N94-15568

Preliminary Results from the Portable Standard Satellite Laser Ranging Intercomparison with MOBLAS-7

Michael Selden, Thomas Varghese, Michael Heinick, Thomas Oldham
Allied Signal Aerospace Company,
BFEC/CDSLR
10210 Greenbelt Road
Seabrook, MD 20706
USA

Abstract
Conventional Satellite Laser Ranging (SLR) instrumentation has been configured and successfully used to provide high-accuracy laboratory measurements on the LAGEOS-2 and TOPEX cube-corner arrays. The instrumentation, refered to as the Portable Standard, has also been used for field measurements of satellite ranges in tandem with MOBLAS-7. Preliminary results of the SLR measurements suggest that improved range accuracy can be achieved using this system. Results are discussed.

1   Introduction

The portable standard (PS) is a collection of ranging instrumentation which was originally brought together as a calibration mechanism for the CDSLR network. The system was designed to take parallel measurements with field stations while sharing the existing telescope/mount, system shelter, power, and laser. It is a method to tie and intercompare the worldwide network to a single standard which periodically travels from system to system to maintain the caliber of the satellite laser ranging measurements. A second role for the PS is as a test bed for new instrumentation and SLR techniques. As a constantly improving system, it provides a means of proving new technology prior to implementing changes to the network. A third use of the portable system has been as a troubleshooting mechanism to resolve conflicts during collocation.
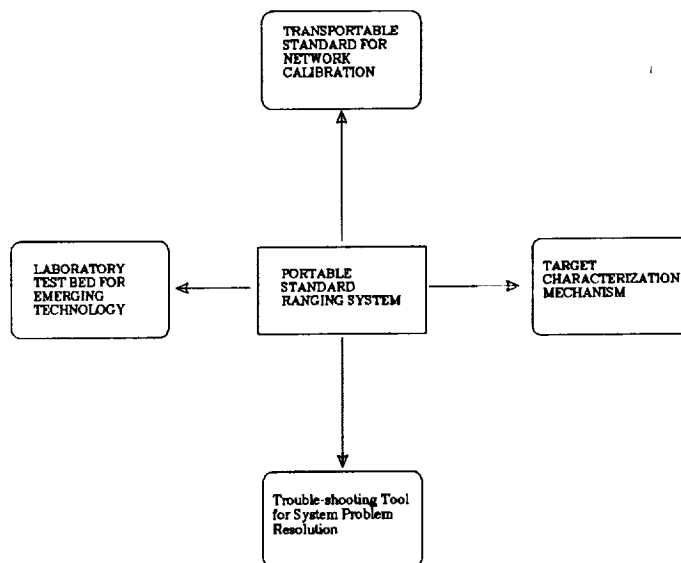

