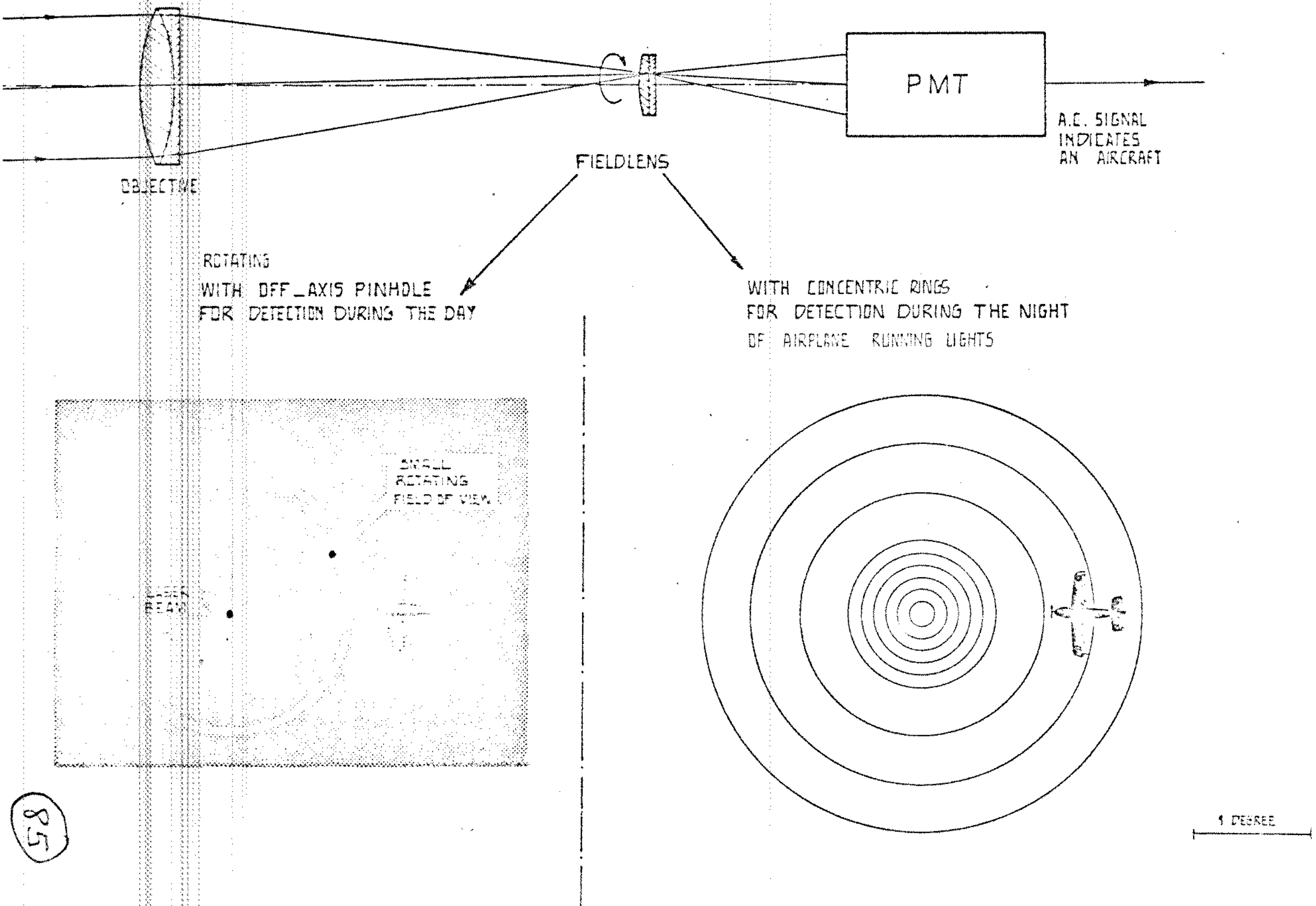

OBJECTIVE
FIELDLENS
PMT
A.C. SIGNAL
INDICATES
AN AIRCRAFT
ROTATING
WITH OFF_AXIS PINHOLE
FOR DETECTION DURING THE DAY
WITH CONCENTRIC RINGS
FOR DETECTION DURING THE NIGHT
OF AIRPLANE RUNNING LIGHTS
SMALL
ROTATING
FIELD OF VIEW
LASER
BEAM
1 DEGREE

