Mobile System

Upgrades/Developments

Allied Signal

N94-15609

TLRS-3 SYSTEM UPGRADES

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Abstract

This presentation describes the upgrades to the Transportable Laser Ranging System, serial number three (TLRS-3), and the impact that these upgrades will have on the TLRS-3 performance in the field. The four major areas of system upgrades are the HP-380 computer, the Optical Attenuation Mechanism (OAM), the upgraded spatial, spectral and temporal filtering for improved daylight ranging capability, and the software upgrade to enable the system to track the Etalon satellites.

The TLRS-3 was returned to the Goddard Geophysical and Astronomical Observatory (GGAO) in December 1991 for system upgrades in preparation of the TOPEX/POSEIDON campaign scheduled to begin in the summer of 1992. Many system upgrades were incorporated into the system while interleaving planned facility maintenance making TLRS-3 a more versatile and more dependable laser ranging system.

The TLRS-3 was initially baselined with the MOBLAS-7 via simultaneous satellite ranging on the LAGEOS, Ajisai, Starlette and ERS-1 satellites. During the upgrades and following completion of the system upgrades intercomparisons with the MOBLAS-7 were made to verify the integrity and accuracy of the system changes.

Several other groups of personnel participated in the TLRS-3 upgrade and they are: the Survey Section, the Precision Measurement Equipment Laboratory, the Architectural and Engineering Services Department, the Precision Timing Section and the station personnel at TLRS-3 and MOBLAS-7.

OBJECTIVES AND GOALS

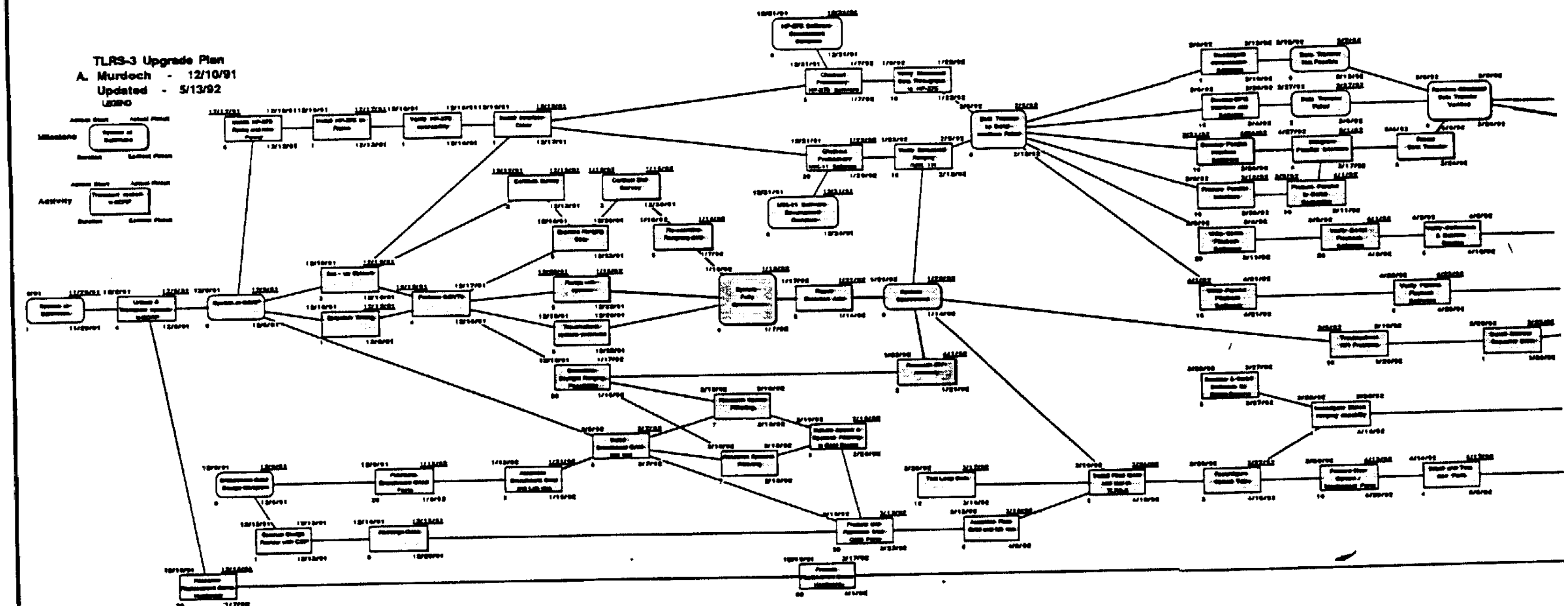
HP-380 COMPUTER UPGRADE

OPTICAL ATTENUATION MECHANISM UPGRADE

DAYLIGHT TRACKING CAPABILITY

ETALON RANGING CAPABILITY

FACILITY MAINTENANCE


TLRS-3 Upgrade Plan
A. Murdoch - 12/10/91
Updated - 5/13/92

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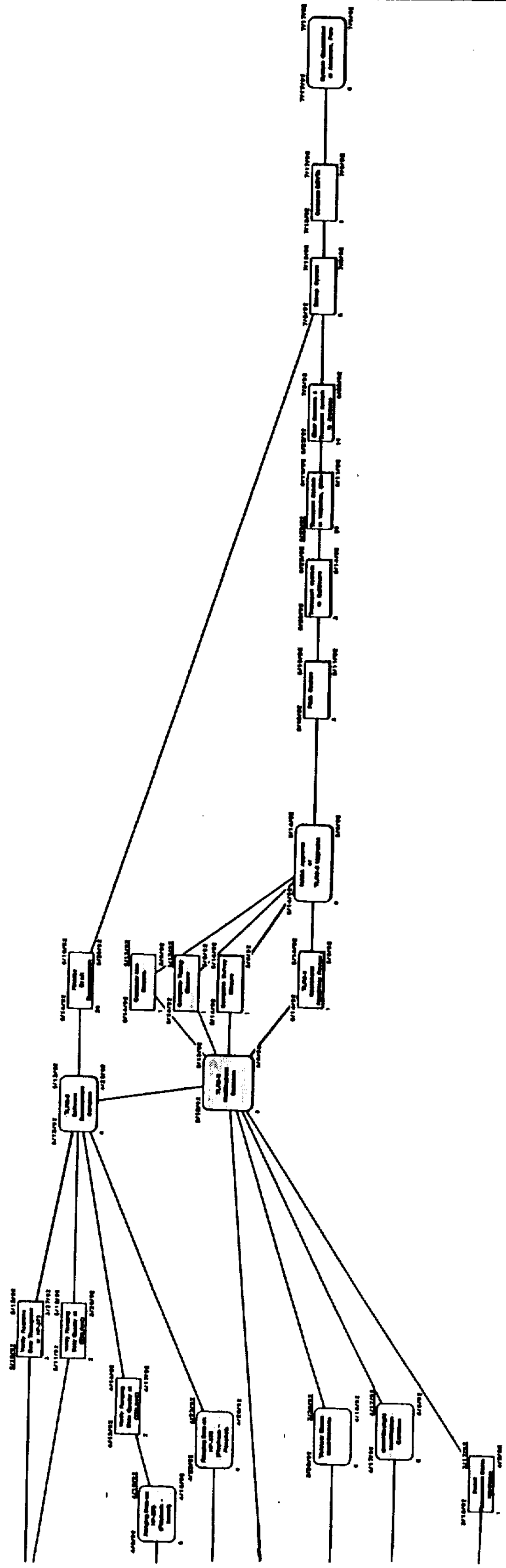


HP 380 COMPUTER FEATURES

HP 380: 16MB RAM, 660MB HARD DISC, 330MB OPTICAL DISC, HP UX 8.0

REAL TIME DSP PARALLEL INTERFACE TO MIK-11/2 COMPUTER

INCLUDED MULTI-SATELLITE/MULTI-LEVEL OPERATIONS CAPABILITY

IMPROVED STAR CALIBRATION PROGRAMS (FK5, GLOBAL/KALMAN, 70 STARS)

ETALON RANGING CONTROL AND DATA AQUISITION

TUNED IRVs; ie TEMPORAL FILTER IMPROVEMENT

OPTICAL ATTENUATION MECHANISM FEATURES

MANUAL CONTROLLED OPERATION

COMPUTER CONTROLLED OPERATION

SOLENOID ACTUATED TRANSMIT ND FILTER: FIXED VALUE

VARIABLE RECEIVE ND ATTENUATION RANGE: 0.01 to 4.0 ND

SOLENOID ACTUATED DAYLIGHT FILTER

DAYLIGHT TRACKING

SPATIAL FILTER APERATURE REDUCED to 500 MICRONS

DAYLIGHT SPECTRAL FILTER REDUCED FROM 10 to 3 ANGSTROMS

ALIGNMENT COLLIMATOR MAKES DAYLIGHT STAR CALIBRATION POSSIBLE

TELESCOPE FOCUS MUST BE ADJUSTED FOR DAYTIME/NIGHTTIME TRACKING

ETALON TRACKING

CAPABLE OF 5 pps OPERATION TO 135 MILLISECOND RANGE

DATA AQUISITION CHANGES TO 2.5 pps FOR GREATER THAN 135 ms

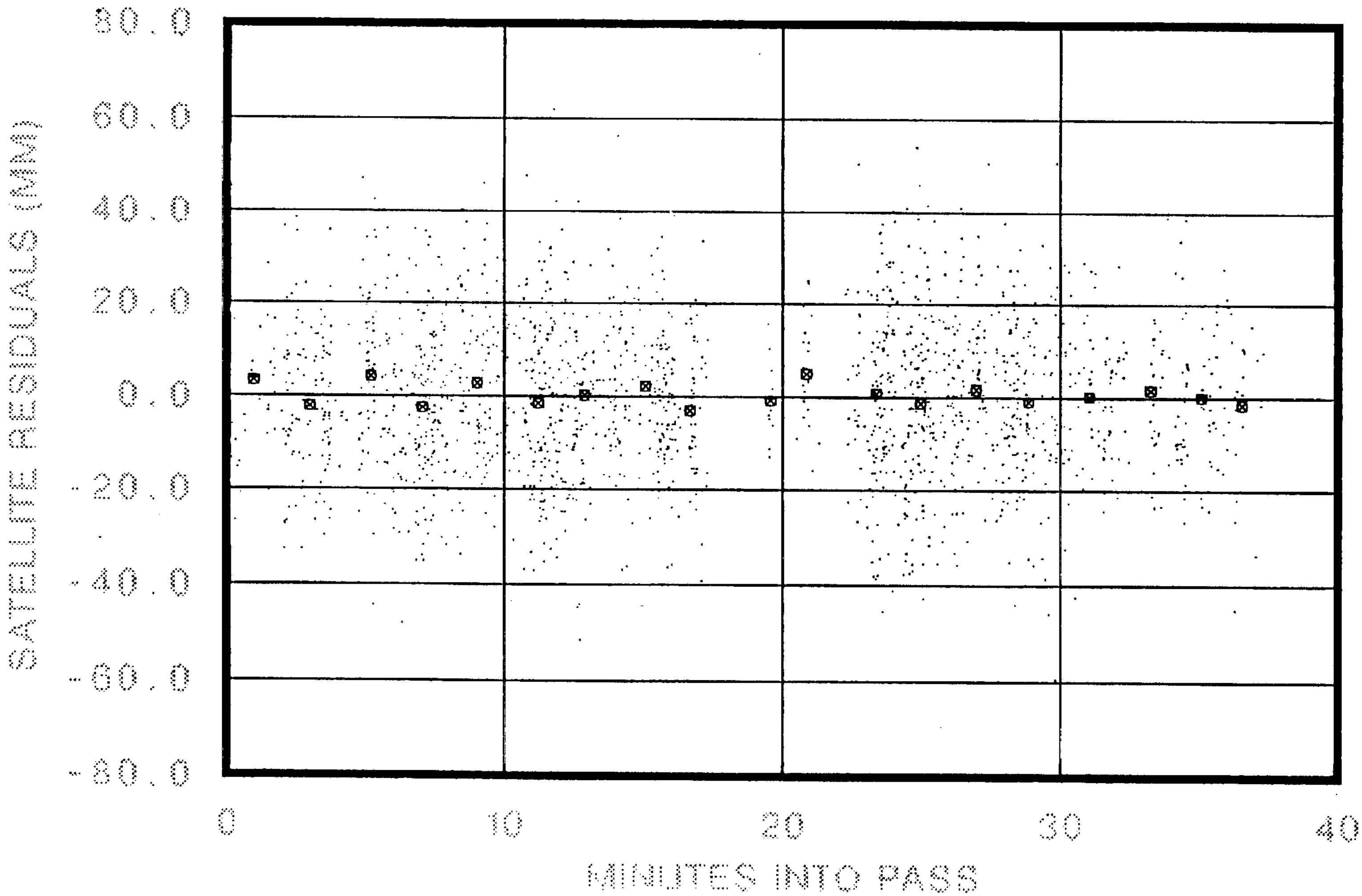
LOW SIGNAL AMPLITUDE RETURNS WHEN TESTED AT GGAO

TLRS-3 IMPROVEMENT SUMMARY

- HP-380 COMPUTER SYSTEM
- OPTICAL ATTENUATION MECHANISM
- AUTOMATED TRANSMIT ND FILTER
- AUTOMATED 3A SPECTRAL FILTER
- COLLIMATOR ALIGNMENT TELESCOPE
- SIMMERED CAPACITOR BANK FOR LASER OSCILLATOR HEAD
- TEMPORAL FILTER REFINED
- SPATIAL FILTER TIGHTENED
- TRANSMIT/RECEIVE OPTICS RECONFIGURED
- BORESIGHT AND COELOSTAT ALIGNMENT PROCEDURES REDEFINED
- CESIUM FREQUENCY STANDARD REPLACED
- FREQUENCY STANDARD UPS REPLACED
- DOME AND VAN REPAIRED
- AC POWER RECONFIGURED

