JPL SELF PULSED LASER SURFACE MEASUREMENT SYSTEM DEVELOPMENT

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The technology of accurately describing the surface shape of large space deployed antenna structures is a requirement for performance evaluation.

Surface deviation tolerance is based upon the requirement for close wave phase coherence. In order to achieve the required antenna gain, pointing accuracy, and minimize the cross talk possibilities realized from excessive side lobe energy it is sometimes necessary to use surface figure tolerances of less than one fiftieth of a wavelength. For some of the higher frequencies contemplated for use in space deployed communications antennas, this could require that surface deviations not exceed one twentieth of a millimeter.

A list of some conceptual space deployable antenna designs and their characteristics and surface tolerance requirements are shown in Table 1.

The assurance that an antenna will operate efficiently after deployment is best ascertained by direct measurement of its surface with respect to design geometry. Further benefits derived from post deployment measurement may include the possibility of periodic adjustments in either the surface or in the feed point location which may have distorted or changed due to thermal or other causes.

SATELLITE MISSION	ANT. DIA. METERS	TYPE*	EFFECTIVE WAVELENGTH, MM	σ, MM ALLOW SURF TOLERANCE	APPROX. $\frac{\sigma}{\lambda}$ TOLERANCE
MOBCOMSAT	75	MDC	400	8.0	1/50
ODSRS	45	EC	9.38	0.745	1/15
VLBI	30	MDC	12.58	1.0	1/15
R/A SETI	24	PDC	0.629	0.05	1/15
PUB. SERV.	22.6	MDO	111.5	2.54	1/40
TELECONF.	4.7	PDO	21	0.4	1/50

*C CASSEGRAIN M MESH
D DEPLOYABLE O OFFSET
E ERECTABLE P PRECISION

TABLE 1. FEATURES OF CONCEPTUAL ANTENNA DESIGNS

MEASURING TECHNIQUES EXPLORED

Several of the state-of-the-art measuring techniques have been studied. Among the more interesting for the thirty meter mesh deployable cassegrain measurement are the Payne, LMSC and JPL systems.

The Payne system uses a modulated laser beam and phase detection to achieve a claimed 100 micron resolution but uses only one modulation frequency and thus is ambiguous beyond the half wavelength range of 27 cm.

The LMSC system overcomes ambiguity by modulating the laser beam with two widely different frequencies. The resolution claimed is in the order of 200 microns. Since the system now uses a CO_2 laser, it has possible size and weight problems.

The HP5501 and the Boeing systems are for measuring small strains or changes in distance and may have usefulness as sensors for reference alignment of antenna axis and surface scan position.

The JPL self pulsed system has promise of being very interesting from the standpoints of non-ambiguity, simplicity weight and ease of data reduction.

The TRW angular measurement system is a bidirectional led and detector system capable of resolving angular deviation equivalent to sub millimeter motion.

SURFACE MEASURING SYSTEMS

TYPE	OPERATING PRINCIPLE	CHARACTERISTICS
Simple Optic Radar	Range = $\frac{\text{Speed of Light x Time}}{2}$	Unambiguous 150 mm Resolution
Payne, LMSC Modulated Laser	Phase Difference Measurement $\phi_r - \phi_s = 4\pi \frac{R}{\lambda}$	Ambiguous ~200 μ Resolution Complex
H.P. 5501 Machine Control	Straight Interferometer with Count Accumulation	±1 Count or 1λ Accuracy
Boeing Multi-Channel	Interferometry with Phase Resolution	1/20 λ Resolution (Optical Straingage) Complex
JPL Self Pulsed Laser	Range = $\frac{\text{Speed of Light}}{2 \text{ x Frequency}}$	Non-Ambiguous ~ 50 μ Resolution
TRW Angular Measurement	Bidirectional Angular Deviation Led & Beamsplitter	Very Fine Resolution ~ 0.1 mm in 45 Meters Limited Travel

LMSC STRUCTURAL ALIGNMENT SENSOR
CONCEPTUAL DEMONSTRATION

A contract was let to Lockheed Missiles and Space Company to demonstrate a system for measuring distance to a target with high resolution capability. The tasks included measurements using both CO_2 and helium-neon laser equipment. An optional task was to demonstrate the ability to unambiguously measure the absolute distance to any given target.

The basic capability was demonstrated using both types of laser. The resolution obtained was in the order of one to two tenths of a millimeter. The capability of unambiguous distance measurement was not achieved due to lack of necessary equipment although there is little doubt that this could have been achieved.

The LMSC system shows real promise of use in the measurement of large antenna surfaces although it is complex and may present size and weight problems.

LMSC STRUCTURAL ALIGNMENT SURFACE MEASUREMENT SYSTEM
HARDWARE CONCEPTUAL DEMONSTRATION

OBJECTIVE

To demonstrate the LMSC developed conceptual breadboard structural alignment sensor system for the high accuracy resolution measurement at a round trip distance in the order of one hundred meters, and to unambiguously measure the absolute distance from a reference to a target.

