UPGRADING THE COMPUTER CONTROL OF THE INTERKOSMOS LASER RANGING STATION IN HELWAN

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ABSTRACT

To fulfill the requirements on the laser ranging systems, the soft/hadware package of the Helwan station was significantly modified in period 1982-84. The max. ranging reprate was increased up to 5 pps. The mount pointing accuracy was increased implementing the mechanical inaccuracies software model. The automatical comparison of the time base to the Loran C signal was put into operation.

UPGRADING THE COMPUTER CONTROL OF THE INTERKOSMOS LASER RANGING STATION IN HELWAN

Software package for the Satellite Laser Ranging Station in Helwan, Egypt was presented at the 4th Workshop, Austin 1981 /1/. This software was used untill June 1983. The significiant modification and expansion were carried out in the period 1983-84.

SATELLITE POSITION PREDICTION

It is based on SAO prediction routines. The new perturbation calculation scheme (GRIPE) was inplemented /2/. The prediction program memory requirements were reduced (<32Kbytes), the special operating system for prediction is not required more.

To make the prediciton algorithm more effective, two step interpolation of predicted position is used. In the prepass phase, the satellite position (x,y,z) is computed - 10 points per pass only. The satellite position is then interpolated onto 150 points, the satellite topocentric coordinates are computed, the mount mechanical inaccuracies are software compensated (program PPP). In the on-line phase, the quadratic interpolation is used.

CONTROL SOFTWARE PACKAGE

The control software package was significantly modified mainly because of the ruby laser transmitter replacement by Mode Locked Train YAG Laser /3/. The software had to take into account that:

- higher repetition rate of laser firing is required,
- 30 arcsec positioning accuracy must be achieved,
- only the single photo-electron echoes are acceptable.

CALIBRATION

The main features of calibration program include:
Programmable reprate up to 10 Hz, parallel reading and raw data processing from two ranging counters (HP5360A, HP5370B), independent time ranging gates for both counters in two ranges (fixed target ~500m, internal pass ~2m), statistical check of the single photo-electron level determined on-line by the ratio : transmitted laser pulses to detected pulses. The ratio must be higher than 5:1.

The calibration results confirm that present accuracy of the Helwan system is determined mainly by single photo-electron PMT jitter

/4/. The ranging counter HP5370B is used for calibration only.

SATELLITE TRACKING

There are two programs simultaneously loaded into memory, which share the system common block for data handling. Using a different priorities and Resource Number flag, the synchronism of the programmes execution is guaranteed.

The segmented background programme STY keeps the structure of the older SATEL. The tracking segment of this programme uses a 4 second loop. During one loop:

- results are avaluated and stored into disc file
- range residuals are displayed on the operator CRT console and transmitted into HP85 for on-line graphics display,
- computation of 4 mount settings and gate positions are carried out,
- on the console is displayed : time, mount setting, no. of stops within the gate for the last 10 shots, range residuals.

The small foreground program has a higher computing priority. Timing of its internal loop is checked by flag derived from the laser trigger pulse. The trigger pulse is generated and synchronised to Station Time Base by Laser Clock. This programme transmits data to Step Motors Controller and Time Gate Window Unit and reads results from Laser Clock (epoch timer) and range counter.

The internal structure of the loops in this programme depends on applied repetition rate of the laser triggers, which can be 1 pps, 2.5 pps and 5 pps.

GRAPHICS

Working with a train of picosecond pulses at the single photo-electron level implies poor signal to noise ratio. In this cases the graphical output of range residuals versus time is simple method to recognize the retrosignal from noise on-line and off-line, as well.

The personal computer HP85F (graphical CRT and graphical printer build in) was installed. The range residuals (+/- 3usec for low satellites, +/-1usec for Lageos) are displayed on the screen , 15 or 30 minutes of tracking per screen.

MOUNT ORIENTING AND ERROR COMPENSATION

To increase the mount positioning accuracy, the mount pointing accuracy is checked, the error model is computed. The mount error model is taking into account:

- the mount gears eccentricities	4 parameters
- the nonperpendicularities	2 parameters
- the coordinates offsets	2 parameters

The first four parameters are determined on the basis of mechanical measurements and ground aiming tests, the others are determined on the basis of the star observations. Ten to thirteen suitably distributed stars are used. The interactive program (Stars) is used for the star catalogue manipulations, selecting of the observing star sequence etc. Program Sky is used for the mount control during star observations. The star position is monitored visually using an aiming telescope (56mm). The program MMP evaluates the (four) mount parameters on the basis of the star observation results /6/.

TIME BASE

Station time base is based on the HP5061 Cs frequency standard/clock. As the epoch reference, the Loran C signal (Mediterranean chain) is used. Laser Clock is synchronized from cesium clock. Propagation dalays of the LORAN C transmitters (Master, Slaves X,Y,Z) were calibrated in 1983 by cesium flying clock.

An automatical comparison of the local time base to the LORAN C signal was developed. The system consist of:

- LORAN C signal receiver + LORAN C rate generator
- delay generator
- oscilloscope
- epoch timer (Laser Clock) + computer + programme LORNT.

Principle of operation:

Output from LORAN C rate generator is connected to input of epoch timer instead of Laser START pulse. The phase of the generator is adjusted to correspond to the phase of the received Loran signal. The oscilloscope is used for this pupose. Recording the phase of the rate generator by the epoch timer, taking into account the delays, one can compute the difference between the station time base and the Loran C timing signal.

The program LORAN is running in the loop and is resposible for:

- reading the data from the Epoch Timer (Ti) - computing of the nearest Time of Coincidence (TOC) ,
- computing the time difference (Di) according to the formulas:

  $Di = (Ti - TOC - n*P)$

  $-P < Di < P$

  where P is the Loran period and n is an integer.
- computing the mean of ten readings,
- identifying the transmitter according to the value of Di,
- applying the corresponding delay.

Copleting the procedure for all the transmitters available, the weighted mean is computed, the protocol is printed.

POSTPASS RANGING DATA ANALYSIS

This part of the Station Software Package was significantly expanded. The programs for noise rejection and orbital fitting programs were completed. The accuracy of the raw results from calibration and satellite ranging (2-4nsec rms) is given by the laser pulse train envelope. Using the "Mode Locked Train YAG Laser Ranging Data Processing" software package /5/ the data are converted into "like single pulse" form and the subdecimeter rms level is achieved.

References

/1/ A.Novotny, I.Prochazka, Software package for station SAO NO.7831 Helwan,Egypt, in Proceedings of the Fourth International Workshop on Laser Ranging Instrumentation,held at Austin,USA,1981,p.89

/2/ J.H.Latimer,D.M.Hills,S.D.Vrtilek,A.Chaiken,D.A.Arnold and M.R.Pearlman, An evaluation and upgrading of the SAO prediction technique, in /1/, p.94

/3/ H.Jelinkova, Mode Locked Train YAG Transmitter in this Proceedings

/4/ K.Hamal, I.Prochazka, J.Gaignebet,Mode Locked Train YAG Laser Calibration Experiment, in this Proceedings

/5/ I.Prochazka, Mode Locked Train YAG Laser Ranging Data Processing, in this Proceedings

/6/ R.L.Ricklefs, Orienting a Transportable Alt-Azimuth Telescope in /1/, p.289

MODE LOCKED TRAIN YAG LASER RANGING DATA PROCESSING

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ABSTRACT

The method of processing of laser ranging data collected using the passively mode locked YAG train laser is decribed. The algorithm for resolving of individual peaks in measured ranges histogram and system internal noise determination is explained together with the crosscorrelation methods for system calibration constant evaluation. The low satellites, Lageos and calibration ranging results are included.

MODE LOCKED TRAIN YAG LASER RANGING DATA PROCESSING

The INTERKOSMOS satellite laser ranging station in Helwan is using the passively mode locked train YAG laser transmitter since late 1982 /1/. The laser generates the train of pulses, 70psec each, spaced at fixed distance 2.0 nsec, most of the energy is concentrated within 3 pulses. The ranging system operates on the single PE signal level only. The software package for the mode locked train (MLT) laser ranging data processing was developed. Its final goal is:

a/ to find out the ranging data sets internal structure, to resolve the echoes from the individual laser pulses within the train,
b/ to determine the calibration constant and system internal noise,
c/ to convert the ranging data into the "like single pulse" form.

In comparison with the TLRS 1 /2/, the spacing of the pulses in the train is much smaller. It is dictated by the laser construction and stability requiremets /5/. However, decreasing the MLT pulses spacing, the analysis of the measured signal becomes more critical. Several laser transmitters with MLT pulses spacings 1.6-2.2nsec were tested during 1982-84. The value adopted (2.0 nsec) is a compromise between the laser stability and the data analysis limitations.

The fundamental procedure in the MLT ranging data processing is to find out the function, describing the distribution of measured values. Suppose the hypotetic ranging system using an individual short laser pulse, single PE ranging. The distribution of the measured ranges may be described by the Gaussian distribution function. Its offset determines the measured range, its dispersion the system noise. For a ranging system using the MLT laser, the problem is more complex. Keeping in mind the shape of the train of transmitted pulses, START discriminator /4/, single PE ranging, one may conclude: the measured values distribution function will be a superposition of the Gaussian distribution functions of unknovn amplitudes, equal dispersion and offsets, differing one to another in the value of pulses spacing within the train.

$$F(t) = \sum_{k=-N}^{N} a_k . \exp(-(t-o-k.r)^2/(2.s^2)) \qquad (1)$$

where
a_k ... amplitudes,
o ... offset,
s ... dispersion
r ... pulse spacing in the train.

Thus, having a set of measured data, one can find out the unknovn parameters s,o,a. (For the system, in which most of the energy is contained in 3 pulses, the value N=2 was found to be optimal.) The measured data distribution is expressed in the form of a histogram, the unknovn parameters of the function (1) are computed using the non linear least square fit process.

On figures 1 to 4 are the prints out of the ranging data analysis precedure for calibration, low satellite and Lageos, respectivelly. The upper histogram corresponds to the measured data distribution, the lower ones to the computed distribution function F. To check the solution stability and confidence, the whole procedure is repeated for different histogram constructions /cell width, starting point/, totaly 5x4=20 solutions are calculated.

The complete ranging data analysis is carried out in 3 steps:
- the satellite ranging residuals are evaluated using algorithm /3/, the distribution functions for the ranging and calibration are found,
- the calibration constant is determined : extremely simple /and fast/ algorith is used to crosscorrelate the ranging and calibration data and to assign to each ranging data histogram peak the corresponding one from the calibration data set. The accurate value of the calibration constant is evaluated from the computed calibration data offset adding/substracting integer multiples of the train pulses spacing.
- the measured values are folded.

Conclusion

The mode locked train laser ranging data analysis procedures were tested by a large number of numerical simulations, indoor calibration tests and real satellite ranging and calibration runs. The minimal number of echoes required for analysis depends on the system noise and the pulse train length. Typicaly, 50 range measurements are sufficient to form a stable solution, although the succesfull data analysis for the set of 30 echoes occured.

The ultimate limit of the ranging system internal noise, for which the mode locking structure may be resolved with the acceptable confidency within the ranging data is 0.32 times the pulse spacing within the train.

Special attention was given to the uncertainty caused by the multipulse character of the laser transmitter. It may cause a systematic error in range measurement of integer multiples of the spacing of the pulses within the train /4/. Calibration tests to internal and/or external targets were carried out to find the calibration constant determination confidence during 1984 mission. It was found, that in at least 90% of the mesurement series, the calibration costant was determined correctly. In the remaining cases, the errors +/- 2.0 nsec occured. On fig.5 there is histogram of pre-postpass calibration differencies /6/, the distribution of the systematic errors may be seen.

If the mode locking structure can not be resolved within the ranging data set, the data may be treated as beeing acquired by the

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MODE-LOCKED YAG LASER RANGING DATA PROCESSING
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EXTERNAL TARGET CALIBRATION    84.7.3. UT 23: 6
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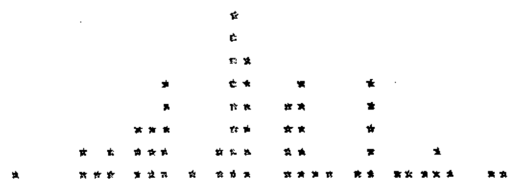

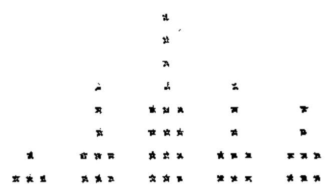


```
B.SPACING  :           .40
OFFSET (ns):        3402.66
SIGMA  (ns):           .32
AMPLITUDES :          2.0      4.6      6.1      5.1      3.6

INTEGRAL TREATMENT RESULTS
MEAN VALUE         3403.24  SIGMA   3.37 (NSEC)

B.SPAC. .500 OFFSET  3402.64+/- .01 SIGMA .26 .36 .32 .32 NSEC
B.SPAC. .400 OFFSET  3402.66+/- .01 SIGMA .25 .57 .29 .29 NSEC
B.SPAC. .333 OFFSET  3402.64+/- .03 SIGMA .59 .34 .22 .61 NSEC
B.SPAC. .266 OFFSET  3402.63+/- .07 SIGMA .18 .60 .33 .33 NSEC
B.SPAC. .250 OFFSET  3402.66+/- .02 SIGMA .26 .22 .26 .23 NSEC
---------------------------------------------------------------

RESULTING : OFFSET  3402.64+/- .04 SIGMA      .32        NSEC
SOLUTION CONFIDENCE     1.00
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Fig.1

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MODE-LOCKED YAG LASER RANGING DATA PROCESSING
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INTERNAL PASS CALIBRATION    84.7.16. UT 22:34
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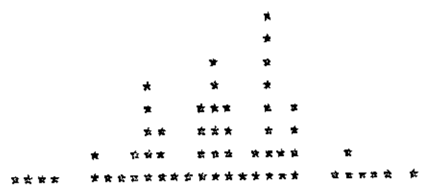

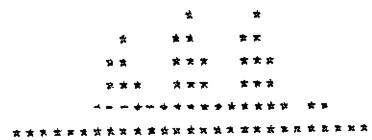


```
B.SPACING  :        .40
OFFSET (ns):      138.31
SIGMA  (ns):        .46
AMPLITUDES :        .6     4.1     5.6     5.4     1.6

INTEGRAL TREATMENT RESULTS
MEAN VALUE        138.26  SIGMA   2.90 (NSEC)

B.SPAC. .500 OFFSET   138.31+/- .02 SIGMA .44 .46 .39 .39 NSEC
B.SPAC. .400 OFFSET   138.36+/- .04 SIGMA .44 .40 .39 .37 NSEC
B.SPAC. .333 OFFSET   138.32+/- .02 SIGMA .45 .35 .41 .41 NSEC
B.SPAC. .266 OFFSET   138.32+/- .02 SIGMA .39 .48 .39 .39 NSEC
B.SPAC. .250 OFFSET   138.31+/- .01 SIGMA .40 .43 .42 .42 NSEC
-----------------------------------------------------------------

RESULTING : OFFSET   138.32+/- .03 SIGMA       .41         NSEC
SOLUTION CONFIDENCE    1.00
```

Fig.2

Mode locked train laser ranging data processing, calibration series.

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MODE-LOCKED YAG LASER RANGING DATA PROCESSING
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SATELLITE 6503201        64. 7. 16.  UT 22:20
```
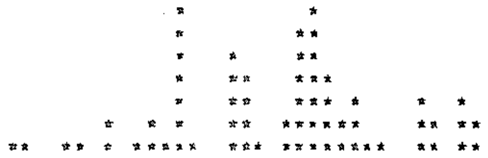
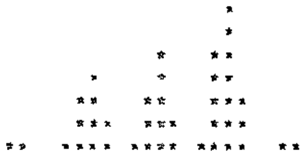



RAW DATA



SOLUTION

```
H.SPACING   :          .40
OFFSET (ns):          1.09
SIGMA  (ns):           .40
AMPLITUDES :       1.3     4.7     4.5     7.7     1.4

INTEGRAL TREATMENT RESULTS
MEAN VALUE            -.05  SIGMA    3.41 (NSEC)

H.SPAC. .500 OFFSET     1.09+/- .04 SIGMA .52 .57 .50 .50 NSEC
H.SPAC. .400 OFFSET     1.14+/- .02 SIGMA .52 .49 .51 .51 NSEC
H.SPAC. .333 OFFSET     1.12+/- .01 SIGMA .53 .56 .57 .57 NSEC
H.SPAC. .286 OFFSET     1.07+/- .04 SIGMA .59 .49 .49 .49 NSEC
H.SPAC. .250 OFFSET     1.09+/- .02 SIGMA .49 .53 .51 .49 NSEC
------------------------------------------------------------------

RESULTING : OFFSET      1.10+/- .04 SIGMA       .52       NSEC
SOLUTION CONFIDENCE     1.00
```

Fig.3

```
MODE-LOCKED YAG LASER RANGING DATA PROCESSING
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SATELLITE  7603901      83.10.30.     UT 22:50
```
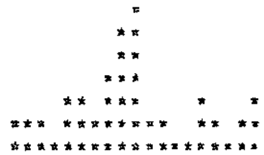



RAW DATA

SOLUTION

```
H.SPACING   :          .45
OFFSET (ns):          -.02
SIGMA  (ns):           .57
AMPLITUDES :       2.0     2.9     6.6     1.5     2.4

INTEGRAL TREATMENT RESULTS
MEAN VALUE             .00  SIGMA   2.32 (NSEC)

H.SPAC. .454 OFFSET     -.02+/-0.00 SIGMA .57 .63 .64 .64 NSEC
H.SPAC. .363 OFFSET      .05+/- .07 SIGMA .62 .57 .56 .56 NSEC
H.SPAC. .303 OFFSET     ---+/- --- SIGMA .63 .65 .64 .64 NSEC
H.SPAC. .259 OFFSET     ---+/- --- SIGMA .56 .67 .60 .60 NSEC
H.SPAC. .227 OFFSET      .02+/- .00 SIGMA .59 .60 .56 .56 NSEC
------------------------------------------------------------------

RESULTING : OFFSET       .03+/- .06 SIGMA      .56        NSEC
SOLUTION CONFIDENCE      .30
```

Fig.4

SLR working with the single pulse of few nsec length. In such a case, the system internal noise (RMS) ranges from 2 to 3 nsec.

