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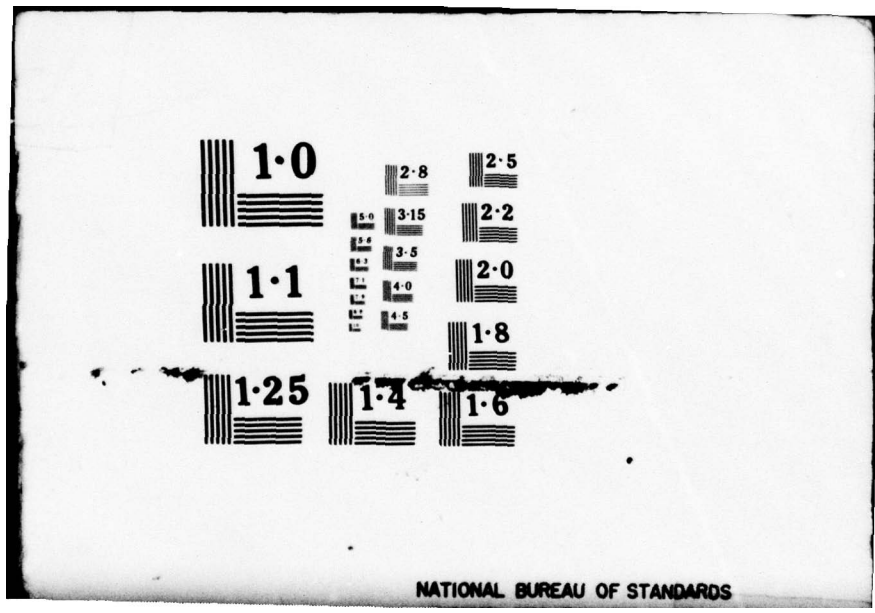
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LASER RANGEFINDER/TANK THERMAL SIGHT INTEGRATION STUDY

Texas Instruments Incorporated
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Dallas, Texas 75222

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FINAL TECHNICAL REPORT
LASER RANGEFINDER/TANK THERMAL SIGHT
INTEGRATION STUDY

Contract DAAK70-77-C-0153
February 1978

SECTION I
INTRODUCTION

→ This report documents the results of a study performed by Texas Instruments Incorporated to analyze a government-proposed design concept for integrating AN/GVS-5 Laser Rangefinder (LRF) modules into the AN/VSG-2 Tank Thermal Sight (TTS). The primary objectives of the study were to determine the compatibility of the two systems and to assess the impact of the proposed integration on the recurring costs associated with the production of the TTS systems.

The initial design concept for the LRF/TTS integration was devised by the U. S. Army Frankford Arsenal. Texas Instruments analysis of this concept revealed certain shortcomings and limitations which prompted an increase in the scope of the study in order to design additional features which were deemed necessary to the successful execution of a tank mission. The study was further expanded to include a brief investigation into the integration of a CO₂ laser rangefinder into the TTS.

In the sections which follow, this report presents brief descriptions of the AN/GVS-5 and AN/VSG-2 systems, and describes the concept for their integration as furnished by Frankford Arsenal. Next, Texas Instruments alternative concept is discussed, along with the technical risks, tradeoffs and cost impact. Also presented are the results of the CO₂ laser alternative investigation.



SECTION II
EQUIPMENT DESCRIPTIONS

A. LASER RANGEFINDER

The AN/GVS-5 Laser Rangefinder is a lightweight device designed to provide an accurate determination of the range from a weapon to its target or other point of interest. This determination is made by measuring the time required for a laser pulse to travel to the target and back, and then converting this time to a distance figure. The AN/GVS-5 is capable of performing this function in a time of one second.

Basic parameters of the AN/GVS-5 are shown in Table 1.

Table 1. AN/GVS-5 Laser Rangefinder Parameters

Maximum range	10 km
Worst case range	5 km
Safe range	1.1 km
Range accuracy	± 10 meters
Minimum range gate	0.2 - 5.0 km
Maximum ranging rate	One per second
Environment	Per MIL-STD-810
Reliability	30,000 mean ranges between failures
Module weight (excluding battery and packaging)	One pound (approximately)

B. TANK THERMAL SIGHT

The AN/VSG-2 Tank Thermal Sight (TTS) is a fire control periscope designed for the M60A3 tank. It is slaved to the XM-21 ballistic computer and the main weapon and consists of three viewing channels; an eight-power daytime channel, a unity power daylight channel, and a far infrared channel. This three-channel approach provides the tank gunner and commander with both daytime and nighttime fire control capability.

Unclassified parameters of the TTS are listed in Table 2.



Table 2. AN/VSG-2 Tank Thermal Sight Parameters

Elevation excursion	+22 -12 degrees minimum
Operating temperature range	-25 to +125°F
Unity field of view	10° elevation 21° azimuth
8X Telescope field of view	8° circular
Thermal channel field of view	
Narrow	2.58° elevation 5° azimuth
Wide	7.74° elevation 15° azimuth
Weight (pounds)	
Periscope	95
(Head Assembly	63)
(Gunner's Display	32)
Power Converter	25
Commander's Display	32
Environment	Per MIL-STD-810
Reliability (MTBF)	400 hours



SECTION III GOVERNMENT-PROPOSED DESIGN

A. DESCRIPTION

In the LRF/TTS integration design furnished by Frankford Arsenal the rangefinder modules are packaged in the TTS Gunner's Display, in an area around the 8X telescope assembly (See Figure 1.) Basic features of the design are listed below.

- (1) The aperture for the laser transmitting beam is 20 mm in diameter.
- (2) The 8X telescope and laser receiver share the same objective optics.
- (3) A beamsplitter is added to the 8X optical path to split the 1.06 μm energy to the detector.
- (4) A fixed reticle is located in the 8X eyepiece focal plane as the boresight point for the LRF.
- (5) The ballistic computer interface with the TTS remains unchanged.
- (6) TTS system controls are rearranged to locate the range readout on the front panel and the firing button on the auxiliary panel. Also, a first and last pulse logic switch has been added.
- (7) Laser connectors are located on the side of the Gunner's Display, behind the firing button.

Major casting changes were confined to the Gunner's Display area. The only risk associated with these changes is that the shock characteristics of the system might change due to the added weight and different mounting webs. However, this risk remains low, and does not threaten the feasibility of the concept. The final true risk evaluation could be based on prototype shock and vibration tests.

B. PROBLEMS AND LIMITATIONS

Certain design limitations and mission scenario problems are inherent in the Frankford Arsenal design concept.

First, the 20mm aperture allowed for the laser transmitting beam yields a beam divergence of .75 milliradian; whereas, the performance level desired for the tank application requires a beam divergence of not more than 0.5 milliradian.

