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Technical Report: NAVTRADEV CEN IH-170

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GALLIUM ARSENIDE INJECTION LASER DIODE
QUICK KILL WEAPON FIRE SIMULATOR

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Physical Sciences Laboratory
Task No. 7881-56

November 1969

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Technical Report: NAVTRADEVCCEN IH-170

GALLIUM-ARSENIDE INJECTION LASER DIODE QUICK-KILL

WEAPON FIRE SIMULATOR

ABSTRACT

This technical report describes the application of a semiconductor, gallium-arsenide injection laser diode to quick-kill weapon fire simulation.

In some combat situations, the ability to fire quickly, without sighting is a valuable asset to the combat soldier. This quick-kill trainer uses a gallium-arsenide, semiconductor laser diode transmitter system and a receiver mounted on a target to train riflemen for quick-kill firing techniques. However, the described system can be easily applied to pistol and other small arms training.

The system consists of inexpensive components. The transmitter is completely contained in a mockup M-16 rifle. A narrow collimated beam of laser pulses in the near-infrared region of the frequency spectrum is emitted by a transistor size laser injection diode in the transmitter. These pulses, which cannot be seen by the human eye, are detected at the target by a receiver and cause a light to flash briefly, indicating, or scoring, the area of the target hit. The generated beam is safe for direct human viewing, providing the laser output energy is not greater than that generated in this application.

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Technical Report: NAVTRADEVGEN IH-170

GALLIUM ARSENIDE INJECTION LASER DIODE
QUICK KILL WEAPON FIRE SIMULATOR

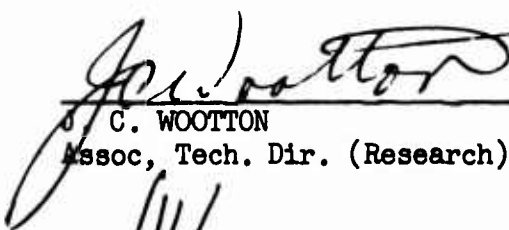
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Physical Sciences Laboratory

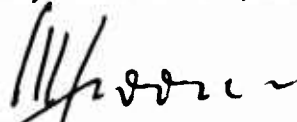
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TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
I	INTRODUCTION	1
II	STATEMENT OF THE PROBLEM	2
III	METHOD OF PROCEDURE	3
	A. Transmitter	3
	1. GaAs Injection Laser Diode	3
	2. Laser Diode Modulator	4
	3. Power Supply	6
	4. Collimating Lens	6
	B. Receiver	8
	C. Laser Safety	9
IV	CONCLUSIONS	12
	REFERENCES	13
	APPENDIX A - Injection Laser Diode Physics	14
	APPENDIX B - Laser Modulator and Power Supply Circuitry	19
	APPENDIX C - Collimation of the Laser Injection Diode's Beam	22
	APPENDIX D - Laser Receiver and Hit Indicator Circuitry	24

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	System Configuration	1
2	GaAs Injection Laser Diode	3
3	Block Diagram of Laser Diode Modulator	4
4	Modulator and Power Supply	5
5	Laser Beam Geometry	6
6	Lens and Diode Holder Assembly	7

NAVTRADEVCEEN IH-170

LIST OF ILLUSTRATIONS (Cont'd)

<u>Figure</u>		<u>Page</u>
7	Block Diagram of Receiver	8
8	Spectral Response of Detector	9
9	Transmission x Absorption vs Wavelength	10
10	Schematic Representation of a Laser Diode	14
11	Density of States vs Energy	15
12	Energy vs Distance	17
13	Transmitter Circuit	20
14	DC-DC Converter Circuit	21
15	Receiver Circuit	24

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Key Specifications of Transmitter System	6
2	Non-Q-Switched Laser Safety Levels	10

SECTION I

INTRODUCTION

This report describes an application of a laser; one to train combat personnel in quick-kill weapon firing techniques. As used in this report, the term "quick-kill weapon firing techniques" is defined as the ability to quickly fire a weapon at a target.

This application requires a two-part system:

- (1) Transmitter, which consists of a gallium-arsenide (GaAs) injection laser diode and associated electronics, optics and power source; and
- (2) Receiver, which consists of a silicon photodiode detector, receiver circuitry, associated hit indicator lamp, etc. The transmitter is installed in a mockup of an M-16 rifle; the receiver is mounted on a target. See figure 1.

The system works this way: (1) The transmitter emits a narrow collimated beam of laser pulses in the near-infrared region of the frequency spectrum; and (2) the receiver detects the pulses and causes a lamp to glow briefly, indicating or scoring a hit. A target containing multiple detectors is also shown in figure 1. Hits are recorded on a separate indicator panel that is connected by cable to the receiver matrix and can be remotely located near the trainee.

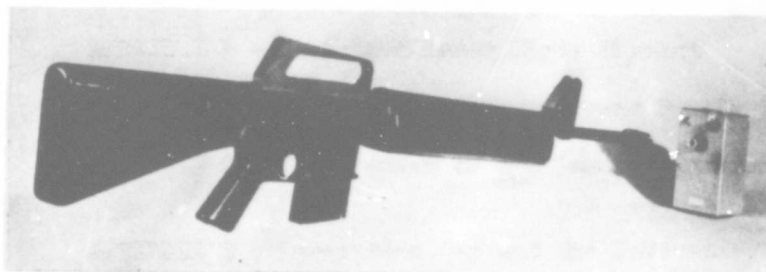
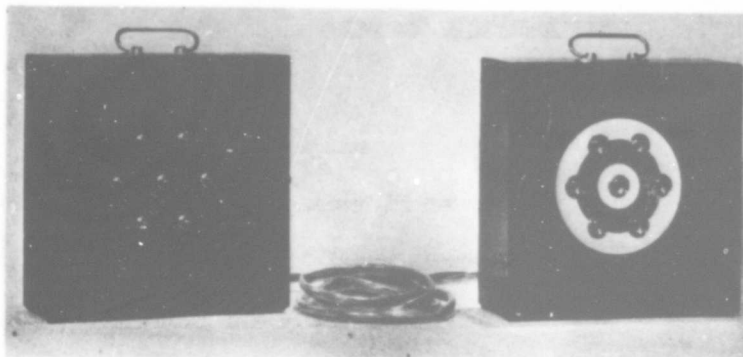
M-16
SimulatorSingle
Detector Hit
IndicatorRemote
Hit
IndicatorMulti-
Detector
Target

Figure 1. System Configuration

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SECTION II

STATEMENT OF THE PROBLEM

There are indications that the Marine Corps and U.S. Army need a simple, inexpensive device to train combat personnel in "quick-kill weapon firing techniques." The device should be portable, capable of being used against both pop-up and moving targets, and be safe for direct-viewing by the human eye into the collimating lens.

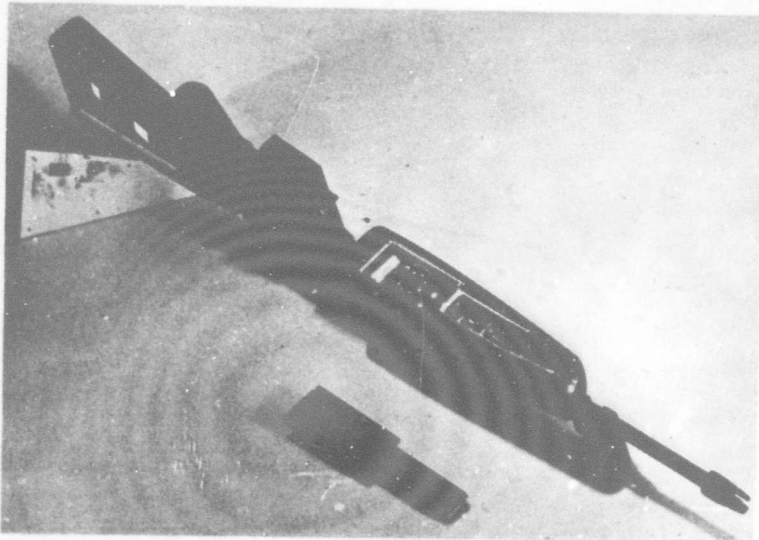


Figure 1a. M-16 Simulator with Electronics
and Battery Compartments Open

SECTION III

METHOD OF PROCEDURE

Using the criteria as stated in Section II, a system, consisting of a GaAs laser transmitter and a receiver, was developed. The system is described as follows:

A. TRANSMITTER

1. GaAs Injection Laser Diode - The heart of the transmitter, which is installed in a mockup of an M-16 rifle, is a miniature, semiconductor p-n junction, GaAs injection laser diode. See figure 2. When forward biased, the diode efficiently generates laser energy in the near-infrared region (9000A at 25° C) of the frequency spectrum. This diode is shown in figure 2.

