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Analog 4-MHz Fiber-Optics Link

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ANALOG 4-MHz FIBER-OPTICS LINK

by

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ABSTRACT

An analog 4-MHz fiber-optics link was designed to send multiplexed FM data over low-loss fiber-optics cable. This operating manual provides specifications, discusses application limitations and design changes required to improve the specifications, describes the link components, and gives instructions for field setup.

I. INTRODUCTION AND SPECIFICATIONS

A. Introduction

1. The J-8 4-MHz fiber-optics link (FOL) is an analog signal-transmission system that is designed to send multiplexed FM data between two points that are ordinarily connected by coaxial cable. It replaces the coaxial cable. In this function it has some limitations, given by the specifications, that must be understood if the FOL is to operate without signal degradation.

B. Specifications

1. Input impedance: 50 Ω

2. Input signal level: intended for 1 V p-p, but gain control permits using any level if setup instructions are followed.

3. Output: will drive up to about 2.8 V p-p into 50 Ω with 0 km of step-index fiber-optics cable (SIFOC) and will drive at least 1 V p-p into 50 Ω with 1 km of SIFOC if the input signal is ≥1 V.

4. Bandwidth: the passband with 1 km of SIFOC is from about 650 Hz to 4 MHz. Figure 1 is a typical frequency-response curve.

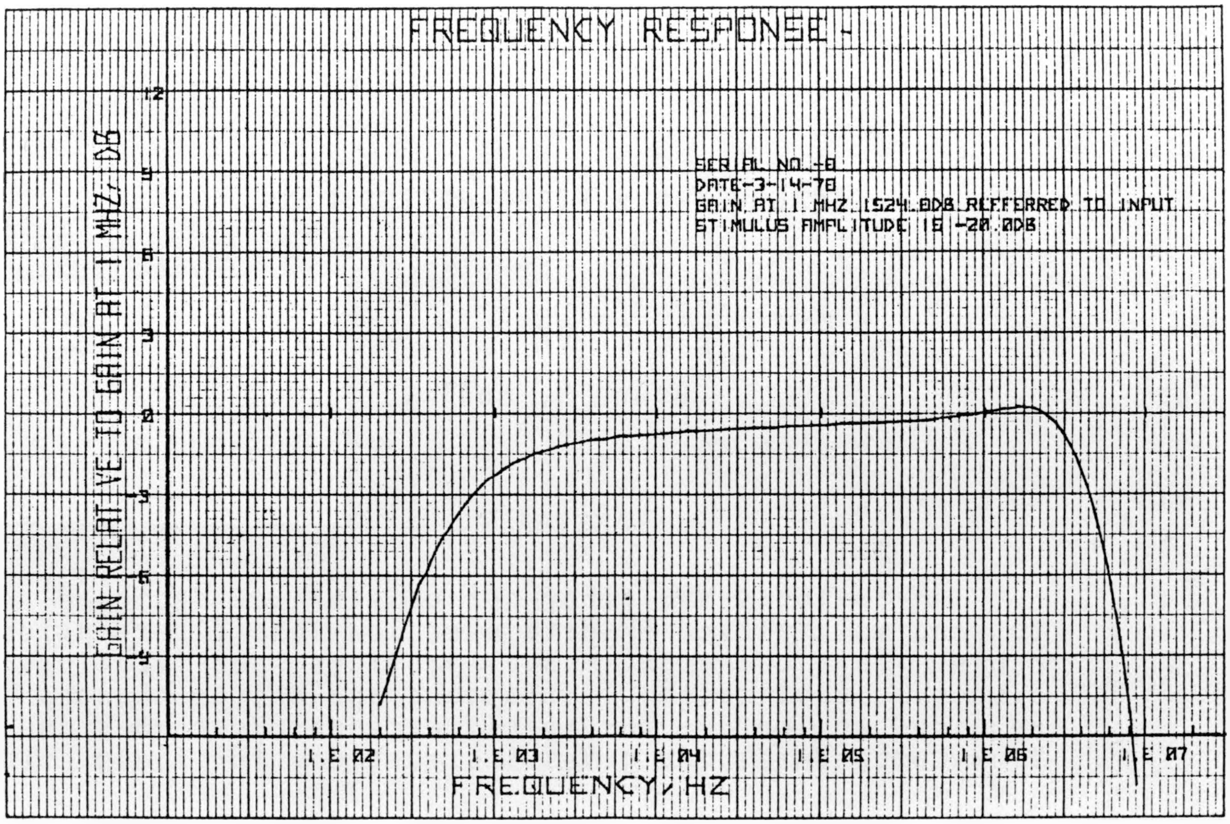

Fig. 1. Typical frequency-response curve.