figure 2

LONG DISTANCES MEASUREMENT ELECTRONIC SYSTEM

P. Hiršl, Vl. Krajíček, M. Pfeifer

Faculty of Nuclear Science and Physical Engineering

Prague, Czechoslovakia

If distances up to 5.10^5 km are to be measured with accuracy better then 15 cm there is necessary to use a clock with short term stability better then 3.10^{-10}. This claim could be satisfied by a good crystal oscillator.

Our electronic device allows the bind to the absolute time /UTC/ better then 1 μs, the accuracy of measured time intervals < 1 ns with resolution ± 0,3 ns.

Measured data represent the instants of start - stop pulses; start pulse from the laser and stop pulses from returns. Measured data are fed in a computer, or other installed hardware, to compute the time intervals.

The 5 MHz signal from the crystal oscillator is translated to 10 MHz square wave and counted by a synchronous counter. Data from the counter are fed in a shift register at the moments of start and stop pulses. After coming the stated series of pulses, one start pulse and three stop pulses, the data from the register, including the data from time expanders, are fed in the computer. Because at least two out of three stop pulses are supposed to be noise pulses the computer program must be able to recognize the right returns.

The transcription of measured data from the register is controled by a device programable from a keybord, computer or punched paper tape/Fig.6./. The data trascription can be made to an individual hardware device /magnetic tape recorder, paper tape puncher, printer or computer/ or to some of them simultaneously. Numerical display used for optical checking of applied program or of measured data makes the part of this device.

The basic period of the clock pulses is 200 ns. This interval is divided by time expanders up to 0,1 ns.

The expander is stretching the intervals between start or stop pulses and the next in time clock pulses/Fig.1./ As to diminish difficulties with mechanical construction there is used special system of automatic calibration. This is very useful because there is no need in using thermal stabilization of expanders, which is used for examle in the counter Hewlett - Packard 5360 A .

As for delays in the unit there are used common signal paths for all start and stop pulses as maximum as possible. Common path is used for all stop pulses and partially for start pulse too. As the next there is used double cycle operation of expanders. In the first cycle of operation one from the expanders is started by a start /or stop/ pulse and stopped by the second next in time clock pulse. The achieved value stretched in the expander is counted up by an up - down counter. In the second cycle of operation instead of start / or stop/ pulse there is fed in a clock pulse through the start / stop / signal path and the expander is started and stopped by two neighbour clock pulses. The interval measured must be 200 ns and its stretched value is counted down by the sama up - down counter. Because all signals are going through the same signal path the resultant preccision is quite high. The operation of an expander is shown on Fig.2.

The expander is started at the moment t and stopped by the second next clock pulse at the moment

$$t_H + d$$

where d is delay of the stop pulse coming through different way. The stretched interval in the first cycle of operation is then $k\,(t_H - t + d) = N_1\,T_o$

where N_1 is the number of clock pulses inside the stretched interval
T_o is the period of clock pulses.

The interval $t_H - t + d$ is chosen greater than T_o.

The second cycle is started after the end of interval $N_1\,T_o$. This time the expander is started by a clock pulse at the moment

$$t_H + N\,T_o$$

and stopped at the moment

$$t_H + d + (N + 1)\,T_o$$

where $N > N_1$.

This second interval is stretched by the same way as in the first cycle of operation.

By the assumption the interval between both cycles is short enough to hold the same conditions for expander function that means

$$k = \text{const}, \quad d = \text{const},$$

the stretched interval in the second cycle of operation is

$$k\,\big(t_H + (N + 1)\,T_o + d - (t_H + N\,T_o)\big) = k\,(T_o + d) = N_2\,T_o .$$

The difference of both stretched intervals is

$$(N_1 - N_2)\,T_o = k\,\big((t_H - t + d) - (T_o + d)\big) = k\,(t_H - t - T_o) .$$

That means that mode of operation eliminates the influence of delays. The difference $N_1 - N_2$ is read on the up - down counter.