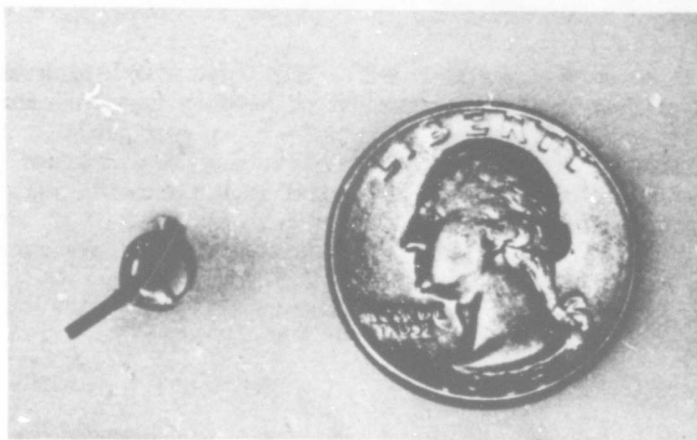


Figure 2. GaAs Injection Laser Diode

Semiconductor lasers, unlike other lasers, convert electrical energy directly into optical energy, and are highly efficient (10% vs 0.1%). They are small in physical size, low in cost, simple in construction and the laser diodes output can be easily modulated, by modulating the input current to the diode.

A GaAs injection laser diode is basically a planar p-n junction in a single crystal of GaAs. The p-n junction is formed by diffusing an acceptor element such as zinc into an oriented wafer of n-type GaAs. To obtain lasing, the holes and electrons in the p-n junction are brought in close proximity by injection of carriers by a narrow high-current pulse. Within a few nsec (the life time of the carrier) they recombine and radiate in the near-infrared region (approximately 9000A at 25° C). Optical gain occurs only in a layer about 2 μ thick at the p-n

junction and 76μ in width parallel to the junction. A Fabry-Perot cavity is formed by two parallel sides of the semiconductor chip. The stimulation is amplified on the axis of the Fabry-Perot cavity. The cavity formed by the Fabry-Perot is approximately 300μ long.

The magnitude of the radiated output is a function of the forward input current thru the diode. The output pulse length is typically 200 nsec (max.) and the maximum prf achievable at room temperature is 1,000 Hz. The emitted wave length is typically near 9000 Angstroms with a spectral half width at the 50% point of about 40 Angstroms. The power efficiency or power radiated per unit input is 10% for both the Radio Corporation of America close-confinement laser diodes and the Laser Diode Incorporated heterostructure process diodes. Most other lasers, such as gas lasers and solid state lasers have efficiencies of less than 1%.

The physics of the laser diode is covered in detail in appendix A.

2. Laser Diode Modulator - The laser diode modulator generates high-current pulses which are used to pulse-modulate the laser diode.

The modulation pulses are formed by using a high-speed electronic switch to discharge a capacitor thru the laser diode. The modulation pulses are typically 200×10^{-9} sec or 200 nsec in length. Modulation of the diode occurs at a prf of 600 Hz, however, prf of 1 to 1000 Hz can be selected. A gate circuit can select the number of pulses transmitted in a single trigger-pull. A peak pulse of approximately 4μ is obtained at the diode output; and power for the laser diode modulator is supplied by a rechargeable silver-cadmium cell and a dc-to-dc converter. A block diagram of the modulator is shown in figure 3.

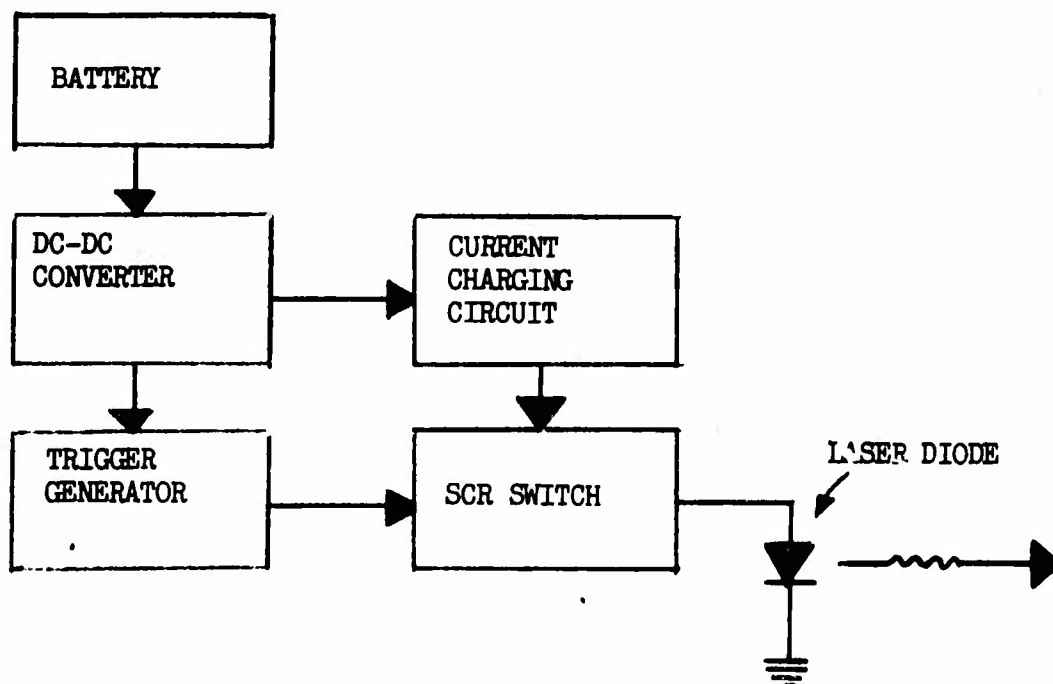


Figure 3. Block Diagram of Laser Diode Modulator

For optimum operation, a GaAs laser must be pulsed with a near-perfect square wave. Such pulses produce the minimum rise time characteristic necessary to prevent the junction from overheating prior to lasing. If the rise time of zero could be achieved, the diode would change immediately to its lasing state and no junction heating would occur.

The applied pulse must also have minimum negative overshoot. If the diode is reversed biased an excessive current flows in the negative direction and the diode will be destroyed. Lead lengths to the laser diode must be very short (under 2 in) to prevent this voltage from being applied. Maximum pulse width that can be applied to the diode is limited, and is a function of room temperature. At 25° C the maximum width of the applied pulse typically is 200 nsec.

The prf is about 1000 Hz for the commercially available laser diodes which are used in the simulator. This limitation on prf is due to the heating of the junction. At excessive prf's the efficiency of the diode laser decreases.

Components for a design to obtain the above cited characteristics must have high-speed and high-current handling capabilities.

Key specification of the Transmitter system are shown in table 1. figure 4 shows the modulator, dc-dc converter and rechargeable battery.