Figure 1 Portable Standard Functions

PORTABLE STANDARD ISOLATED CONFIGURATION

PORTABLE STANDARD COMMON OPTICS CONFIGURATION

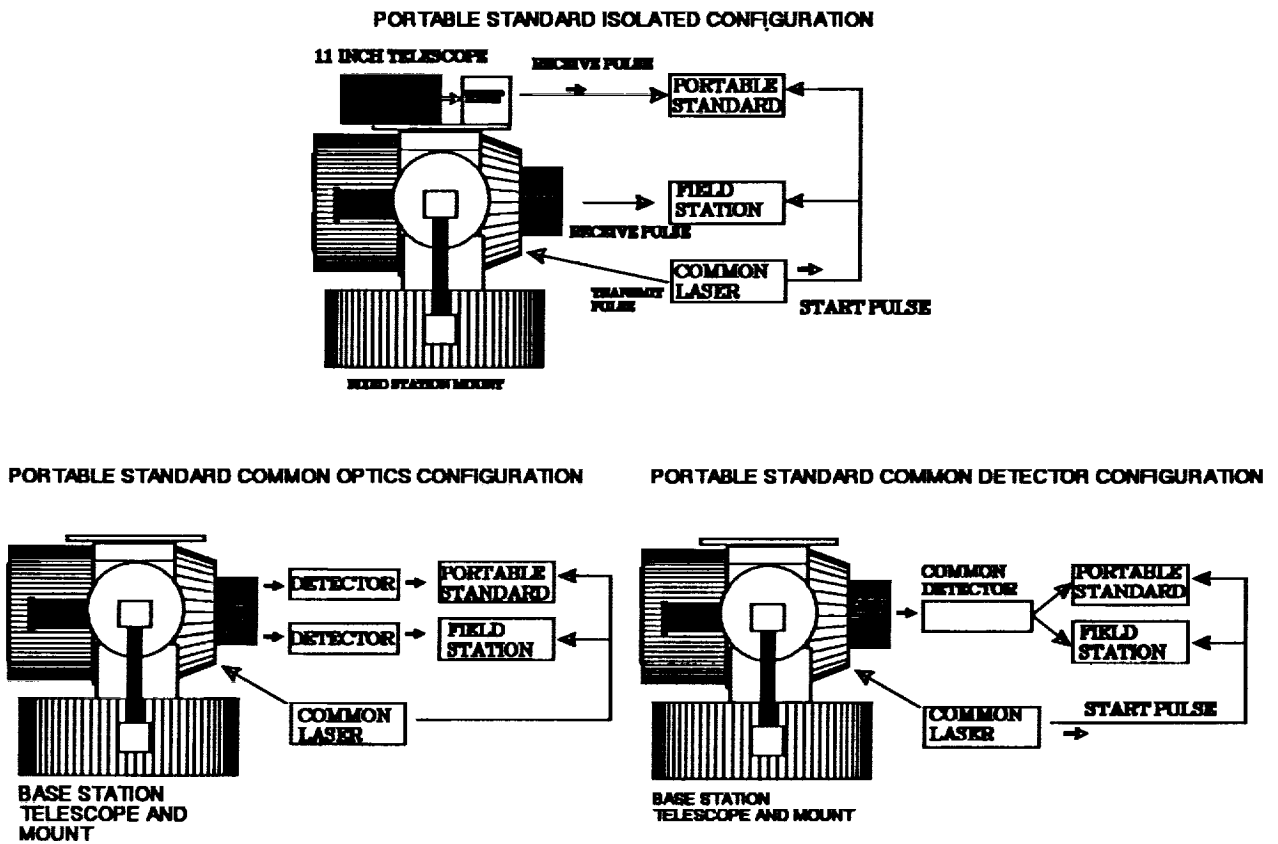**PORTABLE STANDARD COMMON DETECTOR CONFIGURATION**

Figure 2 Portable Standard Test Configurations

The PS ranging instrumentation can sample data in parallel with a field system at any measurement point (see figure 2). It can be configured to independently collect the optical signal using a separate detector; share a common detector with the field system but process the signal separately, or share a common detector and signal processor while separately measuring time intervals. The PS is also able to provide a common frequency source to both systems, should this prove desirable.

1.1 History

One use of the PS has been the optical characterization of the LAGEOS-2 satellite and of two TOPEX array segments. These tests enabled us to employ the instrumentation widely used by many of the SLR stations to measure satellite optical response in the time domain. Earlier Laboratory experiments verified that optical range calibration coupled with instrument thermal stability would make it possible to predict and correct the HP5370 nonlinearities over a limited dynamic range (few nanoseconds) and limited time duration (several hours for one calibration). These calibration techniques, improved data statistics, and instrument temperature control made the necessary sub-millimeter instrumental accuracy achievable.

Recently the PS was installed into MOBLAS-7 for performance intercomparison tests. These tests were aimed at measuring the increase in performance which can be gained using multiple time interval counters for increased statistical advantage, calibration of the discriminator time-walk, increased epoch measurement precision, and to test new opto-electronic detectors in a parallel configuration with the existing detector while employing a shot-by-shot comparison. The first series of satellite passes were used to baseline the current performance of the system with respect to MOBLAS-7. The experimental configuration used a common discriminator for both systems, thereby isolating the performance gained using more than one time interval meter. The results of these first tests are described here.

