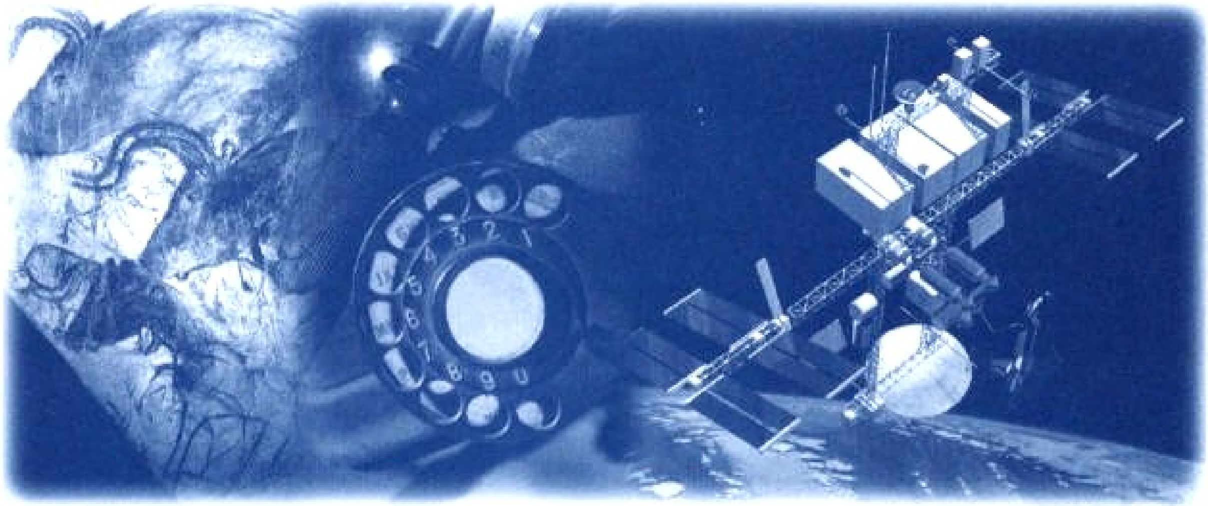

RFL 9720

Pilot Wire Interface

RFL Electronics Inc

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RFL Electronics Inc.

INSTRUCTION MANUAL

RFL 9720
Pilot Wire Interface

U.S. Patent Number 5,329,414

NOTICE

Publication Number MC 9720
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Revised May 31, 2000

RFL Electronics Inc.

WARRANTY

Except where noted, all RFL Electronics Inc. products come with a one-year warranty from date of delivery for replacement of any part which fails during normal operation. RFL will repair or, at its option, replace components that prove to be defective at no cost to the Customer. All equipment returned to RFL Electronics Inc. must have an RMA (Return Material Authorization) number, obtained by calling our Customer Service Department. A defective part should be returned to the factory, shipping charges prepaid, for repair or replacement FOB Boonton, N.J.

RFL Electronics Inc. is not responsible for warranty of peripherals, such as printers and external computers. The warranty for such devices is as stated by the original equipment manufacturer. If you have purchased peripheral equipment not manufactured by RFL, follow the written instructions supplied with that equipment for warranty information and how to obtain service.

WARRANTY STATEMENT

RFL Electronics Inc. products are warranted against defects in material and workmanship for one year from the date of shipment. During the warranty period, RFL will repair or, at its option, replace components that prove to be defective at no cost to the customer, except the one-way shipping cost of the failed assembly to our Customer Service facility in Boonton, New Jersey.

This warranty does not apply if the equipment has been damaged by accident, neglect, misuse, or causes other than performed or authorized by RFL Electronics Inc.

This warranty specifically excludes damage incurred in shipment to or from RFL. In the event an item is received in damaged condition, the carrier should be notified immediately. All claims for such damage should be filed with the carrier.

NOTE

If you do not intend to use the product immediately, it is recommended that it be opened immediately after receiving and inspected for proper operation and signs of impact damage.

This warranty is in lieu of all other warranties, whether expressed, implied or statutory, including but not limited to implied warranties of merchantability and fitness for a particular purpose. In no event shall RFL be liable, whether in contract, in tort, or on any other basis, for any damages sustained by the customer or any other person arising from or related to loss of use, failure or interruption in the operation of any products, or delay in maintenance or for incidental, consequential, indirect, or special damages or liabilities, or for loss of revenue, loss of business, or other financial loss arising out of or in connection with the sale, lease, maintenance, use, performance, failure, or interruption of the products.

RFL Electronics Inc.
Boonton, New Jersey USA

TRADEMARKS

"CPD" is a registered trademark of the General Electric Company.
"GEC" and "MBCI" are registered trademarks of the General Electric Company Plc of England.
"HCB" and "HCB-1" are registered trademarks of ABB Brown-Boveri.

The trademark information listed above is, to the best of our knowledge, accurate and complete.

CAUTION

FOR YOUR SAFETY

THE INSTALLATION, OPERATION, AND MAINTENANCE OF THIS EQUIPMENT SHOULD ONLY BE PERFORMED BY QUALIFIED PERSONS.

WARNING:

The equipment described in this manual contains high voltage. Exercise due care during operation and servicing. Read the safety summary on the reverse of this page.

SAFETY SUMMARY

The following safety precautions must be observed at all times during operation, service, and repair of this equipment. Failure to comply with these precautions, or with specific warnings elsewhere in this manual, violates safety standards of design, manufacture, and intended use of this product. RFL Electronics Inc. assumes no liability for failure to comply with these requirements.

GROUND THE CHASSIS

The chassis must be grounded to reduce shock hazard and allow the equipment to perform properly. Equipment supplied with three-wire ac power cables must be plugged into an approved three-contact electrical outlet. All other equipment is provided with a rear-panel ground terminal, which must be connected to a proper electrical ground by suitable cabling. Refer to the wiring diagram for the chassis or cabinet for the location of the ground terminal.

DO NOT OPERATE IN AN EXPLOSIVE ATMOSPHERE OR IN WET OR DAMP AREAS

Do not operate the product in the presence of flammable gases or fumes, or in any area that is wet or damp. Operating any electrical equipment under these conditions can result in a definite safety hazard.

KEEP AWAY FROM LIVE CIRCUITS

Operating personnel should never remove covers. Component replacement and internal adjustments must be done by qualified service personnel. Before attempting any work inside the product, disconnect it from the power source and discharge the circuit by temporarily grounding it. This will remove any dangerous voltages that may still be present after power is removed.

DO NOT SUBSTITUTE PARTS OR MODIFY EQUIPMENT

Because of the danger of introducing additional hazards, do not install substitute parts or make unauthorized modifications to the equipment. The product may be returned to RFL for service and repair, to ensure that all safety features are maintained.

READ THE MANUAL

Operators should read this manual before attempting to use the equipment, to learn how to use it properly and safely. Service personnel must be properly trained and have the proper tools and equipment before attempting to make adjustments or repairs.

Service personnel must recognize that whenever work is being done on the product, there is a potential electrical shock hazard and appropriate protective measures must be taken. Electrical shock can result in serious injury, because it can cause unconsciousness, cardiac arrest, and brain damage.

Throughout this manual, warnings appear before procedures that are potentially dangerous, and cautions appear before procedures that may result in equipment damage if not performed properly. The instructions contained in these warnings and cautions must be followed exactly.

RFL Electronics Inc.

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LIST OF TABLES

LIST OF EFFECTIVE PAGES

When revisions are made to the RFL 9720 Instruction Manual, the entire section where revisions were made is replaced. For the edition of this manual dated May 31, 2000 the sections are dated as follows:

Front Matter	May 31, 2000
Section 1	May 18, 1998
Section 2	July 12, 1999
Section 3	May 31, 2000
Section 4	July 12, 1999
Section 5	July 12, 1999
Section 6	May 31, 2000
Section 7	July 12, 1999
Section 8	July 12, 1999
Section 9	July 12, 1999

REVISION RECORD

Rev	Description	Date	Approval
07-12-99	Revised in accordance with ECO Numbers: 9720-047, 048, 049, 051,052, 056, 057, 059, 060, 061, 063, 064, 066, 069, 070, 071, 072	1-10-00	C. Steinberg
05-31-00	Deleted references to three terminal operation	5-31-00	C. Steinberg

RFL 9720
Digital Pilot Wire Interface

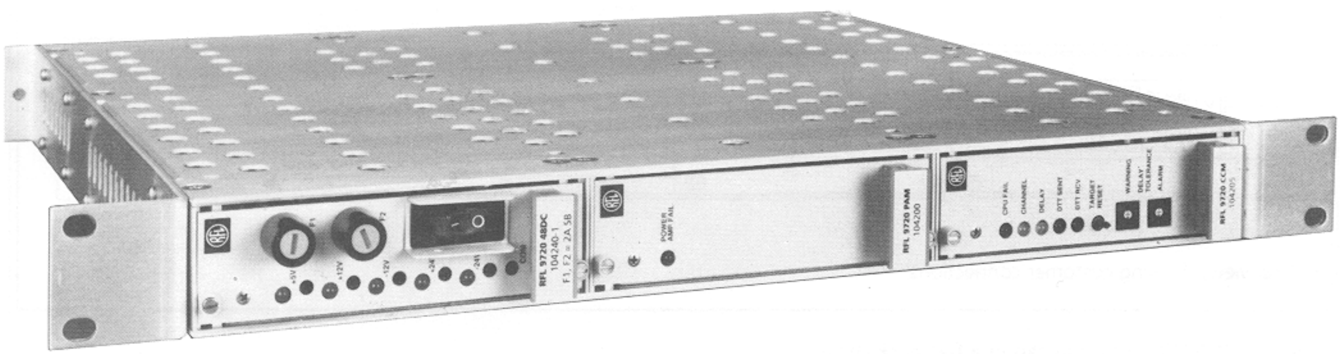
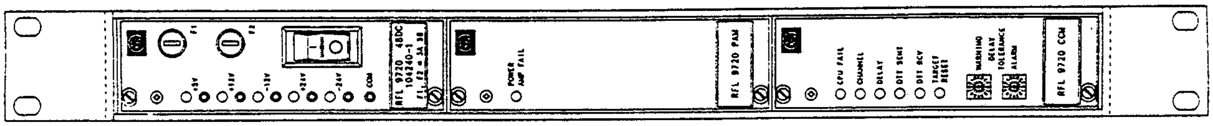


Figure 1. RFL 9720 Digital Pilot Wire Interface

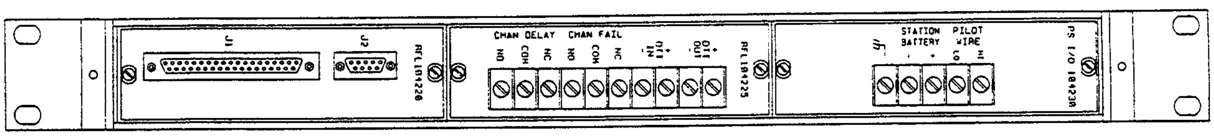
Designed for the harsh substation environment, the RFL 9720 Digital Pilot Wire Interface is a stand-alone unit that digitizes the 60-Hz signal from a current differential relay and transmits it with its own specially-encoded message. The coding structure is based on the proven data format of the RFL 9700 Digital Protection System; this allows it to yield to the same level of security. Because the RFL 9720 is a stand-alone unit, all of its security and self-check features are an integral part of its hardware, and not dependent upon handshake or alarm signals from its communications host. Also included in the design are a number of standard features that enhance the relay system's capabilities. A typical RFL 9720 is shown in Figure 1.

The RFL 9720 can communicate over a 56-Kbps RS-449 synchronous interface; as an alternate, a wide range of fiber heads are available for communication over multimode or singlemode fiber. The RFL 9720 is designed with the protection engineer in mind, offering extensive diagnostics and delay monitoring not found in plug-in current differential modules.

Each RFL 9720 unit consists of three main circuit board modules: the Communications And Control Module (CCM), the Power Amplifier Module (PAM), and the Power Module (PM). Connections to each module are made through I/O modules, which are mounted at the rear of the chassis. The RFL 9720's modular construction allows for a variety of packaging arrangements. For example, a single RFL 9720 unit can be mounted in a flat-pack chassis that is one rack-unit high (1.75 inches, or 4.45 cm), as shown in Figure 2. It can also be mounted in panel-mount chassis that is 5.25 inches high and 6.4 inches wide (13.34 cm x 16.25 cm), as shown in Figure 3. Up to four RFL 9720 units can be mounted in a rack-mount 3U chassis (5.25 inches, or 13.34 cm), as shown in Figure 4.

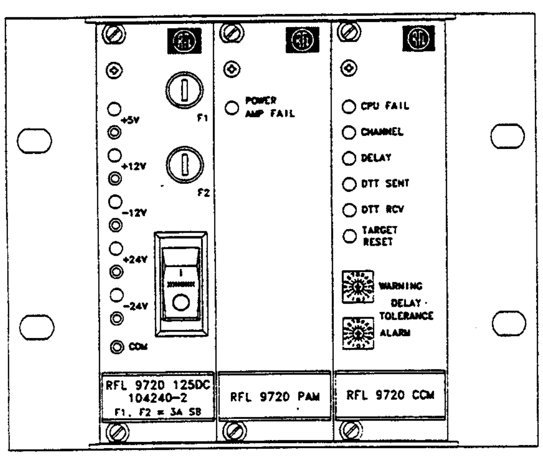


a. Front view.

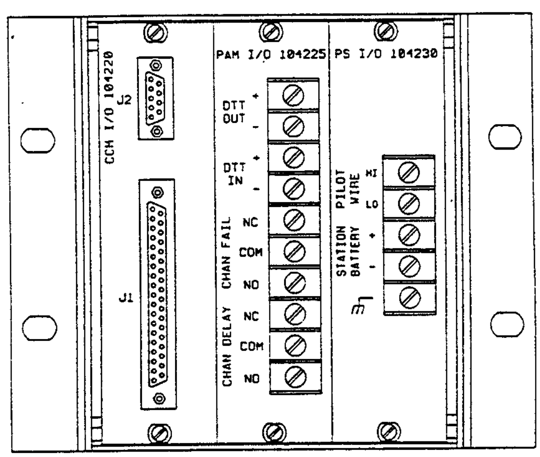


b. Rear view, showing customer connections.

Figure 2. RFL 9720 unit mounted in a flat-pack chassis

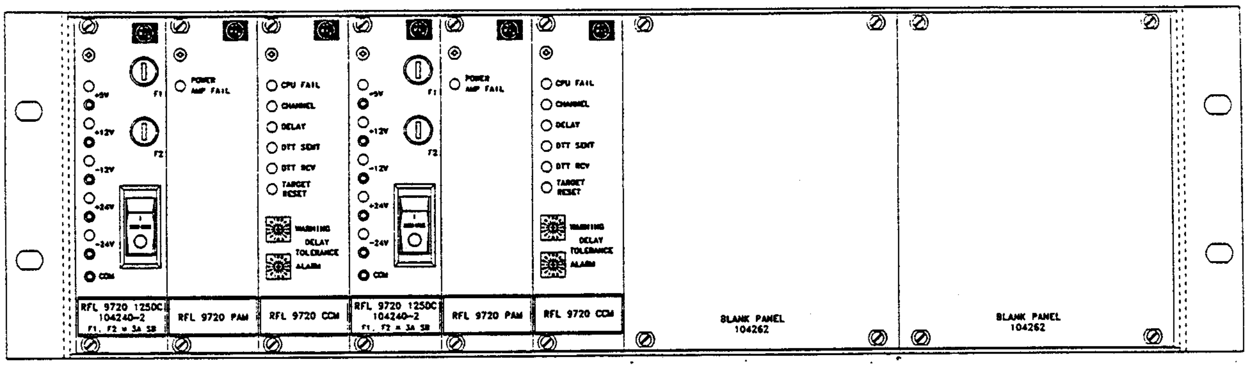


a. Front view.

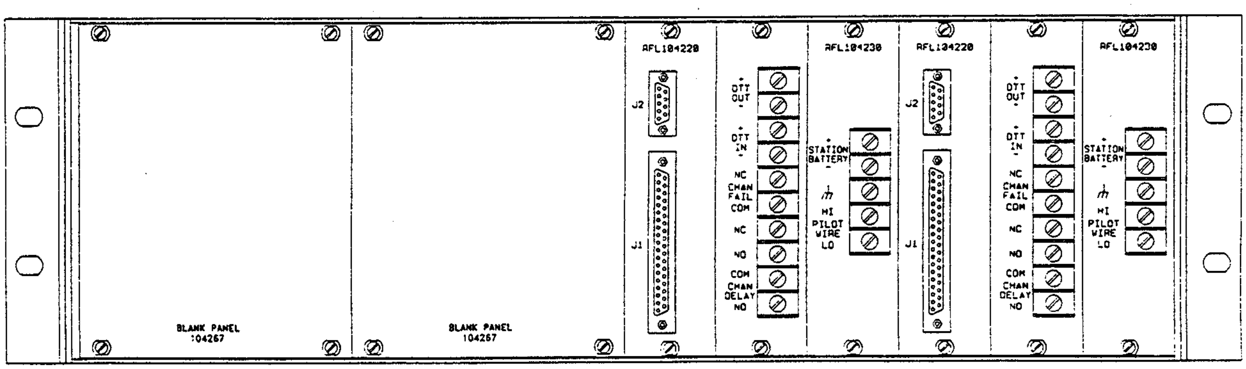


b. Rear view, showing customer connections.

Figure 3. RFL 9720 unit mounted in a panel-mount chassis



a. Front view.



b. Rear view, showing customer connections.

Figure 4. Two RFL 9720 units mounted in a rack-mount chassis

FEATURES

IDEALIZED PILOT CIRCUIT

The RFL 9720 offers various I/O modules to adapt it to many different relay types. Each I/O module is impedance-matched to that relay, giving the representation of an ideal pilot wire circuit. In addition, RFL's technique of using an active hybrid transformer circuit (Patent Applied For) greatly reduces or eliminates any effect from the local signal (feedback). The local end sees a truer representation of the remote end, for a more accurate comparison of the two signals. Because of this accuracy, the RFL 9720 can tolerate longer channel delays than competitive products can. This is a major advantage when applying current differential relaying in networks where propagation delays can become prohibitive.

REMOTE DIAGNOSTICS

You can remotely access the RFL 9720 through its RS-232 port. Software routines can be performed to determine the latest channel delay values, communications integrity, switch settings, system status, and DTT. Diagnostic tests and watchdog timer tests can also be initiated through this port.

AUTOMATIC DELAY MEASUREMENT

The RFL 9720 includes channel delay measurement as part of its checkback testing. This is done because pilot wire relays are sensitive to propagation delay. Two delay alarm outputs are available: CHANNEL DELAY and CHANNEL FAIL.

The CHANNEL DELAY alarm is a warning that the amount of time required for a signal to propagate through the communications channel has become too long for dependable relay operation. This alarm is programmable for any period from 400 µs to 1.15 ms, in 50-µs increments.

The CHANNEL FAIL alarm shows that the RFL 9720's pilot wire output is being squelched. Squelch can be caused by excessive channel delay, corrupted data, power supply failure, amplifier failure, or microprocessor failure. This alarm is programmable for one of 16 different channel periods, from 400 µs to 2900 µs.

When a CHANNEL FAIL alarm occurs, the RFL 9720 can be configured to either short or open the pilot wire circuit. This allows the relay to operate in either trip inhibit or overcurrent mode.

DIRECT TRANSFER TRIP (DTT)

The RFL 9720 also includes a Direct Transfer Trip (DTT) feature. This allows for bi-directional transfer trip signals to be sent and received between RFL 9720 units. TRIP SEND and TRIP RECEIVED indicators on the RFL 9720 CCM Communications And Control Module seal in when the DTT function is sent or received.

UNBLOCK TIMER

If desired, an optional unblock timer can be used along with the RFL 9720's squelch function. This will allow the pilot wire relay to operate in the overcurrent mode for 150 ms after a channel failure before it is placed in trip inhibit.

MODULAR DESIGN

The RFL 9720 incorporates a mid-plane motherboard design. Modules plug into the front of the unit, and matching I/O Modules plug into the rear. This eliminates the need for internal wiring or harnesses when adding new additional interfaces to rack-mount chassis. Upgrading is simplified, and downtime kept to a minimum.

DIGITAL INTERFACE CAPABILITIES

When applying the RFL 9720 to digital circuits, less bandwidth is required because the RFL 9720 communicates in a single 56-Kbps time slot. All RFL 9720 terminals are equipped with an RS-449 interface. When supplied with a digital I/O, the RFL 9720 acts as "Data Terminal Equipment" (DTE), requiring clock synchronization from the "Data Communications Equipment" (DCE) in which it operates.

FIBER OPTIC CAPABILITIES

The RFL 9720 can be adapted to all fiber optic requirements; 850 nm or 1300 nm, LED or laser source, singlemode or multimode. Plug-in fiber optic emitter and detector heads make for simple, trouble-free, field configuration changes. These heads are mounted at the rear of the chassis, allowing them to be removed without drawing the fiber through the chassis.

Figure 5 shows two RFL 9720 terminals equipped with single-channel fiber optic modules. The RFL 97 FO INTX transmitter modules convert RS-422 signals into drive signals for the fiber optic emitter heads. Each emitter head converts the drive signal it receives into an infrared light signal for optic transmission. At the other end of the fiber, a fiber optic detector head converts the light signal into a receiver input signal. This signal is passed to an RFL 97 FO INRX receiver modules and converted back into an RS-422 signal.

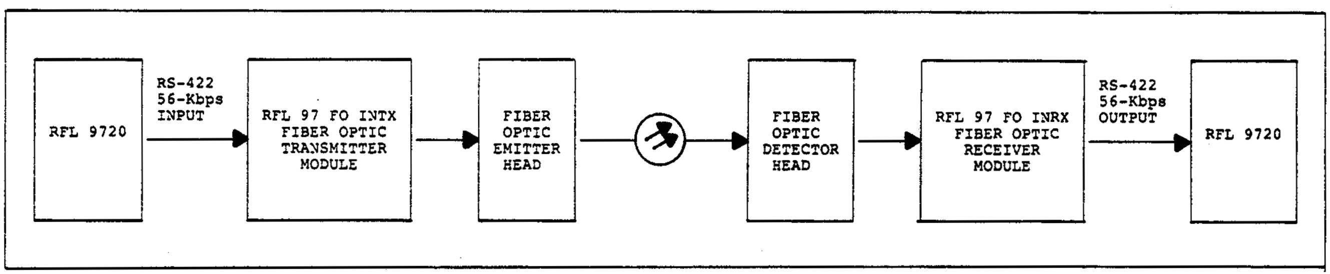


Figure 5. Single-channel RFL 9720 fiber optic system

INTEGRATED FIBER OPTIC MULTIPLEXER (Mini-Mux)

The RFL 9720 terminals can be supplied with eight-input fiber optic transmitters, and eight-output fiber optic receivers. This allows additional functions (such as voice and data) to share the optic path used by the RFL 9720.

In Figure 6, RFL 97 FO INTX-1 and RFL 97 FO INRX-1 eight-channel fiber optic modules are used at each terminal to create a system where eight 56-Kbps channels can be multiplexed and transmitted over a single fiber. One channel is used by the RFL 9720; the other seven channels are available for use by the various voice, data, or RS-449 multiplex options. (See next page.)

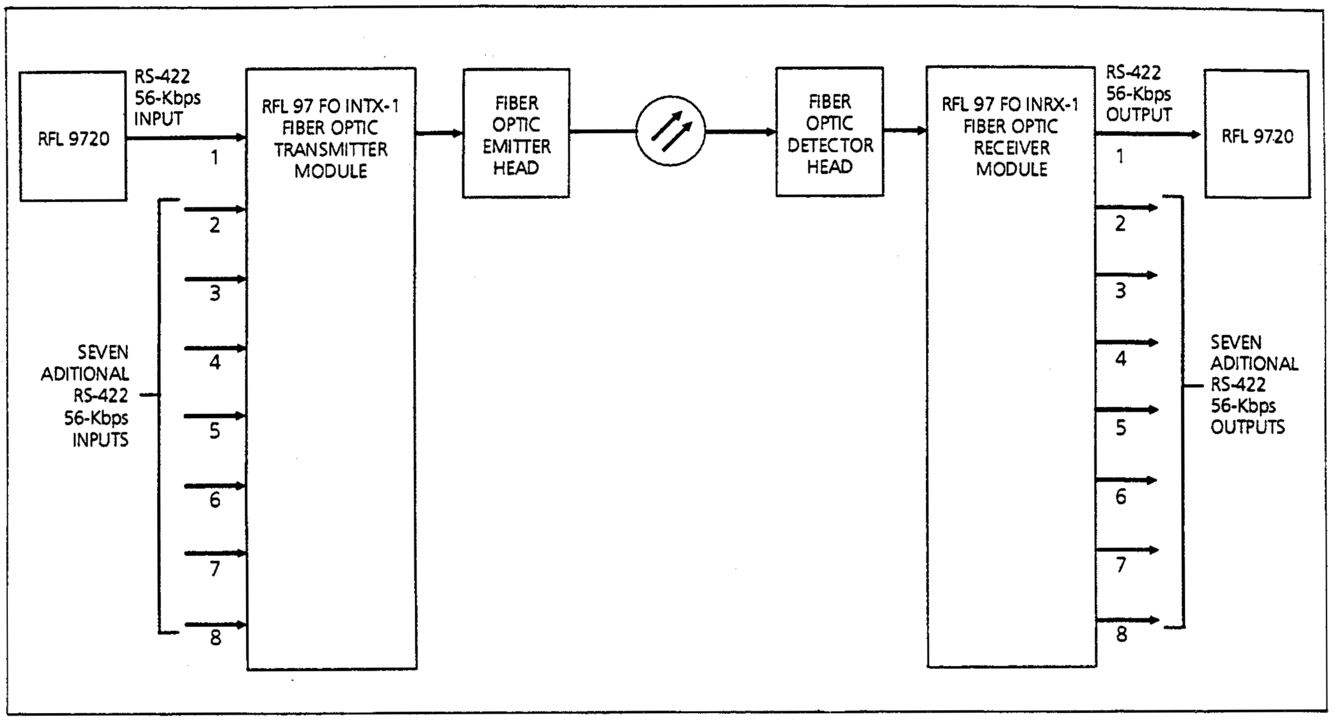


Figure 6. Eight-channel RFL 9720 fiber optic system

VOICE, DATA, AND RS-449 MULTIPLEX OPTIONS

Accessory modules are available for use with RFL 9720 terminals equipped with eight-channel fiber optic modules. These accessory modules allow voice, asynchronous data and synchronous 56-Kbps RS-449 signals to be sent along the fiber optic line along with the current differential signals generated by the RFL 9720. Additional information on RFL 9720 options can be found on page 19 of this Product Information Sheet.

MEETS ANSI SWC AND FAST-TRANSIENT REQUIREMENTS

The RFL 9720 meets the Surge Withstand Capability (SWC) requirements of IEEE 472-1978 (ANSI C.37.90-1978). It also meets the Fast Transient requirements of ANSI-IEEE C.37.90.1.

MEETS EMI/RFI REQUIREMENTS

The RFL 9720 meets the EMI/RFI requirements of IEC 801-3 (1984), BS 6667 Part 3 (1985), and ANSI C.37.90.2 (Trial-Use Standard, 1989).

TYPICAL APPLICATIONS

The following paragraphs describe some typical applications for the RFL 9720. For more information on these or other possible applications, contact the factory or an RFL Sales Representative.

COMMUNICATIONS INTERFACE

The RFL 9720 is suitable for a variety of communications mediums, such as T1 carrier (Fig. 7a), digital microwave (Fig. 7b), or fiber (Fig. 7c).

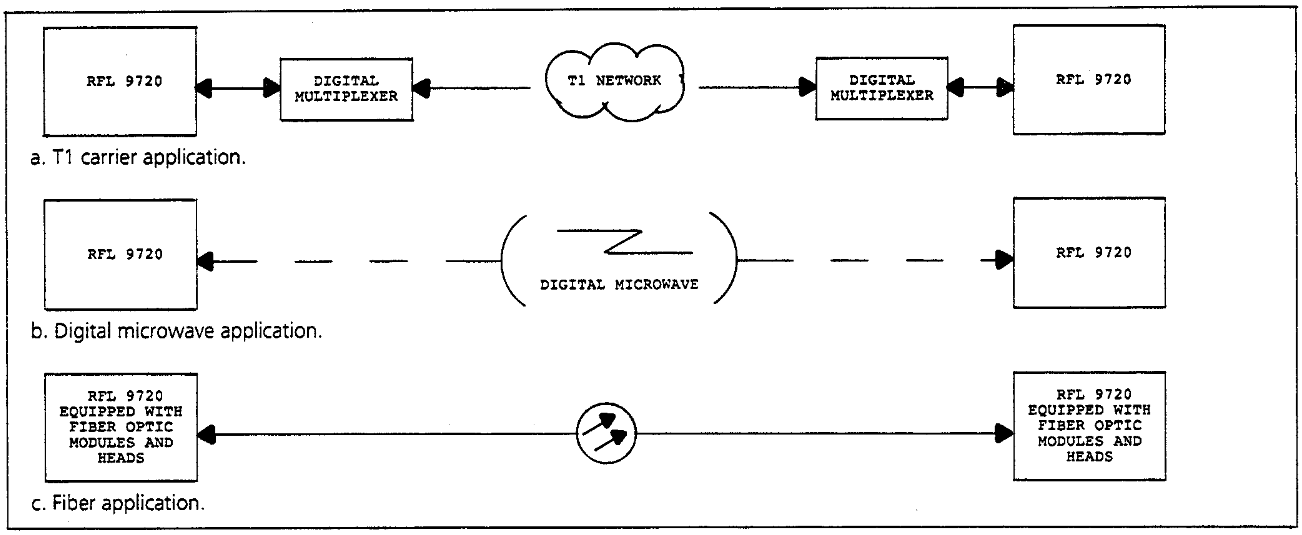


Figure 7. Typical communication interface applications

Optional fiber optic modules allow the RFL 9720 to be applied directly to dedicated fibers. The fiber optic modules fit in the same chassis as the RFL 9720, allowing for maximum utilization of panel space.

T1 CARRIER

The RFL 9720 can operate over a 56-Kbps channel of an RFL 9001 Intelligent T1 Multiplexer, as shown in Figure 8. By using the RFL 9001 system as the communications medium for the RFL 9720, you now have the added flexibility of the RFL 9001's drop/insert capabilities.

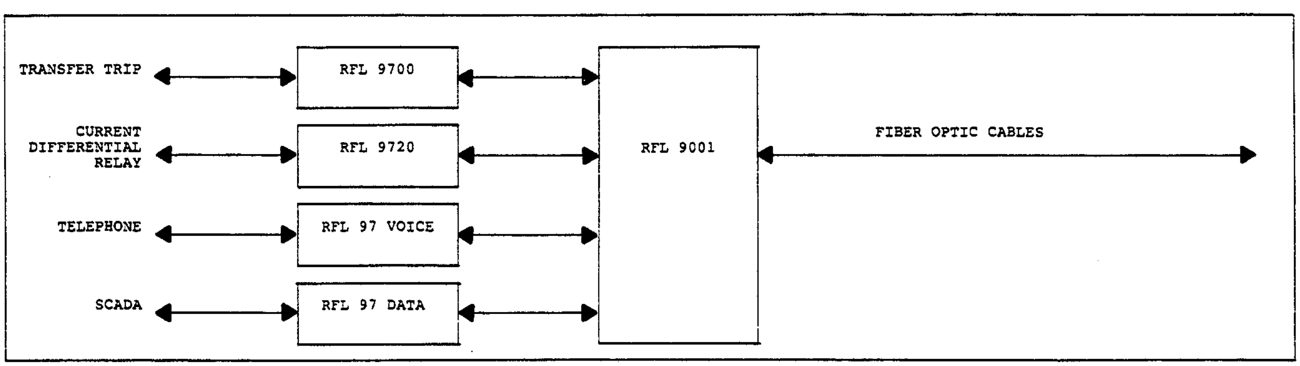


Figure 8. Interfacing the RFL 9720 to an RFL 9001 Intelligent T1 Multiplexer

RFL 9700 APPLICATION

The RFL 9720 can be used to add current differential relays to new or existing RFL 9700 fiber optic transfer trip systems, as shown in Figure 9. If the existing RFL 9700 is equipped with a multiplexer option, the RFL 9720 simply plugs in. If the RFL 9700 was not originally equipped with the multiplexer option, it can be easily upgraded for use with the RFL 9720 by replacing the single-channel fiber optic interface modules with eight-channel modules; no wiring changes are required.

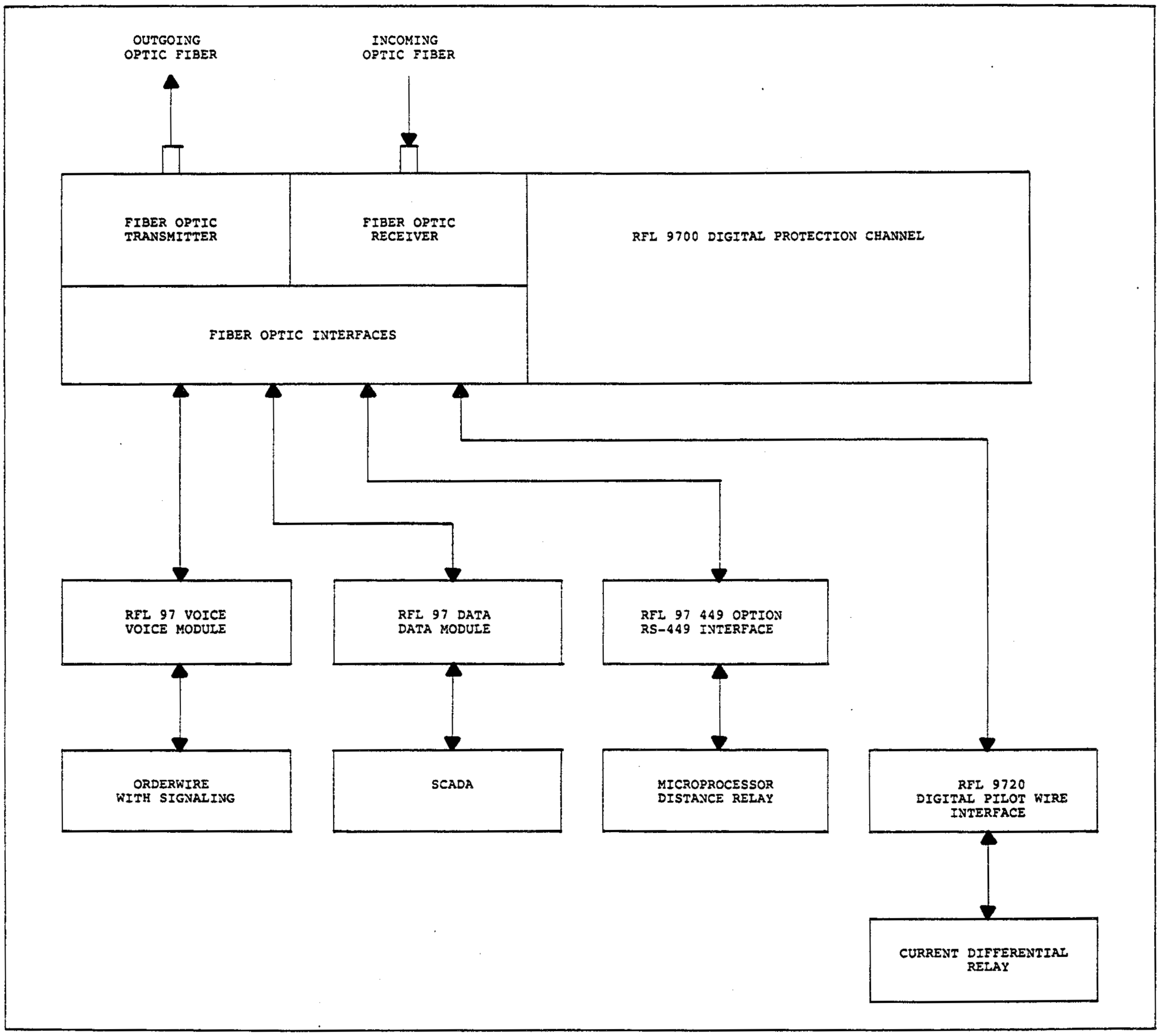


Figure 9. Interfacing the RFL 9720 to an RFL 9700 Digital Protection Channel

FIBER OPTIC MULTIPLEXING

Figure 10 is a block diagram of a typical substation using some of the RFL 9720's fiber optic multiplexing capabilities. Current differential relaying is provided through the RFL 9720, over an RS-449 port on the fiber optic multiplexer. Transfer trip protection is provided by the RFL 9700 Digital Protection Channel, and orderwire is provided over a voice channel. SCADA and distance relay communications are provided over the RS-232 ports of the data channel.

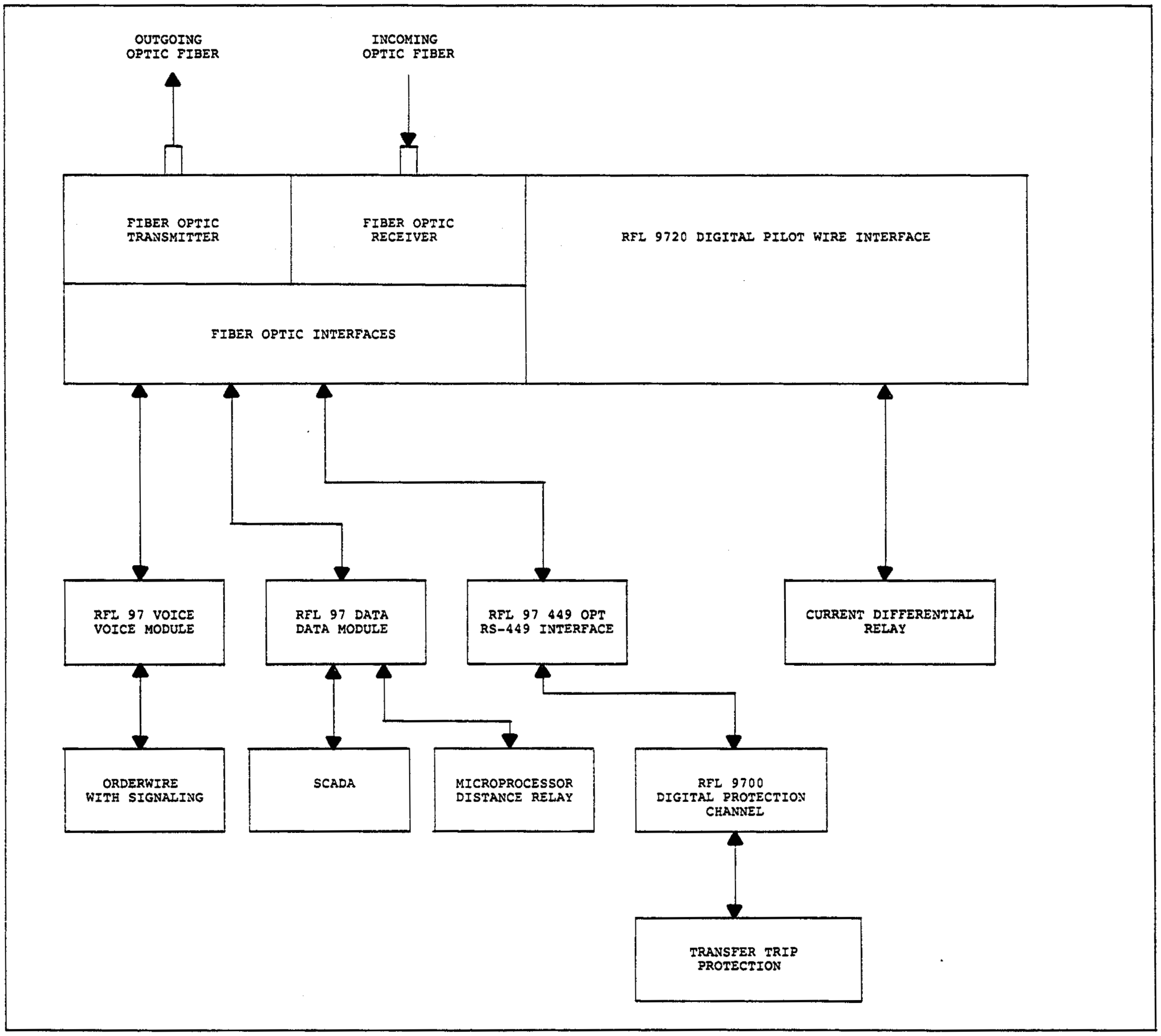


Figure 10. Typical fiber optic multiplex application

SYSTEM PERFORMANCE

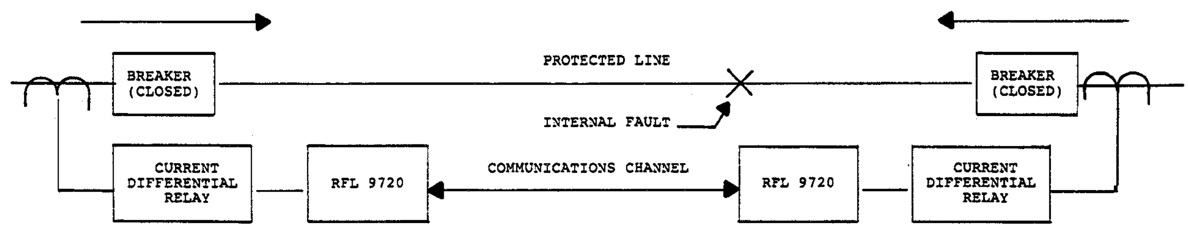
The following paragraphs describe tests that were run on RFL 9720 equipment to verify performance. Figures 11 through 14 are curves that show **typical** results. All tests were run using single-phase current connected to the relay's A-G input terminals. Standard non-modified RFL 9720 circuit boards and I/O modules were used for all tests. "Channel delay" is defined as the actual delay in the communications equipment connected to the RFL 9720; this excludes any delay added by the RFL 9720. When two RFL 9720 terminals are connected back-to-back, there is zero channel delay. The delay causes an effective phase shift of the pilot wire current generated by the far end relay. This shift is compared to the non-shifted line current in the relay at the near end.

INTERNAL FAULT TRIP LEVELS

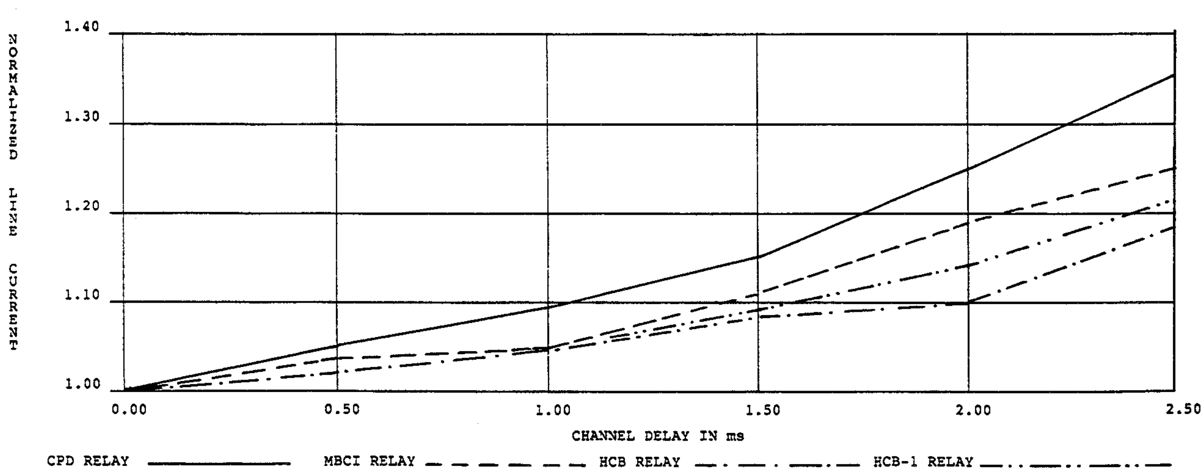
Figure 11 shows the change in internal-fault tripping levels as a function of channel delay. The line current is shown on the vertical axis, and is normalized to the trip current at zero channel delay for each relay type. The graphs show that as channel delay increases, all relays become less sensitive.

When using an HCB relay (for example), the local and remote signals with zero channel delay are in-phase during an internal fault condition. Current will be circulating through the operate coils, with no current circulating in the pilot wires. Since the signals are in-phase, the peak composite of the two yields a higher signal level. As channel delay increases, the local and remote signals begin to move out-of-phase. This reduces the peak composite, and more current is required to trip. With additional delay increases and phase shifts, the signal appears more like an external fault; the RFL 9720 units become less likely to trip, and less dependable.

The graph in Figure 11 is provided so the user can determine if the resultant fault trip level is acceptable for the specific application. Note that some current differential relays (such as the CPD) operate with the opposite principles of the HCB. However, the channel delay will have the same effect.



a. One-line diagram.



b. Effect of increased channel delay.

Figure 11. Typical internal fault trip levels, RFL 9720 Digital Pilot Wire Interface

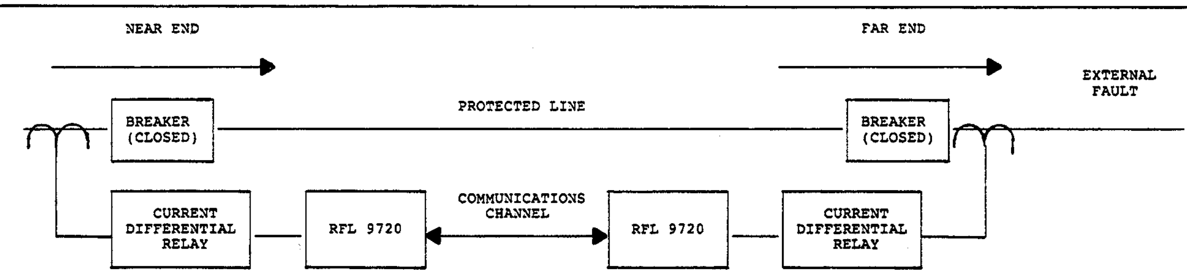
EXTERNAL FAULT TRIP LEVELS

Figure 12 shows the trip levels for external faults with large amounts of channel delay. The line currents on the vertical axis are normalized to the typical pickup levels for each relay type. As channel delay increases, less line current is required to cause a false trip. For delays less than where the curve becomes nearly vertical, the relay will not false trip. For safe operation, channel delay times must be kept well below this threshold.

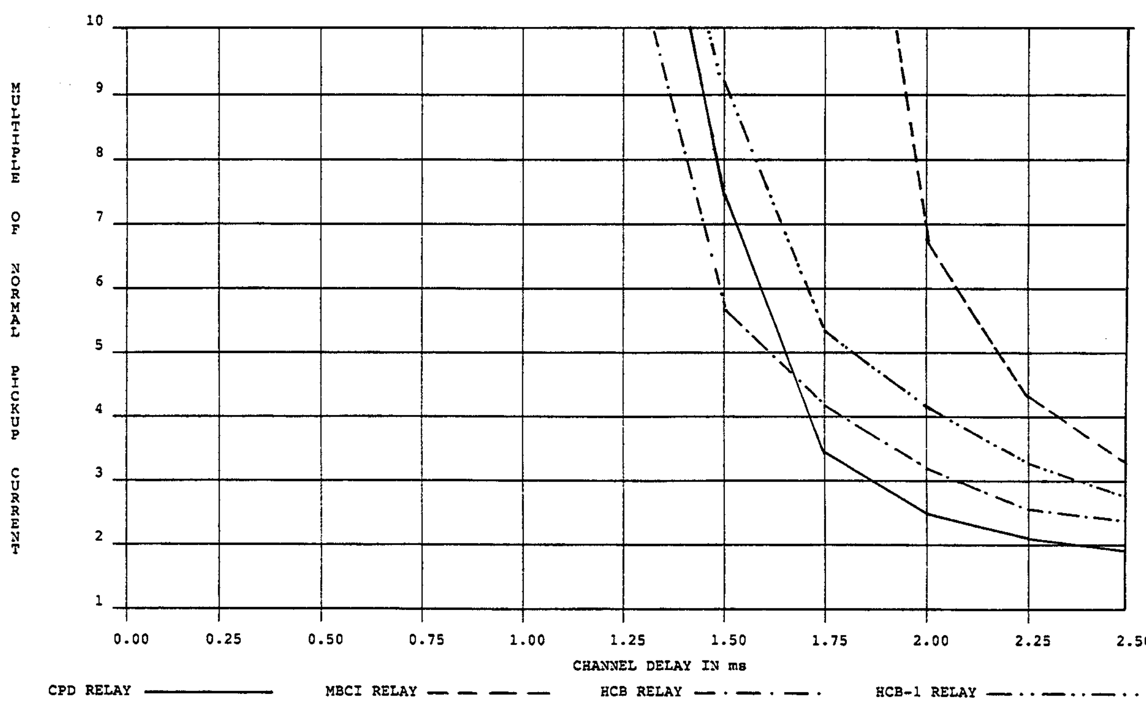
When using an HCB relay (for example), the local and remote signals with zero channel delay are 180 degrees out-of-phase during an external fault. Current will be circulating through the pilot wires, with no current passing through the operate coils. Because the signals are out-of-phase, there is no peak composite (restraint).

As channel delay increases, the local and remote signals begin to move in-phase, so current becomes present in the relay operate coils. The more in-phase the signals appear, the more the peak composite appears like an internal fault. The probability of false trips increases, and the units become less secure.

Note that some current differential relays (such as the CPD) operate with the opposite principles of the HCB. However, the channel delay will have the same effect. When using HCB relays, delay times greater than 1.25 ms are not recommended.



a. One-line diagram.



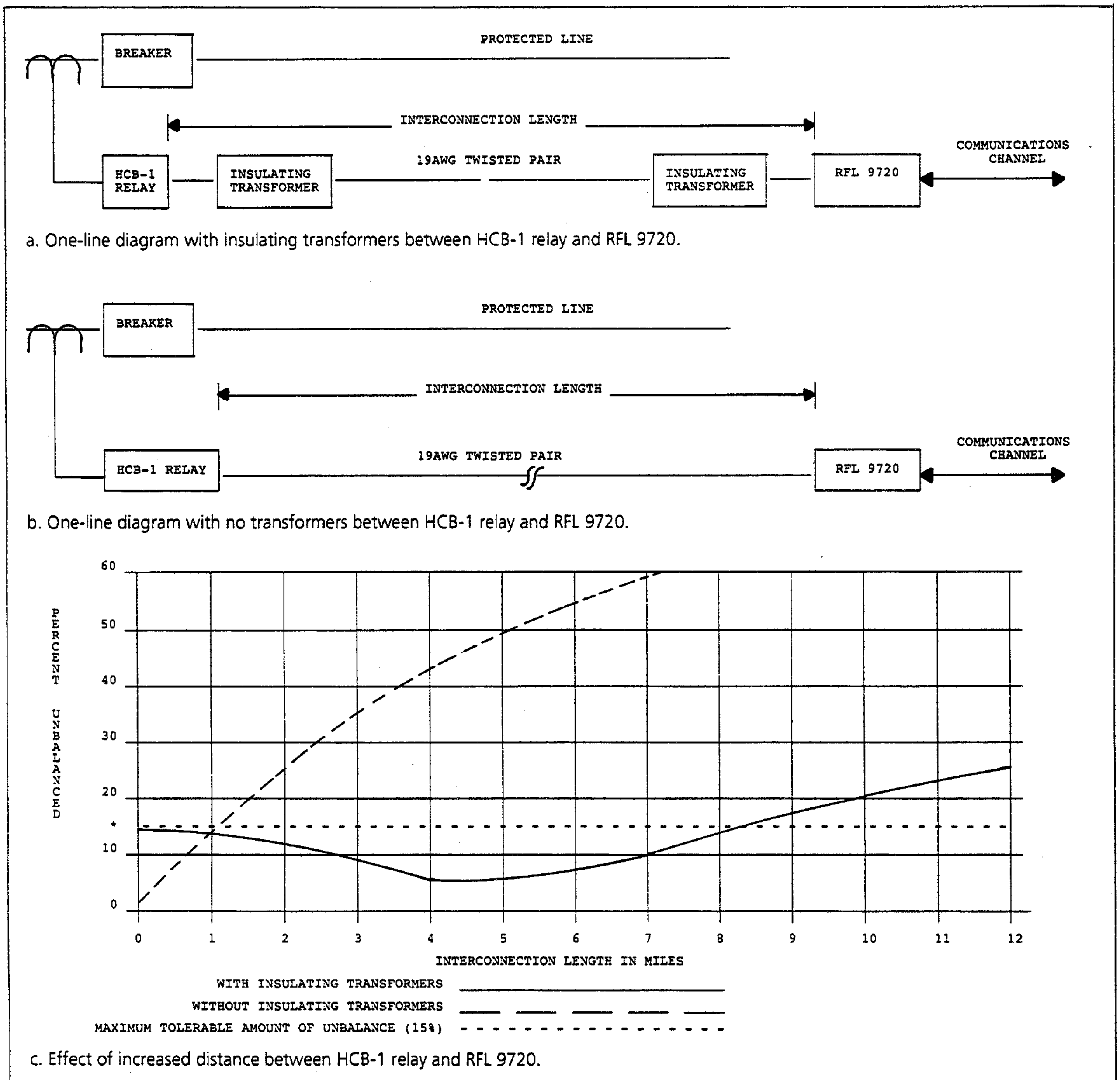
b. Effect of increased channel delay.

