# SEL-49

# LINE THERMAL RELAY WITH DISTANCE RELAY AND FAULT LOCATOR

# INSTRUCTION MANUAL

SCHWEITZER ENGINEERING LABORATORIES
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**Customer** ______________________________

**P.O.#:** ____________

**Book Assembled and Checked by** ____________________

**Date Assembled and Checked** ____________________

**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.

# SEL-49 MANUAL ADDENDUM

## FIRMWARE IDENTIFICATION

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

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

Where:

[PN] = Product Name (e.g.: SEL-49)

[RN] = Revision Number (e.g.: 100)

[VS] = Version Specifications (e.g.: 656mpacp21c)

[RD] = Release Date (e.g.: YYMMDD = 880331)

For the SEL-49 family of relays, the version specifications are interpreted as follows:

V[VS] = V[ABCDEFGHIJK]

| 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 |

## SETTING RANGE ERROR MESSAGES

Some of the setting ranges of the SEL-49 relay thermal element settings are dependent on the relay nominal power system frequency and nominal amps per phase. The error messages and the setting ranges are detailed below for each of the relay versions.

**Setting Range Error Message: !CTR, THC, RAC or RTC out of range**

You will receive this setting range error message when either of the two equations below is false. The range equations are listed in pairs, two for each relay version. If you receive this message, adjust one or more of the listed settings to make both of the equations true.

60 Hz, 5 Amps Nominal Ratings

$$\frac{7.00822x10^{9} \cdot THC}{CTR^{2} \cdot (20.69108 \cdot RAC - RTC)} < 1.2x10^{6}$$

and

$$\frac{\dfrac{7.00822x10^{9} \cdot THC}{CTR^{2} \cdot (20.69108 \cdot RAC - RTC)}}{1000 + \dfrac{1267637 \cdot RTC}{540.588 \cdot (20.69108 \cdot RAC - RTC)}} > 24$$

50 Hz, 5 Amps Nominal Ratings

$$\frac{5.84018x10^{9} \cdot THC}{CTR^{2} \cdot (20.69108 \cdot RAC - RTC)} < 1.2x10^{6}$$

and

$$\frac{\dfrac{5.84018x10^{9} \cdot THC}{CTR^{2} \cdot (20.69108 \cdot RAC - RTC)}}{1000 + \dfrac{1267637 \cdot RTC}{540.588 \cdot (20.69108 \cdot RAC - RTC)}} > 24$$

60 Hz, 1 Amp Nominal Ratings

$$\frac{7.00822x10^{9} \cdot THC}{0.04 \cdot CTR^{2} \cdot (20.69108 \cdot RAC - RTC)} < 1.2x10^{6}$$

and

$$\frac{\dfrac{7.00822x10^{9} \cdot THC}{0.04 \cdot CTR^{2} \cdot (20.69108 \cdot RAC - RTC)}}{1000 + \dfrac{1267637 \cdot RTC}{540.588 \cdot (20.69108 \cdot RAC - RTC)}} > 24$$

50 Hz, 1 Amp Nominal Ratings

$$\frac{5.84018x10^{9}\cdot THC}{0.04\cdot CTR^{2}\cdot(20.69108\cdot RAC-RTC)}<1.2x10^{6}$$

and

$$\frac{\dfrac{5.84018x10^{9}\cdot THC}{0.04\cdot CTR^{2}\cdot(20.69108\cdot RAC-RTC)}}{1000+\dfrac{1267637\cdot RTC}{540.588\cdot(20.69108\cdot RAC-RTC)}}>24$$

**Setting Range Error Message: !RAC out of range**

You will receive this setting range error message when the equation below is false. If you receive this message, adjust the RAC or RTC settings to make the equation true.

All relay versions

$$\frac{RAC}{92.4897x10^{6}}-\frac{RTC}{1.9149x10^{9}}>0$$

## 50 Hz, KILOMETER OPTION

The SEL-49 relay instruction manual is written for relays which typically supply fault locations in terms of miles, on systems with an operating frequency of 60 Hz. If your SEL-49 relay is ordered with the 50 Hz, 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 to the effect of shunt capacitance on the fault location calculation, found in Chapter 3 of the instruction manual. The line length equation and associated paragraphs, corrected for a 100-kilometer line, on a 50 Hz system, 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) * 2 * 3.14159 = 0.1048 radians

The fault location, neglecting capacitance, is about cos(0.1048) = .9945 times the actual fault location. That is, about 0.55 kilometers short for a fault at the remote end of a 100-kilometer line.

In addition, references made to a sampling time of 1/240 seconds should be replaced with a time of 1/200 seconds.

## TARGET RESET BUTTON FUNCTIONS

The TARGET RESET button performs three functions, two of which are new. Pressing the TARGET RESET button on the front panel clears the TAR 0 (see TARGET command description) data and lights all target LED's for one second, as a lamp test. Furthermore, pressing the TARGET RESET button unlatches the TRIP output from the 52A input. This new feature is useful during relay testing, and it minimizes the risk of re-installing the relay with the TRIP output asserted.

## AUTOPORT

Autoport may now be set to 3 or 4 which causes some automatic messages (i.e., short event reports, self-test status reports) to be sent to both ports 1 and 2. This is useful in conjunction with some SEL-DTA installations.

## THERMAL SETTINGS

The lower limit on the line thermal time constants for which the SEL-49 may be set has been lowered.

## THERMAL REPORTS

The thermal line reports generated by the SEL-49 have been improved. Among other new items, actual and limit load MVA and currents are indicated.

## 50FD

Three settable fault detector overcurrent elements have been added, (50A, 50B, 50C), for supervising the mho elements.

## FAULT LOCATOR

Fault data selection logic has been improved.

## THERMAL ALARM

The low-set thermal alarm function has been removed from the ALARM contact output.

## MODEM CONTROL

The modem control logic has been improved. For example, the relay will now cause a modem on port 1 to hang up after the port timeout interval expires, thus avoiding the risk of high telephone tolls when an operator forgets to terminate a communications session.

## REAL TIME CLOCK

The internal time-keeping clock of the SEL-49 now synchronizes to the positive sequence current waveform. Thus, time accuracy is improved in installations where a stable IRIG-B source is not available.

## METER COMMAND

The METER command display has been improved.

## MILLISECOND EVENTS

Event reports are now time-tagged to the millisecond.

## PRIMARY REACH LIMITS

The primary reach setting upper limit has been expanded to 3200% of the set line impedance. (This does not affect secondary setting limits.)

## SET PROCEDURE

The SET command user interface has been improved.

## MHO POLARIZATION

The mhos are now polarized with equal weights of faulted phase voltage and the quadrature term. Formerly, only a small fraction of the quadrature term was employed.

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# CHAPTER 1: FUNCTIONAL DESCRIPTION

## INTRODUCTION

This chapter provides a functional description of the relay from a "black box" point of view. More specifically, models given in this chapter determine relay outputs from relay inputs.

For more information concerning the internal operation of the relay, turn to Chapters 2, 3, and 4.

## INPUTS, OUTPUTS AND COMMUNICATION PORTS

This section gives a brief definition of all of the inputs, outputs and communication ports on the rear panel of the SEL-49 relay. Both the symbols and the terminal numbers are given (terminal numbers in parentheses). Limitations and nominal values for the inputs and outputs are given in Appendix A - Relay Specifications. A typical connection of the inputs and outputs is shown in Appendix B - External Connection Diagram.

### Power Supply Inputs

These supply internal power for the relay and are labeled as POWER with + and - on the rear panel.

| | | |
|---|---|---|
| (37) | + | - positive battery input (or AC) |
| (38) | - | - negative battery input (or AC) |
| (35,36) | GND | - ground |

### Analog Inputs

The SEL-49 has eight analog input channels: three voltage, four current and one for a remote temperature sensing device.

| | | |
|---|---|---|
| (29) | VA | - phase A voltage |
| (30) | VB | - phase B voltage |
| (31) | VC | - phase C voltage |
| (32) | N | - neutral for phase voltages |
| (1) | IA dot | - phase A current in |
| (7) | IA | - phase A current out |
| (2) | IB dot | - phase B current in |
| (8) | IB | - phase B current out |
| (3) | IC dot | - phase C current in |
| (9) | IC | - phase C current out |
| (4) | IRM dot | - parallel circuit residual current in |
| (10) | IRM | - parallel circuit residual current out |
| (33) | +RTD | - remote temperature positive voltage input |
| (34) | -RTD | - remote temperature negative voltage input |

Control Inputs

The SEL-49 has six control inputs. Each input may be asserted by energizing the two terminals listed.

| | |
|---|---|
| (39,40)-DIRECT TRIP | - causes trip relay to close |
| (41,42)-TRANSFER TRIP | - initiates transfer trip (supervised by distance relay) |
| (43,44)-BLOCK TRIP | - used to block closing of trip relay |
| (45,46)-DIRECT CLOSE | - causes close relay to close |
| (47,48)-52A | - monitors state of circuit breaker |
| (49,50)-EXTERNAL TRIGGER | - provides external means of triggering event record |

Control Outputs

The SEL-49 has six output functions implemented with eight pairs of relay points. Relay points are listed in pairs, along with the type of contact. Note that two circuits each are provided for TRIP and CLOSE.

| | | |
|---|---|---|
| (13,14)-A | TRIP | - used to energize trip circuit |
| (15,16)-A | | |
| (17,18)-A | CLOSE | - used to energize close circuits |
| (19,20)-A | | |
| (21,22)-A | A1 | - also referred to as TTO, can be used as transfer trip output to initiate transfer tripping at the other end of the line or as indication of distance relay state when distance relay is not enabled for tripping |
| (23,24)-A | A2 | - also referred to as TH, closes when the estimated line temperature exceeds the high threshold |
| (25,26)-A | A3 | - also referred to as TL, closes when the estimated line temperature exceeds the low threshold |
| (27,28)-B | ALARM | - closes when any one of several conditions exist such as loss of power, self test failure or failure to access relay because of incorrect password |

Communication Ports

The SEL-49 has one clock port and two communication ports. They are:

| | |
|---|---|
| J201 AUX INPUT | - this port is used to input a demodulated IRIG-B time clock signal |
| J202 PORT 1 | - RS232 serial port, also referred to as the modem port |
| J203 PORT 2 | - RS232 serial port, also referred to as the local or printer port |

THERMAL RELAY MODEL

The thermal model employed by the SEL-49 is intended to give a good estimate of line temperature. Furthermore, the model is conservative -- when errors between the model temperature and the actual temperature exist, the model temperature should be the higher one.

The model may be considered as a middle ground between two approaches. One approach lies in the direction of increased sophistication. However, for any model to achieve realistic improvements in accuracy over the model presented here would require taking into account wind speed. It is generally not feasible to take wind velocity and direction measurements for all portions of the line. Unless such a major contributor to heat loss as wind velocity is taken into account further model refinements have little meaning.

In the opposite direction from sophisticated models lies the steady state approaches generally used to rate conductor ampacities. One disadvantage of these approaches is that lines are underutilized on all but hot summer days. In addition, the thermal inertia of the line is only partially taken advantage of by short period overload and emergency overload ratings which must assume high initial conductor temperatures to be safe.

The SEL-49 model is sufficiently sophisticated to utilize significant, readily available information such as ambient temperature and conductor current. It is kept conservative by assuming worst case atmospheric and solar conditions. With this approach a substantial increase in line utilization can be realized over static rating approaches for a minimum investment.

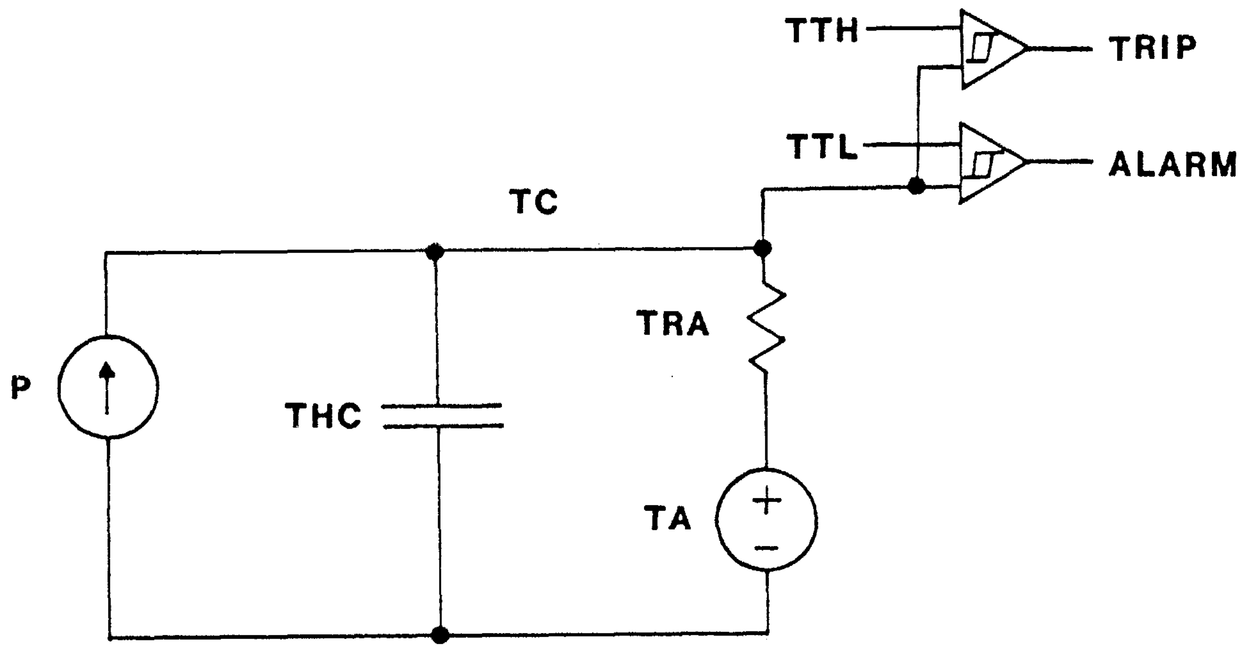
The model may be described as a single node model. It is expressed using familiar electrical components as shown in Figure 1: SEL-49 THERMAL MODEL, VARIABLES AND EQUATIONS, along with equations that describe the model mathematically. Referring to the model: "P" represents the total heat energy being added to the line, "THC" represents the thermal heat capacity of the line, and "TRA" represents the thermal resistance of the line to the atmosphere at temperature "TA", ambient temperature. "TC" is the conductor temperature estimated by the thermal model.

Equation (1) states the thermal model equation. The most significant approximation implicitly made by this model is that the conductor is at a uniform temperature. Small radial temperature gradients are known to exist, but they are secondary in importance compared to overall conductor temperature.

Equation (2) relates the total heat input as a contribution from three terms: heating from current, heating from solar radiation and heating from sky radiation. Current heating is calculated by knowing the conductor current, the AC resistance at 25 degrees Celsius and the temperature coefficient of AC resistance. Contributions of solar and sky radiation are covered in the Solar Model Section.

Equation (3) gives the approximation made to arrive at a formula for cooling. On the right side of the equation, cooling is attributed to two mechanisms: radiation to background, and convection. Although the formulas describing these mechanisms are not linear, they are nearly linear over the temperature range of interest. This justifies the approximation made to the linear equation in (3). For more on the derivation of the linear cooling equation from the radiation and convection effects, refer to the Thermal Relay Settings section.

## THERMAL MODEL




## THERMAL VARIABLES

| | | |
|---|---|---|
| P | - heat power input | (watts/Kft) |
| THC | - thermal heat capacity | (J/deg C Kft) |
| TRA | - thermal resistance to ambient | (deg C Kft/kw) |
| TC | - estimated conductor temperature | (deg C) |
| TA | - ambient temperature | (deg C) |
| TI | - initial conductor temperature | (deg C) |
| TTH | - high temperature threshold | (deg C) |
| TTL | - low temperature threshold | (deg C) |
| I | - conductor current | (Amperes) |
| rac | - AC resistance at 25°C | (ohms/Kft) |
| rdelt | - temperature coefficient of AC resistance | (ohms/deg C Kft) |

**FIGURE 1: SEL-49 THERMAL MODEL, VARIABLES AND EQUATIONS**

FIGURE 1: SEL-49 THERMAL MODEL, VARIABLES AND EQUATIONS (cont.)

## THERMAL MODEL EQUATION

$$(1) \qquad \frac{D\ TC}{dt} * THC = P - \frac{(TC - TA)}{TRA}$$

## HEATING EQUATION

$$(2) \qquad P = I^2 * (rac + (TC - 25) * rdelt) + Qsun + Qsky$$

## COOLING EQUATION

$$(3) \qquad \frac{(TC - TA)}{TRA} = Qradiated + Qconvected$$

## THERMAL EQUATION SOLVED FOR TC

$$(4) \qquad TC = \int_0^t (P/THC - (TC - TA)/(TRA * THC))dt + TI$$

Equation (1) is solved for conductor temperature at the bottom of the previous page. The integration constant TI represents the initial conductor temperature. The SEL-49 implements a discrete version of this integration to estimate line temperature. Unless TI reflects the actual conductor temperature when the SEL-49 is powered up, it will take approximately five conductor time constants for TC to become an accurate estimate of line temperature.

When the line temperature is over TTL (the low temperature threshold), an alarm condition exists. When the line temperature is over TTH (the high temperature threshold), a trip condition exists. The trip and alarm conditions persist until the temperature drops two degrees Celsius below the respective thresholds. This is represented in the figure by the hysteresis symbol in the comparators.

## THERMAL PREDICTOR AND AUTO-REPORT GENERATOR

This section describes the operation of the thermal predictor and auto-report generator functions of the SEL-49.

The equations given in Figure 1 are further manipulated to solve for ttt, the time to trip in seconds. Because the value of line resistance varies, the solution becomes involved without some approximations. The approximation used in the SEL-49 predictor is that the effective line resistance during the time interval before a trip is:

$$R\ \text{effective} = rac + ((TTH + TC) / 2 - 25) * rdelt$$

Once this approximation is made the time to trip may be solved to yield:

$$ttt = THC * TRA * \ln \frac{P * TRA + TA - TC}{P * TRA + TA - TTH}$$

Now let's add some meaning to the equation. The leading factor THC * tra is the thermal time constant. If we were to look at Figure 1 again we would see that this is just like an RC time constant. The denominator of the natural log function can be expressed as the difference between the final temperature and the trip temperature:

$$\underbrace{(P * TRA + TA)}_{\text{final temp}} - \underbrace{TTH}_{\text{trip temp}}$$

Note that as the denominator approaches zero from above that the argument of the log approaches +infinity and the time to trip approaches +infinity. When the denominator is negative the final temperature is below the trip temperature, and there is no impending trip. In the numerator we see that increasing TC, the present conductor temperature, causes the time to trip to decrease. Also note that as P becomes very large, the argument of the log approaches 1 and therefore the time to trip approaches zero.

The time to trip value is used to control the automatic generation of reports as follows. An internal status is assigned to the conductor on the basis of the time to trip and its first derivative. This is shown graphically in Figure 2. Automatic reports are generated when the internal status changes or if a timer has run out. The timer value is determined by the status. In addition to these reports a warning report is generated every ten minutes if no trip is impending, but the temperature is over the low temperature threshold.

The automatic report generator is implemented in this manner for several reasons. First, as the time to trip decreases, reports are generated more often since the operator will want to be updated more often. Second, by looking at the sign of the first derivative, hysteresis can be introduced so that many reports will not be generated if the time to trip jitters about a particular value. Third, the warning report prevents the conductor temperature from rising up close to the trip temperature without letting the operator know about it. This is important since at elevated conductor temperatures the time to trip might be quite short for a given increase in conductor current.

## SOLAR MODEL

The solar contribution to conductor temperature is typically on the order of ten degrees Celsius on a sunny day. Direct measurement of the radiation would require a pyroheliometer. Rigorous application of this information would require knowing the north-south angle of the conductor as well as the shading effects of nearby geographical features.

The solar model used by the SEL-49 estimates worst case (maximum) insolation. It does this by knowing the position of the conductor (assuming worst case alignment with the sun) and the position of the sun. Clouds or shading effects cause the estimated temperature to exceed the actual conductor temperature.

A solar position algorithm along with a lookup table is used to find the solar heating, which is composed of both direct and sky radiation. The lookup table comes from Reference 1. Reference 1 also describes the origins of the lookup table values and conditions under which they should be corrected. The solar position algorithm comes from Reference 2.

Values for the lookup table as well as equations for solar position are summarized in Figure 3. The first equation is for solar declination:

$$d = 23.45 \sin \left(\frac{284 + n}{365} * 360\right)$$

where d is the declination in degrees and n is the day of the year. Once the declination is found the solar time must be found. The solar time is expressed in degrees, with solar noon as 0 degrees and then 15 degrees for every hour before noon. For example, 11:00 AM is the same as 15 degrees, while 2:30 is -37.5 degrees. To convert local time to solar time one needs to know the local

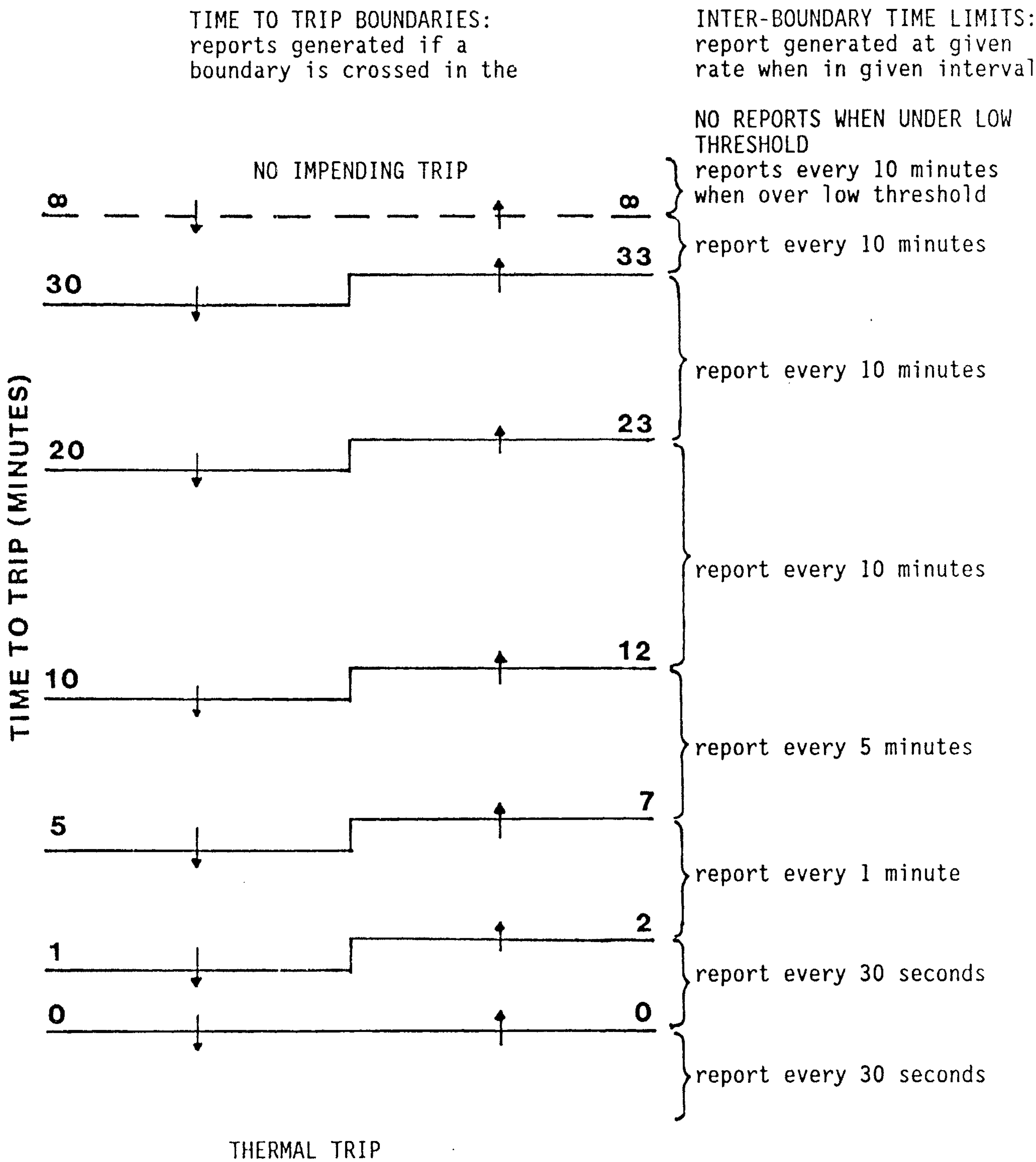



**FIGURE 2. AUTO REPORT FUNCTION**

time meridian and the local longitude. Local time meridians for the United States are given in Figure 3. Solar time may be expressed as:

$$Ws = \text{local time (deg)} + (Lon - Lstd)$$

where Lstd is the standard time meridian and Lon is the local position in degrees west longitude. Stated qualitatively this says that if we judge time by the sun, as we travel east (longitude decreasing) it should seem later, which corresponds to a smaller value for solar time.

Now the value that references the lookup table, z - zenith angle, can be found:

$$\cos(z) = \sin(d) * \sin(lat) + \cos(d) * \cos(lat) * \cos(Ws)$$

where lat is the degrees north latitude of the line. Once the solar incident radiation is found from the lookup table, we can calculate the solar heat contribution:

$$Qsun = SAC * DIA * SIR$$

where SAC is the solar absorption coefficient and DIA is the conductor diameter. The solar absorption coefficient may be expressed as the ratio of solar radiation absorbed to incident solar radiation. The values in the lookup table have been normalized for a 1 inch diameter conductor of 1000 ft. length, with a clear atmosphere at an altitude of sea level. For higher altitudes or an industrial atmosphere the lookup table values may be corrected by multiplying the diameter by a correction factor. These are also given in Figure 3.

Since solar variables change so slowly, the SEL-49 only updates them at a rate of about once every three minutes. Therefore, if you change the date or time the solar heat contribution may not change for several minutes.

## FAULT LOCATOR AND MHO UNITS

The SEL-49 package includes a fault locator in addition to the thermal relay. Six supervised mho units (AG, BG, CG, AB, BC, CA) are included for starting the fault locator.

Support for the mho units includes line and ground timers, transfer trip capability and tripping capability. The addition of these features increases the flexibility of the instrument. For example, the user may wish to set the relay so only the 49 relay will cause a trip, but would like to use the mho units for starting oscillographic recorders. This can be done by disabling the mho tripping but enabling the transfer trip output and using it to reflect the status of the mho units.

## SOLAR VARIABLES

| | | |
|---|---|---|
| d | - solar declination | (degrees) |
| n | - day of year | (days) |
| Ws | - solar time | (degrees) |
| SAC | - solar absorption co. | (no units) |
| DIA | - conductor diameter | (inches) |
| z | - solar zenith angle | (degrees from vertical) |
| LSTD | - standard time meridian | (degrees west longitude) |
| LON | - conductor longitude | (degrees west longitude) |
| LAT | - conductor latitude | (degrees north latitude) |
| SIR | - solar incident radiation | (watts / inch dia of 1000ft. conductor) |
| Qsun | - solar heating | (watts / Kft) |

All variables and table values scaled to 1000 ft. length of conductor where applicable.