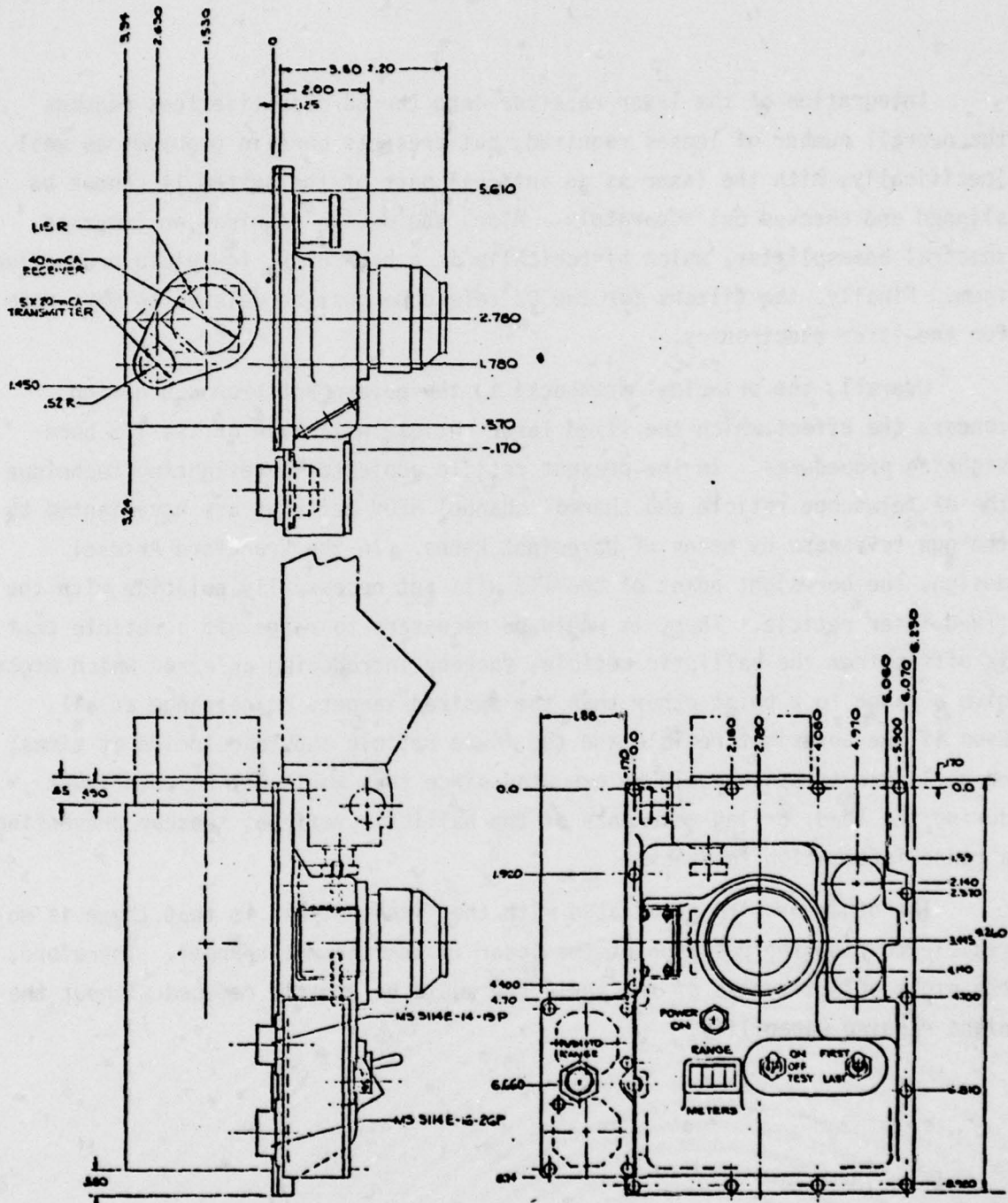


Figure 1. Tank Laser Rangefinder Configuration



Integration of the laser receiver into the 8X objective lens reduces the overall number of lenses required, but presents certain problems as well. Specifically, with the laser as an integral part of the system it cannot be aligned and checked out separately. Also, the design requires an immersed spectral beamsplitter, which historically is a high risk, low yield production item. Finally, the filters for the 8X telescope must be deleted to make room for the laser electronics.

Overall, the principal drawbacks to the government proposed design concern the effect which the fixed laser reticle will have on the TTS boresighting procedures. In the present reticle projector boresighting technique the 8X telescope reticle and thermal channel NFOV reticles are boresighted to the gun telescope by means of boresight knobs. In the Frankford Arsenal design, the boresight point of the TTS will not necessarily coincide with the fixed laser reticle. Thus, it would be necessary to range off a reticle that is offset from the ballistic reticle, thereby introducing an error which might give a range to a point other than the desired target, or no range at all. Even if the boresight reticle and the fixed reticle should coincide at times, no ballistic solution could be executed since they would not be coincident during the lead, or lag movements of the ballistic reticle; thereby preventing a range information feedback.

The other problem associated with the fixed reticle is that there is no reticle to show the position of the laser in the thermal channel. Therefore, the night effectiveness of the periscope would be greatly reduced without the night ranging capability.



SECTION IV TEXAS INSTRUMENTS DESIGN CONCEPT

A. GENERAL

The LRF/TTS integration concept devised by Texas Instruments would eliminate most of the performance limitations discussed previously, and would greatly extend the overall capabilities of the TTS, although at the cost of making additional modifications to the system.

In the TI design, the LRF modules are packaged into the Gunner's Display assembly, and casting changes are made to the Head Assembly and Gunner's Display to accommodate the changes. A layout of the proposed design is shown in Figures 2, 3, and 4.

B. DETAILED DESCRIPTION

1. Rangefinder Location

The laser rangefinder is located on the 8X telescope assembly. With the exception of some of the electronics, the modules are mounted on a plug-in optical bench which can be removed from the telescope. A mirror adjustment on the bench permits alignment of the laser transmitter and receiver to each other prior to installation of the 8X telescope. The LRF is boresighted to the 8X telescope by means of a boresight mirror which can be adjusted in azimuth and elevation until the two optical paths coincide at the point of the 8X reticle. Laser transmitter optics consist of a two-element afocal telescope with $8X \pm 5$ percent magnification and a clear aperture of 32 mm. Beam divergence is 0.5 milliradian. The receiver has a clear aperture of 32 mm with a beam divergence of 0.5 milliradian ± 10 percent.

The laser electronics are located on the rear cover of the Gunner's Display, along with the input power connector. Both are handled as plug-in modules, linked by an interface cable which is integrated with the control switches.

The laser firing switch is located on the gunner's turret control handle. The laser range readout and the mode switch are located on the 8X telescope front panel assembly, as shown in Figure 4.

