SATELLITE LASER RANGING EXPERIMENTS WITH AN UPGRADED MOBLAS STATION

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ABSTRACT

In the present article, we summarized the results of ranging receiver component tests which have been carried out at the NASA/Goddard Space Flight Center since the last workshop. Based on these experiments, we have recommended a new range receiver configuration to the MOBLAS network consisting of an ITT 4128 microchannel plate (MCP) photomultiplier (PMT), a 1 GHz bandwidth ENI amplifier, a gatable Tennelec TC454 constant fraction discriminator (CFD), and Hewlett Packard HP5370A time interval unit (TIU). The ITT MCP PMT has a 450 picosecond impulse response, a 2 cm RMS transit time jitter for single photoelectron inputs, a subcentimeter RMS jitter for signal levels greater than eight photoelectrons, and millimeter level biases resulting from image motion on the photocathode surface. It is far superior to the current MOBLAS network standard, the Amperex 2233B. Similarly, the Tennelec TC454 gatable four channel constant fraction discriminator has a much flatter time walk characteristic than the ORTEC 934 CFD currently used by the network. The RMS deviation of the TC454 from the nominal zero point is about 0.20 cm over the full dynamic range compared to 1.5 cms for the ORTEC device. After substituting the MCP photomultiplier for the Amperex 2233B in a 1981 version MOBLAS receiver, the single shot range residuals and normal point residuals were reduced by roughly a factor of three in ranging experiments to the LAGEOS satellite. The one sigma scatter of the MCP normal points was consistently subcentimeter with 0.3 cm being a typical value. The one sigma single shot scatter of 1.5 cms obtained with the MCP was largely limited by the resolution of the older HP5360 TIU.

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1. INTRODUCTION

During the past several years, the Advanced Electro-Optical Instrument Section at the Goddard Space Flight Center has conducted a series of experiments, in support of NASA's mobile laser (MOBLAS) ranging network, to determine the "optimum" commercial laser ranging components. At the last workshop, we reported on a comprehensive laboratory study of a variety of laser transmitters and demonstrated the performance superiority of modelocked transmitters, of both the active and passive variety, over Q-switched and cavity-dumped systems[1]. In a second paper, we discussed our plans for a general upgrade of the MOBLAS systems based on the ranging hardware available in the fall of 1981[2]. We also discussed some preliminary satellite laser ranging results obtained with a passively modelocked laser built by Quantel International. Since that time, a number of attractive new receiver components have appeared on the commercial market including a microchannel plate photomultiplier (MCP/PMT) built by ITT and a new low time-walk constant fraction discriminator (CFD) offered by Tennelec. In this paper, we compare the performance of these new devices to that of their component counterparts in the operational MOBLAS stations and suggest an "optimal" dual channel receiver configuration for a MOBLAS-like station. We also report on the results of satellite laser ranging tests with a partially upgraded MOBLAS test station.

2. COMPONENT TEST RESULTS

In our previously reported tests of three different modelocked laser transmitters[1], we demonstrated that the bias errors introduced by the laser were consistently less than one centimeter. The pulsewidths of these lasers varied between 60 and 150 picoseconds. Because of the relatively simple nature of passively-modelocked Nd:YAG transmitters, a commercial transmitter built by Quantel was recommended to the NASA Laser Tracking Network. Following successful field tests in the Fall of 1981[2], all of the active MOBLAS stations have since been upgraded to include a 150 picosecond pulse transmitter consisting of a combined actively-passively modelocked Nd:YAG laser oscillator, one double-pass amplifier, a single pass amplifier, and a KD*P doubling crystal. The use of an active acousto-optic Bragg cell modulator in conjunction with a passive modelocking dye cell increases the stability of the laser output energy and reduces the number of missed pulses as compared to a totally passive device. The maximum total output energy of the system is about 200 millijoules at 1.06 microns with about 50 percent conversion to the .53 micron green radiation.

The four nanosecond impulse response of the Amperex 2233B photomultiplier used in the current MOBLAS receiver is a poor match to the new 150 picosecond transmitter. Our choice for a photomultiplier tube in the upgraded MOBLAS receiver was a microchannel plate built by ITT which has an impulse response of about 450 picoseconds. Earlier photomultipliers, such as the electrostatic and static crossed field devices built by Varian, also had impulse responses on the order of a few hundred picoseconds but are no longer available at a reasonable cost. Furthermore, recent experiments have shown that image motion on the photocathode in conventional photomultipliers can result in a greatly varying transit time for the electrons propagating down the amplifying dynode chain, and this, in turn, can lead to substantial time biases on the order of a nanosecond (15 cms)[3]. In MCP tubes, the length of the electron propagation path does not vary greatly with image position since the electrons are confined by the microchannel itself, and preliminary experiments suggest that the potential biases are at the few millimeter level[3].

Figure 1 compares the performance of the ITT 4128 MCP PMT with that of the Amperex 2233B currently used in the MOBLAS network. The one sigma transit time jitter for an ungated MCP tube is about two centimeters for single photoelectron inputs compared to 10 centimeters in the 2233B. For input signal levels of eight photoelectrons or more, the jitter is subcentimeter in the MCP/PMT. The jitter increases between 10 percent and 25 percent, depending on signal level, for one particular gating configuration developed at Goddard. The ITT 4128 is a photomultiplier containing two internal MCP amplifier stages and has an electron gain of 2 X 10^5. In our upgrade recommendations to the network, the 4128 was chosen over the higher gain 4129 model (3 X 10^6), with three stages, because of the former's greater tolerance for the higher background radiation levels expected in daylight tracking experiments although a prototype of the 4129 was the first to be used in actual satellite laser ranging tests to be described later. The lesser gain is compensated for by the inclusion of a 1 GHz bandwidth amplifier available from ENI. A 1 GHz amplifier is an adequate match for the system considering the bandwidth limitations imposed by long receiver cables in typical field systems.

The output from the photomultiplier/amplifier is input to a discriminator. The latter unit generates a logic pulse which, in turn, starts or stops the time interval unit. Extensive discriminator testing has shown the constant fraction discriminator (CFD) to be the logical choice for a ranging system[4]. Other discriminator types such as fixed threshold, rise time compensated, and hybrids typically display time biases on the order of half the input pulsewidth due to input signal amplitude effects. Constant fraction discriminators include circuitry which attempts to compensate for a varying signal level. A plot of time bias versus signal amplitude is a measure of the degree to which the aforementioned compensation circuitry has been successfully implemented. In-house studies further show that discriminator time biases are very repeatable in both short term and long term operation and can be corrected for via a combination of auxiliary hardwired circuitry and appropriate software models. In fact, this approach has been utilized to elevate the performance of threshold and hybrid discriminators to that of the constant fraction

