AEDC-TR-70-34

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INTENSITY MODULATED LIGHT SOURCE USABLE TO 100 MHZ

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ARO, Inc.

March 1970

ARNOLD ENGINEERING DEVELOPMENT CENTER

AIR FORCE SYSTEMS COMMAND

ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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FOREWORD

The work presented herein was sponsored by Headquarters, Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Program Element 65701F, Project 4344.

The results of the work were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of AEDC, AFSC, under Contract F40600-69-C-0001. The research and testing were performed from December to July, 1969, under ARO Project No. BC5919, and the manuscript was submitted for publication on January 6, 1970.

The authors wish to acknowledge the very capable assistance of E. B. Harding of the Experimental Research Branch of the Technical Staff in the circuit design and experimental phase of the development.

This technical report has been reviewed and is approved.

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ABSTRACT

A gallium arsenide light emitting diode, with emission wavelength range from 6000 to 7000 Å, and a driver amplifier assembly are used to simulate the signal produced by a Doppler shift laser velocimeter (LV). The light source device is then used to check the entire electronics portion of the LV without assembling the LV optical components. The frequency domain optical response of the device was found to be flat from 0 to about 15 MHz. However, usable optical output was obtained at 100 MHz.

CONTENTS

TABLE

APPENDIX
Illustrations

NOMENCLATURE

E_r	Reference beam electric field intensity
E_s	Scattered beam electric field intensity
t	Time
ϕ_r	Reference beam phase
ϕ_s	Scattered beam phase
ω_r	Reference beam radian optical frequency
ω_s	Scattered beam radian optical frequency

SECTION I
INTRODUCTION

The first laser velocimeter (LV) exploiting the Doppler principle was announced by Yeh and Cummins[1] in 1964. Since that time a considerable amount of effort has been expended, in various laboratories, to develop the LV from an experimental laboratory instrument to a routine operational device to measure the velocities of fluid flow.

In general, an LV system consists of two major subsystems, (1) the optical subsystem and (2) the electronic and data acquisition subsystem. Certain LV malfunction causes are difficult to assign to either the optical or the electronic subcomponent. A light source device was, therefore, developed to provide a simulated LV signal, whereby it is possible to check out the entire electronics subsystem in the laboratory regardless of the condition of the optical subsystem. The use of the light source device can result in a significantly reduced time required for LV malfunction analysis. For electronic system development purposes, the availability of the light source device obviates the necessity for providing the optical subsystem of the LV.

This report describes a simple but useful light source device intended to contribute to the operational checkout and refinement of the LV. The unit utilizes a gallium arsenide light emitting diode (LED) and a combination bias and driver amplifier driven by a conventional laboratory oscillator or pulse generator, depending on the desired waveform of the emitted light.

SECTION II
BASIC CONSIDERATIONS

The conventional LV produces two beams of laser radiation, (1) a reference beam and (2) a scattered beam. The reference beam originates from a laser, whereas the scattered beam results from an interaction with impurities in the flowing fluid. Because of a scattering interaction, the scattered radiation experiences a shift in optical frequency explained by the Doppler effect. The LV optical system is

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[1]Yeh, Y. and Cummins, H. Z. "Localized Fluid Flow Measurements with an He-Ne Laser Spectrometer." Applied Physics Letters, Vol. 4, No. 10, May 1964, pp. 176-178.

designed so that the wave vectors of the two beams are aligned to precise coincidence at the surface of a photodetector. The two most commonly used photodetectors are the photomultiplier tube and the photovoltaic semiconductor diode.

Both the photomultiplier tube and the photovoltaic diode produce output currents which are linear functions of the intensity of the incident radiation. Now if we consider a reference beam given by

$$E_r \cos(\omega_r t + \phi_r) \tag{1}$$

and a scattered beam given by

$$E_s \cos(\omega_s t + \phi_s) \tag{2}$$

then the photodetector output current is proportional to

$$\begin{aligned}
&[E_r \cos(\omega_r t + \phi_r) + E_s \cos(\omega_s t + \phi_s)]^2 = \\
&\frac{E_r^2 + E_s^2}{2} + E_r^2 \cos 2(\omega_r t + \phi_r) + E_s^2 \cos 2(\omega_s t + \phi_s) \\
&+ E_r E_s \cos[(\omega_r + \omega_s)t + \phi_r + \phi_s] + E_r E_s \cos[(\omega_r - \omega_s)t + \phi_r - \phi_s]
\end{aligned} \tag{3}$$

where E_r and E_s are the peak electric fields of the reference and scatter beams, respectively, ω_1 and ω_2 are the radian frequencies, and ϕ_1 and ϕ_2 are phase constants. From Eq. (3) it can be seen that this optical heterodyning process at the photosensitive surface produces a direct current signal, a current varying at twice the frequency of the reference radiation, a current varying at twice the frequency of the scattered radiation, a current varying at the sum of the two beam frequencies, and a current varying at the difference of the two beam frequencies. Obviously, the photodetector will respond only to the direct current signal and the difference frequency signal since the other signal currents are varying at optical frequencies. The frequency of the difference frequency signal is directly proportional to the velocity of the scattering particles in the fluid flow and is the only signal of interest. From the preceding discussion it can be realized that a light source simulating an LV signal should possess a wavelength close to the LV laser light source and should produce a constant level intensity as well as a signal whose intensity varies sinusoidally at the range of frequencies expected from a typical LV system. This simulation problem is quite simply solved for frequencies up to 100 MHz by use of the LED.

