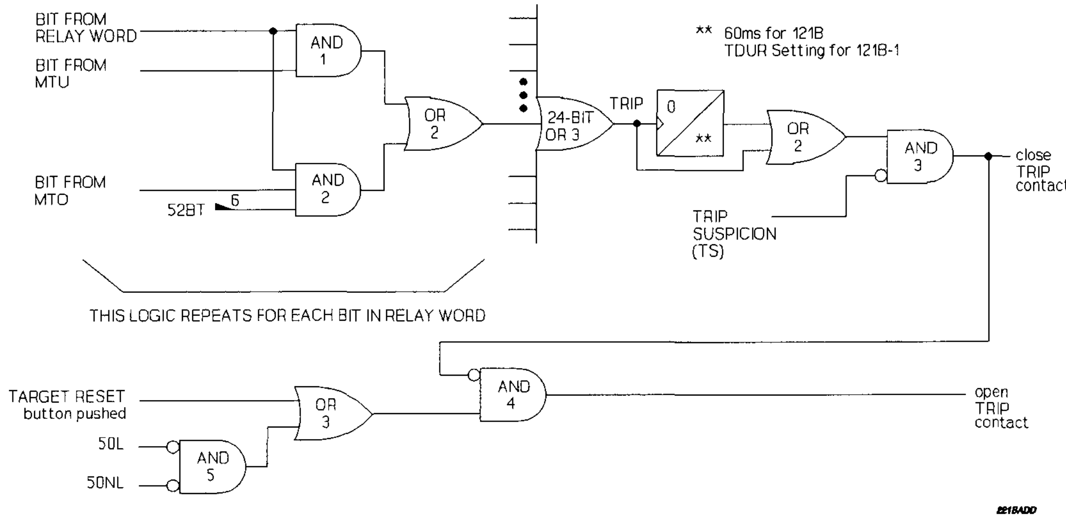

Figure 3.1: SEL-221B Programmable Trip Logic Diagram

TRIP SUSPICION LOGIC

In substations where two independent buses may be connected to the protected line at different times, relay potentials may be obtained from two separate potential transformer banks. It is not desirable to parallel the secondary windings of potential transformers attached to separate sources; thus, a break-before-make potential transfer switch is used to transfer the relay potential source from one bus to the other.

When the potential transfer switch is operated, the break-before-make action removes all polarizing voltages from the relay momentarily. If load currents are above the 50L fault detector setting, this temporary removal of polarizing voltages may cause a race between the three-phase loss-of-potential logic pickup and operation of the three-phase distance element. Three-phase LOP logic is included to address the loss of three secondary potential fuses, not potential transfer switch applications.

The logic developed to address potential transfer switch applications is shown in Figure 3.2.

Note: The 52A input contact on the rear panel of the relay must be deasserted when the operator depresses the potential transfer switch.

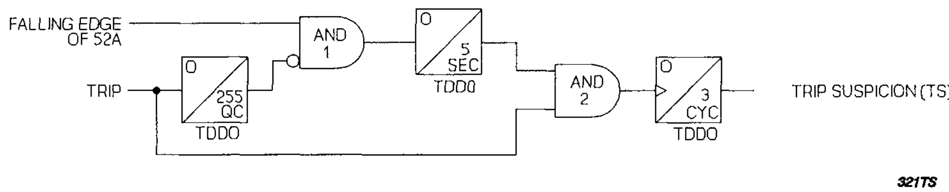

Figure 3.2: Trip Suspicion (TS) Logic

The following two scenarios illustrate Trip Suspicion (TS) logic operation, as shown in Figure 3.2:

Scenario 1) A trip issued by the relay for an actual fault on the transmission line.
Scenario 2) A trip resulting from the temporary loss-of-potential created by an operator moving a bus potential transfer switch from one bus position to another.

Scenario 1 - Actual Transmission Line Fault

When the relay issues a trip with the 52A input energized, the relay does not start the five second timer (T1) because it issued the trip. Thus, this logic does not interfere with the normal relay trip operation.

Scenario 2 - Potential Transfer Operation

If the relay senses the falling edge of a 52A input and did not issue a trip in the previous 255 quarter-cycles, the T1 timer starts. The T1 timer allows the operator five seconds to transfer the relay potentials from one bus to another. If the relay issues a trip during this five second window, tripping is restrained for three cycles. This three-cycle time period is greater than the time required for the three-phase LOP logic to assert or for the polarizing potential magnitude of the second bus to stabilize. Remember that the loss-of-potential condition only occurs when the potential transfer switch is twisted left or right while the switch is fully depressed.

This logic does not depend upon the speed of the actual potential transfer operation. It does require that the procedure last less than five seconds and that the relay 52A input circuit be interrupted when the potential transfer switch is depressed.

This potential transfer switch logic presents an additional benefit if an operator inadvertently transfers potentials to a de-energized or "dead" bus. If LOPE = Y and the LOP bit is set in a programmable output-contact logic mask when the relay is transferred to a dead bus, the LOP bit asserts, causing the programmable output contact to assert. Output contact closure can alert the operator to the dead bus condition.

Loss of relaying potentials due to potential fuse or potential transfer switch operation may cause the relay to trip if phase current is above the 50L setting.

TARGETS

The front panel targets illuminate for the conditions shown below.

TARGET LED	CONDITIONS FOR ILLUMINATION
EN	Normal Operation
ϕ1	Z1P + Z1ABC + 50H + 50MF
G1	67N1
ϕ2	Z2P + Z2ABC
G2	67N2
ϕ3	Z3P + Z3ABC
G3	67N3
51N	51NT

The LEDs for the relay elements illuminate on the rising edge of the TRIP output with the following priority:

51N : For 51N timeout (51NT)
G1, ϕ1: For 67N1 + Z1P + Z1ABC + 50H + 50MF, but no 51NT
G2, ϕ2: For 67N2 + Z2P + Z2ABC, but no Zone 1 or 51NT
G3, ϕ3: For 67N3 + Z3P + Z3ABC, but no Zone 2, Zone 1, or 51NT

At the inception of a new fault the target 0 LEDs are cleared, and the targets for the new fault are displayed.

To clear the targets, press the TARGET RESET button. All eight indicators illuminate for about one second, as a lamp test. Then an LED indicating the setting group selected by the relay is illuminated for about one second. After that, the fault targets are cleared, and the enable light shows the operational state of the relay again.

Movement of the setting group selector switch causes the LED corresponding to the switch location to illuminate. If the switch is left in a location, the LED illuminates for about five seconds at which time the active setting group is updated. If the selector switch is returned to the active setting group position before another setting group is activated, the LED illuminates for about one second before returning the target LEDs to their normal state.

SELF-TESTS

The relay runs a variety of self-tests that ensure reliable operation. This section describes each test and what steps are taken if a self-test fails. Some tests have warning and failure states, while some, 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 self-test causes closure of the ALARM contacts. 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 offset levels of all channels.

Power Supply

The power supply voltages are limit-checked. Table 3.4 summarizes the voltage limits.

Table 3.4: 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

The eight relay setting groups are stored in nonvolatile memory along with a checksum for each group. A second set of checksums are calculated and compared with those stored in memory when the settings are initially set and periodically thereafter. Should the checksums 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

The relay comes with eight selectable setting groups. These setting groups can be activated via a setting group selector switch or by use of the GROUP command (setting group selector switch must be in REMOTE position).

Relay settings are entered using the SET and LOGIC commands via the serial interface ports. The settings are stored in non-volatile memory, so they are retained when the power is off.

The COPY command is used to copy settings from one setting group to another. This feature can save the operator time when the settings for different setting groups are similar.

The SET, LOGIC, GROUP, and COPY command descriptions explain how to enter settings and activate setting groups.

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	command (TRIGGER)

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:** Reports are triggered at the 16th quarter-cycle of data.)

Timing of the triggering instant is recorded to the nearest quarter-cycle, so 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. In all cases, 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 Section 5: EVENT REPORTING.

Execution of the CLOSE command 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 outputs, and user entered commands. However, the fault locator can be either enabled or disabled with the 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 Outputs (rising edge trigger)
Trip