TASKS

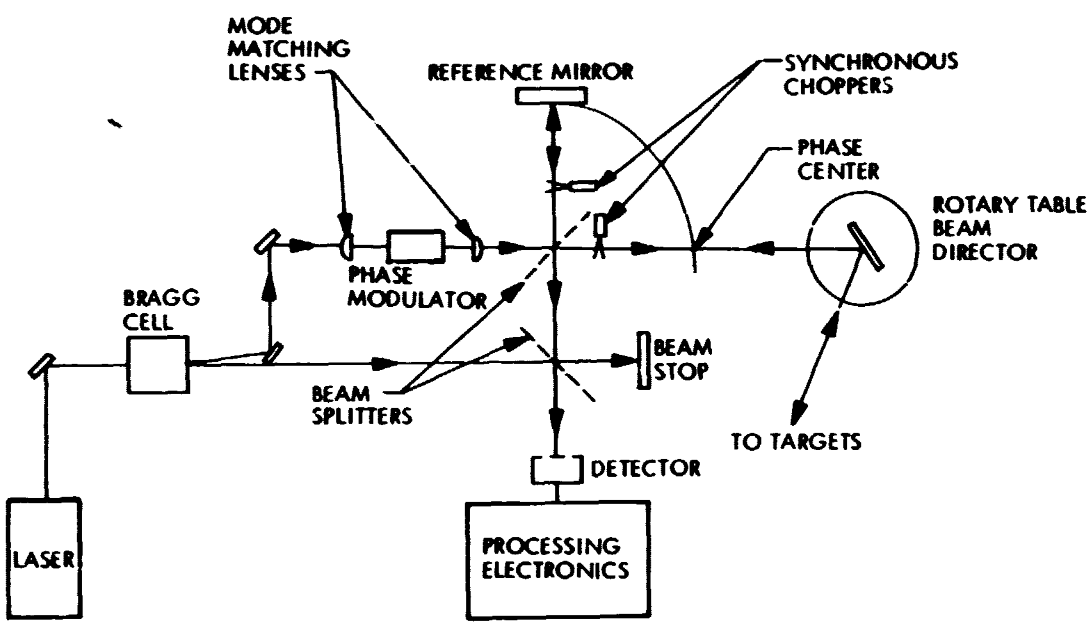
- o Demonstrate the operation and resolution capability of the LMSC system with a CO_2 laser
- o Demonstrate the operation and resolution capability of the LMSC system with a helium-neon laser
- o Demonstrate the LMSC capability to unambiguously measure absolute distance

SIGNIFICANT ACCOMPLISHMENTS

- o The LMSC system demonstrated the capability for resolving distances in the order of one to two tenths of a millimeter in ranges up to 50 meters.

LOCKHEED MISSILES AND SPACE COMPANY CONTRACT
"STRUCTURAL ALIGNMENT SENSOR"
OPTICAL LAYOUT

The Lockheed "structural alignment sensor" system for measuring distances from a scan position to several targets is shown. It consists of a laser optic source which is both frequency and phase modulated. The modulated signal is alternately sent to the target and to a reference mirror. The return signals containing distance information are optically mixed with the original laser frequency and detected. The distance from the reference (or scan mirror) to the target is found by electronic processing. Measurement resolution in the order of one tenth millimeter has been achieved by this system.



SAS Optical Layout Diagram

JPL SELF PULSED LASER RANGING SYSTEM

The objective was to prove and evaluate the concept of a self pulsed ranging system. This included the ability to produce a frequency inversely proportional to range, and to attempt to project resolution capability in order that the system might be evaluated for further development.

The approach was to design and fabricate a breadboard system sufficient to allow projected capability.

The breadboard was fabricated and tested. It verified functional operation with short time resolution in the order of 0.2 millimeter, non-ambiguous ranging and a maximum range capability in the order of 150 meters. Projected capability of the system is resolution of less than 0.1 mm over a reasonable time period and a range extension to over 300 meters.

The FY80 plans are to upgrade the system and perform distance measurements on simulated antenna geometries.

JPL SELF PULSED LASER SURFACE MEASUREMENT SYSTEM HARDWARE CONCEPTUAL DEMONSTRATION

OBJECTIVE

To develop a functional hardware system to accommodate the demonstration of the basic system concept for the unambiguous determination of range and a system evaluation that addresses the limits of performance and the applicability of the system for further development.

APPROACH

- o Design, fabricate and assemble components for functional system
- o Develop system to the point of a functional demonstration and evaluation
- o Generate estimates of potential system performance based on system evaluation
- o Access applicability of system for flight hardware application

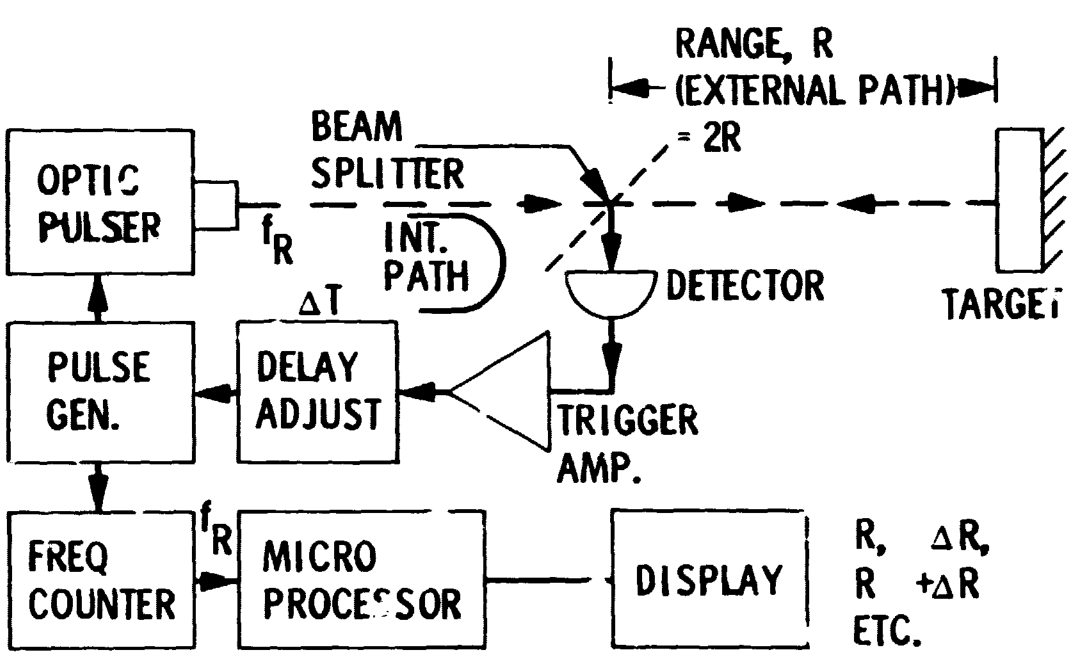
SIGNIFICANT ACCOMPLISHMENTS

- o Functional system operation has been achieved
- o Ranging resolution of 0.2 mm has been achieved for an overall range of 150 meters
- o Approaches for upgrading the system for the next phase of development have been developed

The self pulsed laser ranging system is used for measuring distances from a fixed reference or scan position to several locations on the surface of an antenna reflector. Processing the information thusly obtained is used to define the "Figure" or shape of the surface upon which antenna operational efficiency is directly dependent.