Briefly, the LED light output is produced by the following sequence of events[2].

1. An electrical current flowing in the p-n junction of the LED provides energy in the form of excited electrons and holes.
2. Visible radiation is produced in the p-n junction by radiative recombination of electrons and holes.
3. Internal reflection, scattering, and absorption losses permit only about 2 percent of the emitted photons to leave the LED.

Considering the basic properties of the LED, the LV signal simulation device simply requires an amplifier to bias the LED to some constant light output level while simultaneously driving a sinusoidal current through the LED p-n junction.

SECTION III
APPARATUS

3.1 LED CHARACTERISTICS

The specifications for the particular LED used in this study are shown in Table I. The wavelength range of the emitted light is seen to be from 6000 to 7000 Å, which is suitable for simulating an LV using a helium-neon laser (6328 Å). Light emitting diodes with a peak emission wavelength of 5600 Å are also commercially available for simulating an LV system using an argon ion laser (4880 or 5145 Å). From Table I it can be seen that the current and voltage levels required to drive the LED are compatible with transistor circuitry. The turn-on and turn-off time of the LED is seen to be about 10 nsec, which should permit a flat amplitude frequency response to about 25 MHz.

The brightness of the LED as a function of forward driving current is shown in Fig. 1 (Appendix). The forward current as a function of diode p-n junction forward bias voltage is shown in Fig. 2. The low voltage, medium current characteristics shown in these two figures illustrate the compatibility of the LED with a transistor driver amplifier.

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[2]Technical Staff, Solid State Laboratory, Hewlett-Packard Co. "Solid State Module Makes for Light Reading." Electronics, September 2, 1968.

The angular distribution of LED radiated optical power is shown in Fig. 3. This plot shows that the light output is reasonably well collimated.

TABLE I
SPECIFICATIONS FOR LIGHT EMITTING DIODE

Power dissipation (derate linearly)	175 mw, max, 2.30 mw/°C
Peak forward current (1-sec pulse, 300 pulses/sec)	3 amp, max
Forward current, continuous	100 ma, max
Reverse bias	-3 v, max
Operating and storage temperature	-55 to 100°C
Forward bias for I_f = 50 ma	1.65 v, typical
Dynamic forward resistance (I_f = 50 ma)	2 ohms, typical
Capacitance (bias voltage = 0, frequency = 1 MHz)	200 pf, typical
Light turn-on and turn-off time	10 nsec, typical
Wavelength range	6000 to 7000 Å
Spectral line width	400 Å, typical
Index of refraction, epoxy lens	1.5
Brightness (I_f = 50 ma)	450 ft-L, typical
Radiated power (I_f = 50 ma = 6650 Å)	37 μw, typical
Current to produce 50 ft-L	10 ma, max

3.2 LED-PHOTOMULTIPLIER TUBE ASSEMBLIES

For LV systems utilizing lasers in the milliwatt optical power output range, the photomultiplier tube (PM)-type photodetector is most convenient because of its high gain. A PM tube assembly used in the LV systems developed in our laboratory is shown in Fig. 4. The LED and driver amplifier assembly, which attaches directly to the PM assembly, is also shown in Fig. 4. The LED is shown in the lower right corner of Fig. 4.

The driver amplifier for the LED is schematically shown in Fig. 5 along with its frequency response plot. The flat response (±2 dbm) of the driver amplifier is seen to extend just beyond 200 MHz, which is adequate to drive the LED beyond its useful frequency response range. Resistors R_1 and R_2 are used to set the quiescent current level in the LED.

3.3 INSTRUMENTATION

Figure 6 shows a block diagram of the instrumentation used to evaluate the LED-photomultiplier tube assembly. The LED is driven by its driver amplifier, which is driven by the oscillator. The current flowing in the LED is monitored by a current probe for the frequency range from 0 to 50 MHz. The LED output light signal drives the PM tube. The output of the PM tube is recorded either in real time by oscilloscope display or in the frequency domain on a spectrum analyzer.