(3) User Entered Commands (rising edge trigger)
Trigger
Open

Note: 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 continuous 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, for example, 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 they are not picked up in the first seven rows of pre-fault data or only in the last five rows of the event report. 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 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 pre-fault 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), the fault type is taken as single- or two-phase, or if the ratios are all less than 1.5, the fault type is taken as three-phase. The explicit fault classification logic is as follows, where "I" values are uncompensated mid-fault currents, and "If" values are mid-fault currents compensated for load, yielding true fault current components:

```
     IF ( Imax  >   4·Imed  ) THEN Single-phase
ELSE IF ( Imed  >   4·Imin  ) THEN Two-phase
ELSE IF ( Ifmax > 1.5·Ifmed ) THEN Single-phase
ELSE IF ( Ifmed > 1.5·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 pre-fault and fault data, it compensates for the errors introduced by fault resistance in the presence of load flow. On the other hand, if no pre-fault 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:

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

Although the fault-location computation takes several seconds, faults in quick succession 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 them 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.

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:

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

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 for those 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, when series capacitor gaps did not flash, we have had success in cases 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 this relay, 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·Iab	Vbc - Z1·Ibc
three-phase	Vab - Z1·Iab	-Vc1 (memory)

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

The constant k is a fixed memory constant.

DIRECTIONAL ELEMENTS

Either the negative-sequence or the 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 50N3 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 adjusted by the MTA setting times the sum of the residual voltage, plus the polarizing current shifted in phase by the MTA setting.

TIME-OVERCURRENT ELEMENT AND CURVES

The 51N time-overcurrent element provides directional-forward or non-directional ground 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 given in this section are:

Figure 3.3: Moderately Inverse Time Characteristic
Figure 3.4: Inverse Time Characteristic
Figure 3.5: Very Inverse Time Characteristic
Figure 3.6: Inverse Time Characteristic

The 51N characteristic is formed 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 residual time-overcurrent elements. Plots showing operating time versus multiples of pickup current are shown on the following page.

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

Curve 1 -- Moderately Inverse

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

Curve 2 -- Inverse

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

Curve 3 -- Very Inverse

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

Curve 4 -- Extremely Inverse

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

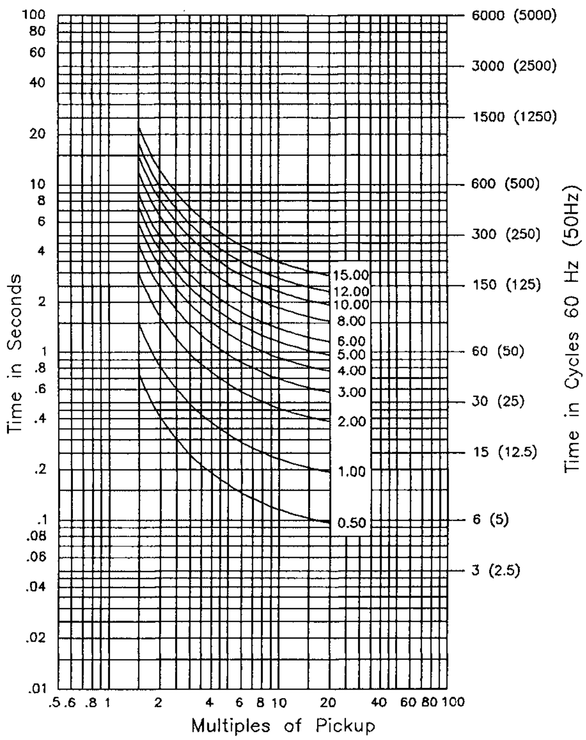

Figure 3.3: Time Curve 1

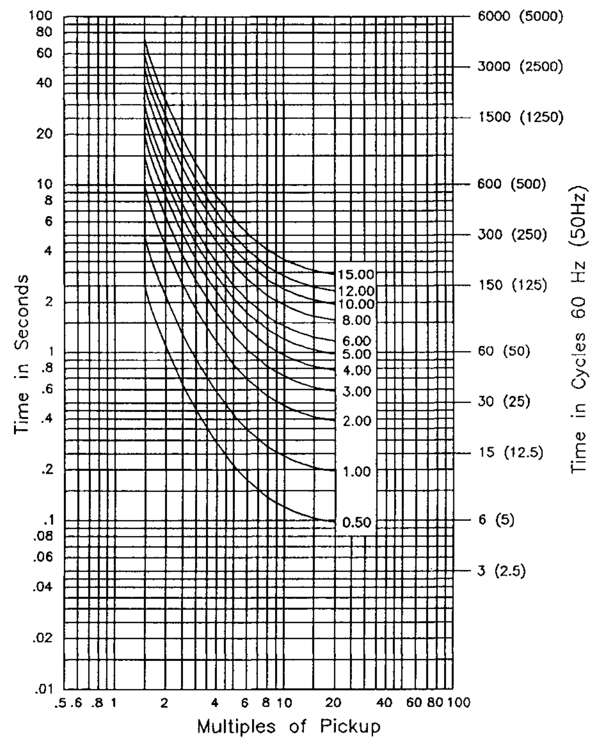

Figure 3.4: Time Curve 2

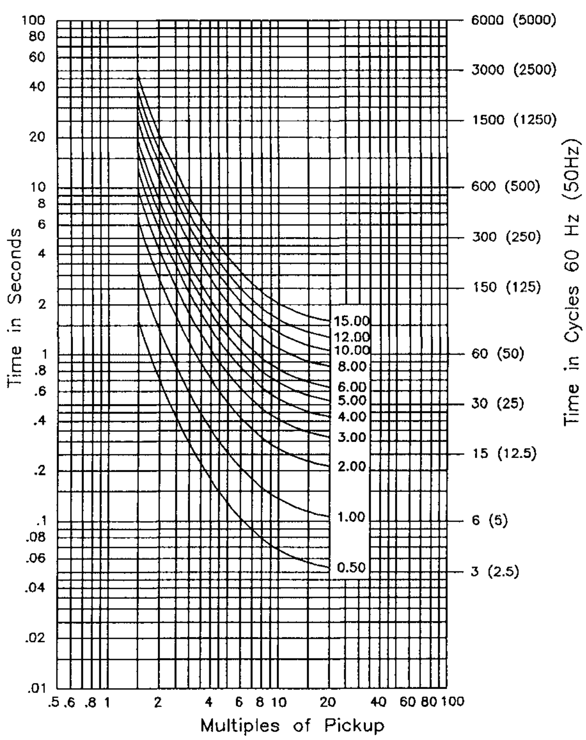

Figure 3.5: Time Curve 3

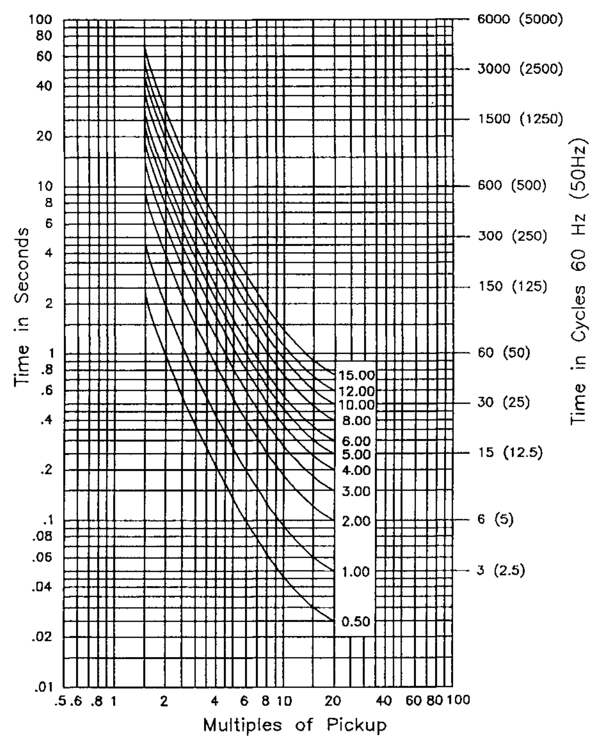

Figure 3.6: Time Curve 4

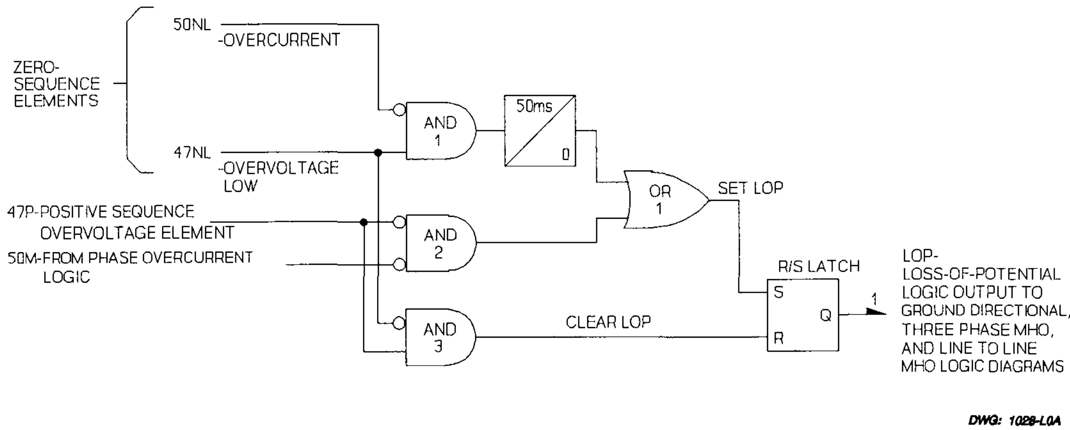

Figure 3.7: SEL-221B/121B Loss-of-Potential Logic Diagram

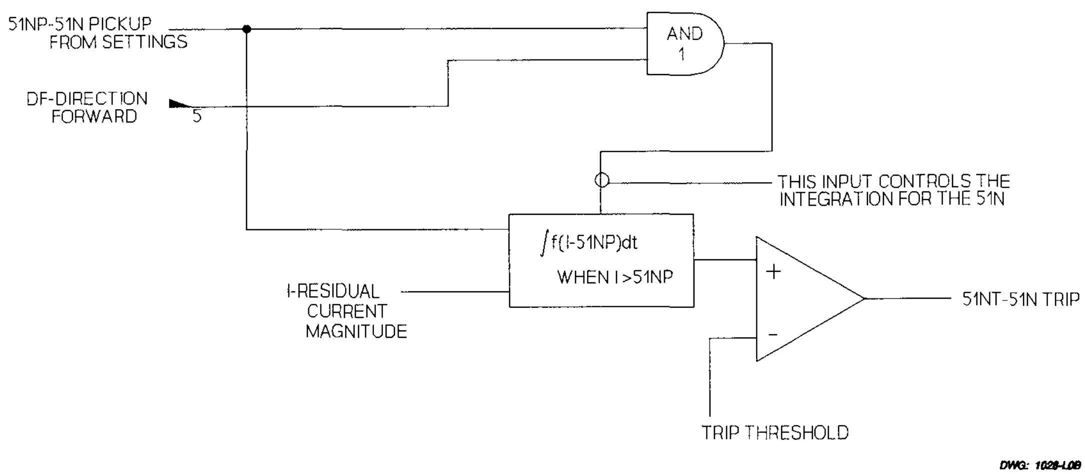

Figure 3.8: SEL-221B/121B Residual Time-Overcurrent (51N) Logic Diagram

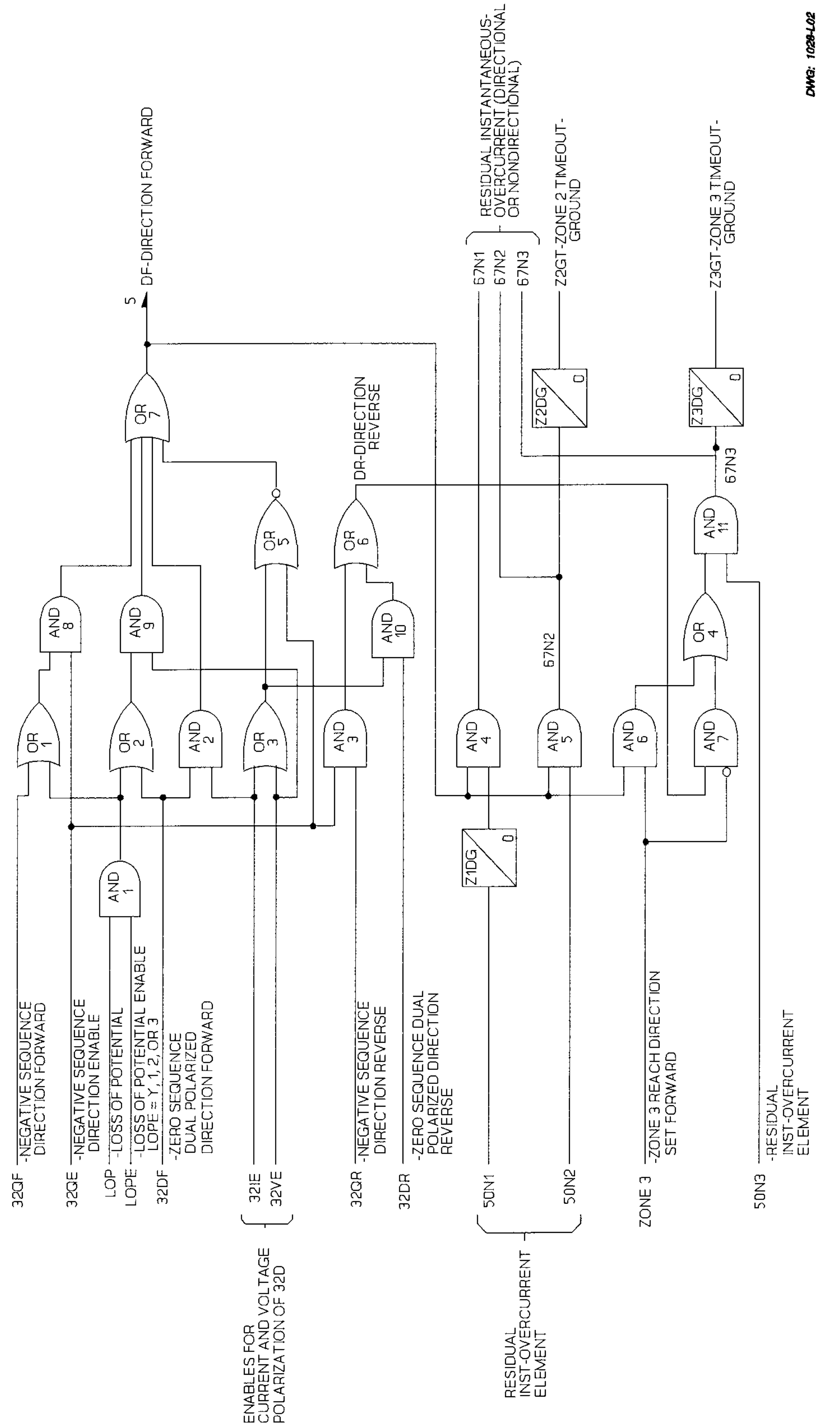

Figure 3.9: SEL-221B/121B Ground Directional and Ground Overcurrent Logic Diagram

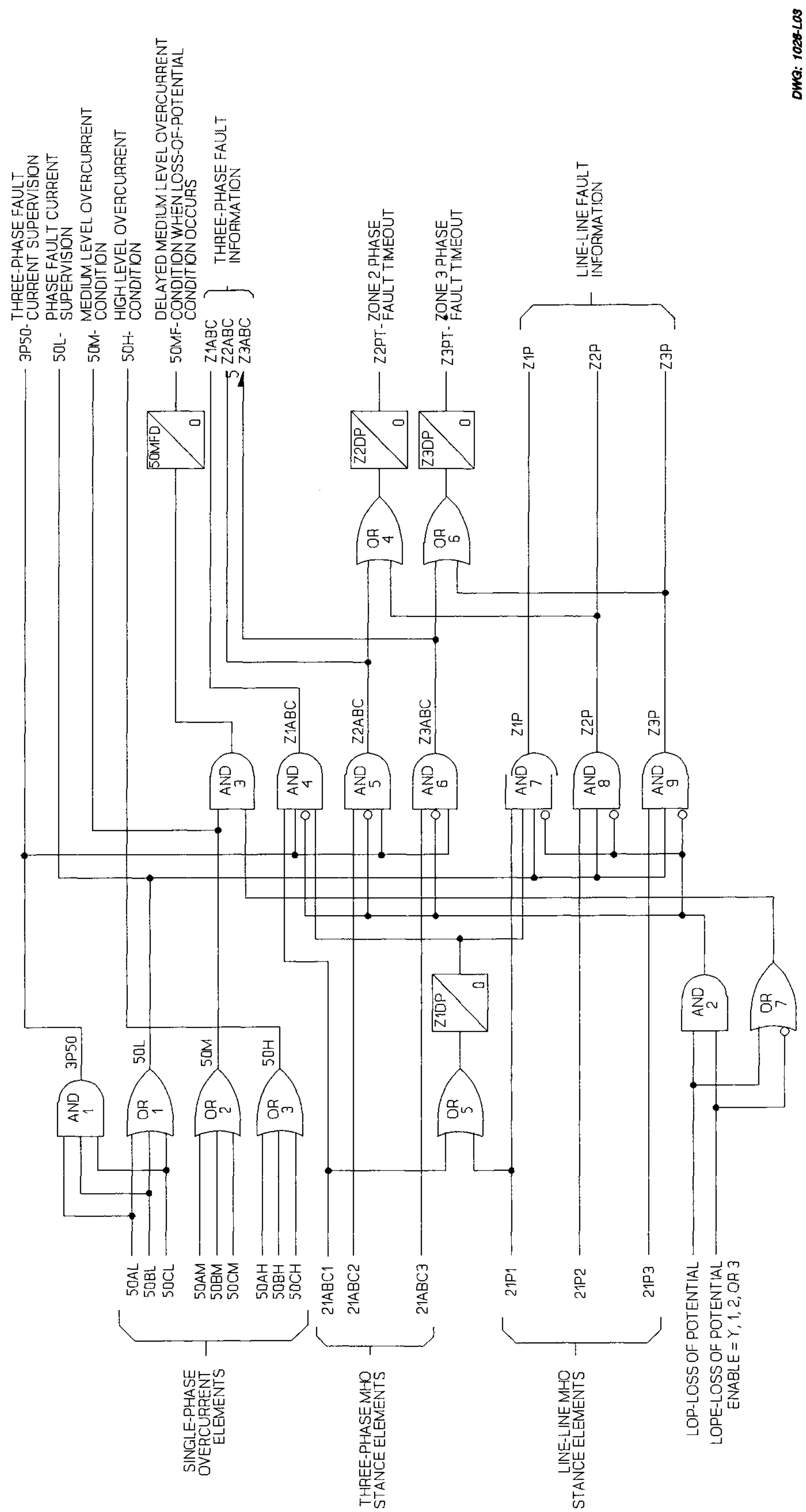

Figure 3.10: SEL-221B/121B Three-Phase Mho, Line-Line Mho, and Phase Overcurrent Logic Diagram

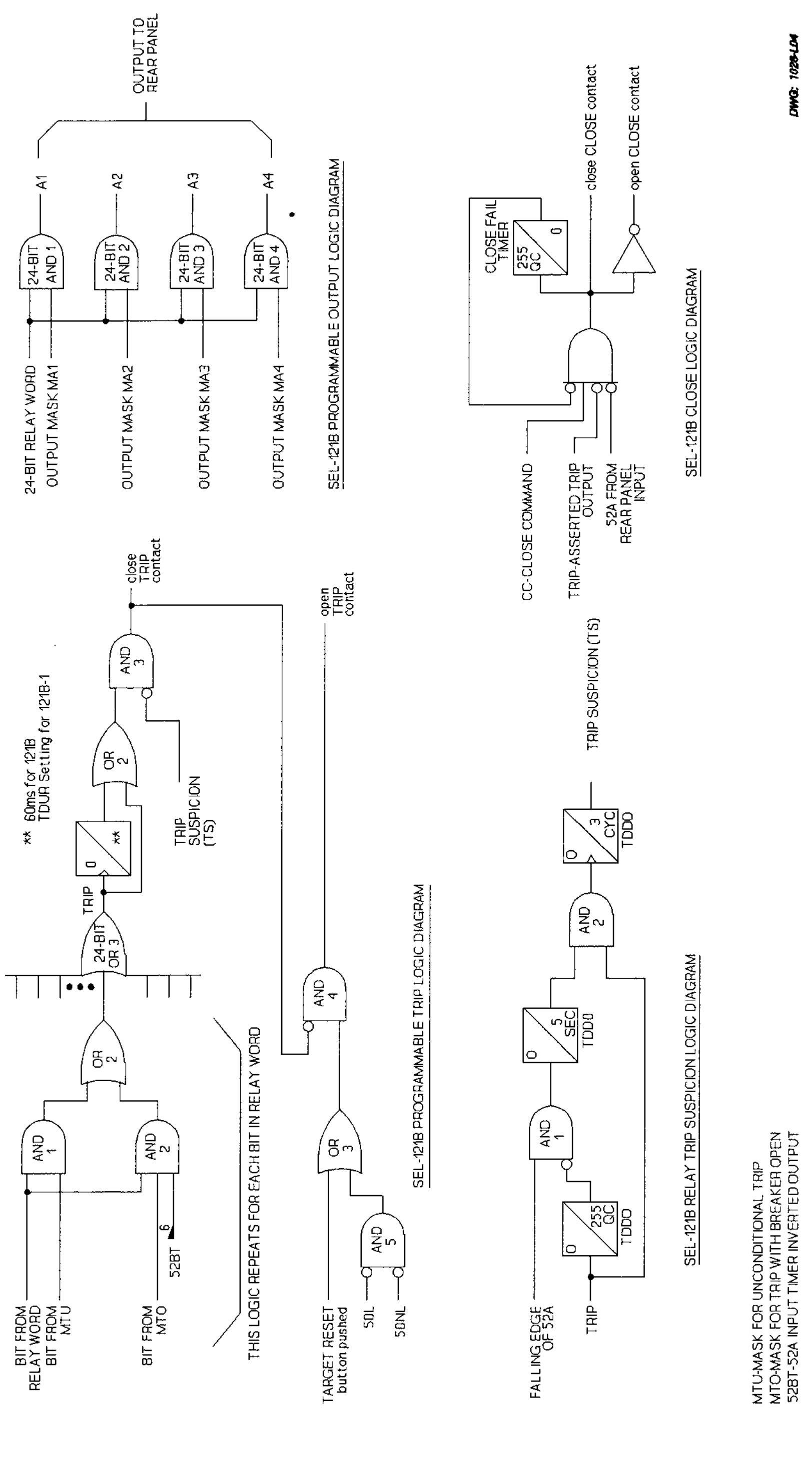

Figure 3.11: SEL-221B/121B Logic Diagram

COMMANDS AND SERIAL COMMUNICATIONS
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COMMANDS AND SERIAL COMMUNICATIONS

INTRODUCTION

The relay is set and operated via serial communications interfaces connected to a computer terminal and/or modem or the SEL-PRTU Protective Relay Terminal Unit. Communication serves these purposes:

1. The relay responds to commands spanning all functions, e.g., setting, metering, and control operations.
2. The relay generates an event record for TRIP output assertions, for an event triggering command, or for pickup of any relay element that triggers an event record.
3. The relay transmits messages in response to changes in system status, e.g., self-test warning.

It is impossible to disable any relaying or control functions via communications, unless a user enters erroneous or improper settings with the SET or LOGIC commands.

Note: In this manual, commands to type appear in bold/uppercase: **OTTER**. Keys to press appear in bold/uppercase/brackets: **<ENTER>**.

Relay output appears boxed and in the following format:

```
Example 230 kV Line                Date: 1/1/91    Time: 01:01:01
```

SERIAL PORT CONNECTIONS AND CONFIGURATIONS

The SEL-221B Relay is equipped with two EIA-232 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's 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 Port 2, remove the relay's 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.

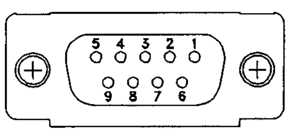
Caution: Do not select two baud rates for the same port as this can damage the relay baud rate generator. The relay is shipped with Port 1 set to 300 baud and Port 2 set to 2400 baud.

The serial data format is:

Eight data bits
Two stop bits
No parity bit

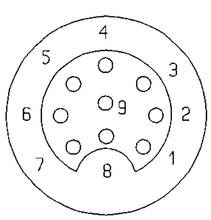
This format cannot be altered.

The SEL-121B Relay does not include a front panel serial interface port.



(female chassis connector, as viewed from outside panel)

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



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

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

Table 4.1 lists port pin assignments and signal definitions.

Table 4.1: SEL-221B 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 SEL-221B 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 SEL-221B 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-121B 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

Communications protocol consists of hardware and software features. Hardware protocol includes the control line functions described above. The following software protocol is designed for manual and automatic communications.

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 followed by either a carriage return or a carriage return and line feed. You may truncate commands to the first three characters. Thus, **EVENT 1 <ENTER>** would become **EVE 1 <ENTER>**. Upper and lower case characters may be used without distinction, except in passwords.

Note: The ENTER key on most keyboards is configured to send the ASCII character 13 (^M) for a carriage return. This manual instructs you to press the ENTER key after commands, which should send the proper ASCII code to the relay.

2. The relay transmits all messages in the following format:

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

   Each message begins with the start-of-transmission character (ASCII 02) and ends with the end-of-transmission character (ASCII 03). Each line of the message ends with a carriage return and line feed.

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

   The relay transmits XON (ASCII hex 11) and asserts the RTS output when the buffer drops below ¼-full.

   The relay transmits XOFF (ASCII hex 13) when the buffer is over ¾ full. The relay deasserts the RTS output when the buffer is approximately 95% full. Automatic transmission sources should monitor for the XOFF character so they do not overwrite the buffer. Transmission should terminate at the end of the message in progress when XOFF is received and may resume when the relay sends XON.

4. You can use an XON/XOFF procedure to control the relay during data transmission. When the relay receives XOFF during transmission, it pauses until it receives an XON character. If there is no message in progress when the relay receives XOFF, it blocks transmission of any message presented to its buffer. Messages will be accepted after the relay receives XON.

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

5. Control characters can be sent from most keyboards with 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 sent to either serial communications interface. A two-level password system provides security against unauthorized access.

When the power is first turned on, the relay is in Access Level 0 and honors only the ACCESS command. It responds "Invalid command" or "Invalid access level" to any other entry.

You may enter Access Level 1 with the ACCESS command and first password. The Level 1 password is factory set to OTTER and may be changed with the PASSWORD command in Access Level 2. Most commands may be used in Access Level 1.

Critical commands, such as SET, operate only in Access Level 2. You may enter Access Level 2 with the 2ACCESS command and second password. The Level 2 password is factory set to TAIL and may be changed with the PASSWORD command.

Startup

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

```
Example 230 kV Line                Date: 1/1/91    Time: 01:01:01

SEL-121B Relay
=
```

You should also hear the ALARM relay pull in, opening its "b" contact.

After about five seconds, the setting group selected by the setting group selector switch will be activated, the alarm contact will pulse closed, and the following message will be displayed.

```

=
Setting group N enabled
=
```

Where N = 1-8.

The instruments are shipped with Port 2 designated as the automatic port; however, a setting called AUTO exists for selecting either Ports 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: 1/1/91    Time: 01:01:01

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: 1/1/91    Time: 01:01:01

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.)

Items in square brackets [...] are optional.

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: 1/1/91       Time:
14:12:01

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: 1/1/91       Time:
14:12:01

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 January 1, 1991, enter:

```
=>DATE 1/1/91 <ENTER>
1/1/91
=>>
```

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, the relay displays the newest event report.

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 (VA, VB, and VC), 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 (e.g. buffer 12 is empty) results in this message:

```
=>EVENT 12 <ENTER>

Invalid event
=>
```

A sample event report and explanation are given in Section 5: EVENT REPORTING.

HISTORY

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

```
=>HISTORY <ENTER>

Example 230 kV Line                    Date: 1/1/91       Time: 07:38:12

#   DATE          TIME        TYPE  GROUP  DIST   DUR   CURR

1   8/28/89   09:03:01.092  3AG    2     100.2  7.25  798
2   8/28/89   09:02:13.041  3AG    2      74.9   7.00  1016
3   8/28/89   09:00:39.962  1AG    2     25.3   7.25  2162
4   8/28/89   09:00:13.345  1BC    2     25.5   7.25  3167
5
6
7
8
9
10
11
12
=>
```

Note: 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 continuous sequence of picked-up relay elements in the report. For example, if relay elements are continuously 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 Zone 3, 2, or 1
H	:	For 50H pickup, but not 51N or Zone 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 continuous relay pickup sequence in the event report. (See the algorithmic details in the Fault Locator portion of Section 3: FUNCTIONAL DESCRIPTION.) 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 SEL-221B 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. TYPE shows "EXT", when the report was generated by execution of the TRIGGER command.

GROUP specifies the active group when the event was triggered.

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 pre-fault 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 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 a Zone 1, 2, 3, 51N, or 50H relay element, until the first dropout of all said relay elements. In other words, it is the duration of the first, continuous 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.

```
=>IRIG <ENTER>

Example 230 kV Line                Date: 1/8/91        Time: 01:45:40

=>
```

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 follows.

```
=>METER <ENTER>

Example 230 kV Line                Date: 1/8/91        Time: 07:56:36

                A         B         C        AB        BC       CA
I (A)         994       995       994      1723      1724     1724
V (kV)      134.4     134.3     134.2     233.1     232.8    232.9

P (MW)     350.91
Q (MVAR)    67.82

=>
```

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.

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 resets the targets to the Relay Targets (TAR 0). The command displays the relay I.D. and the date and time when QUIT is executed. Use this command when you are done communicating with the relay, so that unauthorized access is avoided. (**Note:** Control returns to Access Level 0 automatically after a settable interval of no activity. See the TIME1 and TIME2 settings of the SET command). An example of the QUIT command example shown below.

```
=>QUIT <ENTER>

Example 230 kV Line                 Date: 1/8/91      Time: 01:45:40

=
```

NOTE: The prompt returns to an equal sign indicating Access Level 0.

SHOWSET [n]

Enter SHOWSET [n] (where n=1-8) to inspect the settings of the nth setting group in the relay. The commands display shows the relay settings and logic settings stored in the nth setting group. The settings cannot be modified with this command. The settings are entered using the SET and LOGIC commands under Access Level 2. When typing SHOWSET without the parameter n, the relay defaults to the active setting group.

An example of the output from executing SHOWSET appears on the following page.

```
=>SHOWSET 3 <ENTER>

Settings for group 3:  Example 230 kV Line

R1   =13.90    X1   =79.96    R0   =41.50    X0  =248.57  LL   =100.00
CTP  =N        CTR  =200.00   PTR  =2000.00  MTA =80.80   LOCAT=Y
Z1%  =80.00    Z2%  =120.00   Z3%  =150.00
Z1DP =0.00     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
50N1P=1000.00  50N2P=700.00   50N3P=600.00
Z1DG =0.00     Z2DG =20.00    Z3DG =40.00
52BT =30.00    ZONE3=F        32QE =N        32VE=Y       32IE =Y
LOPE =Y        TIME1=5        TIME2=0        AUTO=2       RINGS=3

Logic settings:

MTU   MTO   MA1   MA2   MA3   MA4
8A    EA    80    40    20    00
C4    F7    44    22    11    80
F2    F2    00    A0    50    00
```

A brief line-by-line description of the 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: Current transformer polarity, current and voltage transformer ratios, maximum torque angle, and fault locator enable.

Line 3: Zone 1, 2, and 3 reach as a percent of the line.

Line 4: Zone 1, 2, and 3 time delays for phase faults.

Line 5: Phase overcurrent element low, medium, and high pickups, and the delay for 50 M to trip after loss-of-potential (50MFD).

Line 6: Residual time-overcurrent pickup, time dial, and curve index.

Line 7: Zone 1, 2, and 3 residual instantaneous overcurrent element pickup thresholds.

Line 8: Zone 1, 2, and 3 time delays for ground faults.

Line 9: 52B time delay, Zone 3 directional elements, and the enables for the negative-sequence directional, voltage polarized zero-sequence directional, and current polarized zero-sequence directional elements.

Line 10: Loss-of-potential enable, PORT 1 and 2 timeouts, the autoport(s) for automatically transmitted messages, and the number of rings after which the modem will answer.

A complete description of the settings appears 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 three Relay Words as follows:

Row 1, of any column:	1ABC	2ABC	3ABC	LOP	50H	50M	50MF	50L
Row 2, of any column:	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Row 3, of any column:	Z2PT	Z3PT	Z2GT	Z3GT	ALARM	TRIP	TC	DF

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 MTO, which is set to F7 hex format. Using the table to convert F7 to binary gives:

F7 -> 1111 0111

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

```
51NT   67N1   67N2   67N3   51NP  Z1P   Z2P   Z3P
 1      1      1      1      0     1     1     1
 ________  F  ________       _______  7  _______
```

STATUS

Inspect the self-test status of the relay 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(s) selected for automatic transmissions. (See AUTO setting of the SET procedure.)

The format of the STATUS report is shown as follows.

```
=>STATUS <ENTER>

Example 230 kV Line                    Date: 1/8/91     Time: 01:08:44

SELF-TESTS

W=Warn   F=Fail
      IP   IR   IA   IB   IC   VA   VB   VC
OS    0    0    0    0    0    0    0    0
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 recently calculated checksums for each of the eight setting groups against checksums which were stored in non-volatile memory when the settings were last changed. 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 targets 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 4.4.

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

Table 4.4: Target LED Assignment

LED: n	1	2	3	4	5	6	7	8	
0	EN	PH1	G1	PH2	G2	PH3	G3	51N	RELAY TARGETS
1	1ABC	2ABC	3ABC	LOP	50H	50M	50MF	50L	RELAY WORD #1
2	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	RELAY WORD #2
3	Z2PT	Z3PT	Z2GT	Z3GT	ALRM		TRIP	TC	DFRELAY WORD #3
4	52AT		52A	S5	S4	S3	S2	S1	CONTACT INPUTS
5		TRIP	CLOS	A1	A2	A3	A4	ALRM	CONTACT OUTPUTS

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 target readings of target number two, execute the following:

```
=>TARGET 2 10 <ENTER>

 51NT 67N1 67N2 67N3 51NP Z1P Z2P  Z3P
 0    0    0    0    0    0   1    1
 0    0    0    0    0    0   1    1
 0    0    0    0    0    0   1    1
 0    0    0    0    0    0   1    1
 0    0    0    0    0    0   1    1
 0    0    0    0    0    0   1    1
 0    0    0    0    0    0   1    1
 0    0    0    0    0    0   1    1

 51NT 67N1 67N2 67N3 51NP Z1P Z2P  Z3P
 0    0    0    0    0    0   1    1
 0    0    0    0    0    0   1    1

=>
```

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.

Pressing the TARGET RESET button on the front panel clears the TAR 0 data, lights up all target LEDs for about one second as a lamp test, and then lights up a target LED corresponding to the selected setting group for about one second. Furthermore, pressing the TARGET RESET button unlatches the TRIP output from the 52A input. This feature is useful during relay testing and minimizes the risk of re-installing the relay with the TRIP output asserted.

The target LEDs also illuminate for movement of the setting group selector switch. When the setting group selector switch is moved, the LED corresponding to the switch location illuminates. When the switch remains in a location for five consecutive seconds, the setting update procedure is initiated, the enable light returns, and the setting group corresponding to the switch location becomes the active setting group. If the selector switch is returned to the active setting group position before another setting group is activated, the LED will illuminate for about one second, and the targets will return to their normal state.

The front panel targets can be reset to TAR 0 and cleared remotely or locally using the TARGET command. Type **TARGET R <ENTER>** to reset and clear the targets as shown in the following example.

```
=>TARGET R <ENTER>
Targets reset

 EN   PH1  G1   PH2  G2   PH3  G3   51N
 1    0    0    0    0    0    0    0

=>
```

TIME [hh:mm:ss]

To read the internal clock, enter **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 example, to set the clock to 23:30:00, enter:

```
=>TIME 23:30:00 <ENTER>
23:30:00
=>
```

A quartz crystal oscillator provides the time base for the internal clock, and the SEL-221B 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 (Section 5: EVENT REPORTING explains how to do this under Interpretation of Voltage and Current Data), and check for the proper polarity and phase-sequence of the inputs.

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 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).

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) ?" Entering **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). Entering **N <ENTER>** to either of the above prompts aborts the closing operation with transmission of the message "Aborted." An example of the CLOSE command procedure is shown below.

```
=>>CLOSE <ENTER>
Close BREAKER (Y/N) ? Y <ENTER>
Are you sure (Y/N) ? Y <ENTER>
Breaker CLOSED
=>>
```

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

COPY [m] [n]

The copy command is useful for copying the relay settings from one setting group to another. This command saves the operator time when many settings used for one line are similar to those used on another. The copy command copies all the settings and the logic masks from the source group (m) to the destination setting group (n) without affecting the source settings. To execute the command type **COPY** followed by the source group number and then the destination group number. An example of the COPY command used to copy settings from Group 1 to Group 4 is shown below. The COPY command clears the event buffer.

```
=>COPY 1 4 <ENTER>
Please wait...
Settings copied

=>>
```

To ensure that the settings were copied correctly, the destination settings and source settings are compared. If they are different, the message "Copy Error" appears on the screen. Shortly thereafter, the relay will output the STATUS message to indicate the setting test failure. Control and protection functions will be disabled, and the ALARM output contact will close.

If the settings are the same, the message "Settings copied" appears on the screen and the settings' checksum value is saved in non-volatile memory. The relay self-test function uses the checksum value to periodically check the settings.