## SOLAR DECLINATION

$$D = 23.45*\sin\left(\frac{284 + N}{365} * 360\right) \qquad Ws = \text{local time(degrees)} + (LON - LSTD)$$

## ZENITH ANGLE

$$\cos(z) = \sin(d)*\sin(LAT) + \cos(d)*\cos(LAT)*\cos(Ws)$$

## SOLAR HEATING

Qsun = SAC*DIA*SIR

## SOLAR LOOKUP TABLE

| z | SIR |
|---|---|
| 85 | 1808 |
| 80 | 3350 |
| 75 | 4516 |
| 70 | 5366 |
| 65 | 5958 |
| 60 | 6416 |
| 55 | 6791 |
| 50 | 7066 |
| 45 | 7283 |
| 40 | 7500 |
| 30 | 7741 |
| 20 | 7916 |
| 10 | 7983 |
| 0 | 8033 |

## STANDARD TIME MERIDIANS

| Time Zone | Meridian |
|---|---|
| Eastern | 75° W |
| Central | 90° W |
| Mountain | 105° W |
| Pacific | 120° W |

## CORRECTION FACTORS

Corrected diameter = dia * K1 * K2

| Elevation | K1 |
|---|---|
| 0 ft | 1.00 |
| 5,000 ft | 1.15 |
| 10,000 ft | 1.25 |
| 15,000 ft | 1.30 |

| Atmosphere | K2 |
|---|---|
| clean | 1.00 |
| industrial | 0.82 |

Fault Locator

The fault locator operates when any event occurs. An event is defined as any supervised mho unit pickup, or assertion of the DT, TT, BT or EXT inputs. Its output is displayed as a part of the EVENT command response and the HISTORY command response.

The fault locator depends on accurate transmission line constants 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 errors
transmission line constant errors.

The algorithm uses prefault and fault information to compensate for the errors introduced by fault resistance in the presence of load flow. A parallel residual current input allows the SEL-49 fault locator to compensate for mutual coupling from a parallel line.

Although the fault-location computation takes several seconds, faults in quick succession, such as occur in a reclosing sequence, are handled. This is because the fault data are stored, and subsequently processed in turn. As an example, suppose three faults occur within a few seconds. The data from 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:

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

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 SEL-49 and capacitors, and beyond the capacitors if the capacitor protective gaps flash. If the gaps do not flash, the measured impedance includes the line impedance and the capacitance impedance, and the errors can be substantial. This problem is aggravated by high-speed clearing and the excitation of eigenmodes or resonances of the line-capacitor system, which may not be much removed from 60 Hz. On the other hand, we have had success in cases where series capacitor gaps did not flash, by recomputing the fault location from the event-report data, using a voltage equal to the measured voltage minus the capacitor voltage drop. The latter is computed from the capacitance value and the measured current.

### Mho Units

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

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

The mho units are supervised using several auxiliary relays. For more on the operation of the mho units and their supervision turn to the chapter entitled "SOFTWARE DESCRIPTION".

## SELF TESTS

The SEL-49 runs a variety of self tests that ensures reliable operation. This section describes each test and what steps are taken if the test fails. Some tests have warning and failure states, while 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 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, except the phase sequence test, are run at least every few minutes.

### A/D Conversion Time Test

The test is failed if the A/D conversion takes too long. If the test fails, then data acquisition and relay protection are disabled. Control functions are retained.

### Power Supply Test

This test is run only if the data acquisition / relay protection is enabled. Each supply (+15, -15, +5) is checked against two limits, a warning and failure limit. The warning limit is +/- 0.3 volts for the +5 supply and +/- 0.8 volts for the 15 volt supplies. The failure limit is +/- 0.4 volts for the +5 supply and +/- 1.2 volts for the 15 volt supplies. Failure of a 15 volt supply disables the data acquisition / relay protection functions. Failure of the +5 supply disables data acquisition / relay functions and control functions. Note that if a 15 volt supply fails, it disables checking of the +5 supply.

Ram Test

The random access memory is periodically checked to ensure that each byte can be written to and read correctly. If the test fails data acquisition / relay functions and control functions are disabled.

Rom Test

The read only memory (program memory) is checked by computing a modulo eight bit checksum for each EPROM. This value is checked against a value in the EEPROM memory. The test is failed if the values do not agree. If the test fails data acquisition / relay functions and control functions are disabled.

Settings Test

Two images of the system settings are stored in nonvolatile memory. The test is failed if the two images do not match. Failure of this test disables data acquisition / relay functions and control functions.

Offset Test

The offsets of the IR (summed internally), IRM, IA, IB, VA, VB, and VC channels are checked against a +/- 50 mV warning limit and a +/- 75 mV failure limit. Failure of the test disables only the running of the offset check. All data acquisition / relay functions and control functions are retained. The Alarm relay is pulsed for one second when this test fails.

Master Offset Test

A zero volt input is selected by the multiplexer. If the offset is greater than 75 mV then the test fails. Failure of the test disables the offset and master offset tests. Data acquisition / relay functions and control functions are retained. The Alarm relay is pulsed for one second.

Phase Sequence Check

A phase sequence check is run just prior to enabling the relay. The phase sequence test compares the positive-sequence voltage or current to the negative-sequence voltage or current. If the negative-sequence voltage exceeds 150% of the positive-sequence voltage, plus a small bias, then the test fails; and, similarly for the current. If the test fails, data acquisition / relay functions are disabled.

## COMPOSITE RELAY FUNCTION (Output Equations)

This section summarizes how the thermal unit, mho units, control inputs and commands via communications link affect the relay outputs.

The SEL-49 output relay states depend on the states of the following:

relay elements
control inputs
setting parameters
commands received over communications link
status of self tests

Since so many binary variables are involved, we define functioning using boolean logic equations. First, all the logic variables are defined as either primary logic variables, intermediate logic variables or output logic variables. Next, the values of the intermediate logic variables are derived from the primary logic variables. Finally, the output variables are defined using the primary and intermediate logic variables.

## DEFINITION OF VARIABLES

### Primary Logic Variables

Relay Elements -

| | |
|---|---|
| thermal relay low set | 49L |
| thermal relay high set | 49H |
| single phase overcurrent relays | 50A, 50B, 50C (50FD setting determines pickup) |
| ground distance relays | 21A, 21B, 21C |
| phase distance relays | 21AB, 21BC, 21CA |
| positive sequence overcurrent relay | 46P **(pickup at 0.14 to 0.7 a sec) |
| high-set pos seq overcurrent relay | 46PH (pickup settable) |
| positive sequence overvoltage relay | 47P **(pickup at 0.14 to 0.7 v sec) |
| negative sequence overcurrent relay | 46Q **(pickup at 0.14 to 0.7 a sec) |

| | |
|---|---|
| negative sequence overvoltage relay | 47Q (pickup at 0.75 v sec) |
| high-set neg seq overvoltage relay | 47QH (pickup at 16.8 v sec) |
| negative sequence directional relay | *32Q |

* This logic variable is also asserted if a three phase fault is indicated by the operation of all ground mho units or all phase mho units.

** Depends on relay reach. For all reaches above two ohms secondary, the lower limit applies.

Control Inputs

| | |
|---|---|
| direct trip | DT |
| transfer trip | TT |
| block trip | BT |
| direct close | DC |
| circuit breaker monitor | 52A |
| external trigger | EXT |

Commands via Communication Channels

| | |
|---|---|
| close command received | CC |
| open command received | OC |

Mho Timers

| | |
|---|---|
| ground fault timer time out | 21GT |
| line fault timer time out | 21LT |

Relay Enables Logic Switches

| | |
|---|---|
| thermal trip enabled | THE |
| mho trip enabled | ZE |
| transfer trip output enabled | TTE |
| neg seq directional supervision enabled | 32QE |
| blown potential fuse detect enabled | BPFE |

## Intermediate Logic Variables

| | |
|---|---|
| composite distance relay | 21 |
| composite distance relay timeout | 21D |
| forward direction fault | GD |
| blown potential fuse detected | BPF |
| ground switch detect | GS |

<u>Output Logic Variables</u>

| | | |
|---|---|---|
| circuit breaker trip | TRIP | |
| circuit breaker close | CLOSE | |
| transfer trip initiate | TTI | (A1 on rear panel) |
| over high temp. threshold | TH | (A2 on rear panel) |
| over low temp. threshold | TL | (A3 on rear panel) |
| system alarm | ALARM | |

<u>DEFINITION OF INTERMEDIATE VARIABLES</u>

```
21  =  (                                           composite distance relay fault

        21A*50A    + 21B*50B      + 21C*50C            ground fault

  + 21AB*50A*50B  + 21BC*50B*50C + 21CA*50C*50A        phase fault

       )

21D =  (                                           composite distance relay fault

         (21A*50A      + 21B*50B  + 21C*50C)*21GT      ground fault and timer

       + (21AB*50A*50B + 21BC*50B*50C                  phase fault and timer

          + 21CA*50C*50A)*21LT
       )

GD  =  (                                           forward direction fault

        32Q                                            neg seq directional pickup

      + NOT(46Q*47Q)                                   not enough neg seq for 32Q

      + NOT(32QE)                                      32 sup. not enabled

       )

BPF =  (                                           blown potential fuse detected

        47QH*NOT(46Q)*BPFE                             large neg seq voltage
                                                       small neg seq current
       )                                               blown fuse detect enabled

GS  =  (                                           ground switch detect

        46PH * NOT (47P)                               large pos seq current
                                                       no pos seq voltage
       )
```

DEFINITION OF OUTPUT VARIABLES

```
Close TRIP contact =                           energize the trip coil circuit
      (

      NOT(BT)*                                    no block trip input
        (
          DT                                        direct trip input

        + OC                                        open command received

        + 49H*THE                                   high temp. and thermal
                                                    trip enable

        + ((21D*GD*46P*47P+GS)NOT(BPF))*ZE          valid mho fault and enable

        + ((21*GD*46P*47P+GS)NOT(BPF))*TT           mho fault and trans. trip
                                                    input
        )

      )

Open TRIP contact =                            open the trip relay
      (

      NOT(52A)*                                   circuit breaker open
        (

          NOT(49H*THE)                              no thermal trip condition

        + NOT(((21D*GD*46P*47P+GS)NOT(BPF))*ZE)     no valid enabled mho fault

        + NOT(((21*GD*46P*47P+GS)NOT(BPF))*TT)      no valid transfer trip

        )

      )

Assert CLOSE contact                           close the breaker
      (

      NOT(52A)*                                     circuit breaker open
        (
            DC                                      direct close input asserted

          + CC                                      close command issued
        )

      )
```

```
Assert TTI output                               initiate transfer tripping
       (
       21*GD*46P*47P*NOT(BPF)*TTE                   valid mho fault and
                                                    transfer trip enabled
       )

Assert TH output                                signal that over high temp.
                                                threshold
       (
       49H                                          49 high set pickup
       )

Assert TL output                                signal that over low temp.
                                                threshold
       (
       49L                                          49 low set pickup
       )

Assert ALARM output                             system alarm
       (
       + BPF                                          blown pot. fuse detected

       + relay or control disabled                    result of failed self
                                                      test or disable during
                                                      setting
       + loss of power

       + processor stall

       )

Pulse ALARM output
       (                                        pulse alarm for one second

          failed level one access on
          third try

       + attempt level two access

       + fail level two access

       + offset, master offset
         self test failure

       )
```

# CHAPTER 2: HARDWARE DESCRIPTION

## INTRODUCTION

This chapter describes the hardware components of the SEL-49. The hardware is discussed in three sections: the microprocessor-based data acquisition subsystem, the interfacing components and the relay's mechanical features. The hardware design enhances ruggedness, reliability and serviceability.

## MICROPROCESSOR-BASED DATA ACQUISITION SUBSYSTEM

The microprocessor-based data acquisition subsystem is the heart of the SEL-49 relay. Its main components include a 6809 microprocessor supported by 40Kbytes of program memory (EPROM), 16Kbytes of static random access memory (RAM), 2Kbytes of non-volatile electrically eraseable memory (EEPROM), two 6850 serial communications ports, a 6840 progammable timer and three 6821 dual parallel ports. The parallel ports and timer control an analog-to-digital conversion section consisting of a 12-bit analog to digital converter (A/D), a programmable gain amplifier (PGA), a sixteen-channel analog multiplexer (MUX) and nine sample and hold circuits (S/H). The sample and hold circuits are fed by eight low-pass filters. The filters consist of a passive RC network to reduce RF interference followed by an active two-pole lowpass filter. An analog summing circuit is employed to find residual current from the phase currents.

The relay uses an optimal four-samples-per-cycle sampling rate that limits the computational burden placed on the microprocessor. For this reason the hardware design can be kept simple. No hardware multipliers, direct memory access or cycle stealing schemes are needed.

Hardware dedicated specifically to self testing includes scaled power supply inputs to the MUX for checking power supply levels and a stall timer-deadman alarm relay setup (located on the interface board) that closes the relay contacts if the processor fails to reset the stall timer, or if the +5 supply is lost.

Reliability is further enhanced by limiting the number of interconnections in the SEL-49. This too stems from a simple hardware design.

All of the EPROMs are installed in sockets. In this way any future software improvements or modifications can be implemented by replacing the EPROMs and the EEPROM, which contains EPROM checksums.

## INTERFACING COMPONENTS

Special attention was given to the problems of noise and surges, and how they might affect the SEL-49 in the substation environment. The results of this attention can be seen in the electrical and mechanical designs of all interface components.

Eight trip-circuit-rated relay outputs are provided. All relay outputs are bypassed to ground with 4700 pf capacitors and protected from contact flashover by MOV's. The relay coils (except the alarm relays) are driven by circuits designed to quicken their response.

Six optically-isolated control input circuits are included. Each input terminal is bypassed to ground with a 4700 pf capacitor. Additional protection is provided by a symmetrical RC network designed to limit both common mode and differential surges. The input circuits include a bridge rectifier, so polarity of the applied input voltage does not matter. Hysteresis provided in the optical isolators contributes more noise immunity. Finally, debouncing of inputs is accomplished in software, and provides additional security.

Four current and three potential transformers are utilized to scale the analog input quantities. The transformer primaries are fastened to the terminal blocks inside the case with number eight screws and ring lugs. The secondaries of the potential transformers terminate in resistive divider networks that include a MOV at their outputs. The current transformer secondaries are terminated across one ohm shunt resistors.

Internal power to the relay circuits is provided by a switching power supply. Additional protection from common mode and differential surges is afforded the switching supply inputs by two balun coil-capacitor networks, 4700 pf bypassing capacitors and a MOV.

Each RS-232 input and output line is protected by an RC network and MOV. They are then connected to current limited RS-232 drivers or input buffers.

The IRIG-B input is optically isolated and protected from surges by MOVs. The opto-coupler output is filtered by an RC network before passing through a decoding circuit on the interface board that connects to a parallel port.

## MECHANICAL FEATURES

Almost all of the SEL-49 components are contained on a drawout assembly. This includes the main circuit board, the interface circuit board, and the switching power supply. The only components to remain in the box are the rear panel board, which has only passive components, and the transformer sub-chassis, which mounts the transformers and the transformer termination board.

# CHAPTER 3: SOFTWARE DESCRIPTION

## INTRODUCTION

This chapter is divided into three parts. The first gives an overall view of the software architecture used in the SEL-49. The next two sections give additional detail concerning the operation of the thermal relay, fault locator mho units and supervisory units.

## SOFTWARE ARCHITECTURE

The SEL-49 software may be divided into two categories: foreground and background. Every quarter cycle an interrupt is generated by the sampling circuit that starts the execution of the foreground program. All real time functions such as data acquisition, digital filtering, thermal integrating, mho relaying and supervisory relaying take place in the foreground program. The execution time of the foreground program varies somewhat depending on what relay units have picked up, but it typically takes about 85% of the time available between interrupts. The remaining time is used to run the background program.

Offline processing and user support are implemented by the background program. Tasks such as self test supervision, fault locating, automatic report generation and IRIG-B clock update are scheduled for execution. Task execution may be invoked by the user, invoked automatically, or both, depending on the task.

## THERMAL ALGORITHMS

The thermal relay models the transmission line by executing a discrete version of the integral presented in Figure 1, Equation 4. The method used may be described as a variable period Euler integration.

If we make the original equation discrete with respect to time we get:

$$THC*\frac{\Delta T}{\Delta t} = I^2*(rac + (TC - 25)*rdelt) + Qsun - (TC -TA)/TRA$$

The time step $\Delta t$ is the sampling time of 1/240 second. Dividing through by THC and $\Delta t$ yields:

| | |
|---|---|
| $T = I^2*(rac + (TC - 25)*rdelt)/THC*240$ | current heating |
| + Qsun/THC*240 | solar heating |
| - (TC -TA)/TRA*THC*240 | cooling to atmosphere |

Now the integration over one sample period may be approximated by the addition

$$T_{new} = T_{old} + \Delta T,$$

and iterated at the rate of 240 times per second.

Now rewrite the equation with the scaling constants K,L,M:

$$\Delta T = I^2*((rac + (TC - 25)*rdelt)/K*THC)*(K/240)$$
$$+ (Qsun/L*THC)*(L/240)$$
$$- ((TC - TA)/M*TRA*THC)*(M/240)$$

The constants K,L,M are chosen so that the new integration periods (K/240), (L/240), (M/240) are on the order of 1/500 of the conductor time constant. This ensures that the integration will not be too "rough." An additional stipulation is made that the number

$$(rac + (TC - 25)*rdelt)/K*THC$$

be a computationally-convenient number to multiply $I^2$ by, and that

$$Qsun/L*THC$$

be kept constant. This is accomplished by the background program, which periodically updates the numbers K and L. Note that the changes in these values depend only on the conductor temperature and solar heating, so K and L are slowly changing numbers. The manipulation of the integration intervals by the background program is why this is called a variable period integrator.

Two digital filters are run by the thermal relay and its associated modules. One is run by the background program to filter the input from the ambient temperature probe. The other filters the value of $I^2$ used by the thermal model.

The $I^2$ filter solves two separate problems: input current selection, and avoidance of false alarms concerning time to trip. Every half cycle the largest input current is selected for filtering. The value for $I^2$ is arrived at by squaring two consecutive sampled values and adding them. This is equivalent to squaring and adding the real and imaginary parts. The result of the addition is used as the input to a recursive filter. This filtered value of $I^2$ is used by the predictor to estimate the time to trip. The filter prevents false alarms due to current spikes, but does not introduce too much delay in front of the thermal model. Its time constant is one second.

## FAULT LOCATOR AND ASSOCIATED RELAY ALGORITHMS

### Fault Location

The system stores about four cycles of prefault data and seven cycles of fault and postfault data, which are processed using the Takagi algorithm. The algorithm is much less sensitive to fault resistance and load flow than a direct reactance computation, since it takes into account load flow conditions prior to the fault. No communications schemes are required for this fault locator algorithm.

Compensation for error induced by zero-sequence coupling from a parallel circuit is provided for by processing the residual current from the parallel line.

The fault location is automatically computed after each fault occurs, and is included in the fault reports.

It is possible to use two-end algorithms for fault location, using the data available in the event reports from units located at both ends of the line. These schemes require additional data processing and communications, but do not depend on the zero-sequence parameters of the transmission line. Consult the factory for further details.

### MHO Relay Algorithms

Six MHO relay algorithms are executed every quarter cycle. These encompass all possible fault types.

Line-to-line voltages and the current differences between associated phases are processed for each three types of phase faults. Line-to-ground voltages and residual-compensated line currents are used for the three types of ground faults.

In each case, the MHO relay determines the difference between the selected voltage and the current times the relay impedance. This difference is compared in phase with the voltage. For impedances inside the circle, the angle between these quantities is acute. For impedances outside the circle, the angle is obtuse. If the impedance is on the circle, then the angle is 90 degrees. The phase comparison process is performed by computing the dot product of the difference voltage phasor and the voltage phasor. If the dot product is negative, then the impedance is outside the circle. If it is zero, then the impedance is on the relay boundary.

Multiplication of the currents by the relay impedance is accomplished by analog scaling using a programmable-gain amplifier (PGA), and by the skewing of the sampling intervals of I and V to introduce phase shift. Thus, the relay reach is controlled by the PGA gain, and the relay angle is controlled by the phase shift introduced by the skew in sampling instants between the voltages and currents.

## Sound-Phase (Cross) Polarization

To ensure correct operation of the relay units for close-in faults, sound-phase polarization is implemented. For ground faults, the voltage used in the MHO algorithm consists of the line-to-ground voltage, plus the sound-phase line-to-line voltage, advanced 90 degrees. For L-L faults, the additional voltage component included is the uninvolved L-G voltage, advanced 90 degrees. Consult the factory for other polarization options.

## Directional Relay

Under some conditions, distance relays can operate for faults in the reverse direction. For example, a close-in AG fault in the reverse direction could cause the BG and CG relay units to operate if they are set to very long reaches. This possibility is eliminated in the SEL-49 by a negative-sequence directional relay. The cross product of the negative-sequence voltage and current phasors is computed: if the result is negative, then the fault is in the forward direction. Supervision, when selected, is used for all unbalanced faults.

Negative-sequence overvoltage and overcurrent units supervise the negative-sequence directional relay: if the negative-sequence components are too small, then tripping for unbalanced faults is not affected by the negative-sequence directional relay state.

## Ground Switch Detection

For extremely close-in three phase events (such as closing into the ground switches) the mho units will not operate due to the lack of voltage. Tripping for this type of event is handled by settable positive-sequence overcurrent element supervised by the lack of pickup from a low set positive-sequence overvoltage relay. In the logic equations of Chapter 1 this is referred to as the "Ground Switch Detect." The relay will operate instantaneously for this if the distance relay trip enable switch is set.

# CHAPTER 4: COMMUNICATION INTERFACES

## INTRODUCTION

This chapter describes the operation of the SEL-49 communication features. The SEL-49 is set and operated via serial communications interfaces, which are intended to be connected to a computer terminal and/or a modem. The communication interfaces are also used to transmit reports invoked automatically by self test status changes, the thermal auto report generator, and fault reports. A clock port provides a way to synchronize the relay using a satellite time clock. The SEL-49 supports two RS-232 serial ports and an IRIG-B clock port for these purposes. Both the hardware features and software protocols of the ports are discussed.

For information on the setting of the baud rates refer to the "INSTALLATION" Section, Jumper Selection. For information concerning the manufacture of RS-232 cables refer to "INSTALLATION" Section, RS-232 and IRIG-B Installation.

## RS-232 PROTOCOL

The RS-232 protocol consists of hardware and software features. First the hardware protocol is described. Next the software protocol is discussed.

### Hardware Protocol

The two nine-pin Con-X-All connectors marked PORT 1 and PORT 2 on the rear panel of the SEL-49 are used for serial communications.

Port 1 is intended for remote communication via a data modem. Port 2 is intended for local communications via a CRT, printing terminal, PRTU or other device. The baud rates of the ports are set by internal jumpers to 300, 600, 1200, 2400, 4800, or 9600 baud.

The serial data format is:

eight data bits
two stop bits
no parity bit

This format cannot be altered.

The port pin assignments and signal definitions are given below.

| PIN | NAME | DESCRIPTION |
|---|---|---|
| 2 | TXD | Transmit data output |
| 3 | RTS | The SEL-49 asserts this line under normal conditions. When its received-data buffer is full, the line is unasserted, and asserts again once the buffer has sufficient room to receive more data. Connected devices should monitor RTS (usually with their CTS input) and stop transmitting characters whenever the line unasserts. If transmission of data continues, data may be lost. |
| 4 | RXD | Receive data input |
| 5 | CTS | The SEL-49 monitors CTS, and transmits characters only if CTS is asserted. |
| 6 | + 5 volts | |
| 7 | + 12 volts | |
| 8 | - 12 volts | |
| 1,9 | Ground wires and shields | |

Software Protocol

1. All commands received by the SEL-49 must be of the form:

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

Thus a command transmitted to the SEL-49 should consist of the command name, followed by either a carriage return, or a carriage return and a line feed.

2. All messages transmitted by the SEL-49 are of the following format:
    <MESSAGE LINE 1><CRLF>
    <MESSAGE LINE 2><CRLF>
    .
    .
    <LAST MESSAGE LINE><CRLF>

That is, each line of the message includes a carriage return and line feed at its end.

3. The SEL-49 indicates the volume of data in its received-data buffer by an XON/XOFF protocol.

XON (ASCII hex 11) is transmitted by the SEL-49 when the buffer drops below 1/4 full. The SEL-49 also asserts the RTS output.

XOFF (ASCII hex 13) is transmitted when the buffer fills above 3/4 full. The SEL-49 unasserts the RTS output, when the buffer is approximately 95% full. Automatic transmitting sources should monitor for the XOFF character so as not to overwrite the SEL-49 received-data buffer. Transmission should terminate at the end of the message being transmitted when XOFF is received, and may be resumed when the XON character is received.

4. An XON/XOFF procedure may be used to control data transmission by the SEL-49. When the SEL-49 receives XOFF while it is transmitting, it responds by pausing until an XON character is received. If no message is being transmitted when XOFF is received, the SEL-49 blocks transmission of any message that may be presented to its transmitting buffer. The message will be transmitted once XON is received.

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

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

| | | |
|---|---|---|
| XON: | control-Q | (hold down the control key, and press Q) |
| XOFF: | control-S | (hold down the control key, and press S) |
| CAN: | control-X | (hold down the control key, and press X) |

## IRIG-B INPUT DESCRIPTION

The port labeled J201 / AUX INPUT is for the IRIG-B input. The pin definitions are:

| PIN | NAME | DESCRIPTION |
|---|---|---|
| 2 | IRIG IN HI | positive IRIGB input |
| 3 | IRIG IN LOW | negative IRIGB input |
| 6 | +5 * | |
| 7 | +12 * | |
| 8 | -12 * | |
| 1,5,9 | GND | chassis ground |

(* Consult the factory before using these power supply outputs)

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

The IRIG-B serial format consists of a one second long, 100 pulse code divided into fields. The SEL-49 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.

# CHAPTER 5: OPERATION OF THE RELAY

## INTRODUCTION

This chapter centers around information used for the operation of the relay.

## FRONT PANEL

The front panel features include the relay power switch, fuse and targets. The targets symbols and significance are explained below:

| TARGET | LED COLOR | MEANING |
|---|---|---|
| EN | RED | Indicates that the 49H unit is enabled for tripping |
| DIS | GREEN | Indicates that the 49H unit is disabled from tripping |
| TRIP | AMBER | Latches on whenever a thermal trip cond. occurs |
| T>> | RED | Indicates that temp. is above low threshold |
| A | RED | Latches pickup of AG, AB, or CA units |
| B | RED | Latches pickup of BG, BC, or AB units |
| C | RED | Latches pickup of CG, CA, or BC units |
| G | RED | Latches pickup of AG, BG, or CG units |

The targets may be reset locally with the target reset button or remotely using the target command. Pressing the TARGET RESET button clears the data and lights all target LEDs for one second, as a lamp test. Furthermore, pressing the TARGET RESET button unlatches the TRIP output from the 52A input. This feature is useful during relay testing, and it minimizes the risk of reinstalling the relay with the TRIP output asserted.

