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LASER MARKSMANSHIP POTENTIAL EVALUATION

BY Albert Marshall
Bon Shaw
Gary Bond

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The MILES tank main gun transmitter was tested for potential marksmanship application. Tests results are included. Recommendations to improve the MILES system for marksmanship application are included. MILES uses eye safe semiconductor laser coded "bullets" which when fired with "blanks" realistically simulate the effective range of a weapon system. Detectors, located on opposing force's personnel and vehicles, receive this coded laser "bullet" and determine if it could do damage, if it was accurate enough to kill, or if →

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20. Abstract (cont'd)

a near miss occurred.
A new concept for long-range marksmanship gunnery using a modulated continuous wave (CW) laser source is described. Design of a CW laser transmitter and two laser receiver circuits; a Phase-Locked Loop and active filter based systems, are described. A companion effort by the University of Central Florida is still in progress to determine a mathematical model to describe propogation effects. A final report will be issued by UCF in Jan. 1981.

SUMMARY

This report describes research and development directed by PM TRADE to study the potential of semiconductor laser systems to satisfy training requirements in the following areas: tank gunnery, anti-tank gunnery, i.e., (Tow and Dragon), and laser designator trainer, etc. This investigation is part of a technology program for the development of cost effective training systems. Since the Multiple Integrated Laser Engagement System (MILES) equipment represents a substantial dollar investment and will be available to almost all of the units of the active Army, the potential of these type devices to satisfy other than engagement training was investigated to allow the development of cost effective training systems.

This study quantifies the marksmanship simulation fidelity, attainable at tank and anti-tank weapons ranges.

The report also recommends changes or add-ons to the existing MILES system to allow tank gunnery, anti-tank gunnery, laser designator training, etc.

The effective beam width of the standard MILES 105 mm laser transmitter was measured to determine the 90 percent and 10 percent hit probability zones. The performance of the MILES transmitter is adequate for engagement simulation but not for marksmanship fidelity. It is suggested the equipment be product improved. Several suggestions for modification are included in this report.

Using a recently available improved laser diode and both phase-locked loop and active filter techniques, an improved laboratory prototype transmitter and receiver system was developed and measured. The performance of the prototype system was found to be within the precision required for marksmanship training.

The PM TRADE project manager was A. J. Boudreaux. The authors wish to thank him for the helpful assistance he gave during this program.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION I

INTRODUCTION

This report analyzes the use of the MILES system for long range and short range marksmanship gunnery training. Measurements were made on a MILES tank main gun transmitter to determine its accuracy for marksmanship application. Suggestions for MILES hardware modification to allow more accurate long range marksmanship gunnery are included.

A new system concept for laser marksmanship gunnery training was developed using a pulsed CW laser. Semiconductor CW lasers are a recent development. Design information and data taken on this new system are included. Measurement and systems for both long and short range were developed.

✓A companion effort is being conducted by the University of Central Florida, (Ref. 1) to develop mathematical models for long range laser propogation to allow more precise evaluation of the design efforts. The study also includes an analysis of the binary union decoder used in the MILES receiver. The study will be completed in December 1980.

Section II of this report discusses the parameters which affect a system's ability to accurately simulate a weapon for marksmanship application.

Section III details the design of a pulsed CW laser system to give optimum performance for a marksmanship application.

Section IV describes measurements made with both the MILES tank Main Gun Transmitter and the pulsed CW laser.

Section V gives the conclusions and suggested modifications to MILES to allow more accurate marksmanship training.

SECTION II

STATEMENT OF THE PROBLEM

The system's designer of weapons engagement and marksmanship trainers has available for selection several controllable parameters which allow optimization for the particular application of an engagement or marksmanship trainer. The controllable marksmanship parameters are:

1. LASER TRANSMITTER PARAMETERS

a. Laser Collimation. The beam divergence of the laser transmitter, which is fixed to the weapon, can be controlled by selection of the lens used to collimate the laser. Generally a long focal length lens will give a smaller beam divergence and hence a smaller laser beam. A narrow beam is necessary to simulate long range weapons.

b. Laser Source Size and Shape. The laser's emitting source size and shape effect both the laser beam size and shape. For perfect collimation of a beam with no divergence, a point source would be helpful. The larger the emitting area or source size the greater the beam divergence or beam width at the maximum ranges. In selecting a laser, the smallest source size, within the required power range, will produce the best collimation or smallest laser beam.

The pulsed laser in MILES has a rectangular shaped laser source and as a consequence the laser beam is also rectangular or elliptical in shape. A rectangular or elliptical beam may be suitable for engagement but is not desirable for marksmanship. A relatively inexpensive and easy way to produce both a round and uniform beam is to use a very small fiber optic bundle in front of the laser beam which shapes the beam to a round area or source. The fiber optic bundle also homogenizes the beam to a uniform power level. Variations in laser power level can cause a non-uniform kill zone across the beam.

c. Laser Power. Output power from the laser transmitter can be controlled by varying the amount of current supplied to the laser. The amount of power in the laser beam affects the kill zone size because the laser receiver on the target is set to indicate a kill whenever a pre-set laser signal threshold or power level is exceeded. If the laser power level varies so does the kill beam size. This produces different kill zone sizes as the power varies. Unfortunately, the semiconductor laser power varies as the ambient temperature varies. The laser power increases when the laser is cold and decreases when it is hot. A solution to this problem is to either temperature stablize the laser or sample the laser output power and adjust the laser power using a feedback control system to maintain a near constant power output.

The output power will also decrease as the laser ages. For precision hit determination the laser power must not change more than 10 percent as the temperature changes or as the laser ages. The MILES laser changes more than 10 percent over its designed ambient temperature range.

d. Laser Pulse Coding. Laser pulse coding is a means of better penetrating or communicating through the atmosphere. A proper pulse code will help defeat the deleterous effects of the atmosphere.

2. LASER RECEIVER PARAMETERS

a. Detector Type. The detector type controls the ability of the receiver electronics to detect the laser's pulses. In engagement, the target must be capable of being attacked at all possible angles. A wide receiver field of view is necessary to be able to detect an aggressor firing at the target at various angles. Usually a large area detector is required to achieve the wide field of view.

In marksmanship type devices the field of view is usually limited and a lens can be used on the receiver to increase the range it can detect a transmitted laser pulse. The detector can also be better shielded against the effects of sunlight and a detector with gain might also be chosen for extremely long ranges.

b. Detector Placement. Detector placement on the target can vary the hit/kill zone size. In engagement situations the detector placement must cover all angles. In marksmanship situations the detectors can be placed to limit the hit/kill zone to simulate the actual target size because the requirement to operate over all angles does not exist. An optimum detector placement can be determined for marksmanship targets which will more precisely define the actual kill geometry of a target.

c. Detector/Receiver Threshold Setting. In engagement trainers the targets can vary widely in range. In marksmanship a smaller range variation will occur which allows an optimal kill threshold to be selected for each known target range. The optimal threshold setting also allows better target definition. In MILES it was found that the size of the beam varied with the sunlight level. A means of compensating for this is to either put a reverse bias on the detector or use an optical gain control. Another means of adjusting the threshold would be to sample the ambient light level and adjust the threshold accordingly.

d. Decoding. Decoding allows better detection in noise. The following are uncontrollable variables:

(1) Smoke
(2) Atmospheric attenuation
(3) Light level

The controllable variables may be manipulated to defeat or minimize the effects of the uncontrollable variables.

The MILES system is optimized for engagement. As an example the MILES system must work at all ranges within the weapons effective range and the number of detectors on a target must be minimized. This requirement basically mandates a larger beam to negate shooting between detectors. The laser receiver on the target must also be set to a single detection threshold which does not allow an optimum beam size detection for a particular range.

The larger MILES beam is therefore a trade-off to decrease the number of detectors.

Suggestions to help optimize MILES for marksmanship are given in the conclusions. Measurements on a MILES tank main gun are explained in Section IV.

The next section describes the design of a pulsed continuous wave (CW), laser system. This system optimizes the variables discussed above to produce a superior long range marksmanship device. The basis for this device is a newly available laser capable of continuous wave (CW) operation.

SECTION III

DESIGN OF A PULSED CONTINUOUS WAVE (CW) SEMICONDUCTOR MARKSMANSHIP LASER SYSTEM

This section covers the design of a new and novel weapon fire simulator for long range marksmanship applications. This system uses a modulated semiconductor CW laser. Semiconductor CW lasers are a recent development. The source size of th CW laser is much smaller than the MILES pulsed laser so a smaller beam can be obtained. The CW pulsed laser is used to send a burst of pulses that can be more readily detected in noise. Because the detection of a burst of pulses is easier than a single pulse, a lower power laser can be utilized. Table 1 compares pulsed and CW lasers.