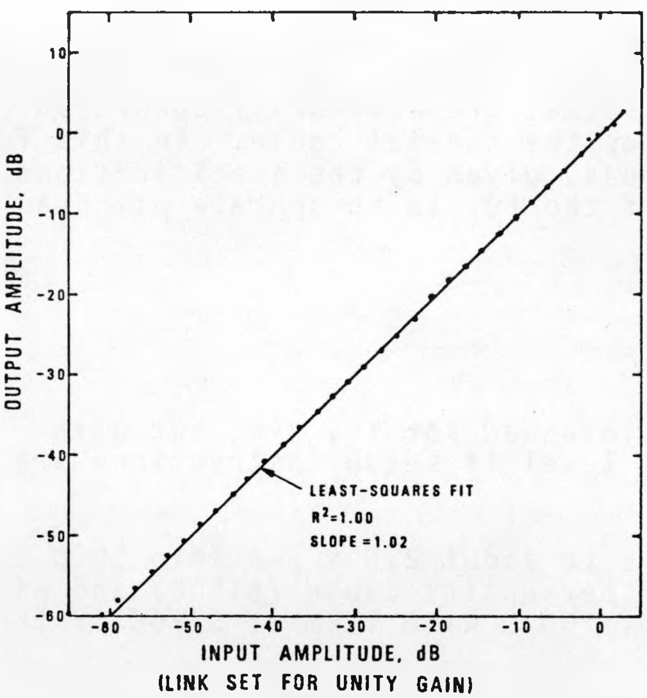

Fig. 2. Linearity (transfer) curve.

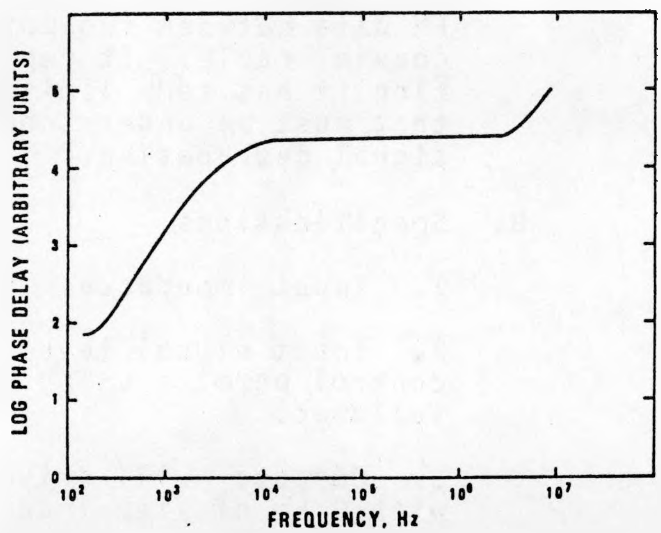

Fig. 3. Phase delay vs frequency.

5. Linearity: the dynamic range over which the input-output transfer curve deviates from a straight line by less than 1% is at least 55 dB. Figure 2 shows a typical transfer curve. The curve has a constant 2% slope above unity (i.e., it is superlinear) over the linear dynamic range.

6. Signal-to-Noise Ratio: the peak undistorted (<1% THD) sinewave output signal-to-rms random noise ratio is ≈200 with 830 m of Corguide graded-index cable. The output-saturated S/N is ≈400.

7. Distortion: THD is <1% for output signals smaller than 1.4 V p-p. Output-signal saturation occurs at about 2.8 V p-p. Phase distortion is negligible from 10 KHz to 3 MHz.

8. These specifications apply to the FOL only when using a Bell-Northern Research (BNR) 40-3-10-3 LED emitter in the transmitter and a BNR D-5-2 p-i-n detector in the receiver.