Note that although the mho unit targets give an indication of which mho units picked up, a better estimate of fault type is available in the fault report.

## RELAY COMMANDS

Relay commands are invoked using a terminal device locally or remotely. Each relay command is assigned an Access Level. The user must be at or above this Access Level to invoke the command. The Access Levels may be adjusted using the ACCESS, 2ACCESS and QUIT commands.

The current Access Level of the user can be deduced by looking at the relay prompt. The prompts are:

| | |
|---|---|
| = | for Access Level 0 |
| => | for Access Level 1 |
| =>> | for Access Level 2 |

When the relay is powered up it is always in Access Level 0. Since ACCESS is the only Access Level 0 command, it must be executed before attempting anything else.

### 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 interchangeably, except in 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 a prompt is received.

### Access Level 0 Command

#### Access

Use ACCESS to gain access to the system from the Level 0 prompt (=). After typing ACCESS <CR>, a prompt for the Level 1 password appears. Enter the password, and press return.

Successful access is indicated by the typical response shown below:

```
=ACCESS <CR>
Password: ? OTTER@ <CR>
Example 230 KV line, Drake Conductor  Date: 1/1/85  Time: 01:01:23
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.

Password protection can be disabled by including Jumper 1 on the main board.

## Access Level 1 Commands

### 2Access

Use 2ACCESS to gain access to Level 2 from Level 1. After typing 2ACCESS <CR>, a prompt for the Level 2 password appears. Enter the password in the same manner as for the ACCESS command, and press return.

Successful access is indicated by the typical response shown below:

```
Example 230 KV line, Drake Conductor  Date: 1/1/85  Time: 01:11:11
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 for any Level 2 access attempt, successful or otherwise.

Password protection can be disabled by including Jumper 1 on the main board.

### Contacts

The state of all contact inputs and outputs can be inspected using this command. For example, if the circuit breaker is closed, and normal conditions exist, we would expect the 52A input to be asserted, and all other inputs to be unasserted. All output relays would be open. Under such conditions the response to executing CONTACTS is:

```
Inputs : DT TT BT DC 52 ET
          .  .  .  .  *  .
Outputs: TP CL TT TH TL AL
          .  .  .  .  .  .
```

The asterisk indicates the 52A input is asserted. Periods indicate all other inputs are unasserted, and all output contacts are open.

## Date [mm/dd/yy]

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

For example, to set the date to February 28, 1985, enter:

DATE 2/28/85 <CR>

When the power is first turned on, the date is 1/1/85.

## Event [N][L]

The event command is used to view the five most recent event records saved by the relay.

To view the Nth event, type EVENT N <CR>. The parameter N is 1 for the most recent event, through 5 for the oldest event stored in the SEL-49 memory.

Recall (from the COMMUNICATIONS PROTOCOL description) that you can terminate any transmission from the SEL-49 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 a long report.

Asking for an event from an empty buffer results in this message:

Invalid event

## History

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

| # | DATE | TIME | TYPE | DIST(mi) |
|---|---|---|---|---|
| 1 | 2/28/84 | 02:00:20 | EXT | |
| 2 | 2/27/84 | 10:02:05 | CG | 76.25 |
| 3 | 1/15/84 | 23:39:56 | BG | 41.55 |
| 4 | 1/01/84 | 18:15:11 | AG | 15.52 |
| 5 | 1/01/84 | 18:15:08 | AG | 15.52 |

The TYPE column indicates "EXT" for externally-triggered events, such as caused by asserting the TRIP, TRANSFER TRIP, EXTERNAL TRIGGER, or BLOCK inputs, or by executing the TRIGGER command under no-fault conditions. For faults, the fault type is given.

When the event buffers are cleared using the SET command, these data are lost.

## Irig

The system time is synchronized with IRIG-B time. If the synchronization is successful the message is of the form:

IRIGB time is XX:XX:XX

If the synchronization is unsuccessful the message is:

ERROR in IRIGB datacq

The data acquisition is aborted if the relay receives a "carriage return" character. The data acquisition process takes about three seconds. The immediate operation of this command is helpful in verifying the IRIG-B operation. Automatic IRIG-B synchronization takes place every five minutes.

## Meter

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

Example 230 KV Line, Drake Conductor Date: 8/3/88 Time: 14:13:21

| | A | B | C | AB | BC | CA |
|---|---|---|---|---|---|---|
| I (A) | 999 | 1004 | 1001 | 1735 | 1734 | 1732 |
| V (kV) | 133.9 | 133.4 | 134.2 | 231.7 | 231.6 | 232.3 |

| | |
|---|---|
| P (MW) | 402.00 |
| Q (MVAR) | 0.64 |

P and Q are positive when the power flow is in the direction of the reach of the relay.

## Quit

Executing the QUIT command returns control to Access Level 0 from either Access Level 1 or 2, and displays the date and time when QUIT is executed. Use this command when you are done communicating with the SEL-49, so that unauthorized access is avoided. (Note that control returns to Access Level 0 automatically after a settable interval of no activity. See the TIM1, TIM2 setting in the SET command.

## Showset

Enter SHOWSET to inspect the settings of the SEL-49. The settings cannot be modified with this command. The settings are entered using the SET command, under Access Level 2.

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

Settings for:
Example 230 KV Line, Drake Conductor

| | | | | |
|---|---|---|---|---|
| R1 = 13.90 | X1 = 79.96 | RO = 41.50 | XO = 248.57 | RMO = 37.35 |
| XMO = 223.90 | MCTR = 200.00 | CTR = 200.00 | PTR = 2000.0 | LL = 100.00 |
| MTA = 80.80 | Z% = 120.00 | ZDG = 0.00 | ZDL = 0.00 | 50FD = 200.00 |
| 46PH = 6000.0 | DSH = 4000.0 | SAC = 0.97 | DIA = 1.11 | LSTD = 125.00 |
| LON = 117.00 | LAT = 47.00 | RAC = 22.16 | RTC = 83.33 | THC = 392.10 |
| TRA = 1.86 | EAT = 20.00 | EOT = 0.00 | TH = 90.00 | TL = 80.00 |
| TIM1 = 5 | TIM2 = 0 | AUTO = 2 | RING = 3 | |
| TTI = Y | ZE = Y | 32QE = Y | BPFE = Y | |
| THE = Y | TSE = Y | SGE = Y | | |

For information about the meaning of the settings consult the "SETTING PROCEDURE" Section beginning on page 6-1.

## Status

The self test status of the SEL-49 is inspected using STATUS. The instrument also automatically executes the STATUS command whenever a self test enters a warning or a failure state, causing the STATUS report to be transmitted out of the port selected for automatic transmissions. (See AUTO setting).

The format of the STATUS report is shown below by example.

```
Example 230 KV Line, Drake Conductor   Date: 1/1/85   Time: 07:24:02
SELF TEST STATUS
W=Warning F=Failure
       IM   IR   IA    IB    IC    VA   VB   VC
OS      7   14  -11    -1     5     8   -3   -6
PS       5.05     +15.54     -14.89
RAM   ROM    A/D     MOF    SET
OK    OK     OK      OK     OK
```

The OS row indicates the measured offset voltages of the seven 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 of the defective part is indicated, in place of OK.

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

## Targets

The targets command provides a remote means of resetting the front panel targets. The response from the command is:

Targets reset

## Temp [L]

The TEMP command causes a thermal report to be printed. Several sample thermal reports are included at the end of this section.

The content of the thermal report depends upon the line thermal condition. It always contains at least the following seven items:

1. Relay/Line identifier setting: This is a setting entered by the user during the SET command.

2. Date: Date when the TEMP command was executed, as given by the relay's internal clock.

3. Time: Similar to item (2), above.

4. Line condition:

   A. Normal: Line temperature is below the Warning setting (TL), and is predicted to remain less than the Thermal Trip setting (TH).

   B. Warning: Line temperature is above the TL setting.

   C. Overload: Line temperature is predicted to rise above the TH setting.

   D. Thermal Trip: Line temperature is measured greater than the TH setting.

5. Load: The sum of the individual loads measured per phase, scaled to primary megavolt amperes (MVA).

6. Limit: The thermal limit of the transmission line for balanced load conditions, scaled to primary MVA.

7. Margin: The minimum additional balanced load which will cause the high-current phase to eventually reach thermal trip conditions (temperature = TH).

   Notes

   A. For balanced conditions, the margin is given as:

      Margin = (Limit - Load)

      For unbalanced conditions, however, the margin figure is adjusted so that the highest current phase will not be jeopardized if the load margin is added in a balanced manner.

   B. The SEL-49 tracks line thermal conditions without respect to system voltage. Measured current is the fundamental input to the thermal model. The MVA quantities of load, limit, and margin are simply the corresponding current quantities scaled by the measured system voltage.

The seven items listed above are always presented in the thermal report. Under any abnormal line conditions, however, (Warning, Overload, or Thermal Trip) two additional items are shown. These items are:

8. Time to trip: the number of minutes before the line temperature is predicted to rise to TH, the Thermal Trip setting.

9. Line Temperature: The temperature of the line, as estimated by the SEL-49 thermal model.

Automatically generated thermal reports contain only the previously indicated nine items. Additional information may be requested, however, when the Temp command is invoked manually. The additional information is requested by including any argument after the Temp command, such as:

    Temp L <CR>

The additional items detail the thermal model. They are:

10. Ambient temperature: Measured by the optional temperature sensor or taken from the settings.

11. Isqdr heating: The thermal heating of the line due to ohmic losses, in watts per foot.

12. Solar heating: The thermal heating of the line due to solar radiation, based on the SEL-49's worst case solar model, or from the settings.

13. Atms. cooling: The heat being exchanged between the line and its surroundings, both by conduction and by radiation.

14. Net heating: Given by

Net heating = (IsqdR + Solar - Atms.)

15, 16, 17. Finally, the load, limit, and margin quantities (items 5, 6, and 7 above) are presented in primary amperes in the expanded report, as well as in primary MVA.

A few thermal report examples follow.

A short report under "Normal" line conditions:

```
=>>TEM

Example 230 KV Line, Drake Conductor    Date:  6/29/88    Time:  12:45:36
Line cond.    :      Normal
Load          :  372.11 MVA
Limit         :  424.83 MVA
Margin        :   51.63 MVA
```

A long report under "Normal" line conditions:

```
=>>TEM L

Example 230 KV Line, Drake Conductor    Date:  6/29/88    Time:  12:45:29
Line cond.    :      Normal       IsqdR heating:   21.5 W/ft
Time to trip  :  999.9  min       Solar heating:    8.5 W/ft
Line Temp.    :   76.5  deg C     Atms. cooling:   30.3 W/ft
Amb. Temp.    :   20.0  deg C     Net heating  :   -0.2 W/ft
Load          :  372.61 MVA        902.9 amps
Limit         :  424.90 MVA       1027.0 amps
Margin        :   51.34 MVA        124.1 amps
```

A short report during abnormal line conditions:

```
=>>TEM

Example 230 KV Line, Drake Conductor    Date:  1/1/85    Time:  23:45:14
Line cond.    :   OVERLOAD
Time to trip  :   16.9  min
Line Temp.    :   25.8  deg C
Load          :  565.26 MVA
Limit         :  469.70 MVA
Margin        :  -95.56 MVA
```

A long report during abnormal line conditions:

```
=>>TEM L

Example 230 KV Line, Drake Conductor    Date:  1/1/85   Time:  23:45:35
Line cond.      :   OVERLOAD          IsqdR heating:   44.2 W/ft
Time to trip    :   16.4  min         Solar heating:    0.0 W/ft
Line Temp.      :   27.9  deg C       Atms. cooling:    4.3 W/ft
Amb. Temp.      :   20.0  deg C       Net heating  :   39.9 W/ft
Load            :  564.7  MVA         1405.1 amps
Limit           :  469.51 MVA         1168.2 amps
Margin          :  -95.19 MVA         -236.8 amps
```

## Time [hh:mm:ss]

To read the internal clock, enter TIME <CR>. To set the clock, enter TIME followed by the desired setting. Separate the hours, minutes and seconds with colons, semicolons, spaces, commas or slashes. For examples, to set the clock to 23:30:00, enter: TIME 23 30 00 <CR> or TIME 23:30:00 <CR>, etc. A quartz crystal oscillator provides the time base for the internal clock. The clock may also be automatically set by the IRIG-B input, or by using the IRIG-B command.

## Trigger

Enter TRIGGER <CR> 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 SEL-49 is first installed, execute the TRIGGER command, and draw the phasors (the EVENT REPORTING section explains how to do this), and check for the proper polarity and phase sequence of the inputs. Event records may also be generated without control action by asserting the EXTERNAL TRIGGER input.

## Access Level 2 Commands

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

## Close

The CLOSE output relay can be closed by execution of the CLOSE command or by asserting the DIRECT CLOSE input, as long as the 52A input is not asserted. The CLOSE output relay then remains closed until the 52A input is asserted, (indicating that the circuit breaker is closed), or for about 1/2 second, whichever comes first.

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

The close command aborts unless the remote open/close Jumper 2 is in place on the main board.

## Open

The TRIP output relay closes in response to the OPEN command as long as the BLOCK TRIP input is not asserted. The TRIP relay remains closed until the 52A input is not asserted AND no fault is detected. Thus, the TRIP output relay seals in.

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 <CR>. A prompt "Open PCB (Y/N) ?" is transmitted. Answering Y <CR> yields a second prompt: "Are you Sure (Y/N) ?" Answering Y <CR> causes the TRIP output relay to close as described above. Answering N <CR> to either prompt aborts the OPEN command with the message "Aborted".

The open command aborts unless the remote open/close Jumper 2 is in place on the main board.

## Password (1 or 2) [password]

To inspect the passwords, enter PASSWORD <CR>.

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

PASSWORD 1 BIKE<CR>

The SEL-49 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. THERE IS NO COMMUNICATIONS PROCEDURE TO ACCESS THE SEL-49 WITHOUT THE PASSWORDS.

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

OTTER otter Ot3456 +TAIL+ !@#$%^ SEL-49 123456 12345. 12345 ab1CDE
Should the passwords be lost, or should you wish to operate the SEL-49 without password protection, install Jumper 1 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 "forgotten" passwords.

## Set

The setting procedure consists of answering prompting messages with new data, or by typing <CR>, indicating no change. Once all data are provided, the new settings are displayed, and a prompt is issued requesting your approval to enable the SEL-49 with the new settings. Error messages are included to indicate when the entered data result in out-of-range settings.

REFER TO CHAPTER 6 AND BE SURE THE SETTINGS YOU CHOOSE RESULT IN RELAY PERFORMANCE APPROPRIATE TO YOUR APPLICATION. WE ARE NOT LIABLE FOR MISAPPLICATION DUE TO INCORRECT SETTING, INTERPRETATION OR APPLICATION.

A printout of a sample set command invokation follows:

```
=>>set
Enter data or RETURN for no change

Relay ID =
Example 230 KV Line, Drake Conductor
 ?

R1 (ohms pri) = 13.90  ?
X1 (ohms pri) = 79.96  ?
R0 (ohms pri) = 41.50  ?
X0 (ohms pri) = 248.57 ?
RM0 (ohms pri)= 37.35  ?
XM0 (ohms pri)= 223.90 ?
MCT Ratio     = 200.00 ?
CT Ratio      = 200.00 ?
PT Ratio      = 2000.0 ?
Line Length (miles) = 100.00 ?
```

```
Max Torque Ang(deg) = 80.80  ?
Z Reach    (% line) = 120.00 ?
Z Delay-Ground(cyc) = 0.00   ?
Z Delay-Line  (cyc) = 0.00   ?
50FD Pickup (A pri) = 200.00 ?
+Seq OCThrsh(A pri) = 6000.0 ?

Default Sol. ht.(watts/Kft) = 4000.0 ?
Solar abs. coeff. (no unit) = 0.97   ?
Conductor Diameter (inches) = 1.11   ?
Long. of T.Std  (deg. w.l.) = 125.00 ?
Long. of cond.  (deg. w.l.) = 117.00 ?
Lat. of cond. (deg. n.lat.) = 47.00  ?
AC resistance      (mohms/Kft) = 22.16  ?
T.C. of res  (uohms/deg C Kft) = 83.33  ?
Ther. heat cap  (KJ/deg C Kft) = 392.10 ?
Ther res to amb (deg C Kft/Kw) = 1.86   ?
Est. ambient temp.  (deg C) = 20.00  ?
Est. offset temp.   (deg C) = 0.00   ?
High temp. thresh.  (deg C) = 90.00  ?
Low temp. thresh.   (deg C) = 80.00  ?
Port 1 timeout (minutes) = 5      ?
Port 2 timeout (minutes) = 0      ?
Automatic port (1,2,3,4) = 2      ?
Modem answer rings       = 3      ?
Trans Trip Init (Y or N) = Y ?
Mho zone trip   (Y or N) = Y ?
Neg Seq Dir Sup (Y or N) = Y ?
Blown Pot Fuse  (Y or N) = Y ?
Thermal trip en (Y or N) = Y ?
Temp. sensor    (Y or N) = Y ?
Solar model en  (Y or N) = Y ?

New settings for:
Example 230 KV Line, Drake Conductor
R1   = 13.90   X1   = 79.96   R0   = 41.50   X0   = 248.57  RM0 = 37.35
XM0 = 223.90   MCTR= 200.00   CTR = 200.00   PTR = 2000.0   LL  = 100.00
MTA = 80.80    Z%   = 120.00  ZDG = 0.00     ZDL = 0.00     50FD= 200.00
46PH= 6000.0   DSH = 4000.0   SAC = 0.97     DIA = 1.11     LSTD= 125.00
LON = 117.00   LAT = 47.00    RAC = 22.16    RTC = 83.33    THC = 392.10
TRA = 1.86     EAT = 20.00    EOT = 0.00     TH  = 90.00    TL  = 80.00
TIM1= 5        TIM2= 0        AUTO= 2        RING= 3
TTI = Y        ZE  = Y        32QE= Y        BPFE= Y
THE = Y        TSE = Y        SGE = Y

OK (Y/N) ? y
Working...
Enabled
=>>
```

Four settings which are not discussed elsewhere in the manual are discussed here.

TIM1, TIM2 - Port 1 and Port 2 timeout (minutes):

These two settings are the timeout intervals for ports 1 and 2, respectively. Upon execution of any command on either port, the timeout interval for that port re-initializes. Upon expiry of the timeout interval, the access level for that port returns to zero. This is a safety procedure limiting the possibility of unauthorized personnel using an unattended terminal.

The timeout interval may be set from 1 to 30 minutes. Entering "0" disables automatic timeout.

Auto - Automatic Port (1, 2, 3, 4):

The SEL-49 automatically transmits some messages, such as STATUS, THERMAL, and FAULT reports. The AUTO setting selects one or both of the two serial ports for STATUS and FAULT reports, but only a single port for THERMAL reports. The table below shows the effect of each possible setting:

| | AUTOMATIC MESSAGE DESTINATION PORT | | |
|---|---|---|---|
| AUTO SETTING | FAULT REPORTS | STATUS REPORTS | THERMAL REPORTS |
| 1 | 1 | 1 | 1 |
| 2 | 2 | 2 | 2 |
| 3 | 1,2 | 1,2 | 1 |
| 4 | 1,2 | 1,2 | 2 |

Ring - Modem answer rings:

Port 1 is designed to connect to a modem, and software is provided to set a dial-up Hayes compatible modem for automatic answer after a settable number of rings. A number of 1 to 255 is allowed. The modem is intialized when the telephone is answered by the SEL-49. Thus if the modem has been turned off and back on between calls, it will answer on the first ring on the next call, and on the programmed number of rings thereafter, until the power to the modem is turned off again.

Additional detail on the use of a dial-up modem with the SEL-49 is provided in Section 8.5 - MODEM COMMUNICATIONS.

# CHAPTER 6: SETTING PROCEDURE

## INTRODUCTION

This chapter explains how to set the SEL-49. The chapter is divided into two main sections. The first one explains the setting of the thermal relay, and the second one describes the setting of the fault locator/mho unit.

Each section discusses the meaning and derivation of each setting, as well as the limit checking applied to internal calculations involving the settings.

The actual setting of the relay is completed using the SET command. A summary of the relay settings may be obtained using the SHOWSET command.

It should be noted that some of the thermal relay and fault locator settings seem to overlap, such as R1 and RAC. This is to allow for the situation where different conductors were used in the same transmission line. When a variety of conductors is used, the fault locator/mho unit settings should reflect the average value while the thermal relay setting should reflect the thermal "weak link" value.

Reading Reference 1 is highly recommended before setting the thermal relay.

BE SURE THAT THE SETTINGS YOU CHOOSE RESULT IN RELAY PERFORMANCE APPROPRIATE FOR YOUR APPLICATION. WE ARE NOT LIABLE FOR MISAPPLICATION DUE TO INCORRECT SETTINGS, INTERPRETATION OR APPLICATION.

## THERMAL RELAY SETTINGS

Seventeen different settings are required for the thermal relay. Where applicable they are scaled to a 1 p.u. = 1000 foot section length of conductor. The settings may be broken down into the following groups:

| Description | Symbol | Units |
|---|---|---|
| Solar model settings | | |
| Default solar heating | DSH | (watts/Kft) |
| Solar absorption coefficient | SAC | (no units) |
| Conductor diameter | DIA | (inches) |
| Longitude of time standard | LSTD | (degrees west longitude) |
| Longitude of conductor | LON | (degrees west longitude) |
| Latitude of conductor | LAT | (degrees north latitude) |

| Description | Symbol | Units |
|---|---|---|
| Thermal model settings | | |
| AC resistance at 25 deg C | RAC | (milliohms/Kft) |
| Temp. co. of AC resistance | RDELT | (microohms / deg C Kft) |
| Thermal heat capacity | THC | (K joules / deg C Kft) |
| Thermal resistance to ambient | TRA | (deg C Kft Kwatt) |
| Temperature settings | | |
| Estimated ambient temperature | EAT | (deg C) |
| Estimated offset temperature | EOT | (deg C) |
| High temperature threshold | TH | (deg C) |
| Low temperature threshold | TL | (deg C) |
| Logic switches | | |
| Thermal trip enable | THE | (Y/N) |
| Temperature sensor enable | TSE | (Y/N) |
| Solar generator enable | SGE | (Y/N) |

## Solar Model Settings

Six numerical and one logic settings are required for the Solar Model. Many of the settings have already been discussed in the SOLAR MODEL section. The settings left to discuss here are the default solar heating and the solar generator enable switch.

The default solar heating and solar generator enable switch provide a means to disable the solar model yet still add a solar heat input quantity. When the solar generator is enabled the value for solar heating comes from the solar model. When the solar generator is disabled, the value used for solar heating is the default solar heat setting.

## Thermal Model Settings

Four numerical settings are required to set the thermal model.

The first of these is the AC resistance at 25 deg C. This value is readily available in books of conductor tables, such as Reference 3. The value of AC resistance should be scaled for 1000 feet of conductor.

The second setting is the temperature coefficient of AC resistance. This may be obtained by subtracting the value of the AC resistance in ohms per mile at 25 deg C from the value of AC resistance in ohms per mile at 75 deg C and dividing by the temperature difference of 50 deg C. Now divide by 5.28 to scale for 1000 feet of conductor. The resulting equation is:

$$RTC = \frac{RAC\ @75\ deg\ C\ \ -\ RAC\ @25\ deg\ C}{50 \times 5.28} \qquad \frac{ohms}{Kft\ deg\ C}$$

The next parameter is THC, the thermal heat capacity of a 1 p.u. piece of conductor. The thermal heat capacity of the conductor may be found by multiplying the number of pounds of aluminum by the specific heat of aluminum and adding it to the product of the number of pounds of steel times the specific heat of steel.

The thermal resistance to ambient is calculated by linearizing the formulas for convected and radiated heat loss. From Reference 1, the equation for radiated heat loss is:

$$Qrad = S*E*A(KC^4 - KA^4)$$

where

S = Stefan - Boltzman constant = 0.5275 e-8 $\qquad \frac{watts}{deg\ K^4\ sq\ ft}$

E = thermal emissivity constant
= .23 for new conductor to
.91 for blackend conductor

A = area of circumscribing cylinder (sq ft)

KC = conductor temperature (deg K)

KA = ambient temperature (deg K)

Adjust the units to obtain:

$$Qrad = 0.138*D*E((KC/100)^4 - (KA/100)^4) \qquad (Kw/Kft)$$

where D = conductor diameter (inches)

Linearization is accomplished using two data points, one for a 0 deg C rise and one for a 50 deg C rise above a 40 deg C ambient. The two quantities are:

$$Qrad\ 1 = 0$$

$$Qrad\ 2 = 0.138*D*E((363/100)^4 - (313/100)^4) = D*E*10715.9 \qquad (Kw/Kft)$$

Now let's take a look at convected heat loss. The standard assumption for lowest realistic wind velocity is 2 ft/sec, which means that we will use the formula for forced convection from Reference 1:

$$Qconv = [1.01 + 0.371 \left(\frac{D*R*V}{H}\right)^{0.52}] *K*(TC - TA) \quad \frac{Kw}{kft}$$

where

| | |
|---|---|
| D = conductor diameter | (inches) |
| R = air density | $(lb/ft^3)$ |
| V = air velocity | (ft/hr) |
| H = absolute viscosity | (lb/hr ft) |
| K = thermal conductivity | (watts/sq ft deg C) |

The rest of this discussion assumes air constant values of:

| | |
|---|---|
| R = 0.0752 | (20 deg C, sea level) |
| V = 2 ft/sec = 7200 ft/hr | |
| H = 0.0439 | (20 deg C) |
| K = 0.00784 | (20 deg C) |

Values that reflect your particular application may be found in Reference 1. Substituting in these constants yields:

$$Qconv = 0.00784\ (1.01 + 49.74\ (D)^{0.52})*(TC - TA) \quad \frac{Kw}{Kft}$$

Now calculate the two sample points needed to linearize:

$$Qconv1 = 0$$

$$Qconv2 = 0.392(1.01 + 49.74(D)^{0.52}) \quad \frac{Kw}{Kft}$$

Now we may find TRA with using the four solution points:

$$TRA = \frac{90 \text{ deg C} - 40 \text{ deg C}}{(Qconv2 + Qrad2) - (Qconv1 + Qrad1)} \quad \frac{\text{deg C Kft}}{\text{Kw}}$$

$$= \frac{50}{Qconv2 + Qrad2} \quad \frac{\text{deg C Kft}}{\text{Kw}}$$

A graph of actual cooling values and those calculated using TRA provides good visual justification of this linear approximation.