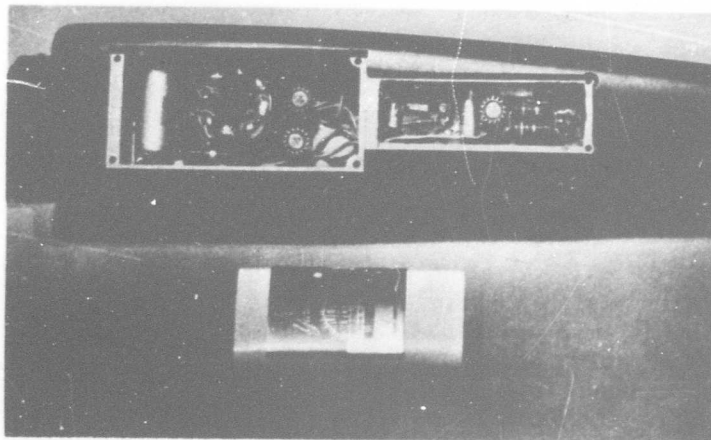


Figure 4. Modulator and Power Supply

TABLE 1. KEY SPECIFICATIONS OF TRANSMITTER SYSTEM

Peak Power Output	4 w
Peak Emission Wavelength	9000 A
Spectral Halfwidth	40 A
Peak Forward Current	40 a
Pulse Width	150 nsec
Pulse Repetition Rate (ungated)	600 Hz

The modulator and power supply circuitry are covered in detail in appendix B.

3. Power Supply - The power supply consists of a 4-v rechargeable silver-cadmium battery and a dc-to-dc converter. See figure 4. Circuit details are covered in detail in appendix B.

4. Collimating Lens - The collimating lens is a simple convex lens, used to collimate the naturally divergent beam of the lasing diode.

In most lasing gallium-arsenide diodes the beam half angles at 25° C is between 15° to 25°. See figure 5 for laser beam geometry. The emitting area in the lasing diode is a function of the semiconductor chip size parallel to the p-n junction and the carrier diffusion lengths perpendicular to the junction. This area which is nominally 2 x 76 μ , is represented by a heavy black line between the p and n materials shown in figure 5.

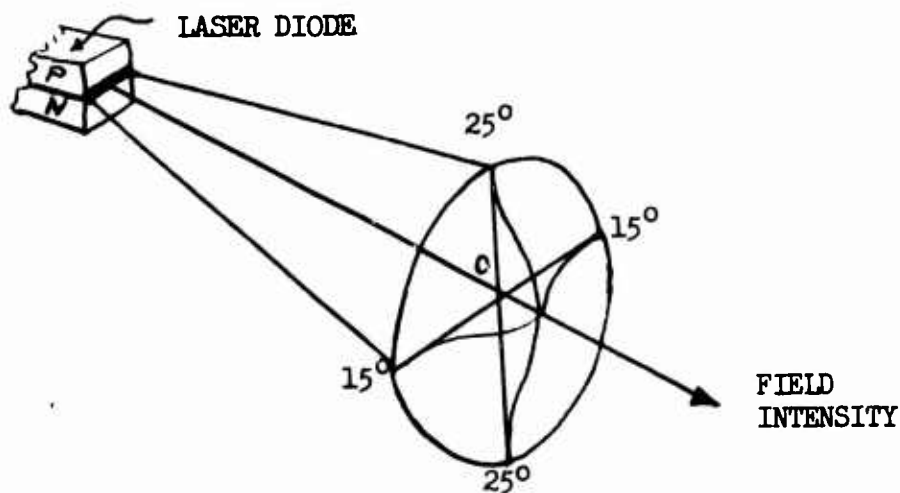


Figure 5. Laser Beam Geometry

The beam angles originate primarily from diffraction of the radiation at the rectangularly shaped emitting area. For a rectangularly shaped p-n junction $\left[\frac{\sin x}{x}\right]^2$ diffraction pattern will result.

The injection laser diode is collimated by a simple single convex lens. The full angle of the beam divergence in the rifle is approximately 0.005 radians. The beam diameter is 1.8 in. at a 30-ft range. By changing the position of the laser diode relative to the focal plane of the lens the beam shape can be adjusted from a rectangular to a circular beam. The size of the beam is also changed.

To collect the maximum power radiated by the diode the f-number, focal length, of the lens must be chosen such that the maximum power will diameter be intercepted by the lens. A lens of f-number 1.5 is sufficient to collect most of the power from commercial room temperature GaAs lasers.

Requirements for this lens are discussed in detail in appendix C. The lens holder and diode-mount permit the size of the beam to be changed by varying the focus. The diode can also be moved in its mount by making screwdriver adjustments allowing the gun to be boresighted. The rifle may be boresighted by continuously pulsing and viewing the beam with an infrared night vision device. The lens and diode holder assembly is shown in figure 6.

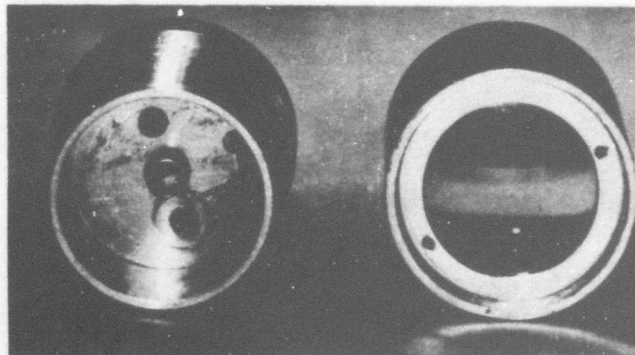


Figure 6. Lens and Diode Holder Assembly

B. RECEIVER

The receiver contains a silicon photodiode which is used to detect the infrared pulses. The output of the photodiode detector causes an electronic switch to turn on a lamp. A variable time delay circuit controls the time the lamp is lighted after a hit is scored. Circuit details of how the receiver operates are covered in appendix D.

A schematic representation of the receiver is shown in figure 7.

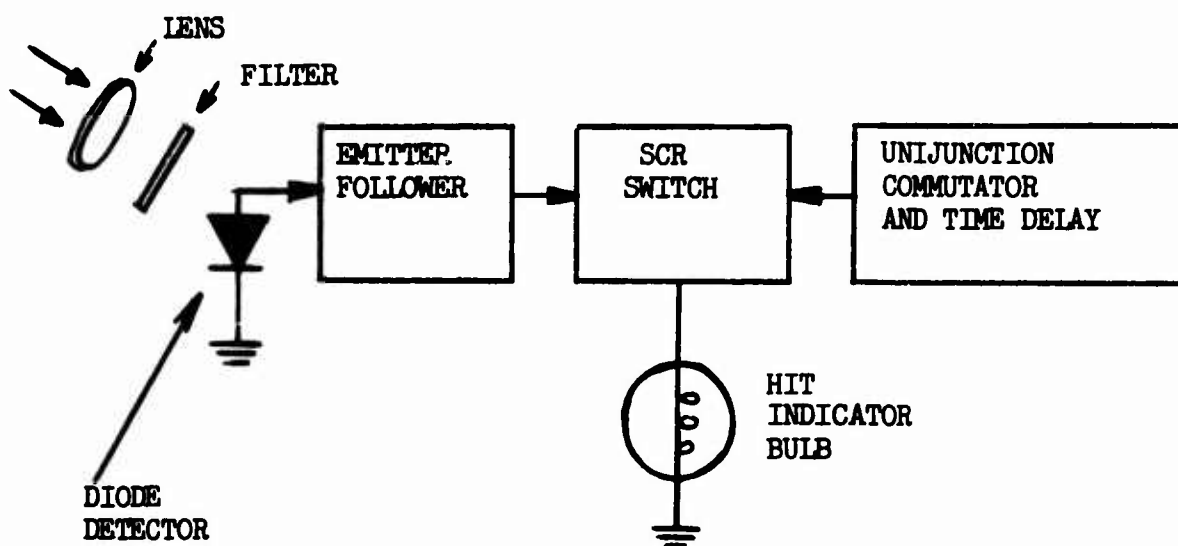


Figure 7. Block Diagram of Receiver

The detector signal is fed to an emitter follower, which is used as an impedance matching device. The output of the emitter follower causes a silicon controlled rectifier to conduct. The rectifier acts as a switch to turn on the hit indicator lamp by effectively providing a ground for the lamp.