TABLE 1. COMPARISON OF SEMICONDUCTOR PULSED AND CW LASERS

Parameters	CW Laser	MILES Pulsed Laser
Beam Divergence	0.4 mr	1.0 to 3 mr
Beam Shape & Uniformity	Round & Uniform	Elliptical and Non-Uniform
Laser Power	0.002 watts	2 watts
Source Size	0.065 mils (round)	3X.08 mils
Safety	Safe	Safe

The laser used is an RCA 2 milliwatt CW laser Model #C86010E equipped with a fiberoptic bundle for beam homogenization.

1. LASER TRANSMITTER

The laser transmitter consists of a pulsed CW laser, RCA Model #C86010E, equipped with a fiber optic bundle and a 135mm focal length collimating lens. Drive signals for the pulsed laser are generated using a differential amplifier and a crystal controlled oscillator (see Figure 1). The crystal controlled oscillator utilizes count-down counters and flip-flops to supply a square wave, TTL level, signal of 16,384Hz at the base of transistor Q1 of the

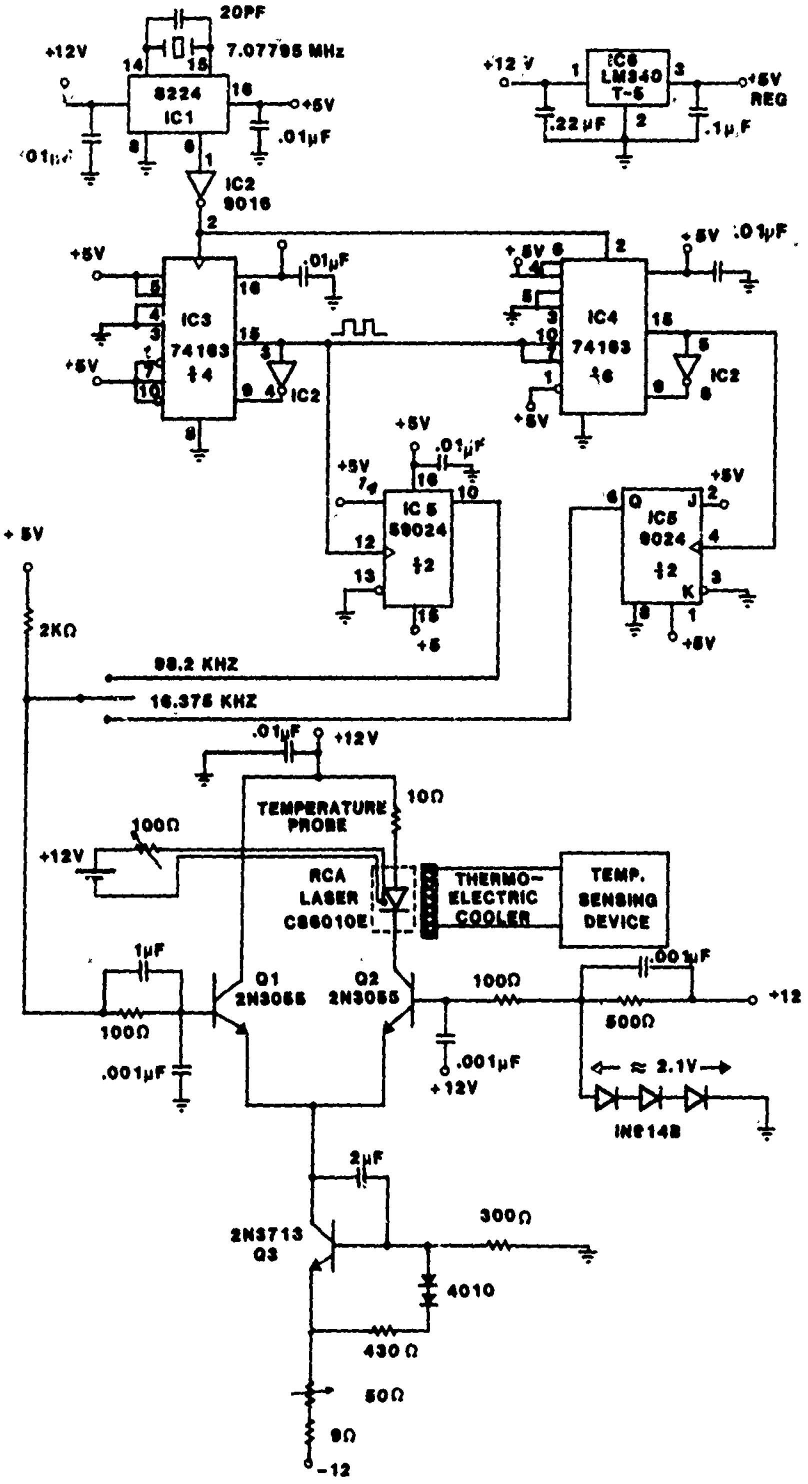

Figure 1. Laser Transmitter

differential amplifier. Diodes at the base of the opposing transister Q2 produce a bias voltage such that the on/off action of Q1, due to the TTL square wave input at the base of Q1, is followed by the simultaneous off/on action of Q2. In this way the CW laser diode, which is connected in series with the collector of Q2 and the +12 volt power supply, emulates the off/on action of Q2 thereby lasing during the intervals when the TTL square wave input of Q1 is in a low state.

Figure 2 contains the characteristics for the output power range of the CW laser as a function of temperature and current. Due to the steep nature of the power curves, these variables must be strictly and independently regulated. Fluctuations of as little as 1 mA in laser drive current causes a 3.8 percent change in output power. Likewise, a temperature rise of merely 1°C drops output power by 5.3 percent.

To control the current at a preselected level on the power curve of Figure 2, a temperature stabilized constant current source Q3 was connected at the common emitters of the differential amplifier transistors. A potentiometer in the emitter of Q3 selects the full range of current levels on the power curve.

Numerous approaches to temperature stabilization are possible. The approach utilized here involves a thermoelectric cooler operating on the Siebeck effect. A temperature probe was mounted between the CW laser and the transmitter case. Upon sensing a change in temperature, current to the cooler is adjusted to compensate for the rise or fall in laser diode temperature.

2. ACTIVE FILTER RECEIVER

A laser receiver was designed using an active filter to detect the transmitted pulsed CW laser signals. For the purpose of demonstrating feasibility a sonalert tone signaling device was used as an indicator that a signal was being received.

The active filter receiver utilizes a Meret MDA7700 silicon photodetector and a 50mm focal length lens. The detector senses and amplifies all light entering the lens. Current pulses from the detector are converted to a voltage using a current to voltage, transimpedance amplifier. Two stages of amplification using operational amplifiers boost the photodetector output and present the signal to the active filter for detection.

A two pole active filter uses a three operational amplifier double integrator feedback loop to generate a complex pole pair (two conjugate poles). The location of the poles in the complex plane (and thus the resonant frequency and Q) are determined by resistors.

The two pole electronic active filter receives the photodiode/amplifier signal and resonants at the frequency to which it has been tuned. The active filter is tuned to the center frequency of the transmitted pulsed CW laser. When the active filter senses an input near its tuned frequency, it responds with an output which is fifty (50) times greater than the level of that signal on its input.

The center frequency to which the active filter was tuned is 16,384Hz. The active filter has a circuit "Q" of 50, therefore, it has a very narrow window or range of frequencies to which it responds. A Q of 50 means that the

