

Type LCB II

Current Differential Line Protection Relay System (with DIN Connectors)

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TABLE OF CONTENTS

APPLICATION	1
INSTALLATION	5
CONSTRUCTION	5
OPERATION	6
LCB II CHARACTERISTICS	12
SETTINGS	14
ROUTINE MAINTENANCE	20
RECOMMENDED TEST EQUIPMENT	21
LCB II ACCEPTANCE TEST PROCEDURE	21
LCB II CALIBRATION PROCEDURE	31
FIELD SETUP AND VERIFICATION PROCEDURE ..	33
LCB II SYSTEM FUNCTIONAL TEST PROCEDURE	36
SYSTEM CALIBRATION	39
RENEWAL PARTS	41
LCB II CATALOG NUMBER	42
LCB II GLOSSARY OF TERMS	43
INSTRUCTION LEAFLET REFERENCE	44
LIST OF FIGURES	45



CAUTION

It is recommended that the user of this equipment become acquainted with the information in these instructions before energizing the LCB and associated assemblies. Failure to observe this precaution may result in damage to the equipment.

Printed circuit modules should not be removed or inserted while the LCB is energized. Failure to observe this precaution can result in an undesired tripping output and/or component damage. In addition, modules should not be interchanged between relays without re-checking calibration.

All integrated circuits used on the modules are sensitive to and can be damaged by the discharge of static electricity. Electrostatic discharge precautions should be observed when handling modules or individual components.

While performing relay tests, care should be exercised to prevent accidental module extractions from chassis while the relay is energized.

1.0 APPLICATION

1.1 Universal Application

The LCB relay is a 3-phase, solid-state current differential relay system for high speed pilot protection applications. It is suitable for any system voltage, sub-transmission through UHV transmission, and may be applied on any length line, up to 250 miles (400 km). The LCB can be supplied loose and unmounted or completely mounted and wired in a panel.

1.2 Construction

The basic LCB is a self-contained, 19" wide rack mounting chassis (3 RU high), prewired for all available options. The relay can be supplied with an integral audio-tone output suitable for interface with the user's leased lines (3002 or equivalent), microwave or carrier with equivalent 3002 characteristics or an

All possible contingencies which may arise during installation, operation or maintenance, and all details and variations of this equipment do not purport to be covered by these instructions. If further information is desired by purchaser regarding this particular installation, operation or maintenance of this equipment, the local ABB Inc. representative should be contacted.

optional fiber-optic interface can be supplied for direct connection to the user's fiber-optic cable. An integral direct transfer trip option can be supplied, eliminating the need for separate channel equipment.

When supplied for audio-tone application, a separate tone protection package is recommended. The tone protection package consists of a surge protector and isolating transformer in a 19" wide rack mounting panel (2 RU high). For the fiber-optic applications, an optional fiber assembly can be supplied with connectors on each end. The user cuts the cable in half for splicing to his cable bundle or connects directly with the appropriate optical connector. All external connections to the relay are made to terminal blocks on the rear of the chassis.

1.3 Installation and Testing

Most adjustments and test points are available from the front panel to simplify installation and testing. An optional test panel consisting of 2 FT-1 switches on a 19" wide steel panel (3 RU) can be used to disconnect the ac inputs and dc outputs and provide a means for direct connection of the type UCTB portable, functional test box. This allows the user to completely, functionally test the relay system. Card extenders can also be supplied for simplified diagnostics. In addition, options can be added in the field or the system can be converted for 3-terminal-line protection by the simple addition of plug-in modules - no rewiring of the relay chassis is required.

1.4 Features

Both relay and channel equipment are contained in one chassis, which is prewired for all available options.

Flexibility of communications channel:

- Integral audio tone suitable for interface with leased line, microwave, single-side-band carrier, or T1 carrier systems.
- Optional fiber-optic interfaces are available for Multi-mode or Single-mode fibers at wavelengths of 850 nm or 1300 nm.

Fiber-optic channel is immune to station ground mat rise or longitudinally induced voltages.

Optional direct transfer trip function (patented).

High speed operation:

- Trip Time
10-30 ms, with time decreasing as multiples above pickup increases.

Current only system - no potential required:

- Extremely low ct burden
- Accommodates 3 to 1 difference in ct ratios.
- Immune to system swings (out-of-step).
- Available for either 1 A or 5 A ct secondary, 50 or 60 Hz.

Provides 2-terminal line protection, with option for 3-terminal line protection.

Weakfeed capability will trip all terminals if pickup level is reached at any one terminal.

High speed channel monitoring circuits (patented), provide condition indication, alarm contacts, and input to trip decision logic.

Fully independent positive, negative and zero-sequence sensitivity settings.

True magnitude comparison up to 5 times pickup – then a gradual change to phase comparison above 5 times pickup.

Advanced SNR detection circuit (patented), minimizes noise effect on audio-tone interface applications.

Self-contained, adjustable channel delay equalization, with independent settings for 2 and 3-terminal applications.

Relay waveform distortion eliminated—comparison based on composite sequence network output with linear response up to 25 p.u.

Unique comparison circuit (patented) performs a true phasor evaluation of the local and remote qualities.

Unique sequence network (patented) vastly improves the phase and magnitude dependency and sequence purity problems found in traditional designs.

Pulse-period modulation (patented) provides secure information transmission and accurate, wide-range current phasor reproduction.

Field set-up adjustments and test points available from front panel of modules.

Optional tone protection package consisting of surge protector and isolating transformer in 19" rack mounting (2RU) panel recommended for all audio-tone interface applications to leased lines. Optional 19-inch

rack mounting (3 RU) test panel with FT-1 switches – disconnects ac inputs and dc outputs to facilitate field testing, and provides breaker simulation.

Optional type UCTB portable test box to perform functional system test.

Optional UME-3 card extender provides access to all adjustments and test points on printed circuit modules.

Meets ANSI C37.90 and IEC-255 specifications

LCB relay system and all major options identified by a single, unique catalog number.

1.5 Benefits

Self-contained 19" rack mounting chassis (3 RU high) requires minimal panel or rack space allocation.

Prewired chassis enables user to add functions or change channel interface at any time – no chassis re-wiring required.

Provides full range of channel options:

- Audio-tone interface for leased line, power line carrier or microwave.
- Fiber-optic interface for direct connection of user's fiber-optic cable.

Use of fiber-optic channel eliminates the need for separate mutual drainage reactor and neutralizing reactor.

Eliminates need for separate channel equipment by providing integral direct transfer trip option.

High speed operation – applicable to any system voltage.

Current only fault detection simplifies installation – eliminates need for potential input for relay operation.

Accommodation of 3 to 1 difference in ct ratios permits simplified upgrades of existing installations.

Universal application – 1A or 5A ct's, 50 or 60 Hz.

Can be converted for 3-terminal-line protection at any time by simple addition of plug-in modules – no field re-wiring of chassis required.

Inherent weakfeed trip capability – no additional relays required.

Provides the user flexibility of choice in a loss-of-channel condition:

- Block tripping following loss-of-channel.
- Trip as an overcurrent relay following loss-of-channel.
- Trip as an overcurrent relay after an adjustable time delay following loss-of-channel (Zone 2 type function).
- Trip as an overcurrent relay for 150 ms following loss-of-channel. Unblock feature.
- Combination of Unblock followed by time-delayed overcurrent trip.

Contains ability to remotely convert the unit to an overcurrent trip mode, with the option to remove or sustain the local channel transmission.

Greater installation flexibility: ct neutral does not need to be formed at the relay; LCB input current transformers are connected to phase currents only.

More reliable operation than conventional systems is possible by advanced LCB features, many of which are patented or have patents pending.

Installation, testing and setting simplified – front panel adjustments and test points.

LCB system test is greatly simplified by use of optional test panel, type UCTB portable functional test box, and type UME-3 card extenders.

Ordering information simplified – complete system defined by a single catalog number.

Simplified wiring – all external connections are made to terminal blocks on the rear of the chassis.

Simplified fiber-optic connection – a cable with connectors at each end (one for transmitter, one for receiver) is available. The user then cuts the cable in half and splices to his cable bundle or connects directly with the appropriate fiber-optic connector.

1.6 Channel Considerations

1.6.1 Audio-Tone

The audio-tone system contains many security oriented features and provides interface with unconditioned 3002 circuits, microwave channels, single-sideband power line carrier, or circuits with equivalent characteristics. Transmit level is adjustable from +15 to -40 dBm with a 600 ohm balanced output. Receiver sensitivity is adjustable from 0 to -40 dBm and with AGC control has a ± 10 dBm dynamic operating

range. The system operates with up to a 17 dB signal-to-noise ratio over a 3 kHz bandwidth.

An optional audio-tone surge protection package is available for added telephone line interface protection. Further recommended protection is shown on Figure 17 (see page 58) for both exposed and unexposed leased cable circuits.

The audio tone protection package is also required as part of an LCB II system where the user requires the audio tone inputs and outputs to have capability for surge withstand protection (impulse and SWC) per ANSI and IEC Standards and dielectric withstand capability in excess of 1500 Vac (1 minute).

1.6.2 Fiber-Optic

The most common fiber being used today for medium range communication systems is a graded index fiber with a core diameter of 50 micrometers referred to as 50/125 (50 micrometer core/125 micrometer cladding).

This type of fiber attempts to limit pulse dispersion and, as a result, has a very large bandwidth for high density communication systems. If fibers are being installed for high density communications along with fibers in the same cable for use with the LCB, then the 50 micrometer graded index fiber is the best choice. If on the other hand, a fiber is being installed only for the purposes of the LCB then the 50 micrometer fiber is not the best choice. In the latter case, a fiber with a larger diameter would be preferred.

The LCB does not need a large bandwidth, in fact, its bandwidth is limited to about 2 kHz, and all optical fibers can transmit this small bandwidth. The most important items of concern are the amount of light that gets into the fiber and the total loss of the fiber. Since the LED used has a light-emitting area of about 300 micrometers in diameter any fiber with a smaller diameter will cause a significant loss of light when coupling to the fiber. When the LED is coupled to a 50 micrometer fiber a light loss of 20 dB is encountered. This is primarily due to the diameter difference of the LED spot and the cable diameter. If a large cable is used then the loss is less and more light is available for transmission.

The 50-micrometer fiber is the reference in the LCB when considering channel loss capability, and the maximum allowable channel attenuation for this fiber is 40 dB when used at a wavelength of 850 nanometers. The 40 dB is based on the given light source and the detector selected. The coupling losses have already been taken into account and the 40 dB is just losses in the fiber-optic cable itself, splice losses, and connector losses. The channel attenuation limit listed above allows for a 3 dB system degradation and a minimum of 20 dB signal-to-noise ratio at the receiver.

The following is an example of a loss calculation. Assume that the fiber being used has an average loss of 4 dB per km at 850 nm and the optical channel length is 8.5 km with 8 fusion type splices (.5 dB/splice) and 2 connectors (1 dB/connector). The example described represents the maximum channel loss for this system. If the cable had been a 100 micrometer cable with the same cable loss per km then the system would handle an added length of 1.5 km. This is because of the extra light which would be coupled to the larger fiber.

The LCB is also available for operation at a wavelength of 1300 nm, where fiber attenuation is generally lower, with either graded-index dual-window 50/125 fiber or with Single-mode 9/125 fiber.

The light power level encountered when the 1300 nm LED is coupled into a 50 micrometer graded-index dual-window fiber is approximately -25 dBm, and that for a 9 micrometer Single-mode fiber is approximately -40 dBm. The loss is basically due to the diameter difference between the LED spot and the fiber core. The larger the fiber used, the lower the coupling loss will be.

At 1300 nm LED systems, the maximum allowable channel attenuation for the 50/125 graded-index dual-window fiber is 30 dB. For Single-mode 9/125 fiber, the maximum allowable channel attenuation is 15 dB. These attenuation levels are based on the LED light source and PIN detector selected, and consist of losses in the fiber-optic cable itself, splice losses, and connector losses. (The LCB coupling losses have already been accounted for.) The stated channel attenuation limits allow for a 3 dB system degradation and a minimum of 20 dB signal-to-noise ratio at the receiver.

The 1300 nm High Power IFO module with Edge Emitting LED provides -30 dBm optical power output into 9/125 μ m Single-Mode fiber over the entire temperature ranges of -20°C to +55°C.

The corresponding worst case PIN Receiver's sensitivity is -58 dBm. The total resulting power budget of 28 dB can be distributed as below:

48 km of 9/125 SMF cable at 0.5 dB/km	=	24 dB
10 fusion Splices 0.1 dB each	=	1 dB
Long Term Channel Degradation	=	3 dB
		<u>28 dB</u>

The maximum repeaterless channel length is 48 km.

The following tabulation compares various options. Please note that the numbers are *for guidelines only* and the power losses are to be calculated for each actual configuration of communication channel.

WAVELENGTH AND MODE	TOTAL ATTENUATION IN SYSTEM (dB)	CABLE ATTEN (dB/km)	DISTANCE (km)
850nm, Multi-mode	40	3.0	12
1300nm, Multi-mode	30	1.5	18
1300nm, Single-mode	15	0.5	24
1300nm, Single-mode, with "High Power"	28	0.5	48

As an example of a loss calculation for a 9/125 fiber:

Assume the average loss of the fiber used to be 0.5 dB/km at 1300 nm, and the optical channel length 20 km, with 6 fusion-type splices (0.5 dB/splice) and 2 connectors (1 dB/connector).

$$\begin{aligned} \text{Channel loss} = & \\ (20 \text{ km}) (0.5 \text{ dB/km}) + & \\ 6 \text{ splices } (0.5 \text{ dB/splice}) + & \\ 2 \text{ connectors } (1 \text{ dB/connector})^* = & 15 \text{ dB} \end{aligned}$$

The example described above represents the maximum channel loss for this system. If the cable had been 50/125 dual-window, with a typical loss of 2 dB/km (at 1300 nm), having the same number of splices and connectors, the maximum repeaterless channel length would have been only 12.5 km. However, if a larger core multi-mode graded-index fiber is used, (with 2 dB/km) this distance would be greater, since more power can be coupled to the fiber.

* These are connectors other than the LCB terminal connectors.

2.0 INSTALLATION

Individual chassis are shipped in separate packing cartons except when supplied as part of a complete relay system. Care should be taken when opening to ensure that the equipment is not damaged or scratched.

The LCB relay, test panel (when used) and audio-tone protection package (when used) should be mounted on switchboard panels or their equivalent, in a location free from dirt, moisture, corrosive fumes, excessive vibration and heat. Mount the chassis by means of the slotted holes on the front of the case. Additional support should be provided toward the rear of the units in order to protect against warping of the front panel mounting due to extended weight within the chassis.

Care should be taken when wiring the LCB inputs and outputs in order to reduce the possibility of false signals induced between the leads and from external sources. Refer to "Silent Sentinels" publication RPL 79-2 for recommended protection practices.

System interconnection when associated with the LCB, test panel (when used) and audio-tone protection package (when used) is shown on systems schematics Figures 8 and 9 (tones) (see page 52) and Figures 10 and 11 (see page 54) (optical). All chassis should be grounded with 14 AWG (or larger diameter) copper wire to the appropriate studs or frame.

All equipment should be operated within an ambient temperature range of -20° to +60°C. Ventilation may be required to insure that environment temperature of 60°C is not exceeded within the enclosure in which the equipment is mounted.

3.0 CONSTRUCTION

3.1 LCB II

The Type LCB II Relay is mounted on a 19" wide panel, 5.25 inches high (3 rack units) with slotted edge holes for mounting on a standard relay rack or panel. For the outline and drilling plan, refer to Figure 12 (see page 56).

The removable front cover has a smoked plexiglass front for viewing of the LED indicators on the various enclosed modules. Two holes in the cover provide accessibility for the dc input power on/off and system indicator reset switches. The front cover is removable with two thumb screws, which also have a hole for sealing if desired.

The rear panel consists of seven 8-point terminal blocks for making all external connections. Screw size is 6/32 and can handle wire sizes from No. 10 to 30 AWG with appropriate lugs. Ground studs are also available on the rear panel/circuit board for system grounding. A cutout exists in this panel circuit board for access to fiber-optic connectors on the fiber-optic interface modules (when used).

Inside the rear panel, the terminal blocks connected to surge capacitors, from terminal to ground, are for those terminals exposed to switch yard environment. These capacitors provide the necessary protection for external surges. Between this rear panel/circuit board and the rear of the module enclosure, the LCB is pre-wired for all possible available options. As of April 1995 all interconnects are made by means of a printed circuit mother board assembly. Prior to this date, all interconnects were done by wire-wrap.

All the circuitry associated with the LCB operation and suitable for mounting on printed circuit boards is contained in the enclosure behind the front cover. The printed circuit modules slide into position in slotted guides at the top and bottom of the enclosure and engage a printed circuit connector at the rear of the compartment. Handles and front plates on the modules are used for identification of the module name and location, indication description, module removal and insertion and as a bumper with the front cover to prevent the terminals from accidentally becoming disconnected from the terminal connector. The modules may be removed for replacement purposes or for use in conjunction with a module extender, Type UME-3D, Style 1355D52G01, which permits access to the module's test points and terminals for making measurements while the relay is energized.

All components used in the LCB are completely tropicalized.

3.2 Test Panel

The optional LCB test panel is mounted on a 19 inch side panel, 5-1/4 inches high (3 rack units) with slotted edge holes for mounting on a standard relay rack or panel. For the outline and drilling plan refer to Figure 13 (see page 56). This unit consists of 2 type FT-1 (10 terminal) FT switches and is used to provide interface between the LCB and the power system for such inputs as the current transformer, dc battery, trip circuits and breaker control. Four resistors and a push-button are included to simulate breaker trip coil current. Fuses are provided for ac voltage.

3.3 Audio-tone Protection Package

The optional audio-tone protection package is mounted on a 19-inch wide panel, 3.5 inches high (2 rack units) with slotted edge holes for mounting on a standard relay rack or panel. For the outline and drilling, refer to Figure 14 (see page 57). Mounted behind the panel are 600 ohm isolating/matching transformers and resistor/zener surge protectors. Connection from the pilot pair and LCB tone output is made via terminal blocks at the rear of the panel. Test jacks on the front panel are available for facilitating measurements of the incoming and outgoing tone levels.

3.4 Portable Test Box (UCTB)

The test box is built to be portable with rubber feet on the bottom or it can be mounted on a 19 inch wide relay rack or panel by means of two thumb screw latches on each side. The height of the unit is 5.25 inches (3 rack units). When mounted in the rack by means of the latches, the bottom should be supported with a steel bracket.

A 6-foot harness and grounding wire comes with the test box to provide connection between the box and test panel.

The UCTB contains an isolating step-down transformer, loading resistors, FT-1 switch and two rotary switches, one for fault selection and one for fault application.

Outline of the UCTB is shown in Figure 15 (see page 57).

4.0 OPERATION

4.1 System Operation

The essential elements of the relay are shown on block diagrams Figures 4 and 5 (see page 48), audio-tones, 2 and 3-terminal lines, and Figures 6 (see page 50) and 7 (see page 51), fiber-optics, 2 and 3-terminal lines. The 3-phase currents are transformed to voltages which are then combined into a representative single-phase voltage by means of the sequence filter. This active solid-state circuit produces a precise, repeatable output as a function of the 3-phase current load or fault conditions. The relative amount of positive (P), negative (N), and zero (Z) sequence may be adjusted independently to best match power system conditions. The only data required for calculating settings are minimum 3-phase fault current from the strongest terminal, minimum phase fault current from the strongest terminal, and maximum expected load current. (See "SETTINGS," Section 6.)

The output of the sequence network is simultaneously fed to a local comparison circuit and a channel interface unit. The interface unit transmits the locally generated signal to the other terminal(s) over one channel while receiving a signal from the other terminal(s) on another channel(s).

For the comparison process, two quantities are generated from the local (VLD) and remote (VR1F and VR2F) voltages. One is called the operating quantity (VOP) and is derived by the vector addition of the local and remote voltages. This addition is performed by a summing and inverting amplifier located on the RELAY module ("L + R"). The output is rectified and filtered to produce a dc voltage for comparison. The other, the restraint quantity (VRES) is obtained by adding the local, VLD, and each remote quantity, VR1F and VR2F, on a magnitude basis, after conversion to dc, in a summing and inverting circuit also located on the RELAY module. This output (VRES) is opposite in polarity to the "operate" voltage (VOP). Further details of the comparison circuit are covered later under "Comparison Technique".

The "operate" and "restraint" voltages are combined and the resultant fed to a level detector which produces a trip signal if the resultant is above the pickup setting. Variable 3-phase system pickup settings are entered by a knob on the front of the RELAY module and may vary from 2 to 40 amperes (5 A ct) depending on link settings or one fifth of that for 1 A ct's. The trip signal lights an indicator labeled "LCB TRIP" on the RELAY module and causes trip relays to operate if tripping has not been blocked by monitoring circuits.

In summary, the local and remote currents are converted to representative voltages at each terminal. By means of a communication channel the remote signals are brought into each local terminal, compared as to magnitude and phase relations, and a trip signal generated accordingly.

The above description has been greatly simplified to cover just the basic system operation. Before covering added functions and logic provided in the system, some discussion of the modulation technique used for remote data transmission is necessary. In order to provide accurate and rapid trip determination, the voltage developed by the sequence network at each terminal is reproduced at the remote terminal(s) with a minimum of delay and distortion. The encoding technique is suitable for both audio-tone and fiber-optic data channels. The technique employed in the LCB is known as pulse-period modulation (PPM), where the carrier period is varied linearly with the modulating signal amplitude. In essence, samples of the line cur-

rent are taken at 3.4 kHz rate and reproduced as a stepped signal at the receiving end. The envelope of this output is an accurate representation of the original voltage.

The device which develops the pulse train is called the **modulator** and the unit which translates the pulses to a magnitude wave is called the **demodulator**. The demodulator uses a sample and hold technique which minimizes the inherent delay in filter circuitry required by other techniques.

One modulator is required at each terminal to produce a local signal for transmission to the remote terminal(s). This unit is part of the modulator-demodulator (MD) module. A demodulator for the signal from one remote terminal is located on the same module. For three-terminal applications a second demodulator is required to convert the signal from the second remote terminal. This demodulator is located on the demodulator/time delay module (DTD).

Further details of the "Modulation Technique" are covered later.

4.2 Functional Operation

The current transformation package is located behind the relay nameplate and consists of three current-to-voltage transformers (current to current with loading resistors). These low-burden transformers are accurate to 100 p.u. symmetrical (1 p.u. equals one or five amperes). The voltage outputs go to the sequence network previously discussed. While it is desirable that the line current transformers have the same ratio, if there are different ratios, the current settings of the relays (T SET, RELAY module) may be adjusted to provide the same primary current sensitivity at each terminal. The setting range is 2 to 40 amperes for the 5 A unit which generally can accommodate a three-to-one ratio difference between line transformers. Careful consideration must be given to the current transformer with the lower ratio, since it may saturate before the current transformer with the higher ratio. The very low-burden of the relay aids in solving this problem.

Correct and reliable operation of a differential relay requires that the quantities being compared be faithful equivalents of the measured primary quantities. This is especially critical during transient conditions since unequal response in terms of magnitude, phase or time delay will result in a false comparison. In the LCB relay, the local signal prior to comparison is conditioned by a series of circuits nearly identical to the ones needed to process the remote signal. Since the

remote terminal may be far enough away to produce a significant real time delay in the received signal with respect to the local signal, to make a valid comparison the local signal must be delayed so that it reaches the comparison circuit at the same time the equivalent real time signal arrives from the remote terminals.

The local delay in the LCB is provided by an adjustable, distortion free delay equalization circuit. This circuit consists of sectionized all-pass delay networks which supply adjustable delay times up to 8 ms and is similar to a lumped parameter delay line circuit. It exhibits a linear phase (constant time delay) characteristic over a wide frequency range. A similar design is also used for equalizing the remote signals of a three terminal line application. The system delay circuitry for the local signal is on the RELAY module. The third terminal delay is on the demodulator/time delay module (DTD).

In the LCB relay all the signals required to transmit information from one terminal to another are generated as an integral part of the relay system. The module which connects the LCB System to the communication channel is the interface module. One module is required for each remote channel. Both are identical, except for the label, for a given type of channel. There are two versions of the interface module, one for a fiber-optic channel (IFO) and one for a tone channel (IFDT).

The LCB Block Diagrams, figures 4 and 5 (see page 48), show the audio-tone interface module, IFDT (see left hand side). This module may be divided into three basic functional elements consisting of carrier receiver, channel monitoring, including receiver for reference frequency, and transmitter.

Terminals 12A-C and 10A-C are the inputs to the IFDT receiver. The incoming signals go through an isolation transformer, then through a common-mode noise-rejection circuit to a scaling circuit. Depending on the received composite signal level, this circuit may be set by a link to act as either an amplifier or attenuator. The carrier signal is then adjusted to the nominal AGC level using a control accessible at the front panel of the module (RX ADJ). At the output of the scaling circuit, the signal is sent to both the carrier receiver circuit and to the frequency detector circuit. Continuing with the carrier receiver path the reference signal is first removed using a notch filter, followed by a band-pass filter which eliminates noise and spurious signals outside the desired 1 to 2.5 kHz modulated carrier range. The automatic gain control (AGC) unit maintains a nearly constant magnitude signal going to the demodulator.

The AGC control voltage is used for High and Low signal level monitoring as well as the reference for signal-to-noise (SNR) monitoring.

In the high/low limit monitoring circuit, the AGC control voltage is compared with predetermined levels. The differential comparison function of the relay is permitted only when the incoming carrier is within these set limits (± 10 dB).

In the SNR monitoring circuit, the carrier signal output from the AGC circuit is conditioned by a band-reject circuit (carrier removal), and only the noise voltage will remain at the output of this circuit. An absolute-value circuit is used to further process the noise into a dc quantity which in turn is to be compared with a voltage derived from the AGC control voltage for the desired SNR level. If the noise voltage equals or exceeds the set level, a block signal will occur. The use of the AGC control voltage for the SNR level setting permits the SNR monitoring to be a truly relative function not tied to any specific input signal or noise level. The noise voltage obtained in this circuit is used yet for another purpose.

In the relay design, as described earlier, the remote and the local current quantities are evaluated by circuits which perform the vector comparison and magnitude comparison. The outputs of the two comparisons are then combined to determine a trip. If the recovered remote current contains noise due to a noisy channel, it is desirable that this noise can be recognized and eliminated. The very nature of the comparison technique and the characteristics of random noise have already provided some inherent noise rejection. However, additional noise rejection is achieved by relating the noise voltage (VN) to the trip reference. This feature provides an adaptive desensitized trip maintaining the comparison accuracy in the presence of channel noise.

The frequency detector circuitry monitors a reference frequency that is received with the carrier signal. The signal from receiver scaling circuit goes through a band-pass filter that eliminates noise and spurious signals outside the desired 2700 to 2850 Hz reference range including the un-modulated carrier signal. The limiter converts the analog signal to a digital signal and provides on board indication if the reference level falls below the setting of 2762 Hz level detector. The frequency discriminator and detector circuitry performs a comparison of received reference frequency to a reference frequency and provides an output if within predetermined frequency limits.