2   Hardware Description

The PS instrumentation is normally rack-mounted in two cabinets, however, due to practical space limitations in MOBLAS-7 the equipment was confined to a single rack. The computer/controller was placed above the tracking console on a plexiglass shelf constructed for these tests. A brief description of the instrumentation used in the PS follows, refer to figure 3 during the description.
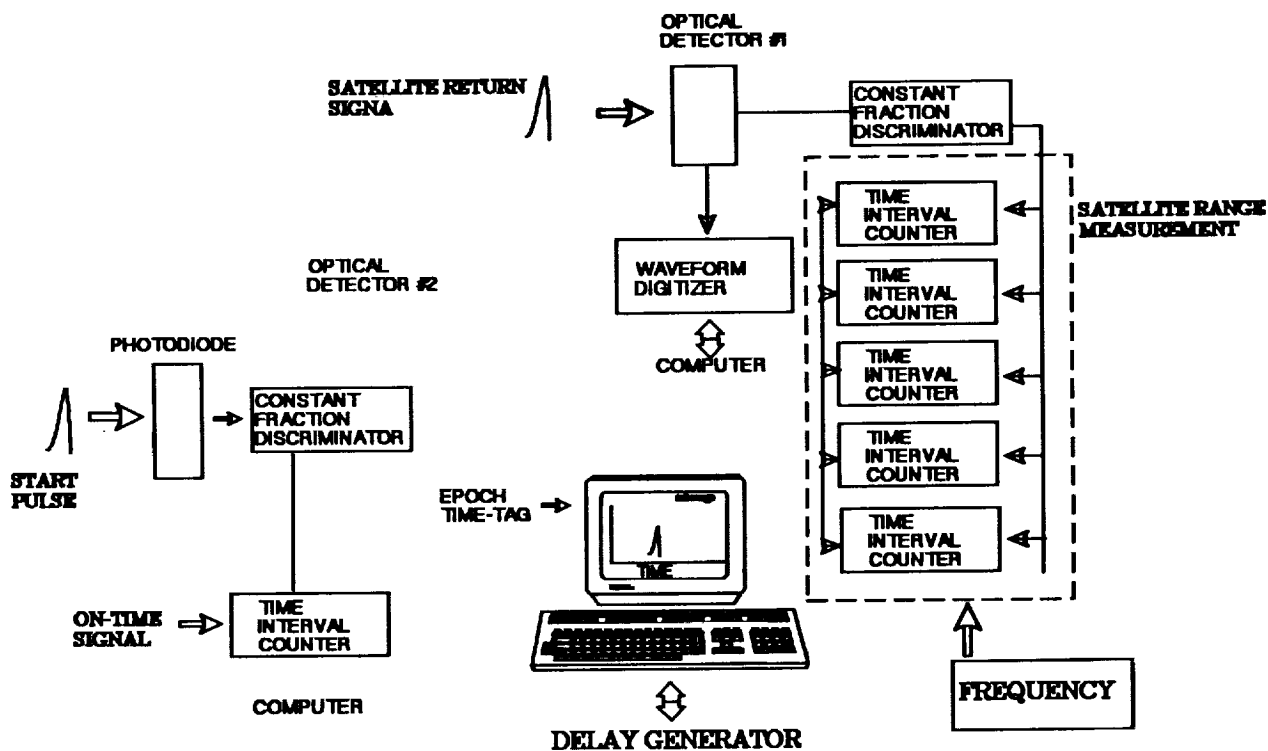

Figure 3 Portable Standard Hardware (SLR Configuration)

2.1   Frequency Source

A Hewlett Packard Cesium beam standard with a high-performance option tube and an Austron disciplined oscillator provide the frequency source for the PS. The disciplined oscillator improves the short-term frequency stability an order of magnitude when compared with use of the Cesium standard alone.

