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PHASED-ARRAY LASER RADAR: CONCEPT AND APPLICATION

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*George C. Marshall Space Flight Center
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TABLE OF CONTENTS

	Page
INTRODUCTION.....	1
DEFINITION OF AN OPTIMUM TRANSMITTER- RECEIVER SYSTEM.....	1
BISTATIC CONFIGURATION	2
BISTATIC CASSEGRAINIANS CONFIGURATION	2
NEWTONIAN CASSEGRAINIAN CONFIGURATION	3
COAXIAL CASSEGRAINIAN CONFIGURATION	3
DEFINITION OF A PAR-LIDAR	5
POINTING AND TRACKING SYSTEM	8
SIGNAL DETECTION AND DATA ACQUISITION ELECTRONICS	9
DATA PROCESSING AND PRESENTATION	11
SUMMARY	13

LIST OF ILLUSTRATIONS

Figure	Title	Page
1.	Transmitter-Receiver Configurations	15
2.	Transmitter-Receiver Optical Efficiency	17
3.	Single Aperture Coaxial Cassegrainian Design	17
4.	Primary Mirror Figure	18
5.	Coaxial Cassegrainian Telescope	18
6.	Phased-Array Coaxial Cassegrainian Design	19
7.	Phased-Array Matrix	19
8.	Laser Radar Mount - Original and Converted	20
9.	Phased-Array Laser Radar System Mount	21
10.	Laser Radar Mount Scan Records	22
11.	Avalanche Photodiode Detector Module	23
12.	Binary Selectable Detector Holdoff Circuit	24
13.	Binary Selectable Detector Holdoff Circuit	25
14.	Timing Diagram - Binary Selectable Detector Holdoff Circuit	26
15.	Signal Detection and Data Acquisition Electronics	27
16.	Six Channel Series Summation Logarithmic Amplifier	28
17.	Par-Lidar Clear Air Turbulence Detection	29
18.	Par-Lidar Climatic Impact Study	30

PHASED-ARRAY LASER RADAR: CONCEPT AND APPLICATION

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INTRODUCTION

Laser radar, as a concept and an instrument for measurement, has provided a valuable means for scientific study of air pollution and atmospheric phenomena.^{1,2} A review of laser radar systems currently in use illustrates incomplete compatibility between the transmitter (e.g., laser) and receiver (e.g., telescope) subsystems. This paper presents a comparison of the current approaches to a configuration currently under development at the NASA-George C. Marshall Space Flight Center (MSFC) and illustrates how this design can be extended to provide a phased-array Laser Radar (PAR-LIDAR) system. The application of PAR-LIDAR to three-dimensional studies of atmospheric aerosol motion, both man-made and natural, and clear air turbulence is explored. Finally, the extent to which one can understand the experimental data derived from laser radar probing and the dependence of the final data on the pointing and tracking ability of the optical mount are discussed.

DEFINITION OF AN OPTIMUM TRANSMITTER-RECEIVER SYSTEM

Unfortunately, the transmitter-receiver configuration for a laser radar system is not always chosen on the basis of optical efficiency. Most often the resources available for the program are the critical determining factor of an optical configuration.

Three configurations have, in general, dominated the laser radar scene. These are (1) bistatic³, (2) bistatic Cassegrainians (or Newtonians)⁴, and (3) Newtonian Cassegrainian⁴. The monostatic configuration⁵ will not be

discussed since its characteristics and poor optical efficiency^{*} make it extremely unattractive for general use. It should be noted, however, that the monostatic and bistatic configurations are identical in principle except that the monostatic configuration requires a larger field of view for the receiver (transmitter and receiver centerlines are parallel) than the bistatic configuration. This large field of view is necessary for either receiver to collect the same degree of backscattered energy originating from the transmitter.

The MSFC began in 1970 to develop a new approach to the design of laser radar transmitter-receiver systems. Several important features were deemed necessary of the final design. Some of these features were (1) coaxial transmitter and receiver, (2) all mirrored optical surfaces, (3) maximum efficiency of the transmitter, (4) sealed dust-free environment design, and (5) automatic calibration capability utilizing only one detector system.

In order to understand the implications of the various aforementioned transmitter-receiver configurations and to fully appreciate the limitations of each design, Figure 1 is used to illustrate the physical description of each configuration to be considered.

Bistatic Configuration

The bistatic configuration (Fig. 1a) has been the most widely used transmitter-receiver configuration to date, as evidenced by a review of the open literature.³ The system is very straightforward in concept. The receiving telescope can be either of a Newtonian or Cassegrainian design. Normally, a field stop is employed to adjust the field of view to compensate for the varying target size and range of interest. The limitations of this system stem from a need for some type of angle adjustment between the transmitter and receiver centerlines, the difficulty in determining the amount of transmitter energy in the receiver field of view as a function of an angle adjustment, and an inability to establish a simple transmitter power output calibration capability referenced to the received backscattered energy.

Bistatic Cassegrainians Configuration

The bistatic Cassegrainians (or Newtonians) configuration (Fig. 1b) has been used by researchers⁴ at Stanford Research Institute in their early

^{*}Area ratio as a function of range, see further Fig. 1.

Mark laser radar systems. The basis for using a large beam-forming telescope for the transmitter will be discussed later. At this point it suffices to say that an ability to adjust the angle between the transmitter and receiver centerlines is not strictly necessary. Again, as in the bistatic configuration, a field stop is used to compensate for the varying target size and range. The transmitter power output can be concentrated on the target of interest by adjustment of the telescope secondary mirror. Still, system limitations exist because of the blockage of the transmitter output profile by the secondary mirror, the need for alignment adjustment between the transmitter and receiver telescopes, and, again, an inability to establish a simple transmitter power output calibration capability referenced to the received back-scattered energy.

Newtonian Cassegrainian Configuration

This configuration is becoming increasingly popular as a sophisticated remote atmospheric probing system.⁴ As indicated in Figures 1c and 1d, the transmitter output is aligned with the receiver centerline. This approach alleviates the need for any range compensation through an angle adjustment, as is necessary in the previous systems, to maintain acceptable optical efficiency. Even with this configuration, limitations exist. These limitations are concerned with the inability to concentrate the transmitter power output on the target of interest and the need for more than one detector in the system. In actual operation¹ one detector is utilized to monitor the transmitter power output and another detector senses the backscattered energy. The transfer function of the two detector systems must be carefully defined to allow consistent calibration of the transmitter output power, even if the transmitter operates in a fundamental output mode such as TEM₀₀^{*}.

Coaxial Cassegrainian Configuration

The coaxial Cassegrainian configuration is an outgrowth of a laser radar program initiated at MSFC in 1970 under the sponsorship of the Applications Technology, Office of Aeronautical and Space Technology, NASA Headquarters. The design, as shown on Figure 1d, is coaxial. Therefore, as in the Newtonian Cassegrainian configuration, the

* TEM refers to Transverse Electromagnetic Mode.
(Subscripts refer to mode number.)

transmitter and receiver are aligned along a common centerline. Contrary to the previous configuration, the transmitter and receiver have a common focal point. This design concept allows the use of a single secondary element and permanently optically aligned and bonded split ring primary mirror. Thus, both the transmitter and receiver coaxial telescopes can be simultaneously adjusted to provide a varying field of view to compensate for changing target size and range. Also, the common focal point should allow the use of molecular scattering from the focal volume as a means of calibrating the transmitter output power and having this information permanently recorded at the beginning of the backscattered signal record. Nevertheless, the design presents stringent requirements on the choice of a system transmitter. The laser must be capable of operating in a mode that allows for an annular output profile. In most laser systems, this output profile is referred to as TEM_{01}^* , the "donut" mode*. Finally, this design necessitates a tandem transmitter-receiver configuration and immediately dictates the system's optical mount requirements.

Figure 2 illustrates a comparison of the merits of the above four systems for one optical and range configuration. The parameters chosen were such as to allow an illuminated and received spot 1 m in diameter at a range of 1000 m. Also, the transmitter output profile is assumed to be a step function distribution, constant over the transmitter aperture. The results clearly indicate that if a system is designed to operate at close range, the optical efficiency is compromised at long ranges. Only the coaxial Cassegrainian system is optimized for both close and distant targets.

A more thorough analysis can be made by including the effects of the transmitter output profile. For example, in the Newtonian Cassegrainian system, Figure 1c indicates that at close ranges the receiver does not "see" optically the maximum transmitter output profile that occurs along the system centerline because of blockage by the telescope secondary mirror. In addition, the divergence of the transmitter in contrast to the receiver would indicate even less optical efficiency than Figure 2 shows as the range increases beyond 1000 m. The data for the bistatic and bistatic Cassegrainians configurations would be even more severely modified since the interception of the transmitter output profile by the receiver begins at the edge of the profile, as indicated in Figures 1a and 1b. Allen and Evans (Ref. 4) commented on this deficiency and indicated that this reason was largely responsible for a recent change to a Newtonian Cassegrainian configuration. Figure 3 presents a detailed cross-section of the NASA-MSFC coaxial Cassegrainian design. The main telescope optical design emulates a standard Dall-Kirkham approach in that the secondary

* 01^* refers to a combination of two modes.

element is a section of a spheroid and the primary element is composed of ellipsoidal sections. However, referring to Figure 4, the ellipsoidal sections are obtained in a very unusual way. For example, assume that segment AB is the desired shape profile for annular primary mirror PMA of Figure 3. Now, ellipse segment AB is transposed so that the segment end A is located on the axis of revolution (z-axis). The subsequent ellipsoidal section contains a cusp on the axis of revolution but since the mirror center is eventually removed, this is immaterial. Segment CD is the desired shape profile for primary mirror PMB and the ellipsoidal section is determined in the same way as for mirror PMA. The receiver section of the coaxial Cassegrainian design consists of a simple on-axis parabolic collector mirror RMA and an off-axis parabolic mirror RMB to image the backscattered energy onto the detector system. Mirror RMA has an on-axis hole properly sized to accommodate the input of the transmitter output. Interestingly enough, the optical fabrication of the type of ellipsoidal mirrors just discussed is very straightforward. However, the testing of the final mirror figure is not easily accomplished. The only thing that readily comes to mind is the use of a type of Hartman test, which is very time consuming and requires preparation of elaborate optical masks. A zonal knife edge test can be used to determine whether the mirror figure is uniform, but this test is really more qualitative than quantitative in nature.

The NASA-MSFC coaxial Cassegrainian telescope (Fig. 3) was fabricated under contract to Sanders Associates, Inc., Diffraction Limited Division. Figures 5a and 5b show different views of the completed telescope. Particular attention should be paid to Figure 5b, where the two primary mirror rings are clearly seen.

DEFINITION OF A PAR-LIDAR

Laser radar, in a single-aperture configuration, can at best derive two-dimensional maps of the target region being probed. In fact, true two-dimensional maps can be obtained only if the target is stationary during the period of the scan across the target or if the target speed is known so as to compensate the scan direction in the reconstruction of the scan records.

