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A video bandwidth communications system utilizing optical fiber transmission.

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A VIDEO BANDWIDTH COMMUNICATIONS SYSTEM UTILIZING OPTICAL FIBER TRANSMISSION

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

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COMMUNICATIONS SYSTEM UTILIZING
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by

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December 1973

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Communications System Utilizing
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Lieutenant, United States Navy
B.S.E.E., Tennessee Technological University, 1967

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requirements for the degree of

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ABSTRACT

A video bandwidth communications system utilizing optical fiber transmission was designed, constructed, and tested. An amplitude modulated gallium arsenide light emitting diode is driven by a transistor circuit. The output is detected by a wide bandwidth silicon detector-preamplifier hybrid circuit. Properties such as bandwidth and harmonic distortion were measured for the individual system elements and the overall system. A closed circuit television signal was sent through the system and a sharp clear picture was observed on the monitor.

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ACKNOWLEDGEMENTS

The author wishes to acknowledge his appreciation to his wife, Sue, for her faith, inspiration and assistance in preparing this paper, to Dr. John P. Powers, Thesis Advisor, for his technical guidance, and to the personnel in the Electro-Optics Division at the Navy Electronics Laboratory . for their assistance and for providing some of the components for this project.

I. INTRODUCTION

A. BACKGROUND

Light emitting diodes, or LED's, are semiconductor diodes which emit relatively pure infrared light when a current is passed through them. This light is concentrated into a very narrow band of the light spectrum, making it possible to select a photo detector that responds only to that band. At optical wave lengths (4000 - 7500 Angstroms), one light channel can carry over 100 billion bits of information per second [Ref. 1]. LED's have a 180 degree cone of radiation. This would constitute a problem for open space transmission since the light-gathering efficiency of the detector is limited. Therefore some sort of a light waveguide is needed to collimate the light. The relatively new optical fiber is an ideal candidate as a guide.

The fibers, which are smaller than a hair, can be bundled together in a particular way so that each fiber may be used as a separate information carrying channel. This type of transmission medium provides security, directionality and virtually zero cross talk or interference from adjacent fibers, and also offers an advantage of high information capacity with low weight compared with the transmission cables in use today.

These features would seem to indicate that the LED-fiber optical system would be ideal for communications purposes. However, there are some problems to be solved especially

when considering long distance communications. There are losses in the fiber associated with impurities in the material, at the ends of the fiber optical bundle, and at the air/fiber interface. There has been considerable progress in eliminating the impurities in the fiber to reduce absorption loss per length of fiber [Ref. 2].

An optical communication system is similar in principle to the conventional system. Therefore, it may be analyzed and studied similarly. Figure 1 shows a block diagram of a basic optical communications system. The transmitter utilizes a light emitting diode (LED) for electrical to light conversions.

The Gallium Arsenide (GaAs) LED is the most efficient for converting input power to output power (light emission) at present. The efficiency of a LED is very dependent upon device geometry and the presence of any transparent coating since the high index of refraction of the semiconductor causes much of the generated light to be internally reflected.

The maximum power output from a LED is limited by the power dissipation capability of the structure and the mount heat sink combination used. A typical dissipation limit of a transistor header not mounted on a heat sink is on the order of 100mw. Therefore, a zinc doped GaAs LED on a similar header can produce approximately 1.0mw of output radiation. With an appropriate heat sink, 20mw of output radiation can be produced [Ref. 3].

To impress information onto the output radiation of the LED, any of the conventional means of modulation (amplitude, frequency, pulse, etc.) may be used. This is possible and comparatively easy since the light can be modulated to carry information by the same electric current that excites the light emission.

Once the modulated light is transmitted through the fiber, there must be a method to convert the light back into electrical energy. Detection of light from an injected source is limited to direct detection systems. These types of detectors are basically photon counters and include photomultipliers, photodiodes, photoconductors, and phototransistors. Spectral match, gain, and speed at response generally limit one to photodiodes and photomultipliers. Photomultipliers are most useful in cases where noise considerations necessitate large post detection gains (for example, power gains over 100 db). Recent improvements in sensitivity and frequency response of silicon photodiodes make them the most useful photo detectors in many receiving applications. They have a peak response at about 8500-9000 Angstroms thus making them compatible with the GaAs LED light source [Ref. 4].

The LED fiber optical system has a promising future in several areas such as: replacing conventional heavy, costly cable with a fiber optical system for particular segments of a cable television system, closed circuit television, inner communication systems within and between buildings. Also, from a military view point, one fiber bundle cable no larger

in diameter than a light cord could be used to replace all of the individual wires running throughout an aircraft connecting various systems with the cockpit. The single fiber would save on weight as well as cost. Also in some aircraft containing communication platforms, there are secure systems which require special shielded cables with minimum radiation leakage. A fiber optical system could be used to replace these cables and would be more secure since there is virtually zero light leakage from the fiber. Also a fiber optical system would be ideal for an inner communication system aboard an aircraft, especially from the weight consideration.

B. OBJECTIVE

The objective of this project was to design, build, and test a LED fiber optical system suitable for wideband transmission using a GaAs LED in the transmitter and a photodiode in the receiver. The system was designed for a video signal as a typical wideband signal. A bandwidth of 5.0 megahertz was required to properly represent a clear, undistorted video signal. The system was to use a flexible optical fiber for transmitting the light. The system was to be designed so that all components are easily accessible and that all power requirements for these components are met through one power supply at the transmitter and one power supply at the receiver.

In addition, compactness in size was another consideration. The feasibility of this system being used on an aircraft would be determined to a certain extent on its size and weight.

II. DETAILED SYSTEM DESCRIPTION

A. TRANSMITTER

The basic components of the transmitter are: the light emitting diode, the diode modulator circuit, the information source (television camera) - modulator interface, and the television camera, Figure 2.

1. Light Emitting Diode

A difused planar, gallium arsenide, infrared emitting diode with a high collimating lens was used to provide the light for the carrier wave. A cross section of the physical configuration of the diode without the collimating lens is shown in Figure 3 [Ref. 5].

The theory of LED operation is explained with the aid of a quantum energy diagram (Figure 4). A voltage greater than 1.4 volts applied in the forward direction will add enough energy to the electrons in the "n" material to force them uphill against the p-n junction potential. Once in the "p" material, the electrons spontaneously lose their excess energy and fall back down across the forbidden gap to the hole conduction band. This recombination of electron-hole pairs in the p material results in the emission of energy, denoted by dE.

In rectifier diodes made of silicon or germanium, electrons in the p material fall across the forbidden gap through an indirect path, and their dE is dissipated in the form of thermal energy. On the other hand, the special

properties of LED materials, such as gallium arsenide, allow approximately ten percent of the recombining electrons to fall through a direct path, and dE is discharged as a photon.

The wavelength of light emitted by an LED is inversely proportional to the energy change, dE, at the instant of electron-hole recombination in the "p" material. It would then appear that the LED has a coherent output frequency determined by a single value of dE. However, this is a highly idealized case since practical light emitting diodes emit a relatively broad spectrum of wavelengths. This results from the fact that individual electrons will reach different levels as they move to the top of the potential hill in the välence band. In addition, the electrons will fall through different distances into the conduction band. Therefore dE will vary for these various distances and thus the light emitted from the LED will not consist of a single wavelength but will be made up of a band of wavelengths centered around the wavelength associated with the band gap energy [Ref. 6]. Figure 5A shows the spectral output of the ME5A infrared-emitting GaAs LED. For this particular diode, the peak wavelength occurs at approximately 9000 angstroms with a spectral bandwidth between half power point of about 500 angstroms.

The nearly linear relationship between the amount of forward current and the light intensity (power output) is shown in Figure 5B. This direct relationship can easily be explained by recognizing that a change in the rate of electron flow through the p-n junction will cause a corresponding

change in the rate of electron-hole recombinations within "p" material. Therefore the power out (light intensity) is increased. This linearity allows direct linear amplitude modulation of the light by the current.

Another factor to be considered that is related to the light output power is temperature. As shown in Figure 5C, LED light output decreases with an increasing ambient (case) temperature. This inverse effect is related to the fact that LED efficiency decreases with increasing temperature. At temperatures near absolute zero, nearly all recombining electrons follow the direct, light emitting path. As temperature increases, the system becomes more inefficient and a majority of the electrons drop across the forbidden gap and follow an indirect heat producing path. A ME5A LED has a 10% approximate efficiency for converting input energy (injected current) to output energy (light).

Figure 5D and 5E are the forward I-V characteristics and the spacial distribution of the ME5A LED respectively. The forward I-V characteristics show a high forward voltage drop. Also another peculiar feature not shown on the I-V curves is that the LED has a reverse breakdown potential of only 3 volts. Therefore, the light-emitting diode can be used only as a source of light but never as a rectifier [Ref. 5].

The final item to consider is speed. The turn-on characteristics of an LED can be considered to consist of two parts: first, a delay between the application of a current

pulse and the start of spontaneous emission (this is merely the time necessary to charge the junction capacitance); second, the rise time of the emission once it begins. The delay time is almost negligible and the rise time for the ME5A is approximately 10ns [Ref. 3].

2. LED Modulator

A circuit was needed that would provide a reference current for the LED as well as a means for modulating the LED with the information signals. The following circuit (Figure 6) was used to provide these requirements. In addition, the wideband requirements made it necessary to choose a transistor that would respond to analog frequencies from D.C. to 5.0 megahertz as well as pass pulses of frequencies 60 hertz and 15,750 hertz. Also, the power requirement made it necessary that the transistor be capable of handling current up to 1 ampere. For this task, a NPN silicon annular transistor (2N3252) for high current saturated switching was chosen. This transistor has an upper 3db frequency of well over 100 megahertz. The electrical characteristics for the 2N3252 are shown in Figure 7. Two designs were tried. The first design utilized a LED current of one ampere which is one half the maximum rated value of the diodes. It was thought that this would be an optimum reference for the modulating signal. However, two problems were encountered. One obstacle resulted from the high emitter-collecter current (Figure 6) needed to operate the LED at one ampere. This high current required that the biasing resistors be of low

omhic value as well as have a high power (8 watts) dissipating capability. Since these specific high power resistors were not available, the required resistors were made by parallel combinations of available one watt resistors. However, this was not satisfactory since the heat produced made it difficult to build a circuit that would satisfy the secondary objective of compactness. The other problem was that at this high value of current, the LED produced too much light output and drove the photo detector in the receiver (Section II-B) into saturation. Therefore a lower value of 0.1 amperes was decided upon as the optimum design value for the LED current. The final design is shown in Figure 6.

An operational test was run on the modulator. Figure 8 is a result of this test. Figure 8A shows that the modulator has a D.C. to 6 megahertz bandwidth. A distortion test was conducted with a wave analyzer to determine signal content of the fundamental, second, third, and fourth harmonic of a 20 KHZ input signal. As can be seen from the results (Figure 8B) that there was negligible distortion introduced indicating a highly linear modulator.