SECTION IV
RESULTS AND DISCUSSION

The LED driver amplifier produces a bias and driving current waveform as shown in Fig. 7a. This waveform was recorded using the current probe shown in Fig. 6. The PM tube response to the driving waveform of Fig. 7a is shown in Fig. 7b. The PM tube signal resembles observed LV signals. Under certain circumstances, observed LV signals contain more white noise than is exhibited in Fig. 7b. However, for simulation purposes, any desired amount of white noise can be superimposed on the sinusoidal signal in the PM tube output simply by admitting ambient light into the PM tube input along with the LED signal.

The sinusoidal driving current to the LED was maintained at a constant level as the frequency was varied from 0 to 40 MHz. The PM tube output was flat from 0 to 15 MHz. Beyond 15 MHz, the PM tube output steadily decreased. The LED assembly was used with high frequency response PM tubes from three different manufacturers, and all three indicated a flat response bandwidth from 0 to 15 MHz. Therefore, it was concluded that the 15-MHz cutoff frequency was characteristic of the LED. This flat response bandwidth is compatible with the 10-nsec turn-on and turn-off times quoted by the manufacturer, as indicated in Table I.

Although the LED output steadily dropped beyond 15 MHz, a usable output was still available at 100 MHz. A spectrum analyzer display of the PM tube output in response to a 100-MHz LED signal is shown in Fig. 7c. The displayed signal level is -70 dbm. With an opaque obstruction placed between the LED and the photocathode of the PM tube, a stray signal level at -90 dbm was still observed. However, removal of the opaque obstruction returned the signal level to -70 dbm, which indicated that the light source device was producing a low level but useful light output at 100 MHz. The light source device signal could not be distinguished from the stray signal level above 110 MHz.

SECTION V
SUMMARY OF RESULTS AND CONCLUSIONS

A simple light source was needed which would simulate the optical subcomponent of the Doppler shift LV. A device utilizing a semiconductor LED was developed which produced good simulation of the LV signal. The light intensity flat response bandwidth was found to extend from 0 to 15 MHz. This device could then be used to determine the frequency response (0 to 15 MHz) of instruments utilizing photodetectors in addition to simulating the LV signal. By driving the light source device with fast rise time pulses (rise time, 10 nsec), the time domain response of instruments utilizing photodetectors could be determined.

Although the sinusoidal light intensity cutoff frequency occurred at about 15 MHz, usable light output was available at 100 MHz utilizing a PM tube and a spectrum analyzer with -100-dbm signal detection capability.

The light source device is quite simple, inexpensive, useful for malfunction analysis of a complete LV system, and permits a quick check of the entire electronics subsystem of an LV system regardless of the condition of the optical subcomponent. The light source device is particularly useful for LV electronic subsystem development work since it eliminates the expense and complexity of setting up an actual LV system.

