MARKSMANSHIP AND GUNNERY LASER DEVICE (MAGLAD)

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INTRODUCTION

The Marksmanship and Gunnery Laser Device (MAGLAD) system (Figure 1) provides simmulation of the firing of live M16A1 ammunition during marksmanship training. An eye-safe laser transmitter produces pulses of harmless light in place of potentially lethal and expensive live ammunition. The system includes simulation of firing against both stationary and moving full-scale targets, in addition to a 1/12th-scale record fire range.

The system provides the following benefits:

a. Economy.
   (1) Allows the optimal use of limited range facilities by eliminating or reducing projectile safety requirements.
   (2) Reduces high-dollar support costs through elimination of range safety personnel
   (3) Cuts costs by reducing the requirements for live ammunition and extends the barrel life of weapons because live ammunition is not required.
   (4) The MAGLAD is attached to the trainee's weapon. Thus, special rifles are not required.

b. Expanded Training Capability.
   (1) By reducing the requirement for live ammunition, the training capability is greatly increased. Time that would have been expended in the replacement of targets can be utilized for simulated firing.
   (2) Firing ranges can be set up in areas where live ammunition firing is prohibited, thereby greatly increasing the training capability.

c. Versatility.
   (1) The system versatility is such that simulated firing may be conducted indoors as well as outdoors. Also, the laser rifle may be fired using blank ammunition or with a trigger switch which simulates the trigger squeeze of a loaded M16A1 rifle.
   (2) The 1/12-scale record range can be easily dismantled and set up for operation at any designated site that is a minimum of 32 feet long and 35 feet wide (such as an armory).

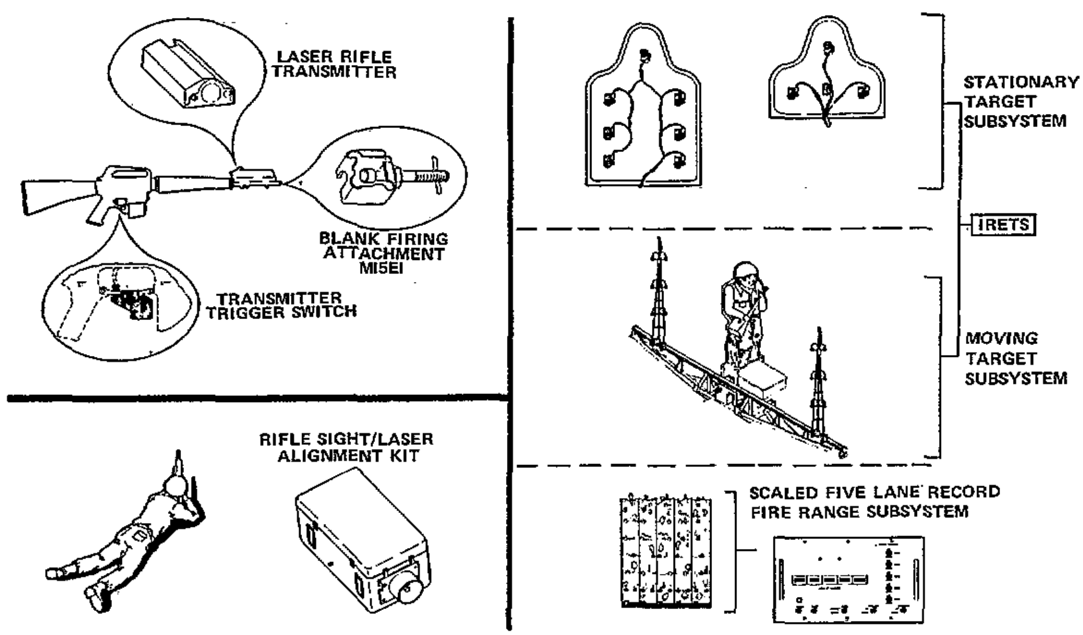

FIGURE 1 - MARKSMANSHIP AND GUNNERY LASER DEVICE (MAGLAD) LASER RIFLE MARKSMANSHIP TRAINER DEVICE P4252

SYSTEM DESCRIPTION

Laser Transmitter.

The laser rifle transmitter (Figure 2) is utilized for simulated range firing at stationary or moving targets equipped with laser radiation detectors, and operated as part of the Infantry Remoted Target System (IRETS), or for simulated firing at the 1/12-scale targets on the scaled record fire range.

The laser transmitter consists of a lightweight, Gallium Arsenide (GaAs) laser diode transmitter configured for attachment to the barrel of the M16A1 rifle, and a trigger switch adaptor which is connected to the transmitter by means of a cable assembly. When in use, the trigger switch adaptor is positioned directly behind the rifle trigger so that when the rifle trigger is pulled the laser transmitter is fired.

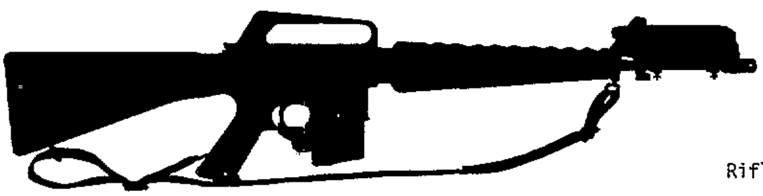

FIGURE 2, MAGLAD TRANSMITTER MOUNTED ON M16A1 RIFLE

Power required to operate the transmitter on the firing range is provided by a 9-volt battery housed in a compartment within the transmitter case. Power required for operation of the transmitter during rifle sight/laser alignment procedures is provided by the 12-volt battery installed in the alignment kit, which is connected to the transmitter by means of a cable assembly.