References

1/ B.Kvasil,K.Hamal,H.Jelinkova,A.Novotny,I.Prochazka,M.Fahim, B.Baghos,A.G.Massevich,S.K.Tatevian, Interkosmos Laser Radar Version Mode Locked Train, in this proceeding

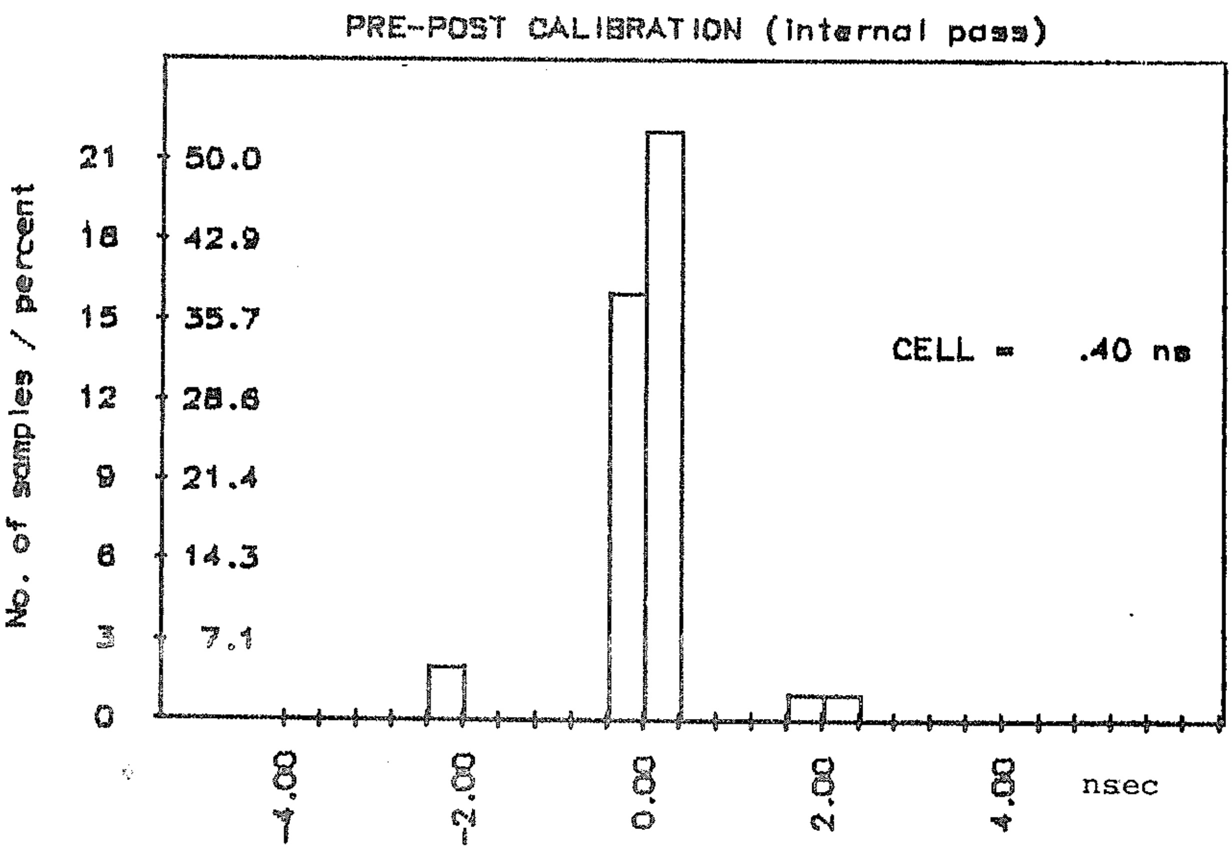
2/ E.C.Silverberg, The Feedback Calibration of the TLRS Ranging System,proceedings of the Fourth International workshop, held at Austin,Texas,1981,published in Bonn,1982

3/ I.Prochazka, Ranging Data Analysis Procedure, FJFI Preprint Series No.82/143 Prague, 1982

4/ P.Wilson , private communication, 1984

5/ H.Jelinkova,Mode Locked Train YAG Laser Transmitter in this proceeding

6/ M.R.Pearlman,N.Lanham,J.Thorp,J.Wohn,SAO Calibration Techniques, in /2/, Vol.II, p.323



Histogram of pre-postpass calibration differencies internal calibration pass,station Helwan,July 1984

Fig. 5.

GLTN LASER DATA PRODUCTS

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ABSTRACT

The Goddard Space Flight Center (GSFC) Laser Data System supports and manages the flow of laser data products from satellite laser ranging stations to the international laser data user community. The GSFC Laser Data System performs quick look data management, operational orbit determination, orbital data analysis in supporting the acquisition message and scheduling requirements of the international laser tracking community. The Data System supports the production and distribution of laser data products including quick look data, the monthly global full rate MERIT 1 data tape, and eventually aggregate laser data. The production and distribution of laser data through the GSFC Laser Data System involves supporting stations, GLTN Communications System, the GLTN Bendix VAX Computer System, the Crustal Dynamics Project Data Information System (DIS), and the Crustal Dynamics Project Investigators.

GLTN LASER DATA PRODUCTS

DATA FLOW

The Goddard Space Flight Center (GSFC) Laser data System supports and manages the flow of laser data products from satellite laser ranging stations to the international laser data user community. The GSFC Laser Data System supports and is supported by laser stations from around the world including the Goddard Laser Tracking Network (GLTN), Australian Laser Network (ALN), Participating Laser Network (PLN), Cooperating Foreign Laser Network (CFLN), and others. Attachment 1 is a data flow schematic of the GSFC Laser Data System, which includes supporting stations, the GLTN Communications System, The GLTN Bendix VAX Computer System, the Crustal Dynamics Project Data Information System (DIS), and the Crustal Dynamics Project Investigators.

The GLTN Communications System receives and transmits quick look data, tracking operations reports, quick look analysis results, acquisition data, scheduling information, and other station information. The GLTN Communications System uses a Micronet 8 to support communications between the laser stations, the GLTN VAX Computer System, and Investigators through Direct Distance Dialing (DDD), TELEX, GE Mark 3, or NASCOM.

The GLTN VAX Computer System supports the management, processing, analysis, and quality control of satellite laser data. Raw satellite data from GLTN, ALN, and PLN stations is managed, processed and merged with processed data from CFLN and other supporting stations to produce a montly global data tape in the MERIT 1 format. The GLTN VAX Computer System also supports quick look laser data management, operational orbit determination, and orbital data analysis used for acquisition message generation and network scheduling. Data processing and orbital analysis results and supporting data quality information from tracking stations and investigators are used on the VAX Computer System to produce data quality evaluation information which supports the quality control of the monthly global MERIT 1 data tape and other laser data products.

The Crustal Dynamics Project Data Information System manages, distributes, and archives processed laser data to support the laser data user community. In managing laser data, laser data information and investigator results, the DIS is the primary interface between the laser data production community and the laser data user community.

The laser data user community is comprised of Crustal Dynamics Project investigators and other scientists doing research in Crustal Dynamics, earth rotation, orbit determination, instrument calibration, data evaluation, and other scientific applications.

MERIT DATA VOLUME (Attachment 2)

Laser data productivity has increased sharply during the MERIT Campaign which began in September 1983. The GSFC Laser Data System has received quick look data from 28 different international laser stations and full rate data from 22 different international laser stations since the beginning of the MERIT Campaign. During the MERIT Campaign the monthly global processed data tapes have averaged over 600 satellite passes and over one half million satellite ranging observations per month.

LASER DATA PRODUCTS

Satellite laser ranging observations have been traditionally available to users in either quick look or full rate form, quick look data meeting the requirements for users needing immediate access to data and full rate meeting the requirements of users who need the complete precision data set. The recent increases in worldwide laser data productivity have led a number of users to investigate data compression techniques to improve computer efficiency in using very large full rate laser data sets. Statistically compressed or aggregate data is needed as a new laser data product. Operational production of aggregate laser data to supplement the quick look and full rate data products is very likely in the near future. Attachment 3 highlights important characteristics of the quick look, full rate, and aggregate data types.

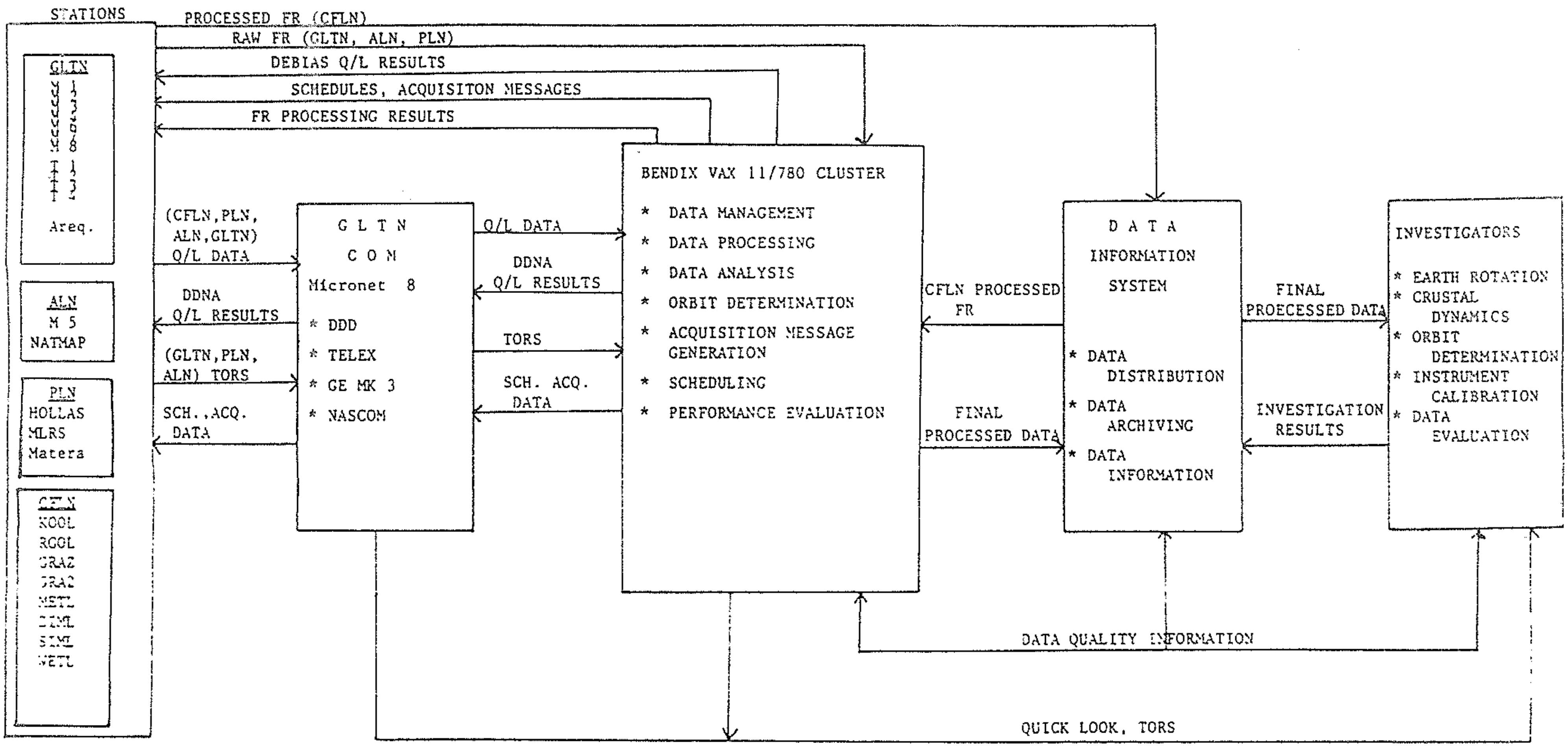
Quick look data is typically produced on site using generic calibration techniques, and is transmitted to the GLTN Communications System daily, making it available to users within approximately 48 hours. Quick look data is generally randomly sampled with only gross filtering to provide a good representation of the full rate data set. Quick look precision and accuracy is generally comparable to full rate. Intermittent data problems occasionally impair quick look data accuracy. Many of these problems are corrected during full rate processing. Quick look data quality is adequate to support scientific applications and orbital maintenance. Operational quality control using quick look data can be very effective if on site data editing does not compromise the representation of the full rate data set.

Full rate data is typically produced offsite using analytic calibration techniques and is generally available within three months. Data editing is limited to provide the most information in a complete precision data set. The primary advantage of full rate data is that it has the necessary data visibility to perform precision data quality control. Full rate has been traditionally used to support scientific applications.

LASER DATA PRODUCTS con't

Aggregate data will probably be produced offsite from full rate data and should also be available within three months. Aggregate data will be produced by using a statistical model to compress the full rate data set into a much smaller precision data set. Aggregate data accuracy should be virtually identical to full data accuracy. The improved computer efficiency of aggregate data will make it ideal for scientific applications. Quality control of laser data using the aggregate data set will be very efficient and should lead to improved techniques using orbital analysis of the global data set. Precision data problems requiring special investigation can be resolved by referring back to the full rate data set. Improved data compression techniques or specialized data compression requirements are likely to evolve in the future. The archived full rate data set can be reprocessed to meet new future aggregate data requirements.

G L T N   L A S E R   D A T A   F L O W



G L T N   L A S E R   D A T A   P R O D U C T S

	FULL RATE	QUICK LOOK	AGGREGATE (FUTURE)
PRODUCTION	OFFSITE PROCESSING	ONSITE PROCESSING	ONSITE/OFFSITE PROCESSING
CALIBRATION	ANALYTIC	GENERIC	ANALYTIC/GENERIC
AVAILABILITY	3 MONTHS	48 HOURS	TBD
USE	SCIENTIFIC PRECISION DATA Q/C	SCIENTIFIC, ORBIT MAINTENANCE, OPERATIONAL Q/C	SCIENTIFIC, GROSS DATA Q/C
DATA SELECTION	N/A	RANDOM/ GROSS FILTER	STATISTICAL MODEL
ADVANTAGES	DATA VISIBILITY	TIMELY	COMPUTER EFFICIENCY
DISADVANTAGES	COMPUTER EFFICIENCY	ACCURACY	DATA VISIBILITY

M E R I T L A S E R D A T A V O L U M E

* QUICK LOOK DATA FROM 28 STATIONS
* FULL RATE DATA FROM 22 STATIONS
* 600 SATELLITE PASSES PER MONTH
* 500,000 RANGING OBSERVATIONS PER MONTH

PERFORMANCE AND EARLY OBSERVATION OF THE SECOND-GENERATION SATELLITE LASER RANGING SYSTEM AT SHANGHAI OBSERVATORY

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ABSTRACT

The satellite laser ranging work at Shanghai Observatory has been presented on the Fourth International Workshop on Laser Ranging Instrumentation held in Austin, Texas in 1981. The development of the second-generation SLR system at Shanghai Observatory was begun in 1978, and has been supported by the Academia Sinica. It is a product of the combined efforts of several institutes under the Academia Sinica. The system design demands and scheme were presented at Shanghai Observatory. The mount of the system was designed at our observatory in collaboration with the Changchun Satellite Observation Station, and manufactured by the Changchun Institute of Optics and Fine Mechanics. The servo subsystem, torque motors and tachometers were developed and fabricated by the Shenyang Automation Institute. The Nd:YAG frequency-doubled laser was built by the Shanghai Institute of Optics and Fine Mechanics. The receiver, timing system, hardware and software of the computer control system were developed at our observatory. The mount was installed at Zo-Se Section of Shanghai Observatory in March 1983. The integration of the system and measurements of ground target were followed. The experimental ranging to satellites was started in October, and the first echo from LAGEOS was successfully received on November 7.

Performance and Early Observation of the Second-Generation Satellite Laser Ranging System at Shanghai Observatory

I. Introduction

The satellite laser ranging work at Shanghai Observatory has been presented on the Fourth International Workshop on Laser Ranging Instrumentation held in Austin, Texas in 1981.[1] The development of the second-generation SLR system at Shanghai Observatory was begun in 1978, and has been supported by the Academia Sinica. It is a product of the combined efforts of several institutes under the Academia Sinica. The system design demands and scheme were presented at Shanghai Observatory. The mount of the system was designed at our observatory in collaboration with the Changchun Satellite Observation Station, and manufactured by the Changchun Institute of Optics and Fine Mechanics. The servo subsystem, torque motors and tachometers were developed and fabricated by the Shenyang Automation Institute. The Nd:YAG frequency-doubled laser was built by the Shanghai Institute of Optics and Fine Mechanics. The receiver, timing system, hardware and software of the computer control system were developed at our observatory.

The mount was installed at Zo-Se Section of Shanghai Observatory in March, 1983. The integration of the system and measurements of ground targets were followed. The experimental ranging to satellites was started in October, and the first echo from LAGEOS was successfully received on November 7.

II. Performance

The characteristics of the system are listed in Table 1. The main observation object of the second-generation SLR system is LAGEOS, so that the receiving telescope is specially designed for two purposes: one is for receiving the laser return signals, the other for visual detection of the faint satellites, such as LAGEOS. The coude optics is prepared so as to install conveniently the high power Nd:YAG laser and to ensure its stabillity. In order to operate smoothly the mount at low angular velocity and reduce the error of mechanic drive, two axes of the mount are directly coupled with torque motors. The optical encoders have 20-bit resolution (1.2 arc second).

The optics of receiving telescope is of Ritchey-Chretien configuration and the field-of-view for receiver is adjustable from 30 arc seconds to 7 arc minutes in seven steps and the field-of-view for visual detection is 30 arc minutes. The width of interference filter is 10A. The type of photomultiplier adopted is GDB-49, a kind of tube made by the Beijing

Nuclear Instrument Factory, Beijing, China, which has a 1.7-1.9 nsec risetime, a gain of $3x10^7$, and a 200 psec transit time jitter. The measured time walk of the receiver electronics, including PMT, pre-amplifier, constant fraction discriminator and computing counter, etc., is less than 0.5 nsec.[2] The Nd:YAG laser has been continuously operated for nine months without any heavy repairs, such as replacement of rods or mirrors. The maximum output energy in 5320A is 330 mj in 4-5 nsec duration time (FWHM), and the efficiency of frequency doubler is about 45 per cent. The maximum repetition of the laser is 3 Hz, but only 0.5 or 1 Hz is adopted in routine operation.

The wobble in each axis of the mount is held to 1 arc second, and the pointing accuracy of the mount is better than 10 arc seconds with systematic errors not being corrected. The alignment of the coude mirrors and transmit optics is made with the aid of a lateral transfer prism set, which will be added at the front ends of both the receiving telescope and the transmitter, if need be. It has been shown in the experiment that the drift of the transmit beam arose from the rotations of two axes of the mount is less than 5 arc seconds and the parallelism between the transmit axis and the receiving one is better than 6 arc seconds.

Fig. 1 is the block diagram of the SLR system at Shanghai Observatory.

Fig. 2 is the block diagram of the SLR servo subsystem.

Fig. 3 is the optical scheme of the Nd:YAG frequency-doubled laser.

III. Preliminary Observation Results

The first echo from LAGEOS was received on November 7, 1983. The visual tracking mode with joystick had been used, because the software of the microcomputer had not been completed yet, so that the number of successful observations per pass was only 10-20. The maximum range we obtained was 7100km, and the lowest elevation angle of LAGEOS was only 40 degrees.

We have transmitted the quick-look data of LAGEOS to NASA/Goddard Laser Tracking Network, United States. These preliminary observation data have been analysed by the Center for Space Research. The university of Texas at Austin.[3] Table 2 is the summary of residuals of LAGEOS quick-look data obtained from Nov. 7 to Dec. 4, 1983, Shanghai SLR station. Fig. 4 is a typical range residuals of LAGEOS, taken by Shanghai station, Dec. 3, 1983 and it has shown that the accuracy of our data for signle shot is about 16 cm. Only using the above 7 passes LAGEOS data, a preliminary adjustment of our station coordinate has been done by the same center (Table 2).

It was rain season during the intensive observation period (April to June, 1984). Thus only a dozen successful observation passes have been obtained from Nov. 1983 to July 1984. Afterward, we have got the long-term precise prediction ephemeris of LAGEOS and relevant software from the Center for Space Research, the University of Texas at Austin, and adopted the "position mode" for LAGEOS ranging. The azimuth, elevation of telescope and range gate (0.5-1.5μs) have been mannually set by observers every 30 seconds. The single photoelectron receiving system has been developed. The first blind track to LAGEOS was obtained on Sept. 3, 1984. Since then, above-mentioned limitations have been broken free from, and the successful observaton passes have been greatly increased. We have obtained 21 passes, 341 observations during 571 minutes of tracking to LAGEOS (no editing) in September, and 13 passes, 264 observations during 342 minutes for Oct. 1 to Oct. 26 (the writing moment). Up to now, the maximum range is about

8542 km, the lowest elelvation angle of LAGEOS is 20 degrees and the maximum number of the observations in a pass is 61, and the longest tracking arc of LAGEOS in a pass is 45 minutes.