Figure 12. Typical external fault trip levels, RFL 9720 Digital Pilot Wire Interface

INTERFACE UNBALANCE (HCB-1 relays only)

Figure 13 shows the effect of long interconnections between an HCB-1 relay and the RFL 9720. The interconnection is assumed to be 19AWG twisted pair cable, which is normally used for pilot wire lines. The vertical axis shows the amount of unbalance in the hybrid interface to the relay. Excessive unbalance will greatly modify the apparent pilot wire characteristics, and affect relay performance.

Two curves are shown in Figure 13c: one for interconnections using insulating transformers (as shown in Fig. 13a), and one without transformers (as shown in Fig. 13b). The unbalance on the transformerless interconnection increases from about 2 percent to almost 15 percent at one mile (1.6 km), with greater unbalances for longer distances. If insulating transformers are used at each end, the unbalance remains less than 15 percent for distances between 1 and 8.5 miles (1.6 to 13.7 km).



a. One-line diagram with insulating transformers between HCB-1 relay and RFL 9720.

b. One-line diagram with no transformers between HCB-1 relay and RFL 9720.

c. Effect of increased distance between HCB-1 relay and RFL 9720.

Figure 13. Typical effect of long interconnections between an HCB-1 relay and the RFL 9720 Digital Pilot Wire Interface

Figure 14 demonstrates the effect unbalance has on external fault trip levels. The five curves represent different amounts of unbalance due to long interconnections between the RFL 9720 and the HCB-1 relay.

The best system performance for HCB-1 relays (about 5 percent or less unbalance) is achieved when using transformerless interconnections up to 2000 feet long (610 meters), or transformer-isolated interconnections that are 4 to 5 miles long (6.4 to 8.0 km). As a result, the following guidelines should be used:

1. Do not use transformers on interconnections less than one mile long (1.6 km).

2. Use transformers on interconnections from 1 to 8.5 miles long (1.6 to 13.7 km).

3. Do not use interconnections longer than 8.5 miles (13.7 km).

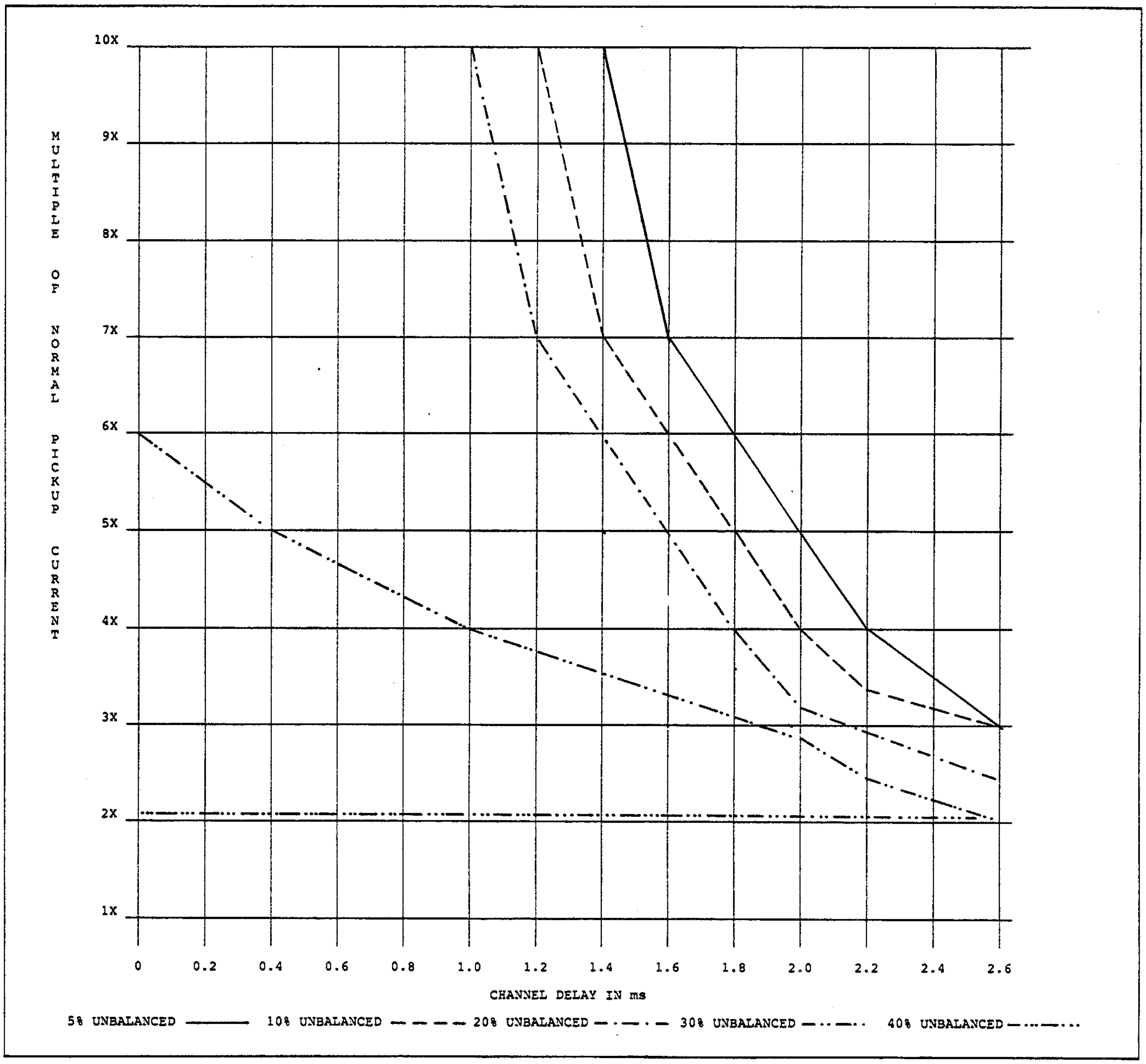


Figure 14. Typical effect of interface unbalance between an HCB-1 relay and the RFL 9720 Digital Pilot Wire Interface

SPECIFICATIONS

Communications Interface:	
Data Rate:	56-Kbps synchronous, as noted in EIA Standard RS-422.
Data Connector:	37-pin D-subminiature connector (DC-37), wired as noted in EIA Standard RS-449. The RFL 9720 is also equipped with a 9-pin D-subminiature connector (DE-9) for RS-232 interfacing, and an eight-pin ribbon cable connector for direct interface to RFL 9700 fiber optic multiplex equipment.
Compatible Relays:	ABB Types HCB and HCB-1, GEC Type MBCI, and General Electric Type CPD. Relay connections are made according to the standard pilot wire connections for each relay type; no modifications need to be made to the relays themselves.
Channel Time:	350 µs, exclusive of channel propagation delay.
DTT KEY Input:	42 Vdc to 150 Vdc, 18 mA maximum.
DTT Output:	Solid-state Form A (SPST); 4 Vdc to 200 Vdc, 10 mA to 1 ampere. The transient power dissipation is 400 watts for 1 ms (non-recurring). Surge current is 5 amperes for one second.
DTT Response Time:	Less than 2.5 ms, exclusive of channel delay.
Alarm Relay Outputs:	Two (CHANNEL DELAY and CHANNEL FAIL). Each relay has one set of Form C (SPDT) contacts, rated for 125 Vdc maximum @ 1 ampere.
Interface Dielectric Strength:	The RFL 9720 meets the Surge Withstand Capability (SWC) requirements of ANSI C.37.90-1978. It also meets the fast-transient requirements of ANSI C.37.90.1.
EMI/RFI Interference:	The RFL 9720 meets the EMI/RFI requirements of IEC 801-3 (1984), BS 6667 Part 3 (1985), and ANSI C.37.90.2 (Trial-Use Standard, 1989).

Temperature:

Operating:	-20°C to +55°C (-4°F to +131°F).
Storage:	-30°C to +70°C (-22°F to +158°F).

Relative Humidity: Up to 95 percent @ +40°C (+104°F), non-condensing.

Input Power Requirements:

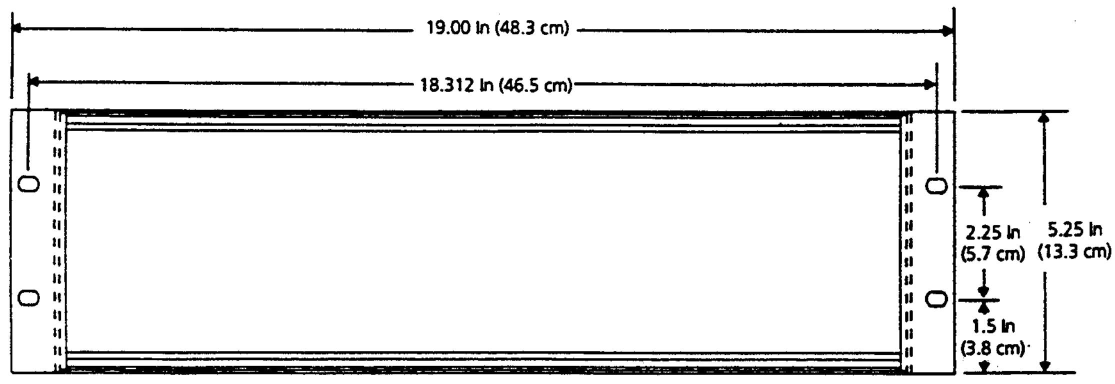
48-Volt Systems:	42 to 58 Vdc, 500 mA nominal. 143 watts peak power consumption (24 watts continuous).
129-Volt Systems:	95 to 150 Vdc, 200 mA nominal. 143 watts peak power consumption (24 watts continuous).

Chassis Dimensions:

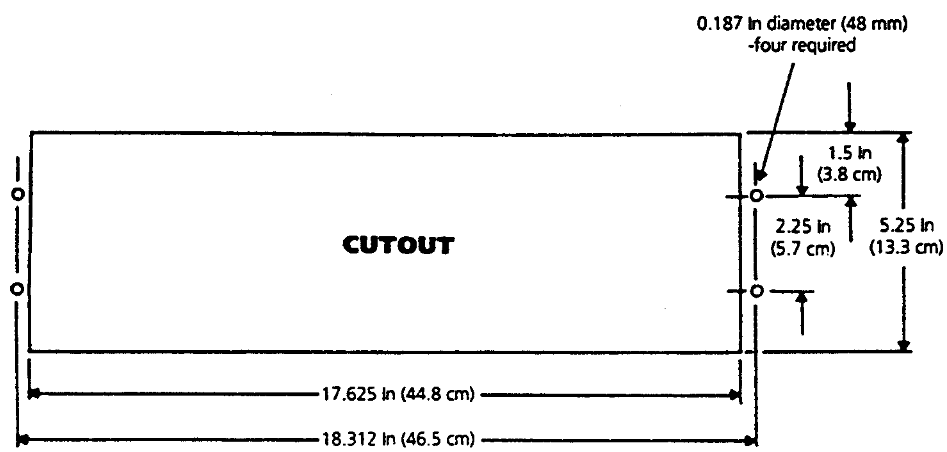
3U Chassis (Fig. 15):	
Height:	5.25 inches (13.4 cm).
Width:	19 inches (48.3 cm).
Depth:	15.18 inches (38.6 cm).
1U Chassis (Fig. 16):	
Height:	1.75 inches (4.45 cm).
Width:	19 inches (48.3 cm).
Depth:	15.18 inches (38.6 cm).
Panel-Mount Chassis (Fig. 17):	
Height:	5.25 inches (13.4 cm).
Width:	6.4 inches (16.25 cm).
Depth:	15.18 inches (38.6 cm).

All chassis dimensions (including mounting hole centers) conform to EIA specifications.

Weight: Approximately 8 lbs (3.6 kg).



a. Rack or cabinet mounting.



b. Panel mounting.

Figure 15. Mounting dimensions, 3U chassis for RFL 9720 Digital Pilot Wire Interface

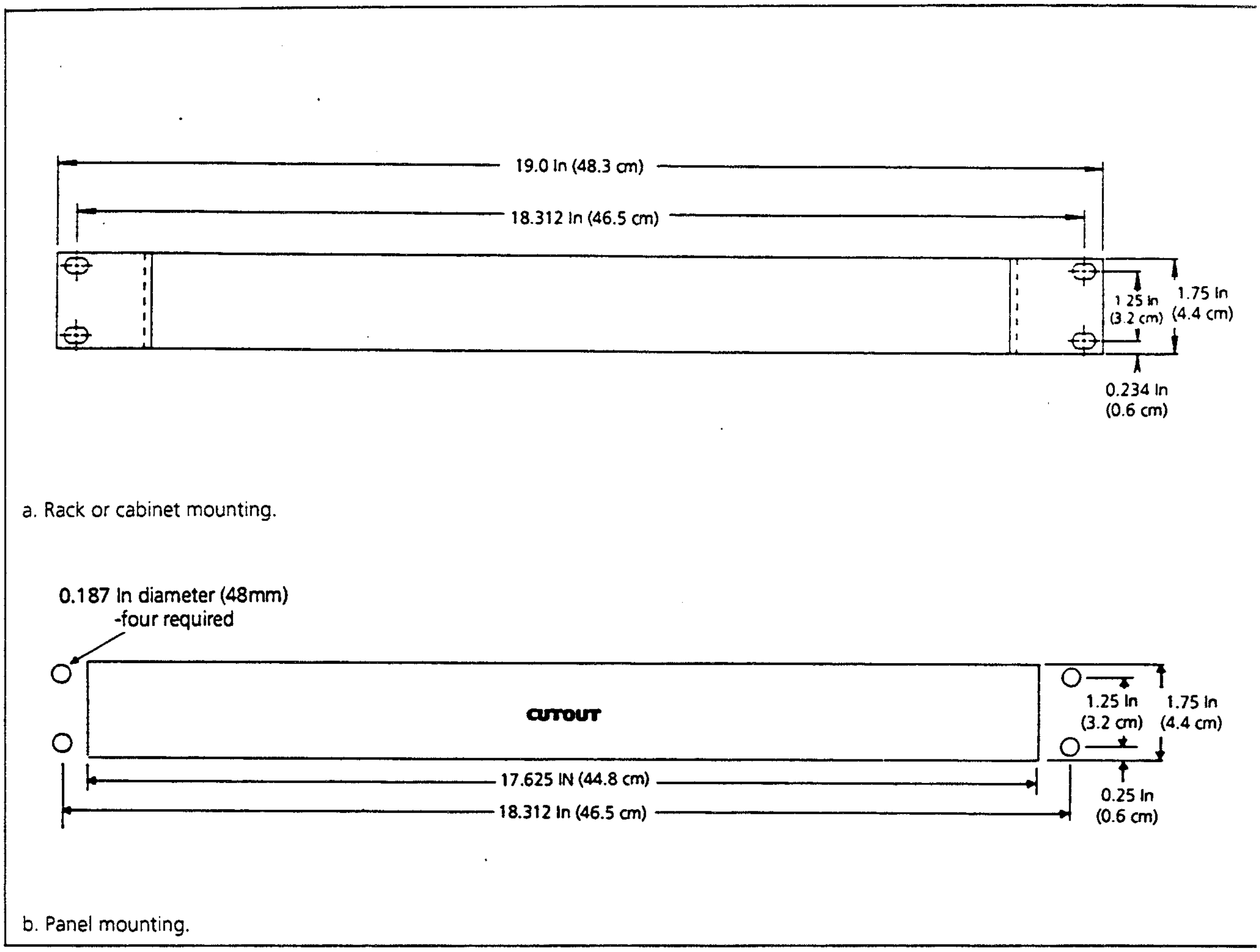


Figure 16. Mounting dimensions, 1U chassis for RFL 9720 Digital Pilot Wire Interface

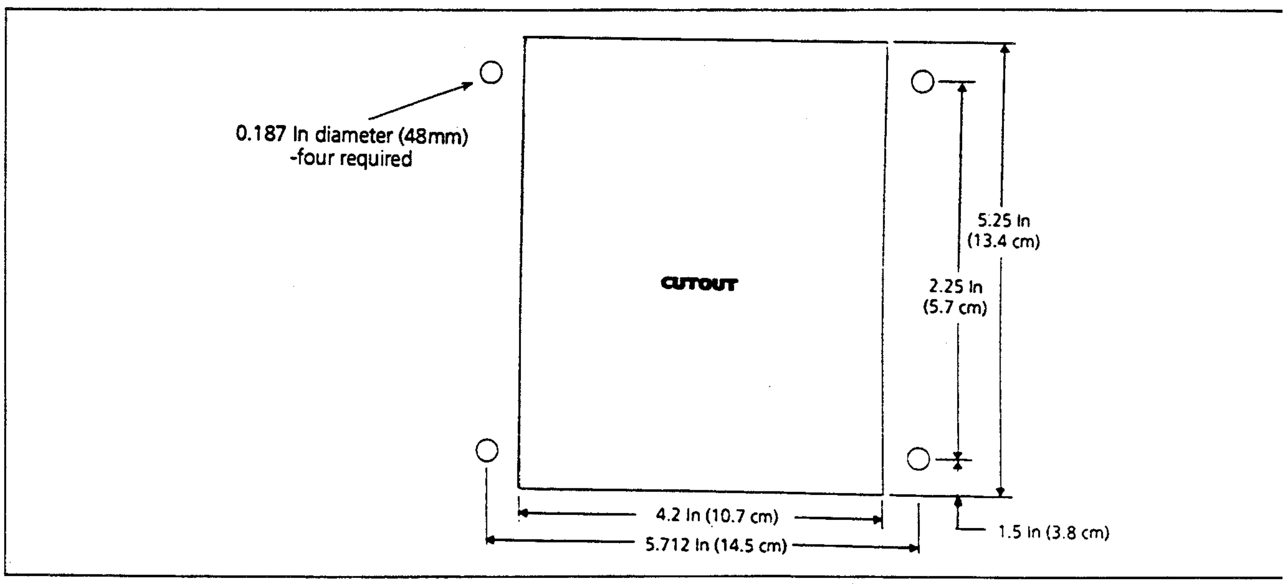


Figure 17. Mounting dimensions, panel-mount chassis for RFL 9720 Digital Pilot Wire Interface

ORDERING INFORMATION

RFL 9720 units are ordered by specifying the chassis style, station battery voltage, and type of relay interface required. These choices are specified by using the following part number scheme.

				Pos. 1	Pos. 2 (1)	Pos. 3 (1)	Pos. 4 (1)
9720	-	3	1	H	0	0	C

Chassis Style:
- 1U Chassis — 1
- 3U Chassis — 3
- Panel-Mount Chassis — P

Station Battery Voltage:
- 48 Vdc (nominal) — 4
- 125 Vdc (nominal) — 1

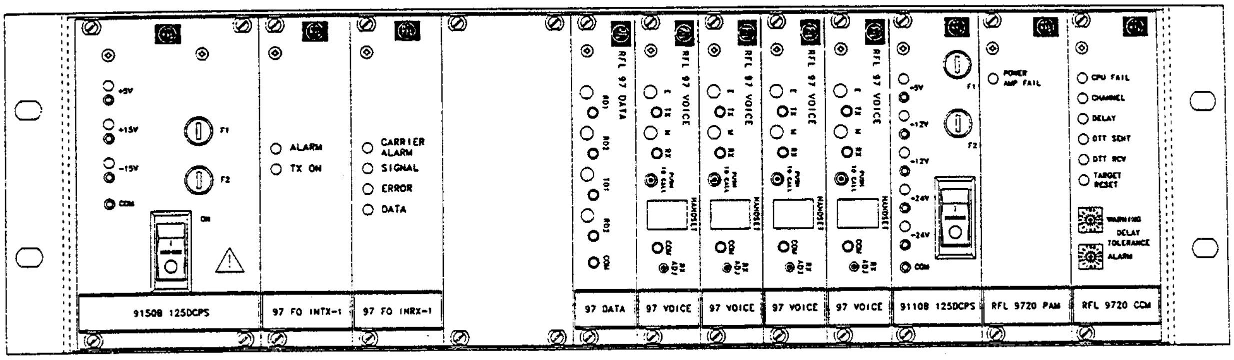
Relay Interface:
- HCB-1 — H
- CPD — C
- HCB — S
- MBCI (2) — M
- Open Position — 0

1. Only available when a 3U chassis is specified. If a 1U or panel-mount chassis is being specified, these portions of the ordering number must be set to zero.
2. Specify MBCI Model 01 or Model 02 when ordering.

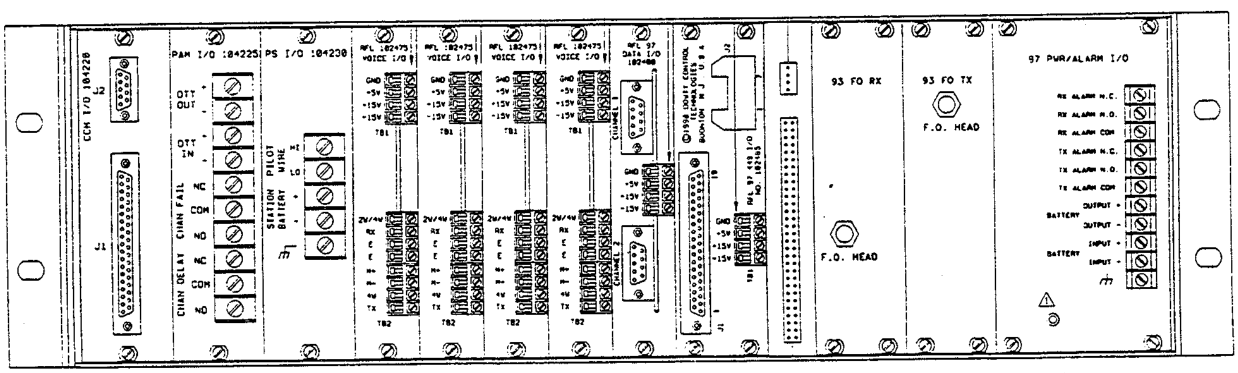
Examples:

3U chassis, 48-Vdc station battery voltage, with four HCB-1 relay interfaces	**9720-3 4 H H H H**
1U chassis, 125-Vdc station battery voltage, with one HCB relay interface	**9720-1 1 S 0 0 0**
Panel-mount chassis, 125-Vdc station battery voltage, with one CPD relay interface	**9720-P 1 C 0 0 0**

RFL 9720 MINI-MUX



a. Front view.



b. Rear view, showing customer connections.

Figure 18. Typical RFL 9720 MINI-MUX

The RFL 9720 MINI-MUX (Fig. 18) allows up to seven additional 56-Kbps ports to be interfaced onto the same fiber as the RFL 9720 signals. These ports can be used for voice, data, or RS-449 interfaces. Up to seven accessory modules can be housed in the same rack-mount chassis as the RFL 9720, and connected to its multiplex fiber optic modules through power and data cables.

RFL 97 VOICE OPTION (P/N 103510)

DESCRIPTION

The RFL 97 VOICE OPTION allows voice signals to be interfaced to the RFL 9720 Digital Pilot Wire Interface. Voice signals are converted to digital data at the sending end, and changed back into voice signals at the receiving end. The RFL 97 VOICE OPTION can be used with data modems operating at baud rates up to 1.2 Kbps. It can be strapped for orderwire, four-wire E&M, or two-wire E&M operation.

The RFL 97 VOICE OPTION includes the following items:

Quan.	Description	Model No.	P/N
1	Voice Module	RFL 97 VOICE	102465
1	I/O Module	RFL 97 VOICE I/O	102475
1	Interconnect Harness	. . .	30374
1	Telephone Handset	. . .	32935

The RFL 97 VOICE Voice Module (Fig. 19) performs all voice-to-data and data-to-voice conversions. It has a modular connector on its front panel to accept a telephone-type handset, and a PUSH TO CALL switch to signal the receiving terminal.

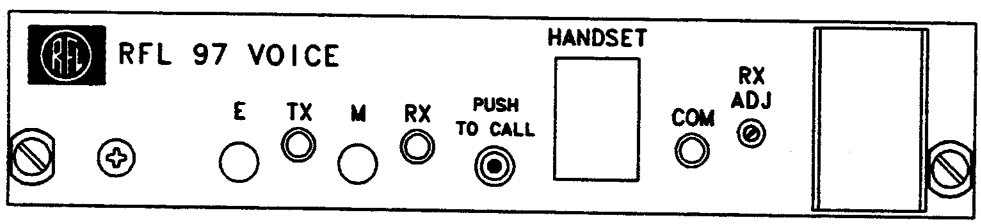


Figure 19. RFL 97 VOICE Voice Module

The RFL 97 VOICE occupies one module space in an RFL 9720 rack-mount chassis. Input power is supplied by the power supply used to power the fiber optics, through a power harness that plugs into a mating connector on the RFL 9720's rear panel. Data connections between the RFL 97 VOICE and the fiber optic modules are made through a ribbon cable that plugs into a mating connector on the RFL 9720's rear panel.

SPECIFICATIONS

Input Levels:

Transmit: -30 dBm to +7 dBm (-16 dBm nominal).

Receive: -19 dBm to +10 dBm (+7 dBm nominal).

Impedance:	600Ω.
Frequency Response:	10 Hz to 3400 Hz.
Echo Return Loss:	28 dB minimum.
Signaling Return Loss:	
HI:	26 dB minimum.
LO:	26 dB minimum.
"M" Input:	42 to 56 Vdc (48 Vdc nominal) @ 17 mA (22 mA maximum).
"E" Relay Contacts:	One set of Form A contacts (SPST), rated for 10 watts maximum (300 Vdc or 1 ampere).
System Interface:	One multiplexed RS-422 channel @ 56 Kbps.
Temperature Range:	
Operating:	-30°C to +65°C (-22°F to +149°F).
Storage:	-40°C to +75°C (-40°F to +167°F).
Relative Humidity:	Up to 95 percent @ +40°C (+104°F).
Power Requirements:	
+5-Volt Input:	115 mA maximum.
+15-Volt Input:	45 mA maximum.
-15-Volt Input:	10 mA maximum.
	All input power is drawn from RFL 9720 chassis.
Dimensions:	23 mm x 12.8 mm x 2.5 mm (0.91 inches x 0.50 inches x 0.10); occupies one module space in an RFL 9720 MINI-MUX chassis.

RFL 97 DATA OPTION (P/N 103505)

DESCRIPTION

The RFL 97 DATA OPTION allows two asynchronous RS-232 inputs to be interfaced to an RFL 9720. At the sending end, the incoming RS-232 data is converted to the synchronous RS-422 signal levels used by the fiber optics. At the receiving end, the RS-422 signals are changed back into RS-232 levels.

The RFL 97 DATA RS-232 Data Module (Fig. 20) performs all conversions between RS-232 and RS-422 signal levels. Front panel indicators provide visual monitoring of module performance, and test jacks are also provided for making connections to the send and receive lines for both RS-232 channels.

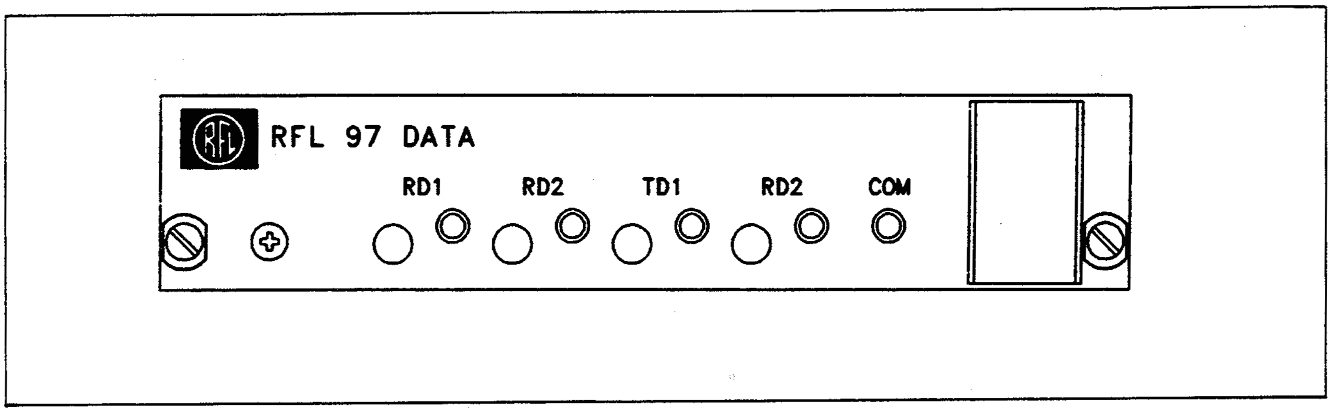


Figure 20. RFL 97 DATA RS-232 Data Module

The RFL 97 DATA OPTION includes the following items:

Quan.	Description	Model No.	P/N
1	Data Module	RFL 97 DATA	102470
1	I/O Module	RFL 97 DATA I/O	102480
1	Interconnect Harness	. . .	30374
2	Connector Adapter	. . .	95573

The RFL 97 DATA occupies one module space in an RFL 9720 rack-mount chassis. Input power is supplied by the power supply used to power the fiber optics, through a power harness that plugs into a mating connector on the RFL 9720's rear panel. Data connections between the RFL 97 DATA and the fiber optic modules are made through a ribbon cable that plugs into a mating connector on the RFL 9720's rear panel.

SPECIFICATIONS

Data Interface:	Two asynchronous full-duplex channels; RS-232C send/receive levels without handshaking.
Jitter:	
Up to 2400 Baud:	1.5 percent maximum.
Up to 4800 Baud:	6.0 percent maximum.
Up to 9600 Baud:	16.7 percent maximum.
System Interface:	Two multiplexed channels.
Temperature Range:	
Operating:	-30°C to +65°C (-22°F to +149°F).
Storage:	-40°C to +75°C (-40°F to +167°F).
Relative Humidity:	Up to 95 percent @ +40°C (+104°F).
Power Requirements:	
+5-Volt Input:	130 mA maximum.
+15-Volt Input:	5 mA maximum.
-15-Volt Input:	5 mA maximum.
	All input power is drawn from RFL 9720 chassis.
Dimensions:	23 mm x 12.8 mm x 2.5 mm (0.91 inches x 0.50 inches x 0.10); occupies one module space in an RFL 9720 MINI-MUX chassis.

RS-449 INTERFACE OPTION (P/N 103515)

The RFL 97 449 OPT converts the ribbon cable connector on multiplex versions of the RFL 9720 to an RS-449 connector. Signal levels meet the requirements of EIA Standard RS-422, and operate as a 56-Kbps synchronous data port.

Specifications subject to change without notice.

ADDITIONAL INFORMATION

For more information about the RFL 9720 Digital Pilot Wire Interface or any of the protective relaying products listed below, please contact the factory or any RFL Sales Representative.

- **RFL 6710 Frequency-Shift Audio Tone Protective Relaying System (single-channel)**
- **RFL 6745 Frequency-Shift Audio Tone Protective Relaying System (dual-subchannel)**
- **RFL 6750 Integrated Transfer Trip System (ITTS)**
- **RFL 9001 Intelligent T1/E1 Multiplexer**
- **RFL 9300 Charge Comparison System (CCS)**
- **RFL 9660 Digital Switch**
- **RFL 9700 Digital Protection Channel**
- **RFL 6720P Checkback System**
- **RFL 6780P Programmable FSK Powerline Carrier System**
- **RFL 6785P Programmable ON/OFF Powerline Carrier System**

Section 2. INSTALLATION

WARNING

THE RFL 9720 PM I/O MODULE IS EQUIPPED WITH A PROTECTIVE COVER THAT EXTENDS ACROSS ITS TERMINAL BLOCK. THIS COVER IS INTENDED TO PROTECT THE OPERATOR FROM POTENTIALLY HAZARDOUS VOLTAGES, WHICH MAY BE PRESENT ON THE TERMINALS. THIS COVER MUST ONLY BE REMOVED BY QUALIFIED SERVICE PERSONNEL WHEN ACCESS TO THE TERMINAL BLOCK IS REQUIRED. IT MUST BE REPLACED BEFORE PLACING THE RFL 9720 IN SERVICE.

CAUTION

1. **Make sure the power switch on the Power Module is in the OFF (down) position before making connections to the RFL 9720. Damage to the RFL 9720 or to external equipment may result if connections are made while the Power Module is on.**

2. **The RFL 9720 should not be powered up (and communications established with another RFL 9720) unless a relay or dummy load is connected to its PILOT WIRE terminals (TB1-1 and TB1-2 on the RFL 9720 PM I/O module). Damage to the RFL 9720 PAM Power Amplifier Module can result if the PILOT WIRE terminals are unterminated. A 500 ohm 1/4 watt resistor will serve as a suitable dummy load, but cannot be used to verify operation. Proper operation of the RFL 9720 can only be verified with a relay connected to its PILOT WIRE terminals. Remove the load resistor when the PILOT WIRE is connected.**

3. **All RS-232 and RS-449 cables must be terminated in metal-shell connectors. The shell of each connector must be connected to the cable shield.**

4. **During normal system operation, the switching of relay contacts can produce voltage spikes. These spikes can travel down the relay output leads and induce currents in other leads. These induced currents can result in misoperation. To reduce this possibility, use a shielded twisted pair for each input lead. The shields must be grounded at the RFL 9720 chassis only. As an added precaution, keep input, output, and power leads as far apart as possible. Do not bundle input, output, and power leads into the same harness.**

2.1. INTRODUCTION

This section contains installation instructions for the RFL 9720, including unpacking, mounting, and interconnection wiring.

2.2. UNPACKING

Each RFL 9720 terminal is packed in its own shipping carton:

1. Open each carton carefully to make sure the equipment is not damaged.
2. Remove the chassis from the carton.
3. Carefully examine all packing material. Make sure no items of value were overlooked, such as manuals, cables, and warranty cards.
4. Temporarily save all packing materials. You may need it if the RFL 9720 has to be returned or shipped to another location.

If you find that the RFL 9720 was damaged in transit once you have it out of the carton, immediately notify our Customer Service Department at the phone number listed on the cover of this manual.

2.3. MOUNTING

Each RFL 9720 chassis has two mounting ears, one on each side. The hole sizes and spacings for the 3U and 1U chassis conform with EIA standards. This allows these chassis to be mounted in any standard 19-inch rack or cabinet. The panel-mount chassis can be installed in the panel space vacated by one of the relays the RFL 9720 is replacing. Complete chassis dimensions are given in Figures 2-1 through 2-3.

2.4. VENTILATION

The specified operating temperature range for RFL 9720 equipment is -20°C to +55°C (-4°F to +131°F). Operation at higher temperatures may affect system reliability and performance. Units installed in enclosed cabinets should be ventilated to keep the temperature inside the cabinet within limits.

2.5. CONNECTIONS

Electrical connections are made to the RFL 9720 through the three I/O modules, shown in Figure 2-4. Paragraphs 2.5.1 through 2.5.3 describe all the connections that must be made; A typical wiring diagram for a two-terminal RFL 9720 appears in Figure 2-5 on page 2-5 of this section. Refer to the "as supplied" drawings furnished with your equipment for more detailed descriptions of the connections that must be made to your system.

2.5.1. Making Connections To Terminal Blocks

The terminal blocks on the RFL 9720 I/O modules are conventional screw-type barrier blocks with 6-32 screws. Wires can either be stripped or terminated in spade or ring lugs, depending on local practice.

To connect wires to the PM I/O module's terminal block, you will have to remove the protective cover from the terminal block by pulling it out of the standoffs holding it in place. After all connections have been made to the terminal block, reinstall the protective cover by lining up its mounting holes with the standoffs on the rear of the PM I/O module. Once they are lined up, push down on the protective cover to secure it in place.

2.5.2. RFL 9720 CCM I/O Input/Output Module

There are two connectors on the RFL 9720 CCM I/O module: RS-449 connector J1 and RS-232 connector J2.

a. RS-449 Connections. J1 is a 37-pin DC-37 connector. It provides an RS-449 DTE interface for the pilot wire communications. Connector pin assignments are as follows:

Pin No.	RS-422 Signal
J1-6	RD (A)
J1-24	RD (B)
J1-8	RT (A)
J1-26	RT (B)
J1-4	SD (A)
J1-22	SD (B)
J1-5	ST (A)
J1-23	ST (B)
J1-1	Chassis Ground
J1-19	Signal Ground
All Other Pins	Not used.

Make sure the mating connector you are using has a metal shell. The shell must be connected to the cable shield. In order to meet the requirements of RS-449, the cable cannot be longer than 4000 ft (1.220 km).

b. RS-232 Connections. J2 is a nine-pin DE-9 connector. It provides an RS-232 DTE interface for auxiliary communication with the RFL 9720. The RS-232 commands must be preceded by "9720" for them to be accepted. Any data applied to this port will be echoed back to its source. Connector pin assignments are as follows:

Pin No.	RS-232 Signal
J2-2	Rx
J2-3	Tx
J2-4	DTR
J2-5	Signal Ground
J2-7	RTS
J2-8	CTS
All Other Pins	Not used.

Make sure the mating connector you are using has a metal shell. The shell must be connected to the cable shield.

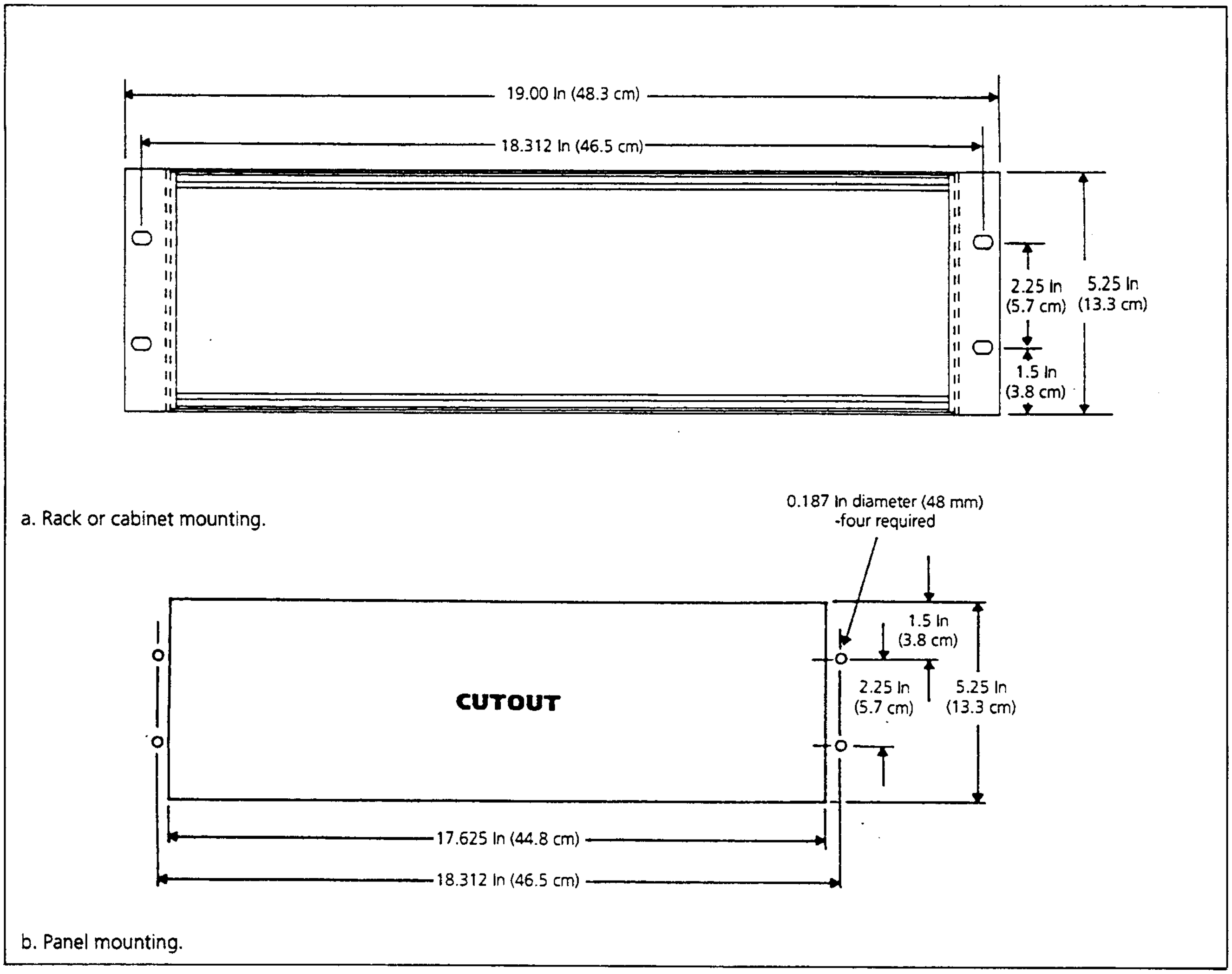


Figure 2-1. Mounting dimensions, 3U chassis for RFL 9720 Digital Pilot Wire Interface

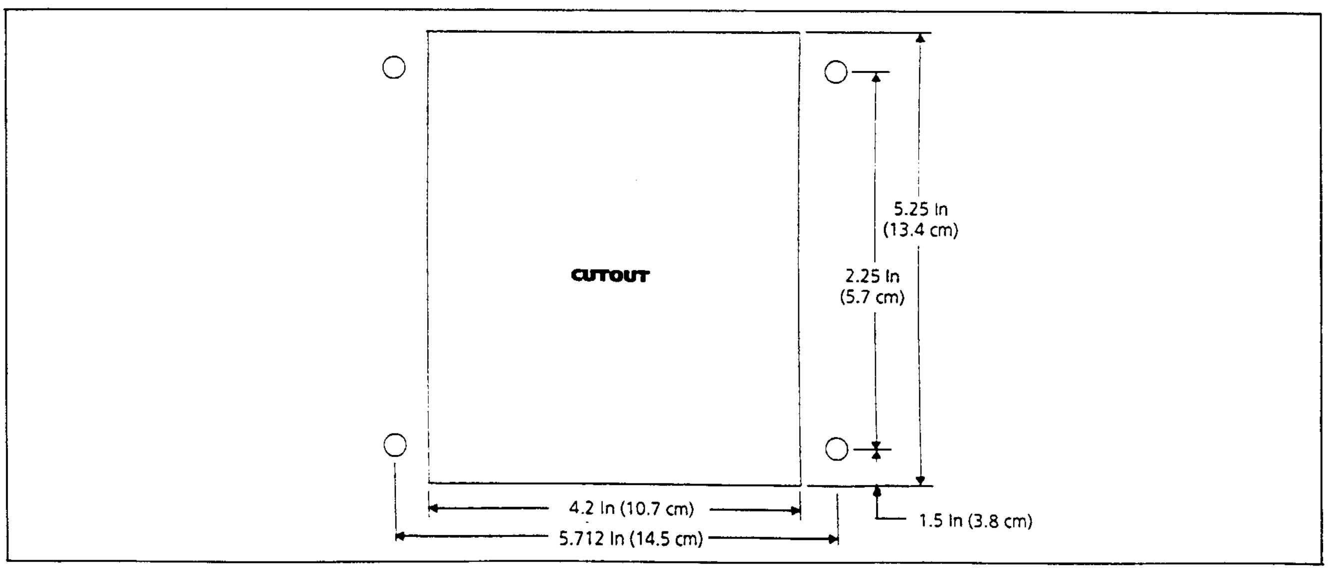


Figure 2-2. Mounting dimensions, panel-mount chassis for RFL 9720 Digital Pilot Wire Interface

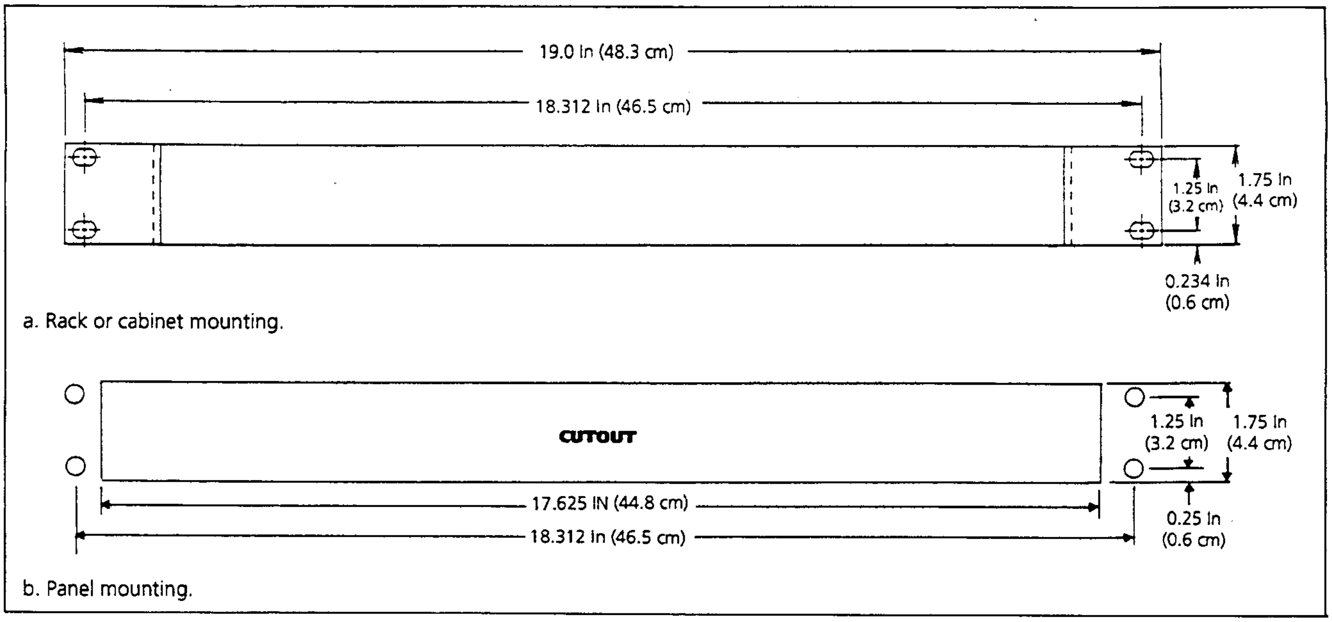


Figure 2-3. Mounting dimensions, 1U chassis for RFL 9720 Digital Pilot Wire Interface

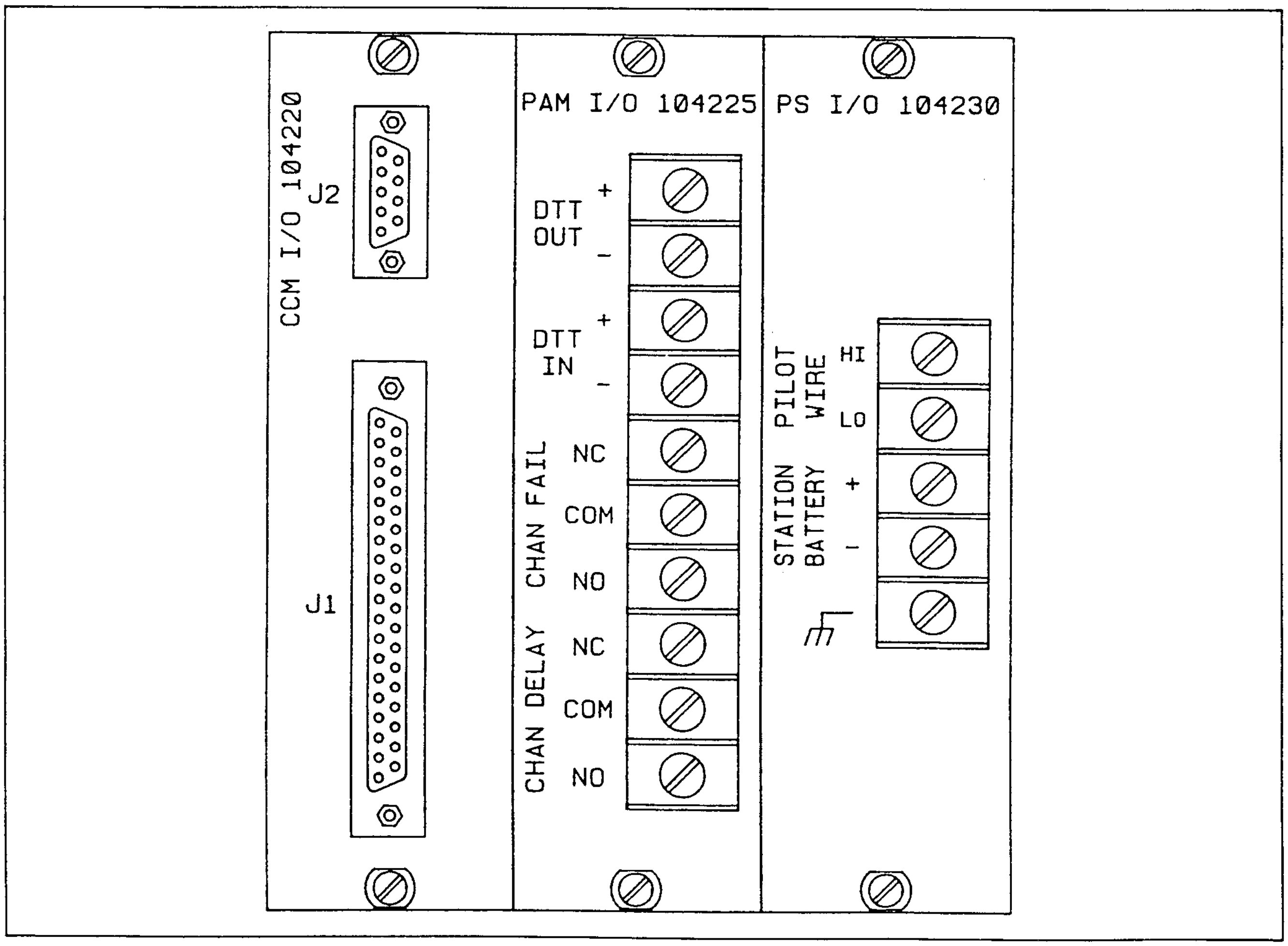


Figure 2-4. RFL 9720 I/O module rear panel connections

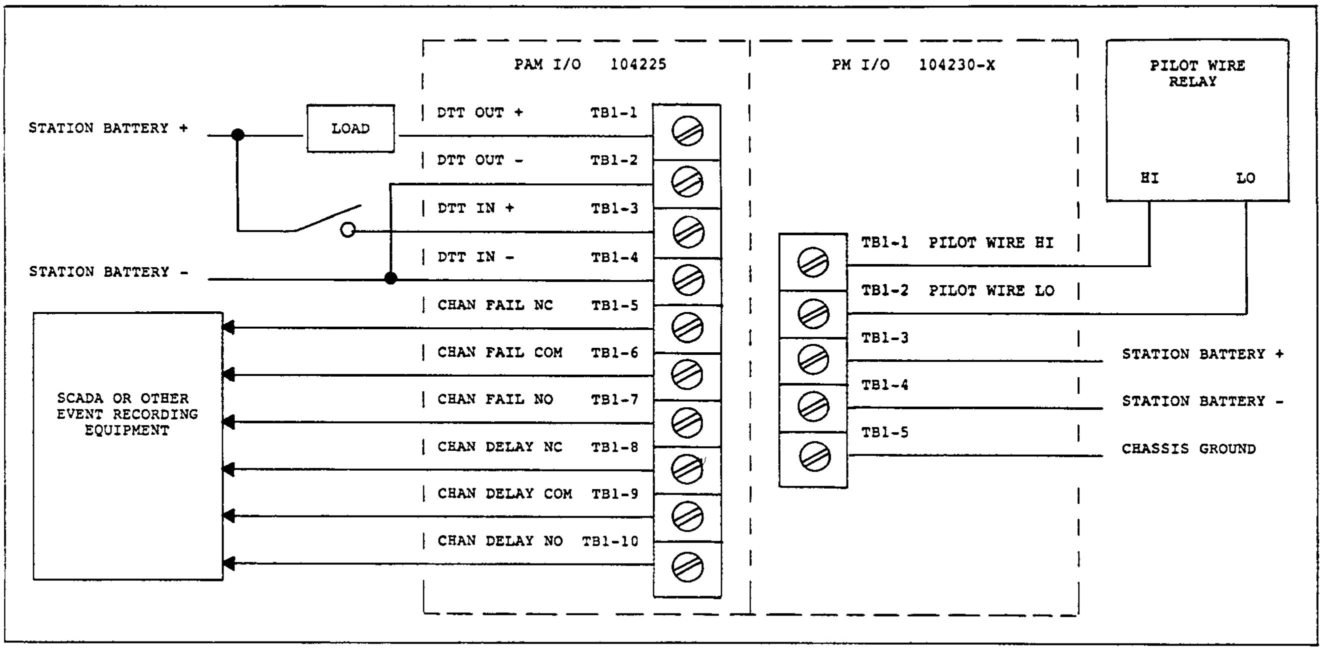


Figure 2-5. Typical two-terminal wiring diagram, RFL 9720 Pilot Wire Interface

c. Connections To RFL 9700. J3 is an eight-pin ribbon cable connector located on the RFL 9720 CCM I/O modules' main board. It provides a direct RS-422 DTE interface to an RFL 9700 Digital Protection Channel. Connector pin assignments are as follows:

Pin No.	RS-422 Signal
J3-1	SD (B)
J3-2	SD (A)
J3-3	ST (A)
J3-4	ST (B)
J3-5	RD (B)
J3-6	RD (A)
J3-7	RT (A)
J3-8	RT (B)

2.5.3. RFL 9720 PAM I/O Input/Output Module

Connections to the RFL 9720 PAM I/O module are made through ten-position terminal block TB1 on the rear panel. Terminal assignments are as follows:

Terminal No.	Function
TB1-1	DTT OUTPUT +
TB1-2	DTT OUTPUT -
TB1-3	DTT INPUT +
TB1-4	DTT INPUT -
TB1-5	CHAN FAIL RELAY NC
TB1-6	CHAN FAIL RELAY COM
TB1-7	CHAN FAIL RELAY NO
TB1-8	CHAN DELAY RELAY NC
TB1-9	CHAN DELAY RELAY COM
TB1-10	CHAN DELAY RELAY NO

2.5.4. RFL 9720 PM I/O Module

The RFL 9720 PM I/O module contains a single terminal block, TB1. This block connects the RFL 9720 to the relay pilot wire terminals and the station battery. Terminal assignments for this block are as follows:

Terminal No.	Function
TB1-1	PILOT WIRE HI
TB1-2	PILOT WIRE LO
TB1-3	STATION BATTERY +
TB1-4	STATION BATTERY -
TB1-5	CHASSIS GROUND

If a GEC MBCI-01 relay is being connected to the RFL 9720, a voltage suppressor must be installed across terminals 18 and 19 on the relay. This suppressor will be supplied with the RFL 9720.

