N94-15581

Two Color Satellite Laser Ranging Upgrades At Goddard's 1.2m Telescope Facility

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Abstract

The ranging laboratory at Goddard's 1.2m telescope tracking facility has recently been upgraded to include a single photoelectron sensitive Hamamatsu streak camera-based range receiver which uses doubled and tripled Nd:YAG frequencies for satellite laser ranging. Other ranging system upgrades include a new Continuum laser, which will deliver up to 30 millijoules (mJ) at both 532 and 355 nm at a pulsewidth of 30 picoseconds (FWHM), and replacement of both ranging and tracking computers with COMPAQ 386 based systems. Preliminary results using a photomultiplier tube based receiver and waveform digitizer indicate agreement within the accuracy of the measurement with the theoretical Marini and Murray model for atmospheric refraction. Two color streak camera measurements will be used to further analyze the accuracy of these and other atmospheric refraction models.

INTRODUCTION

Satellite laser ranging efforts at the 1.2m tracking telescope at Goddard's Geophysical and Astronomical Observatory (GGAO) have evolved over the past few years in response to the demand for more accurate SLR data. This includes a frequency-tripled Nd:YAG laser system and a streak camera based range receiver. The laboratory which houses the Experimental Satellite Laser Ranging System (ESLRS) adjoins a azimuth-elevation mount multi-user facility designed to support the scientific community at the Goddard Space Flight Center. Two of six facility experimenter port locations are dedicated to the laser transmitter and the streak camera based receiver for ranging applications. The ESLRS is a ranging laboratory where new instrumentation, hardware and software are investigated and characterized for planning and developing next generation systems. The SLR data gathered by the ESLRS is considered engineering data and is not archived as is other NASA laser tracking network data. The end users of the ESLRS data are the experimenters and their goal is to use this information to better understand system problems and to help transition laboratory systems more efficiently to field SLR operations. Other system upgrades include a new 386 based tracking computer, a new 386 based ranging computer, and physical plant upgrades at the facility.

The ESLRS has been operational since 1983 except for periods in which high priority flight programs within the Instrument Electro-Optics Branch left the facility without crew support. The initial SLR system [McGarry et al, 1986] included a Quantel YG 402 DP frequency-doubled Nd:YAG laser, a two stage ITT F4128 microchannel plate photomultiplier tube (MCP-PMT), Ortec 934 and later Tennelec TC 453 constant fraction discriminators (CFD's), and a developmental time interval unit (TIU) built by Lawrence Berkeley Laboratory. This system operated at a 5 hertz rate at the doubled YAG wavelength (532nm) and yielded data at the 1 to 2 centimeter level on LAGEOS with a very high return-to-fire ratio.

PROGRAM GOALS

Goddard Laser Tracking Network (GLTN) systems currently operating at or below the 1 cm level RMS must still rely on models of atmospheric range correction which assume certain altitude profiles for temperature, pressure, and possible gradient effects. Knowledge of atmospheric range correction on a shot-to-shot basis is therefore uncertain, and must be addressed to eliminate atmospheric concerns. The best way of accounting for the atmospheric range correction is to measure it on a shot-to-shot basis. The time of flight measurement is made in the conventional manner with a MCP based receiver using the 532nm pulse, while a differential time of flight between the 532nm and 355nm pulses is made with a streak camera based receiver. In making a streak camera differential measurement accurate at the few picosecond level, the atmospheric range correction can be recovered at the few millimeter level. Work in improving ground-based SLR accuracies closely parallel work on planned next generation space-based laser ranging systems. Efforts in the ranging laboratory at the 1.2m facility have been concentrating on both programs in this parallel effort.

SYSTEM UPGRADES

The extension from single color to two color operation at the 1.2m facility required significant system upgrades, one being an improvement in low mirror reflectivities in the UV. Recoating of all telescope mirror surfaces was required since previous coatings revealed mirror reflectivities in the UV of typically 50 to 60% and one as low as 40%. For a 6 mirror coude focus system used in common optics configuration, UV operation was prohibitive. New aluminum mirror coatings with an SiOx overcoating (peaked at 355nm) improved surface reflectivities to typically 92% at 355nm and 88% at 532nm while maintaining broadband characteristics required by other experimenters at the facility.