PHOTOMULTIPLIER PERFORMANCE

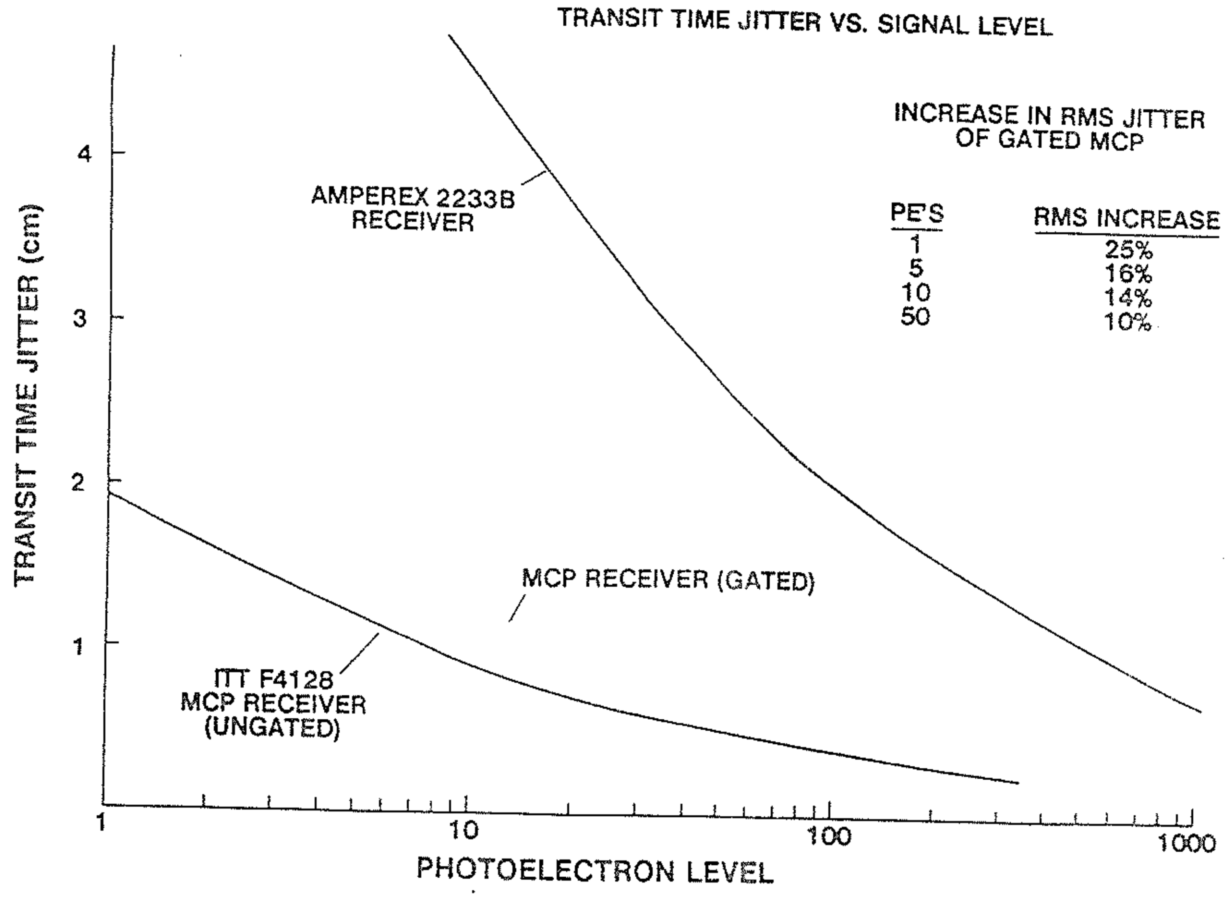


FIGURE 1

discriminator. Furthermore, the performance of constant fraction discriminators can be further improved through careful measurements of the time walk characteristic and signal amplitudes and the use of software corrections.

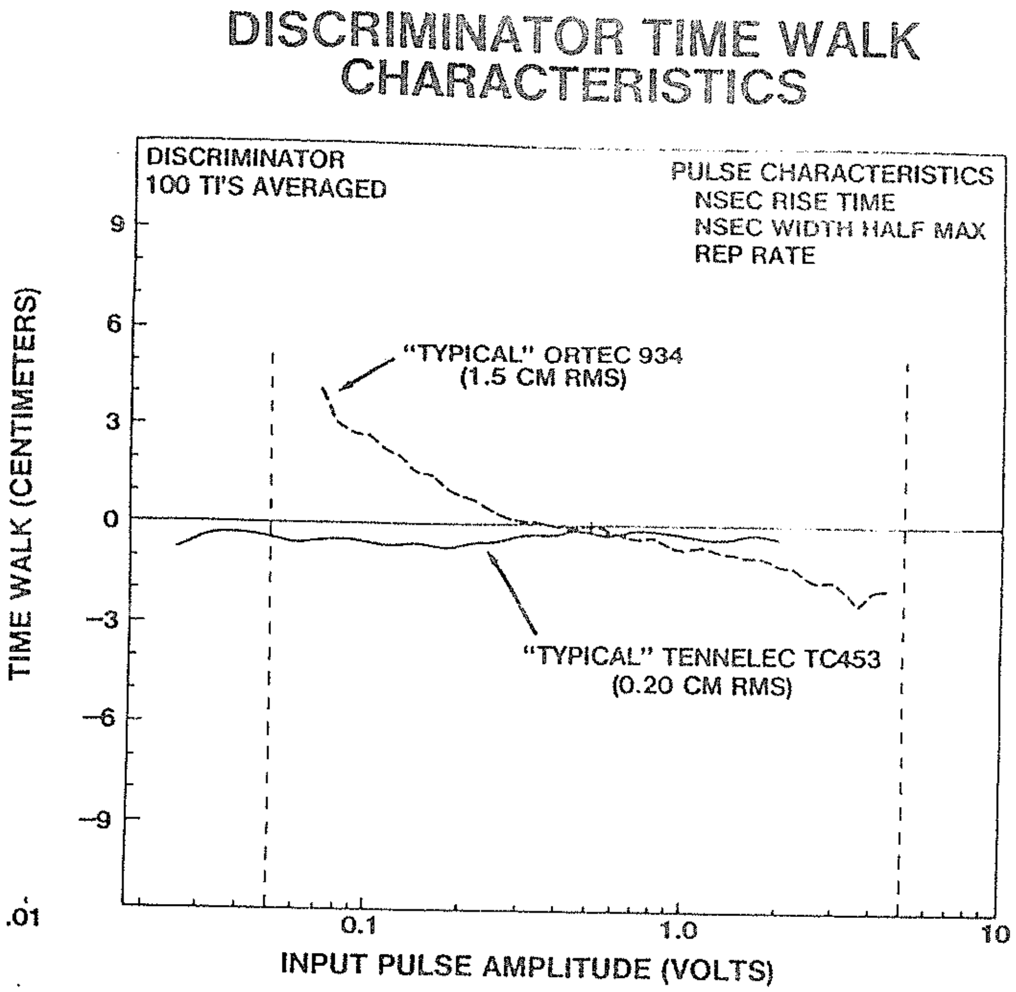
Figure 2 displays the time walk characteristics for the ORTEC 934 constant fraction discriminator, currently used in the MOBLAS network, and a new CFD, the Tennelec TC453. No software correction has been applied in generating these curves. Both discriminators were adjusted for minimum time walk with a one nanosecond full width half maximum input pulsewidth. Each point on the curve represents a mean of 100 time interval measurements at a fixed electronic start and stop signal amplitude. The vertical dashed lines represent the specified dynamic range of the ORTEC unit. As one can easily see from the figure, the TC453 has a much flatter time walk characteristic. The RMS deviation from the nominal zero point is about 0.20 cms over the full dynamic range compared to 1.5 cms for the ORTEC 934. Tennelec also offers a gateable four channel version of their basic CFD, the TC454.

Our 1981 recommendation to the NASA network to upgrade the time interval unit from the 100 picosecond resolution Hewlett-Packard HP5360 to the 20 picosecond resolution HP5370A has now been implemented in all of NASA's operational MOBLAS stations. We are not presently aware of any new commercial products with performance specifications superior to the HP5370A although specialized units with a factor of two better resolution have been successfully built and tested[4].

To summarize, Figure 3 is a block diagram of the upgraded MOBLAS receiver which we have recommended to the network. In addition to the usual ranging components previously described, we recommended the inclusion of two ORTEC 227 integrators for the precise determination of signal amplitude. At this time, all of the MOBLAS stations have installed a Quantel YG402DP modelocked transmitter, a HP5370A time Interval Unit, and the ORTEC 227 integrators. However, the Amperex 2233B PMT and the ORTEC 934 CFD are still the standard equipment in the operational stations. To date, no MOBLAS station has ever been fully upgraded. The change in operational performance of the MOBLAS network as individual components were upgraded is the subject of another paper at this conference[5]. In the next section, we present the results of earlier engineering test measurements to the LAGEOS satellite using prototypes of the Quantel YG402DP laser and the ITT 4129 MCP/PMT to illustrate the marked improvement to be expected when the relatively slow Amperex 2233B photomultiplier tubes are replaced by microchannel devices.