The high/low carrier frequency detector is a fast responding detection circuit which directly senses the carrier signal and provides an output if the signal is outside of its range for more than one cycle.

The output of the SNR circuit is passed thru an "OR" gate with the output of the Reference Frequency detector circuit producing an SNR indication if abnormal noise or a frequency translation condition occurs. This composite signal is stretched to provide an additional 100 ms delay before returning to normal.

The output of the Low and Hi level detectors each provide an indication on the front of the relay when an out-of-limits signal is received. After the indication, the Low and Hi level detectors are passed through an "OR" gate, and the output of the "OR" gate is pulse stretched by 600 ms to be sure the system has returned to normal before un-clamping the LCB II. The outputs of the Reference Frequency Detector, the SNR detector, and the Hi/Low Level detector are combined using an "OR" gate to provide a "HIGH" on the N signal and a "LO" on the CA signal when any of these channel abnormalities occur. The two separate restore times discussed above provide the appropriate time delays for system restoration.

The transmitter combines the carrier signal with a crystal generated reference signal to obtain a composite. The transmitter-level control is a combination unit which is used to adjust the transmitter output to the level required by the tone channel used with the relay system. The signal conditioning circuit converts the incoming square waves to a composite sine wave, and the protection and isolation unit provides a safe and matched connection to the channel.

The LCB Block Diagrams, Figures 6 and 7 (see page 50), shows the optical interface, IFO (see left hand side) which connects the relay system directly to the fiber channel. The transmitter is an amplifier diode combination which turns a fiber-optic emitter on and off to generate light pulses with the off/on period determined by the pulse-period modulation output. The receiver consists of a photo-diode producing electric pulses which are then amplified through a trans-impedance amplifier, passed through a band-pass filter and into an automatic-gain control circuit thereby providing a relatively constant-amplitude carrier signal for the demodulator.

The channel-condition monitoring section is comprised of two detection circuits. The low carrier signal detection uses the AGC control voltage to detect carrier signals that are below a preset level. A low carrier signal signifies a malfunction in the channel. Since the

AGC voltage is relatively a slow responding signal, this detection is implemented primarily to provide an early warning indication that problems are developing in the channel. An adequate margin has been given in the design to accommodate the time delay effect in the AGC voltage. The carrier-frequency monitor, on the other hand, is a fast-responding detection circuit. By sensing the carrier signal directly, any fast interruption or change in the channel lasting for more than one carrier cycle will activate this circuit instantly. The two detection outputs are combined to produce a channel-malfunction signal.

The channel trouble outputs (EN) on the channel-interface modules are applied to logic on the RELAY module to immediately discard the remote signal and block tripping. The LCB under this condition can still be used as an overcurrent function after 45 ms by using the local sequence quantity only, if desired, (link selectable), on the AXLM module.

Time-delayed indication and alarm is provided for sustained loss-of channel by means of a 500 to 5000 ms timer, CA indicator and alarm on the AXLM module.

Final breaker-tripping control is accomplished by means of type-AR relays mounted on the LCB trip module (ARTM-1 for LCB trip, AR-1), (ARTM-2 for DTT trip, AR2). Each AR is provided with four (4) normally open contacts, two (2) for tripping and two (2) for spares. Those contacts for tripping have a series reed relay, which when energized with dc currents in excess of 0.5 amperes operate to cause an LED trip indication.

The AR tripping circuits and relay indication are blocked from false operation for a period of approximately 3.5 seconds during dc power up conditions in order to permit associated relay and communication circuits to become stable. This power-control circuit also blocks the system immediately during momentary loss or dip of +15 Vdc. PSME from the ALS or ALS-1 power supply actuates this circuit as well as blocking the modulator output during power up or down.

Other features incorporated in the LCB system are selection of overcurrent trip on a loss-of-channel, remote control of overcurrent trip, ability to reset indicators remotely, and desensitized trip on line energizing. These are all included as part of the AXLM module, with additional selection on the MD for the OCCC features.

Six options are selectable in the LCB during a loss-of-channel condition, and are controlled by link "LC",

which in turn through signal BS control the LCB trip output. "OT" allows trip while "BLK" blocks overcurrent trip on a loss-of-channel. "OTD" allows overcurrent trip after a time delay of 0.1 to 2.0 seconds, adjustable by the user. Unblock tripping, "UB", is commonly used where the channel medium is power-line carrier, where momentary loss-of-channel could occur during some internal faults. This feature allows overcurrent tripping for 150 ms following loss-of-channel, after which time, trip is blocked. If "UB/OTD" is selected, then unblock tripping is allowed, followed by the time-delayed overcurrent trip. Another feature associated with unblock tripping is unblock trip on reclose. If selected, "UR-IN", then unblock trip on reclose will be permitted again for up to 150 ms assuming the initial LCB trip had occurred in the preceding 2.5 seconds. Unblock trip on reclose requires 52b-breaker status information which is optional via an optically-isolated voltage-selectable input buffer.

Remote control of overcurrent (OCC) is a feature controlled by a contact input through an optically-coupled isolated voltage-selectable input buffer. With an input, OCC becomes "1" to block the loss-of-channel options, while applying a signal to the RELAY module to momentarily block trip while opening the remote signal. The OCC signal also goes to the MD module to control the transmit signal, with link OCC, which does the following:

"OUT" does not affect modulation, "LOC" causes loss-of-channel, "TTO" stops 60 Hz modulation and transfer trip but keeps the channel in service and "TTI" blocks 60 Hz modulation while leaving the transfer trip feature still available.

External reset of targets is accomplished by applying a signal to the LCB target reset input which is optically-isolated and voltage-selectable depending on the system battery voltage and signal source. Reset of indicators can also be performed with the system indicator reset push-button on the LCB trip module.

Trip desensitizing is a feature occasionally used on power systems where excessive line charging inrush may occur on the closing-in of a breaker. This circuit (Link-selectable) provides trip blocking (BS) for 200 ms after closing the breaker unless the magnitude of the trip voltage (VTRIP) as determined by the operate and restraint quantities is at some level above the trip point as determined by the "T" setting. Depending on the power system parameters, this desensitized level can be calibrated at a level of 1 to 10 times the normal pickup. Operation of this feature is dependent upon the breaker 52b contact for indication of breaker status – input of the 52b contact information status is

through an optically-coupled, voltage-selectable isolated buffer.

An optional feature available for LCB systems is direct transfer trip (DTT). The breaker or breakers at the remote terminal(s) of a protected line can be tripped at high speed from local terminal using elements of the LCB and the same communications channel. An additional module, direct transfer trip (DTT), is required at each terminal. To initiate transfer tripping, some external device (keying circuit) must connect battery voltage to terminal DTTBP and DTTBN on the local LCB. The DTT initiate circuit, on the DTT module, provides optical isolation from battery transients and has a jumper which must be set prior to inserting the module to match the battery voltage.

Referring to the block diagrams, the transfer trip signal is conditioned and then switches the operation of the PPM modulator to cut out the local current signal input. At the same time the PPM is modulated to represent a magnitude greater than the maximum current signal at a 420 Hz rate. This signal is transmitted by the channel interface unit to the remote terminal(s).

At the receiving terminals, the signal is processed by the channel interface and demodulator elements. The DTT detector and recognition circuitry checks both frequency synchronization and magnitude of the signal from the demodulator. A valid direct transfer trip signal will be higher in magnitude than 50/60 Hz demodulated signal and at a higher frequency (420 Hz). If these criteria are met, the remote signal is switched off (DTI, DT) to disable the comparison circuit and block LCB tripping on the RELAY module. The transfer trip detector signal starts a timer which produces a trip output if the transfer trip signal is maintained for 10 ms. This time is supervised by the channel monitoring circuitry (CA-1 and CA-2) to prevent tripping in the presence of channel problems.

4.3 Comparison Technique

As mentioned earlier (System Operation), two quantities are generated from the local and remote signals. The first is called the operating quantity and is derived by the vector addition of the local delayed signal, VLD, and the remote signals (VR1F) and VR2F). this is accomplished by a sum and inverting circuit whose output is "L + R". Once summed, the resultant "L + R" signal is converted to a dc level and amplified by unity gain to produce the operating voltage, VOP. The operating quantity is given by equation (1).

$$VOP = |VLD + VR1F + VR2F| \quad (1)$$

where VOP = operating quantity

VLD = delayed local voltage
 VR1F = channel 1 remote voltage vector
 VR2F = channel 2 remote voltage vector
 | | = indicates absolute value

The restraint quality is obtained by adding the local and remote voltages on a magnitude basis, thus phase angle does not enter the result. In reference to the block diagram, the local quantity, VLD, and remote VR1F and VR2F are individually converted to a dc magnitude, summed and amplified (gain = .7) to produce a negative dc magnitude referred to as VRES. The restraint quantity is shown in equation (2).

$$VRES = -0.7 (|VLD| + |VR1F| + |VR2F|) \quad (2)$$

where VRES = the restraint voltage.

The quantities VOP and VRES are then summed and filtered to determine if the fault is internal or external to the protected line. Equation (3) shows how this is accomplished.

$$VOP + VRES = VPU \quad (3)$$

where VPU = a preset pickup threshold

The combined equation is as follows (4):

$$|VLD + VR1F + VR2F| - 0.7 (|VLD| + |VR1F| + |VR2F|) \geq VPU \quad (4)$$

This signal is fed to a trip comparer where the final trip output, TRC, is set for VPU with the pickup setting potentiometer.

Figure 18 (see page 59) represents the characteristic of the comparison circuit if the fault currents at the two ends of the line are either in-phase (internal fault) or out-of-phase (external fault). This curve indicates that tripping occurs for in-phase currents and also for out-of-phase where the differential between them is significant. Since many times the currents at the two ends are not exactly in- or out -of-phase. Figure 19 (see page 59) shows the relay characteristic when the local (VL) is at three times pickup, and the remote varies in-phase and magnitude. A family of curves similar to Figure 19 (see page 59) could be drawn for different magnitudes of local voltage. It can be seen that the relay system will operate for small amount of out-feed at the remote terminal. This is the differential aspect of the LCB, and provides out-feed trip capability in weak terminal applications. As observed in the drawing the relay has about an 82° characteristic; that is, the two quantities can be up to 82° out-of-phase and the relay will trip for any set of magnitudes above pickup.

4.4 Modulation Technique

The modulation technique used in the LCB is PPM – pulse-period modulation. PPM provides a means of accurately transmitting and receiving the sequence quantity output, while also providing the capability of working over fiber-optics or a 3002 unconditioned or equivalent channel without change.

PPM, where the carrier time period is varied linearly to the modulating signal amplitude, is similar to FM when the deviation ratios are small. A prominent merit of the PPM scheme is the comparatively minuscule filter requirements in the demodulator. A sample-and-hold process implemented in the demodulator virtually removes the carrier frequency content without the need of a filter. This feature greatly enhances the relay speed and also simplifies the circuit that is needed to compensate the local sequence signal. Diagrams illustrating the PPM operation are shown in Figure 20 (see page 60) (modulator) and Figure 21 (see page 60) (demodulator).

The modulator formation is based on the charging time of capacitor C_m under a constant current I_m . The voltage on C_m is compared to the modulating voltage V_m . When the voltage on C_m reaches V_m , flip-flop FF-1 is toggled and C_m is reset, commencing another charging cycle. This encoding operation is performed at 27.2 kHz center frequency which is then counted down by 16 to 1.7 kHz for transmission. Performing modulation at a higher frequency permits a more practical design and produces a digitally selectable center frequency.

The PPM modulation can be characterized by equation (5).

$$T(t) = T_o + K_m \times V_m(t) \quad (5)$$

where $T(t)$ = period of modulated carrier
 T_o = period of un-modulated carrier
 K_m = C_m/I_m , a design constant
 $V_m(t)$ = the modulating voltage

$T(t)$ and $V_m(t)$ are time functions.

In the demodulator, the incoming carrier is first shaped to a square wave. Two pulse signals, P1 and P2, generated from transitions of the square wave are used respectively for the sample-and-hold operation and capacitor C_d reset function. Constant current I_d charges C_d to produce a linear ramp voltage. Prior to reset (P2 function) of the ramp, C_d voltage is sampled (P1 function) and stored in capacitor C_3 . C_3 holds the sampled ramp voltage until the next P2 pulse appears. Assume that the modulating signal in the

carrier is a 60 Hz (50 Hz) sinusoidal wave carrying very little residual carrier frequency components. A simple filter removes the steps accurately recreating the original signal. The demodulator operation is given by the equation (6).

$$V_o(t) = K_d \times T(t) \quad (6)$$

where $K_d = I_d/C_d$, a design constant.

To demonstrate the overall PPM process, one can substitute $T(t)$ by the expression given by equation (7). Then

$$V_o(t) = K_d \times T_o + K_m \times K_d \times V_m(t) \quad (7)$$

$K_d \times T_o$ is a constant voltage term and can be removed by a simple highpass filter leaving $V_o(t) = K \times V_m(t)$. $K = K_m \times K_d = C_m \times I_m / C_d \times I_d$, a constant term representing the gain of the PPM process.

It is noted that the demodulation is performed on each half of the carrier signal. This yields an effective sampling rate of 3.4 kHz, or approximately 57 samples per cycle of 60 Hz frequency (68 samples at 50 Hz). This is a more than adequate rate to insure good representation of the original modulating signal.

5.0 LCB II CHARACTERISTICS

1. ac Ratings:

ct Ratio Secondary-A	Continuous Rating-A	Ohm Burden	1 Second Rating-A
5	10.0	.002	250
1	2.0	.006	50

2. Setting Range (amperes):

ct Ratio Secondary	3-Phase Fault Sensitivity (A)	Phase-to-Ground Fault Sensitivity (A)
5	2.0 to 40.0	0.23 - 4.4
1	0.4 to 8.0	0.046 - 0.88

3. Power system Frequency: 50 or 60 hertz.

4. Carrier Frequency: 1700 hertz, un-modulated Maximum Deviation: ± 200 hertz without DTT option.

Modulation Technique: Pulse-period, (PPM).

Reference Tone Frequency: 2762 hertz, Fixed.

5. Direct Transfer Trip (Option): 420 hertz modulating frequency.

6. Channel Delay Equalizer: Adjustable 0 to 8 ms. (local signal) Adjustable 0 to 4 ms. (third term)

7. Input Current Transformers: Linear response up to 100 per unit (1 p.u. = 5A or 1A symmetrical current) with an accuracy of 1%.

8. Power Supply Voltages:

Nominal	Range
60/48 Vdc	38-70
110/125 Vdc	88-140
220/250 Vdc	176-280

9. dc Burden (Watts)

2 Terminal	Added Drain For DTT 3 Terminal	
Standby 20	5	5
Operate 35	15	5

10. Non Seal-In Indicating Lights (LED):

Module	Functions
ALS/ALS-1 (Switching power supply)	dc INPUT dc OUTPUT
IFDT (Audio-Tone Interface)	SNR (Signal-to-Noise) HI (High Level) LO (Low Level)
IFO (Fiber-Optic Interface)	LO (Low Level)

11. Seal-in Indicating Lights (LED):

Module	Functions
RELAY	LCB TRIP
DTT (Direct Transfer Trip)	DTT KEY DTT TRIP
AXLM (Auxiliary Logic)	CA (Channel Alarm) OC/UB TRIP DES TRIP
ARTM-1 (Trip)	LCB TRIP #1 LCB TRIP #2
ARTM-2 (Trip)	LCB TRIP #1 LCB TRIP #2 DTT TRIP #1 DTT TRIP #2

12. Indicator Reset:

- (a) Manual Reset on ARTM Module. (System Indicator Reset).
- (b) AXLM Module has input to allow indicators to be reset remotely. Isolated input buffer, link selectable for 15, 48, 125 or 250 Vdc.

13. Output Contacts

Module	(No.) Contacts
a) ARTM-1	(2) Independent, heavy-duty, seal-in contacts for tripping 2 breakers (LCB trip).
OR,	(2) Light-duty contacts for auxiliary function such as breaker failure initiate or reclose initiate (LCB trip).
ARTM-2	(2) Independent, heavy-duty seal-in contacts for tripping two breakers (LCB trip).
	(2) Light-duty contacts for auxiliary functions such as breaker failure initiate or reclose initiate (LCB trip).
	(2) Independent, heavy-duty, seal-in contacts for tripping 2 breakers (DTT trip).
	(2) Light-duty contacts for auxiliary functions such as reclose block (DTT trip).
b) AXLM	(2) Form C channel alarm.
c) ALS or, ALS-1	(2) Form B loss of dc alarm.

14. Contact Rating:

AR Heavy-Duty (Tripping):

Make and carry 30 amperes for a minimum of 100 ms.

AR Light-Duty (Auxiliary):

3 amperes continuous.

Interrupting Rating (Amperes)		
	Resistive	Inductive
48 Vdc	3.75	1.75
125 Vdc	0.5	0.35
250 Vdc	0.25	0.15

Form C Alarm – make continuous, and interrupt 100 VA, resistive.

Form B Alarm – make continuous, and interrupt 50 VA, resistive.

15. Channel Alarm (Contacts and Indication) output has adjustable time delay of 500 to 5000 ms. (Factory set at 2500 ms.)

16. Fiber-Optic Cable Interface (850 nm, Multi-mode fiber):

Frequency response: 1.0-2.5 kHz

Minimum optical power input to maintain 20 dB SNR is 0.5 nanowatts.

Low signal level setting @ 850 nm: 0.5 nanowatts (-63 dBm).

Optical channel capability is 40 dB when using a 50 micrometer core fiber cable, at 850 nm.

LED optical power output – 1.0 milliwatt. (not fiber-coupled output power.)

17. Fiber-Optic Cable Interface (1300 nm, Single-mode or Multi-mode):

Frequency response: 1.0-2.5 kHz

Minimum optical power input to maintain 20 dB SNR is 1.6 nanowatts.

Low signal level setting @ 1300 nm: 1.6 nanowatts (-58 dBm).

Optical channel capability is 15 dB when using a 9 micrometer core fiber cable, at 1300 nm.

Optical channel capability is 30 db when using a 50 micrometer core graded-index dual-window fiber cable, at 1300 nm.

LED optical power output: 0.5 milliwatt. (Not fiber-coupled output power.)

18. Fiber-Optic Cable Interface (1300 nm High Power)

Frequency response: 1.0-2.5 kHz

Minimum Receiver Optical power input to maintain 20 dB SNR is 1.6 nanowatts.

Low signal level setting @ 1300 nm: 1.6 nanowatts (-58 dBm).

Optical channel capability is 28 dB when using a 9 micrometer core fiber cable, at 1300 nm.

LED optical output 1 μ W(-30 dbm) (fiber-coupled output power.)

19. Audio-Tone Interface:

Transmitter:

Composite Output Level – Adjustable within the following ranges:

- +15 to - 5 dBm
- 4 to - 25 dBm
- 23 to - 40 dBm

Amplitude Stability ± 1 dB for 1700 hz Output
Impedance 600 ohms, balanced Frequency
stability 1% for 1700 Hz Frequency band-
width 1.0 to 2.5 kHz

Receiver:

Input sensitivity +10 to -40 dBm, selectable,
with a 20 dB (± 10 dB) window dynamic
range.

Input impedance 600 ohms, balanced.

Signal-to-noise ratio 17 dB over 1.5 kHz
bandwidth, un-modulated, and 20 dB, full
modulation.

20. Audio-tone interface can be applied over a 3002
unconditioned circuit or equivalent.

21. Temperature range -20°C to +60°C around chas-
sis. Storage Temperature -40°C to +80°C.

Required Settings/Link Options:

Module	Link	Options	Module	Link	Options
DTD	J(MS)	0 2 4	AXLM	TR	15 48 125 250
MD	OCCC	TTI TTO LOC OUT	CAI		S NS S
IFDT	R	AMP ATT +15 -4 -23	AL1		NS 15 48 125 250
RELAY	P	P1 P2 N1 N2 N3 Z1 Z2	OCC		IN OUT 15 48 125 250
	N		52B		5X 10X IN OUT OT OTD BLK UB/ODT UB
	Z		TRDS		
	J(MS)	2 4 6 8	LC		
DTT	DTT KEY	15 48 125 250			

22. Dielectric Capability: 2800 Vdc, 1 minute exposed
terminals. 1400 Vdc, 1 minute between contacts
and across open contacts

NOTE: The above specifications are per IEC 255-5, except relay must not be tested with ac source due to capacitive surge protectors on terminals.

23. Surge withstand capability per ANSI C37.90.1
and IEC-255-6.

NOTE: Items #22 (Dielectric Capability) and #23 (Surge Withstand Capability) apply only when Audio Tone Protection Package is used as part of an LCB II System.

6.0 SETTINGS

There are several Settings and Link Options required for the LCB. They are dependent upon the system configuration, dc voltage, channel considerations and user relaying practices

- Positive-sequence sensitivity (P) – RELAY module.
- Negative-sequence sensitivity (N) – RELAY module.
- Zero-sequence sensitivity (Z) – RELAY module.
- Current sensitivity adjustment (T) – RELAY module.
- Loss-of-channel options (LC-OT, BLK, OTD, UB, UB/OTD) (UR-IN/OUT) – AXLM module.
- dc input selection for
 - DTT initiate (15, 48, 125, 250) – when used – DTT module.
 - Target reset (15, 48, 125, 250)-AXLM module.
 - 52b contact (15, 48, 125, 250)-AXLM module.
 - Overcurrent Control (OCC) (15, 48, 125, 250) – AXLM module.
- Loss-of-channel alarm and indication and time delay (AL1, CAI)-AXLM module.
- Trip desensitizing level (DES ADJ) and selection (TRDS)-AXLM module.
- Time-delayed overcurrent trip (TD ADJ)-AXLM module.
- Overcurrent control channel options (OCC-OUT, LOC TTI, TTO)-MD module
- Trip seal-in feature (J1, J2, J3, J4)-ARTM 1/2 module.

NOTE: The settings listed in this section are in

addition to the FIELD SET UP procedure where the transmitters and receivers for tones (when used) are adjusted and the local and remote magnitude and channel delays are equalized.

6.1 Sequence (P, N, Z) And Current (T Set) Sensitivities – Relay Module

The sequence-network voltage output referenced to secondary current quantities is shown in equation (8).

$$VF = (14.14/T) (C1 \times Ia1 + C2 \times Ia2 + C0 \times Ia0) \quad (8)$$

where

- VF = voltage output of network
- T = current setting of the relay
- C1 = positive-sequence network constant
- C2 = negative-sequence network constant
- C0 = zero-sequence network constant

I_{a1} , I_{a2} , and I_{a0} = A phase positive, negative, and zero-sequence current components respectively (phasor quantities).

T = the ampere tap setting of the relay

The sequence network constants are shown in Table 1. Since there are a large number of combinations to choose from, a list of the preferred combinations are shown in Table 2 (page 16). These combinations of settings and the values of sequence network constants were chosen to assure adequate sensitivity for three-phase faults, phase-to-phase sensing compatible with three-phase fault levels, and high sensitivity to ground faults.

Tripping occurs on a single end basis when V_F is greater than or equal to 1.414 volts. Substituting this value into equation 1, and rearranging, equation 9 is obtained.

$$C1 \times Ia1 + C2 \times Ia2 + C0 \times Ia0 = 0.1T \quad (9)$$

The left side of equation 9 must be equal to or greater than the right side for a single end trip. It should be noted that all terminals of an LCB system generate the V_F quantity, so that for an internal fault, the combination of signals from local and remote terminals can be considered when determining settings as will be shown later in a setting example.

Equation 9 is the basis by which the following setting criteria are developed.

6.1.1 Three-Phase Fault and Load Criteria

Three-phase faults ideally contain only positive-sequence currents, and load current is also positive

sequence in character. When the channel over which the relay system is operating is intact, load current is ignored by the LCB relay system because it is a through current condition to the protected zone. If the relay is strapped to overcurrent trip during a loss-of-channel condition, the LCB relay may trip on load when the channel is lost, and load must be considered in the setting criteria. If tripping is blocked during a loss-of-channel condition, then load current can be disregarded in the setting criteria.

If tripping is allowed during loss-of-channel, then the setting of the positive-sequence sensitivity should be above the maximum load level to avoid undesirable tripping. The setting must also be below the level of the minimum three-phase-fault current fed from all line terminals under any switching condition for which it is desired to protect the line. For a three-phase-fault and load current condition, only I_{a1} exists (I_{a2} and I_{a0} are equal to zero), thus equation 9 reduces to equation 10.

$$I_{3P} \geq |0.1 \times T / C1| \quad (10)$$

Where I_{3P} is the minimum total internal three-phase-fault current fed from all line terminals under any switching condition for which it is desired to protect the line.

Equation 10 is **criteria number 1** in setting the relay. If the relay is set to block on loss-of-channel then this is all that need be considered. However, if the relay is set to overcurrent trip on channel failure, then equation 4 will assume that the relay is set to above load with a 25% margin.

$$|0.10T/C1| \geq 1.25 IL \quad (11)$$

**Table 1:
Sequence Network Constants**

Constant	Position	Value
C1	P1	-0.10
	P2	-0.05
	Off (P)	0
C2	N1	0.23
	N2	0.22
	N3	0.20
	Off (N)	0
C0	Z1	2.45
	Z2	1.25
	Off (Z)	0

Table 2:
Preferred Jumper Combinations

Combination Number	Link Position
1	P1, N1, Z1
2	P1, N1, Z2
3	P2, N2, Z1
4	P2, N2, Z2
5	OFF, N3, Z1
6	OFF, N3, Z2
7	P1, Off, Z1
8	P1, Off, Z2
9	P2, Off, Z1
10	P2, Off, Z2

Where I_L is the maximum load current through the protected line. Equation 11 is then **criterion number 2** in setting the relay.

Some people prefer to use these two criteria together, and when combined together equation 12 is the result.

$$I_{3P} \geq |0.10T/C1| \geq 1.25 I_L \quad (12)$$

6.1.2 Phase-to-Phase Fault Criterion

Discriminating choice of positive and negative-sequence weighting factors ($C1$, $C2$, $C0$) in the design of the LCB relay avoided any problem of incorrect identification of fault location. In general, positive and negative sequence distribution factors are identical. However, in the vicinity of a generating plant with the machine positive-sequence impedances varying with time following the occurrence of a fault and negative-sequence impedance remaining fixed, there will be, with sources on both sides of the fault, different distribution factors for positive and negative-sequence. Because of this, the ratio I_{a1}/I_{a2} will vary. However, with the $C1$ and $C2$ constants in the network equation having been chosen with opposite signs, and the signs of the currents being opposite for a BC phase fault, an additive effect takes place rather than a cancellation effect.

The A-phase oriented filter must serve for all phase contributions of faults. For AB and CA faults, VF is much less than for a BC fault. To make AB and CA fault sensing compatible with the level of three-phase fault sensing, it is necessary to choose $C2$ equal to approximately minus $2C1$. The natural result of this is to produce slightly higher sensitivity ($I_{3P}/1.732$) for BC faults than for the other two combinations ($I_{3P} = I_{3P}$).

Thus, if combinations of strap P and strap N are

selected from Table 2, then combinations 1 to 4 will always provide adequate phase-to-phase fault sensitivity for the minimum case of criterion number 1 above is met. On the other hand, if one of the combinations 7 to 10 is selected it is desirable to check the phase-to-phase fault sensitivity. In this case, the minimum phase-to-phase fault current required to trip the relay is given in equation 13.

$$I_{P-P} \geq |0.1732T/C1| \quad (13)$$

where I_{P-P} is measured for the same conditions as I_{3P} is above.

