

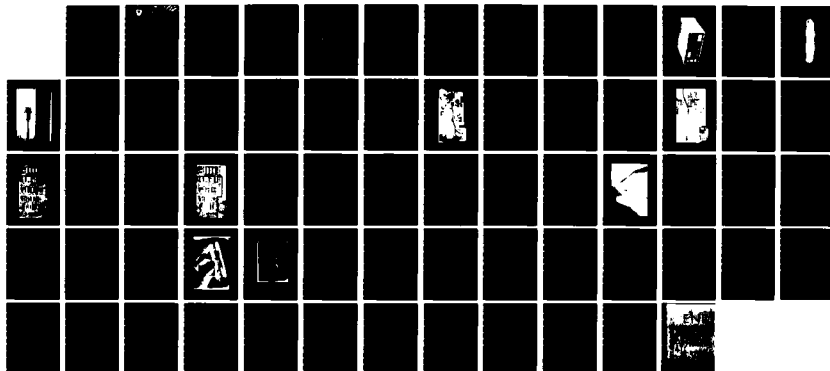
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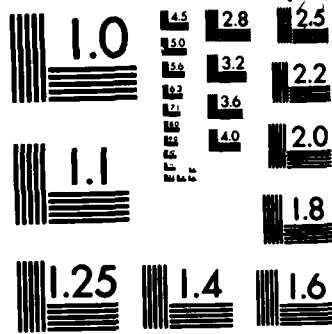
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**RESEARCH AND DEVELOPMENT TECHNICAL REPORT  
CECOM**

**FINAL TECHNICAL REPORT ON BIDIRECTIONAL  
FIBER OPTIC CABLE ADAPTER**

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February 1983

Final Report for Period 30 May 1981 - 15 December 1982

Prepared for  
US ARMY COMMUNICATIONS-ELECTRONICS COMMAND  
DRSEL-COM-RM-1  
Fort Monmouth, NJ 07703

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CECOM-81-C-0077-F	2. GOVT ACCESSION NO. <b>AD-A133 371</b>	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Bidirectional Fiber Optic Cable Adapter		5. TYPE OF REPORT & PERIOD COVERED Final 30 May 81-15 Dec 82
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) M. Linehan, N. B. Gee, R. Taylor		8. CONTRACT OR GRANT NUMBER(s) DAAK80-81-C-0077
9. PERFORMING ORGANIZATION NAME AND ADDRESS GTE Communication Systems Division 77 "A" Street Needham Heights, MA 02194		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L162701AH 92 MA
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Communications-Electronics Command DRSEL-COM-RM-1 Fort Monmouth, NJ 07703		12. REPORT DATE February 1983
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Same as above		13. NUMBER OF PAGES 62
		15. SECURITY CLASS. (of this report) Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE		
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release, distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) Same as above		
18. SUPPLEMENTARY NOTES <i>Amilan</i> <i>(1076-11-018)</i>		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Fiber optics communication Bidirection transmission Wavelength Division multiplexing Single Fiber system		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The technical objective of the BIFOCs program was to develop, build, and test a full-duplex single fiber, fiber optic link, operating in the 1.0 $\mu$ m to 1.6 $\mu$ m region, capable of transmitting 20 Mb/s data ( $10^{-9}$ BER) over a range of at least 10 km, with a goal of 15 km. The link MTBF goal was $5 \times 10^3$ hours and operation over a temperature range of 0°C to 50°C. The fiber optic cable consisted of sections not exceeding 2 km in length joined by commercially available dry fiber optic connectors. The system performed successfully at ambient temperature over 15 km of cable.		

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## 1.1 TECHNICAL REQUIREMENTS

The technical objective of the BIFOCS program was to develop, build, and test a full-duplex single fiber, fiber optic link, operating in the  $1.0\ \mu\text{m}$  to  $1.6\ \mu\text{m}$  region, capable of transmitting 20 Mb/s data ( $10^{-9}$  BER) over a range of at least 10 km, with a goal of 15 km. The link MTBF goal is  $5 \times 10^3$  hours and it must operate over a temperature range of  $0^{\circ}\text{C}$  to  $50^{\circ}\text{C}$ . The fiber optic cable must consist of sections not exceeding 2 km in length joined by commercially available dry fiber optic connectors.

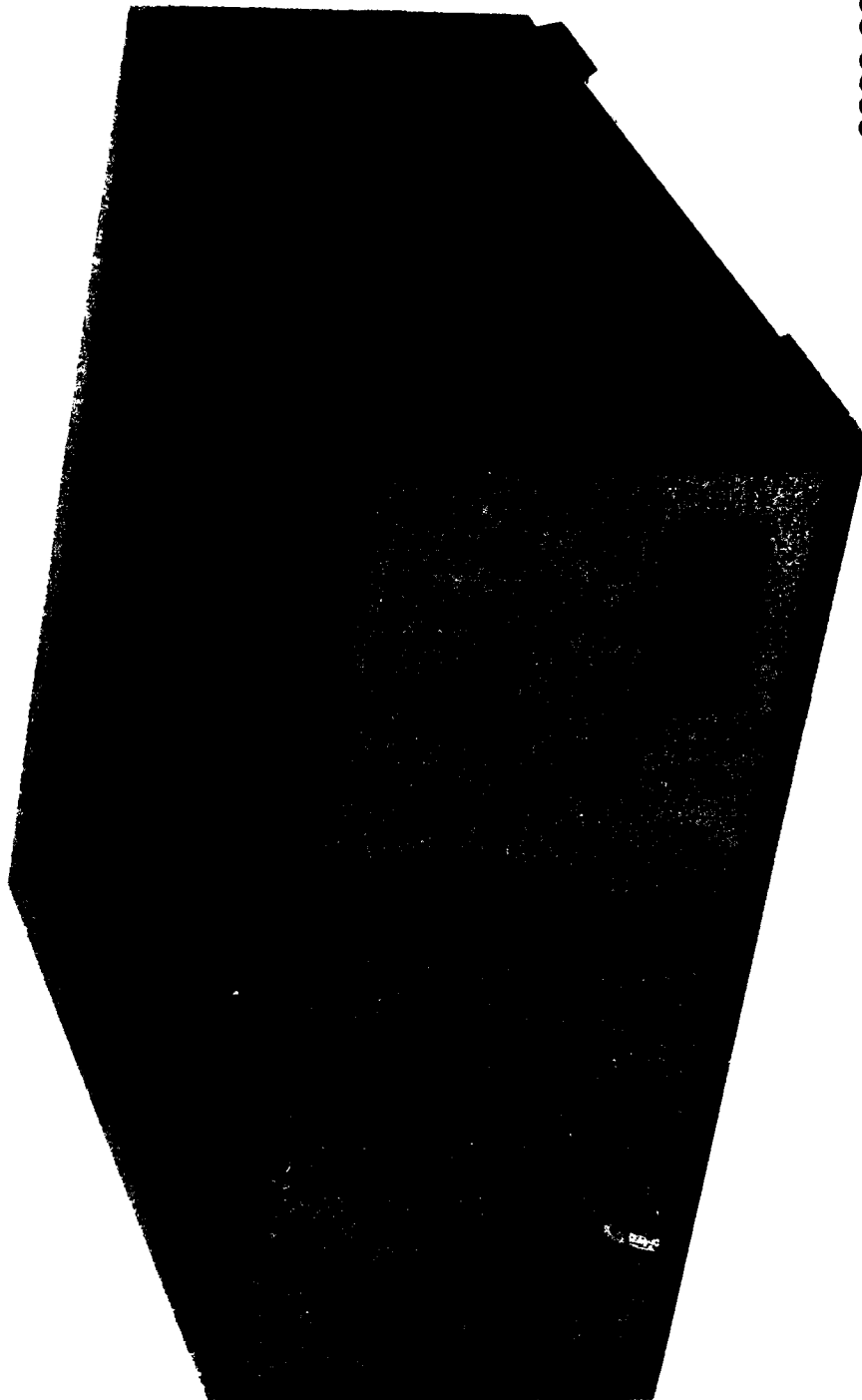
## 2.1 BIFOCS SYSTEM

### 2.1.1 System Description

The BIFOCS System is an exploratory development model of a long-wavelength, optically multiplexed, full-duplex 20 Mb/s transmission system developed for CECOM by GTE Products Corporation (CSD) under Contract DAAK80-81-C-0077. It was developed in accordance with the requirements of CECOM Specification No. 21-81 dated 10 June 1980 entitled "Bi-Directional Fiber Optic Cable Adapter"

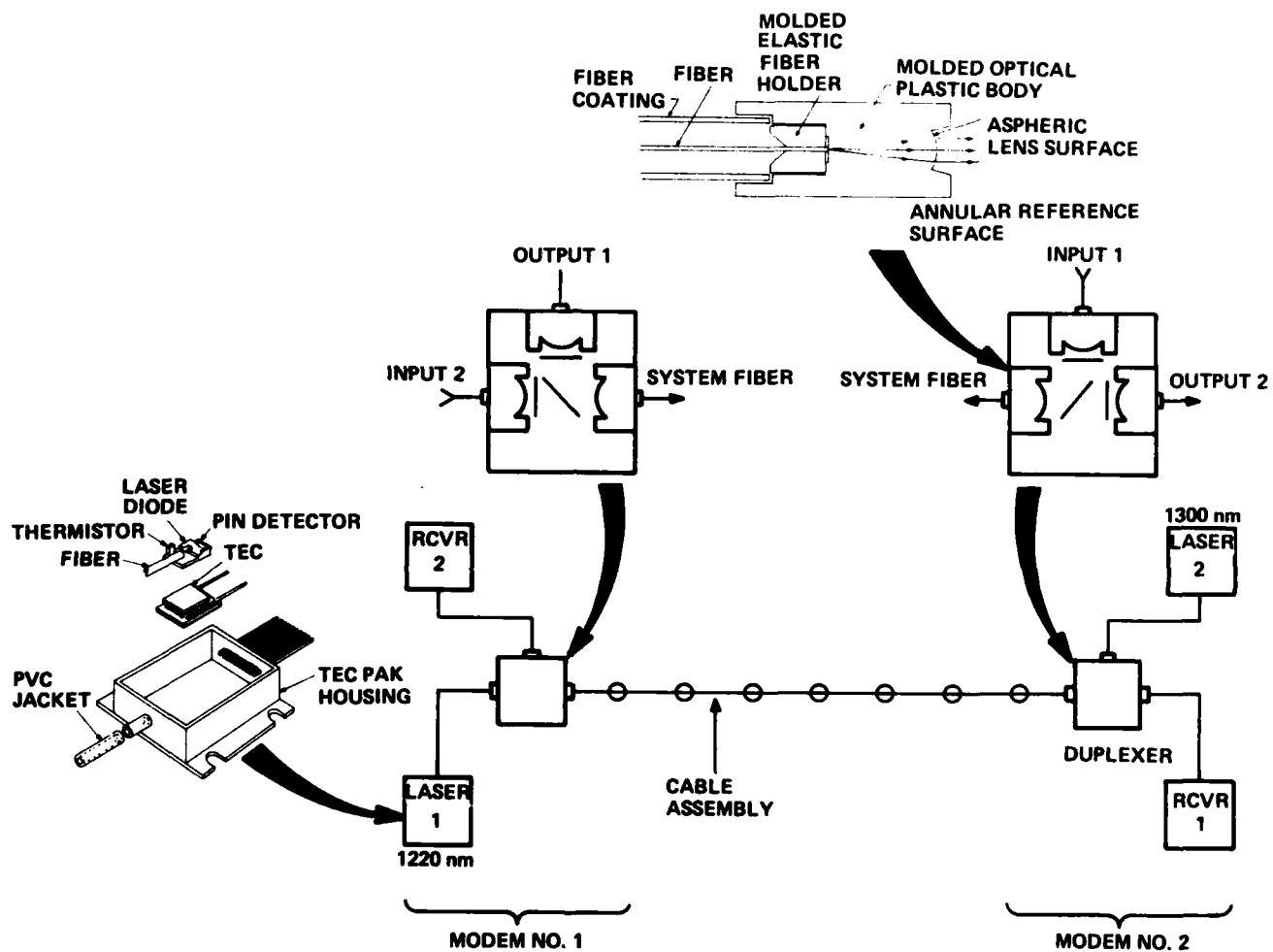
The function of BIFOCS is the simultaneous transmission of two different wavelengths of light in opposite directions over a single optical fiber. The system consists of two modem terminals (see Figure 1) and nine cable assemblies. These modems differ from each other only in the emitted wave length of the diode laser used in each and the connection configuration of the duplexer ports to the electro-optical components (see Figure 2). The cable assemblies, consisting of a single-fiber optical cable connectorized with prototype (plastic, commercial grade) GTE expanded beam connectors (see Figure 3). These cables total 15 km in length as shown in Section 2.1.3.

The prototype GTE connector was designed and fabricated by GTE Connector Products Operation to provide a backshell function for the GTE developed expanded beam microlens (Figure 4). The backshell



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Figure 1. BIFOCs Terminal (Modem)