2.2   Time Interval Measurement

Several HP5370 (A & B) time interval counters and two Stanford SR620 time interval counters are available to take range measurements. The time interval counters are arranged to take multiple measurements of the same event to improve the data quality. These counters can also be configured to measure differential time (figure 4) between two return events or a combination of events depending on the application. For these first tests 4 HP5370 counters were used.
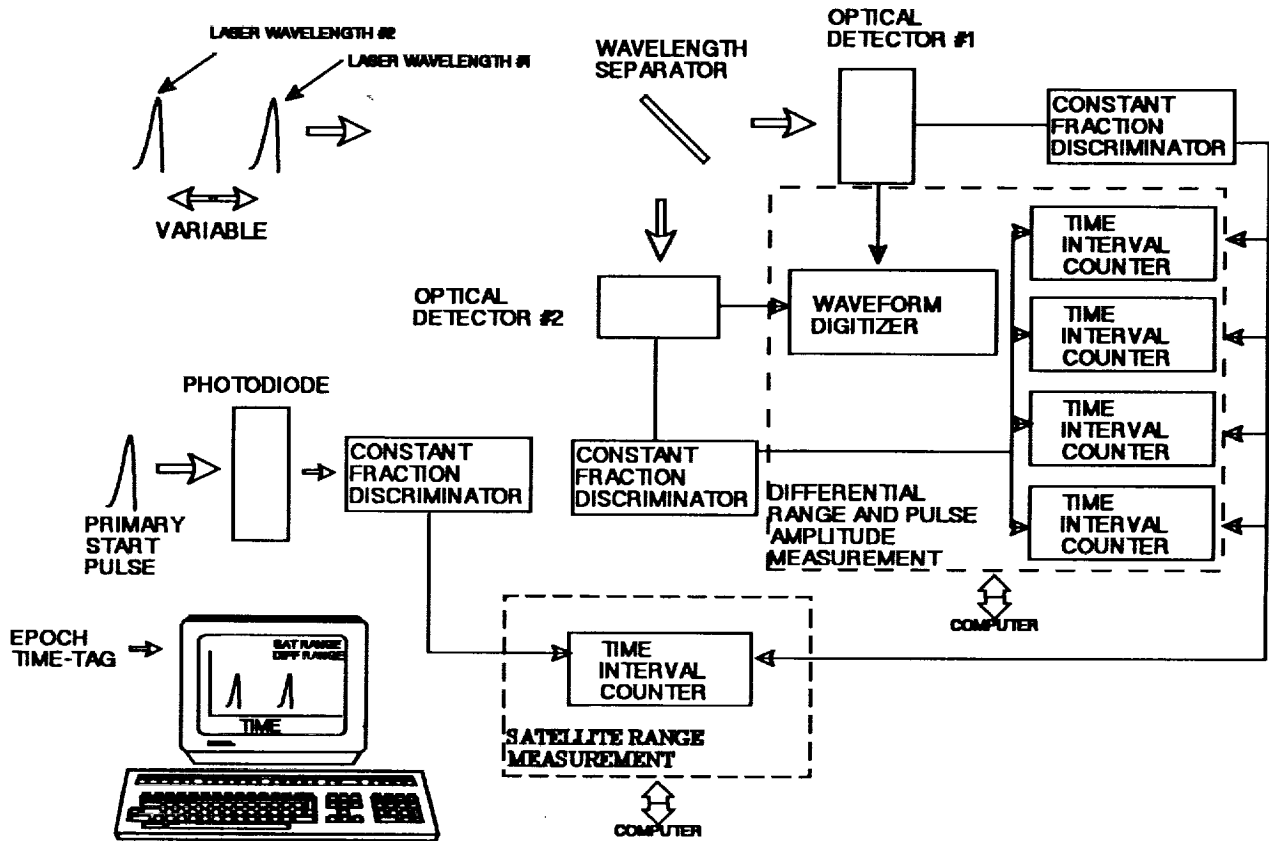
Figure 4 Differential Range Configuration (Two Color etc)

2.3 Signal Processing

A Tennelec constant fraction discriminator (TC-454) is used to process the MCP-PMT detector output. The discriminator is calibrated to remove systematic amplitude-dependent errors (time-walk). For these first tests the MOBLAS-7 discriminator was used and no amplitude measurement was made using the PS.

2.4 Optical Detection

The PS features a detector package which can accommodate several detectors. These may be directly coupled to the optics, or indirectly using fiber-optics. During two-color ranging experiments two MCP-PMT's may be used to separate the wavelenths for differential time measurement. Other types of detectors (PMT, APD, Photodiode) can be used depending on the application, or simultaneously for detection intercomparison. During the first series of passes the MOBLAS-7 MCP-PMT detector was used.