The transmitter is capable of three modes of operation on the firing range; automatic, semi-automatic, and blank firing.

Mode selection (Figure 3) is provided by means of a rotary switch on the bottom of the transmitter case, with a rounds-limiting capability of either 20 or 30 rounds provided by a toggle switch on the bottom of the case. A self-test feature is also provided.

When triggered by the trigger adaptor, or by sensing the muzzle flash during blank ammunition firing, the transmitter emits a burst of 16 laser pulses per round. The bursts are repeated at the firing rate of the weapon.

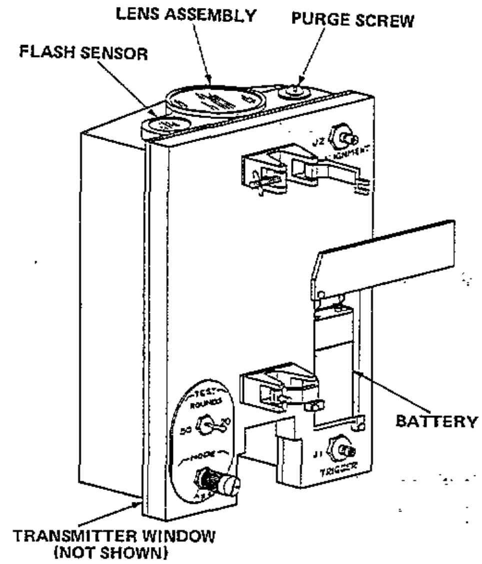

FIGURE 3. LASER RIFLE TRANSMITTER

Rifle Sight/Laser Alignment Kit.

A unique feature of the MAGLAD is the portable and self-contained alignment kit which provides for precise field alignment of the weapon sights to the laser beam axis within the click-stop resolution of the sights.

The alignment kit consists of a portable case equipped with carrying handles, input and output power connectors, a viewing window, ACTUATE switch, and a removable cover.

A sight tube attaches to the M16A1 rifle and installed laser transmitter.

A shroud assembly is attached to the outside of the case to provide light shielding and an entry port for the sight tube assembly.

As shown in Figure 4, the Alignment Kit eliminates the need for cumbersome and inaccurate remote target boards. When the rifle alignment sight tube is installed on the rifle and inserted into the alignment kit shroud assembly, the laser beam appears as a bright orange spot silhouetted by the rifle sights. The shooter adjusts his sight until the orange dot rests on the front sight, producing the correct sight picture.

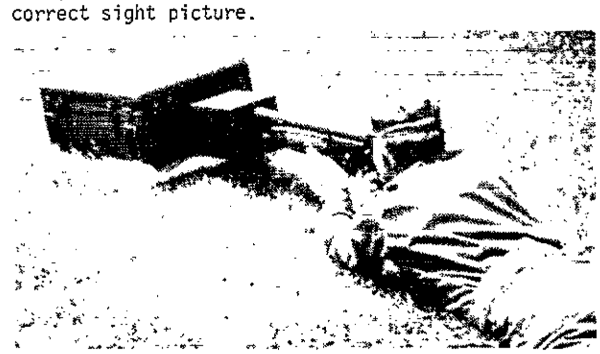

FIGURE 4. MAGLAD ALIGNMENT KIT IN USE

Rifle Laser Radiation Detector, Stationary Target Kit.

The stationary detectors in the MAGLAD system attach to standard 'E' and 'F' silhouette targets as shown in Figure 5. In combination with the sharp beam skirt of the laser transmitter they accurately define the target shape over a wide range of atmospheric conditions.

FIGURE 5. MAGLAD KIT, RIFLE LASER RADIATION DETECTOR, STATIONARY, MOUNTED ON "E" AND "F" TARGETS WITH RECEIVER-DECODER MODULE

The stationary target kit is utilized in conjunction with the Infantry Remoted Target System (IRETS). When the laser beam strikes any detector on the target, the resultant output of the receiver decoder is optically coupled to the IRETS control mechanism, causing the target to drop, and also recording a hit on the IRETS control console. E and F-Type targets are interspersed on a fixed range at distances of 25 to 300 meters to provide realistic marksmanship training.

The detector kit consists of seven laser radiation detectors installed on standard E-Type targets or four detectors installed on F-Type targets, two cable assemblies and a receiver-decoder assembly.

Each detector assembly contains a printed circuit (PC) board consisting of a silicon solar cell for detection of laser rifle transmitted energy, and electronic circuitry for preamplification of the detected energy to a useable level for an input to the receiver decoder.

The receiver-decoder assembly consists of a rectangular metal housing equipped with mounting flanges containing a PC board assembly. It receives and amplifies the summed output of all detector assemblies located on a single target and provides a seven millisecond output pulse to activate the IRETS target mechanism and counter circuitry when a hit is recorded.

Rifle Laser Radiation Detector, Moving Target.

The MAGLAD system also includes a moving target lead-angle mechanism system which requires that the marksman lead the moving target by the correct amount to achieve a hit. The amount of lead varies with the speed and range of the moving target. This MAGLAD moving target system is designed to interface directly with the Infantry Remote Target System (IRETS) moving target.

The moving target kit (Figure 6) consists of two detector arrays mounted on the MAGLAD boom assembly. The array provides aiming points (lead angles) for targets either approaching the shooter at a forty-five degree angle, or going away from the shooter at a forty-five degree angle. Normally the detector arrays will not be visible to the shooter who must determine the lead angle required to score a hit.