3. Voltage-to-Current Converter

Because of the high current, the LED modulator had a low input impedance equal to the emitter resistance (39 ohms) since the transistor is operated in saturation. Therefore an impedance matching device was needed to prevent the modulator from loading down the wideband signal source. To

perform this function, a voltage-to-current converter was used. The designs and operation of the circuit (see Figure 9) is described below.

This circuit is known as the Howland circuit and is used to provide an output current as a representation of an input voltage [Ref. 7]. The Ha2-909 wideband operational amplifier was chosen to implement this circuit. The circuit components were established analytically. The load current, I_L, is equal to the sum of I_2 from the input source and I_o from the output terminal. The feedback network dictates that the output voltage be exactly twice the load voltage (V_L). The load current is given by the following relation:

$$I_L = \frac{V_{IN} - \frac{E_o}{2}}{R_2} + \frac{E_o - \frac{E_o}{2}}{R_2}$$

$$I_L = \frac{V_{IN}}{R_2}$$

V_{IN} and I_L were known quantities. Utilizing these values, R_2 was determined. This value was also used for R_1, R_f, and R_3 as is done in a typical voltage to current converter [Ref. 7].

The following operational tests were conducted on the converter: linearity test, frequency response, and harmonic test. The results of these tests are shown in Figure 10. The linearity test showed that the converter can operate through a large range of voltage without going

into a non-linear region. The frequency response test determined that the required bandwidth of 5.0 megahertz was obtained. Finally, the harmonic test indicated that there was negligible distortion introduced into the output of the converter.

4. Inverter

An unexpected problem with the polarity of the signal at the output of the detector (Section II-B) was encountered. The detector package caused an inversion of the signal. To remedy this problem, a signal inverter was built and the output was fed into the voltage-to-current converter. The circuit (Figure 11) was built to provide this operation. Again, the 2N3252 transistor was used, but in the linear region. Figure 12 shows the common emitter output current voltage characteristics.

A frequency response test was conducted to insure that the inverter met the required bandwidth. The results are shown in Figure 13.

5. The Constructed Transmitter

A compact case was designed and built to contain the required components, circuitry and LED. A photograph of the completely assembled transmitter is shown in Figure 14.

The casing is a 3 X 3 X 4 inches aluminum box supported by four aluminum legs. At one end of the case is located a rectangular metal block which serves as a holder for the LED and as an end terminal for holding the optical fiber and flat against the LED face. On one side of the

case, seven banana plug jacks are mounted. The top three plugs are for the power supply. The other two pair are for ammeter connections for monitoring the LED current and the current output from the voltage-to-current converter. A coaxial cable terminal connecter was mounted on the side of the casing opposite the banana plug jacks. This provided the input signal. A voltage divider network in the form of a 2 kilohm, linear, precision potentimeter was placed between the coaxial cable terminal connecter and the input to the inverter for the purpose of controlling the amplitude of the input signal. The precision potentimeter was needed since the maximum amplitude of the input signal is approximately one volt.

A trace of the converter driver printed circuit design mask is shown in Figure 15. Figure 16 is a schematic of the complete transmitter circuit.

B. RECEIVER

The receiver unit consists of a commercial photo detector/ amplifier package (FDA-425), a video amplifier stage and a television monitor (Figure 17).

1. Photodiode

A photodiode is a device which converts light intensity to electrical current. These diodes are usually operated in a reverse bias condition. The photodiode operates in the following manner. Electrons and holes are generated within the high field region of the junction by incident

photons. These electrons and holes then diffuse to the junction and are collected as photocurrent across the high field region [Ref. 8]. In the case of high speed diode, since diffusion processes are slow compared to carrier drift, excitation must occur close to the junction so that diffusion times are relatively shorter than drift time. Figure 18 shows a cross-section of a photodiode.

The ac characteristics of the photodiode can be described with the aid of the equivalent circuit in Figure 19. The current generator represents the photocurrent produced. C is the junction capacitance of the diode, and R and R_s are the shunt and series resistance respectively.

A well designed diode has a high quantum efficiency, fast speed of response, low dark currents, and low series resistances. Also, a high external efficiency, the efficiency with which the incident photons are converted to current, is desired. The quantum efficiency is dependent upon the depth and width of the junction region and also the wavelength of operation. For this particular case of the FDA-425, a wavelength of 905nm is of interest. Figure 20 shows a plot of quantum efficiency versus wavelength and Figure 21 is a plot of wavelength versus responsivity (a figure of merit indicating the ability of the device to convert incident light power into voltage output).

Finally, the ability of the diode to respond to high frequencies is dependent on the RC time constant of the AC equivalent circuit. The cut-off frequency, F_c,

is given by [Ref. 4]:

$$F_c = \frac{1}{2\ R_s C[1 + (R_s/R)]}$$

2. Photo Detector/Amplifier

The device used for performing the function of detection and amplification was the FDA-425, low noise, high performance receiver (made by Meret, Inc.). The package is a silicon photo detector/transimpedance amplifier which has a nominal bandwidth from D.C. to 10 megahertz. The responsivity is 15mv/micro watt at a wavelength of 905nm. The device is an extremely compact unit packaged in a flatpack. Figure 22 and Figure 23 are a schematic and photograph respectively of the FDA-425 package.

The maximum output from the detector was less than the 1.4 volts needed to drive the television monitor. Therefore an amplifier had to be employed to provide the necessary drive. This service was provided by a commercially made video amplifier. A frequency response test was conducted on the amplifier. The results are shown in Figure 24.

A precision potentimeter was placed in the output of the detector to insure that the amplitude of the input voltage to the video amplifier could be adjusted below the .375 volts necessary to remain in the linear range of the amplifier. A schematic of the complete receiver is shown in Figure 25.

3. Constructed Receiver

A compact case was designed and built to contain the detector. A 3 X 3 X 4 inches aluminum casing supported by three aluminum legs was constructed so that a flatpack which contained the FDA-425 and the flatpack mount could be affixed to one end of the structure. A rectangular metal socket which served to hold the fiber flush against the detector was mounted on the outside of the casing at the detector end. A coaxial cable connector was mounted on the side of the casing to provide the output. The precision potentimeter which provides an adjustable amplitude to the output terminal was mounted on the removeable top. Two banana plug jacks were mounted on the side opposite the output terminal for the power supply input. Figure 26 is a photograph of the receiver unit.

C. PROPAGATION MEDIUM

An optical fiber bundle was used as a wave guide for the light transmitted between the light emitting diode and the detector.

The theory of fiber optics depends on the principle of total internal reflection, a refraction effect, as the light rays travel along a fiber. Whenever light travels at different speeds in different materials such as light traveling from one material to another, refraction occurs. This principle can be applied to a fiber optic light filament by considering a cylindrical core glass with an index of

refraction n_1, clad with a second glass that has an index of refraction n_2. In order to have complete internal reflection, the incident light must fall within a particular angle referenced to a normal to the core surface. This angle is called acceptance angle (A) and is given by the following expression:

$$\sin A = \frac{\sqrt{n_1^2 - n_2^2}}{n_3}$$

where n_1, n_2 and n_3 are the indices of refraction for the core, the cladding and air respectively. Figure 27 summarizes the above expression as applied to an optical fiber.

The maximum angle at which a ray of light may be incident on the core and insure total internal reflection is represented by sin A, the Numerical Aperture (NA). As can be seen in Figure 27, any incident light ray outside the core of acceptance is transmitted through the core into the cladding where it is dissipated.

Losses occurring in the fiber during transmission are primarily due to two factors: attenuation associated with the length of fiber and end losses. The attenuation losses result from the impurities in the fiber which cause absorption and scattering of the light. End losses occur in an optical fiber bundle because light incident on the cladding portion of the bundle is poorly transmitted. Also reflection occurs at the ends for some of the light outside the core of acceptance [Ref. 9].

For this project a three meter length of Corning No. 5011 commercial grade fiber was used. The specification for this fiber are given in Figure 28. Each end of the fiber was provided with a metal socket which could be plugged into metal recepticles which held the ends of the fiber bundle flush with the LED and detector lenses. This arrangement insured that a maximum amount of light was gathered for transmission and reception.

Figure 29 is a photograph of the transmitter, receiver, and optical fiber wave guide.

D. COMMUNICATIONS SYSTEM TESTS

The performance of a communication system may be examined from a technical view point by checking the bandwidth, harmonic distortion, signal-to-noise ratio, and transmission loss, and from a non-technical view point by checking whether or not the system actually works (Figure 30). The system successfully passed a video signal which contained frequencies from 30 hertz to 4.5 megahertz (Figure 31).

1. Bandwidth

The bandwidth of the system was determined experimentally. Constant amplitude sinusoidal inputs from 10 hertz to 10 megahertz were injected into the system. Frequencies and percentage of amplitude were recorded on a semi-logarithmic scale. Figure 32 shows the results of this test. Examination of the frequency response curve shows that the upper -3db frequency occurs approximately

at 6.0 megahertz. Therefore the bandwidth objective was met.

2. Harmonic Distortion

Signal content of the fundamental, second, third, and fourth harmonic of a 20 kilohertz signal was determined using a wave analyzer. The test was conducted with system at optimum operating condition. The results (Figure 33) show that there is no appreciable distortion introduced into the information by the system.

3. Signal-to-Noise Ratio

The signal to noise ratio for the system was determined by measuring the output signal power when much larger than the noise and the mean noise power at the output with no signal. The ratio of these two quantities is the signal to noise ratio [Ref. 10]. A maximum noise level of 1.0 millivolts and a maximum signal of 40 millivolts with sinusoidal signal was observed. These values resulted in a signal to noise ratio of 40:1.

4. Transmission Loss

To determine the maximum length of fiber that could be used with this system and still have sufficient signal at the receiver end, a transmission loss test was conducted. The fiber was disconnected from the receiver end. It was then moved away from the detector until there was no useable signal observed. This distance measured approximately 9cm at which the photo detector current dropped by a ratio of 30:1 (30db). Since the fiber has a 1db/meter loss, these

figures would indicate that an additional 30 meters could be used in the system. Therefore, if more than forty meters of fiber were needed in utilizing this system, a repeater would have to be employed to boast the signal to useable level for continued transmission. However, the fiber employed in this work had a high loss factor compared to the best grade of fiber available at the present. Therefore, if a better quality fiber, having a much lower loss factor, were used, several hundred meters of fiber could be used before a repeater would be needed.

III. CONCLUSION

The gallium arsenide light emitting diode can be used effectively for video and high data rate optical fiber transmission. Since the light intensity is directly proportional to the current through the LED, many of the modulating schemes available should work satisfactorily.

The bandwidth objective of five megahertz to pass a video signal was obtained. The high speeds of the LED and the large bandwidth of the fiber make future work in digital transmission worthwhile.

Also, optical fiber systems are highly practical for use in secure systems. Since there is no radiation leakage from the fiber, the interception of information is virtually impossible. To guard against cutting of the fiber, a thin metal jacket could be used encasing the fiber bundle and coupled to an appropriate alarm system.