Section 3. OPERATING INSTRUCTIONS

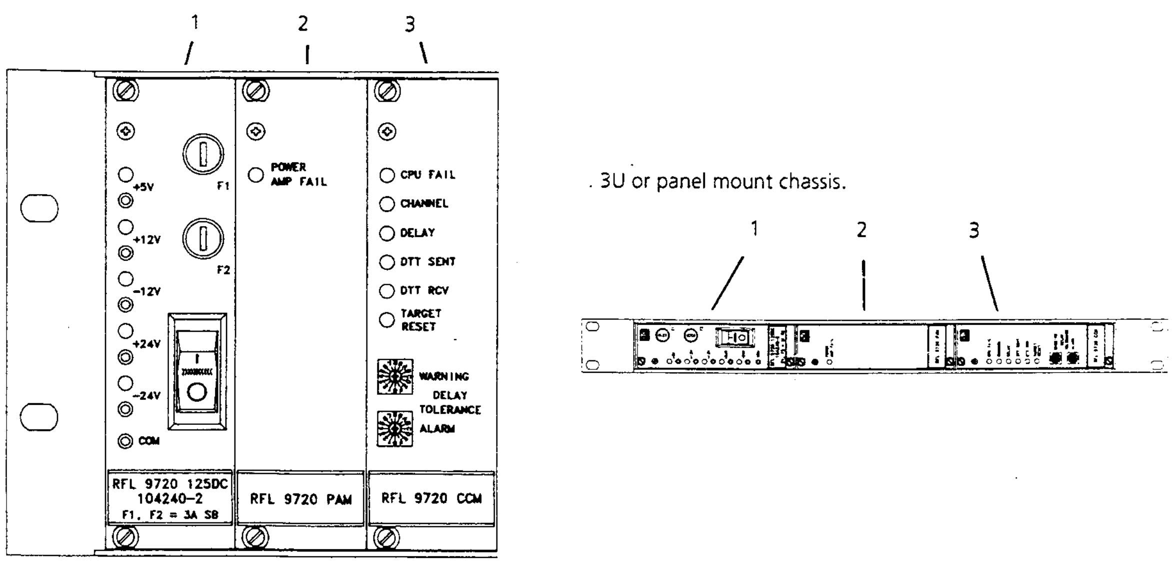
3.1. INTRODUCTION

This section contains the instructions necessary for operating the RFL 9720. All controls and indicators are shown and described. The jumper and switch settings are also described, and a procedure is included for verifying operation before placing the RFL 9720 into continuous service. General information on RFL 9720 system operation is also included.

3.2. CONTROLS AND INDICATORS

The front panels of the circuit card modules in each RFL 9720 contain controls and indicators that are used to prepare it for use, monitor system functions during normal operation, initiate checkback tests, and reset alarms. Figure 3-1 shows the module locations in two typical RFL 9720 terminals. Table 3-1 lists the figures and tables in this section that describe the controls and indicators on each module.

>>> Text continued on page 3-8 <<<



a. 3U or panel mount chassis.

b. 1U chassis.

Figure 3-1. Circuit board module locations in typical RFL 9720 terminals

Table 3-1. Circuit board modules in typical RFL 9720 station

Item	Description	Control And Indicator Information	Page
1	RFL 9720 PM Power Module	Figure 3-2/Table 3-2	3-2
	RFL 9720 PM I/O Power Module Input/Output Module	Figure 3-3/Table 3-3	3-3
2	RFL 9720 PAM Power Amplifier Module	Figure 3-4/Table 3-4	3-4
	RFL 9720 PAM I/O Power Amplifier Module Input/Output Module	No controls or indicators	. . .
3	RFL 9720 CCM Communications And Control Module (main board)	Figure 3-5/Table 3-5	3-5
	RFL 9720 CCM Communications And Control Module (piggyback board)	Figure 3-6/Table 3-6	3-6
	RFL 9720 CCM I/O Communications And Control Module Input/Output Module	No controls or indicators	. . .
. . .	RFL 9720 2TMB Two-Terminal Motherboard For 3U Or Panel-Mount Chassis	Figure 3-7/Table 3-7	3-7
	RFL 9720 1UMB Two-Terminal Motherboard For 1U Chassis	Figure 3-8/Table 3-8	3-8

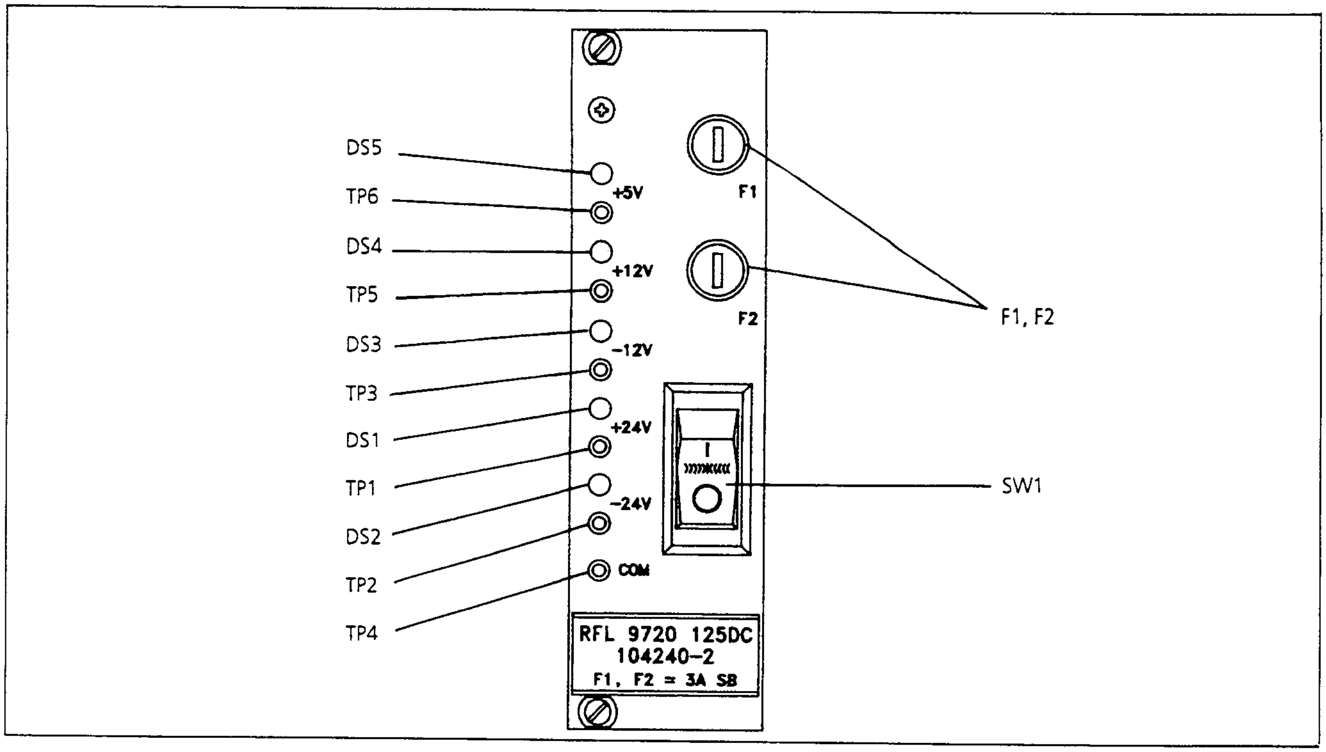
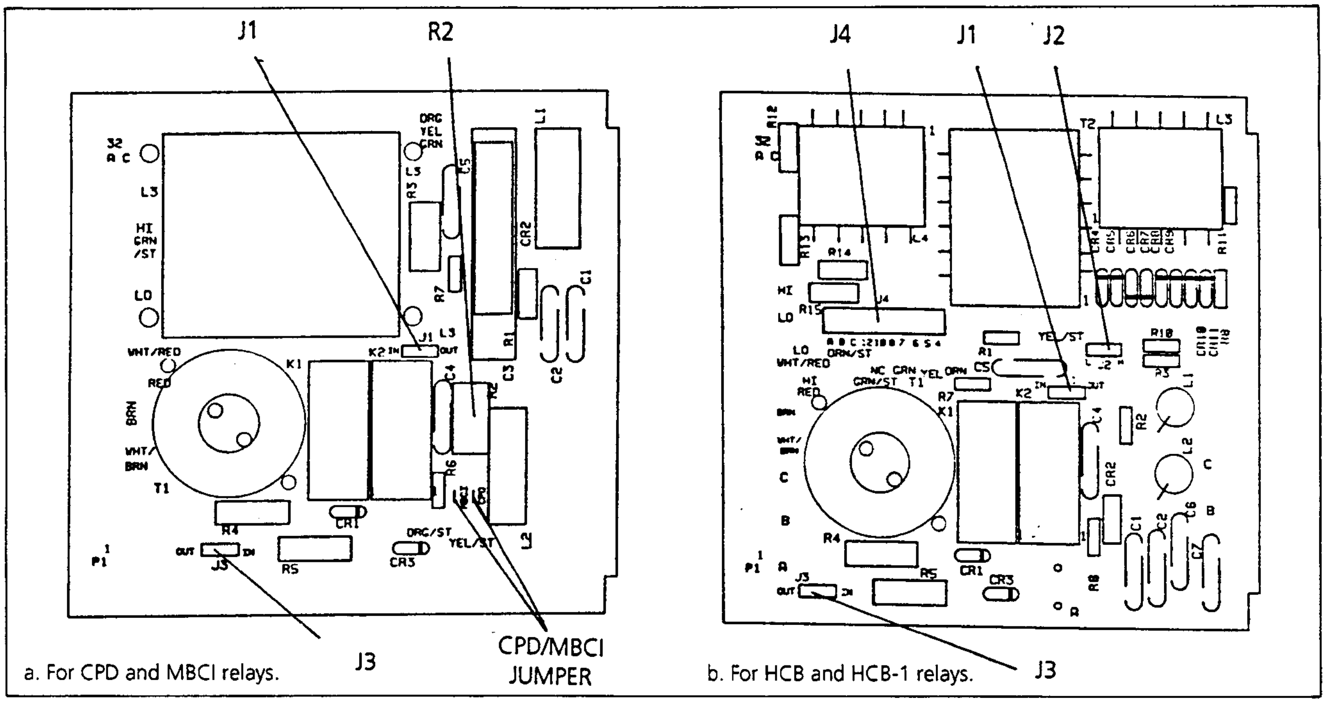


Figure 3-2. Controls and indicators, RFL 9720 PM Power Module

Table 3-2. Controls and indicators, RFL 9720 PM Power Module

Symbol	Name/Description	Function
DS1	+24V indicator	Lights when +24-volt supply is functioning properly.
DS2	-24V indicator	Lights when -24-volt supply is functioning properly.
DS3	-12V indicator	Lights when -12-volt supply is functioning properly.
DS4	+12V indicator	Lights when +12-volt supply is functioning properly.
DS5	+5V indicator	Lights when +5-volt supply is functioning properly.
F1, F2	Fuses	Provide input current protection.
SW1	Power switch	Serves as main power switch for RFL 9720.
TP1	Test point, +24V	Monitoring point for +24-volt output.
TP2	Test point, -24V	Monitoring point for -24-volt output.
TP3	Test point, -12V	Monitoring point for -12-volt output.
TP4	Test point, COM	Ground point.
TP5	Test point, +12V	Monitoring point for +12-volt output.
TP6	Test point, +5V	Monitoring point for +5-volt output.



a. For CPD and MBCI relays.

b. For HCB and HCB-1 relays.

Figure 3-3. Controls and indicators, RFL 9720 PM I/O Input/Output Module

Table 3-3. Controls and indicators, RFL 9720 PM I/O Input/Output Module

Symbol	Name/Description	Function
J1	Mode selection jumper	Determines whether the RFL 9720 will short or open the pilot wire input to the relay when squelch relay K1 is de-energized. (See para 3.3.1a.)
J2	Restraint tap selection jumper (HCB and HCB-1 relays only)	Set according to the relay restraint tap setting. (See paragraphs 3.3.1c and 3.3.1d.)
J3	Unblocking relay control jumper	Enables or disables unblocking relay K2. (See para 3.3.1a.)
J4	Tap block setting selection jumper (HCB and HCB-1 relays only)	Set according to the relay tap block settings (See paragraphs 3.3.1c and 3.3.1d.)
R2	Relay type selection jumper	Installed at the factory when CPD relay is used; replaced by 500Ω resistor for MBCI relays. (See para 3.3.1b.)
. . .	CPD/MBCI jumper	Installed at the factory for type of relay being used. (See para 3.3.1b.)

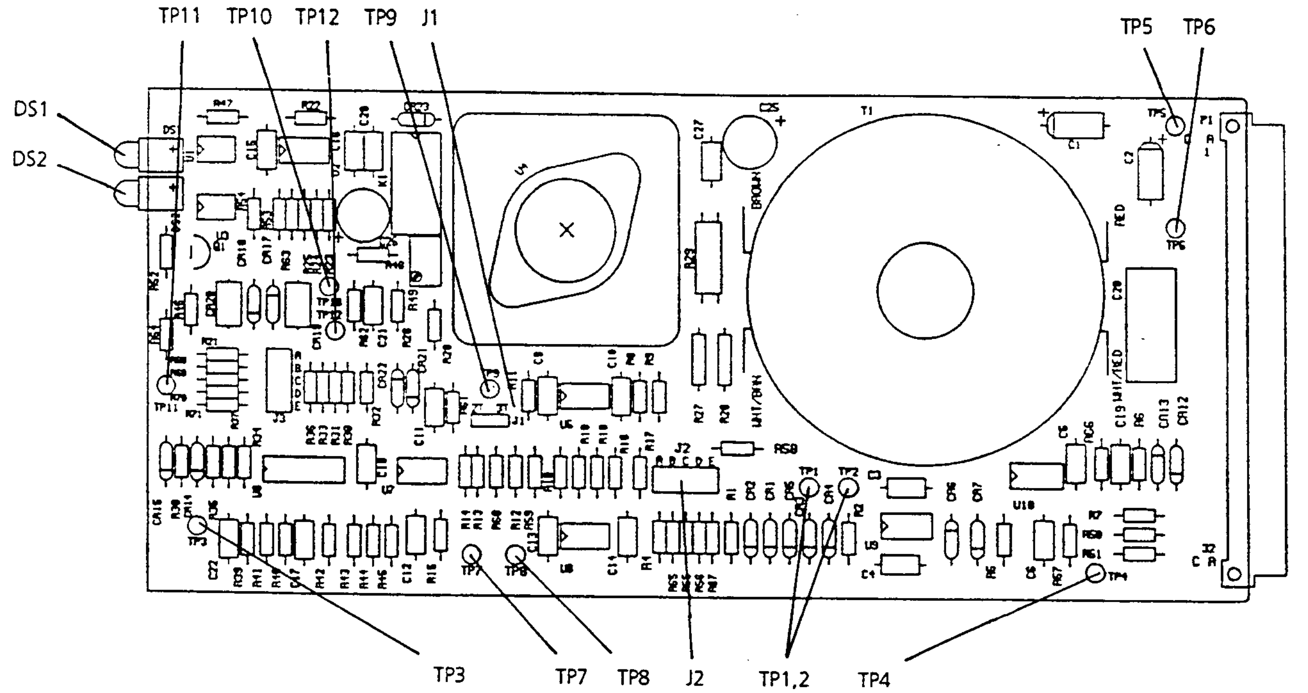


Figure 3-4. Controls and indicators, RFL 9720 PAM Power Amplifier Module

Table 3-4. Controls and indicators, RFL 9720 PAM Power Amplifier Module

Symbol	Name/Description	Function
DS1	POWER AMP FAIL indicator (red)	Lights if a PAM failure is detected.
DS2	SQUELCH indicator	Lights if a squelch command has been sent to the RFL 9720 PM I/O Module.
J1	Terminal configuration jumper	Should always be set to two terminal operation (2T) (See para 3.3.2a.)
J2, J3	Pilot wire relay type jumper	Set at the factory according to the pilot wire relay being interfaced to the RFL 9720. (See para 3.3.2b.)
TP1,2	Test turrets	Measuring points for analog input to RFL 9720 CCM; voltage is proportional to current from the pilot wire terminals of the pilot wire relay. Voltage ranges from zero to 3 Vrms.
TP3	Test turret	Measuring point for output of low-pass filter in precision rectifier section.
TP4	Test turret	Measuring point for output of active transformer sense amplifier.
TP5	Test turret	Power amplifier section analog ground.
TP6	Test turret	Power amplifier section power return. Used as a reference for all signal measurements in the power amplifier section.
TP7	Test turret	Measuring point for output of power amplifier section buffer amplifier.
TP8	Test turret	Measuring point for output of power amplifier section buffer amplifier.
TP9	Test turret	Measuring point for output of power amplifier section summing amplifier.
TP10	Test turret	Measuring point for output of power amplifier section feedback current sense amplifier.
TP11	Test turret	Measuring point for output of power amplifier section PAM fail comparator.
TP12	Test turret	Measuring point for output of power amplifier section high-power voltage-to-current converter (power amplifier).

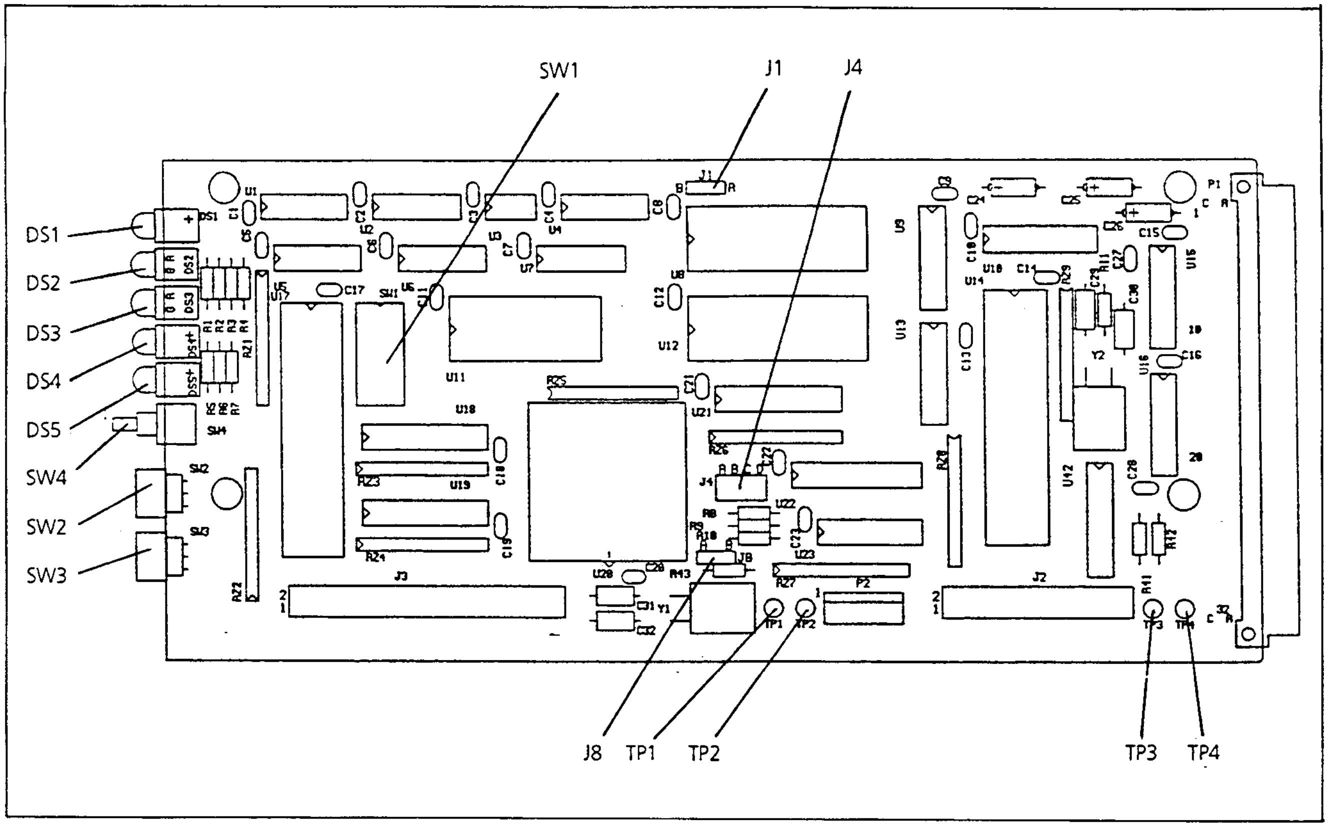


Figure 3-5. Controls and indicators, RFL 9720 CCM Communications And Control Module main circuit board

Table 3-5. Controls and indicators, RFL 9720 CCM Communications And Control Module main circuit board

Symbol	Name/Description	Function
DS1	CPU FAIL indicator (red)	Lights if the microcontroller fails.
DS2	CHANNEL indicator (red/green)	Lights green when good channel data is being received; changes to red if a channel failure has occurred because of CRC failure, frame failure, PAM failure, or excessive delay.
DS3	DELAY indicator (red/yellow/green)	Lights green if channel delay is not excessive. Changes to yellow if the delay time reaches a predetermined warning limit. Turns red if a channel failure has occurred because of excessive delay.
DS4	DTT SENT indicator (red)	Lights when a DTT command has been sent to the remote terminal.
DS5	DTT RCV indicator (red)	Lights when a DTT command has been received from the remote terminal.
J1	EPROM selection jumper	Set at the factory according to the EPROM device type being used. (See para 3.3.3a.)
J4	Command Extend jumper	Sets the desired Command Extend time. (See para 3.3.3b.)
J8	Jumper	Reserved for future enhancement. (See para 3.3.3d.)
SW1	DIP switch	Sets the RS-232 port configuration. (See para 3.3.3e.)
SW2	WARNING switch	Sets the delay time allowed before DELAY indicator DS3 changes from green to yellow. (See para 3.3.3f.)
SW3	ALARM switch	Sets the delay time allowed before DELAY indicator DS3 changes from yellow to red. (See para 3.3.3g.)
SW4	TARGET RESET switch	Resets all latched indicators.
TP1	Test turret	Ground point.
TP2	Test turret	Monitoring point for +5-volt supply rail.
TP3	Test turret	Monitoring point for +12-volt supply rail.
TP4	Test turret	Monitoring point for -12-volt supply rail.

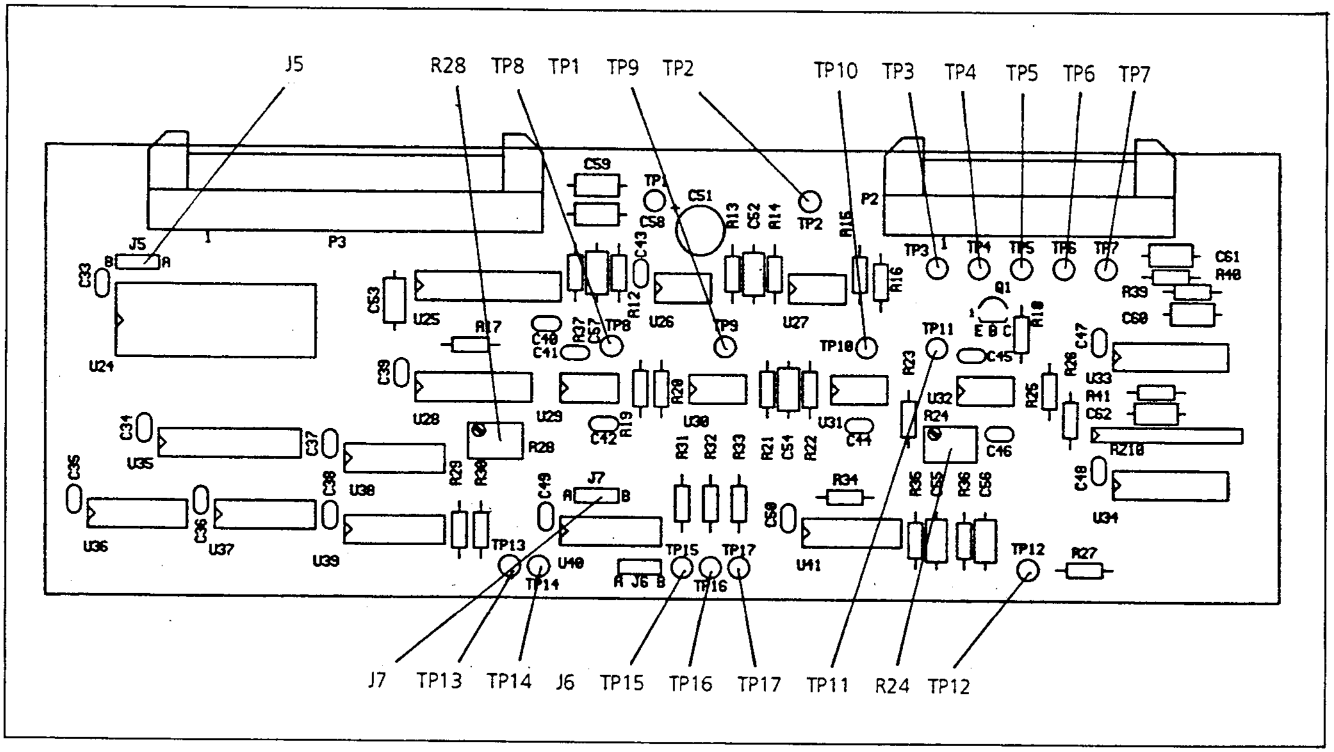


Figure 3-6. Controls and indicators, RFL 9720 CCM Communications And Control Module piggyback circuit board

Table 3-6. Controls and indicators, RFL 9720 CCM Communications And Control Module piggyback circuit board

Symbol	Name/Description	Function
J5	EPROM selection jumper	Set at the factory according to the EPROM device type being used. (See para 3.3.3a.)
J6	Receive Clock polarity jumper	Set for proper receive clock polarity, with respect to incoming data. (See para 3.3.3c.)
J7	Transmit Clock polarity jumper	Set for proper transmit clock polarity, with respect to outgoing data. (See para 3.3.3d.)
R24	Potentiometer	Zero adjustment for A/D converter.
R28	Potentiometer	Zero adjustment for D/A converter.
TP1	Test turret, A/D IN	Monitoring point for signal being applied to A/D converter input.
TP2	Test turret, VIN	Monitoring point for VIN (voltage input) signal.
TP3	Test turret, AGND	Analog ground reference point.
TP4	Test turret, -12V	Monitoring point for -12-volt supply rail.
TP5	Test turret, +12V	Monitoring point for +12-volt supply rail.
TP6	Test turret, GND	Ground point.
TP7	Test turret, +5V	Monitoring point for +5-volt supply rail.
TP8	Test turret, D/A OUT	Monitoring point for D/A converter output signal.
TP9	Test turret, V OUT	Monitoring point for current-to-voltage converter output signal.
TP10	Test turret, VREF	Monitoring point for D/A converter reference voltage.
TP11	Test turret, VCC 5.2V	Monitoring point for A/D converter reference voltage.
TP12	Test turret, TXDATA	Monitoring point for TXDATA signal.
TP13	Test turret, RXINTAPT	Monitoring point for RXINTAPT signal.
TP14	Test turret, TXINTAPT	Monitoring point for TXINTAPT signal.
TP15	Test turret, TXCLK	Monitoring point for TXCLK signal.
TP16	Test turret, RXDATA	Monitoring point for RXDATA signal.
TP17	Test turret, RXCLK	Monitoring point for RXCLK signal.

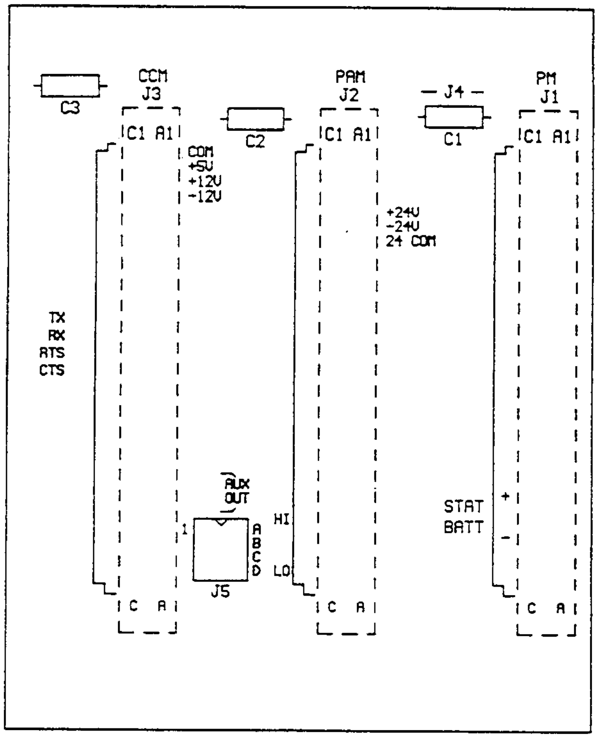


Figure 3-7. Controls and indicators, RFL 9720 2TMB Two-Terminal Motherboard for 3U or panel-mount chassis

Table 3-7. Controls and indicators, RFL 9720 2TMB Two-Terminal Motherboard for 3U or panel-mount chassis

Symbol	Name/Description	Function
J4	Ground jumper	Connects chassis ground to signal ground; removed for floating signal ground. (See para 3.3.4a.)
J5	Function selection jumper	Sets software functions: J5-A Determines whether the CHANNEL FAIL and CHANNEL DELAY indicators on the RFL 9720 CCM will latch in their worst-case condition. J5-B Feedback signal polarity. J5-C Reserved for future enhancement. For more information, see paragraph 3.3.4b.

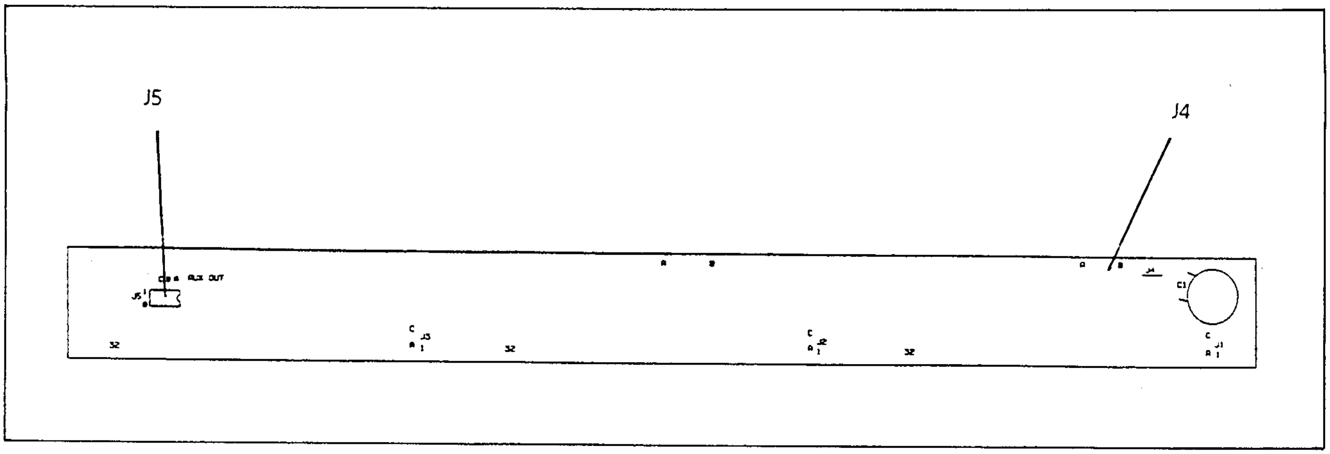


Figure 3-8. Controls and indicators, RFL 9720 1UMB Two-Terminal Motherboard for 1U chassis

Table 3-8. Controls and indicators, RFL 9720 1UMB Two-Terminal Motherboard for 1U chassis

Symbol	Name/Description	Function
J4	Ground jumper	Connects chassis ground to signal ground; removed for floating signal ground. (See para 3.3.4a.)
J5	Function selection jumper	Sets software functions: J5-A Determines whether the CHANNEL FAIL and CHANNEL DELAY indicators on the RFL 9720 CCM will latch in their worst-case condition. J5-B Feedback signal polarity. J5-C Reserved for future enhancement. For more information, see paragraph 3.3.4b.

>>> Text continued from page 3-1 <<<

3.3. JUMPER AND SWITCH SETTINGS

Some RFL 9720 circuit card modules are equipped with programmable jumpers and switches. Circuit card modules supplied as part of a system have their jumpers and switches set at the factory, according to the EPROM devices installed in the modules, system configuration, and the requirements of the specific application. Under normal circumstances, jumpers and switches should only have to be reset in the field if a replacement module is being installed or a change in system configuration is desired. Paragraphs 3.3.1 through 3.3.4 describe the jumper and switch settings that must be made before placing the RFL 9720 in service.

3.3.1. RFL 9720 PM I/O Input/Output Module

There are three different RFL 9720 PM I/O input/output modules available, one for each type of pilot wire relay that can be interfaced to the RFL 9720. On RFL 104230-1 modules (for CPD relays) and RFL 104230-2 modules (for MBCI relays), there are four jumpers: J1, J3, one labeled "CPD," and one labeled "MBCI." There is also a resistor (R2) that may or may not be present, depending on the protective relay being interfaced. Figure 3-3a on page 3-3 shows the location of these jumpers.

On RFL 104230-3 modules (for HCB-1 relays) and RFL 104230-4 modules (for HCB relays), there are four jumpers: J1 through J4. J1, J2, and J3 are two-position jumpers; J4 is a ten-position block, with two movable jumpers that must be set. Figures 3-3b and 3-3c on page 3-3 show the location of these jumpers.

The following paragraphs describe how these jumpers are to be set. If specific input/output modules are not referenced, the paragraph applies to all four RFL 9720 PM I/O input/output modules.

a. Mode Selection. Two-position jumper J1 determines whether the RFL 9720 will short or open the pilot wire input to the relay if squelch relay K1 is de-energized. Two-position jumper J3 determines whether unblocking relay K2 is used. Their settings are interrelated, as follows:

J1	J3	Condition
OUT	OUT	Pilot wire is open after K1 drops out (squelch condition).
IN	OUT	Pilot wire is shorted after K1 drops out (squelch condition).
OUT	IN	Pilot wire is shorted for 150 ms after K1 drops out, then the pilot wire is opened.
IN	IN	Pilot wire is open for 150 ms after K1 drops out, then the pilot wire is shorted.

b. Relay Type Selection. RFL 104230-1 and RFL 104230-2 input/output modules are configured at the factory for the desired relay type. The type of protective relay being interfaced is selected by resistor R2 and the two jumper positions labeled "CPD" and MBCI." If a CPD relay is being interfaced, a jumper wire is installed for R2 and the position labeled "CPD." If an MBCI relay is being interfaced, a 500Ω resistor is installed for R2 and a jumper wire is installed in the position labeled "MBCI." **Do not change these jumper settings in the field.**

c. HCB-1 Relay Tap Settings. Jumpers J2 and J4 on the RFL 104230-3 input/output module must be set to match the tap settings on the HCB-1 relay. They are set at the factory to operate with an HCB-1 relay with the normal "4CH" and "MAX" tap settings.

Jumper J2 has two positions: "H" and "L." J2 must be set in position H if the HCB-1 "MAX" restraint tap is being used. If the "MIN" restraint tap is being used, J2 must be set in position L.

Jumper J4 is a ten-position block with two movable jumpers. One movable jumper must be placed in either position A, B, or C to agree with the HCB-1 relay's R_1 tap block setting. The other movable jumper must be placed in position 4, 5, 6, 7, 8, 10, or 12 to agree with the relay's T tap block setting.

d. HCB Relay Tap Settings. Jumpers J2 and J4 on the RFL 104230-4 input/output module must be set to match the tap settings on the HCB relay. They are set at the factory to operate with an HCB relay with the normal "4CH" and "MAX" tap settings.

Jumper J2 has two positions: "H" and "L." J2 must be set in position H if the HCB-1 "MAX" restraint tap is being used. If the "MIN" restraint tap is being used, J2 must be set in position L.

Jumper J4 is a ten-position block with two movable jumpers. One movable jumper must be placed in either position A, B, or C to agree with the HCB relay's R_1 tap block setting. The other movable jumper must be placed in position 4, 5, 6, 8, 10, 12, or 15 to agree with the relay's T tap block setting.

3.3.2. RFL 9720 PAM Power Amplifier Module

There are three programmable jumpers on the RFL 9720 PAM: J1, J2 and J3. Figure 3-4 on page 3-4 shows the location of these jumpers.

a. Terminal Configuration. Two-position jumper J1 is set at the factory according to the desired terminal configuration - position 2T for a two-terminal configuration.

b. Pilot Wire Relay Type. Five-position jumpers J2 and J3 are set according to the pilot wire relay being interfaced to the RFL 9720. Place J2 and J3 in position A for MBCI-01 or MBCI-02 relays, or position B for CPD, HCB, or HCB-1 relays. (Positions C, D and E are not valid at this time.)

3.3.3. RFL 9720 CCM Communications And Control Module

There are six programmable jumpers on the RFL 9720 CCM Communications And Control Module. Jumpers J1, J4, and J8 are on the main circuit board; J5, J6, and J7 are on the piggyback circuit board. The main circuit board also has one programmable DIP switch (SW1) and two front-panel rotary switches (SW2 and SW3). Figure 3-5 on page 3-5 and Figure 3-6 on page 3-6 show the location of these jumpers and switches.

a. EPROM Device Type Selection. Two-position jumpers J1 and J5 are set at the factory according to the EPROM device type being used. J1 and J5 must be set to position A if 27C256 devices are being used. If 27C64 devices are being used, these jumpers must be set to position B.

b. Command Extend Selection. Jumper J4 is set according to the desired Command Extend time. J4 is an eight-pin jumper block; four different settings are possible:

Pin Connections	Command Extend Time	Jumper Position
Pin 1 to pin 8	9ms	A
Pin 2 to pin 7	6ms	B
Pin 3 to pin 6	3ms	C
Pin 4 to pin 5	0ms	D

Normally, J4 is set at the factory between pins 4 and 5. (See the Software Description in Section 5 of this manual for more information on the Command Extend function.)

c. Receive Clock Polarity Selection. Two-position jumper J6 is set according to the desired receive clock polarity. Normally, J6 is set to position A for normal polarity. If framing is not achieved after both the local and remote terminals are powered, it may be caused by a polarity reversal in the receive data clock. The incoming data should not be changing state on the positive-going edge of the clock signal (Fig. 3-9). If it is, J6 must be moved to position B.

d. Transmit Clock Polarity Selection. Two-position jumper J7 is set according to the desired transmit clock polarity. Normally, J7 is set to position A for normal polarity. If framing is not achieved after both the local and remote terminals are powered, it may be caused by a polarity reversal in the transmit data clock. The incoming data should not be changing state on the positive-going edge of the clock signal (Fig. 3-9). If it is, J7 must be moved to position B.

Two-position jumper J8 is reserved for future enhancements. It is set to position "A" at the factory, and should remain in this position.

e. RS-232 Configuration Selection. DIP switch SW1 configures both of the RFL 9720's RS-232 ports. One port is at connector J2 on the RFL 9720 CCM I/O module. The other port is a diagnostic port on the RFL 9720 CCM module main circuit board that is only accessible when the RFL 9720 CCM module is on an extender board.

(1) Baud Rate Selection. SW1-1 through SW1-3 work together to set the desired baud rate:

Baud Rate	SW1-1	SW1-2	SW1-3
50	ON	ON	ON
300	OFF	ON	ON
600	ON	OFF	ON
1200	OFF	OFF	ON
2400	ON	ON	OFF
4800	OFF	ON	OFF
9600	ON	OFF	OFF
38400	OFF	OFF	OFF

Normally, SW1-1, SW1-2, and SW1-3 are set at the factory for 9600 baud (SW1-1 ON, SW1-2 and SW1-3 OFF).

(2) Parity Selection. SW1-4 and SW1-5 work together to set the desired parity:

Parity	SW1-4	SW1-5
No	Not critical.	ON
Even	ON	OFF
Odd	OFF	OFF

Normally, SW1-4 and SW1-5 are set at the factory for even parity (SW1-4 ON, SW1-5 OFF).

(3) Bits/Character Selection. SW1-6 sets the desired number of bits per character. If seven bits/character is desired, set SW1-6 to the ON position; place SW1-6 in the OFF position if eight bits/character is desired. Normally, SW1-6 is set at the factory for seven bits/character (ON).

(4) Stop Bit Selection. SW1-7 sets the desired number of stop bits per character. If one stop bit/character is desired, set SW1-7 to the ON position; place SW1-7 in the OFF position if two stop bits/character is desired. Normally, SW1-7 is set at the factory for one stop bit/character (ON).

(5) Handshaking Selection. SW1-8 determines whether RTS/CTS handshaking will be used. To disable handshaking, set SW1-8 to the ON position; place SW1-8 in the OFF position if RTS/CTS handshaking will be used. Normally, SW1-8 is set at the factory for no handshaking (ON).

f. Warning Delay Selection. Front-panel rotary switch SW2 is set according to the desired warning delay:

Position	Delay (μs)	Position	Delay (μs)
0	400	8	800
1	450	9	850
2	500	A	900
3	550	B	950
4	600	C	1000
5	650	D	1050
6	700	E	1100
7	750	F	1150

Normally, SW2 is set at the factory for a 400-μs warning delay.

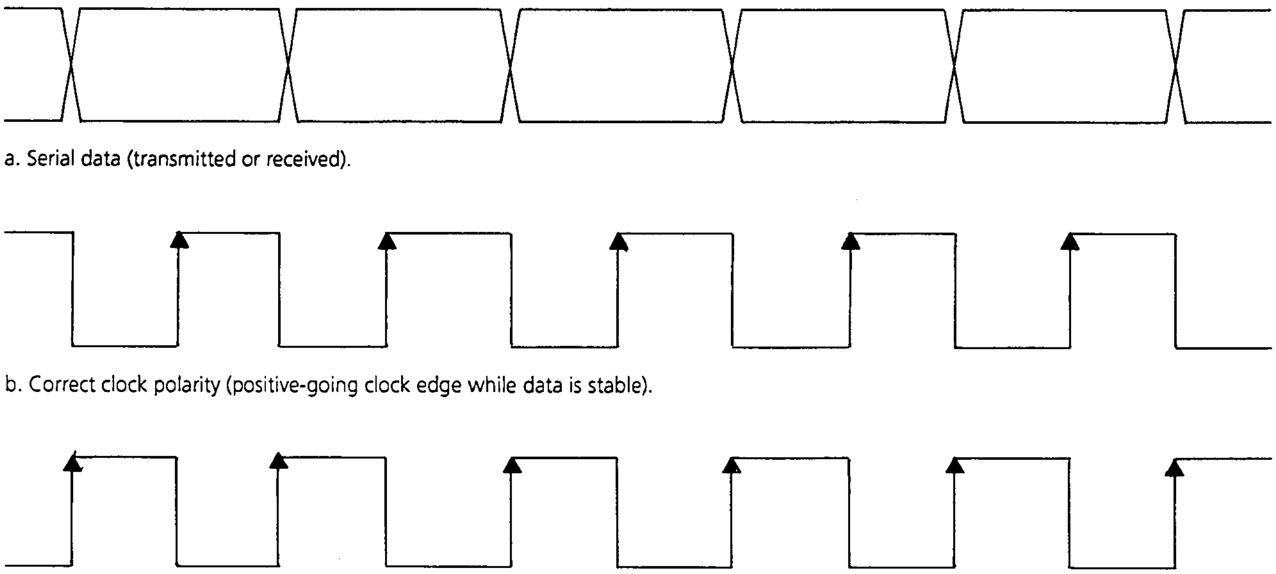


Figure 3-9. Received and transmitted data timing diagram

g. Alarm Delay Selection. Front-panel rotary switch SW2 is set according to the desired warning delay:

Position	Delay (µs)	Position	Delay (µs)
0	400	8	1500
1	525	9	1700
2	650	A	1900
3	775	B	2100
4	900	C	2300
5	1050	D	2500
6	1200	E	2700
7	1350	F	2900

Normally, SW3 is set at the factory for a 1050-µs alarm delay.

3.3.4. Motherboard

RFL 9720 two-terminal motherboards have two jumpers (J4 and J5). Figures 3-7 and 3-8 on pages 3-7 and 3-8 show the location of these jumpers.

a. Ground Reference Selection. Jumper J4 is a factory-installed zero-ohm resistor, which connects chassis ground to signal ground. If you want a floating signal ground, the zero-ohm resistor may be removed.

b. Software Switch Selection. Jumper J5 has three sections (J5-A, J5-B, and J5-C), and each section has two positions ("IN" or "OUT"). J5 is used to set software switches on the RFL 9720 CCM Communications And Control Module. Jumper J5-C is for future enhancement, and does not have to be set.

On 1U motherboards, J5 is a four-section DIP switch. Each section has two positions ("1" or "0"). These positions are equivalent to the "IN" and "OUT" positions on 3U motherboards. Switch section J5-C is for future enhancement, and does not have to be set. The fourth switch section is unmarked; it is not used.

(1) Indicator Latching. Jumper J5-A determines whether the RFL 9720 CCM's CHANNEL FAIL and CHANNEL DELAY indicators will latch in their worst-case condition. If J5-A is placed in the "1" position, they will latch if they start glowing yellow or red. Placing J5-A in the "0" position will disable the latches, and the front panel indicators will follow the current condition of the communications channel.

(2) Feedback Polarity. Jumper J5-B selects the desired feedback polarity, which will vary according to the protective relay being interfaced. J5-B works in conjunction with jumper J1 on the RFL 9720 PM I/O module to determine what mode the protective relay will operate in:

Relay	Mode	Motherboard J5-B	PM I/O Module J1
CPD	Trip Inhibit	0	OUT
	Overcurrent	0	IN
All Others	Trip Inhibit	1	IN
	Overcurrent	0	OUT

WARNING

ALL RFL 9720 STATIONS ARE EQUIPPED WITH A PROTECTIVE COVER THAT EXTENDS ACROSS THE TERMINAL BLOCK ON THE RFL 9720 PM I/O MODULE. THIS COVER IS INTENDED TO PROTECT THE OPERATOR FROM POTENTIALLY HAZARDOUS VOLTAGES, WHICH MAY BE PRESENT ON THIS TERMINAL BLOCK. THE PROTECTIVE COVER MUST ONLY BE REMOVED BY QUALIFIED SERVICE PERSONNEL WHEN ACCESS TO THE TERMINAL BLOCK IS REQUIRED. IT MUST BE REPLACED BEFORE PLACING THE STATION IN SERVICE.

CAUTION

The RFL 9720 should never be operated with the communications channel in a loopback condition. This will cause the current differential relay to trip.

The RFL 9720 should not be powered up (and communications established with another RFL 9720) unless a relay or dummy load is connected to its PILOT WIRE terminals (TB1-1 and TB1-2 on the RFL 9720 PM I/O module). Damage to the RFL 9720 PAM Power Amplifier Module can result if the PILOT WIRE terminals are unterminated. A 500 ohm 1/4 watt resistor will serve as a suitable dummy load, but cannot be used to verify operation. Proper operation of the RFL 9720 can only be verified with a relay connected to its PILOT WIRE terminals. Remove the load resistor when the PILOT WIRE is connected.

NOTE

During the initial startup procedures, the station that initiates a function is called the "local" station; the other station is the "remote" station.

3.4. INITIAL STARTUP PROCEDURE

All RFL 9720 stations are checked and adjusted at the factory. Once all electrical connections have been made as shown in Section 2, and all jumpers have been set as shown in paragraphs 3.3.1 through 3.3.4, the stations at each end of each communication line should be checked for proper operation. To do this, an operator must be at each station. The operators must be in voice contact with each other by telephone, PLC voice channel, or similar means.

The following procedure can be used to check the RFL 9720 stations at each end of a communications line for proper operation, either at time of installation or any time system operation needs to be verified. Perform all steps in each procedure in the order presented. Expected results or comments are indented and appear in **boldface** type.

1. Turn on the RFL 9720 by placing the POWER switch on the RFL 9720 PM Power Module in the ON position.

2. Look at the five indicators on the front of the RFL 9720 PM.

   All five LED indicators must light and remain on (not flashing). If all five indicators do not light (or if any of them flash), turn off the RFL 9720 PM. Refer to Section 7 of this manual and find the source of the problem before going on to step 3.