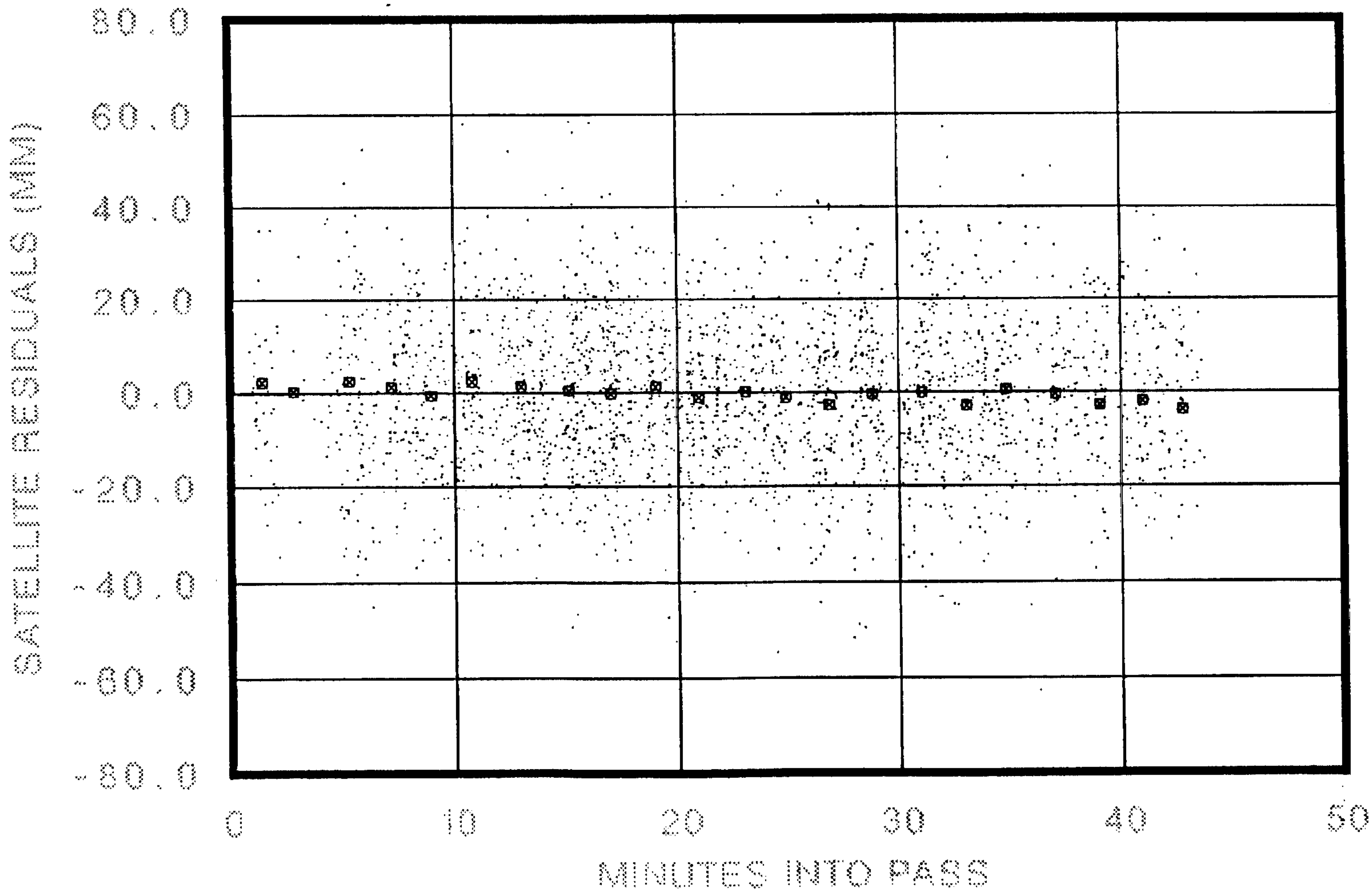
SATELLITE RESIDUALS

TLRS 3   LAGEOS   4/23/92 AT 18:54 GMT



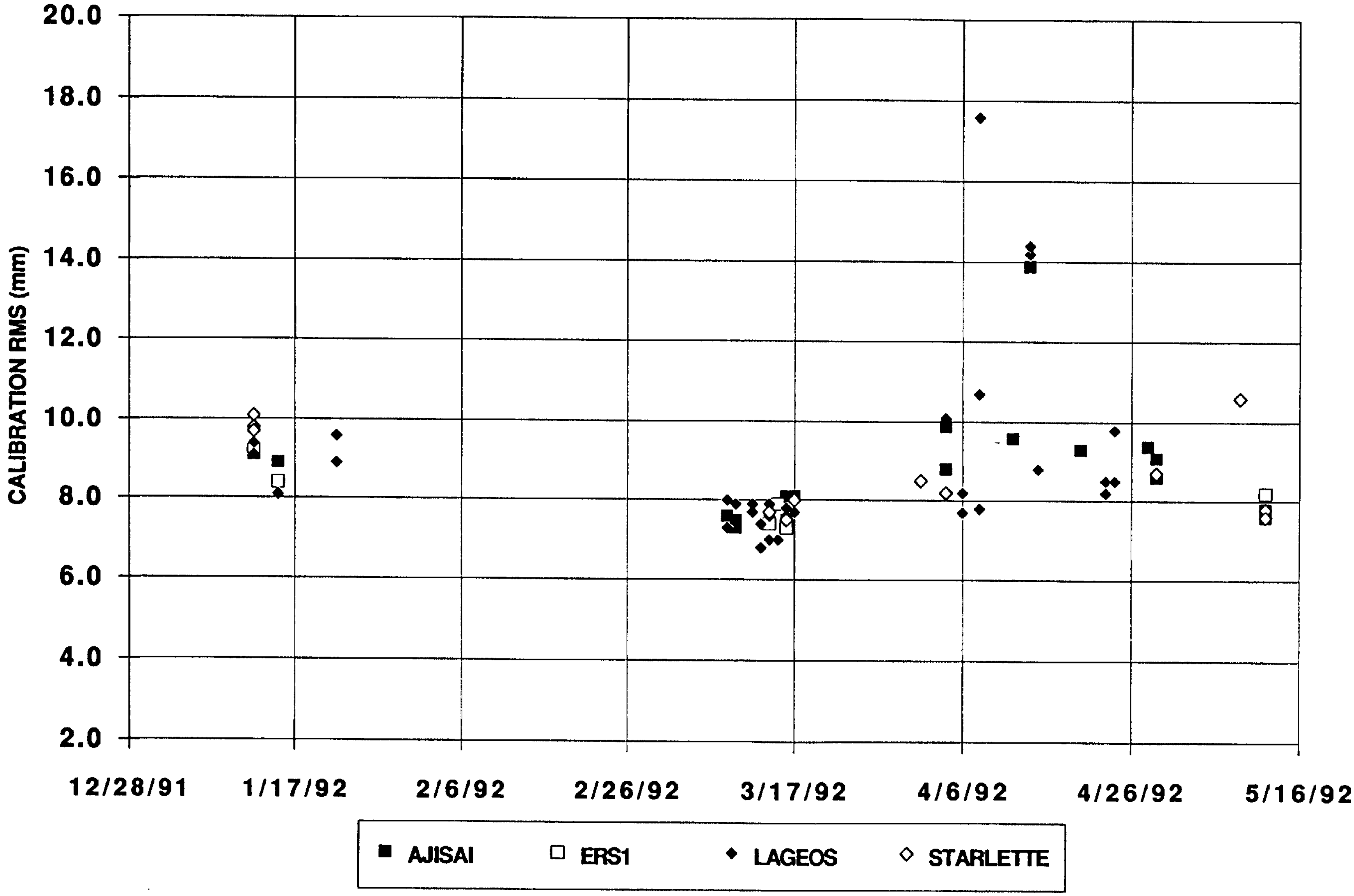
SATELLITE RESIDUALS

TLRS 3 LAGEOS 4/24/92 AT 5:06 GMT



TLRS-3 vs. MOBLAS 7 GORF INTERCOMPARISON

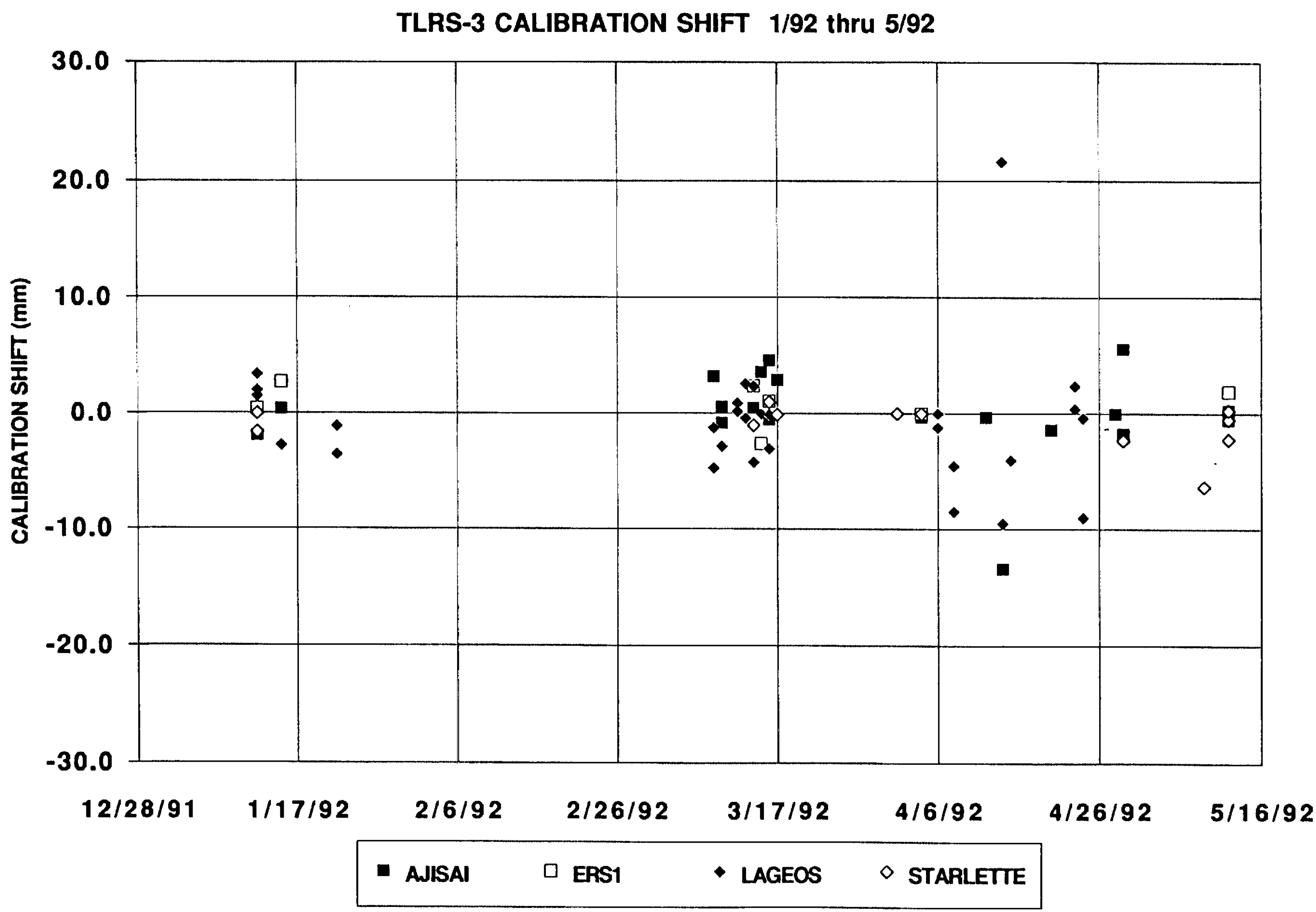
TLRS-3 CALIBRATION RMS 1/92 thru 5/92



CDSLR/NES/S.WETZEL

5/13/92

TLRS-3 vs. MOBLAS 7 GORF INTERCOMPARISON

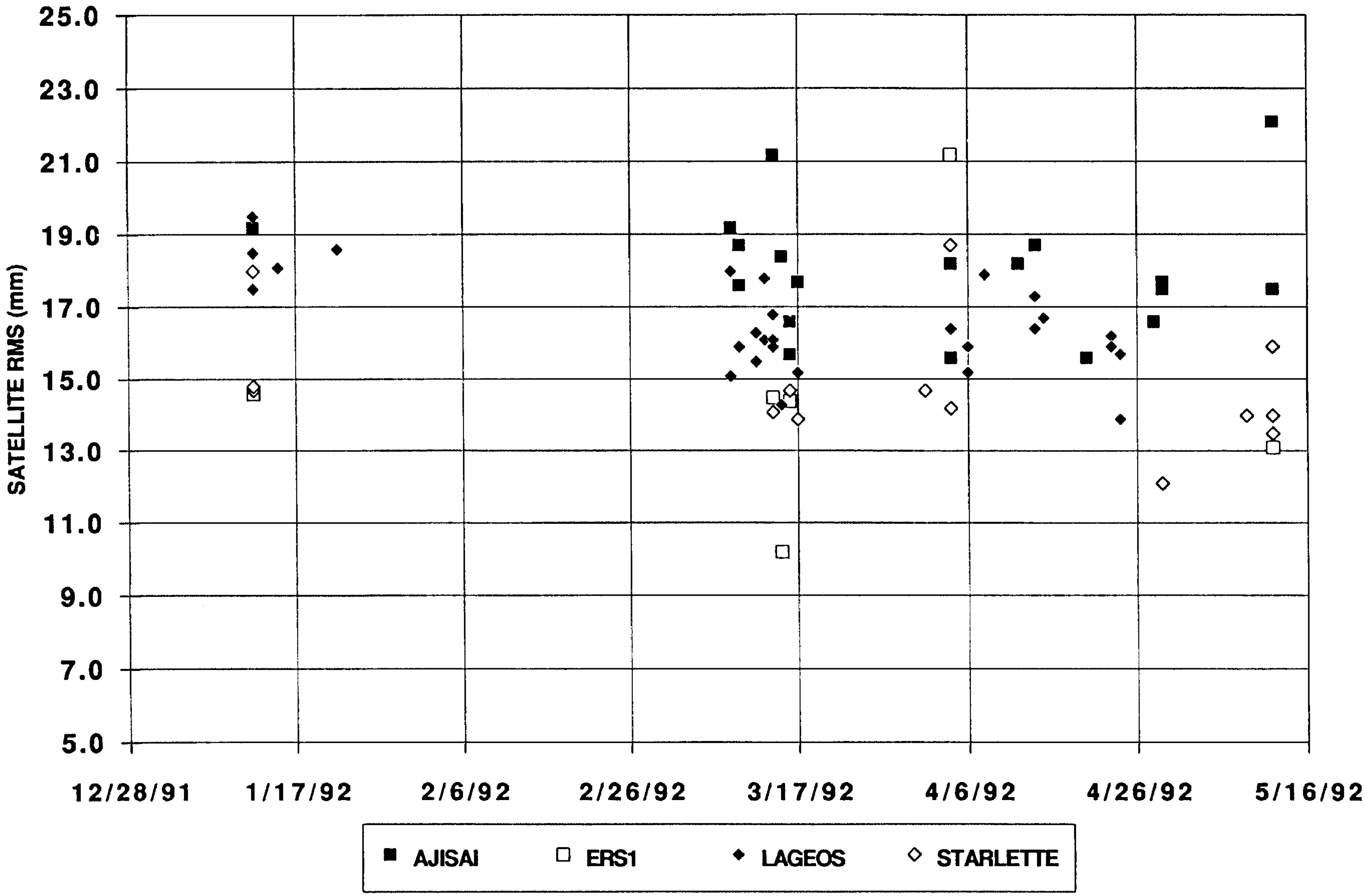


CDSLR/NES/S.WETZEL

5/13/92

TLRS-3 vs. MOBLAS 7 GORF INTERCOMPARISON

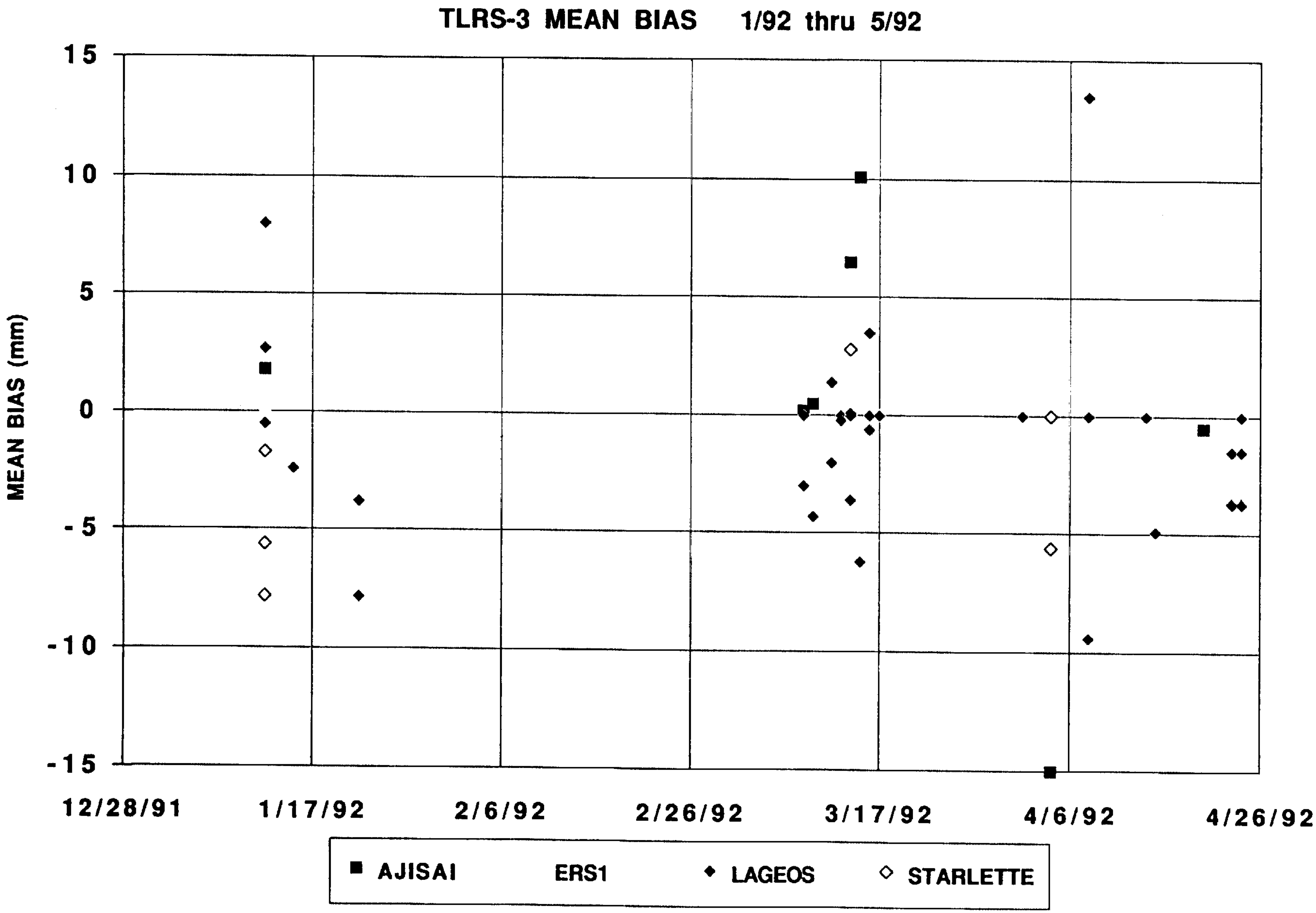
TLRS-3 SATELLITE RMS 1/92 thru 5/92



CDSLR/NES/S. WETZEL

5/13/92

TLRS-3 vs. MOBLAS 7 GORF INTERCOMPARISON



CDSLR/NES/S.WETZEL

5/13/92

N94-15610

Results of the MTLRS-1 Upgrade

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Abstract. In this report the results of the upgrade of the German Modular Transportable Laser Ranging System MTLRS#1 are summarized. A short description of the new components and their influence on the system accuracy is given. It is shown, that the single shot accuracy of the MTLRS#1 has been improved from 5 cm to 1 cm.

1. Introduction

The German Modular Transportable Laser Ranging System MTLRS#1 has been operated successfully since 1984. From 1985 to 1990 the system was employed in the Central and Eastern Mediterranean area and in the U.S.A., contributing to the WEGENER-Medlas and the NASA Crustal Dynamics project.
In order to improve the system reliability and the ranging accuracy from 5 cm to 1 cm a major system upgrade was performed from December 1990 to July 1991.

This upgrade was planned and carried out in five steps:

- Exchange of the Laser
- Exchange of the Start Detector
- Exchange of the Receiving System
- Exchange of the Single Photon Detector
- Improvements in Periphery and Software

In this paper we will summarize the technical specifications of the new systems and show first tracking results.

2. Technical description of the upgrade

2.1. The Laser

The duration and the energy of the emitted laser pulses are critical elements in the determination of the accuracy and the number of returns produced by a satellite laser ranging system. To improve this two points, we exchanged the original Nd:YAP Laser (Pulseduration: 370 ps; Pulseenergy at 536 nm: 10 mJ) for a new Nd:YAG Laser (Pulseduration: 30 ps, Pulseenergy at 532 nm: 30 mJ). To ensure a good reliability of the laser in field, we made use of the self filtering unstable resonator (SFUR), described by R. Bianchi et.al. and K. Hamal et.al, which has a very simple optical layout.
This setup has three major adventages:

- insensitive to inaccurate adjustment
- homogenious spatial energy distribution
- very high pulse energy in the resonator.

The realisation of the optical setup of the laser delivered by Laser Valfivre is shown in Fig. 1. To save place, the resonator M1 - M2 is folded over the prism PR. The laser is cavity dumped through a pockelscell PC and a polarizer PO. An active-passive configuration (acustooptic modelocker ML and dye cell with Kodak 9860 in 1,2-Dichlorethan) is used to generate picosecond pulses.

In the SFUR configuration, the energy of the pulses in the resonator is already reasonable high, therefore a Single Pass Amplifier (AMP) is sufficient to generate a pulseenergy of about 100 mJ in the infrared which gives about 30-40 mJ in the Second Harmonic.

Due to the good isolation of the laser head and the power electronic to environmental influences and due to remote control facilities in the laser head, we are able to operate the laser over long period without opening the shielding.

2.2. The Start Detector

To take full advantage of the short laser pulses it is neccessary to use a start diode with very fast risetime to generate the start signal for the counter. As each component between diode and counter gives some additional jitter we were looking for a solution with a very simple electrical layout. Mainly we tried to find a way where it was no longer neccessary to use a constant fraction discriminator to compensate the amplitude fluctuations of the diode signal.

Therefor we integrated an optically triggered avalanche diode (I. Prochazka et.al.) as start detector. This diode generates an electrical signal, which is independent from the energy fluctuations of the laser pulses. This signal is directly used as start signal for the counter.

The signal has a risetime of 300-400 ps (Fig. 2), the jitter between laserpulse and electrical pulse is less than 20 ps.

To obtain high stability and to have also the possibility to vary the pulse energy during tracking the new start diode is placed before the amplifier to detect the infrared signal. In the previous design the diode detected the green light after the second harmonic generation.

2.3. Receiving Package

In contrast to other SLR System the MTLRS is using an echelle grating for the spectral filtering of the received light. Compared to the common used interference filters this has the advantage to be insensitive to environmental influences. Unfortunately an echelle grating generates a time spread of a pulse due to the different light paths over the grating.

In the old grating this was compensated with an accuracy of about 1 cm by sending the diverse parts of the beam to different mirrors. Due to this splitting of one pulse into several beams, the outcoming beam has not the high optical quality which is necessary for focusing on the small active area ($100\mu m$) of an avalanche diode.