IV. Future Plans

By the end of this year, we hope that the computer control system will be available, and the SLR system will be automatically operated. Further improvement on the performance is under consideration. A contract to build a Nd:YAG frequency-doubled mode-locked system that nominally produces up to a 30 mj, 200 psec FWHM pulse with repetition rates up to 10 pulses per second has been signed with the Shanghai Institute of Optics and Fine Mechanics, and the new laser will be delivered to the observatory in 1986. In the meanwhile, a new 16-bit microcomputer system will be added to improve the control and data collection capabilities of the present system. Therefore, we hope that a third-generation SLR system will be in operation in 1986-1987, and do more contributions to the geodynamics applications.

Acknowledgement: The second-generation SLR system would have not been operated if we had not been in cooperation with before-mentioned those institutes and had not had many colleagues' help in the work. The authors are indebted to each of them. The authors would like to express their gratitude to Prof. B.E. Schutz, the University of Texas, at Austin, for his kind help in data analysis.

References

[1] Yang Fumin et al., Satellite Laser Ranging Work at Shanghai Observatory, Proceedings of the Fourth International Workshop on Laser Ranging Instyrumentation held at Austin, Texas, pp. 65-79, (1981).

[2] Su Jinyuan et al., The Receiver System of the Satellite Laser Ranging System with Decimeter Level Precision, Annals of Shanghai Observatory, Academia Sinica, No. 4, pp. 271-278 (1982).

[3] B.E. Schutz, Private Communication, (1983).

Table 1 Performance of the second-generation SLR system at Shanghai Obs.

I. LASER SUBSYSTEM		III. MOUNT	
material	Nd:YAG	aperture of receiver	600mm
output wavelength	5320Å	type of mount	alt-az &Coudé optics
output energy	250mj		
width of pulse	4-5nsec	optical encoder	20 bits(1"2)
repetition	1pps	range of travel	-5°—$+185^\circ$ in alt 600° in azimuth
aperture of transmitting telescope	150mm	static pointing accuracy	10"(without systematic corrections)
beam divergence	0.2-2mrad		
II. TIMING SUBSYSTEM			
filter bandwidth	10Å	resonant frequency	45Hz
type of photomulti.	GDB-49(chinese type)	max. angular velocity	15°/sec in az. 8°/sec in alt.
quantum effeciency	10%		
risetime	1.8nsec	max. angular accelera.	$20^\circ/sec^2$ in az. $10^\circ/sec^2$ in alt.
resolution of timer	0.1nsec		
threshold detecter	constant fraction	IV. COMPUTER	
freqency standard	rubidium	Dynabyte microcomputer system(Z80 CPU)	
synchronization	Loran-C	8 bit, 64KB	
accuracy of synchr.	2 μs	disk, printer	

Table 2 SUMMARY OF LAGEOS QUICK-LOOK DATA RESIDUAL

SHANGHAI SLR STATION*

+SHANGHAI STATION COORDINATES:

ALTITUDE = 29.0230 Meters
LONGITUDE = 121.191740599 Degrees
LATITUDE = 31.097527357 Degrees

REFERENCE ELLIPSOID FOR STATION COORDINATES:

A_E = 6378137.0 Meters
1/F = 298.2570

STATION WAVELENGTH:

λ = 5320.0 Angstroms
$f(\lambda)$ = 1.025792

STA ID	NO OF PASSES	TOTAL OBS	EDITED OBS++	PCT EDITED	GOOD OBS	RAW RMS	RB TB RMS	PRECISION ESTIMATE
7837 SHANGHAI	7	82	5	6.1	77	54.9	17.7	17.7cm

++20 meters edit criteria imposed

STA ID	NO OF PASSES	NO OF NPTS	PTS/ NPT	NPTS/ PASS	EFSIG	NPT WRMS	AFSIG	NPT RMS
7837 SHANGHAI	7	24	3.2	3.4	9.5	11.7	16.1	14.9cm

*Obtained from Nov.7 to Dec.4,1983, and analysed by Center for Space Research, University of Texas at Austin.

+Preliminary Station Coordinate solution, LPM8402

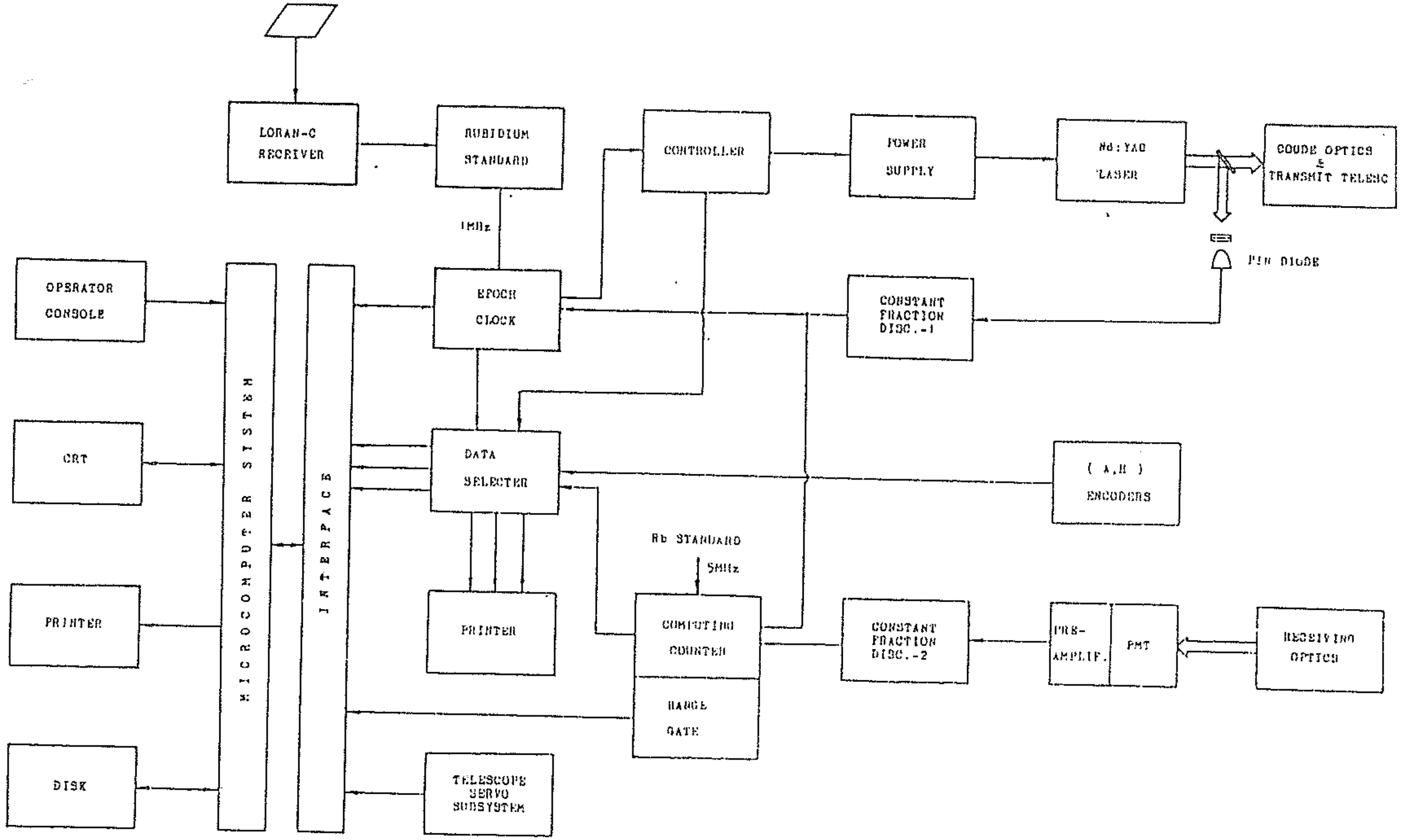


Fig.1 Block Diagram of Second-Generation SLR system at Shanghai Obs.

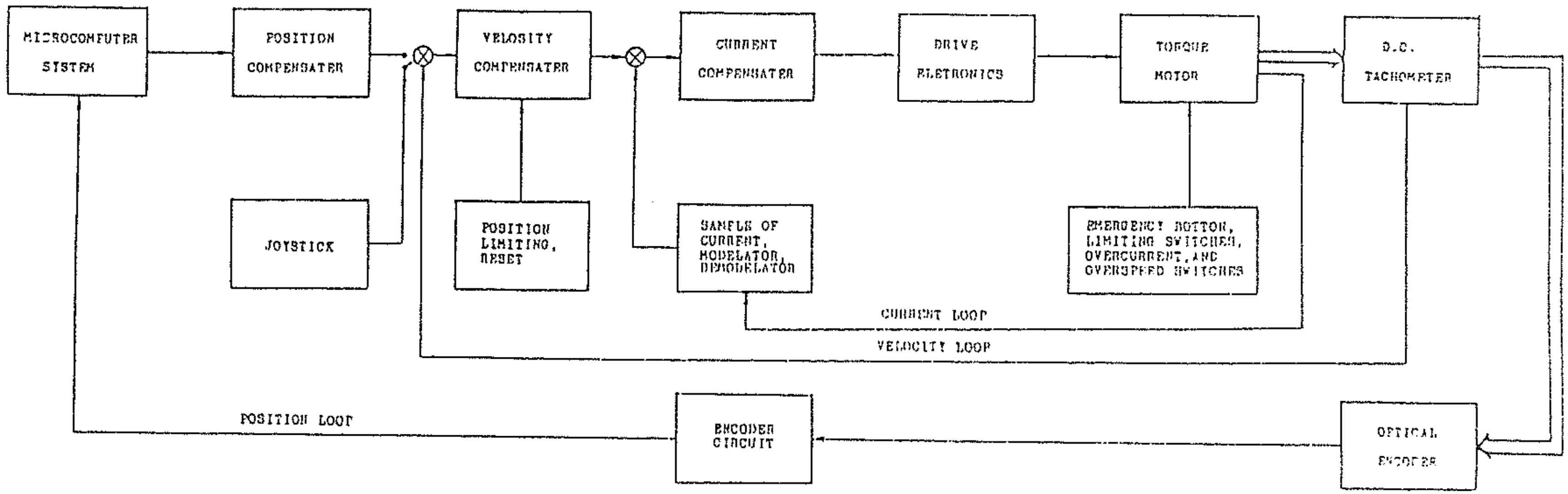


Fig.2 Block Diagram of the Servo Subsystem

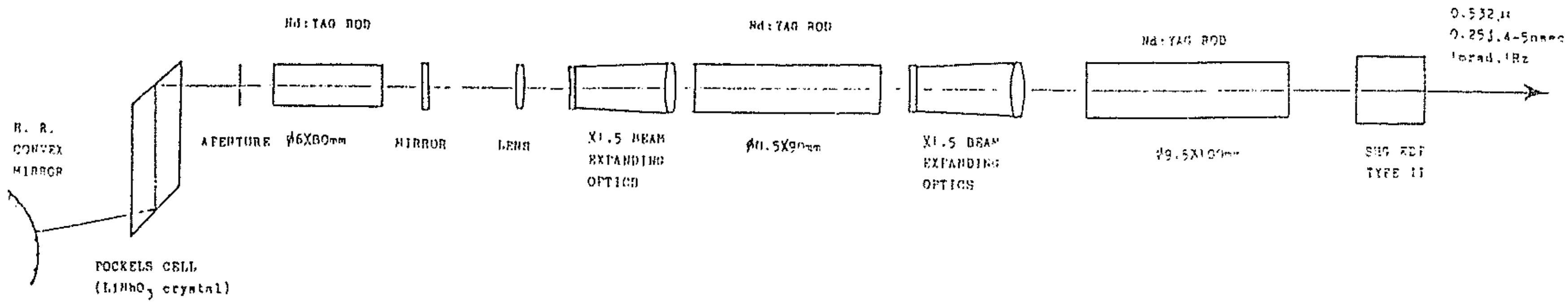
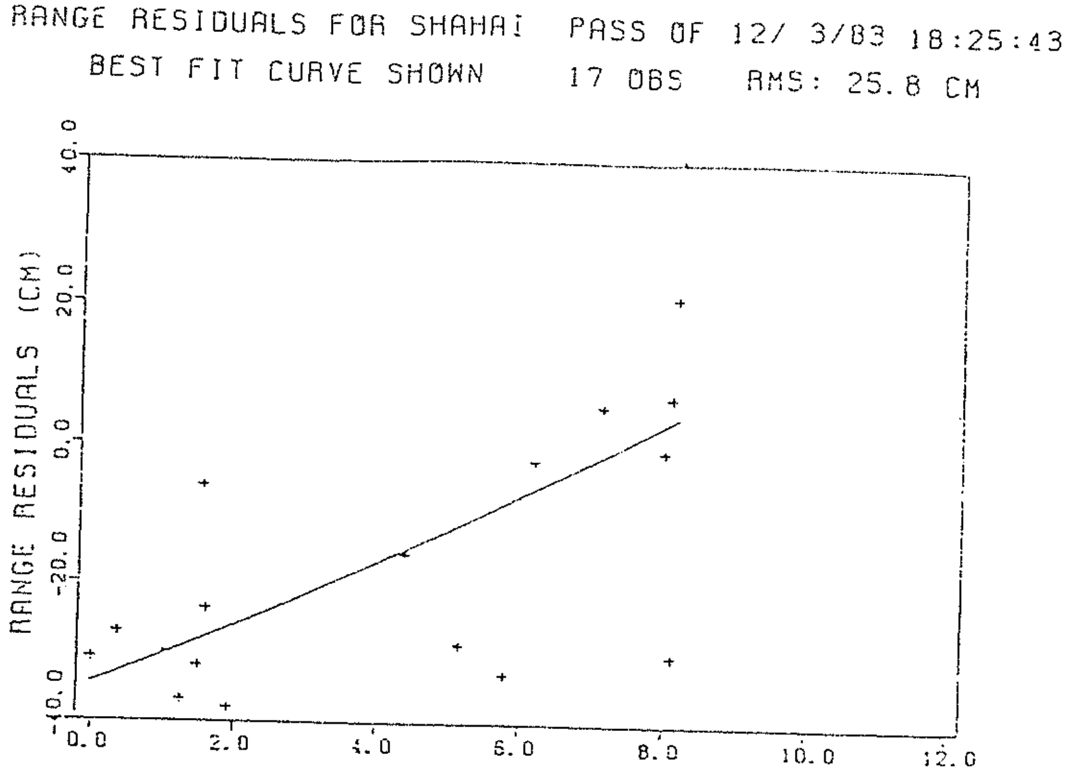


Fig.3 Optical Scheme of the Nd:YAG Laser


RANGE RESIDUALS FOR SHAHAI PASS OF 12/ 3/83 18:25:43
BEST FIT CURVE SHOWN 17 OBS RMS: 25.8 CM
RANGE RESIDUALS (CM)
40.0
20.0
0.0
-20.0
-40.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0

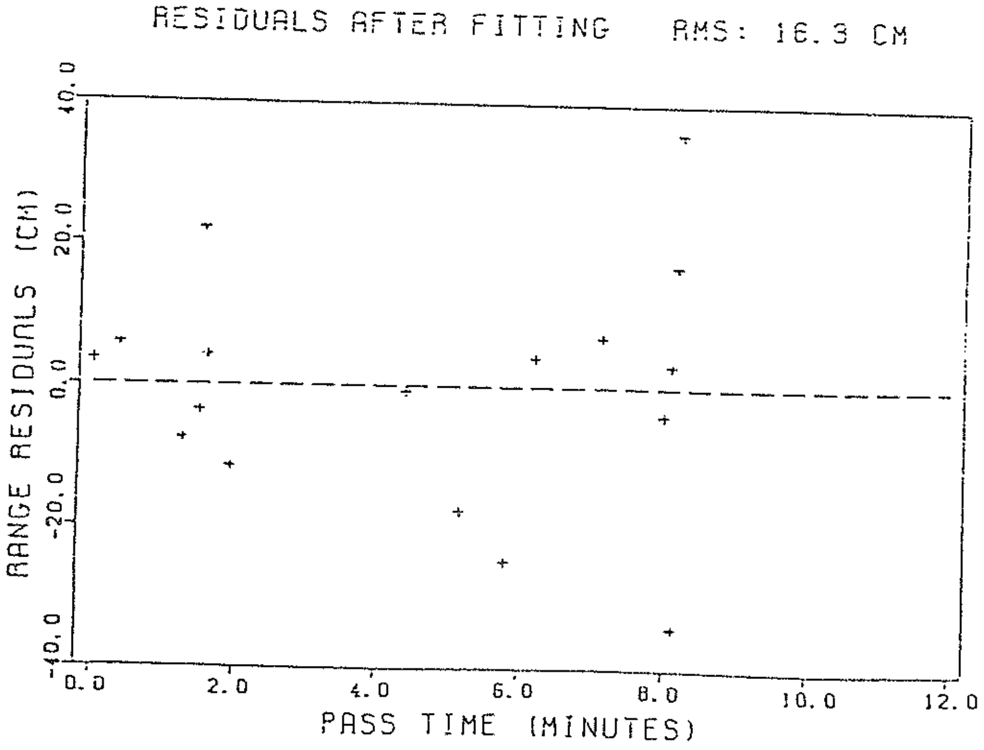
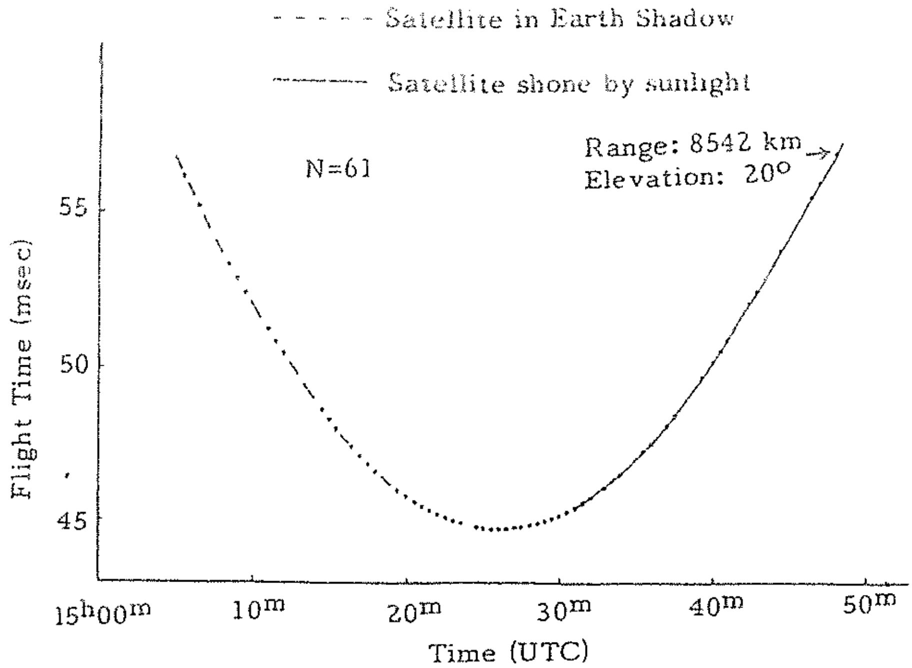