2.5 Amplitude/Waveform Measurement

The output of the MCP-PMT may be digitized using a Tektronix 7912HB (1 GHz bandwidth) digitizer from which amplitude information is extracted. This information can be applied to the range measurements to correct for discriminator time-walk. The digitizer can also be configured to measure the differential time between two pulses while the entire waveform record of each shot is stored on disk. During the TOPEX measurements, a 4.5 GHz bandwidth digitizer coupled to a 60 GHz bandwidth photodiode was substituted for the normal digitizer to map the optical response of the TOPEX array segments.

2.6 Environmental Instrumentation

The thermal environment of the PS instrumentation is monitored and stabilized using microprocessor controlled fans. Thermal sensors are arranged to measure the temperature of the air discharged by the instruments. Thermal stability can be maintained better than 1 degree Centigrade depending on the airconditioning system available. Thermal stability is essential to maintain high data quality.

2.7 Calibration

Optical calibration provides a means to model Time Interval Meter non-linearities for limited dynamic range measurements such as satellite laboratory characterization and two-color differential time interval measurement. The optical calibration mechanism (figure 5) consists of a diode laser, optics and a computer-controlled micropositioner with ~ 2 μm precision. A pulse emitted by the diode laser is split into two pulses, one pulse travels a fixed distance while the second pulse traverses a known but variable range. The two pulses are each detected by a common detector and the signal processed using a common discriminator. The calibration mechanism may be used two ways. For discriminator (amplitude-dependent error) calibration the separation between the pulses is held constant, while the amplitude of one of the pulses is varied using a neutral density filter wheel. A real-time histogram of the varied pulse height is displayed on the computer CRT assuring that a good distribution of data is collected to determine the CFD time-walk curve. For range-dependent error, the amplitude of each pulse is maintained at a constant value, while the pulse-pair separation is varied. A number of data values are collected at each range interval. The variation in separation step size and number of points per position is selectable and is dependent on the desired accuracy. For LAGEOS-2 measurements 0.25 mm instrumental accuracy was desired so an appropriate step size and data volume (500 measurements/position) were used.
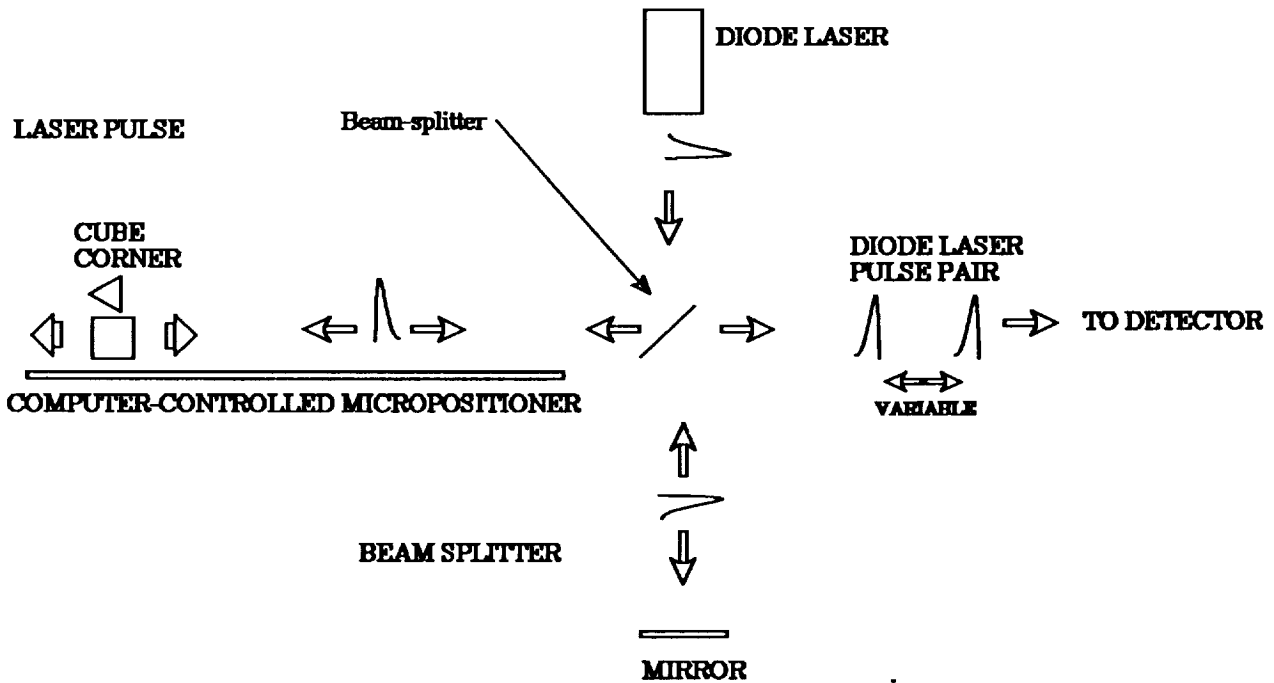