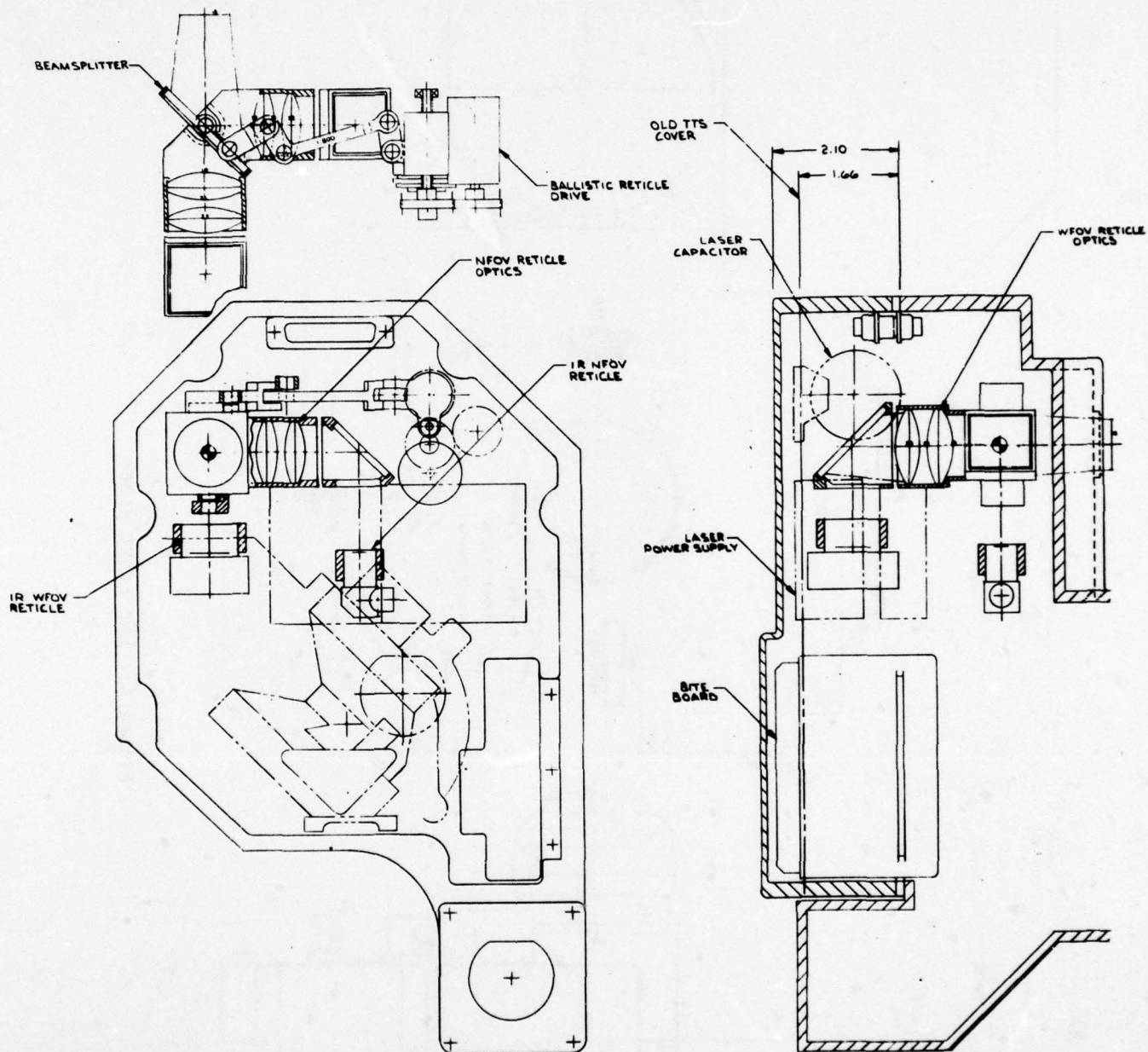


Figure 3. IR Reticle and Laser Electronics

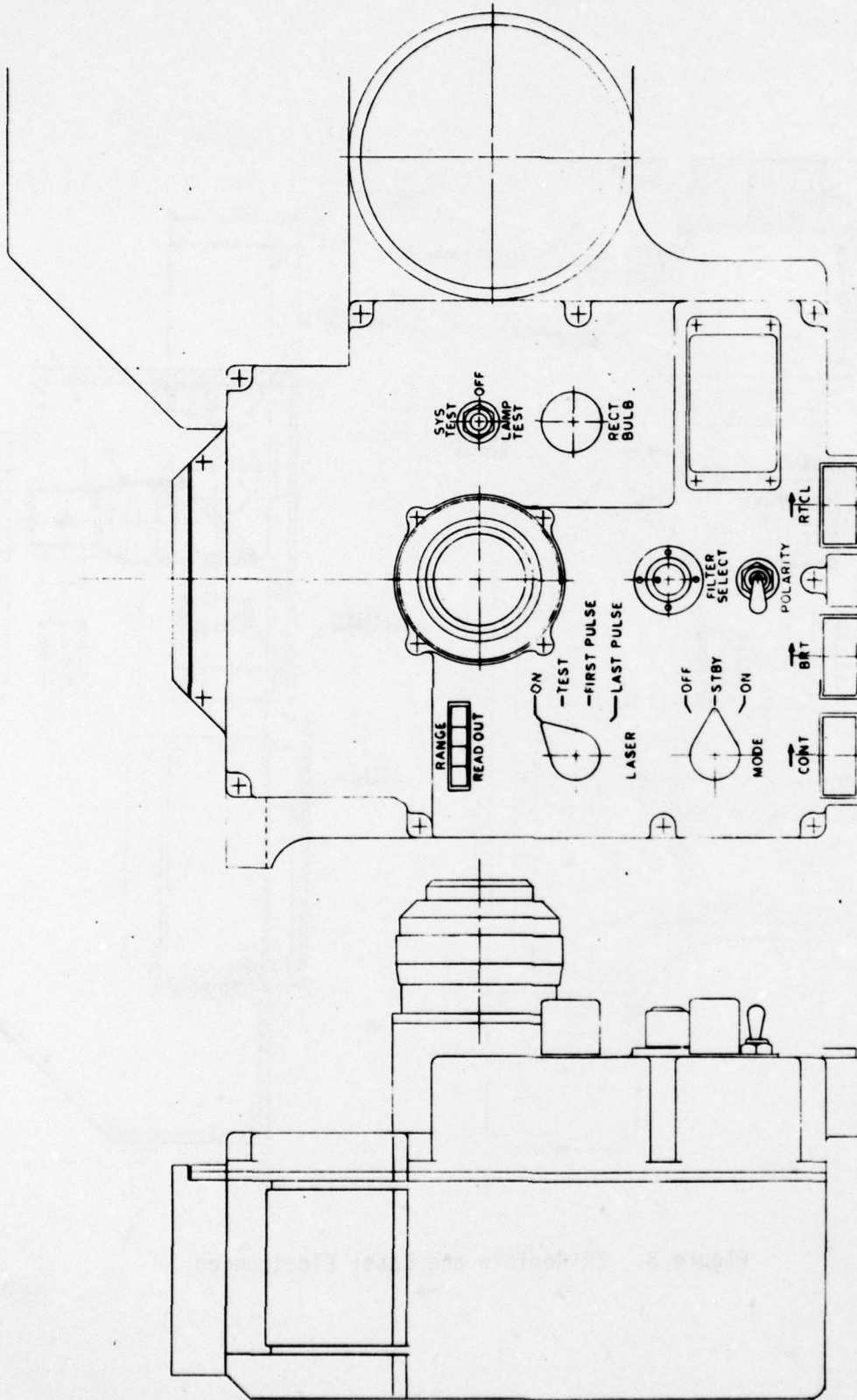


Figure 4. LRF Front Panel



2. Reticle Projection

The present TTS reticle projection unit is eliminated, and ballistic solutions for laser ranging and for the 8X and thermal channel NFOV reticles are accomplished through the use of rotating beamsplitters. One beamsplitter, located in front of the 8X objective telescope, splits the 1.06 μm energy out to the rangefinder, while the 8X reticle is projected onto the back side to the 8X telescope. The thermal channel NFOV reticle is projected into the IR field using a similar drive mechanism and a second beamsplitter. The thermal channel WFOV reticle is also projected through the NFOV beamsplitter, and is not moved for ballistic solutions.