Return signal levels from LAGEOS are not adequate for two color streak camera-based operation with the present system. Therefore we have opted to use low earth orbiting satellites such as STARLETTE, AJISAI, and ERS-1 for two color data collection. As an acquisition aid for sunlit passes, two TV camera systems have been added to the mount, and a third low light level RCA silicon intensified target (SIT) camera has been used in the system prime focus.

Facility upgrades include the replacement of the PDP 11/24 tracking computer with a COMPAQ 386/20 based system, and new meteorological instruments including air pressure, temperature, and relative humidity. The ranging computer, a LSI 11/23 (MINC), was also replaced with a COMPAQ 386/20 system.

Ranging instrumentation upgrades include both laser transmitter and receiver. The laser available for use at the 1.2m facility for ranging from 1983 to March of 1992 was a Quantel passively mode locked Nd:YAG system model number YG402 DP. This laser system generated up to 60 mJ of doubled YAG at 532nm and about 15 mJ of tripled YAG at 355 nm in a 140 picosecond pulse (FWHM). To make differential measurements accurate at the picosecond level laser pulsewidths must be narrowed considerably, and target satellites with low pulse spreading must be used. The Quantel laser was replaced with a Continuum model PY-62 YAG with doubling and tripling capability. The new Continuum laser outputs 30 picosecond pulses with about 30 mJ of energy at both 532nm and 355nm. The laser fire rate is currently 4 hertz, with work underway to increase it to 10 hertz.

The laser is housed in a clean room approximately 10 meters from the base of the mount. The output beam is coupled into the telescope system with a negative lens (negative focal length matching the F28 ray bundle of the 1.2m system) and a 45 degree aperture sharing 'holey' mirror just inside the system focal plane. The outgoing laser beam is translated approximately 1.25 cm from the optical axis of the telescope to avoid the shadowing by the central obscuration (secondary mirror) in the telescope. The output beam is approximately .4m in diameter, exits the system cleanly between the primary and secondary mirror, and travels around that annulus as the system tracks in azimuth. This configuration results in the least amount of loss in the outgoing beam. In the common optics mode the return path at the 45 degree mirror is folded across an NRC table top to another mirror, splitter, and receiver package. In the prime focus of the system is a field stop, to limit the receiver field of view, and a high speed shutter.

The receive signal is split between a two stage ITT model F4128 MCP PMT and a Hamamatsu streak camera. Shown in Figure 1 is a simplified block diagram of the system that was used for both aircraft and Relay Mirror experiments as well as current SLR activities. The streak camera in use up until the Spring of 1992 was