3. LAGEOS Ranging Results

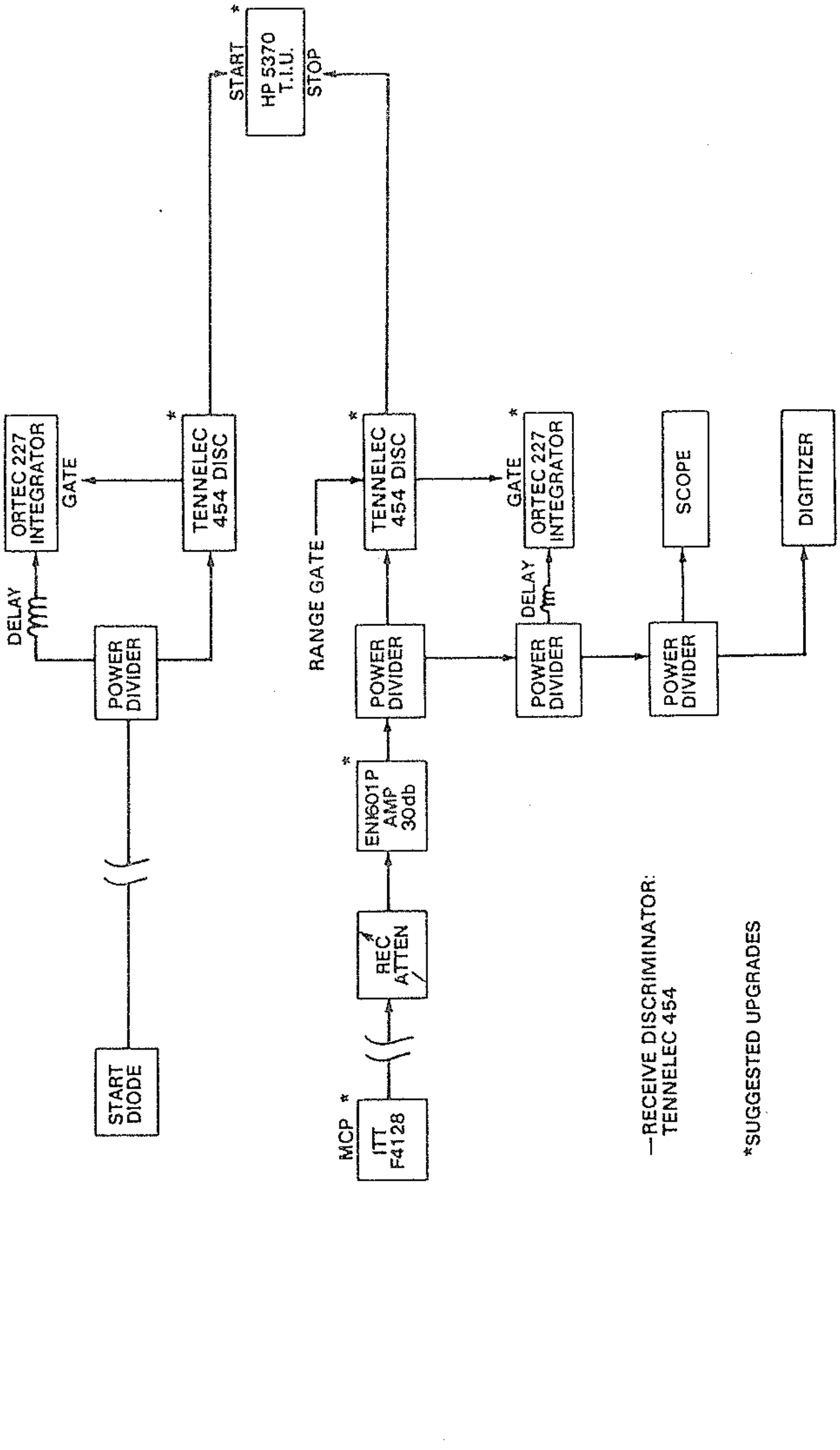
In the summer of 1981, a prototype of Quantel's YG402DP laser was installed in the MOBLAS 4 station at the Goddard Optical Research Facility in Greenbelt, Maryland. The transmitter was passively modelocked and did not include the acousto-optic modelocker supplied to the present MOBLAS network. For these engineering tests, the repetition rate of the system



DISCRIMINATOR TIME WALK CHARACTERISTICS

FIGURE 2

RECOMMENDED UPGRADES FOR MOBLAS RECEIVERS



—RECEIVE DISCRIMINATOR:
TENNELEC 454

*SUGGESTED UPGRADES

FIGURE 3

was also increased from the then standard 1 pps rate to 5 pps which resulted in a substantial increase in data yield and greatly simplified satellite acquisition. The 5 pps rate has since become the standard for the network. Satellite tracking tests were initially performed using the standard operational receiver of the period which consisted of the Amperex 2233B photomultiplier, the ORTEC 934 constant fraction discriminator, and the HP5360 time interval unit. After taking three LAGEOS and one BEC pass with the standard receiver, the 2233B photomultiplier was replaced by a prototype of the ITT F4129 microchannel plate PMT. The latter had only a 5 percent quantum efficiency compared to current commercial devices which have a 12 to 15 percent efficiency. Because of the shorter pulsewidth out of the MCP/PMT, it was necessary to adjust the ORTEC 934 CFD for short pulse operation. The ranging performance of both systems was evaluated using the software package LASPREP which fits the measured range data to an orbit (J2 term only) using best least square estimates of range and time bias, applies a three sigma filter to the data, and repeats the procedure until there is no further improvement in the RMS of the orbital fit. The software also computes running normal points which are obtained by averaging 50 returns and then dropping the first data point in the subset and adding the subsequent data point to compute the next normal point.

Table 1 summarizes the results of the field experiments. Using the Amperex 2233B PMT with the ultrashort pulse laser resulted in single shot RMS precisions to LAGEOS between 2.5 and 4.2 cms, as determined by the LASPREP processor, for three separate passes in September, 1981. The RMS precision of the normal points was between 0.8 and 1.2 cms. In these runs, anywhere from 3 to 8 percent of the raw data was edited out by the iterative processor. Interestingly, the satellite data was better than the ground data, i.e. the tower system calibration data or the pre-and-post calibration agreement. This apparent inconsistency was later traced to the support pole behind the calibration target which reflected spurious pulses into the receiver resulting in a double-peaked range calibration histogram.

After painting the offending pole black and installing the microchannel plate PMT, agreement between the pre-and-post calibrations was typically subcentimeter with only one exception (1.97 cms) for the nine LAGEOS passes. The single shot RMS for the system calibration runs fell between 1.1 and 2.3 cms. The single shot RMS for the orbital data sets was only slightly higher than for the calibration data sets, i.e., typically between 1.5 and 2.5 cms for large data sets. Only 1 to 6 percent of the raw data was edited by the processor in obtaining these results. Extensive laboratory tests have suggested that 1.5 cms is about the limit of precision achievable with the HP 5360 TIU and that the latter was the limiting error source in the field receiver. Nevertheless, the normal point RMS was impressive, varying between 0.05 and 0.83 cms over the nine pass data set. Figure 4 displays a LAGEOS data set taken on October 20, 1981, with the MCP/PMT installed. Figure 4a is a graph of the raw data set totalling 3707 measurements of which approximately 101 were rejected following 10 iterations through the LASPREP processor. The single shot RMS of the edited data was 1.68 cms. Figure 4b is a plot of the resulting normal

SATELLITE PASS SUMMARY

DATE	RETURNS	POINTS REJECTED	SINGLE SHOT RMS SYS CAL	SINGLE SHOT RMS PASS	NORMAL PNT. RMS (50 AV)	PRE/POST	NOTES
BEC PASSES							
10/8/81	450	16.8%	2.7CM	2.7CM	.5CM	0.0CM	2233PMT
10/9/81	287	10.1%	1.3	2.67	.4	.4	MCPPMT
LAGEOS PASSES							
9/25/81	2420	3.5%	5.6	3.7	.8	0.0	2233PMT
9/26/81	3717	3.0%	3.6	4.2	1.2	-8.1	2233PMT
9/29/81	3510	8.0%	5.5	2.5	1.0	-25.8	2233PMT
10/9/81	86	17.%	1.41	1.68	.05	1.97	MCPPMT
10/14/81	2594	6.7%	1.18	1.77	.27	0.0	MCPPMT
10/15/81	5286	4.7%	1.62	2.56	.83	.66	MCPPMT
10/17/81	1877	3.3%	1.15	1.51	.24	.39	MCPPMT
10/20/81	3803	2.6%	1.28	1.68	.30	.88	MCPPMT
10/20/81	2963	1.7%	2.3	2.2/2.0	.4	0.0	MCPPMT
10/21/81	315	24%	2.24	4.1	.79	-.63	MCPPMT
11/3/81	594	4.3%	1.4	2.1	.37	-.58	MCPPMT