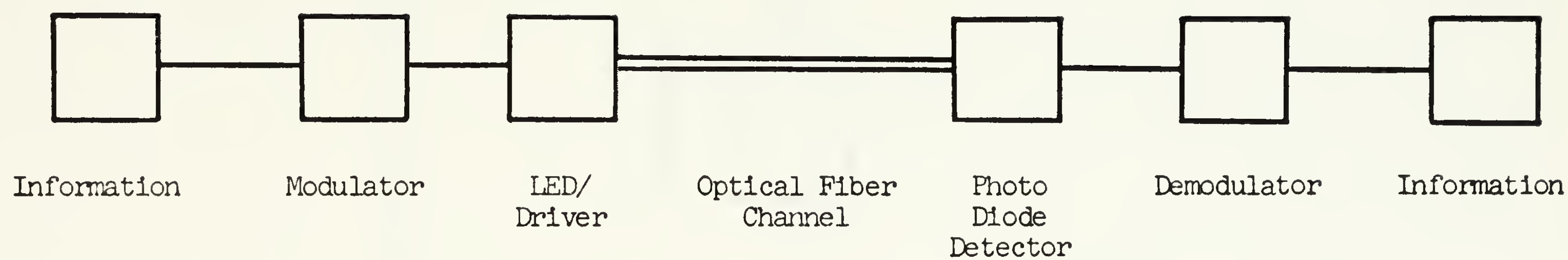


Figure 1: LED Communication System

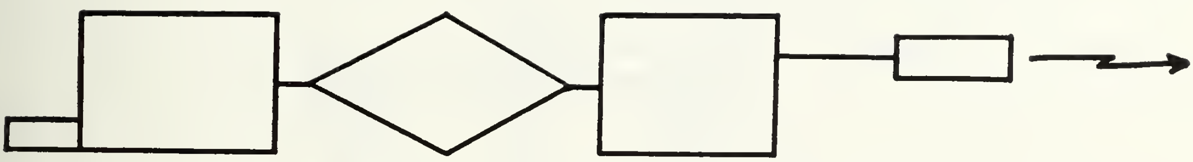


Figure 2: Transmitter Block Diagram

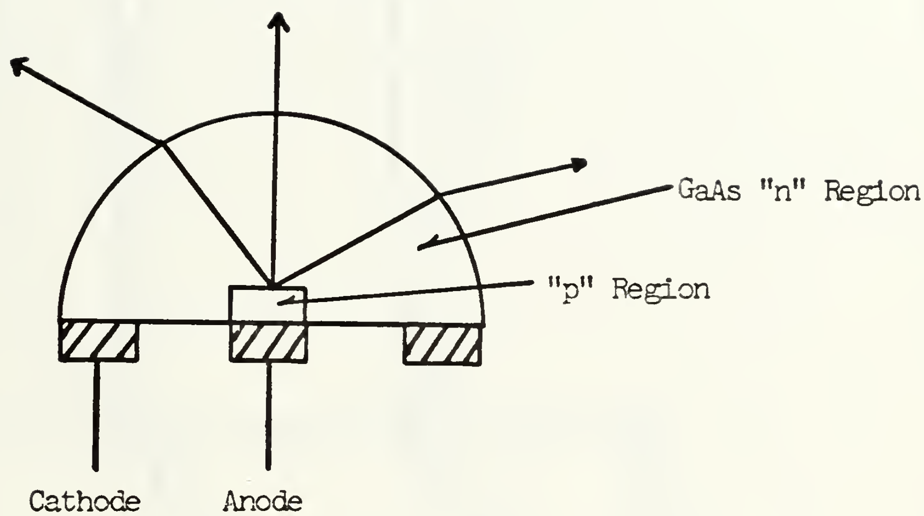


Figure 3: Gallium Arsenide LED

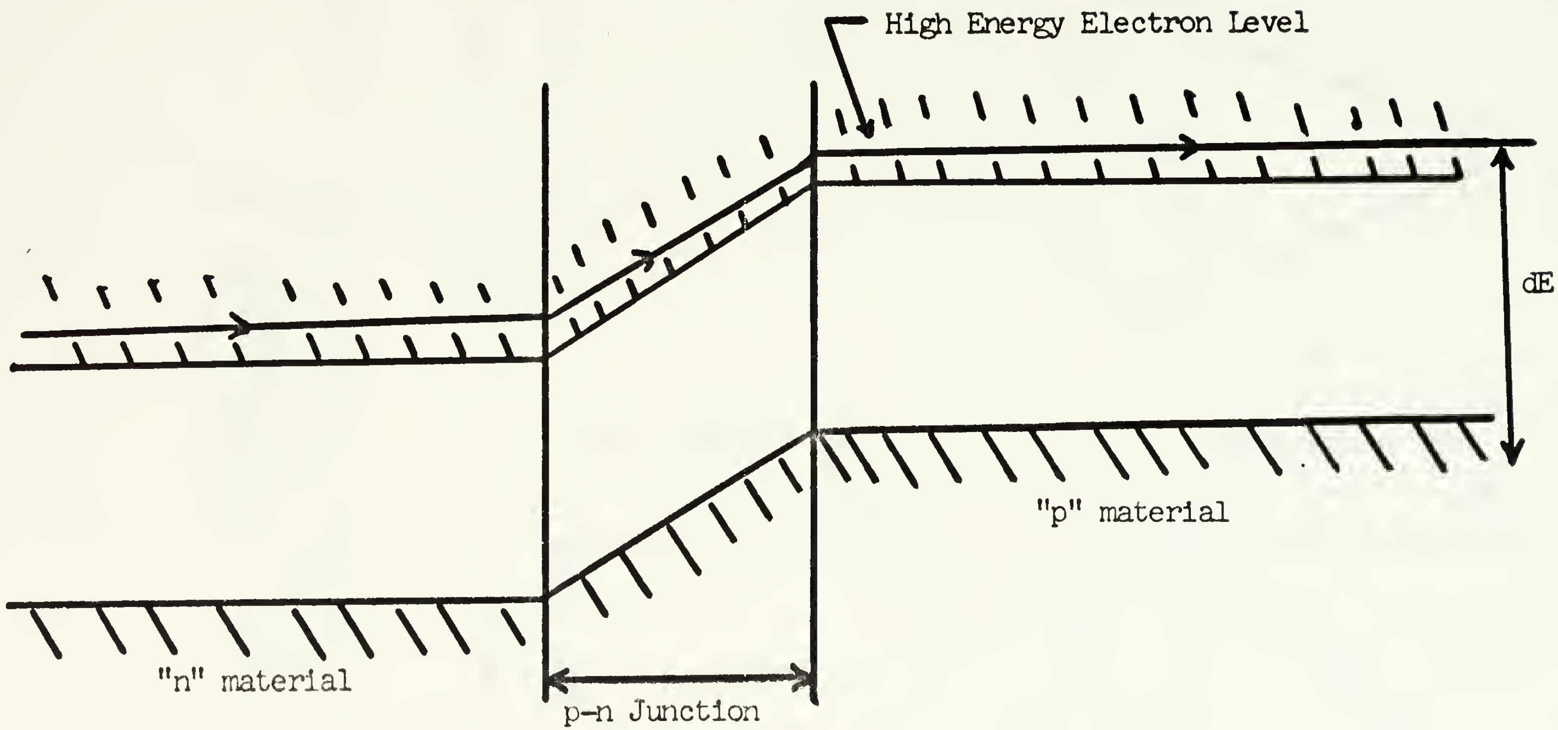


Figure 4: Quantum Energy Diagram for LED

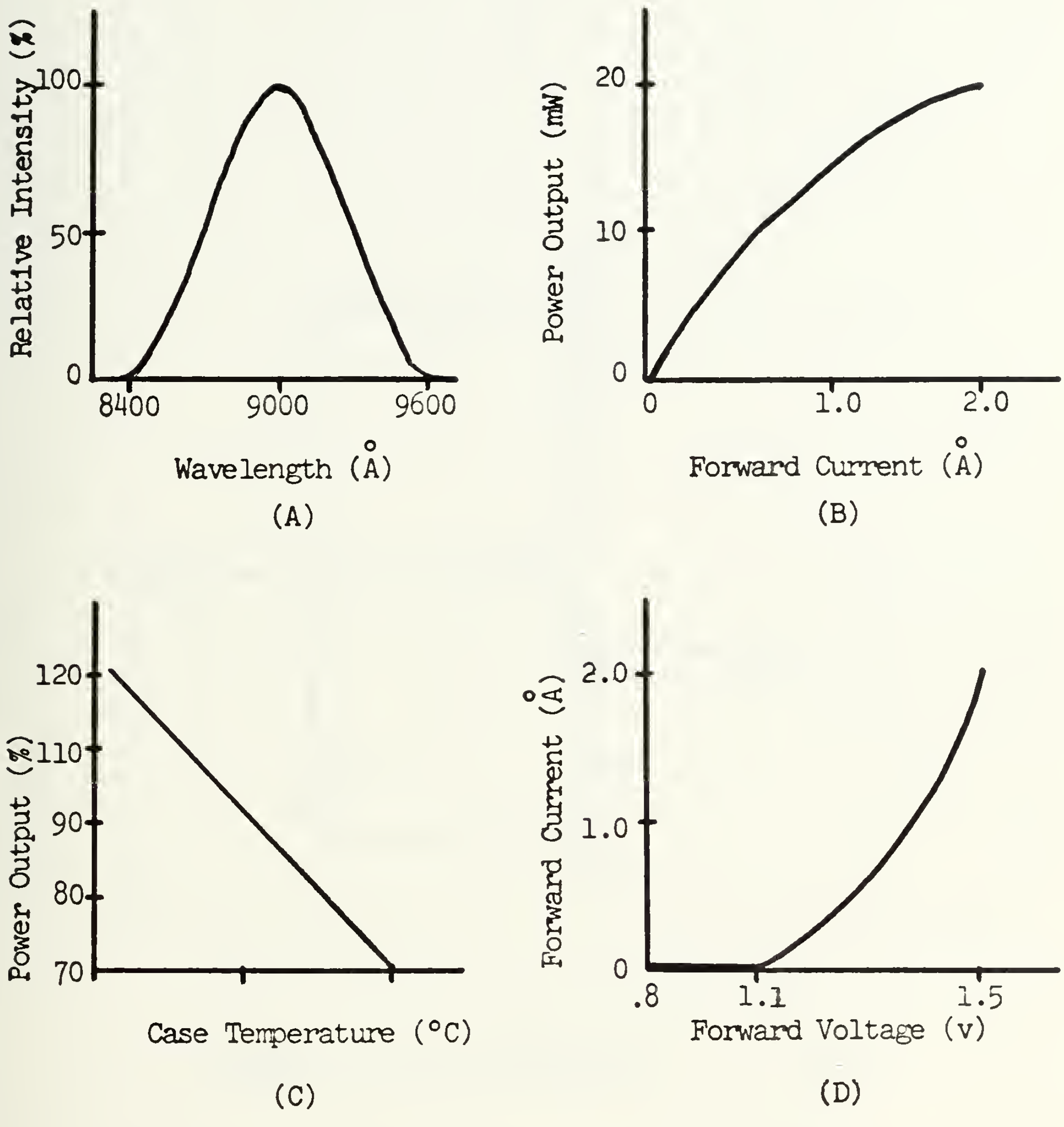


Figure 5: Electro-optical Characteristic Curves of a ME5A (A) Spectral Response (B) Power Output vs. Forward Current (C) Relative Power Out vs. Case Temperature (D) Forward Current vs. Forward Voltage