APPENDIX
ILLUSTRATIONS

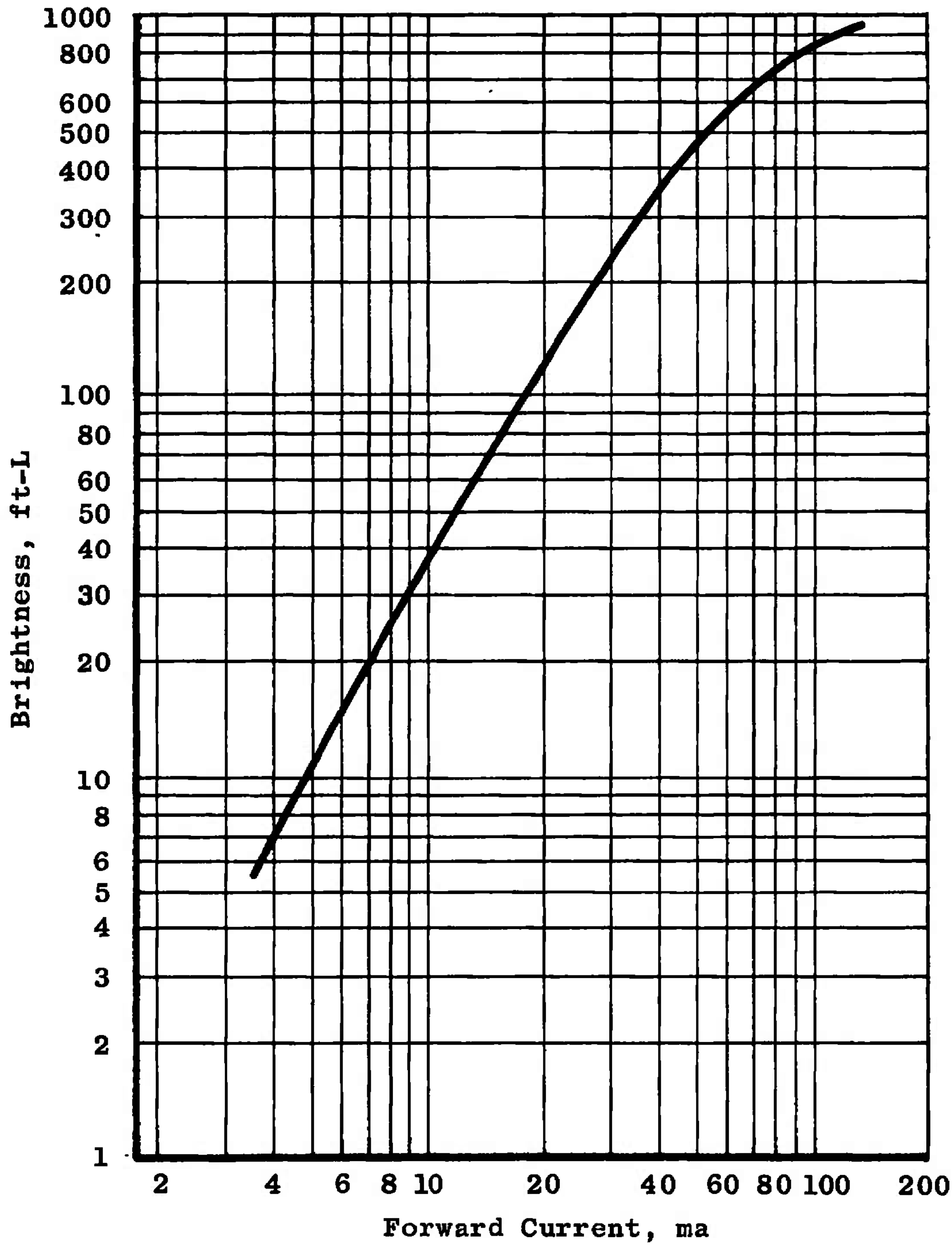

Fig. 1 Light Emitting Diode Brightness, Forward Current Characteristics

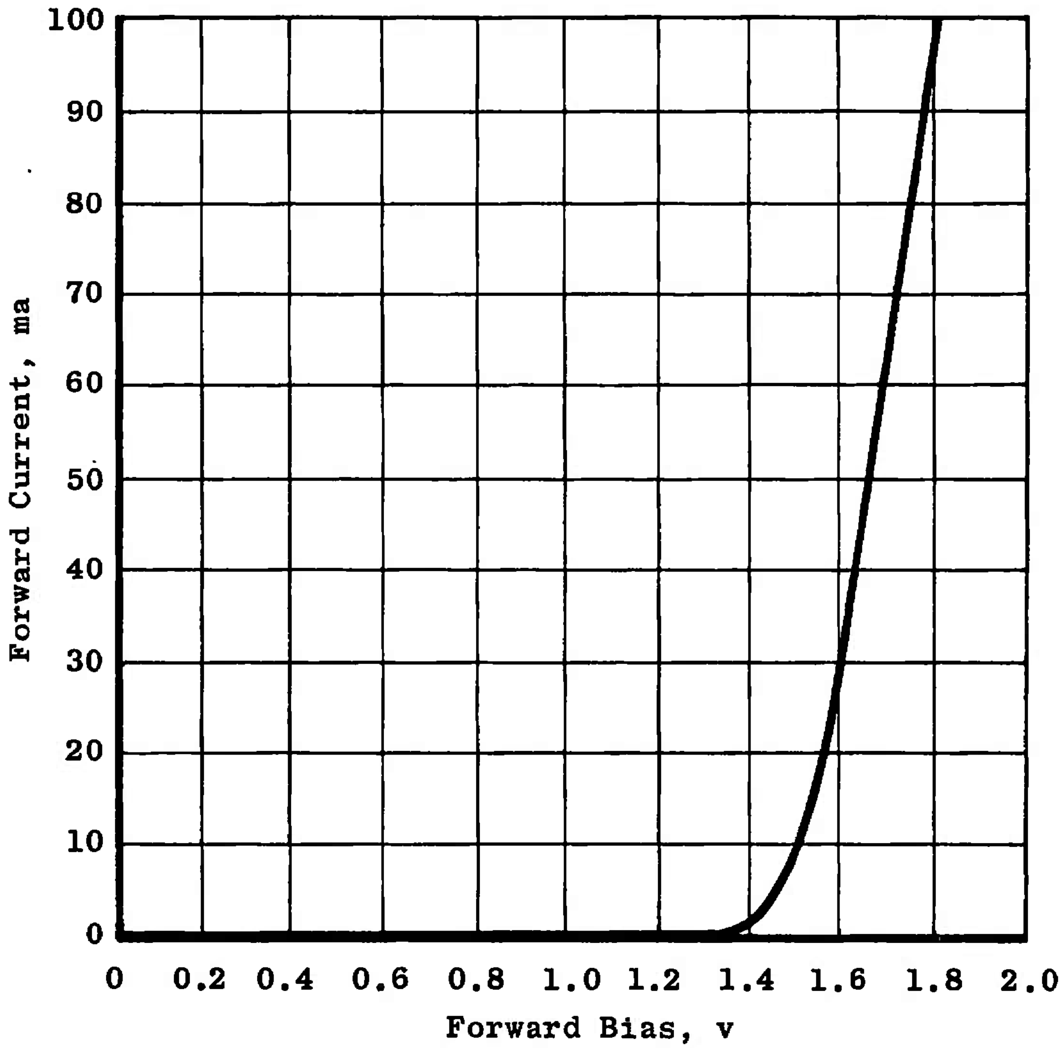

Fig. 2 Light Emitting Diode Forward Current, Forward Bias Characteristic

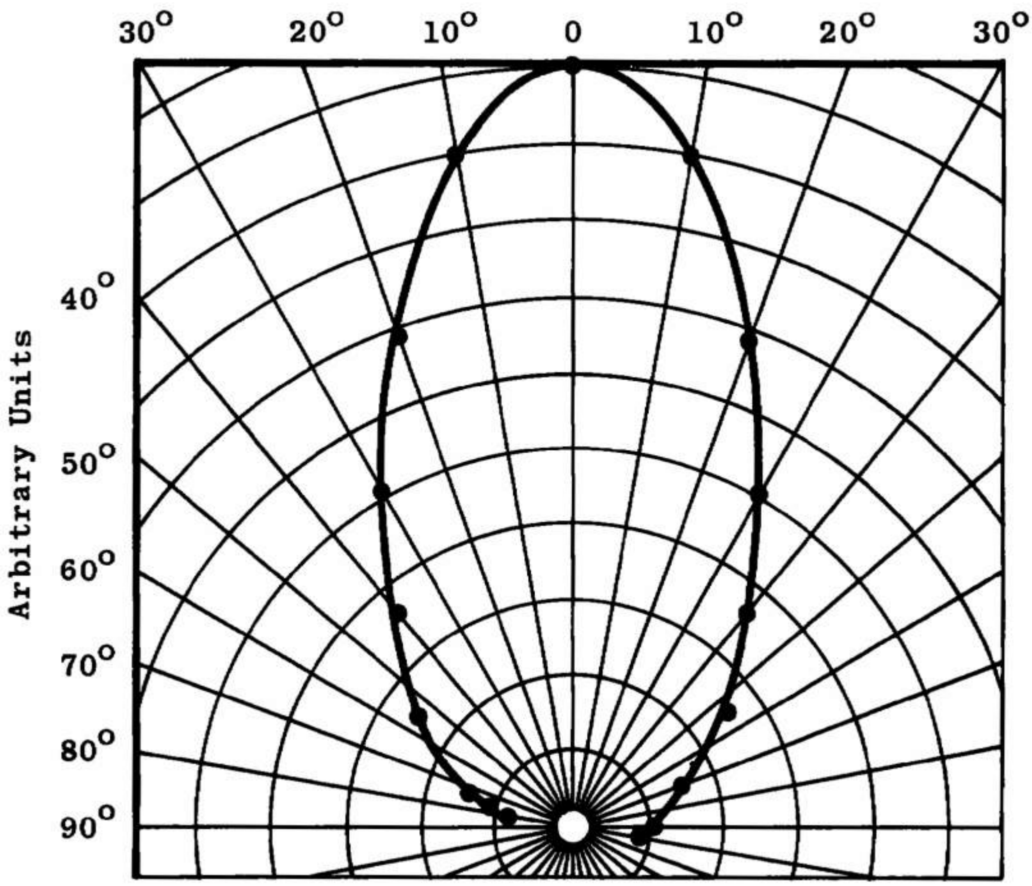

Fig. 3 Light Emitting Diode Radiated Power Angular Distribution

1. Light Emitting Diode Driving Oscillator Input
2. Light Emitting Diode Driver Amplifier Power Input
3. Light Emitting Diode and Driver Amplifier Assembly
4. Photomultiplier Tube Housing
5. Photomultiplier Tube Dynode Bias Assembly
6. Output Signal Amplifier and Transmission Line Driver
7. Output Signal
8. Output Amplifier Power Input
9. Photomultiplier Tube High Voltage Input
10. Light Emitting Diode
11. Photomultiplier Tube
12. Photomultiplier Tube Bias Network