Thus, equation 13 becomes **criterion number 3**, and is used only when the link N of the relay is set to the OFF (N) position.

6.1.3 Phase-to-Ground Faults

Because of the likelihood of appreciable resistance existing in a ground fault path, increased sensitivity is desired to zero-sequence current. This is accomplished in the design by choosing a $C0$ constant 24.5 times larger than $C1$. applications involving continuous zero-sequence current flow or "through" zero-sequence current flow for internal phase faults will require cutting this weighting factor in half or reducing it to zero. Parallel untransposed circuits can cause zero-sequence to be present to the extent of approximately 10% of the load current level.

The **criterion number 4** for setting the relay for phase-to-ground faults is given in equation 14.

$$I_G \geq |0.3T/C1 + (C1 + C2 + C0)| \quad (14)$$

where I_G is the minimum internal phase-to-ground fault current fed from all terminals for which it is desired to protect the line.

Equation 14 is derived from equation 9 and uses the fact that $I_{a1} = I_{a2} = I_{a0}$ and that $I_G = 3I_0$ at the fault location.

6.2 Setting Calculations For The General Case

6.2.1 Case of Equal ct Ratios

This section will show how to calculate and pick the settings on the relay for the general application case. It may be useful to restate the definitions of the currents that will be needed to calculate the settings.

I_{3P} = Minimum total internal three-phase fault current fed from all line terminals under any switching condition for which it is desired to protect the line.

I_{P-P} = Minimum total internal phase-to-phase fault current for the same conditions as I_{3P} above.

I_G = Minimum total internal phase-to-ground fault current fed from all line terminals under any switching condition for which it is desired to protect the line.

I_L = Maximum load current through the protected line.

Also it may be useful to summarize the setting criteria for the relay.

CRITERION #1:	(Equation 10): $I_{3P} \geq 0.1T/C_1 $
CRITERION #2:	(Equation 11): $ 0.1T/C_1 \geq 1.25 I_L$ (See Note 1)
CRITERION #3:	(Equation 13): $I_{P-P} \geq 0.1732T/C_1 $ (See Note 2)
CRITERION #4:	(Equation 14): $I_G \geq 0.3T/(C_1+C_2+C_0) $
NOTE: (1) Criterion 2 only required when the relay is set to trip as an overcurrent device on a loss-of-channel.	
NOTE: (2) Criterion 3 is only required when the sequence network is set for no negative-sequence response.	

First of all, two things must be determined. One, will the relay be allowed to trip as an overcurrent device on loss-of-channel, and two, is there any reason to set the negative-sequence sensitivity of the relay to zero ($C_2 = 0$). For this example, a two-terminal line is used and the relay may have a negative-sequence response. The only time it need be considered to eliminate the relay's negative-sequence response is when there is a load tap on the line with a delta-wye transformer. Also it will be assumed that the overcurrent time delay trip will be used as a backup during channel failure. Based on the above assumptions, it will then be required to use criterion #2 and not use criterion #3. The current and ct information for the example is shown in Table 3.

Table 3:
System Fault Currents For Setting Example

Fault	Station G	Station H
Three-Phase	500A	2500A
Phase-to-Ground	400A	150A
Load Current		
ct Ratio = 600/5		600A

Therefore:

$$I_{3P} = (2500 + 500) 5 / 600 = 25A$$

$$I_L = (600) 5 / 600 = 5A$$

$$I_G = (400 + 150) 5 / 600 = 4.58A$$

The three-phase fault and load current criteria will be considered first: substituting into criterion #1:

$$25 \geq |0.1T/C_1| \quad (15)$$

and substituting into criterion #2:

$$|0.1T/C_1| \geq 6.25 \quad (16)$$

From equation 15 and 16 the value of $|0.1T/C_1|$ can vary anywhere between 6.25 and 25A. The choice should now be made on the basis of the speed of relay operation. In general, the more multiples above pickup the fault current is, the faster the relay will operate. Therefore, it is desirable to set the relay as close to the load criterion as possible. The relay should then be set such that $|0.1T/C_1| = 6.25$. In order to provide the best sensitivity, link P should be set on P1 (most sensitive position). In this case then, $C_1 = -0.1$ (from Table 1) and therefore, T should be set to 6.25. Since link P is set to P1 then link N should be set to N1 (from Table 2) in order to provide proper phase-to-phase fault sensitivity for the same conditions. This makes the value of $C_2 = 0.23$ from Table 1.

Now the ground fault sensitivity should be checked. Substituting for I_G , T, C_1 , and C_2 into criterion #4, equation 17 is obtained.

$$4.58 \geq 0.3 (6.25) / (-0.1 + 0.23 + C_0) \quad (17)$$

Therefore by rearranging, $4.58 (0.13 + C_0) \geq 1.875$ and solving for C_0 equation 18 is obtained:

$$C_0 \geq 0.279 \quad (18)$$

Observing the values of C0 on Table 1, it can be seen that either position Z_1 or Z_2 will meet equation 18. Therefore, since it is desired to make the relay as fast as possible and to handle as much fault resistance as possible the inequality should be as large as possible. Thus, based on the above, the Z link on the relay should be set to Z_1 . For this example, the relay setting that is to be used is $T = 6.25$, $P = P1$, $N = N1$, and $Z = Z1$. It has been past experience that link settings of $P1$, $N1$, and $Z1$ will be appropriate for 90 to 95% of the applications of the LCB relay.

In the above example, the currents that are used in the criteria were selected using the total current with both line terminals closed. The resulting setting of the relay will allow the relay to clear a three-phase fault when line testing from terminal H. However, the setting will not allow clearing of a three-phase fault if the line test occurs by closing station G. All ground faults will be cleared since the ground fault sensitivity is 87.2. A primary current. In order to cover the line test case from station G for three-phase faults it would be necessary to set the system below load current, and then it would be required to block tripping on loss-of-channel condition. If it is both desired to line test from station G and provide overcurrent trip, then possible overtripping must be accepted during a loss-of-channel when loaded above the relay pickup.

6.2.2 Unequal ct Ratios

When the two ct ratios at the ends of the line are different it is necessary to compensate for the current differences by changing the T current sensitivity setting. The P, N, and Z links **must always** be set on the same position at all line terminals.

The settings are calculated on the basis of the higher ct ratio, and then the T setting at the lower ct ratio terminal is modified. The end which has the lower ct ratio has a higher secondary current than that at the higher ratio ct end, and thus, T must be set to a higher value. The equation for making the compensation is given in equation 19.

$$T_{LR} = (R_{HR} / R_{LR})T_{HR} \quad (19)$$

where

T_{LR} = T setting at the terminal with the lower ct ratio

T_{HR} = T setting at the terminal with the higher ct ratio

R_{HR} = Higher ct ratio

R_{LR} = Lower ct ratio

If in the previous example the ct ratio at station H were 400/5 and station G remained 600/5, the tap setting (T) at station G would remain the same as calculated. The tap setting (T) at station H would be modified by equation 19.

T at station H = $(600 / 400) 6.25$ or **T at station H = 9.38**. The links P, N, Z, remain the same at both line terminals.

6.2.3 Setting Considerations for LCB-II Relays Used to Protect Cable Circuits

Cable circuits have considerably more capacitance to ground and between phases than overhead circuits having comparable length. Ordinarily this capacitance has little effect, but during external ground faults, zero sequence current will flow in one terminal of the transmission line which is not matched by zero sequence current in the other. This has little influence for cases where there is a substantial "through" fault contribution, but where this is small and the cable capacitance is large, the LCB-II may have to be desensitized for ground faults.

The filtering in the LCB-II is very effective and high frequency effects are minimized. The principal influence of the cable in causing an undesired "operating" voltage is the rated frequency current that flows for external faults. Since the settings are generally chosen to provide much greater sensitivity to ground faults than to phase faults, the zero sequence contribution through one terminal of the transmission line is the critical value.

Zero sequence cable current can be conservatively estimated by:

$$3I_0 = \frac{3V_{LN}}{(1 + 2Z_1/Z_0)X_{CO}} \quad (20)$$

Where V_{LN} = line-to-neutral voltage

Z_1/Z_0 = positive-to-zero sequence system impedance ratio

X_{CO} = cable zero sequence capacitive reactance

V_{LN} and X_{CO} are power system frequency quantities. The Z_1/Z_0 positive to zero sequence system impedance ratio and V_{LN} are at the respective relay bus, with Z_1/Z_0 as viewed from the fault locations under worst case conditions. It is recommended to use the minimum Z_1/Z_0 value for any switching condition. As a matter of note, this is the inverse of the maximum Z_0/Z_1 ratio used for lightning arrester applications.

The setting of the relay should be chosen so that the

ground fault sensitivity is greater than the zero sequence cable current. For example, it may be necessary to use P_1 , N_1 , Z_2 settings rather than P_1 , N_1 , Z_1 to achieve the additional security.

6.3 T-Setting

The T “tap;” setting is continuously adjustable from 2 to 20 amperes for 5 amp ct rated relays. Setting is made by means of a front mounted 10 turn precision potentiometer with a three digit digital counting dial. The dial is referred to as T-SET and is located on the front of the RELAY module.

Once the ampere value of T is determined, the dial is set by the following formula:

$$DS = 1082.5 - 2000/T$$

where

DS = Dial Setting

T = Tap value in amperes

For example, for a T setting of 6.25 amperes, $DS = 1082.5 - 2000 / 6.25$ which equals 762.5. In this case on the digital dial, the first digit would be 7, the second 6 and the third halfway between 2 and 3. Once the setting is made, the dial can be locked in place by means of the lever below the dial mechanism.

For relays rated for 1 ampere ct's, the setting range is 0.4 to 4 amperes, and, for the dial setting, T is replaced by 5T so that $DS = 1082.5 - 400/T$.

6.4 Loss-of Channel Options (LC, UR) – AXLM Module

- LC-OT: Allows immediate overcurrent trip on loss-of-channel (after 45 ms).
- LC-BLK: Blocks all LCB tripping during loss-of-channel.
- LC-OTD: Allows overcurrent tripping after a preset time of 0.1 to 2.0 seconds (TD ADJ-AXLM module).
- LC-UB: Allows overcurrent trip for up to 150 ms following loss-of-channel (unblock feature for power line carrier).
- LC-UB/OTD: Allows overcurrent trip for 150 ms following loss-of-channel followed by time-delayed overcurrent trip capability.
- UR-IN: Allows the 150 ms unblock (UB) feature, if selected, to be reinserted on

reclose if a trip has occurred in the past 2.5 seconds.

6.5 dc Input Selections

1. Target Reset Input – AXLM Module
Electrical (remote)reset of seal-in indicating lights. Set “TARGET RESET” link for the desired input dc voltage (15, 48, 125, 250).
2. 52b Contact Input – AXLM Module

52b breaker contact input used in conjunction with line energizing trip desensitizing and/or unblock trip capability. Set “52B” link for the desired input dc voltage (15, 48, 125, 250).
3. DTT Initiate Input – DTT Module (When Supplied)

Set “DTT KEY” link for the desired input voltage. (15, 48, 125, 250).
4. Overcurrent Control – AXLM Module.

Set OCC link to the desired input dc voltage (15, 48, 125, 250).

6.6 Loss-of-channel Alarm /Indication Seal-in And Delay – AXLM Module

Loss-of-channel alarm AL1 and indication CA can be set to seal-in by placing links “AL1” and “CAI” on “S” or to follow the signal by placing links on “NS”.

Time delay for alarm after loss-of-channel is factory set at 2500 ms. If a different time between 500-5000 ms is desired, refer to the “CALIBRATION” section.

6.7 Time Delayed Overcurrent Trip (TD ADJ) –AXLM Module

If the LC-OTD option has been selected, then the time can be set from 0.1 to 2.0 seconds. Refer to CALIBRATION section for setting procedures.

6.8 Overcurrent Control Channel Options – MD Module (OCCC)

If this option is to be used to control overcurrent tripping, then several alternatives exist for control of the channel signal to the remote terminal.

- OCCC-OUT: Does not affect channel information (set in this position if this feature is not used).
- OCCC-LOC: Causes loss-of-channel at the remote terminal.

OCCC-TTO: Blocks 50/60 Hz and transfer trip modulation, but keeps the channel in tact.

OCCC-TTI: Blocks 50/60 Hz modulation and keeps the channel in tact for transfer trip (if keyed).

6.9 Trip Desensitizing – AXLM Module

This feature, when utilized, allows the LCB trip level to be desensitized for 200 ms when energizing the line. Factory calibration is for a desensitized level of 5 times (5X) pickup but the link activating this feature is “OUT”. If this feature is desired, then link “TRDS” must be set on “IN”. If a different multiple of trip level setting is required, then recalibrate per the “CALIBRATION” section.

6.10 Trip Seal-In Selection – ARTM-1-2 Module

Links J1 (LCB-Trip), J2 (LCB-Trip 2) on the ARTM-1 and Links J3 (DTT-Trip 1), J4 (DTT-Trip 2) on the ARTM-2 when in, permit the trip AR to be sealed-in, providing 0.5 amperes dc through the respective trip contacts. With the links removed, the AR relays will be energized only when an LCB or DTT trip signal exists. These links are zero ohm jumpers soldered into the module assembly and if removal is required then they must either be cut open or desoldered and removed.

7.0 ROUTINE MAINTENANCE

Periodic checks of the LCB including the relaying as well as the communication portions of the system are advisable to verify the stability of the settings or possibly indicate component degradation. These checks will allow corrective action to be taken before settings may drift out of tolerance or components actually fail.

Any accumulated dust should be removed at regular maintenance intervals.

The AR relays used for tripping and mounted on the ARTM module should be periodically inspected for proper contact action and wear. For worst case operating conditions, 30 amperes resistive, contact make duty; the contacts should be inspected each year or 50 operations and replaced when necessary. Reference, I.L. 41-759.

NOTE: ARTM-1 contains one AR for LCB trip; ARM-2 contains two AR's, one for LCB trip and one for DTT Trip.

7.1 Contact Maintenance

All contacts should be cleaned periodically. A contact burnisher style 182A836H01 is recommended for this purpose. The use of abrasive material for cleaning is not recommended, because of the danger of embedding small particles in the face of the soft silver and thus impairing the contact.

NOTE: When removing or inserting modules, dc power should be turned off.

Special care should be taken when contact maintenance is performed. The ARTM-1/ARTM-2 modules should be de-energized and removed from the chassis. The minimum force necessary should be used when burnishing contacts to prevent damage and disturbance of contact calibration.

In normal operation, or through functional testing, the monitoring function (LED's) on the various modules provide a check on the performance of the system.

The areas set and checked during the SET UP procedure as well as those areas that can be calibrated (refer to CALIBRATION section) are key areas to verify at regular maintenance intervals. Ref: LCB SYSTEM FUNCTIONAL TEST/SYSTEM VERIFICATION PROCEDURE.

7.2 Routine Inspection of Wet Tantalum Capacitors (REF: PNL 092401)

Periodic inspection for leakage, corrosion and discoloration at the soldered terminals of wet tantalum capacitors (100 mfd, 35V, 20%) should be performed on the following relay modules. If defective, they should be replaced to sustain the design life of the product. Contact the ABB Coral Springs Relay Division Quality Coordinator at 1-800-222-1946.

ARTM-1:	C1, C5
ARTM-2:	C1, C5, C14
MD:	C2, C4, C39, C41
DTD:	C39, C41
IFO:	C19, C22, C26
ALS-1:	C10, C11

Vintage LCB relay modules:

MD:	style 1586C13	C27, C28
IFT:	style 1586C07	C49, C50
ARTM-1:	same as current module	
ARTM-2:	same as current module	
IFO:	same as current module	

8.0 RECOMMENDED TEST EQUIPMENT

The following is recommended test equipment and associated test devices for an LCB system.

1. Dual-trace oscilloscope.
2. Frequency counter.
3. Digital multimeter with true rms.
4. Three-phase 50/60 Hz current source with meters.
5. dc voltage source.
6. UME-3D board extender – Style 1355D52G01.
7. Variable attenuator (600 ohm) – tone systems.
8. Optical Power meter-optical systems: (optional but preferred).
9. Random noise generator – tone systems (optional).
10. Optical attenuator – optical systems (optional).
11. Optical cable with connectors for connecting the relay back to back – optical systems (for SMA connectors, 10 meter length, 50/125 fiber Style 1604C71G04 or 9/125 Single-mode fiber Style 1604C71G08. For ST connectors, 10 meter length 50/125 multi-mode fiber Style 1604C71G15 or 9/125 Single-mode fiber Style 1604C71G16).

9.0 LCB II ACCEPTANCE TEST PROCEDURE

It is recommended that an Acceptance Check be applied to the LCB system to verify that the circuits and system components are functioning properly.

The LCB test diagram shown in Figure 16 (see page 57) aids in test of the unit on a stand-alone basis. If the LCB is to be acceptance tested in an operating system, then the communication channel should be set initially as per the FIELD SETUP procedure.

The CALIBRATION section of the I.L. gives further detail on those portions of the LCB that can be calibrated.

NOTE: When removing or inserting modules, dc power should be turned off.

9.1 Preliminary

A. Links And Dial Settings:

Relay Module:

N-N1, P-P1, Z-Z1, J (ms)-2, T-SET Max, clockwise

IFDT-Dual Tone Interface Module(S):
XDB to “+15”, R to “AMP” (when used)

AXLM Module:

AL-1 to “S”; CAI to “S”; UR to “OUT”; LC-BLK; TRDS to “IN”; 5X, 10X links to “5X”; 52B, TARGET RESET, and OCC to rated dc voltage.

DTT Module (when used):

“DTT KEY” Link to rated dc voltage.

MD Module:

“OCCC” link to “OUT”.

B. Test Setup

Connect relay to rated dc voltage and 3 phase current source in accordance with Figure 16 (see page 57).

NOTE: All measurements are with respect to “COM” unless otherwise specified.

9.2 Power Supply (ALS or ALS-1 Module)

Energize relay with rated dc voltage, and with the ALS or ALS-1 module power switch on.

A. Check that the “DC INPUT” and “DC OUTPUT” indicators are on.

B. Measure +15 Vdc to be between +14.90 and + 15.10 Vdc.

C. Measure -15 Vdc to be between -14.90 and - 15.10 Vdc.

D. Insert a board extender in place of the RELAY module. Short the (+ 15) volt terminal 14A-C to common, terminal 32A-C; the dc OUTPUT indicator should go off and the PSA relay contacts (PSA-1, 2 and PSA-3, 4) should close. Repeat by shorting (-15) volt terminal 18A-C to common, terminal 32A-C.

9.3 Sequence Net Work (Relay module)

A. Open communication channels by removing interface module(s). (IFDT-1, 2, or IFO-1, 2).



When verifying the negative and positive

sequence in steps B and C, the three-phase source must be undistorted and balanced, otherwise the low measured levels of <5 mV at TP4, 5 or 6 may be higher.

- B. Apply three-phase balanced positive-sequence current at ct rating (5A or 1A): measure ac voltage per table below:

TP1 .348-.358	TP2 .348-.358	TP3 .348-.358
TP4 <5mV	TP5 .347-.358	TP6 <5mV

- C. Apply 3-phase balanced negative-sequence current at ct rating (5A or 1A) measure ac voltage per table below.

TP1 .348-.358	TP2 .348-.358	TP3 .348-.358
TP4 .347-.358	TP5 <5mV	TP6 <5mV

- D. Apply zero-sequence currents by applying rated single-phase-to-neutral current. Measure ac voltage on TP6 to be 113 to 123 mV.

9.4 Dial Setting (T-set) – (Relay Module)

- A. Open Z jumper (Z-Z), and leave communication channels open.
- B. Apply 3-phase positive-sequence current at 4 amps for 5A ct or .8 amp for 1A ct.
- C. Slowly adjust T-SET for “just trip” by monitoring the TRC test jack and observing the voltage fall from +15 Vdc to -15 Vdc (approx.). “LCB TRIP” should light.

Dial setting should be between 560 and 600.

TP-7 voltage should be between 1.400 and 1.430 Vrms.

Measure VTRIP test jack (or TP14) voltage to be between .45 and .60 Vdc.

NOTE: There is approximately 15% hysteresis in the trip setting. In order to assume proper reading, set T-SET dial to maximum clockwise to “remove trip” then slowly turn T-SET counter-clockwise until “just trip” is observed. Repeat

several times to verify reading.

- D. Refer to Table 4 for verification of pickup values versus other sequence settings and fault types (3-phase, AB, BC, CA, AN, BN, CN). Tolerance of $\pm 5\%$.
- E. Leave the Z jumper out (Z-Z) for the remainder of the Acceptance test.

9.5 Desensitized Trip (AXLM Module)

- A. With channel interface modules still removed, apply single-phase current (IB-N) at 2 amp for 5 amp ct or .4 amp for 1 amp ct. Set T-SET dial for “just trip” as monitored at TP-TRC. “LCB TRIP” indicator should light. (Dial setting approx. 100 or less.)
- B. Close 52b test switch (see Figure 16).
- C. Press “SYSTEM INDICATOR RESET” button. “LCB-TRIP” indicator on RELAY module should turn off.
- D. Increase input current until “LCB-TRIP” indicator just lights. Input current should be approximately 10 amperes for 5A ct or 2 amperes for 1A ct. “DES TRIP” indicator should also light.
- E. Open 52b switch. Push “SYSTEM INDICATOR RESET” button; “LCB-TRIP” indicator should remain lit, “DES-TRIP” will be off.

NOTE: “DES TRIP” is disabled 200 ms after opening 52b.

- F. Remove input current and press “SYSTEM INDICATOR RESET” button to reset indicators.

9.6 Channel Interface (IFDT Or IFO Modules)

Reinsert IFDT or IFO interface modules.

- A. Transmitter Output
1. Tone Interface Module(s) IFDT-1 and IFDT-2 (when used).
 2. Use a true rms voltmeter to measure output at TB3-7, 8 (XMTR #1) or TB3-5, 6 (XMTR-#2) or at the two XMTR POUT terminals on the front of the IFDT modules. Check transmitter output level by moving link and adjusting

“TX-ADJ” per table below:

TX-ADJ	LINK -23	LINK -4	LINK +15
Max ccw	-40 dB (7.8 mV)	-25 dB (43.6 mV)	-5 (.44V)
Max cw	-23 dB (55 mV)	-3 dB (.55V)	+15 dB (4.4V)

NOTE: Ranges stated above represent typical values and are represented to show the overlapping characteristics of link position.

Set output level at 775 mV (0 dBm, 600 ohm) (+15 link) for the remainder of the acceptance checks. Upon setting output level for 775 mV (0 dBm, 600 ohm) at “XMTR OUT”, the Reference to Carrier separation can be verified. Remove “RFO” link, measure and record level at 2762 Hz. Replace “RFO” link and remove “PF1” link, measure and record level at 1700 Hz. The difference in levels recorded should be 6 dB ($\pm .75$ dB).

3. Optical Interface Module(s) IFO-1 and IFO-2 (when used).

NOTE: The Dolran alignment sleeve supplied with the 906-SMA-connectorized Fiber optic cable should be used when interfacing cable to the LED (transmitter). This increases alignment accuracy and thus provides less coupling loss.

- a. 850 nm wave length

There is no transmitter adjustment. The LED (optical Transmitter) light output power level, from a 50/125 graded-index dual-window Multi-mode fiber should be -16 to -22 dBm. This light level can be optimized for the 906 connector by loosening the connector sleeve, rotating it to find the peak output, and tightening it once again. Essentially, this aligns the optical fiber with the LED spot.

- b. 1300 nm wavelength

There is no transmitter adjustment. The LED (optical transmitter) light output power level from a 50/125 graded-index dual-window Multi-mode fiber should be -25 dBm or greater, and that from a 9/125 Single-mode fiber should be -40 dBm or greater. This light level can be optimized for the 906 connector by loosening the connector sleeve, rotating it to

find the peak output, and tightening it once again. Essentially, this aligns the optical fiber with the LED spot.

- c. 1300 nm High Power Output

There is no transmitter output power adjustment. The LED (Optical Transmitter) light output power level from 9/125 μ m Single-mode fiber (at the ST connector) should be 2.5 μ W (-26 dBm) or greater at 25°C.

The output power should decrease by no more than 3% per degree centigrade (-3%/°C).

B. Receiver Sensitivity

1. Tone Interface Module(s) IFDT-1 and IFDT-2 (when used).

Set attenuator to read -15 dBm (138 mV) at RCVR terms TB3-3, 4 (R1), TB3-1, 2 (R2).

Adjust “TX-ADJ” to read 138 mVrms at TP-AGC.

Vary attenuator to check the various indicator thresholds per table below.

Received Level	“LO” Indicator		“HI” Indicator		“SNR” Indicator	
	On	Off	On	Off	On	Off
-3 dBm (548 mV)		x	x			x
-7 dBm (350 mV)		x		x		x
-15 dBm (138 mV)		x		x		x
-22 dBm (61.5 mV)		x		x		x
-27 dBm (34.6 mV)	x			x		x
-35 dBm (13.7 mV)	x			x	x	

NOTE: NOTE: All voltages are measured at received input terminals.

2. Optical Interface Module(s) IFO-1 and IFO-2 (when used)

- a. 850 nm wavelength

If an optical attenuator is available and connected between transmitter output and receiver input, vary attenuation until “LO” level indication occurs. This attenuation should be 40 dB or more, including optical attenuator insertion loss. AGC should read -6 Vdc (± 0.5 Vdc) when the indicator lights.

If an optical attenuator is not available, then simply disconnect the Fiber optic cable between transmitter and receiver,

and observe "LO" level indicator light.

b. 1300 nm wavelength

For 50/125 graded-index dual-window fiber: if an optical (1300 nm) attenuator is available and connected between transmitter output and receiver input, vary attenuation until "LO" level indication occurs. This attenuation should be 30 dB or more, including optical attenuator insertion loss. AGC should read -6 Vdc (± 0.5 Vdc) when the indicator lights.

For 9/125 Single-mode fiber: If an optical (1300 nm) attenuator is available and connected between transmitter output and receiver input, vary attenuation until "LO" level indication occurs. This attenuation should be 15 dB or more, including optical attenuator insertion loss. AGC should read -6 Vdc (± 0.5 Vdc) when the indicator lights.

If an optical attenuator is not available, then simply disconnect the Fiber optic cable between transmitter and receiver, and observe "LO" level indicator light.

c. 1300 nm wavelength receiver used with 1300 nm High Power Output Transmitter

For 9/125 Single-mode fiber: If an optical (1300 nm) attenuator is available and connected between transmitter output and receiver input, vary attenuation until "LO" level indication occurs. This attenuation should be 35 dB or more at 25°C, including optical attenuator insertion loss. AGC should read -6 Vdc (± 0.5 Vdc) when the indicator lights.

If an optical attenuator is not available, then simply disconnect the Fiber optic cable between transmitter and receiver, and observe "LO" level indicator light.