RESIDUALS AFTER FITTING RMS: 16.3 CM
RANGE RESIDUALS (CM)
40.0
20.0
0.0
-20.0
-40.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
PASS TIME (MINUTES)

Figure 4



Fugure 5. A LAGEOS Pass Obtained by Position Mode at Shanghai Station (Oct. 18,1984)

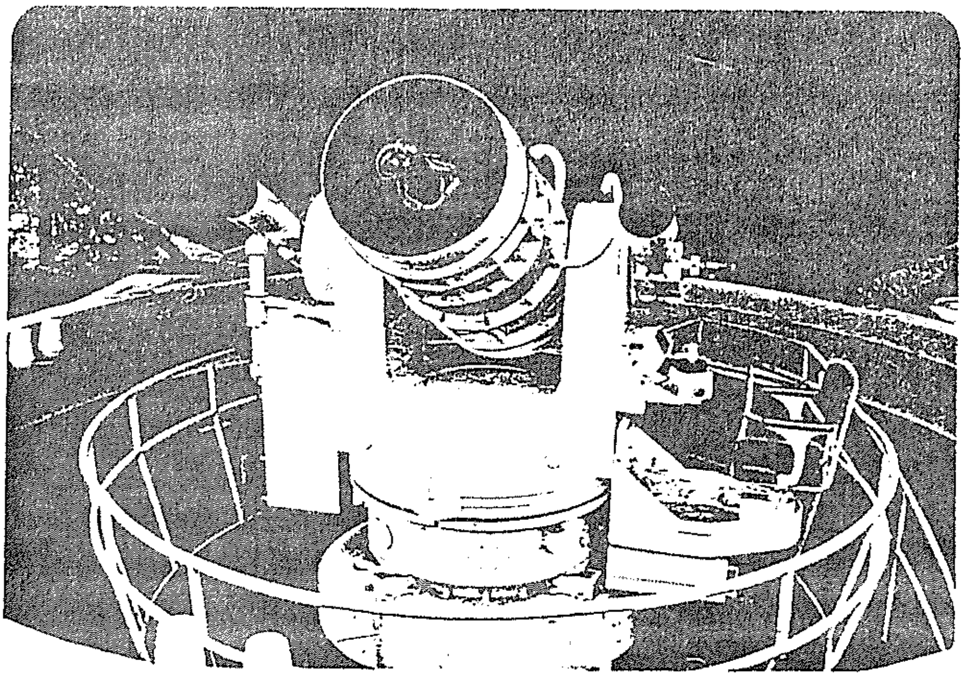


Figure 6. Shanghai SLR Sytem Telescope

REPORT OF THE ACTIVITIES OF THE LASER STATION GRAZ-LUSTBUEHEL

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ABSTRACT

An overview of the laser ranging activities at the observatory Graz-Lustbuehel during the last two years is given; modifications of the system and their result on the measurements accuracy are described.

REPORT OF THE ACTIVITIES OF THE LASER STATION GRAZ-LUSTBUEHEL

In the year 1979 the installation of a third generation satellite laser ranging system was initiated at the observatory Graz-Lustbuehel. First test measurements to LAGEOS started in April 1982. Since October 1982 the laser station Graz is fully operational.

Up to now about 450 passes of LAGEOS, STARLETTE and BEACON-C have been measured (fig. 1). The single shot RMS jitter of the measurements is now in the range of +/- 2 cm to +/- 4 cm for all satellites (fig. 2).

The laser measurements can only be made during night time (from midnight to 6^{00} in the morning) due to restrictions from the aircraft authorities.

Laser

The laser system, made by QUANTEL, consists of a passive mode-locked Nd:YAG laser (100 ps pulse width; 10 Hz/5 Hz/2.5 Hz repetition rate; 100 mJ per pulse at 532 nm) and an additional ruby laser (passive Q-switched; up to 0.25 Hz; 3 ns/2.5 J or 6 ns/4 J).

All results up to now have been obtained with the Nd:YAG laser at a 2.5 Hz repetition rate; most times the single pulse energy is kept in the 30 to 50 mJ region; this provides enough energy for LAGEOS while keeping power densities at mirrors etc. low. Some passes of LAGEOS and STARLETTE have been measured with pulse energies of about 2 to 5 mJ without major problems (the last amplifier of the Nd:YAG laser was switched off).

Mount, telescope, detection package

The mount and telescope system (CONTRAVES) has proven high reliability; one of the most useful features is the ISIT-camera. About 2/3 of all passes allow visual observation of the satellite (night time); therefore the absolute pointing accuracy requirements can be somewhat diminished, while still allowing blind tracking, if necessary. Furthermore, it reduces the necessary re-alignment work: Although there is some drift of the mirror mountings in the Coude path, readjustment of these mirrors is done only in intervalls of about 6 months or more.

The detection package still uses the relatively slow RCA 8852 PMT, a conventional HF amplifier and the Ortec 934 constant fraction discriminator. During the last year some effort has been made to optimize this package (adjustment of the discriminator, use of different amplifiers, different high voltages of the PMT etc.). As a consequence, the RMS jitter of the measurements went down from the initial +/-5 cm to +/- 8 cm and more to around +/-2 cm to +/-4 cm (fig. 2).

The Ortec 934 discriminator still produces some time walk, especially for the multi-photon-electron returns of the lower satellites; therefore a Tennelec TC454 constant fraction discriminator has been bought and will be installed during the next months. With this and some other modifications it is hoped to reach an even better single shot accuracy.

Timing and calibration

Some improvements have been made in the timing system. The 1-Hz-pulse and the 10 MHz standard frequency are transmitted via fibre optics from the TUG time laboratory (within the observatory) to the laser room; there the standard frequency is distributed to all instruments.

The transmission and distribution of the standard frequency introduced some noticeable jitter into the measurements; therefore a new fibre optic transmission and distribution system was developed and built by the TUG time laboratory; this new unit was installed at the end of August 1984, lowering the RMS jitter of the laser measurements again (fig. 3, RMS jitter of the calibration values; notice the step at the end of August 1984). Details of this unit are described in another paper (D. Kirchner).

Pre- and post-calibration measurements are done to a fixed target in about 400 m distance; during calibration, the laser is attenuated to about 2.5 micro-Joules before transmission via two mirrors; this results in single photon-electron detection, as with satellites, and avoids the sometimes dangerous full power ranging to terrestrial targets.

Differences between pre- and postcalibrations are most times less than 1 cm, but show a systematic trend of about 0.4 cm in the average, probably caused by some temperature effects within the system, but up to now not clearly enough identified.

Pass-to-pass variations of the calibration measurements are within a few centimeters, caused mainly by small variations of the initial manual setting of the PMT high voltage; if this voltage remains unchanged, the variations are below 1 cm.

Conclusion

The Graz laser station has now operated for almost two years on a seven days per week schedule. The most severe restriction during this time was the small allowed time of observation between midnight and 6^{00} (restriction from aircraft authorities); the lack of observations in May and July 1983 (fig.1) is due to the absence of any satellite passes within this allowed observation time; other periods with no observations have been caused by more or less continuous bad weather. About 5 % of all possible passes have been lost due to technical problems.

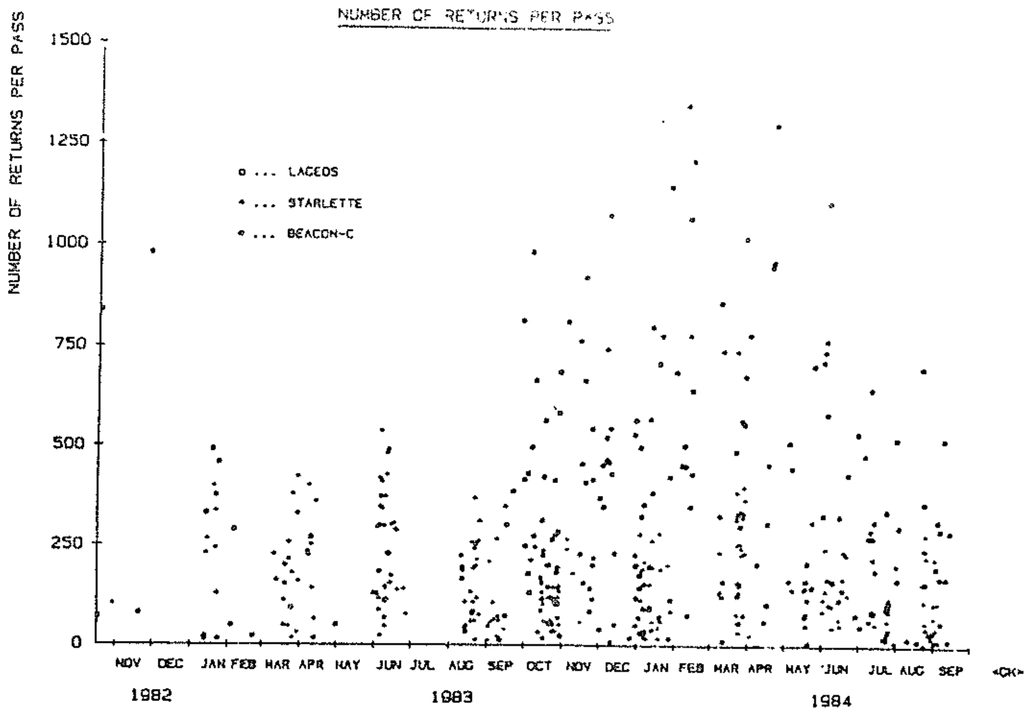

Fig. 1: Number of returns per pass

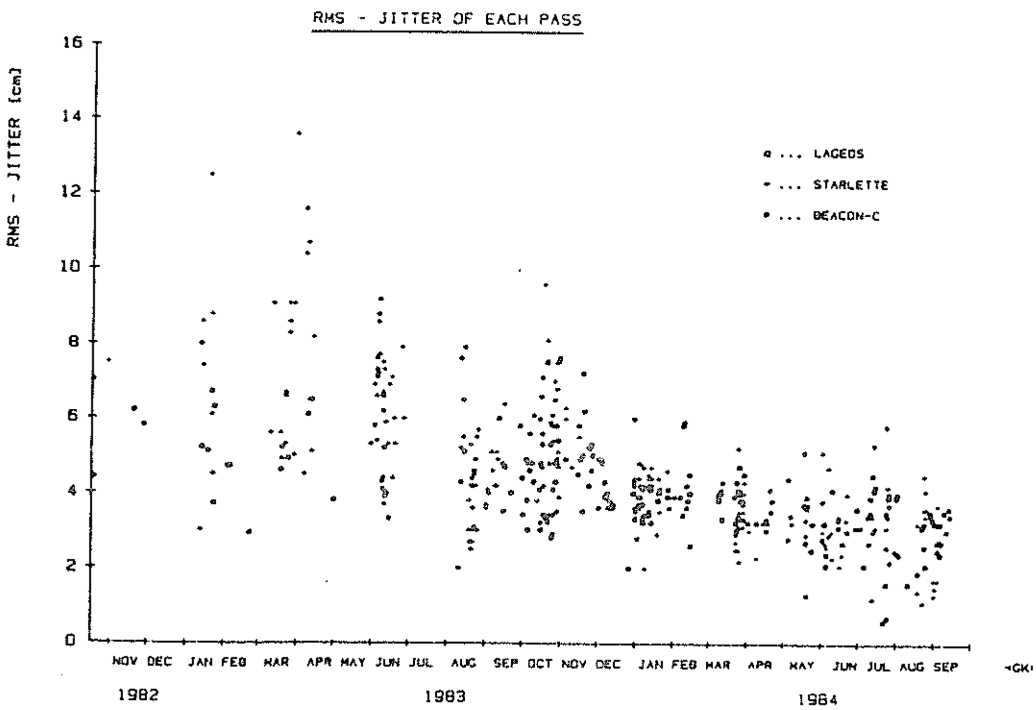

Fig. 2: RMS jitter of each pass

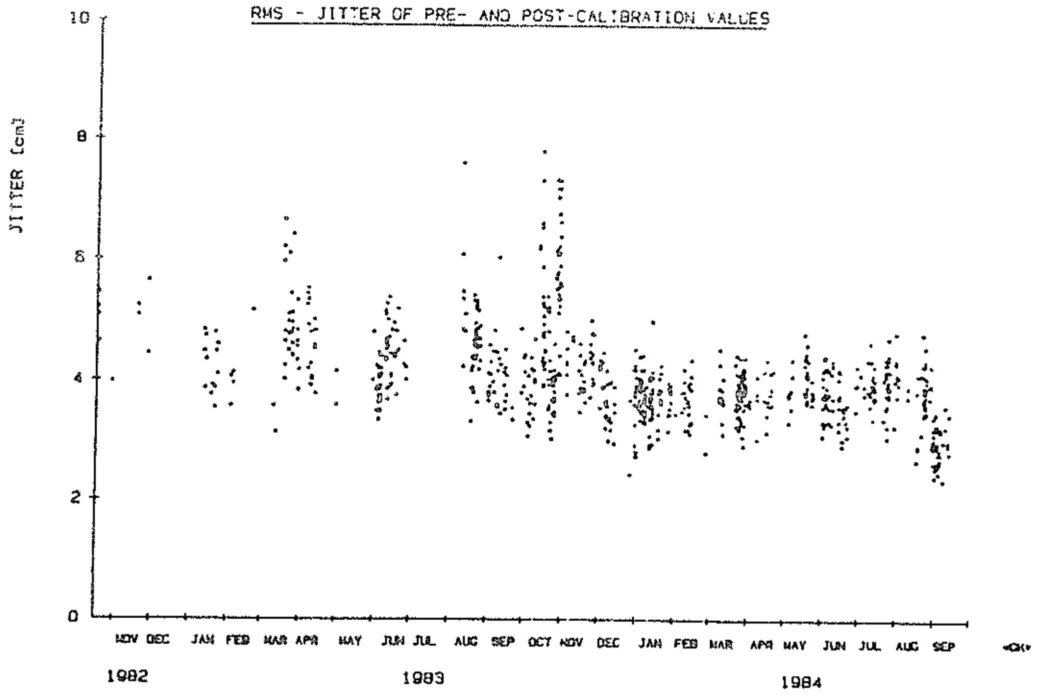

Fig. 3: RMS jitter of pre- and postcalibration values

FIRST RESULTS FROM SATELLITE LASER RANGING ACTIVITY AT MATERA

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ABSTRACT

Since September 1983 the Matera Laser Ranging Station has been tracking passes of LAGEOS, Starlette, Beacon-C, six days a week, on the basis of schedules provides by SAO and, more recently, by GLTN. In twelve months, more than 300 passes of LAGEOS have been observed. In many cases we had between 500 and 800 returns per LAGEOS pass, working at a pulse repetition frequency of 0.5 Hz. The range data for most of LAGEOS passes have a r.m.s. precision between 10 and 15 cm (1 sigma), as is indicated by the comparison of r.m.s. of polynomial fit of range data and the results of detailed calibrations. In this paper we review the system performance and report on preliminary results from the data analysis, in particular on the determination of the station coordinates within a network of laser stations, and preliminary baselines estimates.

FIRST RESULTS FROM SATELLITE LASER RANGING ACTIVITY AT MATERA

1. INTRODUCTION

The Matera Laser ranging station operates since September 1983 under an agreement between the National Aeronautics and Space Administration (NASA) and the Consiglio Nazionale delle Ricerche - Piano Spaziale Nazionale (CNR/PSN). Most of the equipment is an upgraded version of the Smithsonian Astrophysical Observatory (SAO) laser ranging system which has been operational at Natal, Brazil. The site near Matera was selected for several reasons, particularly because of its position in the Mediterranean area, its known seismicity, local geology (bed-rock) and weather conditions. The active support provided by the local Government of Regione Basilicata proved to be very important at every stage of the project. Telespazio provided technical support for the construction of the station and the installation of the equipment, and presently operates the station under a contract with CNR/PSN.

The construction of the station started in late 1982. In the same period, Telespazio engineers spent two months at the SAO station near Arequipa (Peru) and at SAO Headquarters in Cambridge, Mass., becoming familiar with the equipment and maintenance procedures.

In Spring 1983 SAO and Telespazio engineers jointly took care of the installation of the ranging system in the station, as well as of the final tests. Since January 1984 the station operates solely with Telespazio personnel.

In this paper we review the system performance and discuss an estimate of the overall level of repeatibility of the range measurements. Our analysis of calibration measurements indicates a precision between 10 and 15 cm for LAGEOS and

between 4 and 8 cm for Starlette.
Preliminary results are presented on the scientific work centered on the use of the data from the international laser network for the estimation of geodetic parameters, as Matera coordinates, and european baselines.

2. SYSTEM PERFORMANCE

2.1. GENERAL

A summary of the main technical data is given in Table 2.1. The characteristics of the upgraded SAO system are well known and we refer to the paper by Pearlman, Lanham, Wohn and Thorp (1) for their discussion.
With the exception of time synchronization system, some technical difficulties have been encountered, mostly due to aging of the equipment mainly at the beginning of operation. One of the most remarkable problems, during the first months (late September, October and early November 1983), has been the bad performance of the pulse chopping system which caused up to 10% of the pulse amplitude to be leaked in a leading edge extending as much as one half the length of the unchopped oscillator pulse (20 ns FWHM). As a consequence it often happened that, upon reception of the pulse, the stop-channel was anomalously triggered, especially when working at low return areas.
After some weeks of work and testing, the problem was fixed. The overall performance of the chopping system resulted considerably improved (leakage below 4%) even in comparison to the nominal level of performance.
No major problem was encountered in the start-stop system.

2.2. TIMING STABILITY

The time system in Matera is based on two rubidium frequency standards. Since the beginning of October we anticipate the

replacement of the primary standard with a HP 5061 cesium standard, procured by NASA.
Due to the vicinity of the LORAN-C station in Sellia Marina (about 200 km due South), synchronization to UTC (USNO) can be controlled to within 1 microsec by means of an Austron 2100 receiver of LORAN-C signals.
"A posteriori" check is done by means of an independent technique called TV SYNC. The method, proposed by prof. S. Leschiutta (2) (3), consists in comparing the second provided by the local clock with the epoch of the first vertical sync-pulse broadcasted by the national TV network. When two stations simultaneously compare their local second with the common TV sync-pulse, they can determine their relative time offset.
This method assumes a pre-synchronization of the clocks to within 10 msec, to avoid ambiguity with adiacent pulses which in fact are 20 msec long, according to Italian standards.
The precision of the time synchronization can be as high as 1 microsec, provided that the differential time of propagation of the TV signal between the two stations is known to the same accuracy (e.g. clock trip).
The advantages of TV sync are low cost and simple instrumentation, possibility of making measurements during each TV transmission and of monitoring the local time with respect to the national time scale which is maintained by Istituto Elettrotecnico Nazionale (IEN) in Torino. A somewhat cumbersome feature of the method is that a procedure of data exchange must be set up between the stations.
The behaviour of the Station Primary Standard with respect to UTC is shown in fig. 2.1. The initial synchronization to UTC was made on July 29, 1983 using the portable Cesium clock of IEN. This synchronization will be repeated in the occasion of the installation of the new cesium standard.
Although - as mentioned earlier - the synchronization to UTC could be precise to within 1 microsec, the local station time is permitted to drift from UTC (USNO) up to $\pm$ 20 microsec, in order to limit the number of resettings of the cycle-counter or of the frequency of the master oscillator. The epoch of

the observations are corrected to within 1 microsec during the data preprocessing phase.
So far, the average stability of the Primary Standard has been about 2 x 10^{-12} (occasionally 5 x 10^{-13}), so that the resetting of the cycle counter is necessary every 3-4 months. Only three resettings of the frequency of the master oscillator were up to now (August 1984) necessary.
Every time-jump is recorded on paper tape and noted in the log-book. We have noted that the time-jumps can sometimes be caused by electrostatic discharges or fluctuations in the power supply from the regional network. For this reason an autonomous power supply system is being considered to guarantee the necessary stability and continuity.