3. Look at CPU FAIL indicator DS1 on the RFL 9720 CCM Communications And Control Module.

   Under normal conditions, DS1 will light for about two seconds when the RFL 9720 PM is turned on. If it comes back on and starts flashing, a CPU failure has occurred. Turn off the RFL 9720 PM and either repair or replace the RFL 9720 CCM before going on to step 4. (Refer to Section 5 of this manual for more information.)

4. Look at CHANNEL indicator DS2 and DELAY indicator DS3 on the RFL 9720 CCM.

   If both the incoming and outgoing data signals are being framed properly, DS2 and DS3 will glow green, and all other indicators on the RFL 9720 CCM will be off. If they are, the RFL 9720 is ready for continuous service.

Two 16-position rotary switches on the front of the RFL 9720 CCM are used to set the ping-pong delay warning and failure values. These switches can be adjusted while the RFL 9720 is fully powered and operating. The DELAY TOLERANCE WARNING switch can be set for a delay of 400 µs to 1150 µs (1.15 ms), in 50-µs increments. The DELAY TOLERANCE ALARM switch can be set for a delay of 400 µs to 2900 µs (2.9 ms), in non-linear increments.

There are five LED indicators on the RFL 9720 CCM front panel; four of them are controlled by software. These indicators show the status of the RFL 9720 CCM:

CPU FAIL indicator DS1
DS1 is OFF when the RFL 9720 CCM is functioning properly. It flashes RED if the microcontroller fails.

CHANNEL indicator DS2
DS2 lights GREEN when good channel data is being received. It changes to RED if a channel failure has occurred because of CRC or frame failure. It will also glow RED if a failure is detected on the RFL 9720 PAM. (If this is the case, POWER AMP FAIL indicator DS1 on the RFL 9720 PAM will also glow RED.)

DELAY indicator DS3
DS3 lights green if no delay or channel failure has occurred. It changes to YELLOW if the delay time reaches the warning limit. If a channel failure has occurred because of excessive delay, DS3 turns RED.

DTT SENT indicator DS4
DS4 lights RED when a DTT command has been sent to the remote RFL 9720.

DTT RCV indicator DS5
DS5 lights RED when a DTT command has been received from the remote RFL 9720 and the DTT relay is energized.

All indicators on the RFL 9720 CCM except CPU FAIL indicator DS1 remain in their "worst case" condition until TARGET RESET switch SW4 on the front of the RFL 9720 CCM is pressed. CHANNEL indicator DS2 and DELAY indicator DS3 can have their reset function disabled by the setting of a jumper on the motherboard. (See para 3.3.4b.) These indicators will then always display the current channel condition of the RFL 9720 CCM. Table 3-9 shows how these indicators will look for various channel conditions.

If the initial startup procedure can be successfully completed, the RFL 9720 units at both ends of the protected line are ready for continuous service. If the procedure could not be completed at either end, perform the alignment procedures, beginning in paragraph 3.5. If all the alignment procedures cannot be successfully completed, corrective maintenance is required, as described in Section 4 of this manual.

3.5. ALIGNMENT PROCEDURES

The following procedures are used to verify station operation. They can be performed when the system is first put into operation, or anytime its operation needs to be verified. Perform all steps in the order presented. Expected results or comments are indented and appear in **boldface** type.

3.5.1. Equipment Requirements

The following equipment will be required to perform the initial startup procedures:

1. Digital multimeter, 4 1/2-digit with true-rms response and dB function; Fluke Model 8050A or equivalent.

2. Oscilloscope, 100 MHz bandwidth; Tektronix Model 2335 or equivalent.

3. Diagnostic terminal; this can be either a dumb RS-232 terminal, or a laptop computer with an RS-232 port running a communications program such as Pro-Com.

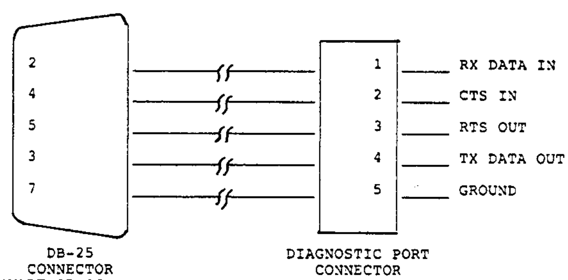
4. Diagnostic terminal cable. (See construction details in Figure 3-10.)

5. RFL 91 EXT card extender (Assembly No. 102080).

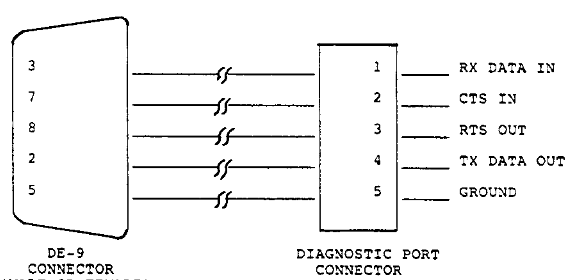
Table 3-9. RFL 9720 CCM indicator status for various channel conditions

Status	CPU FAIL Indicator DS1	CHANNEL Indicator DS2	DELAY Indicator DS3	DTT SENT Indicator DS4	DTT RCV Indicator DS5
Normal	OFF	GREEN	GREEN	OFF	OFF
Channel Delay	OFF	GREEN	YELLOW	OFF	OFF
Channel Failure Due To Delay	OFF	RED	RED	OFF	OFF
Channel Failure Due To Unframed, No Clock, CRC, or PAM Failure	OFF	RED	(1)	OFF	OFF
Direct Transfer Trip	OFF	(2)	(3)	(4)	(5)
CPU Failure	(6)	OFF	OFF	OFF	OFF

1. Whatever state this indicator was in at the beginning of the failure. In addition, the PAM FAIL indicator on the RFL 9720 PAM Power Amplifier Module may light, and then go out when squelched.
2. This indicator will show the state of the channel, disregarding the DTT.
3. This indicator will show the state of the delay, disregarding the DTT.
4. This indicator will be RED as long as the DTT INPUT is active, and for the Command Extend period.
5. This indicator will be RED if a DTT signal was received from the remote station and the DTT relays are energized.
6. This is a RED indicator that will flash on and off if a CPU failure occurs. It flashes because the RFL 9720 CCM's watchdog timer will keep trying to restart the CPU.



a. For terminals with 25-pin RS-232 connectors.



b. For terminals with 9-pin RS-232 connectors.

NOTES:

1. CABLE TYPE AND LENGTH ARE NOT CRITICAL.
2. MAKE SURE DB-25 OR DE-9 CONNECTOR MATES WITH RS-232 CONNECTOR ON DIAGNOSTIC TERMINAL.
3. DIAGNOSTIC PORT CONNECTOR IS 6-CONDUCTOR SHELL WITH CONTACTS ON 0.025-INCH CENTERS (MOLEX 22-01-2067 OR EQUIVALENT).

Figure 3-10. Construction details, diagnostic terminal cable for RFL 9720 CCM verification

CAUTION

To prevent damage to the multimeter, the input voltage being fed to the Power Module must be known before attempting to perform the following procedure.

3.5.2. RFL 9720 PM Output Verification

Each RFL 9720 unit requires five regulated voltages for proper operation: +5 volts, +12 volts, -12 volts, +24 volts, and -24 volts. These voltages are obtained from the RFL 9720 PM Power Module. Because the RFL 9720 PM's outputs cannot be adjusted, this procedure will only verify whether the supplies are working.

The following procedure must be performed at the RFL 9720 units at each end of the protected line.

1. Set the multimeter for dc voltage measurements. Set the multimeter range control as required to produce a station battery voltage reading that does not force the multimeter to overrange.

2. At terminal block TB1 on the RFL 9720 PM I/O module, measure the input supply voltage by connecting the positive multimeter lead to terminal TB1-3, and the negative lead to terminal TB1-4. Note the multimeter indication.

   The multimeter indication must be within the following limits:

   <u>48-Vdc Units</u> - 42 to 57.6 volts
   <u>125-Vdc Units</u> - 95 to 150 volts

   The RFL 9720 PM may not be able to produce enough power to operate the RFL 9720 with input voltages below these limits. Voltages above these limits may result in damage to the RFL 9720 PM.

3. Disconnect the multimeter from terminal block TB1.

4. Set the multimeter for dc voltage measurements, on a range that will produce 24-volt readings without over-ranging.

5. Turn on the Power Module by placing the POWER switch in the ON position.

   All five LED indicators on the Power Module must light and remain on (not flashing). If all five indicators do not light (or if any of them flash), return the power switch to the OFF (down) position and find the source of the problem before going on to step 6.

6. Connect the negative multimeter lead to the COM test point on the front of the Power Module; connect the positive multimeter lead to the +5V test point. Note the multimeter indication.

   The multimeter indication should be between 4.75 and 5.25 volts.

7. Move the positive meter lead to the +12V test point on the front of the Power Module. Note the multimeter indication.

   The multimeter indication should be between +11.4 and +12.6 volts.

8. Move the positive meter lead to the -12V test point on the front of the Power Module. Note the multimeter indication.

   The multimeter indication should be between -11.4 and -12.6 volts.

9. Move the positive meter lead to the +24V test point on the front of the Power Module. Note the multimeter indication.

   The multimeter indication should be between +22.8 and +25.2 volts.

10. Move the positive meter lead to the -24V test point on the front of the Power Module. Note the multimeter indication.

    The multimeter indication should be between -22.8 and -25.2 volts.

11. Turn off the Power Module by placing the POWER switch in the OFF position.

If the above procedure can be successfully completed at both stations, the power supplies are functioning properly. If not, refer to the fuse replacement procedures in Section 4 before proceeding with paragraph 3.5.3. If fuse replacement does not correct the problem, either replace or troubleshoot the Power Module before proceeding to paragraph 3.5.3.

<u>3.5.3. RFL 9720 CCM And RFL 9720 PAM Module Verification</u>

The following procedure can be used to verify operation of the RFL 9720 CCM Communications And Control Module and the RFL 9720 PAM Power Amplifier Module. Figures 3-4 through 3-6 on pages 3-4 through 3-6 of this manual show the location of the controls and indicators used during this procedure. Perform all steps in the order presented. Expected results or comments are indented and appear in **boldface** type.

1. Make sure POWER switch SW1 on the RFL 9720 PM is in the off (0) position.

2. Using a flat-blade screwdriver, turn the two quarter-turn fasteners on the front panel of the RFL 9720 CCM counterclockwise until they are loose.

3. Grab the handle on the front of the RFL 9720 CCM, and pull until the module is out of the chassis.

4. Line up the edges of the card extender with the card guides in the chassis slot vacated by the RFL 9720 CCM.

5. Slide the card extender into the chassis until it is firmly seated.

6. Plug the RFL 9720 CCM module into the card extender.

7. Plug the diagnostic terminal cable into diagnostic connector P2 on the RFL 9720 CCM. Connect the other end to the RS-232 port on the dumb terminal or laptop computer.

8. Place POWER switch SW1 on the RFL 9720 PM in the on (1) position.

9. Set the oscilloscope controls for dc coupling. Connect the vertical input probe ground lead to the probe tip. Set the vertical range controls to the 20 mV/div position, and adjust the vertical positioning controls until the trace is at the center of the screen grid.

10. Connect the oscilloscope vertical input probe to V OUT test turret TP9 on the RFL 9720 CCM piggyback board. Connect the probe ground lead to AGND test turret TP3.

11. Type a "Z" into the diagnostic terminal.
    This will start the Zero DAC test.

12. Note the voltage at TP9, as shown on the oscilloscope.
    With zero voltage applied to the input of the D/A converter, the trace on the oscilloscope should be within 50 mV of zero (or no more than 2 1/2 divisions above or below the center of the screen grid). If not, adjust potentiometer R28 until the trace is as close as possible to the center of the screen grid.

13. Type an "S" into the diagnostic terminal.
    This will stop the Zero DAC test.

14. Type a "V" into the diagnostic terminal.
    This will start the Sine Wave Voltage test.

15. Set the oscilloscope controls for ac coupling. Adjust the vertical and time base range controls until a stable waveform is displayed. Note the waveform's amplitude.
    The waveform should be between 1.35 and 1.65 Vp-p.

16. Set the oscilloscope controls for dc coupling. Connect the vertical input probe ground lead to the probe tip. Set the vertical range controls to the 0.5 V/div position, and adjust the vertical positioning controls until the trace is at the bottom of the screen grid.

17. Connect the oscilloscope vertical input probe to A/D IN test turret TP1 on the RFL 9720 CCM piggyback board. Connect the probe ground lead to AGND test turret TP3. Note the waveform's amplitude.
    The trace on the oscilloscope should be within 100 mV of 2.5 volts (or about five divisions above the bottom of the screen grid).

18. Type an "S" into the diagnostic terminal.
    This will stop the Sine Wave Voltage test.

19. Disconnect the oscilloscope from the test points on the RFL 9720 CCM piggyback board, but leave the diagnostic terminal cable connected to the main circuit board.

20. Place the POWER switch on the power supply module in the off (0) position.

21. Remove the RFL 9720 CCM from the card extender, and pull the card extender out of the chassis.

22. Line up the edges of the RFL 9720 CCM module circuit board with the card guides in the chassis slot vacated by the card extender.

23. Slide the RFL 9720 CCM into the chassis until it is firmly seated and its front panel is against the horizontal rails at the front of the chassis.

24. Using a flat-blade screwdriver, turn the two captive screws on the front panel of the RFL 9720 CCM fully clockwise to secure it in place.

25. Using a flat-blade screwdriver, turn the two quarter-turn fasteners on the front panel of the RFL 9720 PAM counterclockwise until they are loose.

26. Grab the handle on the front of the RFL 9720 PAM module, and pull until the module is out of the chassis.

27. Line up the edges of the card extender with the card guides in the chassis slot vacated by the RFL 9720 PAM module.

28. Slide the card extender into the chassis until it is firmly seated.

29. Plug the RFL 9720 PAM module into the card extender.

30. Place POWER switch SW1 on the RFL 9720 PM in the on (1) position.

31. Make sure the oscilloscope controls are set for dc coupling. Connect the vertical input probe ground lead to the probe tip. Set the vertical range controls to the 10 mV/div position, and adjust the vertical positioning controls until the trace is at the center of the screen grid.

32. Connect the oscilloscope vertical input probe to test turret TP12 on the RFL 9720 PAM. Connect the probe ground lead to test turret TP5.

33. Type a "Z" into the diagnostic terminal.
    This will start the Zero DAC Output test.

34. Note the voltage at TP12, as shown on the oscilloscope.
    This is a measurement of power amplifier U4's output. With zero voltage being produced by the D/A converter, the trace on the oscilloscope should be within 20 mV of zero (or no more than two divisions above or below the center of the screen grid).

35. Move the oscilloscope probe to test turret TP10 on the RFL 9720 PAM. Note the voltage shown on the oscilloscope.
    This is a measurement of the current feedback amplifier output. The trace on the oscilloscope should be within 10 mV of zero (or no more than one division above or below the center of the screen grid).

36. Move the oscilloscope probe to test turret TP1 on the RFL 9720 PAM, and move the probe ground lead to test turret TP2. Note the voltage shown on the oscilloscope.
    This is a measurement of the current sense output. With zero voltage being produced by the D/A converter, the trace on the oscilloscope should be within 20 mV of zero (or no more than two divisions above or below the center of the screen grid).

37. Type an "S" into the diagnostic terminal.
    This will stop the Zero DAC Output test.

38. Reconnect the oscilloscope vertical input probe to test turret TP12 on the RFL 9720 PAM. Reconnect the probe ground lead to test turret TP5.

39. Type a "V" into the diagnostic terminal.
    This will start the Sine Wave Voltage test.

40. Set the oscilloscope controls for ac coupling. Adjust the vertical and time base range controls until a stable waveform is displayed. Note the waveform's amplitude.
    The waveform amplitude will vary according to the relay being interfaced:

CPD	**3.6 to 4.0 Vp-p.**
HCB or HCB-1	**2.05 to 2.45 Vp-p.**
MBCI	**6.8 to 7.2 Vp-p.**

41. Move the oscilloscope probe to test turret TP10 on the RFL 9720 PAM. Note the voltage shown on the oscilloscope.
    This is a measurement of the current feedback amplifier output. The trace on the oscilloscope will vary according to the relay being interfaced:

MBCI	**0.9 to 1.1 Vp-p.**
All Others	**0.7 to 0.9 Vp-p.**

42. Set the oscilloscope controls for dc coupling. Connect the vertical input probe ground lead to the probe tip. Set the vertical range controls to the 50 mV/div position, and adjust the vertical positioning controls until the trace is at the center of the screen grid.

43. Move the oscilloscope probe to test turret TP1 on the RFL 9720 PAM, and move the probe ground lead to test turret TP2. Note the voltage shown on the oscilloscope.

This is a measurement of the current sense output. The trace on the oscilloscope will vary according to the relay being interfaced:

MBCI	**0 to 0.075 Vp-p.**
All Others	**0 to 0.2 Vp-p.**

44. Type an "S" into the diagnostic terminal.

This will stop the Sine Wave Voltage test.

45. Disconnect the oscilloscope from the test points on the RFL 9720 PAM, and disconnect the diagnostic terminal cable from the RFL 9720 CCM.

46. Place the POWER switch on the power supply module in the off (0) position.

47. Remove the RFL 9720 PAM from the card extender, and pull the card extender out of the chassis.

48. Line up the edges of the RFL 9720 PAM module circuit board with the card guides in the chassis slot vacated by the card extender.

49. Slide the RFL 9720 PAM into the chassis until it is firmly seated and its front panel is against the horizontal rails at the front of the chassis.

50. Using a flat-blade screwdriver, turn the two captive screws on the front panel of the RFL 9720 PAM fully clockwise to secure it in place.

51. Place the POWER switch on the power supply module in the on (1) position.

If the above procedure can be successfully completed, the RFL 9720 is working properly and ready for continuous service. If the procedure cannot be successfully completed, refer to Sections 4 through 7 of this manual for further information. Determine the source of the problem and repeat the above procedure after correcting the problem.

3.6. SYSTEM OPERATION

A block diagram of the RFL 9720's drive circuit is shown in Figure 3-11. The drive circuit comprises the RS-449 interface, digital processing circuits, a current amplifier, a current drive transformer, a current sense circuit, an equivalent pilot wire relay load (Z_S), and the pilot wire relay.

The current sense circuit consists of an active transformer circuit with two primary windings. This circuit will ideally measure the current before and after the source impedance (Z_S).

The current source is a high-power current amplifier, calibrated to reproduce the current generated by the relay at the far end. The current at the far end is detected by the current sense circuit at the far end, and transmitted over the communications channel. The local-end currents in the drive circuit are sensed by the active current transformer primary windings, and sent to the far end to its current amplifier.

The turns ratio and polarity of the windings of the current sense transformer are selected so that the source current (I_I) is completely canceled in the current sense transformer when the output is terminated by the actual pilot wire relay. The current sense transformer will only measure the current generated by the actual relay attached to its output terminals. The current sense circuit is calibrated so that this sensed current will produce the proper current amplifier output at the far end.

In each RFL 9720 system, there are two separate data streams. Each stream has a separate clock, supplied by the RS-422/449 communications channel. The first data stream reads the A/D converter, and compands the data. Then it adds the ping-pong and CRC bits, and places the completed data word in the transmission stream. The transmission hardware adds an alternating frame bit to the data word before transmission. (See Figure 3-12.)

The other data stream is read on a word-for-word basis, de-companded, and fed to the D/A converter. CRC and frame checking is done in hardware, using a memory chip. Both data streams are interrupt-driven. An interrupt is given to the RFL 9720 CCM's microcontroller by a counter requesting a new data word. Another interrupt is given to the RFL 9720 CCM's microcontroller to tell it a word has been received.

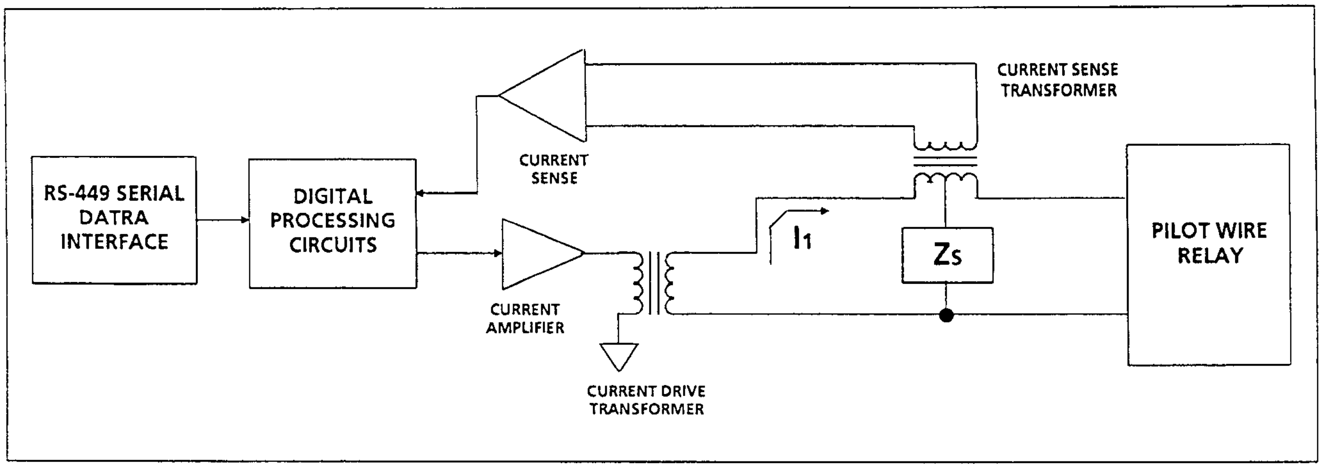


Figure 3-11. Block diagram, RFL 9720 drive circuit

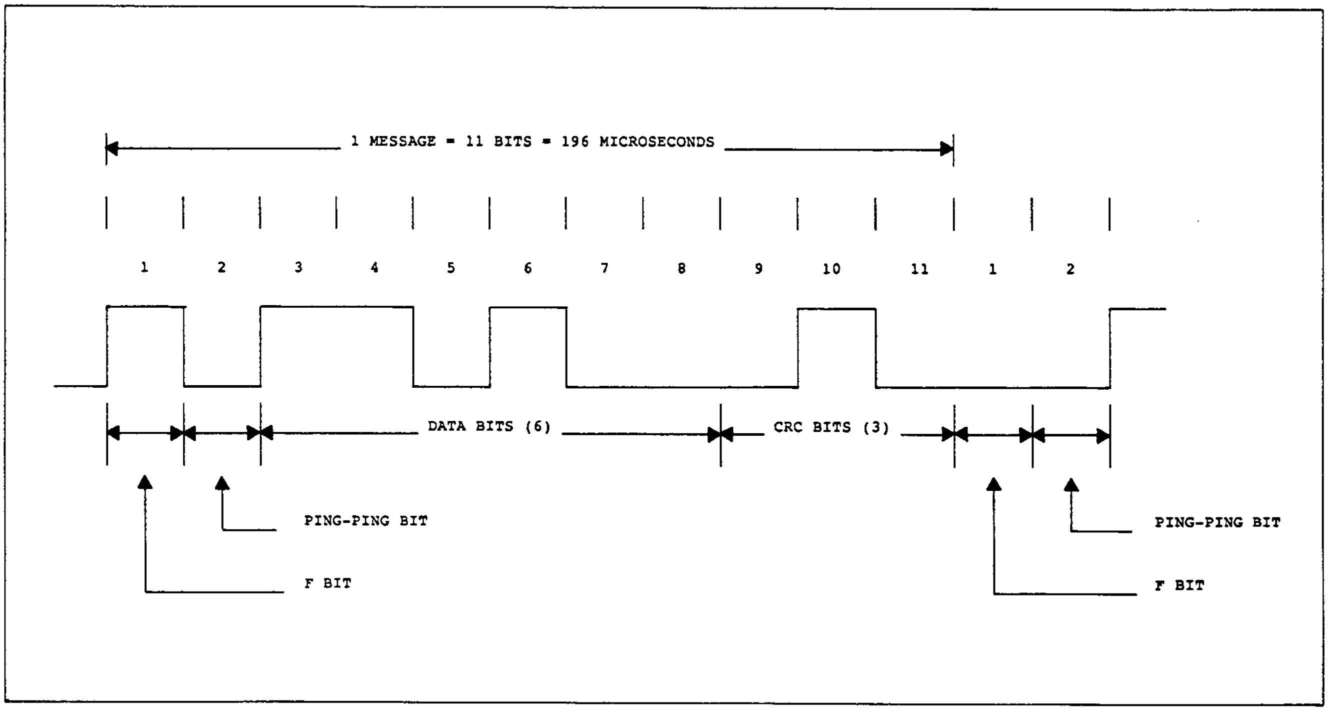


Figure 3-12. Transmission data format, RFL 9720 Pilot Wire Interface

The ping-pong bit has two main functions. It can be used to either request a ping-pong test, or reply to a ping-pong test request from the remote CCM. It also can inform the remote CCM of a channel failure. During normal system operation, each terminal initiates a ping-pong test at 50-ms intervals.

The ping-pong bit is also used to inform the remote CCM of any channel failure. In this mode, the ping-pong bit is constantly set until the local end gets valid data from the remote. When the local CCM receives four or more consecutive incoming words with the ping-pong bits set, it will assumed that the remote has failed and it will squelch the local protective relay. (See Section 5 for more information on the ping-pong test.)

3.7. SYSTEM PERFORMANCE

Paragraphs 3.7.1 through 3.7.3 describe tests that were run on RFL 9720 equipment to verify performance. Figures 3-13 through 3-15 are curves that show typical results. All tests were run using single-phase current connected to the relay's A-G input terminals. Standard non-modified RFL 9720 circuit boards and I/O modules were used for all tests.

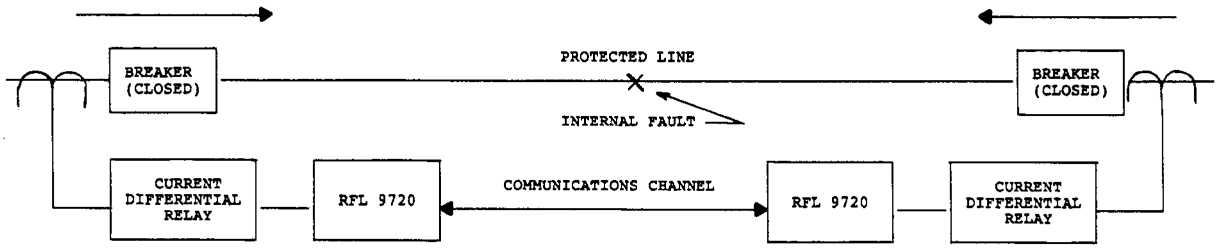
"Channel delay" is defined as the actual delay in the communications equipment connected to the RFL 9720; this excludes any delay added by the RFL 9720. When two RFL 9720 terminals are connected back-to-back, there is zero channel delay. The delay causes an effective phase shift of the pilot wire current generated by the far end relay. This shift is compared to the non-shifted line current in the relay at the near end.

3.7.1. Internal Fault Trip Levels

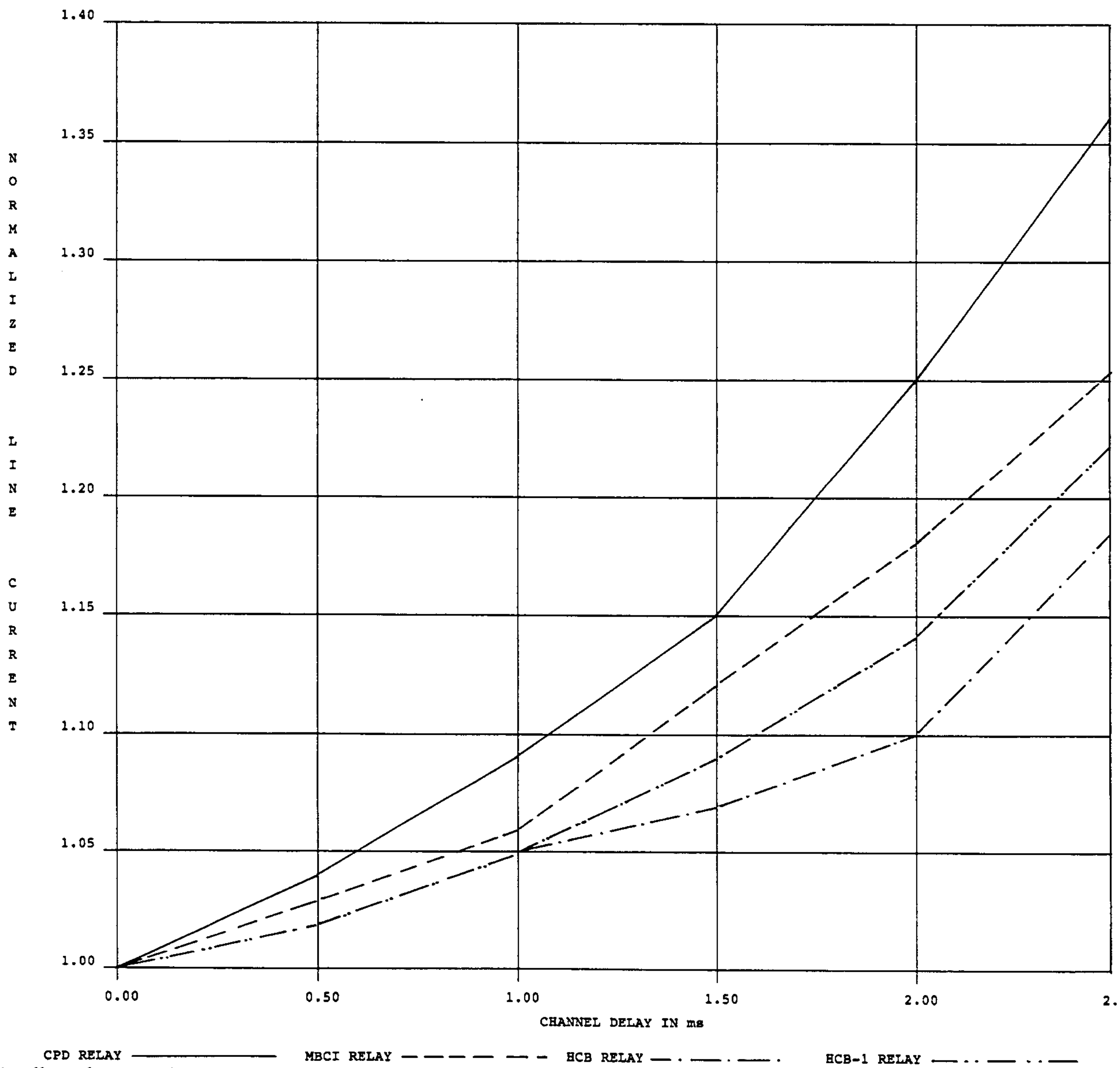
Figure 3-13 shows the change in internal fault trip levels as a function of channel delay. For each relay type, the line current amplitude and phase are identical. The line current is shown on the vertical axis, and is normalized to the trip current at zero channel delay. The graphs show that as channel delay increases, all relays become less sensitive.

3.7.2. External Fault Trip Levels

Figure 3-14 shows the trip levels for external faults with large amounts of channel delay. The line currents on the vertical axis are normalized to the typical pickup levels for each relay type. As channel delay increases, less line current is required to cause a false trip. For delays less than where the curve becomes nearly vertical, the relay will not false trip. For safe operation, channel delay times must be kept well below this threshold.

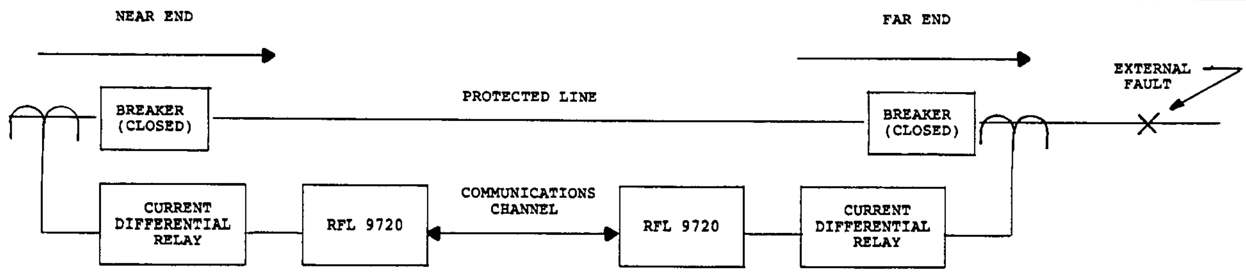


a. One-line diagram.

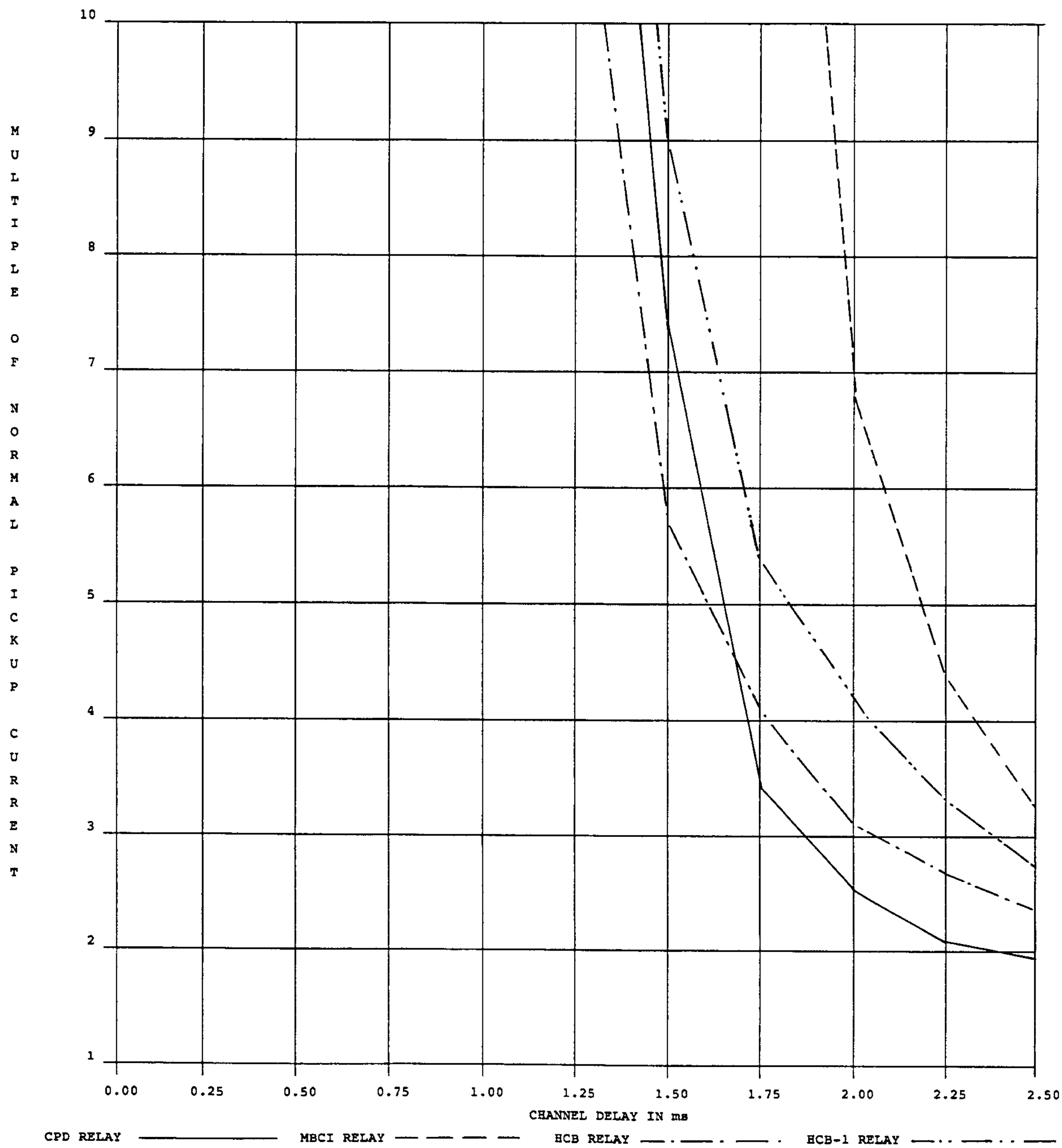


b. Effect of increased channel delay.

Figure 3-13. Typical internal fault trip levels



a. One-line diagram.



b. Effect of increased channel delay.

Figure 3-14. Typical external fault trip levels

3.7.3. Interface Unbalance (HCB-1 relays only)

Figure 3-15 shows the effect of long interconnections between an HCB-1 relay and the RFL 9720. The interconnection is assumed to be 19AWG twisted pair cable, which is normally used for pilot wire lines. The vertical axis shows the amount of unbalance in the hybrid interface to the relay. Excessive unbalance will greatly modify the apparent pilot wire characteristics, and affect relay performance.

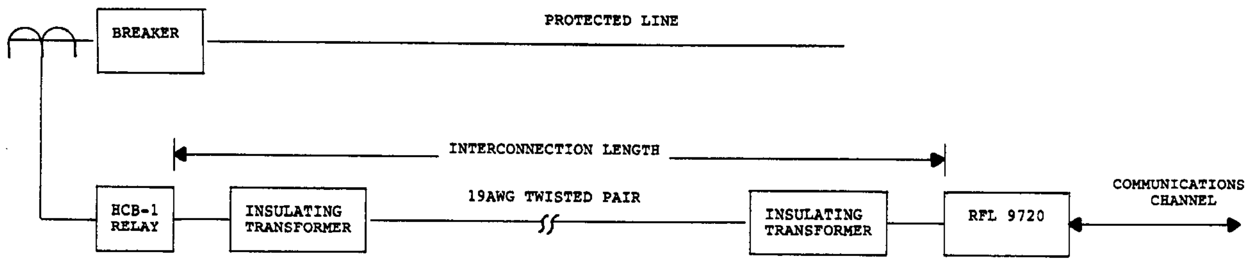
Two curves are shown in Figure 3-15c: one for interconnections using insulating transformers (as shown in Fig. 3-15a), and one without transformers (as shown in Fig. 3-15b). The unbalance on the transformerless interconnection increases from about 2 percent to almost 15 percent at one mile (1.6 km), with greater unbalances for longer distances. If insulating transformers are used at each end, the unbalance remains less than 15 percent for distances between 1 and 8.5 miles (1.6 to 13.7 km). Unbalance levels of 15 percent or less should normally produce acceptable system performance.

The best system performance for HCB-1 relays (about 5 percent or less unbalance) is achieved when using transformerless interconnections up to 2000 feet long (610 meters), or transformer-isolated interconnections that are 4 to 5 miles long (6.4 to 8.0 km). As a result, the following guidelines should be used:

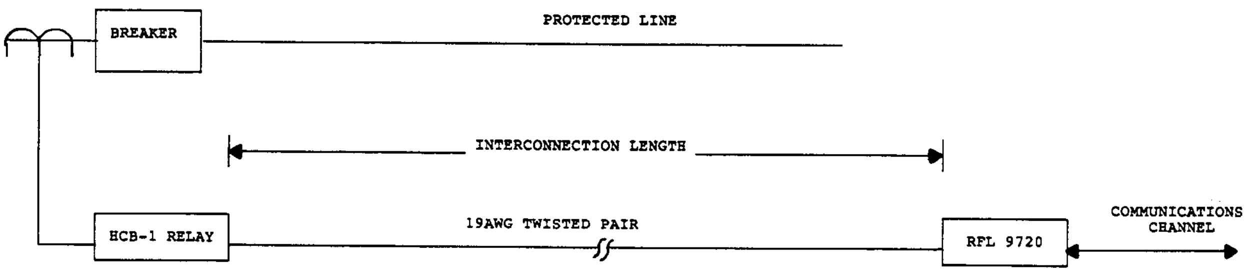
1. Do not use transformers on interconnections less than one mile long (1.6 km).

2. Use transformers on interconnections from 1 to 8.5 miles long (1.6 to 13.7 km).

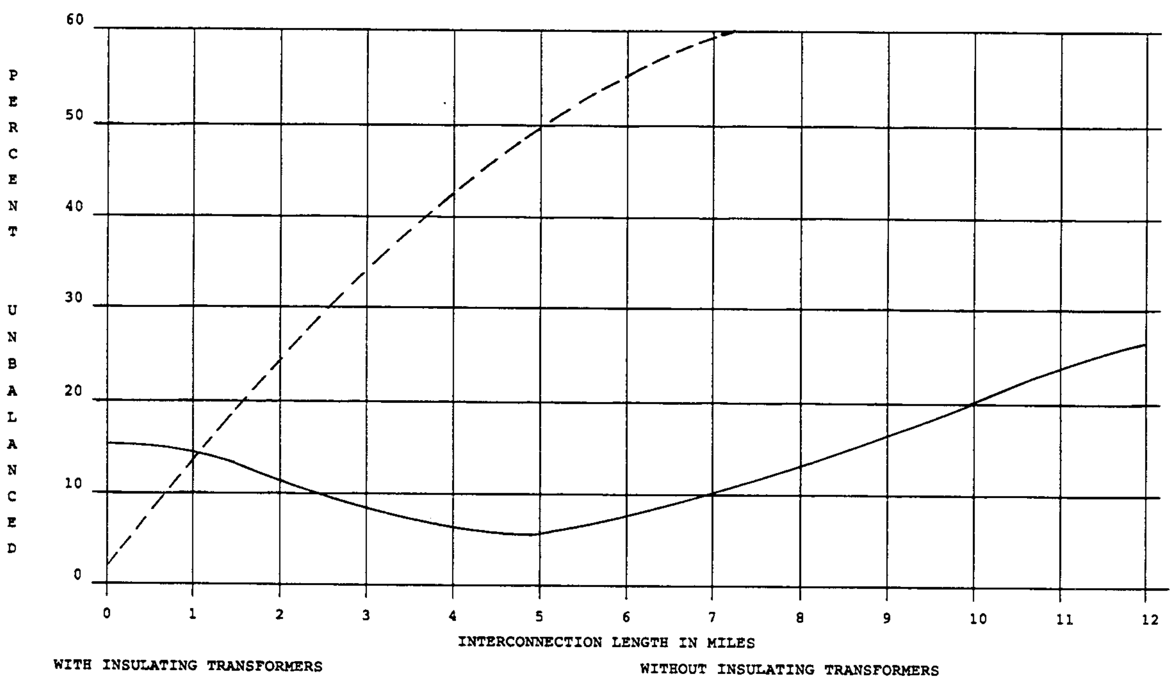
3. Do not use interconnections lines longer than 8.5 miles (13.7 km).



a. One-line diagram with insulating transformers between HCB-1 relay and RFL 9720.



b. One-line diagram with no transformers between HCB-1 relay and RFL 9720.



c. Effect of increased distance between HCB-1 relay and RFL 9720.

Figure 3-15. Typical effect of long interconnections between an HCB-1 relay and the RFL 9720

Section 4. MAINTENANCE

WARNING

HAZARDOUS VOLTAGES CAN BE PRESENT INSIDE THE RFL 9720 SYSTEM. BEFORE ATTEMPTING MAINTENANCE, READ THE SAFETY INFORMATION ON PAGES iii AND iv OF THIS MANUAL.

4.1. INTRODUCTION

This section provides maintenance instructions for the RFL 9720 Pilot Wire Interface. Topics discussed include removal and replacement procedures, corrective maintenance information, and information on how to arrange for service.

4.2. REMOVAL AND REPLACEMENT

Paragraphs 4.2.1 through 4.2.2 provide procedures to be used when removing and replacing RFL 9720 modules and I/O assemblies. Perform all steps in the order presented; expected results or comments are indented and appear in **boldface** type.

4.2.1. Plug-In Modules

All plug-in modules mounted at the front of the RFL 9720 chassis are held in place by two quarter-turn fasteners. To remove any of these modules, proceed as follows:

1. Place the POWER switch on the Power Module in the OFF position.

2. Using a flat-blade screwdriver, turn the two quarter-turn fasteners on the front panel of the module counterclockwise, until they are loose.

3. Grab the handle on the front of the module and pull until the module is out of the chassis.

To replace the module, proceed as follows:

1. Determine the slot in the chassis where the module is to be installed.

   RFL 9720 modules are installed in the following order, when viewed from the front of the chassis:

Left:	**RFL 9720 PM**
Center:	**RFL 9720 PAM**
Right:	**RFL 9720 CCM**

   Each module is keyed, so it cannot be installed in the wrong position.

2. Line up the edges of the module circuit board with the card guides in the chassis.

3. Slide the module into the chassis until it is firmly seated. Make sure its front panel is against the horizontal rails at the front of the chassis.

4. Using a flat-blade screwdriver, turn the two quarter-turn fasteners on the front panel of the module fully clockwise to secure it in place.

5. Place the POWER switch on the Power Module in the ON position.

4.2.2. I/O Modules

All I/O modules mounted at the rear of the RFL 9720 chassis are held in place by two captive screws. To remove any of the I/O modules, proceed as follows:

1. Place the POWER switch on the Power Module in the OFF position.

2. Tag and disconnect all wiring from the rear panel terminal block. If an RFL 9720 CCM I/O module is being removed, disconnect the RS-232 and RS-449 connectors from connectors J1 and J2.

3. Using a flat-blade screwdriver, turn the two captive screws on the I/O module panel counterclockwise, until they are loose.

4. Pull on the I/O module until it is out of the chassis.

CAUTION

The edge connectors on RFL 9720 I/O modules are not keyed. They must be installed in the correct chassis position. If any I/O modules are installed in the wrong position, serious component damage or system malfunctions may result.

To replace the I/O module, proceed as follows:

1. Determine the slot in the chassis where the module is to be installed.
   RFL 9720 I/O modules are installed in the following order, when viewed from the rear of the chassis:

Left:	**RFL 9720 CCM I/O**
Center:	**RFL 9720 PAM I/O**
Right:	**RFL 9720 PM I/O**

2. Line up the edges of the I/O module circuit board with the card guides in the chassis.
3. Slide the I/O module into the chassis until it is firmly seated. Make sure its panel is against the horizontal rails at the back of the chassis.
4. Using a flat-blade screwdriver, turn the two captive screws on the panel of the I/O module fully clockwise to secure it in place.
5. Using the tags placed on the wires during removal, reconnect all wiring to the rear panel terminal block. If an RFL 9720 CCM I/O module is being replaced, reconnect the RS-232 and RS-449 connectors to connectors J1 and J2.
6. Place the POWER switch on the Power Module in the ON position.

4.2.3. Motherboard

If the RFL 9720 motherboard needs to be removed from the chassis, proceed as follows:

1. Remove all three plug-in modules from the chassis. (See para 4.3.1.)
2. Remove all three I/O modules from the chassis. (See para 4.3.2.)
3. Using an Allen wrench, remove the two setscrews that ground the motherboard to the chassis.
4. Using a Phillips screwdriver, remove the four screws securing the motherboard in place.
5. Remove the motherboard from the rear of the chassis.

To replace the motherboard, proceed as follows:

1. Insert the motherboard into the chassis from the rear, and position it in the desired location.
2. Using a Phillips screwdriver, install and tighten four screws to secure the motherboard to the chassis.
   The mounting screws go in the unthreaded holes closest to the corners of the motherboard.
3. Using an Allen wrench, install and tighten the two setscrews through the two threaded holes in the motherboard.
   These set screws bond the threaded inserts to the chassis. They must be firmly in place for the motherboard to be properly grounded.

CAUTION

Never attempt to remove or replace a fuse with the Power Module energized; component damage may result.

For continued safe operation, always replace a fuse with one having the same voltage and current ratings. (See Section 7 for proper replacements.)

4.3. FUSE REPLACEMENT

The input fuses for RFL 9720 Power Modules are located on the front of the module. Fuses can be changed without removing the Power Module from the chassis. To check the fuses, proceed as follows:

1. Place the POWER switch on the Power Module in the OFF position.
2. Remove one of the input fuses from its fuseholder by pushing in on the fuseholder cap and turning it counter clockwise about 1/4 turn.
   Some fuseholders require a screwdriver to remove the fuse, while others can be turned with the fingers.

3. Remove the fuse from the fuseholder cap and inspect it for damage.
   If the fuse is bad, it must be replaced. If the fuse is good, check for presence of input voltage at TB1-3 and TB1-4 on the RFL 9720 PM I/O module. If voltage is present and the Power Module does not function, troubleshoot to determine the cause of failure.

4. Insert a fuse with the proper voltage and current ratings into the fuseholder cap and push it in until it is firmly seated.

5. Insert the fuse and fuseholder cap into the fuseholder. Using a flat-blade screwdriver, push in on the cap and turn clockwise about one quarter-turn.
   This will secure the fuse in place.

6. Repeat steps 2 through 5 for the other fuse.

7. Once both fuses have been checked or replaced, place the power switch in the ON position.
   If all five indicators on the Power Module light, the Power Module is working properly. If all five indicators do not light or if one or both fuses blow again, the Power Module is defective and should be replaced. If one or more indicators flashes on and off, the problem may be with one of the other modules in the RFL 9720. Troubleshoot to determine the cause of the problem.

4.4. CORRECTIVE MAINTENANCE

The RFL 9720 Pilot Wire Interface has been designed for years of trouble-free service. If a malfunction occur involving the RFL 9720, use standard troubleshooting techniques to determine its source. If the problem lies within the RFL 9720, use the schematics in Sections 5 through 8 to localize the problem.

Once the defective module or I/O module is replaced, the problem should be solved. If the problem is in some other connected equipment, refer to its instruction manual for further information.

Defective modules and I/O modules can be repaired locally, or they can be returned for repair (para 4.5).

4.5. HOW TO ARRANGE FOR SERVICING

If necessary, RFL 9720 modules and subassemblies may be returned for repair. Contact our Customer Service Department using the telephone number listed on the cover of this manual. You will be given an authorization number and shipping instructions.

Section 5. COMMUNICATIONS AND CONTROL MODULE AND CCM INPUT/OUTPUT MODULE

5.1. INTRODUCTION

This section contains information on the RFL 9720 CCM Communications And Control Module and the RFL 9720 CCM I/O Input/Output Module. Paragraph 5-2 provides complete technical information on the RFL 9720 CCM; additional information on the RFL 9720 CCM I/O can be found in paragraph 5-3 on page 5-31 in this section.

5.2. RFL 9720 CCM COMMUNICATIONS AND CONTROL MODULE

5.2.1. Description

The RFL 9720 CCM Communications and Control Module (Fig. 5-1) contains the RFL 9720's microcontroller. It performs the following functions:

1. Processes the RFL 9720's analog input and output signals.

2. Controls serial communications with the remote RFL 9720.

3. Controls the RS-232 communications and diagnostic ports.

4. Processes all direct trip and alarm inputs.

5. Controls the output relays and front panel indicators.

5.2.2. Hardware Description

The RFL 9720 CCM has two circuit boards: the main circuit board, and the piggyback circuit board. Paragraph 5.2.2.1 describes the circuit on the main circuit board; the circuits on the piggyback circuit board are described in paragraph 5.2.2.2. A block diagram of the RFL 9720 CCM appears in Figure 5-2. The schematic for the RFL 9720 CCM appears in Figures 5-7 and 5-9 at the end of this section.