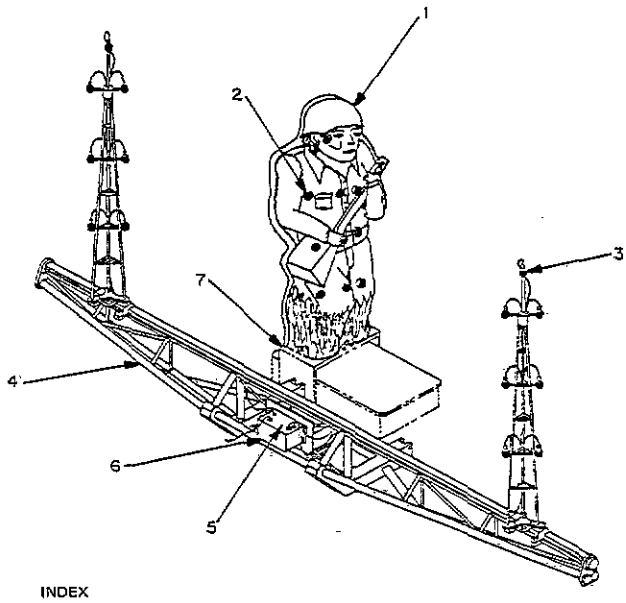

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FIGURE 6. MOVING TARGET KIT

A modified IRETS three-dimensional (3D) target is provided with detectors to record hits when the target is stationary.

A control box mounted on the boom assembly contains three receiver-decoder PC boards to receive and decode the output of the detectors installed on the detector arrays and the 3D target. One additional control board selects the appropriate detector array depending on direction of motion.

Record Fire, Five Lane, Scaled, Kit.

For indoor training, MAGLAD provides a complete 5-lane Record Fire Range, scaled to 1/12 actual size. Each lane consists of 7 "E" and "F" type silhouette targets arranged in the standard record-fire configuration. The target firing distances are from 4 to 25 meters, corresponding to full-scale ranges of 50 to 300 meters. The targets are under control of a master console operated by the instructor. Each bank of targets may be erected or dropped independently, in any sequence and for any interval of time. A hit on any target is logged on the console display and, at the instructor's option, causes the target to drop. The standard MAGLAD transmitter is adapted to indoor, scaled firing by snapping a cap over the exit aperture, reducing the exit aperture and narrowing the beam size. This adaptation, together with the unique design concept employed on the scaled silhouette targets, provides accurate target definition at all scaled ranges, and automatically compensates for parallax so that a weapon which is zeroed for full-scale range can be used indoors with no readjustment of the sights. The scaled Record Fire Range is intended primarily for use by Reserve and National Guard units which have infrequent access to full-scale ranges.

The scaled record range kit (Figure 7) consists of a control console, target assemblies and a cable assembly set. The control console is a portable, lightweight unit which can be transported by one man, within the restraints of system cabling, by means of handles located on the front panel. The console is normally located behind the line of shooters and positioned where the operator can view all targets. The console contains the electronic circuitry, controls and indicators for application of power to the console and for control of target assemblies. The control panel contains two-digit lane hit counters for monitoring target hits.

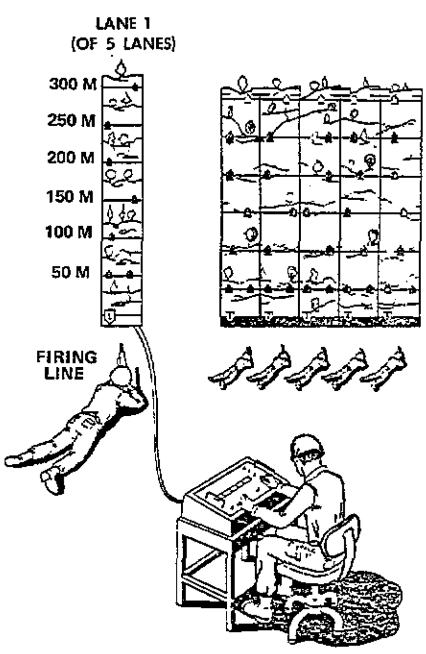

FIGURE 7. SCALED RECORD RANGE

The scaled range target assemblies consist of 20 F-Type scaled targets and 15 E-Type scaled targets. The assembly housing contains the target actuating mechanisms, a detector assembly and a detector amplifier. Each of the thirty-five target assemblies are functionally identical, but are physically different in that detector and target body configuration vary depending upon scale range bank placement.

Technical Considerations (System Design).

The principal requirement of the MAGLAD design, in fact the entire point of the MAGLAD system, is to provide a precise interaction between the laser beam and the target detectors which will accurately simulate the firing of service ammunition against the targets. Simulation accuracy must be maintained at ranges from 25 to 300 meters under all visibility conditions in which the trainee can take a sight picture on the 300-meter target.

The MAGLAD performance specifications appear deceptively simple. After carefully examining the effects of operating/visibility range requirements on scoring accuracy, certain subtleties then become evident, and the design precautions that are necessary to minimize these effects can be appreciated. As in any laser scoring system, interaction between the simulated weapon and the target is by transmission of an optical pulse or pulses. The angular or lateral extent of these pulses, that is, the shape of the transmitted beam, is a principal system parameter affecting scoring accuracy. To score a hit, however, the laser pulses must be detected by some means; the detection process requires that the amplitude of the laser pulse at the target exceed some threshold or sensitivity level. It is the interaction between beam shape, detector threshold sensitivity, and the variables affecting signal amplitude that ultimately determine scoring accuracy and simulation effectiveness. An additional complication affecting scoring accuracy is the cost-imposed requirement of a finite number of detectors comprising the target array.