2.3. CALIBRATION STABILITY

All calibrations are made by ranging to a target board placed at a distance from the station of about 1.17 km. The separation between the center of the target and the Az-El axes intersection of the laser mount has been accurately surveyed by the Istituto Geografico Militare Italiano (IGMI) and is reported on Tab. 2.1.
Differences between the surveyed value and the values obtained by laser ranging are caused in part by gradients of the air refraction index along the line of sight, in part by internal system drift.
The first type of change in path length is correctable by means of local meteo data and a standard formula. Our main concern has been to use the calibration data to monitor the system drifts and to have an estimate of the achievable level of repeatibility in ranging to the target.
We distinguish between detailed target calibrations and prepass-postpass calibrations.
Detailed target calibration consists in ranging to the target and examining the response of the detection system to return pulses of various level of strength. We fire a number of pulses (25 to 100) and attenuate the returning light by means

of a neutral density filter at the receiving telescope. In this way we simulate the response of the detection system to pulse strengths typical of LAGEOS (0.3 to 3 photoelectrons) and of Starlette (3 to 100 photoelectrons).

Fig. 2.2 summarizes the results of the detailed target calibrations done so far. The "leakage" problem mentioned in subsect. 2.1 is evident in the first period of operation. For the remaining data we see that the level of system stability is between 0.7 and 1 nsec (10 to 15 cm) for low areas of the return pulses (up to 3 photoelectrons) and about 0.3 nsec (5 cm) for areas of the return pulses greater than 3 photoelectrons.

Pre-pass and post-pass calibrations are made with different neutral density filters, depending on the satellite.

Fig. 2.3 plots the difference between pre-pass and post-pass calibrations for the Lageos passes since beginning of operations: in most cases, these differences are below 0.2 nsec.

3. SATELLITE TRACKING

At Matera satellites are tracked on the basis of six nights per week, following schedules provided by the Goddard Laser Tracking Network (GLTN). LAGEOS is given top priority during the night. Starlette and - on a lower priority - Beacon-C are tracked also on daytime.

As part of the offline operations at the station, the computer generates schedules of observation. These are memorized on magnetic tape (Linc - Tape) and are used during the online operations (prepass calibration, satellite tracking, postpass calibration).

During each pass, the tracking system is monitored by the operators who intervene to maintain optimal tracking conditions by:

- operating "early-late" corrections on the timing of pulse emission, in order to keep the satellite under conditions of optimal illumination, thus minimizing the effects of non linearities in the photomultiplier;

- attenuating the receiving signal whenever the electronics of the detection system is going to respond non linearly;
- varying the range gate, e.g. to lower background noise or minimize the risk of missing the satellite;
- changing the field of view of the telescope;
- changing the voltage of the flash-lamps, to have the required energy;
- modifying the trigger threshold of the chopping system, to maintain the chopping pulse near or slightly before the maximum of the oscillator pulse, to maximize the energy of the output pulse and keep leakage within tolerance.

In fig. 3.1 a "tracking budget" is summarized since the beginning of operations. "Successful passes" have at least 20 returns.
A pass is acquirable when maximum elevation is above 20 degrees. For LAGEOS the pass must take place during the night. For Starlette, nightly passes cannot conflict with LAGEOS.
In fig. 3.1. one recognizes that bad weather still is the main reason for unsuccessful tracking.
In order to improve the planning of the shifts, a METEOSAT receiver was installed on December 1983.
Its data have proven most useful in local weather forecasting and other operational activities.

4. ANALYSIS OF THE PASSES

Since the beginning of the operational activity of the station, our group is also performing data analysis, as shown in fig. 4.1.
The "full rate" data produced at Matera are saved on linc-tapes and regularly shipped to GLTN. In order to have these data available in a short time for pass-analysis, a procedure was developed to transfer the data on 9-track

magnetic tapes.
The data are then systematically processed by the pass-analysis program with the VAX at Telespazio. In this way we could keep a record of some interesting information for each pass, such as duration, total number of returns, r.m.s. of "best-fitting" (in the weighted least squares sense) polynomials, number of "good" returns (i.e. residual less than 2.5 r.m.s.), the difference between pre and post-pass calibration.
Fig. 4.2 gives an example of "historical record": the r.m.s. of post-fit residuals of the raw data of each pass to the "best-fitting" polynomials is plotted as a function of time. Initially we had the leakage problem mentioned in subsection 2.1, so that large r.m.s.'s are not surprising in passes from late September to early November.
Apart from that, on average the r.m.s.'s are between 10 and 15 cm for LAGEOS and 4 to 8 cm for STARLETTE.
We consider this result very interesting, because it is fully consistent with the system precision independently measured during the detailed target calibrations (see subsection 2.3). Moreover, this level of intrinsic repeability of the ranging system at Matera is also in agreement with the values provided by SAO on its latest upgraded equipment (4).
Finally, we have worked on several orbital solutions with GEODYN, using LAGEOS full rate data from 1 to 15 October 1983 (about 12000 observations from 13 stations) and from 10 to 25 November 1983 (about 11000 observations from 13 stations).
The statistical analysis of the passes over Matera (the coordinates of which were estimated) show that the Matera weighted residuals have a r.m.s. value of 23 cm for the october data and of 19 cm for the november data; the total r.m.s. of residuals for all the stations are respectively 18 cm and 17 cm. These values are slightly larger than the estimates obtained through target calibrations. This increase in r.m.s. values can be interpreted in terms of uncertainties of the force model of the order of 15 cm (1 sigma).

5. PRELIMINARY RESULTS OF SCIENTIFIC WORK

Our data analysis work is part of a scientific project of investigation of Crustal Dynamics in the Mediterranean Basin endorsed by PSN-CNR and approved by NASA within the Geodynamics Program.
The three main goals of our work are:

- to monitor the Matera coordinates and compare the laser estimates with those obtained by means of Doppler and conventional ground-based surveying;
- to obtain polar motion estimates with increasing time resolution, possibly one-day or better;
- to compute baselines joining Matera to other laser stations, particularly the European ones.

Estimates of Matera coordinates with several techniques and obtained by differed Institutions are given in Tab. 5.1. The estimates with GEODYN appear to be significantly repeatable independently of the analyst and of the set of data.
Table 5.2 contains preliminary estimates of european baselines. We remark that these estimates, obtained by means of a multiparameter dynamical solution with GEODYN, await for comparison with a similar solution using other sets of full rate data or normal points, and with solutions obtained with the translocation method.
We have verified that adjusting the coordinates of the polar axis and UT1-UTC at a frequency higher than the usual five days decreases the r.m.s. of the post-fit residuals of a few centimetres.
It is possible that polar motion has structure with nearly diurnal period, in the reference system we use. We are working on solutions with diurnal or even semi-diurnal adjustments of the pole coordinates, and the results will be published soon.

6. CONCLUSION

In 1981 one of us attended at the 4° edition of this Symposium at Austin, Texas. In that occasion the idea of placing a laser station in Southern Italy was first conceived, particularly because of the interest and support of the late prof. G. Colombo.
Three years later, the Matera station is a reality, thanks to the support provided by Piano Spaziale Nazionale and Regione Basilicata, the collaboration from Colleagues of Italian and Foreign Institutions, particularly NASA-GSFC, EG&G and SAO, and the dedicated work of the Station Team, led by Mr. W. Sacchini.
The work done permits to report at this Symposium on preliminary technical evaluations and scientific results.
Still considerable work remains to be done. We feel that the data analysis can probably be continued systematically, since adequate software is available. For the future, most of the effort will have to be put in the replacement of the actual equipment with a third generation laser system in Matera, and in the construction of a transportable system, for the systematic surveying of some reference baselines in Italy.

R E F E R E N C E

1. M.R. Pearlman, N. Lanham, J. Wohn, J. Thorp:
Current Status and Upgrading of the SAO Laser Ranging Systems.
Proc. of the 4° International Workshop on Laser Ranging Instrumentation, Univ. of Texas at Austin, Ed. by P. Wilson, Bonn 1982, Vol. 1, pg 43

2. D.W. Allan, S. Leschiutta, G. Rovera:
TV Frame Pulses Used for Precision Time Synchronization and Their Noise Distribution
Alta Frequenza, Vol. 39, pg 452, 1970

3. S. Leschiutta:
Long Term Accuracy and Time Comparisons Via TV Signal Along Radio Relay Links.
Trans. IEEE, Vol. IM-22, pg 84, 1973

4. Smithsonian Astrophysical Observatory, Experimental Geophysics Group:
Modified Laser Data System Manual
Vol. 1 pg 1-11, Change 4-2-83

LASER SYSTEM	
- wavelength	6943 A°
- energy/pulse	0.5 joule
- pulse width	3 ns
- firing frequency	30 ppm max
OPTICS	
- transmitting telescope	galilean, 12.7 cm lens
- beam divergence	2 arc min
- receiving telescope	Cassegrain, 50.8 cm mirror
- mount type	Az-El, computer controlled
- pointing accuracy	± 30 arcsec, with thermal control of backlash
- slew rate	2°/sec
- pass-band filter	3 A°
PHOTOMULTIPLIER	
- type	Amperex XP2233P
- quantum efficiency	4%
- gain	3-4 x 10^{7}
- rise time	2 ns
TIME AND FREQUENCY SYSTEM	
- frequency standard	Rubidium
- estimated stability	2 x 10^{-12}
- synchronization	Loran C/TV Sync
- resolution of interval counter	0.1 ns
CALIBRATION	
- external target	1172.190 m
- standard deviation of the detection system	± 1 nsec at 1 p.e.
- short term drift (prepass - postpass)	0.1 - 0.5 nsec
METEO SYSTEM	
- Meteosat receiver	24 h coverage
- digital pressure sensor	resol. 1 mB
- digital temperature sensor	resol. 0.1 C
- digital humidity sensor	resol. 1%
COMPUTER	
- Data General NOVA 1200 (16 bit)	32 k core memory

TABLE 2.1.
TECHNICAL CHARACTERISTICS OF THE
SAO LASER STATION AT MATERA

SOURCE	LATITUDE (deg)	LONGITUDE (deg)	HEIGHT (m)	X (m)	Y (m)	Z (m)	SIGMA (m)
IGM (ED79) (FEB 83)	40°38′59″.2245	16°42′19″.6437	490.22				
DOPPLER (SEPT 83)	40°38′55″.546	16°42′16″.097	505.2	4641973.9	1393053.8	4133257.2	
GTDS (24.3.84) (1-15 SEPT 83)	40°38′55″.004	16°42′17″.824	516.281	4641945.5	1393087.6	4133258.9	2.8
GEODYN (15.3.84) (1-15 JAN 84)	40°38′55″.7783	16°42′16″.6955	529.242	4641966.9	1393066.4	4133262.1	0.3
UNIV. OF TEXAS (SL5.1)	40°38′55″.7484	16°42′16″.6608	528.385	4641967.7	1393065.8	4133261.4	
GEODYN (20.8.84) (1-15 OCT 83)	40°38′55″.7969	16°42′16″.6761	528.970	4641966.46	1393065.76	4133262.34	0.21
GEODYN (30.8.84) (10-25 NOV 83)	40°38′55″.7834	16°42′16″.6821	528.751	4641966.52	1393065.93	4133261.89	0.20
GEODYN * (OCT 83)	40°38′55″.79	16°42′16″.69	528.9				

ELLIPSOID	GTDS :	R = 6378.144	1/F = 298.255
	GEODYN :	R = 6378.144	1/F = 298.255
	TEXAS :	R = 6378.145	1/F = 298.255
	DOPPLER :	R = 6378.388	1/F = 298.0

* Private communication of P. DUNN, August 1984

TABLE 5.1

ESTIMATES OF MATERA COORDINATES

	WETTZELL	RGO	GRAZ
MATERA	990118.51 ± 0.80	1694490.71 ± 0.31	719404.63 ± 0.32
GRAZ	302138.21 ± 0.99	1183242.71 ± 0.38	
RGO	917334.43 ± 1.15		

a) Quick look data 1-15 january 1984

	WETTZELL	GRAZ
MATERA	990118.92 ± 0.17	719405.15 ± 0.15
GRAZ	302138.22 ± 0.21	

b) Full rate data 1-15 october 1983

	WETTZELL	GRAZ
MATERA	990119.14 ± 0.15	719405.07 ± 0.16
GRAZ	302138.64 ± 0.13	

c) Full rate data 10-25 november 1983

TABLE 5.2.

SOME EUROPEAN BASELINES IN METERS ESTIMATED WITH GEODYN
(FORMAL ERROR 1 SIGMA)

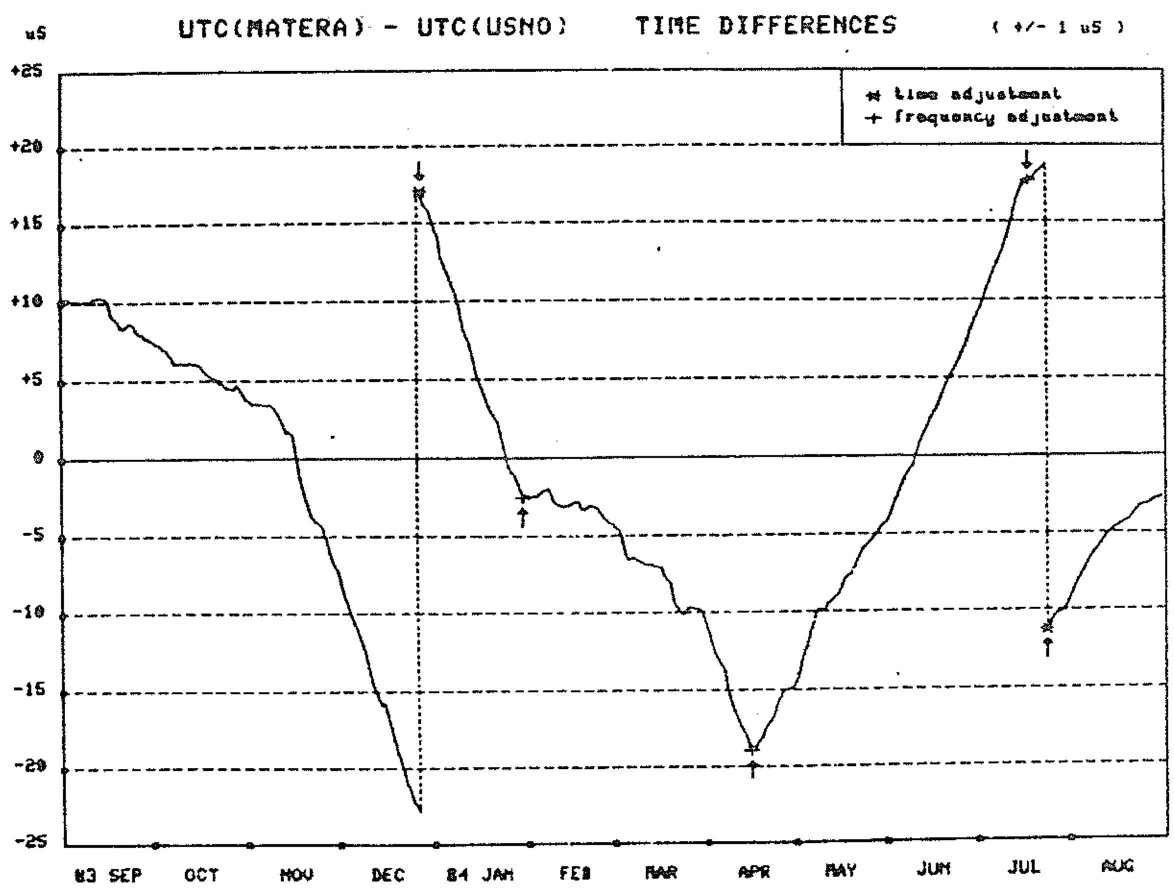

Fig. 2.1 - Behaviour of the Matera master clock with respect to UTC

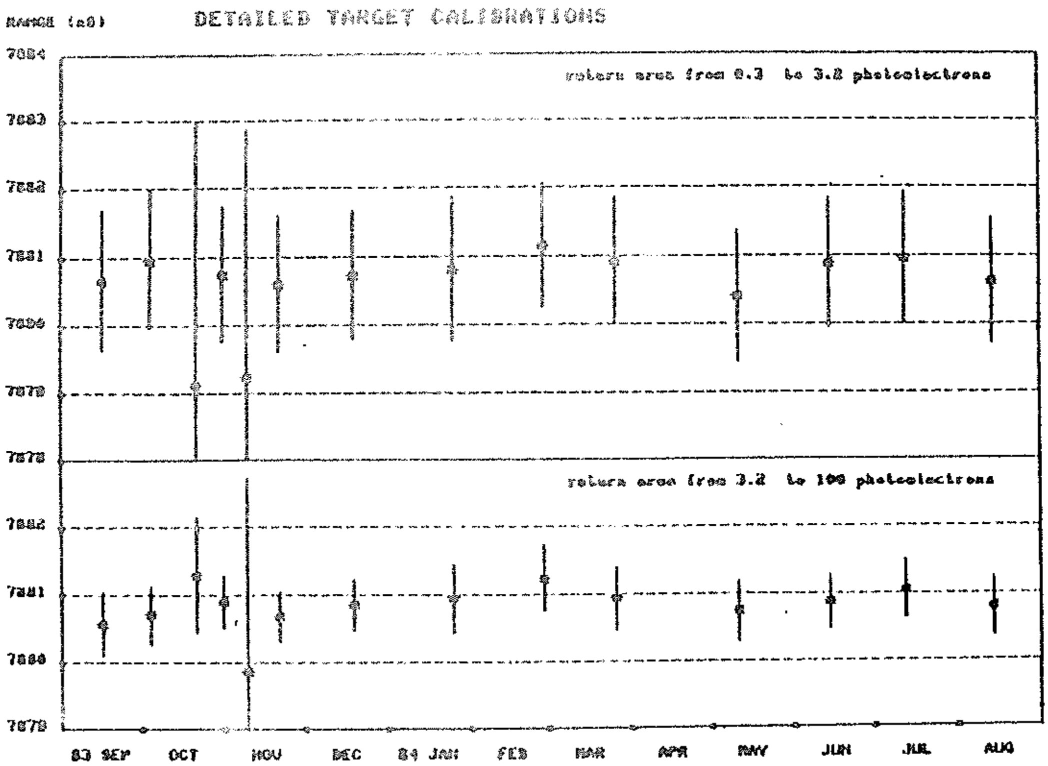

Fig. 2.2 - Results of the detailed target calibrations for different return areas

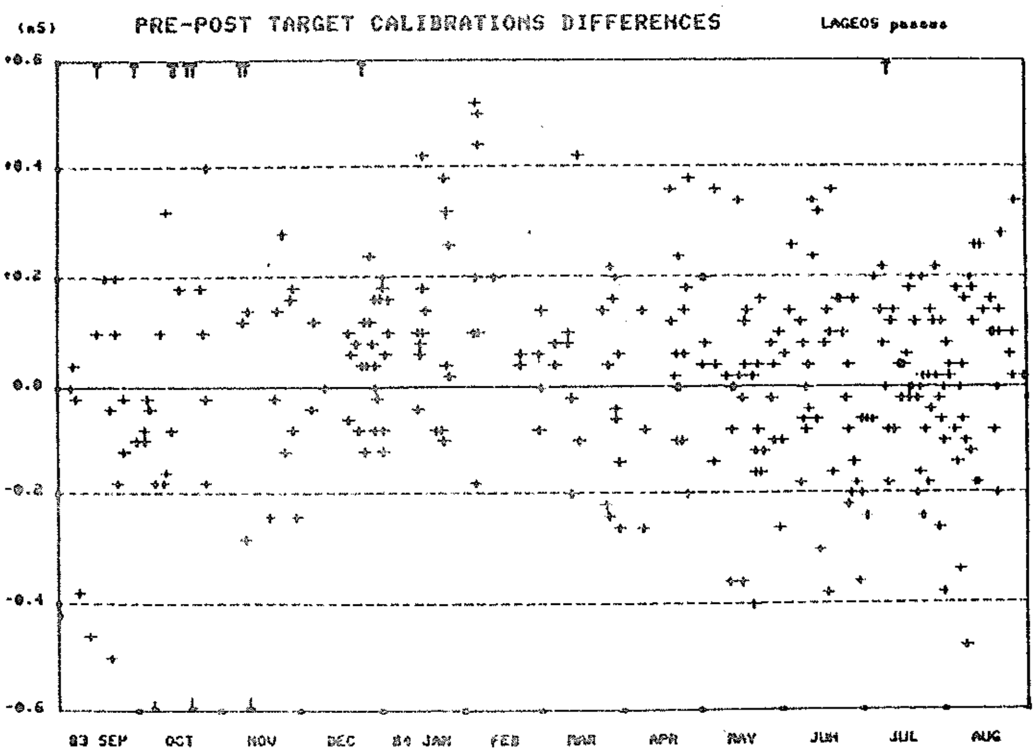

Fig. 2.3.