8287-80E

Figure 2. BIFOCs System Configuration

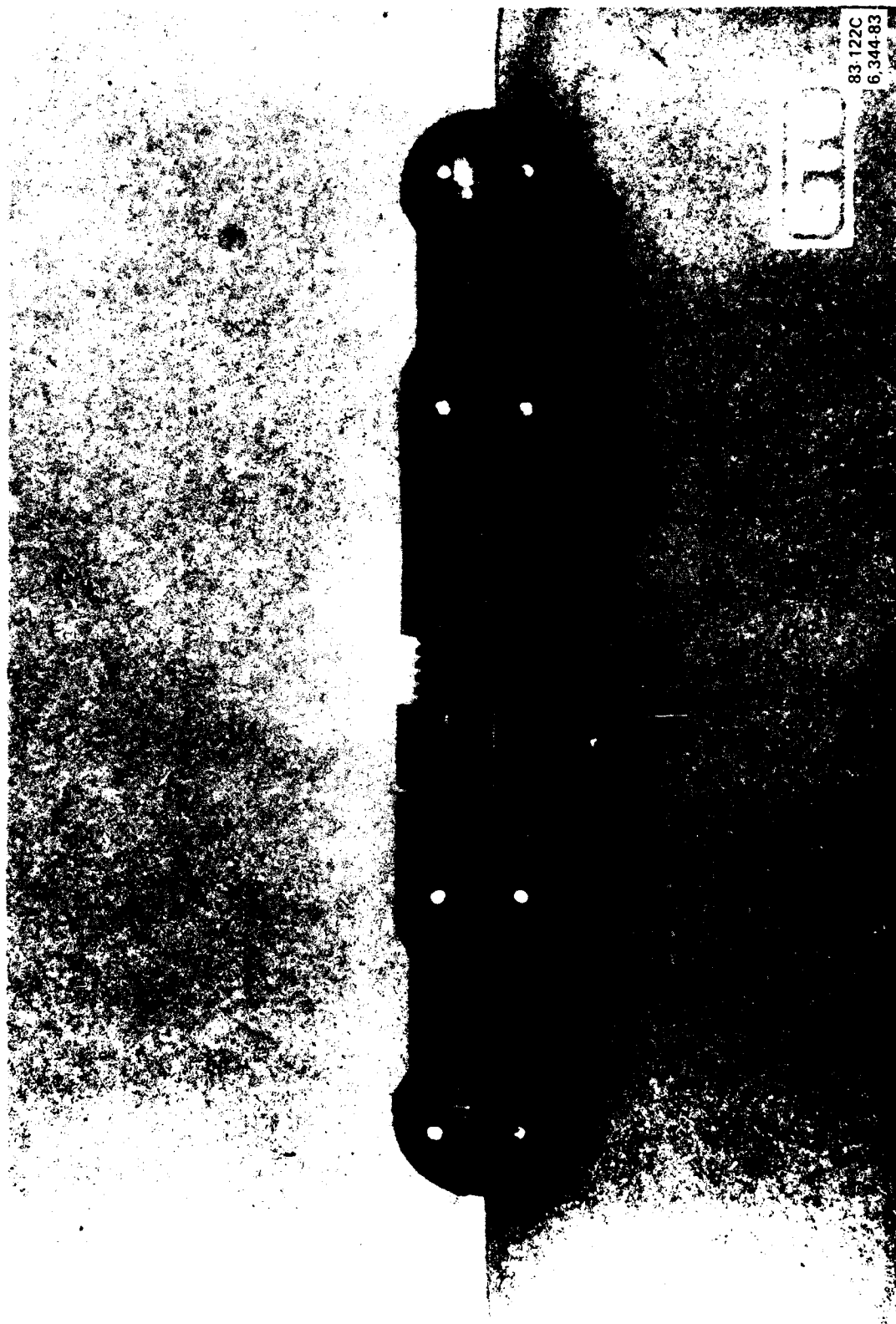


Figure 3. Optical Expanded Beam Connector

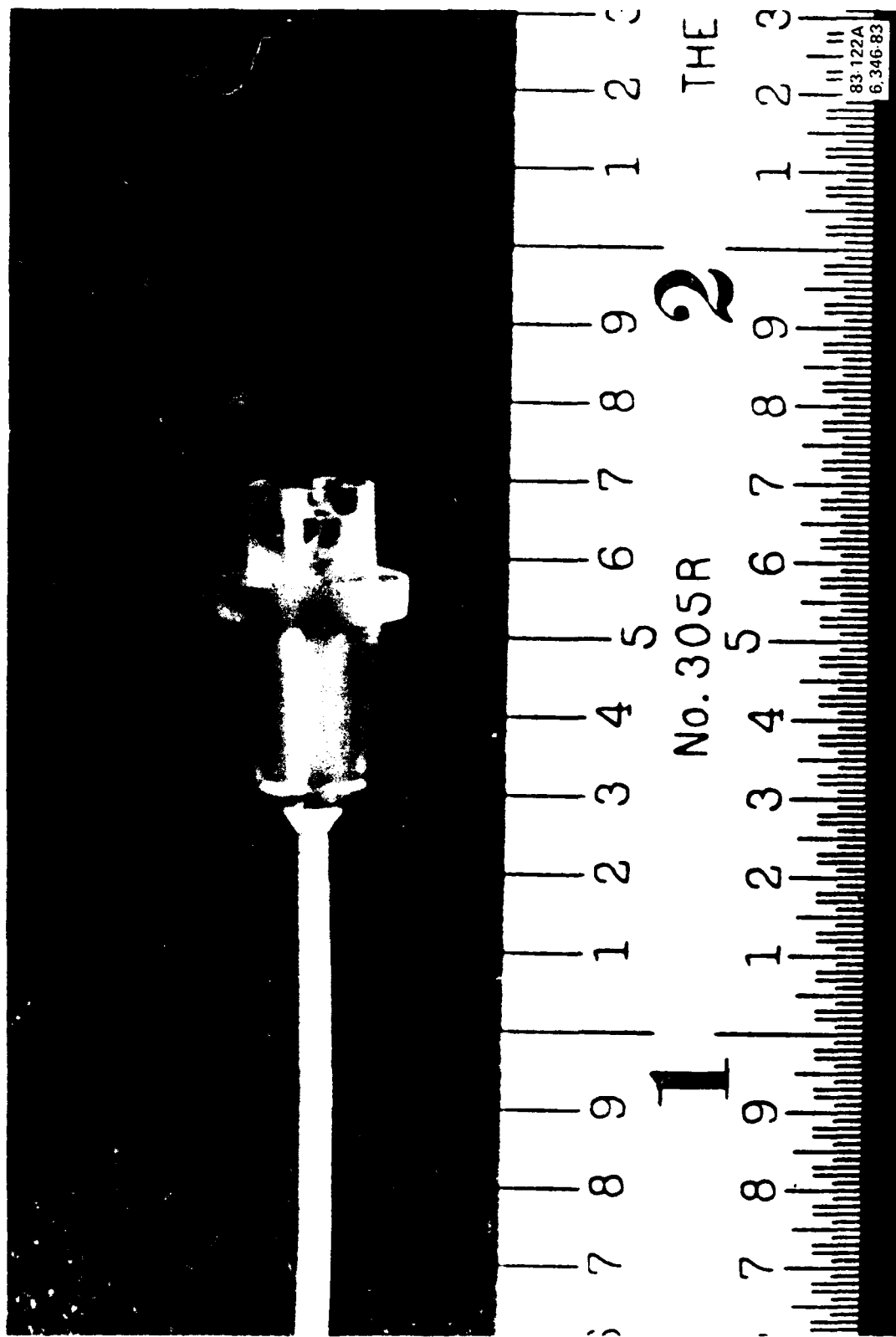


Figure 4. Microlens with Inch Scale and Installed Fiber

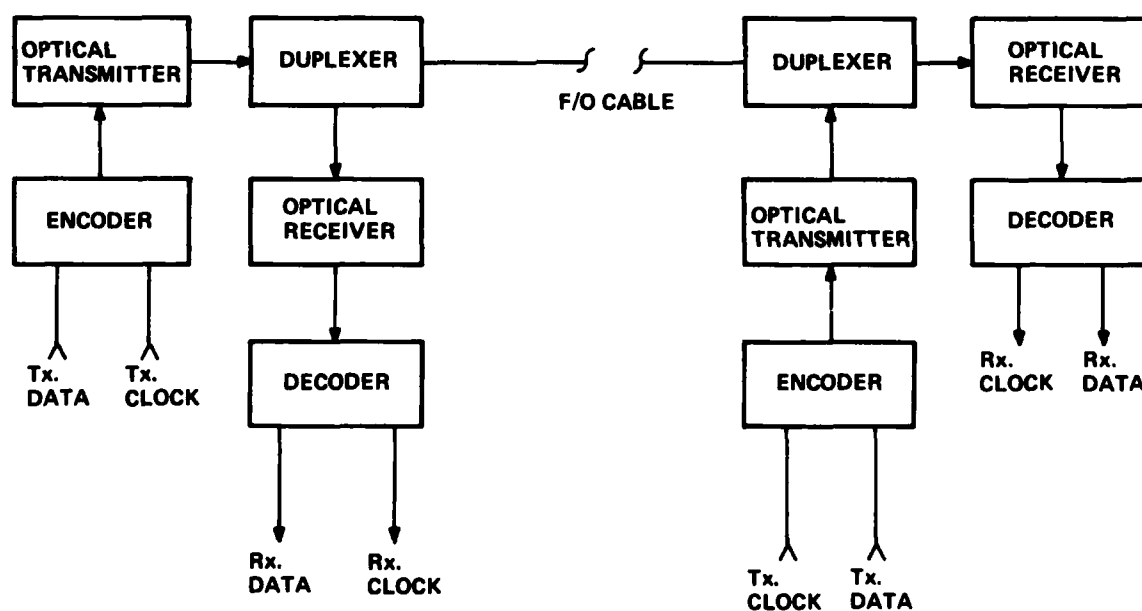
provided coarse axial alignment and a means to press the annular alignment surfaces of the microlens pair together. The connector also provides for limited strain relief of the cable.

### 2.1.2 System Operation

During actual operation, digital data at 20 Mb/s and a clock signal of 20 MHz are applied to the encoder via the Coder/Decoder (CODEC) card. Here the data is converted to Manchester format which is then sent to the transmitter. The transmitter performs a conversion of digital to optical signals and is capable of transmission at one wavelength, either 1.2  $\mu\text{m}$  or 1.3  $\mu\text{m}$ . The optical signal is then sent to the duplexer where it is directed out to the optical transmission cable.

Through a beamsplitter arrangement, the duplexer directs incoming optical signals to the receiver which converts the optical signal to

#### SYSTEM BLOCK DIAGRAM



7741-81

Figure 5. System Block Diagram



an electrical signal in Manchester format. This signal is then converted by the decoder back into a normal digital signal. Correct operation requires a matched pair of duplexers, one transmitting at 1.2  $\mu\text{m}$  and receiving at 1.3  $\mu\text{m}$  and a second unit transmitting at 1.3  $\mu\text{m}$  and receiving at 1.2  $\mu\text{m}$  (See Figure 5, System Block Diagram).

### 2.1.3 System Performance Specifications

The system is capable of simultaneous operation of data at 20 Mb/s, NRZ, under the following conditions:

Distance . . . . . 10 km minimum, 15 km goal

BER . . . . .  $10^{-9}$

Interface . . . . . TTL (data and clock)

Temperature Range . .  $0^{\circ}\text{C}$  to  $50^{\circ}\text{C}$

MTBF (Source). . . . .  $10^4$  hours (estimated) minimum

MTBF (System). . . . .  $5 \times 10^3$  hours target

Power . . . . . 115 Vac

Cable Plant . . . . . 1 to 2 km connectorized single fiber cable assemblies (Qty 4 of 1 km nominal length, Qty 5 of 2 km nominal length, with 15.3 km total) (see Table 1 for specific lengths)

TABLE 1. CABLE ASSEMBLIES

ID Number	Length (Meters)	ID Number	Length (Meters)
1	2222	6	1046
2	2180	7	1085
3	2225	8	1131
4	2230	9	137
5	2015		

### 3.1 MAJOR HARDWARE FUNCTIONS

Each modem consists of five major functional units and associated power supplies, indicators and controls. See Table 2.

TABLE 2. MAJOR FUNCTIONAL UNITS

Unit	Location	Function
Transmitter	On Transmitter Card	Converts encoded data to optical signal
Receiver	On Receiver Card	Converts optical signal to electrical signal
Encoder	On CODEC Card	Codes input data into Manchester format
Decoder	On CODEC Card	Decodes Manchester data to NRZ, TTL data
Duplexer	Located Mid-Chassis	Provides optical mixing/separation function

### 3.1.1 Fiber Optic Transmitter

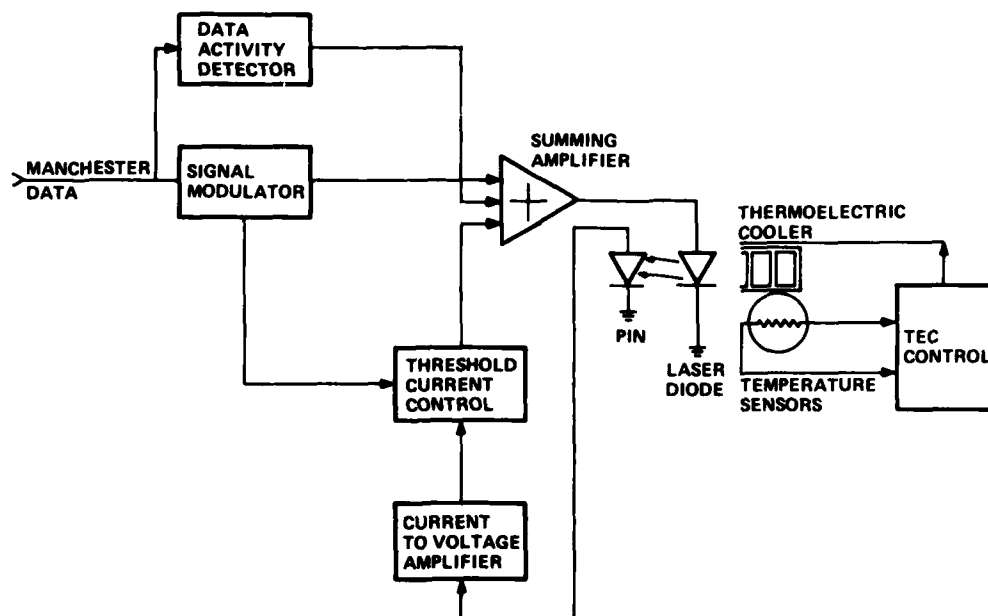
#### 3.1.1.1 Description

The fiber optic transmitter (see Figure 6) accepts data from the encoder and converts the electrical pulses into optical pulses by means of a solid-state laser operating in the 1.20  $\mu\text{m}$  to 1.35  $\mu\text{m}$  wavelength range. The specific wavelength of operation is critical and must be matched to the duplexer connectivity of the particular modem terminal and the wavelength of the terminal at the other end of the link (see Figure 7). The transmitter card (see Figures 8 & 9) includes circuits to set the bias current of the laser, to adjust the bias current by sensing the average optical power output of the laser, and to sense and regulate the temperature of the laser package's thermoelectric cooler in order to stabilize output wavelength and maximize device reliability. The parts list for the transmitter (PN06-1371757-1) is given in Appendix A.

#### 3.1.1.2 Performance Specifications

The transmitter must operate over the voltage and frequency ranges of the expected input (encoder output) bit stream at all points within the operating temperature range. These ranges are:

Logic "0" . . . . 0.2 V to 0.4 V  
 Logic "1" . . . . 2.4 V to 2.7 V  
 Frequency . . . . 20 Mb/s  $\pm$  5% (Manchester)  
 Temperature . . . 0°C to 50°C



7757-81

Figure 6. Optical Transmitter Block Diagram

### 3.1.1.3 Acceptance Limits

The transmitter shall exhibit the minimum performance as shown below at 20°C and 50°C when driven by an input signal within the ranges shown above.