GROUP [n]

The GROUP command is used to change the active setting group when the selector switch is in the remote position (inputs S2 and S5 asserted). The active setting group is changed by typing **GROUP** followed by the desired setting group number (1-8). An example is shown below.

```
=>>GROUP 4 <ENTER>

=>>
Setting group 4 enabled

=>>
```

If the setting group selector switch is not in the REMOTE position the following message will appear on the screen.

```
=>>GROUP 4 <ENTER>
GROUP command disabled

=>>
```

LOGIC [m][n]

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

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

MTU - Mask for unconditional trip
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

The n parameter selects which setting group to program. If n is not specified, the active group is used.

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 three Relay Words rows as follows:

Relay Word 1	1ABC	2ABC	3ABC	LOP	50H	50M	50MF	50L
Relay Word 2	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P
Relay Word 3	Z2PT	Z3PT	Z2GT	Z3GT	ALRM	TRIP	TC	DF

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-221B Relay with the new logic settings. Answering "Y" enters the new data, pulses the ALARM contact closed momentarily, and clears the event buffers. Answering "N" 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 of the output showing the setting of the MTU logic mask follows.

Note: The logic masks must be properly configured for your application.

```
=>>LOGIC MTU 2 <ENTER>

1 selects, 0 deselects.

1ABC 2ABC 3ABC LOP  50H  50M  50MF 50L
 0    0    0    0    0    0    0    0
 ? 10001010 <ENTER>
 1    0    0    0    1    0    1    0
 ? <ENTER>
51NT 67N1 67N2 67N3 51NP Z1P  Z2P  Z3P
 0    0    0    0    0    0    0    0
 ? 11000100
 1    1    0    0    0    1    0    0
 ? <ENTER>
Z2PT Z3PT Z2GT Z3GT ALRM TRIP TC   DF
 0    0    0    0    0    0    0    0
 ? 11110010
 1    1    1    1    0    0    1    0
 ? <ENTER>

New MTU:

1ABC 2ABC 3ABC LOP  50H  50M  50MF 50L
 1    0    0    0    1    0    1    0
51NT 67N1 67N2 67N3 51NP Z1P  Z2P  Z3P
 1    1    0    0    0    1    0    0
Z2PT Z3PT Z2GT Z3GT ALRM TRIP TC   DF
 1    1    1    1    0    0    1    0

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


Example 230 kV Line                Date:  1/1/91     Time:
23:39:38

=>>
```

The MTU and MTO logic masks control the TRIP output.

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, MTU 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 msec.

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, enter **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 and causes an event to trigger. Answering **N <ENTER>** to either prompt aborts the OPEN command with the message "Aborted". An example for this command is shown below.

```
=>>OPEN <ENTER>
Open BREAKER (Y/N) ? Y<ENTER>
Are you sure (Y/N) ? Y<ENTER>
Breaker OPEN
=>>

Example 230 kV Line                Date: 1/8/91     Time: 23:36:10.887

Event    : TRIP   Location    :        mi        ohms sec
Duration:         Flt Current:

=>>
```

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

PASSWORD (1 or 2) [password]

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

```
=>>PASSWORD <ENTER>
1: OTTER
2: TAIL
=>>
```

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

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

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+ !@#$%^ 221B 123456 12345. 12345 ab1CDE

Should the passwords be lost, or should you wish to operate the SEL-221B Relay without password protection, install JMP103 on the main 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 passwords.

SET m [n]

The setting procedure is invoked by typing the SET command followed by the setting group number (m = 1-8). The optional n parameter allows the operator to skip directly to a desired setting.

The setting procedure consists of answering prompting messages with new data, or by typing **<ENTER>**, indicating no change. Once all data are provided, the new settings are displayed, and a prompt is issued requesting your approval to store the new settings in the group selected or to enable the relay with the new settings if the group changed is the active setting group.

Once all desired setting changes are entered, it is not necessary to scroll through the remaining settings. Type "END" after the last setting change to skip to the new settings display and the enable prompt. However, the "END" statement should not be used for the relay I.D. setting.

Error messages indicate when the entered data result in out-of-range settings. If no error messages are received, then the new settings are enabled, the ALARM contact closes momentarily, and the event buffer is cleared.

The optional command parameter n represents one of the setting descriptors (except for the ID setting). The setting descriptor is the abbreviated description of the setting (e.g., 51NP is the setting descriptor for the residual time-overcurrent pickup). See the following list of settings for more setting descriptors. All settings prior to the specified setting are skipped when the parameter n is input. For example, typing **SET 3 Z3DP <ENTER>** will skip all settings prior to the Z3DP setting and start the set procedure at the Z3DP setting of Setting Group 3.

The following data are required to set the relay:

R1, X1	Positive-sequence primary impedance of line (0-9999 ohms)
R0, X0	Zero-sequence primary impedance of line (0-9999 ohms)
LL	Line length (0.1-999 miles)
CTP	CT polarity (N=normal, I=inverted)
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)
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%)
Z1DP	Zone 1 delay for phase and three-phase faults (0-60 cycles in 1/4 cycle steps)
Z2DP	Zone 2 delay for phase and three-phase faults (0-2000 cycles in 1/4 cycle steps)
Z3DP	Zone 3 delay for phase and three-phase faults (0-2000 cycles in 1/4 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 1/4 cycles 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
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)
Z1DG	Zone 1 delay for ground faults (0-60 cycles in 1/4 cycle steps) e.g., enter 10.25 for a delay of 10 1/4 cycles.
Z2DG	Zone 2 delay for ground faults (0-2000 cycles in 1/4 cycle steps)
Z3DG	Zone 3 delay for ground faults (0-2000 cycles in 1/4 cycle steps)

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)
32VE	Do you want voltage polarization for the zero-sequence directional element enabled? (Y or N)
32IE	Do you want current polarization for the zero-sequence directional element enabled? (Y or N)
LOPE	Should tripping be blocked when loss-of-potential is detected? (Y, N, 1, 2, 3, or 4)
TIME1	Timeout for Port 1 (0-30 minutes)
TIME2	Timeout for Port 2 (0-30 minutes)
AUTO	Autoport (Port 1, 2, or 3)
RINGS	The number of rings after which the modem connected to PORT 1 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 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 Zone 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.

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

The AUTO setting selects PORT 1, 2, or both of the two serial ports for automatically transmitted messages. The next table shows the effect of each possible setting:

AUTO SETTING	**AUTOMATIC MESSAGE DESTINATION PORT**
1	1
2	2
3	1 and 2

SEL-221B-1/121B-1 RELAY WITH TRIP DURATION SETTING

The new open TRIP contact logic replaces the fixed 60 msec timer and 52A status criteria with two new criteria: a) dropout of 50L and 50NL elements and b) expiration of a settable trip duration timer (TDUR). This new logic is as follows:

Open TRIP contact: NOT(TRIP)*[NOT(50L)*NOT(50NL) + TARGET RESET button pushed]

Where: TRIP ≡ Any condition resulting in TRIP output contact closure (determined by relay and logic settings)
TDUR ≡ Minimum Trip Duration timer (settable)

TRIP output duration is always a minimum of TDUR cycles. This feature allows you to determine the minimum TRIP contact closure duration to ensure that the circuit breaker trip coil receives a strong, steady trip signal. Figure 4.3 shows the edge triggered Trip Duration Timer (TDUR) in the close TRIP logic.

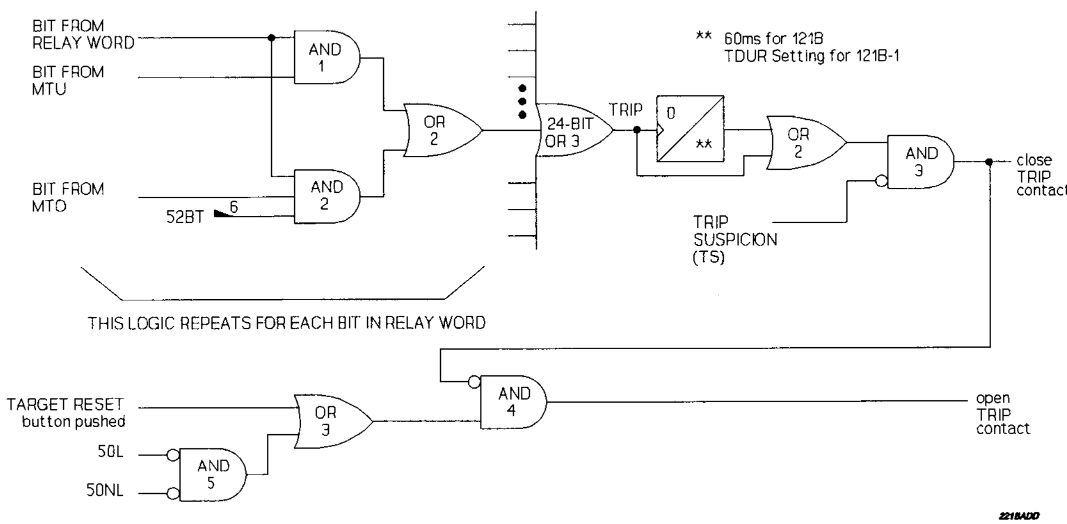


Figure 4.3: Programmable Logic Diagram

Trip Duration Timer (TDUR) Setting

The trip duration timer setting is determined by the minimum length of time you wish to close the TRIP output contacts. The TRIP output contacts close for the greater of the TDUR time or the duration of the trip condition. Typical settings for this timer are 150 msec or nine cycles.

```
TDUR = 9.00
```

- Setting Limit Check

The primary limit check allows TDUR time delay settings of 0 - 2000 cycles. The TDUR setting of 9.00 cycles lies within the relay setting limits. There is no secondary limit check for this setting.

- Other Settings Affected

TRIP bit in the Relay Word.

The showset command is shown with the TDUR setting in Figure 4.4.

```
=>SHOWSET 3 <ENTER>

Settings for group 3:  Example 230 kV Line

R1    =13.90     X1   =79.96     R0   =41.50     X0  =248.57   LL   =100.00
CTP   =N         CTR  =200.00    PTR  =2000.00   MTA =80.80    LOCAT=Y
Z1%   =80.00     Z2%  =120.00    Z3%  =150.00
Z1DP  =0.00      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
50N1P=1000.00    50N2P=700.00    50N3P=600.00
Z1DG  =0.00      Z2DG =20.00     Z3DG =40.00     TDUR=9.00
52BT  =30.00     ZONE3=F         32QE =N         32VE=Y        32IE =Y
LOPE  =Y         TIME1=5         TIME2=0         AUTO=2        RINGS=3

Logic settings:

MTU   MTO   MA1   MA2   MA3   MA4
8A    EA    80    40    20    00
C4    F7    44    22    11    80
F2    F2    00    A0    50    00
```

Figure 4.4: Example Output from Executing SHOWSET with TDUR Setting

SEL-221B, -1 DISTANCE 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 2/3/91 sets date to Feb. 3, 1991. This setting is overridden when IRIG-B synchronization occurs. Pulses the ALARM relay momentarily when a different year is entered than the previously stored.
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. SHOWSET 4 displays the settings for setting group four.
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: Contact Inputs — TAR 5: 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.
COPY*	Copy settings from one setting group to another.
GROUP*	Change the active setting group. Group n activates setting group n (n=1-8). This command only works when contact inputs S2 and S5 are asserted.
LOGIC n	Show or set logic masks MTU, 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 m [n]*	Initiate setting procedure for setting group m (m=1-8). N initiates the procedure at setting n.

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

* Relay pulses ALARM output contact briefly when new settings are stored.

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EVENT REPORTING
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EVENT REPORTING

INTRODUCTION

The SEL-221B 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 the event is a fault, the distance to fault and the impedance to the fault (along the line) in secondary ohms, the fault duration, and a fault current measurement are also displayed. (The LOCAT setting permits you to disable 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 the designated port(s) is(are) 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 pre-fault, fault, and post-fault 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, 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, unless the settings are changed or a new setting group is activated. (This differs from the relay settings, which are retained in non-volatile 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
- 51N pickup
- 67N pickup
- 50H pickup
- 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 either of the following:

- Execution of the CLOSE command
- Changes to the 52A input

See the Fault Locator portion in Section 3: FUNCTIONAL DESCRIPTION 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 Section 2: INITIAL CHECKOUT. An A-to-ground fault 75 miles away was applied to the loaded line. A source impedance of 0.2 of the total line impedance was used. 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 pre-fault load settings for the test set are given below.

VA	VB	VC	IA	IB	IC
66.88	66.88	66.88	1.03	1.03	1.03 volts or amps
-1.4	-121.4	118.6	4.9	-115.1	124.9 degrees

The test set settings for the actual fault are as follows:

VA	VB	VC	IA	IB	IC
52.90	69.52	70.36	5.16	1.03	1.03 volts or amps
-4	-125.8	122.4	-75.7	-115.1	124.9 degrees

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

VA	VB	VC	IA	IB	IC
105.8	139.0	140.7	1032	206	206 kilovolts or amperes

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

PTR = 2000 CTR = 200.

The following paragraphs describe the response of the relay 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 rear panel of the relay 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 sine wave 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. pre-fault, fault or post-fault. 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: 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 first and second rows of cycle seven of data in the full report:

	CURRENTS				VOLTAGES			
IPOL	IR	IA	IB	IC	VA	VB	VC	
0	785	906	76	-198	76.9	28.5	-138.3	(Y-component)
0	648	485	189	-28	-72.6	135.8	-23.7	(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	VA	VB	VC	
0	1018	1028	204	200	105.7	138.8	140.3	(magnitude)
0	50	62	22	-98	133	12	-100	(angle)
0	-87	-75	-115	125	-4	-125	123	(angle-137)

In the third row, 137° are subtracted from all angles of the second row, so as to assign the ϕA voltage phasor as the -4° 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 1027.5 amperes primary, which agrees well with the 1032-ampere test set current referred to the primary.

The indicated fault location is 74.81 miles. The "actual" fault location is 75.00 miles. The error is 75.00 - 74.81, or 0.19 miles, which is about 0.3% 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
213:	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:

<u>OUTPUTS</u>

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

S1 : SETTING GROUP SELECTOR input #1
S2 : SETTING GROUP SELECTOR input #2
S3 : SETTING GROUP SELECTOR input #3
S4 : SETTING GROUP SELECTOR input #4
S5 : SETTING GROUP SELECTOR input #5
52A: BREAKER AUXILIARY 52A SWITCH 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 residual time-overcurrent element (51N) is the first element to pick up for the fault. This is indicated by 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 16th row of data.

In the 18th row of the report, the Zone 2 residual overcurrent element picks up, indicated by the "2" in the 67N column. In response, the programmable outputs A2 and A3 assert. The A2 output is programmed through the MA2 programmable logic mask to assert as soon as any Zone 2 elements pick up. Likewise, the A3 output is programmed through the MA3 programmable logic mask to assert when any Zone 3 elements pick up.

In the 21st quarter-cycle of the report, the Zone 1 residual overcurrent element (67N1) picks up. In response, the TRIP output and programmable output A1 assert. The TRIP output asserts because the 67N1 element was incorporated into the UNCONDITIONAL TRIP MASK (MTU) of the LOGIC settings. The A1 output is programmed through the MA1 programmable logic mask to assert as soon as any Zone 1 elements pick up.

The 52A contact input monitored the latching relay (circuit breaker simulator) state. This input deasserts in the 29th row of the report, indicating that the latching relay had changed to the "open" state about 2 cycles 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 19 quarter-cycles, or 4.75 cycles. This value is reported near the bottom of the report as: Duration: 4.75.