TABLE 1

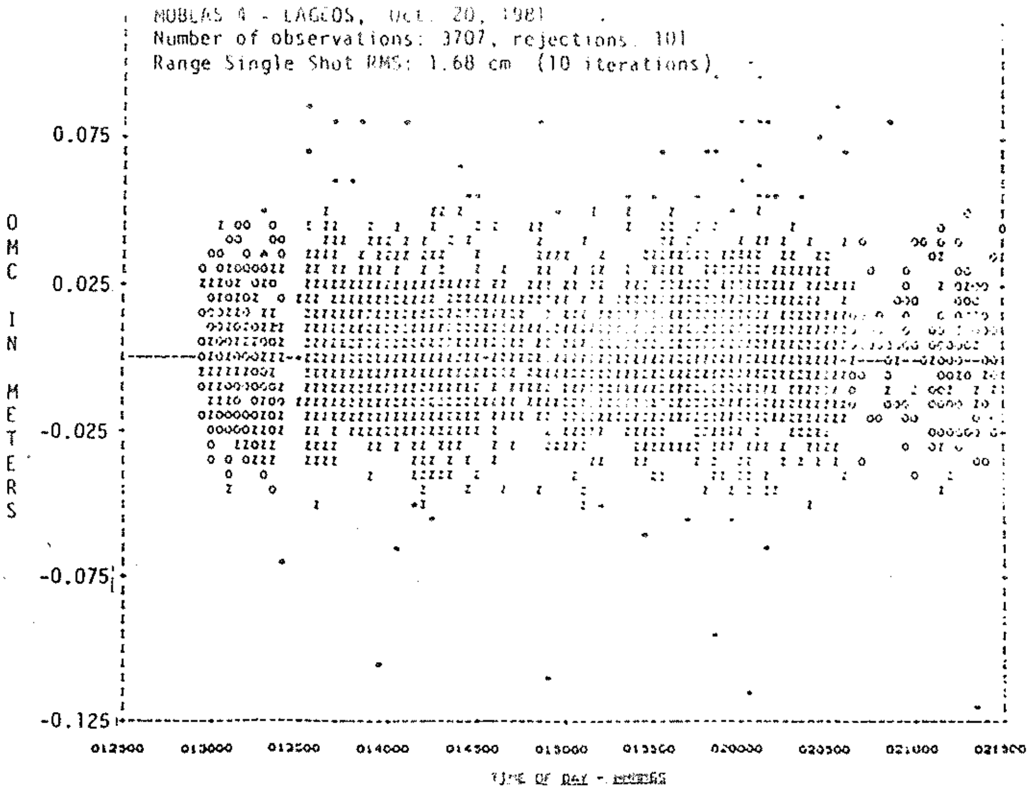


FIGURE 4(a): SINGLE SHOT DATA FROM LAGEOS

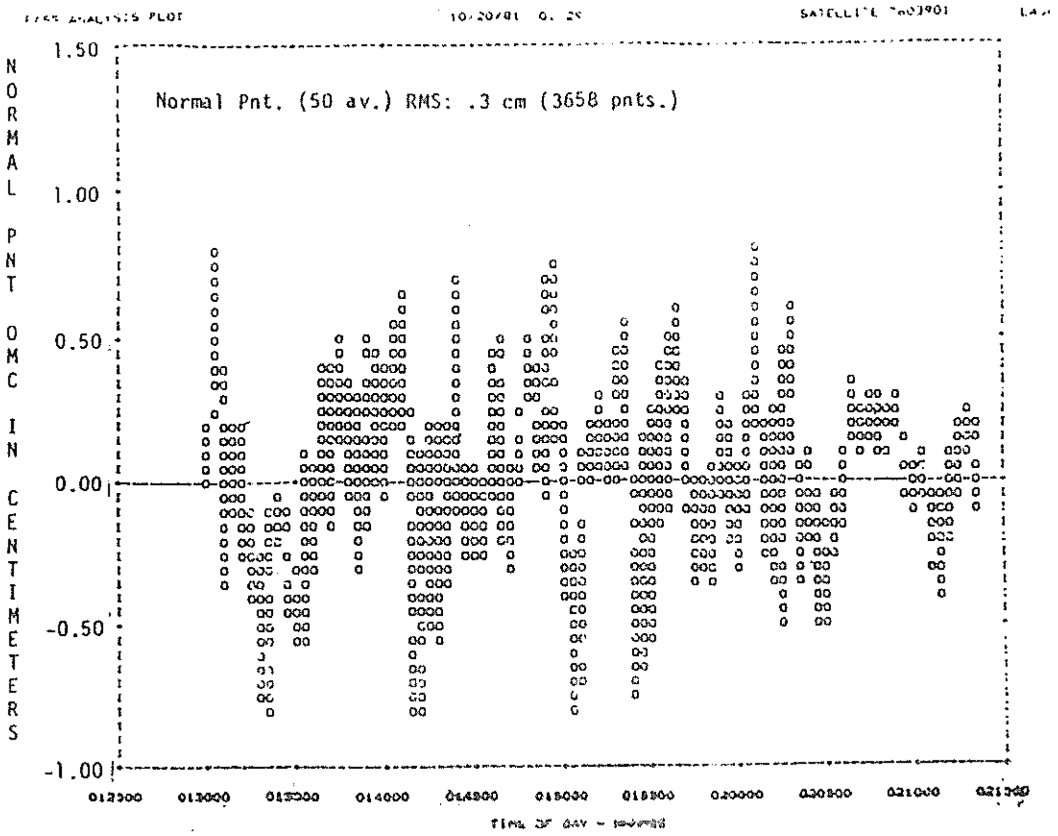


FIGURE 4(b): NORMAL POINTS FOR LAGEOS

points which have an RMS of only 0.3 cms which is only slightly higher than what would be expected for a totally random error, i.e., $1.68/\sqrt{50} = 0.25$ cms. The peak-to-peak variation in the normal points was about ±0.8 cms. Based on tests performed on LAGEOS prior to launch[7], variation in the center of mass correction as a function of satellite aspect angle is not expected to exceed ±0.3 cms.

4. CONCLUDING REMARKS

In this paper, we have suggested a dual channel range receiver configuration, based totally on commercially available parts, which is capable of providing subcentimeter precision single shot laser ranging to LAGEOS for high signal levels (tens of photoelectrons). Laboratory tests over kilometer horizontal range paths have yielded subcentimeter long term (one hour) stabilities in the mean range measurement and range uncertainties as small as 0.5 cms (one sigma). Impressive preliminary results with a partially upgraded MOBLAS field receiver have bolstered our belief that subcentimeter single shot range precisions are achievable from MOBLAS in the very near future with the installation of the microchannel plate photomultipliers and the new low time walk discriminators. So far, our efforts to implement a fully upgraded receiver in an operational field system have been severely hampered by the heavy work schedules of the MOBLAS stations and the resulting inability to schedule adequate engineering modification and test time with the Network. Consequently, we have recently established an independent Experimental Satellite Laser Ranging Station at Goddard to permit the rapid evaluation of new technology in the field independent of Crustal Dynamics Project schedules[8]. Most recently, our attention has been focused on the achievement of subcentimeter absolute range accuracies (as opposed to precisions) through the development of single channel, zero system delay ranging configurations[8]. A streak camera-based two color system is under final development and should reduce the uncertainties associated with the refractive atmospheric delay to about 5 millimeters[9].

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AN EXPERIMENTAL LARGE APERTURE SATELLITE LASER RANGING STATION AT GSFC

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ABSTRACT

An Experimental Satellite Laser Ranging System has recently been installed at the Optical Research Facility of the Goddard Space Flight Center. The facility utilizes Goddard's multiuser 1.2 Meter Diameter Tracking Telescope. The purpose of the system is to facilitate the rapid and timely implementation of advanced laser ranging components and techniques in the field following fundamental laboratory tests. At present, we are also experimenting with a "zero delay" range receiver configuration which dictates that both start and stop pulses follow precisely the same optical and electronic paths in the receiver which, except for calibratable amplitude dependent effects, results in zero system delay. The present paper describes the current experimental configuration and summarizes ground tests and preliminary measurements to the LAGEOS satellite.