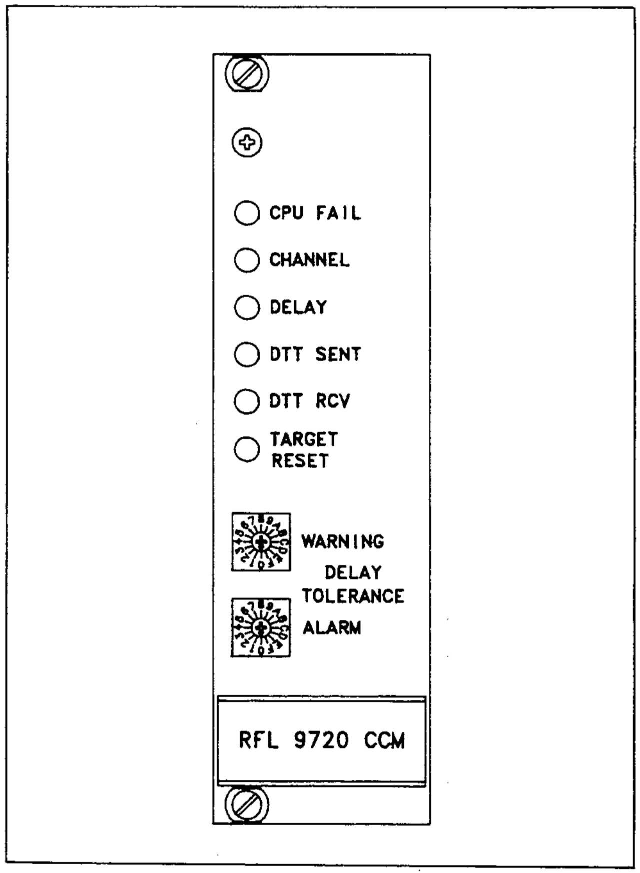


Figure 5-1. RFL 9720 CCM Communications And Control Module

5.2.2.1. Main Circuit Board

The main circuit board contains the microcontroller and its support circuits. It also contains all the input/output peripheral circuits, except the A/D and D/A converters. The jumpers and switches are on the main circuit board, along with the output relay drivers and the front panel display circuits.Figure 5-7 on page 5-19 is the schematic for the main circuit board. Sheet 1 shows microcontroller U20, most of its support circuits, and the RS-232 serial interface components. Sheet 2 is a schematic for the rest of the circuits on the main circuit board. This includes several peripheral devices that communicate with U20 using the address/data bus and the microcontroller control signals.

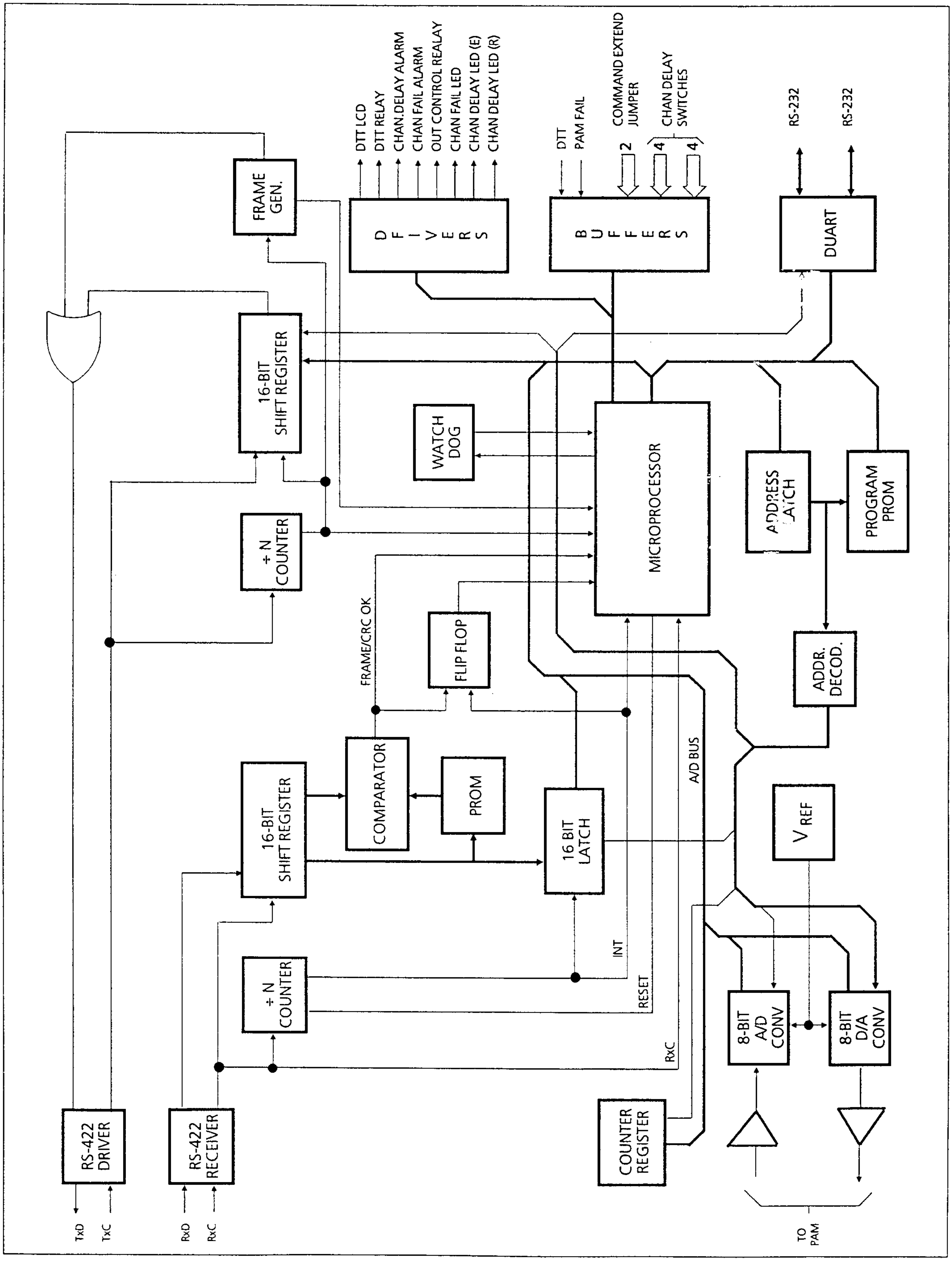


Figure 5-2. Block diagram, RFL 9720 CCM Communications And Control Module

a. Microcontroller. Microcontroller U20 controls all RFL 9720 CCM operations. U20 uses a 16-MHz oscillator, controlled by crystal Y1. The oscillator frequency is divided in half by U20, and appears at U20-65 as an 8-MHz clock signal. The reset input (U20-16) is controlled by the watchdog timer described on page 5-5 of this section. The watchdog timer also includes power supply monitoring circuits.

The READY input to the microcontroller (U20-43) is used to override any read/write wait states programmed into the microcontroller when accessing fast memory. The microcontroller uses wait states for all peripherals but none for program memory.

All peripherals are mapped into the upper half of addressable memory, and program memory is in the lower half. Address/data line AD15 controls the READY input. The BUSWIDTH input (U20-64) controls whether the microcontroller will read or write using eight or sixteen bits.

Microcontroller U20 only uses 16-bit read/writes when accessing program memory or one of the RS-422 data shift register/latches. Address line A15 and Chip Select signals CSØ and CS1 are used to create a logic one at U20-64 when 16 bits are to be used.

Some signals interface directly with the microcontroller using the parallel input/output ports or the high-speed input or output lines. Port Ø on U20 accepts several inputs:

1. The setting of Command Extend jumper J4.
2. The PAM FAIL alarm signal from the RFL 9720 PAM Power Amplifier Module (Section 6).
3. The actual direct trip input signal (DTT IN).
4. Two RS-422 communications control signals.

Port 1 is not used. Port 2 is a mixed input/output port, and is used for four functions:

1. To output the Direct Trip signal.
2. To input three more RS-422 communications control signals.
3. To input a signal from front panel TARGET RESET switch SW4.
4. To input an interrupt signal from the A/D converter.

The high-speed input lines are used for interrupt signals from DUART U14, and a direct trip input delay circuit that is part of U11. They are also used for another RS-422 channel control signal. One of the high-speed output lines (HSO.3) is used to frame the received RS-422 signal, and another (HSO.Ø) drives CHANNEL DELAY LED indicator DS3. A high level on HSO.Ø lights the red LED in DS3, and a low level lights the green LED. In addition, HSO.Ø can be programmed to produce a pulsed output with a controlled duty cycle. A pulsed output will cause DS3 to produce an orange or yellow light. Pull-up resistors are used on all input lines that can be either tri-stated or open-circuited.

Various other input signals are also fed to microcontroller U20. These include the DTT input, the PAM FAIL alarm signal, Command Extend jumper settings, and information from programmable peripheral interface U17, described on page 5-4 of this section. Output latches and driver circuits allow U20 to control several output signal and alarm relays and status indicators. Several spare input and output logic signals are also available for future applications.

b. Address Latch. Microcontroller U20 multiplexes address and data information onto the same address/data bus (ADØ to AD15). The address is placed on the bus first and latched into octal latches U21 and U22 by the ALE pulse at U20-62. This latched address information is then used by the program memory PROM's, all the peripheral interface devices, and the address decoder. The lower half of the external memory map is reserved for program memory, and is only limited by the EPROM capacity. Although 8K by 8 EPROM's are normally used, larger devices can be used in the same sockets to make full use of the available address area.

c. Program PROM. Several circuits on the RFL 9720 CCM support the microcontroller and enhance its operation. The address data for these circuits is latched and used to drive the program memory PROM, formed from U8 and U12. It also drives an address decoder that controls each peripheral circuit's Chip Select input. The address/data bus also interfaces with all the peripherals to transfer data (either eight or sixteen bits).

d. Address Decoder. Blocks of address space in the upper half of memory are decoded by U9 to generate Chip Enable signals. These signals control read/write operations between microcontroller U20 and its peripheral circuits. The RS-422 receive shift register data latch has only one clock input. One of the OR gates in U7 combines U9's YØ output (CSØ) with the microcontroller read signal (U20-61) to generate the required timing signal. Another OR gate in U7 combines U9's Y1 output (CS1) and U20's WRITE signal (U20-40) to create a clock signal. This signal writes data into the RS-422 transmit data shift register.

e. Counters. Counter U11 contains three software controllable counter circuits: Counter Ø, Counter 1, and Counter 2. Counter Ø is configured as a retriggerable one-shot, and makes sure that a state change in the direct transfer trip (DTT) input signal is maintained for a predetermined period of time before it is accepted by the microcontroller. Counter 1 and Counter 2 are programmed as divide-by-N counters, and are used to control the message length for the RS-422 transmit and receive circuits.

Counter Ø It is triggered or retriggered every time the DTT signal changes state. Because of this, it only times out after the signal has been stable for the delay time. The trailing edge of the signal at U11-10 generates an interrupt to the microcontroller, which can then read the actual DTT signal. The change-of-state pulses are generated on the piggyback circuit board, and are applied to the gate input (U11-11). The 8-MHz CLKOUT signal from U20 is applied to U11-9 and used as Counter Ø's clock input.

Counter 1 is in the transmit circuitry, and is clocked by the RS-422 transmit clock signal. The gate input is not used.

Counter 2 is in the receiver circuitry, and is clocked by the RS-422 receive clock signal. The gate (U11-16) is controlled by the microcontroller to reset the counter for framing purposes. Counter 2's output controls the 16-bit latch described on page 5-5 of this section. This latch stores the incoming shift register data before it changes and sends an interrupt to U20 for synchronization. A comparator on the piggyback circuit board constantly compares the CRC portion of the received message in the shift register with the desired CRC data corresponding to the data portion of the message. This is generated from a look-up table in EPROM U24. The alternating frame bits are also checked by the EPROM data. The comparator output and the receive clock are monitored by U20. U20 determines the start of a new message and resets the divide-by-N counter to synchronize the received message frames. Once the received data is locked in, U20 determines the reliability of the data message from the output of flip-flop U39-5. This flip-flop latches the output of comparator U35 at the end of each message.

f. Dual Universal Asynchronous Receiver/Transmitter (DUART). Another peripheral to microcontroller U20 is dual universal asynchronous receiver/transmitter U14, or the "DUART." The DUART has its own 3.6864-MHz clock oscillator, controlled by crystal Y2. The DUART can be programmed by U20 for a variety of baud rates, parity, seven or eight data bits, and the type of handshaking. RS-232 line driver/receivers U15 and U16 convert the RS-232 level signals at the output connector to the digital signals at U14.

Channel A is a standard RS-232 interface. It is not currently available for use; any data fed to this input will simply be echoed back to the source.

Channel B is included for diagnostic testing purposes. It also appears on the circuit board connector, although it is usually interfaced through connector P2.

The signals on P2 are as follows:

Receive data	P2-1
CTS	P2-2
RTS	P2-3
Tx Data	P2-4
Ground	P2-5

g. Input Buffers And Output Drivers. Most of the external connections to microcontroller U20 are made through programmable peripheral interface U17. U17 has three eight-bit ports: Port A, Port B, and Port C.

Port A accepts the settings from DIP switch SW1. These settings contain the setup information for the RS-232 communications.

Port B is used to input the settings of front-panel rotary switches SW2 and SW3. These switches control the warning and alarm delay tolerances. Pull-up resistors provide a high input signal when the switches are open.

Port C controls the output relays and all front panel indicators (except CPU FAIL). Transistor array U10 contains high-current open-collector Darlington drivers, which will conduct when the inputs are high. Quad buffer/line driver U1 provides drivers for CHANNEL indicator DS2. When U17 is in a reset condition, the outputs of Port C are all high. This means the output relays are de-energized and all indicators are off. Hex inverters U5 and U6 provide the proper output signal polarity under this condition. U10's S8 and S7 outputs need to be active in order to pull in the DTT relay. Depending on the state of U17's PC5 output, CHANNEL indicator DS2 will either be red or green.

h. 16-Bit Latch. Latches U18 and U19 store received RS-422 data into the receive shift registers at the end of each message frame. This saves the data. If U20 is busy completing a higher-priority routine when the data is received, it can read the data at the next RS-422 receive clock pulse. Pull-up resistors are used to protect all latch inputs when the piggyback circuit board is disconnected.

i. 16-Bit Shift Register For RS-422 Driver. The message to be transmitted on the RS-422 channel includes the A/D output and CRC information. U20 loads this data into shift registers U13 and U23 at the beginning of each new message. The data is then shifted out by the RS-422 transmit clock signal. The shift register output (U13-9) is then combined with the alternating frame pulse (U7-9) in an OR gate to produce the transmit data (U7-8). The alternating frame pulse is generated in another OR gate (part of U7). Its inputs are a frame time pulse (U7-2) and the output of a flip-flop in U39 on the piggyback circuit board that alternates the signal on U7-1 with every message. The OR gate output (U7-3) is inverted to produce the alternating frame pulse (U7-9).

j. Divide-By-N Counter For RS-422 Driver. The beginning of each new message is determined by a programmable interval timer in U11. This counter serves as a divide-by-N counter. The timer is clocked by the transmit clock signal from the communications channel. The output of the counter (U11-13) is used to synchronize U20 and control the frame generator circuit described on page 5-6 of this section. This circuit inserts an alternating frame bit at the beginning of each message. The remaining data in the message is clocked out of the shift register.

k. Watchdog Timer. Watchdog timer U3 controls microcontroller U20's RESET input (U20-16). This timer will automatically restart the software if the microcontroller malfunctions. U3's output (U3-7) will pull the RESET line low during power-up or low-voltage conditions. It will also pull it low whenever microcontroller U20 has not toggled the WDI input (U3-6) at least once every 1.6 seconds.

The RESET pulse from U3 is also latched into flip-flop U2. U2 will only be cleared by the same signal that drives U3's WDI input. U2's Q* output (U2-6) controls CPU FAIL indicator DS1, which will stay on until microcontroller U20 is running properly.

5.2.2.2. Piggyback Circuit Board

The piggyback circuit board has all the analog interface circuitry, including the A/D and D/A converters. Most of the RS-422 interface and control circuits are also on the piggyback circuit board. Figure 5-9 on page 5-27 is the schematic for the piggyback circuit board. Sheet 1 is a schematic of the RS-422 interface circuits, along with their timing circuits. The analog interface circuits are shown on Sheet 2.

a. 8-Bit A/D Converter. The VIN analog signal received from the RFL 9720 PAM (Section 6) is passed to A/D converter U25 through buffer amplifiers U26 and U27. The input signal is sensed differentially to remove common-mode noise. It is then offset in U27 to produce a negative output at test turret TP2. This signal is then inverted and attenuated in amplifier U26 to result in less than unity gain. This produces an input signal for U25 that varies from zero to +5 volts. Resistor R37 and capacitor C58 act as a low-pass filter for this signal. U25 converts the signal into digital data that is passed to U20 for transmission in the serial output data. Timing is controlled by U20, and is synchronous with the data message rates on the RS-422 serial communications channel.

Potentiometer R24 is used to adjust U25's input signal to 2.5 volts with no analog signal being received. U25 uses a 5-volt reference voltage generated by U31. This reference voltage is also the input signal to a non-inverting amplifier/driver circuit formed from operational amplifier U32 and transistor Q1. This circuit has a gain of 1.04, producing an output at test turret TP11 of 5.2 volts. This output is used to power operational amplifier U26 and A/D converter U25. Data is transferred from U25 to the microcontroller using the normal data bus and control lines.

b. 8-Bit D/A Converter. The analog signal fed to the RFL 9720 PAM (Section 6) is generated by microcontroller U20 writing the amplitude samples it receives to D/A converter U28. Buffer amplifiers U29 and U30 adjust the amplitude and offset of the signal that drives the PAM. U29 converts the current output from U28 into a voltage that varies between zero and -5 volts. (This voltage can be monitored at test turret TP8.) U30 amplifies the signal at TP8 and applies an offset. This produces a voltage swing of -4.5 to +4.5 volts that can be monitored at test turret TP9.

The 5-volt reference generated by U31 is used for the D/A converter reference. Potentiometer R28 is used to set the voltage at TP9 to zero when 8ØH is written to the D/A converter.

c. Voltage Reference. The reference voltage needed to run the A/D and D/A converters is generated by linear voltage reference U31. U31 produces a stable 5-volt output, which can be monitored at test turret TP10.

d. RS-422 Receivers. The differential RS-422 input signals are converted to standard logic by quad RS-422 line receiver U33. U33's outputs are buffered by Exclusive-OR gates in U40. The receive clock signals may be inverted by using jumper J6. This is done to make sure that the clock pulses shift from low to high when the data is stable, assuring proper system operation.

e. DTT Input Circuit. The DDT input signal (P2-13) is applied to U40-1, and a slightly delayed version of the signal is applied to U40-2. This means that the two inputs of the Exclusive-OR gate are different for a short time after any transition of the input signal. The output of the gate (U40-3) will go high whenever a transition occurs in the DDT input signal. This signal is used to trigger the one-shot DTT delay circuit on the main circuit board. The length of the pulse is controlled by R35 and C55. The delayed (filtered) DDT input signal (U41-5) is also read by the microcontroller to determine the present state of the DDT input signal.

f. 16-Bit Shift Register For RS-422 Receivers. The receive clock controls the passing of the incoming RS-422 data at U40-8 into a 16-bit shift register formed from eight-bit shift registers U36 and U37. The parallel outputs from the shift register drive latches on the main circuit board through connector P3. This data is latched each frame time and then read by the microcontroller.

The timing output from the transmit divide-by-N counter is applied to U41-1, along with a delayed version of the signal at U41-2. The output of the NAND gate (U41-3) will create a negative pulse whenever the input signal has a positive transition. This pulse is used to load new transmit data into the shift registers at the beginning of a new transmitted message. The inverted input timing signal (U38-12) also clocks the other flip-flop in U39-11, which is set up as a J-K flip-flop. The Q output (U39-9) controls the alternating frame bit in the transmitted messages.

g. Look-Up Table PROM. The incoming RS-422 data is used to address CRC/frame data in a look-up table stored in EPROM U24. This table makes sure the data is valid before it is processed further. Using the look-up table is faster than generating CRC data, so system response time is shortened.

h. Comparator. The incoming RS-422 data is also fed to comparator U35. The output of the comparator (U35-19) will go low if the actual received CRC/frame bits are correct for the received data bits in the message. This is determined from the look-up table in U24. This output will compare the bits in the shift register as each new bit is shifted in.

i. Flip-Flop. After the input data is framed, the output of the comparator will be latched once each frame into flip-flop U39. It appears at U39-5, where it can be read by U20 to determine the integrity of that message.

j. Frame Generator. One of the flip-flops in U39 serves as a frame generator. Data from the frame generator and the shift register is combined and sent out to the communications channel through RS-422 driver circuitry.

k. RS-422 Drivers. The transmit signal from the transmit shift register on the main circuit board is converted to an RS-422 output signal by quad RS-422 line driver U34. The transmit clock signal may be inverted by using jumper J7. This is done to make sure that the clock pulses shift from low to high when the data is stable, assuring proper system operation.

5.2.3. Software Description

The RFL 9720 software is located in two ROM devices on the RFL 9720 CCM. The software controls how the RFL 9720 CCM handles the communications between RFL 9720 systems. It uses a "ping-pong" test to monitor the communication channel time lapses. The software also monitors the channel integrity by checking for unframed data, CRC errors, and RFL 9720 PAM failures.

In each RFL 9720 system, there are two separate data streams. Each stream has a separate clock, supplied by the RS-422/449 communications channel. The first data stream reads the A/D converter, and compands the data. Then it adds the ping-pong and CRC bits, and places the completed data word in the transmission stream. The transmission hardware adds an alternating frame bit to the data word before transmission.

The other data stream is read on a word-for-word basis, de-companded, and fed to the D/A converter. CRC and frame checking is done in hardware, using a memory chip. Both data streams are interrupt-driven. An interrupt is given to the microcontroller by a counter requesting a new data word. Another interrupt is given to U20 to tell it that a word has been received.

5.2.3.1. Interface Methods

The RFL 9720 software interfaces to the outside world through relays, switches, panel indicators, and the RS-232 and RS-422/449 communications interfaces, as described below.

a. Relay Interfaces. The squelch control, the channel failure, and the channel delay relays are all normally-energized. This means they are pulled in when the RFL 9720 is functioning properly, and drop out when an alarm condition occurs. The direct transfer trip (DTT) relay is driven by enable and drive outputs from microcontroller U20. Both signals must be present before the DTT relay will pull in.

b. Switches. Two 16-position rotary switches on the front of the RFL 9720 CCM are used to set the ping-pong delay warning and failure values. These switches can be adjusted while the RFL 9720 is fully powered and operating. The DELAY TOLERANCE WARNING switch can be set for a delay of 400 μs to 1150 μs (1.15 ms), in 50-μs increments. The DELAY TOLERANCE ALARM switch can be set for a delay of 400 μs to 2900 μs (2.9 ms), in non-linear increments.

c. Indicators. There are five LED indicators on the RFL 9720 CCM front panel; four of them are controlled by software. These indicators show the status of the RFL 9720 CCM:

CPU FAIL indicator DS1
DS1 is OFF when the RFL 9720 CCM is functioning properly. It flashes RED if the microcontroller fails.

CHANNEL indicator DS2
DS2 lights GREEN when good channel data is being received. It changes to RED if a channel failure has occurred because of CRC or frame failure.

DS2 will also glow RED if a failure is detected on the RFL 9720 PAM. If this is the case, POWER AMP FAIL indicator DS1 on the RFL 9720 PAM will also glow RED. (See Section 6.)

DELAY indicator DS3
DS3 lights green if no delay or channel failure has occurred. It changes to YELLOW if the delay time reaches the warning limit. If a channel failure has occurred because of excessive delay, DS3 turns RED.

DTT SENT indicator DS4
DS4 lights RED when a DTT command has been sent to the remote RFL 9720.

DTT RCV indicator DS5
DS5 lights RED when a DTT command has been received from the remote RFL 9720 and the DTT relay is energized.

All indicators on the RFL 9720 CCM except CPU FAIL indicator DS1 remain in their "worst case" condition until TARGET RESET switch SW4 on the front of the RFL 9720 CCM is pressed. CHANNEL indicator DS2 and DELAY indicator DS3 can have their reset function disabled by the setting of a jumper on the motherboard. (See para 3.3.4 in Section 3 for more information on this jumper.) These indicators will then always display the current channel condition of the RFL 9720 CCM. Table 5-1 shows how these indicators will look for various channel conditions.

d. RS-232 Connectors. The RFL 9720 has two RS-232 connections. The first is on the RFL 9720 CCM board, and is used for diagnostics. The second is wired to a connector on the back of the RFL 9720 CCM I/O module, and reserved for future use.

5.2.3.2. Resetting The RFL 9720 CCM

Microcontroller U20 is reset when power is applied to the RFL 9720 CCM. In addition, there is a watchdog timer on the RFL 9720 CCM that must be periodically toggled by U20-39. If it is unable to do so (either because of a hang-up or a loss of power), the watchdog timer will reset U20. U20 also monitors the RFL 9720 CCM for internal problems. If it senses that the board has lost its operational state, U20 will initiate its own reset.

a. Reset Condition. When the RFL 9720 CCM is reset, CPU FAIL indicator DS1 is lit. The control relay is in squelched condition, the channel delay and fail relays are de-energized (active), and the CHANNEL indicator is red.

b. Reset Recovery. During reset, the internal interrupt vectors and microcontroller configuration are restored, the stack pointer is reset, and the internal RAM is cleared. Some diagnostic tests are run to check the integrity of microcontroller U20 and its EPROM memory devices. If U20 cannot be reset or fails its diagnostic routines, the reset condition is maintained. CPU FAIL indicator DS1 will stay lit.

Table 5-1. RFL 9720 CCM indicator status for various channel conditions

Status	CPU FAIL Indicator DS1	CHANNEL Indicator DS2	DELAY Indicator DS3	DTT SENT Indicator DS4	DTT RCV Indicator DS5
Normal	OFF	GREEN	GREEN	OFF	OFF
Channel Delay	OFF	GREEN	YELLOW	OFF	OFF
Channel Failure Due To Delay	OFF	RED	RED	OFF	OFF
Channel Failure Due To Unframed, No Clock, CRC, or PAM Failure	OFF	RED	(1)	OFF	OFF
Direct Transfer Trip	OFF	(2)	(3)	(4)	(5)
CPU Failure	(6)	OFF	OFF	OFF	OFF

1. Whatever state this indicator was in at the beginning of the failure. In addition, the PAM FAIL indicator on the RFL 9720 PAM Power Amplifier Module may light, and then go out when squelched.
2. This indicator will show the state of the channel, disregarding the DTT.
3. This indicator will show the state of the delay, disregarding the DTT.
4. This indicator will be RED as long as the DTT INPUT is active, and for the Command Extend period.
5. This indicator will be RED if a DTT signal was received from the remote station and the DTT relays are energized.
6. This is a RED indicator that will flash on and off if a CPU failure occurs. It flashes because the RFL 9720 CCM's watchdog timer will keep trying to restart the CPU.

Resetting U20 will return the RFL 9720 CCM to its operational state, unless a hardware failure has occurred. During reset, some of the peripheral devices are reprogrammed. Divide-by-N counter U11 is used as a counter for framing the receive and transmit data streams, and as a timer for the DTT signal. Buffer U17 accepts inputs from RS-232 port configuration DIP switch SW1 and DELAY TOLERANCE switches SW2 and SW3. It also feeds outputs to the alarm and DTT relays.

During reset, the RFL 9720 CCM will pause for about one second to allow the Power Amplifier Module to stabilize.

c. RS-232 Communications. Another integrated circuit programmed during reset is the Dual Asynchronous Receiver/Transmitter (DUART). The two RS-232 interfaces are driven by the DUART. It is programmed according to the setting of DIP switch SW1. The DIP switch settings are as follows:

(1) Baud Rate Selection. SW1-1 through SW1-3 work together to set the desired baud rate. (See para 3.3.3 in Section 3 for settings.) Normally, these switch sections are set at the factory for 9600 baud (SW1-1 ON, SW1-2 and SW1-3 OFF).

(2) Parity Selection. SW1-4 and SW1-5 work together to set the desired parity (See para 3.3.3 in Section 3 for settings.) Normally, SW1-4 and SW1-5 are set at the factory for even parity (SW1-4 ON, SW1-5 OFF).

(3) Bits/Character Selection. SW1-6 sets the desired number of bits per character. If seven bits/character is desired, SW1-6 is placed in the ON position; it is placed in the OFF position if eight bits/character is desired. Normally, SW1-6 is set at the factory for seven bits/character (ON).

(4) Stop Bit Selection. SW1-7 sets the desired number of stop bits per character. SW1-7 is set to the ON position for one stop bit/character, or the OFF position for two stop bits/character. Normally, SW1-7 is set at the factory for one stop bit/character (ON).

(5) Handshake Selection. SW1-8 determines whether RTS/CTS handshaking will be used. To disable handshaking, set SW1-8 to the ON position; place SW1-8 in the OFF position if RTS/CTS handshaking will be used. Normally, SW1-8 is set at the factory for no handshaking (ON).

5.2.3.3. Initialization

The following steps are taken in software to initialize the RFL 9720 CCM when the RFL 9720 is first turned on. These steps are also taken when the POWER switch on the RFL 9720 PM Power Module is cycled. Comments are indented and appear in **boldface** type.

1. Disable all interrupts.

2. Load initial values into the following special function registers:
   Stack Pointer.
   Interrupt mask.
   PTS mask.

3. Initialize RAM.
   RAM is initialized in the "squelch mode," with the squelch control and channel failure alarm relays de-energized (active).

4. Run the following diagnostic checks:
   Microcontroller integrity test.
   Parity check on EPROM.

5. Initialize the following programmable devices:
   Divide-by-N counter U11.
   Programmable interface U17.

6. Read jumper and DIP switch settings.
   DELAY TOLERANCE WARNING switch SW2.
   DELAY TOLERANCE ALARM switch SW3.
   DTT COMMAND EXTEND jumper J4.
   DUART configuration DIP switch SW1.

7. Program the DUART, based on the settings of DIP switch SW1.

8. Energize the PAM power relay, and wait for the RFL 9720 PAM to stabilize.

9. Enable all interrupts except the receive interrupt.
   The receive interrupt will be enabled after a successful framing.

10. Start executing the MAIN loop.
    The channel communications have not been established at this point. The check-off for communications is done as part of the ordinary operation. The system gives the communications one additional second (beyond power amplifier stabilization) to establish itself before latching the two communication indicators.

5.2.3.4. Normal Operations (MAIN Loop)

The MAIN loop is the subroutine that microcontroller U20's software remains in until a reboot or power-up condition is received. It executes some background functions, while interrupt routines transmit and receive data. The various portions of the MAIN loop are described below.

a. Check Channel Communications. The channel check software is used to test the communications channel between the local and remote terminals. Any of the following can result in a channel failure:

Corrupted Data

The communications channel can produce corrupted data. This can be caused by the remote terminal not being on-line, excessive noise on the channel, or a channel outage. The CRC and frame validation check is used to detect this condition.

When 16 out of 32 received words fail validation, the channel has failed. After this condition is detected, the system must attempt to re-frame until the system passes CRC and frame validation. The system must then receive 40 more good messages in a row after framing to go back on-line. This is done to make sure that the system does not keep moving in and out of squelch. During this form of channel failure, CHANNEL indicator DS2 is red. The channel failure alarm relay is de-energized (active), and output to the protective relay is squelched by de-energizing the squelch control relay.

Loss Of Transmit Or Receive Clocks

The RFL 9720 CCM constantly monitors the transmit and receive clocks. The software is interrupt-driven from these clocks; if they are lost, proper operation cannot continue. The transmit clock is monitored simply to assure that it exists. If the receive clock has not caused an interrupt within the correct data word transmission time, it is considered the equivalent of a frame/CRC failure.

Failure Indication From Remote Terminal

If the remote terminal detects corrupted data, it will continually set its ping-pong bit. (See page 5-11 for a discussion of ping-pong operation). The local RFL 9720 CCM will de-energize the squelch control relay, the CHANNEL indicator will light red, and the channel failure alarm relay will drop out.

Excessive Channel Delay

Channel failure will also occur if the delay in transmission becomes excessive, as evaluated by a ping-pong test. The squelch control relay, the channel failure alarm relay, and the ping-pong failure alarm relay will all drop out. The CHANNEL and DELAY indicators will light red under these conditions. The local terminal will set the outgoing ping-pong bits true for twenty data words, or enough to cause the remote terminal to go into squelch. It will then cease setting ping-pong bits true. At this point, both the local and remote terminals will attempt to go out of squelch by running ping-pong tests. They should both almost simultaneously have passing tests (since the calculated channel delay values will be equal), and move out of squelch.

RFL 9720 PAM Failure

If the RFL 9720 PAM fails, it sends a PAM FAILURE input to microcontroller U20-11 on the RFL 9720 CCM. U20 will monitor this input for PAM failure. (See page 5-11 for more information.) POWER AMP FAIL indicator DS1 on the RFL 9720 PAM lights. This condition is handled in the same manner as a total channel failure. The failed RFL 9720 CCM will send a steady stream of set ping-pong bits to the remote RFL 9720 CCM until the PAM failure is cleared. The RFL 9720 CCM will monitor the PAM FAILURE input; if it is reset for another 10 ms, the RFL 9720 CCM will move out of squelch.

(1) TARGET RESET Switch. A jumper on the motherboard selects whether the CHANNEL and DELAY indicators are latched into their worse-case conditions. This jumper setting is read after each reset. If the default configuration is set, the indicators can be reset by the TARGET RESET switch on the front of the RFL 9720 CCM; if this switch is not pressed, the indicators will automatically reset as soon as conditions clear. While the RFL 9720 CCM is running its initialization routine (about two seconds), the indicators are not latched.

(2) Applying Squelch To The Protective Relay. Just after the squelch relay drops out, the output of the local A/D converter is applied to the input of the D/A converter. This is done until the relay contacts have stabilized. 150 ms after a channel failure is detected, the unblock relay will also drop out. If the squelch was not caused by a channel failure, the unblock relay will drop out immediately after the squelch relay's contacts have stabilized.

(3) Removing Squelch From The Protective Relay. The following sequence of events occurs when the RFL 9720 is coming out of a squelch mode caused by a loss of communications:

1. Each RFL 9720 CCM sends the other a special data value as long it fails any of the unsquelching tests. This data value can be used to establish communications between CCM modules and run various checks. The first test is for framed data with little or no data corruption, as measured by CRC checks.

2. The transmission clock also must be present.

3. After reset or a PAM failure, the PAM AMP FAIL signal must remain false for 10 ms.

4. After every squelch condition, the RFL 9720 CCM will request ping-pong checks until the ping-pong value is less than the failure level.

5. A DTT condition will cause the system to remain in squelch. The channel check must then wait for the DTT condition to clear before continuing the unsquelch process.

6. Once all other tests have been passed, the RFL 9720 CCM will change its outgoing data value to another special value. It will then wait until it receives this special value from the remote as well. This will mean that both CCM modules are ready to go out of squelch together.

7. After the squelch control relay's contacts have stabilized, the unblock relay will pull in again.

If the communications fail, the ping-pong test fails, or the incoming data shows that the remote has failed, the process of "unsquelching" the local protective relay will return to that step in the unsquelching process. The channel will continue to be squelched or returned to squelch if needed.

A DTT will override all other considerations for both input to and output from the RFL 9720 CCM. Once the incoming data has been successfully framed (step 1 above), six successive DTT signals will cause the DTT output drivers to be energized, without either passing a ping-pong check or a removal of the squelch condition. If a DTT input is sensed, the outgoing data word will be the DTT signal instead of the special squelch signal. If the local CCM is still in channel failure, the ping-pong bit will be set.

(4) Framing And Re-Framing. Before entry into the frame-up routine, the CCM will be in the squelch mode, with the squelch control and channel failure relays de-energized. The DELAY indicator will be green. The CHANNEL DELAY alarm relay and the DTT indicators and drivers will remain in their current condition. The following sequence of events occurs during framing or re-framing:

1. A word that indicates channel failure (with the ping-pong bit set to "1") is written to the output shift register. This is usually the squelch signal value; if a DTT is active, the DTT value will be written to the register.
2. The receive word and transmit word interrupts are disabled for duration of framing.
3. The CCM will attempt to frame input data words by searching for ten consecutive data words that pass frame and CRC checking; this checking is done in receipt hardware.
4. If frame-up is successful, the receive interrupt will be enabled.
5. The transmit interrupt is restored, even if framing was unsuccessful. The system will process other checks (DTT, diagnostics, etc), and then try to frame again if needed.

(5) Ping-Pong Test Bit. The ping-pong bit has two main functions. It can request a ping-pong test, or reply to a ping-pong test request generated by the remote CCM. It can also inform the remote CCM of a channel failure.

Ping-Pong Test Request/Reply

When the ping-pong bit is used to request a ping-pong test or reply to a ping-pong request, request and reply bits will not interfere with each other. Because of this, both functions can be done simultaneously.

The ping-pong reply is a value that represents the time needed to send the reply on the proper frame at the remote. In this mode, a CCM requests a ping-pong calculation by setting the next positive frame transmittal ping-pong bit to "1." This is followed by a specific pattern (0 - 1 - 0 - 1), so that a transmission error cannot start a ping-pong test. The reply comes on zero frame-value input data words, one bit at a time in the ping-pong bit, starting with a "1" followed by ten bits and stopping with another "1."

The calculated channel delay is one half of the time from the transmission of the start ping-pong test output word to the receipt of the first ping-pong reply input word minus the frame time value sent in later input word receipts. Figure 5-3 shows the relationship between outgoing and incoming ping-pong bits, as seen by the requesting CCM. Figure 5-4 shows the relationship between incoming and outgoing ping-pong bits, as seen by the replying CCM.

The channel delay is compared to a delay value and a failure value. These values are set by the DELAY TOLERANCE switches on the front of the CCM. After reset or a channel delay failure, the delay failure value is 25 μs lower than the switch value. This creates a hysteresis, in which the channel fails with a larger delay than when it is restored. The hysteresis prevents the channel from going in and out of squelch because of minor calculated delay variations. The microcontroller obtains the initial value of these switches when booting, and monitors the switches for changes in the MAIN loop.

Channel Failure Notification

The ping-pong bit is also used to inform the remote CCM of any channel failure. In this mode, the ping-pong bit is constantly set until the local end gets valid data from the remote. When the local CCM receives four or more consecutive incoming words with the ping-pong bits set, it will assumed that the remote has failed and it will squelch the local protective relay.

(6) Check PAM For Failure. The software monitors the PAM FAILURE input. If a failure is detected on the RFL 9720 PAM and its POWER AMP FAIL indicator (DS1) has been lit for 10 ms, the channel will fail. The red CHANNEL indicator on the CCM will light, and the CHANNEL FAILURE alarm relay will drop out. The DELAY indicator, the CHANNEL DELAY alarm relay, and the DTT indicators and drivers will remain in their current condition.

During an actual fault condition, the RFL 9720 PAM may be overdriven and indicate a failure. U20 will reset the 10-ms timer whenever the output signal to the D/A converter moves beyond the 3.0 V_{rms} steady-state level accepted by the RFL 9720 PAM. This is done to avoid having the system squelch the protective relay prematurely. Once the PAM failure has been cleared for 10 ms, the squelch condition is removed. (See page 5-10 for details.) The POWER AMP FAIL indicator on the RFL 9720 PAM does not latch in its failure condition.

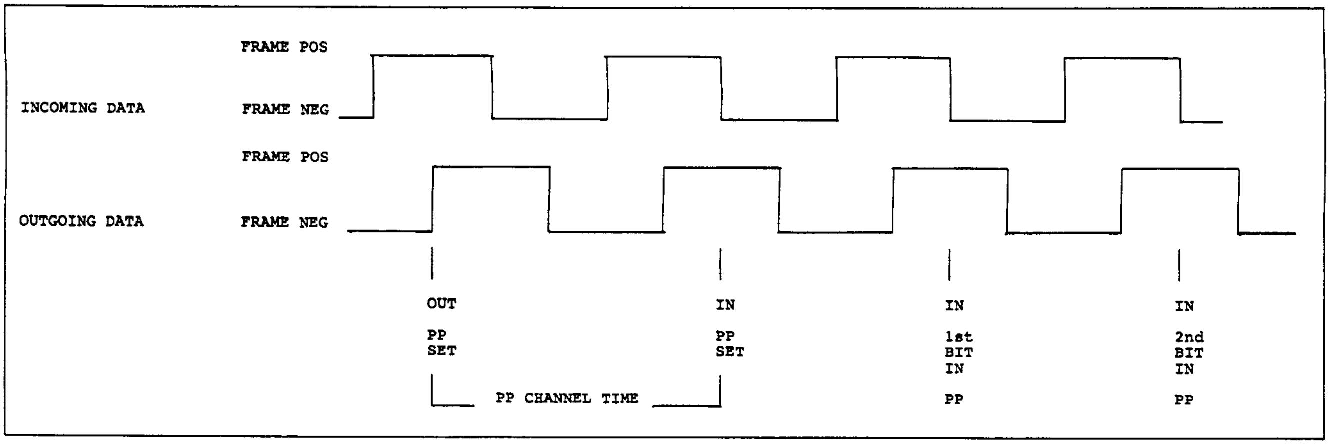


Figure 5-3. Relationship between outgoing and incoming ping-pong bits, as seen by requesting CCM

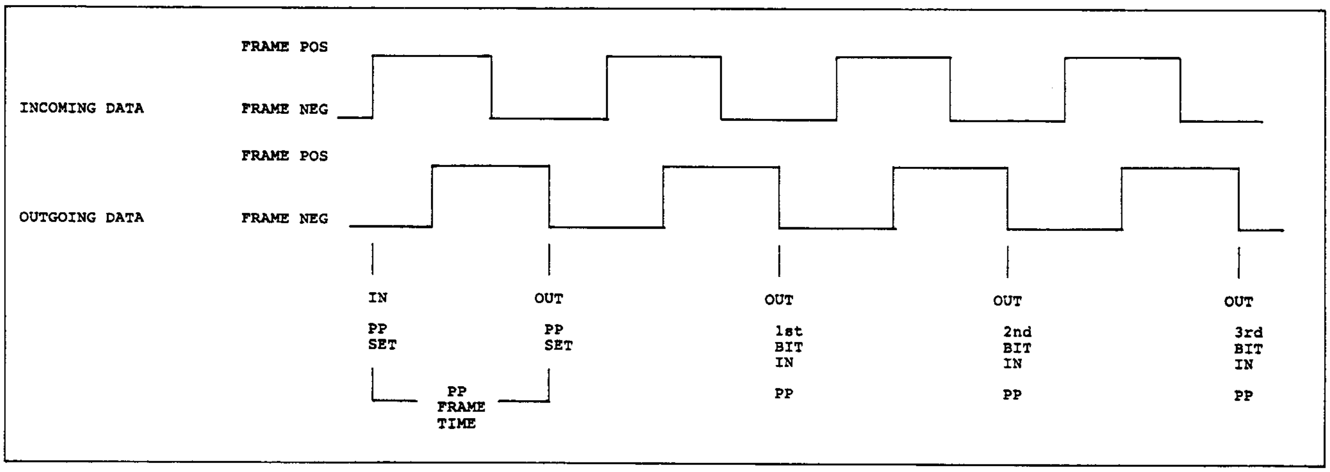


Figure 5-4. Relationship between incoming and outgoing ping-pong bits, as seen by replying CCM

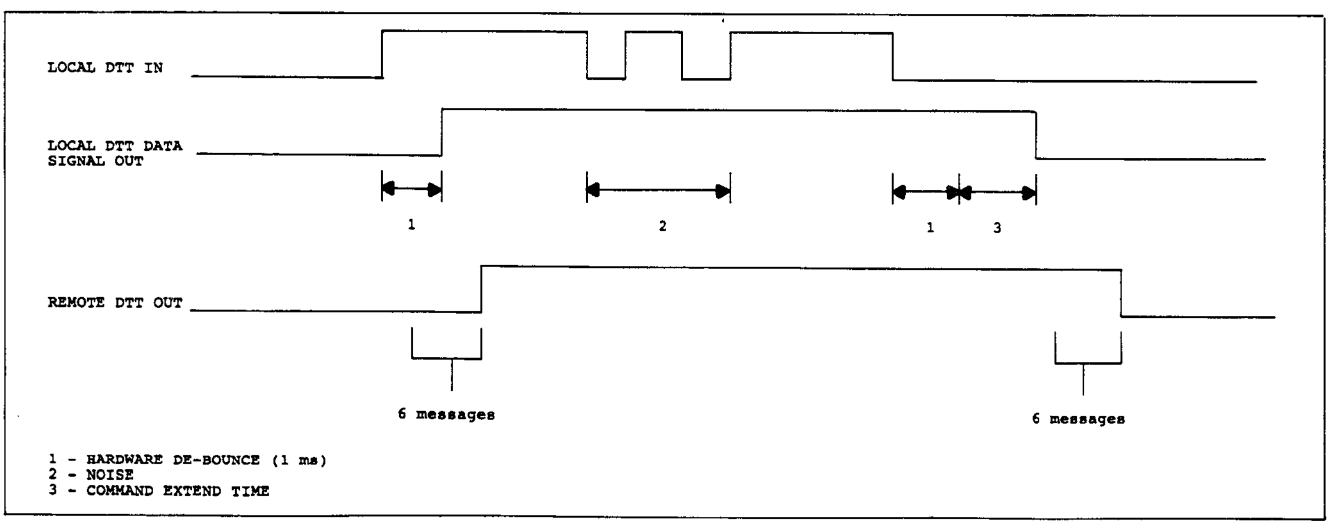


Figure 5-5. Relationship between local DTT IN signal, outgoing signals to remote, and remote DTT OUT signal

The RFL 9720 PAM may fail so that it cannot pass a signal, but return to an "unfailed" state whenever it is not driven by the D/A converter. If the RFL 9720 PAM moves from nonfailure to failure twenty or more times within three seconds, the RFL 9720 system will fail permanently. It will have to be manually reset by removing and re-supplying power to the unit. In addition, this failure will occur if the RFL 9720 PAM is overdriven for more than 200 ms, since a true fault would have already caused a protective trip. This will also happen when the PAM FAILURE input does not clear after 2 seconds, even though squelch has occurred. These are considered permanent PAM failures, and the system will not recover (go out of squelch). When a permanent failure occurs, the PAM power control relay will also drop out.

b. Detect DTT (Direct Transfer Trip) Signal. The Direct Transfer Trip signal is fed to the local CCM for transmission to the remote. The local CCM will replace the ordinary transmission of data with a special DTT signal until the DTT input is removed. The Command Extend value will lengthen the transmission of the DTT beyond the removal of the DTT input.

The protective relay must be squelched during the receipt of a DTT signal, as the ordinary data signal is overwritten. Because of this, the transmitting side also must go into squelch to match the receiving side. Each side remains in squelch until the DTT input signal is removed.

Figure 5-5 shows the relation between the DTT input signal, the local CCM outgoing signals to the remote, and the remote DTT output. The diagram is not drawn to scale.

(1) Monitoring The DTT Input. Before the DTT input is processed by the microcontroller, it is debounced for 1 ms in hardware. This debouncing is done on both transitions, so U20 does not need to service the DTT interrupt more than once every 1 ms. The DTT interrupt sets the trip flag on a false-to-true transition, and the reset flag on a true-to-false transition.

If the trip flag is set, the DTT transmit flag is set and the DTT SENT indicator lights. On the next transmit out interrupt, the DTT signal is substituted for the A/D converter reading.

If the transmit flag and the reset flag are set, the transmission of the DTT signal is extended. The amount of extension is based on how Command Extend jumper J4 is set (2 ms, 5 ms, 8 ms, or 11 ms). If the trip flag goes true during timeout, the timeout must start over.

If the reset flag is set and the TARGET RESET switch has been pressed, the DTT SENT indicator will go out.

(2) Monitoring The DTT Data Signal. If the last received word was a DTT signal, the DTT start counter will be incremented and the DTT end counter will be reset. If the word was not a DTT signal or if it failed CRC checking, the DTT start counter will be reset. This will insure that the DTT signal is "secure," as a DTT is a major disruption in transmission. However, under very noisy conditions, the DTT will be delayed. (The DTT signal will be processed even if the RFL 9720 system is in squelch because of noise). If the word was not a DTT signal but passed the CRC checking, DTT end counter will be incremented.

When the DTT start counter reaches six, the DTT relay will pull in and the DTT RCV indicator will light. When the DTT end counter reaches six, the DTT relay will drop out. When the user presses TARGET RESET switch SW4, the DTT received indicator will go out if the DTT input is inactive.

c. Calculate D/A Converter Values. If a CRC error or a DTT signal is received, but less than the number needed to fail the channel or cause a DTT, microcontroller U20 still outputs a signal to the D/A converter. This routine calculates the signal; the inverted value of the last A/D decoding (180 degrees out of phase) is normally used. A jumper on the motherboard can be set to use the same value as the in-phase A/D converter input. (See paragraph 3.3.4 in Section 3 for more information on this jumper.) Just after a squelch, this signal is continued until the squelch relay's contacts are fully opened.

d. Diagnostic Test Routines. Test program functions are commanded by input through the diagnostic RS-232 port on the CCM. The test functions are requested by typing in a single upper-case character; no carriage return/line feed is needed. Some test functions return a value to the diagnostic port while the CCM is in normal operation.

(1) Latest Ping-Pong Test Values. These values are requested by transmitting a "P" to the diagnostic port. The two values returned are the latest calculated ping-pong test result and the maximum test result. The maximum test result is reset by pressing TARGET RESET switch SW4. If CHANNEL and DELAY indicator latching is disabled, the maximum ping-pong value will be the same as the current value.

(2) Communications Integrity. Communications integrity is measured by the number of CRC errors. This measurement is requested by transmitting a "C" to the diagnostic port. The integrity is displayed as the ratio between data words that failed the CRC test versus total words received. The CRC measurement is updated about once every 15 seconds.

(3) Switch Settings. Transmitting an "E" to the diagnostic port will produce the following information:

1. The settings of DIP switch SW1, formatted as follows:

   Baud rate (**50**, **300**, **600**, **1200**, **2400**, **4800**, **9600**, or **38400**)
   Parity (**N**o, **E**ven, or **O**dd)
   Number Of Bits (**7** or **8**)
   Stop Bits (**1** or **2**)
   Handshaking (**RTS/CTS** or **NO H**and**S**haking)

2. The setting of front-panel WARNING switch SW2, in microseconds (µs).

3. The setting of front-panel ALARM switch SW3, in microseconds (µs).

4. The setting of Command Extend jumper J4, in milliseconds (ms).

(4) System Status. The system status is requested by transmitting a "Q" to the diagnostic port. The state of the channel and the DTT are transmitted in reply. This is done automatically whenever a squelch occurs after start-up.

(5) RFL 9720 Diagnostic Tests. Some test functions place the RFL 9720 in a test mode. While in the test mode, communications are disabled. The CHANNEL indicator will blink red and green to show that the CCM is in the test mode. The local CCM notifies the remote by setting the ping-pong bit true in a static outgoing word (either a zero voltage level or a DTT signal).

When the remote receives the ping-pong bit, it will go into the squelch mode. While in squelch, the squelch, unblock, and PAM power control relays are all de-energized.

The diagnostic tests are halted by transmitting an "S" to the diagnostic port.

Input To D/A Converter

The A/D converter is continually read and the reading is placed on the D/A converter. This is the true, eight bit, uncompanded value. This test is requested by transmitting an "A" to the diagnostic port. The system is in squelch during this test.

Triangle Wave

A triangle wave covering the full extent of the D/A converter ($\pm$4.5 V_{peak}) is output. This test is requested by transmitting a "T" to the diagnostic port. The system is in squelch during this test.

Zeroing The D/A Converter

A zero voltage level is written to the D/A converter. This test is requested by transmitting a "Z" to the diagnostic port. The system is in squelch during this test.

Sine Wave

A $\pm$1.5-V_{p-p} sine wave is generated within the RFL 9720 CCM's software. This test is requested by transmitting a "V" to the diagnostic port. The system is not in squelch during this test.

(6) Testing The Watchdog Timer. The diagnostic port can be used to test the watchdog timer by transmitting a "W." The CCM software will go into an infinite loop. This will eventually cause the watchdog timer to time out and reset the microcontroller. CPU FAIL indicator DS1 will be momentarily lit. The microcontroller will reset as usual. There is no need to stop this test as the reset removes the test condition.