Output Power . . . . . 1 milliwatt average, optical minimum

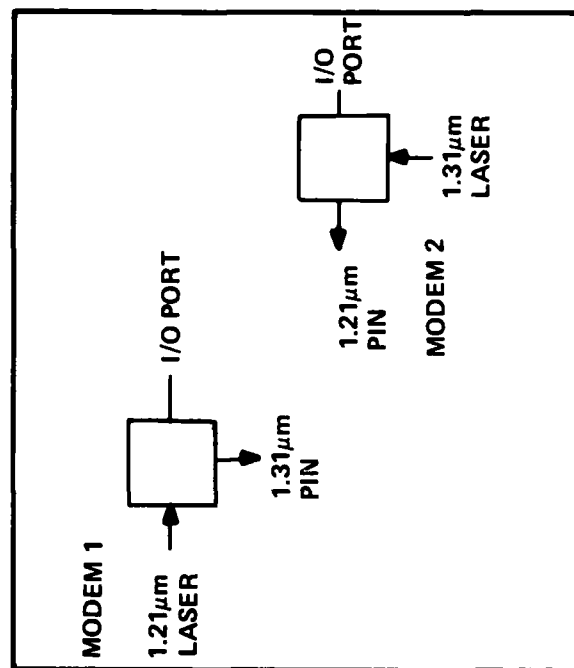
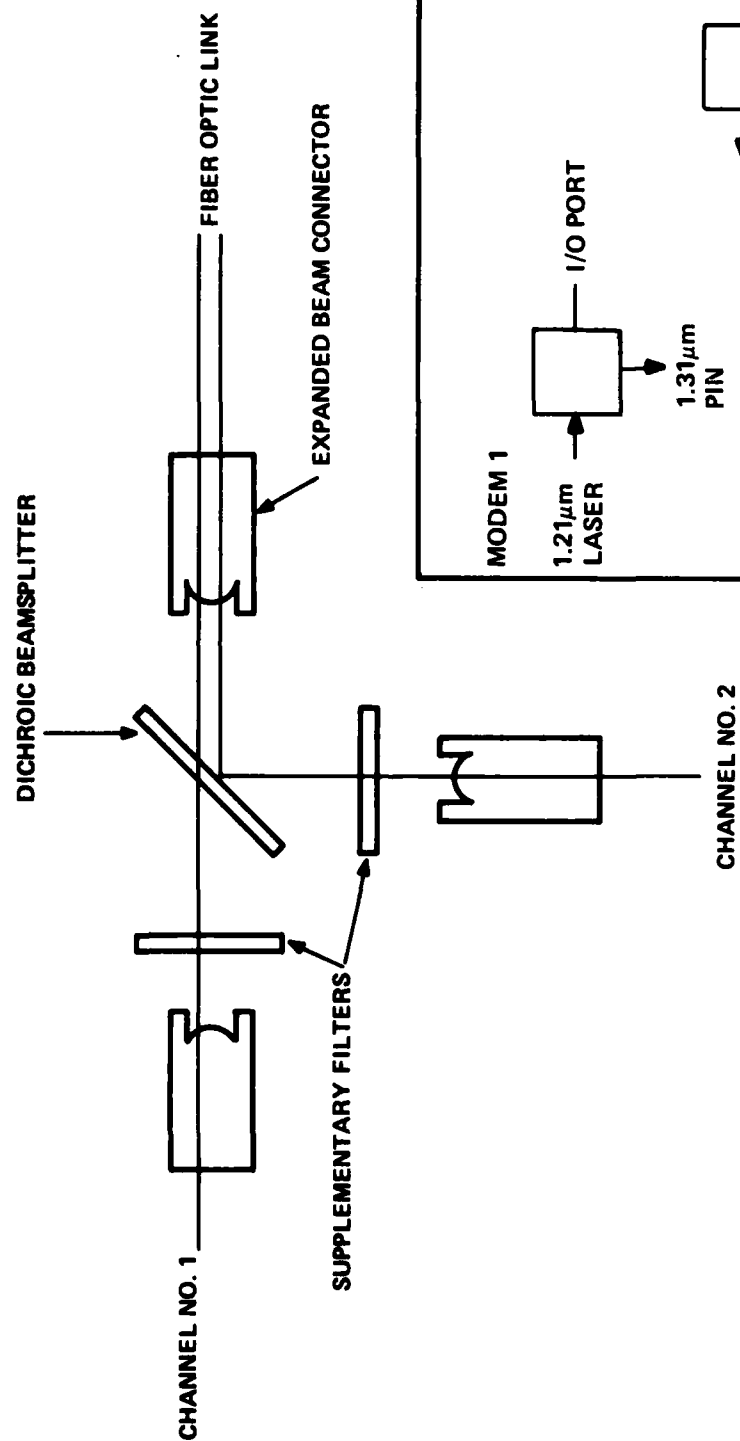
Wavelength . . . . . 1.21  $\mu\text{m}$   $\pm 0.01$

OR  
1.31  $\mu\text{m}$  + 0.02  $\mu\text{m}$   
- 0.00  $\mu\text{m}$

Extinction Ratio . . . . . 12:1 minimum

The power requirement is derived from the link power budget analysis (Section 3.3.4, Table 3) and the wavelengths and tolerances

# GTE OPTICAL WAVELENGTH DUPLEXER



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Figure 7. Modem Configuration Difference

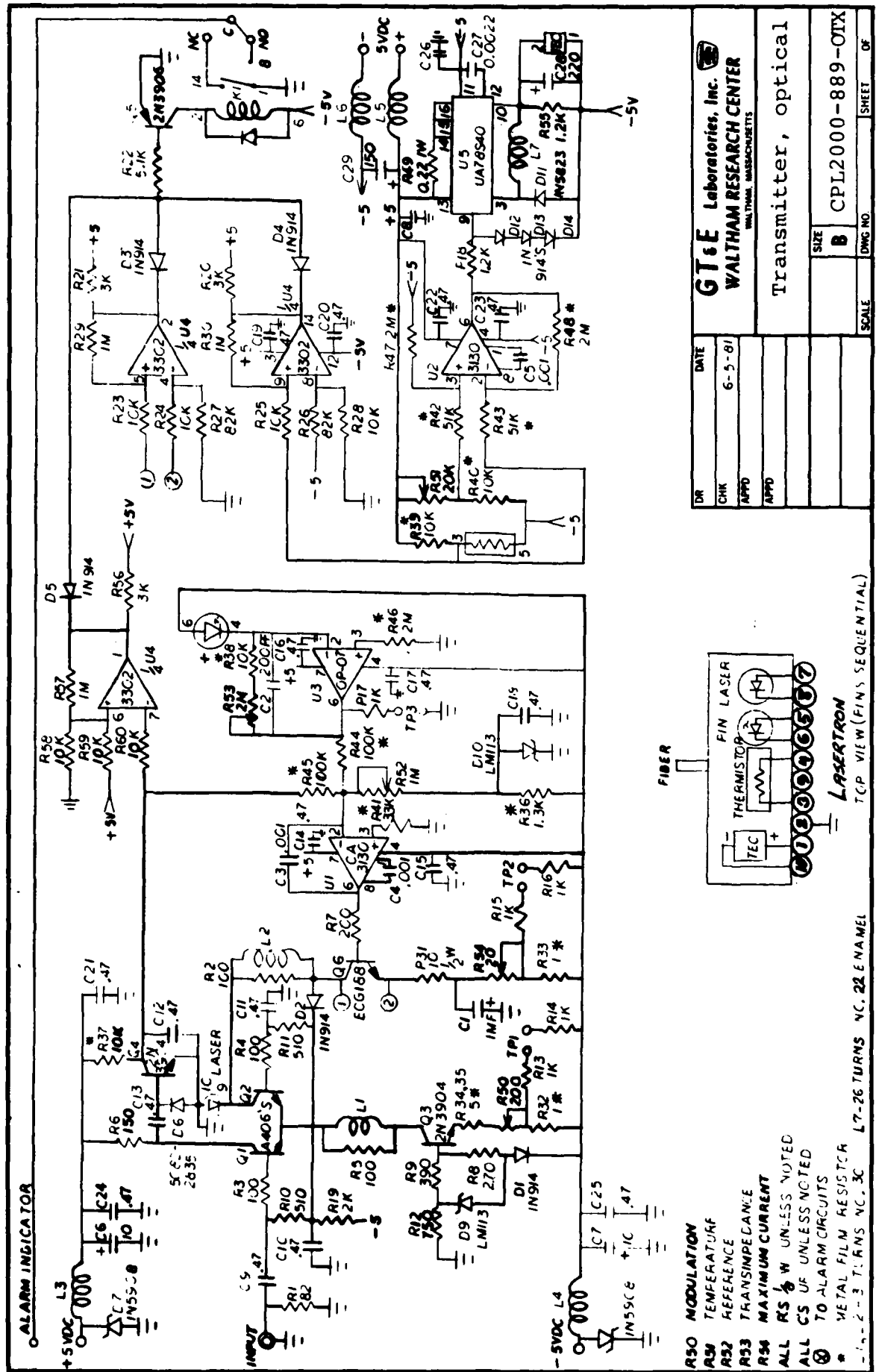
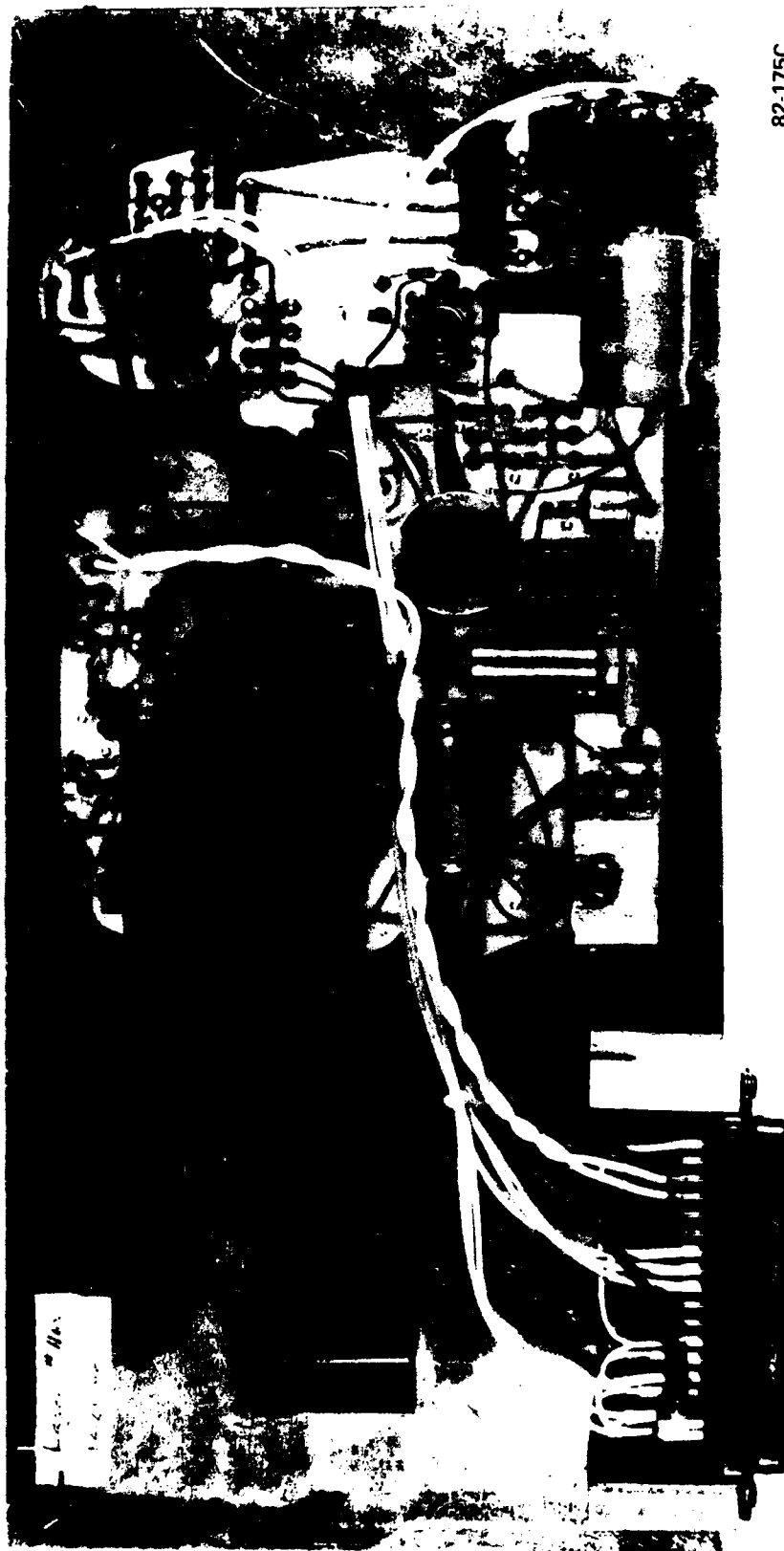


Figure 8. Transmitter Schematic



82-175C  
12643-82

Figure 9. Transmitter Card

from the crosstalk analysis (Section 3.3.4, Table 4) and the duplexer characteristic (Section 3.3.4, Tables 5 and 6).

### 3.1.2 Fiber Optic Receiver

#### 3.1.2.1 Description

The fiber optic receiver (see Figures 10, 11 and 12) converts optical pulse inputs into electrical signals and amplifies them to a TTL voltage level before applying them to the decoder. The optical to electrical conversion is accomplished by a PIN diode, followed by a low noise, high gain transimpedance amplifier. The transimpedance amplifier is followed by several subsequent gain stages. These gain stages are controlled by automatic gain control (AGC) circuits, which allow the receiver to adjust to a wide range of input optical power levels. The signal provided to the decoder is basically an analog electrical representation of the received optical signal.

The parts list for the receiver (PN 06-1371759-1) is given in Appendix A.

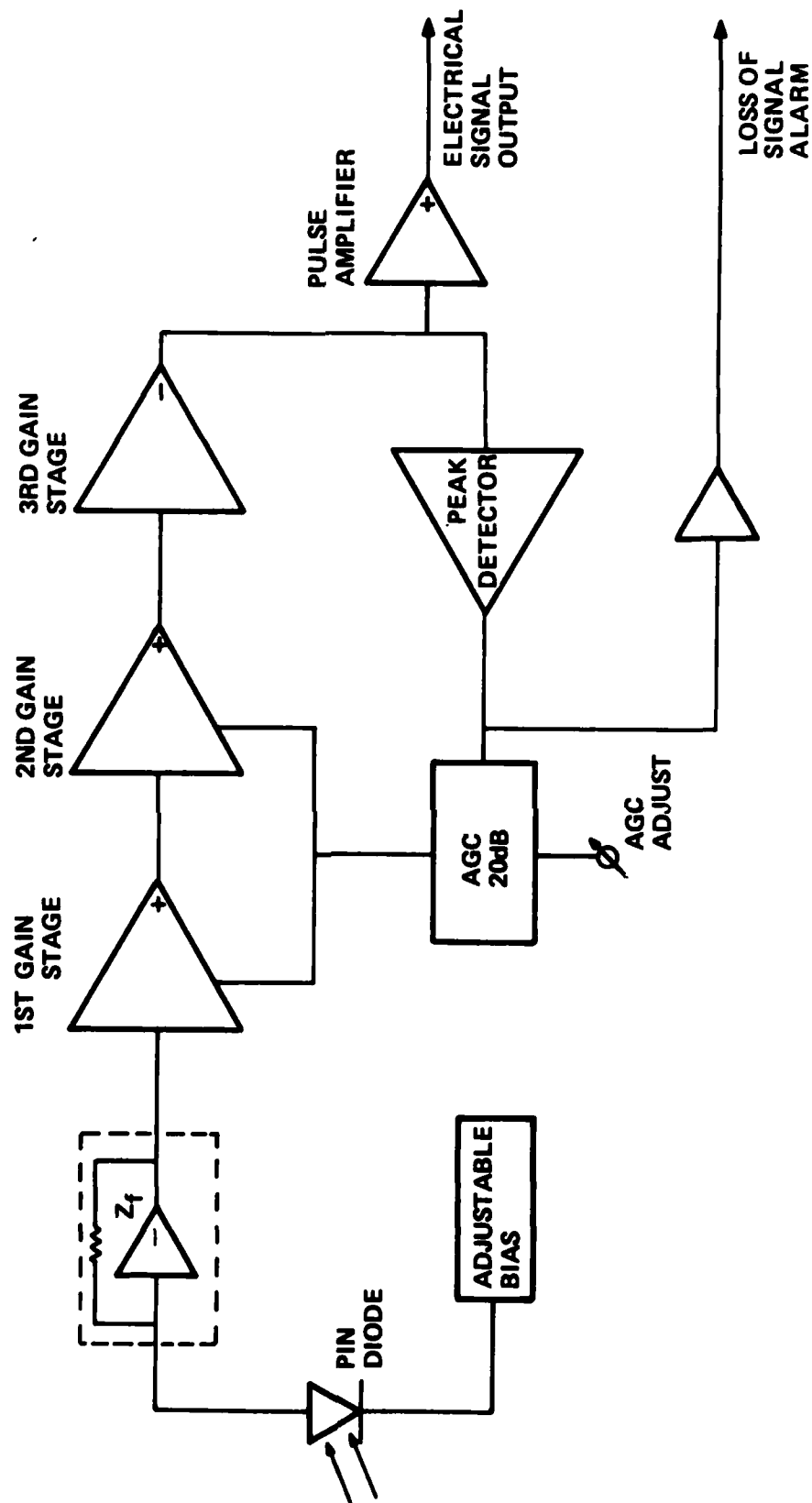
#### 3.1.2.2 Performance Specifications

The receiver must operate over a temperature range of 0°C to 50°C, with average input optical power levels of -45 dBm to -25 dBm, at a frequency of 20 Mb/s (Manchester), for any wavelength in the 1.20  $\mu$ m to 1.35  $\mu$ m range. The average optical input power is to be determined by measurement using a calibrated photometer with adjustment for the specific wavelength being measured.