In this mode of operation there is necessary to control only one of parameters, the parameter k, by means of a special feedback circuit. The number of expanders is chosen for one greater than needed in both groups of pulses and all the time one of each group is calibrated alternatively. In the time the expander is calibrated it is started by a clock pulse in the first cycle of operation too as in the second cycle. Then it is stopped after two periods of clock pulses by means of the path with delay d. The stretched interval will have the length

$$N_1' T_0 = k \left(2 T_0 + d \right).$$

The second cycle of operation is the same as above. Its stretched length will be

$$N_2 T_0 = k \left(T_0 + d \right).$$

The difference of both expessions

$$(N_1' - N_2)\ T_0 = k\ T_0$$

that means $N_1' - N_2$ is the actual value of the parameter k.

If there is no agreement between the actual value and required value of k the feedback calibration is led in action and some of parametrs of the expander are changed to get

$$N_1' - N_2 = k\ .$$

The block diagram of the whole device is on Fig.3. The block diagrams of start and stop pulses are on Fig.4. resp. Fig.5. The selected value of the parameter **k** is

$$k = 1000\ .$$

The time interval resolution of the system is 0,1 ns, with jitter of expanders ± 0,3 ns and accuracy of time interval < 1 ns.

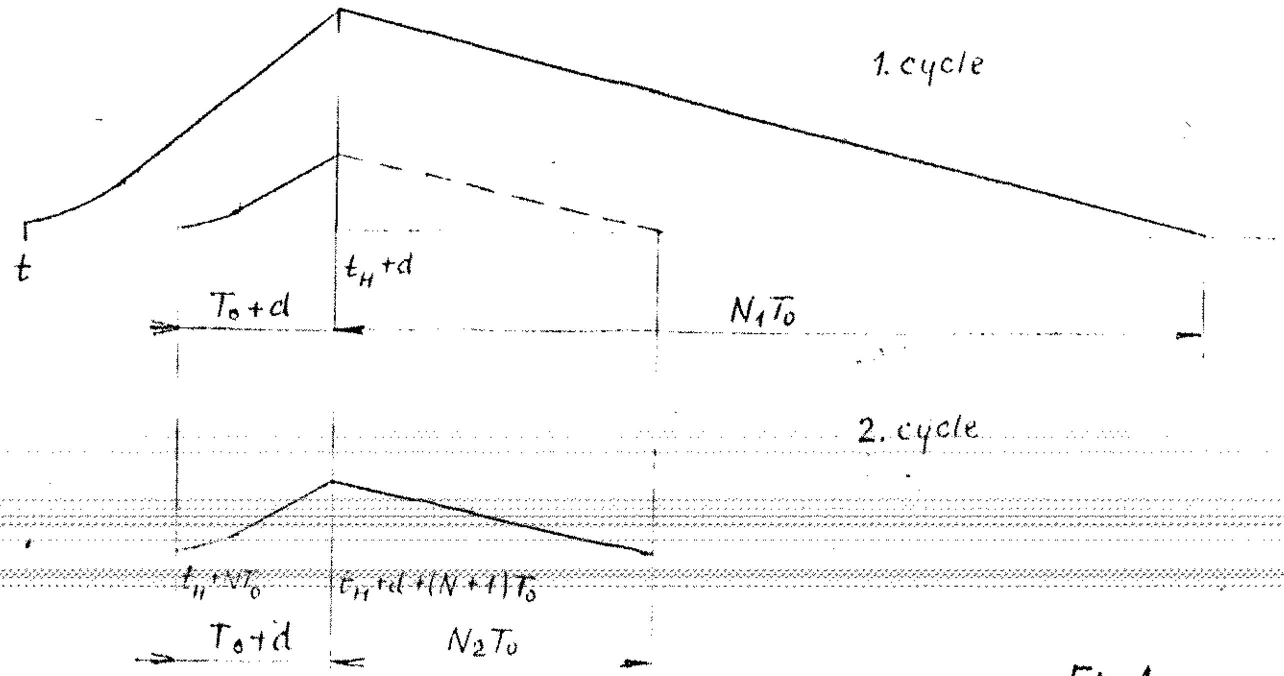
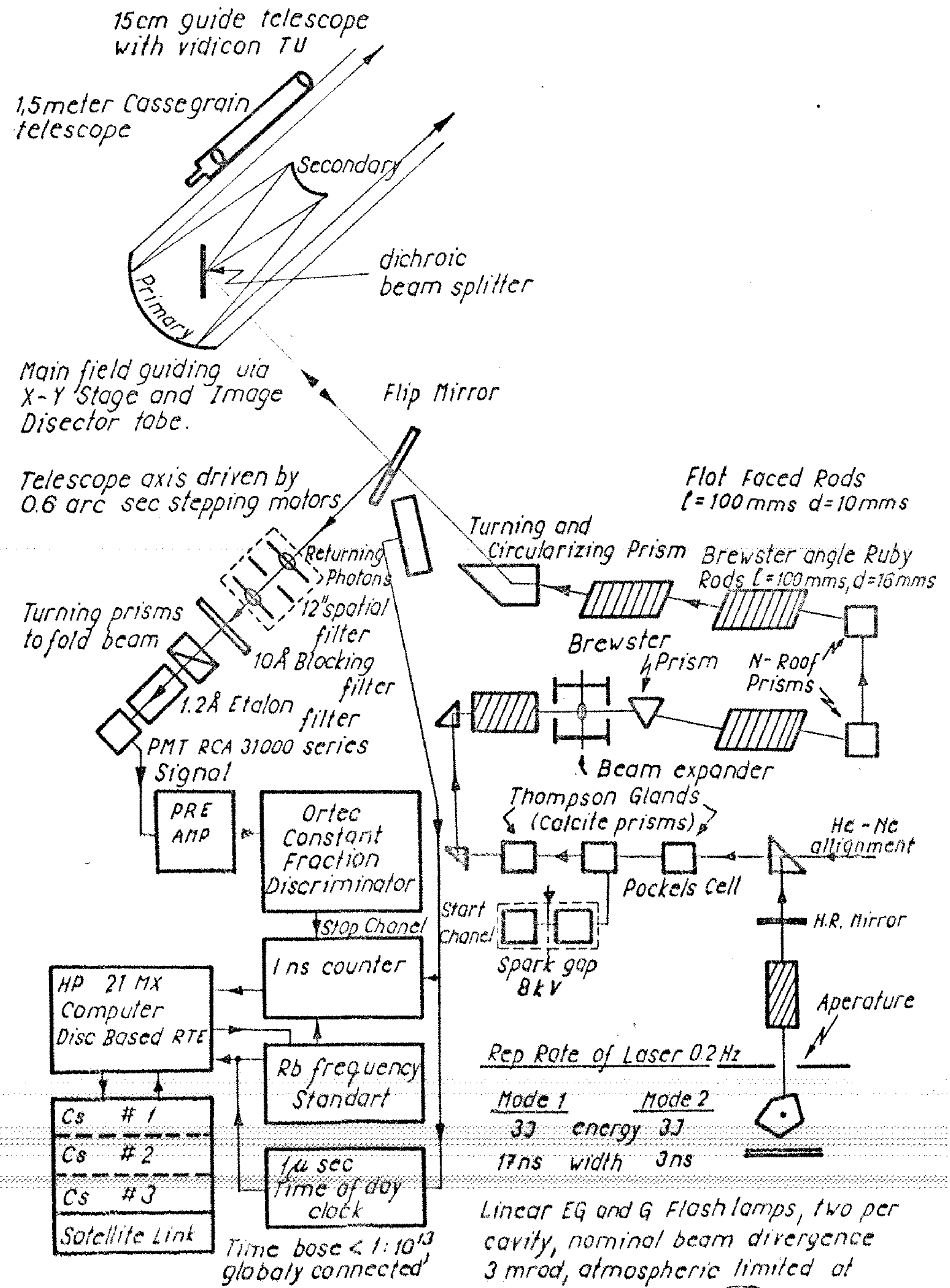


Fig. 1.