In the new package a second echelle grating in opposite position is used to make full compensation. The excellent optical quality of this configuration results in a very homogeneous beam which is necessary to generate small focal spots.

Additionally a remote controled field-of-view pinhole and a better isolation against straylight is installed in the new package. The sketch of the whole receiver is seen in Fig. 3. (H. Visser)

At the input the beam coming from the telescope is directed by a prism to an optical package in which a rotating shutter and some small prism are used for filtering and guiding of the beam. The light has to travel through the rotating shutter and is directed to an echelle grating. After that the pulse is spread in time and frequency. An adjustable pinhole is used for the field of view filtering and for selection of the correct wavelength. To compensate the time spread the beam now propagates a second time to the echelle grating before two lenses form a parallel, 8 mm diameter output beam.

2.4. Single Photon Detector

A major improvement in the accuracy of the time interval measurement was achieved by the exchange of the photomultiplier for a single photon avalanche diode (SPAD) (I. Prochazka et.al., G. Kirchner).

The signal out of the SPAD is independent of the signal strength, so the use of a constant fraction discriminator is not necessary.

A description of the technical details is given in Sperber et.al.

3. System Accuracy

The main reason for the upgrade of the MTLRS was the demand to improve the system accuracy from 5 cm to about 1 cm single shot r.m.s.

In Fig. 4 the developement of the accuracy during each step of the upgrade is depicted. The main influence to the accuracy came from the exchange of the laser and the single photon detector. The start detector has minor effect and the importance of the new receiver package can be seen in the good optical quality which finally allows the usage of the SPAD.

The contribution of each single component of the system to the system accuracy is shown in Fig. 5 for the old and the new configuration. The r.m.s of all components has now about the same size. Further improvements are probably possible at the laser (10 ps) and at the counter. More accurate start and stop detectors are not available at the moment.

The plot of a typical pass before and after the upgrade is given in Fig. 6. Here the significant decrease of the system r.m.s is conspicious.

All this data are showing, that the single shot accuracy of the MTLRS#1 is now 1 cm or less, if all components (mainly start diode, SPAD and laser) are optimally adjusted.

Under field conditions we demonstrated (P. Sperber, H. Hauck) a system accuracy of 1 cm - 1.5 cm and a normalpoint accuracy of a few mm.

3. Perspectives into the next years

The receiving and transmitting part of MTLRS#1 is now again state of the art. To bring the whole system to a status comparable with modern SLR systems two additional upgrade steps are under discussion.

- Installation of a new control electronic and software, designed for future demands to Laser Ranging Systems. IfAG has decided to develop such a control system based on a transputer network in cooperation with MTLRS#2 (OSG Kootwijk). The integration in the MTLRS#1/2 is scheduled for 1993 (E. Vermaat et. al.)
- The Laser and the Receiving system are now prepared to make two color ranging. Only the telescope does not meet the specifications for two color ranging as the reflecting mirrors are optimized only for a wavelength of 532 nm. A further upgrade for two color ranging capability depends strongly on the demand of the international SLR community for two color ranging data.

5. Summary

After the upgrade of MTLRS#1 performed from December 1990 to Juli 1991 a system with the following modified specifications is now available.

- 30 ps laser pulse-width with 30 mJ/pulse at 532 nm
- Optically triggered avalanche diode to start the time interval counter
- Compensated echelle grating filter
- Single Photon Avalanche Diode
- In field normal point generation

As a result of these modifications MTLRS#1 is now capable of tracking high and low satellites day and night with a single shot r.m.s. of about 1 cm.

REFERENCES

Laser Valfivre, *Specifications of a laser system for MTLRS#1 , 1989.*

A. Bianchi, A. Ferrario, P.G. Gobbi, C. Malvicini,G.C. Reali, SPIE 701, p.132, *1989.*

K. Hamal, V. Hraskova, H. Jelinkova, CLEO'85 Proceedings p.82, WE 4, *1987.*

I. Prochazka, K. Hamal,, *Subcentimeter Single Photon Ranging All Solid State Detection Package, 1990.*

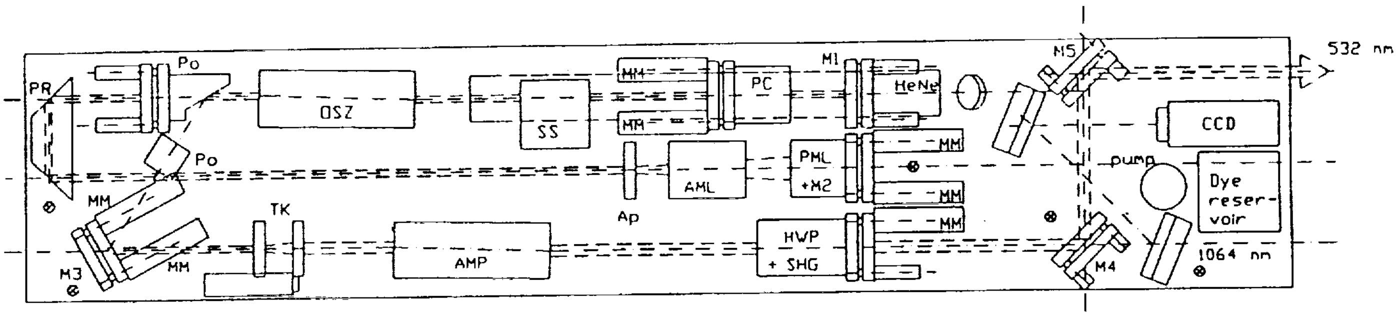
G. Kirchner, Proceedings of the seventh international Workshop on Laser Ranging Instrumentation p. 123, *1989.*

P. Sperber, U. Hessels, R. Motz in this Proceedings, *The new MTLRS#1 Receiving System 1992.*

P. Sperber, H. Hauck, in this Proceedings, *Experience and Results of the 1991 MTLRS#1 USSR campaign, 1992.*

E. Vermaat, J.W. Offierski, K.H. Otten, W. Beek, C. van Es, P. Sperber, in this Proceedings, *A Transputer Based Control System for MTLRS, 1992.*

H. Visser, Technisch Physische Dienste (TPD), Delft private communication, *Design of a new MTLRS#1 receiver package, 1990.*



M1 - M5	Mirrors	OSZ	Oscillator	SS	Safety shutter	HWP	half wave plate
MM	Motor-Mikes	AMP	Amplifier	Ap	Aperture	SHG	Second harmonic gen.
Po	Polarizer	AML	Active mode-locker	PC	Pockels-cell	HeNe	He-Ne alignment laser
Pr	Prism	PML	Passive mode-locker	Tk	Telescope	CCD	CCD camera
⊗	Diagnostic diodes						