Once anode-to-cathode current is flowing through the SCR, the gate has no control over the SCR. External measures, therefore, have to be applied to stop the flow of current or commutate it. A unijunction oscillator circuit performs the commutation and provides a variable time delay when the lamp is lighted.

A silicon diffused photodiode is used as a detector in the receiver. The diode is essentially a current generator. An EGG, SGD-100A photodiode was selected as the detector. The laser output has a nominal 200 nsec pulse width, therefore, a detector with a large bandwidth is required.

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The selected detector has a rise time of 4 nsec and a bandwidth of 100 MHz. The relative spectral response of the detector is shown in figure 8.

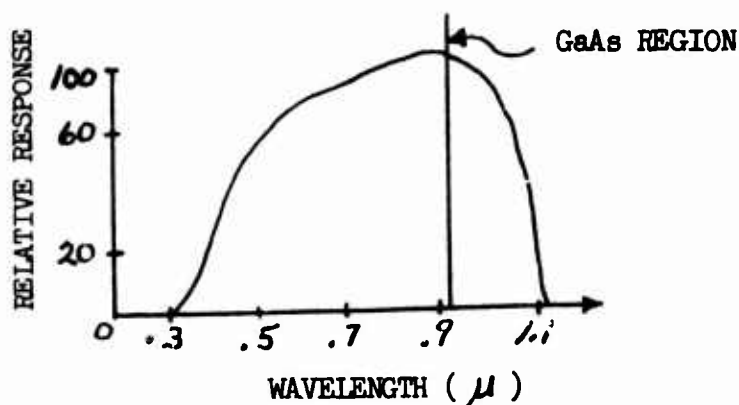


Figure 8. Spectral Response of Detector

It can be seen from figure 8 that the peak spectral response occurs near 0.9μ so an excellent spectral match occurs. The detector has a sensitivity of approximately $0.5 \mu a / \mu w$ at 0.9μ .

C. LASER SAFETY

Lasers can cause irreparable damage to the cornea or retina of the eye. For example, laser energy entering the eye can be focused by the lens to an extremely high energy density. The resultant temperature can be so great that a permanent burn-spot may occur on the retina. This can cause partial or total blindness. For this reason, safety precautions must be taken when transmitting laser energy. The following information is included to satisfy the criteria stated in section II; that is, "the device should be safe for direct-viewing by the human eye into the collimating lens."

The threshold for a non-Q-switched laser with pulse widths of 1 nsec to 0.1 sec and a prf less than 10 has been determined. This threshold is based on biological damage at the retina of the eye. Levels of damage were established from experimental work on animals for radiation at 6943 A. Therefore, using figure 9, the damage threshold value given in table 2 must be adjusted for the room temperature injection laser diode radiation of 9050 A. (Ref. 12)

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TABLE 2. NON-Q-SWITCHED LASER SAFETY LEVELS

pulse length - 1 nsec to 0.1 sec
 prf < 10

<u>Daylight</u>	
<u>3-mm pupil</u>	<u>5.0×10^{-7}</u> (j/cm ²)
Laboratory	
<u>5-mm pupil</u>	<u>2.0×10^{-7}</u> (j/cm ²)
Night	
<u>7-mm pupil</u>	<u>1.0×10^{-7}</u> (j/cm ²)

As can be seen from figure 9, the values in this table can be reduced even further for GaAs lasers.

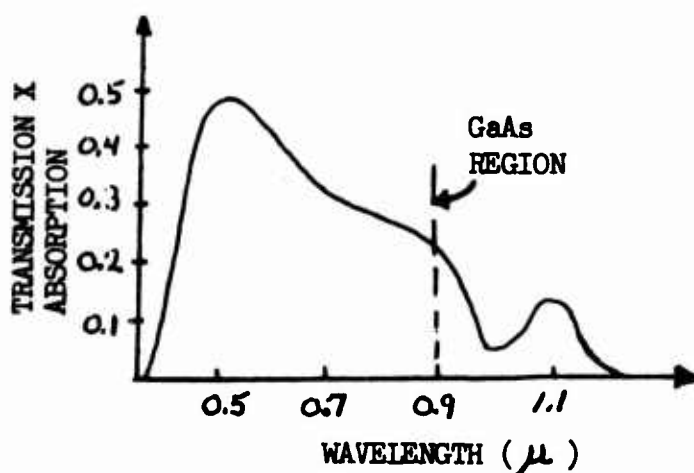


Figure 9. Transmission x Absorption vs. Wavelength

The basic formula to calculate j/cm² for safety determination is:

$$j/cm^2 = \frac{\text{Watts peak power} \times \text{pulse width (50\% pts)}}{\text{Area of GaAs Laser Beam}}$$

NAVTRADEVCEM IH-170

Let us consider the safety of the quick kill weapon fire simulator, which has the following characteristics:

Laser Power - 4 w peak power at lens surface

Pulse Length - 100 nsec

f number 1.0 lens - 3 cm in diameter and a 3-cm focal length

$$j/\text{cm}^2 = \frac{4 \times 100 \times 10^{-9}}{\pi (1.5)^2} = \frac{400 \times 10^{-9}}{7} = 5.6 \times 10^{-8}$$

This number (0.56×10^{-7}) is less than 1.0×10^{-7} j/cm^2 (See table 2) for the worst case condition. From this example, it can be seen that if the 4-w peak-power laser is limited to emitting less than 10 pulses in any 1 sec interval, it may be considered safe when viewed directly into the collimating lens.

However, each system considered for this application must be analyzed separately for safety if any of the parameters are changed.

NAVTRADEVGEN IN-170

SECTION IV

CONCLUSIONS

The miniature laser diode system provides a small, lightweight, relatively inexpensive and safe solution to the quick kill training problem. A properly designed pulsing circuitry and a simple lens satisfy the transmitter requirements. However, the method of pulsing the diode was found to be extremely important. If the diode is improperly pulsed, its low impedance and fast fall time can combine to cause high reverse voltages that can degrade or destroy it. The length of the leads to the diode is critical to prevent destructive ringing in the input current.

The receiver or scoring system also can be designed and constructed using simple components. A matrix of detectors can be used for scoring, and programmed, if necessary, to indicate windage and ballistic drop.

Various firing rates and clip sizes can be simulated by changing the pulsing frequency and the electronic gate width. Several days of constant firing can be accomplished between battery charging.

The system can be sufficiently reduced in size for a variety of small arms training applications.

NAVTRADEVGEN IH-170

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APPENDIX A

INJECTION LASER DIODE PHYSICS

The gallium-arsenide, GaAs, injection laser diode is basically a planar p-n junction in a single crystal of GaAs. The p-n junction is formed by diffusing an acceptor element such as zinc (Zn) into an oriented wafer of n-type GaAs. To obtain lasing, the holes and electrons in the p-n junction are brought in close proximity by injection of carriers by a narrow high current pulse. Within a few nsec, (the life time of the carrier) they recombine and radiate in the infrared region (9000 Å at 25° C). Optical gain occurs only in a layer about 2 μ thick at the p-n junction (see figure 10). Therefore, great care is taken to make the junction planar so that the lasing threshold current is low. A Fabry-Perot cavity is formed by two parallel sides of the conductor chip. The cavity is typically 76 μ in length, parallel to the junction. The stimulation is amplified on the axis of the Fabry-Perot cavity. The cavity formed by the Fabry-Perot is approximately 330 wavelengths or 300 μ long. A schematic representation of a diode laser is shown in figure 10. GaAs cleaves easily along certain crystal planes. These planes are used to form a Fabry-Perot cavity by orienting the GaAs wafer so the cleavage planes will be perpendicular to the plane of the junction.