For a given transmitter power output, the amplitude of the laser pulses at the target is affected by at least four variables:

- The instantaneous value of the atmospheric scintillation envelope;
- The average value of atmospheric attenuation corresponding to prevailing visibility conditions;
- The target range; and
- The aiming error in relation to the shape of the transmitted beam and the target detector geometry.

In the MAGLAD it is only necessary to convey bilevel, that is, hit or miss information to the target, without regard to player identity or weapon hierarchy. Accordingly, the effects of atmospheric scintillation on scoring accuracy can be largely overcome by selecting a pulse transmission format which utilizes redundant pulses transmitted over a time interval exceeding the correlation interval of the scintillation envelope. The only concern here is that the pulse burst not be too long, or rifle motion during the burst could lead to erroneous scoring. Fortunately, studies indicate that an interval of 10 to 15 msec is adequate to ensure reception of the necessary number of pulses in the presence of severe scintillation, and that rifle motion during this interval -- even when firing blanks -- has negligible effect on the fidelity of simulation.

If the only factor contributing to signal level at the detector was the width of the transmitter beam, the effective simulation requirement could be met quite simply by specifying a "width" corresponding to the 0.4 mr, 1 σ dispersion error of the rifle, and assuming that the simulated dispersion error would remain constant over all ranges and all atmospheric conditions. However, the solution is not that simple. We customarily regard a laser beam width as constant, and to the extent that we refer to the off-axis angle at which the beam intensity is down by some specified amount relative to its boresight value, this usage is correct. The skirts of a practical transmitter beam are not infinitely steep, however, but instead have a shape determined by laser source geometry and collimating optics design. In addition, the target detectors do not measure relative power, but produce an output whenever the signal level exceeds some preset absolute power threshold. As a consequence the angular width of the transmitter beam, as measured by the target detector, is not a constant, but depends upon beam skirt taper and signal level. Since signal level, in turn, depends upon both range and visibility, and since skirt shape is a parameter, that is at the designer's disposal, the considerations involved in configuring a system which will provide effective simulation over a variety of range and visibility conditions become more evident.

A further complexity is imposed by the desire to construct the target detector array using a minimum number of detectors. The absolute power threshold is developed from the sum of all detector outputs. As a result the effective beamwidth measured by a single detector is increased by the off-axis energy received by an adjacent detector in the array. The magnitude of the effective beamwidth increase is a function of the beam density distribution and off-axis displacement of adjacent detectors. As can be seen from Figure 8, the result of summing two detectors positioned a beamwidth apart forms a pattern approximating an ellipse. The dimensions of the ellipse are a function of the detector separation, individual detector sensitivity, receiver threshold and illuminating beam power distribution. The proximity of other detectors modifies the pattern in a predictable manner. Since the pattern modification results from summing off-axis energy arriving at adjacent detectors, care must be taken in the laser source and optics to assure repeatable characteristics in the beam power distribution. Similarly, the location of each detector relative to both the target edge and the other detectors is critical.

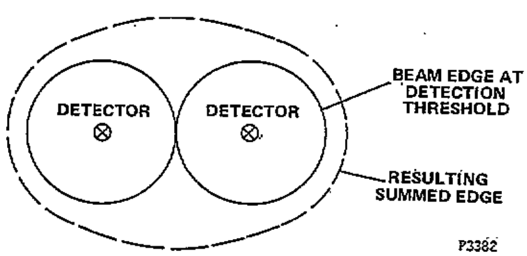

FIGURE 8. EFFECT OF SUMMING DETECTORS

Experience early in the program showed that extensive theoretical analyses could, at best, only approximate the effects that beam shape and detector location and sensitivity produce on simulation effectiveness and that, therefore, there was no analytic substitute for thorough field experimentation. Accordingly, extensive field testing has been used to verify and modify the system design.

FIELD TESTS

Laboratory and field tests were conducted to obtain data from which major design parameters could be derived. Source size and emission power can be traded for optical design parameters to generate a theoretically optimum beam shape. Size and cost constraints of the laser tended to drive the design towards shorter focal length optics. Early experiments with multiple junction diodes indicated "hot" spots within the beam which affected target definition and repeatability. These "hot" spots could be partially smoothed by use of a diffuser, but this approach softened the beam skirts producing large target size variations with simulated weather attenuation.

Figure 9 and Figure 10 are beam intensity profiles measured at 150 and 300 meters using a calibrated threshold detector. The source was a 6 mil dual junction diode with a total output power rating of 10 watts. The output power of the beam using a 9-inch focal length lens and an aperture of 1.125 inches was adjusted to measure 250 milliwatts. This was approximately 50% of the collectable power with this particular focal length and aperture, thus allowing for temperature dependent variations anticipated in the final configuration.