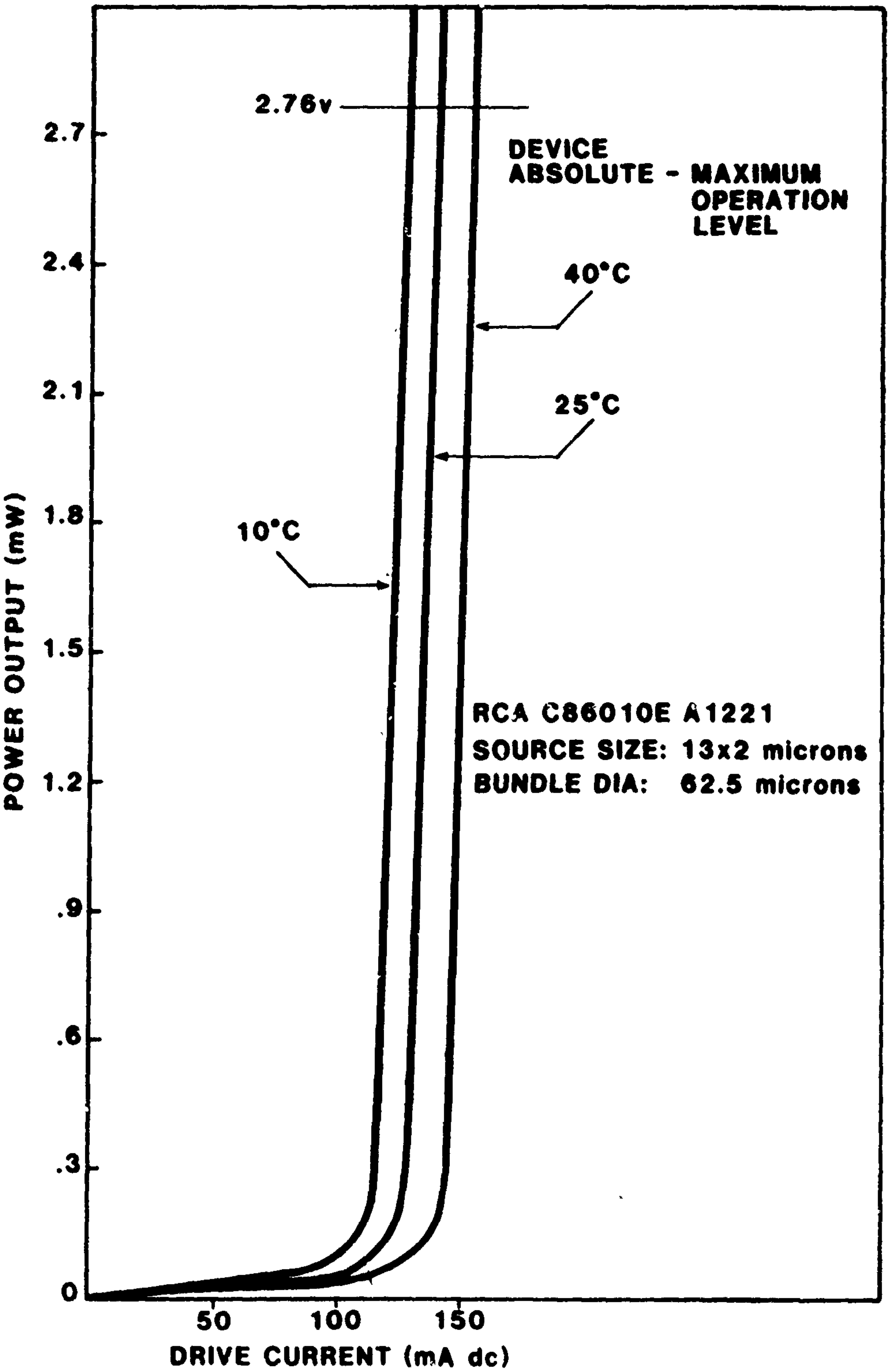

Figure 2. CW Laser Diode Characteristics

active filter will respond only half as much to a signal which is ±328Hz off from its centered frequency (16,384 divided by 50).

The active filter thus enables the pulsed CW receiver to reject random noise which is generated by the sun or other artificial lighting even without special beam coding. Furthermore, signals which are immersed in background noise can be recovered. This reduces the requirement for large laser output power levels by three orders of magnitude. In a pulsed laser system, the laser pulse is threshold detected so that the laser power level must exceed the noise. This requires a higher power laser with a large source size and beam diameter. The active filter receiver is shown in Figure 3.

A voltage comparator is used for a detection threshold level adjust. When the active filter output exceeds the voltage comparator threshold, an output is generated by the comparator which signals a detection of the transmitted signal. The voltage comparator thus acts to adjust the beam diameter as well as reduce false alarms due to background noise near the selected frequency of the active filter.

3. PHASE-LOCKED LOOP (PLL) RECEIVER

An alternate scheme for detecting pulsed CW laser signals employed the use of a Meret phase-locked loop assembly (RE8001). This assembly operates about a center frequency of 16,384Hz and has a center frequency bandwidth of 1000Hz (Q = 17). Upon sensing a signal of 20 pulses or more within the center frequency bandwidth the PLL assembly activates a sonalert to indicate that a signal has been detected.

The PLL receiver utilizes the Meret MDA7700 photodetector described for the active filter receiver and a 50mm focal length lens. Two stages of electronic amplification using operational amplifiers boost the photodetector output and present the signal to the input of the PLL assembly. The schematic for the PLL receiver is given in Figure 4.

The advantage of using the PLL assembly is its ability to detect signals about its center frequency completely immersed in noise. The drawback to this device comes from the requirement that at least 50mV of signal at the center frequency be present at the input for 20 pulses or more before the PLL assembly can activate the sonalert. Once this requirement has been met the PLL assembly will "lock" onto the incoming signal and continue to activate the sonalert so long as the incoming signal remains above 20mV and within the center frequency bandwidth.

Because of the random thresholding capability of the active filter receiver versus the preset 50 mV threshold of the PLL receiver, it was found that the minimum detectable signal was less for the active filter receiver.