A PAR-LIDAR can obtain true two-dimensional maps. This is a result of the fact that a multiple aperture configuration can determine motion across and along the lines of sight of each aperture pair. In other

words, the magnitude and direction of motion in a plane containing each aperture pair. This information is derived by cross-correlating space intervals (partial data records) across the target of interest for data records of differing time. For example, assume that the pulse repetition frequency (PRF), of the laser radar system, is Δt and the pulse number is n with a spacing between lines of sight of d . Then, data record at time t of line of sight (aperture) A would be cross-correlated with data record at time $t+n\cdot\Delta t$ of line of sight (aperture) B. The cross-correlation lag increment, ΔR , is a function of the spatial resolution of the data record along the line of sight. Superimposing cross-correlations for varying values of n , an envelope correlation function can be defined. The time at which the envelope peak occurs ΔT (function of $n\cdot\Delta t$), distance d and the lag ΔR determines the magnitude of the motion. . Therefore, the values of the motion components are:

$$V_{\text{across}} = \frac{d}{\Delta T}$$

$$V_{\text{along}} = \frac{\Delta R}{\Delta T}$$

$$V = \left[\left(V_{\text{across}} \right)^2 + \left(V_{\text{along}} \right)^2 \right]^{1/2}$$

It should be noted that the data records thus used must be obtained from identical space intervals.

The ~~basic~~ problem is how to put together an optical system that can generate a "usable" array matrix, displays high optical efficiency, uses only one transmitter-receiver, and automatically calibrates each detector system of the detector array for every transmitter pulse. A usable array matrix is defined as a matrix that is optically feasible and an array that can be positioned in the target region in a particular physical orientation to allow maximum information retrieval on the motion of the target.

An extension of the NASA-MSFC coaxial Cassegrainian design does provide a PAR-LIDAR transmitter-receiver configuration. A cross section of this design extension is presented in Figure 6. The resultant array matrix was chosen on the basis of mechanical compatibility and maximum optical efficiency and is shown in Figure 7. The mechanical compatibility is a compromise between receiver simplicity and the need for the ability to rotate the position of the array to avoid blockage by spider assemblies in the main telescope. As a result, ± 40 degree rotation of the array can be permitted.

The transmitter is designed to project an annular energy distribution onto a target and the receiver detects the backscattered energy received from each of the array elements. Also, as in the previous coaxial Cassegrainian design, the transmitter-receiver systems share a common focal point. This feature should again allow automatic calibration of all four detector systems. This is possible because the transmitter power output can be circularly polarized and thus the molecular scattering from the focal volume will be isotropic as far as each detector system is concerned.

The optical components are similar to the previous design except that the off-axis parabolic mirror RMB is first fabricated as one mirror and segmented (four pieces). Then the segments are reversed, optically aligned, and permanently bonded.

The main telescope has an added feature in that the transmitter output profile is split and overlaid, as shown in Figure 7. This is not absolutely necessary, but does provide a more uniform distribution of energy in the projected annulus by positioning the receiver annulus between the two transmitted annuli.

Therefore, in actual operation the transmitter output pulse calibrates all four detectors and is projected as an annulus. Then, with an appropriately placed aperture in front of each detector system, the backscattered energy is measured for each element of the array. The resultant data records from the four array elements lines of sight can be processed in a variety of ways, such as feature detection or spatial correlation over target intervals. Regardless of what data reduction method is used, certainly transit times of target features can be obtained between any pair of array element lines of sight. Therefore, if the range of the target feature and the optical parameters of the main telescope (i.e., beam divergence, etc.) are known, the speed of convection of a target feature can be calculated.

POINTING AND TRACKING SYSTEM

Regardless of the degree of sophistication of a transmitter-receiver configuration, a laser radar system is only as accurate as the pointing and tracking ability of the system mount. Many types of surplus microwave radar mounts are available for conversion to laser radar mounts. In the case of the NASA-MSFC coaxial Cassegrainian design, the tandem transmitter-receiver configuration required a system mount capable of translating an optical assembly 0.5 m in diameter, 2 m in length and weighing approximately 200 kg. Figure 8a is a photograph of the type of microwave radar mount chosen for conversion and Figure 8b is a photograph of the converted mount. Figure 9 is an artist's conception of the final mount.

The original AS833 GRS-1 mount (ATLAS Tracking Mounts, manufactured by General Electric Co.) used geared ac drives powered by magnetic amplifiers. The output of the magnetic amplifier was determined by the degree of error between the gearbox indicated mount position (two-speed synchro systems) and the desired mount position set by computer control. A study was made to compare the cost of either refurbishing the existing ac drive system or replacing that system by a stepper drive system. On further investigation, (1) the original mount slewing speed was found to be easily duplicated by a change to stepper drives, (2) the positioning accuracy was essentially governed by the gearing backlash, and (3) the interface and maintenance requirements of a synchro-ac drive system versus an encoder-stepper drive system appeared more complex because of the analog nature of the control. Thus the final decision was made in favor of the encoder-stepper drive system. The interface system operates under either local or remote control. The local control is used to establish spatial azimuth and elevation coordinate references (i.e., terrain features) and manual slewing control through the use of a two-axis joy stick at the mount. The degree of movement of the joy stick determines the slewing speed (voltage-controlled oscillation) and direction of the motion of the mount. The remote control allows for complete computer control of the pointing and tracking of the laser radar mount.

Figures 10a, 10b, and 10d show scanning results for various common analytical functions. Figure 10c shows slew rate compensation as a function of space point to space point change and Figure 10d shows the effects of a constant slew rate. For example, assume for the point-to-point change that the azimuth change in radians is seven times the elevation change in radians. Therefore, the slew rate of the azimuth drive must be seven times as great as the elevation drive. Under computer control this slew rate compensation computation is automatically provided.

In the future, computer control will allow a laser radar system to operate in urban environments. Generally speaking, these areas have a high degree of aircraft traffic, both commercial and private. Safety standards for exposure to laser radiation indicate that the operation of laser radar systems will need to be under the pointing and tracking control of local Federal Aviation Agency aircraft tracking radars. This would ensure a restricted air space that a laser radar system could not probe, and thus not pose a hazard to aircraft operating personnel or passengers.

SIGNAL DETECTION AND DATA ACQUISITION ELECTRONICS

A discussion of signal detection and data acquisition electronics must necessarily be preceded by a decision as to whether a short or long range detection capability is desired. Photomultiplier tubes are generally required for long range detection and photodiodes are commonly used for short range detection. The basis for this separation is simply a consideration of the noise characteristics of the two types of detectors.

The NASA-MSFC coaxial Cassegrainian design was intended to be used for probing the atmosphere to ranges of 10 kilometers or less. Although 10 kilometers are not considered to be close range, a photodiode signal detection system was chosen for the following reasons: The preference for a linear gain response detector, a compact detector pre-amplifier module, and the ability of the photodiode detector to absorb large amounts of backscattered energy without degradation of the detector element.

Recently ultra-sensitive avalanche photodiode detection modules have been made commercially available. These modules are composed of an avalanche photodiode and a matched pre-amplifier capable of DC to 40 MHz bandwidth and a noise equivalent power (NEP) of 5×10^{-9} watts over the entire bandwidth. A photograph of a typical avalanche photodiode detector module is shown in figure 11. It should be noted that the module has the

capability for the direct insertion of a Fabry-Perot filter immediately in front of the detector element for narrow band spectral filtering. Unfortunately, the module shown in figure 11 has a limitation in that the maximum allowable energy level, an amount which would cause the first stage of the pre-amplifier to be damaged, is in the neighborhood of 4×10^{-4} watts. Thus, based on the above noise equivalent power, the useable signal detection dynamic range is approximately 1×10^5 .

Clearly, the maximum allowable energy level could be exceeded by a very dense target located at close range, typically less than 2 kilometers. To alleviate this situation, a binary selectable detection hold-off circuit has been designed. This circuit allows blanking of the detector response for a pre-selected space interval originating from the laser radar system. The blanking is accomplished by high speed switches on the plus and minus voltage supply to the detector pre-amplifier. Also, the high speed switches are of a design incorporating break-before-make action such that when zero voltage is being applied to the detector pre-amplifier, the input is grounded. The length of time required for the break-before-make action is approximately 10 to 20 nanoseconds.

Schematics of the binary selectable detector hold-off circuit are presented in figures 12 and 13. The circuit is composed of a nand gate clock whose frequency is a function of the nand gate switching speed, an eight-bit counter capable of counting to 2^8 or 256 clock cycles, a bit comparator to determine the actual desired clock cycle count that has been preset and other integrated circuit components to provide switching and time delay capability. The hex inverter chain is a simple laser trigger mechanism used to compensate for the inevitable propagation delay of the counting, comparing, and switching components. A circuit timing diagram is shown in figure 14.

The dynamic range capability of the avalanche photodiode detector module must be utilized to be of value. Therefore, the post amplifier (logarithmic amplifiers were chosen) must be capable of tracking the signal from the detector module and provide an output that can be appropriately recorded, as a digital or analog signal, for further analysis as needed.

Figure 15 shows a block diagram of the NASA-MSFC laser radar signal detection and data acquisition system. The broad-band attenuator between the detector module and logarithmic amplifier is used for precise conditioning (± 1 db) of the input signal level to the logarithmic amplifier. This is necessary since the gain steps of the logarithmic amplifier occur in 15 db increments from -80 db to +10 db and the full gain of each stage must

be utilized when switched to active. A circuit diagram of the logarithmic amplifier is shown in figure 16. The basic circuit of each stage is the result of research efforts at the Naval Weapons Center, China Lake, California.*

With the signal output from the logarithmic amplifier confined to approximately 0 to 2.5 volts (regardless of the range of the signal output of the detector module), an ultra-high speed analog to digital converter (e.g., Bio-mation Model 8100) is used to digitize and record the backscatter signal record. The sampling speed of analog to digital converter is chosen on the basis of the desired laser radar spatial resolution. For example, a sampling rate of 100 MHz allows a spatial resolution of three meters, since light travels at a speed of 3×10^8 meters per second.

$$\frac{3 \times 10^8 \text{ meters/sec}}{1 \times 10^8 \text{ samples/sec}} = 3 \text{ meters/sample}$$

Analog to digital converters with high speed shift register memories are commercially available. The maximum sampling rate attainable is 100 MHz with a signal sample amplitude resolution of eight bits (1 part in 256).

DATA PROCESSING AND PRESENTATION

The highest quality data, processed and presented in an inadequate manner, are meaningless and unusable except to the experimenter who obtained the data. Therefore, the data records being obtained must be recorded in a manner that will not degrade the data during the analysis procedure. The previous section discussed a method of directly obtaining digital data records, as opposed to analog video data recording. The dynamic range of the digital system is approximately 48 db (8 bits; i.e., 1 part in 256) whereas analog video systems can obtain 28 to 30 db at best. Also, the digital data, once recorded on magnetic tape, can be reanalyzed on any compatible digital computer system. The analog video data cannot be handled as easily and generally additional dynamic range is sacrificed when data are recorded on one system and played back for analysis on another system. Thus, the digital data acquisition and recording approach is the best approach to be used, costs not withstanding.