Initial azimuth boresight is performed with a zero position potentiometer located on a computer control panel. Elevation boresight is achieved initially by mechanically aligning the thermal channel NFOV reticle with the 8X reticle and adjusting an offset into the head mirror position with a potentiometer similar to the one used for azimuth boresight.

The mechanism which provides the required mirror movement for reticle control and laser steering consists of a stepper motor, loaded ball screw, and linkage assembly. The configuration for the control system is illustrated in Figure 5. Required mirror adjustment is determined in the computer, either in terms of the amount of mirror movement, laser line-of-sight (LOS) movement, or motor movement. All of these are directly related through conversion factors that relate motor movement to equivalent LOS movement as determined by the ball screw ratio and linkage transfer relationships. (Each 15-degree step of the motor corresponds to 0.05 mr of mirror movement and 0.10 mr of laser LOS movement.) The required adjustment is converted to the proper position control by use of Scale Factor I (Figure 5). This commanded position is then compared with the actual position, thus generating the position error ϵ . The actual position is obtained by multiplying Scale Factor II by the potentiometer output. This scale factor is determined by the gear ratio which drives the potentiometer shaft as the motor rotates.

The error signal between commanded and actual position is used to generate a motor drive current which nulls this error signal to zero. Since the motor is a stepper motor and can only achieve discrete steady state

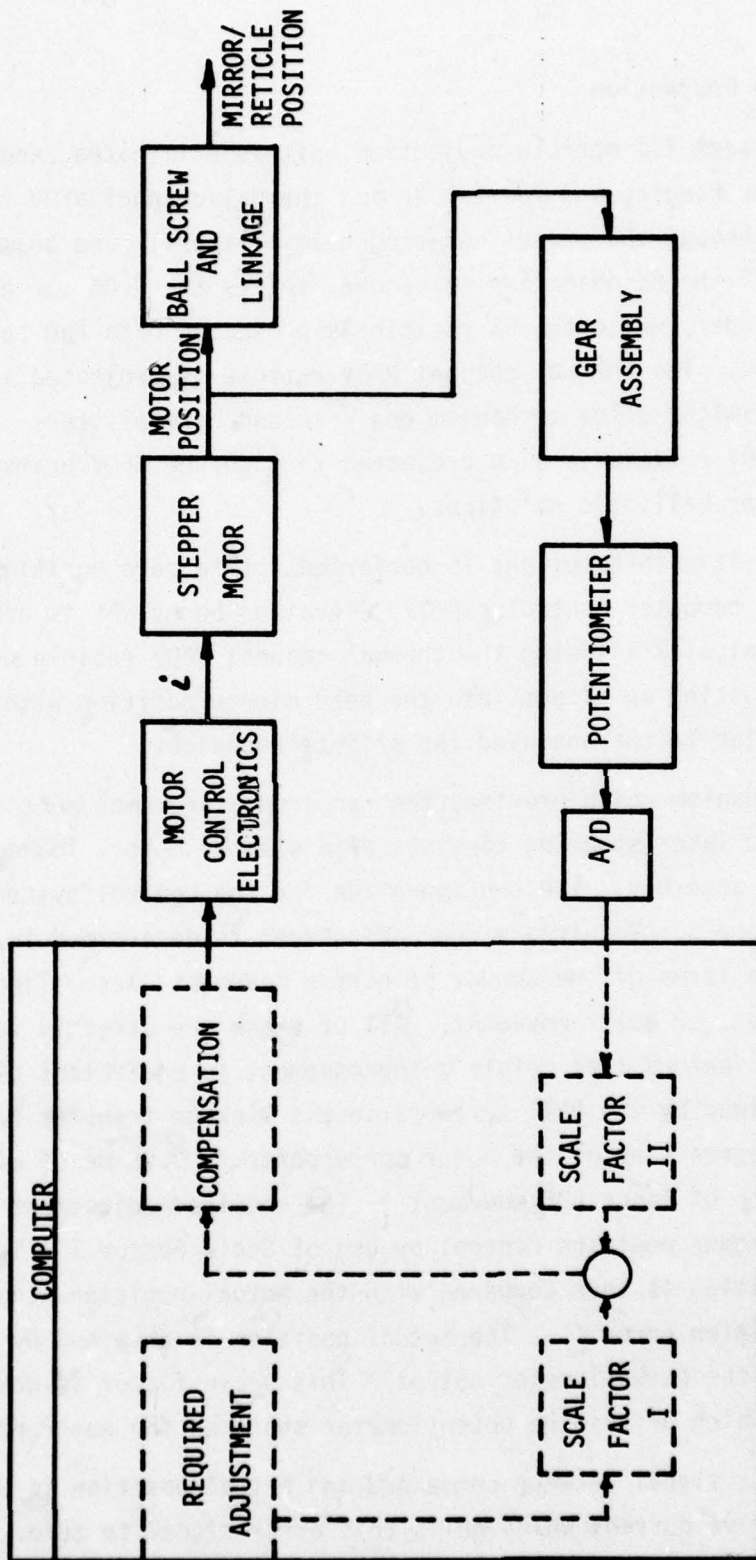


Figure 5. Block Diagram, Steering Mechanism Control System



positions, the error signal will never be driven precisely to zero. Therefore, the compensation algorithm will consist of a threshold operation that only generates a drive signal for the motor when the error exceeds the permissible tolerance of the motor position. In addition, the compensation algorithm can provide dynamic adjustments in order to maintain stability for the overall system (if required) and to achieve any desired degree of position accuracy.

The above operations, whereby the required adjustment is converted into a motor command, are all accomplished in the ballistic computer. There are other techniques by which this system can be controlled, but this procedure places the majority of the control tasks in the computer and thereby minimizes hardware complexity. Since a digital counter can be employed to count the number of steps taken by the stepper motor, it is not necessary to design a closed loop system whereby the potentiometer output is used as a feedback system. However, the illustrated stepper design provides an indication of system status and achieves more definitive mirror control with only minimum additional hardware.

The remainder of the hardware configuration consists of the electronics, stepper motor, and ball screw/linkage assembly. Analysis of the ball screw and linkage assembly has shown that the total backlash in the system should not exceed 0.016 mr of movement in the mirror. That is, the control loop can position the motor at any desired location as specified by the computer (within the tolerance of a stepper motor). Thereafter, the mechanical linkage will achieve the correct location to within 0.016 mr.

The allowable dynamic range of the system can be selected by the proper choice of the stepper motor and the gear-linkage relationships. Mirror freedom is ± 15 mr, and the maximum adjustment from the null position can be reached within one second by appropriate choice of the motor torque capabilities.

3. Eight Power Telescope

Slight modifications have been made to the 8X visible telescope design in the TI integration concept. The beamsplitter used to integrate the 8X reticle into the field of view is eliminated, and the penta prism is moved closer to the objective lenses, causing it to become slightly larger. The



filter lever is eliminated and the filters are housed in a filter wheel located between the penta prism and a rhomboid prism which was added to keep the eyepiece in the same location. A $1.06 \mu\text{m}$ filter is added between the rhomboid and the eyepiece for eye protection. However, total visible transmission through the 8X telescope is reduced by three percent because of this filter. The eyepiece exit pupil size is the same as that of the present TTS 8X telescope.