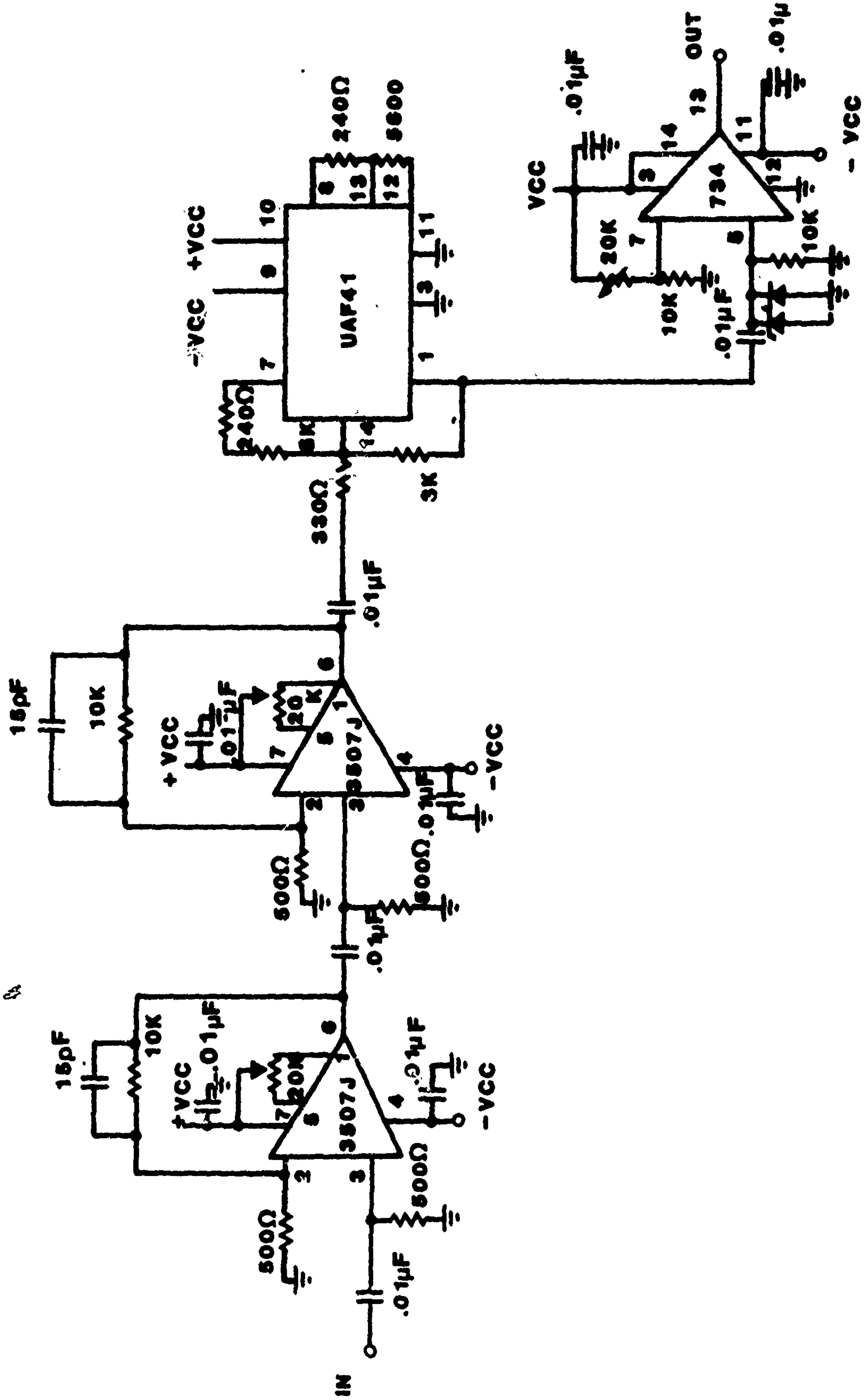

Figure 3. Active Filter Receiver

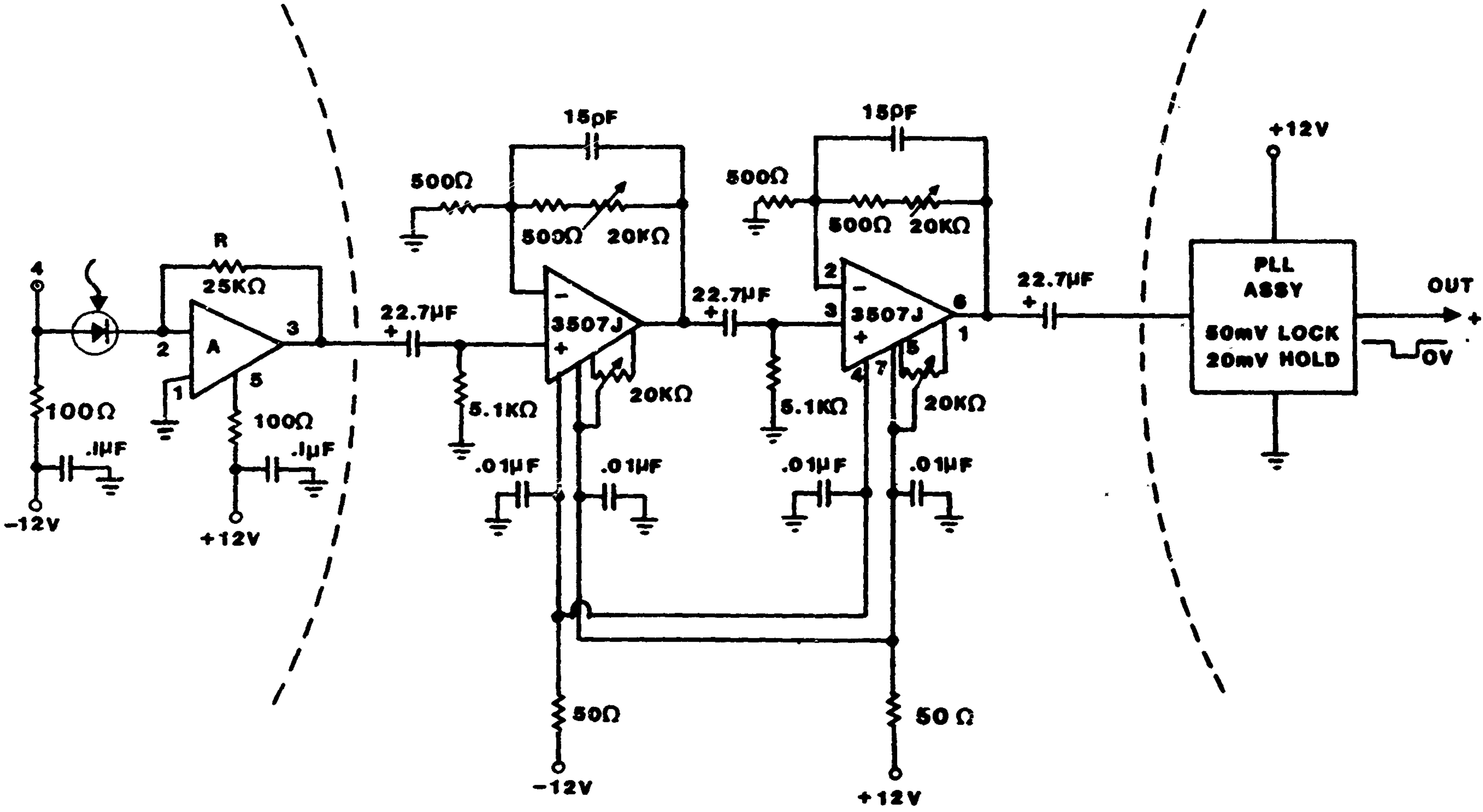

Figure 4. PLL Receiver

SECTION IV

MEASUREMENT OF MILES AND PULSED (CW) LASER SYSTEM

Measurements were conducted on both MILES equipment and the pulsed (CW) laser system described in Section III.

The purpose of these measurements were to compare Xerox computer generated data against actual field measurements. Further, the CW laser system promised greater potential for long range marksmanship but needed field testing. All measurements were carried out using tripod mounted equipment and radio communication over a grassy roadside strip spanning 3,500 meters. These measurements were taken during the summer months in Orlando, Florida where the average temperature reached 92°F and the relative humidity was near 90 percent. Partly cloudy conditions were prevalent.

1. MILES MEASUREMENTS

This section describes the MILES test measurements using a 105 mm tank main gun laser transmitter and an armored personnel carrier (APC) MILES receiver.

Measurements of the transmitter/receiver combination were conducted over a three week period. The test range location was a grassy roadside strip in Orlando, Florida which runs parallel to University Boulevard between Alafaya Trail and Dean Road. The maximum clear line of sight distance is 3,500 meters.

The transmitter was mounted on a Hercules model 5302 tripod. Azimuth, elevation and height were adjustable through gear reduced crank handles. The receiver belt consisted of six detectors, one of which was covered to duplicate the test conditions described in Xerox Trainer Engineering Report (Final) for MILES Volume I, undated. The receiver belt was mounted to the side of an automobile with all detectors (5) facing down range. With the transmitter located at one end of the range, the receiver was positioned at 1,000, 2,000 and 3,000 meters for data collection. Data collection procedures were identical for each range.

The receiver belt was located in the center of the range width. Through radio communication the transmitter was fired and the result relayed back to the Engineer at the transmitter. The transmitter aim point was corrected and refiring continued until a center of hit zone was established. The transmitter was then locked in place and remained fixed throughout the test for that particular range.

The receiver belt was moved a foot at a time across the width of the beam. At each data point, 20 or more shots were fired. Each shot was logged and its result recorded. When locations were found to record a minimum of 18 out of 20 hits (90 percent probability of hit) a marker was placed. Locations were also established for 2 out of 20 hits (10 percent probability of hit) and a marker was placed. The width from marker to marker determined the width of the 90 percent probability of hit (Ph = 90 percent) and the Ph=10 percent points.

Figure 5 shows the Xerox Ph=90 percent line as a dashed line going from zero to over 3,000 meters. The measured data for Ph=90 percent corresponds very closely for 1,000 meters and 2,000 meters. Data taken at the 3,000 meter distance was highly variable and found to be dependent upon the exposure of the sun. The sun was not shining directly into the detectors but a deleterious effect was observed at long ranges. The Xerox data was taken under limited visibility conditions (Vis=50KM) and this fact probably helped the Xerox 3KM performance rather than hindered it. Results of the NTEC laser measurements are shown in Figure 5.

MILES transmitter data taken at the Ph=10 percent points indicates that a hit may be recorded within the Ph=10 percent and Ph=90 percent lines on at least one out of ten shots or as many as eight out of ten shots. Table 2 is a tabulation of this data at the 1,000, 2,000 and 3,000 meter ranges.

On the right hand side of Table 2 is a tabulation of beam diameters for a pulsed continuous wave (CW) laser. This comparison indicates the success of the effort to develop a narrow beam laser which will be discussed in the next section.

TABLE 2. MILES AND NTEC KILL ZONE

(BEAM SIZE VS. RANGE) MEASUREMENTS

Beam Size / Range	MILES XEROX Ph=90%	MILES NTEC Ph=90%	MILES NTEC Ph=10%	NTEC CW LASER 5V REF
1000M	5.0M	4.9M	5.2M	0.61M
2000M	4.9M	4.9M	7.0M	1.4M
3000M	2.85M	NONE	7.2M	1.47M