The data processing algorithms available, as mentioned previously, are numerous. The choice of the algorithm to be used to analyze these data is determined by the type of target being studied. For very slow moving or

* Private communication with R. S. Hughes

dispersing targets, compensation for the target motion is really unnecessary. The basis for this comment is due to the fact that, unless the laser radar system scans the target at a high speed or possesses a high pulse repetition frequency, some type of point to point interpolation would ultimately be necessary in the final analysis. Thus, the moment at which the accuracy of interpolation is less than the error due to target motion, target motion compensation is immaterial.

For single aperture laser radar systems, target motion compensation is at best very difficult. The difficulty centers around the inability to differentiate between target motion or growth. A multiple aperture laser radar system, employing an array matrix, as shown in figure 7, can discern between motion and growth. In order to illustrate this capability, a clear air turbulence phenomena characterized by billows or roll-like vortices known as Kelvin-Helmholtz instabilities are shown in figure 17. A multiple aperture laser radar system, probing a target of this type, obtains structure information across and along the line of sight of each aperture. This structure information would reveal the convection speed of the roll-like vortices, their physical size, and the characteristic scale determined by the spacing between vortices. In other words, the phased-array laser radar system can detect a component of the true convection speed toward or outward along the system's line of sight or between any two pair of receiver elements' lines of sight. The convection speed can be obtained by straightforward feature or pattern recognition in each of the data records obtained for a single transmitter pulse and then "looking for" repetitive features or patterns from pulse to pulse. The pulse repetition frequency (PRF) needs only be slightly more than twice the smallest scale of interest in the phenomena under observation. This criterion is analogous to the Nyquist criteria for digital sampling of data.

Thus, all the information necessary for a prediction of turbulent intensity can be derived from phased-array laser radar data according to a model proposed by Atlas, et al. Reference 6 states that the successful radar detection of clear air turbulence is mainly a question of sensitivity, spatial resolution and the ability to resolve the three-dimensional structure. In the light of the results of these experiments with highly sensitive FM-CW microwave radars, the likelihood of the success of single aperture pulsed laser doppler radars is questionable.

The methods of presentation of microwave radar data have been well established over the years. Unfortunately, the presentation of laser radar data has not taken complete advantage of this history. With the capability to digitally process data with very high spatial resolution, of the order of the

transmitter pulse width, real-time refreshed large screen displays are practical.

For example, suppose a laser radar system operating as a completely remote controlled instrument was being used to monitor air quality (particulate density and distribution) in a highly industrialized region such as exists in Birmingham, Alabama, or Gary, Indiana. To determine the on-set of an air pollution episode, the data presentation must include specific altitude contours of particulate density, such that a total distribution (overlay of all altitudes of interest) could be mapped, and particulate density versus altitude contours such that efflux rates could be ascribed to specific polluters. The altitude contour information coupled with meteorological information (i. e., atmospheric winds, and temperature) provide a continual update of the total particulate loading (grams/cubic meter) and fallout patterns to be expected. The density versus altitude information for specific polluters determines the continual efficiency of the pollution control device being used (i. e., precipitators.)

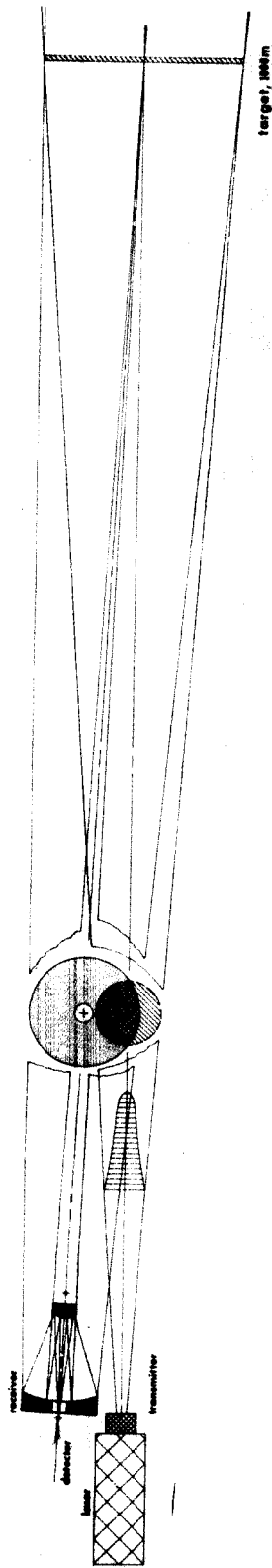
SUMMARY

Various laser radar transmitter-receiver configurations have been reviewed in terms of optical simplicity and efficiency. The MSFC coaxial Cassegrainian design is superior in many respects, such as (a) high optical efficiency, (b) permanent alignment, (c) coaxial, (d) all mirrored system, and (e) detector calibration capability. A comprehensive optical evaluation program is being formulated to ascertain the true performance of the single-aperture telescope shown in Figure 5. The results of these tests will be published in the near future. A decision on the future development and fabrication (the mechanical and optical design is complete) of the phased-array design will be made subject to the results of the tests and the overall need for an instrument capable of three-dimensional remote atmospheric probing.

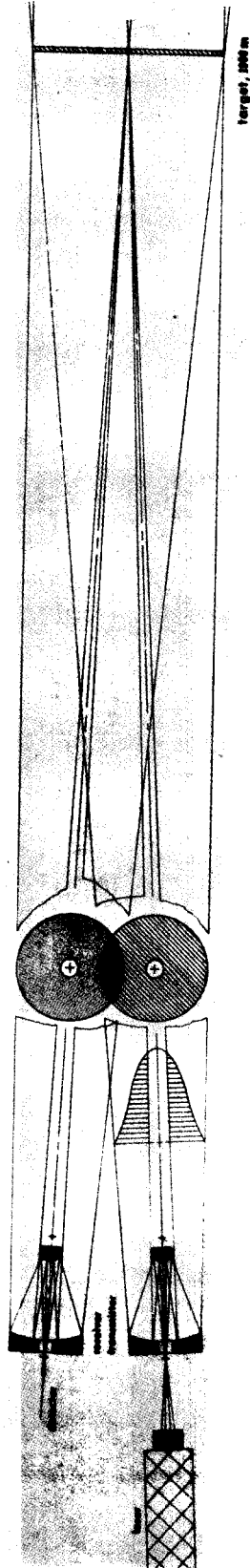
Simultaneously with the optical developments, advanced state-of-the-art signal detection and data acquisition electronics are being tested. These electronic components include linear response avalanche photodiode detectors, logarithmic dynamic range compression post amplifiers and on-line 100 MHz analog to digital conversion, storage, and display.

Also, a laser radar mount has been developed and interfaced with a minicomputer to provide programmed control of the systems pointing and tracking ability. This computer control will be used initially to provide automatic programmed scanning and data acquisition on targets such as the dispersion of launch vehicle exhaust clouds. The automatic programmed scanning sequences will be based on past observations of the dispersion of Apollo launch vehicle exhaust clouds as a function of the atmospheric parameters. The automatic scanning is necessary in the first minutes of the launch because of the rapidity of the dispersion of the exhaust cloud (buoyancy). This "computer control" experience will be used to develop software logic that will allow total automatic control of the surveying of atmospheric targets as a function of the real-time parameters (meteorological data), the method of occurrence of the target, and the results of the real-time analysis of the laser radar data.

Thus, the ability of a laser radar system to survey air pollution over an urban environment comes even closer to reality with the application of technology developed as a result of NASA's space programs.



a. Bistatic configuration .



b. Bistatic Cassegrainian configuration.

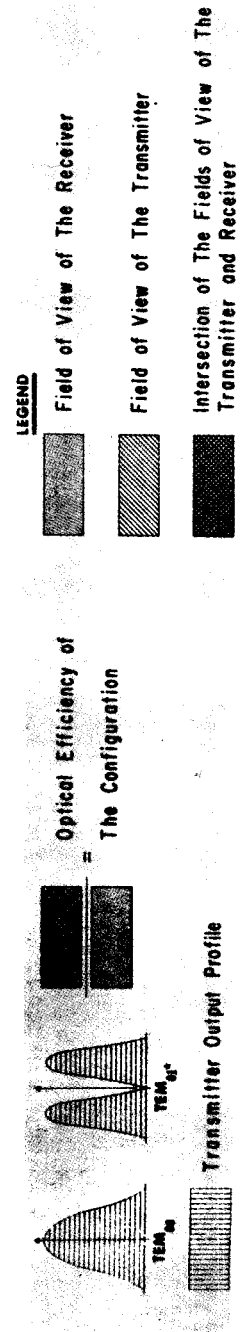
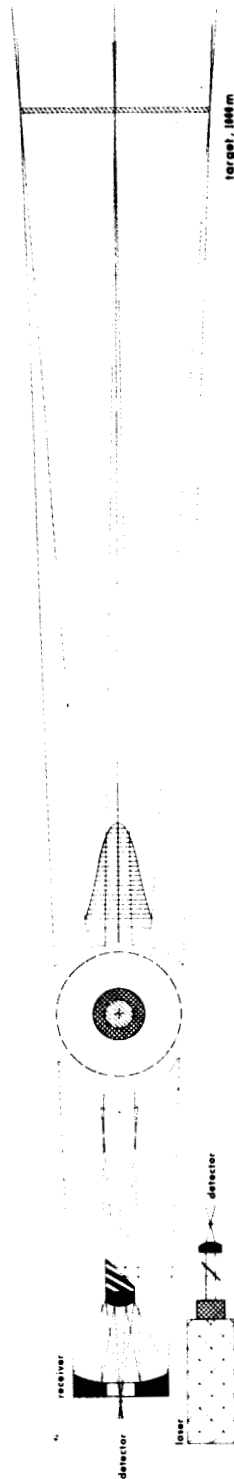
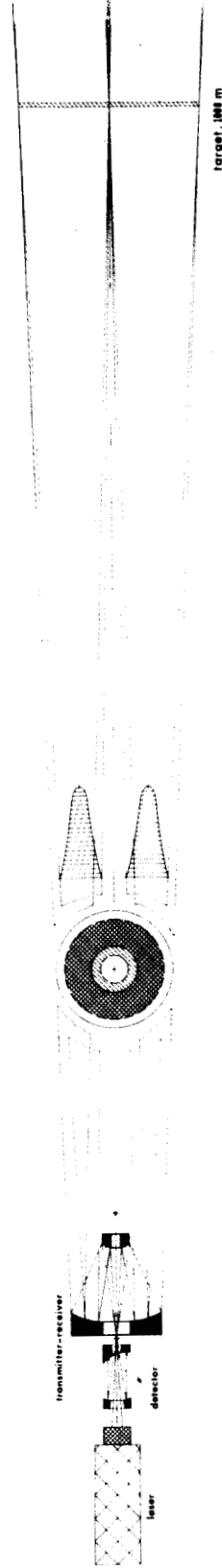


Figure 1. Transmitter-receiver configurations.



c. Newtonian Cassegrainian configuration.



d. Coaxial Cassegrainian configuration.