The 8X reticle projector optics design is new. To keep the design compact, a four-element telephoto lens system was used. The bulb was re-located to permit access from the front panel for removal and replacement.

Thermal channel NFOV and WFOV reticle optics designs are also new, but remain compatible with the existing Gunner's Display and Commander's Display optics. The thermal channel and unity reticle projector are unchanged.

4. Head Assembly

Changes to the TTS Head Assembly are minor. The 1X/8X visible beamsplitter is larger to accommodate the increased aperture through the 8X window, and the head and head cover castings change slightly to allow for the increased size of the window. The unity window and reticle combiner are coated to reflect $1.06 \mu\text{m}$ energy so that less than 0.1 percent is transmitted. Total energy loss in the unity channel is approximately four percent. The 1X/8X beamsplitter coating is changed to peak the $1.06 \mu\text{m}$ transmission, and the visible window and head mirror have added coatings for the same reason.



SECTION V RISKS

Technical risks associated with integrating the AN/GVS-5 and AN/VSG-2 are minimal. The major area of risk is in the development of the coatings necessary to achieve required performance and safety in the system. (See Table 3). The new head mirror coating degrades the IR transfer coefficient on the mirror by three percent, and this transmission loss is translated directly into a three percent degradation in system minimum resolvable temperature (MRT).

An alternative would be to split the coatings; i.e., coat part of the mirror with the 1.06 μm energy peaked, and the other part peaked in the IR. Yield will decrease, but no performance would be lost in the IR.

Additional risks are associated with the 1x/8x beamsplitter and the reticle combiner/1.06 μm beamsplitter coatings. They would require a certain amount of developmental work, and yields would be lower than normal due to the number and complexity of the coatings.

Two approaches are available with respect to coating optics to provide eye protection. One solution - coating two surfaces of BK 7 glass with a multilayer coating - was mentioned earlier. A potential problem with this approach is that if the spectrum is not exactly right, a defective coating might cause the scene to appear yellowish.

An alternative is to make the window of RG-3 filter glass. This will permit a greater yield, but only 75 percent of the energy is passed; whereas the coating passes 85 percent.

A lesser area of concern is EMI. The integration of the laser into the Gunner's Display can be engineered such that it should not create any additional EMI problems. However, a prototype should be tested for verification and risk reduction early in the design cycle.

The laser pointing and reticle drive system introduces problems relating to pointing accuracy and integration with a new computer. Pointing accuracy was discussed in Section IV.



Table 3. New Coating Specifications

<u>LOCATION</u>	<u>COATING</u>
Visible Window	MLAR, One side R < 1% for .45 to .65 microns R < 1% for 1.06 microns
Head Mirror	Special multilayer $R_{AVG} > 85\%$ for .45 to .65 microns R > 99% for 1.06 microns R > 94% for 8 to 12 microns All at 45° incidence
Head Mirror (optional)	Separate visible and IR coatings $R_{AVG} > 85\%$ for .45 to .65 microns R > 99% for 1.06 microns R > 97% for 8 to 12 microns All at 45° incidence
1X/8X beamsplitter	Coat both sides T = 55 ± 5% for .45 to .65 microns T = 93 ± 3% for 1.06 microns All at 60° incidence
Unity window and beamsplitter	Multilayer laser reflector $T_{AVG} \geq 85\%$ for .45 to .65 microns T < .01% for 1.06 microns
Laser pointing and reticle insert beam combiner	Laser side $R_{AVG} < 2.5\%$ for .45 to .65 microns R > 99% for 1.06 microns Reticle combiner side $R_{AVG} = 50 \pm 5\%$ for .45 to .65 microns All at 45° incidence



Two options are available with respect to the reticle drive. The proposed method is to integrate with the digital computer and allow the computer to step the motor to the desired solution. In this method the feedback potentiometer is used only as a zero (boresight) memory. The alternative method is to allow the potentiometer to give a continuous feedback as to mirror location. This solution is somewhat more expensive in terms of electronic circuitry, but does permit greater confidence in the validity of the ballistic solution. A detailed cost/performance tradeoff should be performed during the design phase to balance risk, performance, and cost.



SECTION VI COST IMPACT

The addition of the laser rangefinder to the production TTS periscope results in a manufacturing cost increase of 11.7 percent per system. This figure does not include the cost of the laser modules which were considered to be government furnished. Also, the new computer which houses the drive circuitry for the ballistic drive is not a part of this cost estimate.

Major items eliminated in the TTS are the RPU, relay prism assembly, IR boresight mechanism, 8X reticle knob assemblies, and reticle adjust printed wiring board. The major redesign areas are the rear cover assembly, filter changing mechanism, 8X objective lens assembly, penta prism assembly, boresight lens assembly, major castings, and Gunner's and Head BITE printed wiring boards. Major new designs include reticle drive mechanisms, laser optics, IR reticle optics, and laser module mounting packages.

The proposed design yields approximately 106 new metal fabricated parts, 18 similar but redesigned fab parts, 34 new pieces of glass, 13 similar but redesigned pieces of glass, and approximately 45 new purchased parts, excluding standard hardware items.

The major cost deltas come from the new, more sophisticated coatings and the additional fabricated metal and optical parts.



SECTION VII
CO₂ LASER/TTS INTEGRATION

A. CO₂/ND:YAG LASER COMPARISONS

It is difficult to make a direct comparison between CO₂ and Nd:YAG laser rangefinder systems from the standpoint of effectiveness. The principal difference between the two types of system is their respective wavelengths of operation. CO₂ operates at approximately 10.6 μm, while Nd:YAG operates at 1.06 μm. Most of the performance problems with Nd:YAG systems occur in battle-field smoke and other poor visibility conditions attributed to particulate suspension in the atmosphere. The longer wavelength of the CO₂ laser is less susceptible to particle scattering. Therefore, in typical battlefield conditions, CO₂ rangefinders could out-perform Nd:YAG systems which have comparable performance in clear weather. Additionally, CO₂ rangefinders operate in the same atmospheric window as FLIR systems, making it possible to match rangefinder and FLIR performance rather closely. It is not practical to try to match Nd:YAG rangefinder and FLIR performance. Further, common optics and cryogenics could be used in an integrated FLIR/CO₂ laser design.

Another advantage of the CO₂ laser is that its more stable configuration and output energy make it a candidate for a heterodyne detection rangefinder scheme. This could result in a much lower (perhaps eye-safe) transmitter power output to obtain acceptable performance.

Comparisons between the two types of rangefinder are summarized in Table 4.



Table 4. CO₂ vs Nd:YAG Rangefinder Systems

<u>Characteristics</u>	<u>Advantage</u>	
	<u>CO₂</u>	<u>Nd:YAG</u>
Input power	X	
Efficiency	X	
Clear weather performance	-	-
Battlefield performance	X	
FLIR compatibility	X	
Size		X
Weight		X
PRF	X	
State of the art		X

As the state of the art improves, weight and size for the two systems should become comparable.

B. DESIGN GOALS AND PERFORMANCE CHARACTERISTICS

Design goals for the integration of a CO₂ laser rangefinder into a periscope with night and daylight channels are listed below.