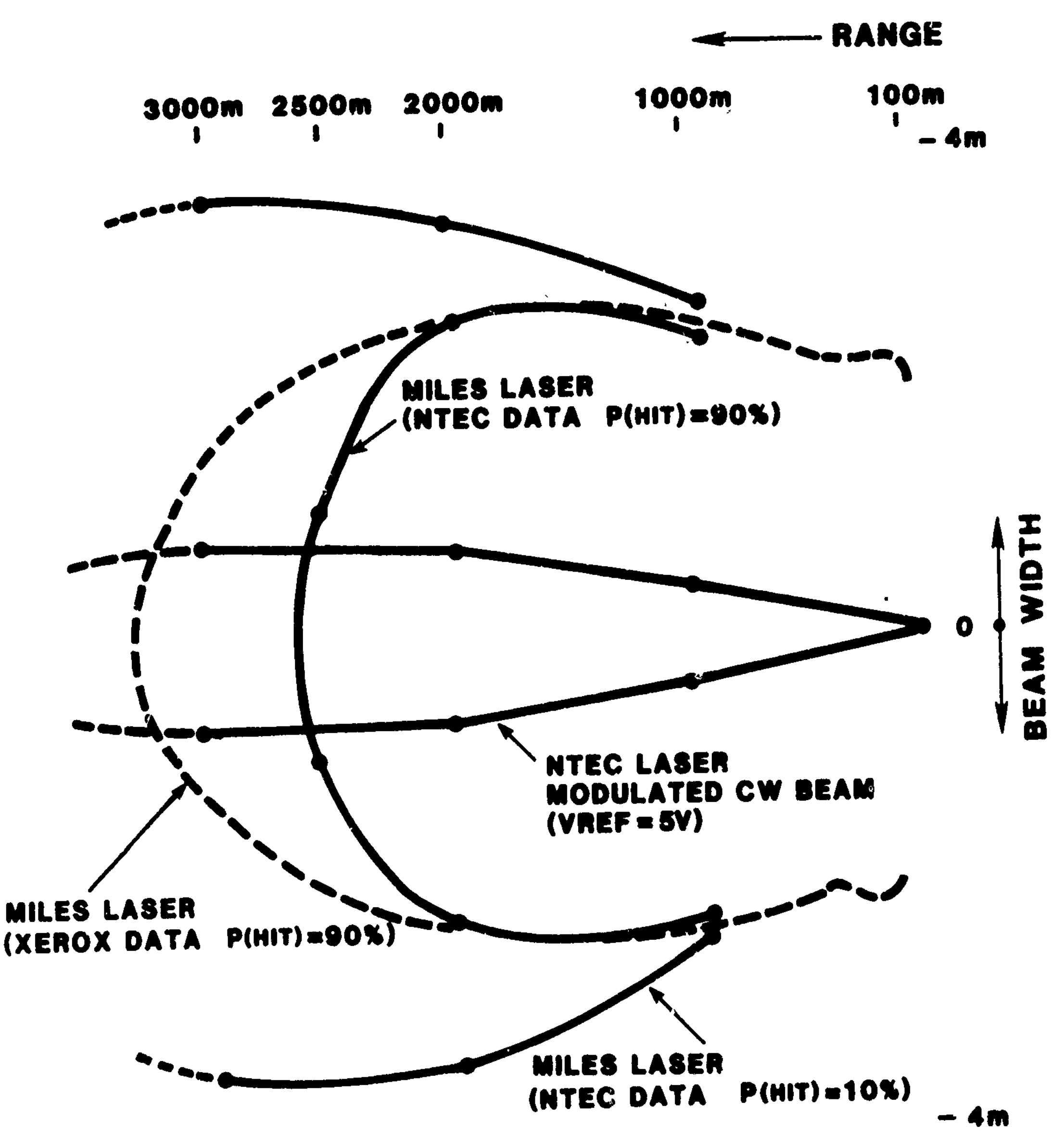

Figure 5. Beam Shape vs. Hit Probability
(Miles & CW Laser)

2. PULSED (CW) LASER MEASUREMENTS

This section describes the equipment and methods used to examine the performance of the new pulsed CW laser weapon fire simulator. The CW laser performance is compared to the MILES laser in Figure 5. The same basic approach of testing the MILES transmitter/receiver was used to test the pulsed CW laser. The test range was along University Boulevard as described in IV-1 and also over distances of 1,000, 2,000 and 3,000 meters. The pulsed CW laser transmitter was mounted on a Hercules Model 5302 tripod. A rifle scope was mounted and aligned with the laser for accurate long range adjustments. Receiving stations at distances of 1,000, then 2,000 and 3,000 meters were set up. Both PLL and active filter receivers were tested for sensitivity. The active filter and phase-locked loop receivers were mounted on Hercules tripods and fitted with rifle scopes for alignment to the transmitter. While testing the active filter an oscilloscope was used to measure actual voltages developed by the receiver circuit. This voltage data was used to compile the various beam spread sizes in Figure 6. Figure 6 shows four beam spread shapes for the CW pulsed laser. In the upper right corner the four beam shape sizes are defined as representing 15,10,5 and 0.1 volt threshold settings on an internal voltage comparator. Adjustment of the voltage comparator effects the apparent beam spread because it determines the level at which a hit is scored. Table 2 lists the Pulsed CW beam diameter along side the NTEC measured MILES beam diameter for comparative purposes. Figure 7 shows a typical pulsed CW beam diameter in comparison to the MILES beam.

Figure 8 represents an effort to duplicate the actual circular error of probability (CEP) of an M16 rifle bullet. The NTEC pulsed CW laser was reduced in power to 0.00006 watts (60µ watts) and tested over a range of 300 meters. The CEP of an actual M16 rifle is approximately 0.5 milliradians. As can be seen in Figure 8, the beam diameter for the reduced power pulsed CW laser was as good as the M16 CEP for all ranges to 300 meters. It should be noted that the ordinate is in true scale (1cm=1cm). Thus, the beam size is in true scale for the ranges shown.

Figures 9 through 12 show the prototype laser transmitter and receivers. No effort was made to minaturize the equipments.

The active filter receiver was more sensitive than the PLL receiver, however the active filter input frequency must be better stabilized.