Fig. 1 - Schematic of Laser Head

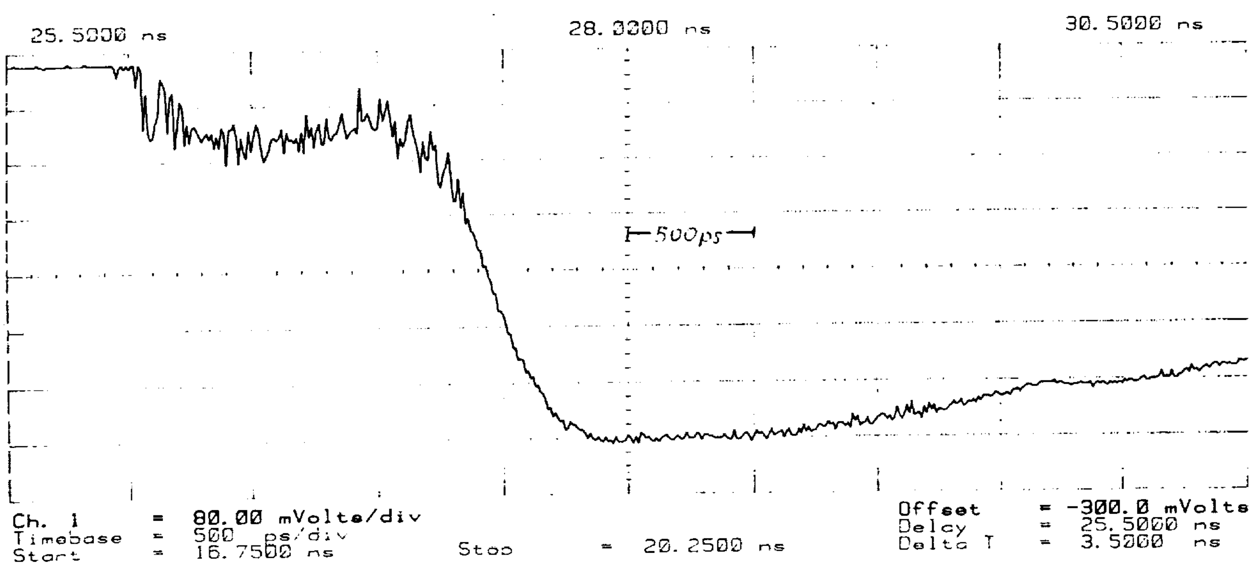


Fig. 2 - Signal of the Start Diode

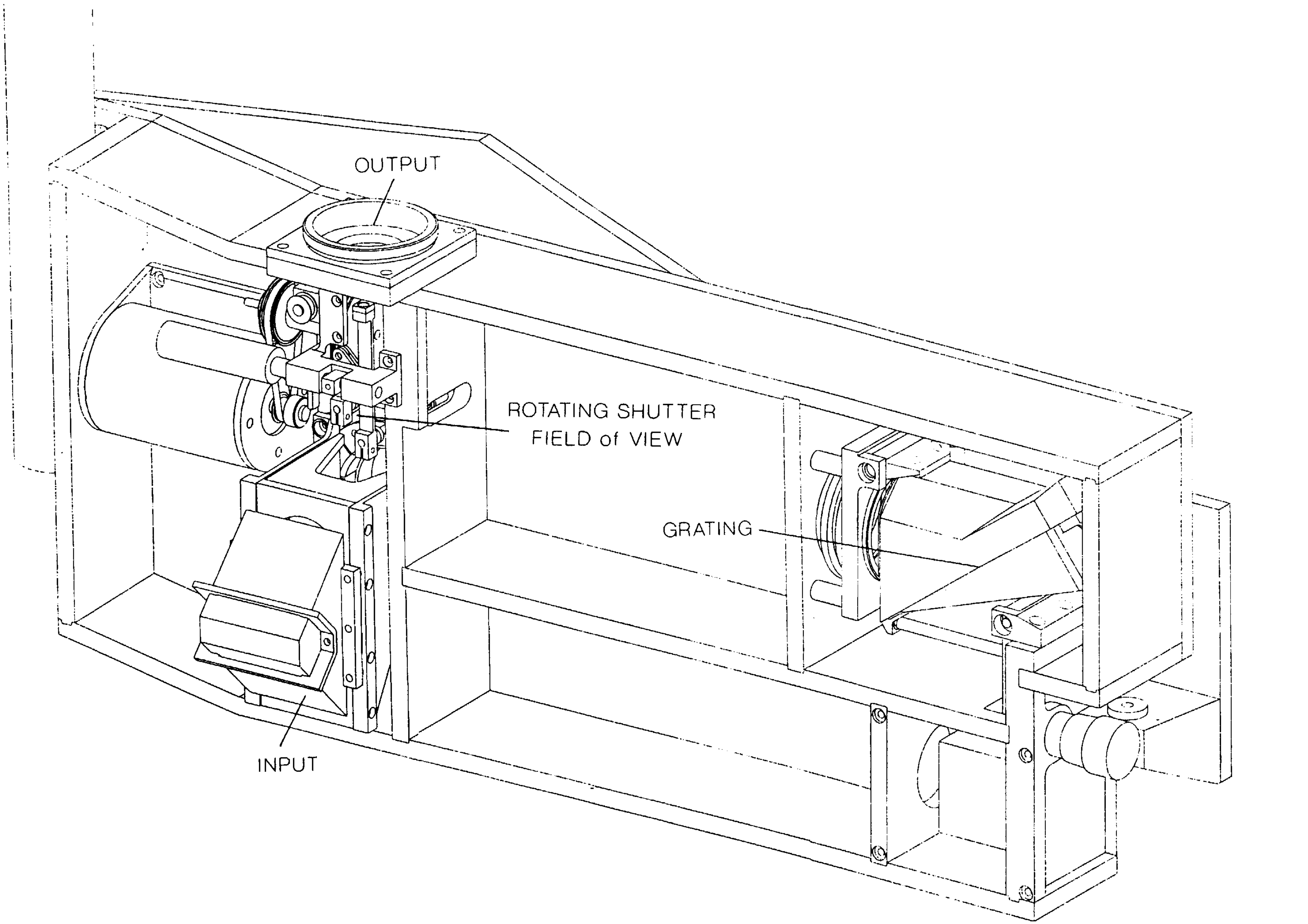


Fig. 3 Mechanical Layout of the MTLRS#1 Receiver Package

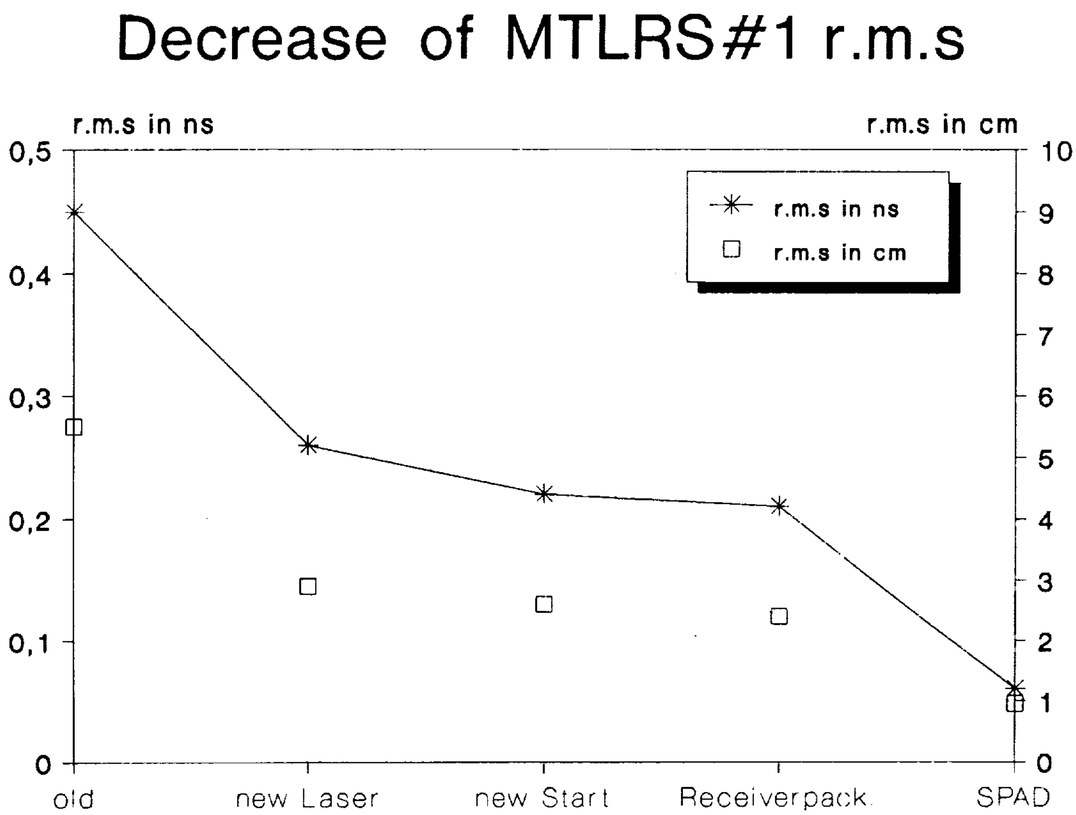


Fig. 4: Decrease of the single shot r.m.s. during upgrade

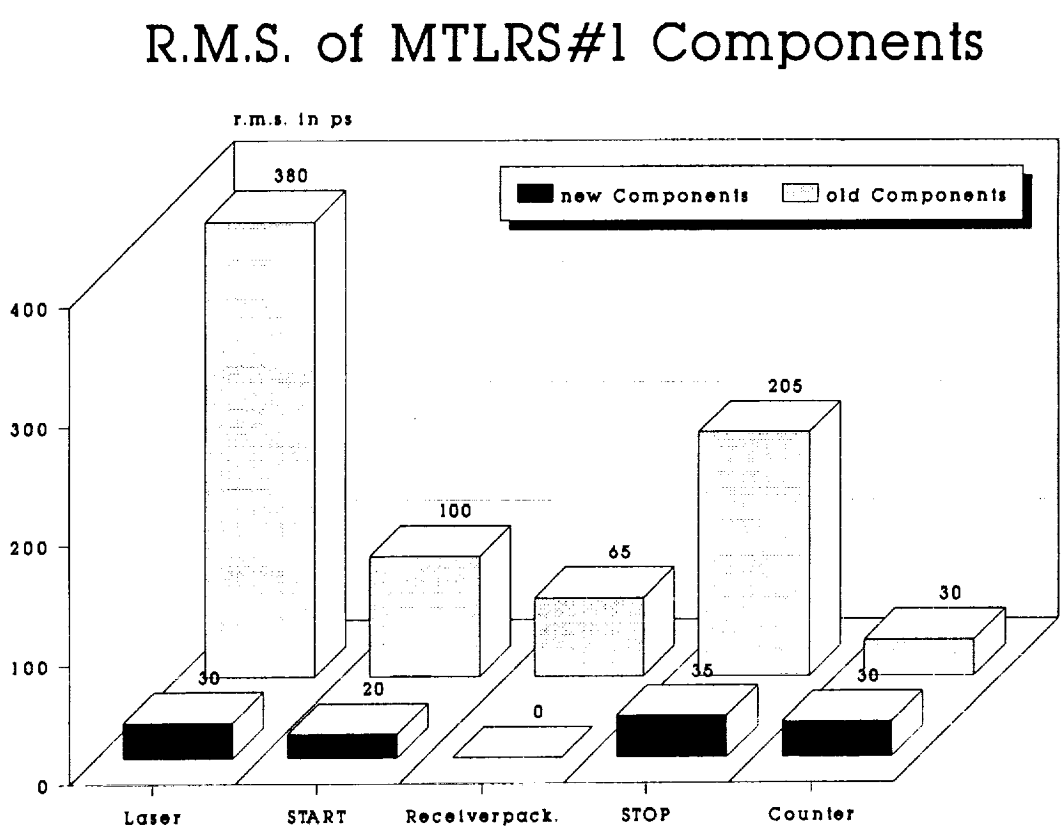
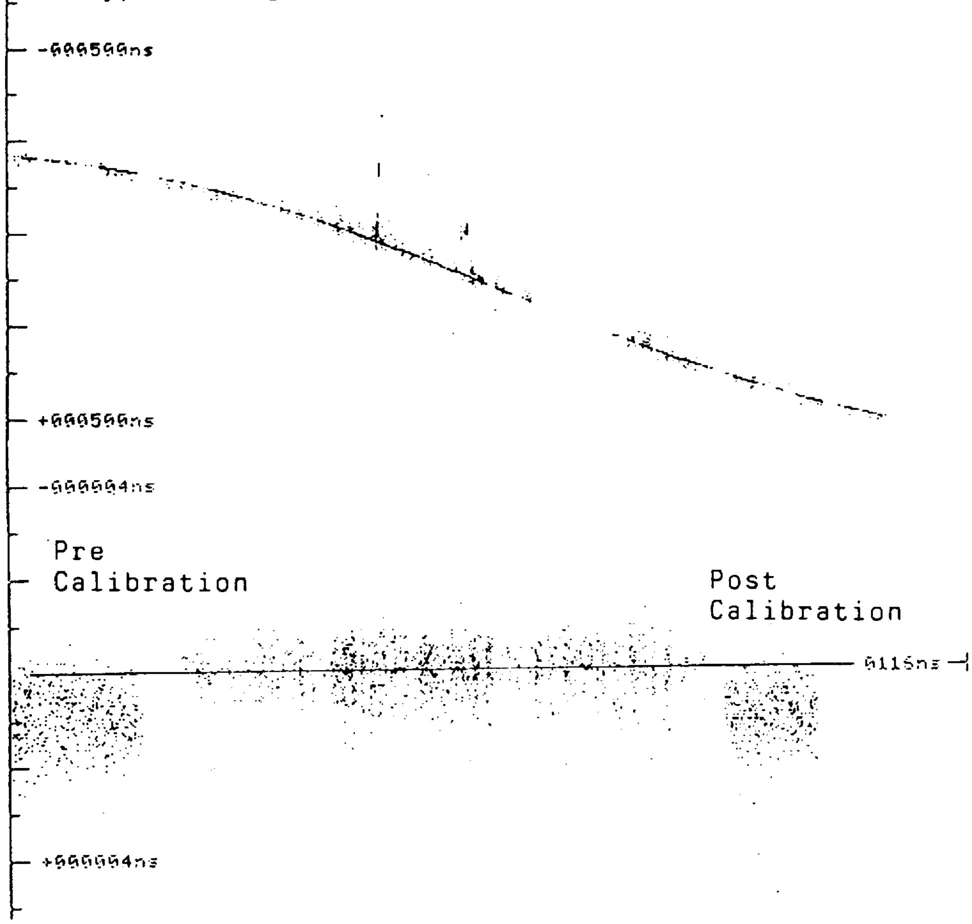


Fig. 5: Single shot r.m.s before and after upgrading

typical Lageos nighttime pass (PMT) before upgrading



typical Lageos day/nighttime pass (SPAD) after upgrading

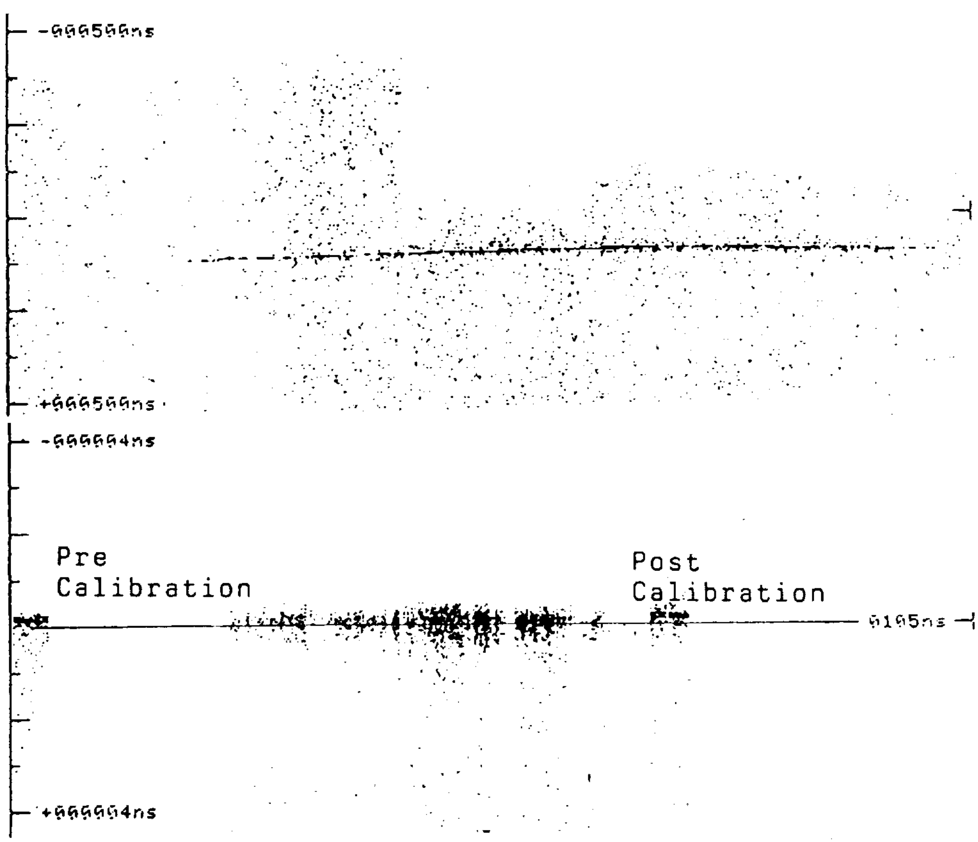


Fig. 6 - Lageos Pass before and after upgrading

N94-15611

The new MTLRS#1 Receiving System

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Abstract.
In this report we are giving a detailed description of the new receiving system of the German Modular Transportable Laser Ranging System MTLRS#1 consisting of a spectral time and field of view filter and a Single Photon Avalanche Diode (SPAD) as single photon detector. The system gives full day and night ranging capability to all satellites with cm accuracy.