This test will remove a permanent PAM failure condition.

e. Process RS-232 Input Routine. The RS-232 input routine is for future use. For now, a character transmitted to the RS-232 port on the RFL 9720 CCM I/O will be echoed back.

f. Read The Panel Switch Settings. The DELAY TOLERANCE WARNING and ALARM values are set using front-panel rotary switches SW2 and SW3. When WARNING switch SW2 is set to "0," the value is 400 µs. The warning value increases by 50 µs per switch increment for a maximum of 1150 µs when the switch is set to position "F." The values for ALARM switch SW3 do not increase evenly; it can be set to 16 different values, from 400 µs to 2900 µs. The switch settings can be changed at any time without resetting the CCM. Microcontroller U20 will monitor these settings at least once a second. (See para 3.3.3 in Section 3 for more information on these switches.)

g. Reset The Watchdog Timer. The microcontroller will retrigger the watchdog timer for each loop in MAIN. Failure to retrigger the watchdog timer will cause it to reset microcontroller U20.

5.2.3.5. RS-422 Communications

The RS-422/449 communications with the remote CCM are interrupt driven. This insures that the pilot wire data is updated as quickly as the communications channel will allow. Other CCM functions that form part of the MAIN loop (RS-232 communications, PAM FAIL monitoring, and DTT monitoring) are of lower priority.

a. Read A/D Converter And Transmit. The interrupt will occur at a point that will allow just enough time for the following functions to occur:

1. The analog-to-digital (A/D) converter input is converted to digital data.

2. The digital data is read and companded.

3. The ping-pong value is added. The SCRAM code and CRC value are added by using a look-up table.

4. The resulting data word is written to the transmit port before being transmitted.

During the execution of this interrupt, the hardware is transmitting the frame bit. The time required for entry into subroutine until the data word is written to the port must be less than the time needed to transmit one data bit over the RS-422/449 interface.

If the frame bit is zero, the ping-pong bit is one, and this is the first word of the ping-pong reply, the interrupt will capture the time and set the ping-pong end frame time. The rest of the ping-pong frame time is then transmitted out one bit at a time on zero-frame bit words. It is finished by setting the last ping-pong bit to one. If the frame bit and the ping-pong bit are both ones, the interrupt will capture the time and set the ping-pong message begin time.

b. Receive Data And Write To D/A Converter. The time required to receive the next data word and write it to the D/A converter is not as critical as transmit time. The process must be done as quickly as possible, but it can be interrupted to process the A/D converter signal.

The input word is read from the RS-422/449 interface. The input word is de-companded by a look-up table and sent to the D/A converter if it meets the following conditions:

1. The CRC and frame bits are valid.

2. The control relay is not squelched.

3. The system is not in DTT.

4. The input word is not a DTT signal.

If the input word fails the CRC and frame check, or is a DTT signal (without the DTT condition), the calculated value is used instead of the received word. If the system is squelched or in a DTT condition, a zero-volt signal is sent to the D/A converter.

If the frame bit and ping-pong bit are both ones, the interrupt will capture the time and set the ping-pong begin frame time. If the frame bit is zero and the ping-pong bit is one, the interrupt will capture the time and set the ping-pong message end time.

Table 5-2. Replaceable parts, RFL 9720 CCM Communications And Control Module main circuit board Assembly No. 104211

Circuit Symbol (Figs. 5-6 and 5-7)	Description	Part Number
	CAPACITORS	
C1-23,27,28	Capacitor,ceramic,0.1µF,GMV,50V,Centralab CY20C104P or equiv.	1007 1366
C24,26	Capacitor,tantalum,15µF,20%,20V,Kemet T322D156M020AS or equiv.	1007 716
C25	Capacitor,tantalum,33µF,10%,10V,Kemet T322D336K010AS or equiv.	1007 1142
C29,30	Capacitor,ceramic,5pF,10%,100V,Murata RPA10COG050K100V or equiv.	0125 10501
C31,32	Capacitor,ceramic,22pF,5%,100V,AVX SA101A220JAA or equiv.	0125 12205
	RESISTORS	
R1-3,7	Resistor,metal film,140Ω,1%,1/4W, Type RN1/4	0410 1206
R4	Resistor,metal film,1KΩ,1%,1/4W, Type RN1/4	0410 1288
R5,6	Resistor,metal film,221Ω,1%,1/4W, Type RN1/4	0410 1225
R8-10,41-43	Resistor,metal film,10KΩ,1%,1/4W, Type RN1/4	0410 1384
R11	Resistor,metal film,499KΩ,1%,1/4W, Type RN1/4	0410 1547
RZ1-9	Resistor network,nine 10KΩ 2% resistors,1.25 W total,10-pin SIP, Bourns 4310R-101-103 or equiv.	32622
	SEMICONDUCTORS	
DS1,4,5	Light-emitting diode,red,right-angle PC mount,extended length, Industrial Devices 5300H1 or equiv.	99294
DS2,3	Light-emitting diode,red/green,high-intensity,PC-mount,Dialight 550-3006 or equiv.	102801
U1	MOS quad buffer/line driver,14-pin DIP,Signetics 74HC125N or equiv.	0615 292
U2	MOS dual D-type flip-flop w/preset and clear,14-pin DIP, National Semiconductor MM74HC74N or equiv.	0615 166
U3	Microprocessor supervisor,8-pin DIP,Maxim MAX690EPA or equiv.	0635 27
U4	MOS triple 3-input NAND gate,14-pin DIP,Motorola MC74ACT10N or equiv.	0615 377
U5,6	MOS hex inverter,14-pin DIP,National Semiconductor MM74HC04N or equiv.	0615 185
U7	MOS quad 2-input OR gate,14-pin DIP,Motorola MC74ACT32N or equiv.	0615 386
U8,12	EPROM,8K x 8,factory-programmed	Contact factory
U9	MOS 1-of-8 line decoder,16-pin DIP,Motorola MC74ACT138N or equiv.	0615 388
U10,42	Transistor array,Darlington,high-voltage,high-current,18-pin DIP, Sprague ULN2803A or equiv.	0720 7
U11	Programmable interval timer,24-pin DIP, Intel TP82C54-2 or equiv.	0635 35
U13,23	MOS shift register,8-input w/input flip-flop,16-pin DIP,Motorola MC74HC597N or equiv.	0615 374
U14	MOS DUART,40-pin DIP,Signetics SCN2681AE1N40 or equiv.	0615 392

Table 5-2. Replaceable parts, RFL 9720 CCM Communications And Control Module main circuit board - continued.

Circuit Symbol (Figs. 5-6 and 5-7)	Description	Part Number
	SEMICONDUCTORS - continued.	
U15,16	RS-232C line driver/receiver,16-pin DIP,Motorola MC145406 or equiv.	0680 8
U17	Programmable peripheral interface,40-pin DIP,Harris IP82C55A or equiv.	0635 21
U18,19	MOS octal tri-state D-type latch,20-pin DIP,Texas Instruments SN74HC573N or equiv.	0615 308
U20	CHMOS microcontroller,16-bit/16-MHz,ROM-less,68-pin PLCC package, Intel TN80C196KC-16 or equiv.	0615 384
U21,22	MOS octal latch,tri-state,20-pin DIP,Motorola MC74ACT573N or equiv.	0615 382
	MISCELLANEOUS COMPONENTS	
SW1	Switch array,8-position,16-pin DIP,AMP 5-435166-3 or equiv.	38933
SW2,3	Switch,rotary,16-position hexadecimal complement code,Kel-Am KDS 16-122 or equiv.	94841
SW4	Switch,SPDT,momentary pushbutton,right-angle PC mount,0.4A @ 20V (ac or dc), C&K Components EP12-D1-A-B-E or equiv.	98488
Y1	Crystal,quartz,16.000 MHz	30297
Y2	Crystal,3.686400 MHz	102803
. . .	Shorting bar,single,Molex 90059-0009 or equiv.	98306

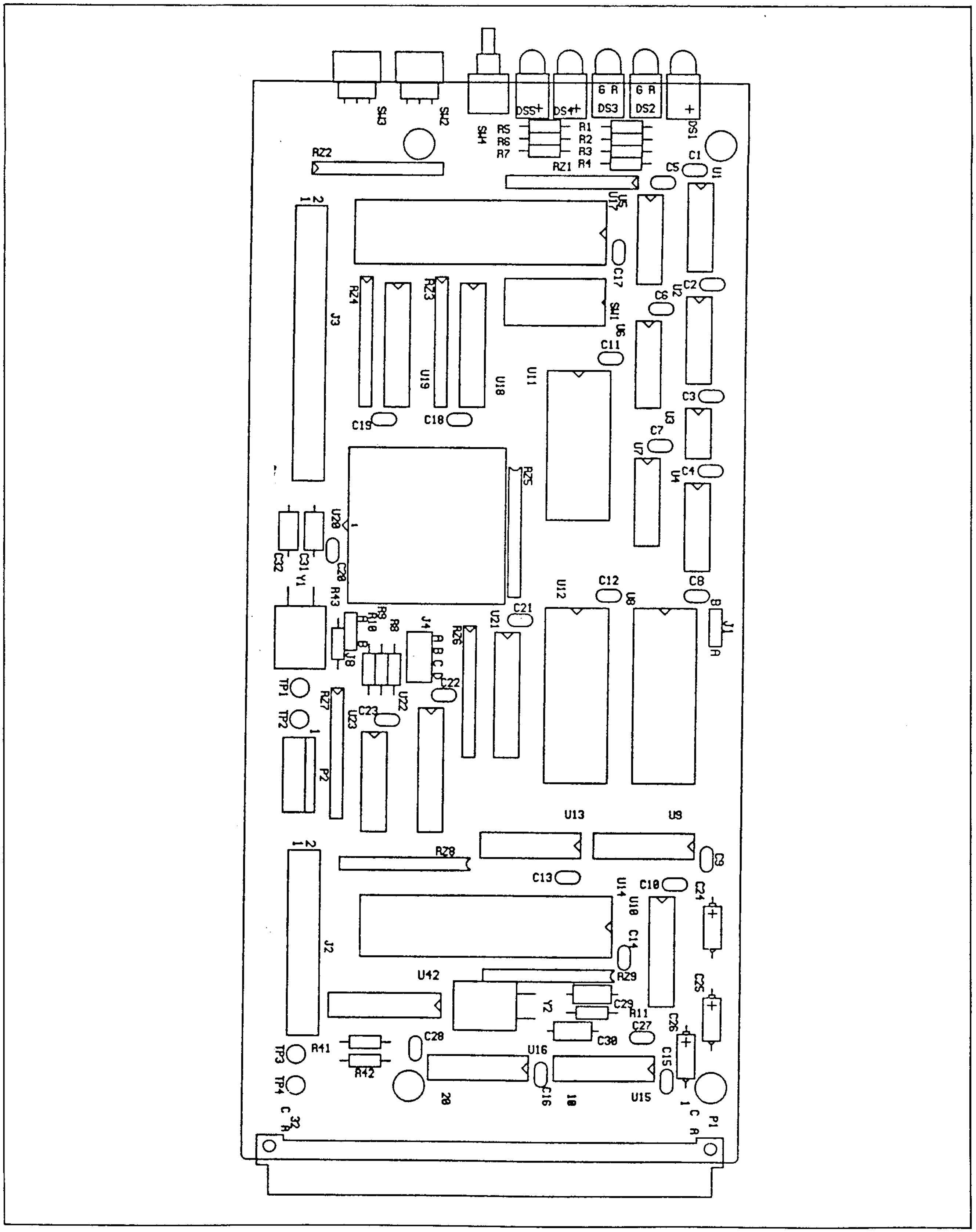
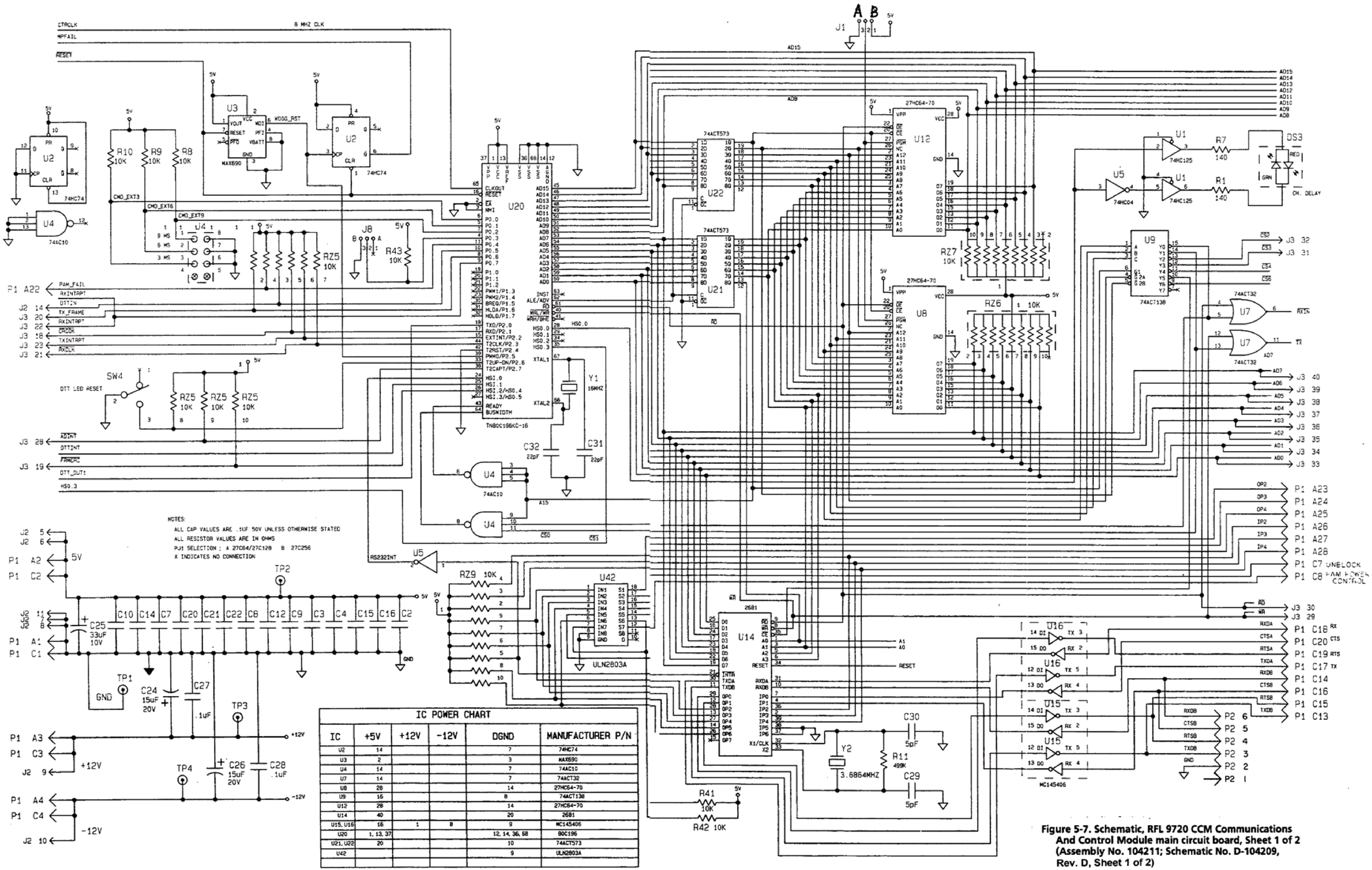


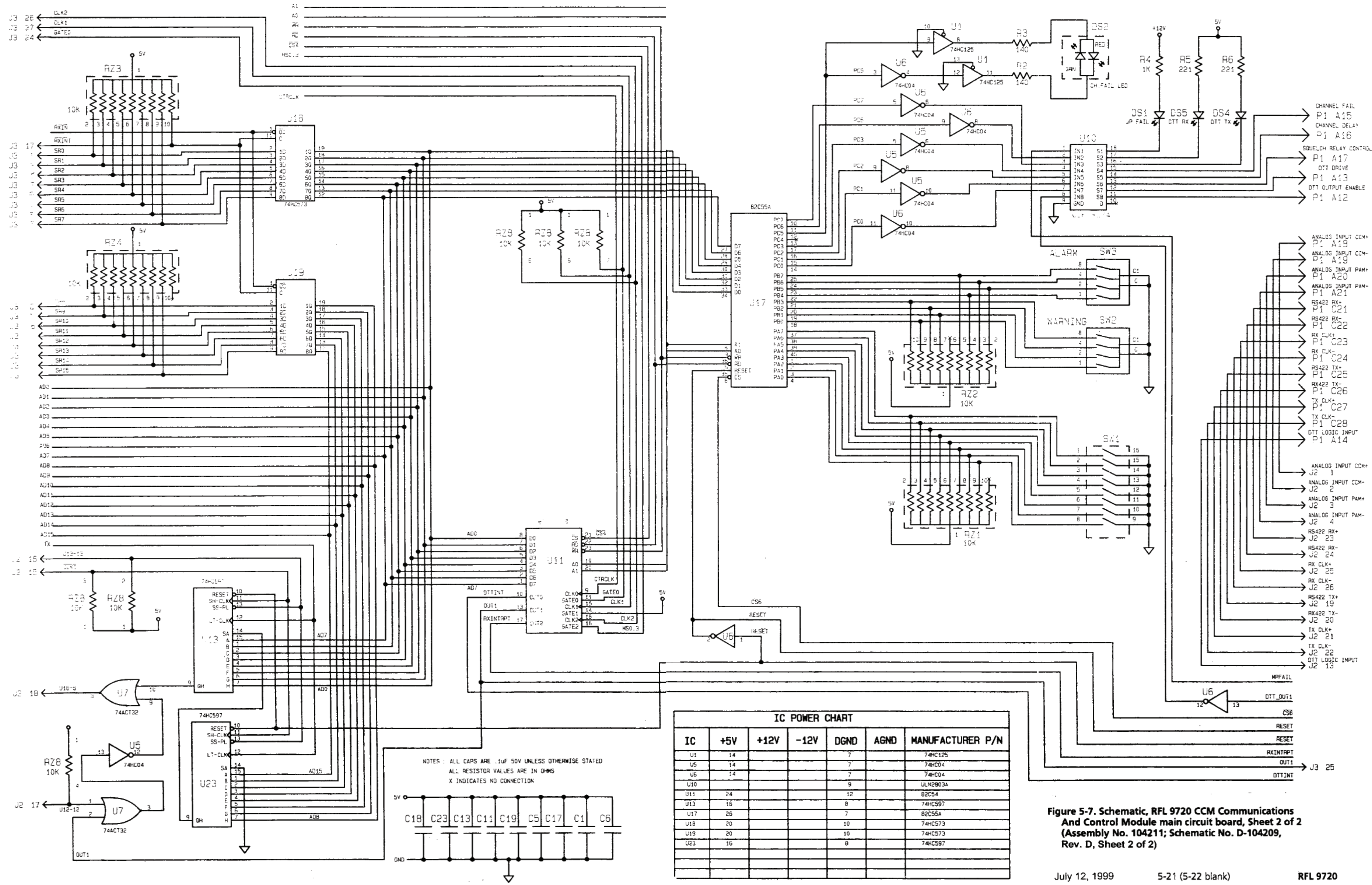
Figure 5-6. Component locator drawing, RFL 9720 CCM Communications And Control Module main circuit board (Assembly No. 104211; Drawing No. D-104208, Rev. B)



IC POWER CHART

IC	+5V	+12V	-12V	DGND	MANUFACTURER P/N
U2	14			7	74HC74
U3	2			3	MAX690
U4	14			7	74AC10
U7	14			7	74ACT32
U8	28			14	27HC64-70
U9	16			8	74ACT138
U12	28			14	27HC64-70
U14	40			20	2681
U15, U16	16	1	8	9	MC145406
U20	1, 13, 37			12, 14, 36, 68	80C196
U21, U22	20			10	74ACT573
U42				9	ULN2803A

Figure 5-7. Schematic, RFL 9720 CCM Communications And Control Module main circuit board, Sheet 1 of 2 (Assembly No. 104211; Schematic No. D-104209, Rev. D, Sheet 1 of 2)



IC POWER CHART						
IC	+5V	+12V	-12V	DGND	AGND	MANUFACTURER P/N
U1	14			7		74HC125
U5	14			7		74HC04
U6	14			7		74HC04
U10				9		ULN2803A
U11	24			12		82C54
U13	16			8		74HC597
U17	26			7		82C55A
U18	20			10		74HC573
U19	20			10		74HC573
U23	16			8		74HC597

Figure 5-7. Schematic, RFL 9720 CCM Communications And Control Module main circuit board, Sheet 2 of 2 (Assembly No. 104211; Schematic No. D-104209, Rev. D, Sheet 2 of 2)

Table 5-3. Replaceable parts, RFL 9720 CCM Communications And Control Module piggyback circuit board
Assembly No. 104212

Circuit Symbol (Figs. 5-8 and 5-9)	Description	Part Number
	CAPACITORS	
C1-32	Located on main circuit board (See above.)	
C33-50	Capacitor,ceramic,0.1µF,GMV,50V,Centralab CY20C104P or equiv.	1007 1366
C51	Capacitor, tantalum, 4.7µF	1007 1458
C52,54	Capacitor,ceramic,0.001µF,5%,100V,AVX SA201A102JAA or equiv.	0125 11025
C53,59	Capacitor,X7R ceramic,0.01µF,10%,50V,AVX SA105C103KAA or equiv.	0130 51031
C55,56	Capacitor,ceramic,100pF,5%,100V,AVX SA101A101JAA or equiv.	0125 11015
C57	Capacitor,ceramic,82pF,5%,100V,AVX SA101A820JAA or equiv.	0125 18205
C58	Capacitor,ceramic,0.0018µF,5%,100V,AVX SA301A182JAA or equiv.	0125 11825
C60-62	Capacitor,ceramic,470pF,5%,100V,AVX SA101A471JAA or equiv.	0125 14715
C63	Capacitor,X7R ceramic,0.001µF,10%,100V,AVX SA101C102KAA or equiv.	0130 11021
	RESISTORS	
R1-11	Located on main circuit board (See above.)	
R12	Resistor,metal film,22.1KΩ,1%,1/4W, Type RN1/4	0410 1417
R13	Resistor,metal film,40.2KΩ,1%,1/4W, Type RN1/4	0410 1442
R14-16,21,22	Resistor,metal film,18.2KΩ,1%,1/4W, Type RN1/4	0410 1409
R17,27,29-33	Resistor,metal film,1KΩ,1%,1/4W, Type RN1/4	0410 1288
R18	Resistor,metal film,392Ω,1%,1/4W, Type RN1/4	0410 1249
R19 ,41-43	Resistor,metal film,10KΩ,1%,1/4W, Type RN1/4	0410 1384
R20,35,36	Resistor,metal film,20KΩ,1%,1/4W, Type RN1/4	0410 1413
R23	Resistor,metal film,19.1KΩ,1%,1/4W, Type RN1/4	0410 1411
R24,28	Resistor,variable,18-turn cermet,2KΩ,10%,1/2W,Beckman Helipot 68WR2K or equiv.	90392
R25	Resistor,metal film,200Ω,1%,1/4W, Type RN1/4	0410 1221
R26	Resistor, metal film, 4.99K, 1%, 1/4W, Type RN1/4	0410 1355
R34	Resistor, metal film, 499Ω, 1%, 1/4W, Type RN1/4	1410 1259
R37	Resistor,metal film,121Ω,1%,1/4W, Type RN1/4	0410 1200
R39-44	Resistor, metal film, 60.4Ω, 1%, 1/4W, Type RN1/4	0410 1171
RZ10	Resistor network, nine 10KΩ 2% resistors, 1.25W total, 10-pin SIP, Bourns 4310R-101-103 or equiv.	32622
	SEMICONDUCTORS	
Q1	Transistor,NPN,plastic package,2N2222A	37445
U1-23	Located on main circuit board (See above.)	
U24	EPROM,8K x 8,factory-programmed	Contact factory
U25	MOS A/D converter,8-bit,20-pin DIP,National Semiconductor ADC0820CCJ or equiv.	0615 391

Table 5-3. Replaceable parts, RFL 9720 CCM Communications And Control Module piggyback circuit board - continued.

Circuit Symbol (Figs. 5-6 thru 5-9)	Description	Part Number
	Piggyback Circuit Board - continued.	
	SEMICONDUCTORS - continued.	
U26	Linear operational amplifier,BIMOS,8-pin DIP,RCA CA3160AE or equiv.	0620 264
U27,29,30,32	Linear operational amplifier,JFET input,8-pin DIP,Texas Instruments TL081IP or equiv.	0620 228
U28	MOS 8-bit buffered multiplying D/A converter,16-pin ceramic DIP, Analog Devices AD7524AQ or equiv.	0615 370
U31	Linear voltage reference,5-Vdc,8-pin DIP,Precision Monolithics REF-02DP or equiv.	0620 308
U33	MOS quad differential line receiver,16-pin DIP,National Semiconductor DS34C86N or equiv.	0615 394
U34	MOS quad differential line driver,16-pin DIP,National Semiconductor DS34C87N or equiv.	0615 395
U35	MOS 8-bit magnitude comparator,20-pin DIP, National Semiconductor MM74HC688N or equiv.	0615 183
U36,37	MOS shift register,8-bit,serial in/parallel out,16-pin DIP, National Semiconductor MM74HC164N or equiv.	0615 173
U38	MOS hex inverter,14-pin DIP,National Semiconductor MM74HC04N or equiv.	0615 185
U39	MOS dual D-type flip-flop w/preset and clear,14-pin DIP, National Semiconductor MM74HC74N or equiv.	0615 166
U40	MOS quad 2-input Exclusive-OR gate,14-pin DIP,RCA CD74HCT86E or equiv.	0615 390
U41	MOS quad 2-input NAND gate,14-pin DIP,Motorola MC74HC132N or equiv.	0615 306
	MISCELLANEOUS COMPONENTS	
...	Shorting bar,single,Molex 90059-0009 or equiv.	98306

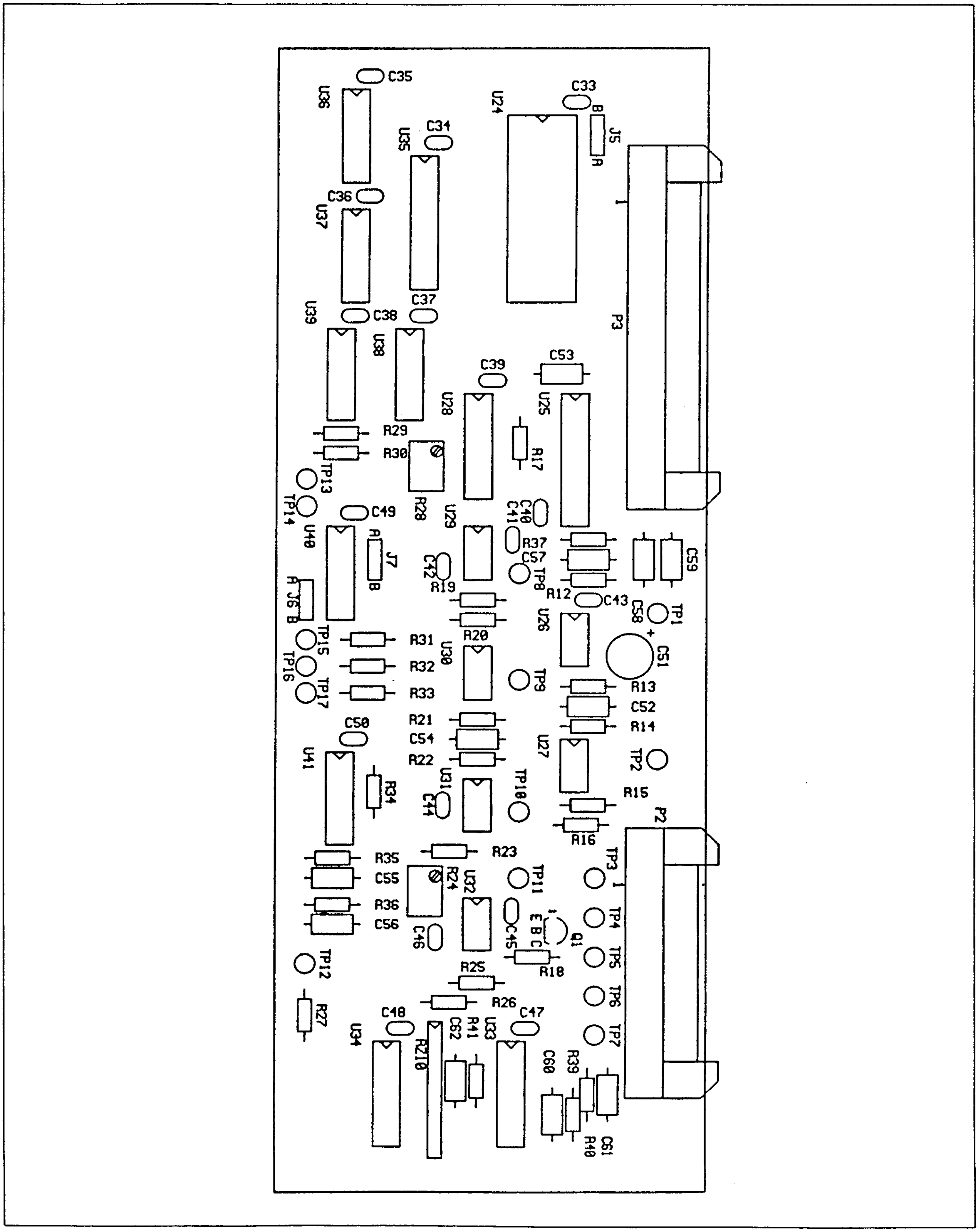
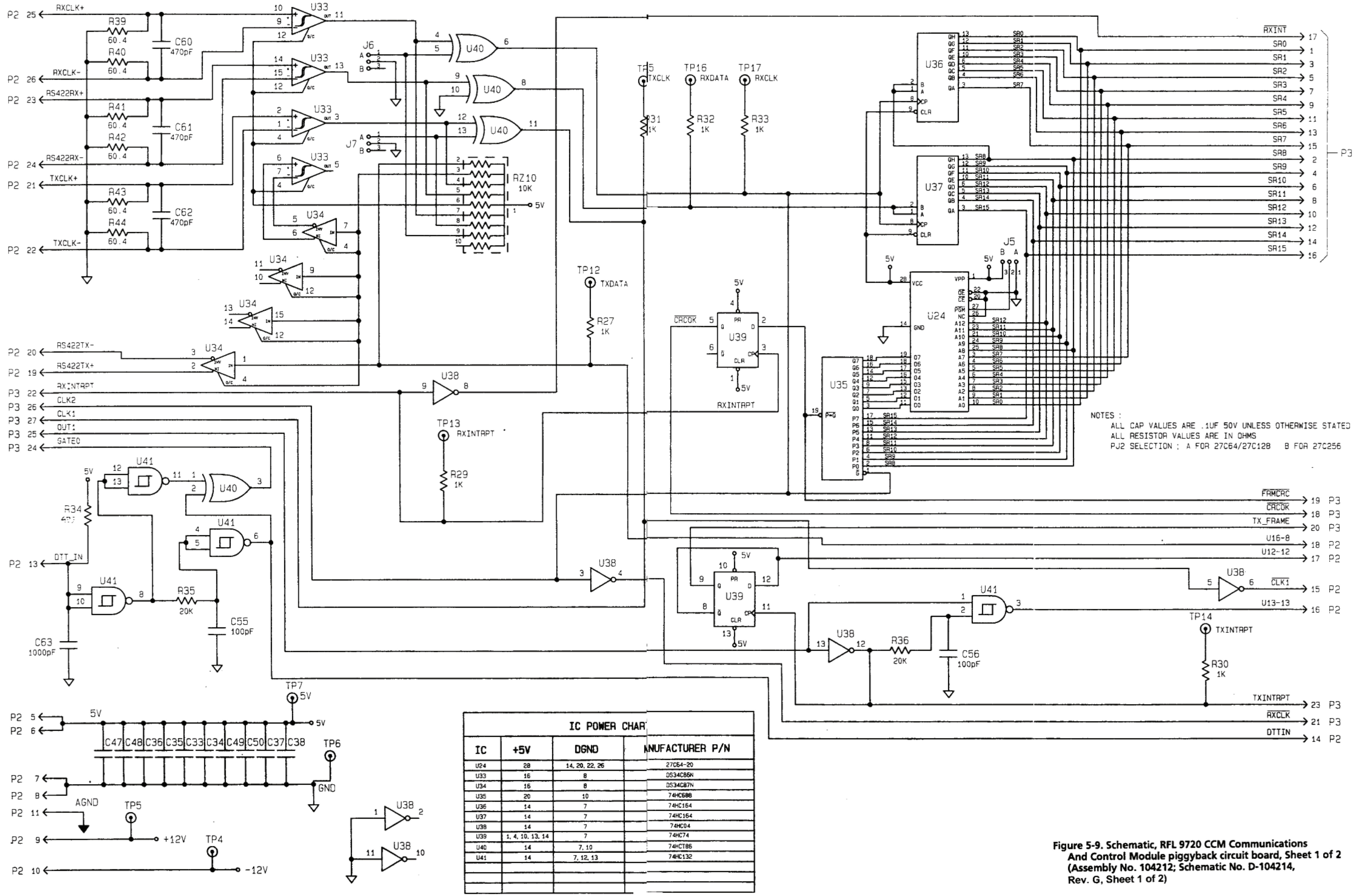


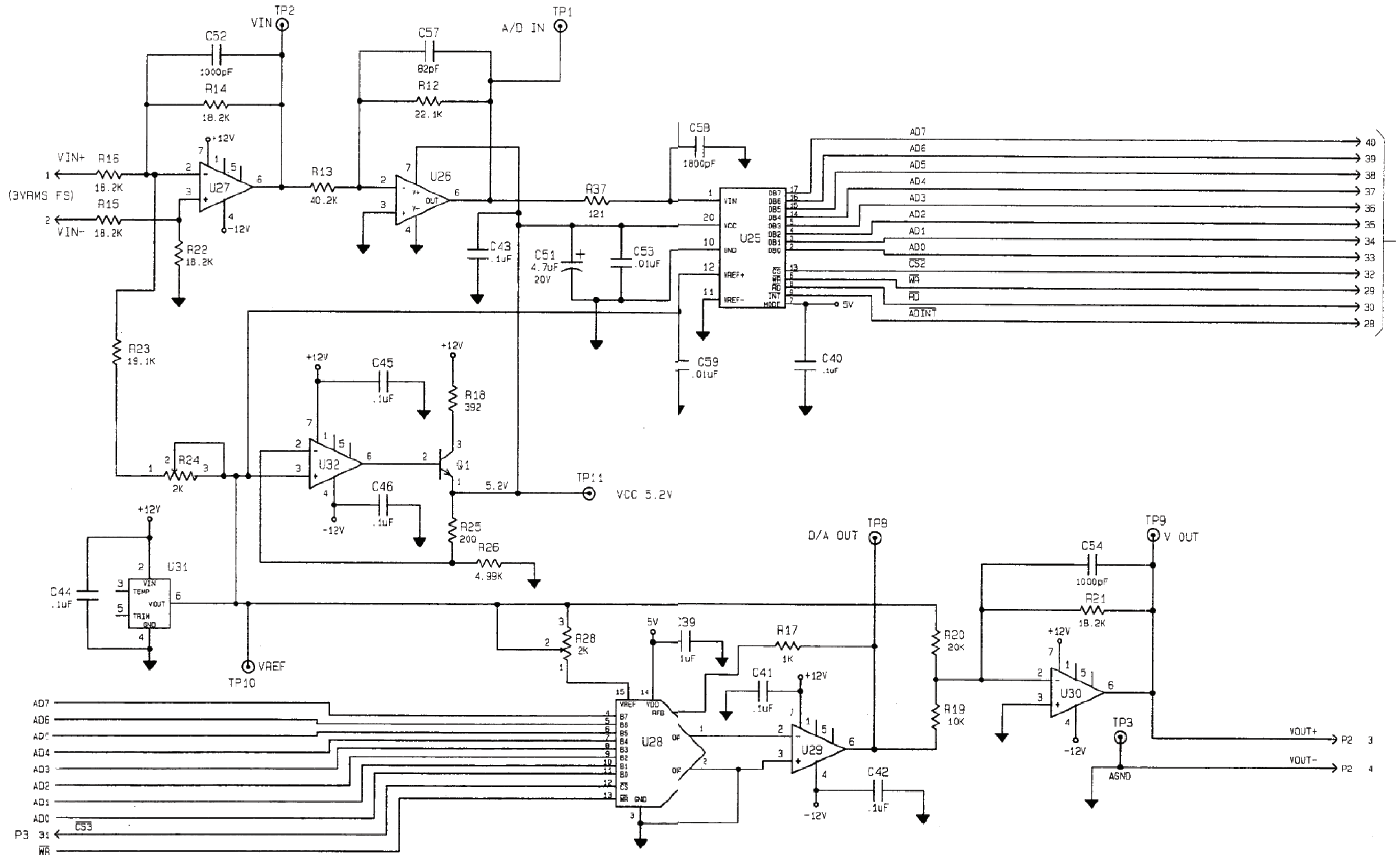
Figure 5-8. Component locator drawing, RFL 9720 CCM Communications And Control Module piggyback circuit board (Assembly No. 104212; Drawing No. D-104213, Rev. C)



IC POWER CHAR[T]

IC	+5V	DGND	[MA]NUFACTURER P/N
U24	28	14, 20, 22, 26	27C64-20
U33	16	8	DS34C86N
U34	16	8	DS34C87N
U35	20	10	74HC688
U36	14	7	74HC164
U37	14	7	74HC164
U38	14	7	74HC04
U39	1, 4, 10, 13, 14	7	74HC74
U40	14	7, 10	74HCT86
U41	14	7, 12, 13	74HC132

Figure 5-9. Schematic, RFL 9720 CCM Communications And Control Module piggyback circuit board, Sheet 1 of 2 (Assembly No. 104212; Schematic No. D-104214, Rev. G, Sheet 1 of 2)



IC POWER CHART						
IC	+5V	+12V	-12V	DGND	AGND	MANUFACTURER P/N
U25	7				10, 11	AD0820
U26					3, 4	CA30160
U27		8	4			TL081
U28	14				2, 3	PM7524
U29		8	4			TL081
U29		8	4			TL081
U30		8	4			TL081
U31		2			4	REF02

Figure 5-9. Schematic, RFL 9720 CCM Communications And Control Module piggyback circuit board, Sheet 2 of 2 (Assembly No. 104212; Schematic No. D-104214, Rev. G, Sheet 2 of 2)

5.3. CCM INPUT/OUTPUT MODULE (CCM I/O)

The RFL 9720 CCM Input/Output Module (Fig. 5-10) provides connectors for the RS-449 and RS-232 communications channels on the RFL 9720 CCM Communications and Command Module. It provides a limited amount of surge and electrostatic discharge protection to the RS-422 and RS-232 circuits on the RFL 9720 CCM. In addition, an eight-pin ribbon cable connector is provided to route the RS-422 communications signals to an RFL 9700.

The RS-422 signals are routed from the rear panel DC-37 connector to the RFL 9720 CCM I/O module's 64-pin connector through the surge protection circuits. Resistor network RZ2, capacitors C6 through C13, and transient suppressors CR6-13 provide a limited amount of surge protection to the RS-422 transmitters and receivers on the RFL 9720 CCM.

The RS-232 signals are routed from the rear panel DE-9 connector to the RFL 9720 CCM I/O module's 64-pin connector through the surge protection circuits. Resistor network RZ1, capacitors C1 through C5, and transient suppressors CR1 through CR5 provide a limited amount of surge protection to the RS-232 transmitters and receivers on the RFL 9720 CCM.

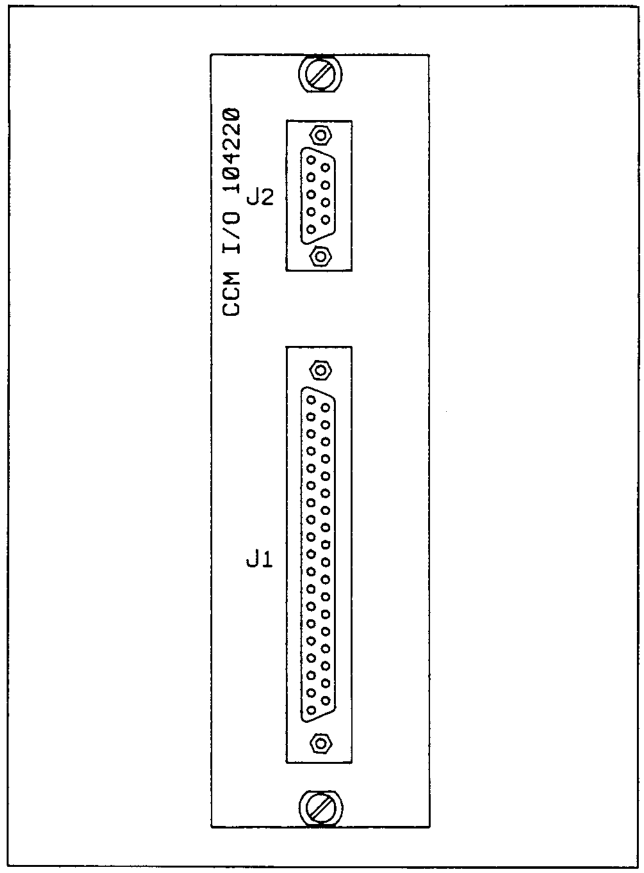


Figure 5-10. RFL 9720 CCM I/O Input/Output Module

Table 5-4. Replaceable parts, RFL 9720 CCM I/O Input/Output Module
Assembly No. 104220

Circuit Symbol (Figs. 5-11 & 5-12)	Description	Part Number
C1-13	Capacitor, X7R ceramic, 0.0082µF, 5%, 50V, AVX SA105C822JAA or equiv.	0130 58225
R1,2	Resistor, metal film, 100Ω, 1%, 1/2W, Type RN1/2	0410 2192
RZ1	Resistor network, five 150Ω, 2% resistors, 2.5W total, 10-pin SIP Dale MSP10C03151G or equiv.	100571
RZ2	Resistor network, eight 22Ω, 2% resistors, 1.75W total, 16-pin SIP CTS 761-3-R22 or equiv.	98260
CR1, 2, 4	Transient suppressor, bidirectional, 15.2 to 16.8-volt breakdown, General Instrument P6KE16CA or equiv.	100572
CR3, 5	Transient suppressor, bidirectional, 28.5 to 31.5-volt breakdown, General Instrument P6KE30CA or equiv.	100576
CR6-13	Transient suppressor, bidirectional, 8.65 to 9.55-volt breakdown, General Instrument P6KE9.1CA or equiv.	103340

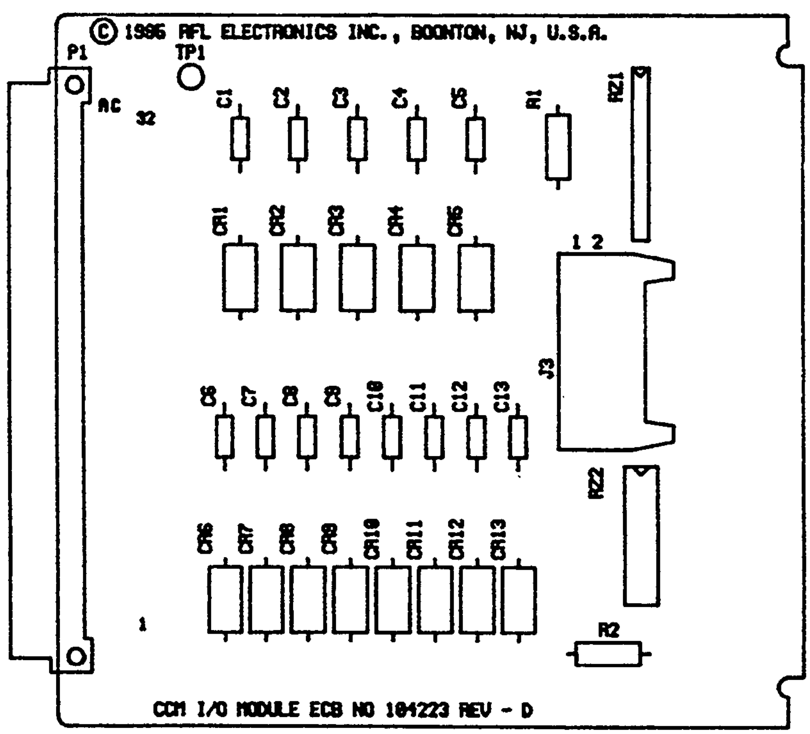


Figure 5-11. Component locator drawing, RFL 9720 CCM I/O Input/Output Module
(Assembly No. 104220; Drawing No. C-104223, Rev D)

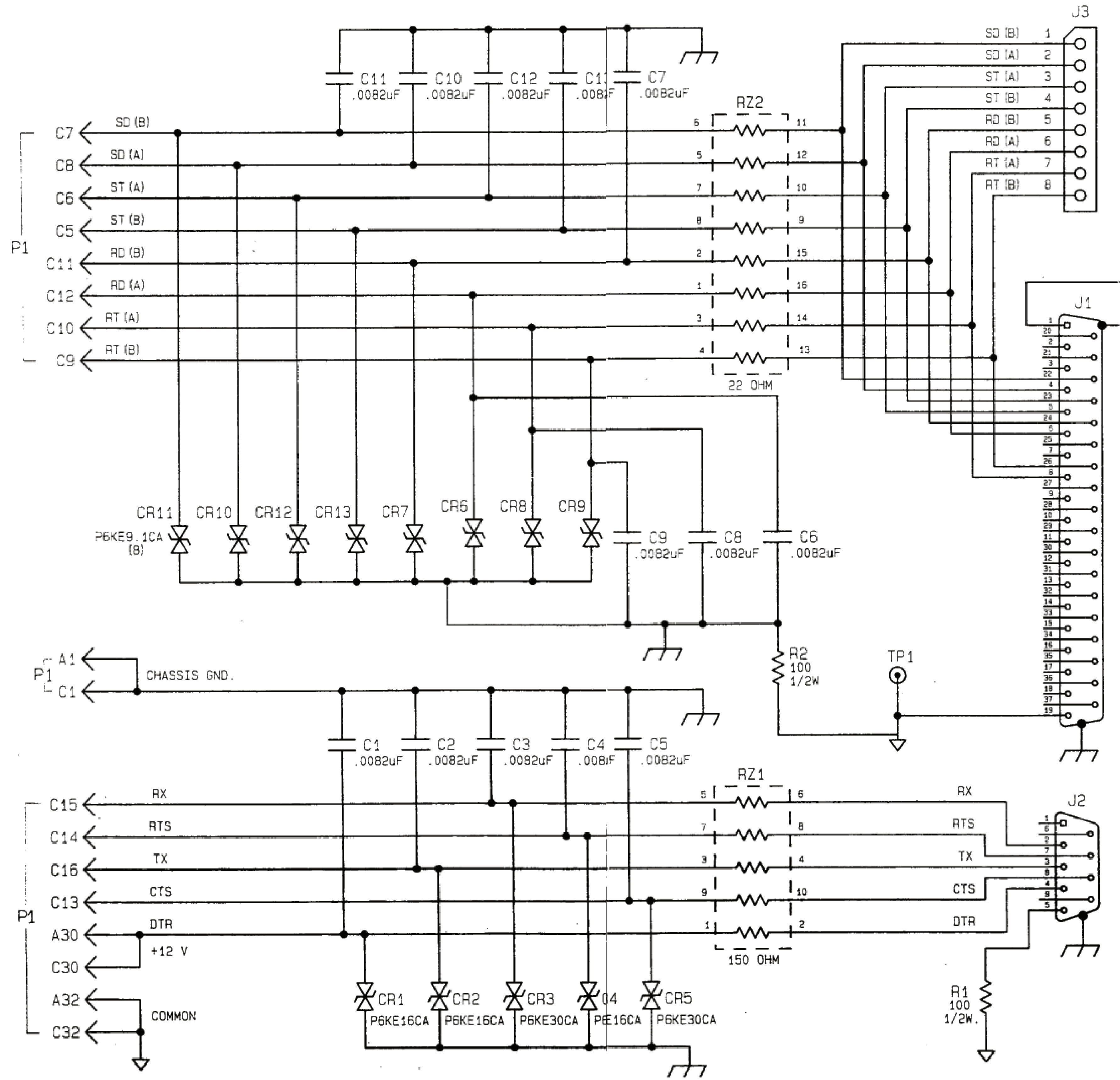


Figure 5-12. Schematic, RFL 9720 CCM I/O Input/Output Module (Assembly No. 104220; Schematic No. D-104224, Rev. C)

Section 6. POWER AMPLIFIER MODULE AND PAM INPUT/OUTPUT MODULE

6.1. INTRODUCTION

This section contains information on the RFL 9720 PAM Power Amplifier Module and the RFL 9720 PAM I/O Input/Output Module. Paragraph 6-2 provides complete technical information on the RFL 9720 PAM; additional information on the RFL 9720 PAM I/O can be found in paragraph 6-3 on page 6-11 of this section.

6.2. RFL 9720 PAM POWER AMPLIFIER MODULE

6.2.1. Description

The RFL 9720 PAM Power Amplifier Module accepts the signals produced by the RFL 9720 CCM (Section 5), and converts them to a current for driving the pilot wire relay. It also senses the current flowing to the pilot wire relay, and feeds this information to the RFL 9720 CCM. A failure detection circuit on the RFL 9720 PAM will shut down the RFL 9720 when a failure is detected.

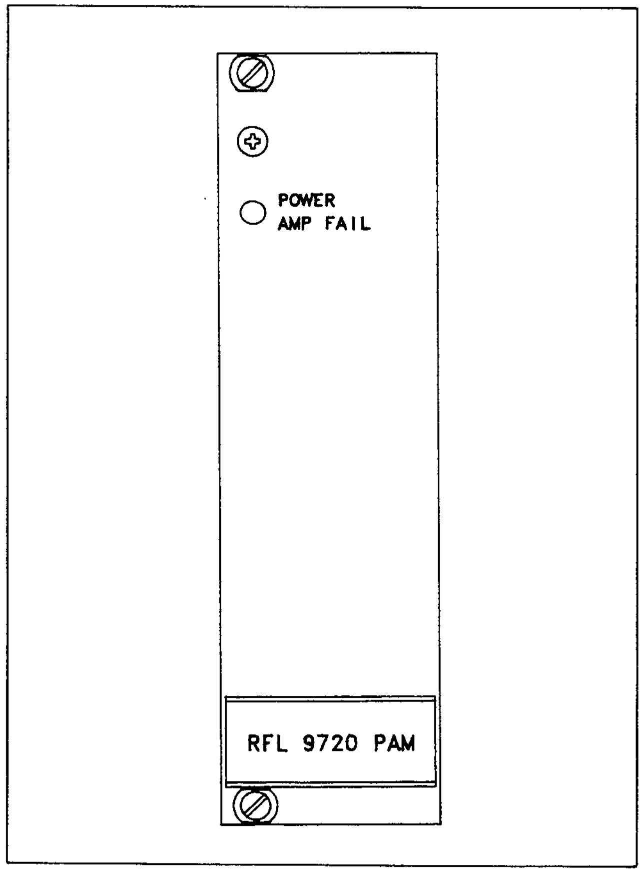


Figure 6-1. RFL 9720 PAM Power Amplifier Module

6.2.2. Theory Of Operation

The RFL 9720 PAM Power Amplifier Module adapts the RFL 9720 to the pilot wire relay. It contains a voltage-to-current amplifier with a transformer output, and a zero-flux active transformer circuit. Paragraphs 6.2.2.1 through 6.2.2.3 describe these circuits; a block diagram of the RFL 9720 PAM appears in Figure 6-2.

6.2.2.1. Voltage-To-Current Amplifier

The analog input applied to the RFL 9720 PAM varies between zero and 3 V_{rms}. The voltage-to-current amplifier converts this voltage into a current that will vary between zero and 3 A_{rms}. The voltage-to-current amplifier contains an input buffer amplifier, a power amplifier, and a current drive transformer.

a. Input Buffer Amplifier. Operational amplifiers U5 and U8, along with their associated components, form the input buffer amplifier. This is a differential-input amplifier, with unity gain and a 20KΩ input impedance.

Op-amp U7 acts as a unity-gain buffer amplifier for U5 when J1 is in the 2T position (position A). This ties one side of resistor R13 to analog ground and disables U8. J1 should always be left in the 2T position (position A).

b. Power Amplifier. The output of U7 is the drive signal for high-power operational amplifier U4, which serves as a voltage-controlled current source. U4 is set up as a floating load with an inverting input. Transformer T1 is the floating load and R29 is a four-terminal shunt resistor.