#### 3.1.2.3 Acceptance Limits

The receiver shall have an electrical output (0.2 V to 0.4 V for "0" state, 2.4 V to 2.7 V for the "1" state) representative of the optical input bit pattern for any optical input signal with a wavelength between 1.20  $\mu$ m and 1.35  $\mu$ m and a power (average) of -45 dBm to -25 dBm, at a nominal 20 Mb/s ( $\pm$  5%) data rate (Manchester) over a 0°C to 50°C temperature range.

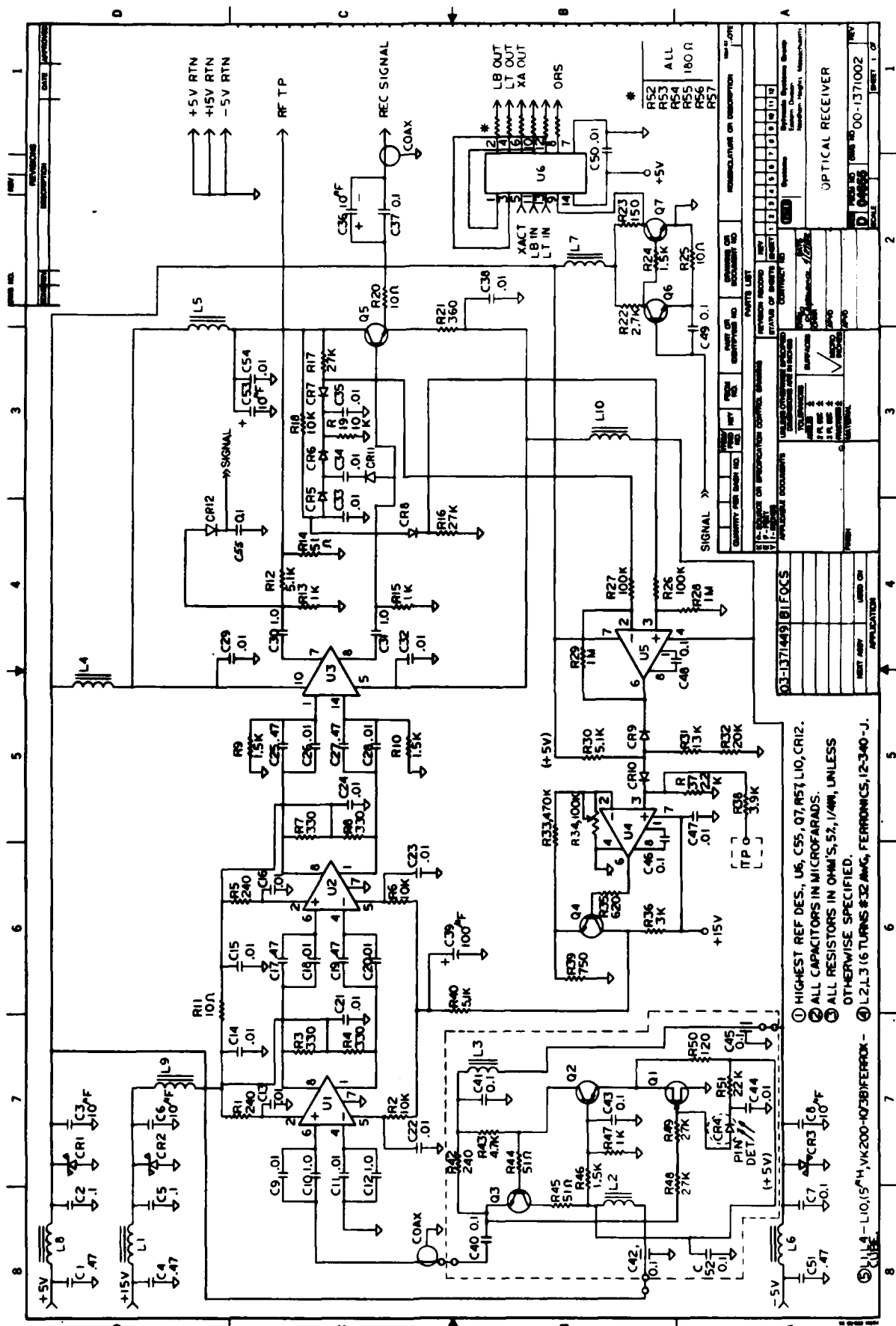
# OPTICAL RECEIVER



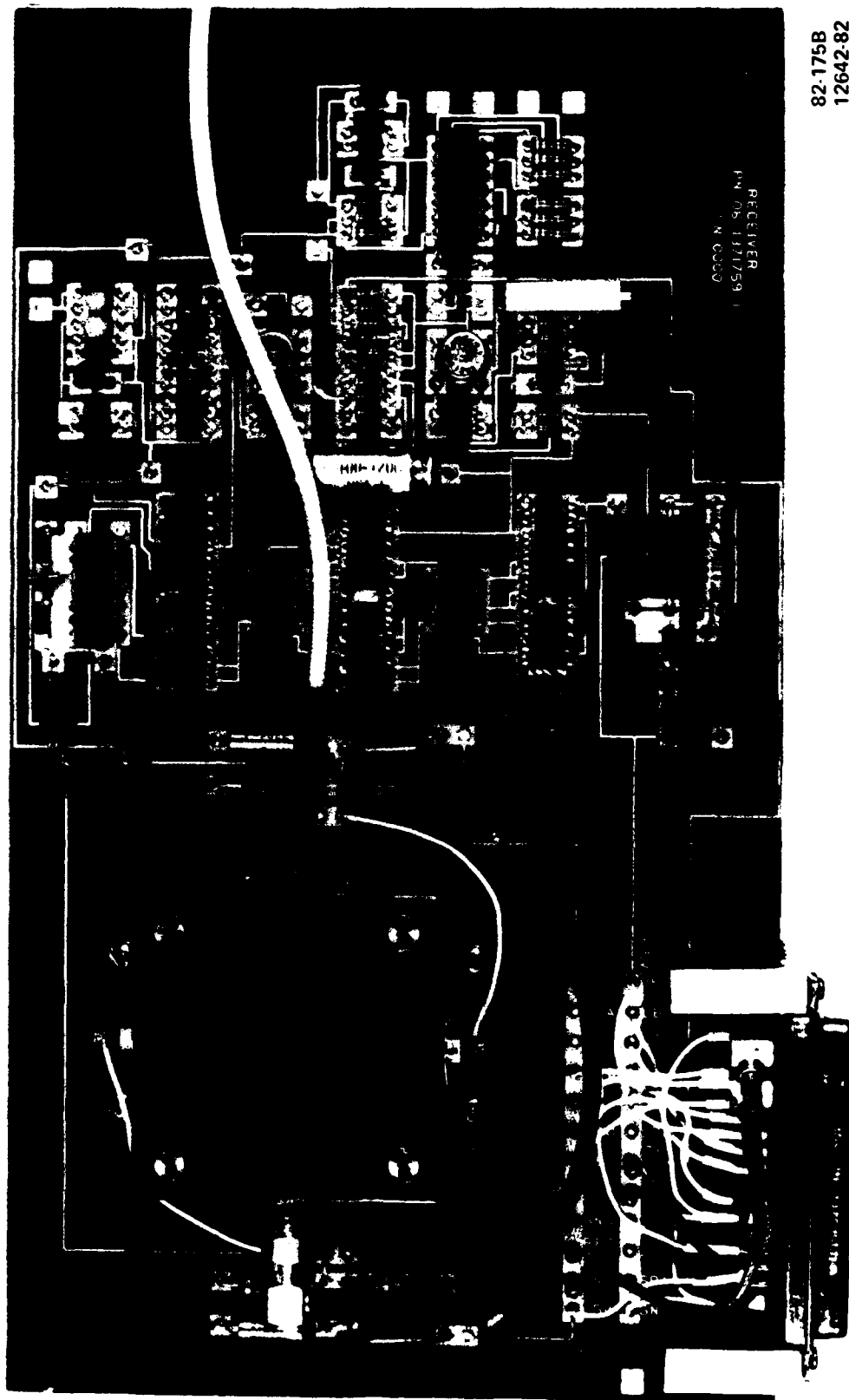
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Figure 10. Optical Receiver Block Diagram





**Figure 11. Receiver Schematic**



82-175B  
12642-82

Figure 12. Receiver Card

### 3.1.3 Encoder

#### 3.1.3.1 Description

The encoder has, as inputs, the TTL level NRZ mission bit stream (MBS) and a 20 MHz clock. The encoder output is a Manchester-encoded MBS that provides a 50% duty cycle to the optical transmission system. This duty cycle is desirable for two reasons: 1) frequent transitions ensure ease of timing recovery at the receiver end, and 2) a 50% duty cycle minimizes possible laser output power "droop" due to thermal effects. The encoder circuitry, shown in Figure 13, is on the CODEC card as shown in Figure 14. The parts list for the encoder (PN 06-1371761-1) is given in Appendix A.

#### 3.1.3.2 Performance Specifications

The encoder must operate over the voltage and frequency range of the expected inputs. The encoder is designed to operate at input data and clock voltages of 0.2 V to 0.4 V for the "0" state, and 2.4 to 2.7 volts for the "1" state. The output signal voltage levels for each state are the same as above. The frequency range for operation is 19.5 Mb/s to 20.5 Mb/s, with clock and data in phase within 15 degrees.

#### 3.1.3.3 Acceptance Limits

The encoder shall operate as specified with nominal input data and clock bit streams within the ranges stated above.

### 3.1.4 Decoder

#### 3.1.4.1 Description

The decoder extracts timing from the analog signal provided by the receiver and uses this timing (clock) signal to sample the analog signal, to regenerate the binary Manchester signal, and to convert the Manchester data stream back to NRZ. These functions are performed with emitter coupled logic (ECL) circuitry, which has greater speed than standard TTL ICs. All card interface lines are, however, TTL-implemented.

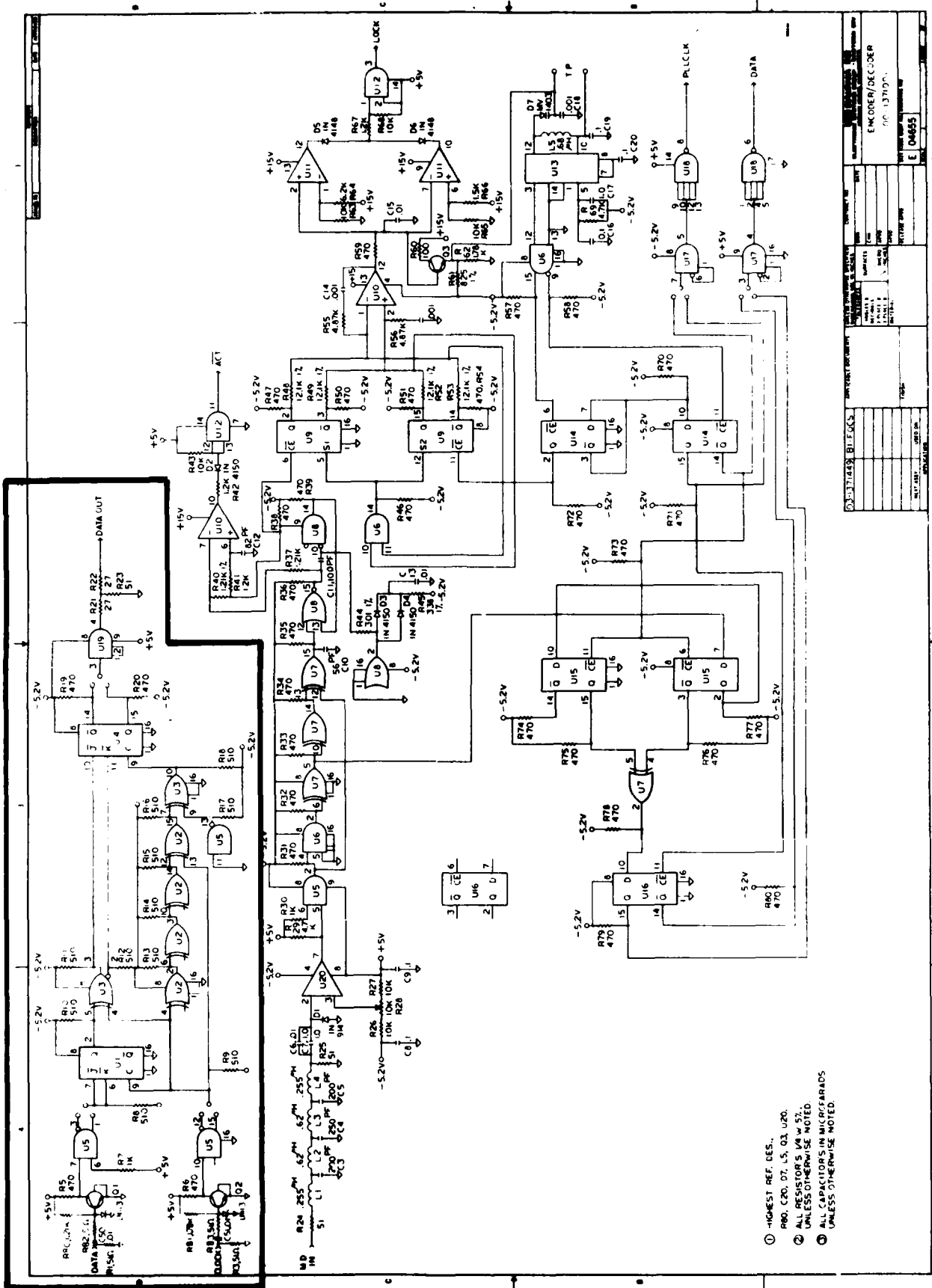


Figure 13. Encoder Schematic (Highlighted)