1. Introduction

In order to improve the ranging accuracy and the sensitivity of the German Modular Transportable Laser Ranging System MTLRS-1 a major system upgrade was scheduled and performed from Dec. 1990 to July 1991 (P. Sperber et.al.). Together with the exchange of the whole transmitting part (Laser and Start Diode) (P. Sperber et.al.) the installation of a new receiving system was the main point of the upgrade.

The receiving system has two parts, which will be shown in detail

- Filter (Frequency, Range, Field of View)
- Single Photon Detector.

2. Receiving System

To extract reflected photons from the satellite from noise photons which are entering the telescope mainly in daylight, a powerful filter equipment has to be installed in SLR systems.

This filtering in modern systems is realized in three steps

- Range (time interval) filter: A rotating shutter is commonly used to supress straylight during laser firing and to open the detector at the time, the echo from the satellite is expected.
- Field of View: A pinhole ensures, that only light coming from a small angle around the telescope axis can hit the detector.
- Spectral Filter: The most effective filtering process is the filtering in frequency which allows just light of the well defined laserwavelength to propagate.

Typeset by $\mathcal{A}\mathcal{M}\mathcal{S}$-TEX

The new receiver package of MTLRS#1 is a very compact, field qualified realization of this three requests, deliverd by Technisch Physische Dienste (TPD), Delft, Netherlands.

The setup is shown in Fig. 1.

The light from the telescope is focussed to a field of view pinhole, which is remote adjustable with a motor driven micrometer from 0 to about 30 millidegrees. Connected to the field of view filter there is a rotating shutter, synchronized to the predicted range window, which opens the receiving system 10 times per second for about 3 ms and mainly protects the single photon detector from straylight during laser firing.

The spectral filtering is done by an echelle grating (efficiency: 55 %) used in 7 th order, which gives a bandwidth of 0.2 - 0.65 nm depending on the opening of the filed of view pinhole. The grating has a surface of almost 100 mm top-top in air, therefore the range difference of the beams over the grating surface is not neglegible. To compensate this range difference the grating is used a second time in opposite order. At the end of the receiving package a lens is generating a 8 mm diameter, parallel beam with excellent optical quality.

3. Single Photon Detector

To see the full advantage of the short laser pulses and of the errorfree receiving package a single photon detector with high accuracy is necessary. In the world of SLR two types of high accuracy receivers are used in the moment:

- Microchannel Plates
- Avalanche Diodes.

We decided to install a single photon avalanche diode (SPAD) (I. Prochazka et al.) developed by the Czech Technical University in our system. The reasons for this decision were:

- High ruggedness under field conditions
- High Quantum Efficiency (20 %)
- Low jitter (35 ps)
- Low operating voltage (25 V)
- High dynamic range and neglectable influence of signal strength to the range measurement
- No additional electronics (CFD) between detector and counter.

The housing for the diode has to meet some demands:

- Adjustable in three dimensions in the μm range.
- Possiblity to cool the diode below -10^o C.
- Protection against humidity (condensation).
- Flexible for usage of different types of diodes.

The cooling of the diode is necessary because of the high termal noise (some 100 kHz) at room temperature. The temperature of -30^oC, which is possible with this setup will decrease the noise far below 100 kHz (Fig. 2) and therefor make the search for satellites at night more easy.

To meet all this points, we designed a new housing (Fig. 3) with the following specifications:

- adjustement accuracy in each dimension: $5 - 10\mu m$

- input beam: 5-10 mm diameter, parallel
- optics: effective focal length: 11 mm
- field of view in our system (100 μm diode): 30 mrad
- cooling: to $-30°C$ with peltier cooler and water ($5°C$)
- good mechanical stability under field conditions (temperature change, humidity)

The housing is made from aluminium, the inner moving part which makes the termal isolation of the diode to the housing is DELRIN.

For the fixing of the diode a very special material with high mechanical stability, high thermal conductivity and good electrical isolation was necessary.

To get a thermal equilibrium even at high outside temperatures we decided not only to cool the diode, but the whole fixing plate with powerful peltiers (the hot side of the peltier is water cooled). As some diodes (mainly the diode we use) needs an electrical isolator around it, a material with the mentioned specifications was necessary.

In cooperation with the Material Research Departement of Hoechst AG, a new ceramic material - Aluminium Nitride- was selected. The important properties of this are its high thermal conductivity of 170 W/mk (comparable to pure Aluminium) and its dielectric constant of about 8.5 (good insulator). The powder, together with a sintering aid, are prepared for pressing. The cold isostatic pressed parts, in the form of rough discs, are then turned to improve their finish and a hole is bored in the centre. The binder is then burned out. The samples are sintered at $1840°C$ for 3 h under a nitrogen atmosphere in a special graphite crucible. After the heat treatment the ceramic parts were finished. They were grond with diamond wheels in all directions to get the high dimensional accuracy and surface smoothness for installation of the measuring diode and for the mounting of the peltier elements. The specifications of the material are given in table 1.

Due to the flexibility and the good experience with this housing in the last field campaign it is now also used at the new Wettzell Laser Ranging System (WLRS) for the tests of different diodes.

3. Summary

The new receiving system of MTLRS#1, consisting of a filter package for field of view, time and spectral filtering and a single photon avalanche diode as detector gives the possibility of SLR with cm accuracy during night and day. The whole system is build very modular and flexible, so easy exchange or usage in other SLR systems is possible.

All parts are designed and manufactured in a way, that even under extreme environmental changes in field an adjustement is not necessary.

In the last field campaign the new receiver proved to work very reliable and satisfactory.

References

P. Sperber, L. Amberg, L. Beyer, G. Blenski, U. Hessels, R. Motz, in this Proceedings, *Results of the MTLRS#1 Upgrade, 1992.*

P. Sperber, U. Hessels, R. Motz, W. Beek, in this Proceedings, *The new MTLRS Transmitting System, 1992.*

I. Prochazka, K. Kamal, B. Sopko, S. 219, *Photodiode Based Detector Package for Centimeter Satellite Ranging,.*

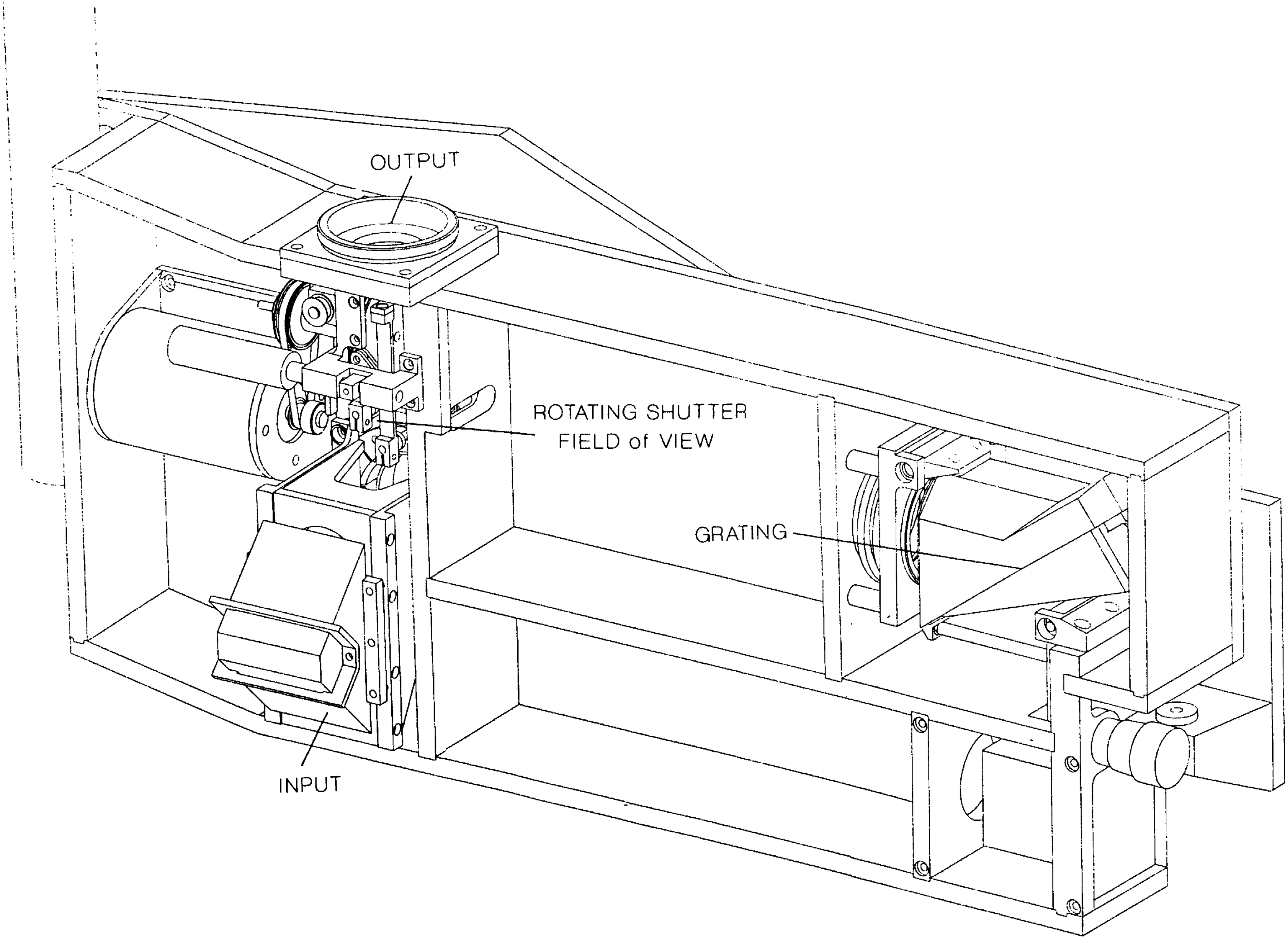

Fig. 1 Mechanical Layout of the MTLRS#1 Receiver Package

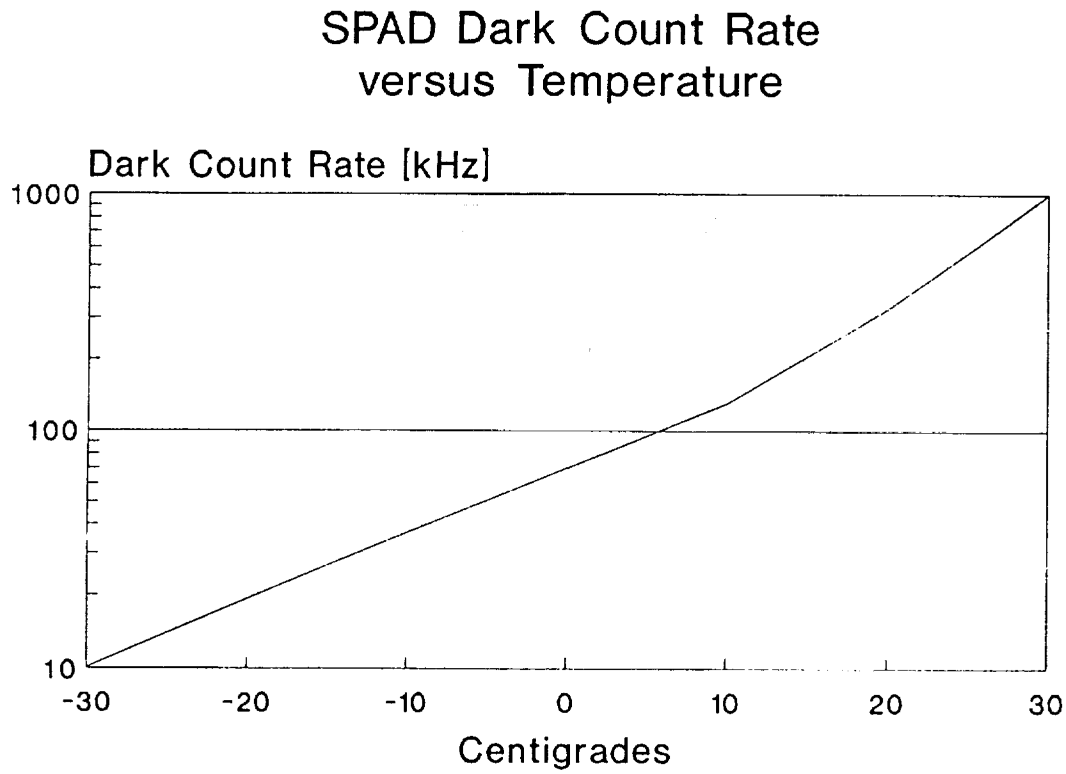

Fig. 2 SPAD Dark Count Rate versus Temperature (2.5 V above Break)

- Density	3,3 g/cm³
- Termal Conductivity	170 W/m K
- Specific Heat	738 J/kg K
- Flexural Strength	300 - 400 MPa
- Electrical Resistivity	> 10^{14} Ohm cm
- Dielectric Constant	8,5 - 9