## Temperature Settings

Four values of temperature are needed to set the thermal relay. The first two are the estimated ambient temperature and the estimated offset temperature. The ambient temperature used in the thermal model and displayed as part of the TEMP command is actually the ambient temperature added to the estimated offset temperature. This allows the user to compensate for known temperature gradients along the length of the line.

The value of ambient temperature that is added to the estimated offset temperature comes from either the remote temperature sensor or the estimated ambient temperature setting, depending on the state of the temperature sensor enable switch.

Here are some example settings and conditions to help clarify the point.

| Outside air temp. | Settings for EAT | EOT | TSE | Value of ambient temp used by thermal model |
|---|---|---|---|---|
| 20 | 25 | 0 | Y | 20 |
| 25 | 25 | 0 | Y | 25 |
| 20 | 25 | 10 | Y | 30 |
| 25 | 25 | 5 | Y | 30 |
| 35 | 20 | 0 | N | 20 |
| 35 | 20 | 10 | N | 30 |

The sum of the estimated ambient temperature and estimated offset settings is also used to initialize the thermal model conductor temperature and ambient temperature filters upon power up. REMEMBER THAT ABOUT FIVE CONDUCTOR TIME CONSTANTS ARE REQUIRED BEFORE THE ESTIMATED CONDUCTOR TEMPERATURE CAN BE CONSIDERED ACCURATE. For example, for a Drake conductor with its 729 second time constant, the estimated temperature is accurate one hour after startup.

The high and low temperature thresholds define the trip and alarm temperature conditions, respectively. Settings should reflect the maximum conductor temperature allowed and a comfortably high conductor temperature based on such considerations as sag and loss of conductor life. Typical settings might be 80 deg C for the low threshold and 90 deg C for the high threshold.

Error Messages

A variety of checks are made on the settings. They are limit checked during the entry process to weed out any wild figures. They are further checked during the calculation of internal settings which the relay uses for algorithm execution.

If a range error is detected during the internal settings calculations the relay will generate an error message, then cancel the set procedure and resume operation using the old settings.

You may see what limit was rejected by using the following list. Each error message is listed followed by the formula used to check the condition.

! Thermal time constant (TRA*THC) out of range

then TRA*THC < 22
or TRA*THC > 2500

! RAC out of range

$$\text{then} \quad TRA*CTR^2 \left(\frac{RAC}{92.4897\ e\ 6} - \frac{RTC}{1.9149\ e\ 9}\right) <= 0$$

! CTR, THC, RAC or RTC out of range

$$\text{then} \quad \frac{\dfrac{7.00822\ e\ 9 * THC}{CTR^2\ (20.69108*RAC - RTC)}}{1000} > 1200$$

$$\text{or} \quad \frac{\dfrac{7.00822\ e\ 9 * THC}{CTR^2\ (20.69108*RAC - RTC)}}{1000 + \dfrac{1267637 * RTC}{540.588\ (20.69108 * RAC - RTC)}} < 24$$

! DSH too large

$$\text{then} \quad \frac{THC*5492.89}{DSH} < 70$$

Logic Switch Settings

The temperature sensor enable and solar model enable switches have already been discussed. The thermal trip enable switch enables closure of the trip relay when the conductor temperature exceeds the high temperature threshold.

Conductor Variable Tables And Setting Worksheets

The next few pages contain a table of conductor constants and relay settings worksheets. Conductor parameters were obtained from Reference 3 for various conductor types. One set of worksheets is filled out for a Drake conductor. The relay is initialized to these settings when shipped.

| CABLE TYPE | D | E | RL = RAC/m $25^oC$ | RH = RAC/m $75^oC$ | lbs. Al | lbs. Steel | Qsun =3.0 D | Qrad= DxEx 10.7159 | Qconv 392 x $1.01+49.74(D)^{0.52}$ |
|---|---|---|---|---|---|---|---|---|---|
| LINNET | 0.720 | 0.5 | 0.273 | 0.327 | 317.1 | 148.5 | 2.160 | 3.858 | 16.832 |
| PELICAN | 0.814 | 0.5 | 0.195 | 0.233 | 447.8 | 70.2 | 2.442 | 4.361 | 17.915 |
| DOVE | 0.927 | 0.5 | 0.166 | 0.198 | 524.9 | 241.1 | 2.781 | 4.967 | 19.140 |
| DRAKE | 1.108 | 0.5 | 0.117 | 0.139 | 750 | 344 | 3.324 | 5.936 | 20.962 |
| CARDINAL | 1.196 | 0.5 | .0983 | 0.117 | 900 | 329 | 3.588 | 6.408 | 21.796 |
| LAPWING | 1.504 | 0.5 | .0620 | 0.0729 | 1500 | 292 | 4.512 | 8.058 | 24.504 |
| BLUEBIRD | 1.762 | 0.5 | .0477 | 0.0555 | 2043 | 468 | 5.286 | 9.440 | 26.573 |

D - conductor diameter (inches)

E - thermal emissivity constant (unitless)

RL - AC resistance per mile at $25^oC$ (ohms/mile)

RH - AC resistance per mile at $75^oC$ (ohms/mile)

lbs. Al - weight of aluminum 1000ft of conductor (pounds/Kft)

lbs. Steel - weight of steel in 1000ft of conductor (pounds/Kft)

Qsun - typical value for solar heating (Kwatts/Kft)

Qrad - radiated heat loss (Kwatts/Kft)

Qconv - convected heat loss (Kwatts/Kft)

| | RAC = $\frac{RL}{5.28}$ | RTC = $\frac{RH - RL}{264}$ | THC = Al x 428.8 + St x 204.9 | TRA = $\frac{50}{Qr+Qc}$ | I = $\left(\frac{\frac{50}{TRA} - Qsun}{\frac{RAC}{10^3} + \frac{65 \times RTC}{10^6}}\right)^{1/2}$ $10^3$ |
|---|---|---|---|---|---|
| LINNET | 51.7 | 204.5 | 165.8 | 2.417 | 533.9 |
| PELICAN | 36.93 | 143.9 | 206.4 | 2.245 | 654.6 |
| DOVE | 31.44 | 121.2 | 274.5 | 2.074 | 736.5 |
| DRAKE | 22.16 | 83.33 | 392.1 | 1.859 | 924.6 |
| CARDINAL | 18.62 | 70.83 | 453.3 | 1.773 | 1,029 |
| LAPWING | 11.74 | 41.3 | 703.0 | 1.536 | 1,394 |
| BLUEBIRD | 9.039 | 29.6 | 971.9 | 1.388 | 1,674 |

All variables assume one per unit conductor length of 1000ft.

RAC - AC resistance per 1000ft at 25°C (mohms/kft)

RTC - temperature coefficient of AC resistance (uohms/°C kft)

THC - specific heat capacity (kjoules/°C kft)

TRA - thermal resistance to ambient (deg C kft/kw)

I - estimated conductor ampacity (amps)
assuming TC = 90°C, TA = 40°C

Power of ten scaling

u - micro - $10^{-6}$

m - milli - $10^{-3}$

k - kilo - $10^{3}$

# THERMAL SETTINGS WORKSHEET DRAKE

PAGE 1

| Symbol | Description | Value | Units |
|---|---|---|---|
| | **Conductor Constants** | | |
| RL | Rac/mile @25$^{o}$C | | ohms |
| RH | Rac/mile @75$^{o}$C | | ohms |
| D | Conductor Diameter | | inches |
| E | Thermal Emissivity | | |
| Sac | Solar Absorption | | |
| lbsAl | Pounds of Al/1000ft | | lbs. |
| lbsST | Pounds of steel/1000ft | | lbs. |
| | **Atmospheric Parameters** | | |
| R | Air Density | | lb/ft$^3$ |
| V | Air Velocity | | ft/hr |
| H | Absolute Viscosity | | lb/ft hr |
| K | Thermal Conductivity | | $\frac{\text{watts}}{\text{sq ft deg C}}$ |
| | **Correction Factors** | | |
| K1 | Elevation Correction | | |
| K2 | Atmosphere Correction | | |

# THERMAL SETTINGS WORKSHEET

## PAGE 2

Default Solar Heating
DSH = 3000 D = ______________ watts

Solar Absorption Coeff.
SAC = ______________

Conductor Diameter
DIA = D x K1 x K2 = ______________ inches

Longitude of Time Standard
LSTD = ______________ degrees west longitude

Longitude of Conductor
LON = ______________ degrees west longitude

Latitude of Conductor
LAT = ______________ degrees north latitude

AC Resistance
RAC = RL/5.28 = ________ ohms x 1000 = ________ milli-ohms

Temp Co of Resistance
RTC = RH-RL/264 = ________ ohms/$^{o}$C x $10^6$ = ________ micro-ohms/$^{o}$C

Thermal Heat Capacity
lbsAl x 428.8
+ lbsSt x 204.9 = ________ J/$^{o}$C x $\frac{1}{1000}$ = ________ KJ/$^{o}$C

Thermal Resistance to Ambient
Qrad = D x E x 10.7159 = ________ Kw/Kft

$$Qconv = 50 * K * [1.01 + 0.371 \left(\frac{D*R*V}{H}\right)^{0.52}]$$ = ________ Kw/Kft

$$TRA = \frac{50}{Qrad + Qconv}$$ = ________ $^{o}$C Kft/Kw

TEMPERATURE SETTINGS (degrees Celcius)

EAT = ________ EOT = ________ TH = ________ TL = ________

LOGIC SWITCHES

THE = ________ TSE = ________ SGE = ________

## SETTING THE FAULT LOCATOR AND MHO UNITS

The fault locator and mho units are set using standard line parameters.

This section starts with a listing of the setting required and ends with some suggestions on settings.

| | | |
|---|---|---|
| R1,X1 | - pos. sequence primary impedance of line | (ohms) |
| R0,X0 | - zero sequence primary impedance of line | (ohms) |
| RM0,XM0 | - mutual zero seq. primary impedance of line | (ohms) |
| | | |
| MCTR | - CT ratio for mutual residual current | |
| CTR | - CT ratio for line | |
| DTR | - PT ratio for line | |
| LL | - line length | (miles) |
| MTA | - maximum torque angle for mho elements | (degrees) |
| | | |
| Z% | - reach of mho elements in percent of the length | (%) |
| ZDG | - trip delay for ground faults | (cycles) |
| ZDL | - trip delay for line faults | (cycles) |
| 50FD | - fault dectector instantaneous overcurrent element pickup | (amps) |
| 46PH | - pos seq over current threshold | (amps) |
| | | |
| TTI | - enable transfer trip output on fault | (Y/N) |
| ZE | - enable tripping on fault | (Y/N) |
| 32QE | - neg. seq. supervision for mhos | (Y/N) |
| BPFE | - block fault tripping when pot. fuse blown | (Y/N) |

1. The negative-sequence directional element can be set to supervise the MHO units. For long transmission lines, under some system conditions, it is possible (although unlikely) for a MHO unit to operate for a reverse direction fault in the leading phase. The 32Q element is tangent to the MHO circle at the origin, i.e., it has the same maximum-torque angle as the MHO units. The 32Q element is bypassed whenever three-phase faults are detected. (Three-phase faults are declared whenever a MHO unit of each type operates simultaneously, e.g.

   (AG mho)*(BG mho)*(CG mho)*(AB mho)*(BC mho)*(CA mho)

   To supervise the MHO units with the 32Q, answer the "Neg Seq Dir Supersn" prompt with "Y".

   To disable this supervision, answer the prompt with "N".

2. MHO unit tripping can be supervised by logic designed to detect open potential circuits. This logic prevents false tripping for blown secondary-potential fuses, and is settable in response to the prompting question in the setting procedure. Note that the detection of a blown potential-circuit fuse does not block direct tripping via the DIRECT TRIP control input, by the OPEN command or from thermal tripping. A blown potential fuse condition is declared when the negative-sequence voltage exceeds a high-set threshold, and when, simultaneously, the negative-sequence current is below a low-set threshold.

The latter prevents faults conditions from appearing to be a blown potential fuse. When enabled, the blown potential fuse logic not only blocks tripping as described above, but also closes the ALARM output relay.

To block tripping when a blown potential fuse is detected by the above logic, answer the prompt "Blown Pot Fuse Det" with "Y".

To allow tripping even if a blown potential fuse is detected by the above logic, answer the prompt with "N".

The blown potential fuse state does not affect the 49 units.

3. Reaches of the mho units are 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 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 ) ]

# CHAPTER 7: INTERPRETATION OF EVENT REPORTS

## INTRODUCTION

The SEL-49 transmits both thermal and fault locator event reports. Reports transmitted automatically come out the "AUTO" port (see AUTO setting of the SET command), regardless of access level, as long as that port has not timed out. The next section discusses the fault locator report. See the Temp command for a discussion of the thermal report.

## FAULT LOCATOR REPORT

The SEL-49 transmits a summary fault report in response to several events, and saves a full report in its memory. The summary report includes the identifier message entered at the beginning of the setting procedure, date, time, and type of event. If it is a fault, then the fault location in miles and secondary ohms, the fault duration, and a fault current measurement are also displayed.

The full report contains current and voltage and information from which phasor diagrams of the prefault, fault, and postfault conditions may be constructed. It also contains 25 points, spanning the states of all relay elements, input and outputs. These are useful in reviewing fault duration, relay element responses, time of arrival of transfer-trip signalling with respect to local relay response, etc.

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

The most-recent five events are stored in the SEL-49 volatile memory. These data are retained as long as the control power remains on, or until the SET command is executed. (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.)

Event reporting is triggered by any of the following:

| | |
|---|---|
| Fault | Execution of TRIGGER command |
| Assertion of DIRECT TRIP Input | Assertion of TRANSFER TRIP Input |
| Assertion of BLOCK TRIP Input | Assertion of EXTERNAL TRIGGER Input |

Event reporting is NOT triggered by any of the following:

| | |
|---|---|
| Assertion of DIRECT CLOSE Input | Execution of the OPEN command |
| Execution of the CLOSE command | Changes to the 52A input |

EXAMPLE FAULT REPORT

A full report is provided at the end of this section. The report was generated in response to a simulated fault on the Example 230 KV Line described in the INITIAL CHECKOUT section of this manual. An A-to-ground fault 50 miles away, was used. For this test, the SEL-49 currents and voltages were provided by a Doble F-3 Test System. A latching relay was used to simulate the circuit breaker action and to provide a contact whose state is sensed by the SEL-49 52A input. An auxiliary relay 'B' contact was wired across the test set current output, so that most of the current initially passed through the relay contact.

To stage a fault, the auxiliary relay was energized, allowing all of the test set current to pass through the SEL-49 current input. Logic was included to deenergize the auxiliary relay once the fault was detected and the latching relay responded, thereby shunting most of the current around the SEL-49, as in the prefault case.

The computed and actual settings for the test set are given below.

| VA | VB | VC | IA | |
|---|---|---|---|---|
| 47.9 | 71.3 | 71.2 | 6.9 | volts or amps (computed) |
| 0 | -125 | 126 | -80 | degrees (computed) |
| 48 | 71 | 71 | 6.9 | volts or amps (actual) |
| 0 | -125 | 125 | -80 | degrees (actual) |

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

| VA | VB | VC | IA | |
|---|---|---|---|---|
| 96 | 142 | 142 | 1380 | kilovolts or amperes |

These were obtained using the potential and current transformer ratios assumed in the Example 230 KV Line. Note that these ratios are displayed at the end of the report: PTR = 2000 CTR = 200.

The paragraphs below describe the response of the SEL-49 to this simulated fault, using information taken from the full event report.

## 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-49)

[RN] = Revision Number (eg: 100)

[VS] = Version Specifications (eg: 656mpacp21c)

[RD] = Release Date (eg: YYMMDD = 880331)

For the SEL-49 family of relays, the version specifications are interpreted as follows:

V[VS] = V[ABCDEFGHIJK]

| 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 |

## 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 SEL-49, 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 degrees. 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 degrees.

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

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

(It may seem confusing to refer to the older data as the leading component of the phasor. The following example may help. Consider a sinewave with zero phase shift with respect to t=0, and having a peak amplitude of 1. Now consider two samples, one taken at t=0, and the other taken 90 degrees 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 degrees, and this agrees with the 90-degree lead that the cosine function has with respect to the sine function.)

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

The effective value of any of the phasors equals the square root of the sum of the squares of the components.

The residual current data are rotated by the angle of the zero-sequence compensation factor. The notation /K*Reff on the column heading indicates this rotation of the residual current. The displayed residual current is the residual current plus the effective additional residual current due to a parallel line.

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

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

| Currents | | | | Voltages | | | |
|---|---|---|---|---|---|---|---|
| /K*Reff | A | B | C | A | B | C | |
| -201 | -185 | | | -95.8 | 85.7 | 77.6 | (use for Y-component) |
| -1371 | -1356 | 0 | 0 | -4.1 | -113.2 | 118.5 | (use for X-component) |

These were taken near the "middle" of the fault, as can be judged from the action of the AG MHO unit.

Convert these to polar form (magnitude and angle):

| | Currents | | | Voltages | | | |
|---|---|---|---|---|---|---|---|
| /K*Reff | A | B | C | A | B | C | |
| 1386 | 1369 | 0 | 0 | 96 | 142 | 142 | (magnitudes) |
| -172 | -172 | -- | -- | -92 | 143 | 33 | (angle) |
| -80 | -80 | -- | -- | 0 | -125 | -125 | (angle + 92) |

In the third row, 92 degrees are added to all angles of the second row, so as to assign the phase-A voltage phasor as the zero-degree reference. The magnitude and shifted angles can be compared to the settings of the test set given earlier. The angle errors are one degree or less, and the magnitude errors are less than one percent.

The residual current compensation factor is:

$$(Z_0 - Z_1)/Z_1 = K$$

Its angle, using the data for the Example 230 KV Transmission Line, is 0.6 degrees. The displayed angle for the residual current is the residual current angle plus the residual current compensation angle. Therefore, the measured angle of the residual current is: -80 + 0.6 = -79.4 degrees, for a 0.6 degree error, since all of the residual current is phase-A current.

The event report indicates a fault current of 1372 amperes primary, which agrees well with the 1380-ampere test set current referred to the primary. The indicated fault location is 50.28 miles. The "actual" fault location is 50 miles.

The error is 50.28 - 50.00, or 0.28 mile which is about 0.3 percent of the set reach.

## RELAY ELEMENT STATUS INDICATORS

The states of all relay elements are indicated in three groups of columns, headed MHO (Mho elements), +Seq (positive-sequence elements), and -Seq (negative-sequence elements).

In the example event report, note that the AG MHO unit was the only MHO unit to respond to the fault. The negative-sequence directional unit (32) indicated a forward-direction fault as soon as the mho unit operated, and tripping, as indicated by the TRIP (TP) output, was initiated as soon as the MHO unit picked up. Since Transfer Tripping is selected (as indicated by TTI=Y), closing of the TRANSFER TRIP INITIATE output relay was initiated as well.

The 52A contact input monitored the latching relay state. The 52A input indicated that the latching relay had changed to the "open" state about one cycle after tripping had been initiated. One-half cycle after that, the output relays for tripping and transfer tripping were de-energized.

The duration of the fault can be estimated from the total time the MHO units are picked up. Note that they were picked up for a total of 20 quarter-cycles, or 5 cycles. This value is reported near the bottom of the report as: Duration: 5.00.

# SAMPLE EVENT REPORT FOR AN A-G FAULT

Example 230 kV Line, Drake Conductor    Date: 1/1/84    Time: 00:09:53.229

FID=SEL-49-R101-V565m-D881007

| | Currents (amps) | | | Voltages (kV) | | | MHO | +Seq | -Seq | Outs | Ins |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | ABCABC | iIv | ivV3 | TCTTTA | DTBD5E |
| /K*Reff | IA | IB | IC | VA | VB | VC | GGGBCA | | 2 | PLTHLL | TTTC2T |
| -16 | -17 | 0 | -2 | -95.9 | 86.4 | 76.9 | ...... | *.* | **.. | ...... | ....*. |
| -171 | -176 | 0 | 0 | -4.4 | -112.7 | 118.9 | ...... | *.* | **.. | ...... | ....*. |
| 25 | 17 | 0 | 0 | 95.8 | -86.3 | -76.9 | ...... | *.* | **.. | ...... | ....*. |
| 171 | 176 | 0 | 2 | 4.4 | 112.8 | -118.9 | ...... | *.* | **.. | ...... | ....*. |
| -25 | -20 | 0 | 0 | -95.8 | 86.2 | 76.9 | ...... | *.* | **.. | ...... | ....*. |
| -171 | -173 | 0 | -2 | -4.4 | -112.8 | 118.9 | ...... | *.* | **.. | ...... | ....*. |
| 29 | 20 | 0 | 2 | 95.8 | -86.2 | -77.0 | ...... | *.* | **.. | ...... | ....*. |
| 171 | 176 | 0 | 0 | 4.3 | 112.9 | -118.9 | ...... | *.* | **.. | ...... | ....*. |
| -29 | -23 | 0 | -2 | -95.7 | 86.1 | 77.1 | ...... | *.* | **.. | ...... | ....*. |
| -171 | -176 | 0 | 2 | -4.3 | -113.0 | 118.9 | ...... | *.* | **.. | ...... | ....*. |
| 25 | 26 | 0 | 0 | 95.8 | -86.0 | -77.3 | ...... | *.* | **.. | ...... | ....*. |
| 176 | 170 | 0 | 0 | 4.2 | 113.0 | -118.8 | ...... | *.* | **.. | ...... | ....*. |
| -16 | -32 | 0 | 0 | -95.8 | 86.0 | 77.4 | ...... | *.* | **.. | ...... | ....*. |
| -239 | -211 | 2 | 0 | -4.5 | -113.3 | 118.6 | ...... | *.* | **.. | ...... | ....*. |
| -62 | -47 | 0 | 2 | 96.1 | -85.7 | -77.3 | ...... | *.* | **.. | ...... | ....*. |
| 679 | 647 | 0 | 0 | 4.5 | 113.4 | -118.6 | *..... | *.* | **.* | *.*... | ....*. |
| -12 | -5 | 0 | 0 | -96.2 | 85.6 | 77.3 | *..... | *.* | **.* | *.*... | ....*. |
| -1195 | -1177 | 0 | 0 | -4.1 | -113.1 | 118.7 | *..... | *.* | **.* | *.*... | ....*. |
| 184 | 167 | 0 | 0 | 95.8 | -85.7 | -77.5 | *..... | *.* | **.* | *.*... | ....*. |
| 1350 | 1333 | 0 | 0 | 4.1 | 113.1 | -118.6 | *..... | *.* | **.* | *.*... | ....*. |
| -201 | -185 | 0 | 0 | -95.8 | 85.7 | 77.6 | *..... | *.* | **.* | *.*... | ....*. |
| -1371 | -1356 | 0 | 0 | -4.1 | -113.2 | 118.5 | *..... | *.* | **.* | *.*... | ....*. |
| 205 | 185 | 0 | 0 | 95.9 | -85.7 | -77.6 | *..... | *.* | **.* | *.*... | ...... |
| 1375 | 1359 | 0 | 0 | 3.9 | 113.3 | -118.5 | *..... | *.* | **.* | *.*... | ...... |
| -205 | -188 | 0 | 0 | -95.8 | 85.6 | 77.7 | *..... | *.* | **.* | *.*... | ...... |
| -1367 | -1359 | 0 | 2 | -3.9 | -113.4 | 118.4 | *..... | *.* | **.* | *.*... | ...... |
| 201 | 188 | 0 | 0 | 95.8 | -85.5 | -77.8 | *..... | *.* | **.* | *.*... | ...... |
| 1367 | 1362 | 0 | 0 | 3.9 | 113.4 | -118.3 | *..... | *.* | **.* | *.*... | ...... |
| -197 | -182 | 2 | 0 | -95.9 | 85.5 | 77.8 | *..... | *.* | **.* | *.*... | ...... |
| -1329 | -1318 | 0 | 0 | -3.7 | -113.4 | 118.3 | *..... | *.* | **.* | *.*... | ...... |
| 272 | 258 | 0 | 0 | 95.8 | -85.5 | -77.9 | *..... | *.* | **.* | *.*... | ...... |
| 901 | 894 | 0 | 0 | 3.7 | 113.5 | -118.2 | *..... | *.* | **.* | *.*... | ...... |
| -209 | -203 | 0 | 0 | -95.8 | 85.4 | 77.9 | *..... | *.* | **.* | *.*... | ...... |
| -369 | -364 | 0 | 0 | -3.7 | -113.5 | 118.3 | *..... | *.* | **.* | *.*... | ...... |
| 50 | 47 | 0 | 0 | 95.9 | -85.3 | -78.0 | ...... | *.* | **.* | ...... | ...... |
| 197 | 197 | 0 | 0 | 3.5 | 113.6 | -118.3 | ...... | *.* | **.. | ...... | ...... |
| -29 | -26 | 0 | 0 | -95.8 | 85.2 | 78.1 | ...... | *.* | **.. | ...... | ...... |
| -171 | -176 | 0 | 0 | -3.5 | -113.6 | 118.1 | ...... | *.* | **.. | ...... | ...... |
| 25 | 23 | 0 | 0 | 95.8 | -85.2 | -78.1 | ...... | *.* | **.. | ...... | ...... |
| 171 | 176 | 0 | 0 | 3.5 | 113.6 | -118.0 | ...... | *.* | **.. | ...... | ...... |
| -25 | -23 | 0 | 0 | -95.8 | 85.2 | 78.2 | ...... | *.* | **.. | ...... | ...... |
| -171 | -176 | 0 | 0 | -3.4 | -113.7 | 118.0 | ...... | *.* | **.. | ...... | ...... |
| 25 | 26 | 0 | 0 | 95.7 | -85.1 | -78.3 | ...... | *.* | **.. | ...... | ...... |
| 167 | 173 | 0 | 0 | 3.3 | 113.8 | -118.1 | ...... | *.* | **.. | ...... | ...... |

Event : AG    Location : 50.28 mi  4.08 ohms sec
Duration: 5.00    Flt Current: 1372

| | | | | |
|---|---|---|---|---|
| R1 = 13.90 | X1 = 79.96 | R0 = 41.50 | X0 = 248.57 | RMO = 37.35 |
| XMO = 223.90 | MCTR= 200.00 | CTR = 200.00 | PTR = 2000.0 | LL = 100.00 |
| MTA = 80.8 | Z% = 120.00 | ZDG = 0.00 | ZDL = 0.00 | 50FD= 200.00 |
| 46PH= 6000.0 | DSH = 4000.0 | SAC = 0.97 | DIA = 1.11 | LSTD= 125.00 |
| LON = 117.00 | LAT = 47.00 | RAC = 22.16 | RTC = 83.33 | THC = 392.10 |
| TRA = 1.86 | EAT = 20.00 | EOT = 0.00 | TH = 90.00 | TL = 80.00 |
| TIM1= 5 | TIM2= 0 | AUTO= 4 | RING= 3 | |
| TTI = Y | ZE = Y | 32QE= Y | BPFE= Y | |
| THE = Y | TSE = Y | SGE = Y | | |

# CHAPTER 8: INSTALLATION

## MOUNTING

The SEL-49 is intended to mount by its front vertical flanges, in a 19-inch vertical relay rack. Four #10 screws should be used for this purpose. Front and rear panel drawings are included in Appendix C of this manual.