- (1) The laser should be part of the ballistic solution.
- (2) The package should be compatible with the M60 Tank.
- (3) Maximization of common elements between FLIR and laser.
- (4) The IR channel should have two fields of view.
- (5) The daylight channel should have unity and 8X telescope sights.
- (6) The thermal channel should have the same performance parameters as the present TTS system.
- (7) The 8X daylight telescope should have the same field of view and exit pupil as the present TTS system.
- (8) The unity channel should have the same field of view as the present TTS.

Performance characteristics of the laser transmitter are summarized in Table 5.



Table 5. CO₂ Laser Transmitter Characteristics

Ranging rate	1 pps continuous, 5 pps burst
Peak power	300 kw (approximately)
Reliability	5×10^{-6} mean ranges between failures
Full angle divergence	2 to 3 milliradians
Environment	Per MIL-STD-810
EMI	Per MIL-STD-461
Maintainability (MTTR)	One hour
Package size (excluding optics)	3 X 6 X 6 inches

C. DESIGN DISCUSSION

The CO₂ laser rangefinder/TTS periscope integration is packaged as shown in Figure 6. Physical features of the design are as follows:

- (1) The Head Assembly and Gunner's Display have been integrated to allow for better packaging of the LRF.
- (2) The afocal was redesigned to provide more back focal length so that the energy for the 10.6 μm wavelength can be split to the laser receiver.
- (3) The IR modules are rotated 90 degrees from their present orientation.
- (4) The Commander's Display is in approximately the same location in the tank as the present unit.
- (5) The 8X telescope and unity window optics designs are the same as the present TTS system, and no new coatings are required.
- (6) The image intensifier tube is replaced by a proximity focus image converter. Advantages of this device are that it is of ceramic construction rather than a vacuum tube; it has zero distortion; better uniformity characteristics across the face; reduced volume; and potentially lower production cost. Disadvantages are increased cost in the near term and slightly lower optical performance (MTF).
- (7) There is some increase in Head Mirror size required, but the impact, if any, on the turret opening should be minimal.

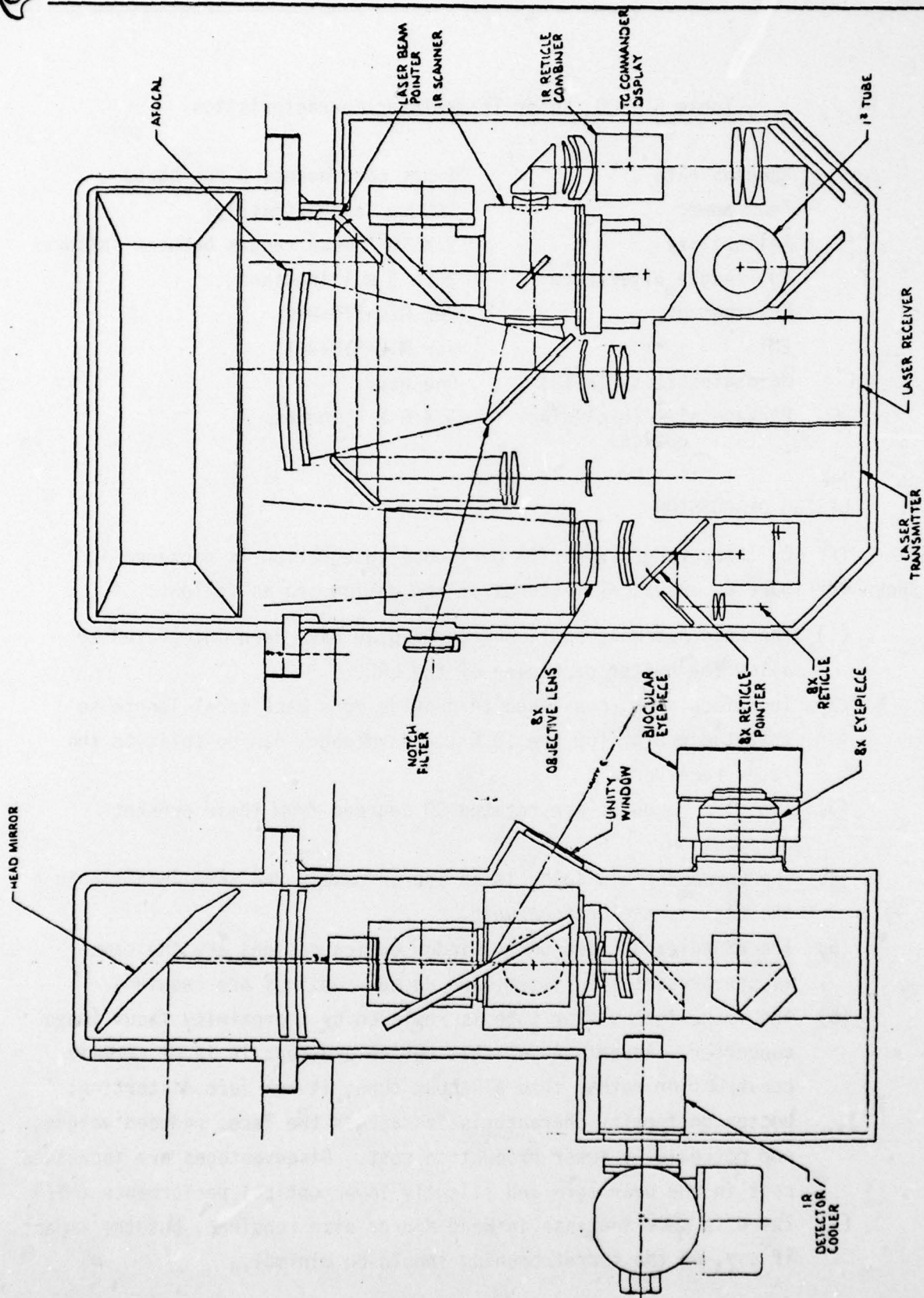


Figure 6. TTS/CO₂ Laser Layout



Ballistic solutions are obtained through computer-driven mirrors which are slewed to project reticles and guide the optical lines of sight. The computer will be furnished by the government and will be compatible with the drive systems. The mirror drives are similar to the ones described in Section IV.B.2.

The 8X telescope reticle is projected into the eyepiece using a beam-splitting mirror. The IR reticles have a similar arrangement, with the thermal channel WFOV reticle being projected through the beamsplitter and the NFOV reticle being pointed by the beamsplitter for the ballistic solution. The 8X and thermal channel NFOV reticles are boresighted to each other by adjusting the 45-degree mirrors in the optical path.

The CO₂ laser transmitter is slewed in azimuth by a beam-pointing mirror, using much of the same drive as was used by the reticle projectors. The transmitter is boresighted to the reticles by means of an adjusting mirror.

The laser receiver shares the first two elements of the afocal with the IR receiver. This arrangement creates difficulty in pointing the laser receiver; however, several possible solutions exist. One is to threshold each of the detectors in an array and process the signal from the one with the largest signal-to-noise ratio. The detector chip cost would be high because a minimum of 50 elements would be required.

A second solution is to use a Bragg cell to guide the beam. The cell uses frequency changes to change the index of refraction and offset the beam. The electronics associated with this method are more sophisticated, and the energy loss through the cell would be approximately 50 percent.