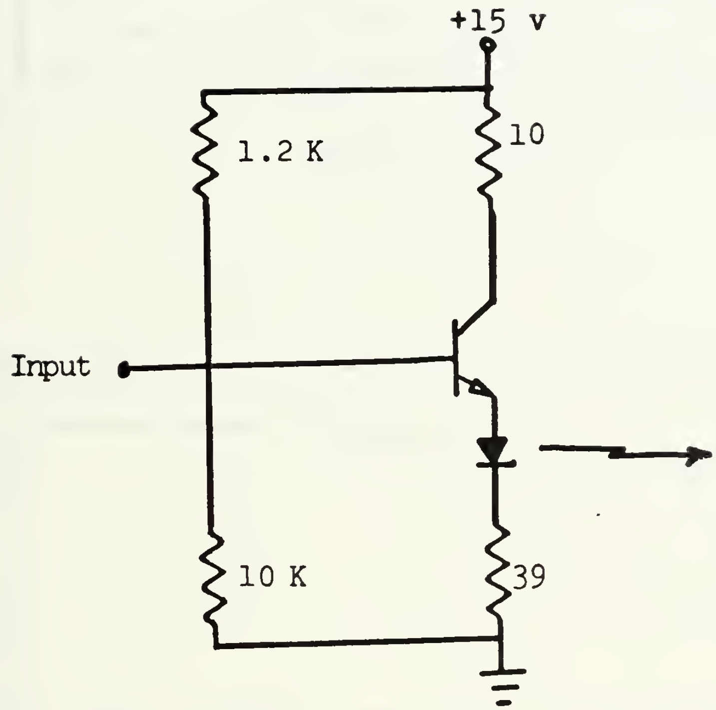


Figure 6: LED Modulator

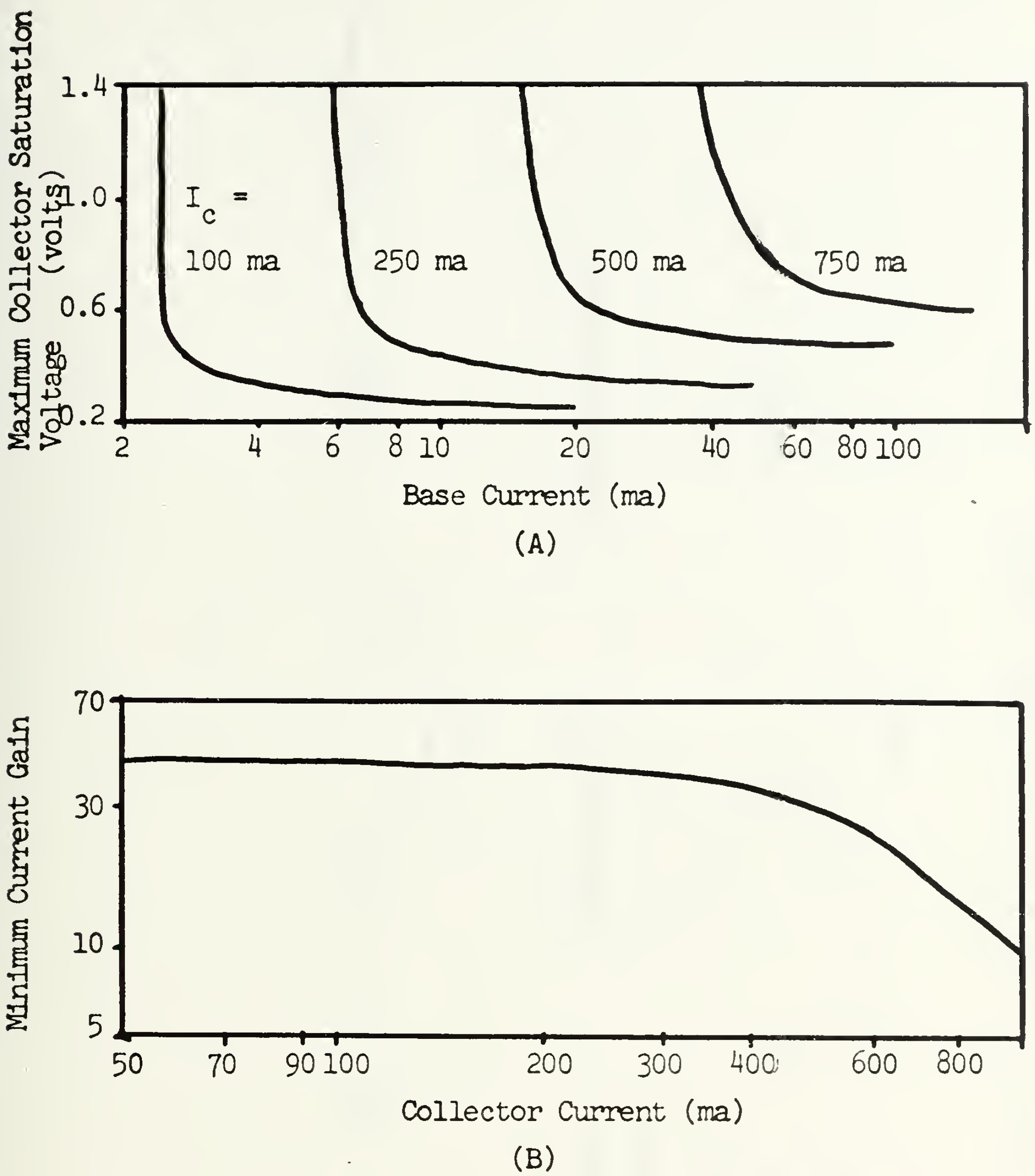
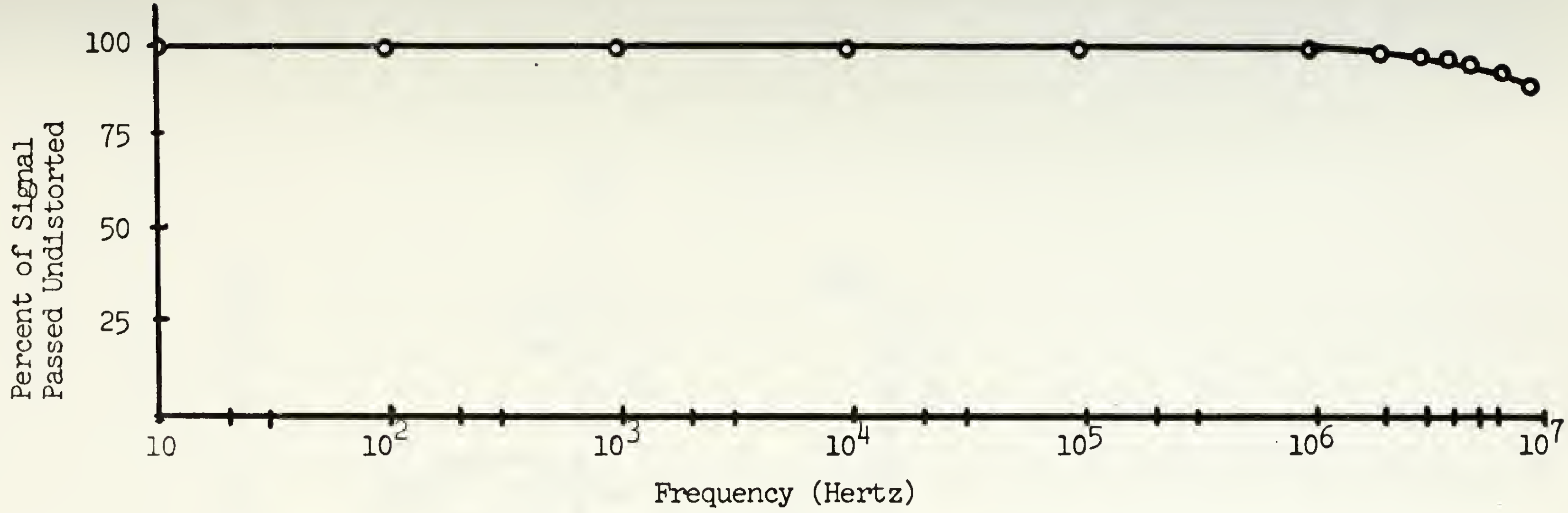


Figure 7: Characteristics of 2N3253 Transistor
(A) Collector Saturation Voltage Characteristics
(B) Minimum Current Gain Characteristics



(A)

Harmonic	Frequency (KHZ)	Signal Content (%)
Fundamental	20	100
Second	40	0.1
Third	80	0.001
Fourth	160	0.0

(B)

Figure 8: LED Modulator Test Results
(A) Frequency Response of Modulator
(B) Harmonic Distortion Test of Modulator