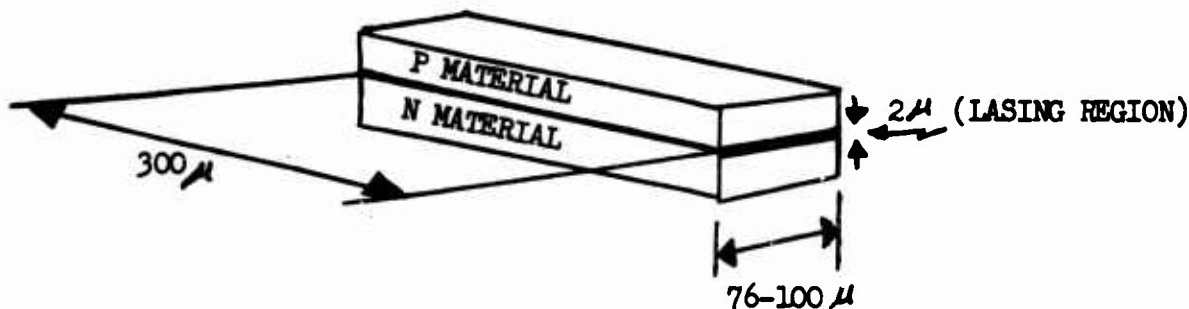


Figure 10. Schematic Representation of a Laser Diode

The faces of the cleaved planes have a reflectivity of approximately 35% without any reflective coating. Silvering the end faces can reduce the threshold current required for lasing to take place. The sides of the cavity are sometimes sawed so as to suppress all but the Fabry-Perot modes propagating between the end-faces.

The magnitude of the radiated output is a function of the forward current through the diode. The pulse length is typically 200 nsec (max) and the maximum prf at 25° C is currently 1000 Hz for the diode selected. The wavelength is typically 9000 Å with a spectral half width at the 50% point of about 40 Å. The power efficiency or power radiated per unit input

is 1%. Recently, however, efficiency ratings of 10% have been achieved. Most other lasers such as gas lasers and solid state lasers only have efficiencies of less than 1%. The new heterostructure diode consists of three distinct layers: n-type GaAs, p-type GaAs, and p-type gallium-aluminum-arsenide. Recombination occurs in the immediate vicinity of the GaAs p-type region. The heterojunction formed at the interface of the p-type GaAs and p-type gallium-aluminum-arsenide serves to confine the injected electrons and also reduce the absorption. As a result, the threshold is reduced by a factor of 2 to 3 and power efficiency is increased by a factor of 2 to 6.

In a laser, stimulated emission is achieved by means of an electron or hole population inversion. A population inversion occurs when an upper energy level has a greater probability of being occupied by electrons or holes than does a lower level. Under these circumstances the electrons or holes are said to be inverted. The new distribution of charges no longer represents the lower energy state. When this occurs, the probability of a photon-induced downward transition will exceed the probability of an upward transition, leading to a net stimulated emission. The electrons then recombine radiatively with the holes by dropping from the conduction band to empty states in the valence band. For each electron transition, light in the form of a photon of energy, $h\nu$ is emitted. (h = Planck's constant and ν = frequency)

In the semiconductor injection diode laser, population inversion is produced by injecting electrons directly into p-type materials or holes into n-type material. The injection of charges to achieve lasing threshold is accomplished by a narrow current pulse (approximately 200 nsec) for conventional injection lasers. The dynamic forward resistance of a diode is typically 0.2 ohms.

Injection is represented schematically in figure 11, which shows a plot of energy versus density of states at thermal equilibrium. The lower level is called the valence band and the upper level the conduction band. The region between the bands is known as the forbidden region and E_g is the value of the energy gap. In the forbidden region there are no allowed charges.

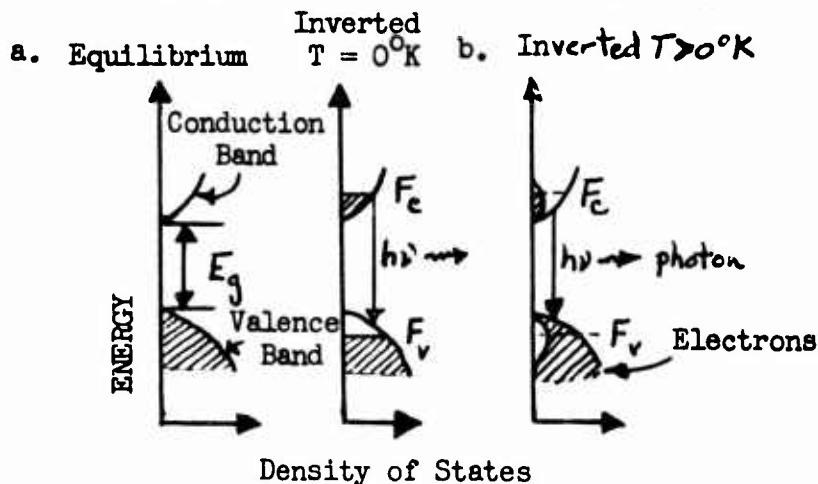


Figure 11. Density of States vs. Energy

The energy gap for GaAs is 1.45 eV which corresponds to a wavelength of 8400 Å at 77° K. At 25° C the energy gap increases to 1.6 eV.

The probability that a state in the conduction band is occupied is given by Fermi-Dirac statistics

$$f_c = \frac{1}{1 + \exp((F_v - F_c)/kt)}$$

where F_c is the quasi-Fermi level for electrons. This level is the energy at which the probability of a state being occupied is equal to one half. To get emission of a photon it is required that the differences in energy be greater than $h\nu$ or

$$\begin{array}{ccc} \text{Conduction} & & \text{Valence} \\ \text{Band Energy,} & - & \text{Band energy,} & > & \text{Photon, } h\nu \\ F_c & & F_v \end{array}$$

In order to get stimulated emission or obtain laser action there must be population inversion and also sufficient gain present to overcome the optical losses. See figure 11-b. The principle loss mechanisms of this semiconductor laser are: the bulk losses due to free-carrier absorption; diffraction of light out of the active region; and surface losses due to imperfect reflections at the Fabry-Perot surfaces, which may be formed by cleaving the crystal. Other items affecting the lasing threshold are the thickness of the region over which a population inversion will exist and the temperature. Threshold current density has a dependence on temperature of approximately T^3 .

The energy vs. distance diagram shown in figure 12-a is another method of representing conditions necessary for lasing. In the unbiased case the Fermi level is continuous across the junction. When a forward bias is applied, the barrier restricting the flow of electrons and holes is reduced (figure 12-b). In this forward biased condition electrons are injected into the p-side and holes into the n-side, this results in a population inversion between the conduction and valence-band levels. The separation in energy is less than the separation of the quasi-Fermi levels for electrons and holes. A transition, shown in figure 12-b, results in the emission of a photon of energy $h\nu$.