Two other solutions involve the use of wedges or a rotating mirror. Both of these solutions necessitate a change in the optics design which would increase the total package size. The head mirror gets larger due to the increased number of optical paths created by the addition of the transmitter. Also, the notch filter added to the afocal reduces the energy to the IR detector by approximately 25 percent. To compensate for this loss the aperture of the thermal channel must be increased, which causes a further increase in head mirror size.



Total transmission of the IR or laser receiver was not calculated as part of this investigation. It is apparent that the laser receiver would not be capable of working in the FLIR wide field of view, or would have very limited ranging ability at best.

D. ALTERNATIVES CONSIDERED

Several other layouts were generated in an attempt to find a feasible configuration for the CO₂/TTS integration. Most had design features and risks that prevented serious consideration. The layout schematic shown in Figure 7 had as its main problem the total size of the package. Placing the notch filter ahead of the afocal caused the head mirror to increase greatly in size, thereby limiting the size of the laser receiver optics. Overall package size became too large for the space currently available for the TTS periscope package in the tank.

Figure 8 shows a layout utilizing rotating wedges to guide the laser rangefinder. The ballistic reticle drive could remain unchanged from the present TTS; however, as in Figure 7 the size of the laser receiver optics is limited and the size of the head mirror increased. Neither of the above schemes utilized any of the IR optics available. The schematic shown in Figure 9 uses a single mirror to point the laser transmitter and receiver. The transmitter is pointed on the top side of the mirror, and the receiver signal is processed through the afocal optics and split with a notch filter to the back side of the mirror. This condition of slewing can exist when the mirror is located a point two focal lengths away from the afocal objective lenses. The primary problems with this technique were that the wide field of view had to be eliminated; the notch filter caused an astigmatism in the thermal channel, which resulted in a loss of vertical modulation; and the location of the steering mirror was approximately 15 inches from the afocal lenses, causing a large package size.

Some preliminary work was done in an effort to integrate some of the laser receiver into the common modules, and to use the cryogenic cooler for the detector and the scanner as a beamsplitter. Both of these investigations would require an extended effort to reach any conclusions.