II. LIMITATIONS

A. The coaxial cable that the FOL replaces is more nearly an ideal black box than the FOL in that it is transparent over much wider bandwidth, linearity, S/N, and distortion ranges. Therefore, it is necessary to carefully observe the limitations imposed by the specifications when the FOL is used to replace coaxial cable.

B. Phase Compensation

The FOL has been designed without phase compensation because the phase delay is virtually constant over each frequency band contained in the multiplexed FM signal it is designed to transmit. Figure 3 shows a phase-delay curve, as obtained from the slope, $d\phi/d\omega$ (ϕ = phase, ω = frequency), of the phase-response curve. The phase delay is constant from 10 KHz to 3 MHz. The transmitted-signal bandwidth could therefore be any value within these limits and the transmitted signal would exhibit no phase distortion. The percentage of phase distortion for any signal containing frequency components outside the specified band can be estimated from the curve.

C. S/N Limitations

1. The S/N obtainable from the link is a function of the cable length. One can estimate the S/N available for a given cable length by linear interpolation between or extrapolation outside of the zero-length and 1-km-length points given in the specifications. This estimate must take into account the cable type. To make an accurate estimate requires data on the loss of the individual fibers being used. We have found experimentally that power losses per km in individual fibers in the same cable can vary by as much as a factor of ten. The specifications in part I.B were obtained

using Corning Corguide and the results given are averages for that cable, wherein the individual fiber loss varied from 9.3 to 16.6 dB/km.

2. The S/N also decreases proportionally to the number of and quality of the fiber-optic connectors or splices in the transmission path. Losses for poorly attached connectors or for bad splices can be 100%. Table I lists available connectors for which loss data were obtainable. Table II lists typical losses in splices.

TABLE I

CONNECTOR LOSSES

Connector	Typical Loss (dB)	Notes
Bell-Northern	0.5	2,3
Corning	1	2,3
Deutsch	1	2
ITT/Cannon (FOT series)	2	2,5
ITT/Leeds	1.5	1,4
Radiation Devices	5-6	2
Thomas & Betts	1.25	2,4,6

Notes:

1. Measured value
2. Manufacturer's claim
3. Available factory-installed only
4. Average value
5. Manufacturer claims losses as low as 1 dB are obtainable
6. Manufacturer claims losses as low as 0.6 dB are obtainable

TABLE II

SPLICE LOSSES

Splice Type	Typical Loss (dB)	Notes
Welded	0.25 - 1	1
Thomas & Betts	0.75 - 1.5	2
Loose tube	0.75 - 2	3

Notes:

1. Using EG&G welder
2. Manufacturer's claimed value using T&B splicer
3. Bell Labs' version of epoxied loose square tube splice.

III. DESIGN CHANGES REQUIRED FOR IMPROVED SPECIFICATIONS

A. Easy Changes

1. Wider Bandwidth. Only very simple changes are required to increase the bandwidth within certain limits.

a. Low Frequencies. The low-frequency cutoff (-3dB point) can be extended by replacing the coupling capacitors with appropriately larger values. The limit will be determined by the physical dimensions of the capacitors; it is relatively easy to reduce the lower -3dB point to 10 Hz. When the low-frequency cutoff is extended, the S/N will be reduced severely proportional to the ratio of the old and new -3dB frequencies because of 1/f noise. The present cutoff was chosen to minimize the 1/f noise contribution to the total noise.

b. High Frequencies. The receiver bandwidth has been constrained to 4 MHz in order to maximize S/N. It can be increased to up to 23 MHz by changing the filter capacitors on the outputs of the two NE592 stages. The S/N will decrease by a factor of approximately $(f/f_o)^2$, where f and f_o are, respectively, the new and old upper -3dB frequencies.

However, the transmitter is limited in its basic design to about 6 MHz and will therefore limit the system response to no more than that value. To increase the overall FOL response to greater bandwidth will require redesign of the transmitter (Sec. III.B)

B. More Difficult Changes

1. Phase Compensation. A phase-compensating network can be added to increase the range over which the phase delay is constant. This can be either passive of active. The passive circuit will decrease the S/N as well as the maximum output signal because it is inherently an attenuator. An active compensator can do the same function without these disadvantages, but at the cost of more circuit complexity. With either type, a compensator should be placed in the transmitter so that there is constant phase delay before the signal is sent along the fiber-optics cable. This is so that the system intermodulation distortion does not cause irremediable signal degradation at the receiver end. A second compensator should be used in the receiver to compensate its phase-delay characteristic.