## FRAME GROUND CONNECTION

Terminal 35 and/or 36 on the rear panel must be connected to frame ground for safety and performance. These terminals connect directly to the chassis ground of the instrument.

## POWER CONNECTIONS

Terminals 37 and 38 on the rear panel must be connected to a source of control potential. Control power passes through these terminals to the front-panel fuse and toggle switch. The fuse value is MDL 1 (1 AMP). It then passes through a surge filter, and connects to the switching power supply. The control power circuitry is isolated from the frame ground.

## SECONDARY CIRCUITS

The SEL-49 presents a very low burden to the secondary current and potential circuits. Each current circuit is independent of the other three circuits. That is, there is no interconnection of current circuits inside the instrument.

The SEL-49 requires four-wire wye potentials, as it includes ground relaying functions. It is not possible to directly apply the SEL-49 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. Each input draws about 6 mA when it is energized with 120 volts.

Control outputs are dry relay contacts rated for tripping duty. Each contact is protected by a metal-oxide varistor (GE V150LA20A or equal). These devices have an energy rating of 80 joules, a maximum clamping voltage of 395 volts, and a minimum varistor voltage (for 1 mA DC current) of 212 volts.

Each control circuit input and output point is bypassed to chassis ground via a 0.0047 uF, 3000 WVDC disc ceramic capacitor.

## COMMUNICATIONS CIRCUITS

Connections to the two RS-232-C serial communications ports are made via the two nine-pin connectors, labeled Port 1 and Port 2 on the rear panel. Pins 1 and 9 connect directly to frame (chassis) ground. THESE CONNECTIONS SHOULD NOT BE RELIED UPON FOR SAFETY GROUNDING, SINCE THEIR CURRENT-CARRYING CAPACITY IS LESS THAN CONTROL-POWER SHORT CIRCUIT CURRENT AND PROTECTION LEVELS.

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

Route the communications cables well away from the secondary and control circuits. In no case should the communications cables be bundled with secondary or control-circuit wiring. Coupling invites the induction of noise from the control or secondary wiring into the communications wiring. This noise could exceed the communications logic thresholds and introduce communications errors.

The IRIG-B clock cable should also be kept away from the control wiring and secondary circuits.

## JUMPER SELECTION

All jumpers are on the front edge of the main board.

### RS232 Jumpers

Jumper 6 provides for RS-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 1 is in place the password protection is disabled. This feature is useful if passwords are not required or if they are forgotten.

Remote Trip/Close Enable Jumper

When Jumper 2 is in place remote trip/close commands may be executed. If Jumper 2 is removed attempts to use the OPEN or CLOSE commands result in an "Aborted" message.

## REMOTE TEMPERATURE SENSOR WIRING

To input the 0-1 mA current loop output of a temperature transducer with the 0-5 volt temperature input of the SEL-49 requires a 5 kohm burden resistor/0.1 uf capacitor combination. (The capacitor is to help minimize noise.)

The burden network is placed directly across the external RTD inputs of the SEL-49.

More than one SEL-49 may be run off the same input by connecting the RTD positive inputs of the extra SEL-49's to the RTD positive input of the SEL-49 with the burden network. The RTD negative inputs should not be tied together to avoid ground loops.

The 0-5 volt input range corresponds to a temperature range of -23.3$^{o}$C to 65.6$^{o}$C. A temperature transducer, such as Fargo DB-4 is suitable when used with the above-mentioned burden resistor and capacitor.

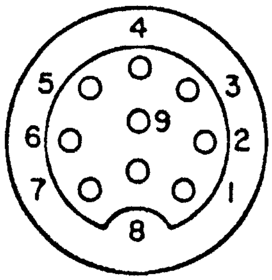
## RS-232 AND IRIG-B INSTALLATION

This section contains specific information concerning pinouts of the communications ports. Section 8.1 discusses the more general topic of cable routing.

The current drive for a IRIG-B "one" is 10 to 20 mA. The application of the current was discussed in Section 4.3.

What follows is a pin definition of the nine-pin port connectors and cabling information for the RS-232 ports. Several types of RS-232 cables are given. These and other cable configurations are available from SEL.

Nine pin connector pin number convention




(Female chassis connector, as viewed from outside rear panel.)

RS-232 cables

(SEL CABLE 123)

| SEL-49 | | CRT | |
|---|---|---|---|
| GND | 1 | 7 | GND |
| TXD | 2 | 3 | RXD |
| RTS | 3 | 5 | CTS |
| RXD | 4 | 2 | TXD |
| CTS | 5 | 4 | RTS |
| GND | 9 | 1 | GND |
| | | 6 | DSR |
| | | 8 | DCD |
| | | 20 | DTR |

(SEL CABLE 422)

| SEL-49 | | MODEM | |
|---|---|---|---|
| GND | 1 | 7 | GND |
| TXD | 2 | 2 | RXD |
| RTS | 3 | 20 | DTR |
| RXD | 4 | 3 | TXD |
| CTS | 5 | 8 | CD |
| GND | 9 | 1 | GND |

(SEL CABLE 331A)

| SEL-49 | | PRTU | |
|---|---|---|---|
| GND | 1 | 1 | GND |
| TXD | 2 | 4 | RXD |
| RXD | 4 | 2 | TXD |
| CTS | 5 | 7 | +12 |
| +12 | 7 | 5 | CTS |
| GND | 9 | 9 | GND |

MODEM COMMUNICATIONS

The SEL-49 Line Thermal Relay/Fault Locator interfaces directly to a commercial-grade Hayes Compatible telephone modem for automatic-answer dial-up communications applications. A field installation consisting of a SEL-49 and a modem can be accessed by telephone, with another modem and a computer or

The modem connects to Port 1 of the SEL-49 with a cable available from SEL. The modem normally is powered from 120 VAC; however a DC powered modem is available which can be powered from the SEL-49. Please contact SEL for further details.

The SEL-49 responds to the control messages sent by the modem to the SEL-49. These are RING, CONNECT, NO CARRIER, ERROR and OK. The SEL-49 responses ensure that the modem is programmed to answer after the number of rings specified using the RING setting.

In applying and using the SEL-49 and a modem in an automatic-answer scheme, keep the following points in mind:

1. Modem setting considerations:

    a. Modem must be compatible with the Hayes "AT" command set.

    b. Modem must be set to auto answer.

    c. Modem must not echo commands sent to it.

    d. Modem must send responses to commands with verbose (English words) result codes.

    e. Modem must automatically or manually set communications parameters to 8 data bits, 2 stop bits, no parity.

2. Always use a finite timeout interval, so that if communications are disturbed, the SEL-49 has a chance to reconfigure the modem and to clear its communications buffers of data and control characters. An interval of five minutes is recommended. (See the TIM1 setting.) When the port 1 timeout occurs the SEL-49 sends a command to the modem to hang up. This feature helps prevent accumulation of a large telephone toll when no activity is sensed by the SEL-49 for the timeout interval.

3. Be careful about the number of rings which is programmed using the RING setting. It can be set up to 30, but large numbers correspond to very long waits.

4. Some communications devices, such as the Radio Shack Model 100 briefcase computer, allow the use of an XON/XOFF communications protocol. We have found that, in general, the SEL-49 functions quite well with these. However, at times, the Model 100 and other devices leave the SEL-49 in the XOFF state upon hanging up. The problem here is that you must wait your timeout interval before the XOFF state is cancelled automatically by the SEL-49, since in that state, the SEL-49 cannot respond to the modem as it has been told to be silent. If you call the SEL-49 and do not get a prompt, send an XON (control-Q).

5. For the same reason, do not hang up after you have stopped a transmission using XOFF (control-S). If you wish to terminate a lengthy transmission, use control-X.

6. When the modem answers the telephone, the SEL-49 forces it into its control state to ensure it is properly initialized. To do that, the SEL-49 sends the following string immediately after the connection is established:

   AT+++

   Wait for the SEL-49 prompt before typing commands. If no prompt appears, send an XON or a RETURN.

7. If modem power is turned off and back on, the modem "forgets" the number of rings to wait before answering. The SEL-49 programs the modem with the number of rings to wait before the modem should answer. Thus, the modem will answer the first call after its power is restored on the first ring. After that, it will answer on the number of rings you programmed with the RING setting until the power to the modem is interrupted again. The SEL-49 retains the number of rings in its nonvolatile memory, so control power interruptions do not disturb that setting.

# INITIAL CHECKOUT

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

A portable terminal or computer is a convenient tool for providing local communications with the SEL-49 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. Using the ACCESS command and the SHOWSET command, check the settings. Set the clock.

2. Apply three-phase potentials. Execute the METER command, and verify that the reading is accurate. If it is not, be sure that the correct PT ratio was entered, and recall that the displayed values are in primary line-to-neutral 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 insure 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 CONTACTS command, check the state of all contact inputs and outputs. For example, if the connections to the circuit breaker 52A contact are made, and if the circuit breaker is closed, the CONTACTS command should show an asterisk (*) under the 52A heading.

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.

6. The tripping function should be tested four ways. First, be sure the circuit breaker can be tripped by the SEL-49 by executing the OPEN command (if the remote open/close Jumper is in place). Second, the circuit breaker may be tripped by asserting the direct trip input. The TRIP output relay opens in both of these cases after the 52A input is unasserted,

testing the 52A contact ensures that the output relay does not inadvertently open while trip coil current is flowing in response to a control operation. Third, the circuit breaker may be tripped by applying voltages and currents representing a fault condition. Here, the TRIP relay closes, regardless of the state of the 52A contact, and opens when the 52A input is unasserted AND fault conditions no longer exist. Fourth, the TRIP relay may be closed by simulating an overheated conductor.

7. Automatic thermal reports should be generated under simulated overloaded conditions. For the settings supplied with the relay, a good secondary current to use is 7.5 amps, corresponding to 1500 amps primary.

8. The IRIG-B circuits may be checked by using the IRIG-B command. The system clock should also synchronize automatically every five minutes.

9. The circuit breaker may be closed two ways, by executing the CLOSE command, or by assertion of the DIRECT CLOSE input. The CLOSE output relay closes for either of these conditions, as long as the 52A input is unasserted (indicating that the circuit breaker is indeed open). The CLOSE relay opens when the 52A input is asserted.

10. If the TRANSFER TRIP and BLOCK TRIP inputs are used, these should also be checked for proper operation.

11. Asserting the EXTERNAL TRIGGER input should trigger the recording of an event record.

12. 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.

# CHAPTER 10: SERVICE AND TROUBLESHOOTING

## REMOVAL OF FRONT PANEL AND DRAWOUT ASSEMBLY

TO PREVENT SHOCK HAZARD, POWER TO THE RELAY MUST BE INTERRUPTED BEFORE REMOVING THE FRONT PANEL ASSEMBLY.

1. Disconnect external power source.

2. Remove the four outermost front panel screws, front panel should be loose.

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

4. Remove the two hex head screws from under the forward outside edges of the drawout assembly.

5. Disconnect the analog input connector from the main board (P 104). It is the right-most connector.

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

## CALIBRATION

Periodic calibration is unnecessary. Calibration should be considered for the conditions listed below, however.

1. Replacement of any analog components in the system, such as op amps, the A/D converter or the sample/hold amplifiers.

2. Replacement of the input transformers or their secondary burden resistors.

3. Out-of-tolerance analog indication of voltages or currents.

Calibration of the system consists of trimming the gains and offsets of the analog channels.

## EQUIPMENT REQUIRED

1. AC digital voltmeter.
2. Precision three-phase voltage and current source (Doble F3 or similar.)
3. Computer terminal.
4. Precision 5-volt dc voltage source. (For RTD channel gain calibration.)

## PROCEDURE

### Offset Adjustments

1. Be sure zero voltage and current inputs are present at the relay rear panel, and remove the top cover of the instrument.

2. Turn the system power on.

3. Execute the STATUS command to observe the offsets, as required, while adjusting potentiometers R135-R142 for indications of 5 mV or less. (Clockwise rotation results in positive offset).

### Adjusting the RTD Channel Offset

1. Remove any RTD connections from the RTD input terminals, numbers 33 and 34.

2. Connect a shorting jumper between the RTD terminals number 33 and 34.

3. Verify that the temperature sensor is enabled in the settings (TSE=Y). If not, then enable it.

4. From access level one or two, type "TAR X" followed by a carriage return. Note the number presented.

5. If the number is negative, turn the potentiometer R143 counter-clockwise. Repeat steps 4 and 5 until the number is zero. (Pause a few seconds between adjustments.)

6. If the number shown is positive, turn the potentiometer R143 clockwise, until it is zero.

### Gain Adjustments For IA, IB, IC, VA, VB, and VC Channels

The procedure below uses an ac source at the relay input, so that the gain adjustments accommodate ratio error in the input transformers, and error in the burden resistors at the input CT secondaries.

1. Connect a 50-volt source to the three voltage inputs, and a nominal secondary current value to the phase current inputs. Turn on the system power.

2. Type "METER <RETURN>" to cause the meter command to display the measured voltages and currents.

3. Adjust R117-R122 for correct indication, taking into account your settings for the CT and PT ratios.

Gain Adjustment for IRM Channel

1. Apply a nominal secondary current to the IRM current input.

2. Trigger an event report, and calculate the magnitude of current in the column labelled "/K*Reff".

3. Adjust potentiometer R116 to get the same magnitude as for the following phasor:

$$\frac{3 \cdot Z\emptyset M \cdot CTR}{Z\emptyset - Z1} \cdot INOMINAL$$

Adjusting the RTD Channel Gain

1. Connect a precision 5V source across the RTD terminals.

2. Adjust R123 to obtain 4.750 volts at U128 Pin 3.

## 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 trouble-shooting table.

1. Measure and record control power voltage present at terminals 37, 38.

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

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

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

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

## TROUBLESHOOTING TABLE

All Front Panel LED'S Dark

1. Power switch off

2. Blown fuse

3. Input power not present

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

System Does Not Respond to Commands

1. Communications device not connected to system.
2. SEL-49 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.)

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).
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 or Thermal Overload when Tested

1. Relay improperly set.
2. Test set improperly set.
3. CT or PT input cable wiring error.

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

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

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

Terminal Displays Meaningless Characters

1. Baud rate incorrectly set.

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

Self-Test Failure: +5 Volts

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

2. A/D converter failure.

Self-Test Failure: +15 Volts

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

2. A/D converter failure.

Self-Test Failure: -15 Volts

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

2. A/D converter failure.

Self-Test Failure: Offset

1. Offset drift. (Adjust offsets)

2. A/D converter drift. (Calibrate A/D converter.)

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.

# APPENDIX A

# RELAY SPECIFICATIONS

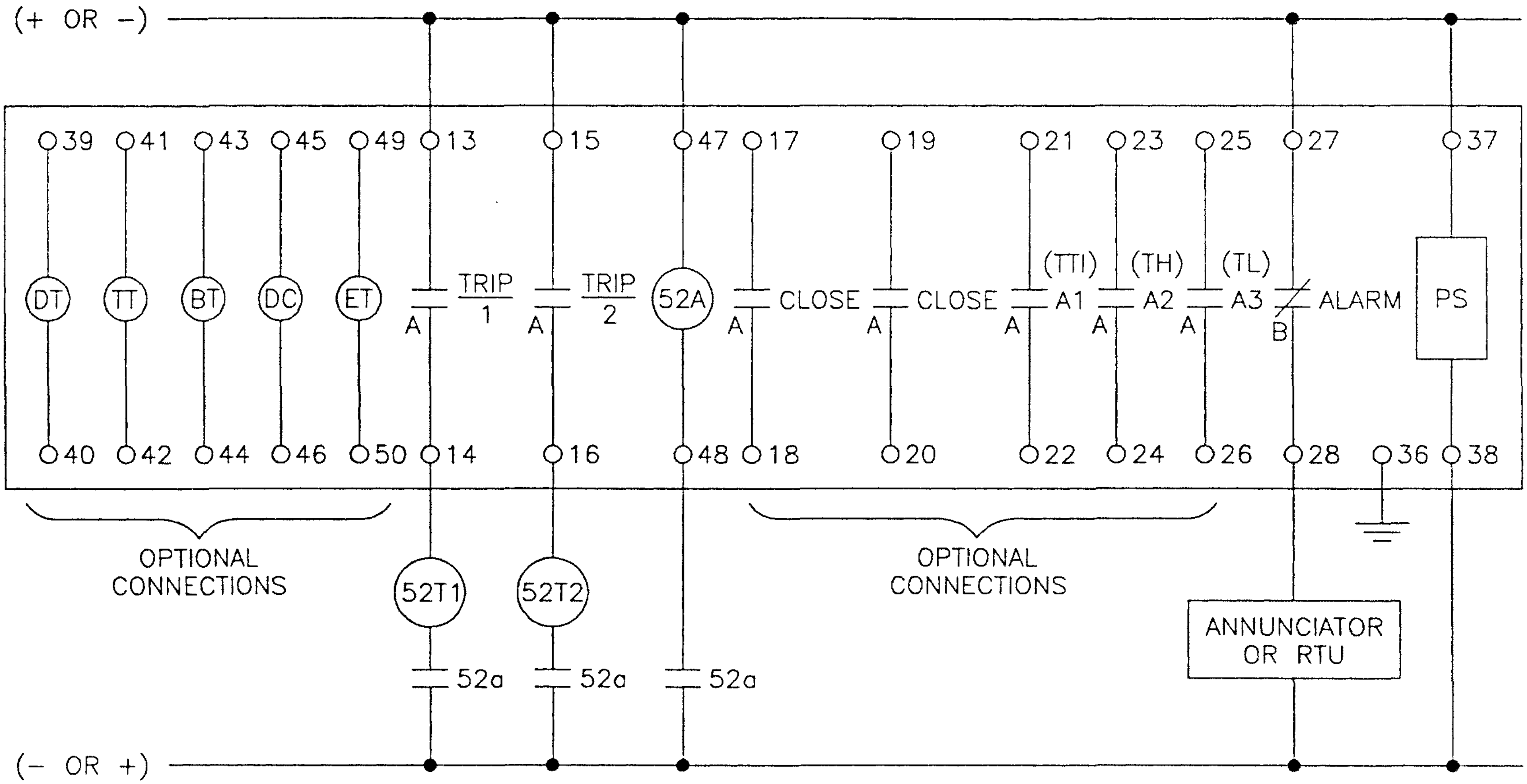
# SPECIFICATIONS

| | |
|---|---|
| Relay Functions | Thermal protection for overhead lines.<br>Estimation of time to overheat.<br>Automatic report generation.<br>MHO characteristics for all fault types.<br>MHO units are sound-phase polarized.<br>Negative sequence directional supervision.<br>Separate timers for line and ground faults.<br>Instantaneous positive-sequence overcurrent unit.<br>Instantaneous positive-sequence overvoltage unit.<br>Instantaneous negative-sequence overcurrent unit.<br>Instantaneous negative-sequence overvoltage unit.<br>Ground switch detection.<br>Blown potential fuse detection.<br>Automatic phase-sequence checking of voltages and currents upon power-up.<br>Separate outputs for high and low set thermal relays. |
| MHO Unit Operating Time | 10 - 32 ms; 20 ms typical, including output relay delay. |
| Steady-state Error (distance relays) | Less than 3% of set reach. |
| Transient Overreach | Less than 5% of set reach. |
| Thermal Status Reporting | Record includes: estimated time to trip, line condition, summary of heating and cooling inputs, estimated line temperature, ambient temperature. |
| Fault Location | Algorithm compensates for prefault load flow and fault resistance for improved accuracy over a wide range of system conditions. Demonstrated accuracy is about one percent of line length. Fault location is reported in miles, and secondary ohms. |
| Fault Reporting | A data record including fault date, time, type, location, duration, current, relay settings and units which operated is generated after each fault. Phasor information on currents and voltages indicates prefault, fault and postfault conditions. This report may also be generated upon command or triggered by a contact closure. The state of all contact inputs and outputs is also reported. |
| Self-Testing | Analog AC channels checked for offset. Stall timer monitors processor and five-volt supply. Power supply voltage level checking. Settings, RAM, ROM and A/D converter checking. These self tests are designed to detect virtually any hardware or firmware failure. Failure of any test generates alarm message, and closes alarm contacts. Critical failures disable protection and control to prevent misoperation. |

| | |
|---|---|
| Thermal Model Range | Models conductors with time constants from 5 minutes to 40 minutes. |
| Reach Setting | 5 Amp Option: 0.5 to 32 ohms<br>1 Amp Option: 2.5 to 160 ohms |
| Rated Input Voltage | 120 volts phase-to-phase nominal |
| Rated Input Current | 5 Amp Option: 5 amps per phase nominal<br>15 amps per phase continuous<br>390 amps for 1 seconds<br><br>1 Amp Option: 1 amp per phase nominal<br>15 amps per phase continuous<br>390 amps for 1 seconds |
| Temperature Sensor Input | One temperature input (0-5V corresponds to -23.3 to 65.6 deg. C) |
| Time Code Input | One demodulated Irig-B input: 10-20 mA |
| Setting Means | Digital, via RS-232C serial communications ports. Parameters are entered in response to prompting messages. Parameters of line are entered in primary ohms. Line length and CT, PT ratios are entered, and displayed quantities are scaled into primary units (e.g. miles, KV, A). Settings are retained in nonvolatile memory in two identical arrays. Self-tests compare these arrays. Should any difference ever be detected, alarm is generated, and relay and control functions are disabled to prevent misoperation. |
| Output Contact Ratings | 30 amp make per IEE C37.90 para 6.6.2<br>6 amp carry continuously<br>MOV protection provided |
| Logic Input Ratings | 48 VDC: 20 - 60 VDC<br>125 VDC: 60 - 200 VDC<br>220 VDC: 175 - 250 VDC<br>250 VDC: 200 - 280 VDC<br>Input Current: 6 mA at nominal voltage |
| Power Supply | 48 volt: 30- 60 VDC; 12 watts<br>125 volt: 85-200 VAC or VDC; 12 watts<br>250/220 volt: 85-280 VDC or 85-200 VAC; 12 watts |
| Surge Filtering | Power supply line filter.<br>All control inputs and outputs bypassed to ground.<br>Contact inputs filtered by RC networks.<br>Relay outputs protected by MOVs.<br>SWC tested. |
| Dimensions (HWD) | 5.25" x 19" x 13". Mounts in standard 19" relay rack. |
| Weight | 20 pounds |

# APPENDIX B

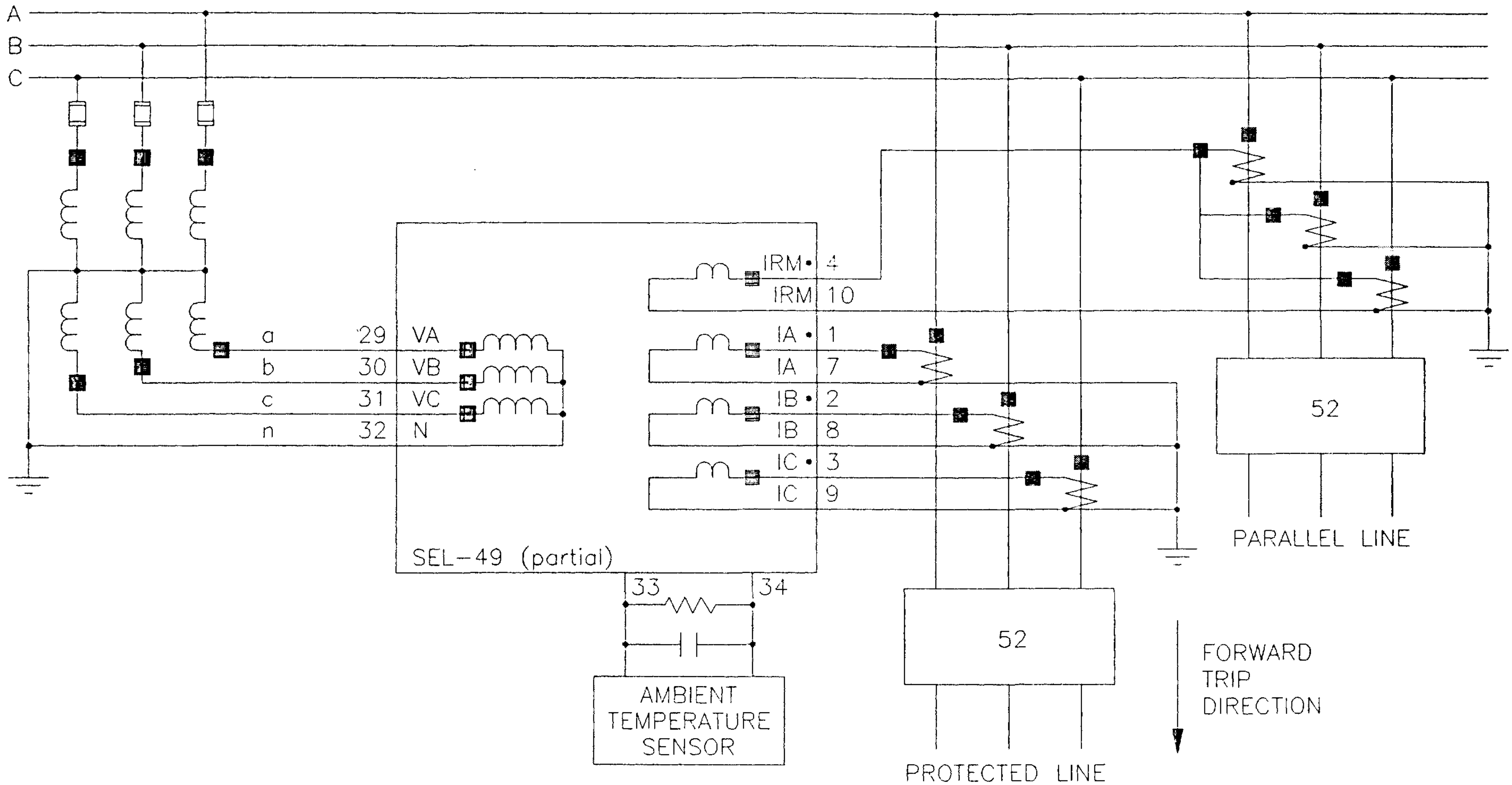
## DC EXTERNAL CONNECTION DIAGRAM (TYPICAL)
## EXTERNAL CURRENT, VOLTAGE, AND TEMPERATURE SENSOR CONNECTIONS