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

FIRMWARE IDENTIFICATION

A means of determining relay Firmware Identification Data (FID) is 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 (eg: SEL-121B)

[RN] = Revision Number (eg: 400)

[VS] = Version Specifications (eg: 656m)

[RD] = Release Date (eg: YYMMDD = 890914)

An example of the FID string is:

FID=SEL-121B-R400-V656m-D890914

For the SEL-121B family of relays, the version specifications are interpreted as follows:

V[VS] = V[ABCDEFGH]

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 LEDs
G	c, r	cumulative, recent	Target LED Update Logic
H	y, n	has TDUR, no TDUR	121B-1 has trip duration timer

Please contact Schweitzer Engineering Laboratories, Inc. for the available versions of the SEL-221B Relay. The version specifications are not intended for ordering purposes but are an identification of the software installed in a relay.

SAMPLE EVENT REPORT

```
Example 230 kV Line                          Date: 11/15/93     Time: 02:51:45.208
FID=SEL-121B-R400-V656mptr-D931114

                   Currents                        Voltages        Relays Outputs Inputs
                    (amps)                           (kV)
                                                                   52265L TCAAAAA SSSSS5
   IPOL     IR      IA      IB      IC     VA      VB      VC      011710 PL1234L 123452
                                                                   P3PNNP              A

     0       2     123      76    -201   93.0    37.0  -129.5     M..... ....... **...*
     0       0    -160     189     -28  -95.8   128.3   -31.5     M..... ....... **...*
     0      -2    -123     -76     198  -93.0   -37.0   129.5     M..... ....... **...*
     0       0     160    -189      25   95.8  -128.3    31.5     M..... ....... **...*

     0       2     123      76    -195   93.0    37.0  -129.5     M..... ....... **...*
     0       0    -160     189     -28  -95.8   128.3   -31.5     M..... ....... **...*
     0      -2    -123     -76     198  -93.0   -37.0   129.5     M..... ....... **...*
     0       0     160    -189      31   95.8  -128.3    31.5     M..... ....... **...*

     0       2     123      79    -201   93.0    37.0  -129.5     M..... ....... **...*
     0       0    -160     189     -31  -95.8   128.3   -31.5     M..... ....... **...*
     0      -2    -123     -82     201  -93.0   -37.0   129.5     M..... ....... **...*
     0       0     160    -189      28   95.8  -128.3    31.5     M..... ....... **...*

     0       2     123      79    -198   92.3    36.8  -129.7     M..... ....... **...*
     0     168       6     189     -28  -92.2   129.1   -30.7     M..... ....... **...*
     0    -202    -321     -76     198  -86.6   -34.0   132.6     M..... ....... **...*
     0    -470    -308    -189      28   81.5  -132.5    27.3     M...P. ....... **...*

     0     568     689      79    -198   79.7    30.0  -136.6     M...P. ....... **...*
     0     624     459     189     -28  -73.7   135.4   -24.2     M..2P. ...**.. **...*
     0    -756    -878     -79     198  -77.4   -28.7   138.1     M..2P. ...**.. **...*
     0    -647    -481    -192      28   72.8  -135.7    23.8     M..2P. ...**.. **...*

     0     781     903      79    -198   76.9    28.5  -138.3     M..1P. *.***.. **...*
     0     649     485     189     -28  -72.6   135.8   -23.7     M..1P. *.***.. **...*
     0    -785    -906     -79     198  -76.9   -28.5   138.3     M..1P. *.***.. **...*
     0    -648    -485    -186      28   72.6  -135.8    23.7     M..1P. *.***.. **...*

     0     785     906      76    -198   76.9    28.5  -138.3     M..1P. *.***.. **...*
     0     648     485     189     -28  -72.6   135.8   -23.7     M..1P. *.***.. **...*
     0    -785    -906     -76     198  -76.9   -28.5   138.3     M..1P. *.***.. **...*
     0    -648    -485    -189      28   72.6  -135.8    23.8     M..1P. *.***.. **...*

     0     785     906      76    -201   77.6    28.6  -138.2     M..1P. *.***.. **...*
     0     480     340     151      -6  -76.1   135.0   -24.6     M..2P. *..**.. **....
     0    -585    -667     -60     148  -83.3   -31.4   135.1     M..2P. *..**.. **....
     0    -178    -113     -66      -9   86.8  -131.7    28.1     M..3P. *...*.. **....

     0     218     242      25     -53   90.3    35.5  -131.2     M...P. *...... **....
     0      25      16       9       3  -94.6   128.7   -31.1     M...P. *...... **....
     0     -29     -31      -3       6  -92.6   -36.9   129.7     ...... *...... **....
     0      -3       3       0       0   95.5  -128.3    31.4     ...... *...... **....

     0       5       3       0       0   93.0    37.0  -129.5     ...... ....... **....
     0       0      -6       0       0  -95.8   128.3   -31.5     ...... ....... **....
     0      -2       0       0       0  -93.0   -37.1   129.5     ...... ....... **....
     0       0       6       0       0   95.8  -128.2    31.5     ...... ....... **....

     0       2      -3       0       3   93.0    37.1  -129.5     ...... ....... **....
     0      -1      -3       0      -3  -95.8   128.2   -31.5     ...... ....... **....
     0      -1       3       0      -3  -93.0   -37.0   129.5     ...... ....... **....
     0       2       3       0       3   95.8  -128.3    31.5     ...... ....... **....

Event    : 1AG     Location    : 74.81  mi   6.07    ohms sec
Duration: 4.75     Flt Current: 1027.5
Setting Group Number: 2

R1   =13.90     X1   =79.96     R0   =41.50     X0   =248.57    LL   =100.00
CTP  =N         CTR  =200.00    PTR  =2000.00   MTA  =80.80     LOCAT=Y
Z1%  =80.00     Z2%  =120.00    Z3%  =150.00
Z1DP =0.00      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
50N1P=1000.00   50N2P=700.00    50N3P=600.00
Z1DG =0.00      Z2DG =20.00     Z3DG =40.00
52BT =30.00     ZONE3=F         32QE =N         32VE =Y         32IE =Y
LOPE =Y         TIME1=5         TIME2=0         AUTO =2         RINGS=3

Logic settings:

MTU  MTO  MA1  MA2  MA3  MA4
8A   EA   80   40   20   00
C4   F7   44   22   11   80
F2   F2   00   A0   50   00
```

INSTALLATION
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FIGURES

INSTALLATION

MOUNTING

The SEL-221B 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 in this section.

FRAME GROUND CONNECTION

The rear panel terminal marked GND must be connected to frame ground for safety and performance. This terminal connects directly to the chassis ground of the instrument.

POWER CONNECTIONS

The rear panel terminals marked + and - 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.

The relay requires four-wire wye potentials, because it includes ground relaying functions. It is not possible to directly apply the relay to circuits where line-to-line potential transformers are used.

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.

SETTING GROUP SELECTOR SWITCH

General Description

Five of the six contact inputs of the relay are designated for selecting setting groups locally with a setting group selector switch. A setting group is activated when a single pair combination of the five input contacts is asserted. Table 1.1 in Section 1: INTRODUCTION shows which setting group is selected when different pairs of input contacts are asserted.

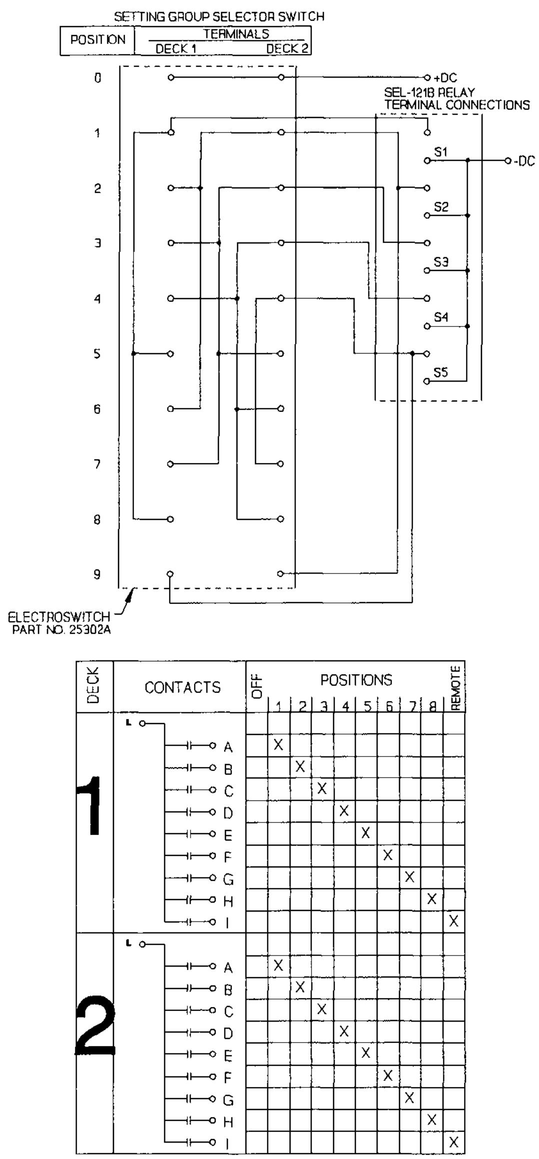
The SEL-221B Relay Selector Switch Wiring Diagram shows two possible switch setups, one without SCADA control and one with SCADA control. The first option shows the wiring connections from the selector switch (Electroswitch part no. 25302A) to the rear panel of the relay when the switch is used to select between local and remote control of setting group selection. The second option shows the wiring connections when SCADA control is used to switch between local and remote control.

Local control refers to manually changing from one setting group to the next with the selector switch, whereas remote control refers to changing setting groups with a command (GROUP command) from a local or remote terminal.

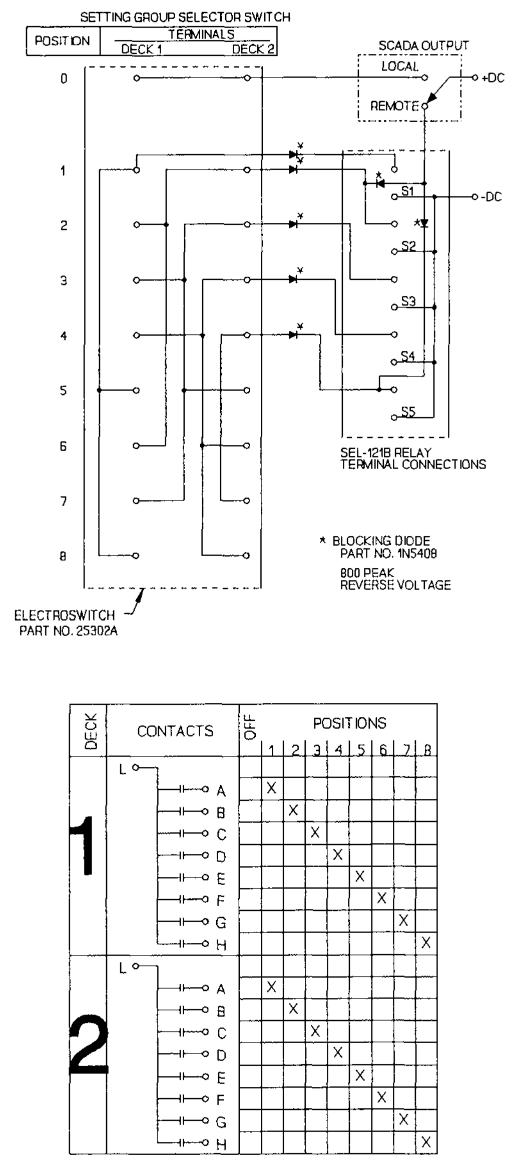
Selector Switch Contact Designations (Electroswitch part no. 25302A)

Contact "L" on both decks of the selector switch must be connected to a source of control voltage. Use the SEL-221B RELAY SELECTOR SWITCH WIRING DIAGRAM to connect the appropriate contacts of the selector switch to input contact terminals S1-S5 on the rear panel of the relay. Install the selector switch in the Setting Group Selector Switch panel so that the "L" contact of the switch is aligned with the OFF position label of the selector switch panel. When installed, positions 1-8 should correspond with contacts A-H of the selector switch, and if used, the REMOTE position should correspond with the "I" contact on the selector switch.

Another option not shown would be to use an electronic switch activated by SCADA to change the setting groups.



REMOTE POSITION SELECTED
MANUALLY



REMOTE POSITION SELECTED
USING SCADA

Figure 6.1: Selector Switch Wiring Diagram

COMMUNICATIONS CIRCUITS

Connections to the two EIA-232 serial communications ports are made via three 9-pin connectors, labeled Port 1 and Port 2R on the rear panel and Port 2F on the front. Pins 5 and 9 connect directly to frame (chassis) ground. These connections should not be relied upon for safety grounding, because 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-232 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. Noise could be coupled into the communications wiring from the control or secondary wiring. This noise could exceed the communications logic thresholds, introducing communications errors. The IRIG-B clock cable should also be routed away from control wiring and secondary circuits.

JUMPER INSTALLATION INSTRUCTIONS

The power available from these ports is limited and should be used only for SEL-RDs, SEL-DTAs, dc-powered modems, or other low-wattage devices approved by SEL.

The power is available on either Port 1 or Port 2R. Port 2F, located on the front of the relay, does NOT have power available.

To install jumpers for supplying power through the rear EIA-232 ports on all SEL-200 series relays (except SEL-279 and SEL-279H Relays), perform the following steps:

1. Remove the relay top cover or withdraw the main circuit board.
2. Locate jumpers JMP12 (+5 Vdc), JMP13 (+12 Vdc) and JMP14 (-12 Vdc) near the AUX INPUT connector.
3. Remove and install the needed jumpers in the "on" position.
4. Replace the top cover or reinsert the main circuit board. (Ensure that the board is correctly seated and the cables to the power supply and input transformers are reconnected).

JUMPER SELECTION

All jumpers are on the front edge of the main board. They are easily accessed by removing the top cover or removing the drawout unit through the front of the relay with the front panel removed.

EIA-232 Jumpers

Jumper J105 area provides for EIA-232 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 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.

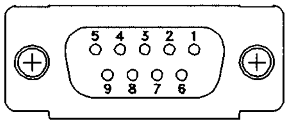
EIA-232 AND IRIG-B INSTALLATION

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 9-pin port connectors and cabling information for the EIA-232 ports is given below. Several types of EIA-232 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 6.2: SEL-221B Relay Nine-Pin Connector Pin Number Convention

EIA-232 Cables

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

RXD  2 ------------------- 3   TXD
TXD  3 ------------------- 2   RXD
GND  5 ------------------- 5   GND
CTS  8 ----------------+-- 8   CTS          (SEL CABLE 234A)
                       +-- 7   RTS
                       +-- 1   DCD
                       +-- 4   DTR
                       +-- 6   DSR
```

```
SEL-221B                    **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-221B

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 (Computer, Terminal, Printer, etc.)
** DCE = Data Communication Equipment (Modem, etc.)

INSTALLATION

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 2 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.

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-neutral and 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 degrees apart, of reasonable magnitudes, and rotating in the positive-sequence direction. The zero-sequence voltage Y and X components (times a factor of three) are obtained by adding the three Y components of voltage together and adding the three X components of voltage together. These sums should be near zero if balanced three-phase potentials are present.