Operation of the system consists of initiating a pulse from the laser emitter which is pointed at the scan mirror. The emitted pulse strikes the scan mirror, is reflected and sent to one of several targets located on the surface of the antenna. Upon reflection from the target, the pulse returns to a detector via the scan mirror. The detected pulse is amplified and used to trigger the next emitted pulse. After the first pulse is emitted, received and used to trigger another pulse the process becomes repetitive with a repetition rate uniquely determined by the distance traveled to the target and back. A measure of the repetition rate or frequency thus created provides the means required for determining range since the total distance traveled is inversely proportional to the frequency.

During its round trip travel, the emitted pulse traverses the distance from the laser to the target and back to the detector at the speed of light. It then proceeds through electronic circuitry with some delay until it triggers another light pulse. A distance equivalent to the time delay realized by the travel time of the returning pulse from the scan mirror to the detector, through the electronics and back to the scan mirror may be subtracted from the total distance to provide a precise measure of the round trip distance from the scan mirror to the target.



JPL SELF PULSED LASER MEASUREMENT SYSTEM

SIMPLE CALCULATIONS

The self pulsed laser ranging system is made possible by the relation which ties wavelength and frequency to the speed of propagation, in this case the speed of light in a vacuum. (See equation 1). In our case, the wavelength will be the round trip distance to the target and will include any optical and electronic path or equivalent time delay included in the loop containing the electronic equipment out to the reference position from which surface measurements are to be made. A more correct equation relating distance and frequency then is given by equation 2.

The value for the equivalent internal path length is found by reflecting the signal back to the detector by the scan mirror. The frequency thus obtained will uniquely define the equivalent internal path distance. (Equation 3). By subtracting the equivalent internal path from the total path to the target and back, the desired distance from the reference, or scan mirror, to the target is obtained. Since the object is to find the range from a reference position, the total path length is divided by two. (Equation 4). Since the internal path length is a constant when a scan mirror is used, a value for the internal range may be found and subtracted from all target measurements to obtain range from the reference to the target. (Equation 5).

$$\text{Wavelength, } \lambda = \frac{\text{Speed of Light, C}}{\text{Frequency, f}} \qquad (1)$$

$$\text{Round Trip Distance} = \frac{c}{f} - S_{\text{internal}} \qquad (2)$$

$$\text{Internal Path, } S_{\text{int}} = \frac{c}{f_{\text{int}}} \qquad (3)$$

$$\text{Range, R} = \frac{c}{2f} - \frac{c}{2f_{\text{int}}} \qquad (4)$$

$$\text{Range, R} = \frac{c}{2f} - K \qquad (5)$$

$$\text{Where K} = \frac{c}{2f_{\text{int}}}$$

SYSTEM PERFORMANCE

System performance is nearly totally dependent upon the stability with which the ringing frequency is established when aimed at a distant target. Most of the stability problems of the self pulsed ranging system occur in electronic circuits in the form of varying component delay time, wave form jitter, and temperature effects. Some problems arise from varying signal strength with target distance; however, this type of problem is more easily handled by using automatic gain control and wave shaping techniques. The former problems are sometimes an inherent characteristic of the equipment and can only be improved by component selection, use of state-of-the-art devices and careful attention to thermal problems.

When the ranging system uses a standard frequency counter for measuring the pulse repetition rate, it is interesting to note that using a one second time gate will automatically provide an average of one million round trip samples if the ringing frequency were one megahertz. At one megahertz the round trip path would be three hundred meters or would correspond to a range of one hundred fifty meters. Such a total range might easily correspond to a scan mirror to target distance of the order of one hundred meters or to the measurement of an antenna dish of one hundred meters diameter. Resolution of measurement in this case would be one part in a million corresponding to one one millionth of three hundred meters. Since range is one half of the round trip distance this resolution is halved along with the division to obtain range. (See equation 6). It may be seen that resolution, providing the sample time gate remains constant, will increase with shorter distances and smaller antennas. This is fortunately in the right direction since smaller antennas may operate at shorter wavelengths and require higher resolution measurement. The relation between a change in frequency with respect to a change in wavelength is obtained by differentiating equation (1). (See equation 7).

$$\text{Resolution (1 count)} = \frac{\text{Range}}{10^6} = \frac{150 \times 10^3 \text{mm}}{10^6} \qquad (6)$$

Resolution = 0.15 millimeters

$$f = \frac{c}{\lambda} \qquad (1)$$

$$\frac{df}{d\lambda} = -\frac{c}{\lambda^2} \qquad (7)$$

Inverting and substituting $\lambda = 2R$ gives the distance increment resolvable as

$$\frac{dR}{df} = -2\frac{R^2}{c} \qquad (8)$$

from which resolution also = 0.15 mm/Hz

INCREASING RESOLUTION BY GATING A HIGH STANDARD FREQUENCY

As antenna size increases and frequencies become lower, the resolution is decreased by the significance of plus or minus one hertz error in the length of sample time for frequency measurement. In order to overcome this problem a predetermined number of pulses of the ringing frequency may be used to define the time gate through which a precision high frequency is passed and counted. The time gate may be made very precise by edge triggering the opening and closing of the gate on the leading edges of pulses of the ringing frequency. If the count of N_f pulses of the ringing frequency, f, is used for determining the gate time t, the gate time will be N_f divided by f. (See equation 9).

If a standard high frequency, F, is passed through a gate of time duration, t, the count accumulation, N_F, of standard frequency, F will be given by equation 10.