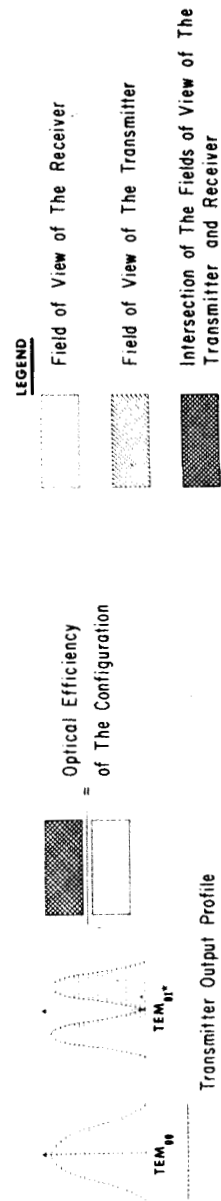
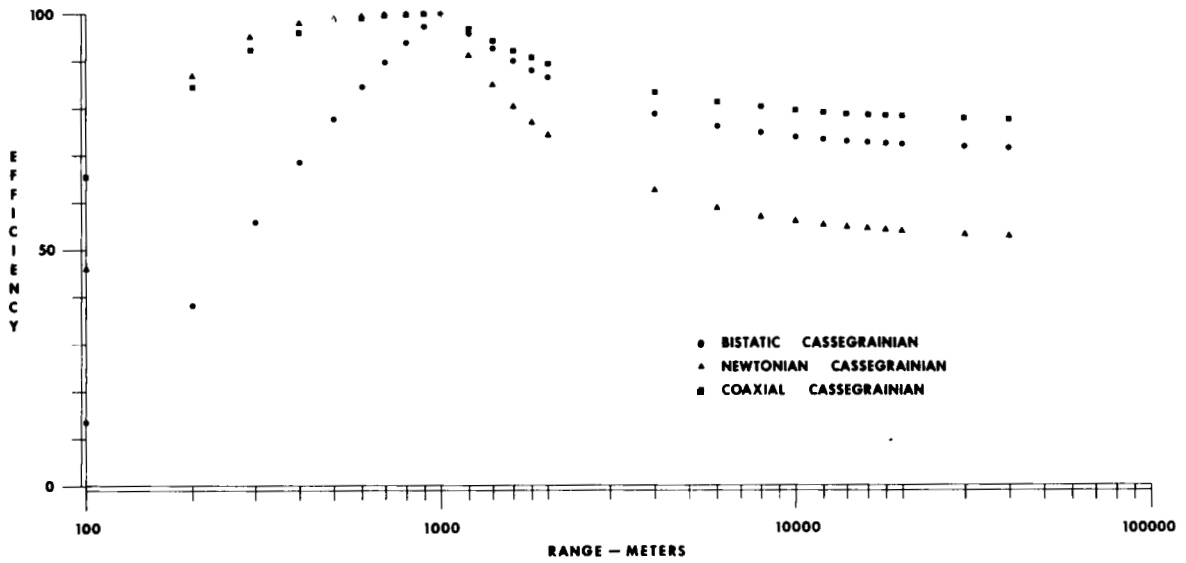


Figure 1. (concluded).



TRANSMITTER-RECEIVER OPTICAL EFFICIENCY

Figure 2. Transmitter-receiver optical efficiency.

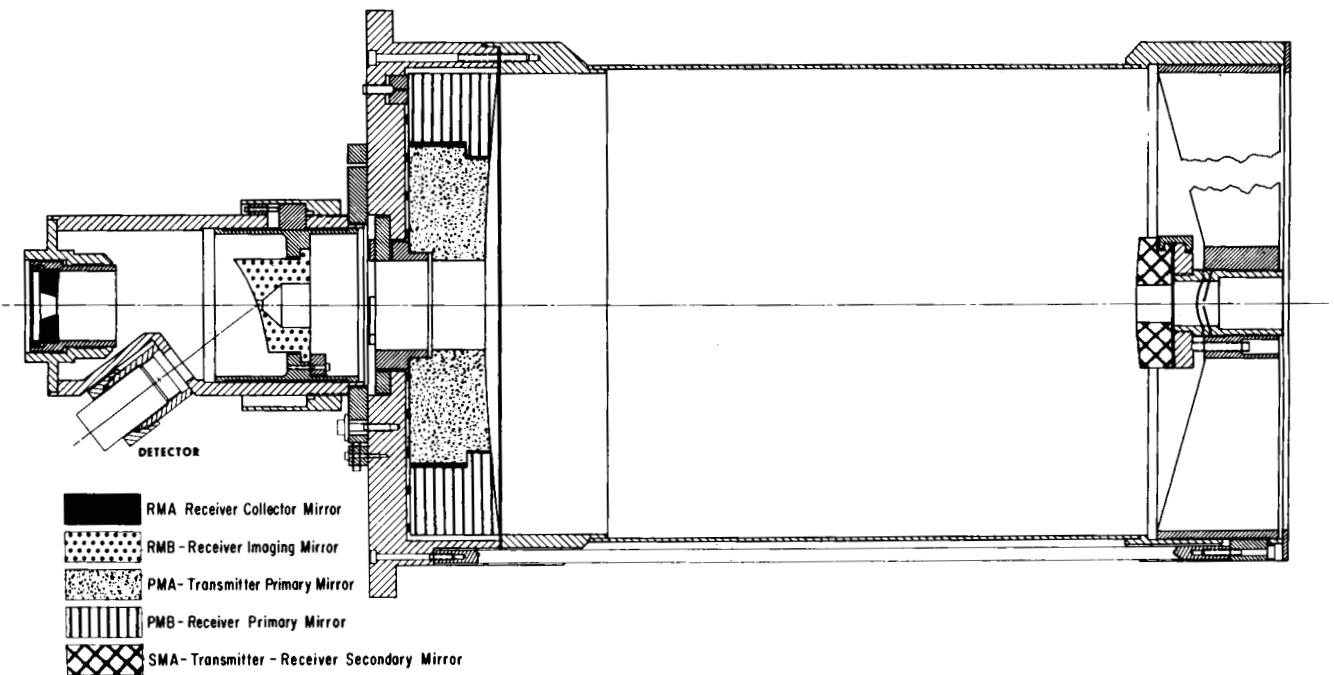


Figure 3. Single aperture coaxial Cassegrainian design.

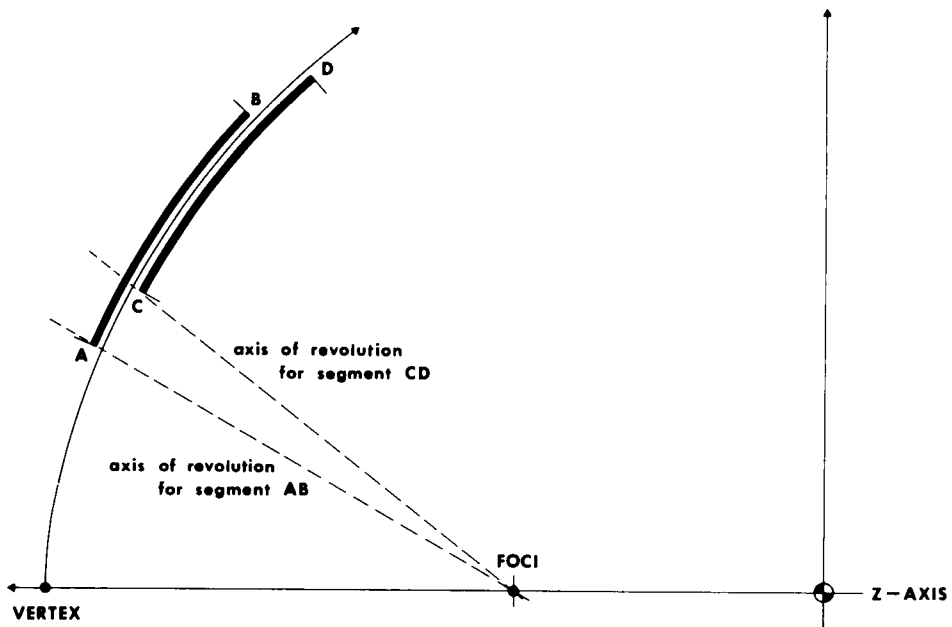


Figure 4. Primary mirror figure.

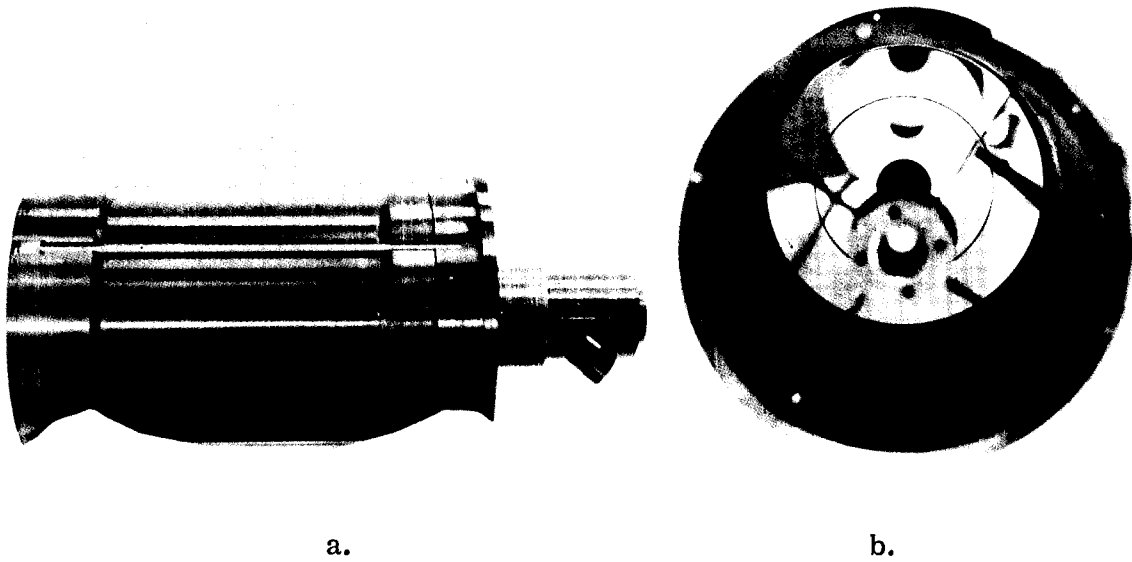


Figure 5. Coaxial Cassegrainian telescope.