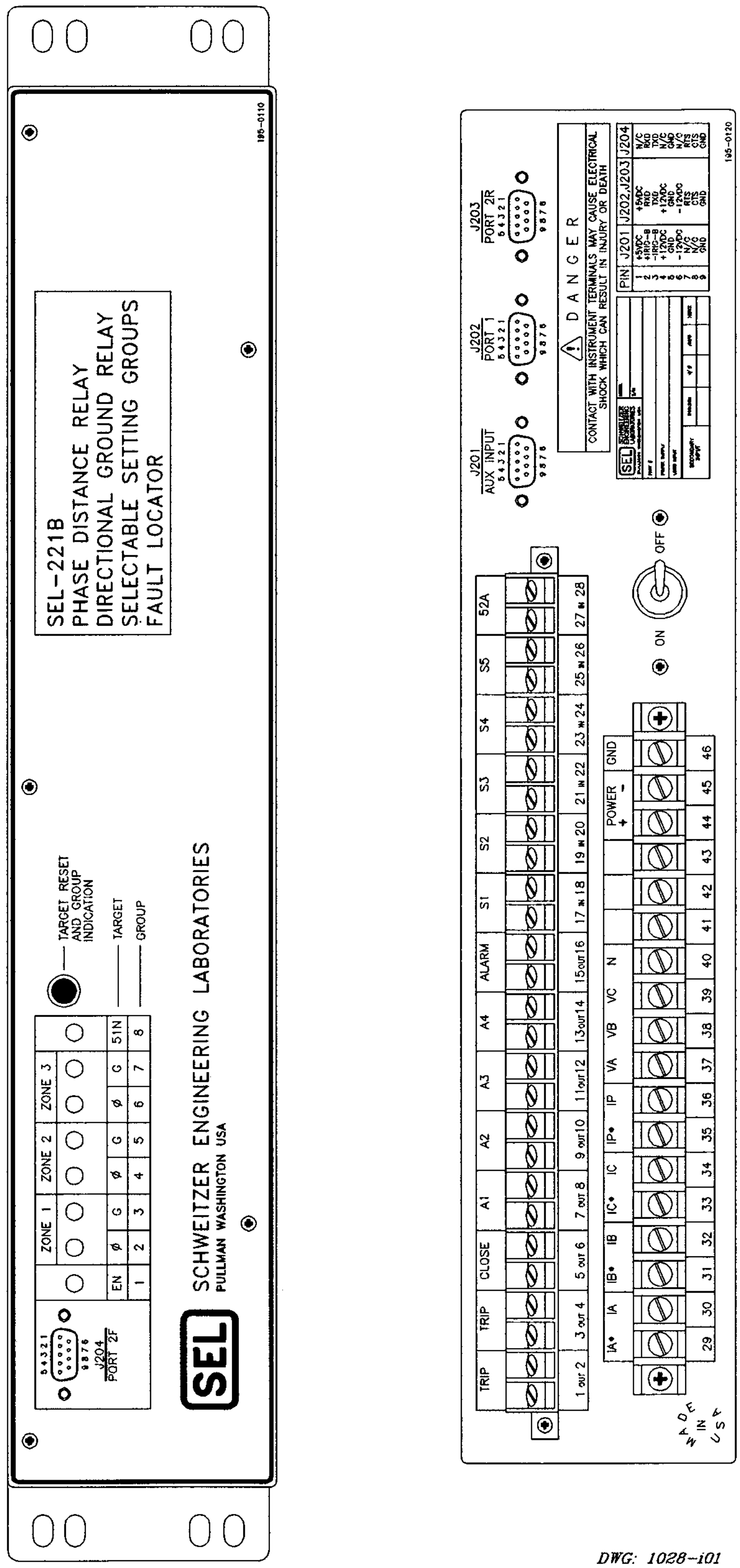
4. Using the TARGETS command, check the state of all contact inputs and outputs. For example, if the connections to the circuit breaker 52A contact are made and the circuit breaker is closed, the TARGET command with option 4 should show a one (1) under the 52A heading (type **TARGET 4 <ENTER>**).

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 two ways. First, be sure the relay can trip the circuit breaker when you execute the OPEN command. Be sure the **TC** bit is set in the MTU mask. The TRIP output relay opens in this case after a minimum of 60 msec. Second, the circuit breaker may be tripped by applying voltages and currents representing a fault condition to which the relay should respond. Here, the TRIP relay opens when the current stops flowing AND fault conditions no longer exist. The TRIP output always remains closed for at least 60 msec.

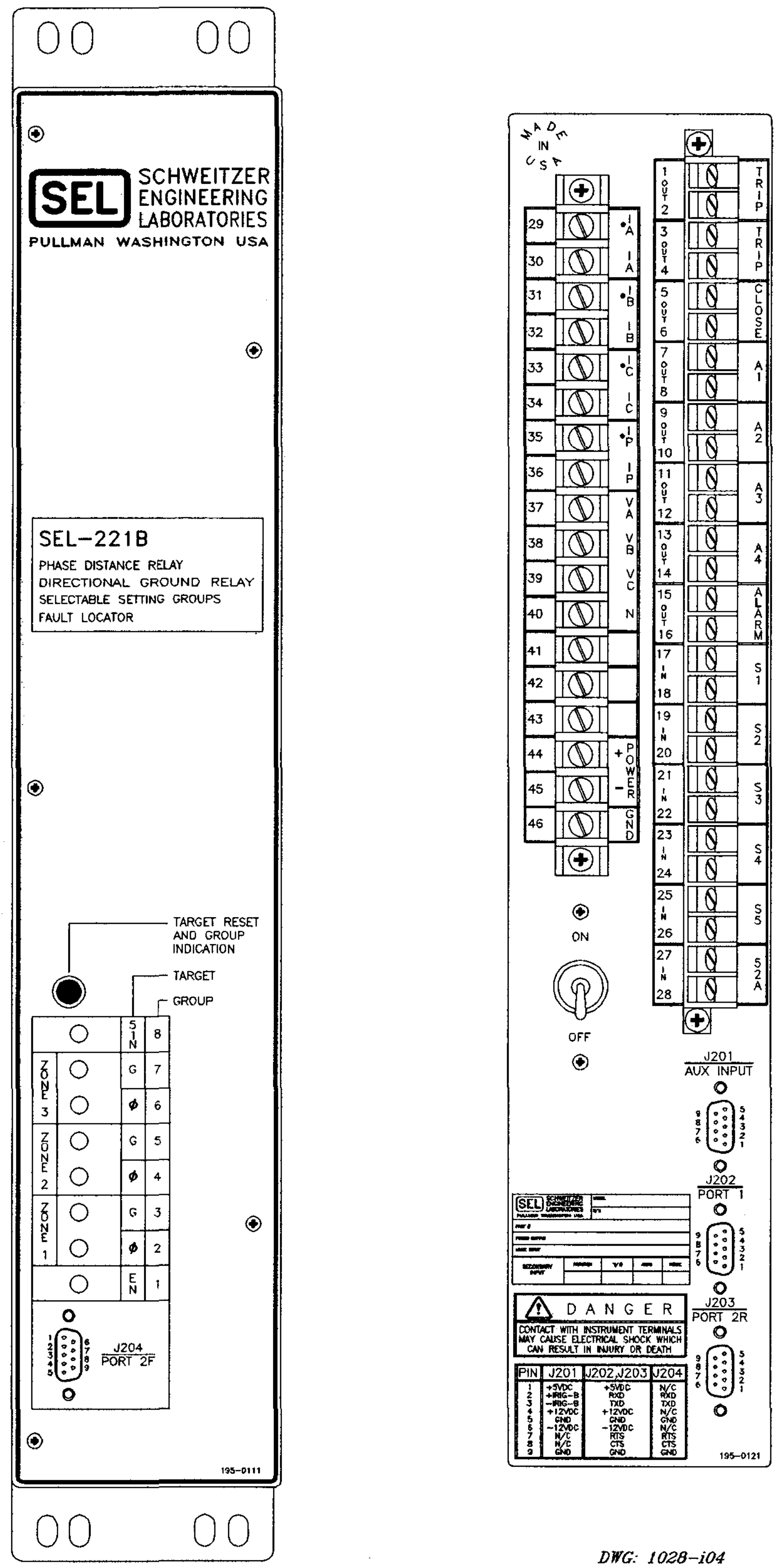
7. The circuit breaker may be closed, by executing the CLOSE command. The CLOSE output relay closes for this condition, as long as the 52A input is deasserted (indicating that the circuit breaker is indeed open). The CLOSE relay opens when the 52A input is asserted.

8. 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.



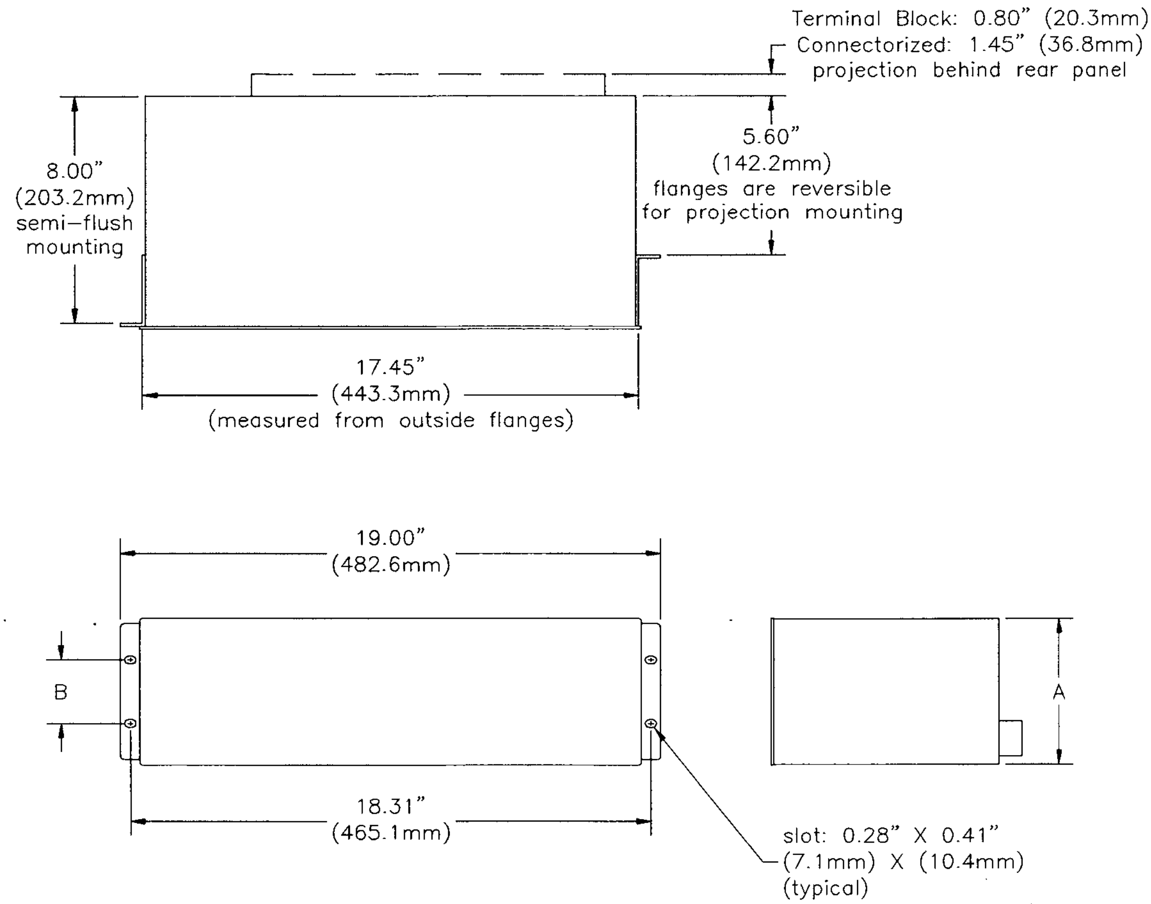
DWG: 1028-i01

Figure 6.3: Horizontal Front and Rear Panel Drawings



DWG: 1028-i04

Figure 6.4: Vertical Front and Rear Panel Drawings



DIMENSION	MAIN BOARD ONLY (2U)	ONE I/O BOARD (3U)	TWO I/O BOARDS (4U)
A	3.47" (88.1mm)	5.22" (132.6mm)	6.97" (177.0mm)
B	3.00" (76.2mm) 1.75" (44.5mm) optional	2.25" (57.2mm)	4.00" (101.6mm)

NOTE:

1. ALL TOLERANCES ARE ± 0.020" (0.51mm)
2. TO DETERMINE THE CUTOUT DIMENSIONS CONSIDER BOTH SEL'S SPECIFIED TOLERANCE AND THE CUSTOMER'S ALLOWED TOLERANCE.
3. DRAWING NOT TO SCALE
4. SLP DIMENSIONS APPLY TO THE FOLLOWING SEL DEVICES:
   a) ALL SEL-200 SERIES RELAYS EXCEPT FOR LP RELAYS WHICH INCLUDE: 279, 279H (1 Amp or 5 Amp), 251, 251C and 267-4 (1 Amp only)
   b) ALL SEL-300 SERIES RELAYS EXCEPT 321 RELAYS
   c) SEL-2020 and 2030

DWG. I1367
DATE: 12 AUG 98

Figure 6.5: Relay Dimensions and Drill Plan

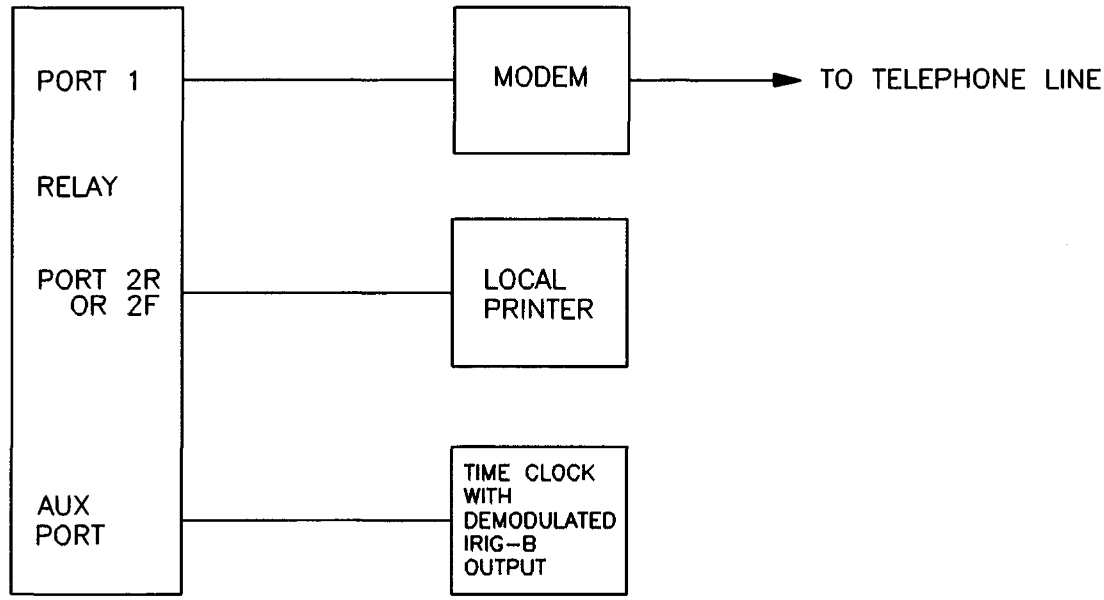


Figure 6.6: Communications and Clock Connections - One Unit at One Location

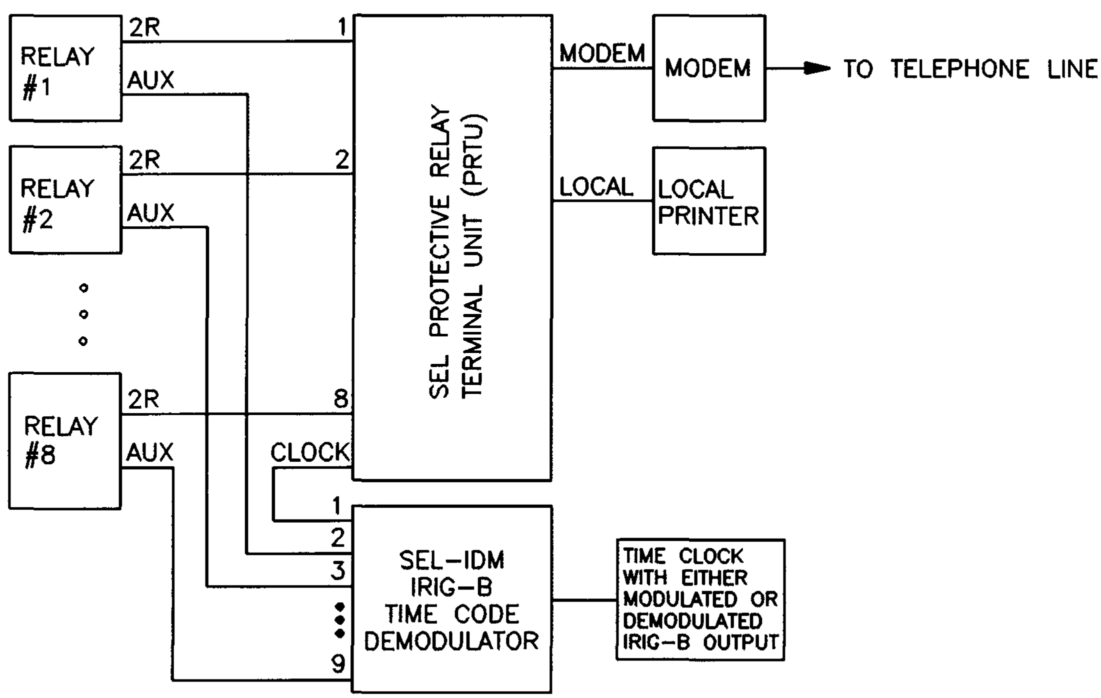


Figure 6.7: Communications and Clock Connections - Multiple Units at One Location