Introduction

To facilitate the transition from experimental laboratory laser ranging systems to field operable satellite laser tracking systems an engineering test facility has been incorporated into the 1.2 meter tracking telescope at the Optical Research Facility at the Goddard Space Flight Center (GSFC). The system was built to support the testing and field evaluation of advanced instrumentation, ideas and philosophies in a satellite tracking system. Use of this facility frees the experimenter from operational and scheduling constraints dictated by NASA's Crustal Dynamics Project. Having system control allows experimenters to make timely component and configuration changes to optimize system performance. Interesting problems may also be studied in detail. This effort is a continuation of laboratory work at the GSFC in which subcentimeter single shot RMS range measurements to fixed ground targets have been made. This engineering test facility will allow for the monitoring of instrument performance levels which should result in satellite tracking accuracies approaching that of laboratory systems.

System Description

Shown in Figure 1 is a block diagram of the Experimental Satellite Laser Ranging Station (ESLRS). The ELRS consists of commercially available, specially ordered, and custom built in-house instrumentation, the majority of which has come from other laser ranging programs within the GSFC. The two computer system approach was determined by the availability of existing hardware and cost constraints.

The laser ranging system is physically housed in several different work locations. The 1.2 meter diameter telescope is situated in a dome building with the controlling Honeywell tracking computer in an adjoining room. At the base of the telescope, near the system focal plane, is the receiver package and Transmit/Receive (T/R) switch. The laser transmitter is housed in a clean room adjacent to the rack mounted PDP 11/23 computer and ranging electronics. System timing is maintained at a separate building with precision 1 pps, 1 MHz, 5 MHz, and NASA 36-bit time code brought in on coaxial cables.

The Honeywell 716 (H716) computer is responsible for the pointing and tracking operation of the 1.2 meter coude focus telescope. The H716 also calculates azimuth, elevation, and range data required for the Digital 11/23 Ranging System Computer. Satellite acquisition data is input in the form of an Inter-Range Vector (IRV) which gives the position and velocity of the satellite at a specific time. A simplified model of the earth's gravity field (J2 term only) is used to compute satellite acceleration. The simplified gravity model and the initial position and velocity from the IRV are used to produce position and velocity at points one second apart along the orbit by using a fourth order Runge-Kutta numerical integrator. IRV's must be supplied for each pass since the gravity model and numerical integrator are not accurate enough to integrate orbits around the earth from one pass to the next.

To maintain smooth tracking the servo system requires pointing updates at a 20 Hz rate. The numerical integrator supplies the pointing angles and range data at one second intervals. A second order polynomial is used to interpolate between one second points to obtain data at the required 20 Hz rate.

In order to attain the required pointing accuracy for satellite ranging the telescope pointing errors must be modelled. The mount modeling coefficients are determined periodically by recording angle biases required to boresight the telescope onto predetermined stars in a grid. Absolute pointing at or near the arcsecond level is possible with this mount error modeling technique.

The range data is sent from the H716 to the Ranging Computer (Digital 11/23) at a 5 Hz rate. Each range is sent 150 milliseconds before the corresponding laser fire. This allows the ranging computer time to input, decode, and output the data to the range gate generators before laser fire.

Along with the ranging data, the H716 also sends current pointing angles, time-bias and system mode to the ranging computer to be recorded on magnetic tape. Every 200 milliseconds a record is made of the predicted angles and range, the observed range, time bias, cross track bias and other pertinent data corresponding to the current laser fire. This data is analyzed after the pass to determine data quality.

The Ranging System Computer provides for operator interface by displaying on the CRT the observed minus calculated (O-C) plot of satellite range data and indicates signal strength of either transmit or satellite return with an audible tone. The ranging computer is responsible for recording all pass data on the log tape and controls all the I/O and electronic functions required to operate the ranging system.

The transmitter is a Quantel passively mode locked Neodymium YAG laser model YG402 DP. Laser output is 100 millijoules (mj) at 5320Å with a pulsewidth less than 200 picoseconds. Laser repetition rate is 5 pulses per second. The beam exits the laser with a diameter of about 7/16 inch. Approximately 10 meters away at the coupling lens the beam diameter has grown to about 5/8 inch. The negative coupling lens is positioned at its focal length inside of the telescope's focus, matching the cone angle of the F29 system. The whole primary mirror is illuminated resulting in a final transmitted beam diameter of 1.2 meters and a beam divergence of about 10 arcseconds.

The laser ranging system incorporates a common optics, common channel range receiver. The system transmits and receives through the same telescope optics and uses one common detector, amplifier, and discriminator chain for both outgoing and return pulse measurements. This configuration has proven to be the most accurate with single shot RMS accuracies approaching 5mm in horizontal range tests over kilometer distances. Single channel receivers, although simple in theory, are more difficult to implement than the more common dual channel approach. The range receiver must view through the telescope optics as the 100mj pulse exits the system. Near perfect isolation is required to prevent receiver saturation from backscatter of the outgoing pulse. The single channel approach requires that a small portion of the outgoing laser pulse be sampled as it leaves the telescope. This has been done with a rather unique Transmit/ Receive switch. Shown in Figure 2 is the configuration used in the T/R switch to permit single channel operation. The glass disk in the T/R switch is geared to a synchronous motor and is matched to the laser repetition rate of 5 Hz. The laser fire circuitry is enabled only during a short period of time in which a Hall Effect pick-off is properly aligned with a small magnet mounted in the disk hub. This insures that the laser fires only through the windowed portion of the glass disk. This window is an anti-reflective (AR) coated 24° sector of the disk. The remaining disk surface is coated for maximum reflectivity at 5320Å. To further protect the range receiver from a laser misfire, the non- windowed back surface of the disk is covered with an opaque absorber.

Normal T/R switch operation permits passage of the outgoing laser pulse into the telescope while controlling the optical level into the receiver. Disk rotation during satellite round trip time provides for the high reflectivity mirrored surface required to complete the T/R sequence efficiently. By transmitting through a window rather than a hole in the rotating disk a start pulse may be derived from any point beyond the T/R switch. This is done by placing a cube corner reflector in the outgoing beam facing back toward the laser transmitter and receiver. As the laser pulse exits the system, the small portion intercepted by the cube corner is reflected back on axis towards the source. Over 99 percent of the start cube return is transmitted through the AR coated window in the T/R switch. The remaining fractional percent is reflected into the range receiver. This start pulse requires an additional attenuation of 3 to 4 Neutral Densities (ND's) to maintain the proper start signal level. The ND's are held in a small hub mounted holder which rotates with the glass disk. These ND filters protect the receiver from the outgoing backscatter, and then rotate from view for the satellite return. The key for reliable operation is to maintain a start cube corner signal level well above backscatter.

All range measurements are made relative to a start cube corner mounted in the system reference plane in the telescope. Optical and electrical path lengths are identical for both start pulse and satellite return from the point of the apex of the cube corner. This unique feature means the system is self calibrated and has zero system delay.

System calibration is a serious problem with current ranging systems in NASA's Laser Tracking Network (LTN). These systems generally require calibration procedures which rely on geodimeter ground surveys over several kilometers. It appears that the upgraded short pulse laser ranging systems in use in the LTN are actually more accurate than current ground survey techniques used to establish system delay. The latter techniques appear to be accurate only to a few centimeters which in turn limits the absolute accuracy of LTN systems such as NASA's Mobile Laser Ranging Systems (MOBLAS). This inconsistency in calibration is eliminated in the Experimental Satellite Laser Ranging System by designing a system with no system delay.

The range receiver consists of a microchannel plate (MCP) photomultiplier tube (PMT), amplifier, constant fraction discriminator, and choice of time interval units. The photomultiplier tube is an ITT model F4128 two-stage MCP. This PMT has a full width at half maximum impulse response of 450 picoseconds and a gain of approximately $2X10^5$. Tube transit time for the MCP PMT is 3 to 4 nanoseconds with a single photoelectron transit time jitter of 100 picoseconds. The system is capable of single photoelectron detection with the 1 GHz amplifier and Tennelec TC454 Constant Fraction Discriminator. A choice of three time interval units are available for system use. They include a 20 picosecond resolution Hewlett-Packard HP5370 time interval unit and two developmental units built for NASA by Lawrence Berkeley Laboratory (LBL), i.e., a 19.5 picosecond resolution event time and a 9.7 picosecond resolution time interval unit.