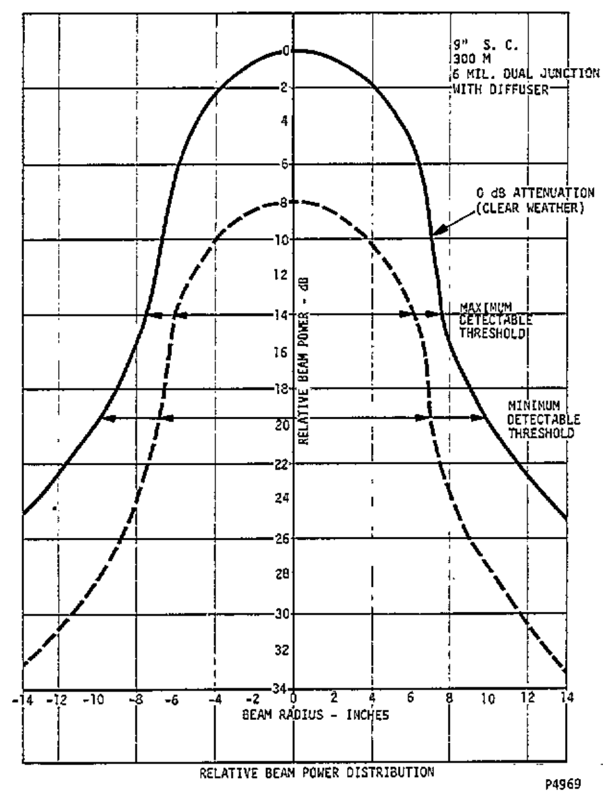

FIGURE 9. MEASURED BEAM POWER DISTRIBUTION

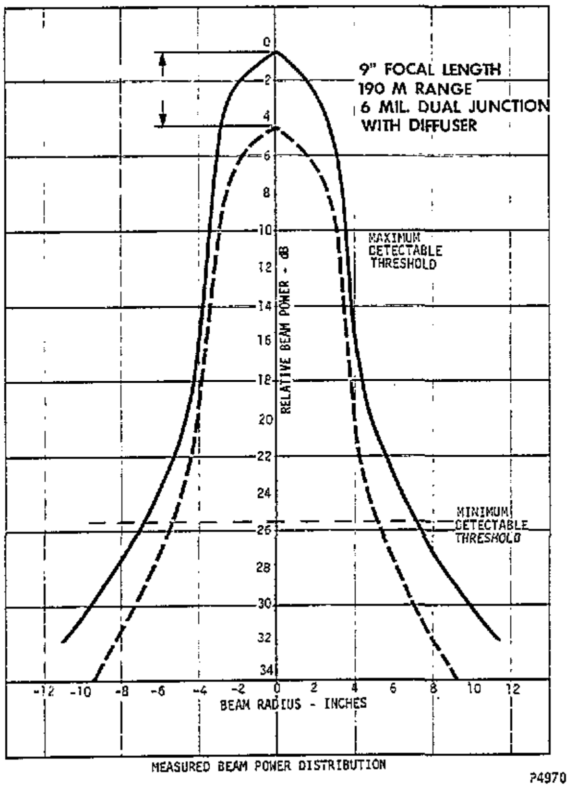

FIGURE 10. MEASURED BEAM POWER DISTRIBUTION

The dash lines on the figures resulted from insertion of neutral density attenuators in the beam to simulate reduced visibility conditions. At 300 meters, as shown in Figure 9, an 8 dB N.D. attenuator was inserted. Examination of the curve at a relative beam power corresponding to achievable receiver thresholds (19.5 dB) shows that the beam pattern diameter under the condition of 0 dB attenuation (corresponding to clear day) was 20 inches. Introduction of 8 dB of simulated weather attenuation reduced the diameter to 14 inches.

This is a delta of 6 inches.

Only a small reduction of this weather-induced delta could be accomplished by moving the detected threshold higher on the curve. Adjustment of the threshold is possible, however, if reduction of the mean diameter is desired.

At 150 meters, using the same source, it is apparent on the curves of Figure 10 that the diameter reduction caused by the insertion of 4 dB weather-induced attenuation is not beyond reason at this range. Considerable improvement in the delta can be made by raising the threshold to the 14 dB level, however. This also has the effect of reducing the mean beam pattern diameter from 12 inches to approximately 8 inches. Further raising of the threshold is possible if a reduction in the effective beam pattern diameter is desired when configurating a target array. The limit is reached when the threshold is raised to within 6 dB of beam extinction. This is considered to be an allowable safe power margin in a good design.

Referring again to the 300 meter case shown in Figure 9, a limit is reached at approximately 14 dB. This level allows 8 dB attenuation for weather and a 6 dB power margin. The effective mean beam diameter at this level is approximately 14 inches. It can be seen from these curves that at each range there is an optimum threshold to minimize the apparent diameter change as a function of weather attenuation. Furthermore, it is possible to adjust the effective beamwidth dimensions within limits when configuring a target edge.

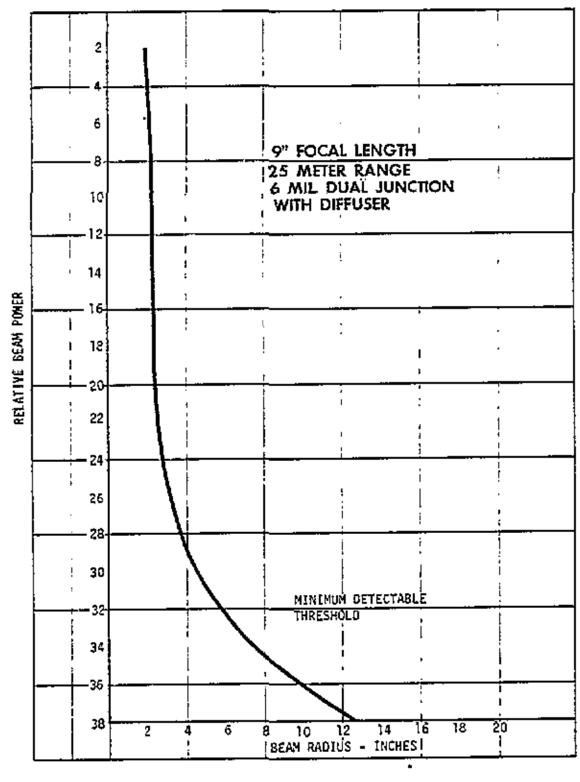

FIGURE 11. MEASURED BEAM POWER DISTRIBUTION

At ranges of 100 meters or less, the problem is reversed. Here the desire is to increase the effective beam dimensions beyond the divergence profile. It was expected that the diffuser would broaden the beam and, in effect, this is the case. Here, operation at or near the minimum detectable threshold is necessary to obtain diameters large enough to cover the target with a minimum detectable threshold when the beam diameter is 10 inches. Fortunately, at minimum range, minimum attenuation is incurred due to weather. Because of the slope of the curve a small change in the received signal level causes a large change in the effective diameter.