3. Noise evaluation test (IFDT) modules only

- a. Connect an oscillator set at 1000 Hz or noise generator (continuous noise) through a 600 ohm attenuator to printed circuit board (PCB) terminals 10A-C and 12A-C.
- b. With the oscillator turned off, but attenuator connected to terminals 10A-C and 12A-C and at least 10 dB attenuation, measure and record the signal at "AGC

IN" and "RX IN" with the normal received tone signal (measured in dB).

- c. Increase amplitude of oscillator until the "SNR" indicator just begins to operate, terminal 26C should drop from +15 to 0 volts dc.
- d. Disconnect the incoming transmitted signal from receiver input by removing the "XdB" link on corresponding IFDT module. The measured signal at "AGC IN" should be 17dB (± 2 dB) less than the signal measured in step b.
- e. Replace "XdB" link to +15 dB position and remove "PF1" link on same module. Set oscillator for 2762 Hz and adjust level to obtain the same voltage at "RX IN" as recorded in step b above.
- f. Gradually increase frequency, not level, of oscillator until "SNR" indicator just turns "ON", voltage on terminal 26C should be +15 Vdc and voltage on terminal 28C should be 0 Vdc. Frequency of oscillator should be 2777 to 2787 Hz.
- g. Gradually decrease frequency, not level, of oscillator below 2762 Hertz until "SNR" indicator again just turns "ON". Voltage on terminal 26C should be +15 Vdc and voltage on terminal 28C should be 0 Vdc. Frequency of oscillator should be 2747 to 2737 Hertz.
- h. Remove oscillator from terminals 10A-C and 12A-C. On board indicator should be on. Replace "PF1" link on IFDT module. On board indicator should be off.

9.7 PPM Modulator (MD Module)

With no ac input current applied, monitor the "RFO" test jack. Adjust P1 on MD module for a frequency of 1700 Hz ± 5 Hz. RFO voltage should be a square wave from 0 to approximately +14 Vdc (tone systems) or +12 Vdc (optical systems).

9.8 PPM Demodulator [MD And DTD (When Used) Modules]

- A. Set channel attenuation to nominal signal level.
 1. Tone Interface – Set received signal level(s) to -15 dBm (138 mV).

2. Optical Interface – No attenuation or nominal attenuation representing expected loss for user's optical system.
- B. Null Adjustment (residual carrier signal removal).
1. With no ac current input applied, monitor "VR1" terminal (MD module) and "VR2" (DTD module when used) with a scope. Adjust P4 on MD module and DTD module (when used) for a null. The waveform should be at zero dc level with minimum separation.
- C. Demodulator Gain (MD Module) Channel #1
1. Set T-SET dial (RELAY module) to 580 and apply single-phase ac current (IB-N) at 5 amperes for 5A ct or 1 ampere for 1A ct.
 2. Use dual trace scope to monitor "VLD", RELAY module, and "VR1F", MD module, terminals.
Set the "DM GAIN" pot on the MD module so that waveform on "VR1F" is equal in magnitude to "VLD", as measured with an ac voltmeter.
- D. Demodulator Gain (DTD) module (when used – Channel #2 – 3 terminal lines)
1. Repeat step C using "DM GAIN" and "VR2F" on the DTD module.
- E. Channel #2 Delay (DTD Module) when used – channel #2 – 3 terminal lines).
1. Set "J (ms)" link on RELAY and DTD modules to "2", RELAY module, and "0", DTD module. Apply single-phase ac current (IB-N) input of 5 amperes for 5A ct or 1 ampere for 1A ct.
 2. Monitor "VLD", RELAY module, and "VR2F", DTD module.
 3. Observe "VLD" and "VR2F" waveforms for time delay between respective zero crossings.
 4. Move J (ms) link on DTD module to 2.
 5. Adjust "DEL-ADJ" on DTD module; observe the adjustment range to be up to approximately 2 ms more than step 2.
 6. Move J(ms) link on DTD module to 4. Two additional ms of delay should be observed.
 7. Reset J(ms) link to "0" (DTD).

9.9 CHANNEL DELAY EQUALIZER CIRCUIT (RELAY MODULE)

- A. Apply single-phase ac input current (IB-N) at 5 amperes for 5A ct or 1 ampere for 1A ct.
- B. Monitor "VLD", RELAY module, and "VR1F", MD module.
With "J (ms)" link set on "2"; adjust "DELAY ADJ" on the RELAY module to observe a range of adjustment approximately 2 ms.
Set "DELAY ADJ: (module front) so that waveforms are in phase.
- C. Move "J(ms)" link to "4", "6" and "8" positions. Check the effect of each adding 2 ms per link position.
- D. Reset "J(ms)" link to "2".

9.10 Loss Of Channel Alarm/indication Logic (AXLM Module)

- A. Set channel attenuation (between transmitter and receiver) of each channel to receive normal signal level.
Remove ac input current.
Push "SYSTEM INDICATOR RESET" button to reset all indicators.
- B. Momentarily open channel #1 communication by removing connection to receiver terminals; observe "CA" indicator light after approximately 2.5 seconds. AL-1 and AL-2 relays should pick up.
Restore normal channel; "CA" indicator should remain on; AL-1 and AL-2 should remain picked up.
Push "SYSTEM INDICATOR RESET" button to turn "CA" indicator off and dropout AL-1 and AL-2.
- C. Repeat B with AL-1 and CAI links set to NS. In this case the CA light and AL-1 and AL-2 will drop out when the channel is restored.
- D. Repeat the Above procedures for communication channel #2 (if used).

9.11 Overcurrent Trip/loss-of-channel

Options (AXLM Module)

- A. LC-BLK: "Block trip on loss-of-channel".
 1. Set LC link to "BLK".
 2. Open communication channels #1 and #2 (if used).
 3. With T-SET dial (RELAY module) set at 580, apply single-phase ac current (IB-N) at 6 amperes for 5A ct or 1.2 amperes for 1A ct: "OC/UB TRIP" indicator (AXLM module) and "LCB TRIP" indicator (RELAY module) should remain off.
 4. Remove current then restore channels.
- B. LC-OT: "Allow trip on loss-of-channel".
 1. Set LC link to "OT".
 2. Open communication channels #1 and #2 (if used).
 3. With T-SET dial (RELAY module) set at 580, apply single-phase ac current (IB-N) at 6 amperes for 5A ct or 1.2 amperes for 1A ct: "OC/UB TRIP" indication (AXLM module) and "LCB TRIP" indication (RELAY module) should occur.
 4. Remove input current; press "SYSTEM INDICATOR RESET" pushbutton (ARTM Module) and "OC/UB TRIP" and "LCB TRIP" indicators should turn off.
 5. Restore channels.
- C. LC-OTD: "Time-delayed trip on loss-of-channel".
 1. Set LC link to "OTD".
 2. Monitor "TRC" (RELAY module) and "OCTD" (AXLM module).
Open communication channels #1 and #2 (if used).
 3. With T-SET dial set at 580; apply single-phase ac current input (IB-N) at 6 amperes for 5A ct or 1.2 amperes for 1A ct.
"TRC" should fall to -15 Vdc immediately and "OCTD" from +15 Vdc to zero after a time delay as set by "TD ADJ" on the AXLM module.
"OC/UB TRIP" (AXLM) and "LCB TRIP" (RELAY) indication should occur when "OCTD" drops to 0 volts.
4. Remove input current; press "SYSTEM INDICATOR RESET" button and "OC/UB TRIP" and "LCB TRIP" indication should reset.
5. Restore channels.
- D. LC-UB: Unblock trip for 150 ms on loss-of-channel.
 1. Set LC link to "UB".
 2. Set communication channels to normal whereby receivers are receiving nominal level. Set T-SET (Relay module) to 580.
 3. Monitor "TRC" and printed circuit terminal 2C (LCB TRIP) on the RELAY module.
Apply single-phase input current (IB-N) at 6 amperes for 5A ct or 1.2 amperes for 1A ct.
"TRC" voltage should fall from +15 to -15 Vdc. Printed circuit terminal 2C (LCB TRIP) should fall from +15 to 0 Vdc. "LCB TRIP" indicator should light.
 4. Open channel #1 communication by removing input signal to receiver.
TP-TRC voltage should remain at approximately -15 Vdc; printed circuit board terminal 2C (LCB TRIP) voltage should rise to +15 Vdc for 45 ms immediately following channel loss then returns to 0 Vdc for approximately 105 ms and rises to +15 Vdc, and remains at that level. Press "SYSTEM INDICATOR RESET", "LCB TRIP" indicator should turn off and remain off.
 5. Repeat for channel #2 (if used).
 6. Remove input current and restore channels.
- E. LC-UB/UR-IN: Reclose unblock tripping on loss-of-channel.
 1. Set link LC to "UB", link UR to "IN", and TRDS to "OUT". (All links are on AXLM module). Set T-SET dial (RELAY) at 580.
 2. With the channel(s) set for normal received signal, close 52b switch (Reference Figure 16) and apply single-phase ac current (IB-N) of 6 amperes (5A ct) or 1.2A (1A ct). "LCB TRIP" indication should occur.
 3. Open channel by removing the input signal, remove input current, then reset indicators with "SYSTEM INDICATOR RESET", and ALL within 2.5 seconds, reapply input current. "LCB TRIP" and "OC/UB" should reoccur.

4. Repeat step 2 then 3, but wait longer than 2.5 seconds in step 3. "LCB TRIP" should not occur.
 5. For systems utilizing channel #2, (3 terminal lines), repeat the process by opening channel #2.
 6. Open 52b and restore all channels.
- F. LC-UB/OTD: "Unblock and time-delayed trip on loss-of-channel".
1. Set LC link to "UB/OTD".
 2. Set communication channel(s) to normal. Set T-SET dial (RELAY) to 580.
 3. Monitor TP-TRC and printed circuit terminal 2C (LCB TRIP) on the RELAY module.
 4. Apply single-phase input current (IB-N) at 6 amps for 5 A ct, or 1.2 amps for 1 A ct. "TRC" voltage should fall from +15 to -15 Vdc. Printed circuit terminal 2C (LCB TRIP) should fall from +15 to 0 Vdc.
 5. Open channel #1 communication by removing input signal to receiver. "TRC" should remain at -15 Vdc. Printed circuit terminal 2C (LCB TRIP) should rise to +15 Vdc for 45 ms immediately following channel loss, then return to 0 Vdc for approximately 105 ms, rise to +15 Vdc, then drop back to 0 Vdc when an output for the overcurrent time delay circuit, OCTD, AXLM module occurs. *Note: if the OCTD is set for 150 ms or less, then terminal 2C will remain at "0".*

Press "SYSTEM INDICATOR RESET", "LTCB TRIP" and "OC/UB TRIP" indication should remain.
 6. Repeat for channel 2 (if used).
 7. Remove input current. Press "SYSTEM INDICATOR RESET". "LCB TRIP" and "OC/UB TRIP" should reset.
 8. Restore channels.

9.12 Overcurrent Control (OCC) (AXLM And

MD Module)

- A. Set LC link to BLK (AXLM). T-SET dial to 580.
- B. Open communication channels #1 and #2 if used, by disconnecting the received signal or simulating LO level.

Apply single-phase ac current (IB-N) of 6 amperes (5A ct) or 1.2 amperes (1A ct).

"LCB TRIP" indication should not occur.
- C. Simulate an OCCBP/OCCBN input (Reference test diagram Figure 16).

"LCB TRIP" indication should occur.
- D. Observe "RFO" (MD module) with a scope with the following OCC link options on the MD module.
 1. OCC-OUT: 1700 Hz square wave with 50/60 Hz modulation.
 2. OCC-LOC: Signal remains 0 Vac.
 3. OCC-TTO: 1700 Hz steady square wave with and without DTT keyed.
 4. OCC-TTI: 1700 Hz steady square wave normally. DTT modulated square wave when DTT is keyed.
- E. Return channels to normal, set OCC link to TTI and remove OCC contact input. Reset all indicators.

9.13 Trip Output Circuit (ARTM Module)

- A. With communication channels set for normal condition, and T-SET dial (RELAY module) set at 580, apply single-phase input current (IB-N), at 6 amperes for 5A ct or 1.2 amperes for 1A ct: AR-1 trip relay should pick up, "LCB TRIP" should light.
- B. Close Trip control switch (reference Figure 16) "LCB TRIP-1" and "LCB TRIP-2" indicators should light.
- C. Remove input current and press "SYSTEM INDICATOR RESET". "LCB TRIP-1" and "LCB

TABLE 4
Fault Current Magnitudes in Multiples of
T-Setting for All Combinations of
Sequence Tap Settings

Sequence Taps	Positive (P)	Negative (N)	Zero (Z)	Fault Current in Multiples of T	Sequence Taps	Positive (P)	Negative (N)	Zero (Z)	Fault Current in Multiples of T
3-Phase Fault	0	0	1	Infinite	A-B or	0	0	1	Infinite
	0	0	2	Infinite	C-A	0	0	2	Infinite
	0	1	0	Infinite	Fault	0	1	0	.748
	0	1	1	Infinite		0	1	1	.748
	0	1	2	Infinite		0	1	2	.748
	0	2	0	Infinite		0	2	0	.785
	0	2	1	Infinite		0	2	1	.785
	0	2	2	Infinite		0	2	2	.785
	0	3	0	Infinite		0	3	0	.864
	0	3	1	Infinite		0	3	1	.864
	0	3	2	Infinite		0	3	2	.864
	1	0	0	1.000		1	0	0	1.732
	1	0	1	1.000		1	0	1	1.732
	1	0	2	1.000		1	0	2	1.732
	1	1	0	1.000		1	1	0	.861
	1	1	1	1.000		1	1	1	.861
	1	1	2	1.000		1	1	2	.861
	1	2	0	1.000		1	2	0	.905
	1	2	1	1.000		1	2	1	.905
	1	2	2	1.000		1	2	2	.905
	1	3	0	1.000		1	3	0	.998
	1	3	1	1.000		1	3	1	.998
	1	3	2	1.000		1	3	2	.998
	2	0	0	2.000		2	0	0	3.464
	2	0	1	2.000		2	0	1	3.464
	2	0	2	2.000		2	0	2	3.464
	2	1	0	2.000		2	1	0	.821
	2	1	1	2.000		2	1	1	.821
	2	1	2	2.000		2	1	2	.821
	2	2	0	2.000		2	2	0	.864
	2	2	1	2.000		2	2	1	.864
	2	2	2	2.000		2	2	2	.864
	2	3	0	2.000		2	3	0	.959
	2	3	1	2.000		2	3	1	.959
	2	3	2	2.000		2	3	2	.959

TABLE 4 (Cont'd)
Fault Current Magnitudes in Multiples of
T-Setting for All Combinations of
Sequence Tap Settings

Sequence Taps	Positive (P)	Negative (N)	Zero (Z)	Fault Current in Multiples of T	Sequence Taps	Positive (P)	Negative (N)	Zero (Z)	Fault Current in Multiples of T
B-C Fault	0	0	1	Infinite	A-Ground Fault	0	0	1	.124
	0	0	2	Infinite		0	0	2	.242
	0	1	0	.748		0	1	0	1.296
	0	1	1	.748		0	1	1	.113
	0	1	2	.748		0	1	2	.204
	0	2	0	.785		0	2	0	1.359
	0	2	1	.785		0	2	1	.113
	0	2	2	.785		0	2	2	.205
	0	3	0	.864		0	3	0	1.497
	0	3	1	.864		0	3	1	.114
	0	3	2	.864		0	3	2	.208
	1	0	0	1.732		1	0	0	3.00
	1	0	1	1.732		1	0	1	.129
	1	0	2	1.732		1	0	2	.263
	1	1	0	.523		1	1	0	2.282
	1	1	1	.523		1	1	1	.117
	1	1	2	.523		1	1	2	.219
	1	2	0	.540		1	2	0	2.484
	1	2	1	.540		1	2	1	.118
	1	2	2	.540		1	2	2	.220
	1	3	0	.577		1	3	0	2.988
	1	3	1	.577		1	3	1	.119
	1	3	2	.577		1	3	2	.224
	2	0	0	3.464		2	0	0	6.000
	2	0	1	3.464		2	0	1	.126
	2	0	2	3.464		2	0	2	.252
	2	1	0	.615		2	1	0	1.653
	2	1	1	.615		2	1	1	.115
	2	1	2	.615		2	1	2	.211
	2	2	0	.640		2	2	0	1.757
	2	2	1	.640		2	2	1	.115
	2	2	2	.640		2	2	2	.213
	2	3	0	.692		2	3	0	1.995
	2	3	1	.692		2	3	1	.116
	2	3	2	.692		2	3	2	.216

TABLE 4 (Cont'd)

Fault Current Magnitudes in Multiples of T-Setting for All Combinations of Sequence Tap Settings				
Sequence Taps	Positive (P)	Negative (N)	Zero (Z)	Fault Current in Multiples of T
B Ground or	0	0	1	.124
	0	0	2	.242
C Ground Fault	0	1	0	1.296
	0	1	1	.129
	0	1	2	.263
	0	2	0	1.359
	0	2	1	.129
	0	2	2	.262
	0	3	0	1.497
	0	3	1	.129
	0	3	2	.260
	1	0	0	3.000
	1	0	1	.121
	1	0	2	.232
	1	1	0	1.019
	1	1	1	.126
	1	1	2	.248
	1	2	0	1.055
	1	2	1	.126
	1	2	2	.247
	1	3	0	1.132
	1	3	1	.125
	1	3	2	.246
	2	0	0	6.000
	2	0	1	.122
	2	0	2	.237
	2	1	0	1.153
	2	1	1	.128
	2	1	2	.255
	2	2	0	1.202
	2	2	1	.127
	2	2	2	.254
	2	3	0	1.307
	2	3	1	.127
	2	3	2	.253

TRIP-2" indicators should remain on and AR1 should remain picked up. "LCB TRIP" indicator (RELAY module) should turn off.

- D. Open Trip control switch: AR-1 should drop out but "LCB TRIP-1" and "LCB TRIP-2" indicators should remain on.
- E. Press "SYSTEM INDICATOR RESET" button; "LCB TRIP-1" and LCB TRIP-2" indicators should reset.

9.14 Direct Transfer Trip (DTT Module) – When Supplied

- A. With the channels set for normal signal, and no ac current applied, close DTT switch (reference Figure 16) "DTT KEY" and "DTT TRIP" indicators on the DTT module must light, and AR-2 on the ARTM-2 module will operate.
- B. Close Trip control switch; "DTT TRIP-1" and "DTT TRIP-2" indicators (ARTM-2) must light.
- C. Open DTT switch; all indicators should remain on.
- D. Push "SYSTEM INDICATOR RESET". "DTT TRIP-1 and 2" indicators (ARTM-2) should remain on, "DTT KEY and TRIP" indicators (DTT) should turn off, AR-2 should remain picked up.
- E. Open Trip control switch, push "SYSTEM INDICATOR RESET". All indicators must turn off, AR-2 must drop out.
- F. Apply single-phase ac input current (IB-N) at 6 amperes for 5 A ct or 1.2 amperes for 1 A ct with T-SET dial at 580. "LCB TRIP" indicator should light.
- G. Close DTT switch. "DTT KEY and TRIP" indicators should light.
- H. Press "SYSTEM INDICATOR RESET": "LCB TRIP" indicator should turn off. "DTT KEY and TRIP" indicators should remain on.
- I. Remove ac current, open DTT switch. Press "SYSTEM INDICATOR RESET". "DTT KEY and TRIP" indicators should turn off.

9.15 Target Reset (AXLM Module)

- A. Set up an LCB trip condition as in section 9.13 or a DTT trip as in section 9.14. Open the trip control switch and remove ac current (LCB trip) or DTT Key (DTT trip). Trip indicators should be on and sealed-in.
- B. Close the target reset switch TR (Reference Test Diagram, Figure 16). All sealed-in indicators must reset, and remain reset when TR is opened.

9.16 Power-up Trip/indication Block (ARTM Module)

- A. Set up an LCB trip condition as in Section 9.13 or a DTT trip as in section 9.14.
- B. Turn off dc power switch. Trip AR(s) will drop-out and indication will turn off.
- C. Turn on dc power switch. Trip AR(s) will operate and indication will occur 2.5 to 4.5 seconds after turning on dc.
- D. Remove trip condition and reset indicators.

9.17 At Completion Of Acceptance Test, Refer To "Settings" Section For Desired Position Of Links.

10.0 LCB II CALIBRATION PROCEDURE

The proper adjustments to insure correct operation of the LCB have been made at the factory and should not be disturbed after receipt by the customer. However, if the adjustments or any components have been changed or modules interchanged, then that portion of the LCB should be recalibrated and acceptance checked, and the Field Setup procedure rechecked.

The following procedure applies to those areas of the LCB that can be recalibrated, and does not cover those adjustments required for Field Setup. All measurements are with respect to "COM" unless otherwise specified.

10.1 ALS or ALS-1 Power Supply Module

The output adjust potentiometer on the front panel of the ALS power supply is used to adjust the +15 Vdc output to +15.00 (± 0.01). Once adjusted, -15 Vdc should be -15.0 (± 0.2) Vdc.

The ALS-1 power supply does not have a front panel adjust potentiometer. The output is fixed at +15 ± 0.1 Vdc and -15 ± 0.1 Vdc.

10.2 DTD Module — 3 Terminal Lines

With the channel levels properly set, (refer to Field Setup), and a signal being received either from the remote terminal or connected back to back, adjust P4 for minimum residual carrier signal (minimum waveform separation) at "VR2" as observed on a scope. If the received signal is modulated, the waveform at "VR2" will be a sine wave; if not modulated, a zero dc level will exist.

10.3 MD Module

A. Modulator

With no modulation (no 50/60 Hz input current to the relay), set potentiometer P1 for 1700 Hz as measured with a counter on "RFO".

B. Demodulator

With the channel levels properly set (refer to Field Setup) and a signal being received either from the remote terminal or connected back to back, adjust P4 for minimum residual carrier signal (minimum waveform separation) at "VR1" as observed on a scope. If the received signal is modulated, the waveform at "VR1" will be a sine wave or clipped sine wave; if not modulated, a zero dc level will exist.

10.4 Audio Tone Interface Modules (IFDT-1 And IFDT-2 For 3 Terminal Lines)

A. "HI" Level Adjustment (IFDT)

With the channel receiving a signal either from the remote terminal or back to back, adjust the signal at "AGC IN" to 0.436 Vrms with "RX ADJ". At this level (+10 dB from normal) adjust potentiometer P5 so that the "HI" level indicator just lights. ***This adjustment has been factory set and should not be adjusted unless absolutely necessary.***

B. 1700 Hz Trap Adjustment (IFDT)

Remove connections to IFDT module terminals 10 A, C and 12 A,C from the channel by either opening the proper switches on the extender card or by disconnecting terminals 1 and 2 on TB 3 and connect an oscillator through a 600 ohm attenuator to these terminals. Adjust the level at "AGC IN" for .138 Vrms

with 1710 Hz applied. Then monitor TP12 and adjust P4 for a voltage null. Gradually decrease the input frequency until a peak reading is obtained and record the level (< 200 mV rms). Gradually increase the input frequency above 1700 Hz until another peak voltage is obtained and record this level (< 200 mV rms). Readjust P4 so that the average voltage reading of the two peaks is within 5 mV.

C. 2762 Hz Trap Adjustment (IFDT)

With the channel receiving an unmodulated signal, remove "RFO" link from transmitting IFDT module and adjust potentiometer P3 for minimum ac voltage at TP4. ***This adjustment has been factory set and should not be adjusted unless absolutely necessary.***

10.5 Relay Module



Calibration of Negative or Positive Sequence requires an undistorted and balanced three-phase source.

A. Negative Sequence

Apply a balanced 3-phase positive-sequence current at power system frequency (50 or 60 Hz) and ct rating (5 A or 1 A). Adjust P1 for a null at TP4.

B. Positive Sequence

Apply balanced 3-phase negative-sequence current (reverse phase A and B) at the power system frequency (50 or 60 Hz) and ct rating (5A or 1A). Adjust P2 for a null at TP5.

C. Trip Pickup

1. This setting requires local quantities only, and
 - (a) The channel "lost" from the remote terminal(s) ("LO" level), or
 - (b) The channel interface cards (IFT – $1/2$ or IFO – $1/2$) removed so that they don't affect calibration. In addition, if either the "UNBLK" or TRDES" option on the AXLM module have been selected, then this module should be removed to prevent trip blocking.

2. Apply 3-phase or single-phase current to obtain 1.414 Vac rms at test point TP7. This level is more readily settable by applying a fixed current and adjusting the "T" dial to obtain the 1.414 Vrms. The waveform should be clean undistorted sine wave.

NOTE: Due to the high gain associated with zero sequence, and depending on the cleanliness of the current source used, it may be advisable to temporarily remove the zero sequence sensitivity link (Z).

3. Adjust potentiometer P5 for trip to just occur. This can be observed by
 - (a) Observing the "LCB TRIP" indicator and
 - (b) Tip jack "TRC" should fall from "1" (+15 Vdc) to "0" (-15 Vdc). The value for trip, as measured at VTRIP test jack, TP14, or terminal 28, should be approximately 0.5 Vdc.

4. Repeat several times to insure the proper setting.

NOTE: The trip output has some hysteresis (approximately 15%), so to recheck the trip level it must be reset below the trip hysteresis level by removing and reapplying the input ac current, or changing the "T SET" dial.

10.6 AXLM Module

A. Line Energizing Trip Desensitizing

Initial factory calibration is for a desensitized level of 5 times pickup. For different multiples of trip level setting, the following recalibration is required.

1. Determine the multiple of trip for desensitizing. For 1 to 5 times pickup, set link on 5X. For 5 to 10 times, set link on 10X. Set TRDS link to "IN".
2. Apply current to the LCB relay to just cause an LCB trip (per method as described for the RELAY module). The voltage is measured on VTRIP (RELAY module) should be .45 to .60 Vdc.
3. Apply signals to simulate the desired desensitized trip level by one of the following methods:
 - (a) Apply current at the desired multiple, or
 - (b) Simulate the VTRIP voltage level (multiple times VTRIP level at pickup) by,
 - (1) Removing the RELAY module and

place the AXLM module on a board extender.

- (2) Jumper TP9 to TP8 and adjust potentiometer P3 for the desired dc voltage.

NOTE: Remove jumper on completion of final setting.

4. With the proper current of VTRIP dc voltage applied, adjust P1 "DES ADJ" so that the "TRDS" jack just changes from "0" to "1" (+15 Vdc).
- B. Channel alarm (AL-1 and AL-2) time delay. Initial factory calibration is for 2500 ms. For different times, the following recalibration is required.
1. Simulate a low signal by increasing attenuation or opening the channel.
 2. Adjust potentiometer P2 for the desired time between 500 to 5000 ms.
- C. Time Delayed Overcurrent Trip (OCTD). This time is adjustable from 0.1 to 2.0 seconds with front mounted potentiometer P4, "TD ADJ", and is initially factory set for 250 ms (.25 seconds). For different times, then the following recalibration is required. Link LC should be set to OTD.
1. Simulate a low signal by increasing attenuation or opening the channel.
 2. Monitor "TRC" (RELAY module) and "OCTD" (AXLM module).
 3. Apply ac input current above LCB pickup.
 4. Measure the time between TRC dropping from +15 Vdc to -15 Vdc (when ac current is applied) and "OCTD" changing from + 15 Vdc to zero. This is the Time Delayed Overcurrent trip time and is adjustable with "TD ADJ".