$$\text{Gate time,} \quad t = \frac{N_f}{f} \tag{9}$$

$$\text{Count Accumulation,} \quad N_F = Ft \tag{10}$$

$$\text{from which} \quad t = \frac{N_F}{F} \tag{11}$$

Equating (9) and (11)

$$\frac{N_f}{f} = \frac{N_F}{F} \tag{12}$$

and

$$f = \frac{FN_f}{N_F} \tag{13}$$

using $\lambda = \frac{C}{f}$ or $2R = \frac{C}{f}$ and substituting in (13)

$$\text{gives} \quad \text{Range,} \quad R = \frac{CN_F}{2FN_f} \tag{14}$$

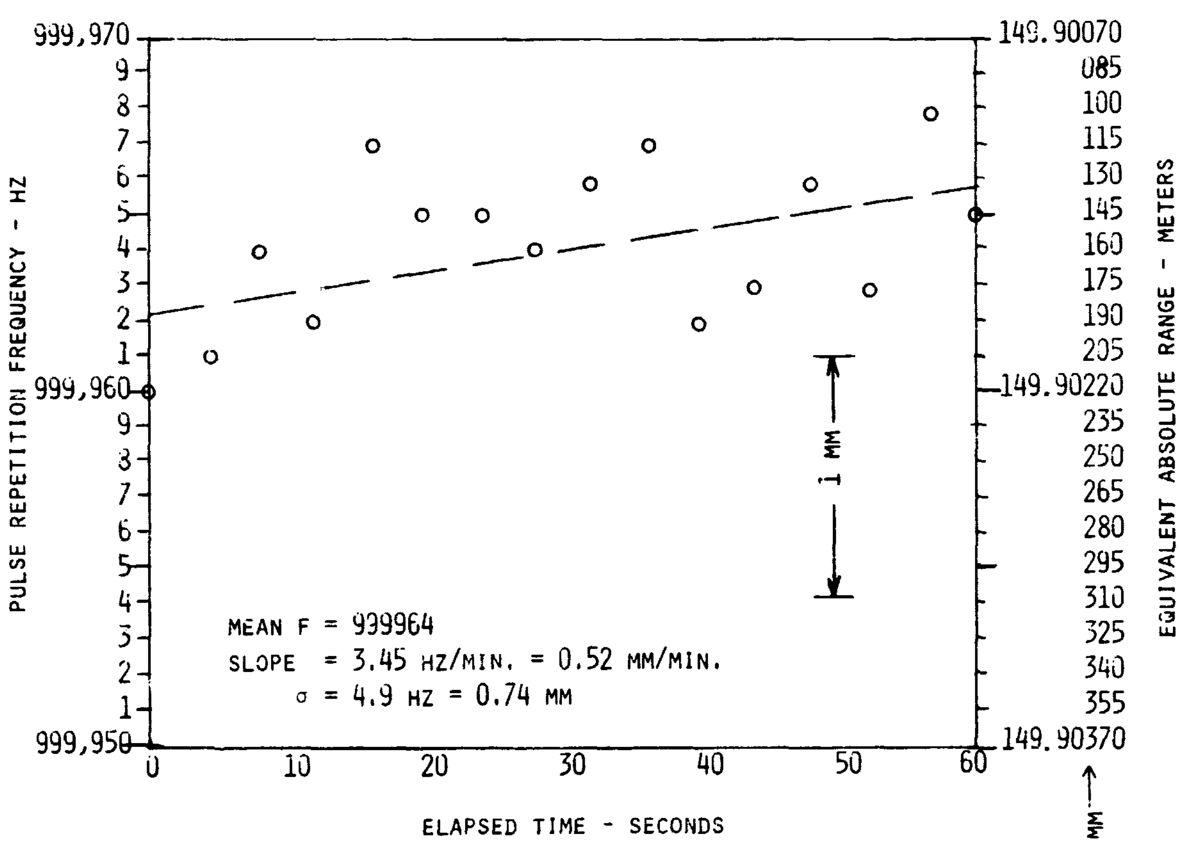
which gives range in terms of the high frequency standard. Resolution then may be as good as one count of the standard frequency in the number of counts passed through the gate, or one part in N_F parts of the path distance.

CONCEPTUAL DESIGN TEST RESULTS

A breadboard test setup was made using a separate pulsed led source, a reflecting target mirror placed at about four meters distance, and a pin diode detector to receive the reflected pulses. The detected pulses were amplified, shaped and transmitted through a length of RG58 coaxial cable. The combined equivalent optical path of cable, range and internal electronic delay was approximately three hundred meters corresponding to a range of the order of one hundred fifty meters. The signal from the delay cable was fed to the led pulse driver to initiate new pulses and produce a self oscillating system. The system repetition rate was very nearly one megahertz.

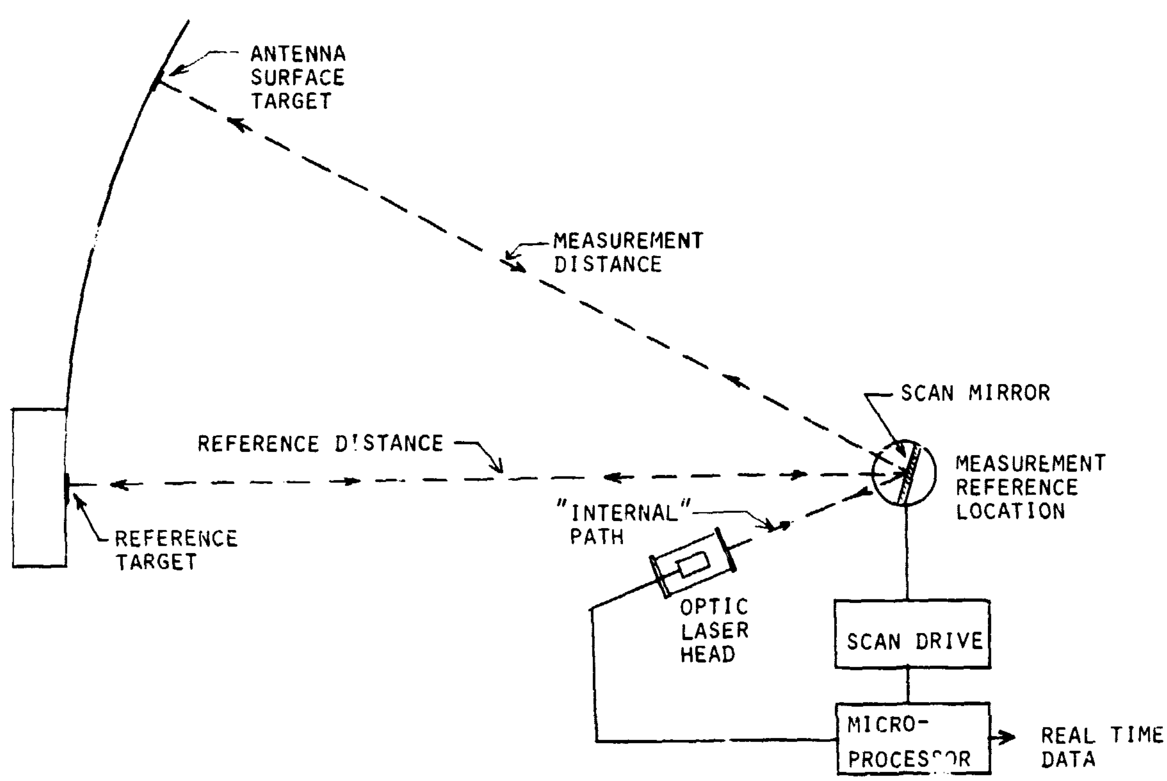
After several modifications to electronic circuitry, stabilization of power supplies, and adjustments to optic components some promising results were obtained. Criteria for system feasibility include stability of frequency and data point scatter. Several short runs were made over one minute time intervals and the data plotted. The results of one such run are shown. It may be seen that the standard deviation fell within 0.74 millimeters and that the drift rate was in the order of one half a millimeter per minute. With improved electronics, optics and delay means, it is entirely feasible that readings may approach the one tenth millimeter or one hundred micron achievement goal.