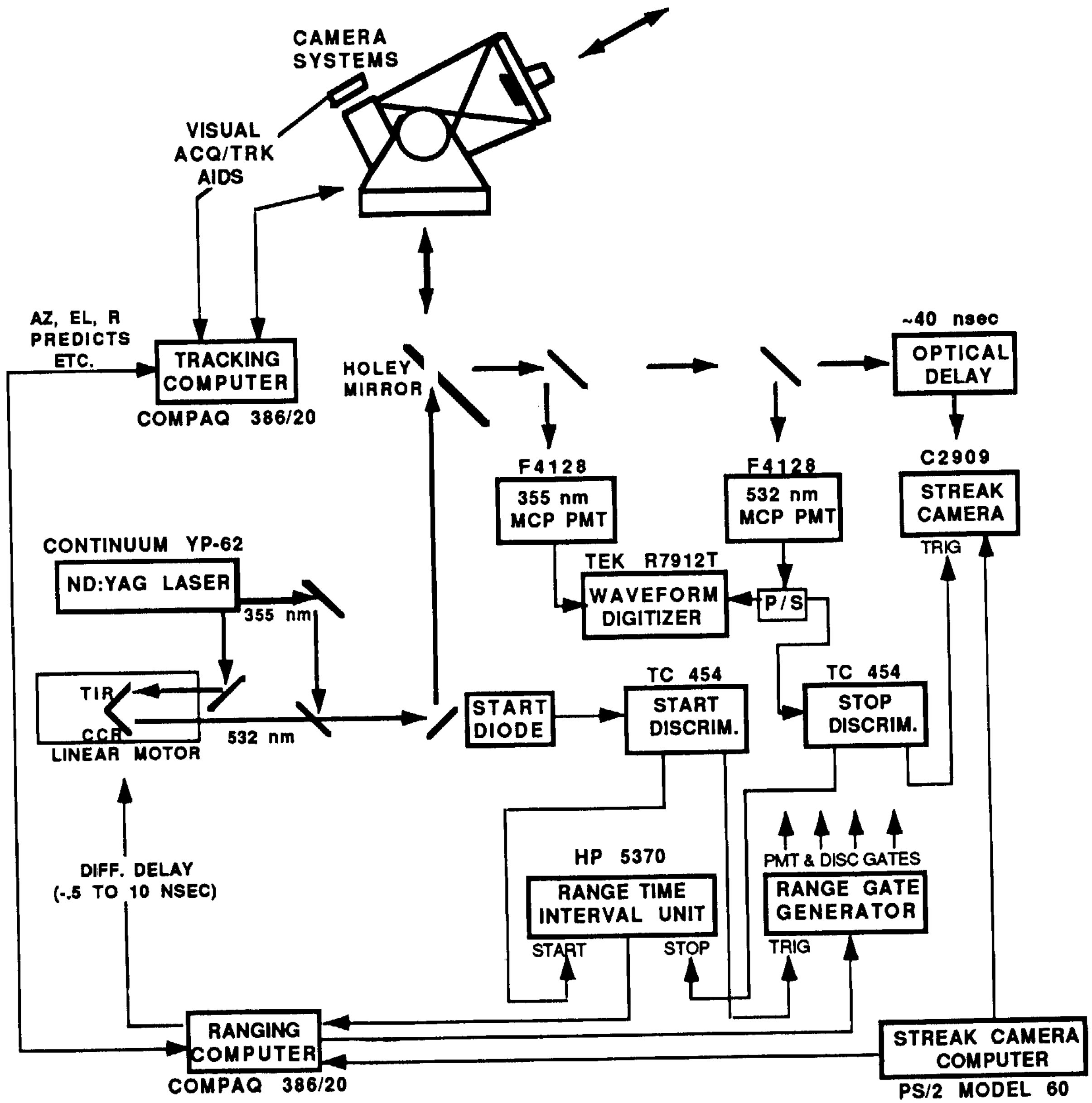

Figure 1. Two Color SLR Simplified Block Diagram

a 2 picosecond resolution Hamamatsu model 1370. This unit was integrated into the system in support of two color experiments which included both aircraft and the NASA/Air Force Relay Mirror Experiment (RME) programs. The signal threshold for the Hamamatsu 1370 streak camera is estimated at several thousand photoelectrons and could be used only for ground work, aircraft, and the RME program where signal levels were extremely high. The Hamamatsu 1370 streak camera has since been replaced with a newer Hamamatsu model 2909 which has an additional internal microchannel plate intensifier giving the unit single photoelectron sensitivity. A summary of upgraded system parameters is given in Table 1.

Table 1. Laser Ranging System Parameters and Instrumentation

Laser	Continuum PY-62, active/passive mode-locked	
Energy	30 mJ @ 532 nm, 30 mJ @ 355 nm	
Pulsewidth	30 picoseconds (FWHM)	
Beamwidth	.0057 degree (FWHM)	
Telescope	1.2 meter diam., f/28 Cassegrain Common optics configuration	
Trans/Rec Sw	Aperture shared	
System trans	60%	
Detector	ITT F4128 MCP PMT	
Discriminator	Tennelec TC 454	
Time Interval Unit	HP5370, 20 ps resolution	
Streak Camera	Hamamatsu model 2909	
Minicomputers	COMPAQ 386/20:	Tracking
	COMPAQ 386/20:	Ranging
	PS/2 model 60:	Streak camera

In the ranging mode a small fraction of the return signal is detected with the MCP PMT, discriminated with a CFD, and triggers the streak camera sweep. Both streak cameras require a pretrigger of 25 to 40 nanoseconds dependent on the sweep speed selected. Sweep speeds available in both cameras are .3, 1, 2, 5, and 10 nanoseconds full scale. The pretrigger is accomplished by delaying the optical return by one of two means. The streak camera input signal is delayed with either a white cell optical delay, or a spot to slit 10m multimode fiber optic bundle. Each technique has it's own advantages and disadvantages. The fiber optic bundle is easy to align and has the largest field of view, but introduces pulse spreading, while the white cell has the best throughput, no pulse spreading, but is difficult to align. To maintain the best differential timing capability at the receive end an artificial delay on the 532nm pulse is introduced at the laser transmitter. This delay is a dogleg optical path into a total internal reflection (TIR) cube corner on a Compumotor linear motor stage. The linear translation stage provides the differential delay control from -.5 to 10 nanoseconds additional optical path length for the 532nm pulse so that both return pulses can be maintained within the 1 nanosecond sweep window. The linear motor stage under computer control uses the differential delay predicted by differencing the Marini & Murray model delays at 355nm and 532nm The optical delay is adjusted so that the two spatially separated pulses are incident in the streak camera slit at approximately the same time. This minimizes nonlinearity problems in the streak camera sweep. To resolve simultaneous pulses in the PMT based receiver using the waveform digitizer two PMT'S must be used.