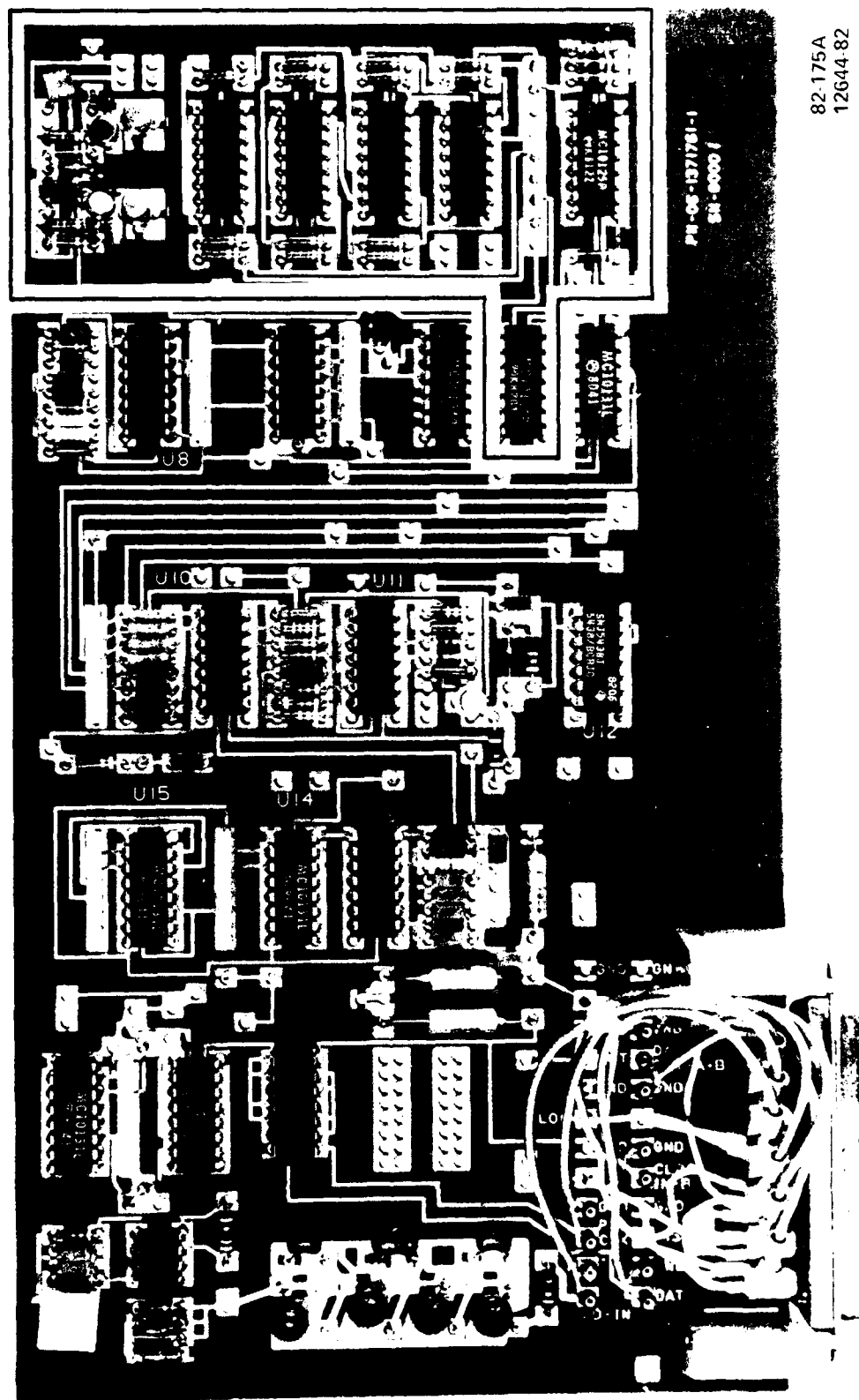


Figure 14. CODEC Card (Encoder Circuit Highlighted)

The timing extraction is performed with a phase lock loop (PLL) and, due to the frequent transitions of Manchester encoded data, the reconstituted clock is stable. Strapping is provided to change the internal data/clock phase relationship from  $90^{\circ}$  to  $270^{\circ}$ , if required.

The circuitry for the decoder is shown in Figure 15, and the function highlighted in the photograph of the CODEC card (Figure 16). The parts list for the decoder (PN 06-1371761-1) is given in Appendix A.

#### 3.1.4.2 Performance Specifications

The decoder must extract a clock from, and decode, an analog electrical output from the receiver for all cases when the frequency is  $20 \text{ Mb/s} \pm 0.5 \text{ Mb/s}$ , and the voltages are within the TTL (0.2V-0.2V, 2.4V-2.7V) specifications.

#### 3.1.4.3 Acceptance Limits

The decoder card must be capable of decoding data received from the receiver. It is recommended that the acceptance for the decoder be an in-line test with a known-functional encoder, at a temperature in the range  $0^{\circ}\text{C}$  to  $50^{\circ}\text{C}$ .

### 3.2 SYSTEM ALARM AND CONTROL CIRCUITS

#### 3.2.1 Modem Circuits

The BIFOCs modem circuits include several alarms which correspond to the front panel indicator lights. These include:

- Laser over-temperature alarm (transmitter)
- ILD over-current alarm (transmitter)
- PLL out-of-lock alarm (CODEC)
- Signal loss alarm (receiver)

#### 3.2.2 Control Circuits

Control circuits necessary to adjust automatically operating parameters as required to compensate for device temperature or aging effects include:

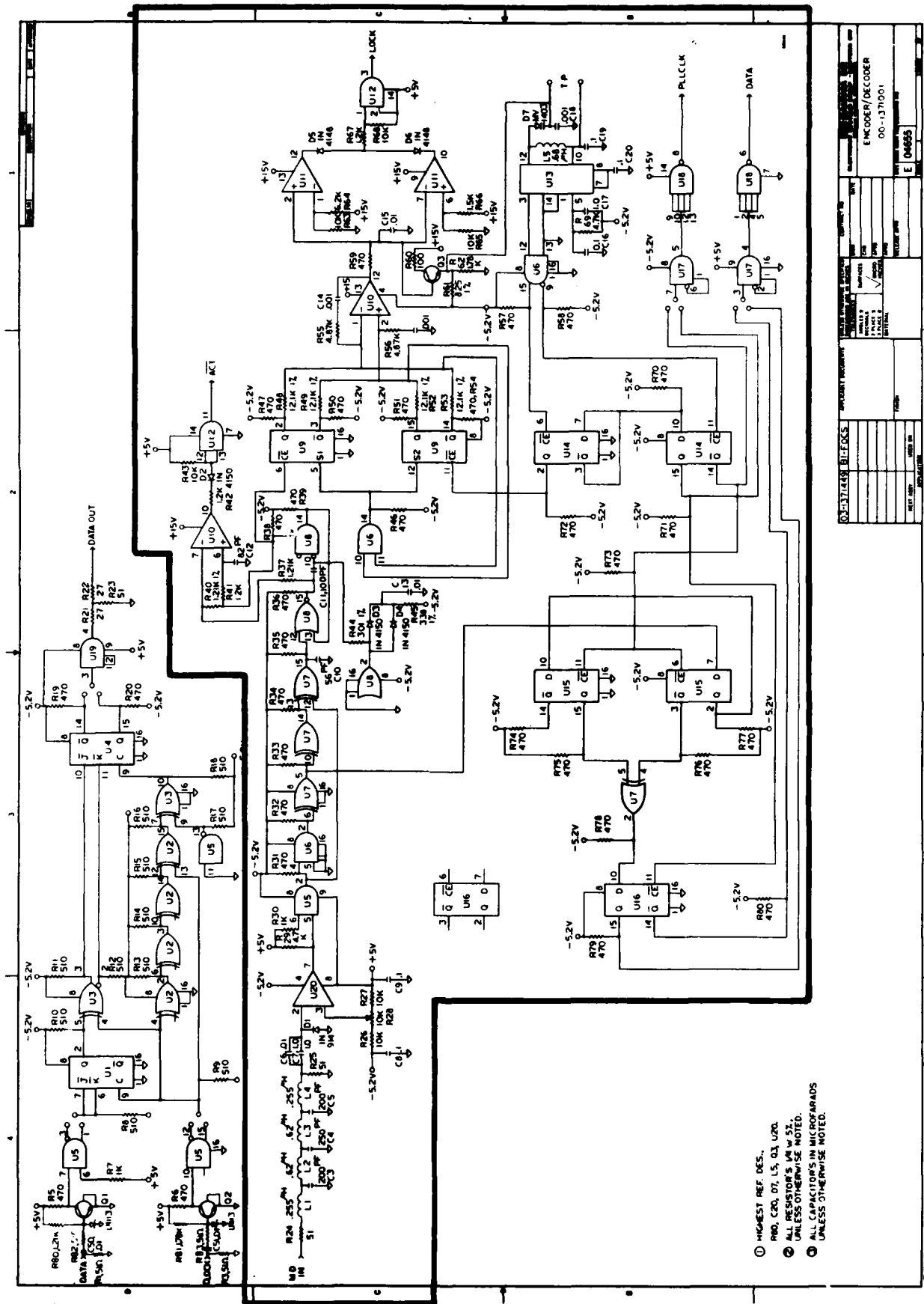


Figure 15. Decoder Schematic (Highlighted)

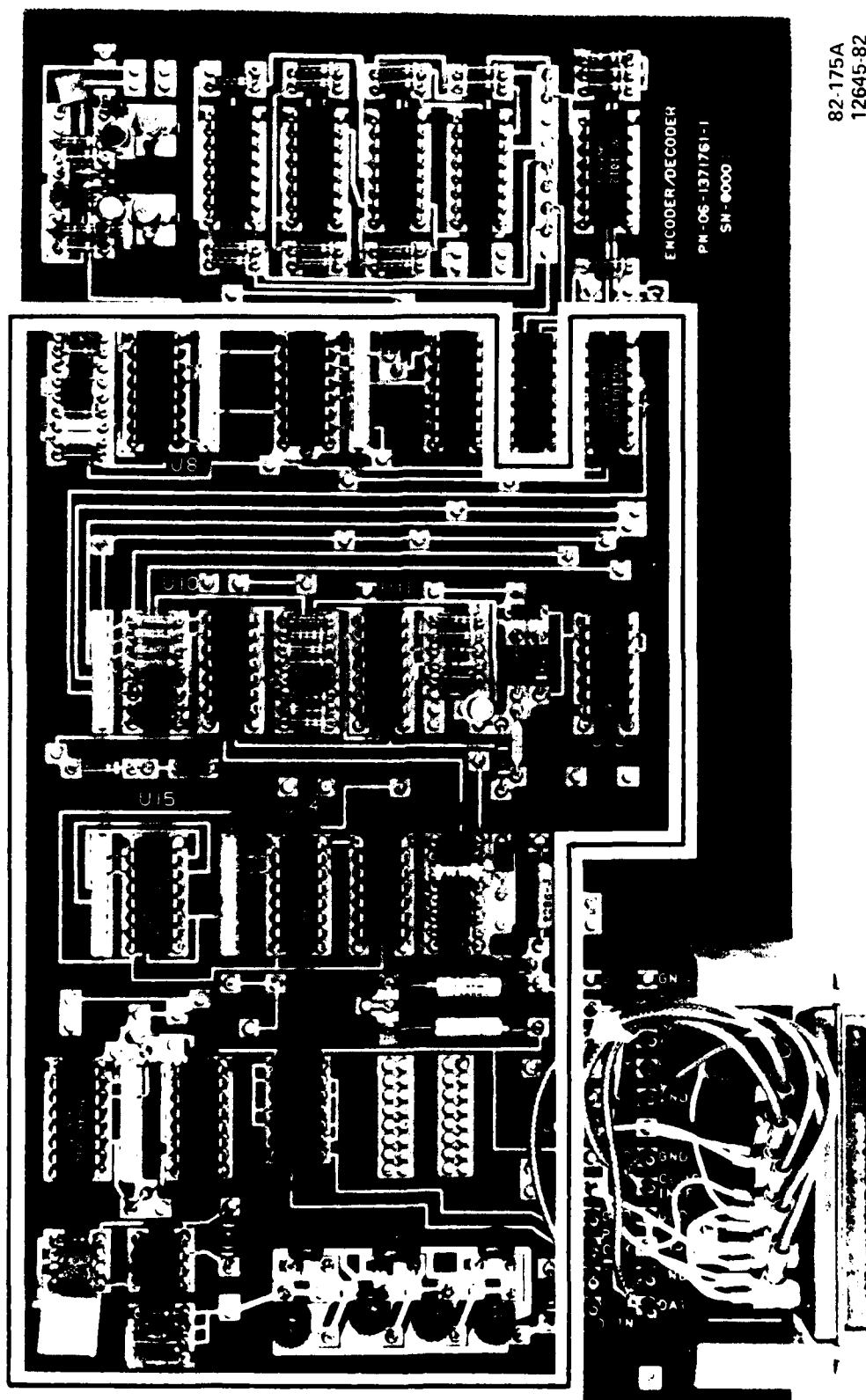


Figure 16. CODEC Card (Decoder Circuit Highlighted)



- Thermal cooler drive circuits compatible with device characteristics (transmitter)
- Optical feedback level detection circuit (transmitter)
- Bias current level adjustment for InGaAsP threshold level (transmitter)
- Modular pulse level driver circuit (transmitter)
- Loss-of-signal laser shutoff circuit (transmitter)

### 3.3 MAJOR BIFOCS OPTICAL COMPONENTS

#### 3.3.1 InGaAsP Diode Laser Module

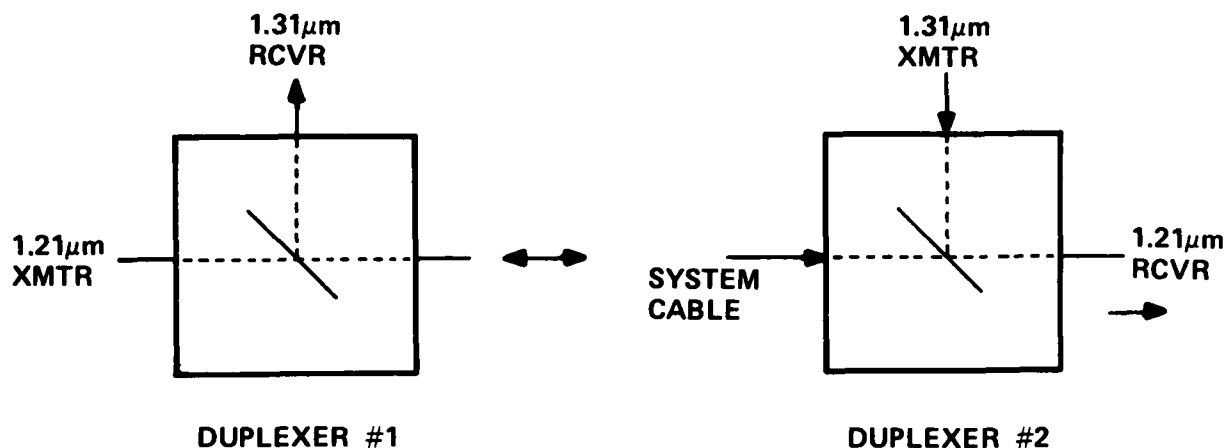
The choice of thermoelectrically cooled InGaAsP diode laser transmitters was dictated by a realistic estimate of the link losses associated with the fiber optic cable, connectors, and duplexers. In order to provide the highest possible power margin and signal-to-noise ratio, the receivers used for the BIFOCS program contain InGaAs PIN diode detectors coupled to hybrid GaAs MESFET preamplifiers.

#### 3.3.2 Optical Wavelength Duplexer

##### 3.3.2.1 Description

The duplexer is an optomechanical component that has three fibers which act as optical "Input/Output" (I/O) ports. These fibers are 50  $\mu\text{m}$  core, graded index fibers and are assigned for use with specific wavelengths as shown in Figure 17. The duplexer has internal collimating lenses which make the fiber exit beams parallel (or, conversely, focus a parallel beam onto a fiber core) for more efficient beamsplitter and filter operation as shown in Section 3.3.3 (Figure 20). The 45° beamsplitter provides beam direction in accordance with the dichroic characteristics (reflect 1.31  $\mu\text{m}$ , pass 1.21  $\mu\text{m}$ ). The supplemental 90° filters provide out-of-band attenuation of the signals since the detectors (PIN diodes) are broadband (non-selective) and there is finite out-of-band laser emission (Figures 18a and 18b).

Figure 19 is a schematic representation of the duplexer. The duplexer will be housed in a package with the approximate dimensions of 3cm X 3cm X 1.5cm.