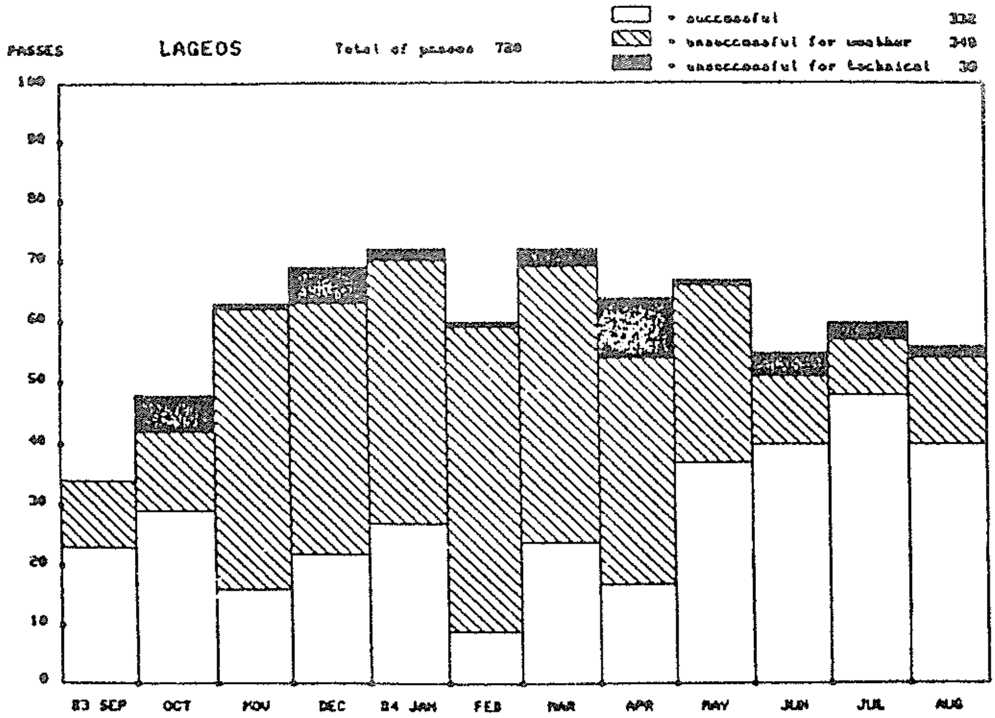

Fig. 3.1.a - Influence of weather and technical problems in the tracking of LAGEOS

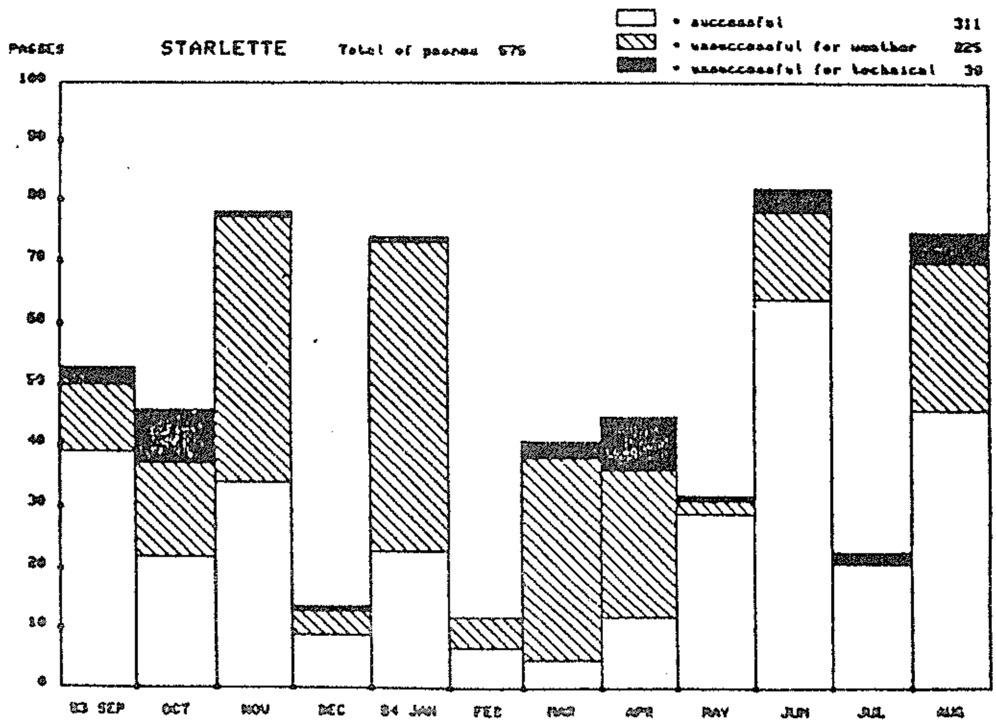

Fig. 3.1.b - Influence of weather and technical problems in the tracking of STARLETTE

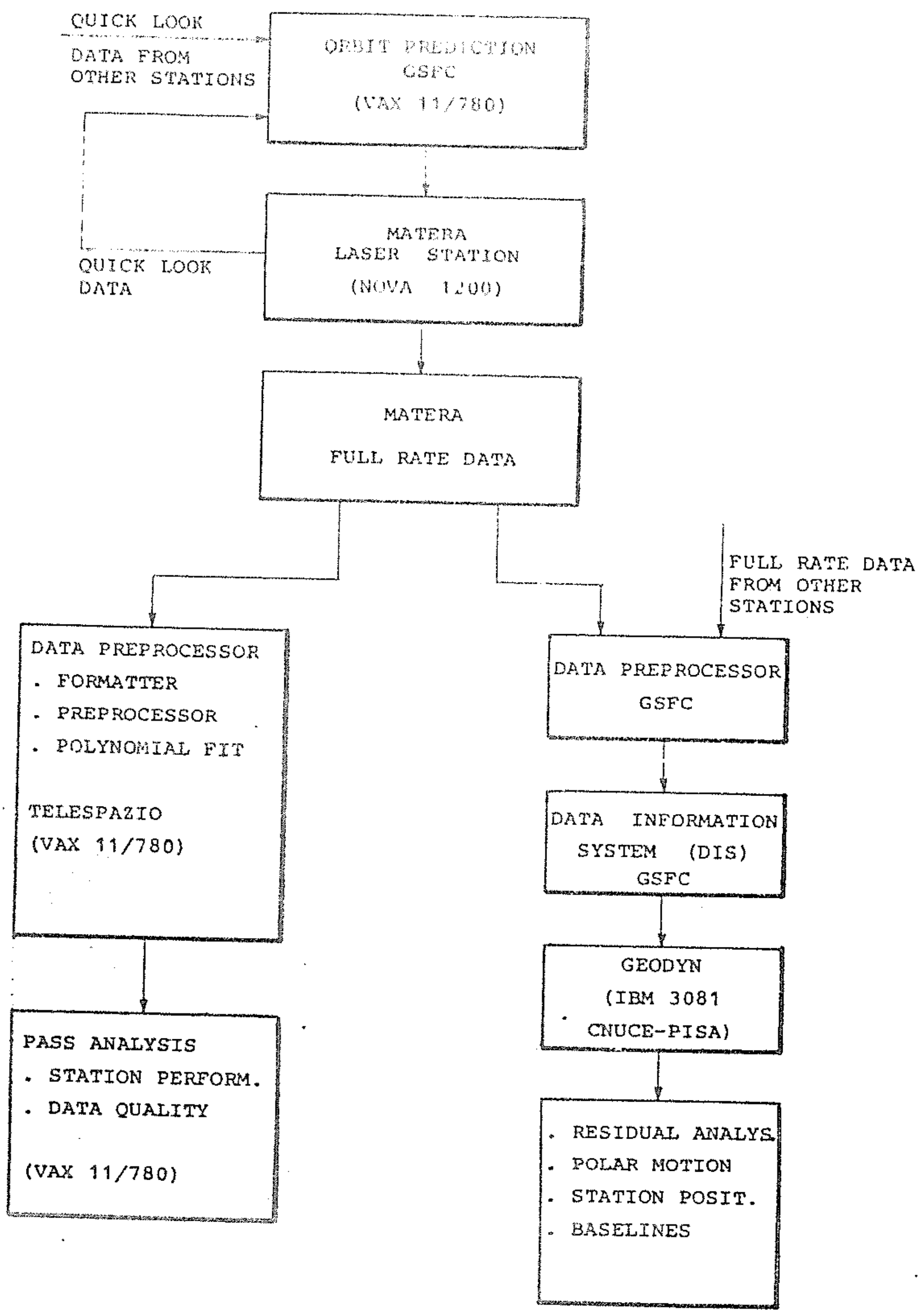

FIG. 4.1. - BLOCK DIAGRAM OF MATERA LASER DATA HANDLING AND SCIENTIFIC ANALYSIS

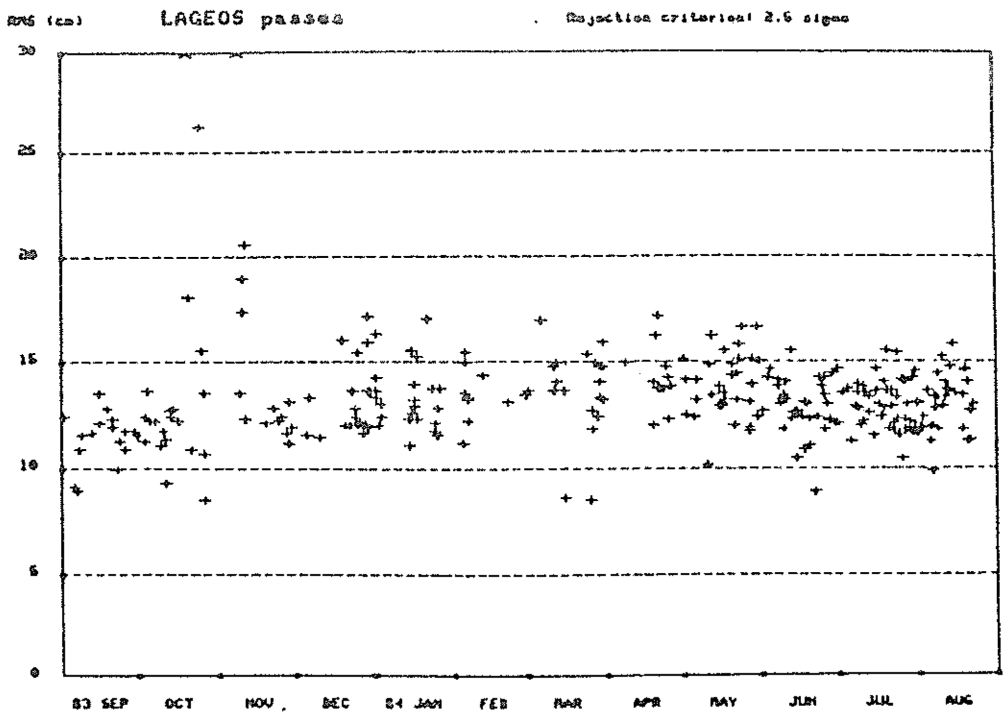

Fig. 4.2.a - Time-behaviour of the r.m.s. of best fitting polynomials to LAGEOS DATA

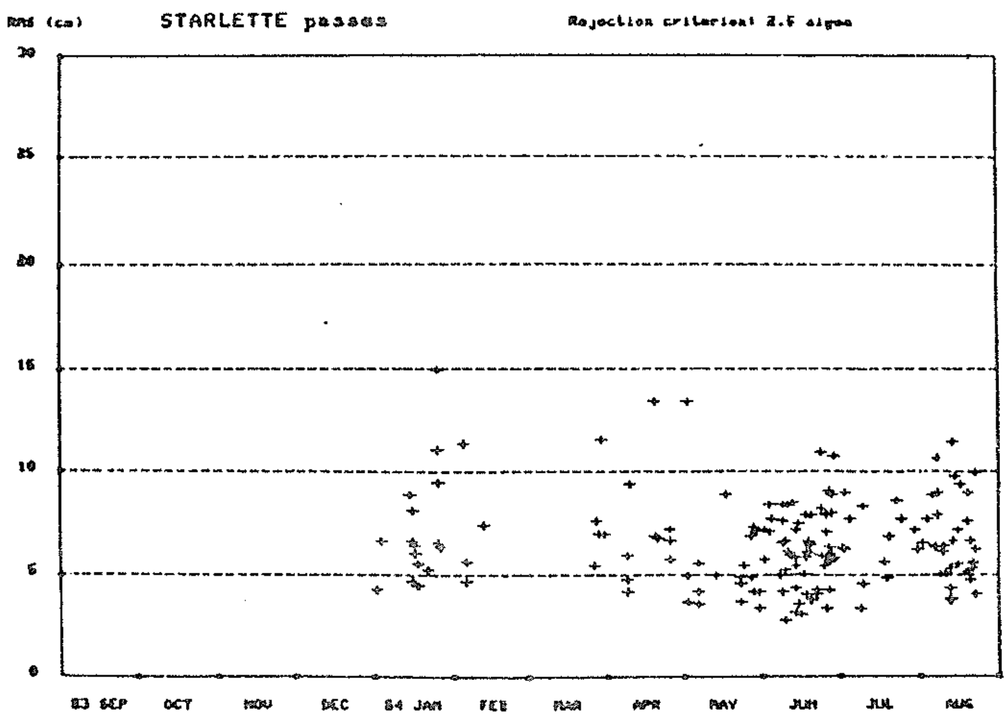

Fig. 4.2.b - Time-behaviour of the r.m.s. of best fitting polynomials to STARLETTE DATA

PROGRESS REPORT 1984

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1. INTRODUCTION

Purpose of this report

The report presented in this brochure covers the progress achieved at Zimmerwald Laser Observation Station during the years 1979-1984. It also outlines some plans for further development of the Sation. Form and contents of the report have been chosen to serve the following two purposes:

- Exchange of experience with stations both already existing or under construction.
- Progress report to the organisations which provide funds for our research. These organisations are:

  The Swiss National Science Foundation
  The Canton of Berne
  The Geodetic Commission of the Swiss Academy of Science and
  The Swiss Federal Department of Defense .

1.1. Historical Remarks

The experiences with the original ruby laser (Klöckler et al., 1978) during SHORT MERIT (August/September 1980) have shown that any further efforts with this system would be inefficient and could no longer be justified. With the aim of joining the main MERIT campaign 1983/84, the acquisition of a third generation laser system was immediately initiated (Bauersima, 1981, paragraph 4.3.5). The scientific importance of this development had already been laid down in (Bauersima, 1979, Table 2).

The building of the new LRS was delayed by financial problems until spring 1983. The construction itself was taking a relatively slow pace because many obstacles had to be overcome. (Optical and mechanical properties of components were not consistent with the vendor's specifications.) A diagram of the LRS is presented in Fig. 1.
The first successful ranges to LAGEOS were finally obtained on May 15, 1984. From there on, an increasing amount of ranging data could be acquired and sent to the computing centres.

1.2. Direction Observations

The original dye laser for illumination/purposes is no more contained in the present system. It should have permitted photographic direction observation to geodynamic satellites as STARLETTE and LAGEOS. The importance of such observations had often been noted (e.g. Klöckler et al., 1978 or Bauersima, 1981). Since then we have evaluated the possibility of optoelectronic observation of certain celestial fields along the satellite's orbits. The concept of illumation lasers appears for many reasons to be outdated.

The development of an appropriate digital image processing system could not be started yet because of scarcity of funds. Yet we hope to tackle this challenge in the frame of our CQSSP*) project (Bauersima, 1984) which has won support of the Swiss National Science Foundation.