# SEL–49 DC EXTERNAL CONNECTION DIAGRAM (TYPICAL)



DWG. NO. A7–0399
DATE: 10–12–88
REV. 02–22–89



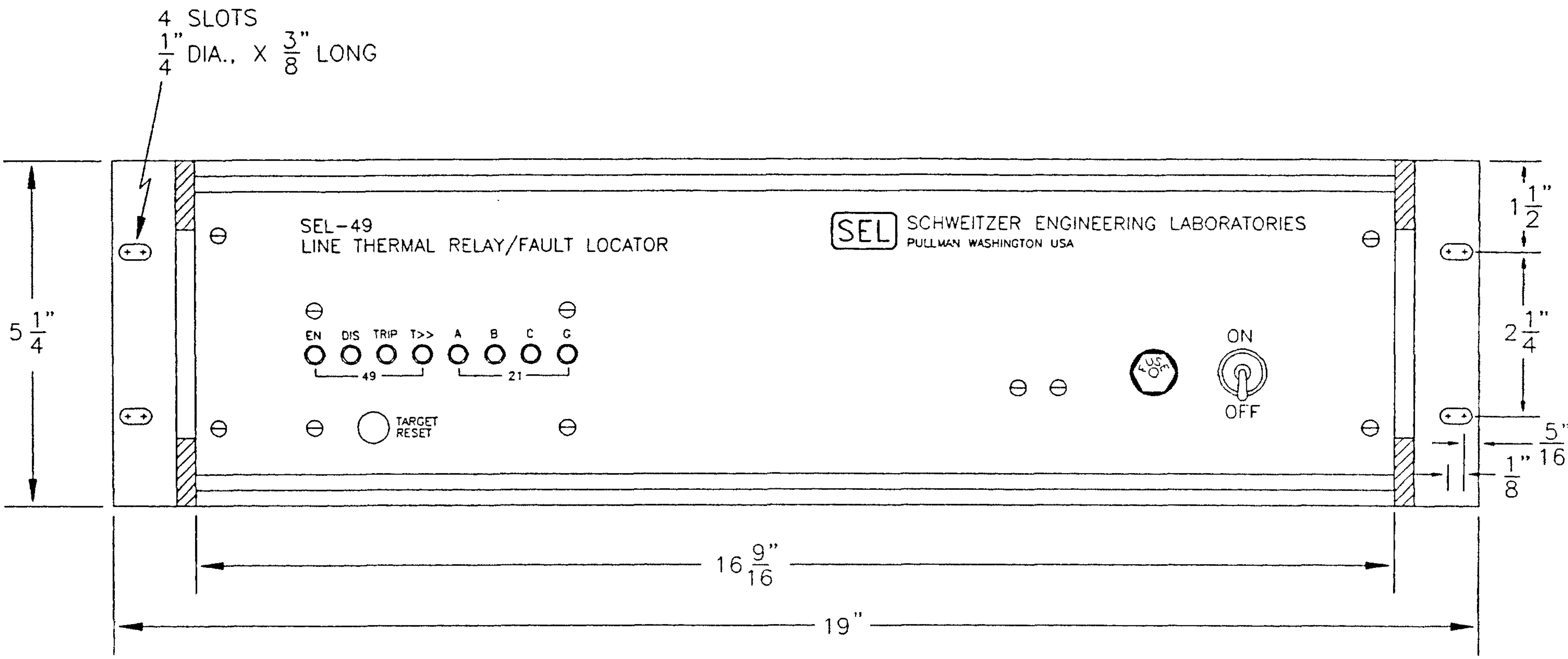

# SEL-49 EXTERNAL CURRENT, VOLTAGE, AND TEMPERATURE SENSOR CONNECTIONS



DWG. NO. A7-0398
DATE: 09-28-88

# APPENDIX C

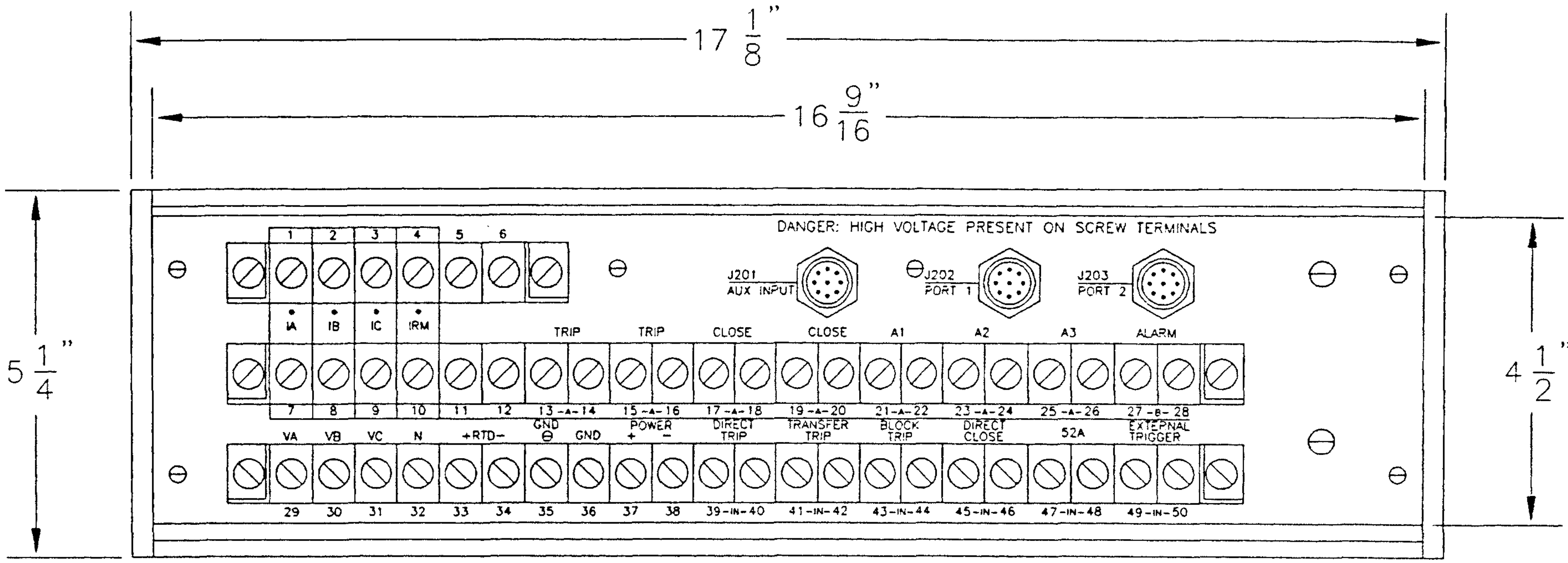
## MECHANICAL DIMENSIONS
## PANEL CUTOUT AND DRILL PLAN
## PARTS LIST AND PLACEMENT DIAGRAMS




SEL–49 HORIZONTAL
FRONT PANEL DRAWING



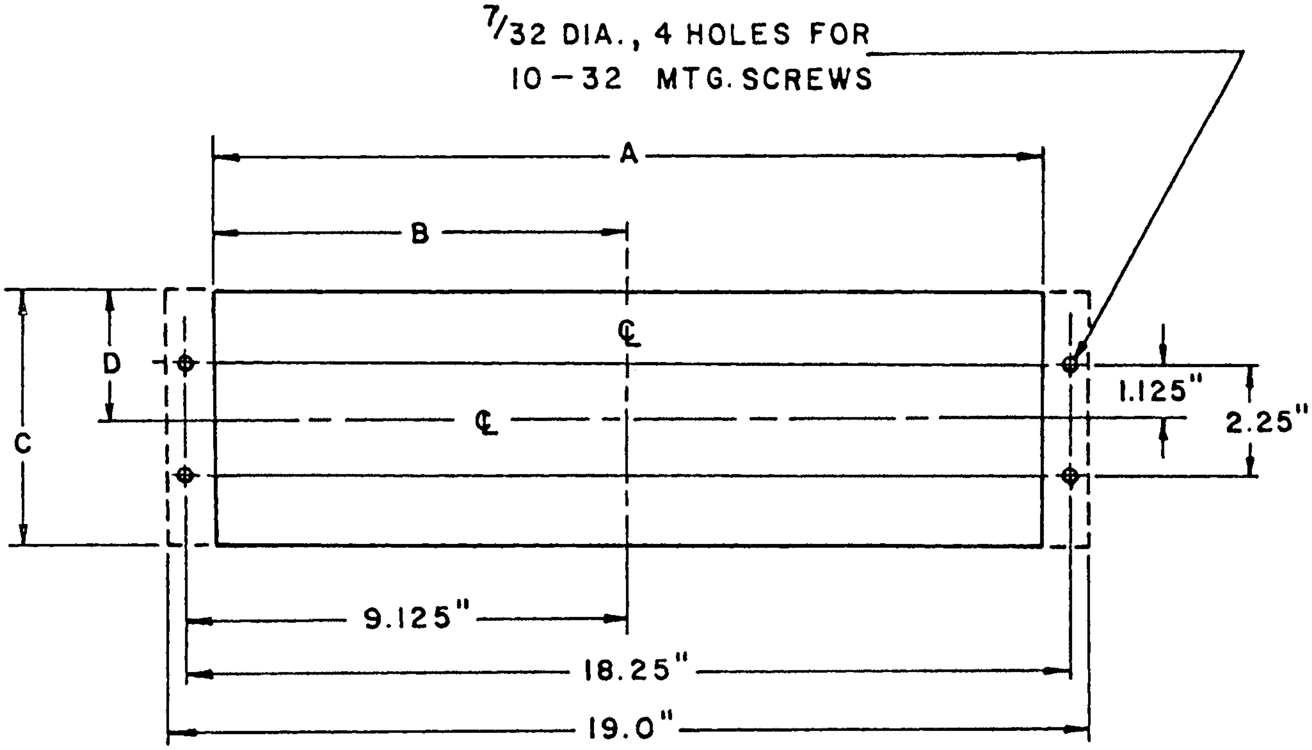
DWG. NO. A7–0414
DATE: 10–10–88




# SEL-49 HORIZONTAL REAR PANEL DRAWING



DWG. NO. A7-0415
DATE: 10-10-88




DIMENSION A:
CASE: 17.00"
CUT OUT: 17.25" - 17.875"
17.375" PREFERRED

DIMENSION B:
CASE: 8.5"
CUT OUT: 8.625" - 8.9375"
8.688" PREFERRED

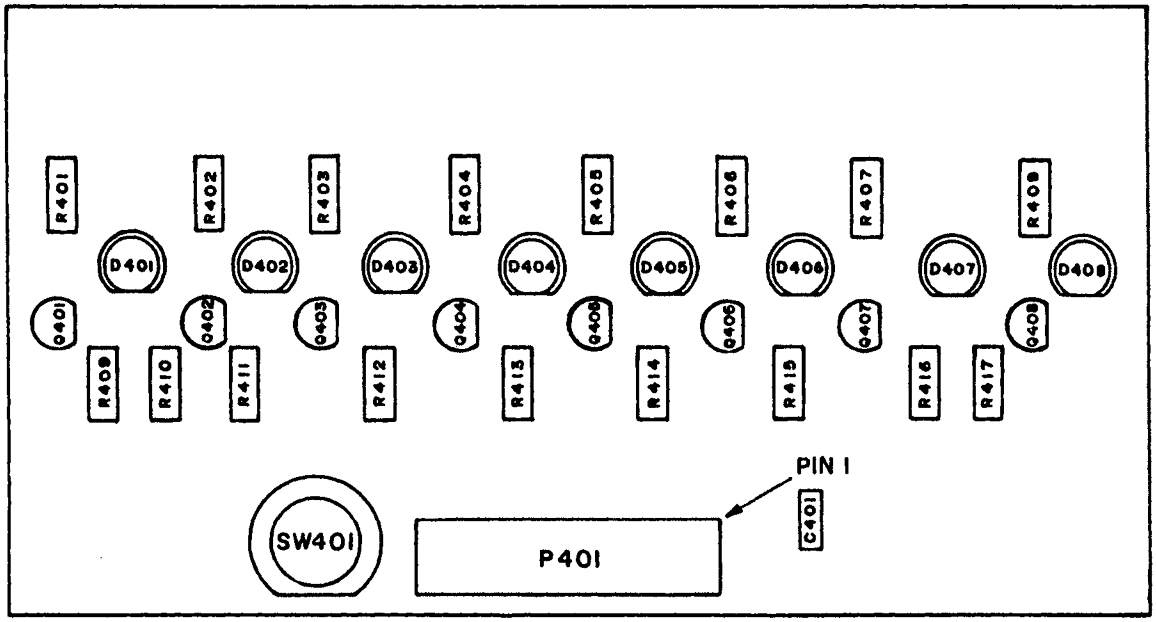
DIMENSION C:
CASE: 5.25"
CUT OUT: 5.35" - 5.45"

DIMENSION D:
CASE: 2.625"
CUT OUT: 2.675" - 2.725"

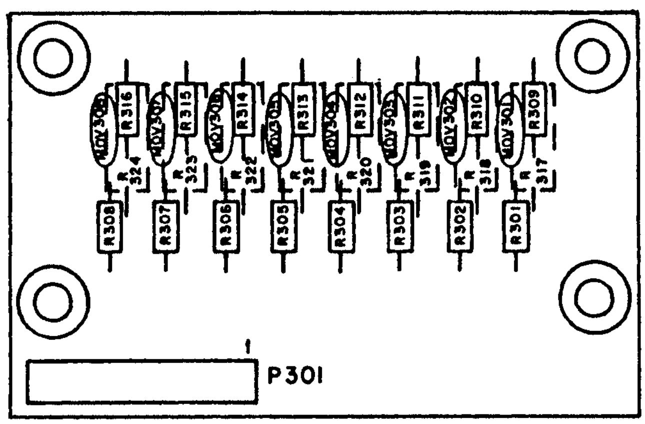
NOTE: ALL INSTRUMENTS MAY BE MOUNTED HORIZONTALLY (AS SHOWN) OR VERTICALLY.

PANEL CUTOUT AND DRILL PLAN FOR SEMI-FLUSH MOUNTING OF 5.25 INCH HIGH CASE

DWG. NO. A7-0174
DATE 5/11/87 JS
REV. 3/9/88



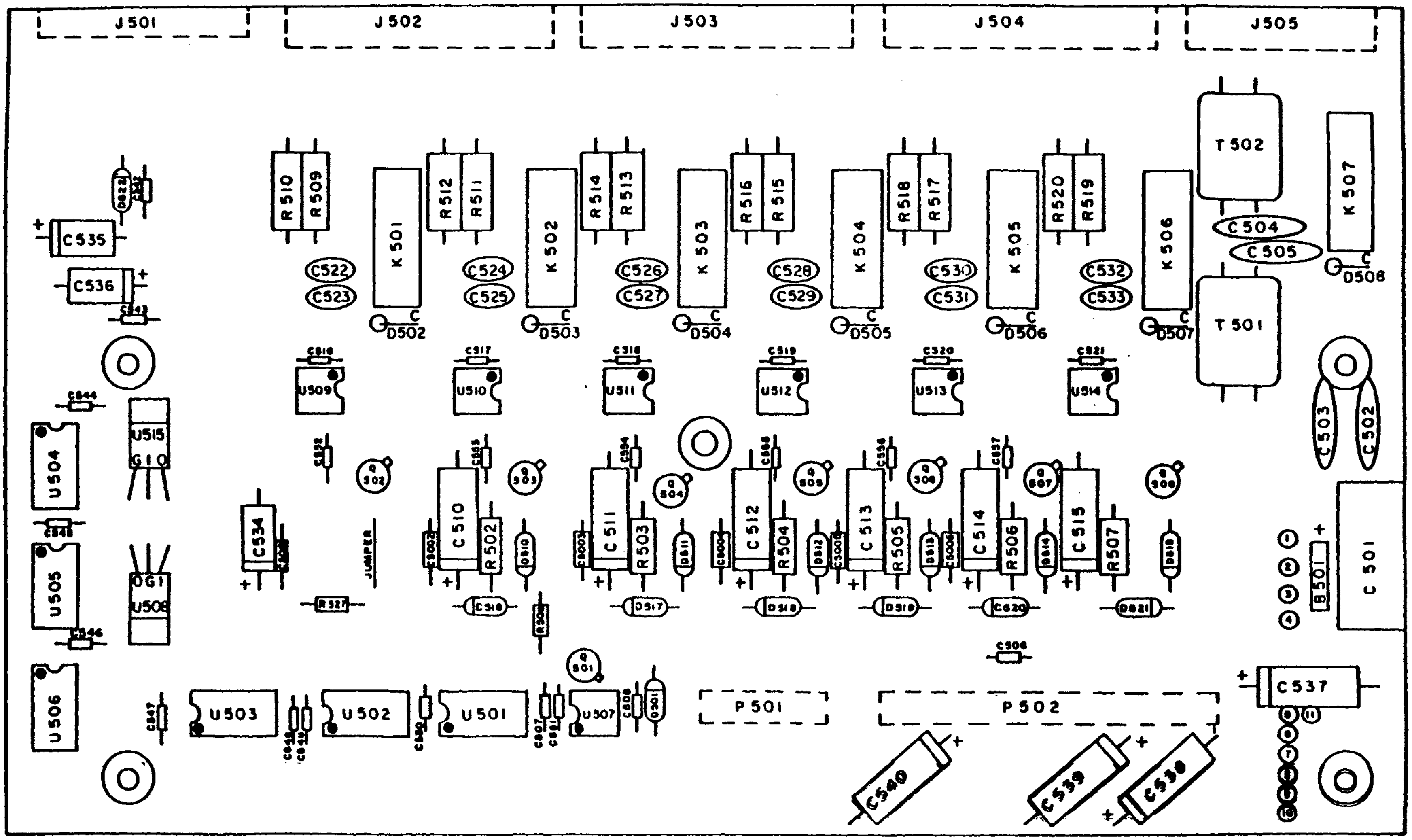

DPR-FP1



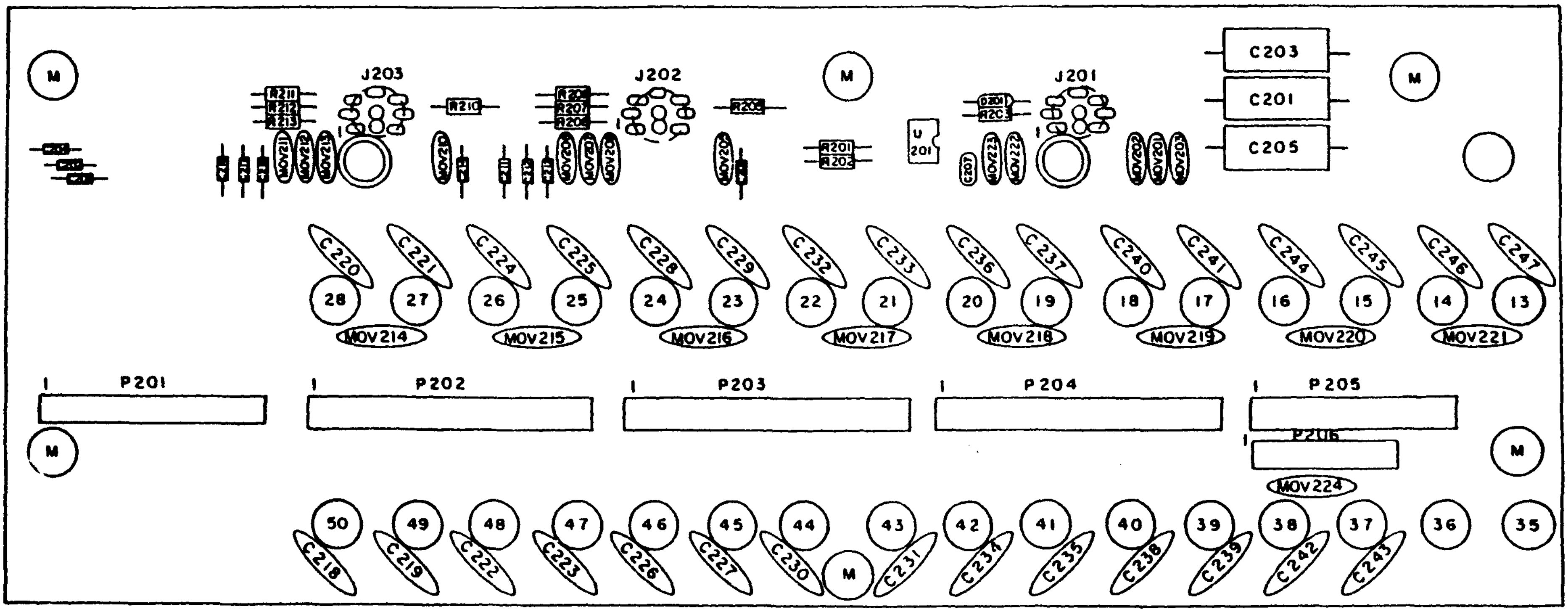

DPR-TT2

PARTS PLACEMENT DWGS
DPR-FP1 FRONT PANEL BOARD
AND
DPR-TT2 TRANSFORMER TERMINATION BOARD

SCHWEITZER ENGINEERING LABORATORIES
A1-0200

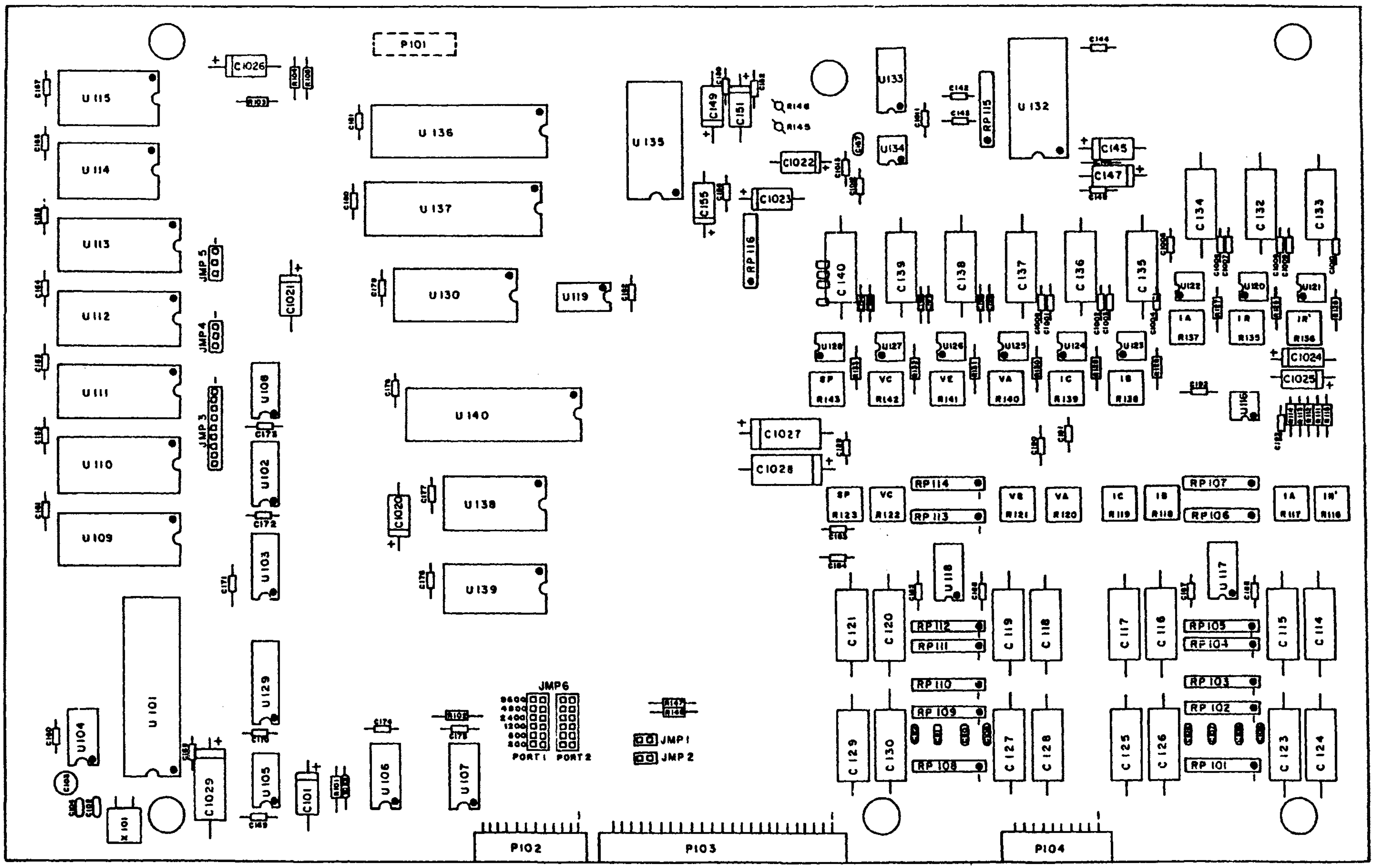



DPR INTERFACE ASSEMBLY
CI-0105 PARTS PLACEMENT
SCHWEITZER ENGINEERING LABS
REV. DATE: 3/30/88






DPR BACKPLANE
C1-0101 PARTS PLACEMENT
SCHWEITZER ENGINEERING LABS




REV. DATE: 7/19/88

DPR MAIN BOARD CI-0100 PARTS PLACEMENT SCHWEITZER ENGINEERING LABS

## SEL-49 BACKPLANE COMPONENT LIST DWG NO. C1-0101

| IDENTIFIER | DESCRIPTION | MFR | PART |
|---|---|---|---|
| ------- | CIRCUIT BOARD | SEL | X4-0101 |
| U201 | OPTO COUPLER | MOT | 4N35 |
| C201,203 | 15 UF 20V 10% TANT. CAP | | CSR13E156KM-2289 |
| C205 | 39 UF 10V 10% TANT. CAP | | CSR13C396KM-2259 |
| C202,204,206,<br>209,211,<br>214,216 | .1 UF MONOGLASS | CENTRALAB | C43C104ZNP |
| C207 | .01 UF/50V | | SR155E1032AA<br>OR<br>C320C103K1R5CA |
| C210,212,213,<br>215,217 | .022 UF 50V | CENTRALAB | C43C223MNP |
| C218-247 | .0047 UF 3000 WVDC CERAMIC | SPRAGUE | 564CZ5UAA30ZEJ472M |
| D201 | 1 AMP 1000 PRV | MOTOROLA | 1N4007 |
| R201 | 6.8K OHM 1/4W C.F. | | |
| R202 | 2.7M OHM 1/4W C.F. | | |
| R203<br>205-208,<br>210-213 | 56 OHM 1/4W C.F. | | |
| MOV201-203,<br>205-208,<br>210-213,222,223 | 18V VARISTOR | GE | V18ZA1 |
| MOV214-221<br>224 | 150V VARISTOR<br>(B240: 48/125V RELAYS)<br>250V VARISTOR<br>(B242: 220/250V RELAYS) | GE<br>MAIDA<br>GE | U150LA20<br>D65Z0V151RA20<br>V250LA40 |
| J201,202,<br>203 | CONNECTORS, 9-PIN FEMALE | CON-X-ALL | 4282-956 |
| P201 | 0.1" 17-PIN HEADER | MOLEX | 22-10-2171 |
| P202,203,204 | 0.2" 11-PIN HEADER | MOLEX | 10-16-1111 |
| P205 | 0.2" 8-PIN HEADER | MOLEX | 10-16-1081 |
| P206 | 0.2" 6-PIN HEADER | MOLEX | 10-16-1061 |