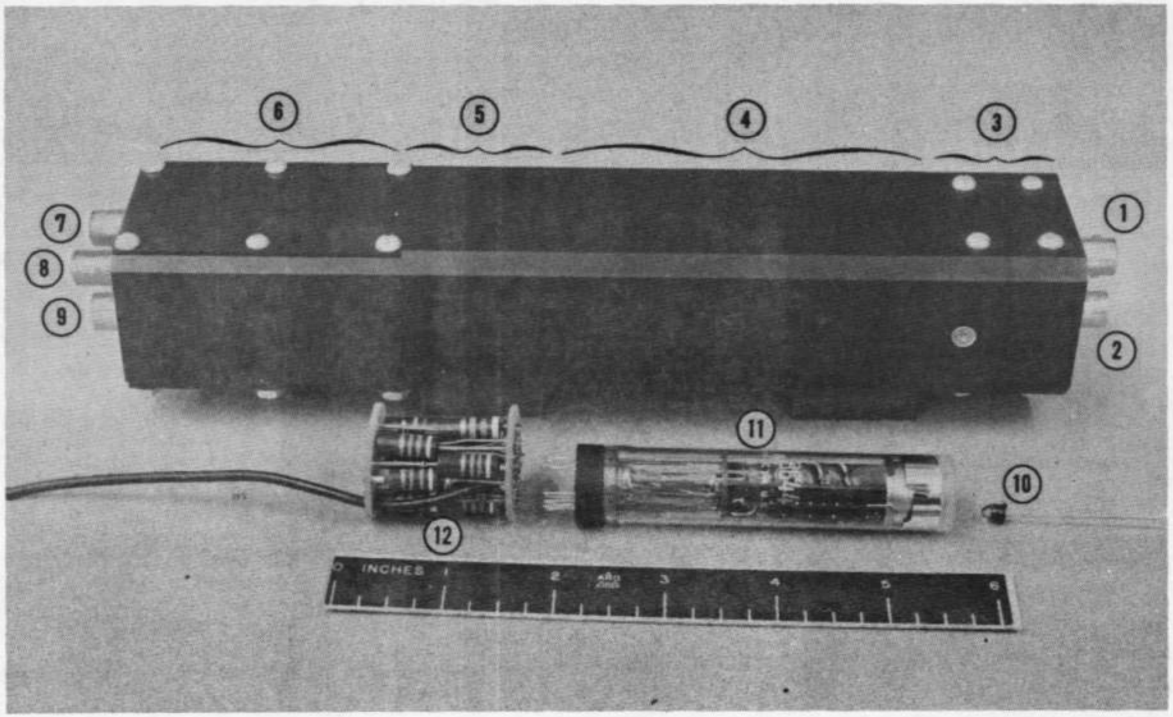

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Fig. 4 Light Emitting Diode and Photomultiplier Tube Assemblies