2. Bandwidths greater than 6 MHz. As mentioned in Sec. III.A, the transmitter will require redesign to increase its bandwidth. This will involve using different output transistors, adding peaking circuits, and so forth. It

will probably not be possible to get as large an output signal swing as now exists, so the system S/N will be reduced.

For frequencies greater than about 70 MHz, the transmitter will have to be completely, redesigned, as the 3400B and LH0002 are each limited to 100 MHz.

For frequencies above about 150 MHz, the LED will bandwidth-limit, and one will have to use a laser diode, which will also require a new transmitter design. It will also result in considerably poorer input-output linearity.

The receiver will have to be redesigned when frequencies are greater than 23 MHz. The transimpedance amplifier's bandwidth is about 19 MHz. Peaking inherent in the NE592s helps extend this to about 23 MHz. For frequencies between about 23 to 58 MHz, one can simply replace the transimpedance amplifier by a wider-bandwidth unit. But the later stages limit the overall bandwidth to about 58 MHz, so higher frequencies than that will require complete redesign. The bandwidth limitation on the p-i-n diode is about 300 MHz. At higher frequencies, an avalanche photodiode (APD) is the only choice presently available. Because of its gain, it would be desirable to use the APD when <u>any</u> frequency increase is accomplished to take advantage of the improved S/N.

IV. SYSTEM DESCRIPTION

A. Block Diagram

1. Figure 4 is a block diagram of the FOL.

B. Circuit Diagrams

1. Transmitter. Figure 5 is a circuit diagram of the transmitter. The 3400B provides voltage gain to drive the LH0002 to its maximum. The LH0002 is a shunt current driver that supplies drive to the parallel 2N3300 output stages. The 2N3300s in parallel can supply enough dc current to the LED to bias it quiescently to the point ($\approx$130 mA) where the maximum undistorted signal swing is attained. The shunt driver eases the requirements on the output transistors for providing both bias and signal swing. A separate bias power supply is used for the LED to minimize loading on and decoupling problems in the rest of the circuit.

a. The BNR 40-3-10-3 LED has an integral fiber-optics pigtail for coupling to the fiber-optics cable through a splice or connector. Its light output is nominally 200$\pm$40 μW at the end of the pigtail.

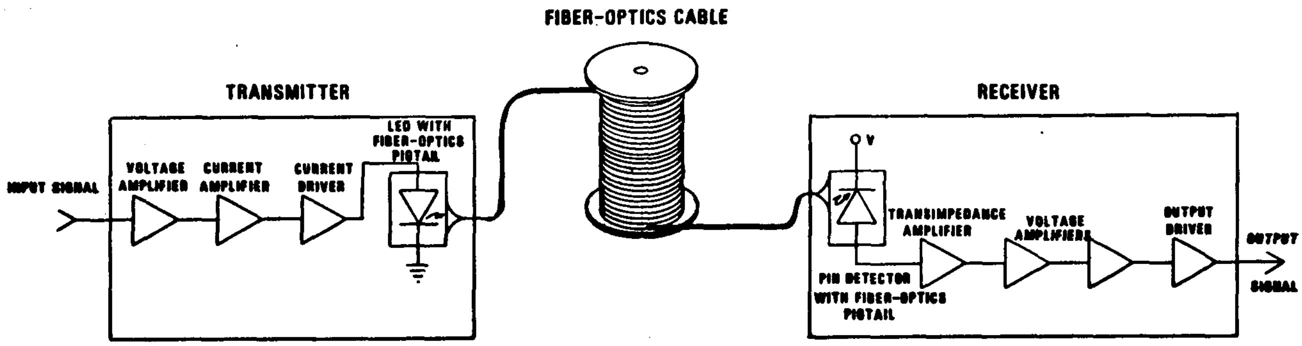

Fig. 4. Block diagram.