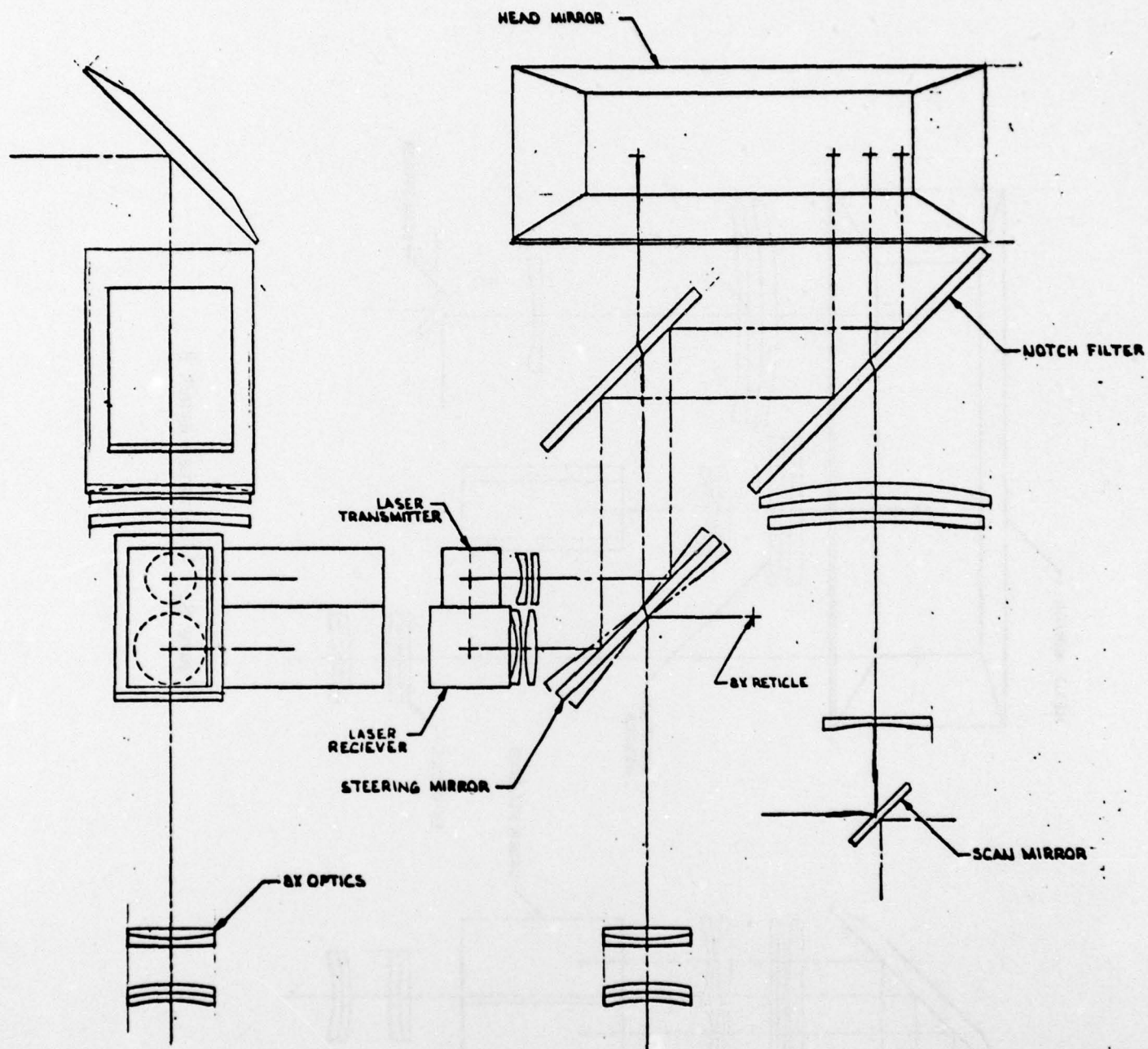


Figure 7. Alternate Layout A

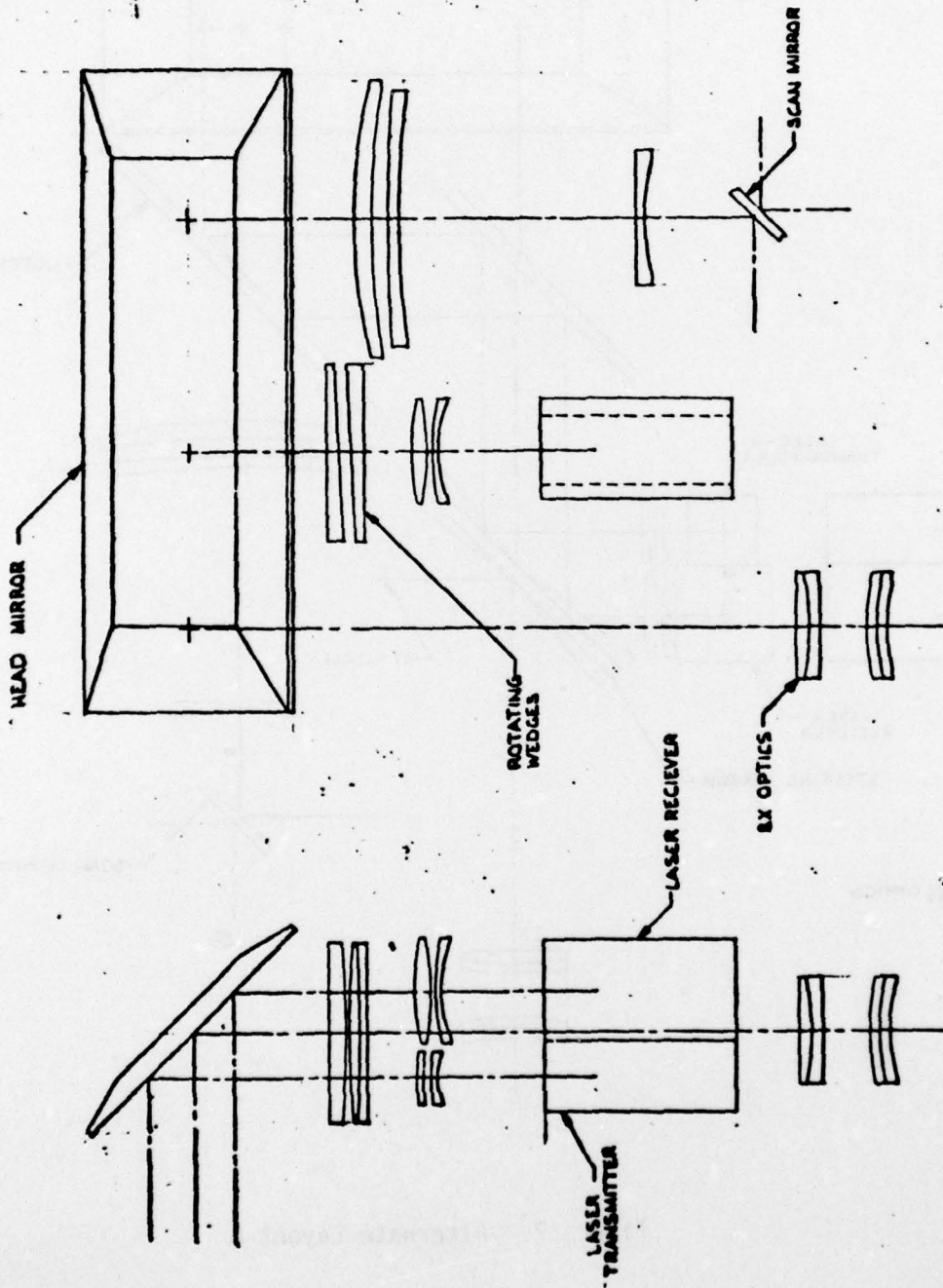


Figure 8. Alternate Layout B

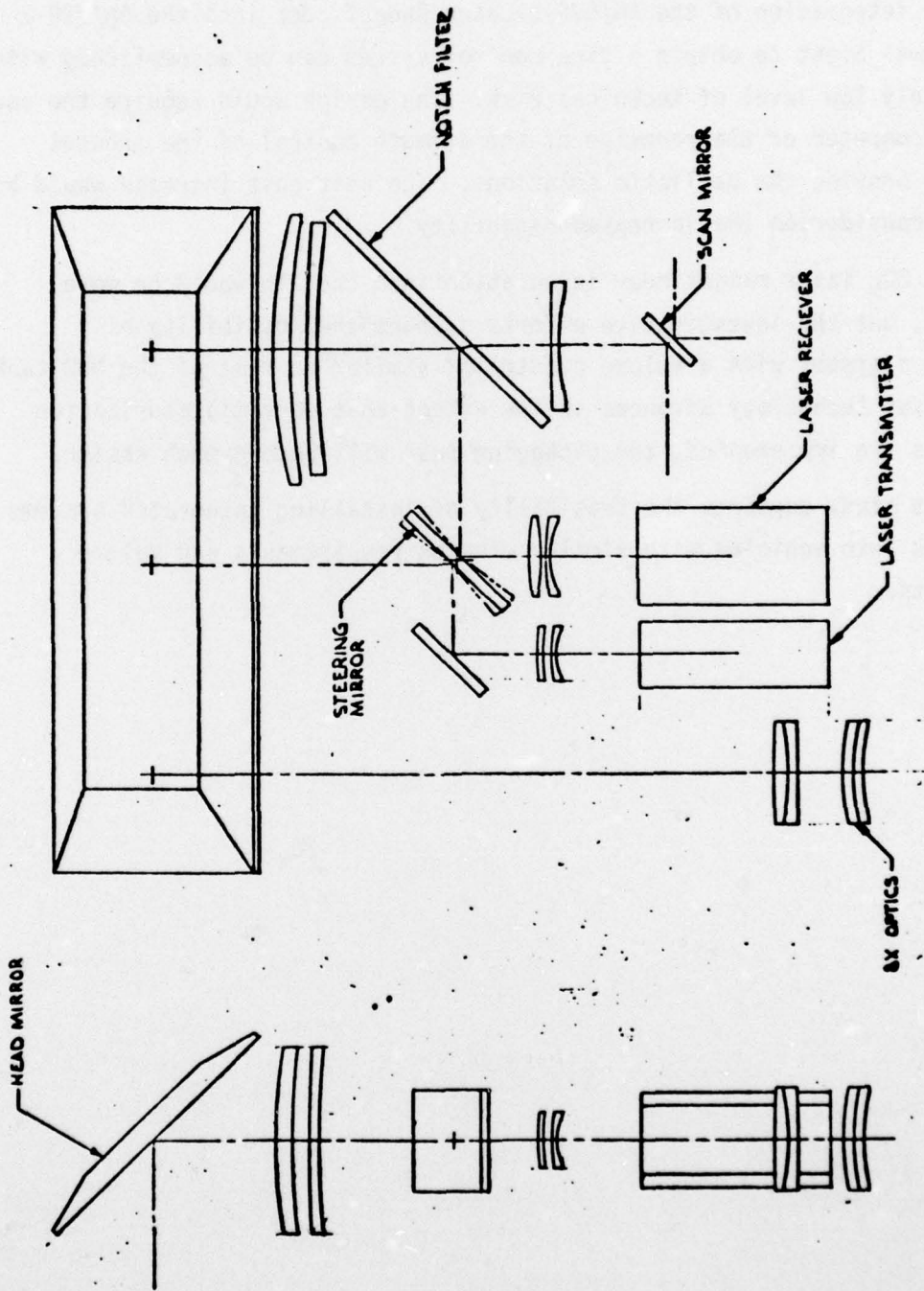


Figure 9. Alternate Layout C



SECTION VIII
CONCLUSIONS

The integration of the AN/GVS-5 Laser Rangefinder into the AN/VSG-2 Tank Thermal Sight to obtain a fire control system can be accomplished with a relatively low level of technical risk. The design would require the use of a new computer or the redesign of the azimuth control of the present system to provide the ballistic solutions. The unit cost increase would be minimal, considering the increased capability.

The CO₂ laser rangefinder integration into the TTS would be more difficult, but the investigative efforts support the possibility of packaging a system with a volume constraint similar to that of the M60 tank. As CO₂ laser technology advances to the extent that more miniaturization techniques are implemented, the packaging task will become much easier.

This study supports the feasibility of installing integrated systems of both types into vehicles with similar mission requirements and volume constraints.