A Schematic of the Australian Lunar Ranger

P. Morgan



Rep Rate of Laser 0.2 Hz

Mode 1		Mode 2
3J	energy	3J
17ns	width	3ns

Linear EG and G Flash lamps, two per cavity, nominal beam divergence 3 mrad, atmospheric limited at transmission.

INTERKOSMOS SATELLITE FOR LASER RANGING.

Pavel NAVARA [+/].

ABSTRACT:

The basic data of the INTERKOSMOS satellite AUOS-Z, that as the first IK satellite enables laser ranging, are presented. The satellite orbital data, the description of the corner cubes panel, the brief explanation of the technical solution as well as the preliminary satellite technical parameters are summarized. The parameters depending on the final technical realization /like the transfer function/ are omitted and will be supplied in the report that is prepared for COSPAR Plenary Meeting 1976.

+/

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THE SATELLITE LASER RADAR WITH IMPROVED PARAMETERS.

P. NAVARA, Astronomical Inst. Czech. Ac. of Sciences.

SHORT PRELIMINARY INFORMATION:

The satellite laser radar with the improved technical parameters /compared with Interkosmos laser radars in the action now/ will be complected on Ondrejov Observatory at the end of this year. We suppose the following technical parameters / the cross marks the realized instruments till now/.

TRANSMITTER+ /one stage ruby laser/: Faculty of Nuc. Phys. Prod.

Output power	~ 100 MW
Pulse length	< 15 nsec
Repetition rate	60 ppsec
Output beam divergence	0.5 ÷ 1 mrad /first version/ + 0.1 mrad /second version/

RECEIVER /Cassegrain - Manging/+: Astronom. Inst. Prod.

Diameter		630 mm
Filter	HBW =	1 Å T ~ 20%
PMT	RCA	C 31 000 /ERMA/.
Field of view		0.1 mrad /according to tests/

MOUNT /two axes/ : Škoda Plzeň Prod.

Pointing accuracy	5 arc sec
Axes step	10 arc sec
Stepping motor	1.5 deg/step, step accuracy 0.5 deg. +
Tracking	punched tape /first step/ + minicomputer /second step/

ELECTRONICS:

Time base	5 µsec +
Universal counter	1 nsec /aut. addaptive thr. level/ +
Absolute time	0.1 usec /TV comparision with OMA osc./ +
Range gate	programmable

We wish to reach the accuracy better then 0.5 m and the action radius during the second step realisation 10 ÷ 20 Mm.

A NOVEL CENTIMETER ACCURACY, SUBNANOSECOND DOUBLE-PULSE SATELLITE LASER RANGING METHOD

Matti V. Paunonen

All current laser ranging systems are using single pulses. In this case discrimination against noise pulses is not very effective, and therefore for reliable detection a considerable number of return photoelectrons are needed. The use of multiple laser pulses to discriminate against background /1/ or to get greater accuracy or efficiency /2/ is known, but perhaps for technical reasons not used.

The proposed ranging method is based on the use of a precise double-pulse. In the detection process two signal pulses are needed, single or multiple photoelectrons, with known spacing, fig. 1 .