1.3. Outlook

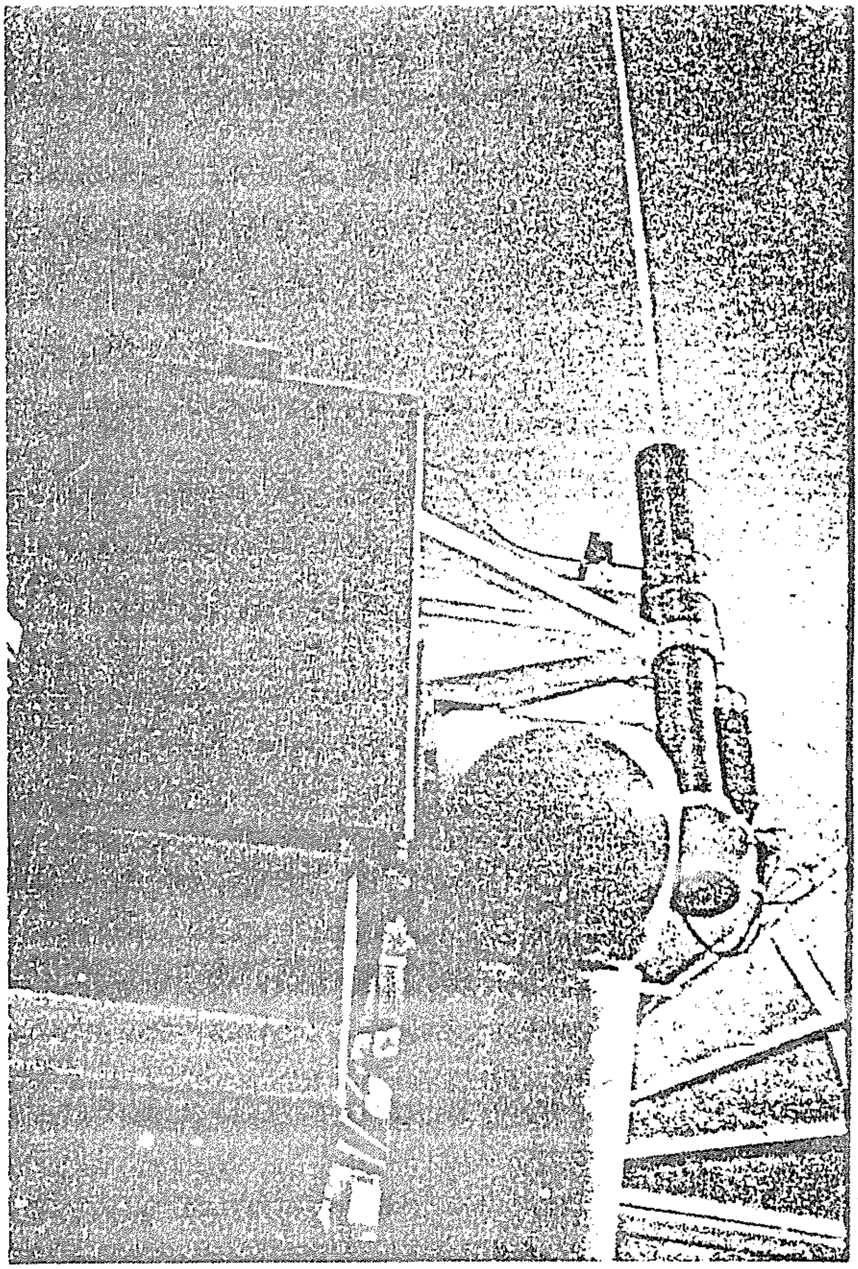
The digital optoelectronic image processing system that will comprise the cornerstone of project CQSSP*) will also be linked with the tracking TV-camera of our LRS. This will allow simultaneous ranging and direction observations of geodetic satellites.

The accuracy of relative station positions determined by laser ranging observations increases with the number of such observations. To each number of observations, an average time interval can be related in which these observations have been made. There exists a characteristic time interval such that the local anomaly of corresponding position shift due to crustal dynamics significantly becomes greater than the mean error of the station's positions gained during this interval. This characteristic interval is generally not known in advance; therefore it is suggested that periodical surveying links between the LRS and a large network of triangulation markers be made (e.g. once per year). The latter should be resting in a common and geologically stable formation. This task is equally important as the laser observations themselves are. Not long ago, the surveying expense for this goal would have been enormous. In the near future, this high precision local survey will be made possible thanks to radio-interferometric observations of GPS satellites (Bauersima, 1983a),b) and Beutler et al., 1984). Here we want to stress the point that if a network of more than three points has to be surveyed, a minimum of four receivers (e.g. MACROMETER-stations) is necessary for high precision surveying. This for the reason that the influence of ephemeris errors practically cancel if during each quasi-simultaneous observation set at least three receivers are placed at sites which have been previously surveyed in a quasi-simultaneous mode (Bauersima, 1983b), p. 41).
In order to undertake autonomously radio-interferometric GPS observations in a country like Switzerland, at least four receiving sets will have to be either acquired, loaned or rented.

---

*) The aim of CQSSP is, briefly spoken, to provide a reliable link between a star catalog (as the one being generated by project HIPPARCOS) and a quasar fixed reference frame. One segment, called CSSP, will link catalog stars and satellites of the Global Positiong System by optical observations. The other, CQSP, will provide a link between quasars and GPS-satellites by radio-interferometry.

The result of such periodic surveying ties between the LRS and the surveying markers mentioned above would be equivalent to the fictive foundation of that LRS in the local primitive rocks. Besides the importance of this fact for global geodynamics, also questions about local or regional geodynamics can be tackled in the same radio interferometric survey. With regard to the organisation of such local GPS campaigns we hope to gain support from organisations which have supported the activities of Zimmerwald Laser Observation Station so far, as well as from such organisations that have an interest in these campaigns for other reasons.



NIGHT EXPOSURE OF THE UPGRADED ZIMMERWALD LASER RANGING TELESCOPE

2. HARDWARE

2.1. Laser Transmitter

The new Nd-YAG laser has the characteristics of a QUANTEL YG 402 DP model, although it has been built from components on the existing stone bench without the performance warranty which usually is part of the deal. The mechanical and optical quality of components supplied by QUANTEL (France) was not always satisfactory, heavy radio interference had to be coped with, and the pulse selector crystal had to be replaced because of electrode disintegration.

Since early 1984, the laser operates satisfactorily, though at a reduced output level. A pyroelectric energy meter (LASER PRECISION RJ7100) was utilized to monitor the output. Its readings appear doubtful, but calibration is under way. Lifetime problems exist with KD*P crystals of the second harmonic generator.

Further improvements of the laser should include spatial filtering and possibly active/passive mode locking to improve beam quality and reduce energy fluctuations.

2.2. Receiver, Timing

The receiver subsystem and the associated electronics are depicted in Fig. 2. It is shown as used in MERIT 1984 and is commented on in the following paragraphs.

Photomultiplier

Various types can be housed in the refrigerated cabinet by PRODUCTS FOR RESEARCH Inc. Presently used is the linear focused, 13 dynode device D341B by EMI-GENCOM, yielding a gain of $5 \cdot 10^7$ @ 2400 V. The timing resolution was found to be approx. 500 ps at 1 photoelectron and 100 ps at 10 photoelectrons.*)

A second detector tube utilizing two microchannel plates was experimentally being used. The results indicate that a timing resolution below 200 ps can be achieved in single photoelectron regime.*)

The P.M. tube is preceded by the laser line filter, where two band widths can be selected. A BALZERS Inc. 60 Å filter was utilized throughout MERIT 1984, because only night time tracking was performed. The second one, a DAYSTAR 3 Å filter, will be employed as soon as daytime operations commence. Its transmission is approx. 20 - 30 %, if temperature is optimized.

The chopper wheel was not in use as to this date in order to keep receiver complexily as low as possible. Backscatter from the laser is a problem if the microchannel device is used (lifetime problem). It also blocks the pulse amplitude reading when in-pass calibration is made (viz. 4.1.).

---

*) viz. the paper "First Experiences with Microchannel Photomultiplier" at this workshop

Time-of-Flight Electronics

An ORTEC 934 model constant fraction discriminator, preceded by a LECROY 133B amplifier (risetime 1 ns , gain 10x), discriminates all pulses above 100 mV. The residual time walk is substantial (viz. Figs. 3 and 4), so leading edge discrimination is still considered, particularly with the 380 ps risetime pulse of the microchannel device. In this case, the amplifier used will be the model AC 3000 by B&H (risetime 130 ps).
The pulse charge (number of photoelectrons x gain) is monitored by a LECROY 2249 mod. charge-to-digital converter.

Time-of-flight is measured with a LECROY 4202 model extended time-to-digital-converter (T.D.C.). Resolution is 156 ps, with a differential nonlinearity of ± 2 LSB. This could only be achieved after an external 100 MHz clock pulse was used instead of an internal crystal oscillator, which had too much phase noise. The external standard is derived from the 5 MHz station oscillator by harmonic multiplication, so its time bias is monitored and controlled to be smaller than $10^{-10} \hat{=} 1{,}5$ mm/15000 km.

The range gate delay and width, and the epoch are generated in 3 separate real time clock modules, the resolution being 100 ns with an uncertainty of ± 50 ns. Minimum gate width is chosen to be 200 ns. Gating is performed within the T.D.C.

The range gate is controlled by a real time filter algorithm*) in the computer which adapts gate delay and width to the return pulse offsets. Once the filter is in "lock"-mode, very few false return are noticed (night operation).

Epoch timing

The epoch is compared with the LORAN-C second (a total timing delay of 33.074 ms being applied) for a quick look timing accuracy of ± 5 µs. Daily TV comparisons with UTC (OFM) allow an "a posteriori" adjustment to within ± 1 µs.

Station frequency standard is basically a model B1326 oven-controlled crystal oscillator by OSCILLOQUARTZ SA. Its phase vs. LORAN-C is registered and steered to be < 10 µs/day.

*) viz. the paper "Real Time Filtering of Laser Range Observations" at this workshop

Mount and Associated Electronics

The mount is driven by two DC servo motors and computer controlled via CAMAC. Position feedback comes from two incremental angle encoding systems (resolution 16 microradians). An angular readout processor corrects the optical encoder outputs for bias variations. The encoder disks are mounted directly in the instrument's axes in order to avoid gear errors.

The errors in the mount axes could be well determined by star tracking. Still lacking is a model of the transmit/receive noncollimation which would be necessary for daylight tracking.

The transmit optics have been fitted with a divergence control (.1 through 1 mrad).

On the receiving side, the calibration paths (light fibre and direct) with variable attenuator and the light collection optics have been added. A variable speed/laser synchronous chopper and a safety shutter are part of the receiver package, as well as the refrigerated photomultiplier cabinet and the associated HV supply.

A digital remote control unit monitors the above devices from the operator's console which also comprises a joystick to allow for tracking corrections by joystick.

The most valuable asset for this purpose is still the Intensified-Silicon-Intensified-Target TV-camera seated on top of the receiving telescope (limiting magnitude m $\sim$ 14).

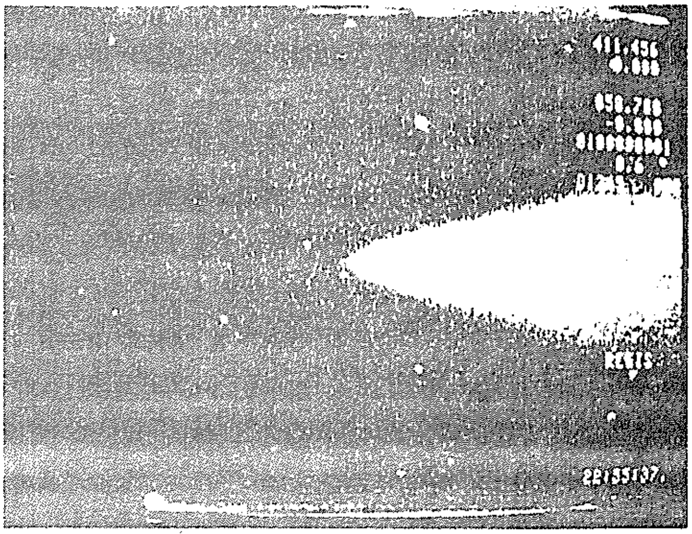


IMAGE PRESENTED TO THE OBSERVER DURING TRACKING SESSION. LAGEOS IS BARELY VISIBLE AT THE APEX OF THE LASER BEAM. SOME OF THE DISPLAYED INFORMATION IS NOT LEGIBLE BECAUSE OF LASER FIRING.

3. COMPUTER FACILITIES

3.1. Hardware

Station computer is a PDP-11/40 under RT-11 operating system. Core memory is 64 K bytes. Peripherals comprise a graphic display (VT 11 graphic processor), a second data terminal, two RKØ5 disk drives, a 9-track magtape (800/1600 bpi), a CAMAC interface system and 5 channel paper tape reader and punch.

Off-line data processing can be done on the University's IBM 3083/ 3033 mainframe computer. Data communication between mainframe and mini is by magtape or via telephone modem.

This modem also will facilitate access to G.E. Mk. III data network, which possibility is presently considered.

3.2. Software

General software for telescope handling allows positioning, initializing and testing of angle encoders and determination of the telescope's axes by evaluation of encoder readings to catalog stars.

Preparatory programs perfom the following tasks:

- input and error detection of SAO mean elements telex message.
- listing of possible satellite passes and ephemeris computation thereof. AIMLASER (adapted to IBM mainframe by Delft University) and University of Texas IRVINT have been adapted to run on the University's mainframe computer.
- computation of coefficients and parameters used for the on-line filter algorithm.*)

The tracking software controls the laser and collects time-of-flight, angle encoder readings, epoch, return pulse strenght and various relevant system parameters. It also performs on-line filtering of data, range gate control and in-pass range calibration.**) This data can be monitored by the operator on the TV screen, along with the tracking camera's image.

Further off-line data screening of range measurements affords graphic display of residuals against ranges computed with AIMLASER or IRVINT reference orbit. Subsequent orbit improvement is made by least squares parameter estimation using numerical orbit integration. R.m.s. values of ranges are displayed and false returns eliminated. In-pass calibration values**) are first screened and then curve fitted and interpolated for each range measurement.

*) viz. paper "On-line Filter Control of the Range Gate" at this workshop

**) viz. paper on "In-Pass Calibration during Laser Ranging Operation" at this workshop

Final data handling procedures are:

- storing of range data and system parameters in an internal format on backup disk or tape.
- extraction of a portion of observations for quick look data and generation of a telex paper tape in SAO format.
- copying of range data onto magtape in the SEASAT format for distribution to computing centers.
- display of residuals (raw and respective to best fit orbit). Also being displayed are range residuals vs. return strenght to visualize residual discriminator systematics.

4. RESULTS

4.1. Calibration

A prerequisite for precise ranging results is certainly a good and consistent range calibration. During MERIT 1983/1984, this calibration value was subject to change because of delay line adjustment of the constant fraction discriminator. The temporal variations of the calibration "constant" are presented elsewhere *).

The noise contributions of the various timing components have been partly isolated. It was demonstrated that the main contributor to timing noise (jitter) is still the photomultiplier. What accuracy concerns, there have been rangings made to an external target at about 1.4 km. This distance has been verified by an independent survey of the Federal Office of Topography to within ± 1 cm, as compared with the laser results using "in-pass" (internal) calibration.

4.2. Ranging Data

A list of data submitted to the computing centers in a "quick-look" selection is presented in the appendix. The given r.m.s. noise of the data is estimated after passing our off-line screening where 4 (Starlette) or 5 (Lageos) orbital parameters are fitted. This being an absolute minimum of coefficents to be estimated, we believe these values to be a conservative estimate.
A set of plots is presented in Figures 3 - 6 , where the present capabilities of our data screening and displaying software are demonstrated.

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*) viz. the separate paper on "In Pass Calibration during Laser Ranging Operation" at this workshop

CONTRIBUTORS

The following persons have contributed to this project for the reported period:

Dr. Ivo Bauersima (group leader geodynamics); Dr. Gerhard Beutler (celestial mechanics, digital filtering, numerical analysis); Dr. Werner Gurtner (geodesy, hard- and software design, operations); Paul Klöckler (electronics and hardware design, operations); Eugen Pop (laser physics, operations); Markus Rothacher (software); Samuel Röthlisberger (mechanical engineering); Thomas Schildknecht (electronics, operations); Prof. Max Schürer (optical design); Christine Strickler (secretary).

REFERENCES

Bauersima, 1979	Memorandum über die Aufgaben und den heutigen Stand der Satellitengeodäsie in der Schweiz
Bauersima, 1981	Konzept der Satelliten-Beobachtungsstation Zimmerwald (Bericht an den Schweizerischen Arbeitskreis Geodäsie/Geophysik), Mitteilungen der Satellitenbeobachtungsstation Zimmerwald, Nr. 6
Bauersima, 1983 a)	Navstar/Global Positioning System (GPS) (II), Radiointerferometrische Satellitenbeobachtungen, Mitteilungen der Satellitenbeobachtungsstation Zimmerwald, Nr. 10
Bauersima, 1983 b)	Navstar/Global Positioning System (GPS) (III), Erdvermesssung durch radiointerferometrische Satellitenbeobachtungen, Mitteilungen der Satellitenbeobachtungsstation Zimmerwald, Nr. 12
Beutler et al., 1984	Some Theoretical and Practical Aspects of Geodetic Positioning Using Carrier Phase Difference Observations of GPS Satellites, Mitteilungen der Satellitenbeobachtungsstation Zimmerwald, Nr. 14
Klöckler et al., 1978	Progress Report 1978 of the Zimmerwald Satellite Observation Station, Mitteilungen der Satellitenbeobachtungsstation Zimmerwald, Nr. 3
Bauersima, 1984	Coupled Quasar, Satellite and Star Positioning (CQSSP), Mitteilungen der Satellitenbeobachtungsstation Zimmerwald, Nr. 13

TECHNICAL SPECIFICATION OF ZIMMERWALD LASER RANGING STATION
(1984, SEPTEMBER)

1. Telescope

	Tracking:	Receiving:
mirror size	525 mm	
focal length	1 m	
field of view	33' × 44'	6' diameter
spectral bandwidth	400-500/550-650 nm	532 ± .15 nm

Transmitting

type	coudé refractor
front lens diameter	.1 m
beam expantion factor	5 ×

Mount

type	biaxial horizontal
drive	DC servo disc motors
angular readout accuracy	5"
gear ratio	4800 : 1
max. speed	4^{o}/sec
min. speed	5"/sec

2. Tracking

methods	closed-loop by computer with mount flexure model or visual using ISIT camera
pointing accuracy (visual)	± 30" (objects m < 15)
pointing accuracy (computer)	± 10"

3. Laser

type	mode-locked, frequency doubled Nd-YAG laser
emitted energy	450 mj IR, 125 mj green
puls width	100 ps
beam divergence	laser: .6 mrad, telescope: variable from .1 to 1 mrad
pulse frequency	5 Hz or less

4. Echo detection

line filter	DAYSTAR 3 Å / BALZERS 60 Å
photomultipliers	a) HAMAMATSU R1244 TANDEM MICROCHANNEL PLATE b) EMI GENCOM D341B
quantum efficiency	10/12 % at 532 nm
pulse rise time	.35/1.3 ns
timing system	Le Croy 4202 TDC
timing resolution	156 ps
calibration method	internal, pre & post pass plus one cal. shot in n (n=2,3...)