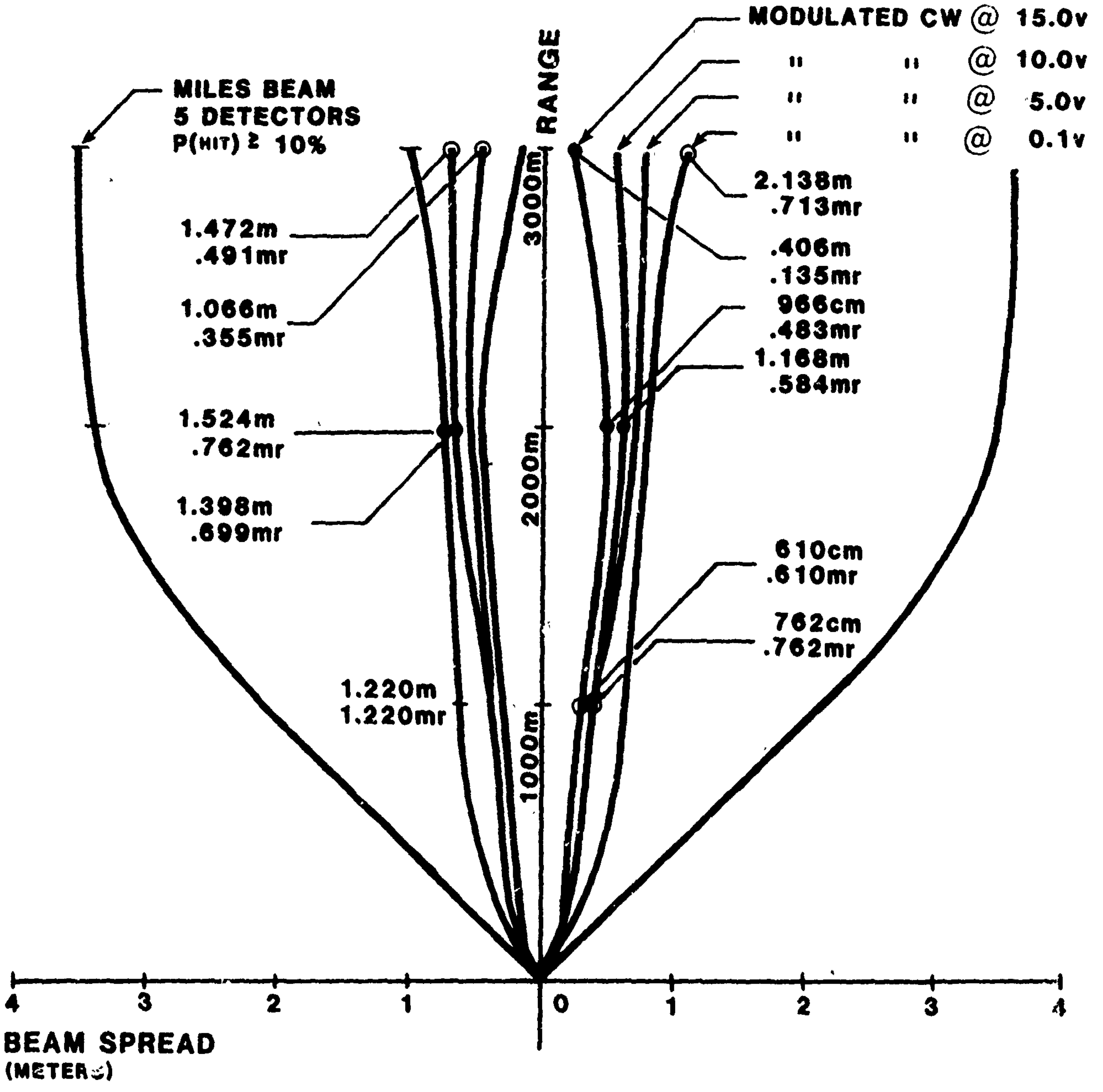

Figure 6. Miles and Modulated CW Beam Spread vs. Range

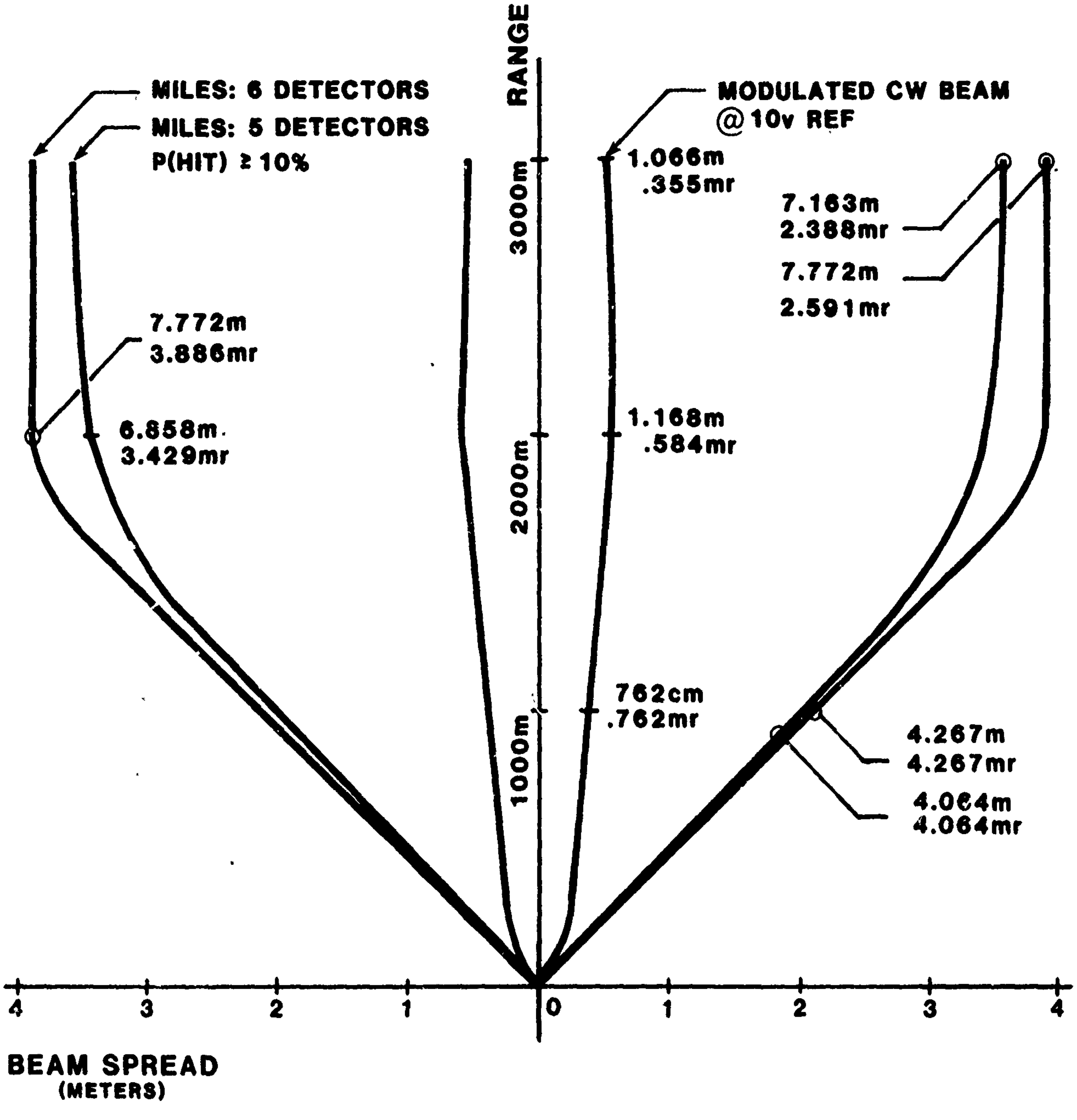

Figure 7. MILES and Modulated CW Beam Spread vs. Range

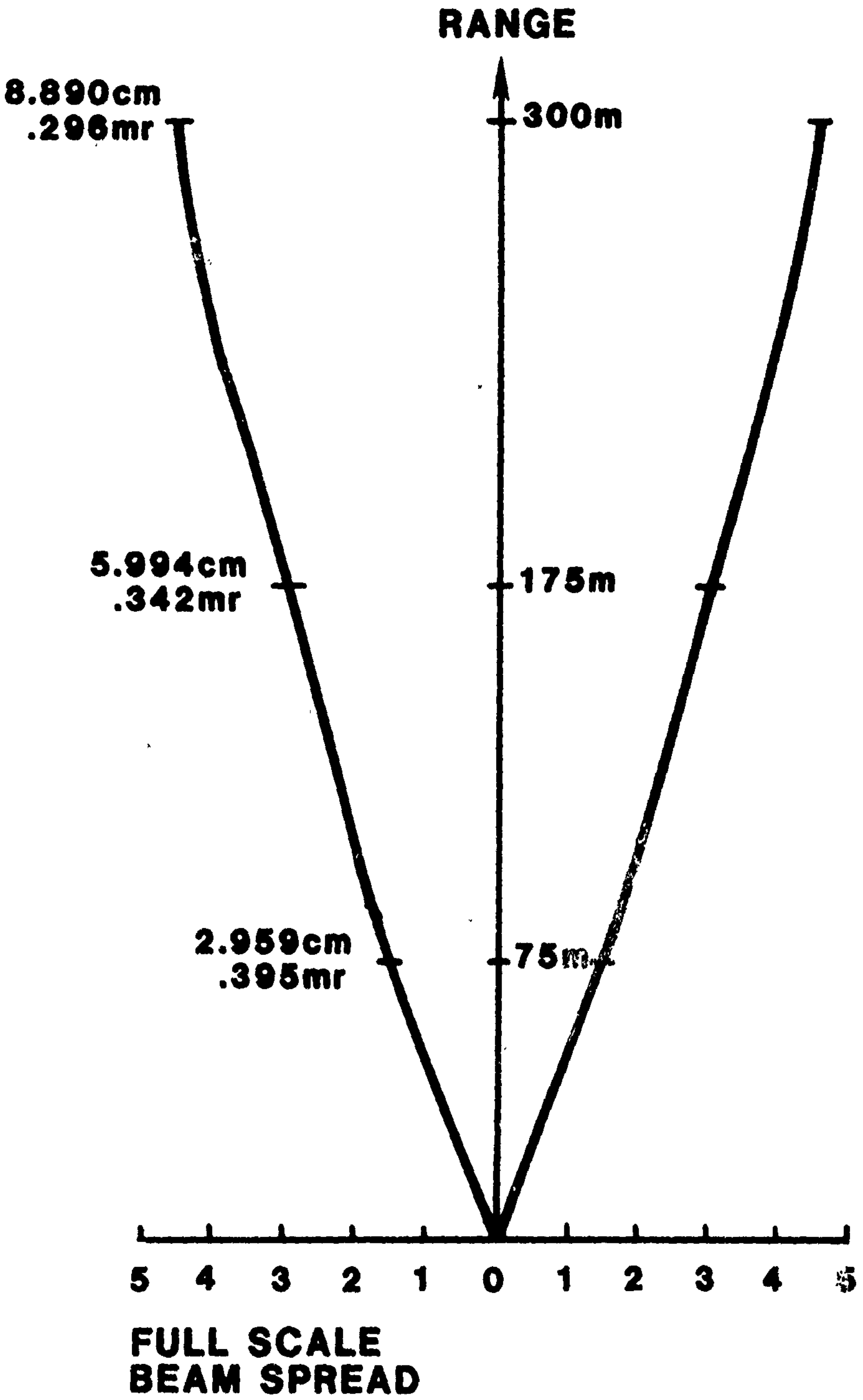

Figure 8. Rifle Simulation Using a Modulated CW Transmitter (1/2 Power Beam Spread vs. Range) P_{out} = 60 micro watts)