JPL SELF PULSED LASER RANGING SYSTEM
PROOF OF CONCEPT - STABILITY TEST



IMPROVED HARDWARE SYSTEM

The promising results obtained using relatively crude breadboard encouraged the design and construction of more sophisticated hardware and electronics with which to obtain feasibility information. The objectives of the improved system include a demonstration of the system to scan and unambiguously measure distances to several targets as would be required for measuring the contour of an antenna surface. A simplified layout of the complete pulsed laser ranging system is shown. The laser is located in a fixed position and transmits pulses to a conveniently located scan mirror. The mirror is programed to scan surface targets, a reference target and to reflect the pulses back on themselves to the detector. Subtraction of the path from the transmitter to the scan mirror and return from measurements made to the various targets provides the distances from the scan mirror, or reference position, to the targets. A microprocessor is used to control the scan process, to compute distances and to possibly analyze the surface figure in real time so that it may be used for active control.



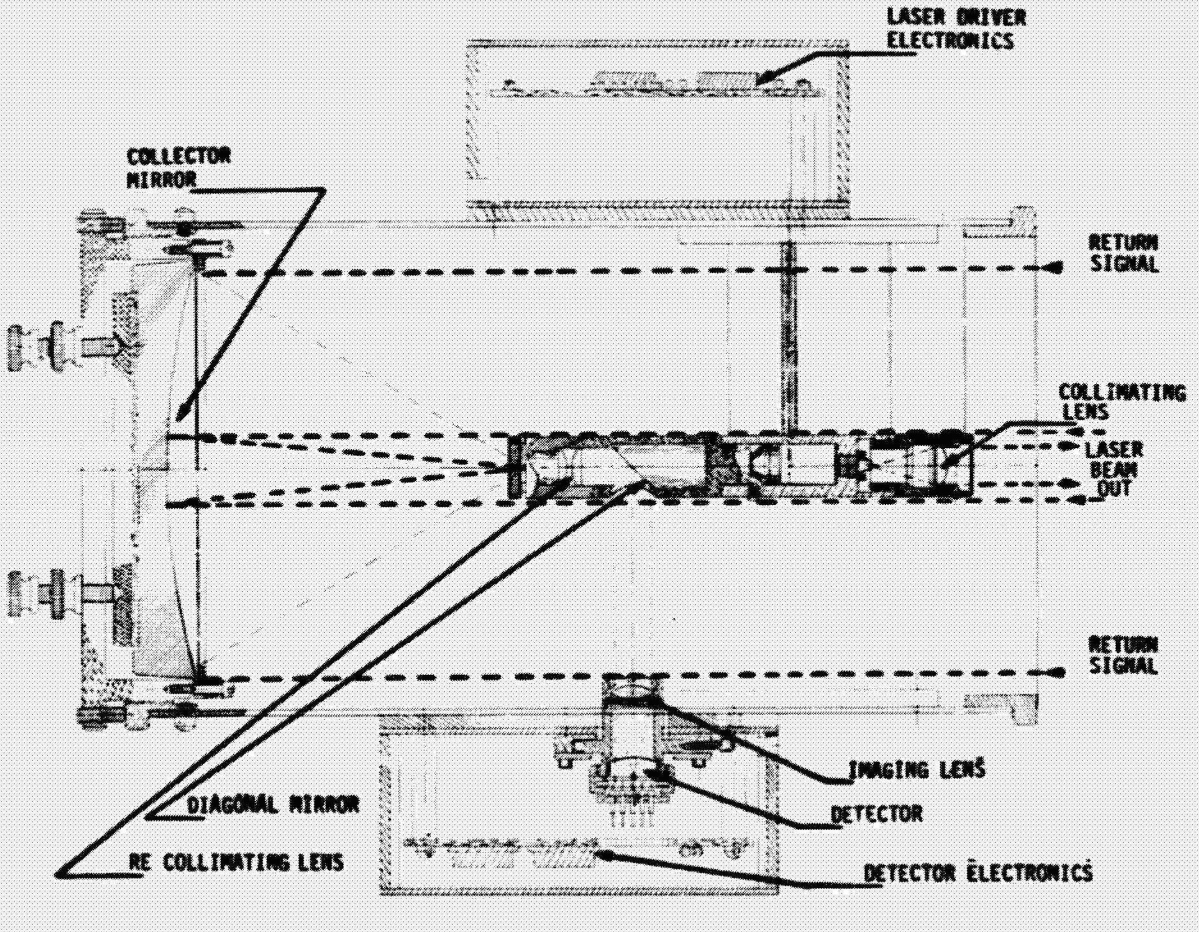
JPL SELF PULSED LASER RANGING SYSTEM

FEASIBILITY TEST HARDWARE OPTIC/ELECTRONIC HEAD

A new combined optical head has been designed and constructed. The head contains both led transmitter and pin diode detector together with driver and pulse conditioning electronics. The optic axis of the led transmitter is coincidental with the receiving optics so that transmitter and detector pointing is achieved simultaneously.