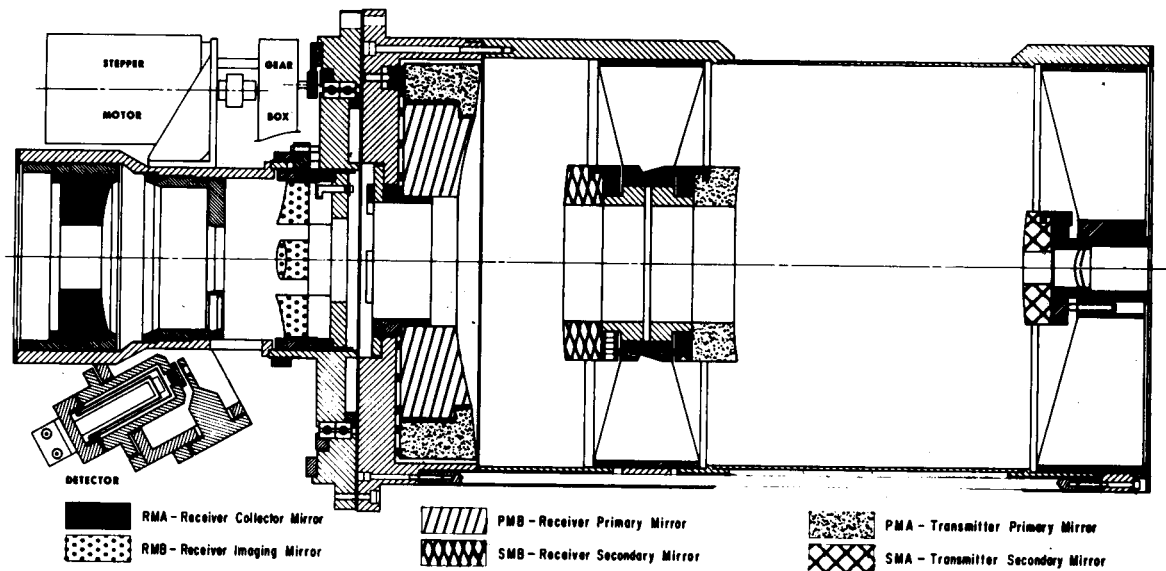


Figure 6. Phased-array coaxial Cassegrainian design.

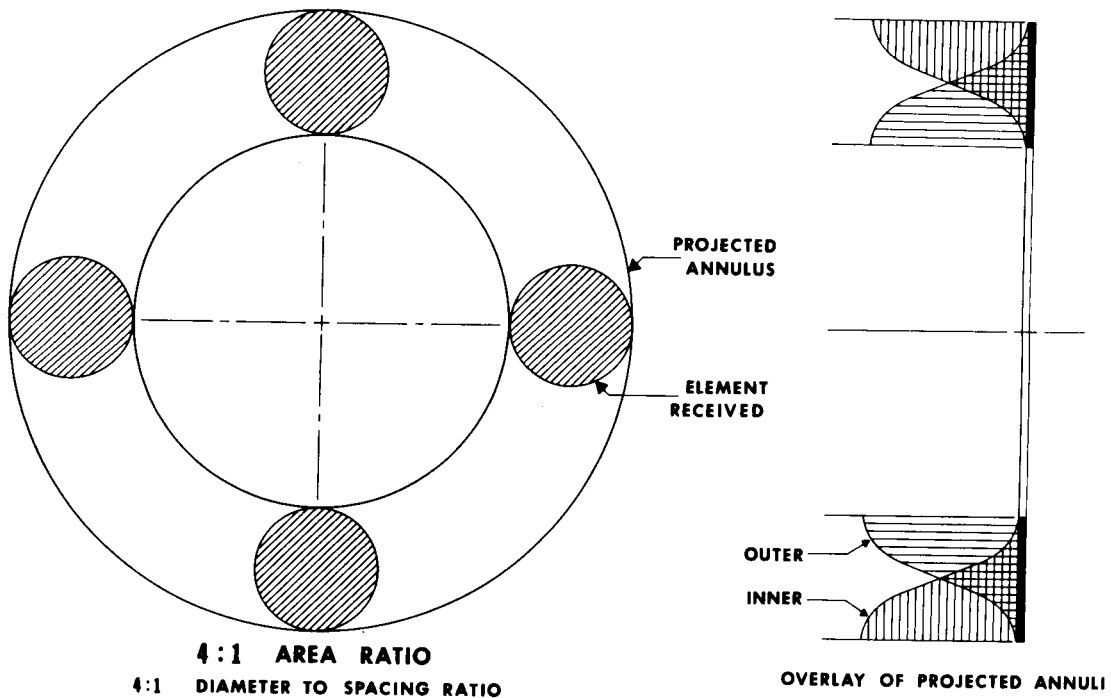


Figure 7. Phased-array matrix.

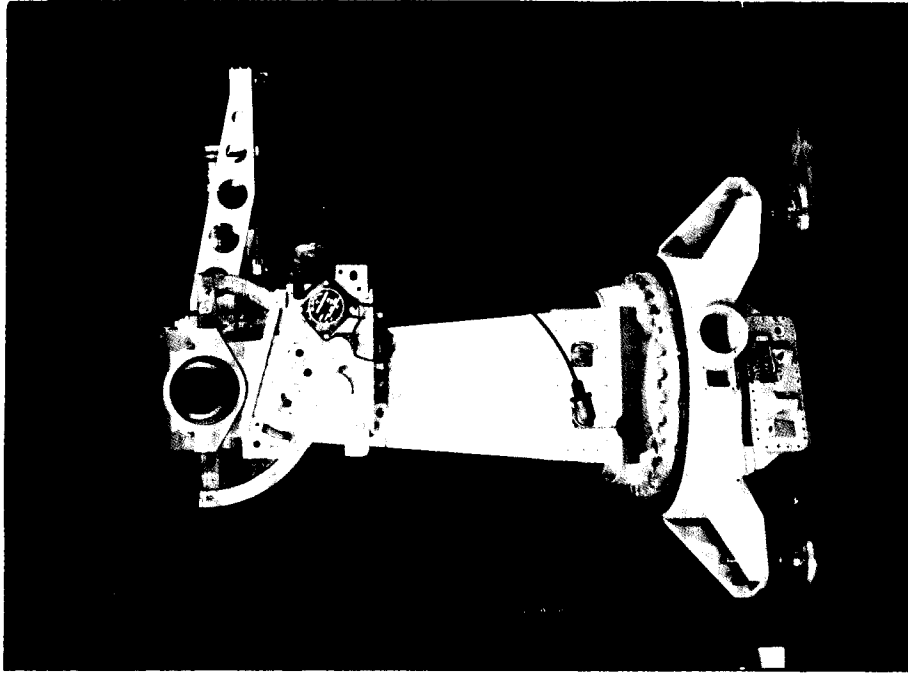
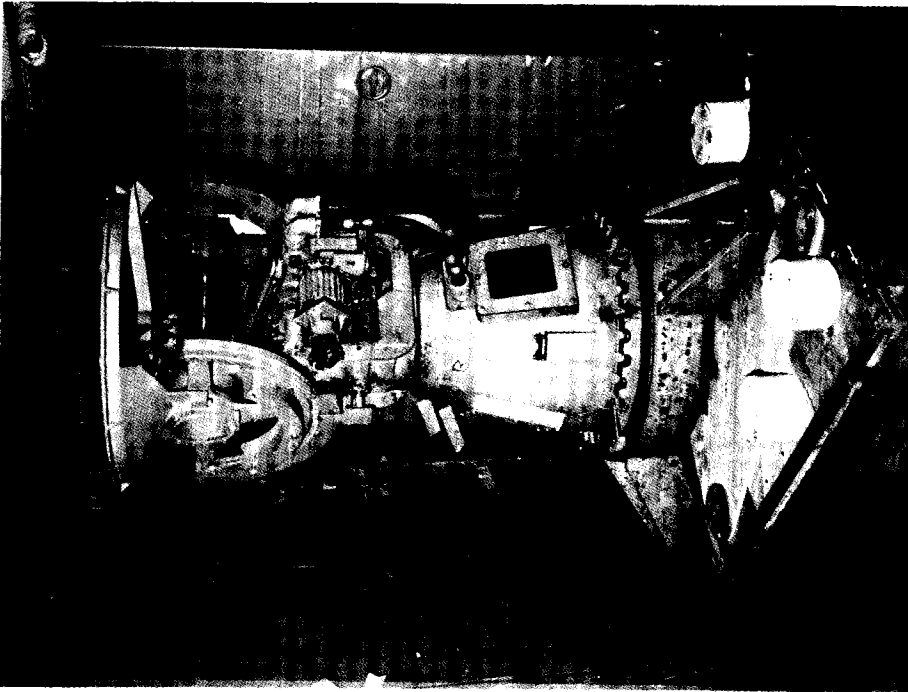
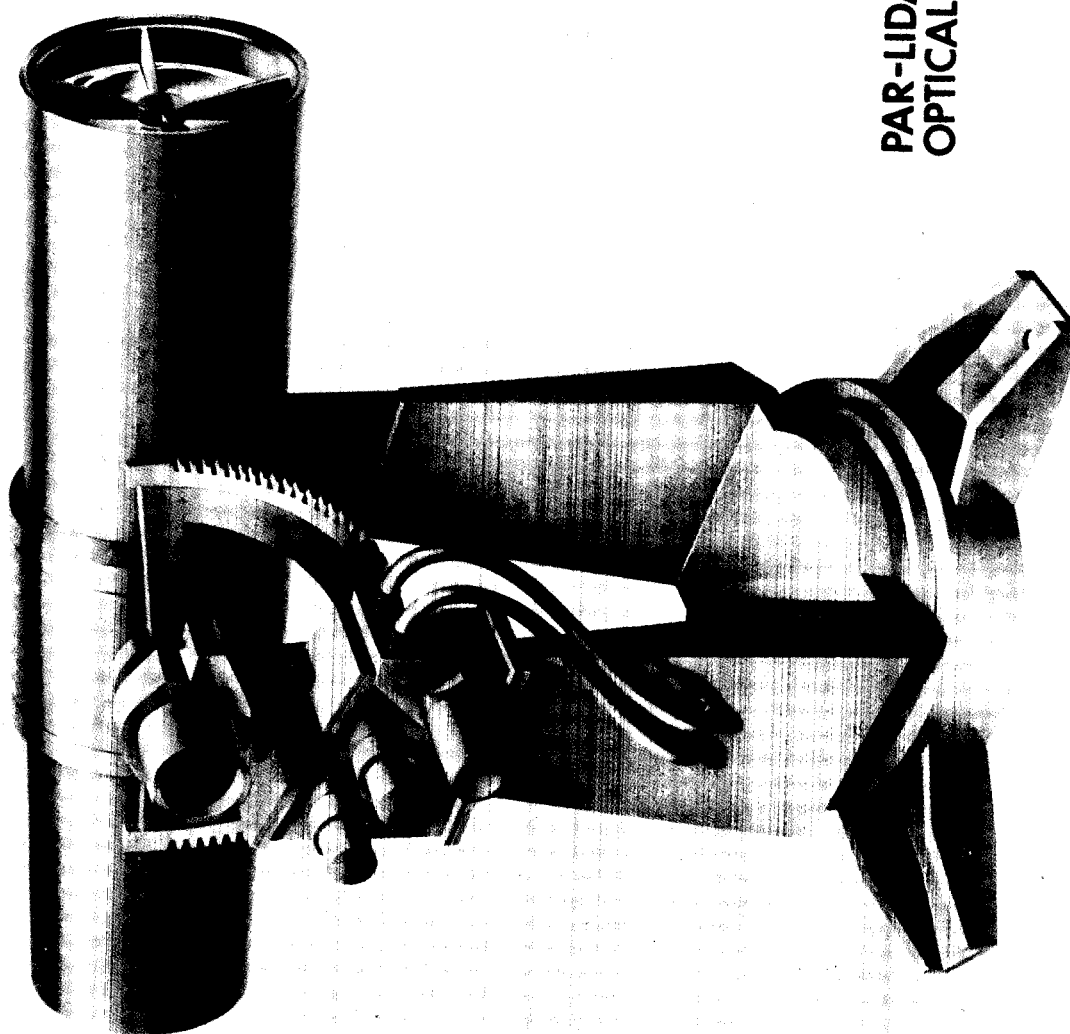
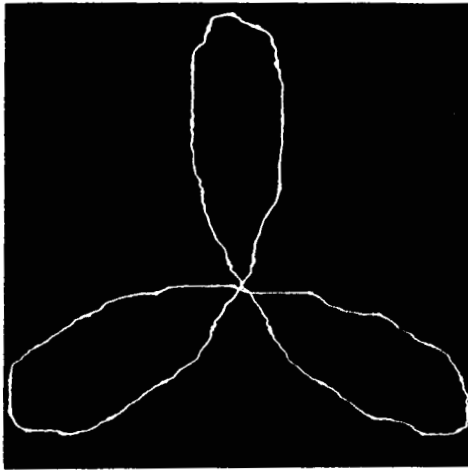