Table 1 Specification of Aluminium Nitride

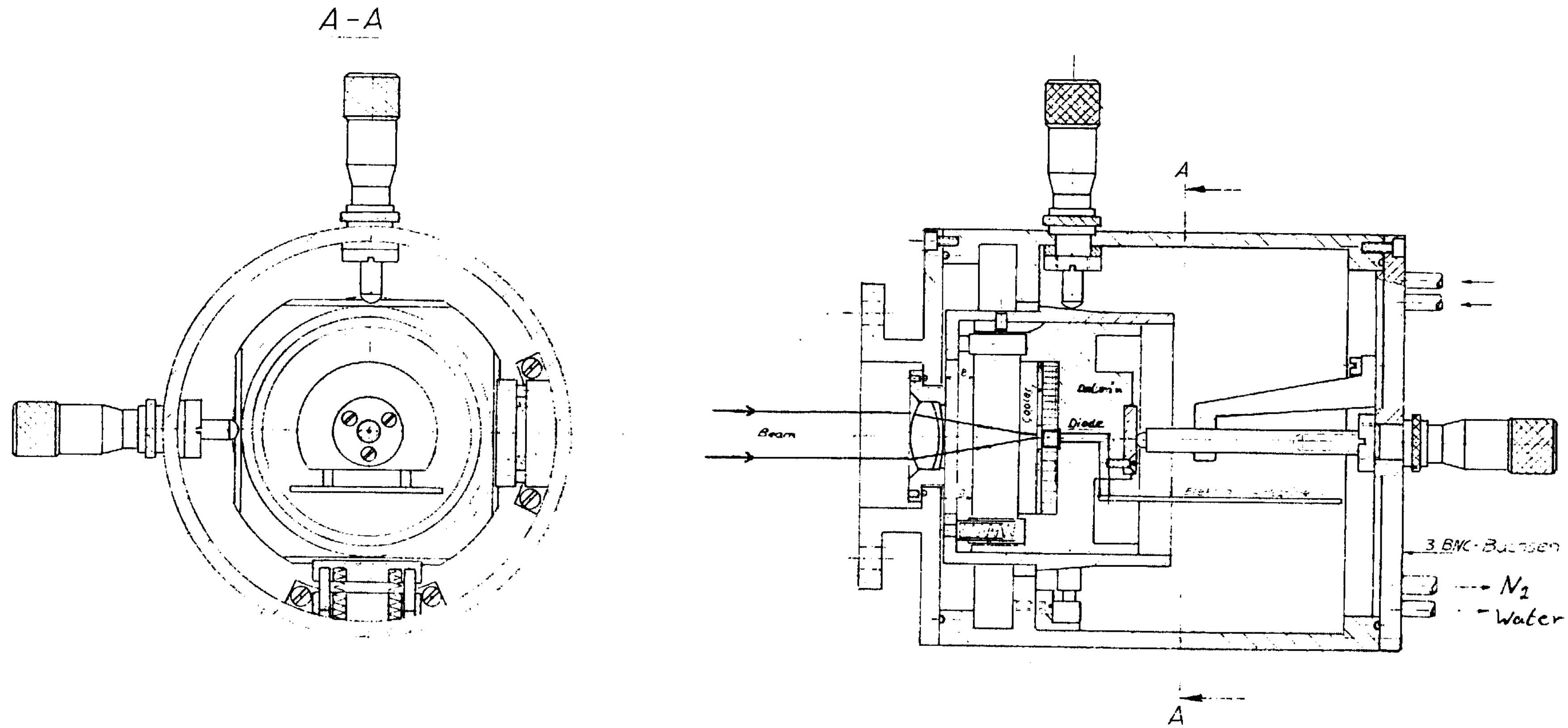

Fig. 3 Housing of the Single Photon Avalanche Diode

N94-15612

The new MTLRS Transmitting System

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Abstract

This paper presents a detailed description about the new transmitting system of the Modular Transportable Laser Ranging Systems MTLRS-1/2. A simplified theory of the Self Filtering Unstable Resonator (SFUR) is explaned. Laser design details are discussed concerning the extreme environmental conditions in which these mobile systems are operating. Details are given concerning the new avalanche START detector. The new SFUR laser and START detector are necessary parts in order to bring both mobile systems towards 1 cm ranging accuracy.

1. Introduction

Since 1984 the two European Modular Transportable Laser Ranging Systems MTLRS-1, operated by the Institute for Applied Geodesy (IfAG, Germany), and MTLRS-2, operated by the Delft University of Technology (DUT, The Netherlands), have supplied the international network with laser ranging data from sites in Europe, CIS (former USSR) and North America. To improve the ranging accuracy from 5 cm to the 1 cm level, both systems carried out a major upgrade in 1991. The main part of this upgrade was the exchange of the transmitting system consisting of the Laser and the Start Detector (The German MTLRS-1 system also upgraded the receiver package [1].

2. The Laser

The accuracy and the number of returns produced by a satellite laser ranging system is mainly influenced by the duration and energy of the emitted laser pulses. To improve these two points, the original Nd:YAP laser (370 ps FWHM pulse-duration, 10 mJ pulse-energy at 539 nm) was exchanged for a new Nd:YAG laser (30 ps FWHM pulse-duration, 30 mJ pulse-energy at 532 nm). To realize this high demands with a simple and reliable optical configuration, a new resonator setup, the Self Filtering Unstable Resonator (SFUR) [2,3] was used. Together with a simple optical setup, this resonator has the advantage to be less sensitive to optical adjustments and operates with a very homogeneous spatial pulse-shape, minimizing the danger of destroying optical components at high resonator energy output levels.

2.1 Simplified SFUR Theory [4]

Fig. 1 shows the principle of the SFUR resonator.

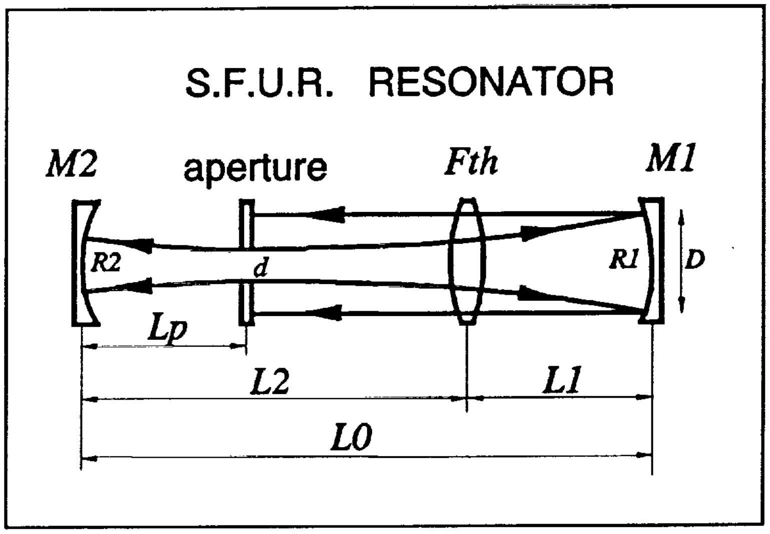

Fig. 1

Two mirrors M_1 and M_2 are forming an instable, confocal resonator:

$$R_1 + R_2 = 2 \cdot L_o$$

R_1 and R_2 are the (concave) radii of the mirrors and L_o the optical resonator length. This resonator configuration generates a spot in the resonator, which usually destroys optical elements. If a small pinhole is placed in this focal point this problem disappears and some major advantages can be seen. The diameter d of the aperture has to be chosen in a way, that only the central lobe of the Airy pattern (generated by mirror M_2) propagates to M_1.

$$d = \sqrt{2.44 \cdot f \cdot \lambda}$$

(f: focal length of M_2, λ: laser wavelength)

The mode, generated by the central maximum of the Airy pattern has a smooth, nearly Gaussian shape, with zero intensity at radius r_0 where

$$r_0 = - M \cdot \frac{d}{2} \qquad \left(M = - \frac{R_1}{R_2} \right)$$

If the parameters of the resonator are correct, the mode is exactly filling the whole volume of the active medium. Therefore nearly all the energy stored in the rod is converted into the laser pulse. The outcoupled pulse-energy is much higher compared to usual resonator configurations. The aperture (typical diameter $d \leq 1$ mm) gives a strong spatial filtering at each round trip smoothing the energy distribution in the beam and avoiding hot spots. In an exact analysis of the SFUR configuration the influence of the thermal lens (f_{th}: focal length) in the laser rod has to be taken into account.

$$L_0 = L_1 + L_2 - \frac{L_1 \cdot L_2}{f_{th}}$$

$$g_1 = 1 - \frac{L_0}{R_1} - \frac{L_2}{f_{th}}$$

$$g_2 = 1 - \frac{L_0}{R_2} - \frac{L_1}{f_{th}}$$

$$g = 2 \cdot g_1 \cdot g_2 - 1$$

$$M = g - \sqrt{g^2 - 1}$$

(L_1 and L_2 are the distances of M_1 and M_2 to the virtual position of the thermal lens). The optimum position L_p (distance from M_2) of the aperture, the diameter d of the aperture and diameter D of the laser beam are given by:

$$\frac{1}{L_p} = \frac{1}{R_2} + \frac{\sqrt{g^2 - 1}}{2 \cdot g_1 \cdot L_0}$$

$$d = \sqrt{4.88 \cdot L_p \cdot \lambda \cdot \left(1 - \frac{L_p}{R_2}\right)}$$

$$D = 1.5 \cdot M \cdot d \cdot \left(1 - \frac{L_2 - L_p}{\frac{1}{\frac{2}{R_2} - \frac{1}{L_p}} - L_p}\right)$$

2.2 Technical Realization

The laser system consists of four separate units, the laser head, the power supply with electronics, an external dye-cooling unit and the control panel.

A schematic drawing of the laser head is shown in Fig. 2. To save place, the SFUR Resonator M_1 - M_2 is folded over a prism PR. Picosecond pulses are generated with an acousto-optic modulator AML and a bleachable dye (Kodak 9740 in 1,2 Dichloroethane) (PML). The intense 30 ps long pulse is cavity dumped by the pockelscell PC and two polarizers PO. Because of the high energy of the output pulse of a SFUR resonator a single stage amplification (AMPL) is sufficient to get 100 mJ per pulse in the infrared. The second Harmonic Generator SHG converts about 40% of the energy into green light at 532 nm. The two wavelengths are separated by the dichroic mirror M_4. The excessive use of diagnostic diodes and motor driven micrometers allows the fine adjustment of the laser without opening the dust cover. Even the spatial shape of the pulse is monitored by a CCD - Camera. For maximum mechanical stability, the whole laser head is built on a temperature controlled, reinforced invar plate.

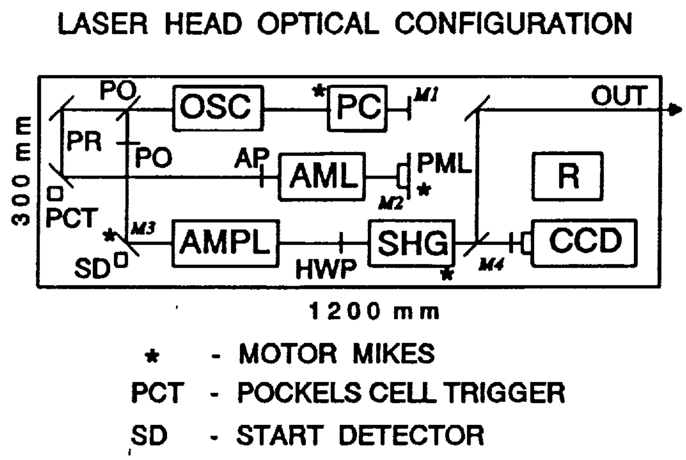

Fig. 2

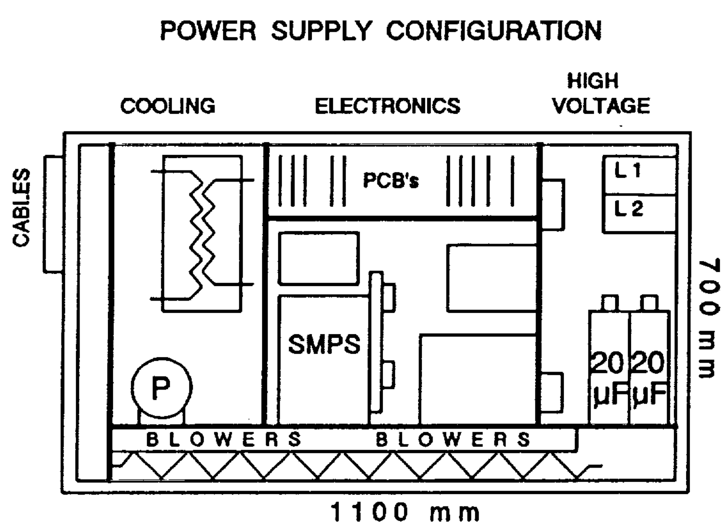

Fig. 3

Fig. 3 shows an inside picture of the power supply. The power supply and control electronics are also built in an isolated, temperature stabilized housing. The laser switches automatically between 380 V/50 Hz and 460V/60 Hz input, and the 3 phase power consumption is 5 KVA. Two independent control panels for the laser can be used; one for the Cabin, in use during ranging, and another one in the Cart for maintenance purposes.

Fig. 4 shows the laser temperature control system. The telescope together with the laser are built in the Cart which is located in full sunshine in the middle of the concrete platform (Pad). During satellite tracking this Cart is open and because of extreme environmental conditions (-20°C to +40°C), considerable attention is given to the stability and reliability of the laser (komacel-isolation of the head and power supply, excellent mechanical stability of all optical components). The heat generated by the flashtubes in the secondary cooling system is exchanged to the primary cooling system by means of an internal water to water heat exchanger connected to an external water flow with temperatures between 5-16°C.

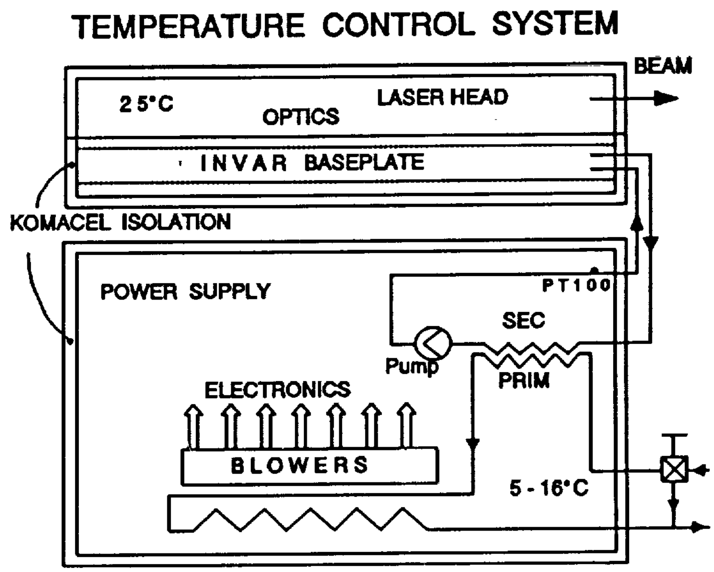

Fig. 4

The laser was first tested under field conditions during the campaign of MTLRS-1 in CIS (Common wealth of Independant States - the former USSR). The experiences were excellent.

The specifications of the laser are summarized in Fig. 5.

LASER SPECIFICATIONS	
Wavelength	532 nm
Pulse energy	30 mJ
Pulse width	30 ps
Rep. rate	20 pps (max)
Divergence	0.4 mrad
Mode locking	active + passive
SHG	KD * P
Beam diameter	7 mm
Environment	- 20°C to +40°C
Power	5 kVA
Voltage	380/460 - 5A/ph.