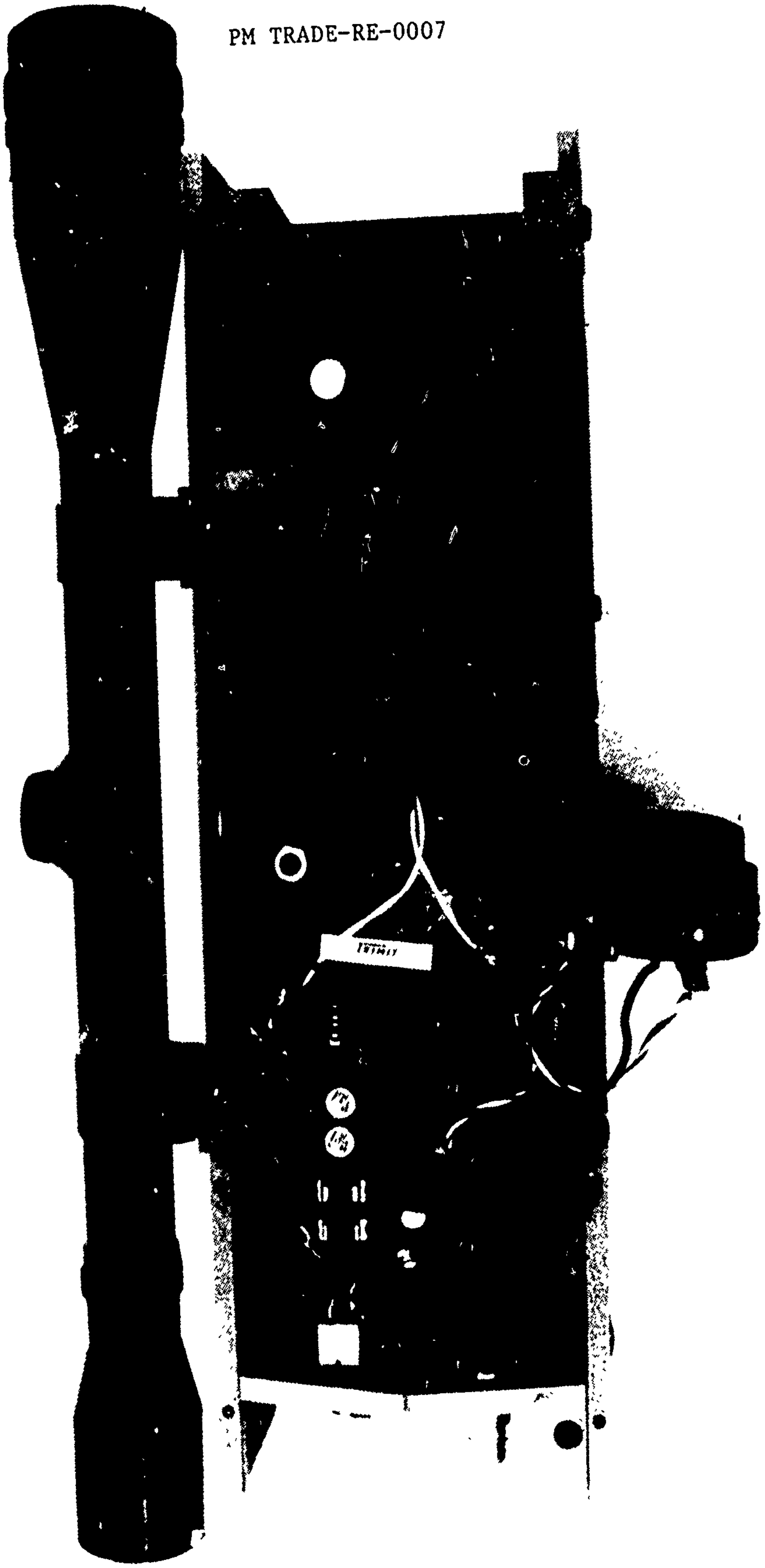

Figure 9. Phase-Locked Loop Receiver

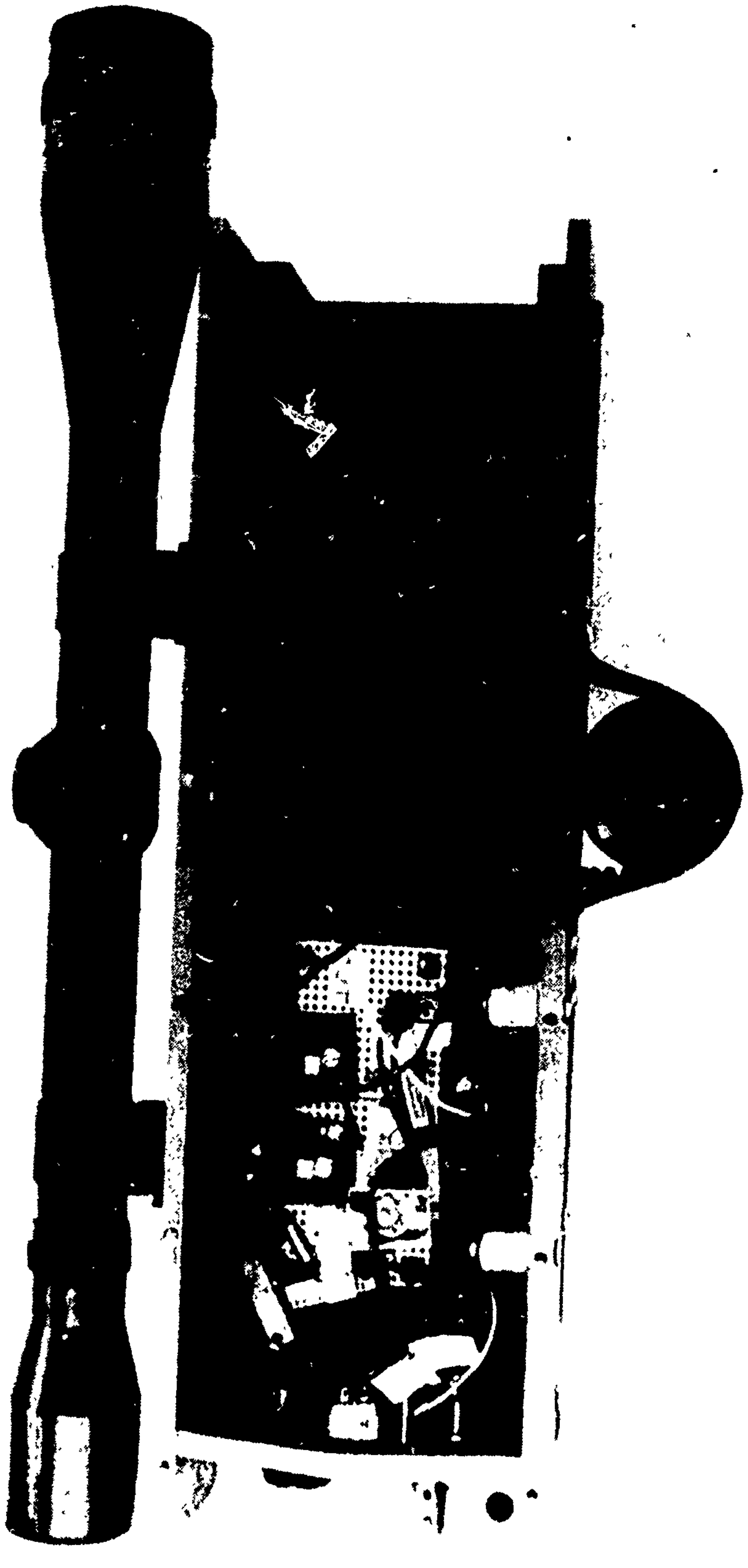

Figure 10. Active Filter Receiver

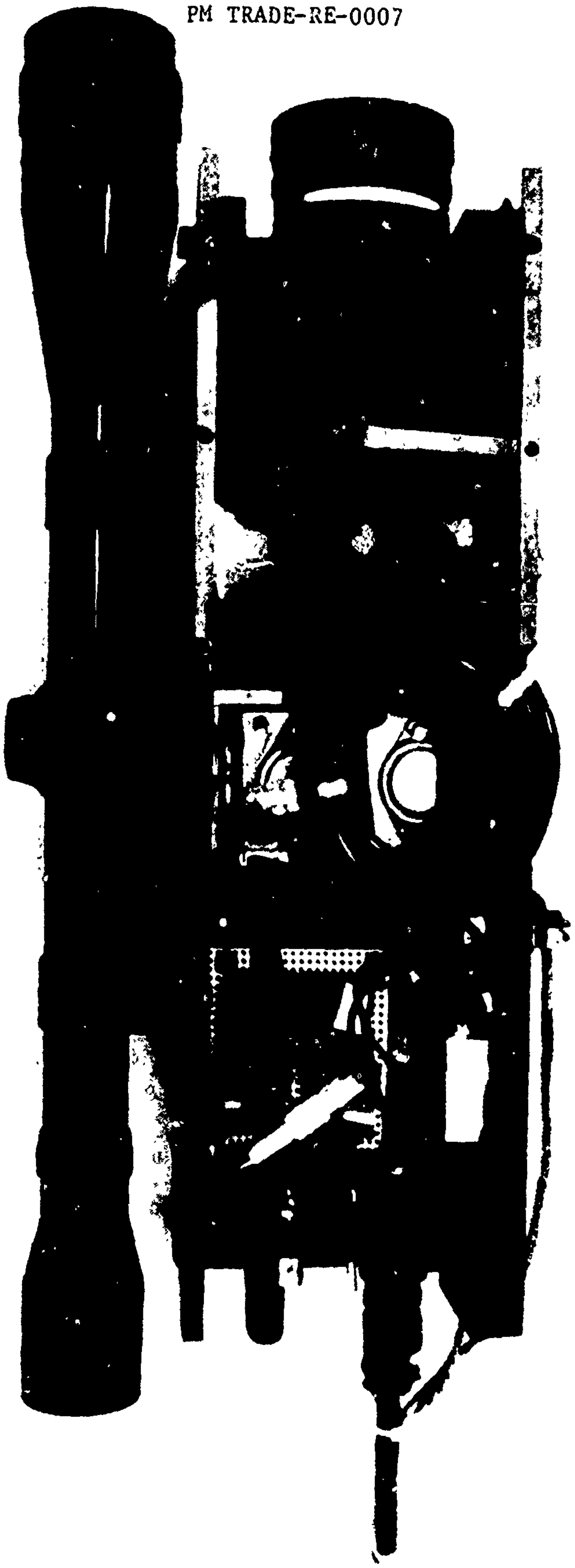

Figure 11. Laser Transmitter

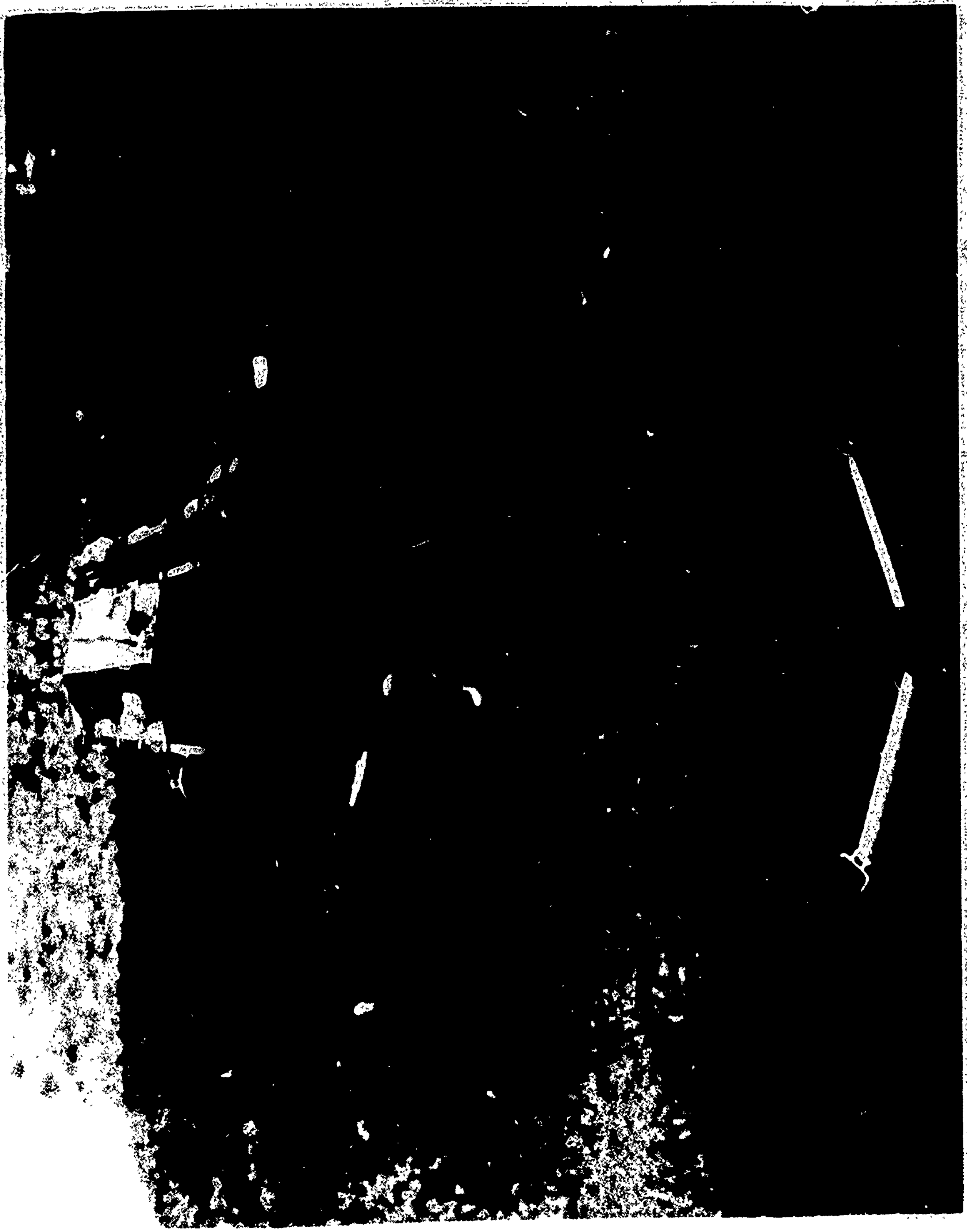

Figure 12. Laser Transmitter Mounted [illegible] Tripod

SECTION V

CONCLUSION

The MILES tank main gun transmitter was tested to ranges of 3,000 meters. Due to the laser transmitter's wide beam at long ranges plus variations in the apparent beam shape as a function of both ambient light level and variations in transmitter output power, this equipment is not highly satisfactory in its current configuration for long range (over 300 meters) marksmanship training.

Requirements for engagement training are different than marksmanship training therefore equipment modifications are suggested to possibly enable marksmanship training with the modified MILES equipment. Incorporation of the following modifications will greatly enhance the marksmanship potential of MILES:

1. FIBER OPTIC BEAM INTEGRATOR

Gallium arsenide lasers typically have an elliptical shaped beam. However, lasers can be purchased with fiber optic integrators that are placed in front of the laser to produce a round and uniform intensity beam. The round beam more closely simulates a real rounds circular error of probability, CEP. A uniform beam also improves the marksmanship results by not allowing variations in power across the beam to cause erratic scoring results. The cost to add a fiber optic integrator is a fractional cost of the laser.

2. LASER OUTPUT POWER STABILITY

In order to have a repeatable hit zone the laser beam must be constant in output power. An increase in power will make it easier to hit the target and a decrease in power more difficult or impossible to hit the target. Variations in ambient temperature cause the MILES laser transmitter to vary in power. Laser aging also causes the output power to change. Laser power variation can be compensated for by precisely controlling the current drive to the laser as a function of ambient temperature or stabilizing the temperature of the laser. While some temperature compensation is used in MILES it is suggested that the temperature compensation be improved to avoid variation in the kill beam geometry. Sampling of the transmitted laser beam and a closed loop control system should be considered.

3. LASER OPTICS

The beam collimation or shape can be improved by using a laser transmitter lens more suitable for long range use. A longer focal length lens is suggested.