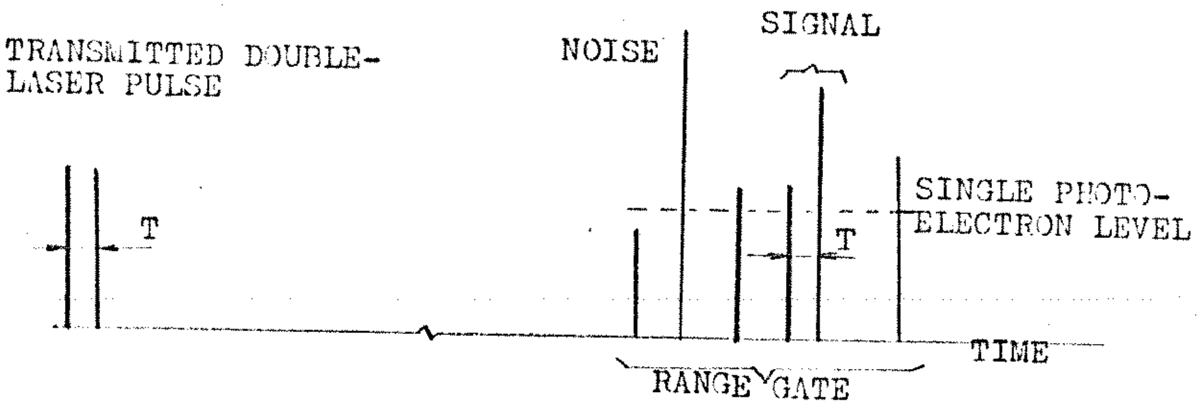

Fig.1. Double-pulse ranging method

The advantages of this system are: a) Automatic discrimination of background to a high degree. It is rare that during night time there appears two noise pulses with short spacing, say 5 ns, b) Effective received energy is increased without having to increase the transmitter power. The basic time resolution is better with two pulses than with only one. c) Detection is extended to a single photoelectron level.

The accurate double-pulse generation can be accomplished by slicing a Q-switched pulse or isolating two adjacent mode-locked pulses.In this proposal slicing is preferred for the following reasons: a) Both Q-switching and slicing methods are well proved b) Pulse length is easily adjustable, c) Relatively easy to accomplish d) Pulse quality is good. e) Well-suited for the double-pulse method. f) The same system can be used normally Q-switched or sliced at will. The shortening of the diffraction limited Q-switched pulse can be accomplished by a fast 50 ohm Pockels cell electro-optical shutter. driven by a laser triggered spark gap. A short pulse can be obtained by pulsing the Pockels cell with a short Vλ/2-pulse, whereas the double pulse formation needs two times Vλ/2-voltage. There are also three possible operating modes with this system, fig.2. The Q-switched pulse may be useful in preliminary seek of the satellite before precision measurements. With some commercially available Pockels cells and LTSGs one can obtain at least 0,5 ... 1 ns pulse widths.

The receiving method is straightforward and simple. Two photomultiplier pulses,comprising single or multiple photoelectrons,

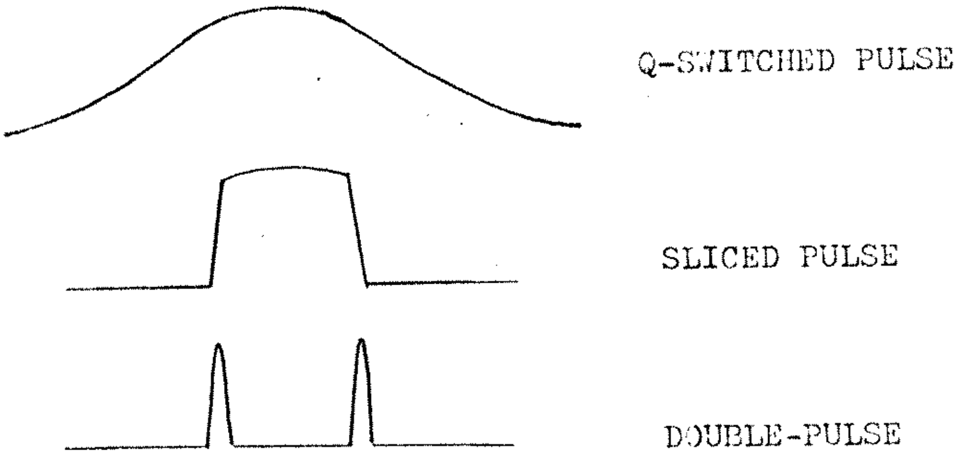

Fig.2. Operational modes of the system

separated in time by T, are needed for detection. The pulse sequence is detected, and using a simple delay line both the pulses are linearly multiplexed and processed e.g. in a CFD-discriminator to take care of pulse height variations. Modern PMT's have single-electron transit time spread about 300 ps or less. Possible electronic resolution seems to be some tens of picoseconds in a dynamic range of 1:200. Also modern interpolating range counters give a resolution of better than 100 ps. The total receiving resolution is near 300 ps (FWHM) in this case.