PRELIMINARY RESULTS

The NASA/Air Force two color RME experiment mentioned earlier generated the first streak camera returns for the ESLRS [Zagwodzki et al, 1992]. The RME satellite was very attractive for several reasons. The RME satellite represented an active, single cube corner response target with an extremely high lidar cross section (~$6x10^9$ m^2). With a short pulse laser transmitter and streak camera based receiver, the individual cube corners on the satellite, separated by 41.2 mm, could be resolved in time. In the Fall of 1991 the only streak camera available at the 1.2m facility for the RME program was the Hamamatsu model 1370. The high threshold of several thousand photoelectrons for this streak camera made the RME the only viable satellite target. Shown in Figure 2 are streak camera return waveforms from the RME satellite at 532nm only. Three cube corners on the satellite could clearly be resolved in time (separation of 41.2mm). The horizontal sweep speed was 1.2 nanoseconds in time and the laser pulsewidth was 140 picoseconds. Unfortunately satellite control problems ended the experiment prematurely before UV operation began.

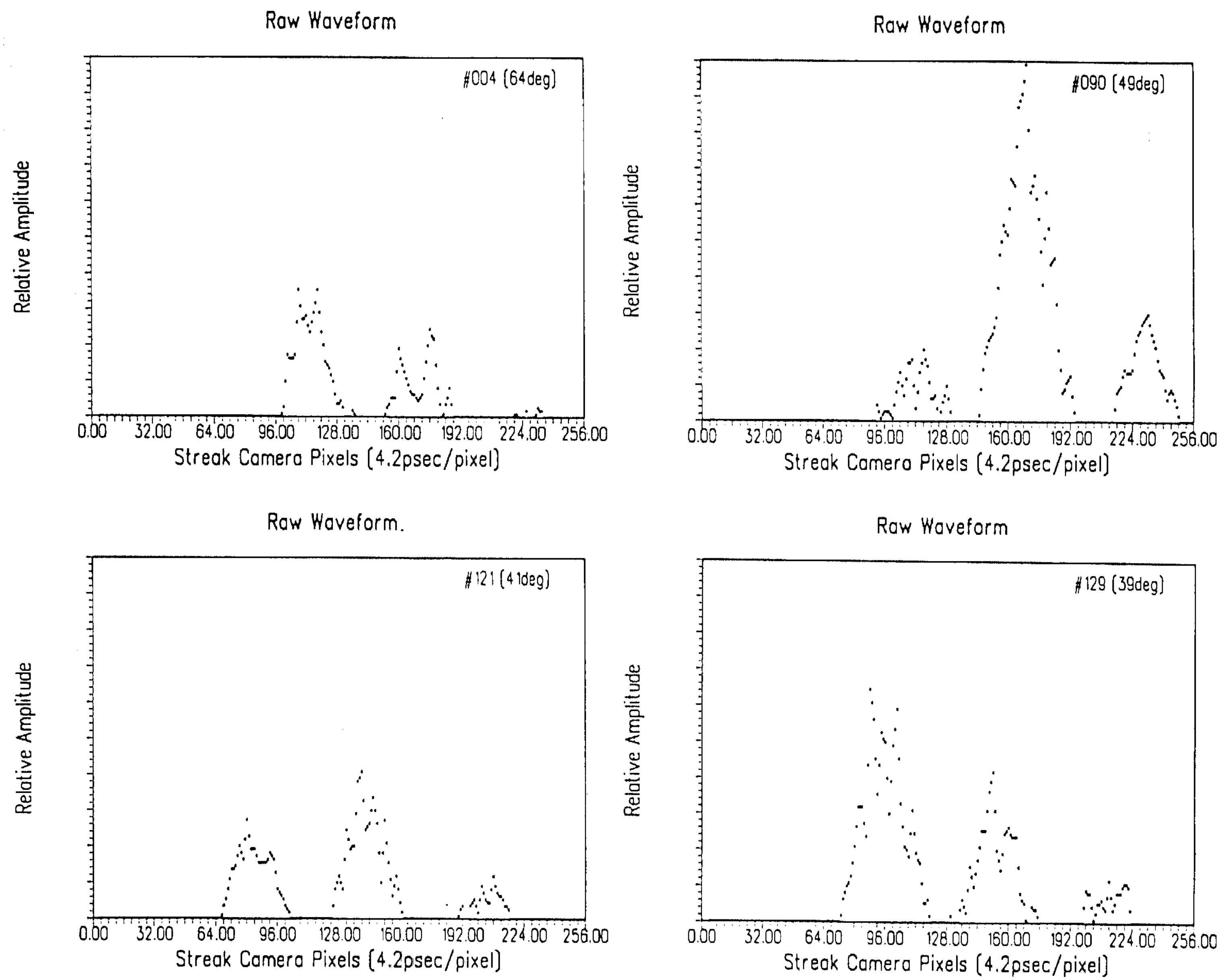

Figure 2. 532nm streak camera returns from the RME

The loss of the RME as a target meant satellite streak camera work had to wait for the installation of the more sensitive Hamamatsu 2909 unit. In the interim, two color efforts have continued at the 1.2m facility using the MCP PMT based receiver with a 1 Ghz bandwidth Tektronix model 7912 waveform digitizer. The ranging system can be configured with two PMT's (one each for 532nm and 355nm) or a single PMT (usually the 355nm). For night time operation, when no bandpass filters are required, a single PMT is used. Since the UV link is the weakest, the PMT with peaked quantum efficiency at 355nm is used. To resolve two