It could be concluded from the experiments described thus far that a beam approaching a theoretically optimum dimension of 12 inches could be generated at all ranges below 250 meters. At 250 and 300 meters, the body portion of the "E" target could be adequately covered with a single row of detectors.

The "head" of the "E" target, however, with a dimension of 8 inches, presented a major problem. The minimum diameter obtainable at 300 meters with an allowable power margin was 15 inches. Alternative solutions included the use of two detectors at the head which could be combined logically in such a way that a detectable threshold must be reached in both detectors to indicate a "hit". The body then would be covered by a single row of detectors. Since this would incur the use of two additional receiver amplifiers and threshold detector circuits with associated increase in cost, this approach was considered undesirable.

Instead, efforts were directed toward improving the beam density profile with a fiber optic collector attached integrally with the laser diode. Tests of these units indicated characteristics considered desirable. Namely, a more uniform source and a relatively sharp-edge profile.

The photograph shown in Figure 12 was taken of a beam imaged at infinity and viewed at 10 meters by an infared sensitive television camera. The uniformity of the brightness appeared to be a definite improvement over the diffuser smoothed image.

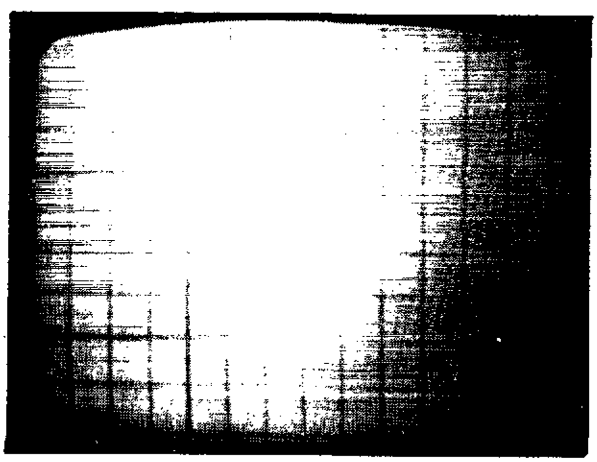

FIGURE 12. BEAM IMAGED AT INFINITY AND VIEWED AT 10 METERS

Beam profiles were generated using the fiber optic laser. Due to the sharpness of the beam profile a shorter focal length lens was necessary to obtain beam widths comparable to those experienced with a 9 inch focal length lens using a dual junction diode and diffuser. Figures 13, 14, 15 and 16 are profiles generated at 25, 100, 150 and 300 meters using a 136 mm achromatic lens. Dashed lines on the curves result from the insertion of weather induced attenuation. It can be seen that the reduced delta incurred by this attenuation is a function of the steepness of the skirts of the beam at usable threshold levels. At 300 meters the beam diameter can be adjusted to approximately 8 inches, providing a delta of 5 inches.