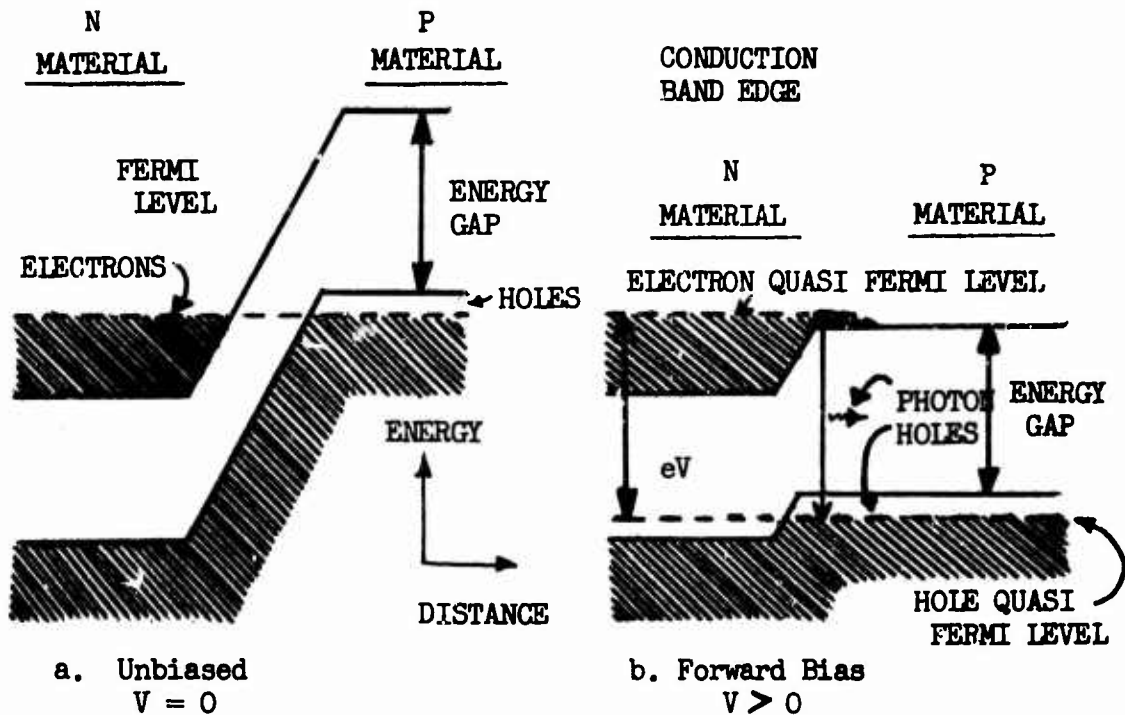


Figure 12. Energy vs. Distance

Laser diode output is known to degrade over a period when a laser diode is operated at the high current-density levels as required at 25° C. This type of degradation is known as noncatastrophic degradation.

Failure can also occur due to catastrophic failure over a few pulses. The catastrophic mode of failure is the result of mechanical damage of the material facets and has been shown to be related to the optical flux density rather than the current density in the p-n junction.

In the remainder of the appendix the physical basis of noncatastrophic degradation in GaAs injection laser diodes is reviewed.

Many manufacturers guarantee their diodes for 1000 hours of operation at 25° C. With the recent reduction in threshold current and the improvements in the GaAs materials the life of the diode should increase greatly. The new diodes announced early in 1969 feature low threshold current and increased junction uniformity. Using this process the threshold currents are reduced to 50%. Since experimenters have found that degradation varies superlinearly with current, the life of the diodes should be increased significantly above 1000 hours due to the reduced current necessary to achieve lasing. Further improvement may also eventually allow cw operation at room temperature.

Studies are underway to understand the physical mechanisms responsible for the gradual degradation. Some researchers believe the degradation is caused when carriers recombine nonradiatively, causing thermal spikes.

The thermal spikes displace a zinc dopant atom from a substitutional site into an interstitial site causing the degradation. The degradation process is therefore due to bulk effects involving fundamental material changes in the diode with the dominant factor being the gradual reduction in the internal radiative quantum efficiency and optical loss in the junction region. The rate of this gradual degradation has also been found to depend on the initial uniformity of the nearfield pattern of the laser.

A diode laser which emits nonuniformly degrades up to an order of magnitude faster than a laser which emits uniformly along the planes of the p-n junction. It is possible that the lasers' material nonuniformity causes higher local current densities than in a uniform laser. The non-uniformity of the near-field patterns indicates the presence of a structural flaw which may cause the formation of nonradiative centers.

When the degradation process begins, the near-field emission patterns become nonuniform. Also, the pulse-to-pulse output varies up to 15% about the mean-power output. This is caused by part of the p-n junction "turning-on" randomly and not emitting during each current pulse.

It is believed that better materials and methods of manufacture, which reduce the threshold current, will increase the life of the diodes.

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APPENDIX B

LASER MODULATOR AND POWER SUPPLY CIRCUITRY

This appendix contains the details of the gun's transmitter system modulator and power supply.

The modulation pulses are basically obtained by discharging a capacitor through the low impedance (0.2 ohms) laser diode to create a current pulse. The rise time of the pulse is essentially determined by the response time of the SCR switch which controls the capacitor discharge. A current charging circuit is utilized to charge the capacitor.

Modulation of the diode occurs at a rate of 600 Hz, controlled by a unijunction oscillator clock. However, various rates from 1 to 1000 Hz can be selected as the clock frequency. A gate circuit can select the number of pulses transmitted in a single pull of the trigger. A single pulse will indicate a hit. Multiple pulses can be utilized to simulate automatic weapon fire. The current pulse delivered to the laser diode is approximately 40 a with a maximum pulse length less than 200 nsec.

A unijunction transistor triggering circuit or relaxation oscillator is used to produce the pulse to trigger the SCR switching device into its conducting state. This generator produces the pulses by discharging a capacitor into the SCR gate. (See figure 13). When the trigger switch is closed, transistor Q_1 ceases to conduct for a time interval dependent upon the values of C_3 and R_2 . During this time period the unijunction relaxation oscillator will generate pulses. Either single pulse or a burst of pulses can be generated.

The capacitor C_2 is charged through R_4 until the emitter reaches a voltage V_p , at which time, Q_2 the UJT, turns on and discharges C_2 through R_9 . When the emitter voltage Q_2 falls to about 2 volts, the emitter ceases to conduct, the UJT turns off and the cycle is repeated. The period of oscillation is given by

$$T = \frac{1}{f} \eta 2.3 R.C. \log_{10} \frac{1}{1-\eta}$$

The intrinsic standoff ratio η , 0.63. Frequency of the oscillator is 600 Hz.

The UJT method of pulsing the SCR was selected because of its inherent stability and low power consumption.