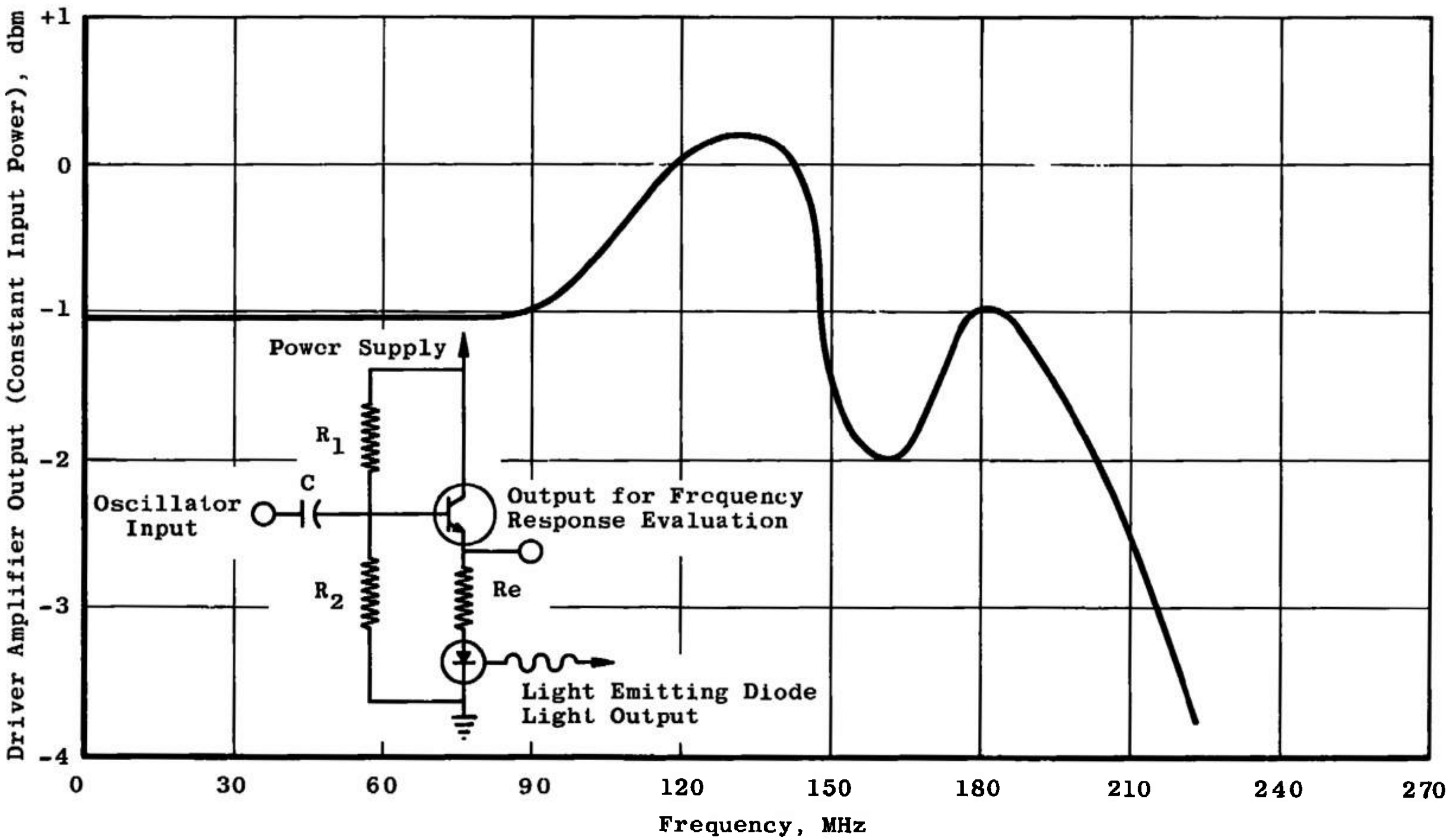


Fig. 5 Light Emitting Diode Driver Amplifier Schematic and Frequency Response Plot

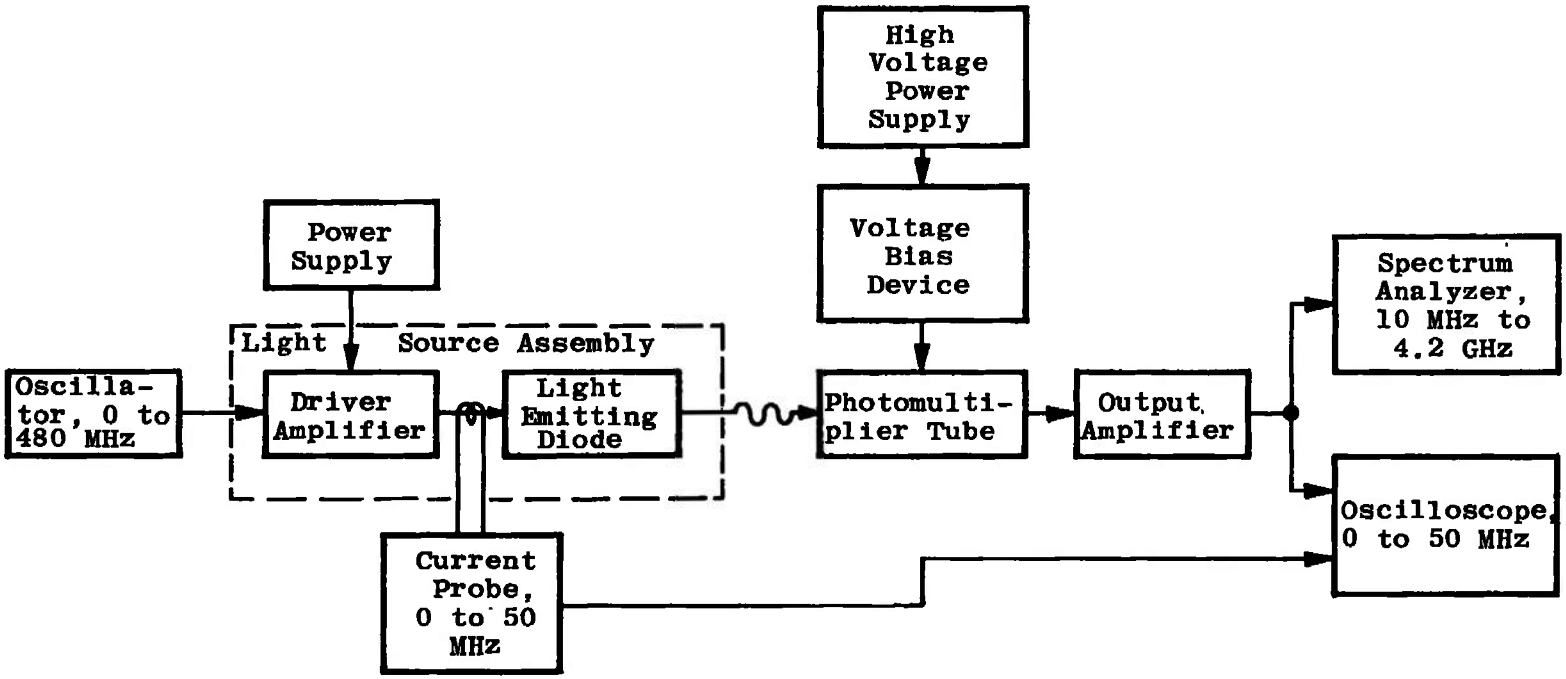
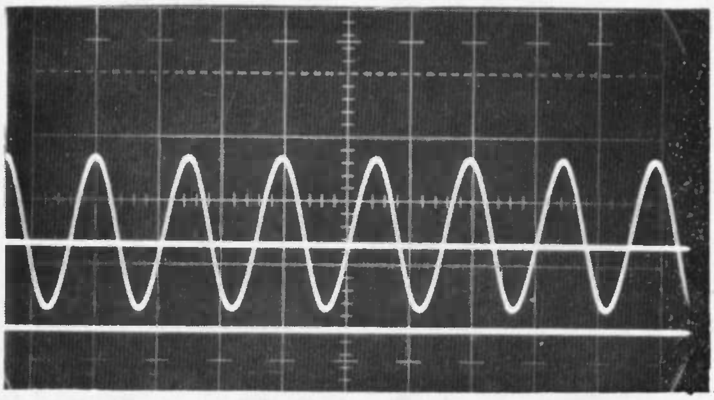