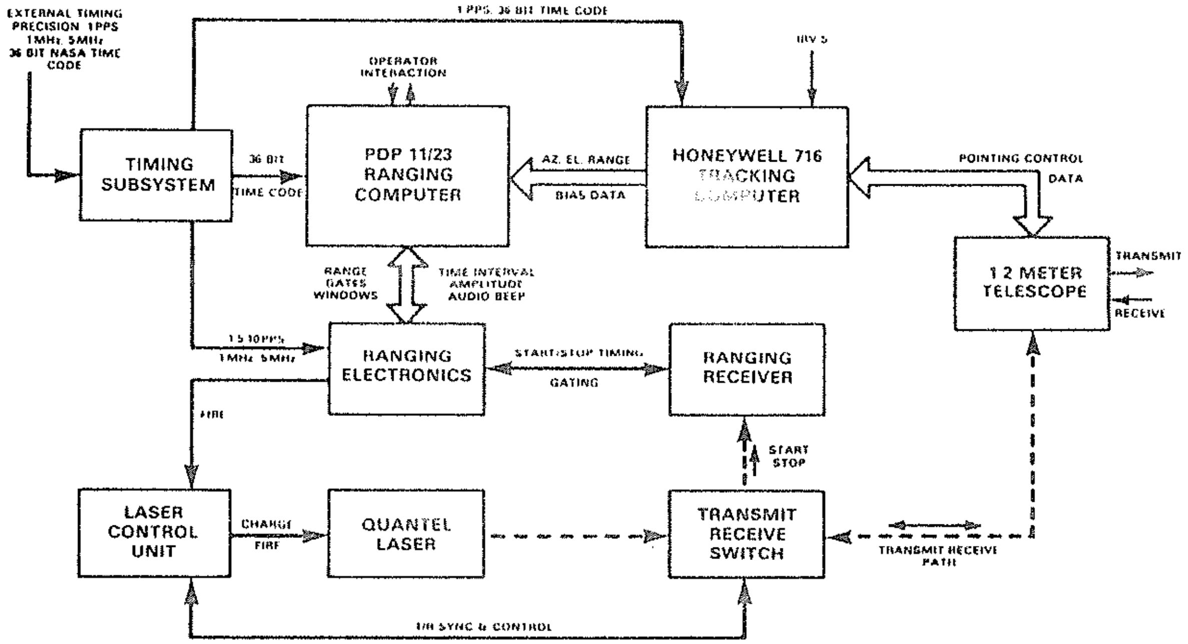
Results

Although system configuration has not reached the final goal as shown in Figure 2, preliminary results of the Experimental Satellite Laser Ranging System are very encouraging. Start cube corner placement in the telescope was temporarily moved 26.075 inches forward to prevent self shadowing on the primary mirror. Satellite tracks taken early as proof-of-concepts of the common optics approach, and common receiver approach were convincing enough to proceed without hesitation. The system presently derives the start pulse from within the T/R switch and uses common transmit/receive optics and common MCP range receiver. Cube corner placement in the telescope will be finalized upon fabrication of a non-shadowing holding fixture which assures reliable operation in all telescope azimuth positions.

Ground ranging tests to a fixed cube corner over a 3.4 kilometer horizontal path repeatedly show the system capable of single shot RMS accuracies of 1 centimeter or less. System stability over a 1 hour period is typically a few millimeters for 100 point averages.

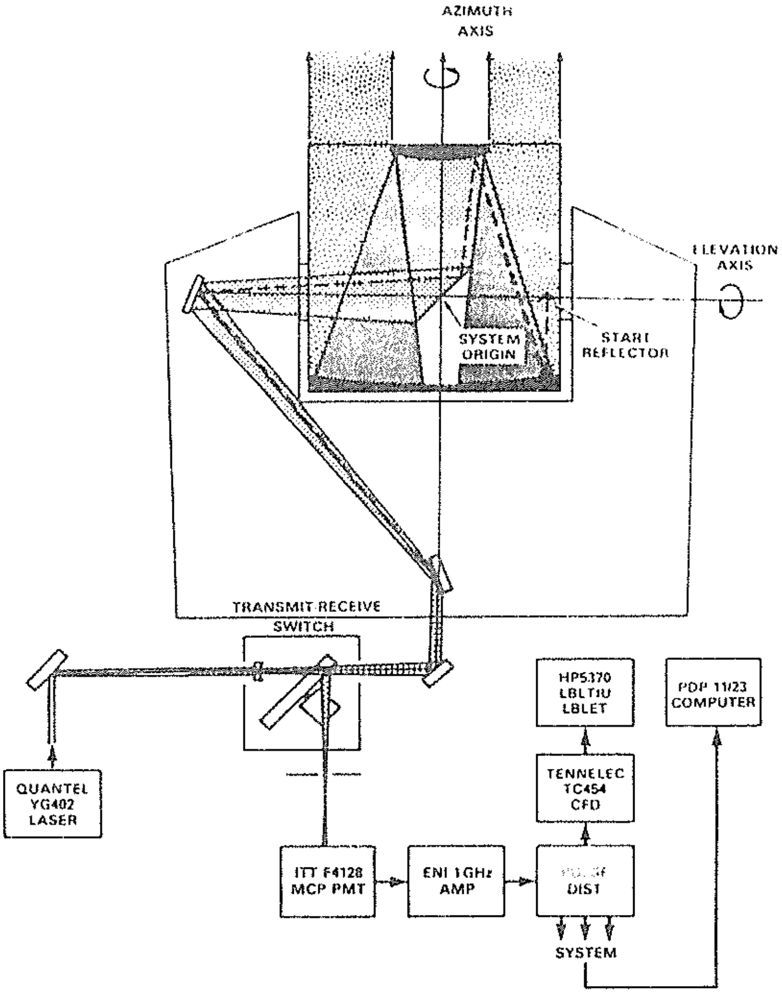
LAGEOS satellite passes taken in late August and early September 1984 show the system is now comparable to NASA's best tracking MOBLAS systems. The ELRS has achieved a 60 to 80 percent data return rate from the LAGEOS satellite on a single pass with typically 8000 to 10000 range measurements. Early analysis of pass data using a 15th order polynomial fit appears inadequate for centimeter range data. The polynomial fit used by the LTN appears to introduce a modeling error which limits system performance to approximately 3 centimeters, while rejecting good data. Other methods of actually fitting the data to an orbit as in the GSFC's LASPREP program are being investigated. Absolute system accuracy at the moment may be known only to a few centimeters but as the final system configuration is implemented this accuracy should approach one centimeter. Work will continue on this system to better characterize new instrumentation, techniques and procedures required to achieve one centimeter satellite laser ranging accuracies.

Future plans for the 1.2 meter ESLRS include single photoelectron versus multiphotoelectron studies, daytime tracking, simulated synchronous satellite range measurements for time transfer experiments, lunar range measurements and multiwavelength range measurements.



SIMPLIFIED BLOCK DIAGRAM OF
EXPERIMENTAL SATELLITE LASER RANGING SYSTEM

FIGURE 1



COMMON OPTICS, SINGLE CHANNEL
RANGE RECEIVER

FIGURE 2

TUNABLE ETALON USAGE AT MLRS
McDOANLD LASER RANGING STATION

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ABSTRACT

A tunable etalon is tried as a spectral filter in the signal return path of the McDonald Observatory Laser Ranging Station (MLRS). The piezoelectric elements of the etalon are actively tuned for 532 nanomenters by sensing a helium neon laser passing through the etalon at an angle.

Goal: To use the spectrally tunable etalon to reduce background optical noise during,

a) daylight Lageos and lunar ranging, and
b) near full moon lunar ranging.

Advantages: This etalon has a narrow bandpass (≈1 Å). Because this etalon is piezoelectrically driven, using active feedback circuits, it is thermally and mechanically stable.

Restrictions: Used with a 76 cm telescope, the effective aperture of this etalon is ≈4 arcsecond.

Results: The calculated normalized throughput of 0.8 units has not been reached. The maximum throughput obtained is 0.5 units. This lower than expected throughput is disappointingly low. Therefore, the Burleigh etalon is not now used at MLRS.

Equipment used: See Figure 1.

Description of setup: The etalon is positioned in the optical path ahead of the photomultiplier (Figure 2). It is used as a fixed and stable narrow-band filter by stabilizing the cavity spacing using the narrow scanning mode (Figure 3). For this technique the ramp amplitude is reduced until the etalon scans only a fraction of the half-width of the reference HeNe laser line (Figure 4) and both stabilization windows are set to span the whole ramp duration.