Figure 8. Laser radar mount — original and converted.

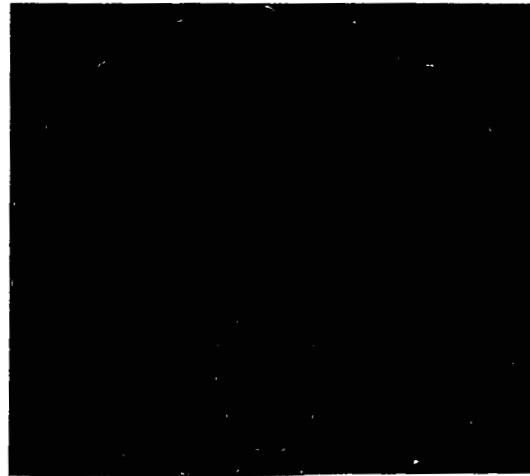


PAR-LIDAR FIELD SYSTEM
OPTICAL MOUNT

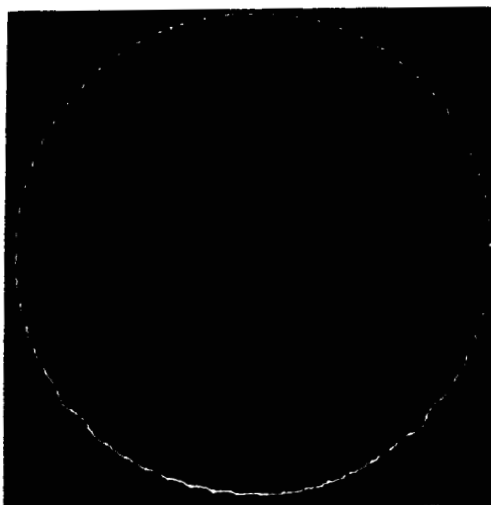
Figure 9. Phased-Array Laser Radar system mount.



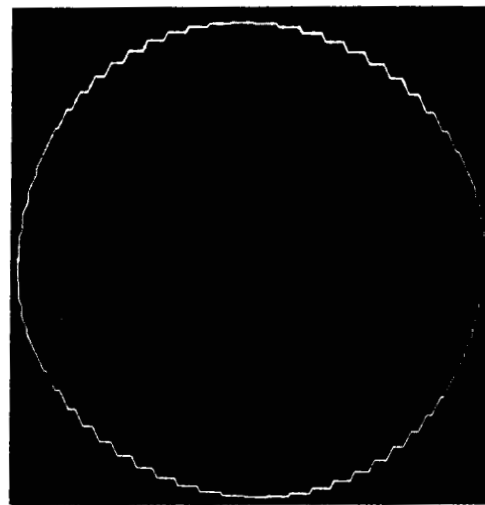
a.



b.



c.



d.

Figure 10. Laser radar mount scan records.

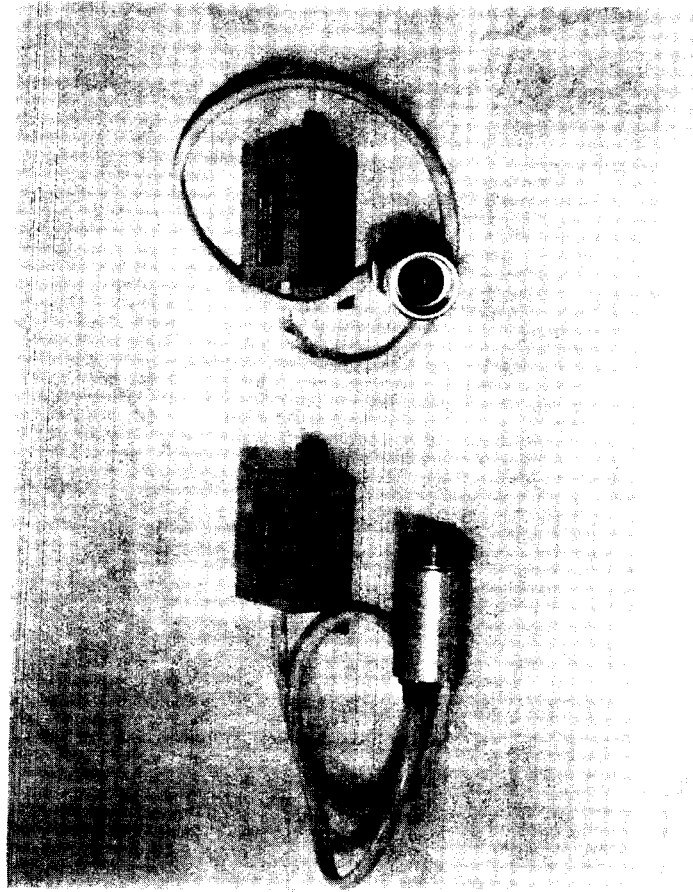
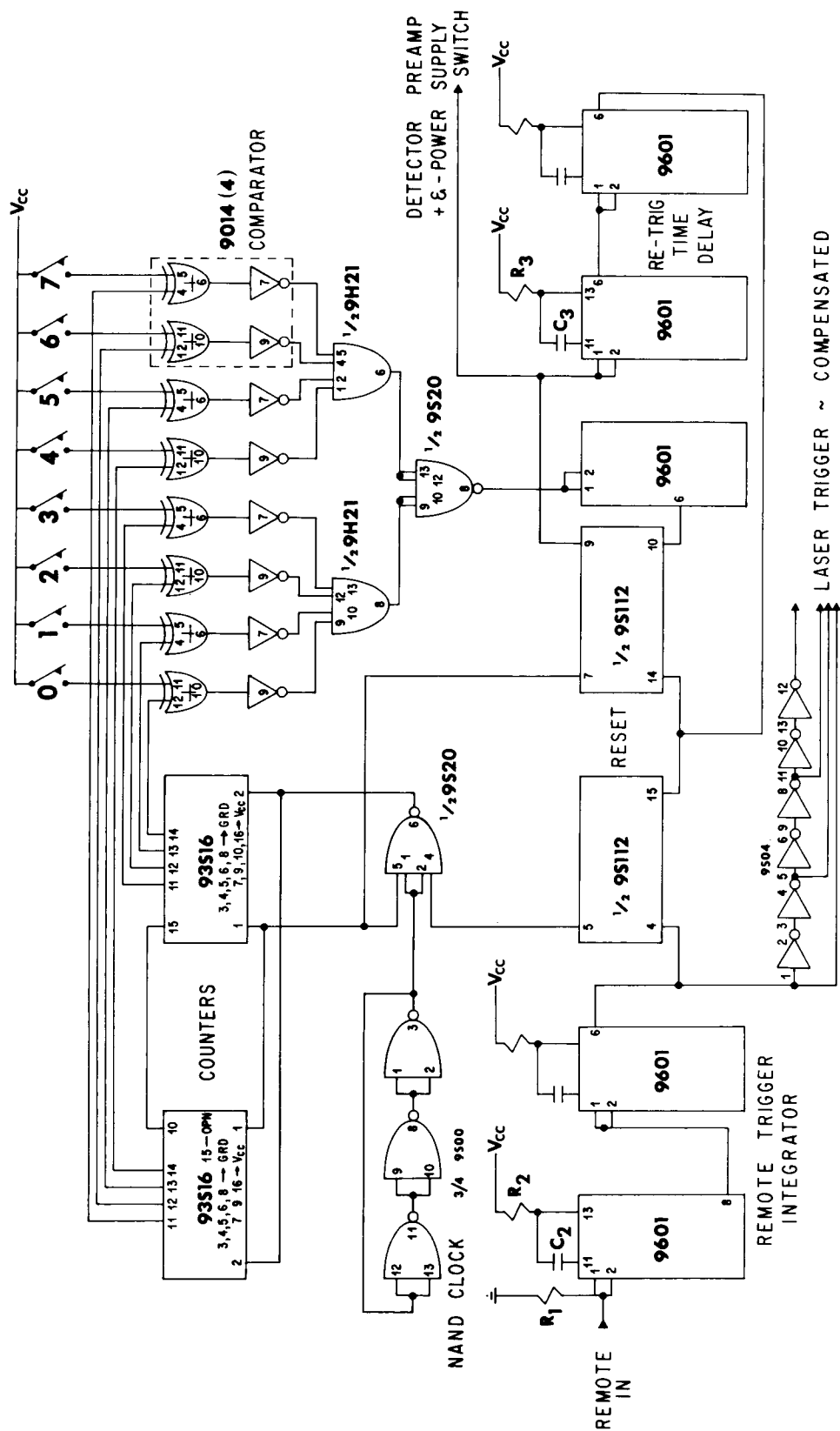
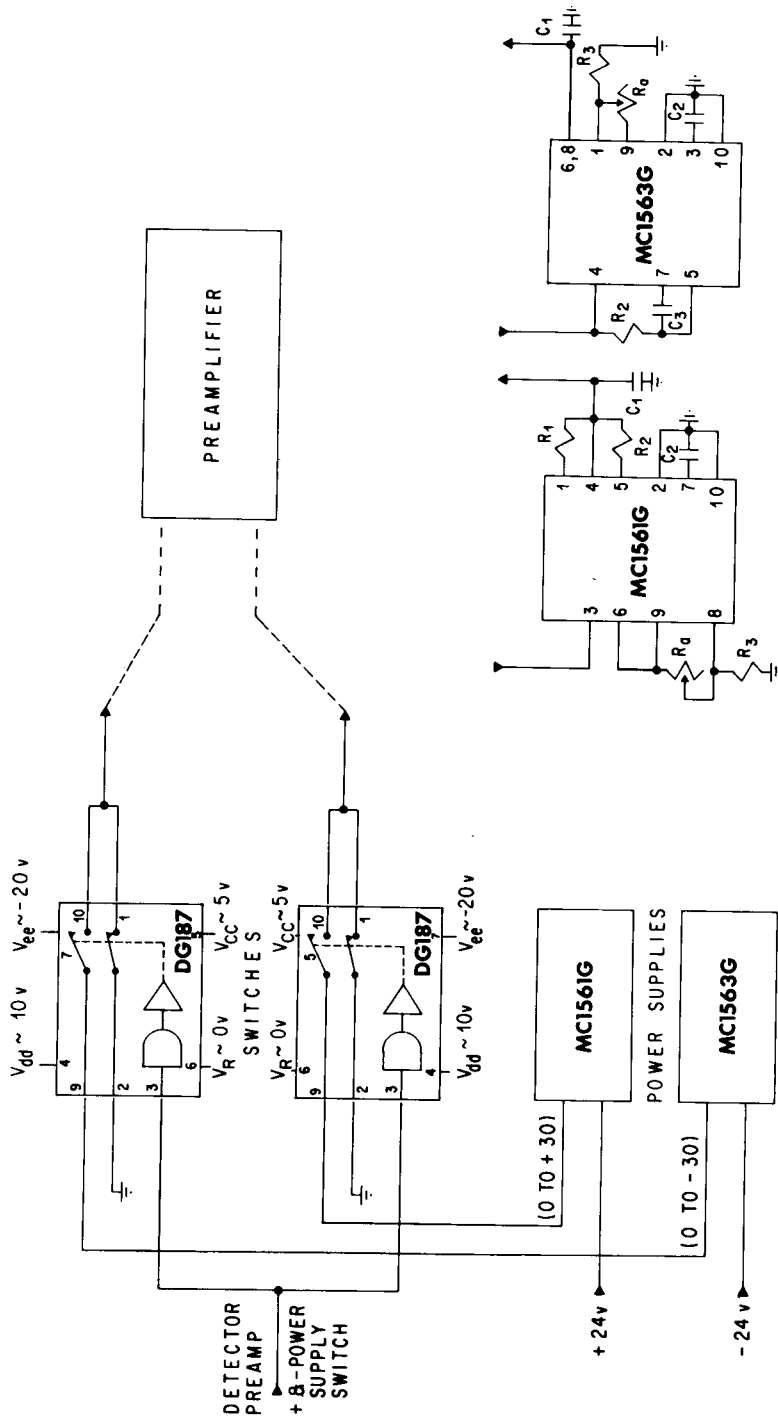