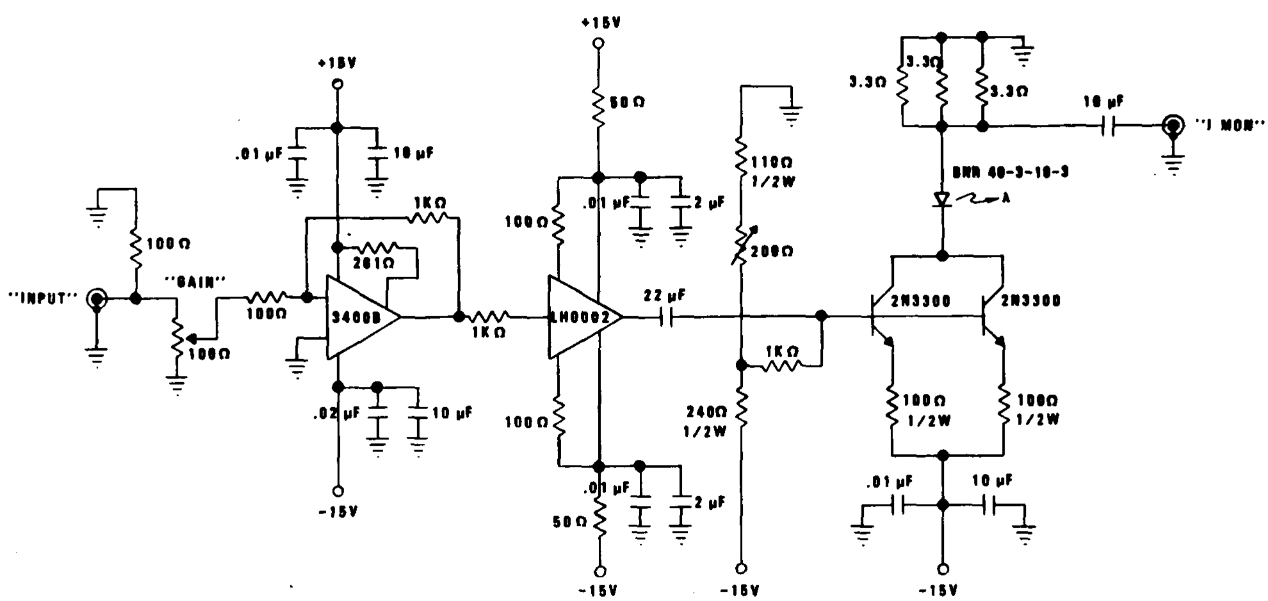

Fig. 5. Transmitter circuit diagram.

b. Cable/Source Compatibility. The core diameter of the fiber pigtail is 100 μm. This is larger than the cores of most fibers presently commercially available, so that there is a significant power loss at the pigtail-to-fiber interface. For fibers with numerical apertures $\gtrsim$.22, this power loss is approximately 20 log (D/100) in dB, where D is the diameter of the fiber in micrometers. There is additional loss, due to imperfect coupling, that cannot be predicted. We thus have two rules that should be observed when selecting cable: Assuming the cable bandwidth and its loss are satisfactory over the required length, choose that cable with (1) the largest numerical aperture $\geq$.22 and (2) the largest core diameter.

The cable choice will also be strongly influenced by what connectors and/or splices one plans to use. At present, connectors in particular are extremely limited as to what diameters of fibers they will accept. Table III lists some cables currently available, some of their more important specifications, and connectors that are available to use with them.

2. Receiver. Figure 6 is a circuit diagram of the receiver. The receiver's optoelectronic element is a BNR D-5-2 p-i-n photodiode. The photodiode has an integral fiber-optics pigtail. The fiber core diameter is 100 μm. The diode operates into a Texas Instruments' TIEF 152 transimpedance amplifier that acts as a impedance transformer to convert the high-impedance photodiode to a low impedance capable of driving a 50-Ω load at unity voltage gain. The transimpedance amplifier is followed by two NE592 voltage-gain stages with an overall gain of about 400. The LH0002 current driver will drive a 50-Ω load.

V. FIELD SETUP

A. Transmitter Setup

The FOL requires an initial adjustment when first set up in the field and when a component has been replaced. Otherwise it should require no maintenance. If input signal levels change, the transmitter input attenuation should be readjusted as in part V.A.2.

1. Initial Bias Adjustment

a. Turn the transmitter power on.

b. Connect a dc voltmeter between the junction of the three parallel 3.3-Ω resistors mounted on the PC board and chassis ground.