4. DETECTOR PLACEMENT AND RECEIVER THRESHOLD SETTING

A smaller laser beam size will force a different detector placement scheme to be determined because with a smaller beam is possible to shoot between detectors.

In marksmanship ranges the targets are stationary or move insignificantly; therefore it is possible to adjust the receiver threshold settings as a function of range to optmize the hit/kill zone of the laser transmitter for a particular range.

5. HIT LOCATION

Marksmanship trainers may require the determination of hit location. This can be accomplished by using a matrix of detectors on the target.

6. POWER LEVEL

In the MILES equipment the maximum range is tailored to correspond to the maximum range of the weapon. In the vicinity of the maximum range the hit/kill data is not repeatable and changes as a function of sunlight level. A possible solution for marksmanship training is to increase the laser transmitter output power slightly to insure repeatable results at the maximum target range and then assign various range targets their own hit probabilities as a function of range of the weapon.

7. ORING DETECTORS

Another possible solution is to digitally "OR" the solar cell detectors together thus eliminating the analog addition of solar cell diffusion capacitance. This diffusion capacitance reduces the MILES detector pulse sensitivity especially in sunlight.

The pulsed CW laser system developed during this program, in our opinion, has the greatest potential for marksmanship because all the above improvements are already incorporated into its design. The collimation achieved and the new detector circuitry allow precise marksmanship training. The CW laser was also successfully demonstrated to be adjustable to exactly duplicate the CEP of a M16 rifle of 0.5 milliradians. The laser power used was only 0.00006 watts.

It is suggested that the MILES improvements be studied further to determine it's cost and efficacy. Although the performance of the laboratory prototype laser is highly promising for use in marksmanship training, there has not been as assessment of the relative cost of implementing these techniques in relation to other alternatives.

It is suggested that development of a pulsed CW laser system for long range marksmanship continue as a parallel effort, for future use where more precision gunnery is required. The CW laser system does not change the basic MILES system but rather changes some components in the system to enable more precise long range gunnery.

LIST OF REFERENCES

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