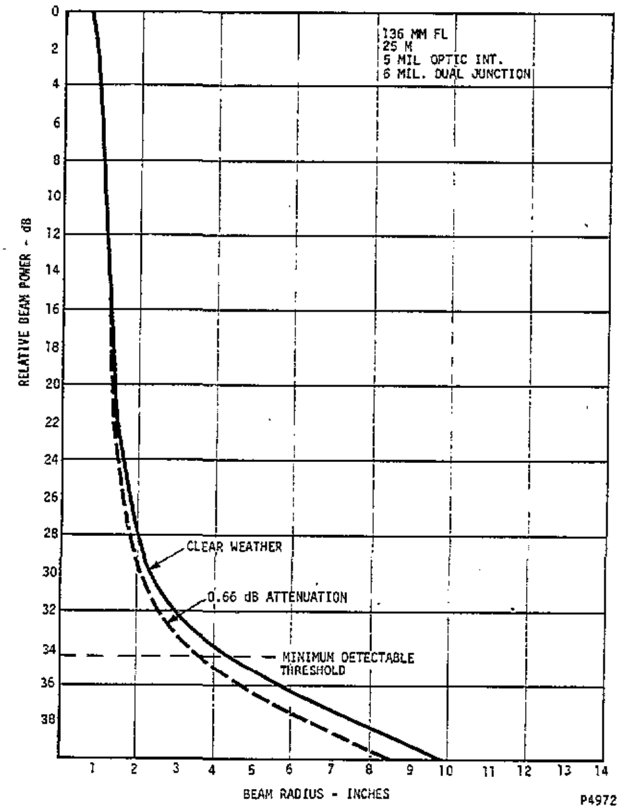

FIGURE 13. MEASURED BEAM POWER DISTRIBUTION

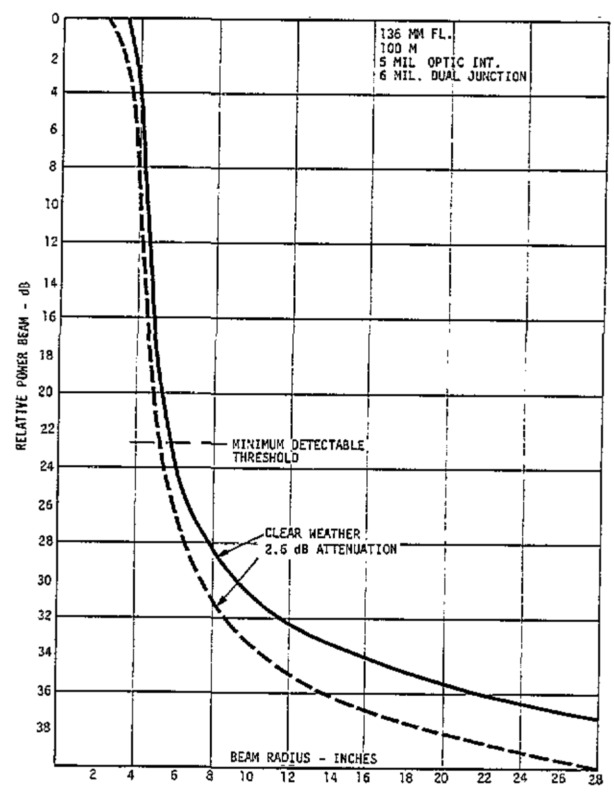

FIGURE 14. MEASURED BEAM POWER DISTRIBUTION

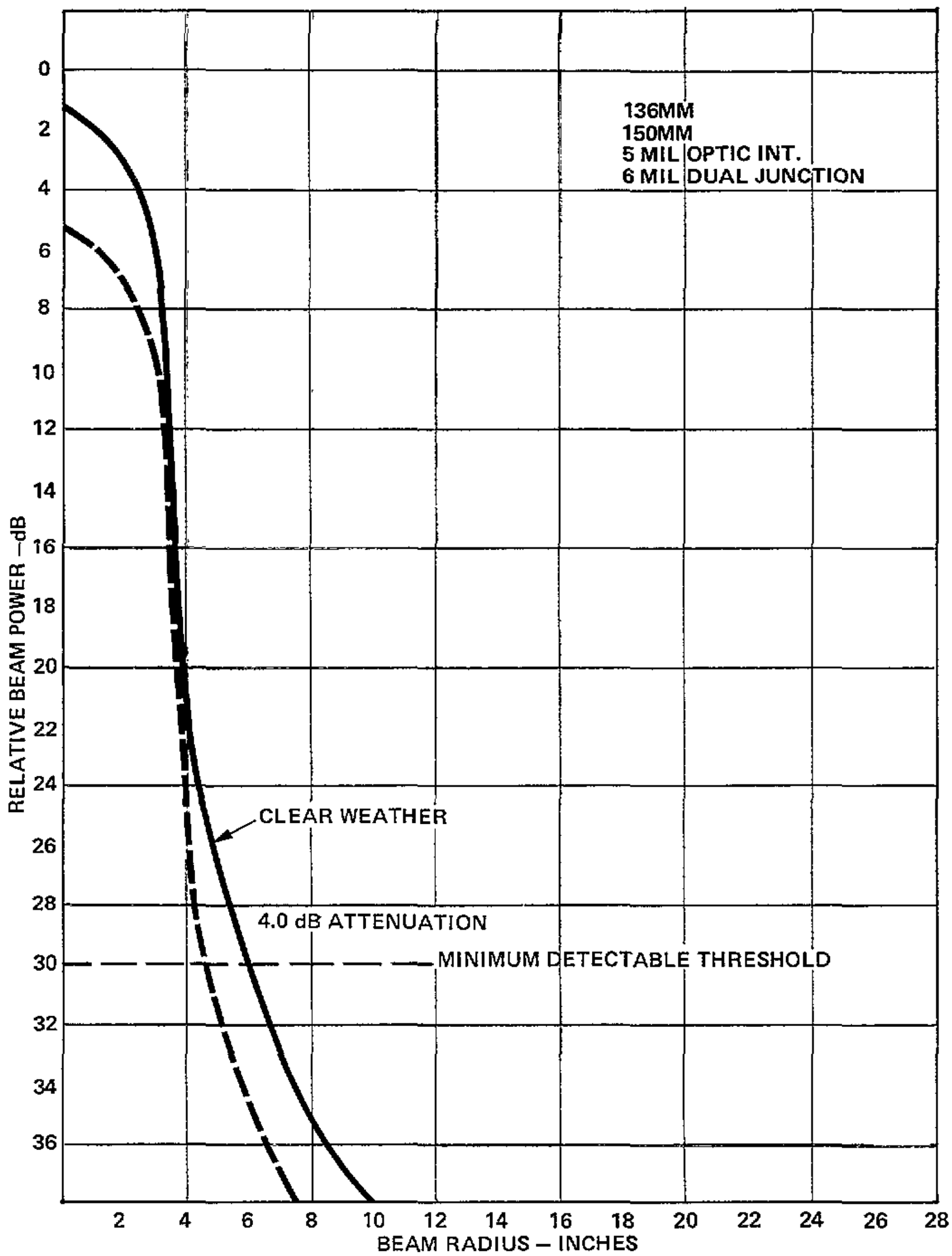

FIGURE 15. MEASURED BEAM POWER DISTRIBUTION

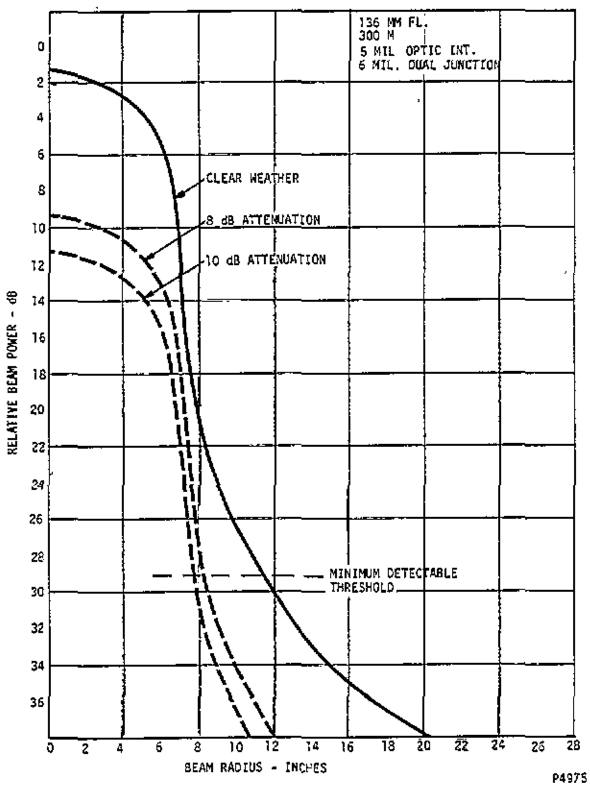

FIGURE 16. MEASURED BEAM POWER DISTRIBUTION

Five inches of change in apparent target edge was considered to be a good design goal at the 300 meter range since this is an error of roughly ± 0.2 mr which is one-half of the standard deviation of the weapon dispersion.

Examination of the beam profiles of 25, 100, 150 and 300 meters shows that a beam radius delta on an individual detector is minimum at each range when the detector threshold is at the maximum allowable threshold. This indicates that an increase in laser radiated power causes a decrease in the weather induced delta. Of more importance, however, is the corresponding decrease in beam profile diameter. A decrease in diameter is desirable at 300 meters to improve edge definition on the head. Reduction in diameter at the short range, however, though improving edge definition, tends to increase the required number of detectors to paint the short range "F" targets. The compromise selection of 5.35 inches for focal length optics is therefore justified.

Transmitter Design.

The primary design emphasis in the achievement of a sharply defined and homogeneous laser beam of very narrow dimensions that accurately defines the target for all ranges and conditions of operation has been accomplished. The resulting, optimized, MAGLAD beam has an angular divergence of 1-milliradian with extremely steep skirts produced by a fiber optic-homogenized laser source working into a corrected lens of 132 mm focal length. An internal temperature control maintains the laser output power substantially constant over the environmental temperature range.

Laser Radiation Detector Design.

The MAGLAD detectors employ inexpensive, reverse-biased, PN photodiodes (solar cells) to detect the transmitted laser energy. This type of detector may also be operated in an unbiased (photo-voltaic) mode. When operated in a reverse-bias mode and exposed to sunlight, a direct current flow is produced through the detectors which must be supplied by the system battery. When several detectors are involved, the current demand in strong sunlight far exceeds what can be supplied by a small battery for a period of time corresponding to a typical training exercise.

Some system designs recognize that it is difficult to meet the solar background current demand of reverse-bias operation and, instead, employ unbiased or photo-voltaic operation. This solves the battery problem but introduces an entirely different problem: the sensitivity of a solar cell in the unbiased mode varies greatly according to the amount of sunlight to which it is exposed, which means that the size and shape of targets instrumented with unbiased detectors will change with ambient light conditions.