11.0 FIELD SETUP AND VERIFICATION PROCEDURE

This adjustment procedure assumes that the LCB has been checked per the Acceptance Test, set for proper sequence sensitivities, pickup and link selections per the Settings, and that the relay is wired into a relay system and connected to a communications channel. This procedure must be followed before closing the breaker trip circuits. Refer to Figure 22 (see page 60)

for typical waveforms.

NOTE: For three terminal line relays being used as two terminal line applications, the channel interface card (IFDT-2 or IFO-2), in location E and the DTD card in location C must be removed.

11.1 Communication Channel Adjustment

A. Transmitter

1. Optical Channel

NOTE: The Dolran alignment sleeve supplied with a 906-SMA-connectorized Fiber optic cable should be used when interfacing cable to the LED (transmitter). This increases alignment accuracy and thus provides less coupling loss.

(a) Channel 1 (IFO-1)

(1) 850 nm wavelength

There is no transmitter adjustment. However, the LED (optical transmitter) light output can be optimized by loosening the connector sleeve, rotating it to find the peak output, and tightening it once again. Essentially, this aligns the optical fiber with the LED spot. The light output power level from a 50/125 graded-index dual-window fiber should be -18 to -22 dBm.

(2) 1300 nm wavelength

There is no transmitter adjustment. However, the LED (optical transmitter) light output can be optimized by loosening the connector sleeve, rotating it to find the peak output, and tightening it once again. Essentially, this aligns the optical fiber with the LED spot. The light output power level should be as follows:

For 50/125 Graded Index Dual-window Fiber	-25 dBm or greater
For 9/125 Single-mode Fiber	-40 dBm or greater
For 9/125 Mm Single-mode Fiber With High Power Output	-26 dBm or greater

(b) Channel 2 (IFO-2) — 3 terminals lines (when used)

Follow same procedure as for IFO-1.

2. Audio Tone Channel

(a) Channel 1 (IFDT-1)

(1) Set link (XDB) on the IFDT-1 module for the desired transmitter output range (XDB to "+15" for -5 dBm to +15 dBm; "-4" for -25 dBm to -3 dBm; "-23" for -40 dBm to -23 dBm).

(2) Connect a true rms ac VM to the transmitter output "XMTR OUT" on the IFDT-1 module and adjust "TX ADJ" for the desired composite output level (Reference 0 dBm = 0.775 Vrms).

NOTE: This level can also be measured on the rear terminal block, TB3-terminal 7 and 8; or the output of the audio tone protection package, with level reduced by several dB.

(b) Channel 2 (IFDT-2) — 3 terminal lines. For the majority of 3 terminal line applications, only one transmitter output is required, and through proper matching in the audio tone protection package, the signal from IFDT-1 can be transmitted at the same level to the two remote terminals. If this is the case, follow step 1).

If, however, it is desired to transmit at different levels to the remote terminals, than step 2 below should be followed.

(1) When the second transmitter is not required, set the transmit level link to minimum (XDB to "-23") and adjust "TX ADJ" for minimum output.

(2) When the second transmitter is required;

(a) Set link (XDB) on the IFDT-2 module for the desired transmitter output range (XDB to "+15" for -5 dBm to +15 dBm; "-4" for -25 dBm to -3 dBm; "-23" for -40 dBm to -23 dBm).

(b) Connect a true rms ac VM to the transmitter output "XMTR OUT" on the IFDT-2 module and adjust "TX ADJ" for the desired composite output level (Reference: 0

dBm = 0.775 Vrms).

NOTE: This level can also be measured on the rear terminal block TB3-terminal 5 and 6; or the output of the audio tone protection package, with level reduced by several dB.

B. Receiver

NOTE: Transmitters must be adjusted first.

1. Optical Channel

(a) Channel 1 (IFO-1) no adjustment is required, but insure that the "LO" level indicator is not on. The AGC dc voltage at "AGC" test jack on the IFO module must be -10 to -14 Vdc.

For 850 nm and 50/125 graded-index dual-window fiber, the "LO" level indicator should light with 40 dB or more Fiber optic cable, connector, and splice losses.

For 1300 nm, and 50/125 graded-index dual-window fiber, the "LO" level indicator should light with 30 dB or more Fiber optic cable, connector, and splice losses.

For 1300 nm, and 9/125 Single-mode fiber, the "LO" level indicator should light with 15 dB or more Fiber optic cable, connector, and splice losses.

For 1300 nm, and 9/125 μ m Single-mode fiber connected to the High Power Output Transmitter, the "LO" level indicator should light with 35 dB (at 25°C) or more Fiber optic cable, connectors and splice combined losses.

(b) Channel 2 (IFO-2)-3 terminal lines (when used), follow same procedure as for IFO-1 above.

2. Audio Tone Channel

(a) Channel 1 (IFDT-1)

(1) With a true rms ac VM, measure the normal received signal at "RX IN" with respect to COM. *Note this signal can also be measured at the output of the audio-tone protection package or on the LCB rear terminal block, TB3, terminals 3 and 4.* Set link "R" on the IFDT-1 module to

“ATT” if the measured signal is -15 dBm to +10 dBm or to “AMP” if the signal is -40 dBm to -15 dBm.

- (2) Measure the level at “AGC IN” with respect to COM with a true rms ac VM and adjust “RX ADJ” for 138 mV ac (-15 dBm/600 ohm).

3. Insure the “HI” and “LO” level and “SNR” indicators are not on.

NOTE: “HI” and “LO” level will come on with a +10 dBm or -10 dB signal around the adjusted level.

(b) Channel 2 (IFDT-2) 3 Terminal Lines

- (1) With a true rms ac VM, measure the normal received signal at “RX IN” with respect to COMN. *Note this signal can also be measured at the output of the audio-tone protection package or on the LCB rear terminal block, TB3, terminals 1 and 2.* Set link “R” on the IFDT-2 module to “ATT” if the measured signal is -15 dBm to +10 dBm, or to the “AMP” if the signal is -40 dBm to -15 dBm.

- (2) Measure the level at “AGC IN” with respect to COM with a true rms ac VM and adjust “RX ADJ” for 138 mV ac (-15 dBm/600 ohm).

- (3) Insure the “HI” and “LO” level and “SNR” indicators are not on.

11.2 Carrier Frequency Verification

- A. With no modulation at the local terminal (no 50/60 Hz current applied) verify that the RFO signal measured with a counter on the front of the MD module is 1700 ± 5 Hz.
- B. If required, this frequency can be fine tuned with potentiometer P1 on the MD module (not front accessible).

11.3 Demodulated Signal Verifications

- A. With modulation from the remote terminal(s) (50/60 Hz current applied) monitor VR1 (MD module) and VR2 (DTD module — 3 terminal lines) with a scope. The waveform(s) should appear as a clean sine wave or clipped sine wave with mini-

mum distortion and no waveform separation.

- B. If the waveform appears distorted (not clipped) or separated, the residual carrier frequency can be removed by readjusting the limiter potentiometer P4 on the MD module (VR1) or DTD module (VR2). This potentiometer is not front accessible.

11.4 Signal Level Equalization Adjustment

- A. With no modulation at any terminal (no 50/60 Hz current to any LCB), temporarily set the channel delay equalization link to minimum (Link J (ms) to J1 (2ms), RELAY module).

- B. At the local terminal, connect a jumper between the RELAY module “SETUP” and the MD module “SETUP” front test jacks.

C. Channel 1

1. At the remote terminal for channel 1, connect a jumper between the RELAY module “SETUP” and the MD module “SETUP”.
2. At the local terminal, measure signal “VLD” on the RELAY module and “VR1F” on the MD module with an ac VM (approximately 3.4 Vac).
3. Adjust “DM GAIN” on the MD module so that “VR1F” is the same magnitude as “VLD”.

D. Channel 2 (3 Terminal Lines)

1. At the remote terminal for channel 2, connect a jumper between “SETUP” on the RELAY and MD modules.
2. At the local terminal, measure signals “VLD” on the RELAY module and VR2F on the DTD module with an ac VM.
3. Adjust “DM GAIN” on the DTD module so that “VR2F” is the same magnitude as “VLD”.

- E. Remove all SETUP jumpers and return the delay equalization jumpers to the original position.

11.5 Channel Delay Equalization Adjustment

NOTE: For 3-terminal line systems, channel 1 must be the slowest channel since additional delay equalization adjust is available for channel 2.

A. Channel 1

1. Set the "channel delay equalization links" on the RELAY module for the anticipated channel delay. Link J (ms) -2 = 0 to 2 ms, J (ms) -4 = 2 to 4 ms, J (ms) -6 = 4 to 6 ms, J (ms) -8 = 6 to 8 ms. Optical channels will generally be set on J (ms) -2, whereas audio tone channels will generally be longer, depending on the communication medium.

2. Apply equal modulation at each terminal of channel 1.

This is done by energizing each LCB relay with a single-phase current which is in phase. In-phase currents are most easily derived from voltage to current auxiliary test transformers which have a consistent angle between input voltage and output current. This angle must be the same at both terminals. Of course, this technique also requires in-phase voltages at the two line terminals. The most direct way to obtain in-phase voltage is to energize the transmission line from one end only and use line side potential supply at the open breaker terminal, and either bus or line side potential supply at the closed breaker terminal.

Equal modulation also requires the sequence sensitivity settings (PN, and Z) to be identical at each station, and for the "T" pickup setting to be the same, or for different ct ratio's, the magnitude of single-phase current to be proportionally different.

3. Monitor waveforms VR1F (MD Module) and "VLD" (RELAY Module) on an oscilloscope (dc coupled). With in-phase current simulation (internal fault) at each terminal, "VR1F" and "VLD" will appear as sine waves, equal in magnitude and close in-phase. Adjust "DELAY ADJ" (RELAY Module) so that VLD is exactly in-phase with VR1F. To check this, "L + R" will be a maximum.

To further prove validity of this calibration, one of the input currents can be reversed 180° to simulate an external fault. In this case "VLD" and VR1F" will be equal and opposite (180° out-of-phase). "L + R" in this case will be a minimum.

B. Channel 2 (3 Terminal Line Systems Only)

1. Set the second channel (fastest channel) "channel delay equalization links" on the DTD module for the anticipated additional delay required to match channel 1 (the slowest channel).
2. Apply equal modulation at each terminal of channel 2.
3. Monitor waveforms "VR2F" (DTD Module) and "VLD" (RELAY Module) on an oscilloscope (dc coupled). With in-phase current simulation (internal fault) at each terminal, "VR2F" and "VLD" will appear as sine waves, equal in magnitude and close in-phase. Adjust "DEL ADJ" (DTD module) so that VR2F is exactly in-phase with VLD. To check this, "L + R" will be a maximum.

To further prove validity of this calibration, one of the input currents can be reserved 180° to simulate an external fault. In this case, "VLD" and VR2F" will be equal and opposite (180° out-of-phase). "L + R" will be a minimum.

12.0 LCB II SYSTEM FUNCTIONAL TEST PROCEDURE

After commissioning, the LCB system should be tested at routine maintenance intervals to verify operation. The exact functional test varies depending upon particular user preference. The recommended "standard" functional tests are performed with the LCB relay and associated channel equipment in place, properly set and operating. The tests require an operator at each terminal with voice communications between them.

Functional Test Equipment

The following "standard equipment" is recommended.

- Test Panel: Test panel with 2 FT-1 switches and breaker trip current simulator.
- Test Box: Type UCTB test box.
- ac/dc voltmeter for channel magnitude equalization verification, and for the channel, AGC level verification.
- Dual trace oscilloscope for channel delay equalization and residual carrier signal removal verification.
- Electronic counter for carrier signal frequency verification.

Functional Test Procedure

The following is the suggested procedure. If the standard test panel was not supplied, refer to user's sup-

plementary instructions.

NOTE: The input voltage to the test boxes at all ends must be in phase to provide a common reference for test.

12.1 Disconnect Outputs

The first step is to prevent false breaker operations by disconnecting the trip output circuits at all line terminals by OPENING THE RED FT-1 SWITCHES ON THE TEST PANEL, followed by the auxiliary trip contacts, DDT key and 52b inputs with the black FT switches.

12.2 Disconnect the LCB Relays

Disconnect the LCB relays from the ct's by operating the current shorting blades in the FT-1 switch on the Test Panel at each station.

12.3 Verify Status at Each Station

- A. dc power switch is on and "DC OUTPUT" and "DC INPUT" indicators on the ALS or ALS-1 module are on.
- B. Press "SYSTEM INDICATOR RESET".
- C. All channel status and trip indicators are off.

12.4 Current Differential Test

At each station (for 3-terminal lines, test two station at a time, not all three) connect the UCTB or equivalent test box using the FT-1 switches and the multiconductor cable furnished with the UCTB.



Be Sure To Plug The Personnel Safety Ground Wire on the FT-1 plug Into The Special Jack On The FT-1.

After connecting, check that the "Test Box Energized" light is ON. Initially set the Fault Locator (FA) to OFF.

- A. At both stations, turn the fault selector (FS) switch on the UCTB to position phase A.
- B. At Station B, turn the fault application (FA) switch on the UCTB to the forward (FWD) position. A single-end-feed trip condition will be satisfied at both stations as indicated by

the "LCB Trip" indicator on the RELAY module. Also, both the "LCB TRIP-1" and "LCB TRIP-2" indicators on the ARTM module will indicate and seal when the push-button on the test panel is depressed.

- C. At station A, also turn the FA to FWD. All conditions now exist for a double end feed internal fault. Press "SYSTEM INDICATOR RESET" (on ARTM module) at both stations. All indicators as in step B should remain on. ***Trip LED's will not remain sealed unless the test panel pushbutton is held in.***
- D. At station A, return the FA switch to OFF, then reverse, REV. This simulates an external fault. Press "SYSTEM INDICATOR RESET" at both stations. All indicators at both stations should turn off.
- E. At station B, turn FA switch to OFF and then REV, trip indication should occur and remain at both stations, both in OFF and REV.
- F. At station A, turn FA to OFF then FWD. Press "SYSTEM INDICATOR RESET". All indicators at both stations should reset.
- G. Return FA to OFF at both stations; all indication should reset.
- H. Repeat this procedure for phase B and phase C faults. For three-terminal line applications, repeat this procedure for the third terminal.
- I. Reset all indicators at completion of tests and insure that the trip AR's are not operated by depressing the pushbutton on the test panel.

12.5 Loss-of-Channel/Overcurrent Trip Test

- A. At station B, turn off the dc with the ON-OFF switch on the ALS or ALS-1 module. At station A, "LO" indication and S/N (Tone systems) should occur on the channel interface module. CA will indicate and its associated alarm relays on the AXLM module will operate after approximately 2.5 seconds.
- B. Overcurrent Trip or Block
 - 1. For systems strapped to block or unblock for 150 ms on loss-of-channel. (Link LC = BLK or UB.)
At station A, apply a FWD or REV fault for

Phase A, B, or C. “LCB TRIP” and “OC/UB TRIP” should not occur.

or

2. For systems strapped to trip as an overcurrent or time-delayed overcurrent on loss-of-channel. (Link LC = OT, OTD, or UB/OTD.) At station A, apply a FWD or REV fault for phase A, B, and C. “LCB TRIP” and “OC/UB TRIP” should occur. For those systems strapped for a time-delayed trip, delay should be observed between fault application and indication.

- C. Repeat steps A and B above by reversing the procedure i.e., turning off the dc at station A and applying current at station B.
- D. Turn FA to OFF. Restore dc and reset all indicators at completion of tests and insure that the trip AR's are not operated by depressing the pushbutton on the Test Panel at both stations.

12.6 Desensitized Trip

- A. Simulate an open breaker (52b contact closed) at both stations by applying rated positive dc to the open FT-1 switch (Test Panel) associated with 52b.
- B. For systems strapped for desensitized trip: TRDS link — IN, ALXM module.
 1. At both stations, turn the fault selector switch on the UCTB to phase A.
 2. At station B turn the fault applicator (FA) to FWD. A single-end-feed trip condition will be satisfied at both stations as indicated by an “LCB TRIP” and “DES TRIP” indication. *This is assuming the 12 amperes (5A ct) or 2.4 amperes (1A ct) phase to neutral current from the UCTB is above the desensitized relay pickup. Refer to Table 1 of LCB Acceptance Test.*
 3. At station A, turn FA to FWD. This simulates a double-end-feed internal fault. Press “SYSTEM INDICATOR RESET” at both stations. All indicators as in step 2 should remain on. *If in step 2, trip indication did not occur due to user's settings, this step due to feed from both terminals is twice as sensitive and in most cases should permit desensitized trip.*

4. At station A, turn FA to REV. This simulates an external fault. Press “SYSTEM INDICATOR RESET” — all indicators must reset and remain off.
5. Repeat for phase B and C if desired. At completion of tests remove current, FA to OFF, and reset all indicators.

- C. For systems strapped for no desensitized trip: TRDS link — OUT, AXLM module, the LCB should respond as per step 12.4 – current differential test.

12.7 Direct Transfer Trip Test (When Supplied)

- A. Direct transfer trip keying can be simulated by applying rated positive dc to the Test Panel FT-1 switch associated with the DTT key input.
- B. At station B, simulate DTT key initiation as per step A.
 1. At station B, the “DTT KEY” indicator will turn on.
 2. At station a, “DTT TRIP” will light, and “DTT TRIP-1” and “DTT TRIP-2” will indicate when the TEST pushbutton on the test panel is depressed.
- C. Reverse procedure by simulating DTT key at station A, and observing DTT trip at station B.
- D. Optional test (DTT priority).

With no DTT simulated at either station, apply an internal fault by setting the UCTB fault selector to phase A and fault applicator FA to FWD at both stations. “LCB TRIP” and “LCB TRIP-1” and “LCB TRIP-2” should occur at both stations.

1. With an LCB trip sustained, simulate DTT KEY at station B as described earlier.
 - a. At station B, “DTT KEY” indicator should occur and “LCB TRIP” should remain.
 - b. At station A, DTT TRIP should occur and take priority over LCB TRIP. Press “SYSTEM INDICATOR RESET” then depress the TEST pushbutton on the test panel. “DTT TRIP” only (no “LCB TRIP”) should indicate.
2. Repeat 1, except simulate DTT KEY at station A and observe station B.

- E. At completion of tests, remove current, FA to OFF, and DTT key inputs, and reset indication.

12.8 Overcurrent Control Option (When Used)

For users employing the overcurrent control function (OCC), and with the LCB set to block trip on loss-of-channel (LC = BLK), the following function test can be performed.

- A. At station B, turn off the dc with the ON/OFF switch on the ALS or ALS-1 module. At station A, "LO" indication will occur and CA will indicate after a time delay.
- B. At station A, apply a FWD or REV fault for phase A, B or C. "LCB TRIP" and "OC/UB TRIP" should not occur.

Return FA to Normal.

- C. At station A, simulate an OCC contact input by applying rated positive dc to the LCB OCCBP input, TB5, terminal 7. **(TB5, terminal 8, is negative.)** At station A, again apply a FWD or REV fault for phase A, B or C. This time, "LCB TRIP" and "OC/UB TRIP" should occur.

Return FA to Normal and remove the OCCBP input at station A.

- D. At station B, simulate an OCC contact input by applying rated positive dc to the LCB OCCBP input, TB5, terminal 7.

Restore dc at station B.

Observe the following at station A, depending on the OCC link selection on the MD module.

1. At station B, apply a FWD or REV fault for phase A, B, or C.
 - (a) OCC = OUT
"LCB TRIP" should occur at station A.
 - (b) OCC = LOC
LO level and CA indication, and no trip should occur at station A.
 - (c) OCC = TTI or TTO
"LCB TRIP" should not occur at station A.
2. Return FA to Normal at station B and simulate direct transfer trip DTT at station B by applying rated positive dc to the test panel FT-1

switch associated with the DTT KEY input.

- (a)OCCC – OUT or TTI
"DTT TRIP" should occur at station A.
- (b)OCCC – TTO
LO level and CA indication and no trip should occur at station A.
- (c)OCCC – TTO
"DTT TRIP" should not occur at station A.

Remove OCC and DTT simulation at station B.

- E. Repeat the preceding steps by reversing the station.

- F. Reset all indicators at completion of tests and insure all simulated inputs are removed.

12.9 System Restoration (ct's, DTT, 52b)

- A. Remove UCTB test harness assembly at all stations.
- B. Close the FT-1 switches on the test panel associated with the ct circuits at all stations.
- C. Close the Ft-1 switches on the test panel associated with the DTT key and 52b inputs at all stations.

12.10 System Trip Restoration (AR's)

- A. Press "SYSTEM INDICATOR RESET" at all stations: all indicators except those indicating DC INPUT/OUTPUT must be off.
- B. Depress the TEST pushbutton on the test panel at each station to insure that no standing trips exist.
- C. Restore the trip circuits by closing the remaining FT-1 switches on the test panel at each station, RED ONES LAST.

13.0 SYSTEM CALIBRATION VERIFICATION PROCEDURE

The following is a recommended procedure to perform on a periodic basis and generally in conjunction with the Functional Test procedure. This procedure verifies those calibrations as made during the FIELD SET UP PROCEDURE.

13.1 Test Procedure

As in the functional test procedure, first disconnect all trip outputs from the breaker trip circuits; then disconnect the ct and remaining circuits with the appropriate FT-1 switches on the Test Panel.

NOTE: Measurements are with respect to “COM” unless specified otherwise. Refer to Figure 22 for typical waveforms.

13.2 Receive Levels

A. Audio Tone Channel(s) When Used).

1. Measure the ac level at “AGC IN” on the IFDT module(s). A reading of 137 mVrms should be obtained for a normal received signal level.
2. “HI”, “LO”, and “SNR” indication must be off.

B. Optical Channel(s) (When Used).

1. Measure the dc voltage at “AGC” on the IFO module(s). A reading between -10 to -14 Vdc (typically -13 Vdc) should be obtained for a normal received signal level.
2. “LO” level indication must be off.

13.3 Carrier Frequency Verification

- A. Measure the frequency at “RFO” on the MD module. It must read 1700 Hz (± 5 Hz).
- B. Fine tuning of this frequency can be made by extending the MD module and adjusting potentiometer P1.

13.4 Signal Level Equalization Adjustment Verification

- A. At the local terminal, connect a jumper between the RELAY module “SET UP” front test jacks.
- B. Channel 1
 1. At the remote terminal for channel 1, connect a jumper between the RELAY module “SET UP” and the MD module “SET UP”.
 2. At the local terminal, measure signal “VLD” (RELAY Module) and “VR1F” (MD Module) with an ac VM. They should be equal in magnitude. ($\pm 5\%$).
 3. For fine tuning, adjust “DM GAIN” on the MD module so that “VR1F” is the same magnitude as “VLD”.

C. Channel 2 (3-terminal lines)

1. At the remote terminal for channel 2, connect a jumper between “SET UP” on the RELAY and the MD modules.
2. At the local terminal, measure signal “VLD” (RELAY Module) and “VR2F” (DTD Module) with an ac VM. They should be equal in magnitude.
3. For the tuning, adjust “DM GAIN” on the DTD module so that the “VR2F” is the same magnitude as “VLD”.

- D. Repeat above procedure for all line terminals, then remove all SET UP jumpers.

13.5 Demodulated Signal Verifications

- A. At remote terminal(s), connect the UCTB test box to the Test Panel as in the functional Test Procedure. Set the fault selector (FS) to phase A and the fault application (FA) to FWD.
- B. At the local terminal monitor “VR1” (MD module) and “VR2” (DTD module – 3-terminal lines) with a scope. The waveform(s) should appear as a clean sine wave or clipped sine wave with minimum distortion and waveform separation.
- C. If the waveform(s) appears to be separated, fine tuning can be accomplished by extending the MD module and, for 3-terminal lines, the DTD module, and readjusting potentiometer P4, limiter adj.
- D. Repeat above procedure for all line terminals. At completion of tests, remove the simulated fault current by turning FA off on the UCTB.

13.6 Channel Delay Equalization Verification

NOTE: For 3-terminal line system, channel 1 will be the slowest channel since additional delay equalization is provided for channel 2.

- A. Channel 1
 1. Connect the UCTB to both line terminals of channel 1. Set the fault selector (FS) and applicator (FA) to the same positions at each terminal (i.e, A and FWD). For proper delay verification, the voltage source energizing the UCTB must be in phase at both terminals.
 2. Monitor waveforms “VR1F” (MD Module) and “VLD” (RELAY Module) with a dual trace oscil-

oscope (dc coupled). These waveforms should be equal in magnitude and in phase, unless the "T" setting was changed according to 6.2.2. They will be in phase but the magnitude will be different. Fine tuning of the phase relationship can be accomplished with the "DEL ADJ".

3. Reverse the fault polarity at one terminal by changing the fault applicator (FA) to REV. The waveforms must now appear equal in magnitude but opposite in polarity.
- B. Channel 2
1. Repeat the procedure as in channel 1 except apply current to the 2-line terminals of channel 2.
 2. Fine tuning of this delay is accomplished with the "DEL ADJ" on the DTD module. The second remote "VR2F" is observed on the DTD module.
- C. Above procedures A and B should be performed at all line terminals.

13.7 System Restoration (ct's, DTT, 52b)

- A. Remove UCTB test harness assembly at all stations.
- B. Close the FT-1 switches on the test panel associated with the ct circuits at all station.

- C. close the FT-1 switches on the test panel associated with the DTT key and 52b inputs at all stations.

13.8 System Trip Restoration (AR's)

- A. Press "SYSTEM INDICATOR RESET" at all stations: all indicators except those indicating DC INPUT/OUTPUT must be off
- B. Depress the TEST pushbutton on the test panel at each station to insure that no standing trips exist.
- C. Restore the trip circuits by closing the remaining FT-1 switches on the test panel at each station. RED ONES LAST

14.0 RENEWAL PARTS

Repair work can be done must satisfactorily at the factory. However, interchangeable spare modules or components can be furnished to the customers who are equipped for doing repair work. When ordering parts (components, modules, etc.) always give the complete catalog number, appropriate ABB Style number(s), and for modules, sub number identification.

15.0 LCB II CATALOG NUMBER

The following illustrates the LCB system catalog number designations:

Catalog Number: LCB 8 T 1 T 5 A P
Position: 123 4 5 6 7 8 9 10

Position Code Description:

1,2,3 4	LCB	Current Differential Relay-Standard 8 Two-terminal line 9 Three-terminal line
5	T	Direct Transfer Trip – 2 terminal
	U	Direct Transfer Trip – 3 terminal
	N	No Transfer Trip
6	4	48/60 Vdc power supply
	1	110/125 Vdc power supply
	2	220/250 Vdc power supply
7	A	Fiber optic, 850 nm, Multi-mode fiber-SMA connector
	B	Fiber optic, 1300 nm, Single-mode or Multi-mode fiber, SMA connector
	C	Fiber optic, 1300 nm, High Power/ Single-mode fiber, ST connector
	E	Fiber optic, 850 nm Multi-mode fiber, ST connector
	F	Fiber optic, 1300 nm Single-mode or Multi-mode fiber, ST connector
	T	Audio Tone
8	1	1A ct, 50 Hz
	2	1A ct, 60 Hz
	5	5A ct, 60 Hz
	6	5A ct, 50 Hz
9	A	Two-terminal tone protection pkg.
	B	Three-terminal tone protection pkg.
	N	No tone protection pkg.
10	P	Standard test panel
	N	No test panel

Following are the associated ABB Style numbers of the components/modules associated with the LCB catalog number.