12,676-82

Figure 17. Duplexer Configurations

#### 3.3.2.2 Performance Specifications

The total duplexer in-band insertion loss in either channel should not exceed -4 dB, while the total out-of-band loss in the duplexer must be -37 dB minimum (crosstalk attenuation). The duplexer must operate from 0°C to 50°C.

#### 3.3.2.3 Acceptance Limits

The duplexer must exhibit the following performance when used with the modem lasers and tested per the Test Plan.

- a. In-Band Insertion Loss . . . -4 dB maximum
- b. Out-of Band Crosstalk Rejection . . . -37 dB minimum

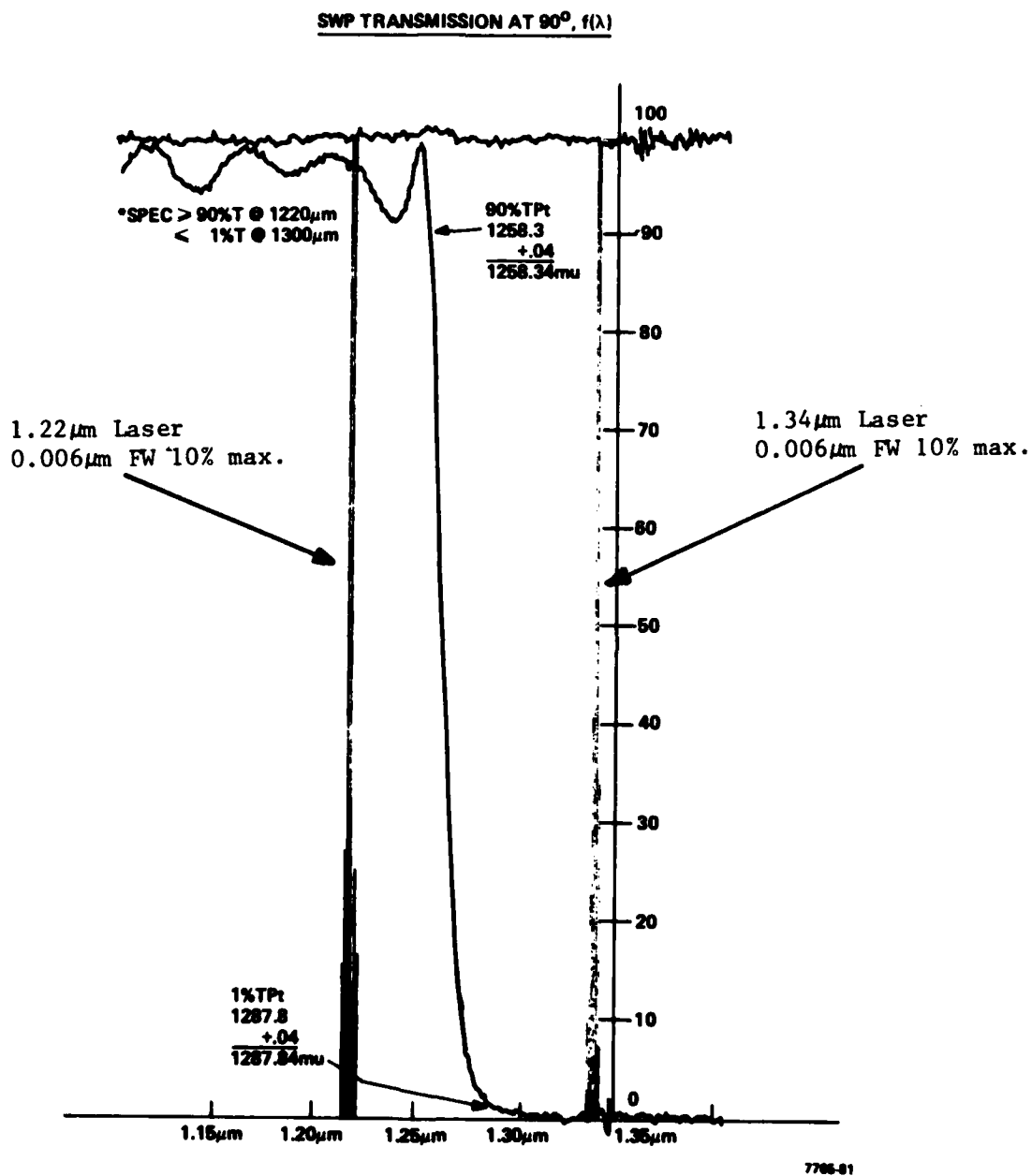


Figure 18a. SWP Transmission at 90°, f (λ)

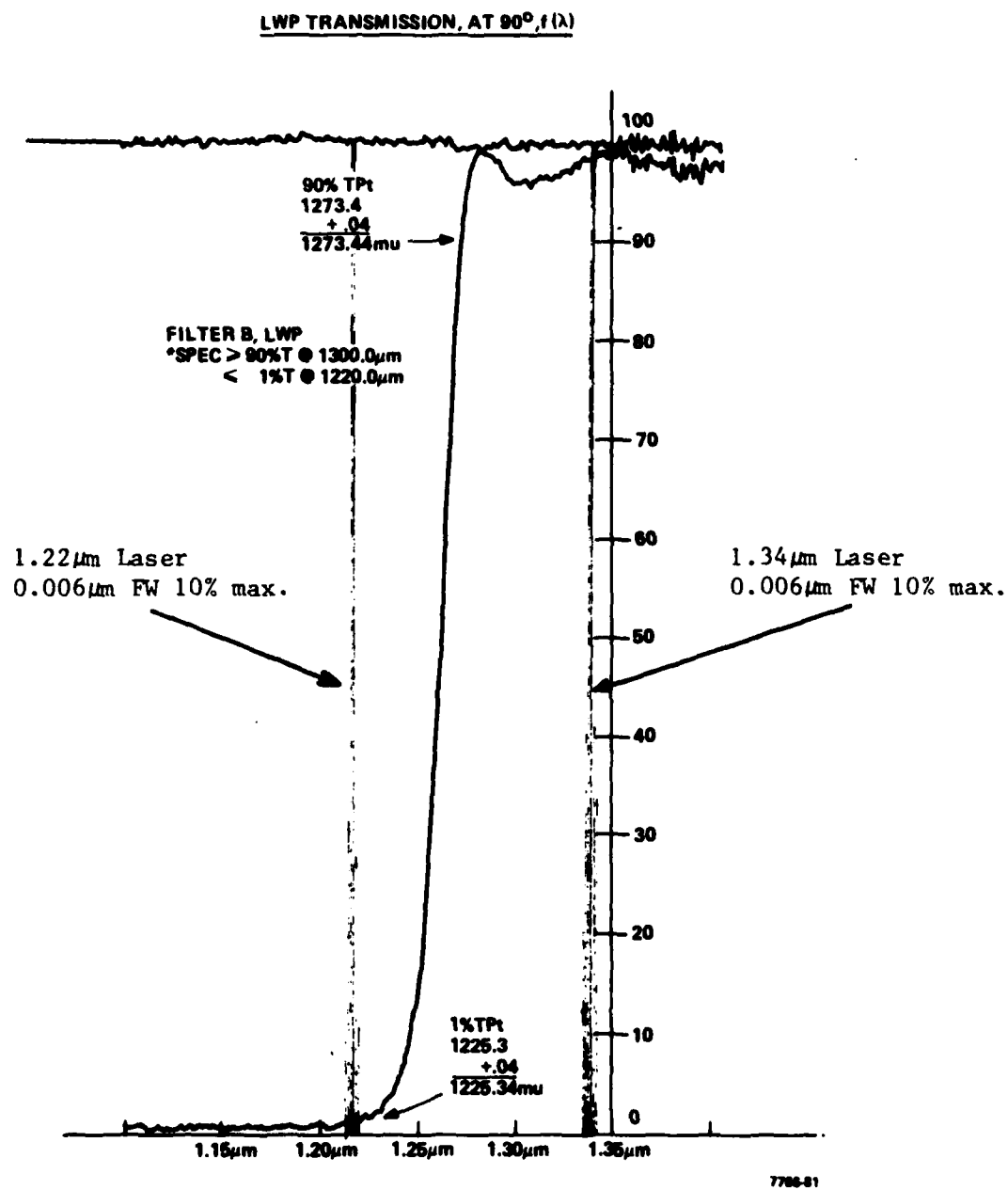
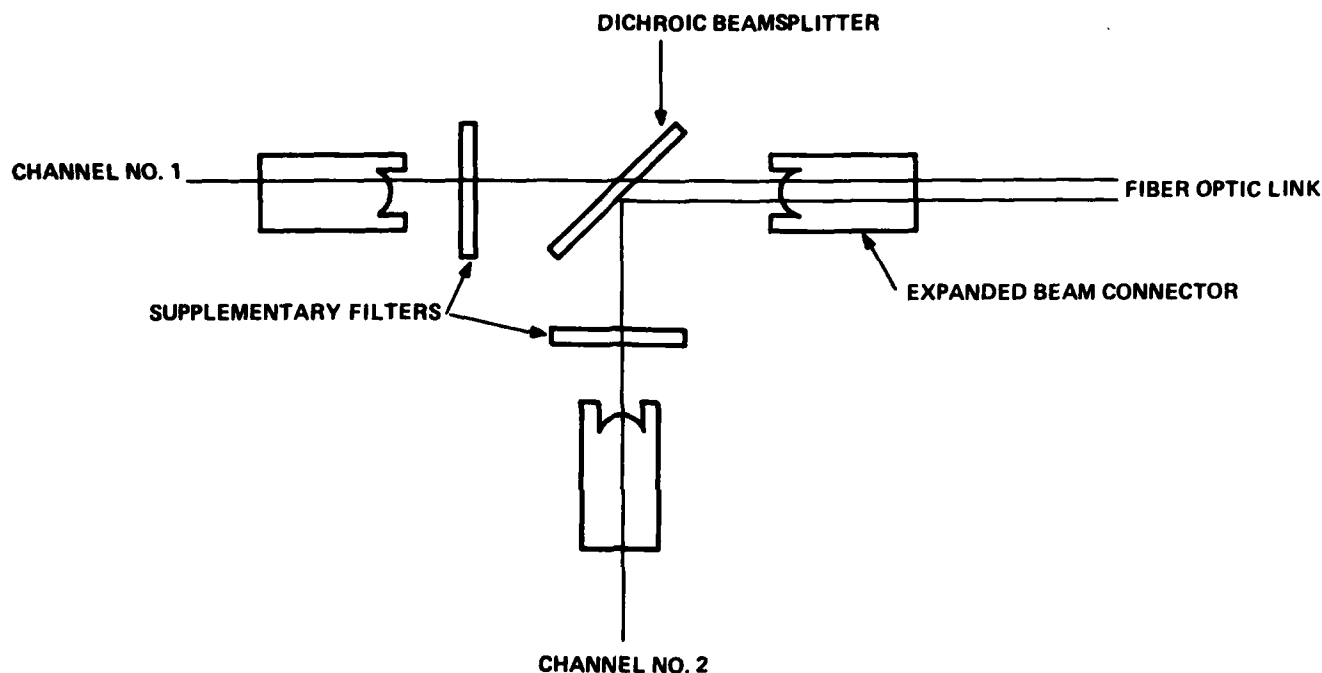


Figure 18b. LWP Transmission at 90°, f (λ)



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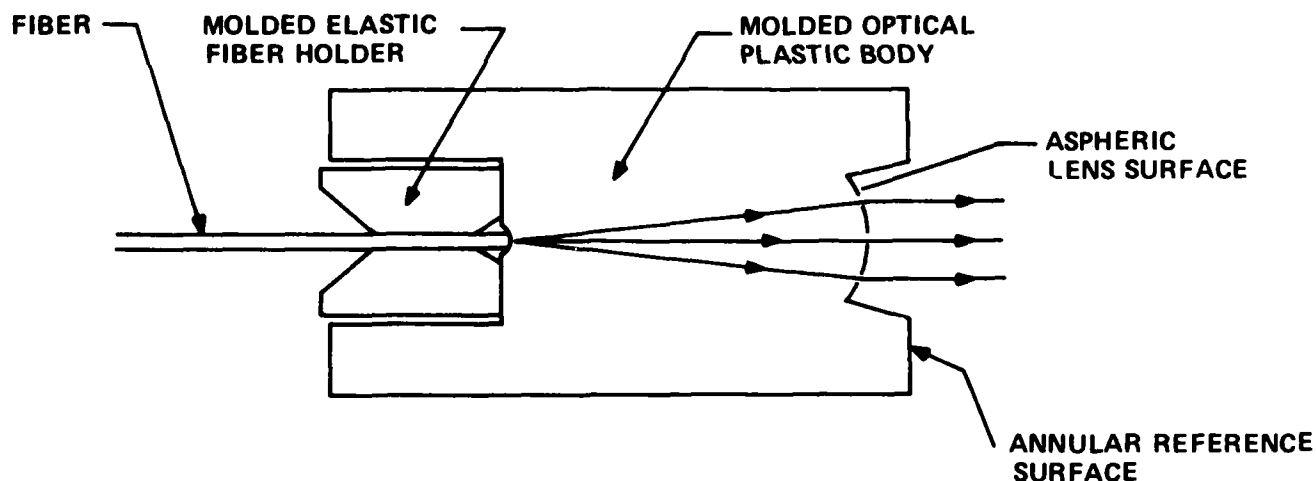
Figure 19. GTE Optical Wavelength Duplexer

### 3.3.3 GTE Expanded Beam Microlens

The GTE expanded beam microlens (see Figures 20 & 21) is a collimating lens housed inside the duplexer. The function of the lenses is to make the fiber exit beams parallel (or, conversely, focus a parallel beam onto a fiber core), resulting in a more efficient beamsplitter and filter operation.

### 3.3.4 Dichroic Beamsplitter and Filters

The 45° dichroic beamsplitter and supplementary normal-incidence dichroic filters used in the optical wavelength duplexer represent state-of-the-art designs developed through a joint effort of GTE Laboratories and Optical Coating Laboratories, Inc. At the wavelengths of 1.21  $\mu\text{m}$  and 1.31  $\mu\text{m}$ , the beamsplitter transmittance and reflectance are independent of the polarization of the incident light beam, resulting in a very low insertion loss for the unpolarized light emitted from the optical fibers. The worst-case insertion loss in each wavelength-multiplexed optical channel is less than the 4 dB maximum allotted by the link power budget.



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Figure 20. Schematic of GTE Microlens

A dichroic beamsplitter approach was selected over possible prism or grating designs for the duplexer device on the basis of the dichroic duplexer's high performance, mechanical simplicity, and potential for satisfying tactical environmental requirements. The operating wavelengths of  $1.21 \mu\text{m}$  and  $1.31 \mu\text{m}$  correspond to the largest interchannel wavelength separation that is consistent with a low-absorption band in the spectral characteristic of the molded plastic collimating connectors.

The optical specifications for the dichroic beamsplitter optical wavelength duplexer were established by the analyses conducted on the link power budget and crosstalk of the system. Tables 3 and 4 summarize the analyses.

The measured optical characteristics of the dichroic beamsplitter and supplementary filter and the resulting duplexer crosstalk characteristics are summarized in Tables 5 and 6 respectively.