If a 1 ns bell-shaped pulse is supposed, the standard deviation of the the double-pulse system might be 5 cm in a single measurement even at minimal conditions, i.e. one photoelectron in both the sub-pulses.

Also the use of closely rectangular pulses, say 5 ns long , is interesting. It has been shown/3/ that the minimum-square-error with rectangular pulses decreases quadratically as the photoelectron number. Also the timing method is worth noticing: the optimum estimate for time measurement is the mean value of the first and last photoelectron pulse.

References:

/1/ S.Ackerman, T.S.Morrison, and R.L.Iliff: A programmed multi-pulse range measurement system. Appl.Opt. 6(1967)353.

/2/ I.Bar-David: Communication under the Poisson regime. IEEE T. Inf. Theory IT-15(1969)31.

/3/ I.Bar-David: Minimum-mean-square error estimation of photon pulse delay. IEEE T. Inf. Theory IT-21(1975)326.

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SF-02150 ESPOO 15, Finland

RELIABILITY AND LASER HAZARDS

Michael Pearlman

This session concentrated on the issue of aircraft safety. The general concensus of the attendees was that most attention should be devoted to our interaction with local authorities, since current laser exposure standards for the eye are extremely conservative and, in general, authorities appear to be overreacting to the situation.

Representatives from each group currently operating or planning to operate laser ranging systems were asked to discuss their programs for aircraft safety.

Many of the groups have agreements with local agencies for restricted air space based on location and schedule. Most of the groups reporting use spotters, either direct visual or with T.V. Several groups had performed analyses to show the extreme remoteness of an aircraft being struck by a laser beam.

Dr. F. Zeeman from the Netherlands described an optical scanning system that his group is building to detect aircraft in the vanicity of the laser beam during both daytime and nighttime conditions. Dr. P. Morgan from Australia discussed a precursor pulsing system using a small laser to check the beam direction before his lunar ranging system is fired.

The attendees agreed that we should make literature on eye safety readily available. Each member was requested to send pertinent material or biographies to Dr. M. Pearlman of the Smithsonian Astrophysical Observatory who will distribute copies to requesting individuals.

THE NEW TELESCOPE OF THE LASER STATION AT ZIMMERWALD

M. Schürer, W. Lüthy

Astronomical Institute, University of Berne

A new telescope system for laser satellite telemetry, placed on a biaxial horizontal mounting, has been constructed for the Zimmerwald astronomical observatory. The system is charakterized by using the main mirror simultaneously in the receiver and the sighting telescope. The sighting telescope is equipped with a TV system designed to allow observation of objects of a magnitude up to 9.5 .

In the domain of satellite telemetry by means of laser radar systems optical components are used for transmitting and receiving the laser pulses. These optical components have to be mounted in a way to permit the tracking of a satellite. Up to now such possibilities have not been available at Zimmerwald. Therefore, a new laser telescope has been designed for this laser station. The instrument has been constructed at the Astronomical Institute of the University of Berne. The mechanical components have been completed and the optical components, the main mirror and several lenses, are presently under construction.

The laser telescope is mounted horizontally, the two axes being horizontal and vertical respectively. The two axes are driven by a stepping motor each permitting an angular resolution of 2.7 seconds of arc in elevation and 5.4 seconds of arc in azimuth. The stepping frequency of the motors is controlled manually with the aid of two potentiometers while observing the satellite in the sighting telescope.

The mounting carries the optical and electrical components of the sighting telescope, the receiver of the laser telemeter and the transmitter optics. The laser output is guided to the transmitter optics (1:5 beam expander) by means of a Coudé [illegible] system. The mechanical construction of the receiver and sighting part of the telescope is made up of glued aluminium tubing and sheet metal for good stability and light weight. A schematic view of the whole instrument is given in Figure 1 .