Basic standard LCB Relay includes:

LCB Chassis Style 1355D48G01 (wire wrap)
LCB Chassis Style 1355D48G05 (motherboard)
MD Module (POS D) Style 1609C38G01
RELAY Module (POS G) Style 1609C41G01
AXLM Module (POS L) Style 1609C43G01

Audio Tone Channel 2 terminal
IFDT-1 Module (POS F) Style 1609C39G01

Audio Tone Channel 3 terminal
Includes 2 Terminal Interface plus
IFTD-2 Module (POS E) Style 1609C39G01
DTD Module (POS C) Style 1609C38G02

Fiber optic Channel 2 terminal
IFO1 Module (POS F)
Style 1609C40G01 – Fiber optic, 850 nm,
Multi-mode fiber, SMA connector
Style 1609C40G02 – Fiber optic, 1300 nm
Single-mode or Multi-mode fiber, SMA connector
Style 1609C96G01 – Fiber optic, 1300 nm,
high power LED, Single-mode fiber, ST connector
Style 1609C40G03 - Fiber optic, 850 nm
Multi-mode fiber, ST connector
Style 1609C40G04 - Fiber optic, 1300 nm Multi-mode
fiber, ST connector

Fiber optic Channel 3 terminal
Includes 2 Terminal Interface plus same Style
module as IFO 1 in POS E
DTD Module (POS C) Style 1609C38G02

dc Power Supply

48/60 Vdc: ALS Module (POS A) Style 1355D49A01
110/125 Vdc: ALS Module (POS A) Style 1355D49A02
220/250 Vdc: ALS Module (POS A) Style 1355D49A03
48/60 Vdc: ALS-1 Module (POS A) Style 1615C51G01
110/125 Vdc: ALS-1 Module (POS A) Style 1615C51G02
220/250 Vdc: ALS-1 Module (POS A) Style 1615C51G03

Trip Output (No transfer trip)
ARTM-1 Module (POS M) Style 1609C44G01

Direct Transfer Trip
DTT Module (POS K) Style 1609C42G01
(2 Term)
Style 1609C42G02
(3 Term)

ARTM-2 Module (POS M) Style 1609C44G02

Frequency and ct rating

50/60 Hz, 5A ct:
Transf. Assembly (POS J) Style 1581C70G03
50/60 Hz, 1A ct:
Transf. Assembly (POS J) Style 1581C70G04

Audio Tone Protection Package (Separate item)
2 terminal Style 2047D16G11
3 terminal Style 2047D16G03

Test Panel (Separate item) Style 1579C61G02

The following are additional items that can be supplied as part of an LCB system, but are not included in the catalog number system.

UCTB Test Box:

50/60 Hz, 5A ct: Style 1337D24G02

50/60 Hz, 1A ct: Style 1337D24G03

UME-3 D Board Extender: Style 1355D52G01

Fiber optic connector cable:

Style 1604C71G04 10 meter long,
50/125 micrometer, Multi-mode dual window
(850/1300 nm) graded-index Fiber
optic cable with SMA connectors on each end.

Style 1604C71G08 10 meter long,
9/125 micrometer, Single-mode SMA (1300 nm)
fiber-optic cable with SMA connectors on each end.
Style 1604C71G15 10 meter long 50/125 Multi-mode
dual window (850/1300 nm) Fiber optic cable with ST
connectors at each end.

Style 1604C71G16 10 meter long,
9/125 micrometer, Single-mode (1300 nm)
Fiber-optic cable with ST connector at each end.

16.0 LCB II GLOSSARY OF TERMS**16.1 MODULES**

<u>Name</u>	<u>Description</u>
ALS/ALS-1	Analog Logic dc Power Supply
ARTM1	AR Trip – One AR
ARTM2	AR Trip – Two AR's
AXLM	Auxiliary Logic
CT	Current Transformation Assembly
DTD	Demodulator and Time Delay
DTT	Direct Transfer Trip
IFO	Fiber-Optic Interface
IFO1	Fiber-Optic Interface – Channel 1
IFO2	Fiber-Optic Interface – Channel 2
IFDT	Audio-Tone Interface
IFDT-1	Audio-Tone Interface – Channel 1
IFDT-2	Audio-Tone Interface – Channel 2
MD	Modulator and Demodulator
RELAY	Relay Sensing Logic

16.2 Input Signals

<u>Name</u>	<u>Source</u>	<u>Description</u>
BP	ALS/ALS-1	Battery Positive
BN	ALS/ALS-1	Battery Negative
GND	ALS/ALS-1	Chassis Ground
IA	CT	Phase A Current
IAR	CT	Phase A Current Return
IB	CT	Phase B Current
IBR	CT	Phase B Current Return
IC	CT	Phase C Current
ICR	CT	Phase C Current Return

RCVR1	IFDT-1	Audio-Tone Receiver Channel 1
RCVR2	IFDT-2	Audio-Tone Receiver Channel 2
OR1	IFO1	Optical Receiver – Channel 1
OR2	IFO2	Optical Receiver – Channel 2
52bBP	AXLM	52b Contact– Battery Positive
52bBN	AXLM	52b Contact– Battery Negative
TRBP	AXLM	Target Reset Contact– Battery Positive
TRBN	AXLM	Target Reset Contact– Battery Negative
OCCBP	AXLM	Overcurrent Control– Battery Positive
OCCBN	AXLM	Overcurrent Control– Battery Negative
DTTBP	DTT	DTT Contact – Battery Positive
DTTBN	DTT	DTT Contact – Battery Negative

16.3 Output Signals

<u>Name</u>	<u>Source</u>	<u>Description</u>
XMTR1	IFDT-1	Audio-Tone Transmitter – Channel 1
XMTR2	IFDT-2	Audio-Tone Transmitter – Channel 2
OT1	IFO1	Optical Transmitter – Channel 1
OT2	IFO2	Optical Transmitter – Channel 2
PSA1	ALS/ALS-1	Form b Contact – Loss of dc
PSA2	ALS/ALS-1	Form b Contact – Loss of dc
PSA3	ALS/ALS-1	Form b Contact – Loss of dc
PSA4	ALS/ALS-1	Form b Contact – Loss of dc
CA1NO	AXLM	Form c Contact – Loss-of-Channel
CA1NC	AXLM	Form c Contact – Loss-of-Channel
CA1COM	AXLM	Form c Contact – Loss-of-Channel
CA2NO	AXLM	Form c Contact – Loss-of-Channel
CA2NC	AXLM	Form c Contact – Loss-of-Channel
CA2COM	AXLM	Form c Contact – Loss-of-Channel
LCB		
TRIP 1	ARTM 1/2	LCB AR Trip 1 Contact
LCB		
TRIP 2	ARTM 1/2	LCB AR Trip 2 Contact
LCB		
SPARE 1	ARTM 1/2	LCB AR Spare 1 Contact
LCB		
SPARE 2	ARTM 1/2	LCB AR Spare 2 Contact
DTT		
TRIP 1	ARTM 2	DTT AR Trip 1 Contact
DTT		
TRIP 2	ARTM 2	DTT AR Trip 1 Contact
DTT		
SPARE 1	ARTM 2	DTT AR Spare 1 Contact
DTT		
SPARE 2	ARTM 2	DTT AR Spare 2 Contact

16.4 Internal Analog Signals

<u>Name</u>	<u>Source</u>	<u>Description</u>
VA	CT	IA Current Voltage
VB	CT	IB Current Voltage
VC	CT	IC Current Voltage
RF11	IFDT-1/IFO1	RF Input – Channel 1
RF12	IFDT-2/IFO2	RF Input – Channel 2
VN1	IFDT-1	Noise Voltage – Channel 1
VN2	IFDT-2	Noise Voltage – Channel 2
AGC	IFO	AGC Output DC
AGC IN	IFDT	AGC Input
VR1	MD	Remote Voltage – Channel 1
VRIF	MD	Remote Voltage Filtered – Channel 1
RFO	MD	RF Output
RFIF1	MD	RF Input Filtered – Channel 1
VR2	DTD	Remote Voltage – Channel 2
VR2F	DTD	Remote Voltage Filtered and Delayed
VR2DF	DTD	Remote Delayed Filtered Voltage – Channel 2 (same as VR2F)
RFIF2	DTD	RF Input Filtered – Channel 2
VL	RELAY	Local Voltage
VLD	RELAY	Local Delayed Voltage
VRES	RELAY	Restraint Voltage
VOP	RELAY	Operate Voltage
VTRIP	RELAY	Trip Voltage
L + R	RELAY	Voltage Local + Remote
V1	RELAY	Positive-Sequence Voltage
V2	RELAY	Negative-Sequence Voltage
V0	RELAY	Zero-Sequence Voltage

16.5 Internal Digital Signals

<u>Name</u>	<u>Source</u>	<u>Description</u>
PSMP	ALS/ALS-1	Multi-Power Supply Control
PSME	ALS/ALS-1	Power Supply dc Status
NA1	IFDT-1	Noise Alarm – Channel 1
NA2	IFDT-2	Noise Alarm – Channel 2
LA1	IFDT-1	Low Alarm – Channel 1
LA2	IFDT-2	Low Alarm – Channel 2
FA1	IFDT-1	Carrier Frequency Alarm – Channel 1
FA2	IFDT-2	Carrier Frequency Alarm – Channel 2
EN1	IFDT-1/IFO1	Channel Loss – Channel 1
EN2	IFDT-2/IFO2	Channel Loss – Channel 2
CA1	IFDT-1/IFO1	Channel Loss Alarm – Channel 1
CA2	IFDT-2/IFO2	Channel Loss Alarm – Channel 2
LCB		
TRIP	RELAY	LCB Trip Output

RST	RELAY	Indicator Reset
RB	RELAY	Remote Signal Block
TRC	RELAY	Trip Comparator
DTI	DTT	DTT Key Initiate
DTQ	DTT	DTT Receive (Solid Output)
DT	DTT	DTT Receive (Pulse Output)
DTT		
TRIP	DTT	DTT Trip Output
BS	AXLM	Block Trip Signal
TRDS	AXLM	Trip Desensitize Output
OCC	AXLM	Overcurrent Control
RFS1	MD	RF Sync – Channel 1
RFS2	DTD	RF Sync – Channel 2

16.6 Miscellaneous Terminology

<u>Name</u>	<u>Source</u>	<u>Description</u>
Z, Z1, Z2	RELAY	Zero-Sequence Component
P, P1, P2	RELAY	Positive-Sequence Component
N, N1, N2, N3	RELAY	Negative-Sequence Component
T-SET	RELAY	Tap Dial Pickup Setting
DM		
GAIN	MD/DTD	Demodulator Gain Control
DELAY		
ADJ	RELAY/DTD	Channel Delay Equalization Adj.
TD	ADJ	Time Delay on Overcurrent Trip Adjust
OUTPUT		
ADJ	ALS/ALS-1	+15 Vdc Adjust
DES ADJ	AXLM	Desensitize Trip Adjust
TX ADJ	IFDT	Tone Transmitter Adjust
RX ADJ	IFDT	Tone Receiver Adjust
SET UP	RELAY/MD	Amplitude Setup Calibration

17.0 INSTRUCTION LEAFLET REFERENCE

The following is a list of additional LCB system supporting instruction leaflets.

Power Supply
(ALS, DLS) Module I.L. 41-830.11

Power Supply
(ALS-1, DLS-1) Module I.L. 41-830.12

LCB II Modules I.L. 40-220

UCTB Functional Test Box I.L. 40-250

Tone Protection Package I.L. 40-475

Application Data RPL 83-2
RPL 85-2

LIST OF FIGURES

Figure Number	Figure Description	Page Number
1	LCB II Photograph – Front View	46
2	LCB II Photograph – Rear View	46
3	LCB II Tone System Photograph	47
4	LCB II Block Diagram – Audio Tone (2-Terminal lines)	48
5	LCB II Block Diagram – Audio Tone (3-Terminal lines)	49
6	LCB II Block Diagram – Fiber optic (2-Terminal lines)	50
7	LCB II Block Diagram – Fiber optic (3-Terminal lines)	51
8	LCB II System Schematic – Audio Tone (2-Terminal Lines)	52
9	LCB II System Schematic – Audio Tone (3-Terminal Lines)	53
10	LCB II System Schematic – Fiber optic (2-Terminal Lines)	54
11	LCB II System Schematic – Fiber optic (3-Terminal Lines)	55
12	LCB II Outline and Drilling	56
13	Test Panel – Outline and Drilling	56
14	Tone Protection Package – Outline and Drilling	57
15	UCTB Test Box Outline	57
16	LCB Test Diagram	58
17	Leased Cable Circuit Protection	58
18	LCB Operating Characteristics (IN/OUT phase)	59
19	LCB General Operating Characteristics	59
20	LCB PPM Modulator	60
21	LCB PPM Demodulator	60
22	Field Set Up Waveforms	61

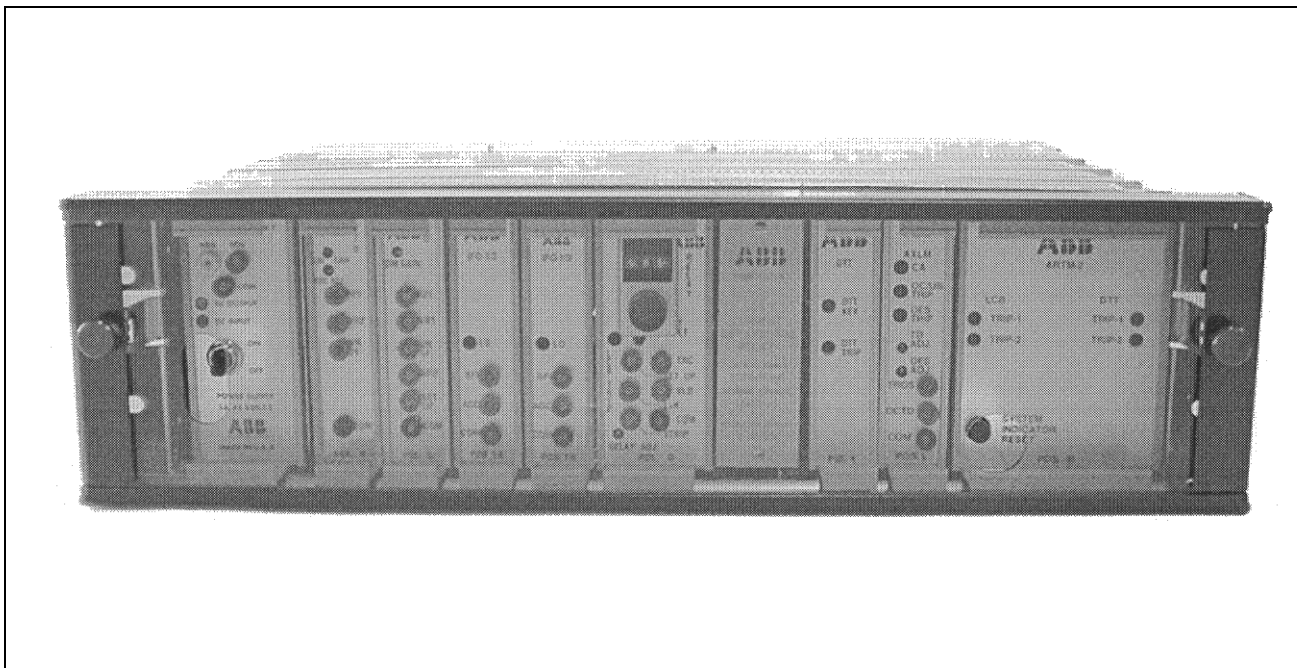


Figure 1: LCB II Photograph – Front View

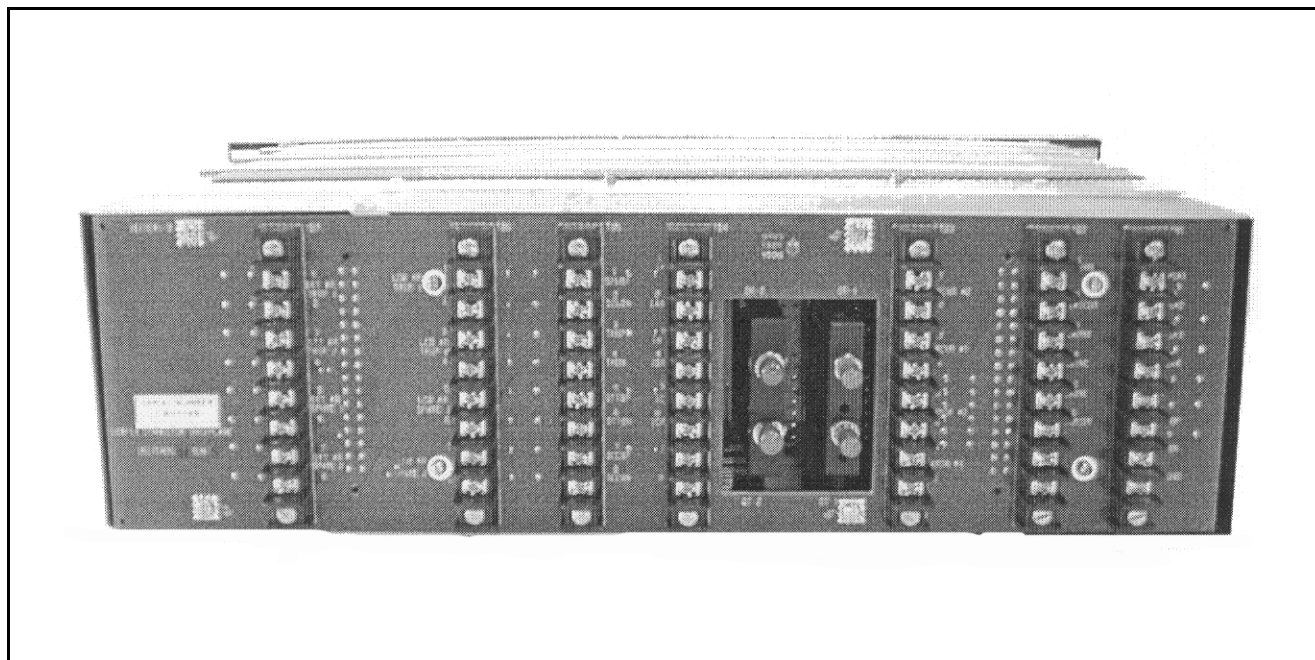


Figure 2: LCB II Photograph – Rear View

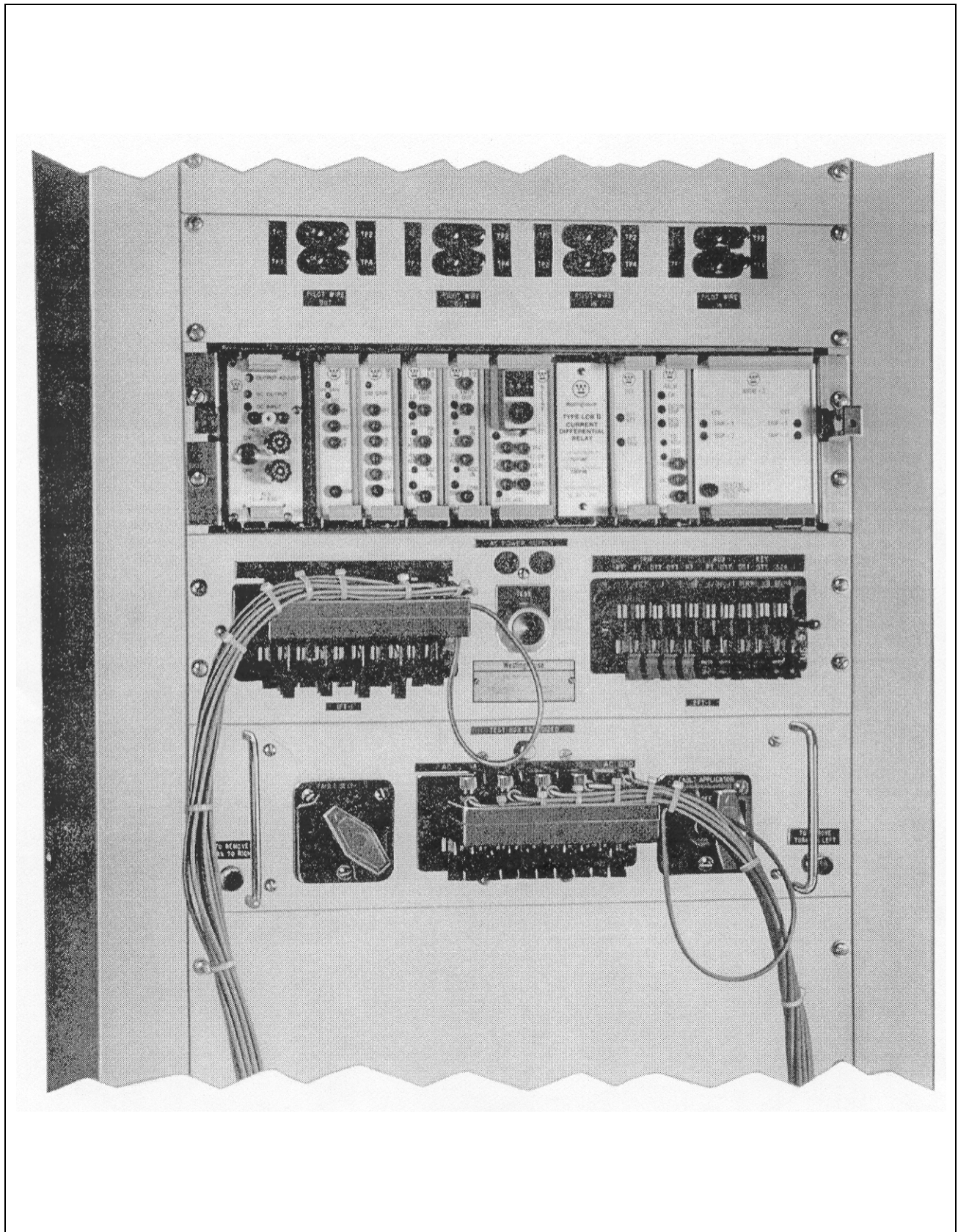
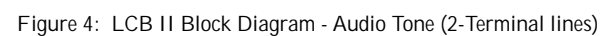
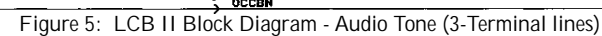


Figure 3: LCB II Tone System Photograph



48



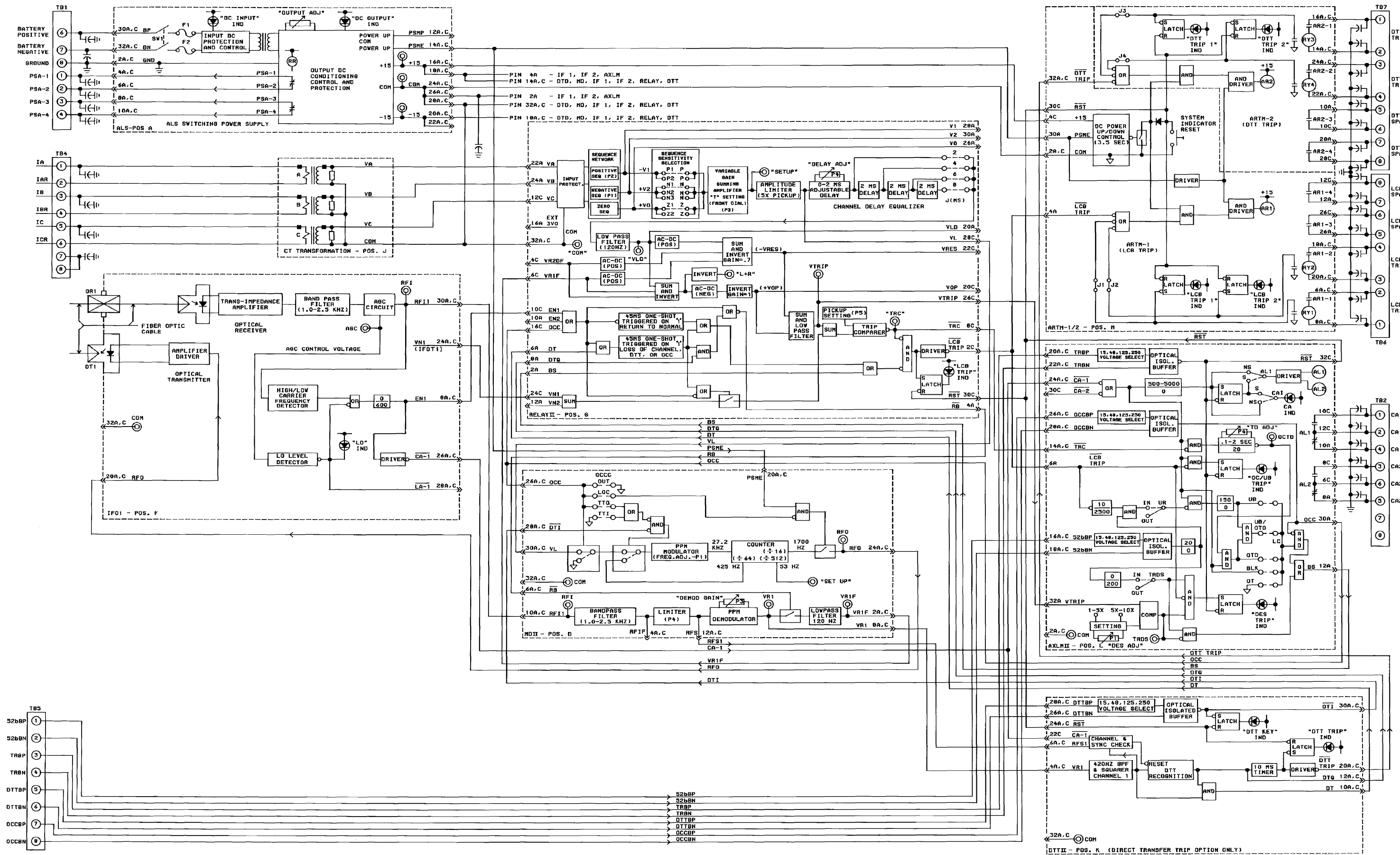


Figure 6: LCB II Block Diagram - Fiber optic (2-Terminal lines)