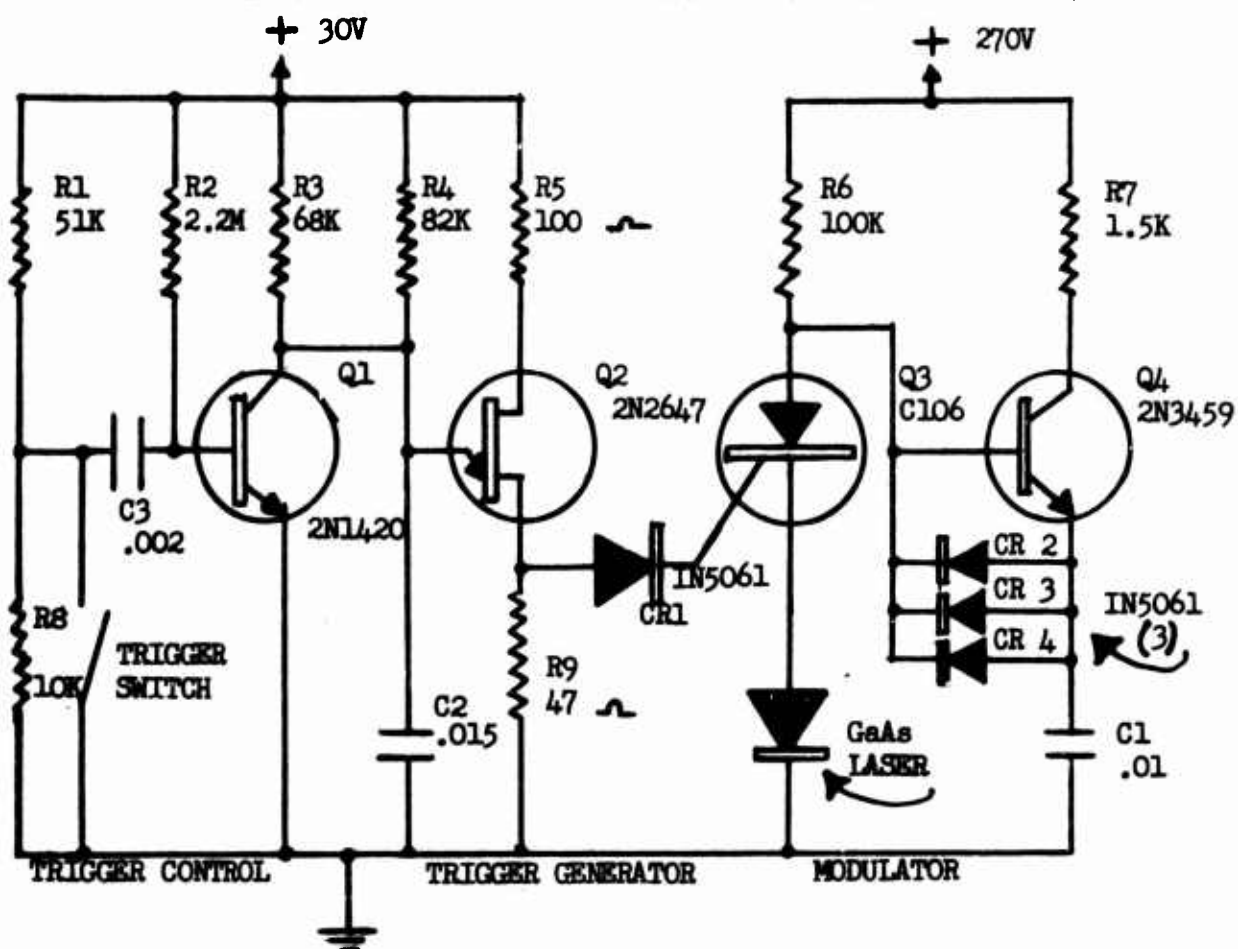


Figure 13. Transmitter Circuit

Pulses from the unijunction trigger generator Q_2 are used to fire the SCR, Q_3 . When the SCR is fired capacitor C_1 discharges through the laser diode giving an output pulse. The peak voltage to which the capacitor is charged is limited by the maximum breakdown voltage of the bipolar transistor. Q_4 , the bipolar transistor, is utilized to commutate the SCR. The laser power output is a function of the value of the high voltage input.

The power supply consists of a rechargeable silver-cadmium battery cell and a dc-to-dc converter.

The battery consists of three semi-sealed silver-cadmium cells. The positive electrode is silver and the negative electrode is cadmium. The electrolyte consists of a strong potassium hydroxide solution.

The battery has a nominal capacity of 5 amp-hr. A fully charged battery has a nominal open circuit voltage of 4.2V. After about 25% of the amp-hr capacity has been discharged, the open circuit voltage will drop to about 3.5V and will continue to read this value until the battery

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is discharged. The battery was designed for discharge at the 2- to 5- a rate with pulses up to 15a for short period duration.

The charge rate of the battery is 0.2 a maximum to an end-charging of 4.6 to 4.7V. A Yardney Semi-Sealed Sliced Battery Model BD 315 was used in this prototype model.

The dc-to-dc converter is used to convert the direct current power source or battery at a nominal 4V to a dc voltage of 300V.

This power converter basically consists of two power transistors and a special transformer. The transformer, which has a core material with a hysteresis curve approaching a square loop, is so connected that switching occurs between the two transistors. The combination of these components forms a free running multivibrator which utilizes the saturating effect of a transformer and the switching properties of the transistors to generate a square wave. The transistors essentially switch the battery from one-half of a center tapped primary to the other half. In effect, this generates a square wave which is stepped up to 300V by the transformer secondary winding. The transformer output is then rectified by a bridge rectifier. The 300V is used as an input to the current charging circuit SCR trigger generator. Efficiencies of 85% have been realized from this unit. The circuit for the converter is shown in figure 14.

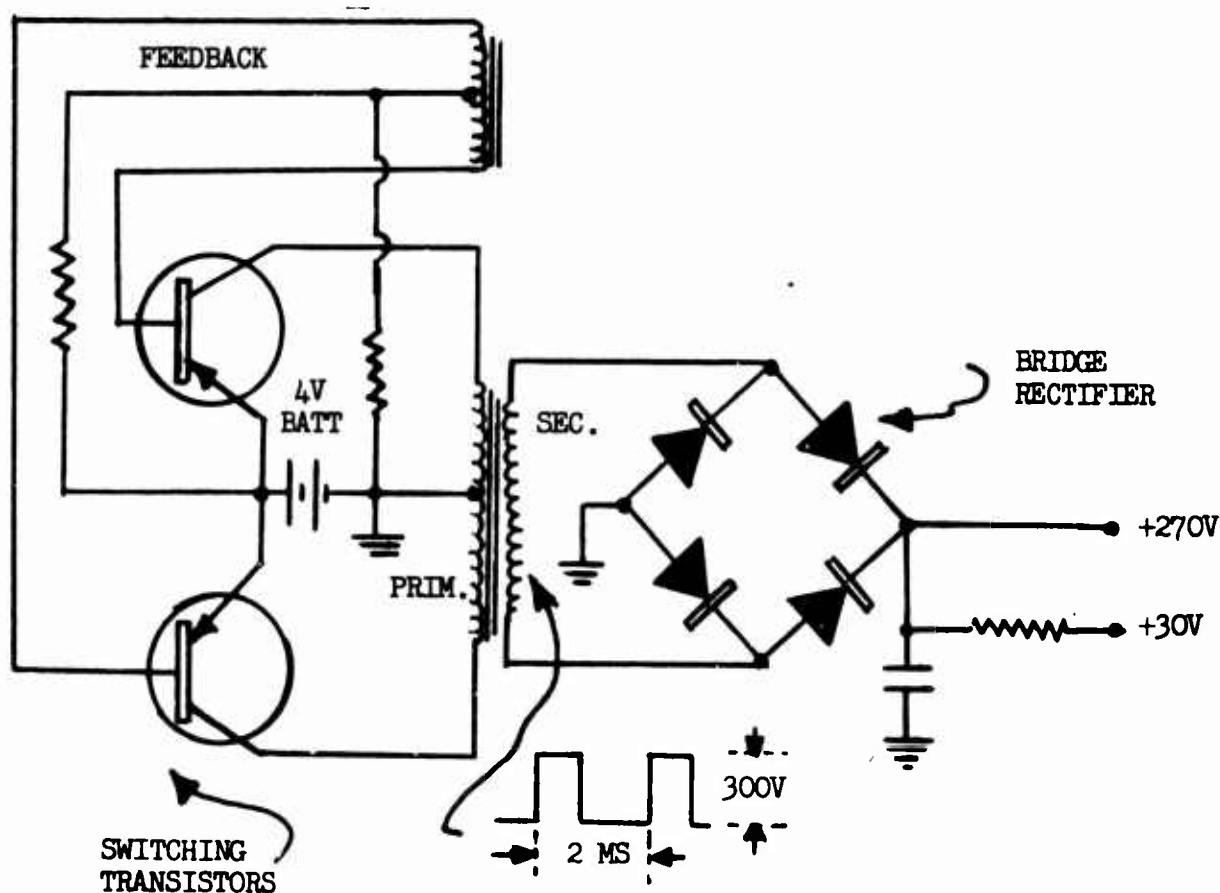


Figure 14. dc-to-dc Converter Circuit

APPENDIX C

COLLIMATION OF THE LASER INJECTION DIODE'S BEAM

This appendix discusses lens requirements to collimate the laser injection diode's naturally divergent beam. In most lasing GaAs diodes the beam half angles at 25° C are 15° to 25° with a typical solid angle of 0.1 steradian. The emitting area in a diode is a function of the semiconductor chip-size parallel to the p-n junction and the carrier diffusion lengths perpendicular to the junction. This area, which is nominally 2 x 76 μ, is represented by a heavy black line between the p and n materials shown in figure 5.