9630-82

Figure 21. GTE Microlens (Used in Connectors and Duplexer)

TABLE 3. LINK POWER BUDGET ANALYSIS

Laser power output	+ 0 dBm	
Receiver sensitivity	-45 dBm	
Power available for losses	45 dB	
Worst-case losses (dB)	10 km	15 km
Cable losses (1.5 dB/km)	15	22.5
Connector loss (1.5 dB/conn)	9	13.5
Duplexer losses	6	6
Total losses	30	42
Power margin	15 dB	3 dB

TABLE 4. CROSSTALK ANALYSIS

	10 km	15 km
Expected receiver power	-30 dBm	-42 dBm
Desired margin	6 dB	3 dB
Worst-case receiver power	-36 dBm	-45 dBm
Required crosstalk attenuation *	-12 dB	-12 dB
Maximum permissible crosstalk power	-48 dBm	-57 dBm
Source power output	+ 0 dBm	+ 0 dBm
Required crosstalk isolation	48 dB	57 dB

\* 12 dB for  $10^{-9}$  BER



TABLE 5. BEAMSPLITTER AND FILTER CHARACTERISTICS

Component	Wavelength	
	1.21 $\mu\text{m}$ ( $\lambda 1$ )	1.31 $\mu\text{m}$ ( $\lambda 2$ )
45° Beamsplitter	T = - 0.36 R = - 14.0	T = - 18.0 R = - 0.13
Long-Wave-Pass Filter	T = - 23.0	T = - 0.18
Short-Wave-Pass Filter	T = - 0.18	T = - 23.0

T = Transmission Loss (dB) R = Reflection Loss (dB)

TABLE 6. DUPLEXER CROSSTALK CHARACTERISTICS

Item (See Section 3.3.5.3)	Channel #1	Channel #2
	$\lambda 2 \rightarrow \lambda 1$	$\lambda 1 \rightarrow \lambda 2$
Internal Crosstalk	< -80 dB	< -80 dB
External Crosstalk	-41 dB	-37 dB

It can be seen that the supplementary dichroic filters on the receiver ports of the duplexers provide adequate external backscatter rejection for a 15 km link length. The difference between the crosstalk and loss characteristics of the 1.21  $\mu\text{m}$  and 1.31  $\mu\text{m}$  channels results from the use of identical dichroic beamsplitters at each end of the link in order to reduce system cost and parts proliferation.

### 3.3.5 Precision Duplexer Package

The requirement of the duplexer package is to maintain the alignment of the lenses, beamsplitter and filter so as to minimize optical insertion loss and maximize optical channel separation. Consequently, maintaining the alignment tolerances of the system is critical.

To maintain these tolerances, GTE conducted a computer ray-trace analysis of insertion loss due to lens tilt and offset to define

machining tolerances for the duplexer package, and a ray-trace analysis to determine thickness and parallelism tolerances for beamsplitter and filter substrates. In addition, the worst case tilt between reflected beams and the worst case offset between transmitted beams in the duplexer had to be such as to result in a negligible increase in insertion loss.

### 3.3.5.1 Critical Design Parameters

The critical design parameters of the system are:

- a. Angular - The most critical and difficult to attain and control (part of design - adjustable)
- b. Axial (precision machined, adjustable)
- c. End separation (less critical with use of collimating lenses)
- d. Adjustability (part of design)
- e. Manufacturability (part of design)

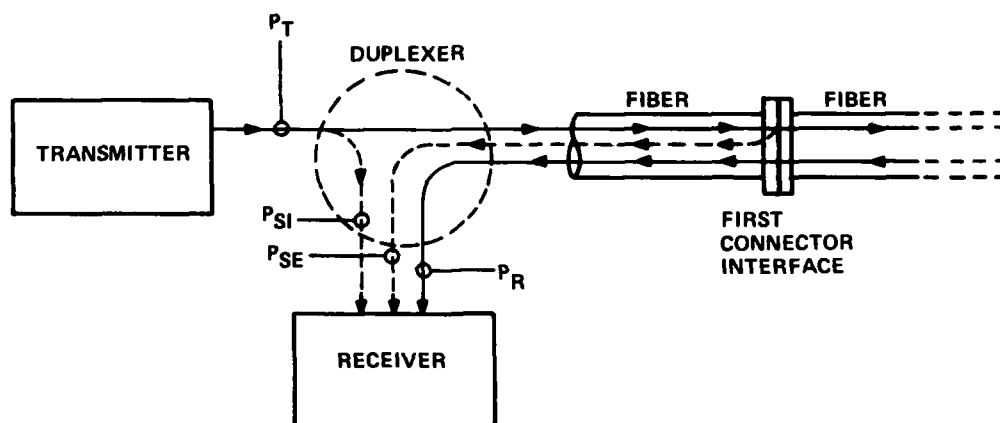
### 3.3.5.2 Predicted Loss Characteristics of Duplexer Based on Measured Beamsplitter and Filter Characteristics

<u>COMPONENT</u>	<u>LOSSES</u>	
	1.21 $\mu$ m	1.31 $\mu$ m
	$\frac{(\lambda 1)}{<.4 \text{ dB}}$	$\frac{(\lambda 2)}{<.2 \text{ dB}}$
Beamsplitter		
Supplementary Filters	<.2 dB	<.2 dB
Expanded Beam Connectors	<2.8 dB	<2.8 dB
(4 per channel; <.7 dB each)		
Total WDM Loss		
(2 Beamsplitters, 2 Filters		
and 4 connectors per channel)	<4.0 dB	<3.6 dB

Note: The measured characteristics of the beamsplitter and filters indicate that the WDM loss will be less than 4 dB.

### 3.3.5.3 Crosstalk In Duplexed System

The most critical system parameter of the duplexer is the crosstalk, specified as the dB ratio of the unwanted optical signal to the optical signal measured at the receiver input. Sources of crosstalk are shown in Figure 22, and are classified as internal (duplexer-generated) or external (caused outside duplex器). The system specifications require suppression of optical crosstalk to less than -12 dB in each channel. From Table 4 it is seen that the optical duplexer must therefore have less than -42 dB and -54 dB of internal crosstalk for the 10 and 15 km links, respectively, in order to maintain the required system bit error rate. Assuming that the external backscatter from the optical fiber link is at most -20 dB, the duplexer must also provide at least 34 dB of external backscatter rejection. This -34 dB external crosstalk figure neglects the spontaneous wideband emission from the InGaAsP diode lasers.



- $P_T$  : POWER TRANSMITTED ( $\lambda_1$ )
- $P_R$  : POWER RECEIVED ( $\lambda_2$ )
- $P_{SI}$  : POWER SCATTERED, INTERNAL ( $\lambda_1$ )
- $P_{SE}$  : POWER SCATTERED, EXTERNAL ( $\lambda_1$ )

8280-80E

Figure 22. Sources of Crosstalk in Duplexed System

Measurements of wideband spontaneous emissions of the InGaAsP diode lasers were made at GTE Laboratories. These measurements indicate that the total spontaneous emission is less than -3 dBm for a diode laser emitting 6 dBm of nearly monochromatic stimulated emission. The process of coupling the diode laser to a low-NA optical fiber selectively attenuates the spontaneous emission. When the level of stimulated emission radiating from the fiber pigtail of a coupled laser is 0 dBm, the total spontaneous emission is only -18 dBm. Since less than half of the spontaneous emission spectrum falls within the passband of the other optical channel, a fiber backscatter of -20 dB could result in an interfering signal level of as much as -41 dBm at the detector. In order to overcome this problem, the GTE optical wavelength duplexer includes a normal-incidence dichroic filter at the transmitter port which reduces the crosstalk from spontaneous emission by at least 20 dB. With the interfering signal level from spontaneous emission reduced to less than -61 dBm, this source of crosstalk is no longer a limitation to system performance at any link length.

#### 3.3.5.3.1 Predicted Crosstalk Characteristics of Duplexer (Based on Measured Beamsplitter and Filter Characteristics)

- o Internal crosstalk is negligible ( $\approx -80$ dB) due to good surface quality of beamsplitter
- o External crosstalk is -41 dB in 1.21  $\mu$ m channel and -37 dB in 1.31  $\mu$ m channel
  - Beamsplitter plate alone allows -18 dB crosstalk in 1.21  $\mu$ m channel and -14 dB crosstalk in 1.31  $\mu$ m channel
  - Supplementary filters reduce crosstalk by an additional 23 dB in each channel

#### 3.3.6 Low Loss Cable and Bulkhead Connectors

The cable and bulkhead connectors utilize the same GTE molded plastic collimating lens as the duplexer. The lenses are mounted in prototype plastic backshells which permit the connector to have relatively loose tolerances with very low connector loss. This is due to the incorporation of all the critical alignment parameters within

the molded lens itself. The lens was shown previously in Figures 20 and 21.

### 3.3.7 Internal Splice Assemblies

The pigtailed transmitter and receiver cards are optically connected to the duplexers with GTE elastomeric splices mounted in splice housings. Figure 23 shows such a splice mounted in its housing. The splice, which actually aligns the fiber ends relative to each other, is the small cylinder in the center of the splice housing.

#### 3.3.7.1 GTE Elastomeric Splice

The elastomeric splice aligns and holds the fiber ends by axially aligning the fibers by means of restoring forces applied to the outer diameters of the fiber. These forces result from the slight distortion of the elastomer when the fiber is inserted. As shown in Figure 24, this device, unlike V-groove alignment devices, permits precise alignment even when the fiber diameters are unequal.

#### 3.3.7.2 Splice Housing

The splice housing, together with the splices, provides the functions of initial fiber alignment prior to insertion into the splice, guiding of the fiber into the splices, fiber jacket strain relief, and protection of the completed splice.

## 4.1 FINAL REPORT CONCLUSIONS AND RECOMMENDATIONS

The BIFOCS system operated as required over the full 15 km cable assembly plant at room temperature, and thereby demonstrated the feasibility of wavelength division multiplexing in a tactical, connectorized system. Just prior to temperature testing, the 1.3  $\mu\text{m}$  laser failed and was replaced with a less optimum unit. When this unit did not perform adequately in the system, it was replaced with a unit of more appropriate wavelength and extinction ratio, but which was strongly modal. This, unfortunately, led to a significant increase in the noise in that channel and the 1.3  $\mu\text{m}$  channel did not again operate as well as with the original laser.



Figure 23. GTE Elastomeric Splice and Housing



Figure 24. Elastomeric Splice Operation

Certain receiver and cable assembly anomalies also arose during temperature testing and were considered due to the fact that these items were adaptations of previously designed items, and not specifically designed for temperature variations.

Thus while the BIFOCS development model demonstrated the feasibility of using wavelength division multiplexing (OWM) as a means of achieving tactical bidirectional communication over a single fiber cable, it also highlighted several technical areas in which normal component variations typical of current production tolerances are excessive for assured reliable, reproducible system operation.

Emitter characteristics requiring very rigid control or specification are output spectrum and modal structure. These parameters must be tightly defined in order to minimize performance variations of other system components. Other components, such as cable assemblies, connectors, and duplexers, are very sensitive to small variations in wavelength (approximately  $0.02\ \mu\text{m}$ ) and/or modal distribution. While long-term ( $>2$  bit times) variations alter the basic operational efficiency of passive components, short-term effects manifest themselves as noise, reducing the signal-to-noise ratio. Control of emitter parameters, including precise wavelength and modal distribution, is therefore necessary at this time to ensure consistent operational performance. Unless this rigid parametric control is assured, system performance may be compromised. This condition could be improved by utilizing several techniques, including emitter tuning by means of temperature, or the use of component materials with different absorption bands.



APPENDIX A  
PARTS LISTS

PARTS LIST		CKTCDASSY-EN/DC		PL06-1371761-1		PL REV --	
ASSEMBLY PART NUMBER 06-1371761-1							
FIND NO	QTY REQD	UNIT MEAS	FSCM	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION	NOTE NO.
1	1		04655	06-1371761-101		PC CKT CARD ASY	
2	1		04655	73-588394-1		CONNECTOR	
3	2		04655	13-588453-1 A406 AMPEREX		TRANSISTOR	Q1, Q2
4	2		04655	15-588438-1 MC10135		DUAL J-K FLIP F	U1, U4
5	2		04655	15-588058-1		IC, TYPE 10113	U2, U7
6	1		04655	15-587992-1		IC, TYPE 10107	U3
7	2		04655	15-587995-1		IC, TYPE 10125	U17,U19
8	1		04655	15-587994-1		IC, TYPE 10124	U5
9	1		04655	15-588057-1		IC, TYPE 10104	U6
10	1		04655	15-587990-1		IC, TYPE 10102	U8
11	4		04655	15-587996-1		IC, TYPE 10131	U9,14,15,16
12	2		04655	15-586416-1		IC, TYPE 747	U10, U11
13	1		04655	15-588022-1		IC, TYPE 7438	U12
14	1		04655	15-587972-1		IC, TYPE 1648	U13
15	6				750-81-R470	RESISTOR PACK	PULL DOWN RESISTOR
16	1		81349	RCR07G101J3S	MIL-R-39008/1	RES.,FXD,CMPSN	R60
17	1		81349	RN55D3010F	MIL-R-10509/7	RES.,FXD, FILM	R44
18	1		81349	RN55D3380F	MIL-R-10509/7	RES.,FXD, FILM	R45

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PARTS LIST		CKTCDASSY-EN/DC		PL06-1371761-1		PL REV --	
ASSEMBLY PART NUMBER 06-1371761-1							
FIND NO	QTY REQD	UNIT MEAS	FSCM	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION	NOTE NO.
19	6		81349	RCR07G471JS	MIL-R-39008/1	RES.,FXD,CMPSN	PULL DOWN RESISTOR
20	11		81849	RCR07G511JS	MIL-R-39008/1	RES.,FXD,CMPSN	R8,9,10, R11 to R18
21	REF			OPEN		FOR FUTURE USE	
22	7		81349	RCR07G510JS	MIL-R-39008/1	RES.,FXD,CMPSN	R1,3,23,24, 25, 82, 83
23	1		81349	RN55D8250F	MIL-R-10509/7	RES.,FXD,FILM	R61
24	2		81349	RCR07G102JS	MIL-R-39008/1	RES.,FXD,CMPSN	R7, R30
25	2		81349	RCR07G270JS	MIL-R-39008/1	RES.,FXD,CMPSN	R21, R22
26	6		81349	RN55D1211F	MIL-R-10509/7	RES.,FXD,FILM	R37, 40, 42, 44, 67, 80
27	1		81349	RCR07G152J3	MIL-R-39008/1	RES.,FXD,CMPSN	R66
28	2		81349	RN55D1781F	MIL-R-10509/7	RES.,FXD,FILM	R62, R81
29	2		81349	RCR07G472JS	MIL-R-39008/1	RES.,FXD,CMPSN	R69, R29
30	2		81349	RN55D4871F	MIL-R-10509/7	RES.,FXD,FILM	R55, R56
31	REF			OPEN		FOR FUTURE USE	
32	7		81349	RCR07G103JS	MIL-R-39008/1	RES.,FXD,CMPSN	R26, 27, 43, 63, 64, 65, 68
33	4		81349	RN55D1212F	MIL-R-10509/7	RES., FXD, FILM	R48, 49, 52, 53
34	1		81349	CK05BX560K	MIL-C-11015/18	CAP.,FIXED,CER	C10
35	2		81349	CK05BX820K	MIL-C-11015/18	CAP.,FIXED,CER	C12
36	1		81349	CK05BX101K	MIL-C-11015/18	CAP.,FIXED,CER	C11
37	2		81349	CK05BX102K	MIL-C-11015/18	CAP.,FIXED,CER	C14, 18
38	5		81349	CK05BX103K	MIL-C-11015/18	CAP.,FIXED,CER	C6, 13, 15, 50, 51