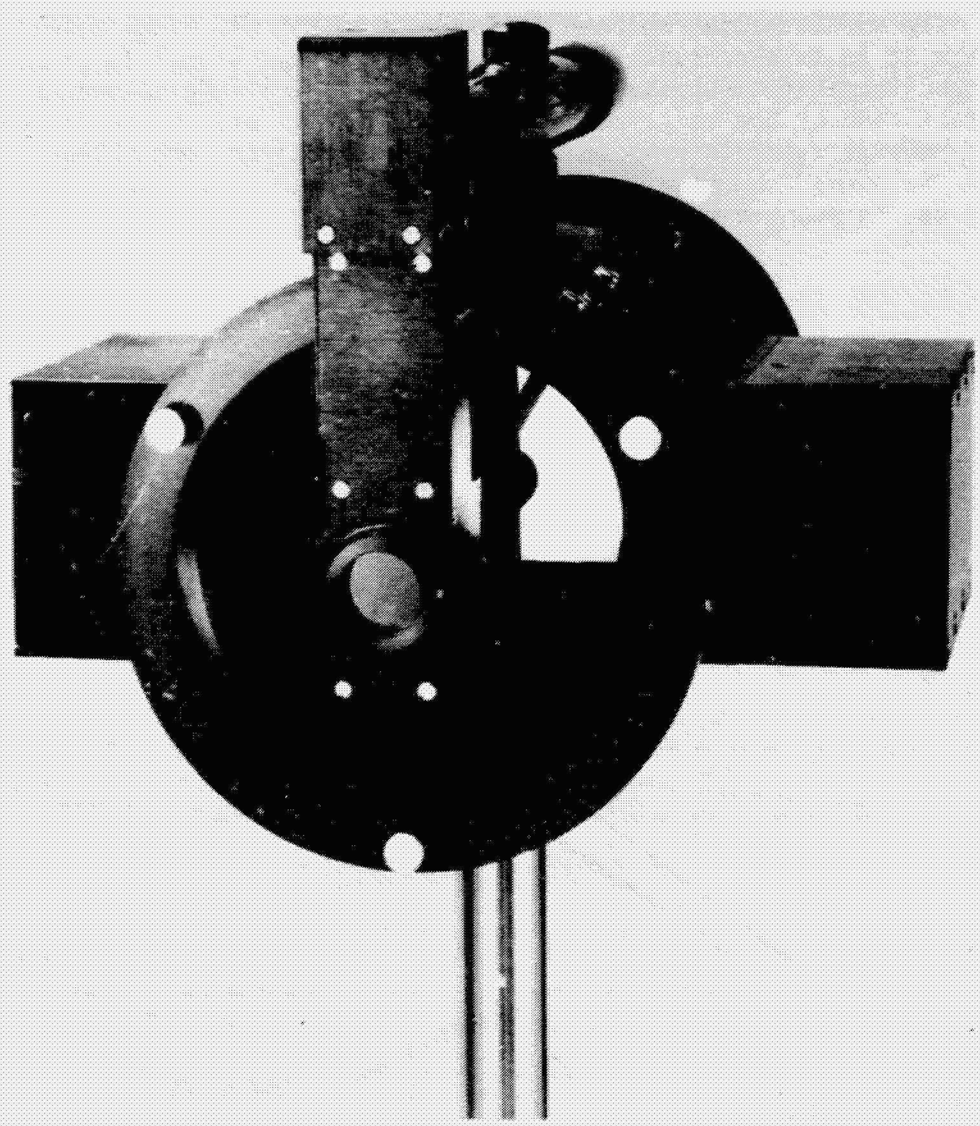
The led/laser pulser is located near the forward end of the small diameter axial tube. Its output is better collimated by a lens and transmitted. The beam expands slightly as it proceeds to the target and returns to the collector mir r in the rear of the head. The collector mirror focuses the return beam to point near the rear entrance of the axial tube. Upon entering the tube the beam is collimated and reflected to the detector box on one side of the large tube. The small collimated beam is focussed on the pin diode detector which converts it to an electrical signal. The electrical signal is processed, conditioned and leaves the detector through a delay line to the pulser driver on the opposite side of the large tube. It is also split off to the micro-processer to provide range information. The electronics for both pulser and detector receive power from an external source. The head is intended to be a stationary device pointed only at the scan mirror.