distinct pulses with the single UV PMT the differential delay at the transmitter is set to allow at least two nanoseconds offset between the peaks of the two pulses. This assures adequate separation of return pulses at the receiver, but reduces the temporal resolution of the differential time-of-flight measurement.

Figure 3 shows a comparison plot of the theoretical differential delay versus the measured delay calculated from the two color returns as seen by the Tektronix 7912. The theoretical differential delay was calculated by differencing the 355nm and 532nm delays computed using the Marini and Murray model. The Marini and Murray calculations used the weather conditions from the log file taken during the pass. This weather information was taken in real-time, so the actual temperature and pressure were not constant. The pressure changed minimally (1006.27 to 1006.31 millibars) as did the temperature (14.24 to 14.48 C). The gaps (thinner lines) in the Marini and Murray curve represent times that no weather information was available, and so the data had to be interpolated for those regions.

For this pass the linear translator was fixed at 6 nanoseconds. This necessitated a slow sweep setting on the 7912 waveform digitizer in order to capture both frequency's return waveforms during the entire pass. Setting the green delay at 6 nanoseconds always placed the 355nm return ahead of the 532nm return and caused the UV pulses to move toward the green as the elevation decreased.

The measured differential delay was computed by taking the inverted raw 7912 waveforms (no smoothing) and computing the pixel locations of the highest two peaks. The location of these two pixels was differenced, converted to nanoseconds, and subtracted from the fixed 6 nanosecond green delay. This was a "quick-look" at the data so no interpolation was performed between pixels, and