Figure 5 Optical Calibration Mechanism

2.9   Range Gate Generator

A Stanford model DG535 delay generator is used to generate range gates and to perform range simulation for diagnostic purposes. The delay generator may be used to simulate the various ranges encountered during experimental operations. In this mode it is useful for diagnosing internal problems and for software development. The DG-535 uses an external frequency source for enhanced performance.

2.9   Controller

Virtually all instrument control and data acquisition is done using the IEEE-488 interface standard. The controller is a Hewlett Packard model 380 computer which operates using the HP Basic-UX program development environment.

3   Experiment Description

The intercomparison with MOBLAS-7 is a multi-stage experiment. The first stage has been in a common discriminator configuration. One of the output ports of the constant fraction discriminator was divided and fed to four HP 5370 time interval counters. This configuration is the least invasive test and did not affect normal station performance. For this test, no measurement of amplitude was performed, thus, no time-walk correction has been applied to the data. There are two differences to the measurements made by the PS and MOBLAS-7. The PS used its own frequency source (with enhanced short-term stability), and four time interval meters for each event. The choir effect of the counters provides an improvement to the time interval measurement component of the ranging error.

4   Results and Discussion

The resulting satellite data (see table 1) shows significant improvement over MOBLAS-7 data on a shot-by-shot basis. The low-orbit satellite (starlette, ERS-1) trend (see figure 6) shows a somewhat less pronounced improvement when compared to the LAGEOS data. It should be noted that during the period of the intercomparison, MOBLAS-7 was not delivering the level of performance which it is capable of achieving. Historically, MOBLAS-7 has routinely delivered data of 7 - 9 mm single shot rms, whereas, during these tests its typical performance was in the 9 - 11 mm neighborhood. Ground target residuals for the PS varied between 2.5 mm rms (best) and 4.5 mm rms (worst), typically is was in the 3 - 3.5 mm range. There is a consistent bias between the MOBLAS-7 time interval counter and the average of the 4 PS time interval counters. The average of the bias was 3.8 mm with a standard deviation of 1.3 mm. Applying a 3 sigma criteria to the results would eliminate one satellite pass resulting in a mean difference of 3.54 mm with a standard deviation of 0.86 mm. This bias can be largely attributed to the MOBLAS-7 time interval counter. The bias is at a level consistent with HP-5370 counters: agreement better than 1 cm and typically better than 5 mm.