5. Epoch Timing

system	Quartz time base controlled by LORAN-C
time base accuracy	± 10 µs (quick look); ± 1 µs (final data)
time base verification	travelling clock plus daily TV comparison with UTC(OFM)

6. Overall Performance

ranging accuracy	± 10 cm or better single shot
range	to LAGEOS

7. Operatability

manned	5 nights a week / 8 months per year

Table A

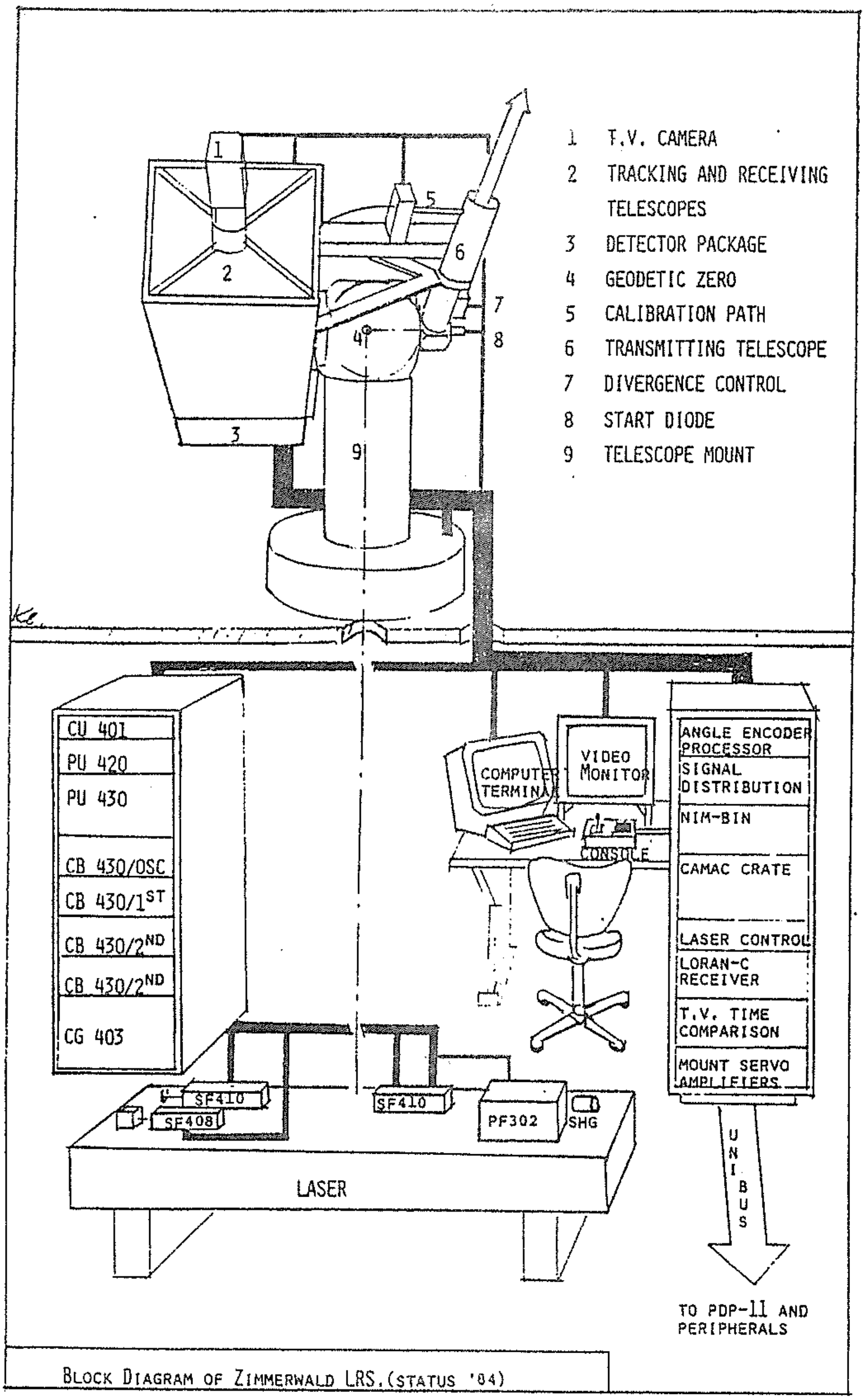
1 T.V. CAMERA
2 TRACKING AND RECEIVING TELESCOPES
3 DETECTOR PACKAGE
4 GEODETIC ZERO
5 CALIBRATION PATH
6 TRANSMITTING TELESCOPE
7 DIVERGENCE CONTROL
8 START DIODE
9 TELESCOPE MOUNT
CU 401
PU 420
PU 430
CB 430/OSC
CB 430/1ST
CB 430/2ND
CB 430/2ND
CG 403
COMPUTER TERMINAL
VIDEO MONITOR
CONSOLE
ANGLE ENCODER PROCESSOR
SIGNAL DISTRIBUTION
NIM-BIN
CAMAC CRATE
LASER CONTROL
LORAN-C RECEIVER
T.V. TIME COMPARISON
MOUNT SERVO AMPLIFIERS
SF410
SF408
SF410
PF302
SHG
LASER
UNIBUS
TO PDP-11 AND PERIPHERALS
BLOCK DIAGRAM OF ZIMMERWALD LRS.(STATUS '84)

Figure 1

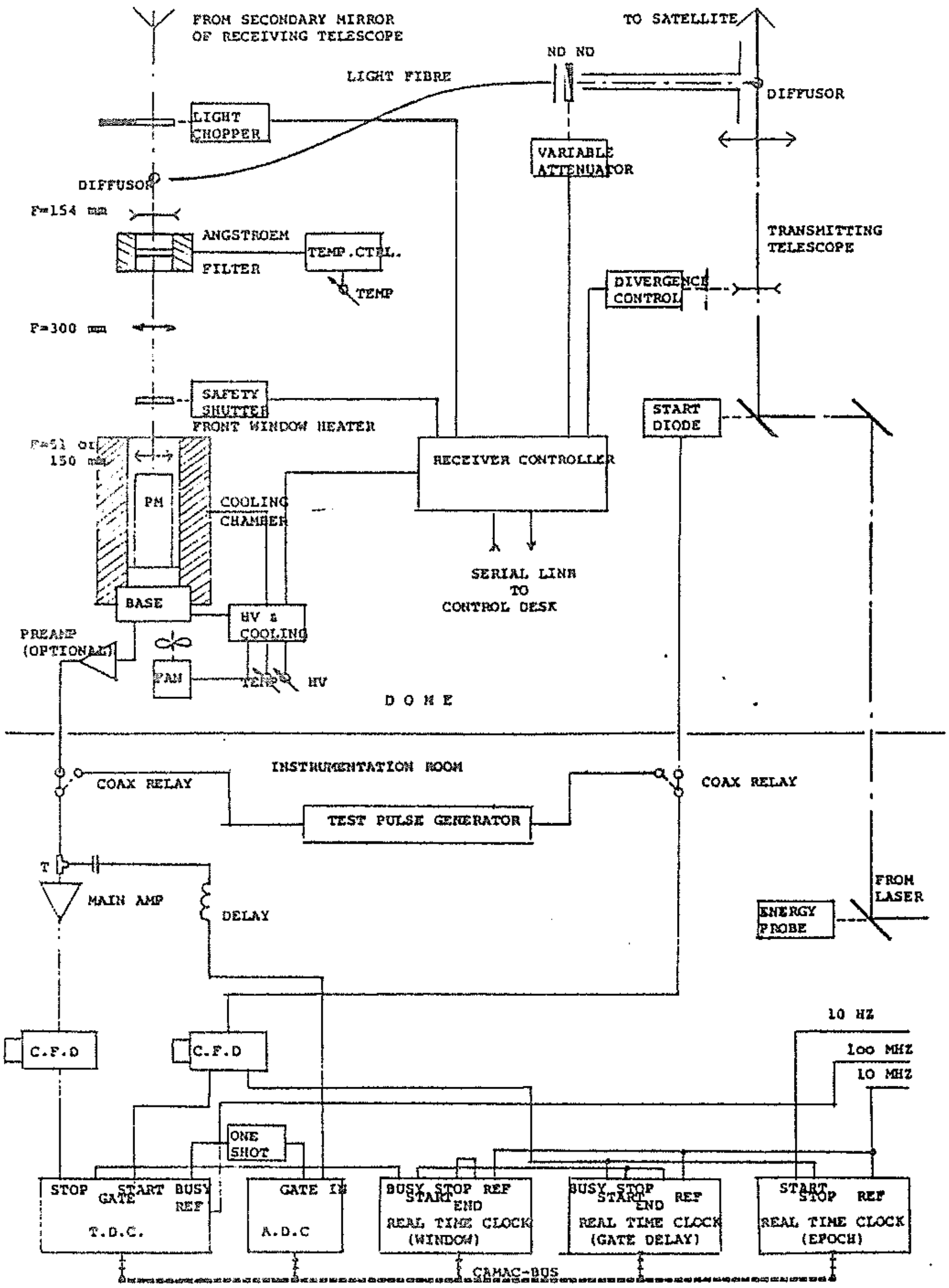

FIGURE 2 THE ZIMMERWALD LRS RECEIVER

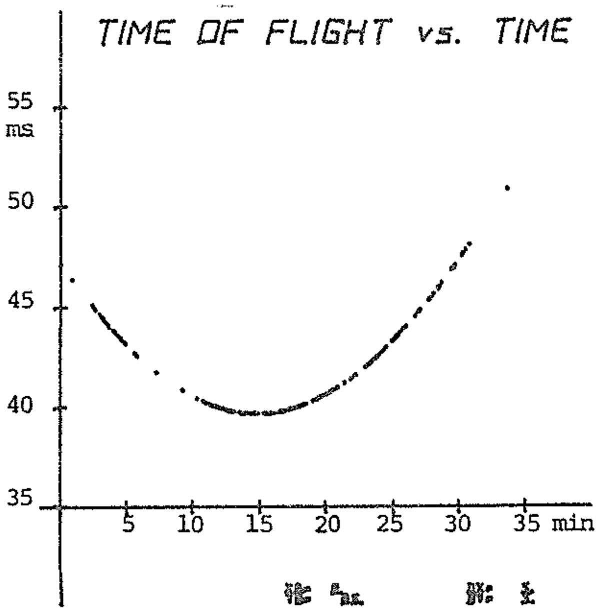

Fig.3 Raw results of one LAGEOS-pass

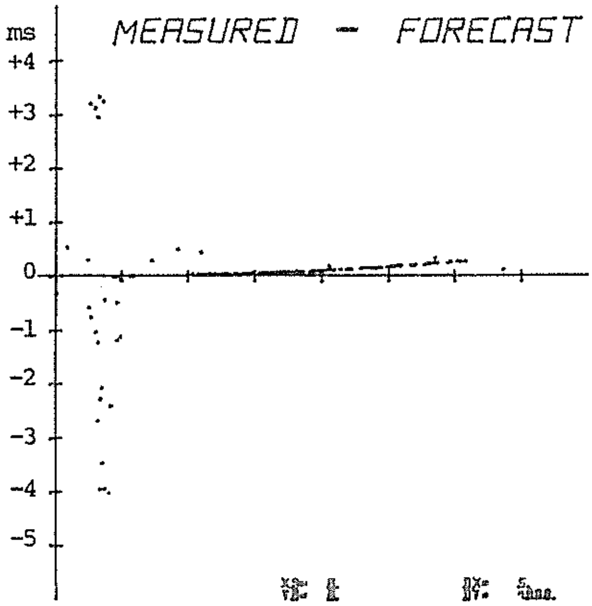

Fig.4 Same pass, forecast subtracted

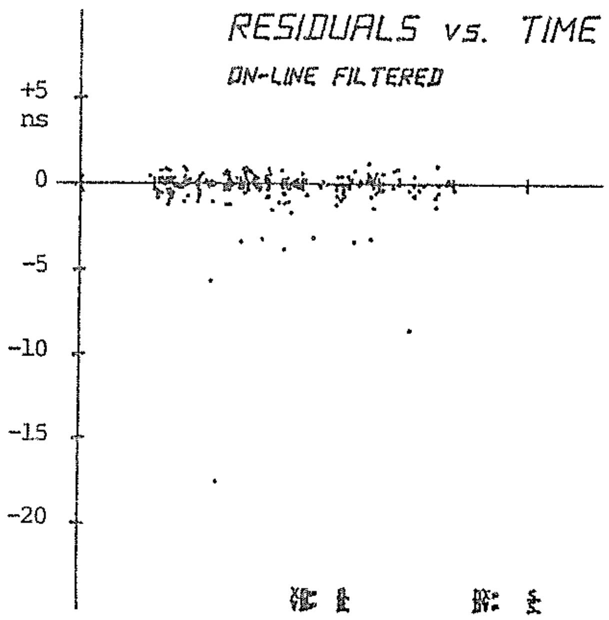

Fig.5 Result of on-line filtering

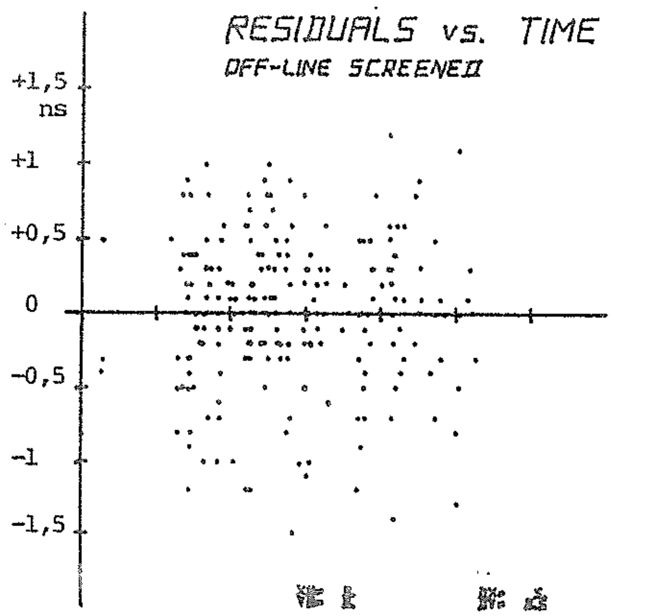

Fig.6 Final residuals after off-line screening. Vertical scale is equal to 7.5 cm per division.

SATELLITE		DATE	TIME	RET	RMS NS
7603901	LAGEOS	15- 5-1984	1:22: 0	131	0.6
7603901	LAGEOS	16- 6-1984	22:44: 0	43	0.8
7603901	LAGEOS	17- 6-1984	21:27: 0	184	0.6
7501001	STARLETTE	17- 6-1984	0:16: 0	81	0.5
7501001	STARLETTE	17- 6-1984	20:57: 0	223	0.7
7501001	STARLETTE	18- 6-1984	0:37: 0	111	0.5
7603901	LAGEOS	18- 6-1984	0:50: 0	164	0.6
7501001	STARLETTE	17- 6-1984	22:47: 0	256	0.7
7501001	STARLETTE	18- 6-1984	21:16: 0	140	0.6
7501001	STARLETTE	19- 6-1984	0:56: 0	45	0.5
7501001	STARLETTE	19- 6-1984	21:36: 0	20	0.5
7603901	LAGEOS	19- 6-1984	22:12: 0	343	0.6
7501001	STARLETTE	19- 6-1984	23:24: 0	250	0.8
7603901	LAGEOS	20- 6-1984	1:37: 0	436	2.7
7501001	STARLETTE	20- 6-1984	23:46: 0	32	0.5
7603901	LAGEOS	25- 6-1984	21: 8: 0	33	0.5
7501001	STARLETTE	25- 6-1984	21:44: 0	151	0.9
7501001	STARLETTE	26- 6-1984	22: 4: 0	66	0.5
7603901	LAGEOS	26- 6-1984	23: 9: 0	240	0.8
7603901	LAGEOS	27- 6-1984	21:52: 0	93	0.5
7501001	STARLETTE	27- 6-1984	22:25: 0	30	0.5
7603901	LAGEOS	29- 6-1984	22:37:18	189	0.6
7603901	LAGEOS	17- 7-1984	0: 6:10	42	0.5
7603901	LAGEOS	17- 7-1984	22:43:36	345	0.6
7603901	LAGEOS	18- 7-1984	2:16: 2	395	0.5
7603901	LAGEOS	19- 7-1984	23:28: 1	316	1.0
7603901	LAGEOS	20- 7-1984	22: 9:28	308	1.9
6503201	BEACON-C	21- 7-1984	1:18: 6	124	0.7
7603901	LAGEOS	21- 7-1984	1:39:57	885	0.5
7603901	LAGEOS	22- 7-1984	22:54:58	318	0.8
6503201	BEACON-C	22- 7-1984	23:55:33	173	0.6
7603901	LAGEOS	23- 7-1984	2:33:18	29	0.7
7603901	LAGEOS	27- 7-1984	23: 7:51	504	2.1
7603901	LAGEOS	29- 7-1984	20:32:36	235	2.5
6503201	BEACON-C	29- 7-1984	22:49:54	183	0.5
7603901	LAGEOS	29- 7-1984	23:59:20	215	0.8
7603901	LAGEOS	30- 7-1984	22:34:58	95	1.5
6503201	BEACON-C	30- 7-1984	22: 8:13	108	0.7
7603901	LAGEOS	31- 7-1984	2:13:24	230	0.5
7603901	LAGEOS	2- 8-1984	22: 1:54	329	0.5
7603901	LAGEOS	3- 8-1984	1:36:16	286	0.6
7603901	LAGEOS	5- 8-1984	21:29:26	460	0.5
6503201	BEACON-C	3- 8-1984	21:17:17	76	0.8
7603901	LAGEOS	14- 8-1984	23:16:15	219	0.6
7603901	LAGEOS	15- 8-1984	21:55: 1	205	0.5
7501001	STARLETTE	15- 8-1984	1:53:55	295	0.8
7501001	STARLETTE	16- 8-1984	0:26:28	71	0.4
7603901	LAGEOS	16- 8-1984	1:33:29	87	0.5
7501001	STARLETTE	16- 8-1984	2:13:26	197	0.8
7603901	LAGEOS	16- 8-1984	20:36:58	203	0.5
7603901	LAGEOS	17- 8-1984	0: 5:25	493	0.5
7501001	STARLETTE	17- 8-1984	0:46:18	113	0.5
7501001	STARLETTE	17- 8-1984	2:33: 9	110	0.5
7603901	LAGEOS	17- 8-1984	22:41:45	408	0.6
7501001	STARLETTE	18- 8-1984	1: 3:45	242	0.6
7603901	LAGEOS	19- 8-1984	23:36: 2	606	0.5
7501001	STARLETTE	20- 8-1984	3:31:48	119	0.4
7603901	LAGEOS	20- 8-1984	22: 8:10	142	0.5
7603901	LAGEOS	21- 8-1984	1:52:11	141	0.5
7501001	STARLETTE	21- 8-1984	0:13: 6	132	0.5
7501001	STARLETTE	20- 8-1984	1:42:36	332	0.7
7603901	LAGEOS	21- 8-1984	20:49:29	423	0.5
7603901	LAGEOS	22- 8-1984	0:21:28	356	0.5
7501001	STARLETTE	22- 8-1984	2:21:36	157	0.6
7501001	STARLETTE	27- 8-1984	21: 2:25	100	0.5
7603901	LAGEOS	27- 8-1984	23:10: 5	230	0.6
7501001	STARLETTE	28- 8-1984	19:33:31	124	0.5
7501001	STARLETTE	28- 8-1984	21:21:31	246	0.8
7603901	LAGEOS	28- 8-1984	21:48:12	358	0.5
7501001	STARLETTE	29- 8-1984	19:52:11	140	0.5
7603901	LAGEOS	29- 8-1984	20:29:27	261	0.5
7501001	STARLETTE	29- 8-1984	21:42:39	212	0.5
7603901	LAGEOS	30- 8-1984	0: 5:25	249	0.5
7603901	LAGEOS	30- 8-1984	22:35:49	178	0.5
7501001	STARLETTE	31- 8-1984	20:30:56	390	0.7
7603901	LAGEOS	31- 8-1984	21:14:57	504	0.6
7501001	STARLETTE	31- 8-1984	22:20:21	152	0.5
7501001	STARLETTE	1- 9-1984	0:14: 8	18	0.6
7603901	LAGEOS	1- 9-1984	0:53:45	308	0.5
7603901	LAGEOS	1- 9-1984	19:58:23	592	0.5
7603901	LAGEOS	1- 9-1984	23:24:50	494	0.5
7501001	STARLETTE	2- 9-1984	19:22: 1	37	0.6
7501001	STARLETTE	2- 9-1984	21:10:17	259	0.6
7501001	STARLETTE	2- 9-1984	22:59:22	106	0.5
7603901	LAGEOS	2- 9-1984	22: 3:40	376	0.6
7603901	LAGEOS	3- 9-1984	20:43:38	37	0.6
7501001	STARLETTE	3- 9-1984	21:30: 6	173	0.5

Table B: List of Passes as per September,3