Fig. 5

3. Start Detector

To start the time interval counter with high accuracy, the optical output signal of the laser has to be converted with minimum jitter to an electrical pulse, which is used in the start channel of the counter. Until 1990 this problem was solved in the MTLRS in the conventional way: a part of the green pulse was sent to a fast photo diode which generates an electrical pulse with an amplitude corresponding to the energy of the laser pulse which is fluctuating from shot to shot. These amplitude fluctuations were compensated by a constant fraction discriminator. Changes in the temporal pulse shape and strong energy fluctuations in this setup caused errors in the start-channel of the counter.

To minimize these errors, an optically triggered avalanche diode [5,6] was integrated into the system. This diode delivers an output signal with a constant amplitude independent on the energy of the laser pulse. The output signal is directly used as startsignal for the counter, a constant fraction generator is superfluous. Furthermore, to introduce high stability and the possibility to vary the pulse energy during tracking, the start diode is placed before the amplifier (behind mirror *M3* in Fig. 2) to detect the infrared light. Fig. 6 shows the output signal of the start diode which has a risetime of 300 - 400 ps and the jitter between optical and electrical pulse is less than 20 ps.

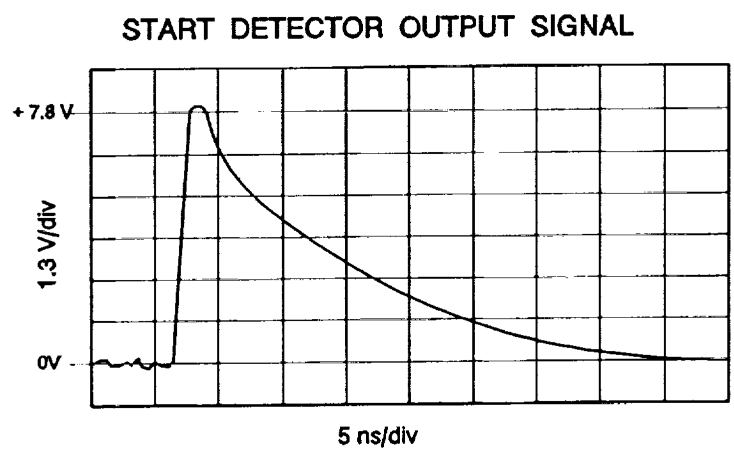

Fig. 6

In order to get stable results from the avalanche start detector under field conditions, the fibre together with the electronics have to be built inside the laser head where the temperature of the optical bench is stabilized at 25°C.

4. Summary

The upgrade of the transmitting part of MTLRS-1/2 formes the basis to improve the ranging accuracy of the systems significantly and makes them again some of the most advanced SLR systems worldwide.
First tracking results [7] show, that the system's single shot accuracy is about 1 cm after the upgrade of the receiver package which is already completed in MTLRS-1.

References:

[1] The new MTLRS-1 Receiving System, 1992 by P. Sperber, U. Hessels, R. Motz, in this Proceedings.

[2] Paper 1989 by A. Bianchi, A. Ferrario, P.G. Gobbi, C. Malvicini, G.C. Reali, SPIE 701, p.132.

[3] Paper 1987 by K. Hamal, V. Hraskova, H. Jelinkova, CLEO'85 Proceedings p.82, WE 4.

[4] Paper 1989 by C. Malvicini, A. Ferrario, G. Gabetta, G.P. Banfi, G.C. Reali, Proceedings of the seventh international Workshop on Laser Ranging Instrumentation p. 181.

[5] Paper 1990 Subcentimeter Single Photon Ranging All Solid State Detection Package, by I. Prochazka, K. Hamal, B. Sopko.

[6] Paper 1989 by I. Prochazka, K. Hamal, B. Sopko, Proceedings of the seventh international Workshop on Laser Ranging Instrumentation p. 219.

[7] Results of the MTLRS-1 Upgrade by P. Sperber, L. Amberg, L. Beyer, G. Blenski, W. Etling, U. Hessels, R. Motz, in this Proceedings.

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Transputer Based Control System for MTLRS

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Introduction

The Modular Transportable Laser Ranging Systems (MTLRS-1 and MTLRS-2) have been designed in the early eighties and have been in operation very successfully since 1984. The original design of the electronic control system was based on the philosophy of parallel processing, but these ideas could at that time only be implemented to a very limited extent. This present system utilizes two MOTOROLA 6800 8-bit processors slaved to a HP A-600 micro-computer. These processors support the telescope tracking system and the data-acquisition/formatting respectively. Nevertheless the overall design still is largely hardware oriented. Because the system is now some nine years old, aging of components increases the risk of malfunctioning and some components or units are outdated and not available anymore.
The control system for MTLRS is now being re-designed completely, based on the original philosophy of parallel processing, making use of contemporary advanced electronics and processor technology [Beek, 1989]. The new design aims at the requirements for Satellite Laser Ranging (SLR) in the nineties, making use of the extensive operational experience obtained with the two transportable systems.

Design goals

Major considerations followed in the design are to bring down the operational costs, to ensure full capability for all present and future SLR satellites and to facilitate future modifications and alternative applications through a highly structured and modular approach.

I. Optimize cost of operations

Deploying SLR systems is quite expensive, in particular in transportable mode. A modern design aiming at minimizing these costs, must minimize crew size, increase the mean-time-between-failure (MTBF) and facilitate trouble shooting and repair.

a. Minimize crew size
The default mode of operation will be fully automatic. This means that the system will initiate and perform all basic tasks, e.g. maintaining satellite alert information, ephemeris calculation, initiate and perform calibration and tracking procedures, data screening, Normal Point calculation and data mailing. The routine task for the operator (if any) will be to monitor system performance and to respond to problems. Manual mode of operation is always possible through operator intervention.

b. Reliability

Increasing the MTBF will be primarily accomplished through defining a maximum of all functions in software, running in a multiprocessor parallel architecture. The remaining hardware will be built from high quality, highly integrated components, including Programmable Gate Array (PGA) logic. Integrated components also allow a great deal of miniaturization.

c. Self-diagnostics capability

Diagnostic tasks running concurrently with the control tasks will enable rapid detection and localization of problems. Parallel processors are very convenient for hosting these functions.

d. Modular hardware design

The hardware is designed with an optimum number of printed circuit (PC) boards. Same processor-functions at different locations use identical PC-boards. Different application-functions are realized with a minimum number of different PC-boards. Interface-functions are accomplished by separate PC-boards in order to optimize hardware portability. Most spares will be available at PC-board level which enables rapid replacement, reducing system down-time under field conditions.

II. All-satellite capability

a. Satellite altitude

This decade a variety of high and low SLR satellites are or will become available. Typical extreme altitudes are ARISTOTELES (200 km) and METEOSAT (geostationary). A design goal is to eliminate any logical restriction to the satellite range in the control system (e.g. by accommodating time interval measurement and event timing).

b. Satellite interleaving

Because the system will be designed for automatic ranging, the implementation of decision schemes in software for interleaving observations to different satellites will be relatively easy.

III. Flexible design

The design of the control system must simplify future modifications in view of new or modified requirements as well as implementation of more advanced technologies. This calls for a highly structured design in software and hardware, which may also enhance the portability of the design to other SLR stations, with different hardware environments.

a. Adaptation to modifications

<u>Hardware.</u> The general electronic design is separated into three major types of functions: 1. interfaces, 2. applications and 3. processors. These different types are physically separated in PC-boards which are individually exchangeable. The hardware uses PGA logic, which can be easily modified (by software).

<u>Software</u> The RT-software system is strictly separated into three independent layers: 1. global (functional), 2. device dependent, 3. interface dependent. In this way, modifications can be implemented locally in the related module at one layer, without affecting other layers.

Because of this high level of structurization it is feasible to implement this design in SLR systems which are quite different from the MTLRS concept, with a minimum of modifications, primarily in software.

b. Expanding processor capability

If new requirements dictate additional computer power (e.g. RT-filtering, Frame Grabbing) this capability can be easily implemented in the structured design by adding standard processor boards hosting additional software tasks. To enable implementation of different types of (parallel) processors than the transputer which has been selected in the present design, all software is written in ANSI based high-level languages and no RT-program modifications have to be made because the 3L-compiler [3L] supports different processors.

c. Highly manufacturer independent

Custom made hardware usually increases the dependence on particular manufacturers. This is avoided by full restriction to standard bought-out components and self-designed PC boards.

The parallel processor set-up eliminates the necessity of selecting a vendor dependent RT operating system and thus ensures the flexibility of adopting any brand of (future) parallel processor. In the current design the INMOS transputer (see below) has been selected because of its early availability and its capabilities. Any future transition to another parallel processor is possible and will basically only require the exchange of the ***T805*** credit card size processor board.

Lay-out of the design

I. Hardware

In SLR the great progress in (opto-)electronics of the last decades has been applied to aspects such as detection, laser technology and timing, but seems to have largely by-passed the issue of Control System design. Here state-of-the-art electronics is introduced in the MTLRS Control System, resulting in a modular design with a high level of reliability, miniaturization and flexibility.

Probably the most dominant feature in the design is the application of a parallel processor architecture. This choice supports most of the design goals in a unique way, in particular the issues of modularity and of adaptivity to future requirements for extended computing power.

The INMOS transputer

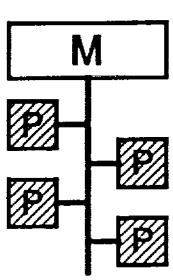

Fig 1

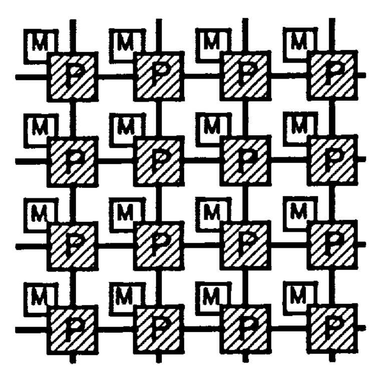

Fig 2

Parallel-processing computers [BYTE nov '88] can be divided into two basic architectures; the shared-memory multiprocessor (fig. 1) and the multicomputer type (fig. 2). All existing microprocessors can be used in the first architecture which will be limited in practice to about 4 processors due to the so called "von Neumann" bottleneck. This bottleneck arises when one processor reads or writes to the shared-memory while the other processors have to wait during this time till the "shared-memory bus" is free! Only few processors like the INMOS T800 transputer family [INMOS 1989] and the Texas Instruments TMS320C40 [TMS User guide] can make an optimal use of the multi-computer architecture because these processors possess high

speed communication ports besides their standard address and data busses. Through these ports (links) the processors communicate with each other in a network where each processor possesses its own memory and thus eliminating the von Neumann bottleneck. In a practical multicomputer network the number of processors can be almost unlimited.
The INMOS transputer family consists of T2.., T4.., T8.. and T9... processors supported by link-crossbarswitches and periferal link-adapters. All INMOS processors are equipped with 4 links. Each link consists of one serial transmitting wire and one serial receiving wire both having an unidirectional speed of 20 Mbaud. If a link sends and receives data at the same time, the total data transport will be limited to 23.5 Mbaud/link. The T9000 will be available at the end of 1992 and has a peak performance of 200 MIPS and 25 MFLOPS with link speeds up to 100 Mbaud.

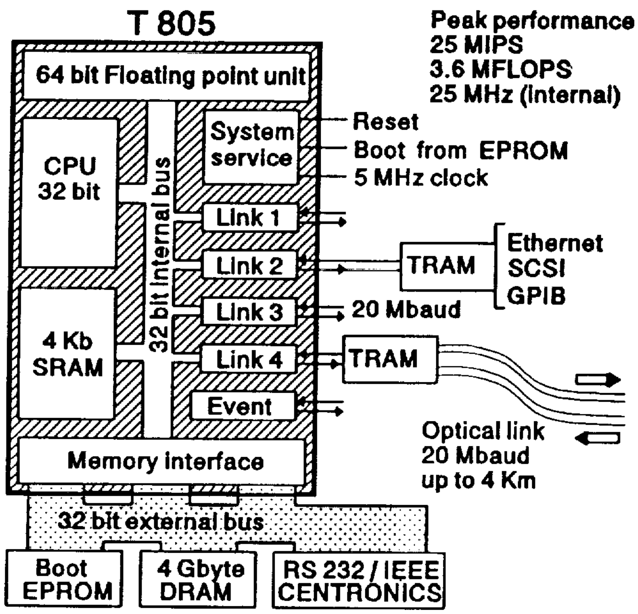

Fig 3

For the MTLRS Control System the T805 has been selected and is running at an internal clock speed of 25 Mhz giving 25 MIPS and 3.6 MFLOPS peak performance. The external 5 Mhz clock is internally multiplied by 5. Fig. 3 illustrates how the processor can be interfaced to the outside world in a flexible way. The present Control System is designed around a minimum of 5 transputers T805 which are interconnected through their links. A link is connected to a server-program running on a host-PC and through this link all the different programs are distributed through the network and loaded to a particular transputer. Each program is started automatically after it is loaded onto the destination processor. The design makes no use of the boot-EPROM facility but this makes the processor also very powerful for embedded designs. The word TRAM is an abbreviation for TRAnsputer Module which is an off-the-shelf interface board delivered by several manufacturers.
For parallel processor networks the software can be programmed in various ways; one task can be cutted into pieces which run in parallel at different processors, different tasks can run in two or more processors so that each processor runs a different task. Also multitasking in one processor can be programmed in a partly parallel way because the T805 can perform processes like cpu- operation, link-communication, timing and memory-IO concurrently. This means that while e.g. one task is busy with link-communication, the cpu is free for other tasks, scheduled in a sequential way following task priority. When a task consists of a number of processes, running concurrently in different processors, process-synchronization can be accomplished by the use of channel I/O (inter process data exchange) and semaphores.
Part of the internal CASH of 4 Kb SRAM is used to hold all registers for up to 99 different tasks and internal processes. If more than 99 modules are running concurrently, external DRAM is also used to hold registers. In contrast to conventional processors where the cpu has to share time to all processes, the T805 is doing this partly parallel which leads to a much higher performance.