PORTABLE STANDARD RMS -VS- MOBLAS-7 RMS
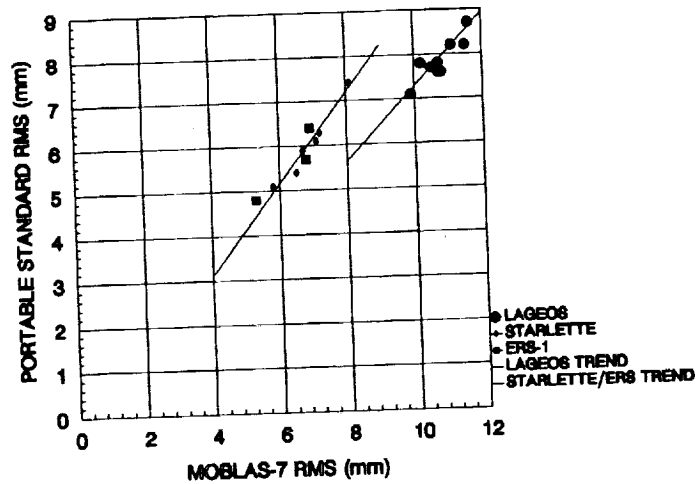FOR VARIOUS SATELLITES

Figure 6

PORTABLE STANDARD PASSES

TAKEN AT MOBLAS 7

DATE	SATELLITE	OBS.	PS RMS (mm)	M7 RMS (mm)	Bias (mm)
19-OCT-91	LAGEOS	8098	7.8	10.7	-3.4
25-OCT-91	LAGEOS	3140	7.8	10.7	-3.4
29-OCT-91	LAGEOS	6478	7.8	10.2	-4.0
29-OCT-91	LAGEOS	989	8.7	11.6	-4.1
30-OCT-91	LAGEOS	2547	8.2	11.1	
31-OCT-91	LAGEOS	2626	7.6	10.7	-3.1
6-NOV-91	LAGEOS	4787	7.1	9.9	-2.6
6-NOV-91	LAGEOS	3591	7.7	10.5	-2.5
6-NOV-91	LAGEOS	829	7.6	10.8	-3.3
29-APR-92	LAGEOS	815	8.2	11.5	-5.4
19-OCT-91	STARLETTE	1343	6.1	7.1	-3.7
29-OCT-91	STARLETTE	443	5.1	5.8	-4.5
29-OCT-91	STARLETTE	598	5.4	6.5	
29-OCT-91	STARLETTE	1443	6.3	7.2	-4.3
30-OCT-91	STARLETTE	881	6.4	6.9	
30-OCT-91	STARLETTE	757	7.4	8.1	
6-NOV-91	STARLETTE	970	5.9	6.7	-7.8
30-OCT-91	ERS-1	463	5.7	6.8	-3.4
30-OCT-91	ERS-1	1062	6.4	6.9	
6-NOV-91	ERS-1	384	4.8	5.3	-1.9

Table 1 Satellite Ranging Intercomparison Results

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5   Future Plans

As noted, MOBLAS-7 is not achieving its best performance at this time. For the second stage of the experiment we plan to perform adjustments and fine-tuning of the MOBLAS-7 instrumentation to regain its typical performance, then make the intercomparison again. During the the next series of passes amplitude measurements will also be taken to apply the discriminator time-walk correction to the data. For the third stage of the experiment, we will install a second detector in the MOBLAS-7 receive package for dual-detection tests. The new detector exhibits enhanced bandwidth and jitter characteristics ("Performance Comparison of Microchannel Plate PMTs", Varghese, Selden and Oldham, These Proceedings). We also plan to obtain an APD detection system to perform direct intercomparison measurements between APD and MCP-PMTs at both the multi-photoelectron and single photoelectron level.

Stanford time interval counters will also be used for range measurement. In the past, We have tested the performance of Stanford counters in the laboratory with varying results. Of the five counters tested, two exhibited large and un-predictable (100 ps) jumps in range while the remaining three counters behaved normally and were comparable to the HP-5370 in performance. At least one Stanford SR620 counter which performs well in the laboratory will be used for a shot-by shot comparison with the other time interval meters.

Other plans have begun to perform in-orbit satellite characterization experiments using TOPEX. For these tests the PS will be used in optical isolation mode; a celestron C-11 telescope will be "piggy-backed" on the MOBLAS-7 Contraves telescope for parallel measurement. The test will also provide a comparison between large and small aperture systems on other satellites. Recently, a study of the relative effect of thermal-loading on the two telescopes was done to determine their focal-length stability for small detector (APD) applications.

6   Conclusions

The portable standard, developed and proven through laboratory experiments, has shown improved satellite range residuals through the use of multiple time interval counters over data acquired by MOBLAS-7. Use of its full capabilities should provide even more improvement and test the accuracy limitations imposed by current ranging instrumentation. Sequential testing and replacement of measurement components (detector, signal processor, time interval/event meter, etc.) will offer a controlled measurement baseline and increase our understanding of SLR error sources.

Detector Technology