This effect has been confirmed by laboratory and field tests conducted by ILS, and it is the reason that biased detectors are necessary, and are used, in the MAGLAD receiver. Thus, it is evident that the use of photo-voltaic detectors to instrument the MAGLAD targets would result in targets whose size and shape vary with weather, orientation to the sun, and time of day a clearly unacceptable basis for accurate, transferable marksmanship training.

The signal present at the solar cell output is at a very low level, so that many EMI sources could produce equivalent signal levels on the cabling between the solar cells and the amplifier. Amplitude discrimination would therefore be impossible. Time domain or digital filtering is not practical because the detector must respond to only a few pulses of a transmitted pattern which has already been randomized by atmospheric scintillation. With no reverse voltage bias applied to the solar cell detector, the detector would bias itself into saturation in the presence of strong background light even when the detector is preceded by an infared filter. A variety of solar cells were investigated, but none were found with the required sensitivity and which would not saturate when subjected to strong background illumination. Therefore, a solar cell detector/pre-amplifier package was placed at each sensor location on the target. This accomplished two objectives:

a. A supply voltage was made available to each solar cell so that sensitivity could be made independent of background light level by applying reverse bias to the cell; and

b. The gain present in the preamplifier allowed higher signal levels to be placed on the cabling between the detectors and the main amplifier so that noise pickup on this cabling is no longer of sufficient amplitude to cause a significant detection error rate.

STATUS:

Production of advanced design prototypes is complete and testing has been conducted at Fort Benning and Aberdeen Proving Ground. Although the final tests reports have not been completed, preliminary results appear to verify the design concept and the utility of MAGLAD for marksmanship training.

SUMMARY:

The MAGLAD system provides marksmanship training for the M16A1 rifle, using an eye-safe Gallium-Arsenide laser and silicon diode detectors. At the user's option, the system will function with a trigger switch (no ammunition) or with blank ammunition. Detectors mounted on "E"-Type, "F"-Type and "3-D" moving targets accurately simulate the targets' profiles for a wide range of visibility and environmental conditions.

A 1/12-scale range is provided which allows marksmanship training indoors or outdoors where full-scale ranges are not practical.

An alignment kit allows fast, accurate alignment of the MAGLAD beam to the M16A1 rifle.

An engineering development program will soon be under way to refine the configuration of the MAGLAD and prepare it for full-scale production.

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