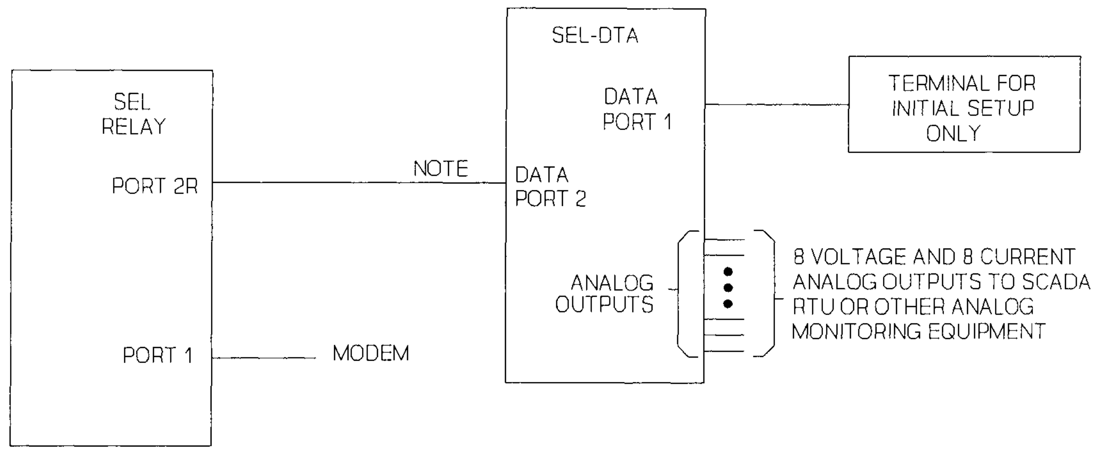


Figure 6.8: SEL Relay Communications Diagram for Connection to the SEL-DTA

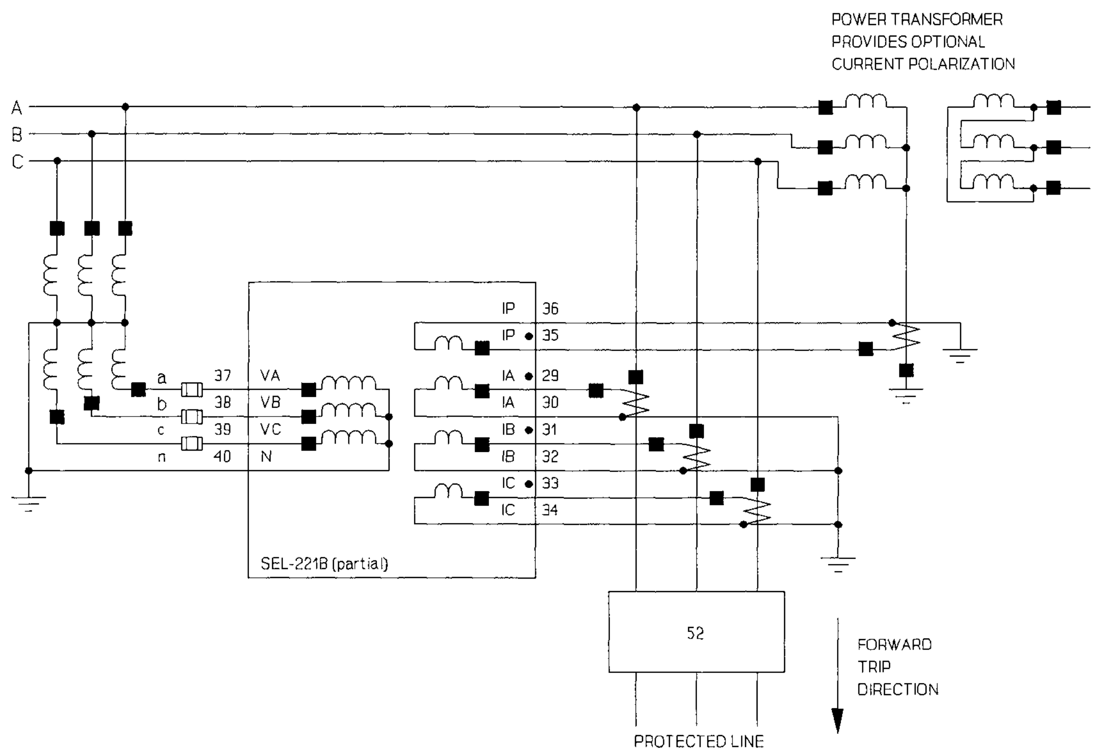


Figure 6.9: External AC Current and Voltage Connections

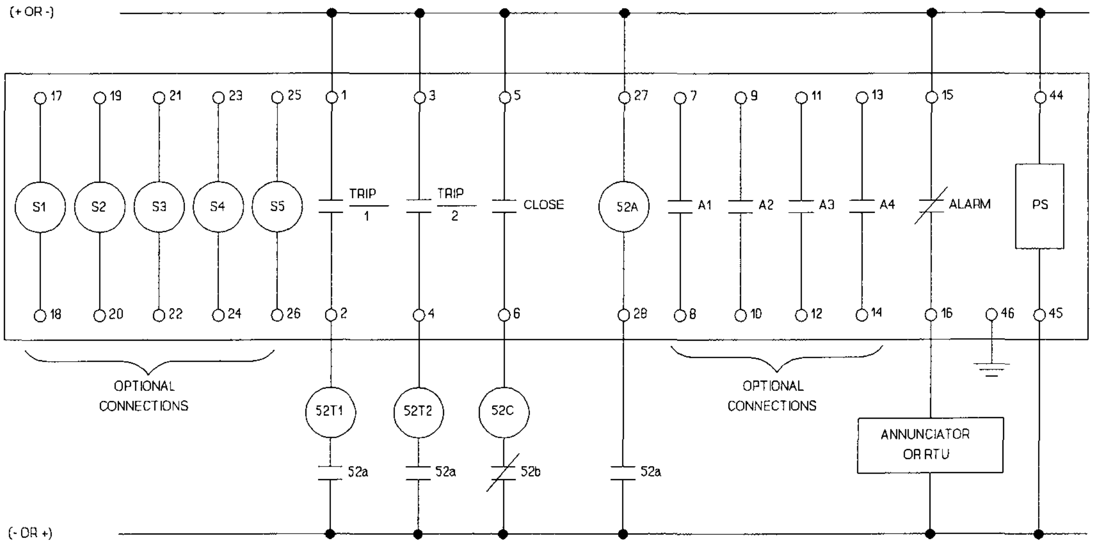


Figure 6.10: External DC Connection Diagram (Typical)

SEL DIRECTION AND POLARITY CHECK FORM

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

SWITCH NO.: __________________ EQUIPMENT: ______________________________________

INSTALLATION: ________ ROUTINE: _______ OTHER: ______________________________________

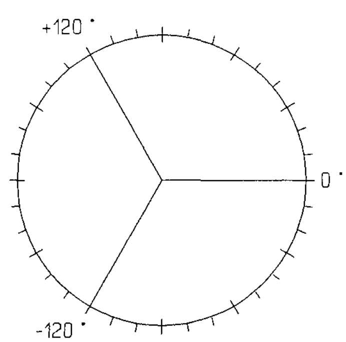
LOAD CONDITIONS

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

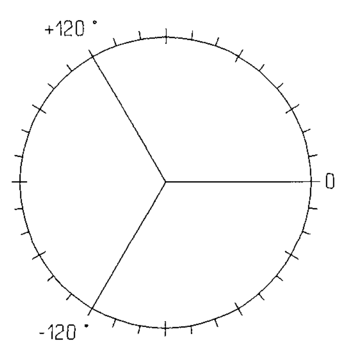
SEL READINGS: ________ MW (+)(-) ________ MVAR (+)(-)

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 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

DWG: A7-0446

SEL DIRECTION AND POLARITY CHECK FORM

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

SWITCH NO.: ____________________ EQUIPMENT: ____

INSTALLATION: ________ ROUTINE: _______ OTHER: ____

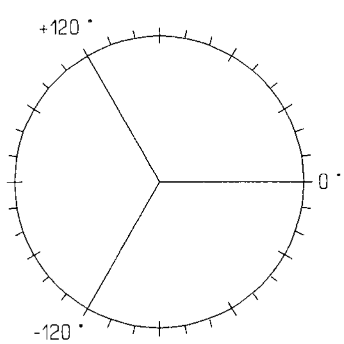
LOAD CONDITIONS

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

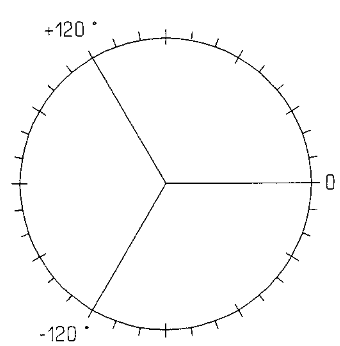
SEL READINGS: ________ MW (+)(-) ________ MVAR (+)(-)

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 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

DWG: A7-0446

SERVICE AND CALIBRATION
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SERVICE AND CALIBRATION

Testing of the SEL-221B 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 Section 2: INITIAL CHECKOUT. 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 SEL-221B Relay accepts settings, perform the following steps:

1. Gain Level 2 Access. (See Access and 2Access commands.)
2. Type SET 1.
3. Change one setting. For example change Zone 1 reach from 80 to 82%.
4. Type "END" to complete the setting procedure. Type in "YES" 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. Type SHOWSET 1.
7. Use the SET and SHOWSET commands again to restore and check the settings.
8. Type LOG MTU 1.
9. Change one bit.
10. Complete the logic setting procedure.
11. Type LOG MTU 1 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 and phase balance of the relay. It is a single-phase test.

1. Connect the voltage input terminals VA, VB, and VC together, and apply about 50 Vac from those terminals to the neutral point.

2. Connect the current inputs in series, and apply a current of five amperes through the three inputs. One way to do this without a test set is to derive this current using a resistor and a stepdown transformer, energized from the same source providing the 50 Vac input to the voltage inputs, so that the phase angle between the current and the voltage is nearly zero.

3. Using the METER command, inspect the measured voltages, currents, and power. Voltages VA, VB, and VC should equal the applied voltage times the potential transformer ratio setting. With the Example 230 kV Line settings, you should obtain:

   $$VA = VB = VC = 50 \cdot 2000 = 100 \text{ kV}. \quad (\pm\ 0.5\ \%)$$

   Voltages VAB, VBC, and VCA should be less than 1.5 kV.

   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:

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

   Difference currents IAB, IBC, and ICA should be less than 20 amperes.

   The power reading should be:

   $$VA \cdot IA + VB \cdot IB + VC \cdot IC = 300 \text{ MW}.$$

   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 four-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 short BASIC program given at the end of this section. Using zero source impedance further simplifies the test. (Entering Z0=Z1 allows you to use the single-phase fault current calculation for Aϕ 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 ohms
   Z0 = 1.39 + j 7.996 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 an Aϕ-to-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 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
```

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 volt of 5 volts.

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

RELAY CALIBRATION

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

TROUBLESHOOTING 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 the power input terminals.

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 LEDs 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, or 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. PCB 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 Section 4: COMMANDS AND SERIAL COMMUNICATIONS.)

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.

6. Contact inputs S1-S5 asserted in some pattern other than the patterns shown in Table 1.1.

Firmware Upgrade Instructions, SEL-121B 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 in 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 are bent 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 Level 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-221B Relay

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 are bent 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.

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

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FIGURES

APPENDIX A: FIRMWARE VERSIONS

The firmware versions are listed in chronological order (most recent firmware at top).

Firmware Part/Revision No.	Description of Firmware
SEL-121B-R408	5 amp, 60 Hz, Miles, ABC rotation
SEL-121B-R506	5 amp, 60 Hz, Kilometers, ABC rotation
SEL-121B-R608	5 amp, 60 Hz, Miles, ACB rotation
SEL-121B-1-R403	5 amp, 60 Hz, Miles, ABC rotation
SEL-121B-1-R503	5 amp, 60 Hz, Kilometers, ABC rotation
SEL-121B-1-R604	5 amp, 60 Hz, Miles, ACB rotation
SEL-121B-R607	Negative-Sequence Version
SEL-121B-1-R603	Negative-Sequence with TDUR
SEL-121B-R407	Base Product
SEL-121B-R505	Kilometer Version
SEL-121B-R606	Negative-Sequence Version
SEL-121B-1-R402	Base Product with TDUR
SEL-121B-1-R502	Kilometer with TDUR
SEL-121B-1-R602	Negative-Sequence with TDUR
SEL-121B-R406	Base Product
SEL-121B-R504	Kilometer Version
SEL-121B-R605	Negative-Sequence Version
SEL-121B-1-R401	Base Product with TDUR
SEL-121B-1-R501	Kilometer with TDUR
SEL-121B-1-R601	Negative-Sequence with TDUR
SEL-121B-R405	Base Product
SEL-121B-R503	Kilometer Version
SEL-121B-R604	Negative-Sequence Version
SEL-121B-1-R400	Base Product with TDUR
SEL-121B-1-R500	Kilometer with TDUR
SEL-121B-1-R600	Negative-Sequence with TDUR

To find the firmware revision number in your relay, obtain an event report (which identifies the firmware) using the EVENT command. This is an FID number with the Part/Revision number in bold:

FID=**SEL-121B-R403**-V656mptrs2-D931114

For a detailed explanation of the FID refer to Section 5: EVENT REPORTING.

The following table shows firmware that does not precisely match this manual.

Firmware Part/Revision No.	Description of Firmware
SEL-121B-R404	Base Product
SEL-121B-R502	Kilometer Version
SEL-121B-R603	Negative-Sequence Version
SEL-121B-R403	Base Product
SEL-121B-R501	Kilometer Version
SEL-121B-R602	Negative-Sequence Version
SEL-121B-R402	Base Product
SEL-121B-R500	Kilometer Version
SEL-121B-R601	Negative-Sequence Version
SEL-121B-R401	Base Product
SEL-121B-R600	Negative-Sequence Version
SEL-121B-R400	Base Product

APPENDIX B: SEL-221B RELAY MAIN BOARD JUMPER CONNECTOR AND SOCKET LOCATIONS

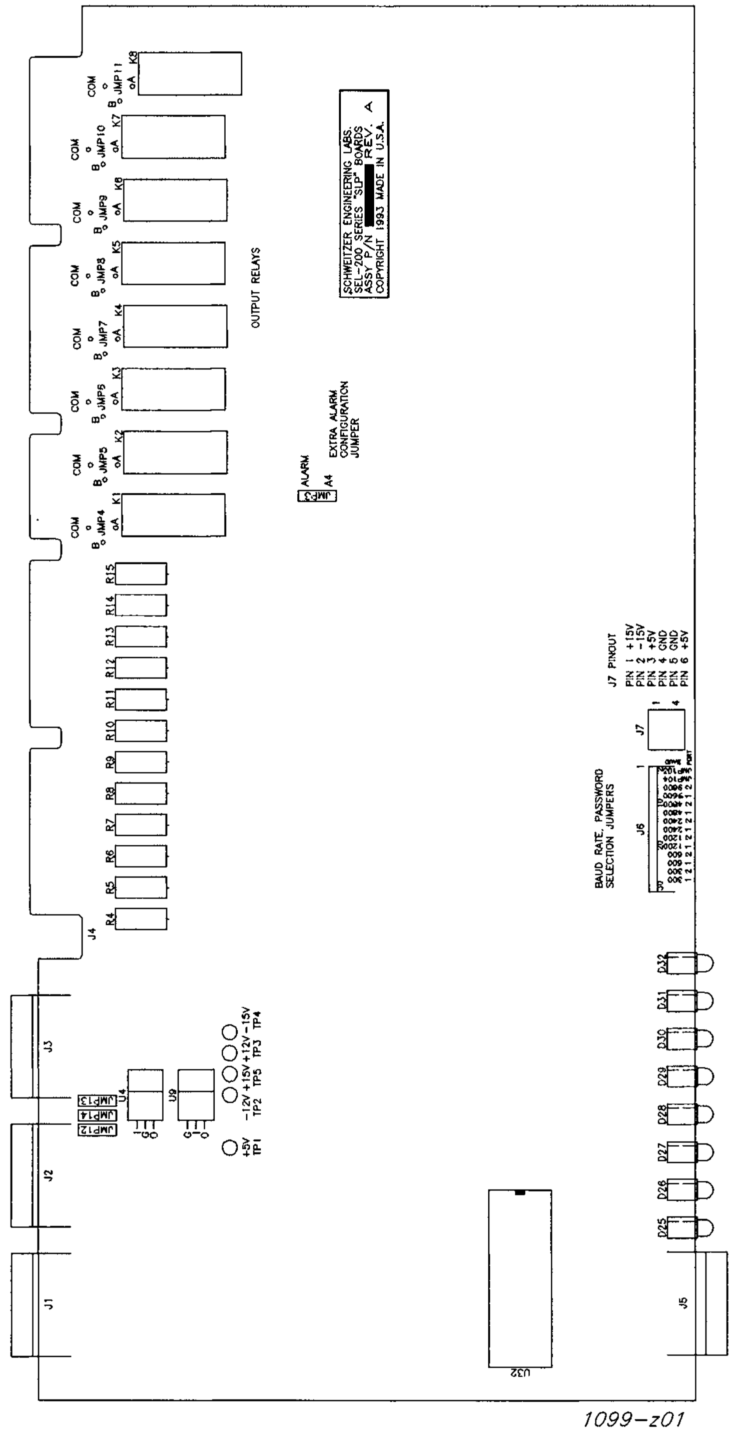

Figure B.1: SEL-221B Conventional Terminal Block Model Main Board Troubleshooting Test Points and Jumper Locations

APPENDIX C: ONEBUS: 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 voltage and current 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.

The program 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 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$="A-G"
320   GOSUB 4041
500   REM  B-C FAULT
510   AR=1: AI=0
520   BR=2*R1*(S+F):BI=2*S1*(S+F)
530   GOSUB 2000
540   I=RR:J=RI
550   IA=0:JA=0
560   AR=I:AI=J:BR=0:BI=-67*SQR(3)
570   GOSUB 1000
580   IB=RR:JB=RI:IC=-IB:JC=-JB
590   UA=67:VA=0
600   AR=I:AI=J:BR=S*R1:BI=S*S1
610   GOSUB 1000
620   AR=RR:AI=RI:BR=0:BI=SQR(3)
630   GOSUB 1000
635   TR=RR:TS=RI
640   UB=67*(-0.5+TR)
650   VB=67*(-SQR(3)/2+TS)
660   UC=67*(-0.5-TR)
670   VC=67*(0.5*SQR(3)-TS)
675   FF$="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
```

DATE ___

SETTINGS SHEET
FOR SEL-221B/121B RELAY
SETTING GROUP #___

SUBSTATION ___ CIRCUIT ___

BREAKER ___ DEVICE NO. ___

FUNCTION ___

MAKE ___ C.T. SETTING ___

MODEL/STYLE NO. ___ P.T. SETTING ___

PART # ___ SOFTWARE VERSION ___

SERIAL #___ POWER SUPPLY ___ VOLTS ac/dc LOGIC INPUT ___ Vdc

SECONDARY INPUTS: V/Ø = 67L-N, NOMINAL AMPS = 5, Hz = 60

HEXADECIMAL REPRESENTATION

MASK: MTU (UNCONDITIONAL TRIP)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	1ABC	2ABC	3ABC	LOP	50H	50M	50MF	50L	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	Z2PT	Z3PT	Z2GT	Z3GT	ALRM	TRIP	TC	DF	

MASK: MTO (SWITCH-ONTO-FAULT)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	1ABC	2ABC	3ABC	LOP	50H	50M	50MF	50L	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	Z2PT	Z3PT	Z2GT	Z3GT	ALRM	TRIP	TC	DF	

MASK: MA1 (A1 CONTACT)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	1ABC	2ABC	3ABC	LOP	50H	50M	50MF	50L	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	Z2PT	Z3PT	Z2GT	Z3GT	ALRM	TRIP	TC	DF	

SETTINGS SHEET
FOR SEL-221B/121B RELAY
SETTING GROUP #________

SUBSTATION ________

MASK: MA2 (A2 CONTACT)

									HEXADECIMAL REPRESENTATION SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	1ABC	2ABC	3ABC	LOP	50H	50M	50MF	50L	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	Z2PT	Z3PT	Z2GT	Z3GT	ALRM	TRIP	TC	DF	

MASK: MA3 (A3 CONTACT)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	1ABC	2ABC	3ABC	LOP	50H	50M	50MF	50L	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	Z2PT	Z3PT	Z2GT	Z3GT	ALRM	TRIP	TC	DF	

MASK: MA4 (A4 CONTACT)

									SETTING
ROW #1: RELAY WORD BINARY REPRESENTATION	1ABC	2ABC	3ABC	LOP	50H	50M	50MF	50L	
ROW #2: RELAY WORD BINARY REPRESENTATION	51NT	67N1	67N2	67N3	51NP	Z1P	Z2P	Z3P	
ROW #3: RELAY WORD BINARY REPRESENTATION	Z2PT	Z3PT	Z2GT	Z3GT	ALRM	TRIP	TC	DF	

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

ACCESS Command passwords: (6 Characters excluding "SPACE, COMMA, SEMI-COLON and SLASH")

LEVEL 0: "=" **ACCESS <ENTER>**
PASSWORD: ________________

LEVEL 1: "=>" **2ACCESS <ENTER>**
PASSWORD: ________________

LEVEL 2: "=>>" ENTER SETTINGS PER MATRIX TABLE

Note: FOR NEW RELAYS BEGIN WITH LEVEL 1 PASSWORD = OTTER AND LEVEL 2 PASSWORD = TAIL. WHEN IN LEVEL 2 MODIFY PASSWORDS VIA PASSWORD 1 AND 2 COMMANDS.

SEL-221B/121B RELAY SETTING TABLE
**** FOR SETTING GROUP #_____

SUBSTATION __________

DESCRIP. RANGE	POS-SEQ. IMPEDANCE 0-9999 (PRI. OHMS)		ZERO-SEQ. IMPEDANCE 0-9999 (PRI. OHMS)		LINE LENGTH* 0.1-999 MILES
ABBREV. SETTING	**R1**	**X1**	**R0**	**X0**	**LL**
DESCRIP. RANGE	C. T. POLARITY N=NORMAL I=INVERTED	C. T. RATIO 1-5000:1	P. T. RATIO 1-10,000:1	MAX. TORQUE ANGLE 47° - 90°	ENABLE FAULT LOCATOR (Y OR N)
ABBREV. SETTING	**CTP**	**CTR**	**PTR**	**MTA**	**LOCAT**
DESCRIP. RANGE	ZONE 1 REACH (0.125-32Ω SEC) 0-2000% OF R1+jX1	ZONE 2 REACH** (0.125-128Ω SEC) 0-3200% OF R1+jX1	ZONE 3 REACH** (0.125-128Ω SEC) 0-3200% OF R1+jX1		
ABBREV. SETTING	**Z1%**	**Z2%**	**Z3%**		
DESCRIP. RANGE	ZONE 1 Ø-Ø, & 3Ø SHORT TIMER 0-60 CYCLES (¼ CYCLE STEPS)	ZONE 2 Ø-Ø, & 3Ø TIME-STEP BACKUP TIMER 0-2000 CYCLES (¼ CYCLE STEPS)	ZONE 3 Ø-Ø, & 3Ø TIME-STEP BACKUP TIMER 0-2000 (¼ CYCLE STEPS)		
ABBREV. SETTING	**Z1DP**	**Z2DP**	**Z3DP**		
DESCRIP. RANGE	Ø O/C LOW-SET PICKUP (0.5-40A SEC.) 0.25-50,000 AMP PRI.	Ø O/C MEDIUM-SET PICKUP (0.5-40A SEC.) 0.25-50,000 AMP PRI.	Ø O/C LOP DELAY (LOSS-OF-POTENTIAL) 0-60 CYCLES (¼ CYCLE STEPS)	Ø O/C HIGH-SET PICKUP (0.5-40A SEC.) 0.25-50,000 AMPS PRI.	
ABBREV. SETTING	**50L**	**50M**	**50MFD**	**50H**	
DESCRIP. RANGE	GND TIME O/C PICKUP (0.25-6.3A SEC) 0.25-50,000 AMP PRI.	GND TIME O/C TIME DIAL 0.5-15 (0.01 STEPS)	GND TIME O/C CURVE SHAPE 1, 2, 3, OR 4		
ABBREV. SETTING	**51NP**	**51NTD**	**51NC**		

SEL-221B/121B RELAY SETTING TABLE
**** FOR SETTING GROUP #_____

SUBSTATION __________

DESCRIP. RANGE	ZONE 1 GND INST. O/C *** (0.25A-48x51NP) 0.25-50,000 AMP PRI.	ZONE 2 GND INST. O/C *** (0.25A-48x51NP) 0.25-50,000 AMP PRI.	ZONE 3 GND INST. O/C *** (0.25A-48x51NP) 0.25-50,000 AMP PRI.		
ABBREV. SETTING	**50N1P**	**50N2P**	**50N3P**		
DESCRIP. RANGE	ZONE 1 GND SHORT TIMER 0-60 CYCLES (¼ CYCLE STEPS)	ZONE 2 GND TIME-STEP BACKUP TIMER 0-2000 CYCLES (¼ CYCLE STEPS)	ZONE 3 GND TIME-STEP BACKUP TIMER 0-2000 CYCLES (¼ CYCLE STEPS)		
ABBREV. SETTING	**Z1DG**	**Z2DG**	**Z3DG**		
DESCRIP. RANGE	52BT TIME DELAY 0-10,000 CYCLES	ZONE 3 DIREC-TION (F OR R)	GND O/C NEG.-SEQ. POLAR. (Y OR N)	GND O/C ZERO-SEQ. VOLTAGE POLAR. (Y OR N)	GND O/C ZERO-SEQ. CURRENT POLAR. (Y OR N)
ABBREV. SETTING	**52BT**	**ZONE 3**	**32QE**	**32VE**	**32IE**
DESCRIP. RANGE	LOSS-OF-POTEN-TIAL ENABLE (Y, N, 1-4)	PORT #1 TIMEOUT 0 - 30 MINUTES	PORT #2 TIMEOUT 0 - 30 MINUTES	AUTOMATIC MESSAGE TRANS-MIT AUTOPORT SELECTION PORT 1, 2, OR 3(BOTH)	# RINGS AFTER WHICH MODEM ANSWERS 1 - 30
ABBREV. SETTING	**LOPE**	**TIME1**	**TIME2**	**AUTO**	**RINGS**

SEL-221B/121B RELAY SETTING TABLE
**** FOR SETTING GROUP #_____

SUBSTATION __________

* Line Length = Station #1 (relay location) to Station #2; the full distance in miles between stations.

Note: Length can also be represented in metric units, primary or secondary ohms, etc., but conversion to miles would be required.

** Zones 2 and 3 are limited as follows:

- For Zone 1 < 8Ω: 1 to 16-times Zone 1
- For Zone 1 > 8Ω: 1 to 4-times Zone 1
- Zone 2 may not be set greater than four times Zone 1 when Zone 3 is less than four times Zone 1.

*** Lower setting limit for 50N1P, 50N2P, and 50N3P:
0.25 A for 51NP < 3.15 A secondary
0.5 A for 51NP ≥ 3.15 A secondary

**** The 221B/121B Relay has 8 setting groups which can be selected by either the "group" command followed by the group number (1-8) or with a local selector switch (2 pole - 9 position) see instruction manual, Section 1: INTRODUCTION for details.

Comments: ____

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Settings recommended by ______________________________

Settings approved by ______________________________

Settings approved by ______________________________

Settings performed by ______________________________

Test printout required ______ Yes ______ No Substation ________

SEL-221B, -1 DISTANCE 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 2/3/91 sets date to Feb. 3, 1991. This setting is overridden when IRIG-B synchronization occurs. Pulses the ALARM relay momentarily when a different year is entered than the previously stored.
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. SHOWSET 4 displays the settings for setting group four.
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: Contact Inputs TAR 5: 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.
COPY*	Copy settings from one setting group to another.
GROUP*	Change the active setting group. Group n activates setting group n (n=1-8). This command only works when contact inputs S2 and S5 are asserted.
LOGIC n	Show or set logic masks MTU, 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 m [n]*	Initiate setting procedure for setting group m (m=1-8). N initiates the procedure at setting n.

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

* Relay pulses ALARM output contact briefly when new settings are stored.

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