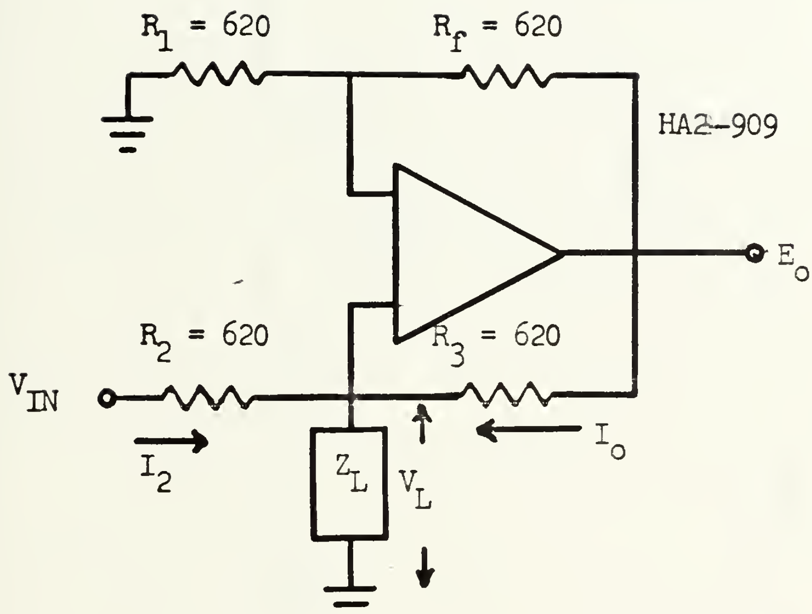


Figure 9: Voltage-to-Current Converter

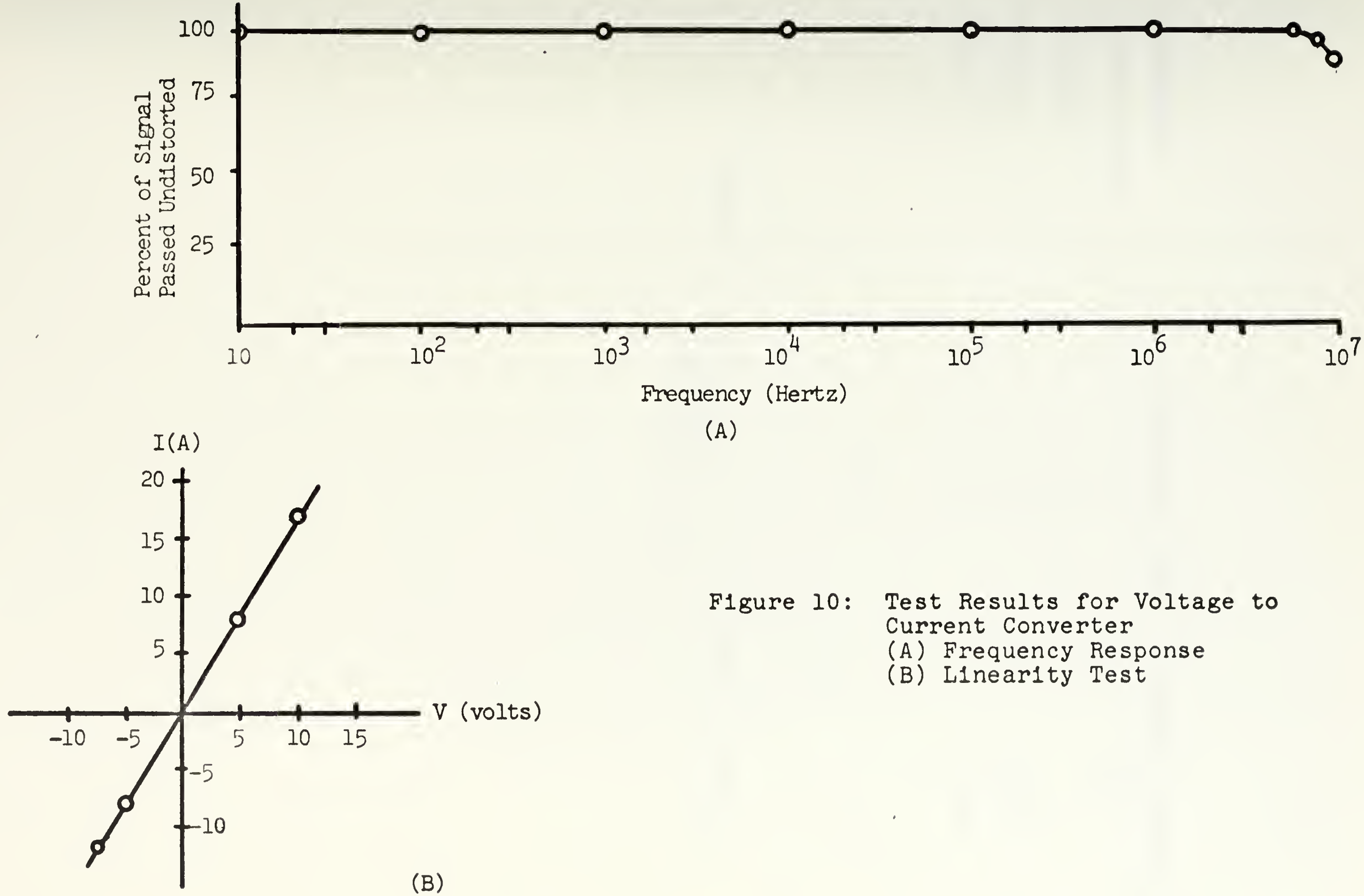


Figure 10: Test Results for Voltage to Current Converter
(A) Frequency Response
(B) Linearity Test

Harmonic	Frequency (KHZ)	Signal Content (%)
Fundamental	10	100
Second	20	4
Third	30	0.08
Fourth	40	0.13

(C)