881121
B235- 48V
B230-125V
B231-220V
B232-250V

## SEL-49 INTERFACE BOARD COMPONENT LIST   DWG NO: C1-0105

| IDENTIFIER | DESCRIPTION | MFR | PART |
|---|---|---|---|
| ------- | CIRCUIT BOARD | SEL | X4-0105 |
| U501,503 | QUAD LINE RECIEVER | | MC1489 |
| U502 | QUAD LINE DRIVER | | MC1488 |
| U504 | QUAD SCHMITT NAND | | 74LS132 |
| U505 | DUAL 4 BIT COUNTER | | 74LS393 |
| U506 | DUAL D F/F | | 74LS74 |
| U507 | TIMER | | 555 |
| U508 | +12 REGULATOR | | 7812 |
| U515 | -12 REGULATOR | | 7912 |
| U509-514 | OPTO COUPLER | HP | HCPL3700 |
| R502-507 | 1K 1/4W 5% RESISTOR | | RCR07G102JS |
| R508 | 100K 1/4W 5% RESISTOR, CARBON | | RC07GF104J |
| R509-520 | 3.6K 1/2W 5% RESISTOR, CARBON (B235: 48V LOGIC INPUT) | | RC20GF362J |
| | 10K 1W 5% RESISTOR, CARBON (B230: 125V LOGIC INPUT) | | RC32GF103J |
| | 27K 1W 5% RESISTOR, CARBON (B231: 220V LOGIC INPUT) | | RC32GF273J |
| | 30K 2.5W 5% RESISTOR, CARBON (B232: 250V LOGIC INPUT) | | RS-2C |
| R527 | 3.3K 1/4W 5% RESISTOR | | RC07GF332J |
| C501 | .1 UF 600 VDC POLYESTER | SPRAGUE OR MALLORY | 6PS-P10 PXC-601 |
| C502-505 | .0047 UF 3000 VDC CERAMIC | SPRAGUE | 564CZ5UAA30ZEJ472M |
| C506,507,508 C516-521, 5001-5006 C542-557 | .1 UF 50V MONOGLASS | CENTRALAB | C43C104ZNP |
| C537,C540 | 100 UF 20V | KEMET | T310D107M020AS |
| C522-533 | 500 PF ± 20% 3KV | CENTRALAB | DD30501 |
| C510-515,538, 539 | 47UF35V ± 10% | KEMET | T310D476K035AS |
| C535-536 | 15 UF 20V TANTALUM 10% | MALLORY | CSR13E156KM-2289 |
| C534 | 39 UF 10V TANTALUM 10% | MALLORY | CSR13C396KL-2259 |
| Q501 | NPN TRANSISTOR | MOTOROLA | 2N2222A |
| Q502-508 | NPN DARLINGTON TRANS. | MOTOROLA MOTOROLA | MM6427 MPSA13 |
| D501-D508; 510-515;522 | DIODE | | 1N4007 |

| IDENTIFIER | DESCRIPTION | MFR | PART |
|---|---|---|---|
| D516-D521 | ZENER DIODE, 2.0V | MOTOROLA | 1N4679 or 1N4615 |
| D509 | JUMPER | | |
| B501 | BRIDGE RECTIFIER NOT USED IN 125/220/250 VOLT RELAYS | MOTOROLA | MDA206G |
| J501 | .1" RIGHT ANGLE, 17 CKT GOLD, PC BOARD CONNECTOR-FE | MOLEX | 22-16-2171 |
| J502,503,504 | .2" RIGHT ANGLE, 11 CKT TIN, PC BOARD CONNECTOR-FE | MOLEX | 10-10-1111 |
| J505 | .2" RIGHT ANGLE, 8 CKT | MOLEX | 10-16-1081 |
| J506 | .156 CONNECTOR TO POWER SUPPL | " | 09-50-7181 |
| P501 | LOW PROFILE STRAIGHT, 20 PIN HEADER | ANSLEY | 609-2053 |
| P502 | LOW PROFILE STRAIGHT, 50 PIN HEADER | ANSLEY | 609-5053 |
| J507 | FEMALE SOCKET, 20 PIN W/STRAIN RELIEF | | 609-2001M |
| J508 | FEMALE SOCKET, 50 PIN | | 609-5001M |
| ____ | 20 PIN CABLE | | |
| ____ | 50 PIN CABLE | | |
| K501-507 | RELAY, 5 VOLT COIL | P & B<br>SCHRACK<br>FUJITSU | RK11Z-4.5W<br>RP820-005<br>FBR621ND005 |

## SEL-49 TRANSFORMER TERMINATION COMPONENT LIST DWG NO. A1-0200

| IDENTIFIER | DESCRIPTION | MFR | PART |
|---|---|---|---|
| ------- | CIRCUIT BOARD | SEL | X4-0102 |
| J301 | 20-POS. 0.1" CONNECTOR | ANSLEY | 609-2001M |
| P301 | 20-POS. 0.1" SLIMLINE PCB HEADER | ANSLEY | 609-2053 |
| MOV305-308 | 18 VOLT MOV | GE | V18ZA1 |
| R305-308 | 10.0K 1/8W METAL FILM 1% | | |
| R313-316 | 2.49K 1/8W METAL FILM 1% | | |
| R317-320 | 1 OHM 2W METAL FILM 1% (B210: 5 AMP RELAYS) | | RS-2B |
| | 5 OHM 2W METAL FILM 1% (B211: 1 AMP RELAYS) | | RS-2B |
| C301 | .1 UF 50V MONOGLASS | | |
| CENTRALAB | C43C104ZNP | | |

## DISPLAY BOARD COMPONENT LIST DWG NO: A1-0200

| IDENTIFIER | DESCRIPTION | MFR | PART |
|---|---|---|---|
| ------- | CIRCUIT BOARD | SEL | X4-0103 |
| C401 | 0.1 UF 50V CERAMIC CAP | CENTRALAB | C43C104Z |
| D401;404-408 | RED LED | GI or PANASONIC | MV5753 or LN21RPHL |
| D402 | GREEN LED | GI or PANASONIC | MV5253 or LN31GPHL |
| D403 | AMBER LED | GI or PANASONIC | MV5353 or LN41YPHL |
| P401 | RIGHT ANGLE PCB HEADER | ANSLEY | 609-2007 |
| Q401-408 | NPN TRANSISTOR | | 2N2222 |
| R401-402; 404-408 | 330 OHM 1/4W 5% RESISTOR | MEPCO | 5043CX330R0J |
| R403 | 220 OHM 1/4W 5% RESISTOR | MEPCO | 5043CX220R0J |
| R409,411-417 | 1K 1/4W 5% RESISTOR | DALE | RCR07G102JS |
| R410 | 3.3K 1/4W 5% RESISTOR | | RC076F332J |
| PB1 | PUSHBUTTON | ITT | D60201 |

## SEL-49 MAIN BOARD COMPONENT LIST DWG NO. C1-0100

| IDENTIFIER | DESCRIPTION | MFR | PART |
|---|---|---|---|
| ----- | CIRCUIT BOARD | SEL | X4-0100 |
| U109-13 130,132,135 | 28 PIN SOCKETS | | |
| U115,138,139 | 24 PIN SOCKETS | | |
| U101,136,137, 140 | 40 PIN SOCKETS | | |
| U133 | 16 PIN SOCKET | | |
| U101 | 2 MHZ 8-BIT MICROPROCESSOR | MOTOROLA | MC68B09 |
| U136,137,140 | 2 MHZ PIA | " | MC68B21 |
| U130 | 2 MHZ PTM | " | MC68B40 |
| U138,139 | 2 MHZ ACIA | " | MC68B50 |
| U104 | QUAD NAND | MOTOROLA | 74LS00N or HD74S00P |
| U108 | QUAD AND | " | 74LS08 |
| U119 | TRIPLE THREE INPUT NOR | " | 74LS27 |
| U105 | QUAD OR | " | 74LS32 |
| U102,103 | 3 TO 8 DECODE | " | 74LS138 |
| U106 | 4-BIT U/D COUNTER | " | 74LS193 |
| U129 | BUS BUFFER | " | 74LS245 |
| U107 | CMOS 12BIT COUNTER | RCA | CD4040B or MC4040B or 74HC4040 |
| U109,110 | 16K EPROM | | 27128 |
| U111, | 8K EPROM | | 2764 |
| U112,113 | 8K CMOS RAM | | 6264 |
| U114 | NOT USED | | |
| U115 | 2K EEPROM | XICOR | X2816A |
| U117,118 | QUAD BIFET OPAMP | MOTOROLA | MC34004AP |
| U116,134 | DUAL BI-FET OPAMP | " | MC34002AP or LM353 or TL072 |
| U120-U128 | TRACK AND HOLD | NATIONAL | LF398A or LF398N8 |
| U132 | 16 CHANNEL MUX | HARRIS | AD7506 |
| U133 | 10-BIT DAC | A. DEVICES | AD7533JN |
| U135 | 12-BIT A/D CONVERTER | A. DEVICES | AD574AK |
| C145,147,149, 151 C1022-1025 | 15 UF 20V TANT CAP 10% | MALLORY | CSR13E156KM-2289 |
| C101,155, C1020,1021 | 39 UF 10V TANT CAP 10% | MALLORY | CSR13C396KM-2259 |

| IDENTIFIER | DESCRIPTION | MFR | PART |
|---|---|---|---|
| C160-199 | .1 UF MONO-GLASS | CENTRALAB | C43C104ZNP |
| C1000-1013 | | | |
| C142-144,146,148 | | | |
| C150,152,156 | | | |
| C104 | 15 pf 10% CERAMIC 50V | AVX | CSR151A150KAA |
| C105-112 | .01 UF 10% CERAMIC | KEMET | C320C103K1R5CA |
| C102 | 27 pf 10% CERAMIC | AVX | SR151A270KAA |
| C157 | 10 pf MONO-KAP | CENTRALAB | CN15A100J |
| C103 | 3.5-20 pf | JOHNSON | 274-0020-005 |
| C1026,1029 | 100 UF 20V | KEMET | T310D107M020A5 or T110D107K020A5 |
| C1027,1028 | 47 UF 35V 10% | KEMET | T310D476K035A5 or T322F476K035A5 |
| C114-121 | .033 UF 100V 1% | F-DYNE | PPA11-.033-100-3 |
| | | MEPCO | 703E1FJ333PF161AX |
| C123-130; 132-140 | .01 UF 100V 1% | F-DYNE | PPA11-.01-100-3 |
| | | MEPCO | 703E1FE103PF161AX |
| R101 | 22K 1/4W 10% RESISTOR | | RC07GF223 |
| R102,104,105, | 4.7K 1/4W 10% RESISTOR | | RC07GF472 |
| R112-114; 147,148 | 10K 1/8W ± 1% RESISTOR | | RN55D1002F |
| R115 | 3.32K 1/8W ± 1% RESITOR | | RN55D3321F |
| R145,146 | 49.9 OHMS 1/8W ± 1% RESISTOR | | 49R9FJ |
| R103 | 15K 1/4W 10% RESISTOR | | RC07GF153 |
| R111 | 2.43K 1/8W ± 1% RESISTOR | | RN55D2431F |
| R125-133 | 24.3K 1/8W ± 1% RESISTOR | | RN55D2432F |
| R116-123 | 2K 10T POT | BOURNS | 3296Y-1-202 |
| R135-143 | 1K 10T POT | " | 3296Y-1-102 |
| RP101,115 | 6.8K 8-PIN CONFORMAL | AB | 708B682 |
| RP108 | 4.7K 8-PIN CONFORMAL | AB | 708B472 |
| RP102,103 | 120K 8-PIN ± 1% | AB | 108B124 |
| RP109,110 | | | |
| RP107,114 | 10K 8-PIN | AB | 708B103 |
| RP116 | 6.8K 8-PIN | AB | 708A682 |
| D101 | DIODE | | 1N4007 |
| Y101 | 8 MHZ CRYSTAL | CRYSTEK | CY-86 - 8.000 |
| J101 | 20-PIN FEMALE CONN. W/ SR | ANSLEY | 609-2001M |

| IDENTIFIER | DESCRIPTION | MFR | PART |
|---|---|---|---|
| P101 | 20-PIN SLIMLINE SOLDER TERM. | ANSLEY | 609-2053 |
| P102,104 | 20-PIN RIGHT ANGLE PCB HEADER | ANSLEY | 609-2007 |
| P103 | 50-PIN RIGHT ANGLE PCB HEADER | | 609-5007 |
| J101-P101 | CABLE, FLAT | | |
| | SINGLEROW HEADER | | 929647-01-36 |
| | CONNECTOR | | 92995506-I |

# APPENDIX D

## PROGRAM TO COMPUTE TEST SET SETTINGS FOR TESTING DISTANCE RELAYS

# 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.

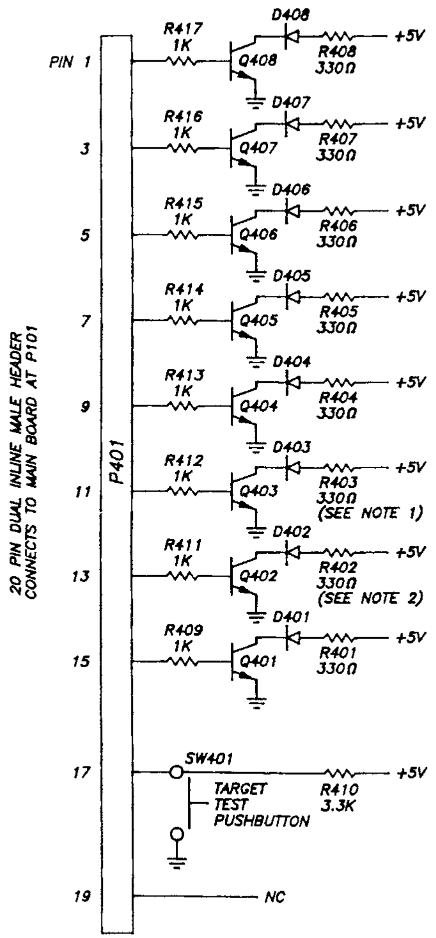
After you enter this data, the program begins computations. The display then shows voltages and currents for both an AG and BC fault. These data can be entered into any active test source.