Mirror angle ø is adjusted to yield a maximum throughput of 532 nanometer. The detector position must be re-peaked for each angle adjustment. To fully utilize the finesse stabilization option, the reference laser beam must be made nearly as large as the etalon aperture by using expanding lenses. In the MLRS station, space is not available to install expanding lenses therefore, finesse correction circuits are not used. Since ranging passes are usually shorter than 60 minutes, it is reasonable to not use the finesse correction.

Since this etalon has a free spectral range of 14 Å, it will pass ≈1 Å of bandpass every 14 Å. Therefore it is necessary to use a fixed filter whose bandpass is less than 14 Å centered on the desired wavelength. In this setup a 10 Å filter was used which happens to be our standard filter (Figure 5).

The etalon is mounted so that it can be removed quickly or installed and aligned in less than 5 minutes. Throughput was determined by observing the photomultiplier signal with the etalon in position and also removed. Three different throughput tests were used:

1. Observing the raw photomultiplier signal,
2. Observing the feedback calibration signal during ranging, and
3. Observing the data during Lageos ranging.

The maximum etalon throughput observed was 0.5 units of signal. Many possible failure modes were studied (Figure 6) and eliminated. The etalon throughput is less than expected and required. This is probably due to the coatings favoring the reference laser instead of the ranging laser to assure a good finesse for the reference laser. The coatings range from 550 nm to 650 nm. Unfortunately, Burleigh does not offer a better coating choice.

Comments: The MLRS ranging system does not use the etalon and has resorted to replacing the 10Å filter with a 3Å filter during unfavorable light conditions. These are both multilayer interference-coated filters centered at 532 nanometer. The results have been much better than expected.

Recoating the etalon plates with a better range would probably enhance the throughput. Using a capacitive servo etalon would avoid this coating conflict entirely.

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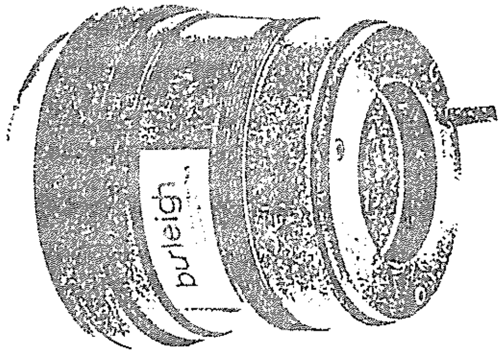

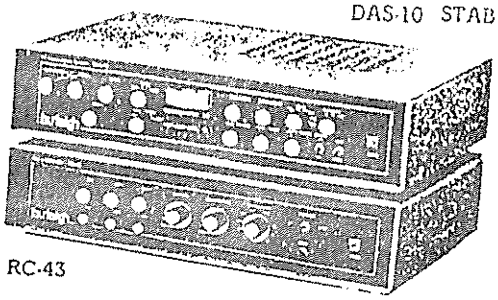

burleigh

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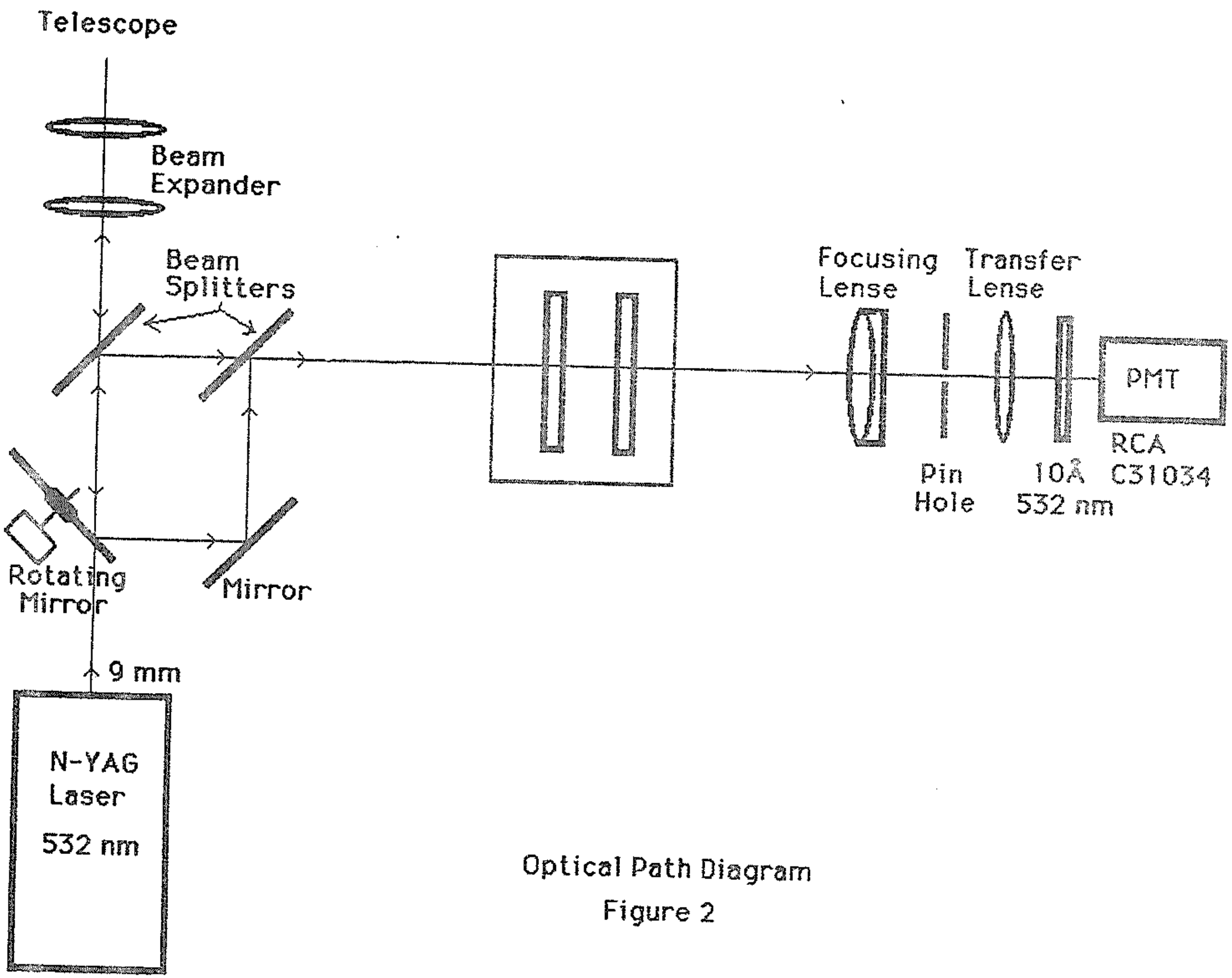
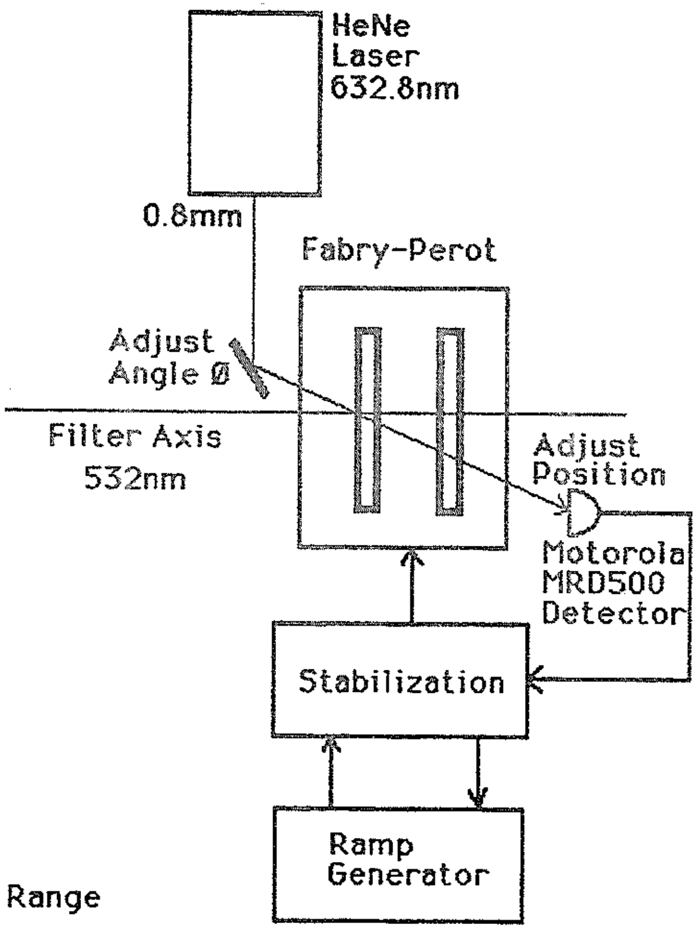
Etalon Equipmen
Figure 1