TABLE III

LOW-LOSS SINGLE FIBERS AND SINGLE FIBER CABLES

Manufacturer	Part No.	Core/Clad Materials (Note 1)	Index Profile	Attenuation dB/km@λ, nm	Dispersion, ns/km(3dB)	Bandwidth MHz-km	N.A.	Core/Clad diameters, µm	Nominal jacket diameter µm	Available in cabled format, No. of fibers	Available Connectors
Bell-Northern	7-1-A	G/G	Step	15@840	NA(note2)	20	.20	100/150	600	Upon request	Bell-Northern
" "	7-2-A	"	graded	15@840	NA	100	.22	100/150	600	" "	" "
" "	7-2-B	"	"	8@840	NA	200	.22	75/150	400	" "	" "
Corning	1051	G/G	graded	5@820	NA	400	.24	62.5/125	130	1,2,4,6,8,10	Amphenol, Corning, Deutsch, T&B
"	1052	"	"	10@820	NA	200	.24	62.5/125	130	"	" " " "
"	1053	"	"	5@820	NA	400	.21	62.5/125	130	"	" " " "
"	1054	"	"	10@820	NA	200	.21	62.5/125	130	"	" " " "
FCI(Times)	SA7-90	G/G	Step	7@800	NA	50	.16	90/125	200	1, 2, 3	Amphenol, T&B
	SA10-90	"	"	10@800	NA	50	.16	90/125	200	"	" "
	GA10-90	"	graded	10@800	NA	300	.16	90/125	200	"	" "
	GA15-90	"	"	15@800	NA	300	.16	90/125	200	"	" "
Galileo	Galite 5000	G/S	Step	18@820	NA	100	.20	60/175	2230	1, 7, 19	Amphenol
ITT	PS-05-20	S/P	Step	20@790	30	NA	.30	125/300	500	1,6,7(note 3)	Amphenol, Cablewave Systems, ITT/Cannon, ITT/Leeds, T&B
	PS-05-10	"	"	10@790	30	"	.30	125/300	500	"	
	GS-02-12	G/G	Step	20@850	15	"	.25	50/125	500	"	
	GS-02-8	"	"	10@850	15	"	.25	50/125	500	"	"
	GS-02-5	"	"	6@850	15	"	.25	50/125	500	"	"
	GG-02-12	"	graded	20@850	2.5	"	.25	50/125	500	"	"
	GG-02-8	"	"	10@850	2.5	"	.25	50/125	500	"	"
	GG-02-5	"	"	6@850	2.5	"	.25	50/125	500	"	"
Math Assoc.	OF-1000	G/G	Step	10@850	NA	NA	.16	55/90	200	NO	None
	OF-1100	"	"	15@820	"	20	.16	90/135	200	"	"
	OF-1150	"	graded	12@805	"	400	.16	90/135	200	"	"
Maxlight	200-1	G/G/G (note 4)	Step	20@820	NA	NA	.27	50/90/125	275	NO	NA
	200-2	(G+G)/S	graded	8@820	5	"	.24	75/125	225	"	"
	200-3	" (note 5)	"	8@820	5	"	.24	100/165	250	"	"
	200-4	"	Step	6@820	10	"	.15	85/125	200	"	"
Meret	SC	NA	NA	10@905	NA	NA	NA	NA	NA	1-fiber cable only	Meret
Quartz Products	QSF-A-200	G/P	Step	3@850	3	NA	.22	200/400	NA	Pending	NA
Siecor(also includes Corning above)	NA	G/G	graded	10@820	NA	200	.21	62.5/125	132	1,2,4,6,8,10	Deutsch, Siecor, T&B
	NA	"	"	6@820	NA	400	.21	62.5/125	132	"	" " "

NOTES

1. G=glass, P=plastic, S=fused silica (manufacturer differentiates from "glass")
2. Information was not available at the time the table was compiled
3. Available with up to 19 fibers on request
4. Includes G/G core-and-cladding plus glass waveguide
5. Core plus cladding is glass, waveguide is fused silica. Core/clad diameters given are for (core + cladding)/waveguide

c. Adjust the PC-board-mounted bias potentiometer for a voltmeter reading of -140 mV.