Sub 1

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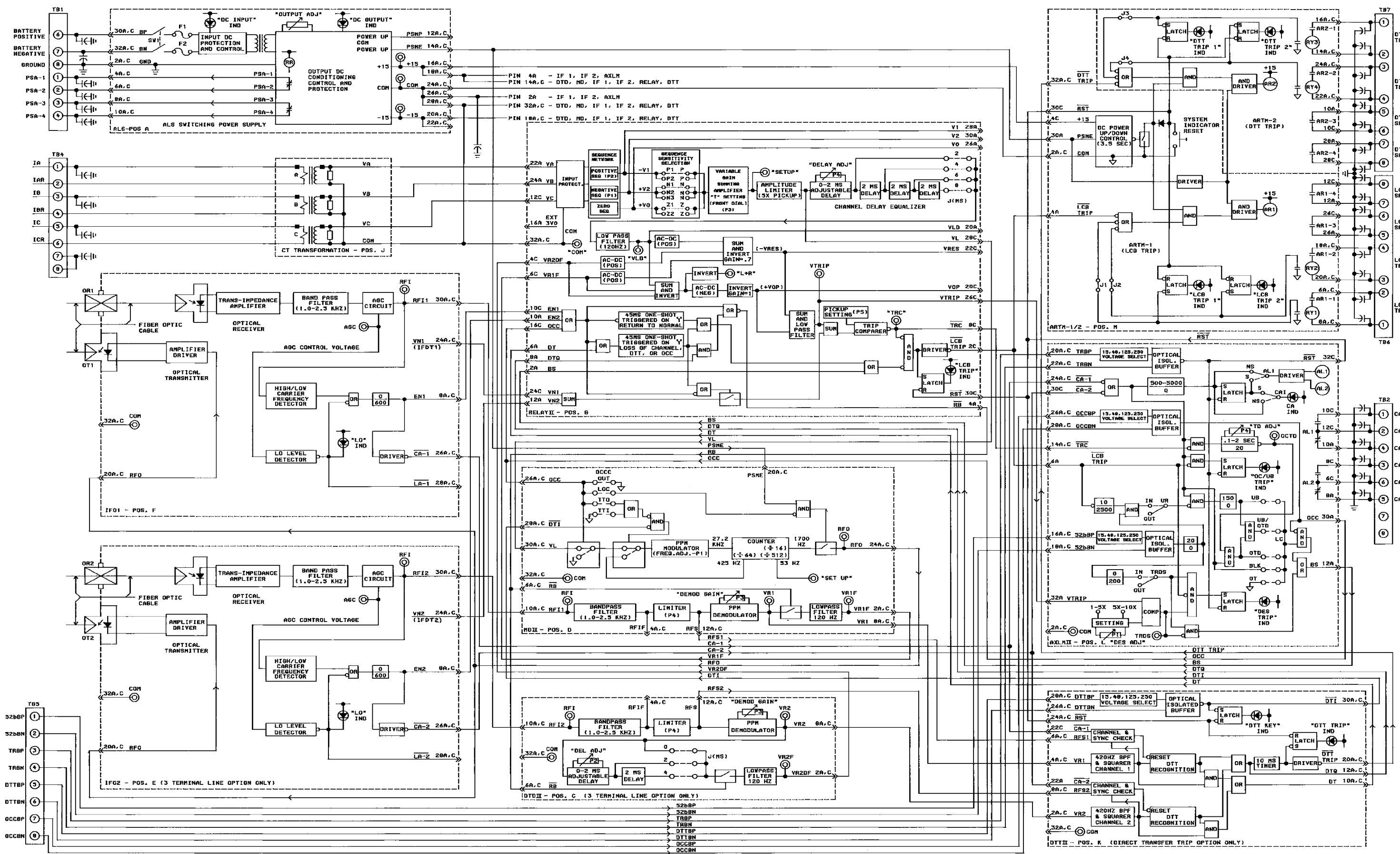


Figure 7: LCB II Block Diagram - Fiber optic (3-Terminal lines)

WIRING DWG. REF. - 1355953
GENERAL DWG. REF. - 1355049

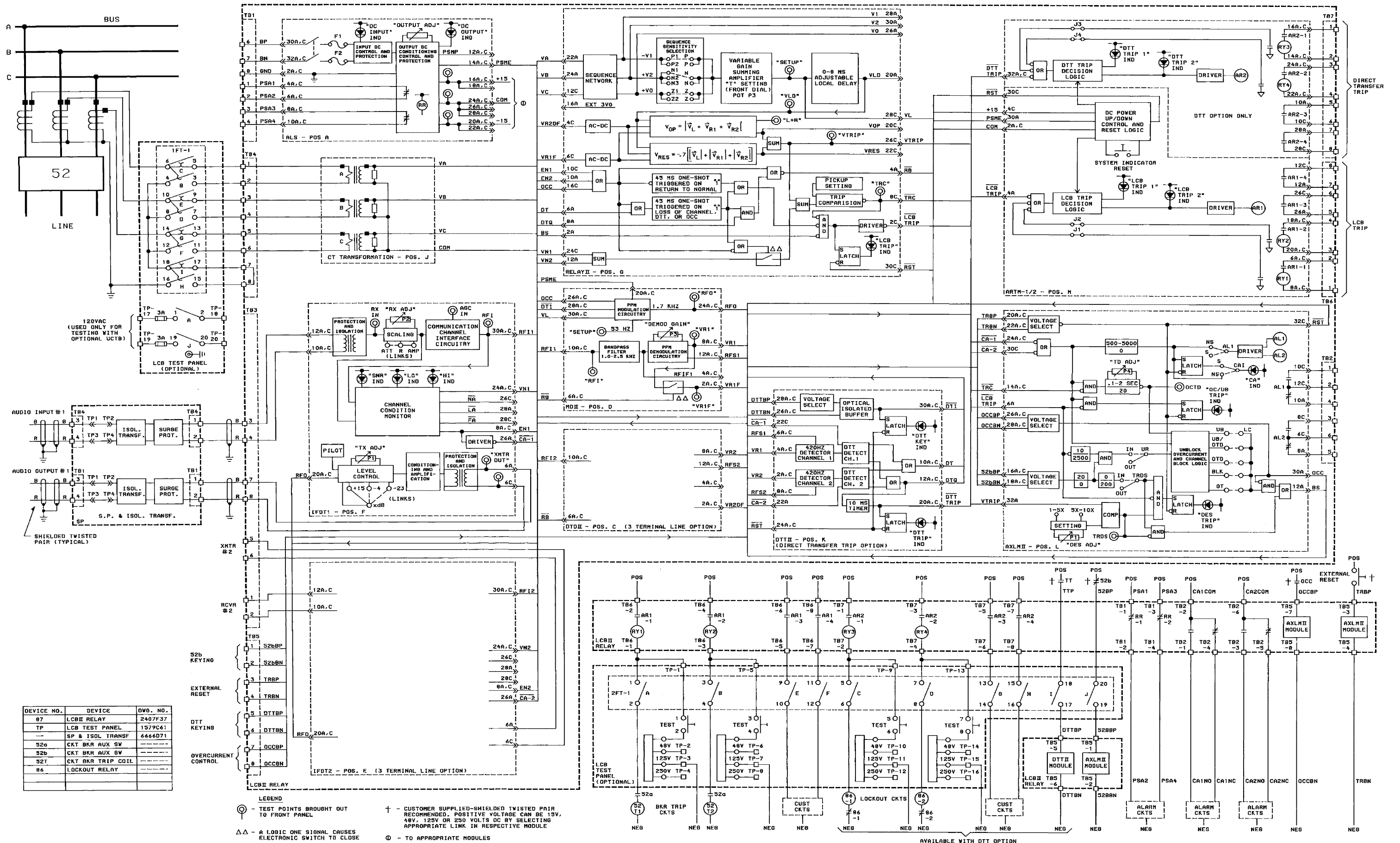


Figure 8: LCB II Block Diagram - Audio Tone (2-Terminal lines)

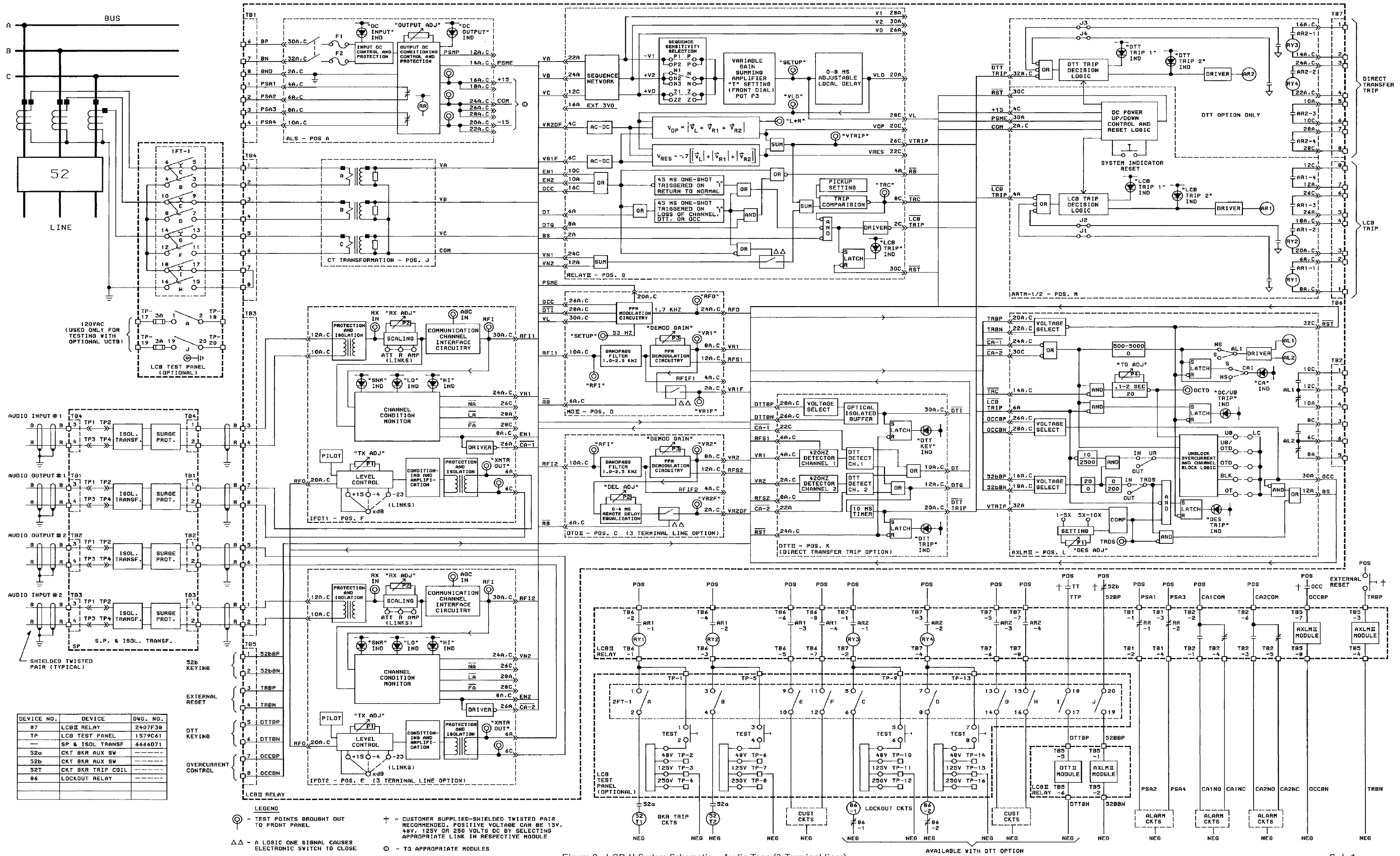


Figure 9: LCB II System Schematic - Audio Tone (3-Terminal lines)

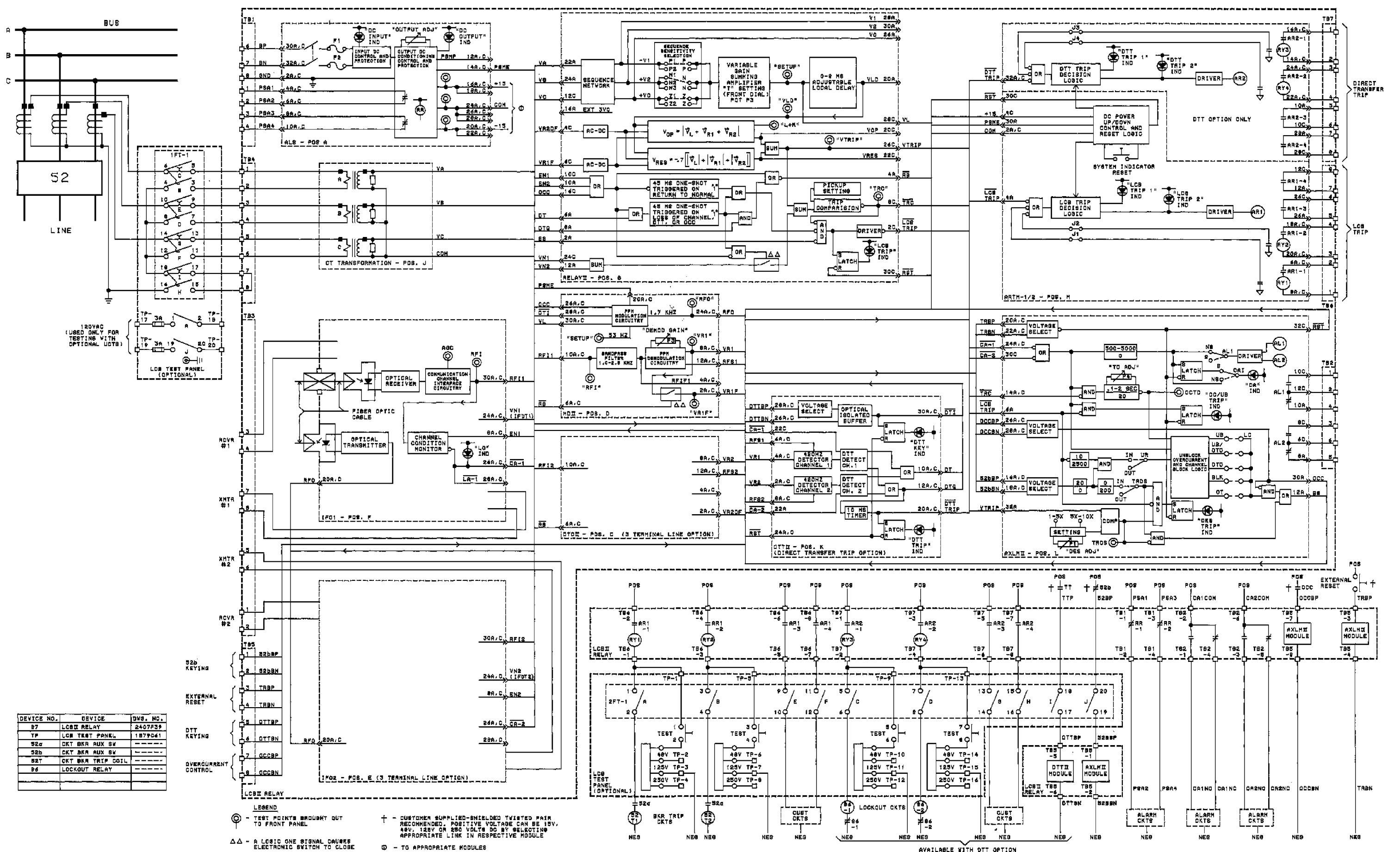


Figure 10: LCB II System Schematic - Fiber Optic (2-Terminal lines)

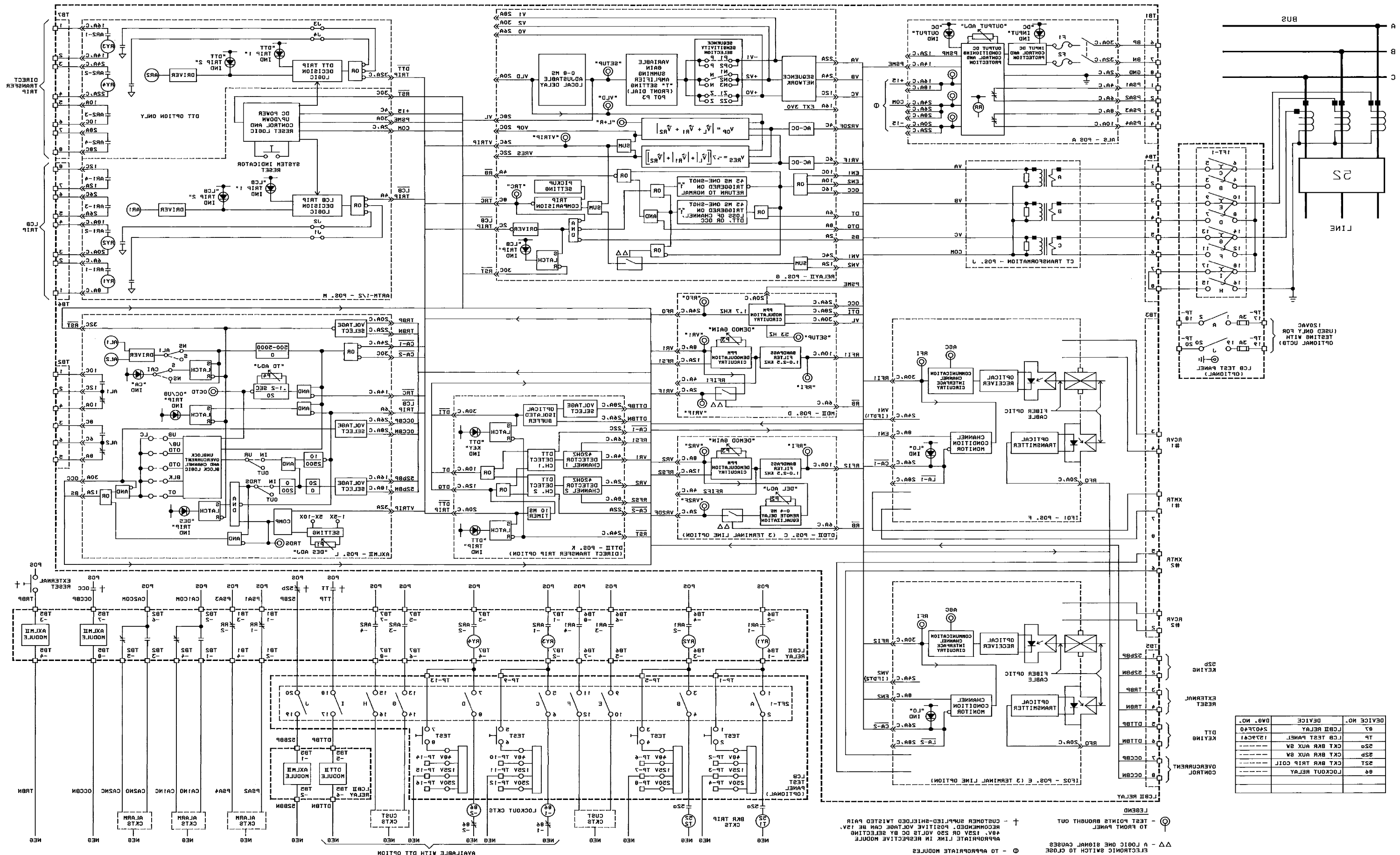


Figure 11: LCB System Schematic - Fiber Optic (3-Terminal lines)