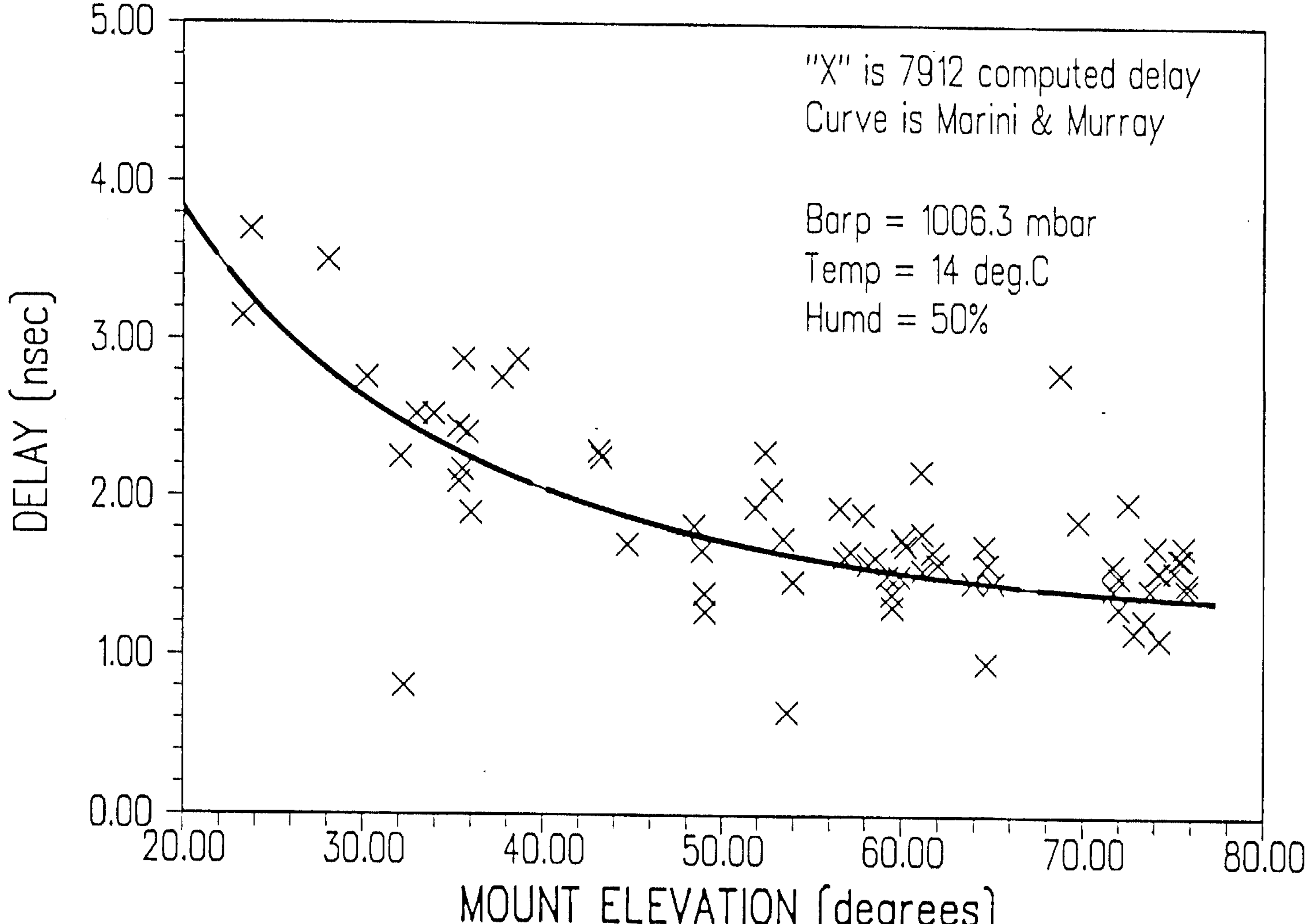

Figure 3. Two color differential delay comparison of AJISAI pass of June 27, 1992.

there was no 7912 calibration data used to correct any nonlinearities in the sweep.

The calibration of the linear translator was not performed as accurately as it will be for streak camera data. The actual zero point of the translator for the 7912 data was good to approximately +/- 200 picoseconds. Actual raw 7912 return waveforms at different elevations are shown in Figure 4. In these plots the 7912 data is inverted, but not smoothed in any way.

FUTURE WORK

Two color laser ranging activities will continue at the 1.2m facility to complete the installation of the streak camera based receiver with single photoelectron sensitivity. This will enable tracking of all low earth orbit satellites in two colors and will yield a good data set for atmospheric model comparisons. Investigative work will begin in the areas of system automation, and optical time interval units. [Degnan, 1985]

ACKNOWLEDGEMENTS

The authors wish to thank the Strategic Defense Initiative Organization Office of Directed Energy for use of the Relay Mirror Experiment satellite, the Phillips Laboratory of Albuquerque, New Mexico for their coordinating efforts, and the Consolidated Space Test Center of Sunneyvale, California for their work in providing NASA the satellite maneuvers for optical engagements.