Fig. 6 Instrumentation for Evaluation of Light Emitting Diode-Photomultiplier Tube Assembly



Vertical Scale: 20 ma/cm

Horizontal Scale: 0.020 μsec/cm

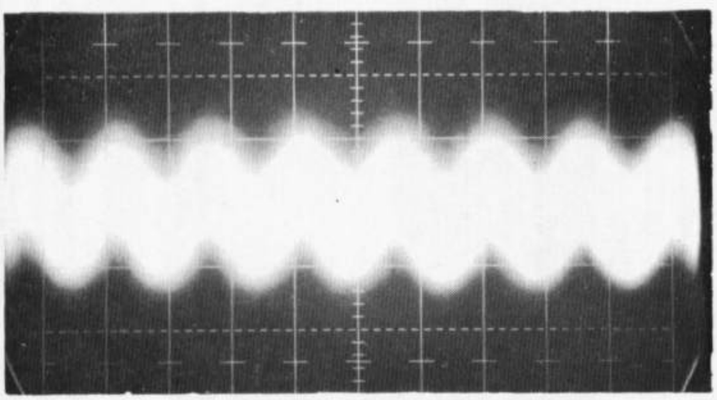
35-MHz Sinusoidal

← Driving Current

← Quiescent Bias Current

← Zero Reference

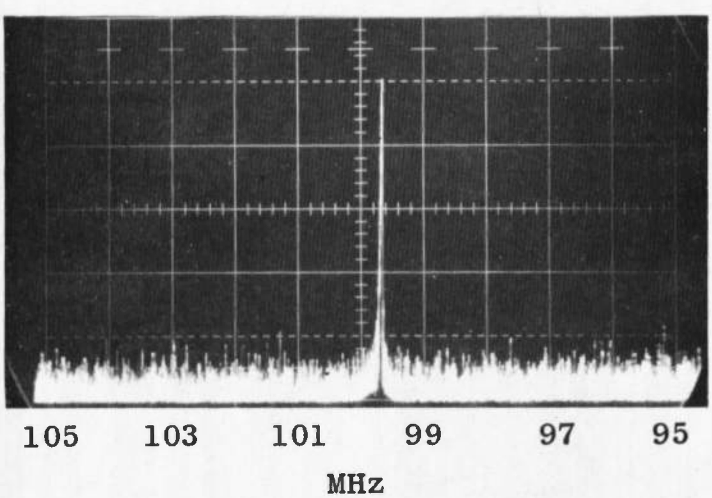
a. Driver Amplifier Bias and 35-MHz Sinusoidal Driving Currents (Real Time)



Vertical Scale: 0.020 volt/cm

Horizontal Scale: 0.020 μsec/cm

b. Photomultiplier Tube Response to 35-MHz Input (Real Time)



Vertical Scale: Arbitrary

Horizontal Scale: 1 MHz/cm

Displayed signal level is −70 dbm.

c. Photomultiplier Tube Response to 100-MHz Input (Spectrum Analyzer)

Fig. 7 Response Characteristics of the Light Emitting Diode-Photomultiplier Tube Assembly

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Arnold Engineering Development Center, ARO, Inc., Operating Contractor, Arnold Air Force Station, Tennessee 37389	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

INTENSITY MODULATED LIGHT SOURCE USABLE TO 100 MHZ

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

December to July 1969 - Final Report

5. AUTHOR(S) *(First name, middle initial, last name)*

F. L. Crosswy and H. T. Kalb, ARO, Inc.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1970	21	2

8a. CONTRACT OR GRANT NO. F40600-69-C-0001	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 4344	AEDC-TR-70-34
c. Program Element 65701F	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	N/A

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Available in DDC	Arnold Engineering Development Center, Air Force Systems Command, Arnold AF Station, Tennessee 37389

13. ABSTRACT

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
diodes						
light sources						
photodetectors						
photomultiplier tubes						
photovoltaic semiconductor devices						
gallium arsenide lasers						
speed indicators						

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