OPTIC HEAD SECTION VIEW



OPTIC LASER HEAD
ALIGNMENT CONFIGURATION

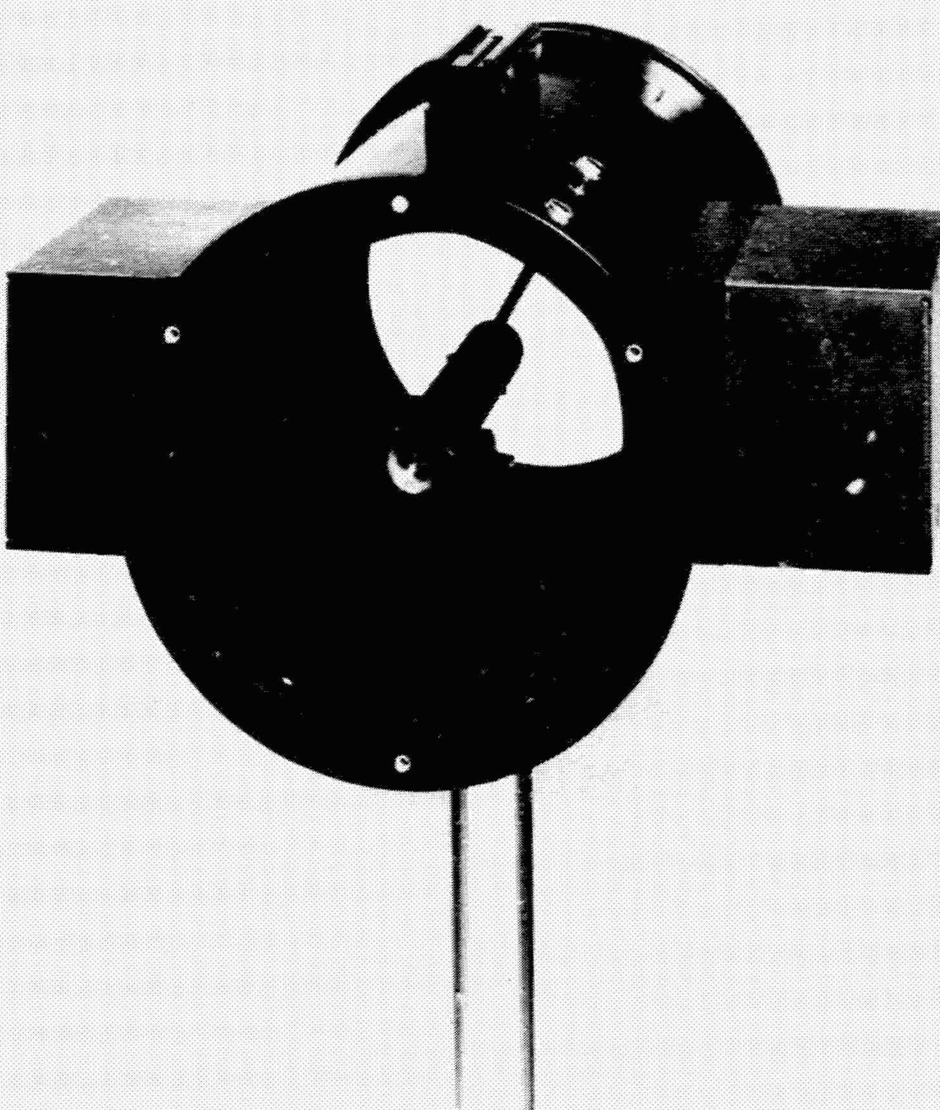
The photograph below shows the improved laser head with alignment optics mounted for use. No signals are transmitted or received during alignment of the head to the scan mirror or a target. The telescope mounted on top of the case looks into a periscope whose exit window allows the telescope optic axis to be displaced to coincide with the optic axis of the laser head. The periscope is uniquely located and attached to the laser head with a registration ring and pin to permit rapid and accurate alignment when attached.



ORIGINAL PAGE IS
OF POOR QUALITY

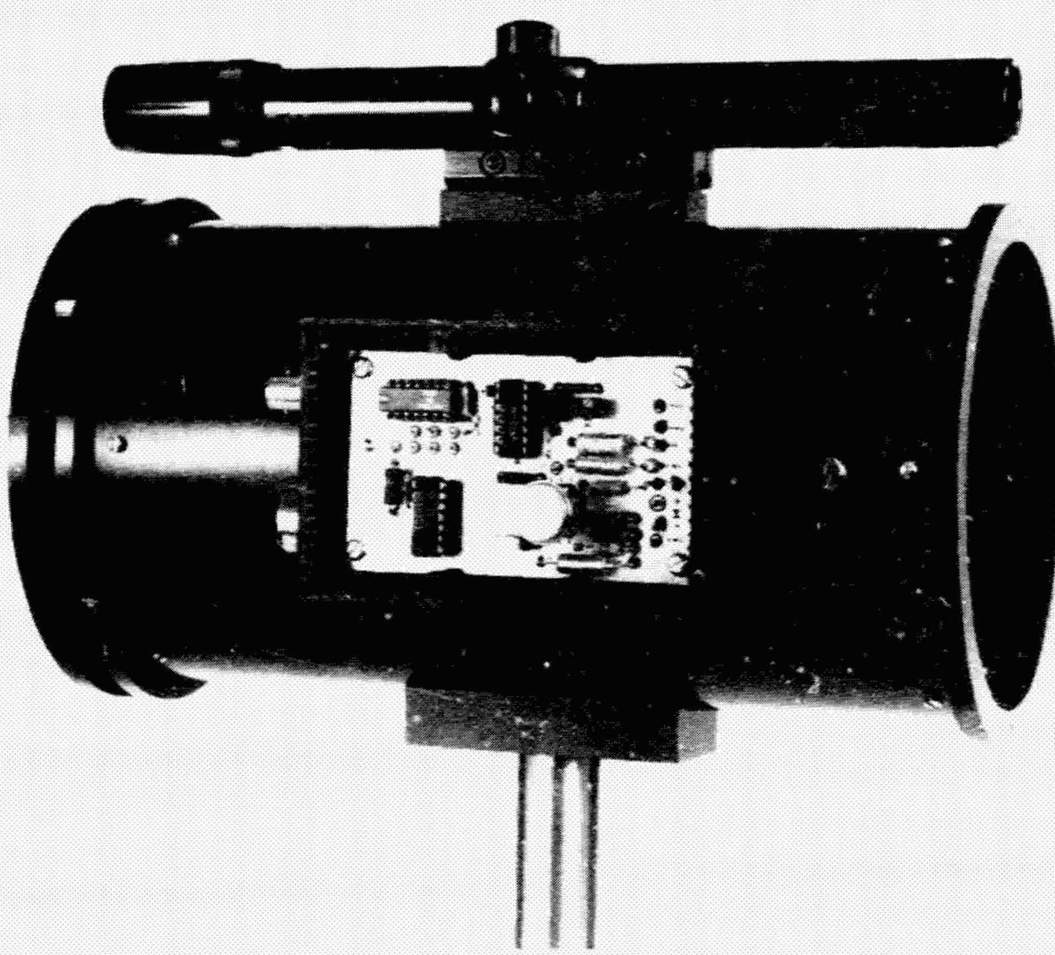
OPTIC LASER HEAD
USE CONFIGURATION

The photograph below shows the optic laser head with alignment optics removed. The laser collimating lens may be seen in the small centrally located tube. Most of the return beam misses the small central tube and is collected by the mirror at the rear of the case. The collected beam is focussed to enter the rear of the small central tube where it is collimated and reflected out to the detector electronics in the box at the right. The box at the left contains the laser pulse driver. The case is approximately thirteen centimeters in diameter by thirty centimeters long and weighs approximately three kilograms including electronics in the use configuration.