Figure 10: Test Results for Voltage to Current Converter
(C) Harmonic Test

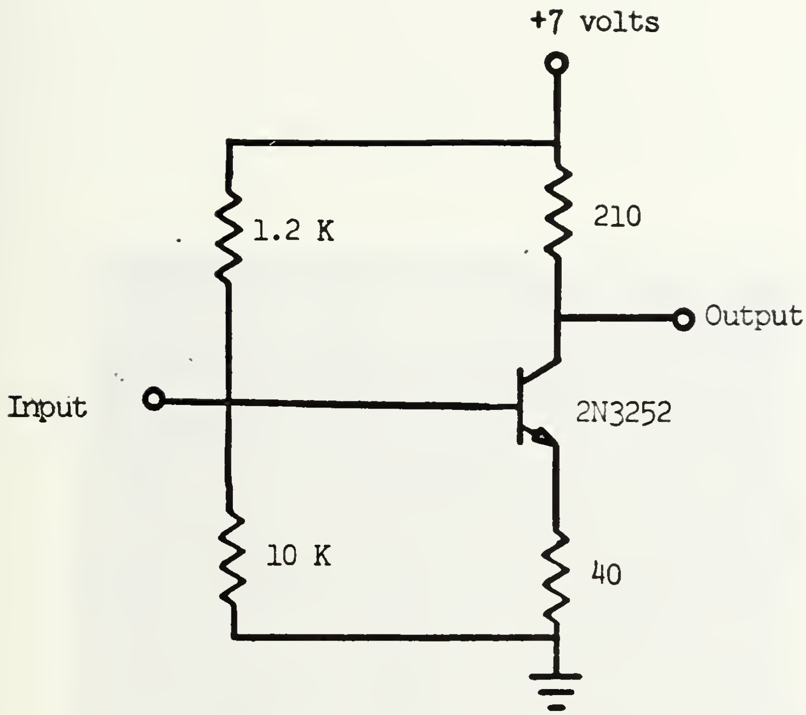


Figure 11: Inverter Circuit

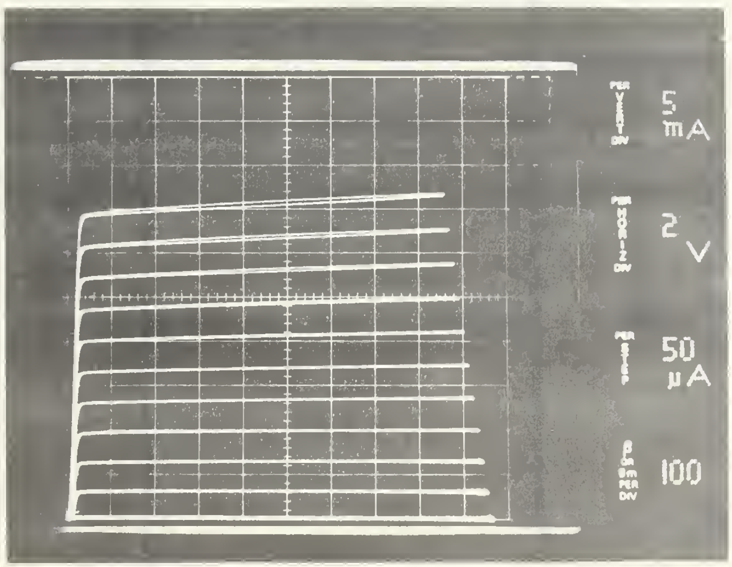


Figure 12: 2N3252 Common Emitter Output Characteristics

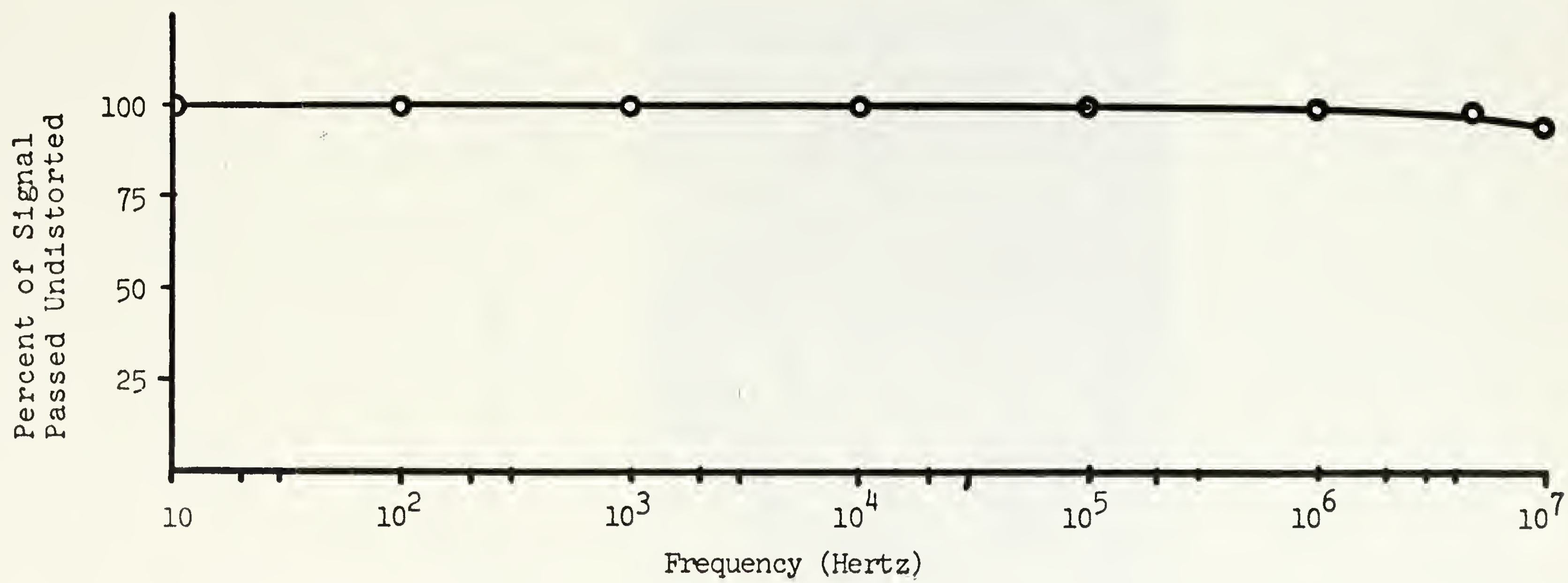


Figure 13: Frequency Response of Inverter

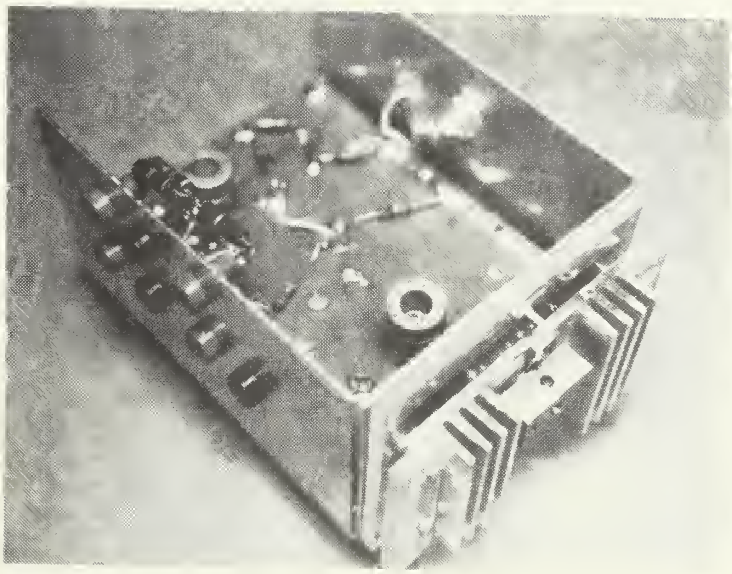


Figure 14: Assembled Transmitter

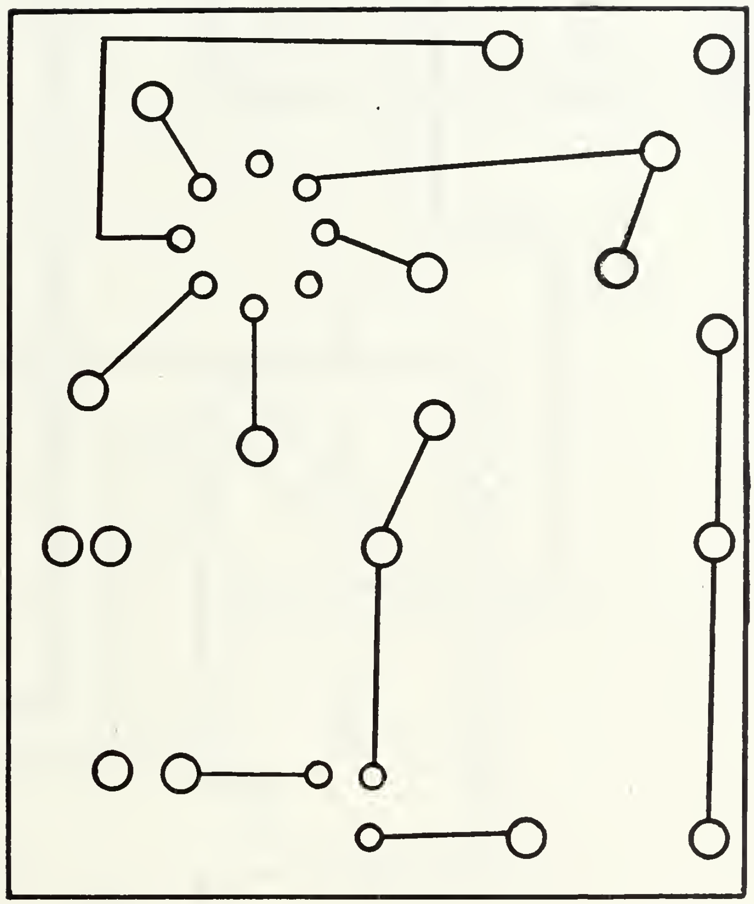


Figure 15: Printed Circuit Design Mask for the Converter Driver Components

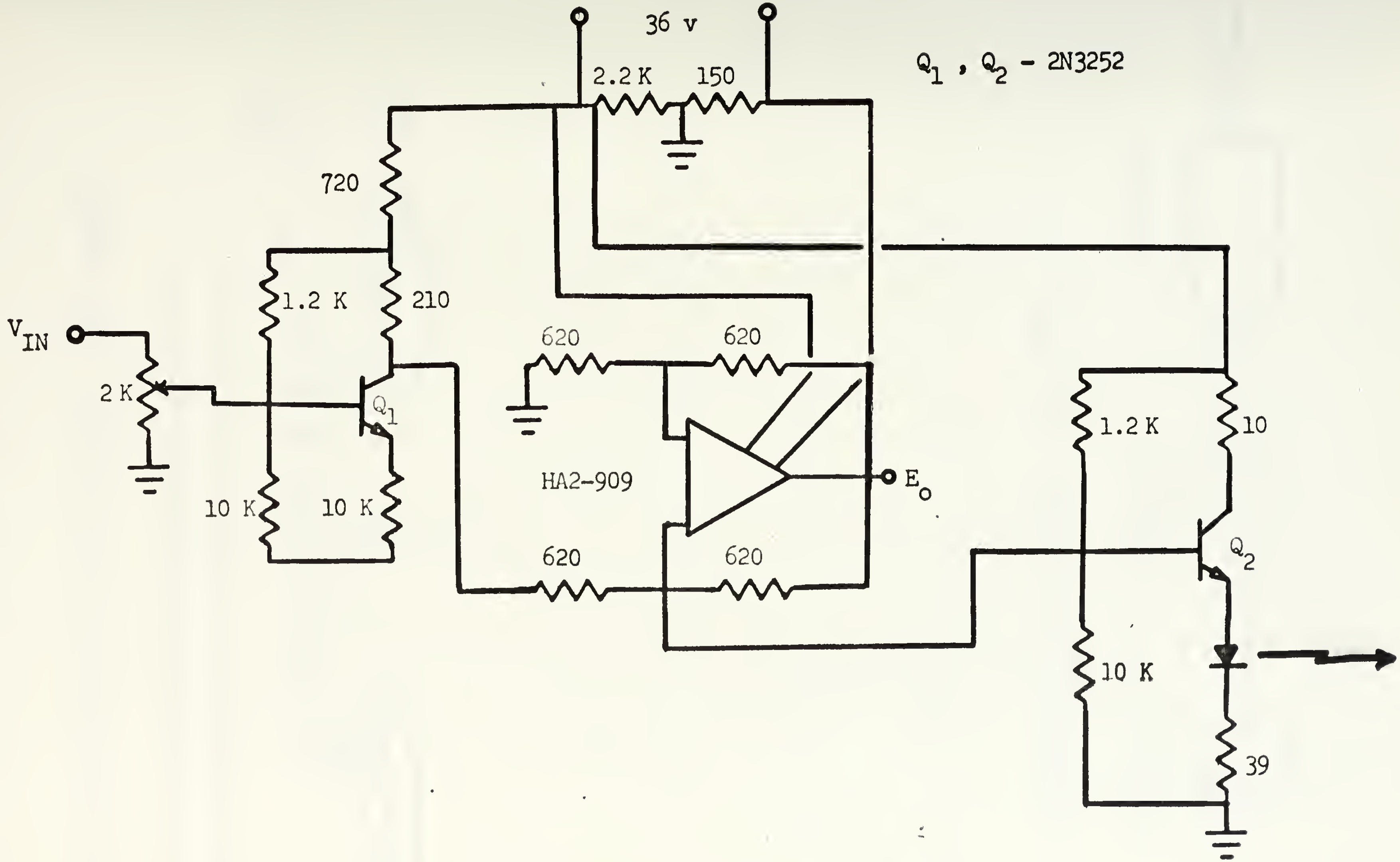


Figure 16: Schematic for Transmitter Circuit

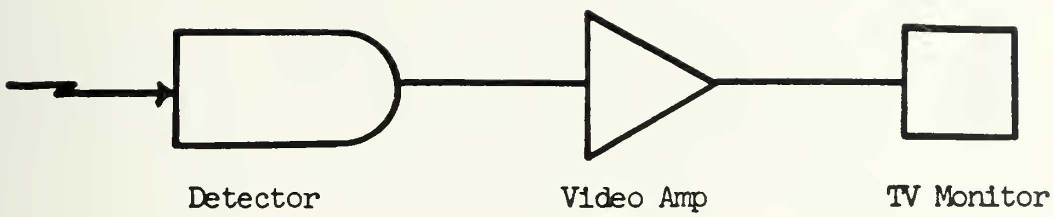


Figure 17: Receiver Block Diagram

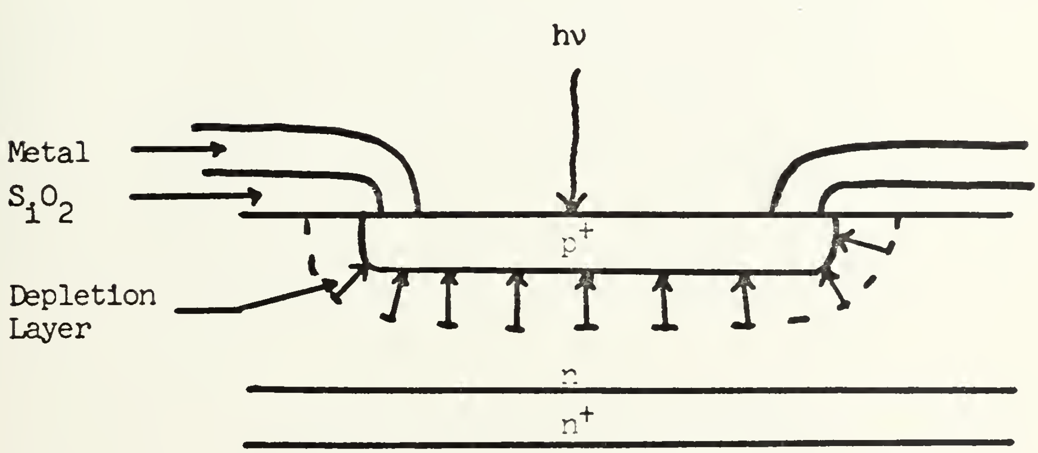


Figure 18: Construction of a High Speed Photodiode

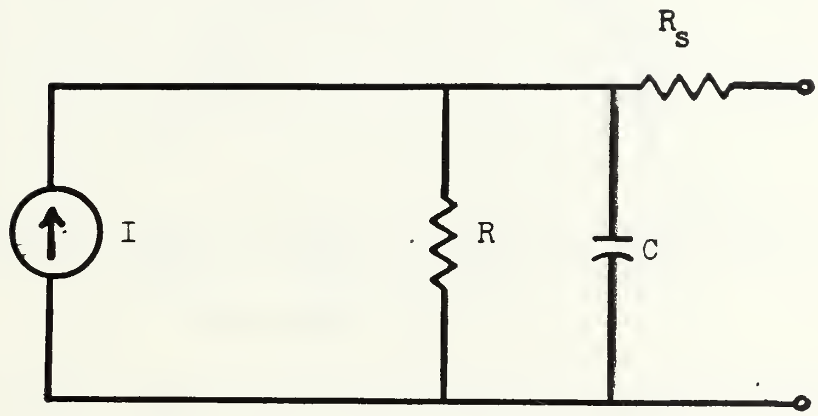


Figure 19: Photodiode Equivalent Circuit

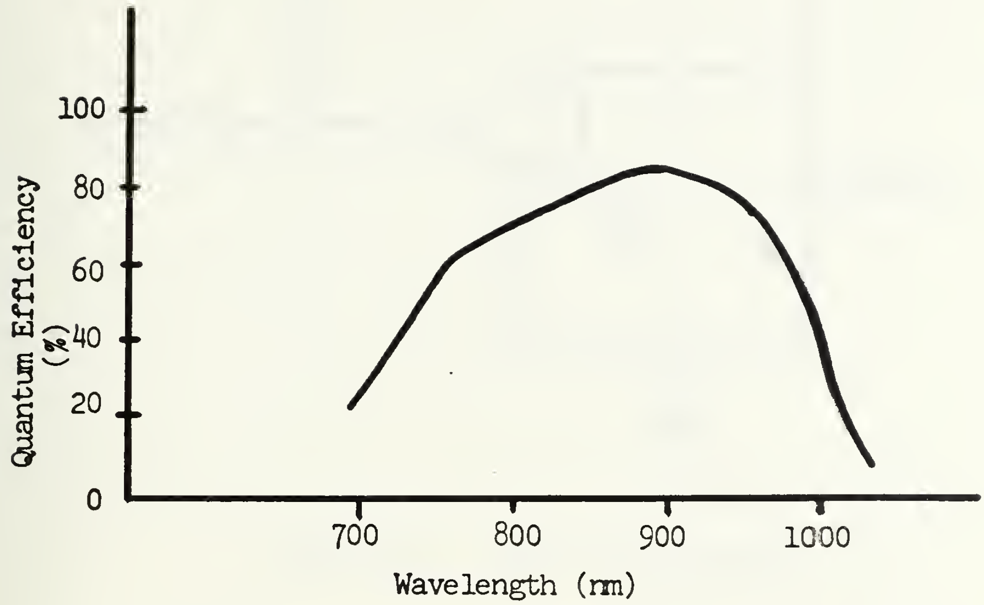


Figure 20: Wavelength Dependence on Quantum Efficiency of a High Speed Photodiode