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
```

# APPENDIX E

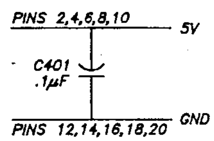
# CIRCUIT DIAGRAMS

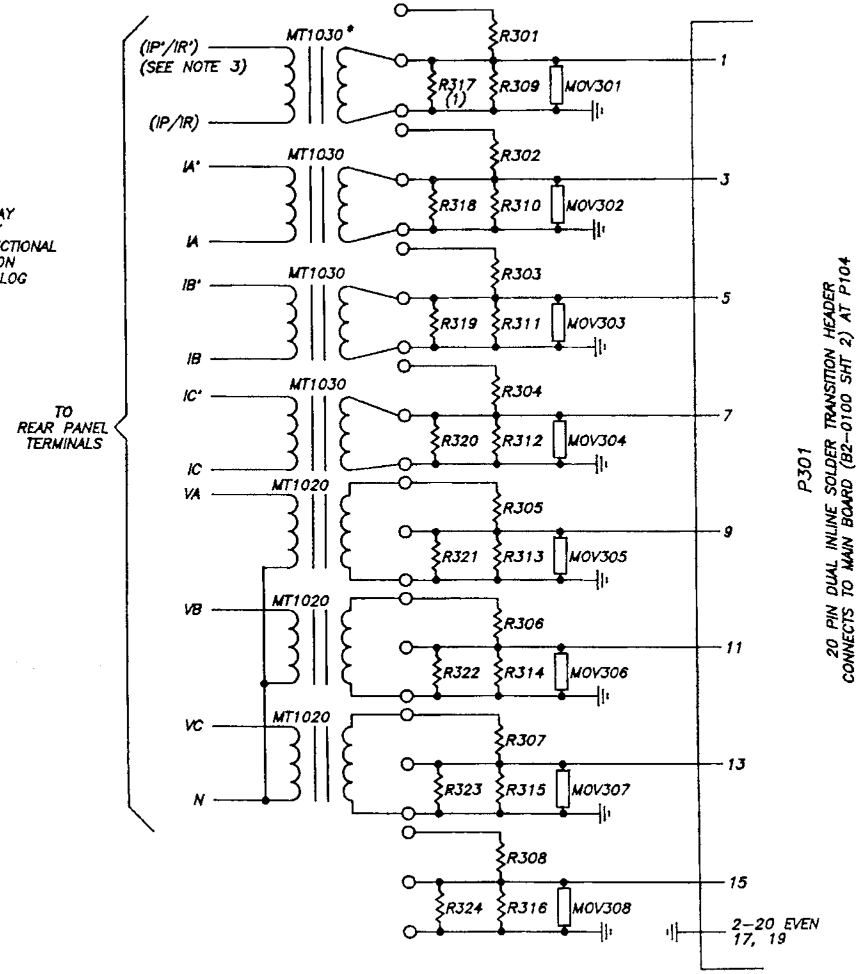



FRONT PANEL LED DISPLAY DPR–FP1
(B2–0103)

NOTES:

1. FOR SEL–49, USE R403=220 OHMS FOR AMBER LED.
2. FOR SEL–PG10, USE R402=220 OHMS FOR AMBER LED.
3. THIS ANALOG INPUT CHANNEL MAY OR MAY NOT BE INSTALLED DEPENDING ON RELAY PURCHASED. PLEASE CONSULT THE FUNCTIONAL DESCRIPTION SECTION OF THE INSTRUCTION MANUAL FOR MORE DETAILS ON THE ANALOG INPUTS.




TRANSFORMER TERMINATION BOARD DPR–TT2
(B2–0102)





| | | |
|---|---|---|
| UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE IN INCHES | | |
| .XXX DIMENSIONS NOT TO SCALE | | |
| USED ON | RELEASED | |
| | APP. | |
| | CH. | |
| | DR. | |

TOL. EXCEPT AS NOTED

HOLE DIA.

.XX ± .01"
.XXX ± .005"
ANG. ± 1°

| ITEM | PART NO. | DESCRIPTION | QTY. |
|---|---|---|---|

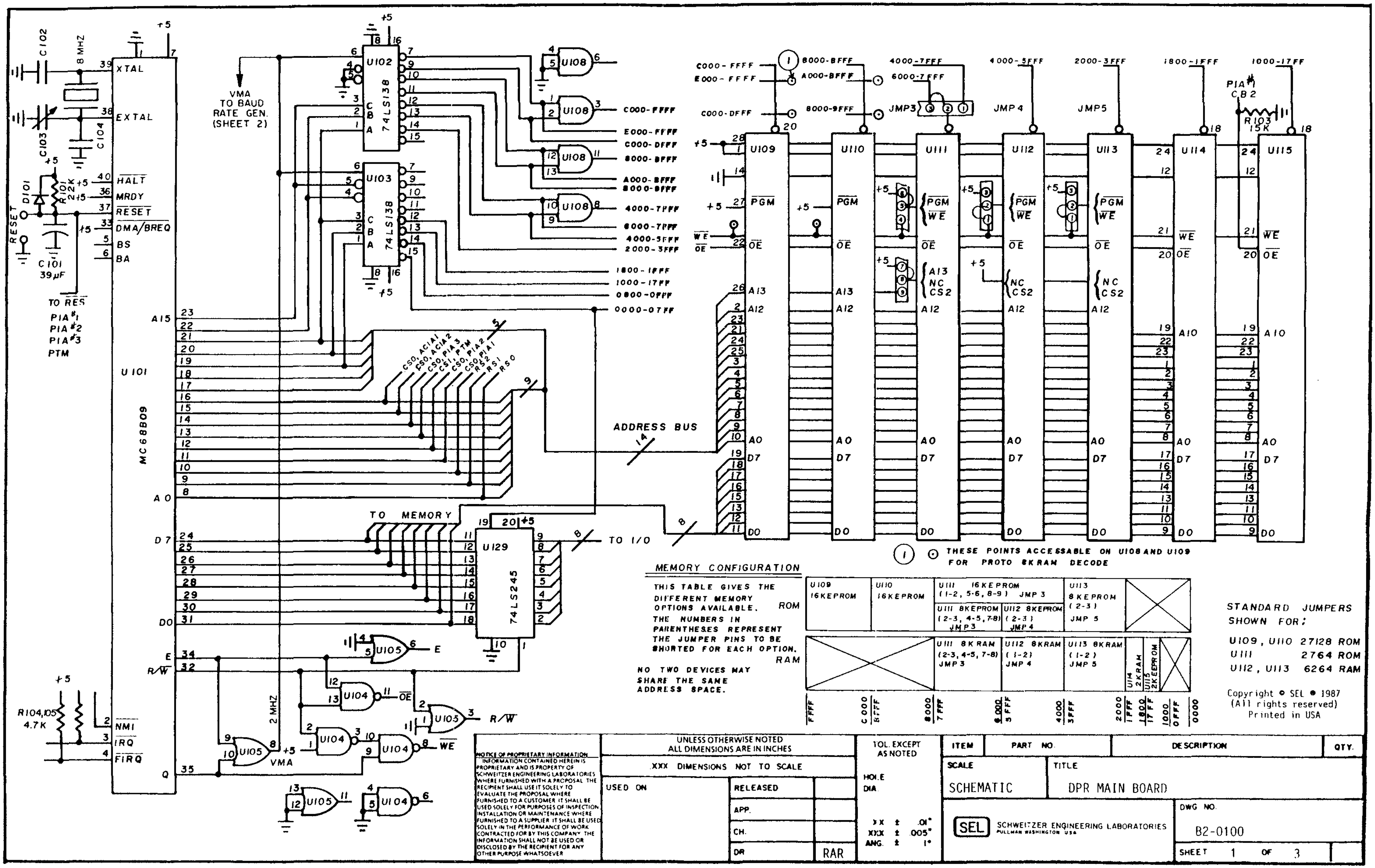
SCALE: NONE

TITLE: TRANSFORMER TERMINATION BOARD (TT2)
FRONT PANEL LED DISPLAY (FP1)

SEL SCHWEITZER ENGINEERING LABORATORIES
PULLMAN WASHINGTON USA

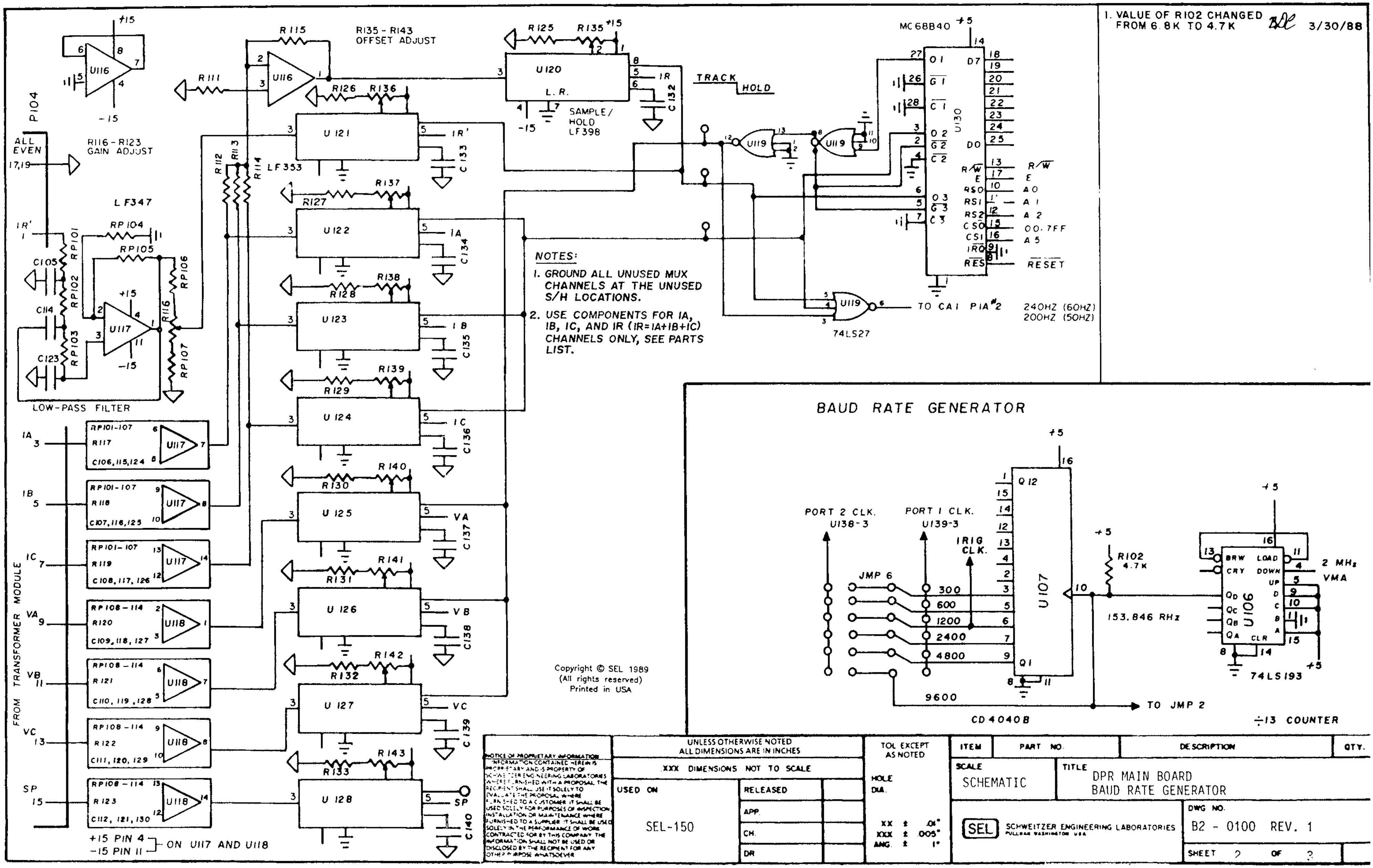
DWG. NO. B2–0103 (FP1)
B2–0102 (TT2)
REV. 1

SHEET 1 OF 1



MC68B09
U101
XTAL
EXTAL
HALT
MRDY
RESET
DMA/BREQ
BS
BA
NMI
IRQ
FIRQ
C102
8 MHZ
C103
C104
D101
R101 22K
C101 39µF
RESET
TO RES
PIA #1
PIA #2
PIA #3
PTM
R104,105 4.7K
VMA TO BAUD RATE GEN. (SHEET 2)
U102 74LS138
U103 74LS138
U108
C000-FFFF
E000-FFFF
C000-DFFF
8000-BFFF
A000-BFFF
8000-9FFF
4000-7FFF
6000-7FFF
4000-5FFF
2000-3FFF
1800-1FFF
1000-17FF
0800-0FFF
0000-07FF
CS0, ACIA1
CS0, ACIA2
CS0, PIA 3
CS1, PTM
CS0, PIA2
CS0, PIA1
RS2
RS1
RS0
ADDRESS BUS
TO MEMORY
U129 74LS245
TO I/O
U105
U104
2 MHZ
VMA
R/W
WE
OE
E
Q
U109
U110
U111
U112
U113
U114
U115
JMP3
JMP4
JMP5
PIA #1 CB2
R103 15K
PGM
A13
A12
A10
A0
D7
D0
NC
CS2
THESE POINTS ACCESSABLE ON U108 AND U109 FOR PROTO 8K RAM DECODE
MEMORY CONFIGURATION
THIS TABLE GIVES THE DIFFERENT MEMORY OPTIONS AVAILABLE. THE NUMBERS IN PARENTHESES REPRESENT THE JUMPER PINS TO BE SHORTED FOR EACH OPTION.
NO TWO DEVICES MAY SHARE THE SAME ADDRESS SPACE.
ROM
RAM
U109 16K EPROM
U110 16K EPROM
U111 16K EPROM (1-2, 5-6, 8-9) JMP 3
U113 8K EPROM (2-3) JMP 5
U111 8K EPROM (2-3, 4-5, 7-8) JMP 3
U112 8K EPROM (2-3) JMP 4
U111 8K RAM (2-3, 4-5, 7-8) JMP 3
U112 8K RAM (1-2) JMP 4
U113 8K RAM (1-2) JMP 5
U114 2K RAM
U115 2K EEPROM
FFFF
C000 BFFF
8000 7FFF
6000 5FFF
4000 3FFF
2000 1FFF
1800 17FF
1000 0FFF
0000
STANDARD JUMPERS SHOWN FOR:
U109, U110 27128 ROM
U111 2764 ROM
U112, U113 6264 RAM
Copyright © SEL ● 1987
(All rights reserved)
Printed in USA
UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE IN INCHES
XXX DIMENSIONS NOT TO SCALE
TOL. EXCEPT AS NOTED
HOLE DIA.
.XX ± .01"
.XXX ± .005"
ANG. ± 1°
USED ON
RELEASED
APP.
CH.
DR RAR
ITEM
PART NO.
DESCRIPTION
QTY.
SCALE SCHEMATIC
TITLE DPR MAIN BOARD
SEL SCHWEITZER ENGINEERING LABORATORIES PULLMAN WASHINGTON USA
DWG NO. B2-0100
SHEET 1 OF 3
NOTICE OF PROPRIETARY INFORMATION
INFORMATION CONTAINED HEREIN IS PROPRIETARY AND IS PROPERTY OF SCHWEITZER ENGINEERING LABORATORIES WHERE FURNISHED WITH A PROPOSAL THE RECIPIENT SHALL USE IT SOLELY TO EVALUATE THE PROPOSAL WHERE FURNISHED TO A CUSTOMER IT SHALL BE USED SOLELY FOR PURPOSES OF INSPECTION, INSTALLATION OR MAINTENANCE WHERE FURNISHED TO A SUPPLIER IT SHALL BE USED SOLELY IN THE PERFORMANCE OF WORK CONTRACTED FOR BY THIS COMPANY. THE INFORMATION SHALL NOT BE USED OR DISCLOSED BY THE RECIPIENT FOR ANY OTHER PURPOSE WHATSOEVER

1. VALUE OF R102 CHANGED FROM 6.8K TO 4.7K 3/30/88




NOTES:

1. GROUND ALL UNUSED MUX CHANNELS AT THE UNUSED S/H LOCATIONS.
2. USE COMPONENTS FOR IA, IB, IC, AND IR (IR=IA+IB+IC) CHANNELS ONLY, SEE PARTS LIST.





UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE IN INCHES

XXX DIMENSIONS NOT TO SCALE

| USED ON | RELEASED | |
|---|---|---|
| SEL-150 | APP. | |
| | CH. | |
| | DR | |

TOL EXCEPT AS NOTED

HOLE DIA.

XX ± .01"
XXX ± .005"
ANG. ± 1°

| ITEM | PART NO. | DESCRIPTION | QTY. |
|---|---|---|---|

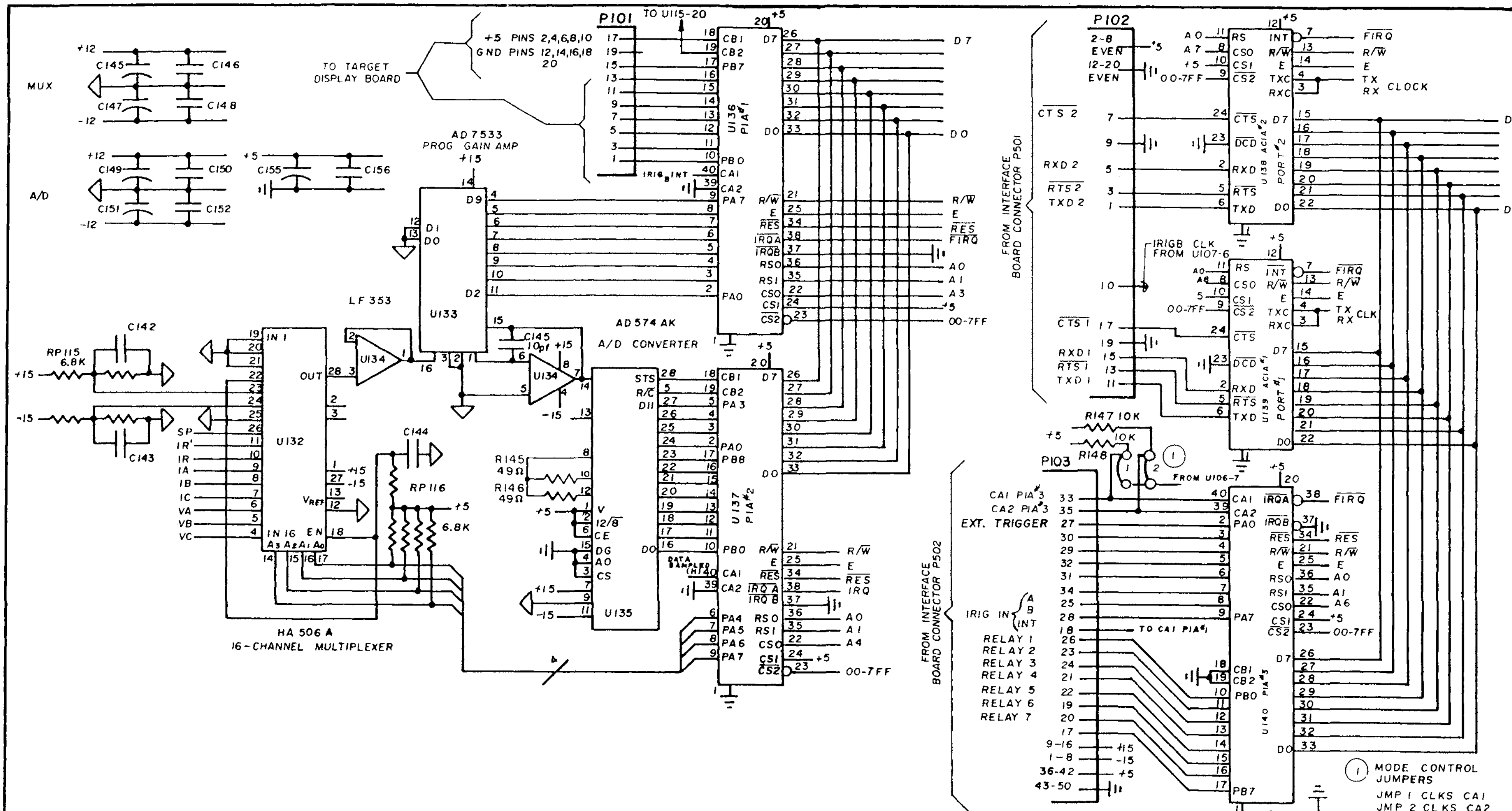
SCALE: SCHEMATIC

TITLE: DPR MAIN BOARD BAUD RATE GENERATOR

SEL SCHWEITZER ENGINEERING LABORATORIES PULLMAN WASHINGTON USA

DWG NO. B2 - 0100 REV. 1

SHEET 2 OF 2




1 R140 AND R141 CHANGED TO R143 AND R144, RESPECTIVELY. CHANGED R145 AND R146 TO 49Ω RESISTORS. BBC 3/30/88





UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE IN INCHES

XXX DIMENSIONS NOT TO SCALE

| USED ON | RELEASED |
|---|---|
| SEL-150 | APP. |
| | CH. |
| | DR |

TOL EXCEPT AS NOTED

HOLE DIA.

XX ± .01"
XXX ± .005"
ANG. ± 1°

| ITEM | PART NO. | DESCRIPTION | QTY. |
|---|---|---|---|

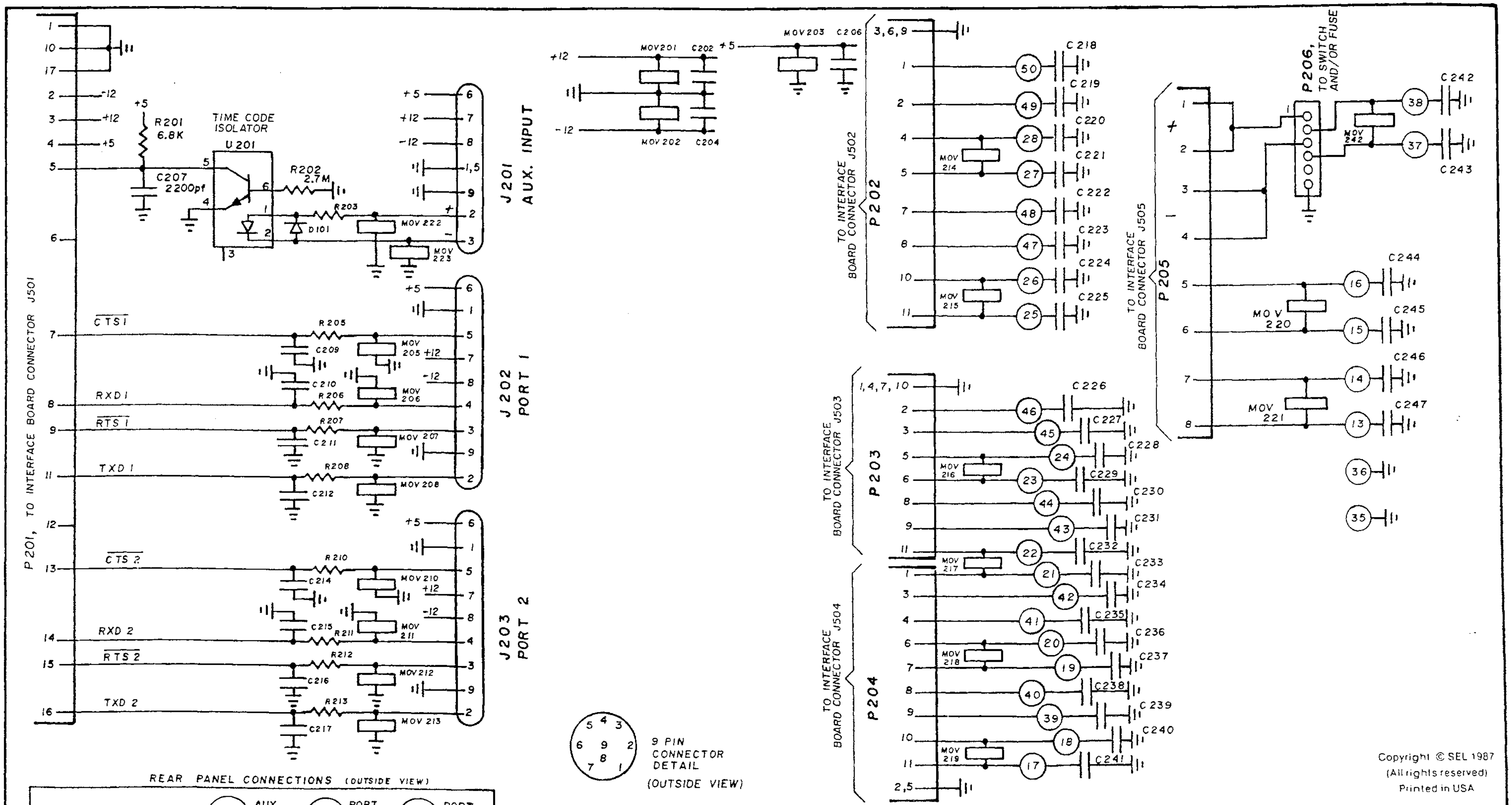
SCALE: SCHEMATIC

TITLE: DPR MAIN BOARD

SEL SCHWEITZER ENGINEERING LABORATORIES PULLMAN WASHINGTON USA

DWG NO. B2 - 0100 REV. 2

SHEET 3 OF 3








UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE IN INCHES
XXX DIMENSIONS NOT TO SCALE

| USED ON | RELEASED | |
|---|---|---|
| | APP. | |
| | CH. | |
| | DR | RAR |

TOL. EXCEPT AS NOTED
HOLE DIA.
XX ± .01"
XXX ± .005"
ANG. ± 1°

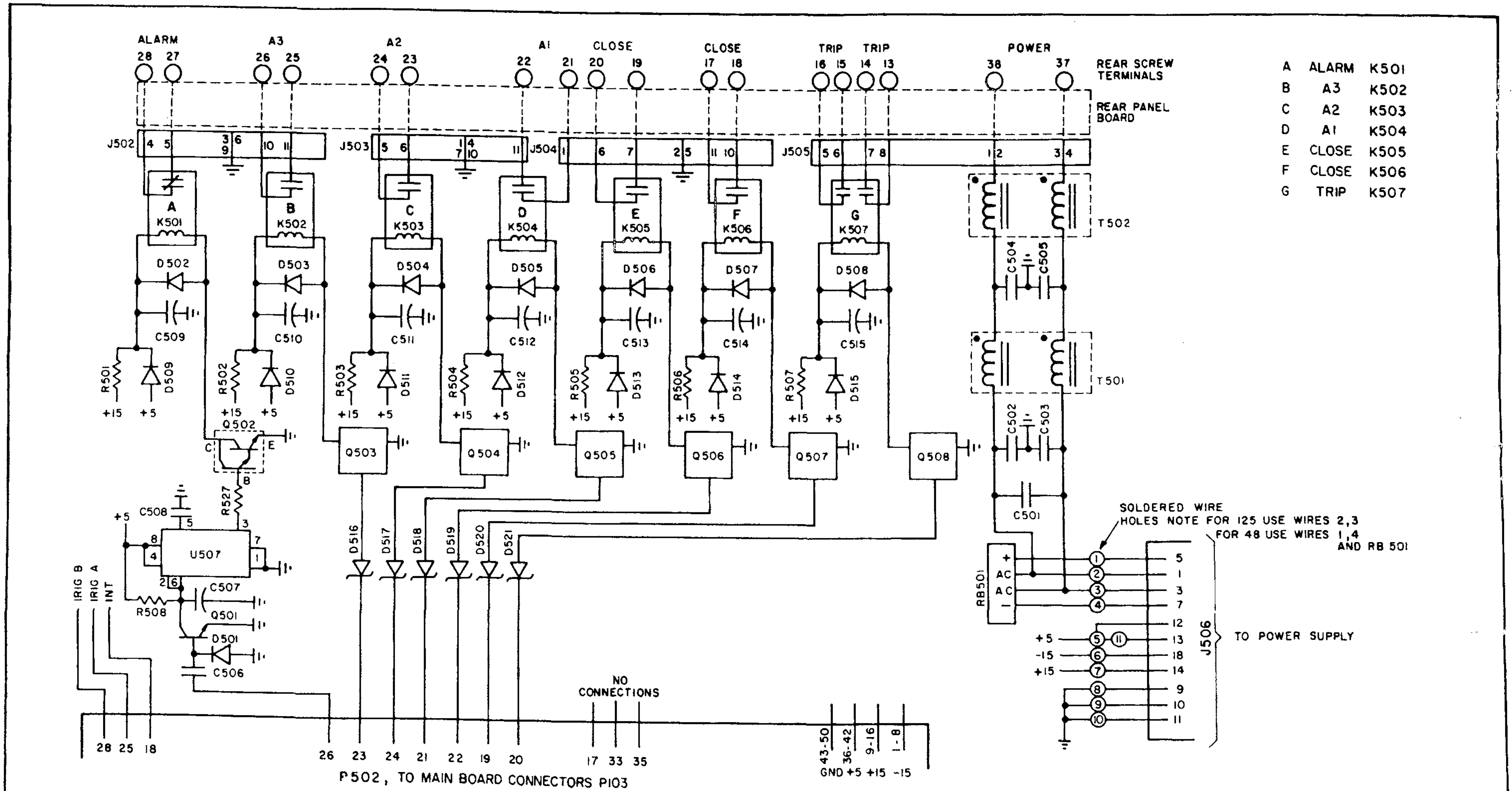
| ITEM | PART NO. | DESCRIPTION | QTY. |
|---|---|---|---|

SCALE: SCHEMATIC
TITLE: DPR BACKPLANE

SEL SCHWEITZER ENGINEERING LABORATORIES, PULLMAN WASHINGTON USA

DWG NO. B2-0101

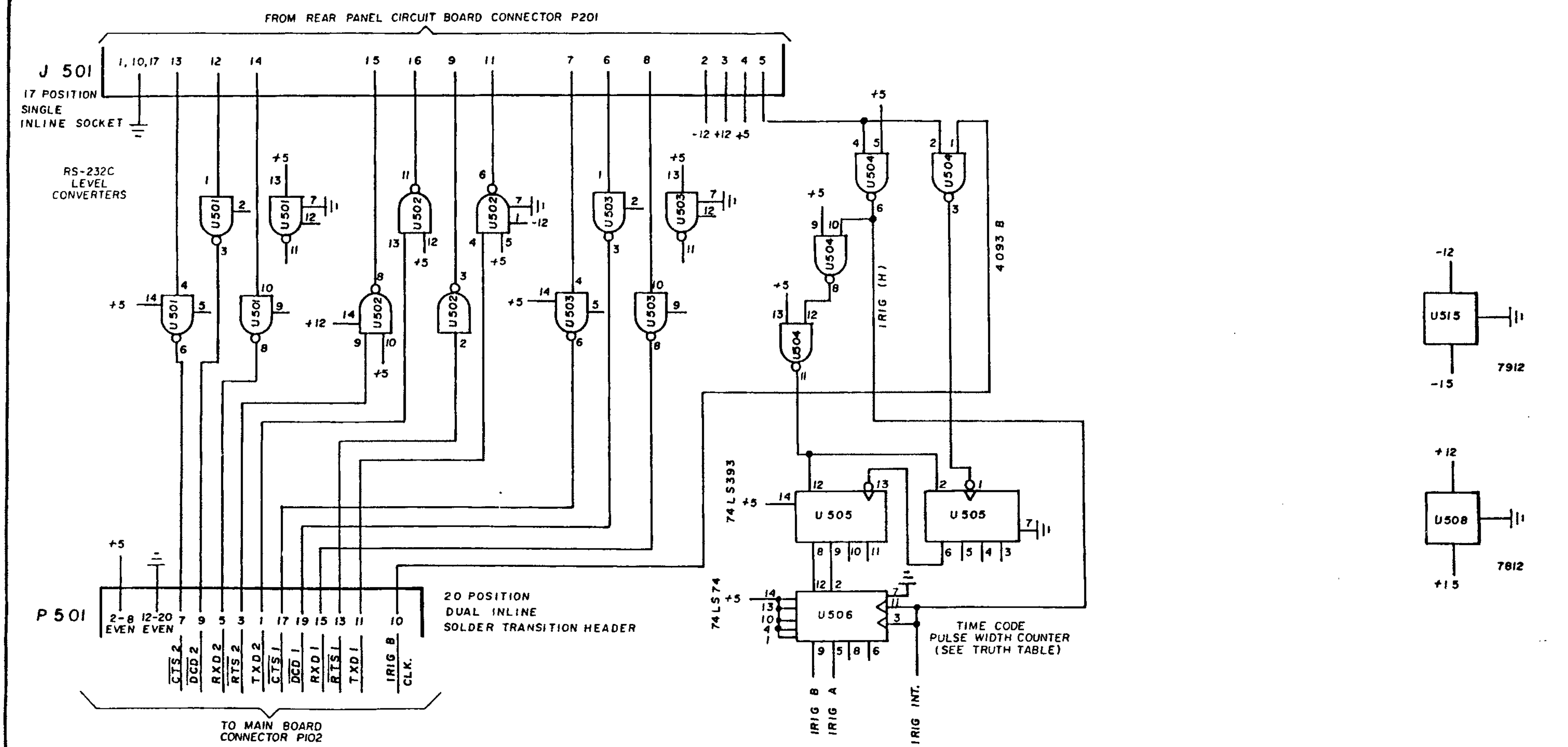
SHEET 1 OF 1








| | | | |
|---|---|---|---|
| UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE IN INCHES | TOL. EXCEPT AS NOTED | ITEM / PART NO. / DESCRIPTION | QTY. |
| .XXX DIMENSIONS NOT TO SCALE | HOLE DIA. | SCALE: SCHEMATIC | TITLE: DPR INTERFACE BOARD |
| USED ON: SEL-49 | XX ± .01" | DWG. NO. 82-0105B | REV. 1 |
| RELEASED | XXX ± .005" | SEL SCHWEITZER ENGINEERING LABORATORIES PULLMAN WASHINGTON USA | |
| APP. | ANG. ± 1° | SHEET 1 OF 3 | |
| CH. | | | |
| DR JS | | | |




IRIG TRUTH TABLE

| IRIG B | IRIG A | PULSE DURATION (μs) | | DECODE AS |
|---|---|---|---|---|
| O | O | O → 3328 | NOM 2000 | START |
| O | I | 3328 → 6656 | NOM 5000 | MARK |
| I | O | 6656 → 9984 | NOM 8000 | ZERO |
| I | I | — | — | — |
| PA 7 | PA 6 | | | |





UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE IN INCHES

XXX DIMENSIONS NOT TO SCALE

USED ON | RELEASED | APP. | CH. | DR

TOL EXCEPT AS NOTED

HOLE DIA.

XX ± .01"
XXX ± .005"
ANG. ± 1°

| ITEM | PART NO. | DESCRIPTION | QTY. |
|---|---|---|---|

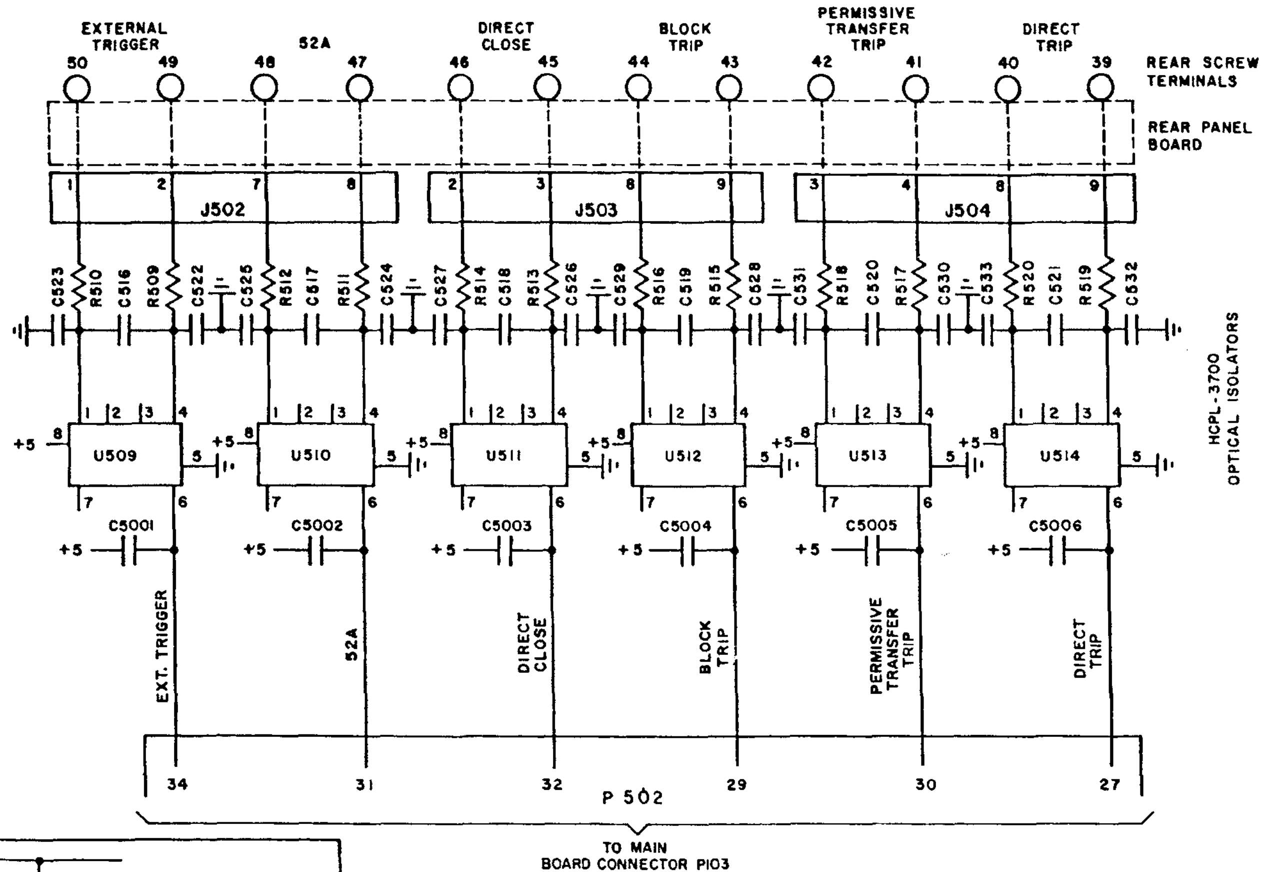
SCALE: SCHEMATIC

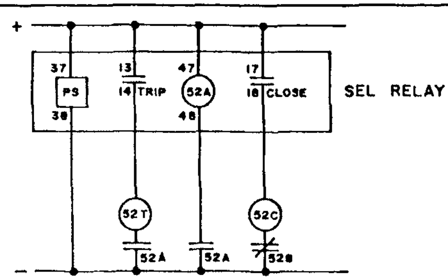
TITLE: DPR INTERFACE BOARD

SEL SCHWEITZER ENGINEERING LABORATORIES PULLMAN WASHINGTON USA

DWG NO. B2-0105

SHEET 2 OF 3




TYPICAL DC CONNECTIONS (PARTIAL)





UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE IN INCHES

XXX DIMENSIONS NOT TO SCALE

| USED ON | | |
|---|---|---|
| | RELEASED | |
| | APP | |
| | CH | |
| | DR | JS |

TOL EXCEPT AS NOTED
HOLE DIA
XX ± .01"
XXX ± .005"
ANG ± 1°

| ITEM | PART NO | DESCRIPTION | QTY |
|---|---|---|---|

SCALE: SCHEMATIC

TITLE: DPR INTERFACE BOARD

SEL SCHWEITZER ENGINEERING LABORATORIES PULLMAN WASHINGTON USA

DWG NO. B2-0105

SHEET 3 OF 3

# APPENDIX F

# REFERENCES

# REFERENCES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2. Duffie, J.A., and Beckman, W.A., Solar Energy Thermal Processes, A Wiley-Interscience Publication, 1974, John Wiley and Sons, New York, N.Y.

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