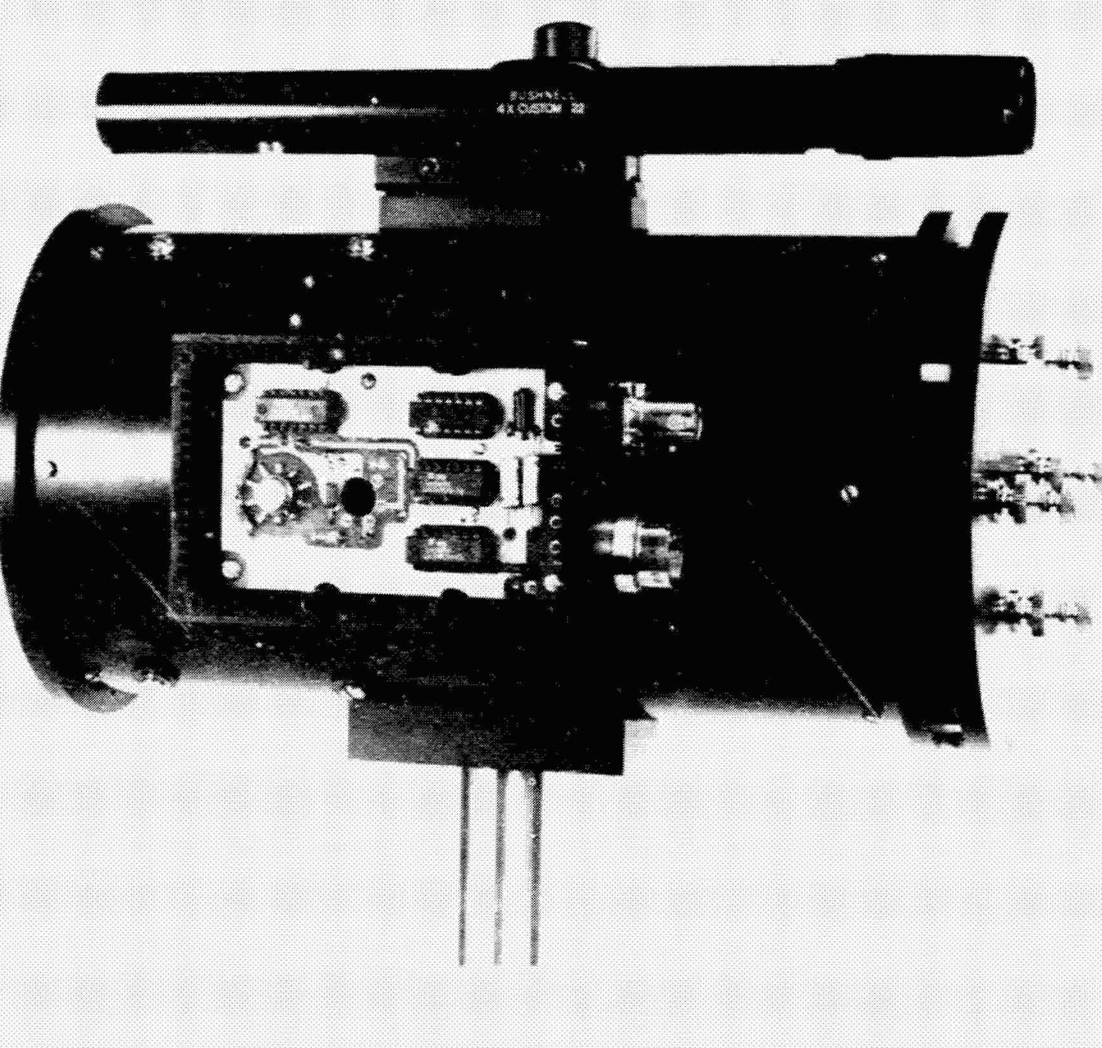
OPTIC LASER HEAD
LASER PULSE DRIVER

In a box mounted to the side of the optics case is shown the laser pulse driver electronics. The electronics are mounted on a double sided printed circuit board measuring five and one half by nine centimeters. In the pulse driver, signals are received from the detector by way of a delay line, shaped and power amplified to the level required for driving a led or laser. Heat dissipation and temperature control of this package and the laser may have a significant bearing on the system performance. Precautions were taken to radiate laser heat.



OPTIC LASER HEAD
DETECTOR ELECTRONICS

The accompanying photograph shows the detector electronic circuit board required to amplify and shape the received pulses for precise time triggering and for driving the transmission/delay line to the laser pulser. The receiver electronics also includes provision for automatic gain control to assure that pulses from different distances and targets will time trigger consistently. The detector and concentrating optics are located below the electronics and are adjustable by means of screws and holes in the sides of the housing box. The box and printed circuit board are approximately the same size as those used for the pulse driver.



LSST - STRUCTURAL CONCEPT - DEPLOYABLE REFLECTORS
ANTENNA SURFACE MEASUREMENT SUMMARY

Many possible systems for use in measuring antenna surface contour were investigated. Most of these systems were optical types capable of fine distance or angle resolution. Complexity varied as the capability to resolve distance.

Of the systems investigated, there were at least three which showed promise of use on early deployed antennas. The Lockheed Missiles and Space Company's "structural alignment sensor" has the capability desired and may be a logical choice although it is not yet perfected and its present complexity indicates that there may be problems with size and weight. The TRW angular measuring system has the capability of resolving very small angles and would be useful where a dependably stiff panel of confident contour must be aligned to become a part of an overall surface. It appears to have fine resolution and cost effectiveness for what it does although it does not have the capability of measuring local distortions in a large surface. The JPL self pulsed laser ranging system has resolution limitations; however, at this time it appears to be a viable candidate for measurement of large antenna surfaces where cost, weight, and simplicity are important factors.

At the present time, we are working on the JPL system which shows promise of resolving distances in the order of less than one tenth of a millimeter. Our goal for FY80 will be to set up a practical demonstration to show the capability of the JPL system. Other activities will include continuation to explore other surface measuring systems and to perform some studies with regard to the application of measuring systems to specific selected antenna candidates.

SUMMARY

- Concept Successfully Demonstrated
- Present Capability Includes
  - Greater Than 150M Range Capability
  - Less Than One Millimeter Resolution
  - Unambiguous Distance Measurement
- Projected Performance
  - One Tenth Millimeter Resolution
  - Low Power Consumption
  - Low Volume and Weight
  - Relatively Low Cost
- Probable Measurement Applications
  - Early Deployed Antennas
  - Large, Low Frequency Antennas

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