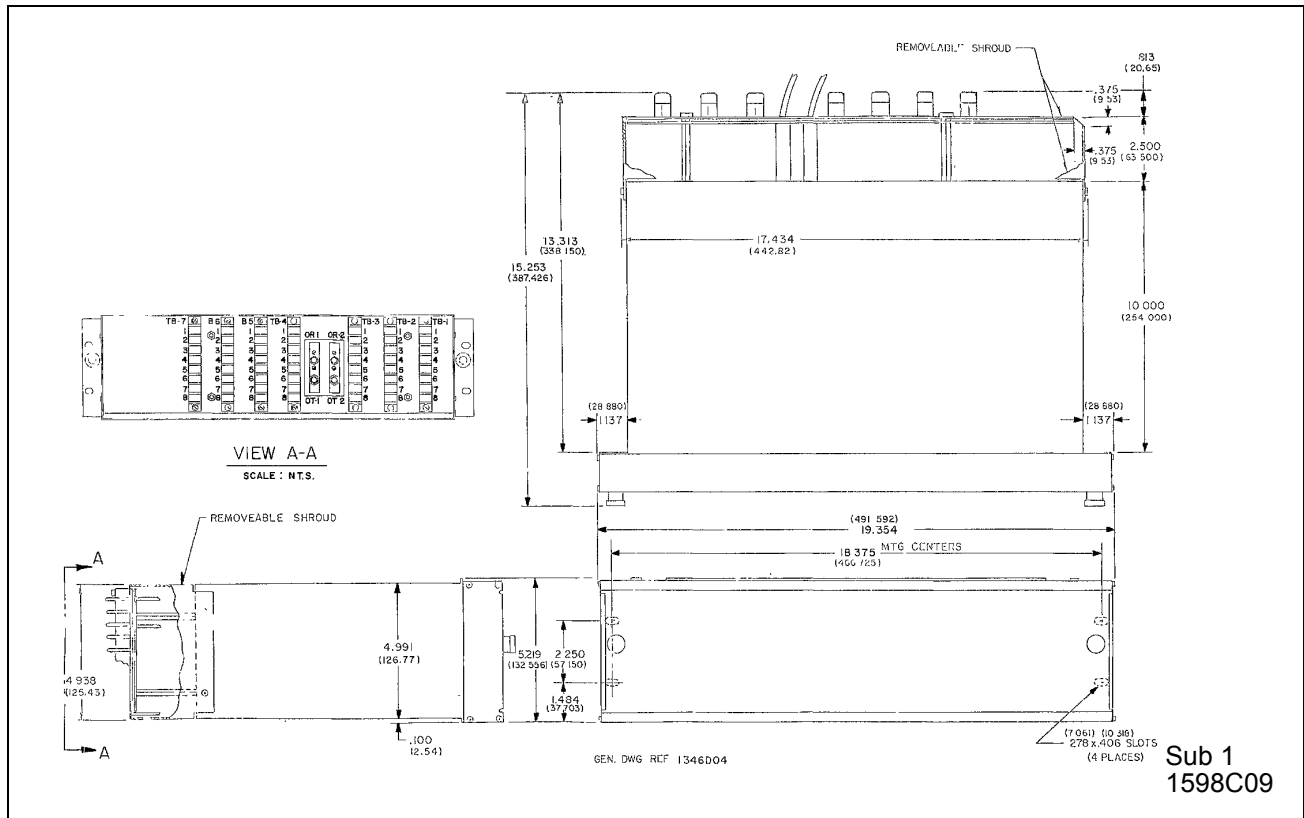


Figure 12: LCB II Outline and Drilling

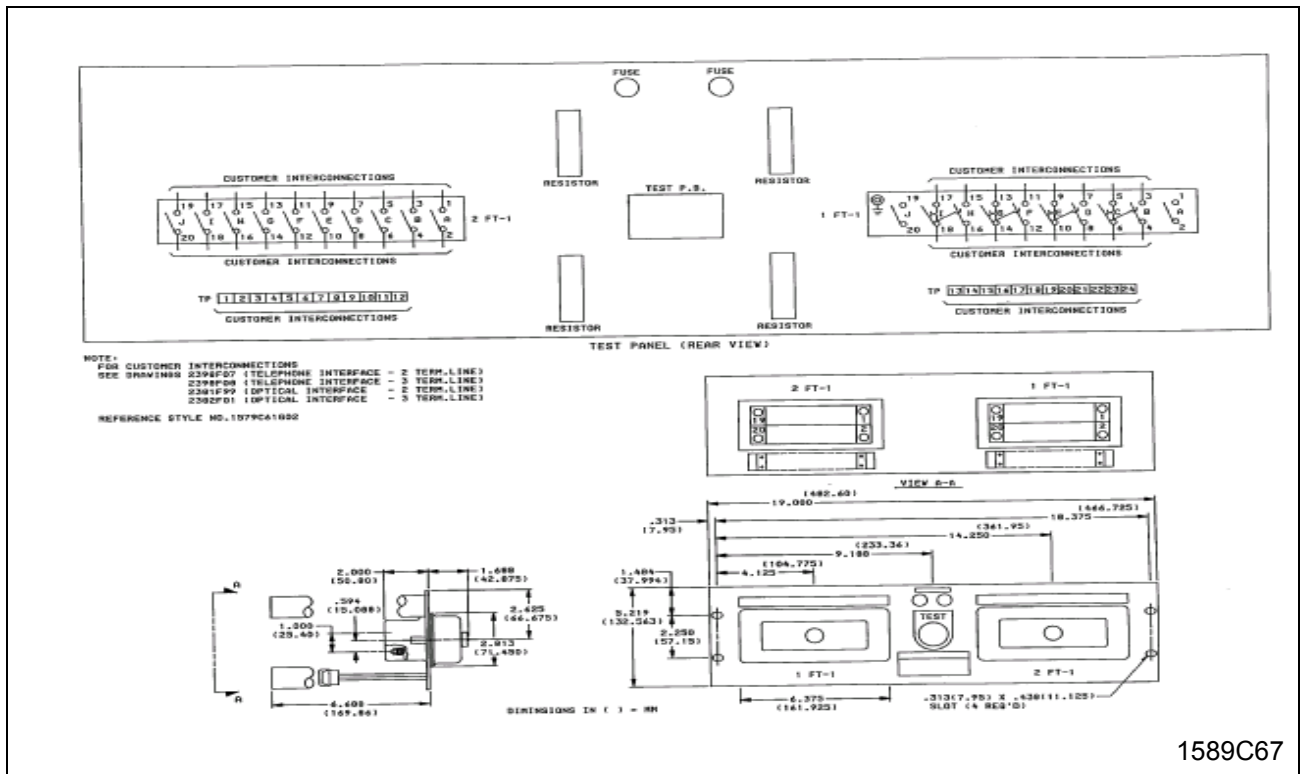


Figure 13: Test Panel – Outline and Drilling

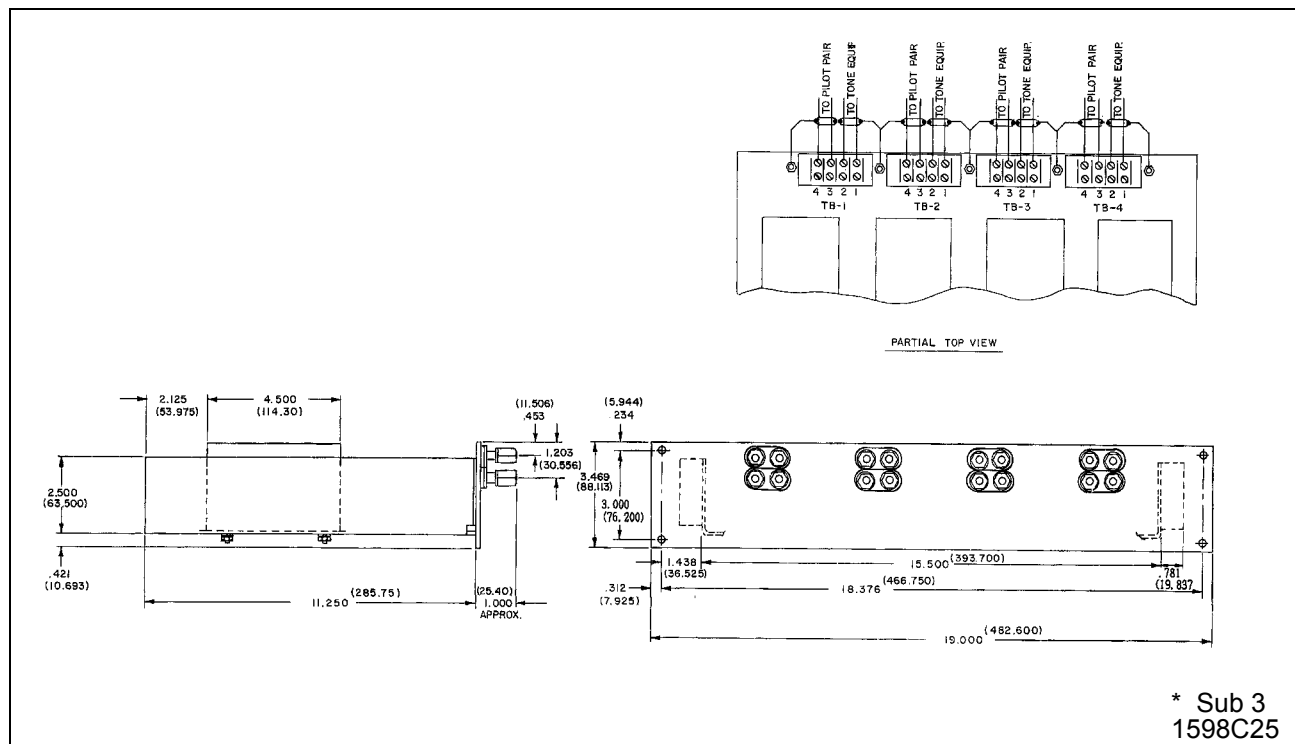


Figure 14: Tone Protection Package – Outline and Drilling

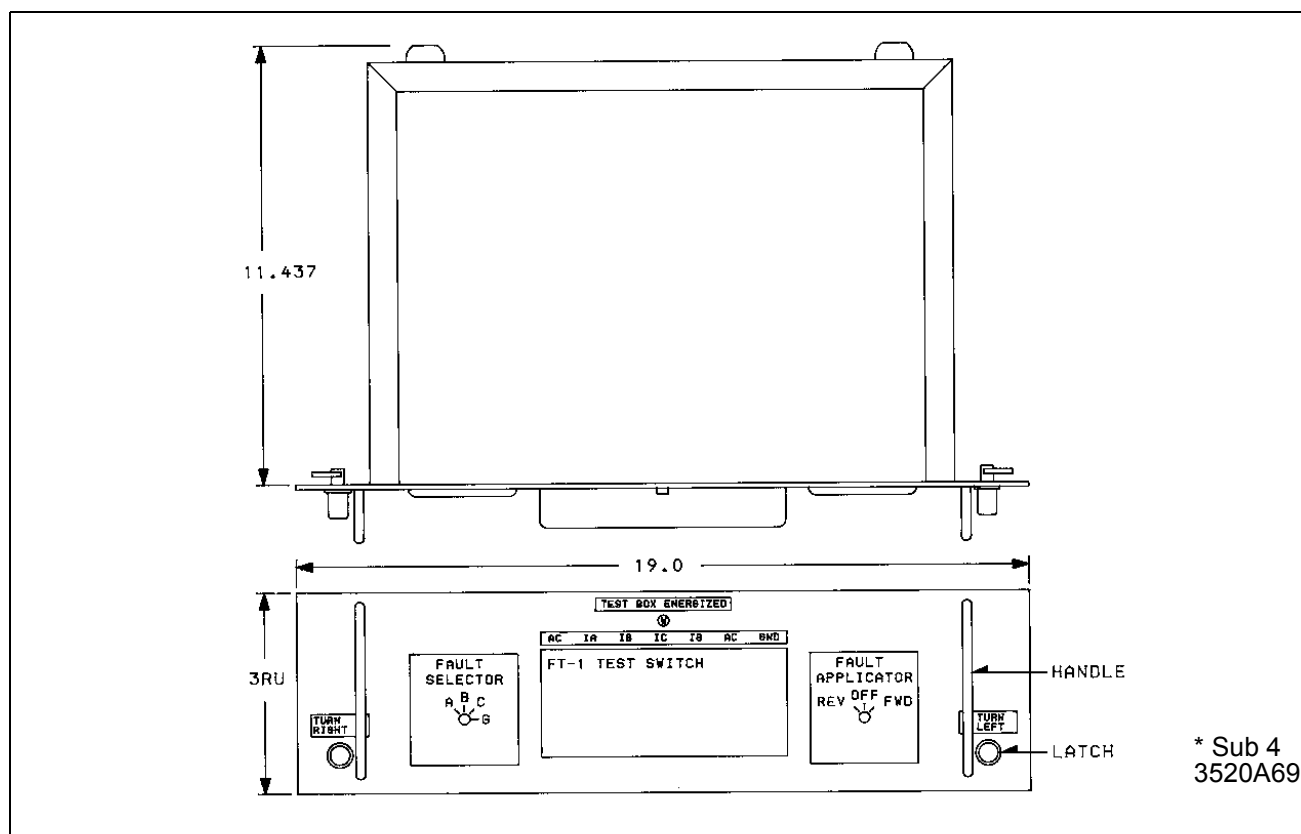


Figure 15: UCTB Test Box Outline

* Denotes Changed since previous issue

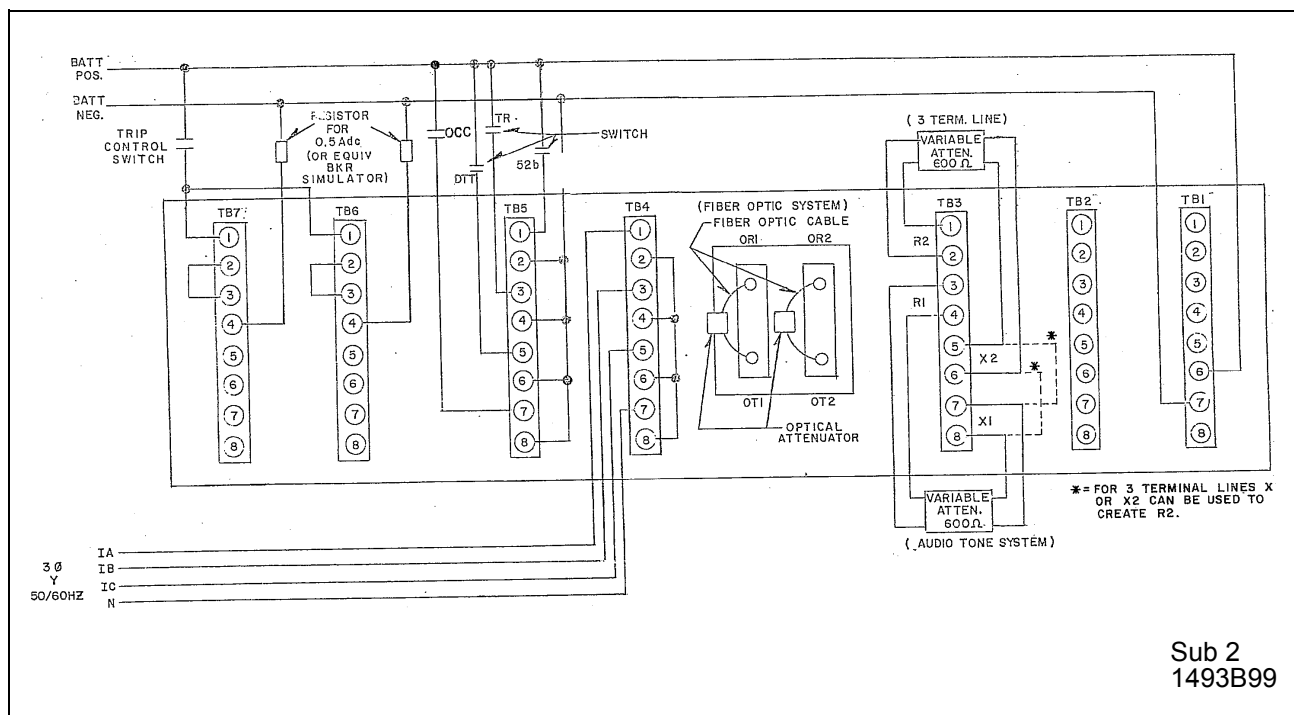


Figure 16: LCB Test Diagram

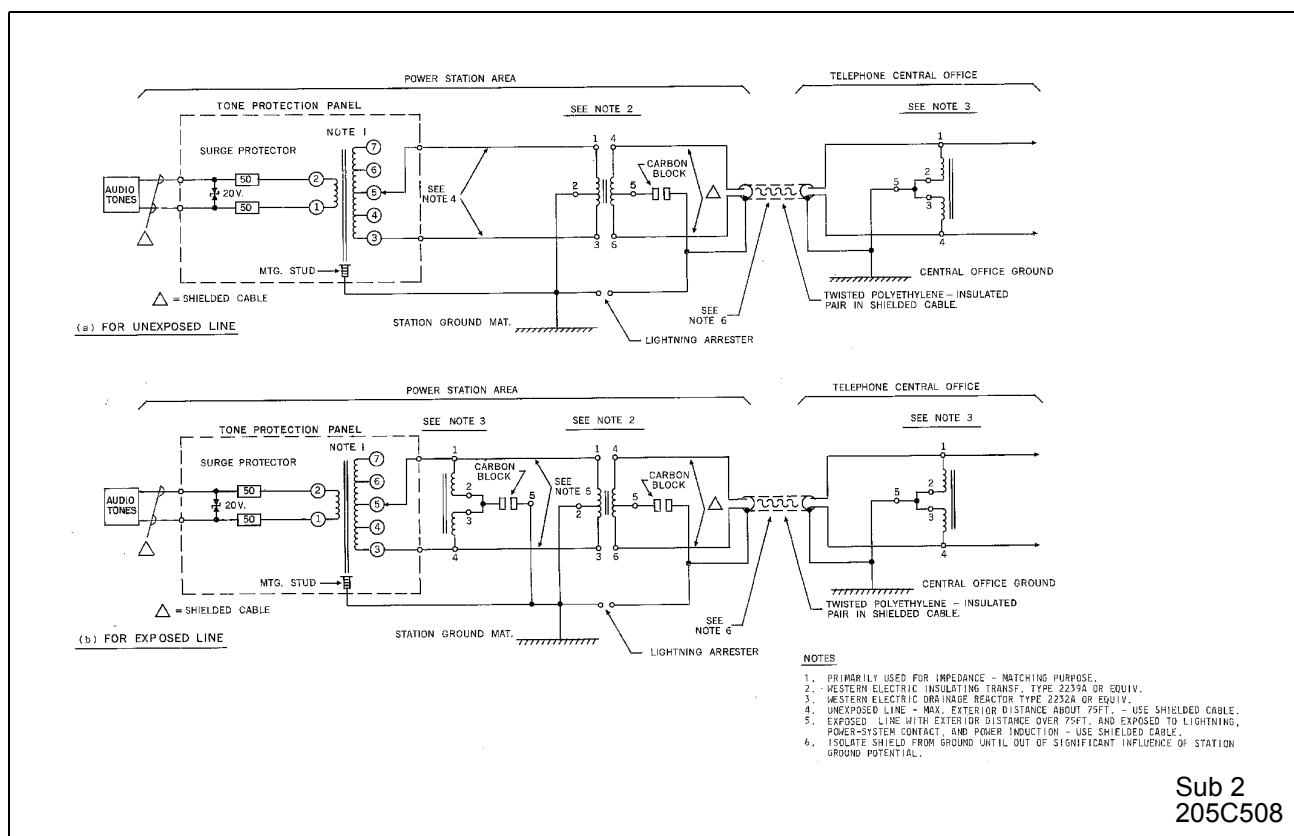


Figure 17: Leased Cable Circuit Protection

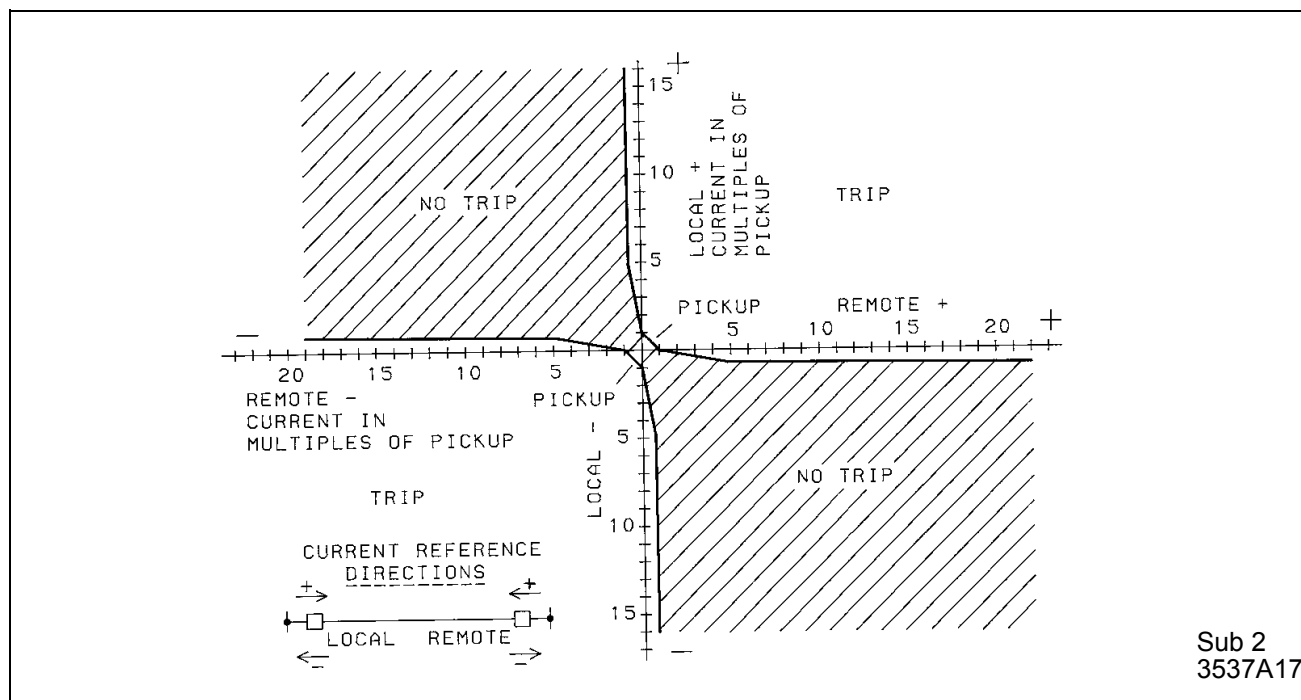


Figure 18: LCB Operating Characteristics (IN/OUT phase)

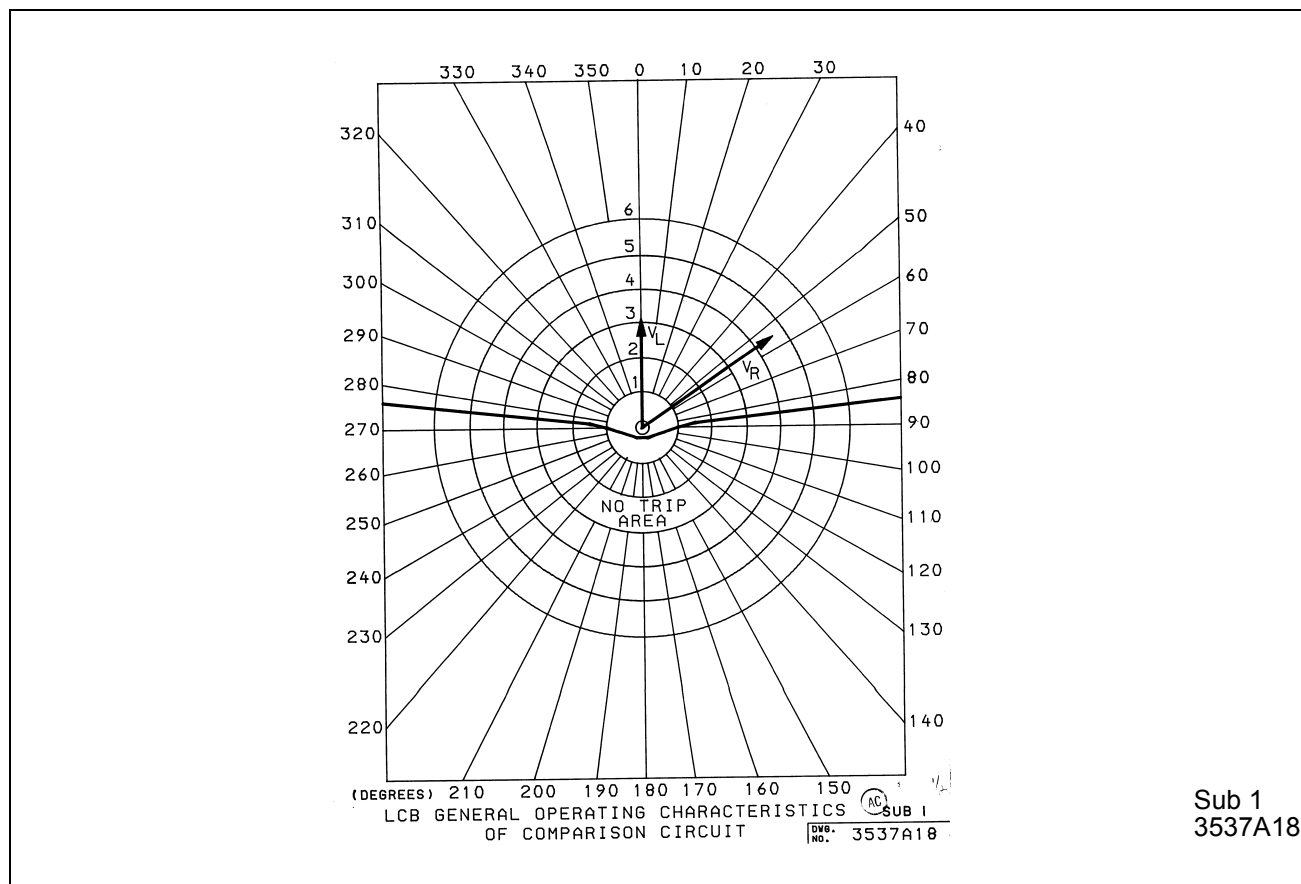


Figure 19: LCB General Operating Characteristics

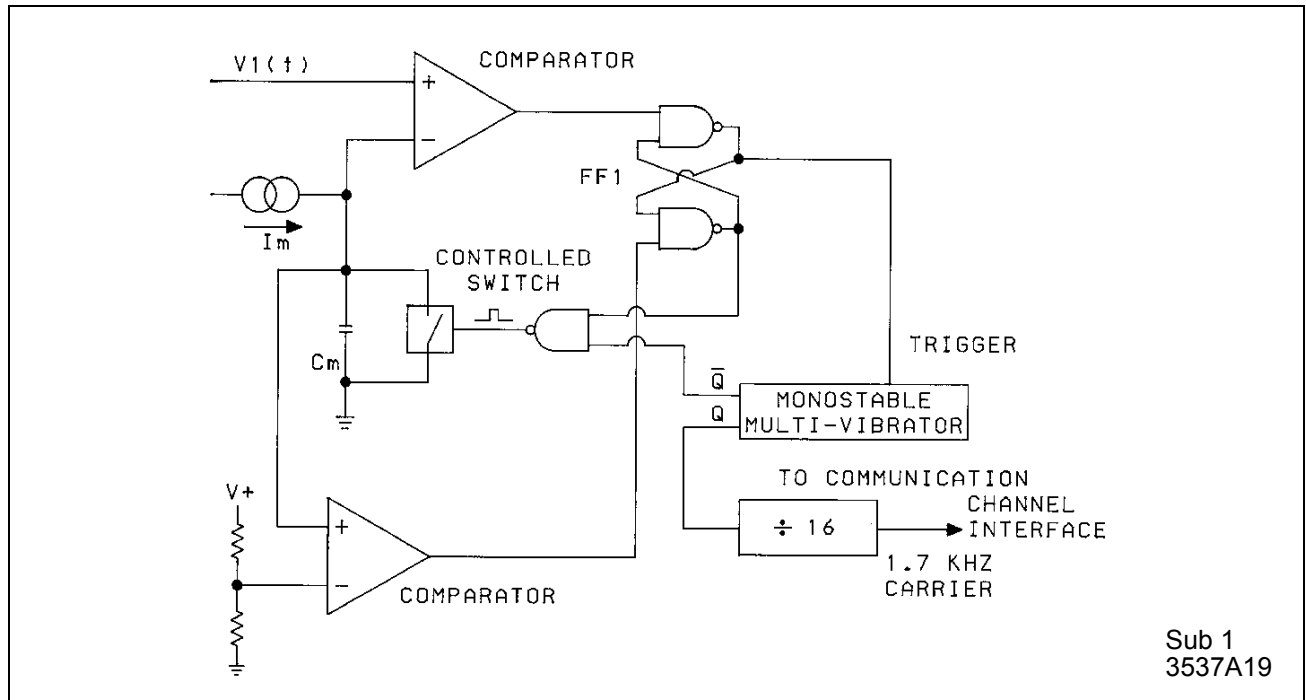


Figure 20: LCB PPM Modulator

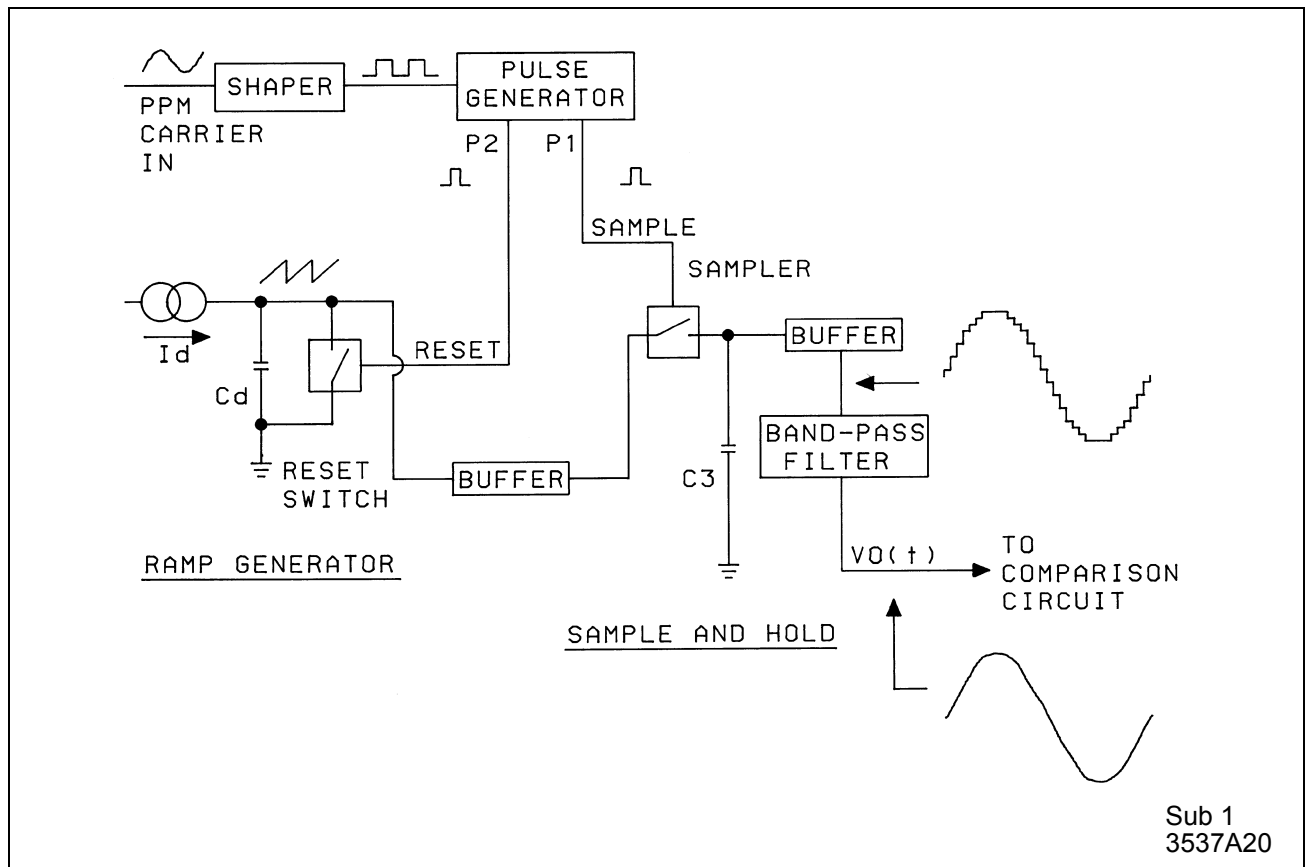
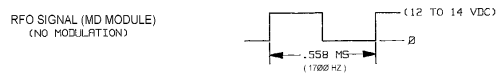


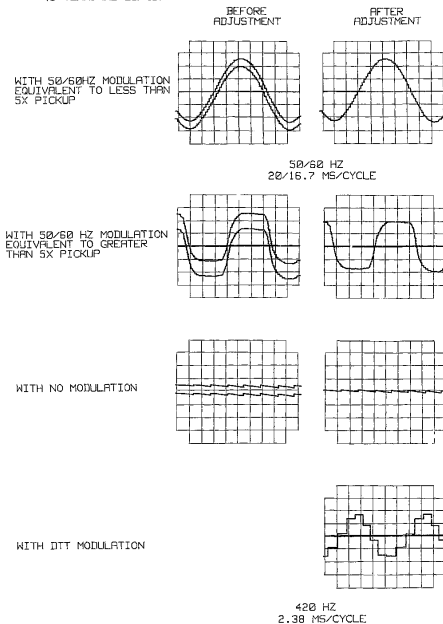
Figure 21: LCB PPM Demodulator

CARRIER FREQUENCY VERIFICATION AND ADJUSTMENT

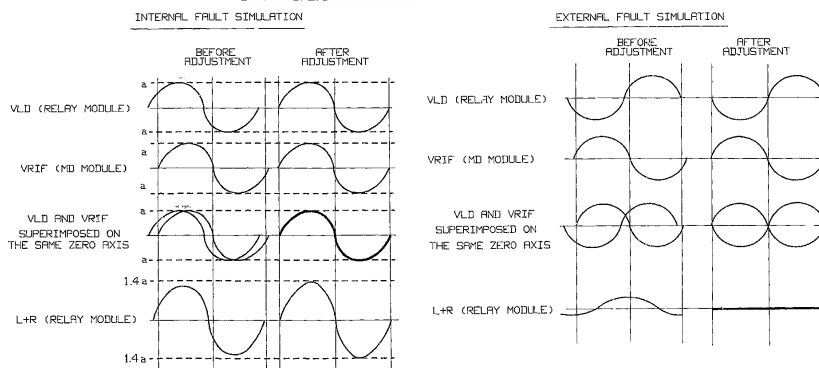


DEMODULATED SIGNAL VERIFICATION AND ADJUSTMENT

VR1 SIGNAL (MD MODULE)
VR2 SIGNAL (DTD MODULE)
(3 TERMINAL LINES)



CHANNEL DELAY EQUALIZATION ADJUSTMENT



ADJUSTMENT PROCESS AND WAVEFORMS ARE THE
SAME FOR VLD AND VR2F (DTD MODULE) FOR 3
TERMINAL LINES EXCEPT THAT VR2F IS DELAYED
WITH RESPECT TO VLD

Sub 2
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ABB

Figure 22: Field Set Up Waveforms