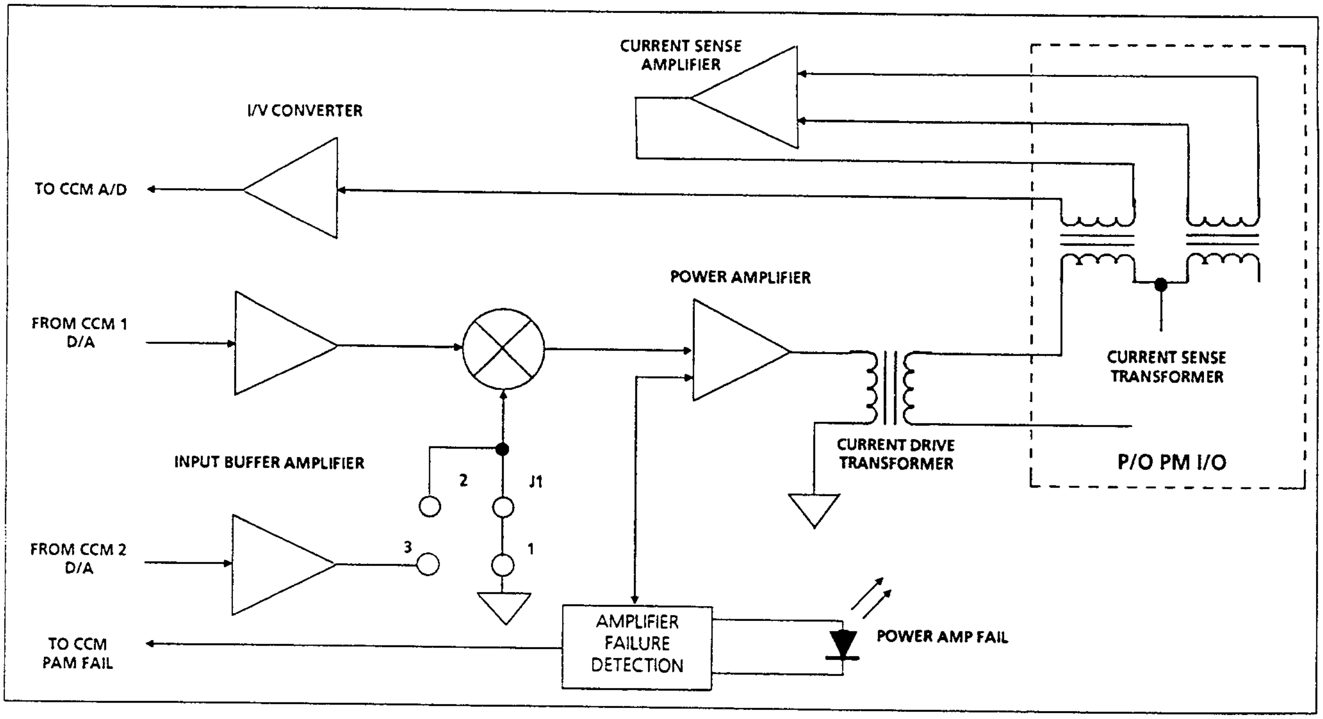


Figure 6-2. Block diagram, RFL 9720 PAM Power Amplifier Module

The voltage developed across R29 is proportional to the load current. The voltage across R29 is amplified by differential amplifier U2. U2 amplifies the voltage by ten to produce the negative feedback signal. The scaling of U2 is controlled by the ratio of resistor R20 and the resistor selected by jumper J3. With a 0.1Ω resistor used for R29, a control signal of 3 V_{rms} will produce an output current of 3 A_{rms}.

The ±24-volt input voltages for U4 are routed through the contacts of relay K1, which is controlled by the RFL 9720 CCM module (Section 5). If the RFL 9720 CCM module detects a PAM failure, it will stop supplying coil voltage to K1; the relay will drop out and supply voltage will be removed from U4. This will protect U4 against permanent damage that may occur during a PAM failure.

c. Current Drive Transformer. Transformer T1 has a primary-to-secondary turns ratio of 1:12. This ratio divides U4's output current by 12. T1 provides impedance matching and 1500-volt isolation between the RFL 9720's low-voltage circuits and the pilot wire relay. This excludes other voltage limiting components used for SWC protection.

6.2.2.2. Fault Detection Circuit

Quad operational amplifier U6 and its associated components serve as the fault detection circuit. This circuit has three sections: a differential amplifier, an absolute value circuit, and a comparator.

a. Differential Amplifier. U6C serves as a differential amplifier. It senses the input voltage applied to at U4. Under normal conditions, these inputs are at virtual ground. During abnormal operation (such as during an overcurrent condition), the amplifier cannot maintain its transfer function. When this happens, a small signal is developed on the input. This signal is amplified by U6C, then fed to the absolute value circuit.

b. Absolute Value Circuit. The absolute value circuit is formed from U6D and U6A and their associated components. The absolute value circuit converts the error signal generated by the differential amplifier into a dc level. The output of U6A is applied to the comparator.

c. Comparator. U6B and its associated components serve as a comparator. The reference input to the comparator is the voltage at the junction of resistors R43 and R44. When the voltage applied to the comparator exceeds the 3-volt level set by R43 and R44, the comparator output swings from -12 Vdc to +12 Vdc. This condition will disable the light-emitting diodes in optical isolators U1 and U3, causing their output transistors to go high-impedance. PAM FAIL indicator DS1 will turn on, since the shunt applied through the V_{ce} junction of U1 has been removed. In addition, U3's output transistor will cause the PAM FAIL output (P1-C27) to go high. This logic high will be passed to the RFL 9720 CCM (Section 5).

6.2.2.3. Active Transformer Circuit

The active transformer circuit monitors the current in the current transformer on the RFL 9720 PM I/O Input/Output Module (Section 7). It then generates a correction current that cancels out the flux in the current transformer. The active transformer circuit contains two sections: a current sense amplifier and a current-to-voltage converter.

a. Current Sense Amplifier. Operational amplifier U10 amplifies the signal developed across the 1000-turn sense winding of the current transformer on the RFL 9720 PM I/O module. U10's output is a current that drives the 100-turn feedback winding of the current transformer. This will reduce the signal on the sense winding to almost zero. The current required in the feedback winding is equal to the primary current multiplied by the turns ratio between the primary and feedback windings.

b. Current-To-Voltage Converter. Operational amplifier U9 serves as a current-to-voltage converter. The output voltage from this converter is equal to I_{in} (0 to 5 mA) multiplied by the value of the resistor selected by jumper J2.

Table 6-1. Replaceable parts, RFL 9720 PAM Power Amplifier Module
Assembly No. 104200

Circuit Symbol (Figs. 6-3 & 6-4)	Description	Part Number
	CAPACITORS	
C1,2	Capacitor,tantalum,15µF,20%,20V,Kemet T322D156M020AS or equiv.	1007 716
C3-6,9-18,22,27,28	Capacitor,X7R ceramic,0.1µF,10%,50V,AVX SA305C104KAA or equiv.	0130 51041
C19	Capacitor,ceramic,0.001µF,5%,100V,AVX SA201A102JAA or equiv.	0125 11025
C20	Capacitor,metallized polycarbonate,0.2µF,5%,50V,Wesco 32MPC or equiv.	1007 1372
C21	Capacitor,ceramic,0.0068µF,5%,100V,AVX SA401A682JAA or equiv.	0125 16825
C25,26	Capacitor,electrolytic,100µF,20%,50V,Nichicon ULB1H101M or equiv.	1007 1513
C29	Capacitor,X7R ceramic,0.047µF,10%,50V,AVX SA205C473KAA or equiv.	0130 54731
	RESISTORS	
R1,2	Resistor,metal film,1.62KΩ,1%,1/4W, Type RN1/4	0410 1308
R4	Resistor,metal film,590Ω,1%,1/4W, Type RN1/4	0410 1266
R5,6,20,41,57-64	Resistor,metal film,1KΩ,1%,1/4W, Type RN1/4	0410 1288
R7	Resistor,metal film,301KΩ,1%,1/4W, Type RN1/4	0410 1526
R8-14,16-19,23,24,30,31, 34-37,40	Resistor,metal film,10KΩ,1%,1/4W, Type RN1/4	0410 1384
R15,38,44	Resistor,metal film,4.99KΩ,1%,1/4W, Type RN1/4	0410 1355
R21	Resistor,metal film,681Ω,1%,1/4W, Type RN1/4	0410 1272

Table 6-1. Replaceable parts, RFL 9720 PAM Power Amplifier Module - continued.

Circuit Symbol (Figs. 6-3 & 6-4)	Description	Part Number
	RESISTORS - continued.	
R22,25,32,33,45	Resistor,metal film,100KΩ,1%,1/4W, Type RN1/4	0410 1480
R26,27	Resistor,non-inductive wirewound,0.2Ω,1%,1W,IRC Style T-1A-70 or equiv.	1780 831
R28,42	Resistor,metal film,499Ω,1%,1/4W, Type RN1/4	0410 1259
R29	Resistor,shunt,non-inductive,0.1Ω,1.25W,Precision Resistor SM155-4 or equiv.	102653
R39	Resistor,metal film,80.6KΩ,1%,1/4W, Type RN1/4	0410 1471
R43	Resistor,metal film,15KΩ,1%,1/4W, Type RN1/4	0410 1401
R46,51,52	Resistor,metal film,2KΩ,1%,1/4W, Type RN1/4	0410 1317
R47	Resistor,metal film,5.9KΩ,1%,1/2W, Type RN1/2	0410 2362
R48	Resistor,metal film,60.4KΩ,1%,1/4W, Type RN1/4	0410 1459
R49	Resistor,variable,18-turn cermet,2KΩ,10%,1/2W,Beckman Helipot 68WR2K or equiv.	90392
R50	Resistor,metal film,20KΩ,1%,1/4W, Type RN1/4	0410 1413
R53,54	Resistor,metal film,49.9KΩ,1%,1/4W, Type RN1/4	0410 1451
R65 *	Resistor,metal film,698Ω,1%,1/4W, Type RN1/4	0410 1273
R66 *	Resistor,metal film,10Ω,1%,1/4W,Type RN60D	1510 1015
R68	Resistor,metal film,576Ω,1%,1/4W, Type RN1/4	0410 1265
R72	Resistor,metal film,100Ω,1%,1/4W, Type RN1/4	0410 1192
	SEMICONDUCTORS	
CR1-4,6,7,12-15,21,22	Diode,silicon,1N914B or 1N4448	26482
CR5	Diode,Zener,9.1V,5%,400mW,1N960B	41014
CR17,18	Diode,fast recovery,400V,2A,General Electric A114D or equiv.	47659
CR19,20	Transient suppressor,28.5 to 31.5-volt breakdown, General Semiconductor 1.5KE30CA or equiv.	100556
CR23	Diode,silicon,200 PIV,1N4003	30769
DS1	Light-emitting diode,red,right-angle PC mount,extended length, Industrial Devices 5300H1 or equiv.	99294
DS2	Light-emitting diode,clear red,Lumex LXR124S or equiv.	44944
Q1	Transistor,field-effect,N-channel VMOS,TO-237 case,Siliconix VN10KM or equiv.	0715 13
U1,3	Photo-coupled isolator,6-pin DIP,General Electric 4N35 or equiv.	47104
U2,5,7,8	Linear operational amplifier,JFET input,8-pin DIP,Texas Instruments TL081IP or equiv.	0620 228
U4	Linear operational amplifier,high-power (5A peak output), 12V to 50V supply voltage,8-terminal TO-3 case,Apex PA07 or equiv.	0620 343
U6	Linear operational amplifier,quad,JFET input,14-pin DIP,Texas Instruments TL084IN or equiv.	0620 182

Table 6-1. Replaceable parts, RFL 9720 PAM Power Amplifier Module - continued.

Circuit Symbol (Figs. 6-3 & 6-4)	Description	Part Number
	SEMICONDUCTORS - continued.	
U9, 10	Linear operational amplifier,low offset voltage,8-pin ceramic DIP, Precision Monolithics OP77EZ or equiv.	0620 340
	MISCELLANEOUS COMPONENTS	
K1	Relay,DPST,24-volt 1920Ω coil,normally-open 5A contacts, Omron G6B-2214P-US-DC24 or equiv.	102667
T1	Transformer,current drive	102658
...	Shorting bar,single,Molex 90059-0009 or equiv.	98306

* - Deleted at factory if not required.

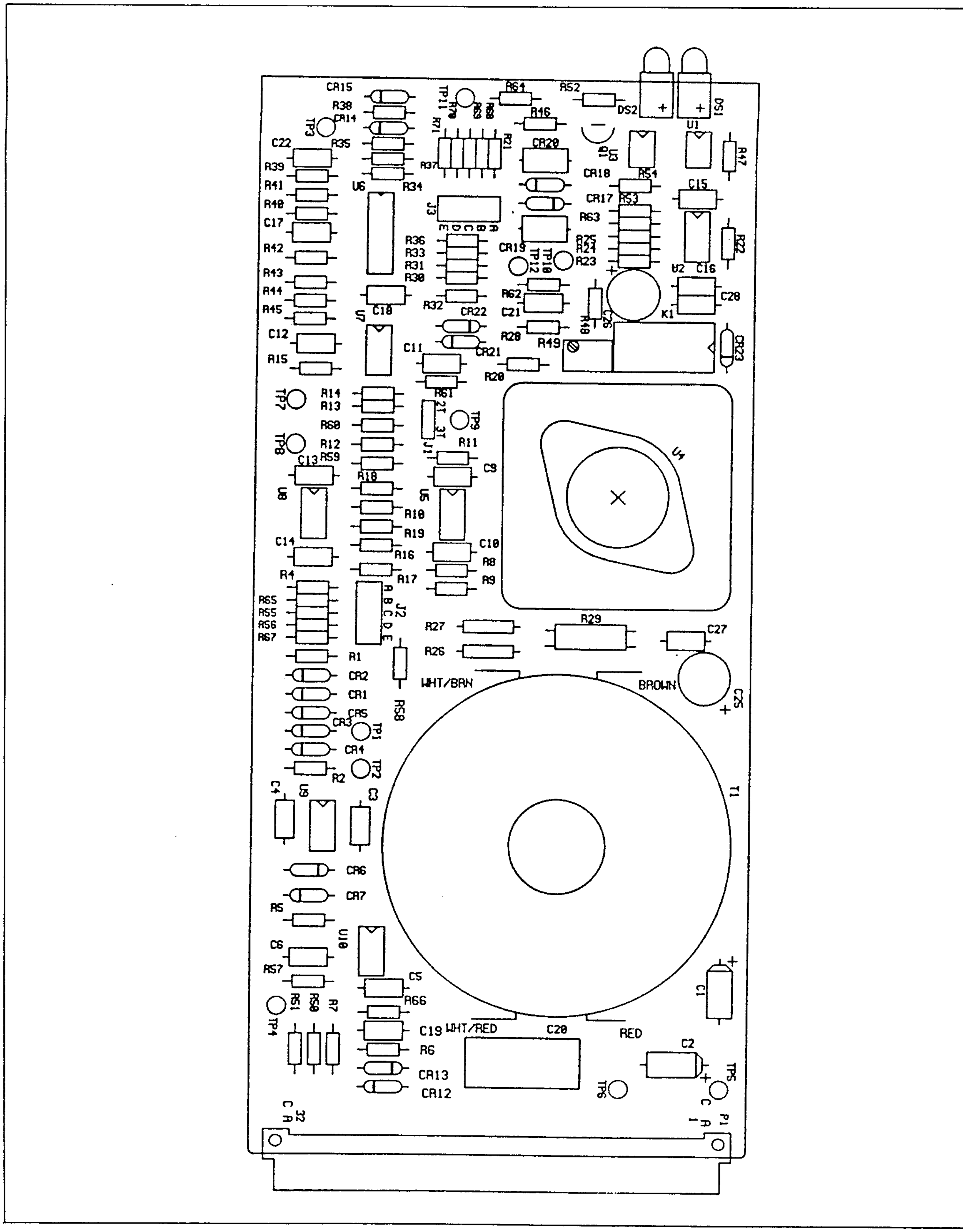


Figure 6-3. Component locator drawing, RFL 9720 PAM Power Amplifier Module (Assembly No. 104200; Drawing No. D-104203, Rev. D)

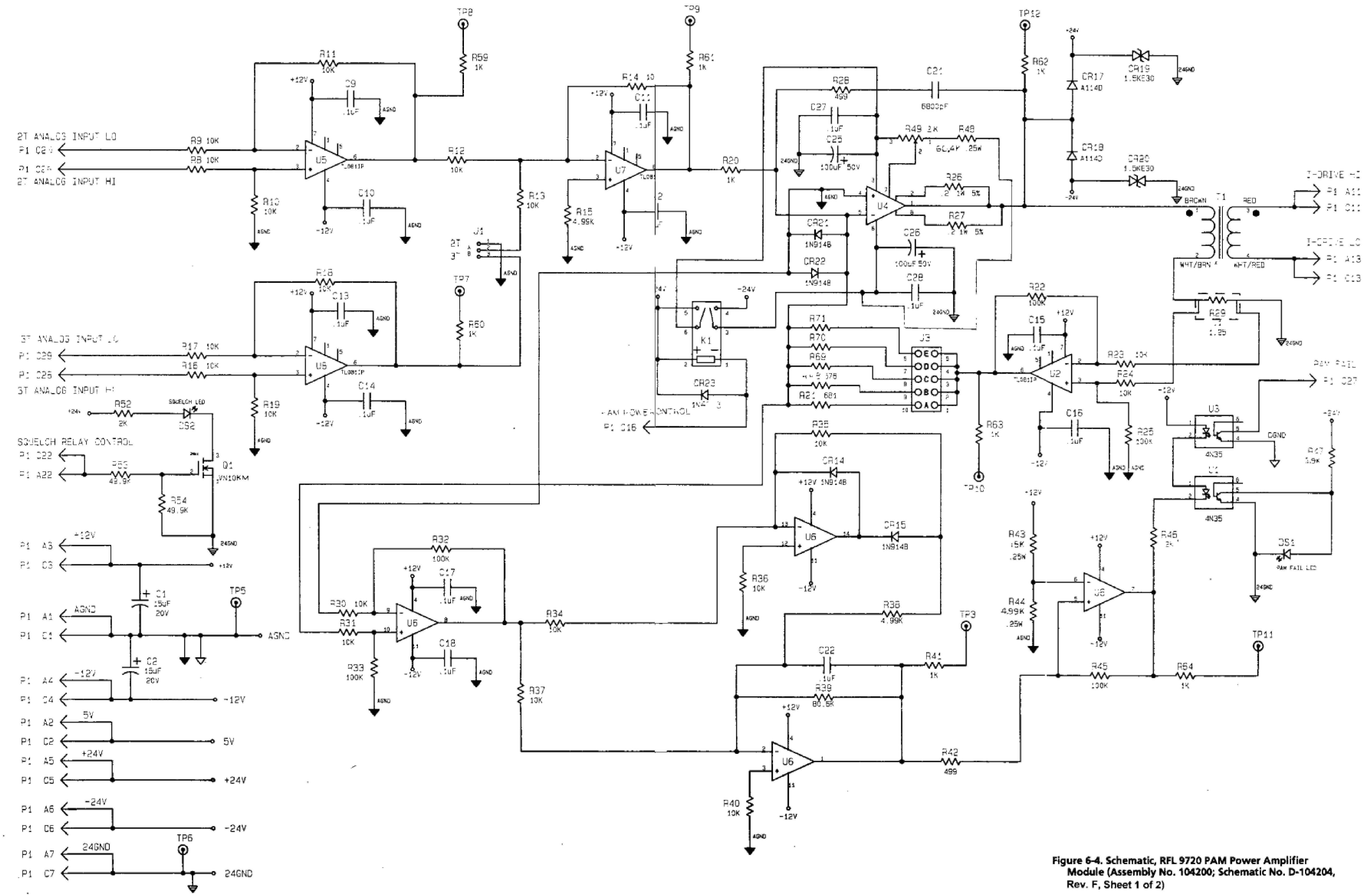


Figure 6-4. Schematic, RFL 9720 PAM Power Amplifier Module (Assembly No. 104200; Schematic No. D-104204, Rev. F, Sheet 1 of 2)

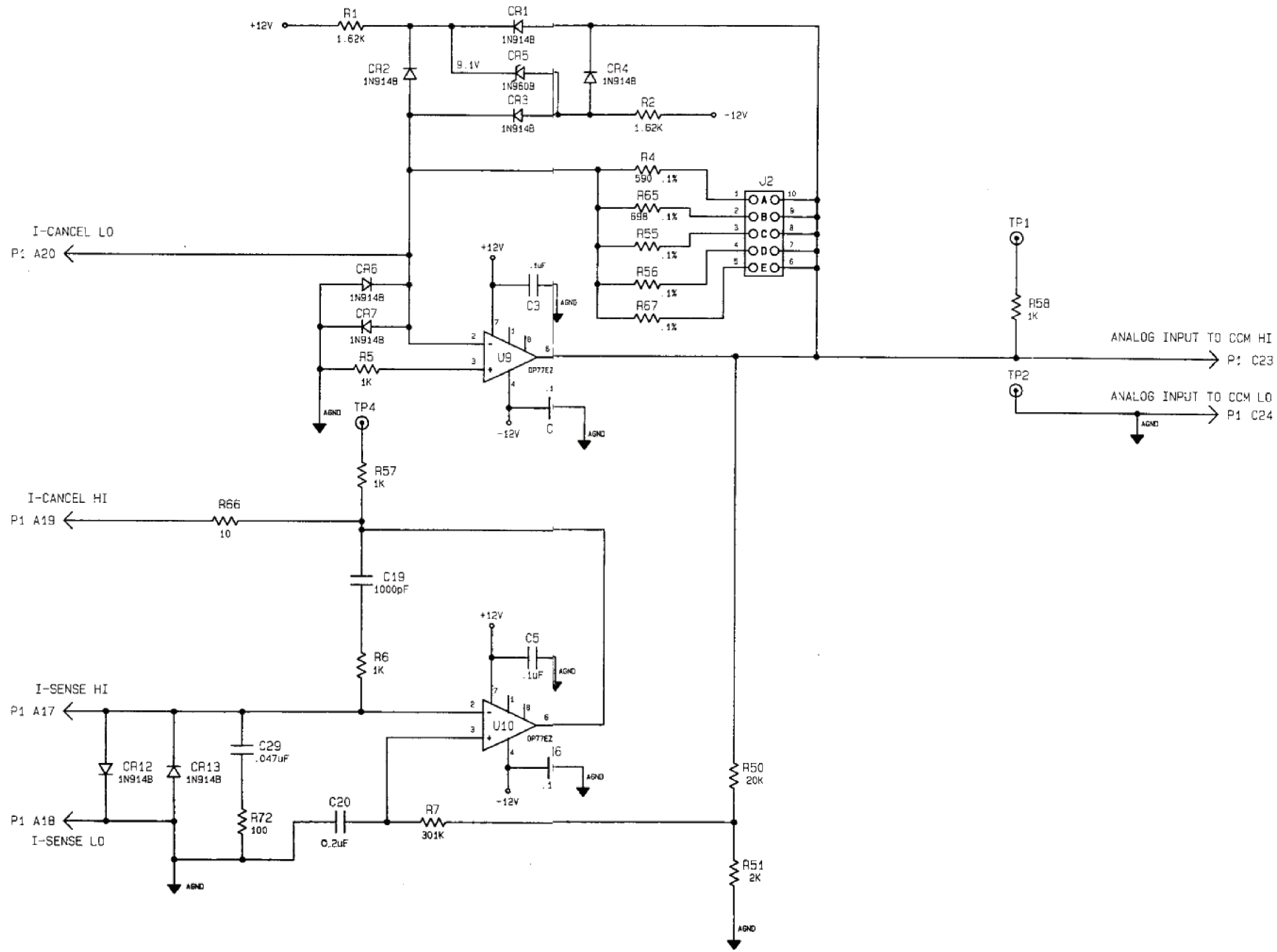


Figure 6-4. Schematic, RFL 9720 PAM Power Amplifier Module (Assembly No. 104200; Schematic No. D-104204, Rev. F, Sheet 2 of 2)

6.3. RFL 9720 PAM I/O INPUT/OUTPUT MODULE

6.3.1. Description

The RFL 9720 PAM I/O Input/Output Module (Fig. 6-5) contains an optically-isolated DTT input circuit. It also contains an optically-isolated DTT output circuit, and two Form "C" relays. One relay is for channel delay WARNING, and the other is for channel failure ALARM. Each I/O function has its own SWC protection circuit.

6.3.2. Theory Of Operation

The RFL 9720 PAM I/O Input/Output Module contains four relays and four SWC protection circuits. These are interfaced to the drive circuits on the RFL 9720 CCM. A block diagram of the RFL 9720 PAM I/O appears in Figure 6-6.

6.3.2.1. Direct Transfer Trip (DTT) Output

Optically-isolated output module K1 switches the current applied to an external trip device. Inductors L1 and L2, capacitors C2 and C3, and the surge protection circuit inside K1 combine to provide SWC protection.

In order to generate a DTT output, transistor Q1 must be turned on (P1-C16 pulled to common). This will apply +5 volts to pin 3 of K1 (+In). In addition, K1's -In terminal (pin 4) must be pulled to signal ground (P1-C15) through an open-collector transistor on the RFL 9720 CCM. Once these two drive signals are applied to the RFL 9720 PAM I/O, the output transistor in K1 will conduct.

6.3.2.2 Direct Transfer Trip (DTT) Input

Input module K2 contains an optoisolator driven by a divider network. The module provides an open collector output. The output is fed to the RFL 9720 CCM. When the appropriate voltage (48Vdc or 125Vdc nominal, depending on the version of PAM I/O) is applied between the input terminals 1 and 2 of the terminal block, an active low signal is sent to the 9720 CCM through the edge connector terminal P1-C14. Chokes L9, 10 and capacitors C11, 12 provide SWC protection.

When 9720 PAM I/O 48V is used:

Input range:	38V to 58Vdc.
Nominal:	48Vdc at 5.5mA.

When 9720 PAM I/O 125V is used:

Input range:	88V to 150Vdc.
Nominal:	125Vdc at 4.5mA.

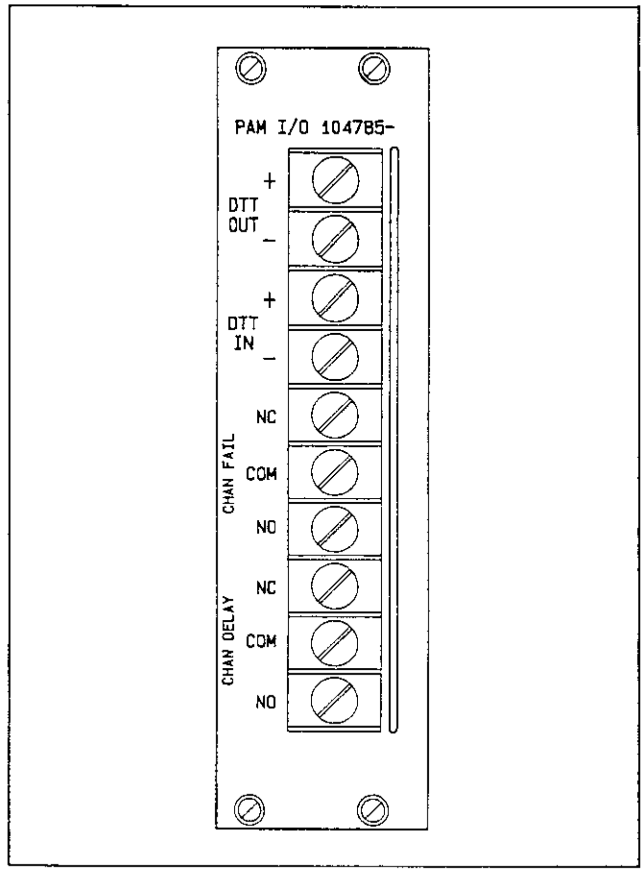


Figure 6-5. RFL 9720 PAM I/O Input/Output Module

6.3.2.3. Channel Fail Alarm Output

Normally-energized Form C relay K3 provides a connection to external SCADA or event recording equipment. K3 is energized by a driver on the RFL 9720 CCM, which pulls P1-C13 to common. When this driver shuts down, K3 drops out to show that a CHANNEL FAIL alarm has occurred. Inductors L3 through L5 and capacitors C4 through C6 provide SWC protection. The contact-to-coil spacing inside K3 adds to the SWC protection.

6.3.2.4. Channel Delay Alarm Output

Normally-energized Form C relay K4 provides a connection to external SCADA or event recording equipment. K4 is energized by a driver on the RFL 9720 CCM, which pulls P1-C12 to common. When this driver shuts down, K4 drops out to show that a CHANNEL DELAY alarm has occurred. Inductors L6 through L8 and capacitors C7 through C9 provide SWC protection. The contact-to-coil spacing inside K4 adds to the SWC protection.

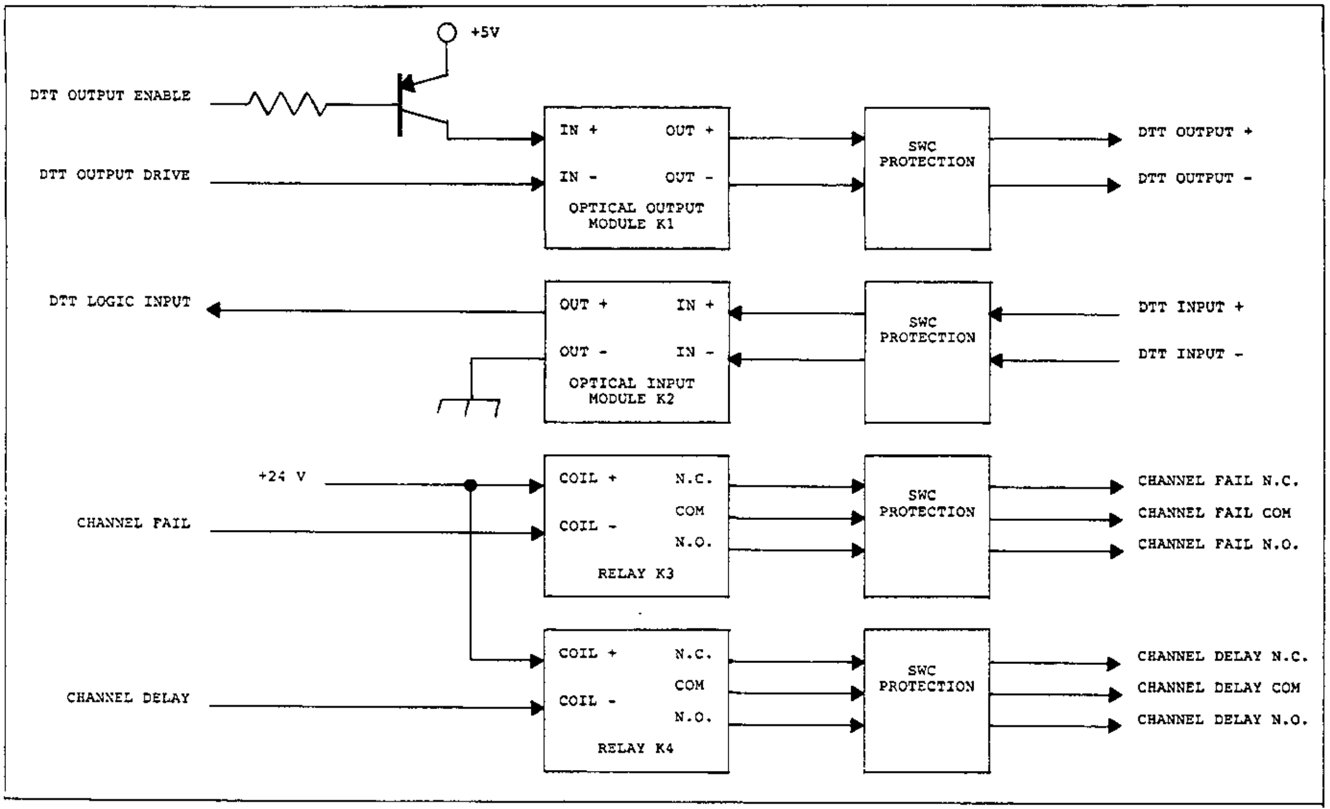


Figure 6-6. Block diagram, RFL 9720 PAM I/O Input/Output Module

Table 6-2. Replaceable parts, RFL 9720 PAM I/O Input/Output Module
Assembly No. 104785-1 (48V), and 104785-2 (125V)

Circuit Symbol (Figs. 6-7 & 6-8)	Description	Part Number
C2-9, 11, 12	Capacitor, ceramic disc, 0.005µF, 20%,3KV	1007 1264
C10	Capacitor, tantalum, 15µF, 20%, 20V	1007 716
CR1, 2	Diode, silicon, rectifier, 1 Amp, 1N4003	30769
Q1	Transistor, silicon, PNP, 2N2907A	37439
R1,2	Resistor, metal film, axial, 30.1K, 1%, 1/4W	0410 1430
K1	Optical output module	30267
K2	Input module, 104785-1: 48V	104780-1
	Input module, 104785-2: 125V	104780-2
K3, 4	Relay, DPDT, 5A, 24Vdc	97029
L1-10	Inductor, 10µH, 5%, 1.5A max	30285

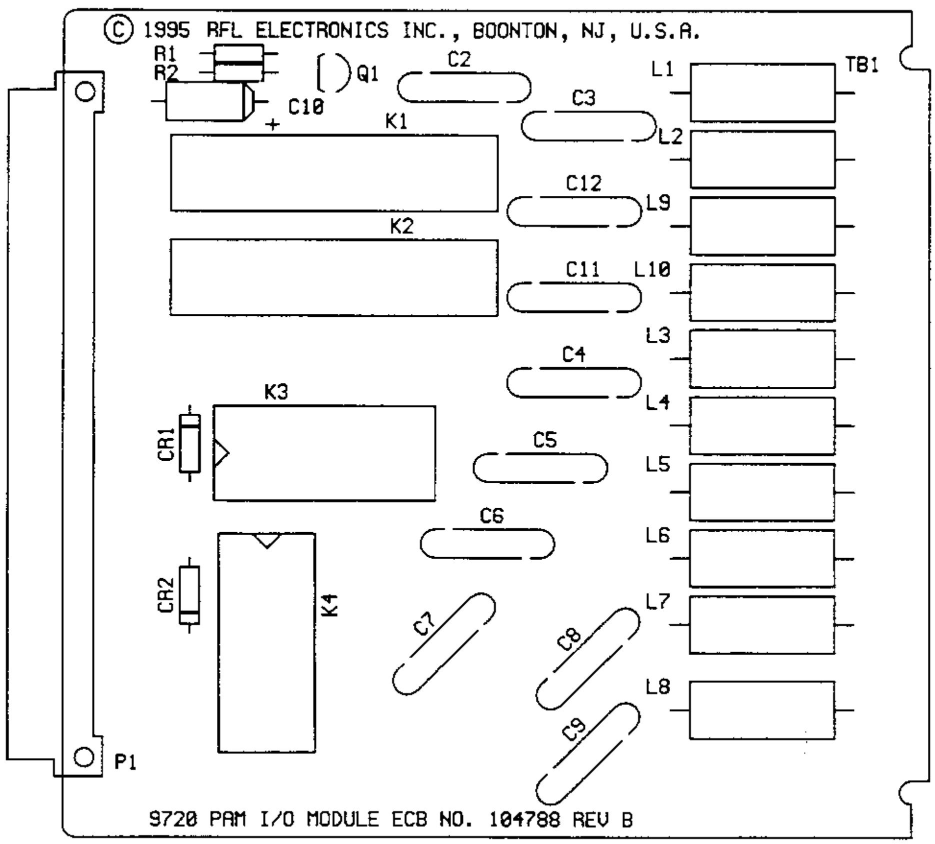


Figure 6-7. Component locator drawing, RFL 9720 PAM I/O Input/Output Modules
(Assembly Nos. 104785-1, 48V and 104785-2, 125V; Drawing No. C-104785-1, Rev A, 48V and C-104785-2, Rev A, 125V)

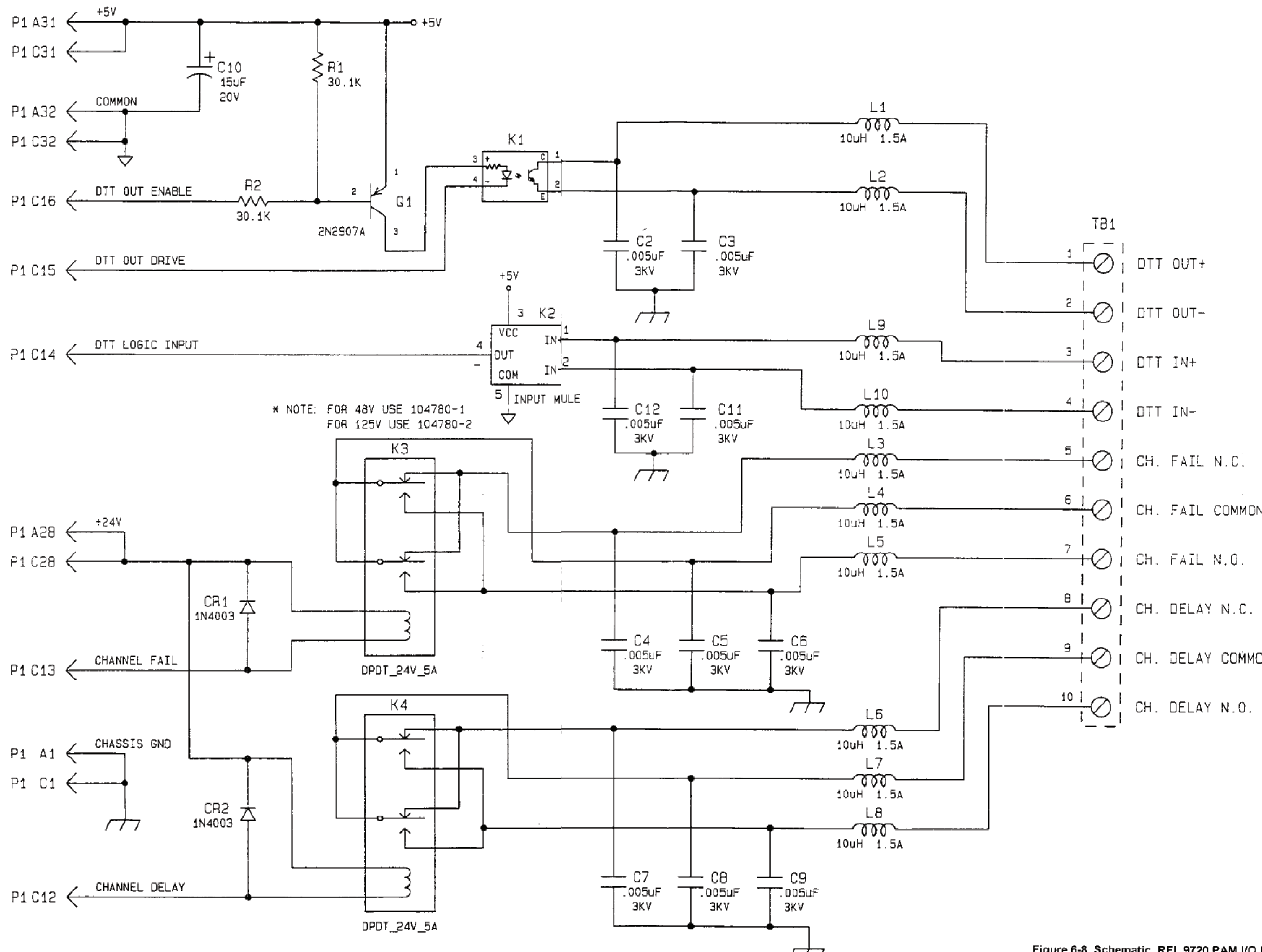


Figure 6-8. Schematic, RFL 9720 PAM I/O Input/Output Module (Assembly Nos. 104785-1 and –2; Schematic No. 104789, Rev A)

Section 7. POWER MODULE AND PM INPUT/OUTPUT MODULE

7.1. INTRODUCTION

This section contains information on the RFL 9720 PM Power Module and RFL 9720 PM I/O Input/Output Module. Paragraph 7.2 provides complete technical information on the RFL 9720 PM; additional information on the RFL 9720 PM I/O can be found in paragraph 7.3 on page 7-7 of this section.

7.2. POWER MODULE

7.2.1. Description

The RFL 9720 PM Power Module (Fig. 7-1) supplies all the voltages required by the RFL 9720. It contains an input filter, an SWC protection circuit, input fuses, a power switch, and voltage regulator modules.

7.2.2. Theory Of Operation

The RFL 9720 PM Power Module converts 48-volt or 125-volt station battery power into the five dc voltages required to operate the RFL 9720: +5, +12, -12, +24, and -24. The RFL 9720 PM has three basic sections; the input filter and control section, the power amplifier supply section, and the control supply section. A block diagram of the RFL 9720 PM appears in Figure 7-2.

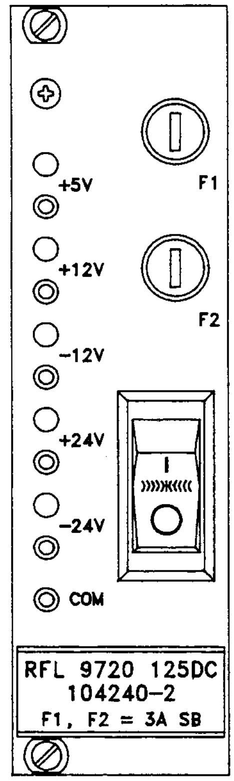


Figure 7-1. RFL 9720 PM Power Module

7.2.2.1. Input Filter And Control

Station battery power enters the RFL 9720 PM between edge connector terminals P1-A25/P1-C25 (positive) and P1-A28/P1-C28 (negative). Inductors L1 and L2, capacitors C1 and C2, and transient suppressors CR1 and CR2 provide SWC protection. Capacitor C19 is a low-ESR reservoir at the input to the two 24-volt dc/dc converters, X1 and X2. Line fuses F1 and F2 provide input current protection, and power switch SW1 serves as a main power switch for the entire RFL 9720.

7.2.2.2. Power Amplifier Supply

Dc/dc converters X1 and X2 produce the bipolar 24-volt input power required by the RFL 9720 PAM Power Amplifier Module (Section 6). Under normal operation, these converters do not require a heat sink. However, the converters may be heat-damaged if large currents are drawn for more than 200 ms.

X1's output is filtered by capacitor C12; capacitor C11 filters X2's output. After filtering, the outputs are routed to the module edge connector, and to the input of triple-output dc/dc converter X3. EMI/RFI bypassing is provided by resistor/capacitor pairs R1/C3, R2/C4, R3/C5 and R4/C6. Additional bypassing is provided by capacitors C7 through C10.

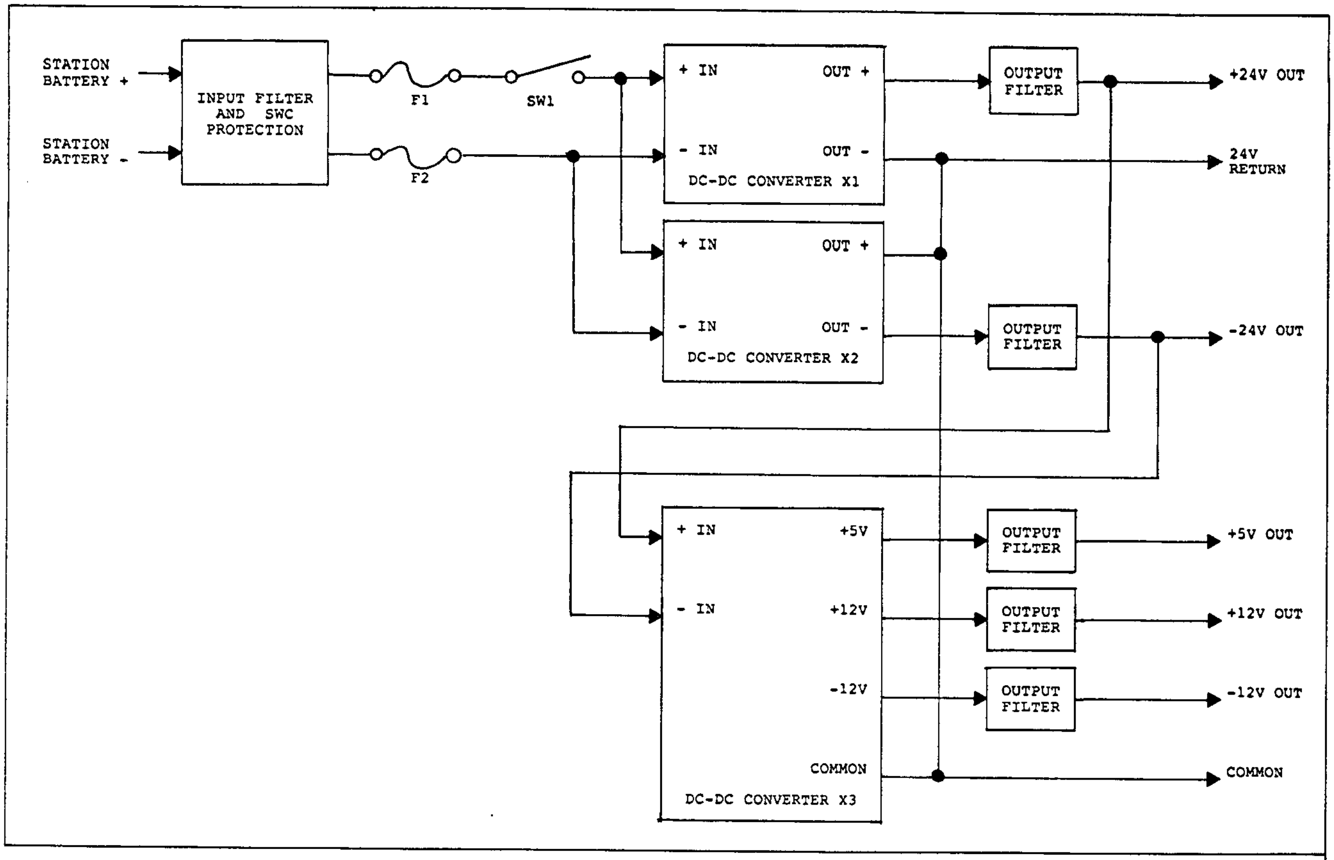


Figure 7-2. Block diagram, RFL 9720 PM Power Module

7.2.2.3. Control Supply Section

Triple-output dc/dc Converter X3 supplies power to the control electronics section of the RFL 9720. The input to X3 is 48 Vdc, and is supplied by the outputs from X1 and X2. X3's +12-volt output is filtered by inductor L6 and capacitors C15 and C18. +12V indicator DS4 lights when +12-volt power is present. It can be measured between front-panel test points TP5 (+12V) and TP4 (COM).

X3's -12-volt output is filtered by inductor L5 and capacitors C14 and C16. -12V indicator DS3 lights when -12-volt power is present. It can be measured between front-panel test points TP3 (-12V) and TP4 (COM).

X3's +5-volt output is filtered by inductor L7 and capacitors C13 and C17. +5V indicator DS5 lights when +5-volt power is present. It can be measured between front-panel test points TP6 (+5V) and TP4 (COM).

If X3's outputs are not properly loaded, DS3, DS4, and DS5 will flash on and off.