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PARTS LIST		CKTCDASSY-EN/DC		PL06-1371761-1		PL REV --	
ASSEMBLY PART NUMBER 06-1371761-1							
FIND NO	QTY REQD	UNIT MEAS	FSCM	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION	NOTE NO.
39	23		81349	CK05BX104K	MIL-C-11015/18	CAP.,FIXED,CER	C1, 2, 8, 9, 16, 19, 20, PLUS ac FILTER CAP FOR ICs
40	2		81349	M39003/01-2286 10 $\mu$ F	MIL-C-39003/1	CAP.,FXD,ELCTLT FILTER CAP.	
41	1		81349	M39003/01-2254 4.7 $\mu$ F	MIL-C-39003/1	CAP.,FXD,ELCTLT FILTER CAP.	
42	2		81349	JAN1N4148	MIL-S-19500/116	SEMICON DEV,DIO	D5, D6
43	3		81349	JAN1N4150	MIL-S-19500/231	SEMICON DEV,DIO	D2, 3, 4,
44	REF			OPEN		FOR FUTURE USE	
45	1		04655	13-588455-1	MU1403	DIODE	D7
46	1		81349	JAN2N2222	MIL-S-19500/255	TRANSISTOR	Q3
47	REF			OPEN		FOR FUTURE USE	
48	1		04655	50-588451-1		COIL	L4
49	2		04655	50-588450-1		COIL	L2, 3
50	1		04655	15-586782-1		IC. TYPE 360	U20
51	1		04655	15-586781-1		IC. TYPE 74S140	U18
52	REF			OPEN		FOR FUTURE USE	
53	1			9250-681		INDUCTOR,0.68 $\mu$ H	L5
54	1				BOURNS 3262P-10K	10K VARIABLE RESISTOR	R28
55	1			250pF	DM-251J	CAP., FXD, CER.	C4
56	2			240pF	DM-241J	CAP., FXD, CER.	C3, C5
57	2			LM113		DIODE, ZENER	D10, D11

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PARTS LIST		CKTCDASSY-RCVR		PL06-1371759-1		PL REV --	
ASSEMBLY PART NUMBER 06-1371759-1							
FIND NO	QTY REQD	UNIT MEAS	FSCM	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION	NOTE NO.
1	1		04655	06-1371759-101		PC CKT CARD ASY	
2	1		04655	73-588394-1		CONNECTOR	
3	2		04655	15-588435-1	MC1349P	INTEGRATED CKT	U1, U2
4	1		04655	15-588436-1	LM733CN	INTEGRATED CKT	U3
5	2		04655	15-588437-1	CA3130A	INTEGRATED CKT	U4, U5
6	1			15-586448-1	SN5406J	INTEGRATED CKT	U6
7	2		81349	RCR07G100JS	MIL-R-39008/1	RES.,FXD,CMPSN	R11, 20
8	1		81349	RCR07G510JS	MIL-R-39008/1	RES.,FXD,CMPSN	R14
9	1		81349	RCR07G101JS	MIL-R-39008/1	RES.,FXD,CMPSN	R25
10	1		81349	RCR05G121JS	MIL-R-39008/4	RES.,FXD,CMPSN	R50
11	1		81349	RCR07G151JS	MIL-R-39008/1	RES.,FXD,CMPSN	R23
12	6		81349	RCR07G181JS	MIL-R-39008/1	RES.,FXD,CMPSN	R52 to R57
13	2		81349	RCR07G241JS	MIL-R-39008/1	RES.,FXD,CMPSN	R1, R5
14	1		81349	RCR07G361JS	MIL-R-39008/1	RES.,FXD,CMPSN	R21
15	5		81349	RCR07G621JS	MIL-R-39008/1	RES.,FXD,CMPSN	R3, 4, 7, 8, 35
16	1		81349	RCR07G751JS	MIL-R-39008/1	RES.,FXD,CMPSN	R39
17	2		81349	RCR07G102JS	MIL-R-39008/1	RES.,FXD,CMPSN	R13, 15
18	3		81349	RCR07G152JS	MIL-R-39008/1	RES.,FXD,CMPSN	R2, 9, 24
19	1		81349	RCR07G222JS	MIL-R-39008/1	RES.,FXD,CMPSN	R37
20	1		81349	RCR07G272JS	MIL-R-39008/1	RES.,FXD,CMPSN	R22

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PARTS LIST		CKTCDASSY-RCVR			PL06-1371759-1		PL REV --	
ASSEMBLY PART NUMBER 06-1371759-1								
FIND NO	QTY REQD	UNIT MEAS	FSCM	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION	NOTE NO.	
21	1		81349	RCR07G302JS	MIL-R-39008/1	RES.,FXD,CMPSN	R36	
22	1		81349	RCR07G392JS	MIL-R-39008/1	RES.,FXD,CMPSN	R38	
23	1		81349	RCR05G472JS	MIL-R-39008/4	RES.,FXD,CMPSN	R43	
24	2		81349	RCR07G512JS	MIL-R-39008/1	RES.,FXD,CMPSN	R12, 30	
25	5		81349	RCR07G103JS	MIL-R-39008/1	RES.,FXD,CMPSN	R2, 6, 18, 19, 40	
26	1		81349	RCR07G133JS	MIL-R-39008/1	RES.,FXD,CMPSN	R31	
27	1		81349	RCR07G203JS	MIL-R-39008/1	RES.,FXD,CMPSN	R32	
28	2		81349	RCR07G273JS	MIL-R-39008/1	RES.,FXD,CMPSN	R16, 17	
29	2		81349	RCR05G513JS	MIL-R-39008/4	RES.,FXD,CMPSN	R48, 49	
30	6		81349	RCR07G105JS	MIL-R-39008/1	RES.,FXD,CMPSN	R26, 27, 28, 29, 33, 34	
31	23		81349	CK05BX103K	MIL-C-11015/18	CAP.,FIXED,CER	C9, 11, 13, 14, 15, 16, 18, 20, 21, 22, 23, 24, 26, 28, 29, 32, 33, 34, 35, 38, 44, 47, 50, 54	
32	9		81349	CK05BX104K	MIL-C-11015/18	CAP.,FIXED,CER	C2, 5, 7, 37, 40, 41, 43, 46, 48, 49, 52	
33	7		81349	CK06BX474K	MIL-C-11015/19	CAP.,FIXED,CER	C1, 4, 17, 19, 25, 27, 51	
34	4		81349	CK06BX105K	MIL-C-11015/19	CAP.,FIXED,CER	C10, 12, 30, 31	

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PARTS LIST		CKTCDASSY-RCVR		PL06-1371759-1		PL REV --	
ASSEMBLY PART NUMBER 06-1371759-1							
FIND NO	QTY REQD	UNIT MEAS	FSCM	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION	NOTE NO.
35	2			196D106X9020JA1		CAP, ELEC	C36, 53
36	2		04655	50-588439-1		CORE	L2, L3
37	8		04655	50-588448-1		CHOKE	L1, 4, 5, 6, 7, 8, 9, 10
38	1		04655	13-588440-1 (1N6280)		DIODE	CR3
39	2		04655	13-588441-1 (1N6267)		DIODE	CR1, CR2
40	REF			OPEN		FOR FUTURE USE	
41	6		81349	JAN1N914	MIL-S-19500/116	SEMICON DEV,DIO	CR5, 6, 7, 8, 9, 10
42	1		04655	13-588444-1	NE21889	TRANSISTOR	Q1,
43	1		04655	13-588443-1	NE88935	TRANSISTOR	Q2
44	1		04655	13-588445-1	NE21935	TRANSISTOR	Q3
45	1		04655	13-588442-1	HRD 200F	DIODE	CR4
46	1		04655	84-588446-1		RF SHIELD BOX	
47	1		81349	M39003/01-2301	MIL-C-39003/1	CAP.,FXD,ELCTLT	C39
48	4		04655	13-588449-1	2N3904	TRANSISTOR, NPN	Q4, 5, 6
49	REF			OPEN		FOR FUTURE USE	
50	REF			DELETE		DELETED ITEM	
51	3		81349	M39003/01-2374	MIL-C-39003/1	CAP.,FXD,ELCTLT	C3, C6, C8
52	1		81349	RCR05G223JS	MIL-R-39008/4	RES.,FXD,CMPSN	R51
53	3		81349	RCR05G510JS	MIL-R-39008/4	RES.,FXD,CMPSN	R41, 44, 45

8,246-83

PARTS LIST		CKTCDASSY-RCVR			PL06-1371759-1		PL REV --	
ASSEMBLY PART NUMBER 06-1371759-1								
FIND NO	QTY REQD	UNIT MEAS	FSCM	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION	NOTE NO.	
54	1		81349	RCR05G152JS	MIL-R-39008/4	RES.,FXD,CMPSN	R46	
55	1		81349	RCR05G102JS	MIL-R-39008/4	RES.,FXD,CMPSN	R47	
56	1		81349	RCR05G241JS	MIL-R-39008/4	RES.,FXD,CMPSN	R42	
57	2		04655	43-588447-1		CAPACITOR	C42, C45	

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PARTS LIST		CKTCDASSY-XMTR		PL06-1371757-1		PL REV --		
ASSEMBLY PART NUMBER 06-1371757-1								
FIND NO	QTY REQD	UNIT MEAS	FSCM	PART OR IDENTIFYING NO.	MANUFACTURE	NOMENCLATURE OR DESCRIPTION	NOTE NO.	DESIGNATION
1				BB82C5	Allen-Bradley	82 ohm 1/8 W resistor		R1
2				BB1015	Allen-Bradley	100 ohm 1/8 W resistor		R2-R5
3				BB1515	Allen-Bradley	150 ohm 1/8 W resistor		R6
4				BB2015	Allen-Bradley	200 ohm 1/8 W resistor		R7
5				BB2715	Allen-Bradley	270 ohm 1/8 W resistor		R8
6				BB3915	Allen-Bradley	390 ohm 1/8 W resistor		R9
7				BB5115	Allen-Bradley	510 ohm 1/8 W resistor		R10, R11
8				BB7515	Allen-Bradley	750 ohm 1/8 W resistor		R12
9				BB1025	Allen-Bradley	1K ohm 1/8 W		R13-R17
10				BB1225	Allen-Bradley	1.2K ohm 1/8 W resistor		R18, R55
11				BB2025	Allen-Bradley	2K ohm 1/8 W resistor		R19
12				BB3025	Allen-Bradley	3K ohm 1/8 W resistor		R20, R21
13				BB5125	Allen-Bradley	5.1K ohm 1/8 W resistor		R22
14				BB1035	Allen-Bradley	10K ohm 1/8 W resistor		R23-R25, R28

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PARTS LIST		CKTCDASSY-XMTR		PL06-1371757-1		PL REV --		
ASSEMBLY PART NUMBER 06-1371757-1								
FIND NO	QTY REQD	UNIT MEAS	FSCM	PART OR IDENTIFYING NO.	MANUFACTURE	NOMENCLATURE OR DESCRIPTION	NOTE NO.	DESIGNATION
15				BB8235	Allen-Bradley	82K ohm 1/8 W resistor		R26, R27
16				BB1055	Allen-Bradley	1M ohm 1/8 W resistor		R29, R30
17				EB1005	Allen-Bradley	10 ohm 1/2 W resistor 2%		R31
18				L04D1.00R	Corning	1 ohm precision resistor 2%		R32, R33
19				RLR05C10R0GR	Corning	10 ohm precision resistor 2%		R34, R35
20				RLR05C1301GR	Corning	1.3K ohm precision resistor 2%		R36
21				RLR05C1002GR	Corning	10K ohm precision resistor 2%		R37-R40
22				RLR05C3302GR	Corning	33K ohm precision resistor 2%		R41
23				RLR05C5102GR	Corning	51K ohm precision resistor 2%		R42, R43
24				RLR05C1003GR	Corning	100K ohm precision resistor 2%		R44, R45
25				RN55D2004F	Allen-Bradley	2M ohm precision resistor 1%		R46-R48
26				BW-20	TRW	.22 ohm 1 W resistor		R49
27				66WR200	Beckman	200 ohm 1/2 W cermet trimpot		R50
28				66WR10K	Beckman	20K ohm 1/2 W cermet trimpot		R51

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PARTS LIST		CKTCDASSY-XMTR		PL06-1371757-1		PL REV --		
ASSEMBLY PART NUMBER 06-1371757-1								
FIND NO	QTY REQD	UNIT MEAS	FSCM	PART OR IDENTIFYING NO.	MANUFACTURE	NOMENCLATURE OR DESCRIPTION	NOTE NO.	DESIGNATION
29				66WR1M	Beckman	1 M ohm 1/2 W cermet trimpot		R52
30				66WR2M	Beckman	2 M ohm 1/2 W cermet trimpot		R53
31				3250W-1-200	Bourns	20 ohm 1 W cermet trimpot		R54
32				TBD	Lasertron	TBD		Laser Pkg.
33				BB3025	Allen-Bradley	3K ohm 1/8W resistor		R56
34				BB1055	Allen-Bradley	1M ohm 1/8 W resistor		R57
35				BB1035	Allen-Bradley	10K ohm 1/8 W resistor		R58-R60
36				503D108F010PE	Sprague	1 mf electrolytic capacitor 10V		C1
37				5FA201J	Arco	200 pf Mylar capacitor		C2
38				8121-100X7RC10	Erie	0.001 uf ceramic capacitor 100V		C3-C5
39				503D106F035LA	Sprague	10 uf electrolytic capacitor 35V		C6, C7
40				2CZ50474X0500	Sprague	0.47 uf electrolytic capacitor 50V		C8-C26
41				8121-100X7R022	Erie	0.0022 uf 100V		C27
42				CSR-13C227KL	Sprague	220 uf 10V		C28
43				503D157F016NC	Sprague	150 uf 16V		C29
44				1N914	-----	Diode		D1-D5

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PARTS LIST		CKTCDASSY-XMT3		PL06-1371757-1		PL REV --		
ASSEMBLY PART NUMBER 06-1371757-1								
FIND NO	QTY REQD	UNIT MEAS	FSCM	PART OR IDENTIFYING NO.	MANUFACTURE	NOMENCLATURE OR DESCRIPTION	NOTE NO.	DESIGNATION
45				5082-2835	H-P	Diode		D6
46				IN5908	Gen. Semi. Inc.	Transzorb		D7-D8
47				LM113	Natl. Semi.	Zener Diode		D9, D10
48				1N5823	Motorola	Diode		D11
49				1N914	-----	Diode		D12-D14
50				CA3130T	RCA	Operational Amplifier		U1, U2
51				OP-07	PMI	Operational Amplifier		U3
52				LM3302n	Natl. Semi.	Comparator		U4
53				UA78S40	Fairchild	Switching Regulator		U5
54				A406	Amperex	Transistor, RF		Q1, Q2
55				2N3904	-----	Transistor, Signal		Q3, Q4
56				2N3906	-----	Transistor, Signal		Q5
57				ECG188	Sylvania	Transistor, Power		Q6
58				W172 DIP-5	Magnecraft	Relay		K1
59				104-20-B	Ferronics Inc.	Choke, form		L1, L2
60				VK20010/3B	Ferrox Cube	Choke, Power		L3-L6
61				F1146-1-TC9-4	Indiana Gen.	Pot Core	} NOTE 1	L7
62				B475-1	Indiana Gen.	265 $\mu$ H Inductor Bobbin		L7
63				B659	Indiana Gen.	Bracket		L7

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NOTE 1: 26 turns no. 22 enamel wire.

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