We would like to thank Arnie Abbott of NASA for his services in maintaining the 1.2m facility, and Tammy Bertram for her operational support. We would also like to thank Bendix Field Engineering Corporation crew members Dick Chabot, Jim Fitzgerald, Dave Grolemund, Mike Seldon, Tom Oldham, and Jack Cheek of Hughes- STX for their continued effort in support of this program.

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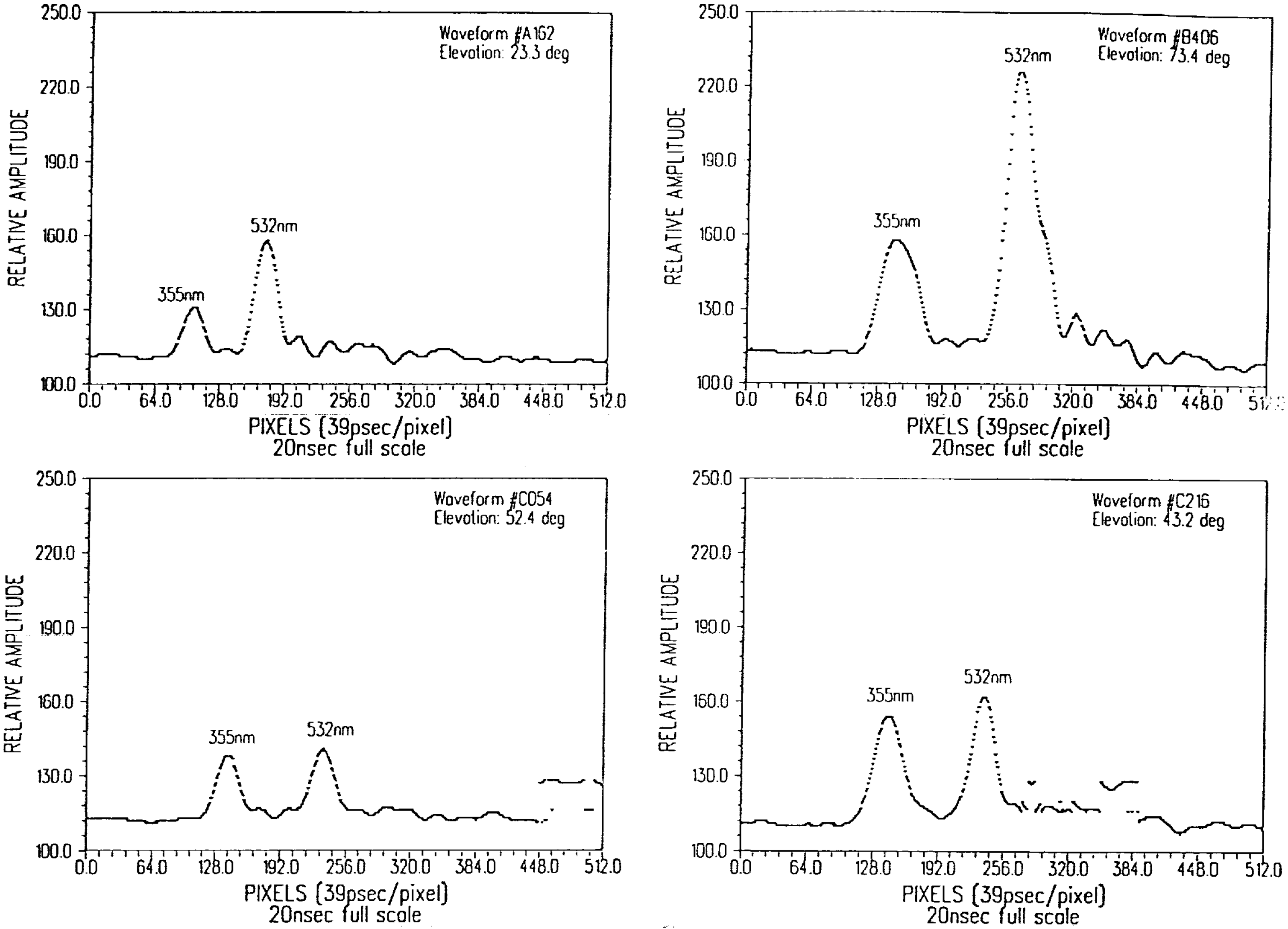

Figure 4. Two color return waveforms from AJISAI pass of June 27, 1992.

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