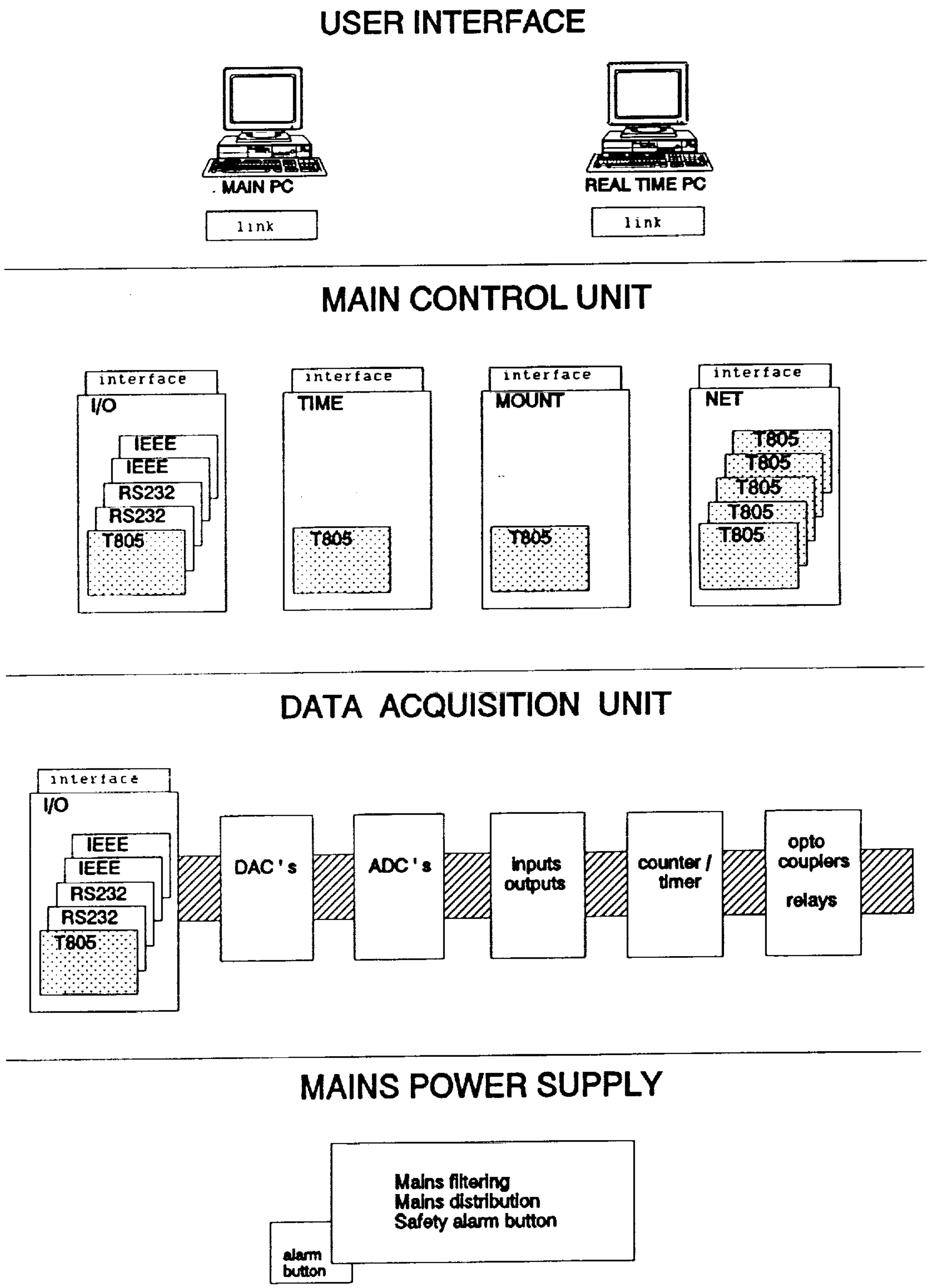
USER INTERFACE
MAIN PC
link
REAL TIME PC
link
MAIN CONTROL UNIT
interface
I/O
IEEE
IEEE
RS232
RS232
T805
interface
TIME
T805
interface
MOUNT
T805
interface
NET
T805
T805
T805
T805
T805
DATA ACQUISITION UNIT
interface
I/O
IEEE
IEEE
RS232
RS232
T805
DAC's
ADC's
inputs
outputs
counter /
timer
opto
couplers
relays
MAINS POWER SUPPLY
Mains filtering
Mains distribution
Safety alarm button
alarm
button

Fig 4

The hardware lay-out

The hardware system can be separated into four major units, the user interface, the main control unit, the data acquisition unit and the mains power supply (fig. 4). It consists of several printed circuit boards, which largely demonstrate the modularity of the design and make it flexible to future modifications.
The basic board is the processor board ***T805***. On this creditcard size board the T805 transputer is placed, which is dedicated to parallel processing (see above). In addition this processor board contains 4 MByte memory, a special reset system for checking that the processor is still alive (EMI protection) and four 20 MBaud serial link drivers.
Other creditcard size boards in the system are ***IEEE-488*** and ***RS-232*** interfaces for connection to standard devices. These creditcard size boards are daughter boards to the extended eurocard size boards of the Main Control Unit and the Data Acquisition Unit.

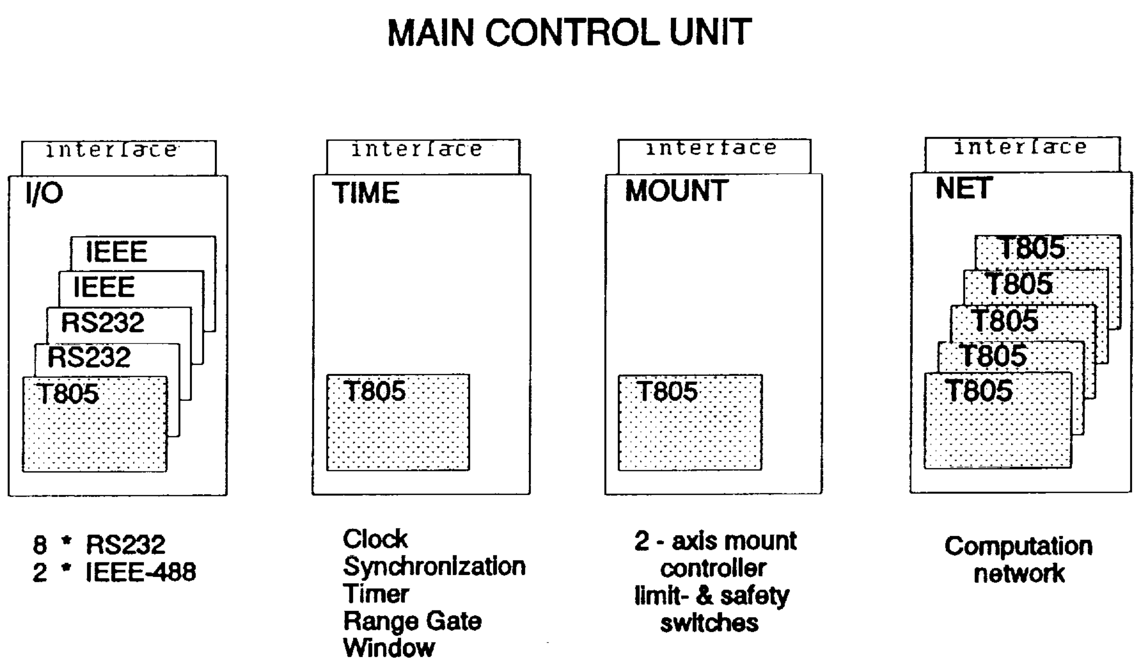

Fig 5

The ***Main Control Unit*** (fig. 5) is made up of four extended eurocard size boards:

1) the ***I/O*** board for connecting the processor to IEEE, RS-232 devices.

2) the ***TIME*** board for all time dependent tasks:
   - 4 channel event counter (low accuracy 20 ns),
   - range gate programmable generator (400 ps one shot accuracy),
   - window programmable generator (20 ns resolution),
   - programmable generator/synchronizer for the shutter, independent from window,
   - RT-clock with battery backup,
   - programmable synchronization for all required signals (e.g. laser firing).

   The ***TIME*** board requires 10 Mhz and 1 pps input signals.

3) the ***MOUNT*** board for driving a 2-axis telescope. The specifications for both axes are:
   - 32 bit position and 16 bit velocity and acceleration controlling,
   - three 16 bit coefficient programming for PID filter,
   - DC and DC-Brushless motors driving,
   - position and velocity mode of operation,
   - interface for quadrature incremental encoder with index pulse,
   - absolute encoder up to 32 bit,
   - limit-, safety switches, etc. ports,
   - joystick connection,
   - nonvolatile RAM for storing position, offset, etc. during power off, without battery backup.

4) the ***NET*** board with a minimum of one processor board with the possibility of extending computer power up to five processor boards. Additional ***NET*** boards can be implemented for expanding the network even further.

Instead of one big backplane interface, four individual backplane ***interface*** boards are designed. The design of each small backplane is dedicated to the typical hardware application, e.g. dependent on the type of encoders etc.
Each backplane can easily be modified to different input signal levels e.g. negative, positive, NIM, TTL, 50 Ω, ...

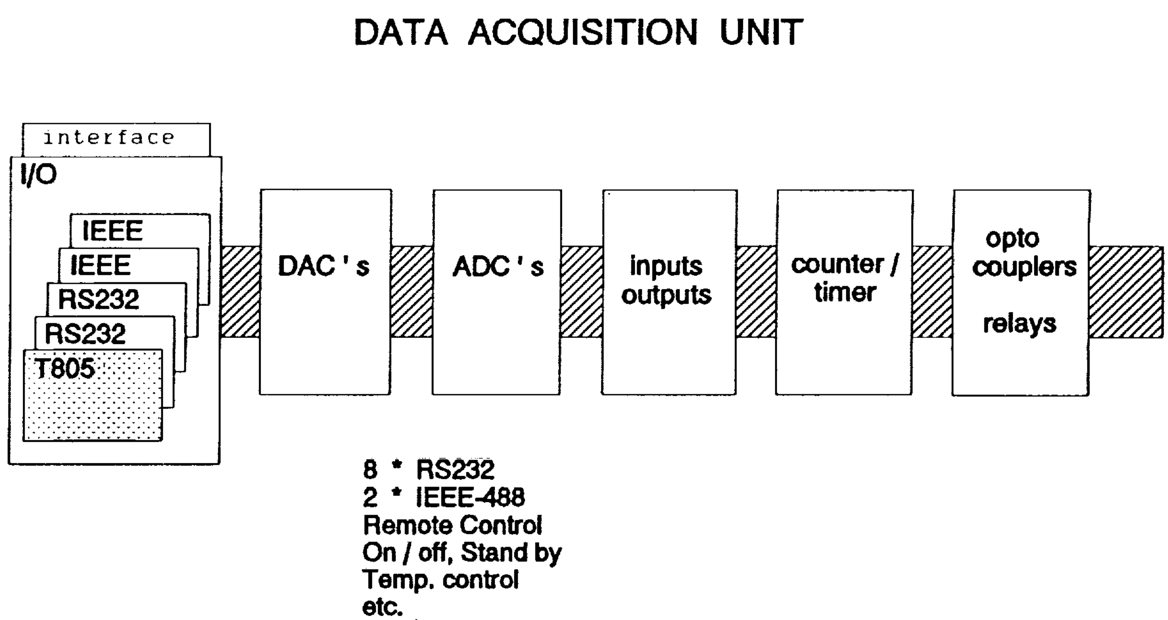

Fig 6

The ***Data Acquisition Unit*** (fig. 6) will be used for controlling additional hardware for the purpose of automation e.g. DC-motors, stepper-motors, temperature control, contacts checking and on/off-switching of equipment. It consists of an ***I/O*** extended eurocard size board which is identical to the one in the main control unit, together with several Data

Acquisition boards like:

- 12 bit D/A-converter (multiplexed for 8 outputs) with programmable range and offset.
- 12 bit A/D-converter (multiplexed for 8 inputs) with programmable range, offset and auto-calibration.
- 24 parallel input/output ports.
- Counter/timer for controlling counting/timing functions.
- Galvanic separation by opto-couplers and solid state relays.

The ***User Interface*** (fig. 4) consists of two identical 486 Personal Computers (PC) which are linked to the transputer network by means of 20 Mbaud ***link*** extension boards located in each PC. At this level the system can also be connected to Local and Wide Area Networks by adding standard interface boards to the PC-ISA bus, utilizing standard protocols.

Finally the ***Mains Power Supply*** (fig. 4) is designed for distribution, switching and filtering mains. It also features an alarm button for safety.

II. Software

General aspects

The computer configuration includes a transputer network and two identical PC-486AT's, the ***Main PC*** and the ***Real-Time PC***, each connected to the transputer network by a so called 'link'(fig. 4). On both PC's the operating system MS-DOS is running together with the highly efficient and friendly Microsoft WINDOWS which is a widely accepted industry standard graphical environment for PC's. In the transputer network the RT-software is running without any operating system. On both PC's the WINDOWS TRANSPUTER FILE SERVER is running. The ***Main PC*** hosts the off-line software and is used for data storage. Tasks like: site installation, preparing predictions, real time processes, data screening, normal point calculations and data mailing are initiated from or performed by the ***Main PC***. The ***Real-Time PC*** interacts with the ranging process as a terminal through the on-line Real-Time (RT) windows transputer file server program, supporting graphics capabilities for the transputer network during all real time processes like: satellite ranging, target calibration, telescope alignment and diagnostics. Through the ***Real-Time PC*** the operator interacts with all ranging related processes. The transputer network is built around several transputers where the actual RT-software is running in order to directly control the hardware. Modification of (default) input parameters for the various modules by the operator is based on WINDOWS dialogue boxes and menus which are on both PC's supported by extensive help information. In case of malfunctioning of one of the PC's, the software is designed to run on one PC only, with minimum inconvenience to the operator. Thus each PC is a back-up unit for the other one.

The off-line software

This software is largely based on the original MTLRS system and will be updated for compatibility with the PC-hardware platform under MS-DOS. The software will be embedded in the WINDOWS graphical environment. Error handling is supported by supplying help information and by allowing operator intervention in run-time whenever feasible. Primarily the new software package has been re-written in C, whereas individual existing modules are kept in FORTRAN-77, callable from C-programmes. Both the C- and the FORTRAN coding are based on to the ANSI-standard to ensure maximum portability of the software. All data files have been defined in ASCII-format, unless specific requirements dictated the use of a binary format.

The RT-software

The transputer software system consists of a set of communicating processes, logically combined in functions. To make the software usable for other ranging systems and to facilitate future developments, the software has been structured into three layers:

a. the GLOBAL, SLR SYSTEM independent software
b. the DEVICE or data format dependent DRIVER software
c. the INTERFACE type dependent DRIVER software

Diagnostic capabilities are integrated in all three layers of the RT-software and are running concurrently by default or can be activated to run concurrently.

a. Global system

The global system includes all functions of the present MTLRS RT-software. The current MTLRS limitations concerning the observation range, the correction domain and the fixed firing epoch have been eliminated. Interleaving satellite ranging is made possible. To optimize this, the coarse pass prediction integration and the fine prediction interpolation are moved into the RT-software. This also allows firing epoch dependent range residual calculation to speed up data filtering. The meteo data and the UTC-GPS time are made available to the RT-time system.

b. Device driver

A device driver prepares the standard information from the global system to meet the requirements of the device and vice versa. It executes a device function by preparing a device command according to the operational device protocol and by calling interface drivers for data transfer. Device drivers are available for all external devices to be accessed by the global software.

c. Interface driver

An interface driver transfers the data from the transputer network through a hardware interface to each device and vice versa. No modifications are applied to the data. Interface drivers are available for each type of interface and protocol used by the external devices. Event interrupt processing is supported for devices which are capable of asserting the transputer event signal.

International design standard

Because of the structured approach to the design of this control system it is hoped that this activity will contribute to the establishment of an international standard for SLR control systems.

References

- Beek, W. and K.H. Otten, "MTLRS-2 Upgrade", Proceedings Seventh International Workshop On Laser Ranging Instrumentation, Matera, 1989, OCA/CERGA, Grasse, France.
- INMOS, "The Transputer Databook", Second Edition, document No.72 TRN 203 01, 1989, Redwood Burn Ltd, Trowbridge.
- TMS User guide, Texas Instruments Data Book: TMS320C40 User guide.
- BYTE: November 1988, Parallel Processing in depth, T800 and counting.
- 3L Ltd. Peel House, Ladywell, Livingston EH54 6AG SCOTLAND, UK Telefax: -506-415944.