Table 7-1. Replaceable parts, RFL 9720 PM Power Module
48-Vdc Input - Assembly No. 104240-1
125-Vdc Input - Assembly No. 104240-3

Circuit Symbol (Figs. 7-3 & 7-4)	Description	Part Number
C1,2	Capacitor,ceramic disc,0.01µF,20%,3000V,Sprague 30GA-S10 or equiv.	1007 1442
C3-10	Capacitor,ceramic disc,0.005µF,20%,3kV,Centralab DD30-502 or equiv.	1007 1264
C11,12	Capacitor,electrolytic,470µF,20%,35V,radial leads,Illinois Capacitor 477RZS035M or equiv.	1007 1722
C13	Capacitor,electrolytic,1000µF,20%,10V,Illinois Capacitor 108RZS010M or equiv.	1007 1756
C14,15	Capacitor,electrolytic,470µF,20%,16V,Illinois Capacitor 477RZS016M or equiv.	1007 1755
C16-18	Capacitor,electrolytic,220µF,20%,16V,Illinois Capacitor 227RZS016M or equiv.	1007 1754
C19	Capacitor,electrolytic,22µF,20%,250V,radial leads,Illinois Capacitor 226RMR250M or equiv.	1007 1726
CR1	Transient suppressor,bi-directional,380- to 420-volt breakdown, General Semiconductor 1.5KE400CA or equiv.	30442
CR2	Transient suppressor,unipolar,breakdown voltage dependent upon model: Assy. No. 104240-1: 64.6- to 71.4-volt breakdown; General Semiconductor 1.5KE68A or equiv. Assy. No. 104240-3: 190- to 210-volt breakdown; General Semiconductor 1.5KE200A or equiv.	 30448 30449
DS1-5	Light-emitting diode,green,right-angle PC mount,Industrial Devices 5300H5 or equiv.	32567
F1,2	Fuse,3AG slow-blow,250V,current rating dependent upon model: Assy. No. 104240-1: 2A; Littelfuse 313002 or equiv. Assy. No. 104240-3: 1A; Littelfuse 313001 or equiv.	 7549 6645
L1,2	Choke,high-current,12µH,4.5A,10%,40 MHz series resonant frequency, Caddell-Burns 6860-02 or equiv.	30436
L3,4	Not used.	
L5-7	Inductor,powerline,10µH	30063
R1-4	Resistor,composition,1Ω,5%,1/2W, Allen-Bradley EB Series or equiv.	1009 978
R5,8-10,12-14	Resistor,metal film,1KΩ,1%,1/4W, Type RN1/4	0410 1288
R6,7	Resistor,metal film,2KΩ,1%,1/4W, Type RN1/4	0410 1317
R11	Resistor,metal film,432Ω,1%,1/4W, Type RN1/4	0410 1253
SW1	Switch,rocker,SPST,marked,high inrush current	30441-1
X1,2	Converter,dc-dc,24V/100W output,input voltage dependent upon model: Assy. No. 104240-1: 42 to 60 Vdc input Assy. No. 104240-3: 100 to 200 Vdc input	 102651 102650-1
X3	Converter,dc-dc,triple output,36 to 72 Vdc input,+5V/1.5A and ±12V/250 mA outputs,15W total	102652

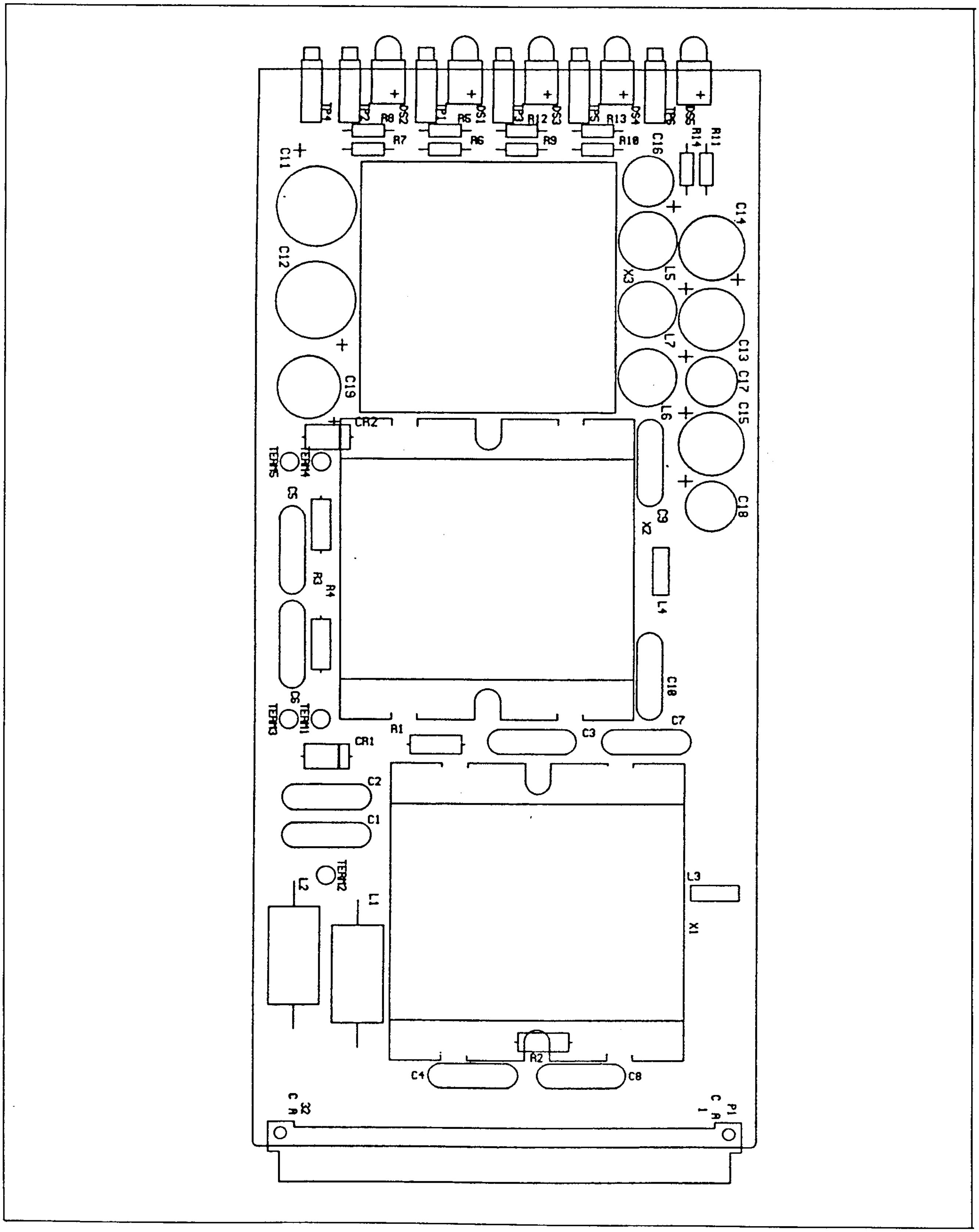
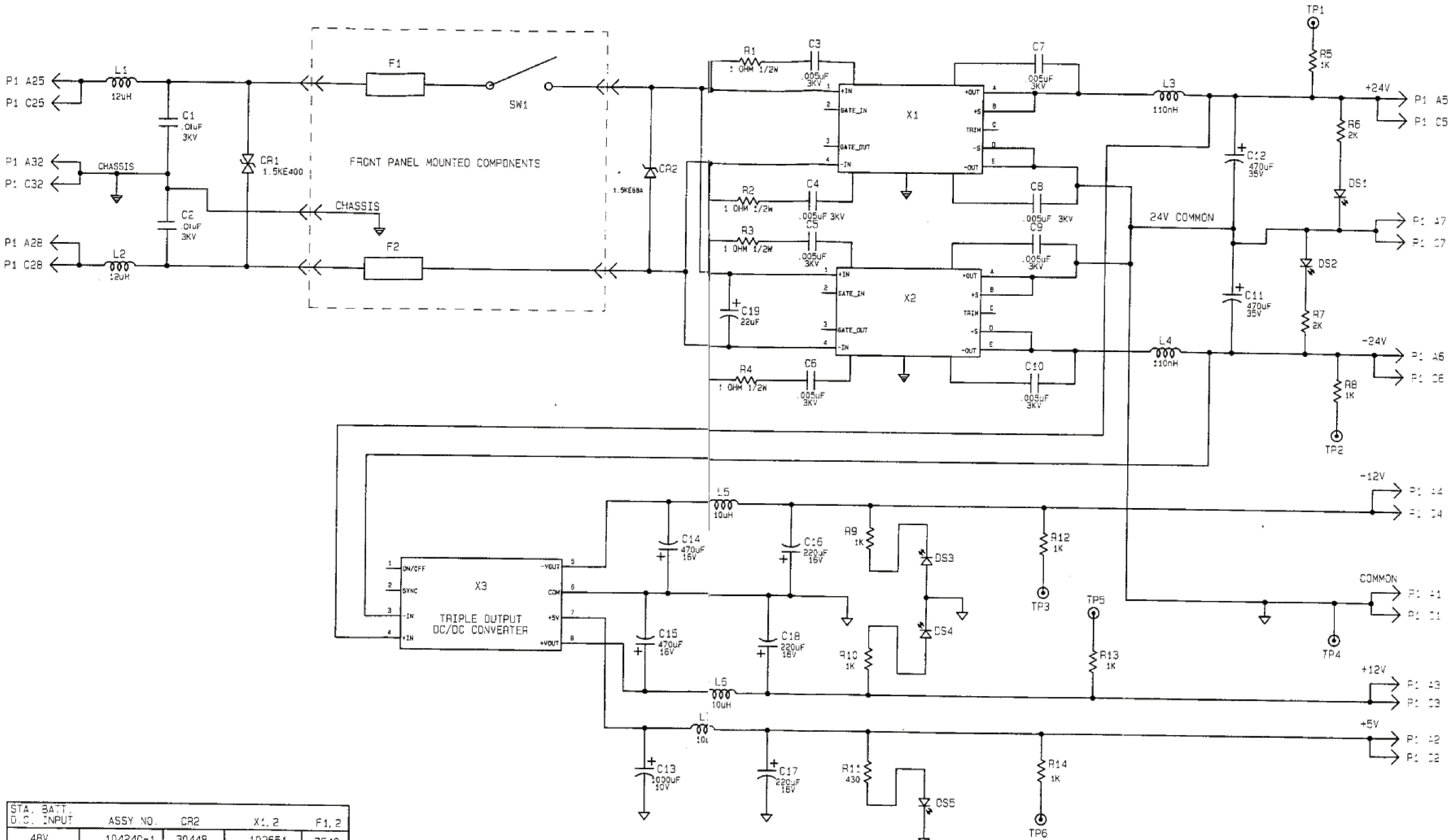


Figure 7-3. Component locator drawing, RFL 9720 PM Power Module (Assembly No. 104240-X; Drawing No. D-104243, Rev. A)



STA. BATT. D.C. INPUT	ASSY NO.	CR2	X1, 2	F1, 2
48V	104240-1	30448	102651	7549
125V	104240-3	30449	102650-1	6645

Figure 7-4. Schematic, RFL 9720 PM Power Module (Assembly No. 104240-X; Schematic No. D-104244, Rev. C)

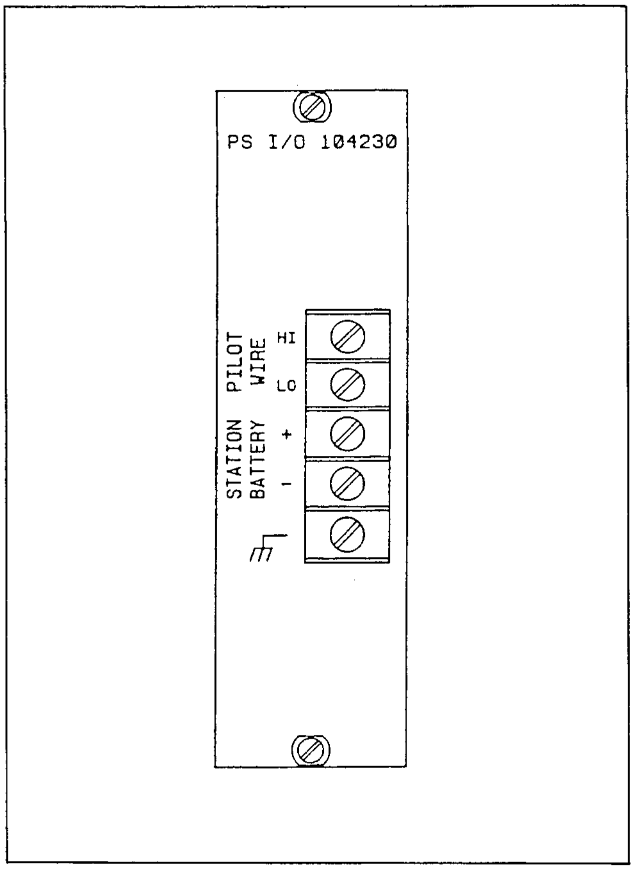


Figure 7-5. RFL 9720 PM I/O Input/Output Module

7.3. PM INPUT/OUTPUT MODULES

7.3.1. Description

PM input/output modules connect station battery and chassis ground to the RFL 9720 system. They also contain circuits that interface the RFL 9720 to the pilot wire relay.

A typical PM input/output module is shown in Figure 7-5. There are four different modules, identified by the assembly numbers on their rear panels:

RFL 104230-1	For General Electric CPD relays
RFL 104230-2	For GEC Type MBCI relays
RFL 104230-3	For ABB Type HCB-1 relays
RFL 104230-4	For ABB Type HCB relays

7.3.2. Theory Of Operation

The RFL 9720 PM I/O module routes the station battery voltage to the RFL 9720 PM Power Module. It contains an impedance matching network for the current differential relay, a squelch relay, an unblocking relay, a current sense transformer, and SWC protection components. A block diagram of the RFL 9720 PM I/O appears in Figure 7-6.

7.3.2.1. Relay Impedance Matching Network

The relay impedance matching network on each RFL 9720 PM I/O matches the RFL 9720 to the impedance characteristics of the current differential relay being interfaced.

On the RFL 104230-1, inductor L3, capacitor C3, and resistor R3 are the relay impedance matching components. On the RFL 104230-2, resistor R1 replaces L3, C3 and R3, and resistor R2 replaces jumper J2.

On the RFL 104230-3, the non-linear impedance of an HCB-1 relay is simulated by inductors L3 and L4, transformer T2, diodes CR4 through CR11, and their associated components. Resistors R1 and R2 emulate the optimum 60Ω pilot wire resistance. The RFL 104230-4 is similar to the RFL 104230-3, but its component values are selected for use with HCB relays.

7.3.2.2. Squelch And Unblocking Relays

Squelch relay K1 and unblocking relay K2 control the connections to the current differential relay's pilot wire input terminals. Depending on how J1 is set and the type of protective relay being used, the pilot wire relay is operated in either the trip inhibit or overcurrent mode when K1 drops out.

K2 is controlled by jumper J3. With J3 in the OUT position, K2 will not operate, and the unblocking function is disabled. With J3 in the IN position, K3 will be held in for 150 ms after squelch relay K1 drops out.

When J3 and mode selection jumper J1 are both in the IN position, the pilot wire input to the protective relay be open-circuited for 150 ms after relay K1 drops out. After 150 ms, K2 will drop out and the pilot wire input to the protective relay will be short-circuited.

When J3 is in the IN position and J1 is in the OUT position, the pilot wire input to the protective relay be short-circuited for 150 ms after relay K1 drops out. After 150 ms, K2 will drop out and the pilot wire input to the protective relay will be open-circuited. (See paragraph 3.3.1 for more information on these jumpers.)

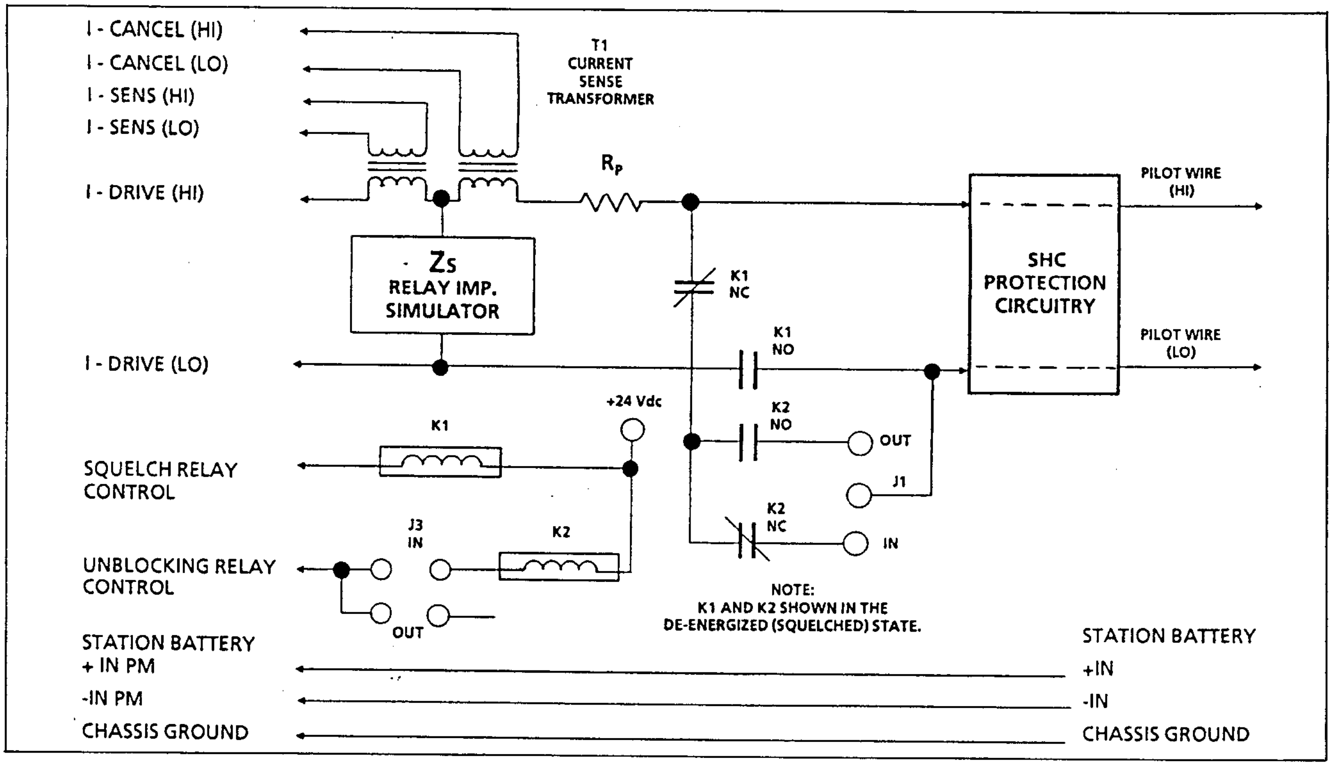


Figure 7-6. Block diagram, RFL 9720 PM I/O Input/Output Module

7.3.2.3. Current Sense Transformer

Current sense transformer T1 senses the current in the pilot wire circuit and the impedance matching circuit. It uses these currents to produce a combined signal that is fed to the RFL 9720 PAM Power Amplifier Module (Section 6). The current sense circuit on the RFL 9720 PAM supplies the flux canceling signal, which is applied to T1's T1 I-CANCEL winding.

7.3.2.4. Surge Protection Components

Inductors L1 and L2, capacitors C1 and C2, and transient suppressor CR1 provide SWC protection for the RFL 9720 PM Module.

Table 7-2. Replaceable parts, RFL 9720 PM input/output modules
RFL 104230-1 (For CPD Relays) - Assembly No. 104230-1
RFL 104230-2 (For MBCI Relays) - Assembly No. 104230-2
RFL 104230-3 (For HCB-1 Relays) - Assembly No. 104230-3

Circuit Symbol (Figs. 7-7 thru 7-10)	Description	Part Number
	CAPACITORS	
C1,2	Capacitor,ceramic disc,0.005µF,20%,3kV,Centralab DD30-502 or equiv.	1007 1264
C3	Capacitor,value and type dependent upon model: RFL 104230-1: Metallized polyester,1.5µF,5%,400V, Wesco 33MM1504J-400 or equiv. All Others: Not used.	1007 1750
C4,5	Capacitor,Z5U ceramic,0.02µF,20%,500V,Erie 841-000Z5U0-203M or equiv.	1007 82
C6,7	Capacitor,ceramic disc,0.01µF,20%,3000V,Sprague 30GA-S10 or equiv.	1007 1442

Table 7-2. Replaceable parts, RFL 9720 PM input/output modules - continued.

Circuit Symbol (Figs. 7-7 thru 7-10)	Description	Part Number
	RESISTORS	
R1	Resistor,value and type dependent upon model: RFL 104230-1: Not used. RFL 104230-2: Wirewound,1.2KΩ,5%,12W,Ohmite 1738 or equiv. RFL 104230-3 And RFL 104230-4: Metal film,30.1Ω,1%,1/4W,Type RN60D	 1100 684 1510 877
R2	Resistor,value and type dependent upon model: RFL 104230-1: Zero-ohm,1/4-watt size,Corning OMA07 or equiv. RFL 104230-2: Wirewound,500Ω,5%,3.25W,Ohmite 4411 Style 995-3A or equiv. RFL 104230-3 And RFL 104230-4: Metal film,128KΩ,1%,1/8W,Type RN60C	 1510 2217 1100 308 1510 887
R3	Resistor,carbon composition,value dependent upon model: RFL 104230-1: 22KΩ,5%,2W,Allen-Bradley HB Series or equiv. RFL 104230-2: Not used. RFL 104230-3 And RFL 104230-4: Resistor,composition,8.2Ω,5%,1/4W, Allen-Bradley CB Series or equiv.	 1009 521 1009 971
R4,5	Resistor,wirewound,330Ω,5%,3.25W,Ohmite 4404 Style 995-3A or equiv.	1100 330
R6,7	Resistor,metal film,100Ω,1%,1/4W, Type RN1/4	0410 1192
R8	Resistor,metal film,value dependent upon model: RFL 104230-1 and RFL 104230-2: Not used. RFL 104230-3: 267Ω,1%,1/4W, Type RN1/4 RFL 104230-4: 226Ω,1%,1/4W, Type RN1/4	 0410 1233 0410 1226
R9	Not used.	
R10	Resistor,metal film,value dependent upon model: RFL 104230-1 And RFL 104230-2: Not used. RFL 104230-3 And RFL 104230-4: 10.5Ω,1%,1/8W,Type RN55D	 1510 1389
R11	Resistor,metal film,value dependent upon model: RFL 104230-1 And RFL 104230-2: Not used. RFL 104230-3: 1.5KΩ,1%,1/4W, Type RN1/4 RFL 104230-4: 1KΩ,1%,1/4W, Type RN1/4	 0410 1305 0410 1288
R12	Resistor,composition,value dependent upon model: RFL 104230-1 and RFL 104230-2: Not used. RFL 104230-3: 1Ω,5%,1/2W, Allen-Bradley EB Series or equiv. RFL 104230-4: 4.7Ω,5%,1/4W, Allen-Bradley CB Series or equiv.	 1009 978 1009 964
R13	Resistor,composition,value dependent upon model: RFL 104230-1 and RFL 104230-2: Not used. RFL 104230-3: Same as R12. RFL 104230-4: 1Ω,5%,1/2W, Allen-Bradley EB Series or equiv.	 1009 978
R14	Resistor,composition,value dependent upon model: RFL 104230-1 and RFL 104230-2: Not used. RFL 104230-3: Same as R12. RFL 104230-4: 1.3Ω,5%,1/2W,Allen-Bradley EB Series or equiv.	 1009 1100
R15	Resistor,composition,value dependent upon model: RFL 104230-1 and RFL 104230-2: Not used. RFL 104230-3: 2Ω,5%,1/2W,Allen-Bradley EB Series or equiv. RFL 104230-4: Same as R14.	 1009 1060

Table 7-2. Replaceable parts, RFL 9720 PM input/output modules - continued.

Circuit Symbol (Figs. 7-7 thru 7-10)	Description	Part Number
	SEMICONDUCTORS	
CR1,3	Diode,silicon,200 PIV,1N4003	30769
CR2	Transient suppressor,type dependent upon model:	
	RFL 104230-1 and RFL 104230-2: 380- to 420-volt breakdown, General Semiconductor 1.5KE400CA or equiv.	30442
	RFL 104230-3 And RFL 104230-4: 71.3- to 78.8-volt breakdown, General Semiconductor 1.5KE75CA or equiv.	102665
CR4-11	Diode,value and type dependent upon model:	
	RFL 104230-1 And RFL 104230-2: Not used.	
	RFL 104230-3 And RFL 104230-4: Schottky,1A,30V,1N5818	30073
. . .	Transient suppressor,71.3- to 78.8-volt breakdown, General Semiconductor 1.5KE75CA or equiv. (Used on RFL 104230-2 only.)	102665
	MISCELLANEOUS COMPONENTS	
K1,2	Relay,DPDT,pc-mount,12-volt coil,5A contacts (24 Vdc or 240 Vac), AMF/Potter & Brumfield RKA-11DZ-12 or equiv.	101237
L1,2	Inductor,rf,10µH,5%,J.W. Miller 4622 or equiv.	30285
L3	Inductor,value dependent upon model:	
	RFL 104230-1: Selected value for CPD relay	102659
	RFL 104230-2: Not used.	
	RFL 104230-3 And RFL 104230-4: 820mH	102670
L4	Inductor,value dependent upon model:	
	RFL 104230-1 And RFL 104230-2: Not used.	
	RFL 104230-3 And RFL 104230-4: 4.18mH	102669
T1	Transformer,current sense	102675
T2	Transformer,matching,type dependent upon model:	
	RFL 104230-1 and RFL 104230-2: Not used.	
	RFL 104230-3 And RFL 104230-4: Non-audio,multiple-tap	102671
. . .	Safety cover,terminal block	100786
. . .	Shorting bar,single,Molex 90059-0009 or equiv.	98306

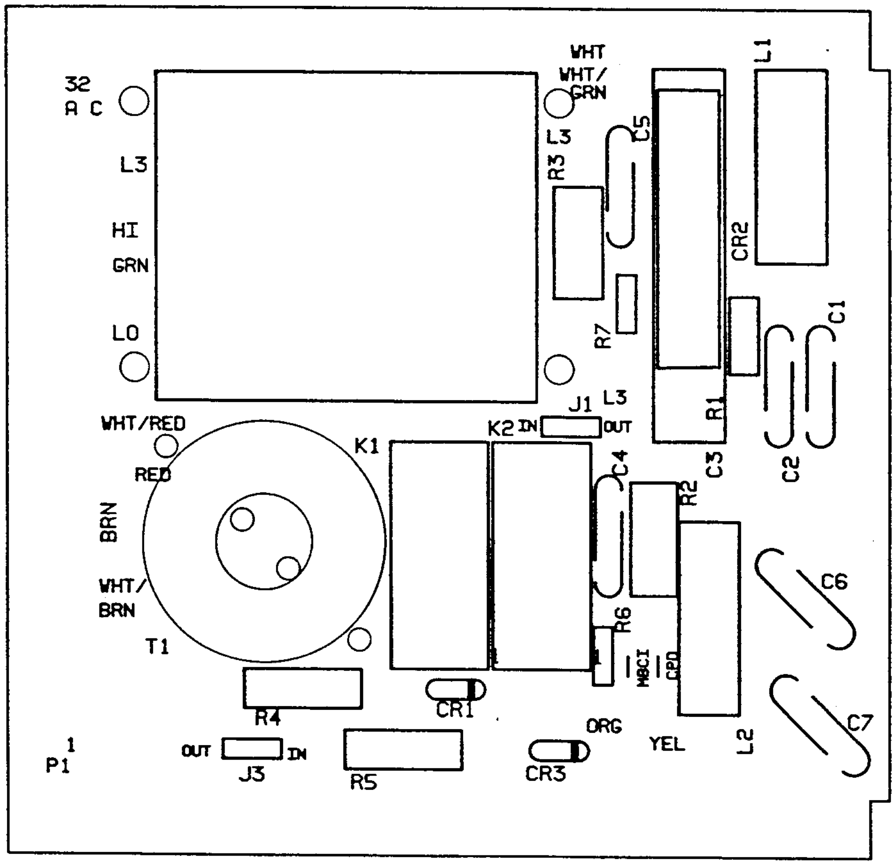


Figure 7-7. Component locator drawing, RFL 9720 PM input/output module for CPD and MBCI relays (Assembly Nos. 104230-1 and 104230-2; Drawing No. C-104233, Rev. E)

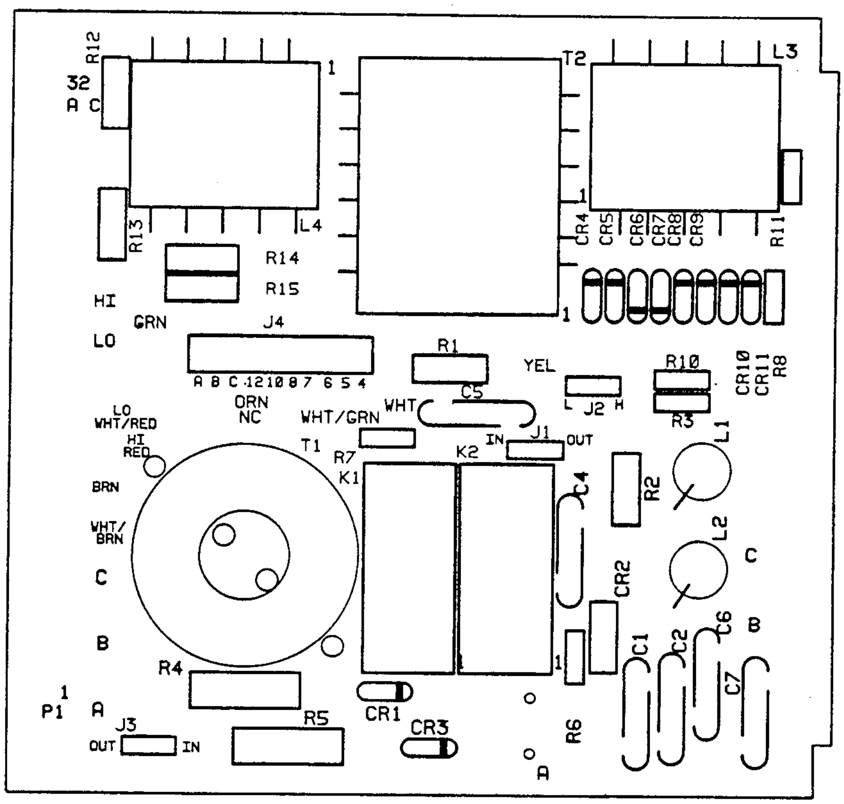


Figure 7-8. Component locator drawing, RFL 9720 PM input/output module for HCB-1 relays
(Assembly No. 104230-3; Drawing No. C-104248, Rev. E)

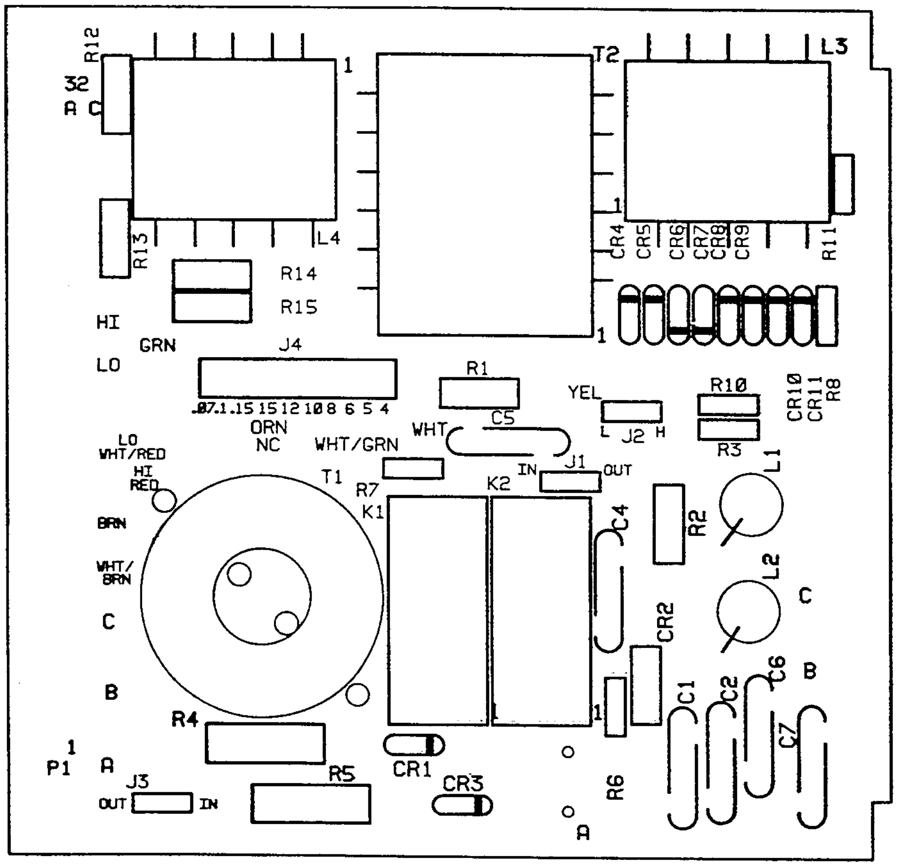


Figure 7-9. Component locator drawing, RFL 9720 PM input/output module for HCB relays (Assembly No. 104230-4; Drawing No. C-104253, Rev. A)

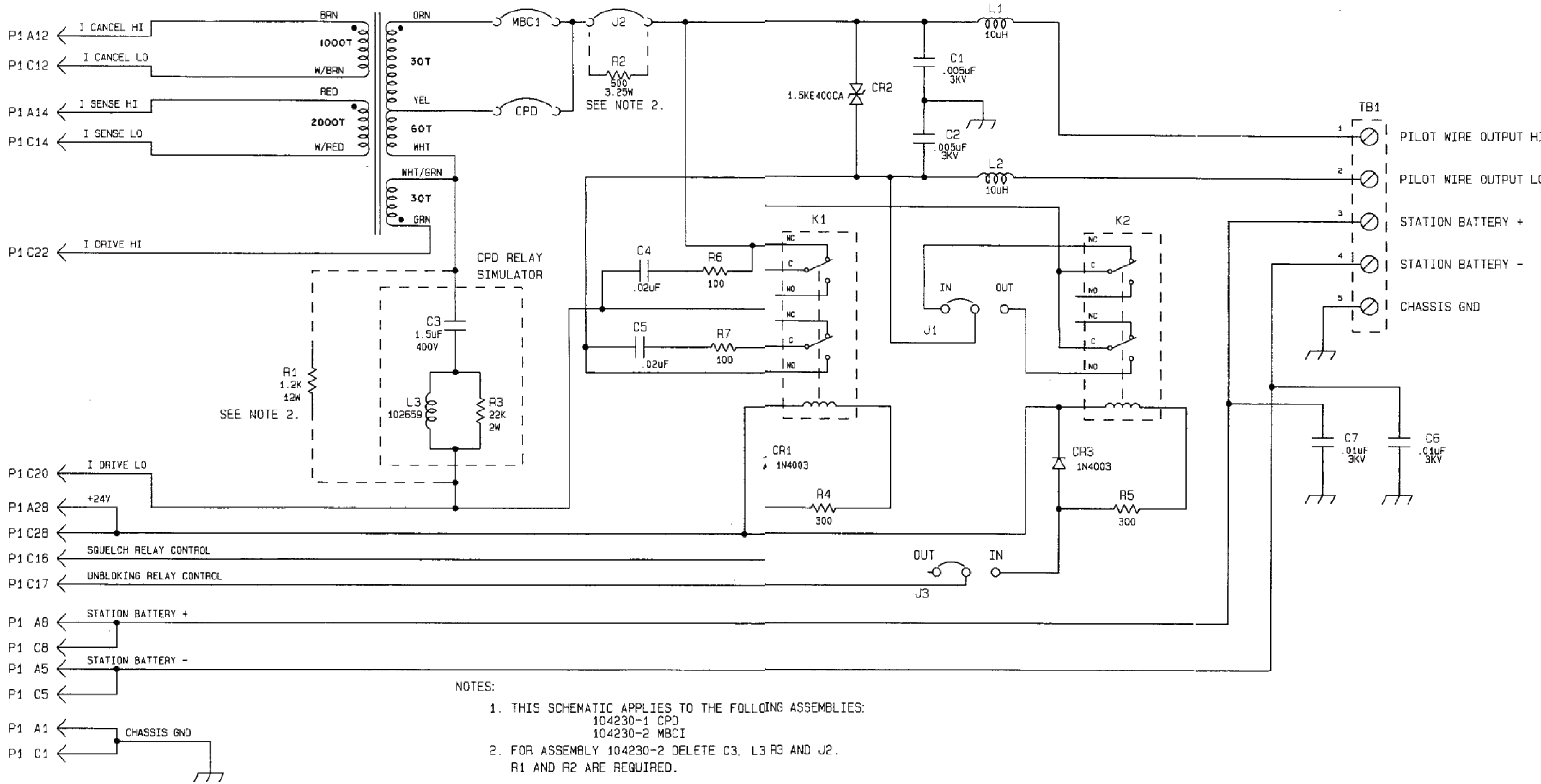


Figure 7-10. Schematic, RFL 9720 PM input/output module for CPD and MBCI relays (Assembly Nos. 104230-1 and 104230-2; Schematic No. D-104234, Rev. E)

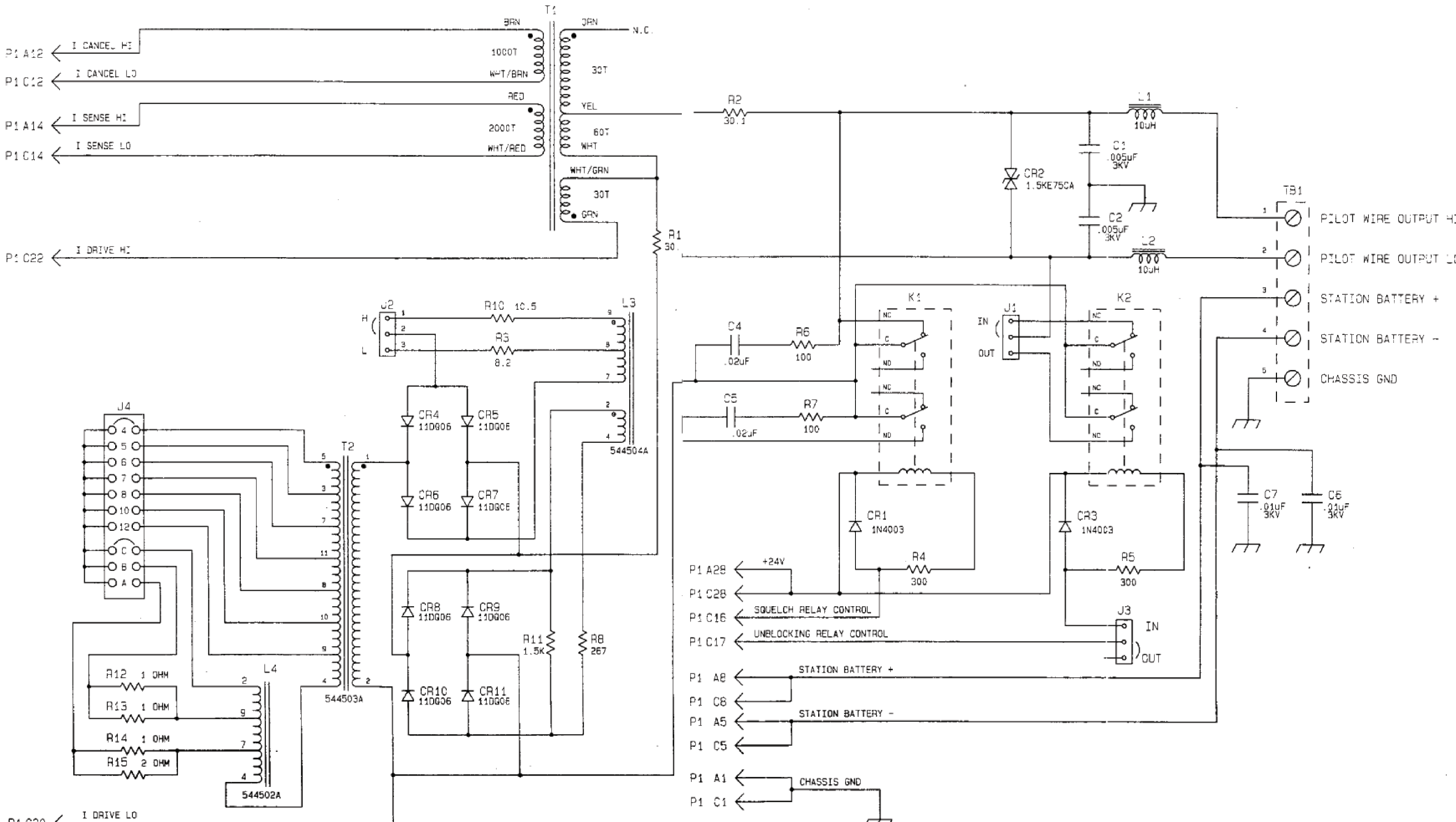


Figure 7-11. Schematic, RFL 9720 PM input/output module for HCB-1 relays (Assembly No. 104230-3; Schematic No. D-104249, Rev. B)

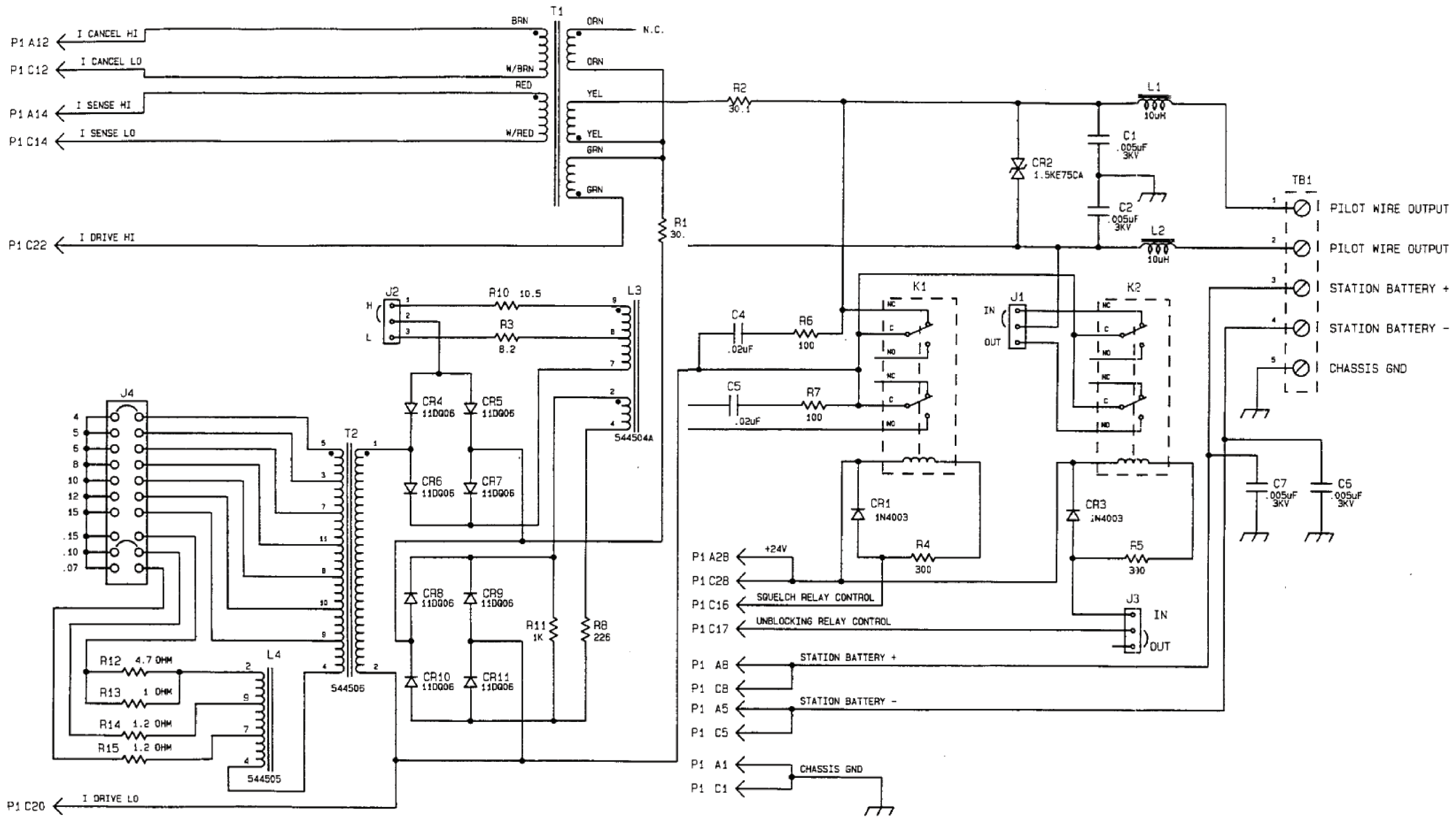


Figure 7-12. Schematic, RFL 9720 PM input/output module for HCB relays (Assembly No. 104230-4; Schematic No. D-104254, Rev. A)

Section 8. CHASSIS AND MOTHERBOARDS

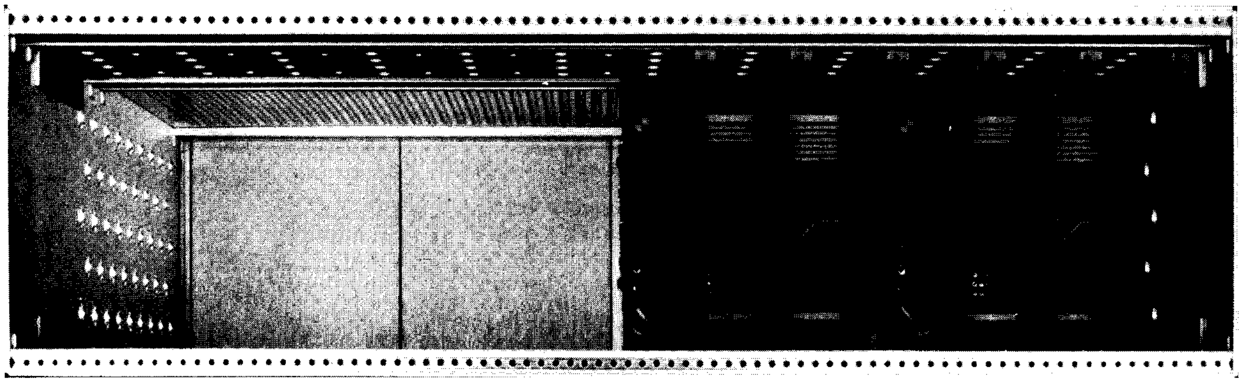


Figure 8-1. Typical RFL 9720 chassis with modules removed, showing location of motherboards

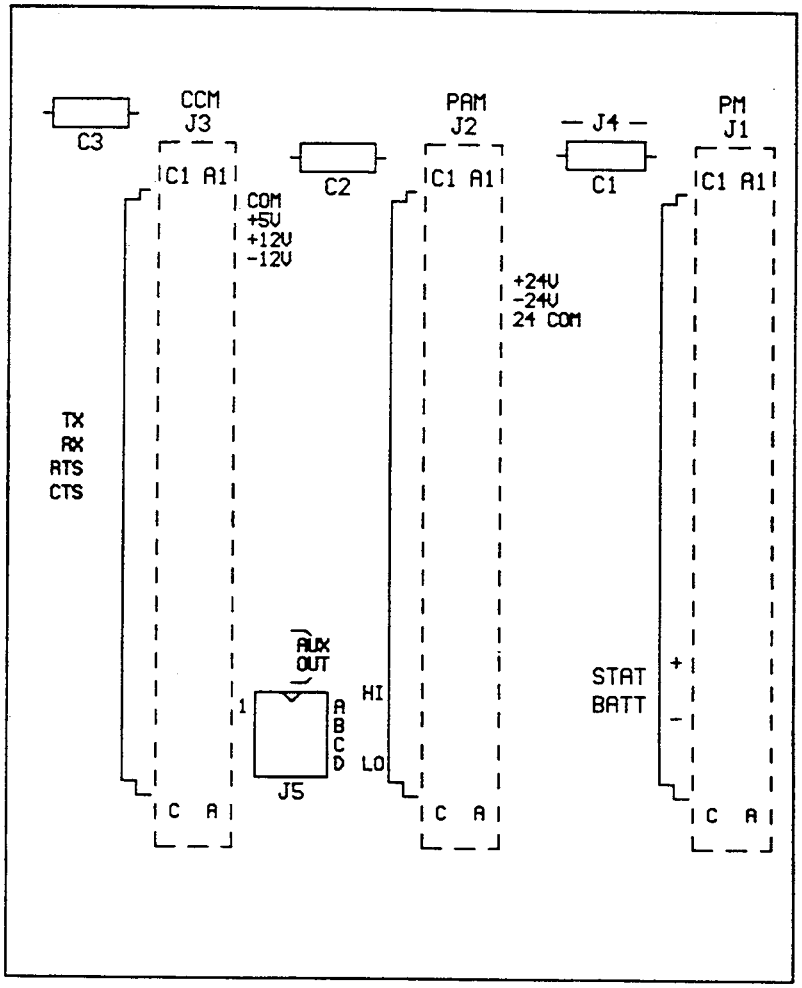
There are three different chassis available for RFL 9720 equipment. The most common is the 3U chassis; it will house up to four two-terminal RFL 9720 interfaces in 5.25 inches of vertical rack space (13.3 cm). A 1U flat-pack chassis is available for housing one RFL 9720 terminal in 1.75 inches of rack space (4.45 cm). A panel-mount chassis is also available for housing one two-terminal interface. Because none of the chassis contain field-replaceable components, no parts lists are provided in this manual. Figure 8-1 shows a typical RFL 9720 chassis and motherboard.

Each chassis contains a motherboard that contains the connectors and conductors used to interconnect all of the RFL 9720's main modules and I/O modules. Three different motherboards are available, depending on terminal and chassis configuration.

Table 8-1 lists the chassis/motherboard combinations used for all RFL 9720 configurations. A list of replaceable parts for all RFL 9720 motherboards appears in Table 8-2.

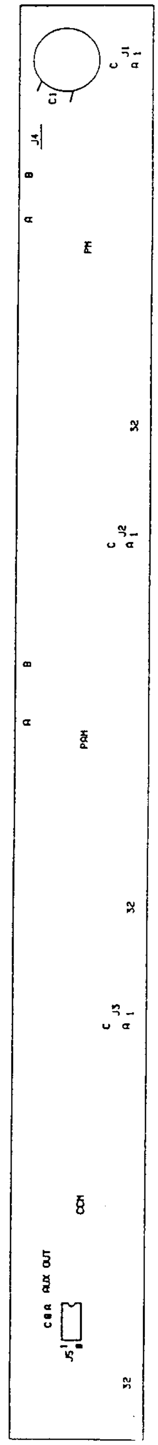
Table 8-1. Chassis/motherboard combinations, RFL 9700 Pilot Wire Interface

Configuration	Mounting Method	Number Of Interfaces Per Chassis	Chassis Model No.	Chassis Assy. No.	Motherboard Model No.	Motherboard Assy. No.
Two-Terminal	3U Rack-Mount	One to four	RFL 9720 3U	104250	RFL 9720 2TMB	104215
	1U Rack-Mount	One	RFL 9720 1U	104255	RFL 9720 1UMB	104235
	3U Panel-Mount	One	RFL 9720 PNL	104280	RFL 9720 2TMB	104215
Three-Terminal	3U Rack-Mount	One to three	RFL 9720 3U	104250	RFL 9720 3TMB	104275



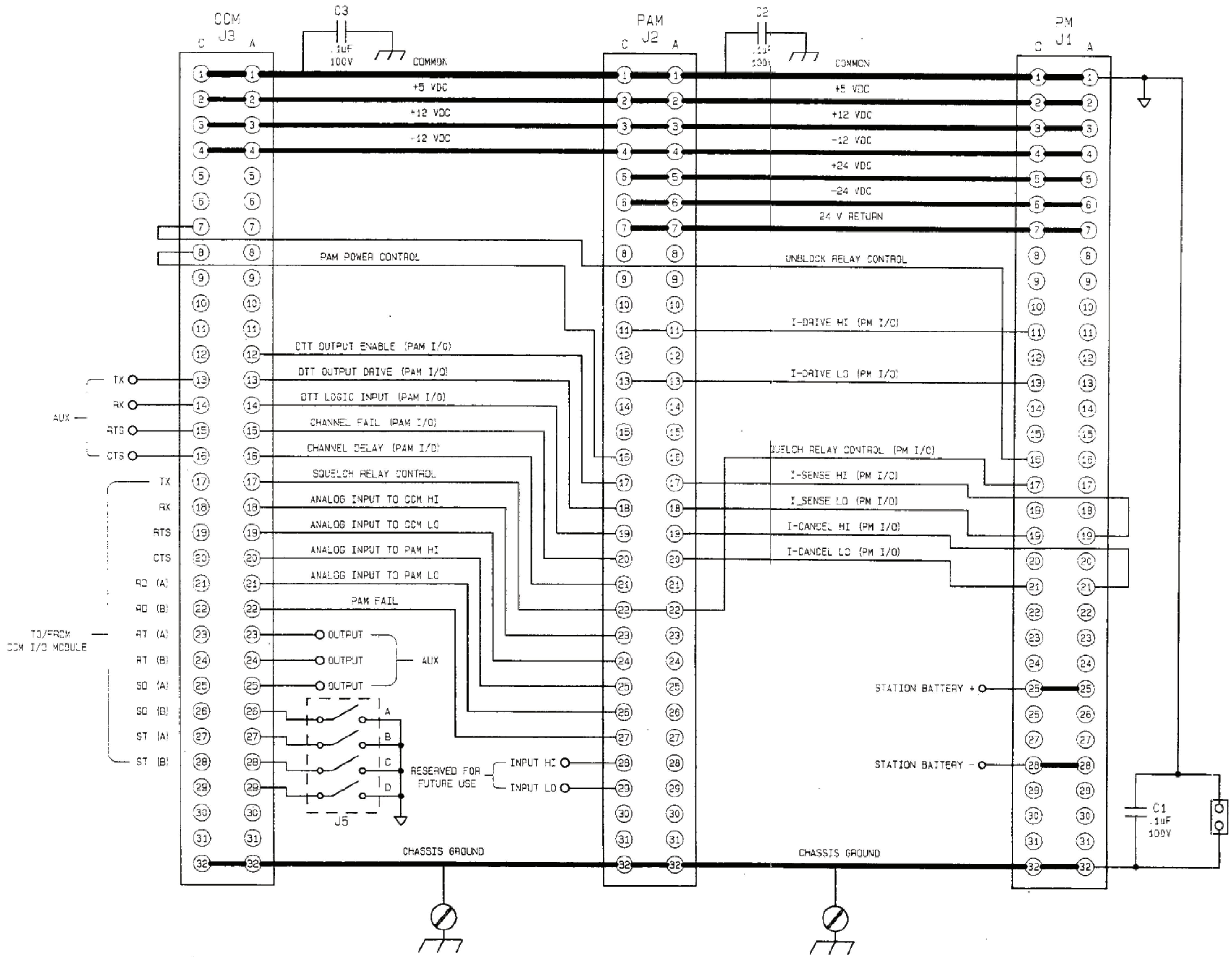
NOTE: AS VIEWED FROM REAR OF CHASSIS.

Figure 8-2. Component locator drawing, RFL 9720 2TMB Motherboard (two-terminal configuration for 3U or panel-mount chassis) (Assembly No. 104215; Drawing No. C-104218, Rev. D)



NOTE: AS VIEWED FROM REAR OF CHASSIS.

Figure 8-3. Component locator drawing, RFL 9720 1UMB Motherboard (two-terminal configuration for 1U chassis) (Assembly No. 104235; Drawing No. C-104238, Rev. B)



NOTE:
THIS SCHEMATIC APPLIES TO ASSEMBLIES 104215/3U & 104235/1U.

Figure 8-4. Schematic, two-terminal RFL 9720 motherboards (Schematic No. D-104219, Rev. C)

Section 9. ACCESSORY EQUIPMENT

If any accessory equipment was furnished with your RFL 9720 station at the time of purchase, information on these accessory items will be found immediately following this page. This may include Instruction Data Sheets, schematics, wiring diagrams, or other documents.