Figure 11. Avalanche Photodiode Detector Module



SHEET 1

Figure 12. Binary Selectable Detector Holdoff Circuit



SHEET 2

Figure 13. Binary Selectable Detector Holdoff Circuit

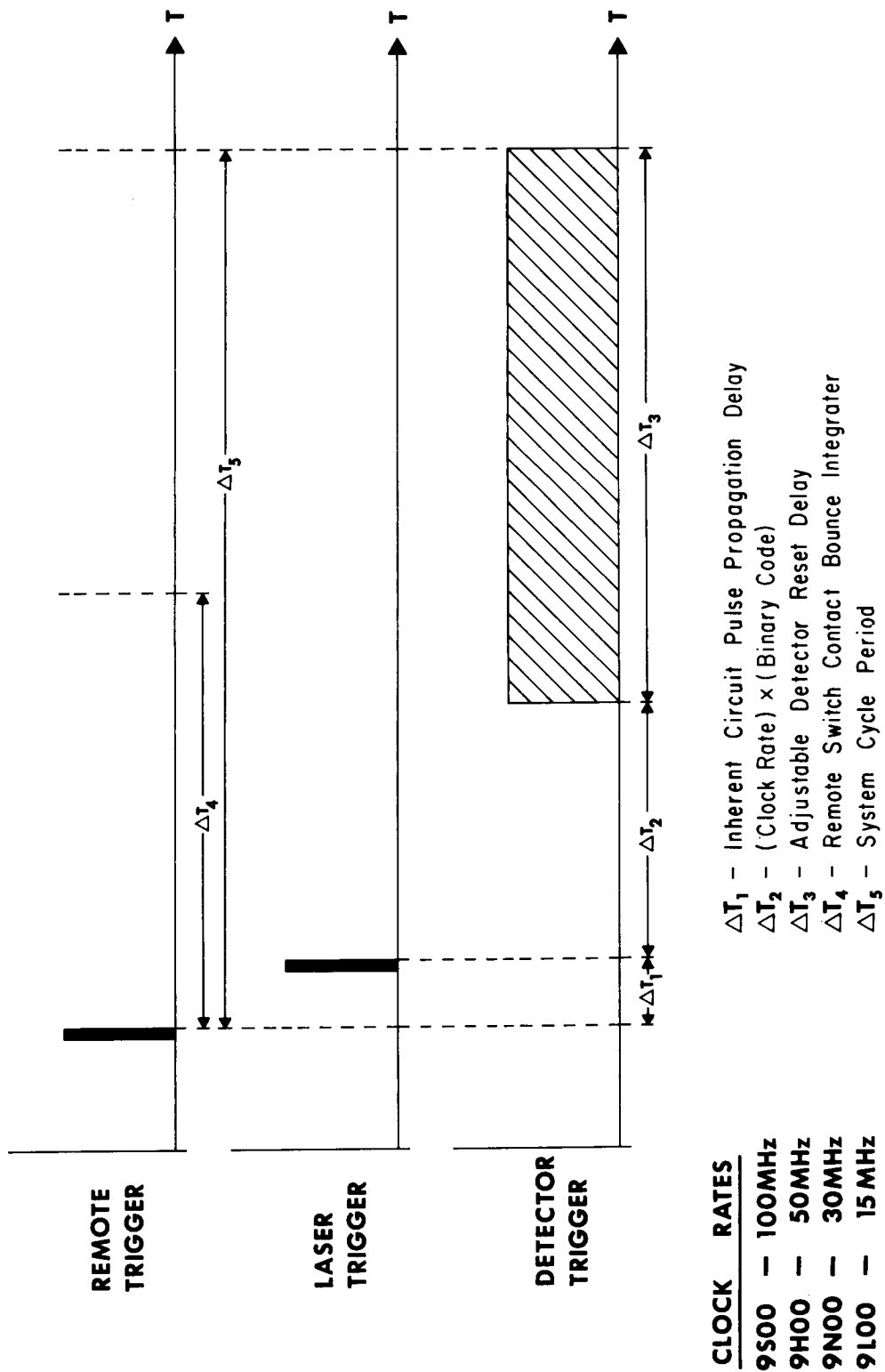


Figure 14. Timing Diagram - Binary Selectable Detector Holdoff Circuit

RESISTORS:

$R_1 = 43 \Omega$
 $R_2, R_3, R_6, R_7 = 1 K \Omega$
 $R_4 = 4.7 K \Omega$
 $R_5 = 5.1 K \Omega$
 $R_8 = 3 K \Omega$
 $R_9, R_{10} = 100 \Omega$
 $R_{11} = 200 \Omega$

CAPACITORS:

$C_1, C_3 = 100 K p F$
 $C_2 = 1 K p F$
 $C_4 = AS REQUIRED$
 $C_5 = 5 p F$

SWITCHES:

$S_1 = 431 DD (TELEDYNE)$

TRANSISTORS:

$Q_1, Q_2 = MD918A$
 $Q_3 = 2N929A (2N2369A)$
 $Q_4 = 2N2222A$
 $Q_5 = 2N2369A$

AMPLIFIERS:

$A_1 = LH0033CG (NAT. SEMI.)$

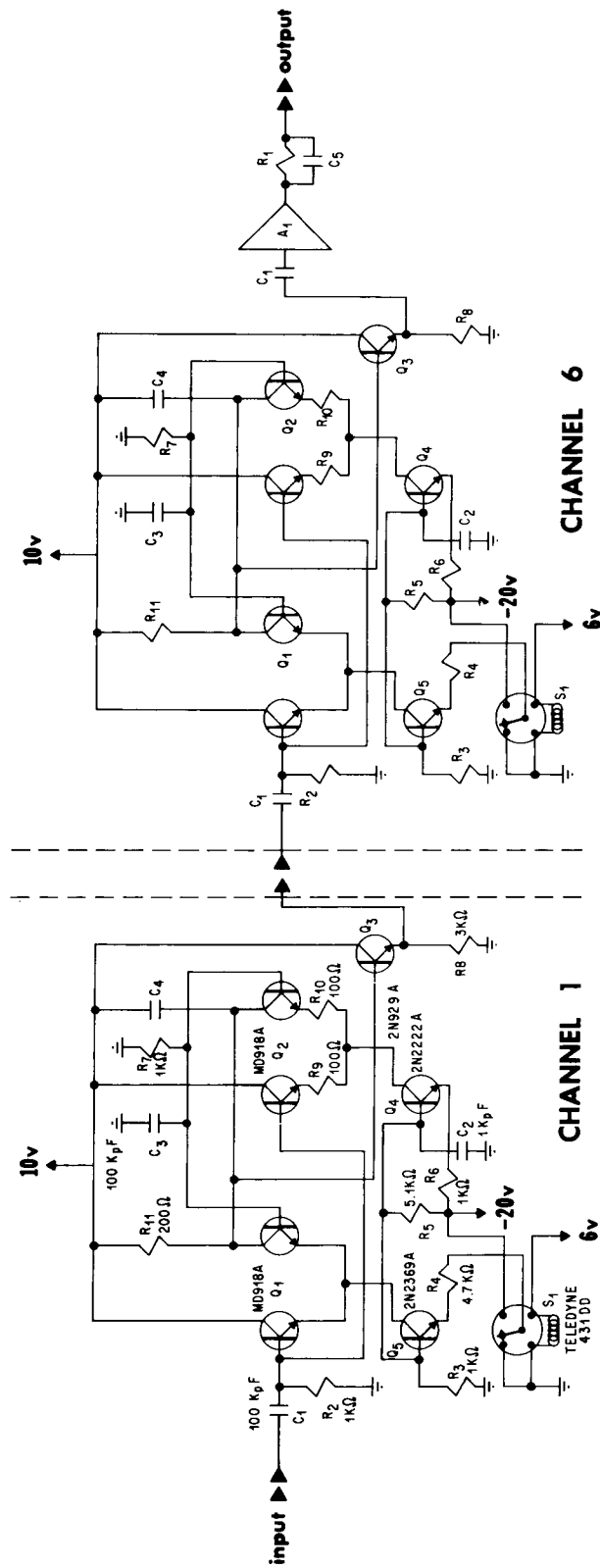


Figure 16. Six Channel Series Summation Logarithmic Amplifier

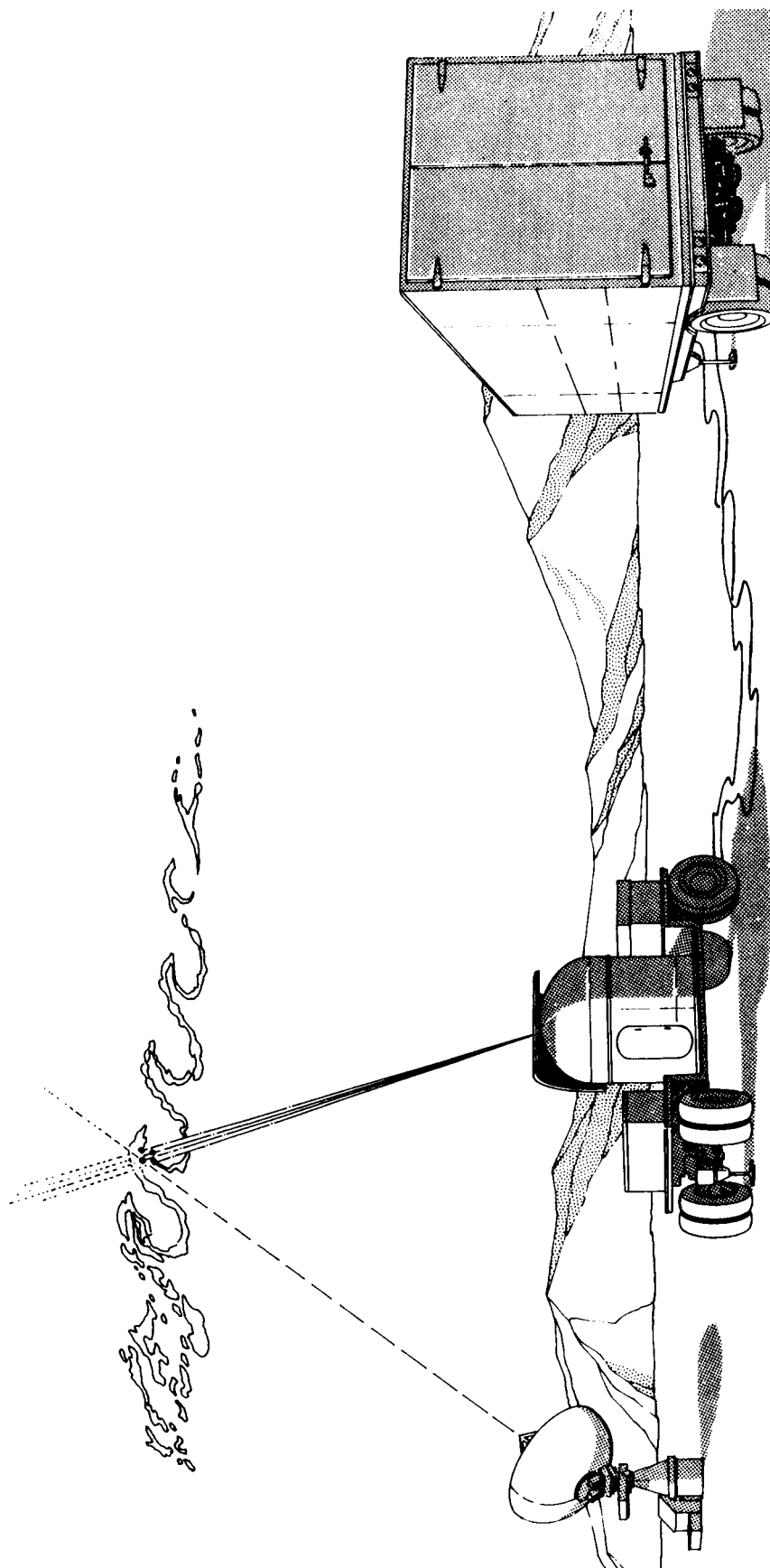


Figure 17. Par-Lidar Clear Air Turbulence Detection

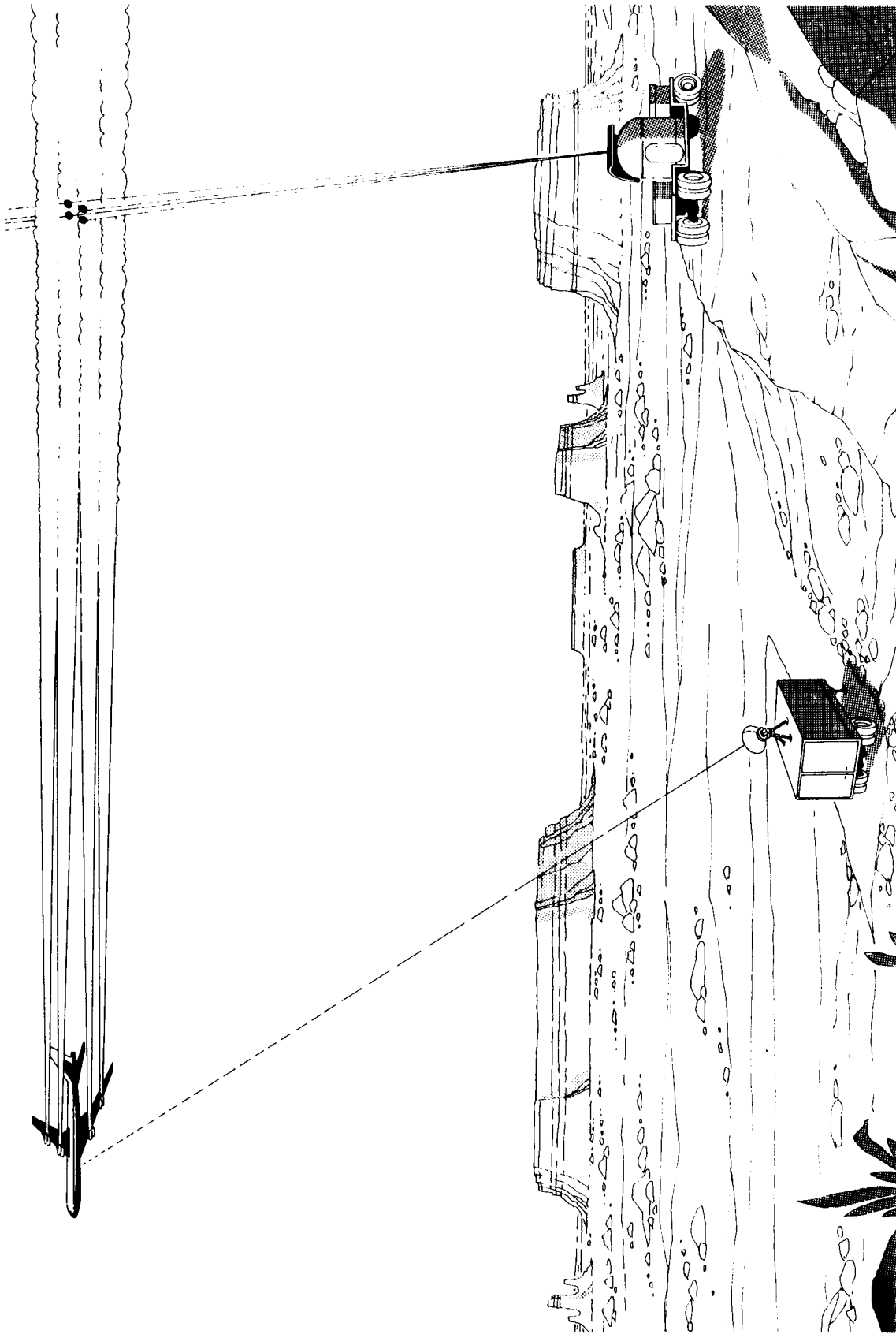


Figure 18. Par-Lidar Climatic Impact Study

REFERENCES

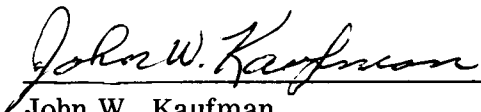
1. Derr, V. E. and Little, C. G.: A Comparison of Remote Sensing of the Clear Atmosphere by Optical, Radio, and Acoustic Radar Techniques. *Applied Optics*, Vol. 9, No. 9, September 1970.
2. Gauger, J. and Hall, F. F.: Laser Applications in the Geosciences. *Proceedings of a Symposium at the Douglas Advanced Research Laboratories, Huntington Beach, California, June 30 through July 2, 1969.*
3. McCormick, M. P. and Fuller, W. H.: Lidar Applications to Pollution Studies. AIAA Paper No. 71-1056. Joint Conference on Sensing of Environmental Pollutants, Palo Alto, Calif., Nov. 8-10, 1971.
4. Allen, R. J. and Evans, W. E.: Laser Radar LIDAR for Mapping Aerosol Structure. *The Review of Scientific Instruments*, Vol. 43, No. 10, October 1972.
5. Grams, G. W. and Wyman, C. M., Compact Laser Radar for Remote Atmospheric Probing. *Journal of Applied Meteorology*, Vol. 11, pp. 1108-1113, October 1972.
6. Atlas, D.; Metcalf, J. I. and Stratmann, E.: *Proceedings of the 14th Radar Meteorological Conference, Tucson, Ariz., Nov. 17-20, 1970, pp. 83-88.*

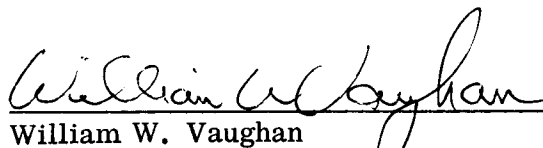
PHASED-ARRAY LASER RADAR: CONCEPT AND APPLICATION

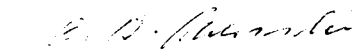
By Kenneth A. Kadrmas

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This document has also been reviewed and approved for technical accuracy.


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16. ABSTRACT Basic principles of laser radar, LIDAR, have been documented by numerous authors. In spite of this intensity of effort, present day system concepts have not been sufficiently concentrated on improving the "optical compatibility" of the LIDAR transmitter-receiver combination. A unique new approach has been undertaken in the design and construction of a coaxial transmitter-receiver combination. Major emphasis has been placed on simple permanent optical alignment, transmitter-receiver field of view matching, use of a pulsed gas laser as a transmitter, maximum optical efficiency, complete digital control of data acquisition, and optical mount pointing and tracking. Also, a means of expanding the coaxial transmitter-receiver concept to allow phased-array LIDAR, par-LIDAR, is described.					
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