Optical Path Diagram

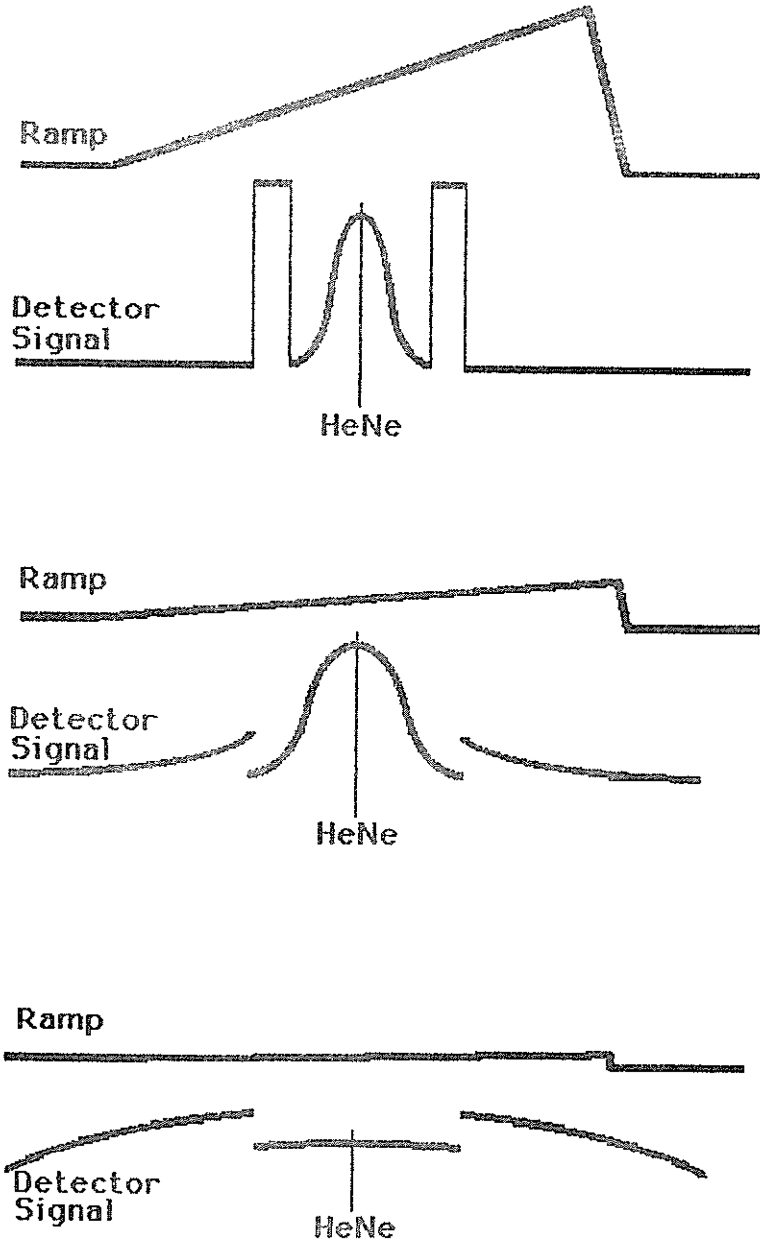
Figure 2



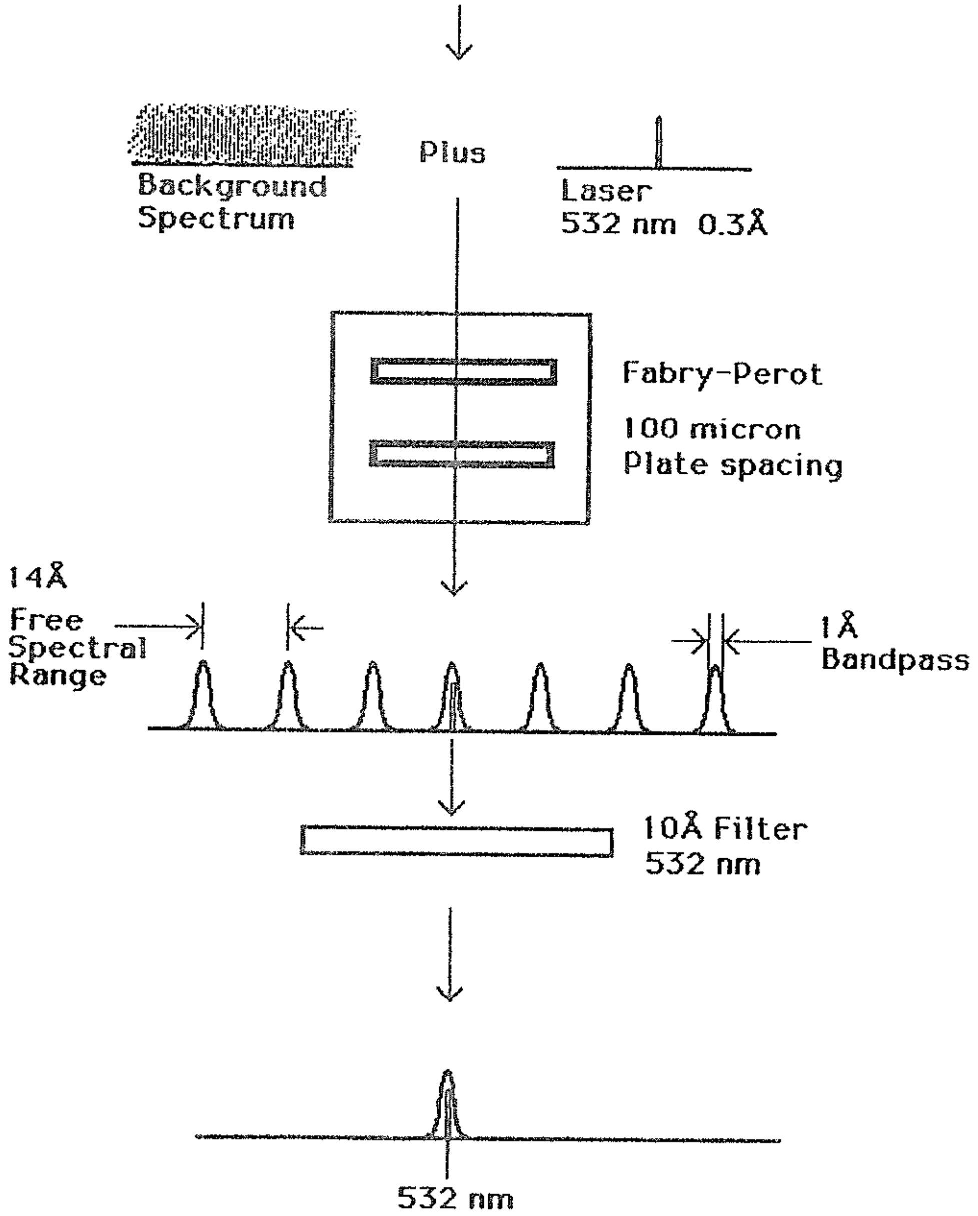
Coating Range
550nm to 650nm

Narrow Filter Diagram

Figure 3



Ramp Amplitude Figure 4



Etalon Bandpass Figure 5

Possible Throughput Failure Modes

1. Etalon damage
2. Ramp generator or Stabilizer malfunction
3. Controls set improperly
4. Mechanical alignment poor
5. Plates not parallel to incoming beam
6. Temperature changes affecting etalon
7. Vibrations affecting etalon
8. Detector poor
9. Detector not aligned
10. ◇ Plate coating improper
11. Plate spacing improper
12. Finesse poor
13. Incoming beam not collimated
14. Bandpass of laser greater than etalon
15. Reference laser output amplitude varying

Figure 6