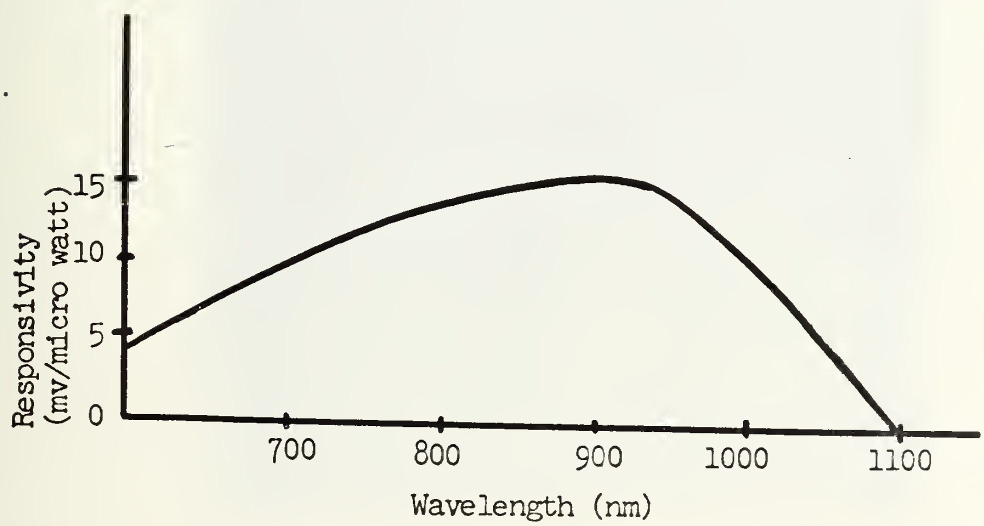


Figure 21: Spectral Responsivity of the FDA-425 Photo Detector

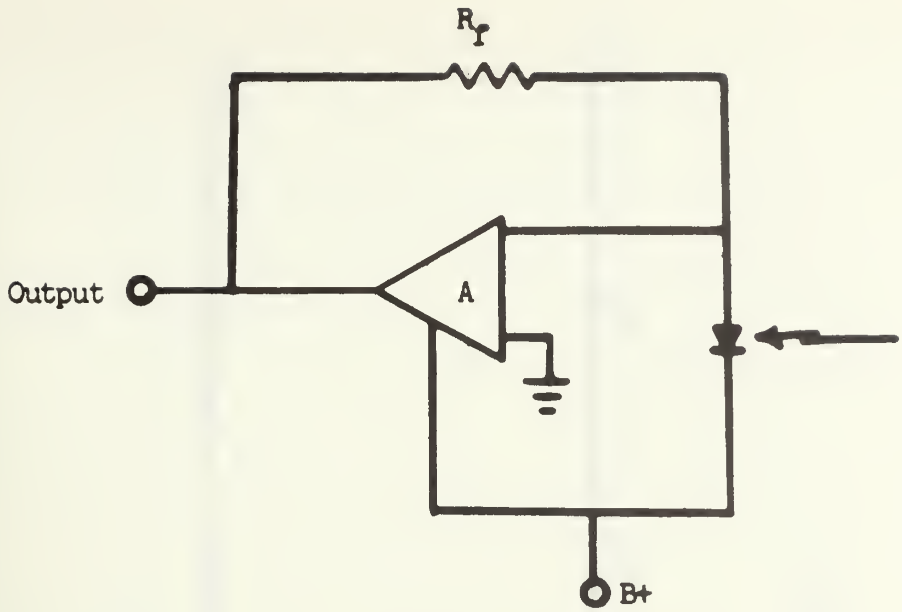


Figure 22: FDA-425 Schematic

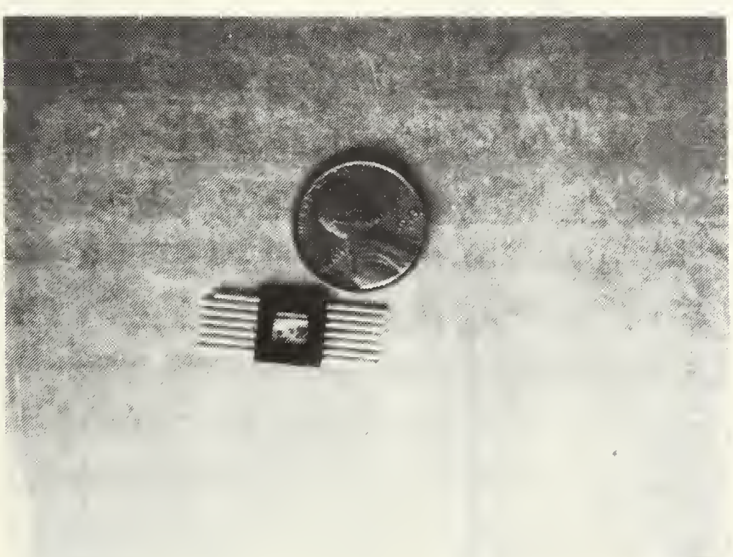


Figure 23: Photograph of FDA-425

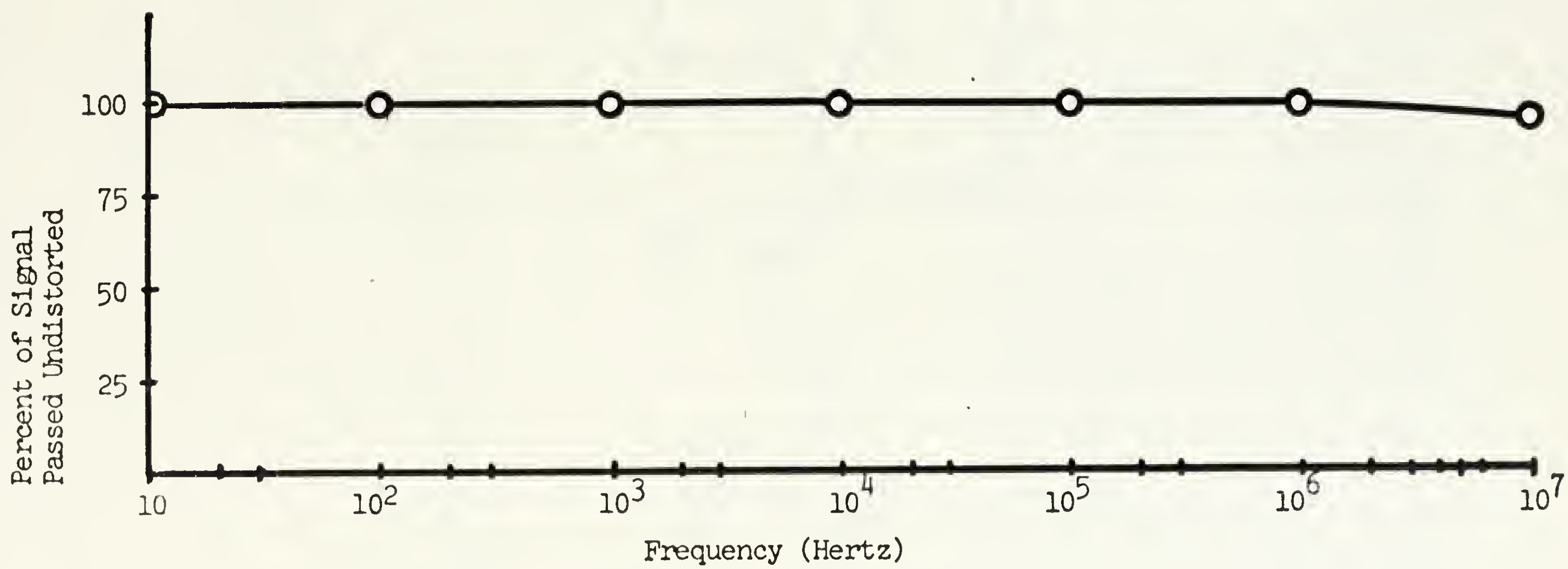


Figure 24: Frequency Response of Video Amplifier

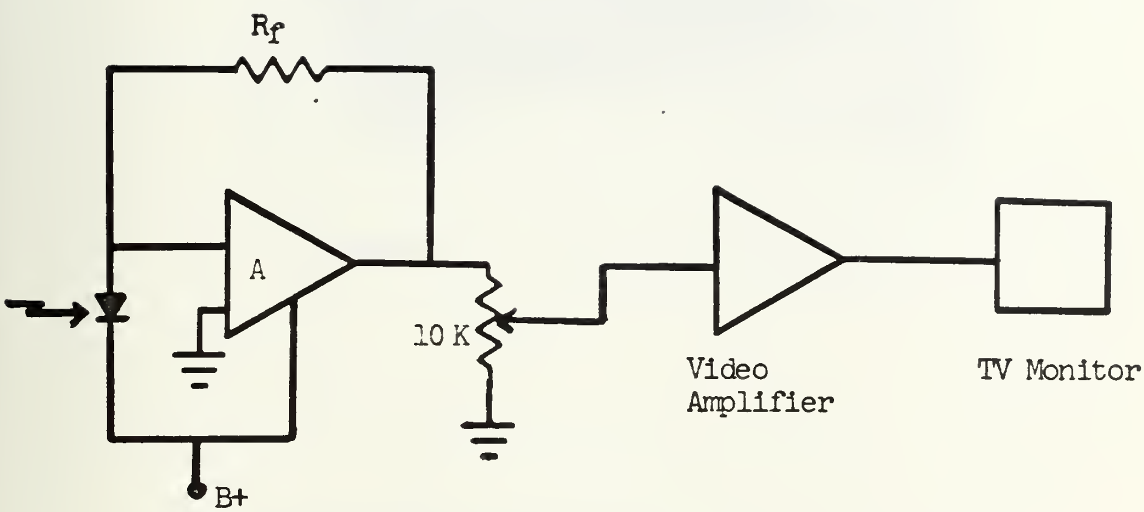


Figure 25: Receiver Assembly

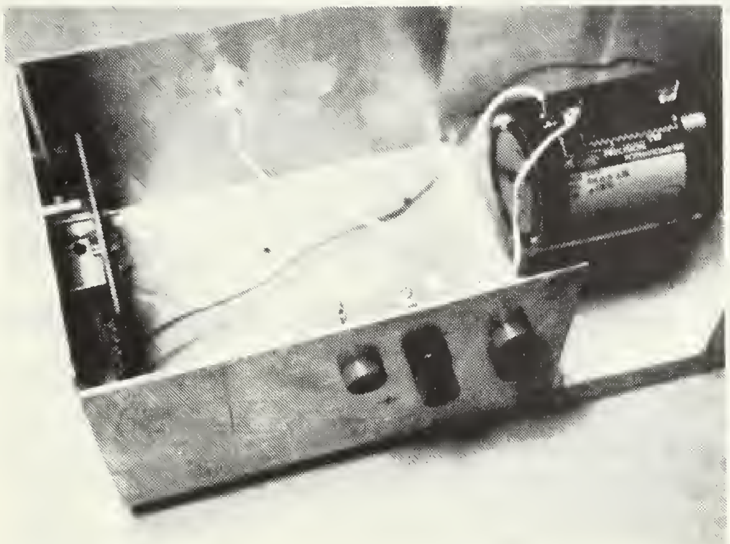


Figure 26: Constructed Receiver

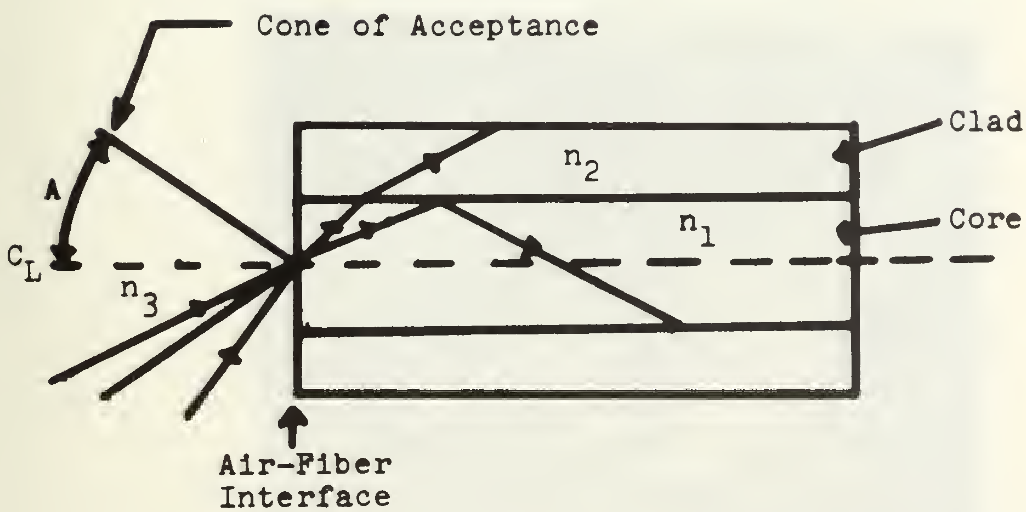


Figure 27: Light Ray Action Inside an Optical Fiber Filament

Type	Corning No. 5011
No. of Fibers per Bundle	400
Numerical Aperture	0.63
n of core	1.43
n of cladding	1.63
Acceptance Angle	80 degrees
Core Diameter	50 microns
Loss	100 db/kilometer

Figure 28: Optical Fiber Specifications

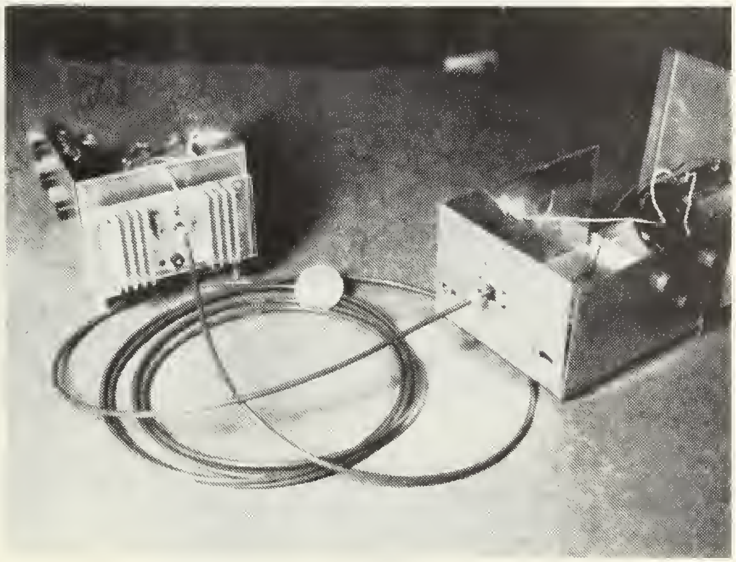


Figure 29: Transmitter, Receiver, and Optical Fiber

Figure 30: Visual Display of Output of System

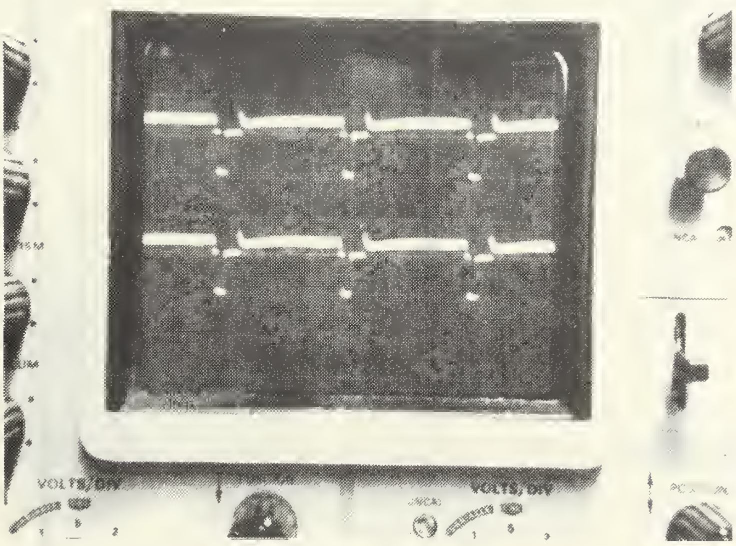