The beam angles originate primarily from diffraction of the radiation at the rectangularly shaped emitting area. For a rectangularly shaped p-n junction a $\left[\frac{\sin x}{x}\right]^2$ diffraction pattern will result. The injection laser diode can be collimated by a simple single convex lens. The full angle of the beam divergence is approximately

$$\theta = \frac{L}{f}$$

$$\theta = \frac{10 \times 10^{-2} \text{ mm}}{20 \text{ mm}}$$

$$\theta = 0.5 \times 10^{-2} = 0.005 \text{ radians} \approx 0.3^\circ$$

where θ = Full angle of beam divergence \approx 0.005 radians or 0.3°

L = Dimension of diode source - ie, 10 x 10⁻² mm

f = Focal length of lens - 20 mm

D = Lens diameter = 20 mm

The beam size is given by

$$S = r\theta$$

where

S = diameter of the beam

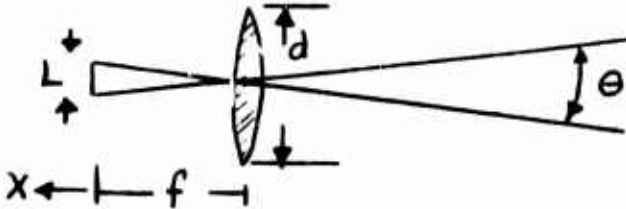
r = range

θ = divergence in radians

For example where r = 30 ft and θ = 0.005 radians, the beam diameter is, S = 1.8 in.

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By changing the position of the laser diode relative to the focal plane of the lens, the beam shape can be adjusted from a rectangular to a circular beam. The size of the beam is also adjusted by changing x .



The beam divergence is then given by

$$\theta = \frac{L + X/(f/\text{No.})}{f+x} \text{ radians}$$

where

$$f/\text{No.} = f/d$$

If $x = 0$ the beam is rectangular; if $x > 0$, the beam is more circular.

To collect the maximum power radiated by the diode the f number, (focal length / diameter), of the lens must be chosen such that the maximum power will be intercepted by the lens. A lens of f number = 1.0 to 1.5 is sufficient to collect most of the power from commercial room temperature GaAs lasers.

APPENDIX D

LASER RECEIVER AND HIT INDICATOR CIRCUITRY

A silicon diffused photodiode is used as a detector in the receiver. The diode detector is reversed biased so current will flow under the period of illumination. Detector current is caused by incident photons raising electrons in the detector material from non-conducting to conducting states, where they contribute to the current flow. The current is composed of photo-current and dark-current. Dark I_D is constant under fixed bias and temperature conditions and the photocurrent varies linearly with the intensity of the incident laser light. The diode is essentially a current generator. An EGG, SGD-100A diode was selected as the detector. The laser output has a pulse width of less than 200 nsec, therefore, a detector with a large bandwidth is required. The selected detector has a rise time of 4 nsec and a bandwidth of 100 MHz. The relative spectral response of the detector is shown in figure 8.

It can be seen from figure 8 that the peak spectral response occurs at 0.9μ , the wavelength which the laser injection diode emits. The detector has a sensitivity of approximately $0.5 \mu a / \mu w$ at 0.9μ . The detector active area is 0.051 cm^2 . The detector field of view is approximately 25° .

The receiver circuit is shown in figure 15.

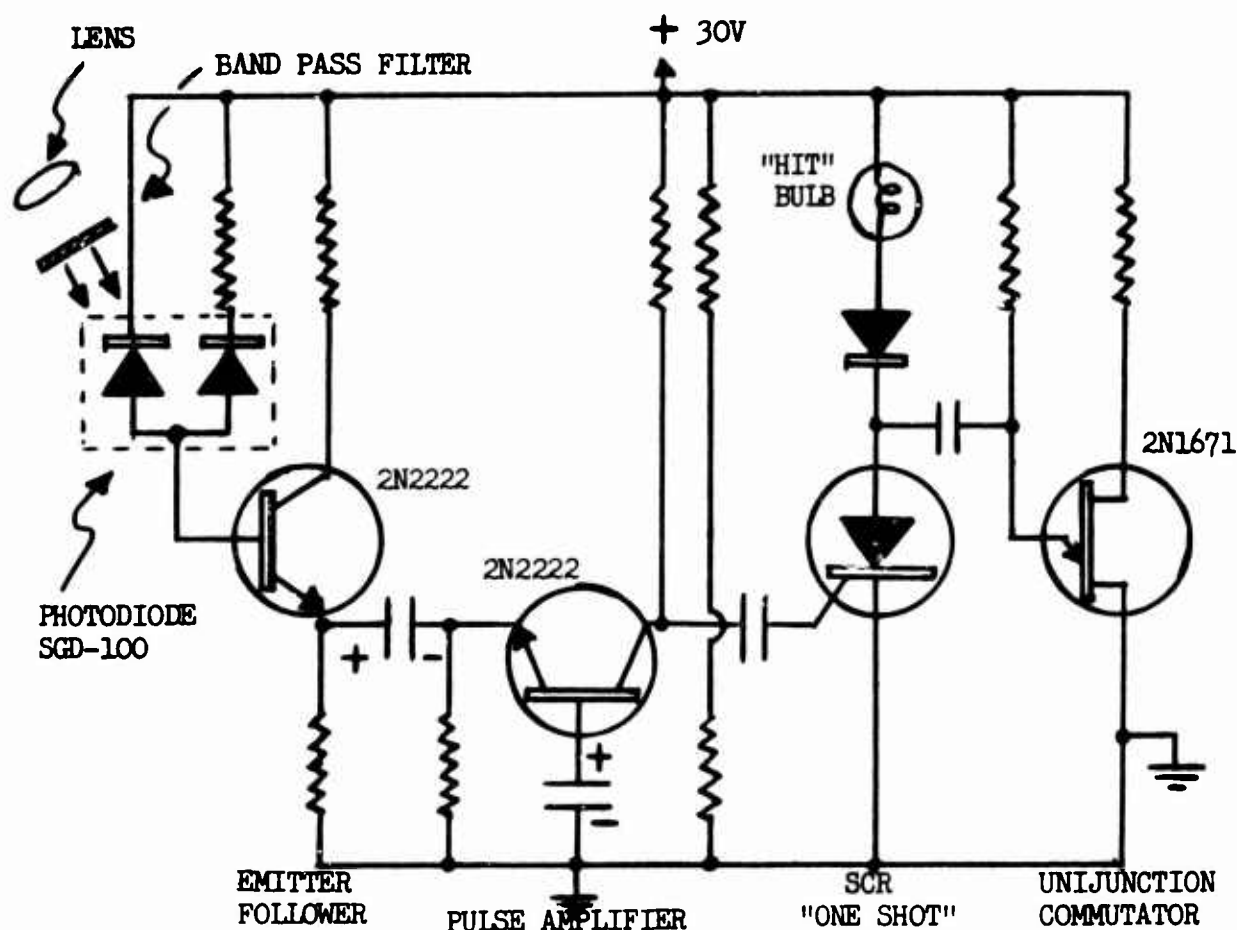


Figure 15. Amplifier Circuit

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The detector signal is fed to an emitter follower which is used as an impedance matching device. A pulse amplifier is used to increase the signal level. The output of the pulse amplifier is used to turn on a silicon controlled rectifier. The silicon controlled rectifier acts as a switch to turn on the hit indicator lamp by effectively providing a ground for the lamp.

Once anode-to-cathode current is flowing through the SCR, the gate has no control over the SCR. External measures therefore have to be applied to stop the flow of current or to commutate it. A unijunction oscillator circuit is used to perform the commutation and also provides a variable time delay when the hit lamp is lighted. When the SCR is turned off or commutated the ground is effectively removed from the lamp turning it off. A sawtooth voltage is placed on the anode of the SCR by the capacitor.

If a gate voltage is not present at the SCR when the anode drops to a low voltage, the SCR is commutated. This method of commutation effectively removes or lowers the anode's voltage causing the SCR to turn off.

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