2. Input Attenuation Adjustment

a. Measure the peak-to-peak voltage swing into 50 Ω of the signal to be applied. Call the value obtained V_s.

b. Set the transmitter GAIN (front panel) potentiometer fully counterclockwise.

c. Set the output amplitude of a 1-MHz sine-wave generator to V_s volts into 50 Ω. If V_s is not more than 1.5 volts, set the generator to 1.5 volts.

d. Connect the generator to the transmitter INPUT jack.

e. With an oscilloscope connected to the transmitter I MON (current monitor) jack, adjust the GAIN potentiometer until clipping just occurs on both the top and bottom of the observed waveform. Readjust the bias potentiometer slightly, as necessary, to obtain clipping on both the top and bottom. Note that the waveform distortion will not have the same shape on the top and bottom.

f. Decrease gain until the clipping just disappears.

g. This completes the transmitter adjustment.

B. System Interconnections

1. Fiber Optics

a. Make the necessary fiber-optics connections between the transmitter and the receiver.

C. Receiver Setup

1. Gain Adjust

a. Set the TEST/FIBER switch to FIBER.

b. With the 1-MHz signal generator set at V_s, as in V.A.2.c above, and connected to the transmitter INPUT, the signal into 50 at the receiver OUTPUT jack should be $\leq$2.8 V p-p.

c. If the signal is larger than 2.8 V, reduce the transmitter GAIN until the signal is $\leq$2.8 V p-p.

2. Final Setup

a. Replace the signal generator at the transmitter with the signal to be transmitted.

b. This completes the setup.

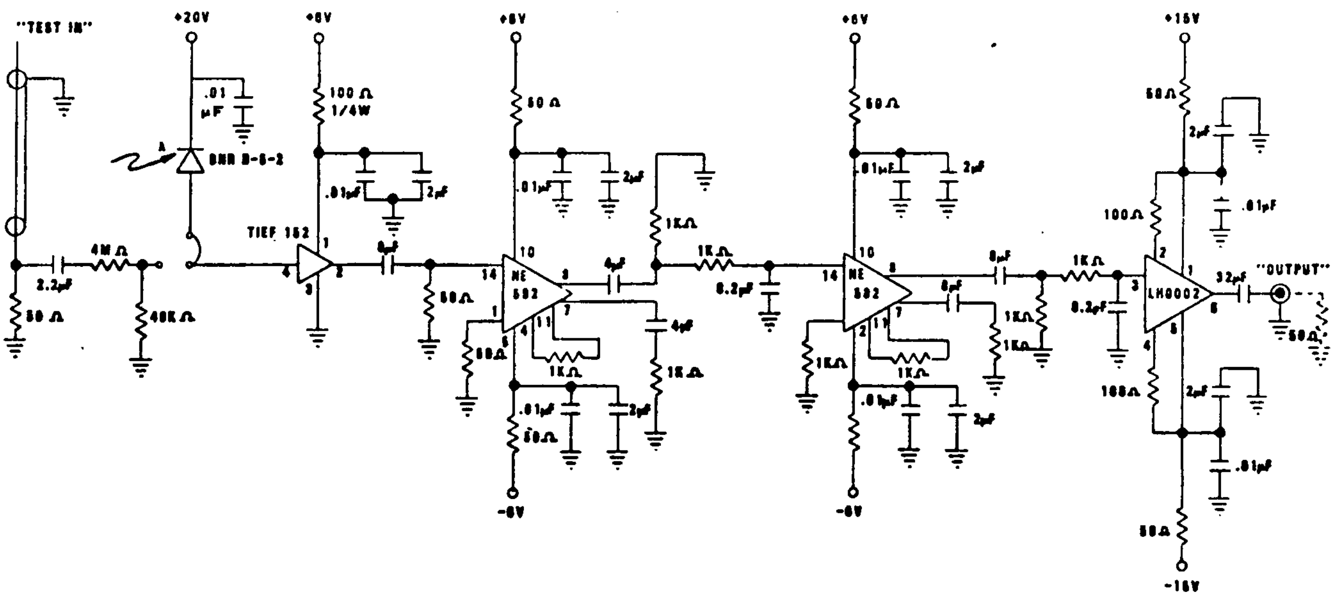

Fig. 6 Receiver circuit diagram.