Figure 31: System Response to Video Signal. Input Video Signal (TOP) Output Video Signal (BOTTOM) Horizontal Scale, 20 Microsec/cm. Vertical Scale 1 Volt/cm

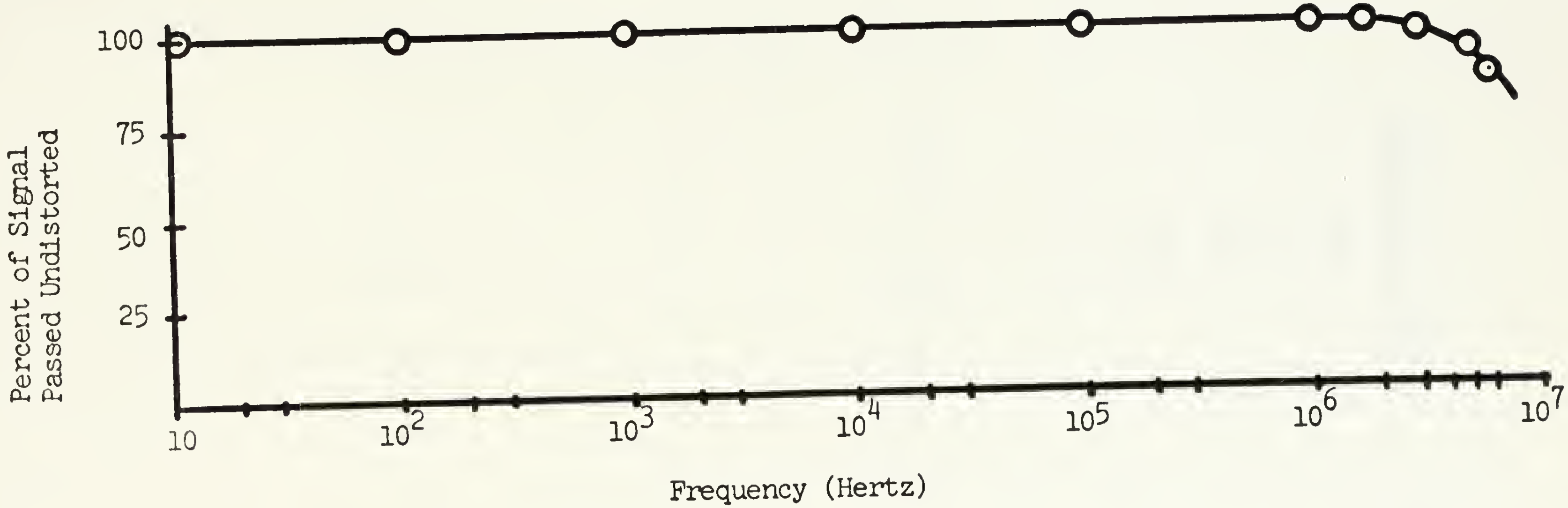


Figure 32: Frequency Response of Overall System

Harmonic	Frequency (KHZ)	Signal Content (%)
Fundamental	20	100%
Second	40	2%
Third	80	0.15%
Fourth	160	0.035%

Figure 33: Harmonic Distortion Test for Overall System

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A video bandwidth communications system utilizing optical fiber transmission was designed, constructed, and tested. An amplitude modulated gallium arsenide light emitting diode is driven by a transistor circuit. The output is detected by a wide bandwidth silicon detector-preamplifier hybrid circuit. Properties such as bandwidth and harmonic distortion were measured for the individual system elements and the overall

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system. A closed circuit television signal was sent through the system and a sharp clear picture was observed on the monitor.