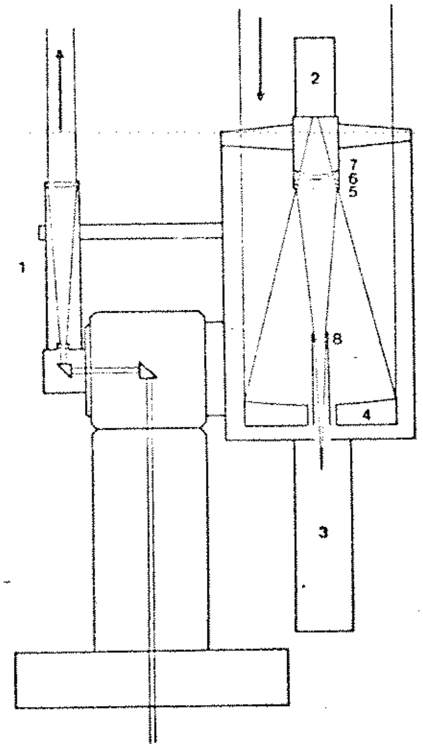


Fig. 1. The Zimmerwald laser tracking telescope.
1: beam expander
2: TV camera
3: photomultiplier
4: main mirror
5-8: lenses

The telescope for receiving the retroreflected laser light is a modified Cassegrain-type instrument. The spherical main mirror (4) has a diameter of 52.5 centimeters and a focal length of one meter. The second mirror used in usual telescopes is replaced by a system of three lenses (5-7). The front of the lense (5) facing the main mirror has a dielectric coating for optimum reflectance at the laser wavelength

The resulting focal length of the system at this wavelength is 3 meters. This focal length is enlarged up to 4.5 meters with a Barlow lense (8). Subsequently, the laser light passes a mechanical shutter, interference filter and Fabry lense after which it is detected by an RCA 7265 photomultiplier (3).

The sighting telescope views the sky in the light transmitted through the dielectrical mirror (5). Three correcting lenses (5-7) assure good image quality on the cathode of the TV camera (2). The most important advantage of the optical system described above is the large entrance diameter of the sighting telescope. It makes it possible to use a TV camera of relatively low sensitivity and therefore low cost.

A Grundig FA 42 S camera is used in the sighting telescope. The field of view covers an area of 33 x 44 minutes of arc with a focal length of one meter. The resolution is 3.2×10^5 points in the picture plane corresponding to a bandwith of 8 megacycles. The TV system is designed for observation of objects up to a magnitude of 9.5 if the object does not move in the picture plane. The visibility of objects passing the field of view in a time interval of one second is reduced to magnitudes of about 8.

We would like to thank Messrs S. Röthlisberger and W. Schaerer for their expert help in the construction and design of the instrument.
We further acknowledge the financial support of the Swiss National Foundation.

FUTURE PLANS: A MOBILE LUNAR LASER STATION

The University of Texas has been involved for some time in the design of a transportable lunar laser ranging station. It is hoped to start construction on this system in the near future so that it may be used for validation tests in late 1977. Table 1 presents the basic specifications for this system as they are currently envisioned. Figures 1, 2 and 3 are largely self-explanatory and we present them without further comment.

E. C. Silverberg
Fort Davis, Texas
July 21, 1975

Table I

Basic Specifications of the University of Texas Mobile Lunar Laser Station

I. Telescope

- A. Aperture: 0.8 single transmitting, receiving, and guiding aperature
- B. Configuration: alt-alt, symmetric yoke or cradle mount with fixed laser coude focus
- C. Field of view: 30 arc minutes at the folded Cassegrain guide focus and 14 arc seconds at the Coude focus

II. Laser

- A. Type: frequency doubled, mode-locked neodymium system
- B. Energy per pulse: 150 millijoules
- C. Pulse width: approximately 200 picoseconds
- D. Repetition rate: 10 hertz
- E. Beam divergence: less than 10 times diffraction limit

III. Guiding: Computer biasing the telescope track rate via a T. V. sensor which is offset to the edge of the moon. Observer correction using the visual display of the image is also available.

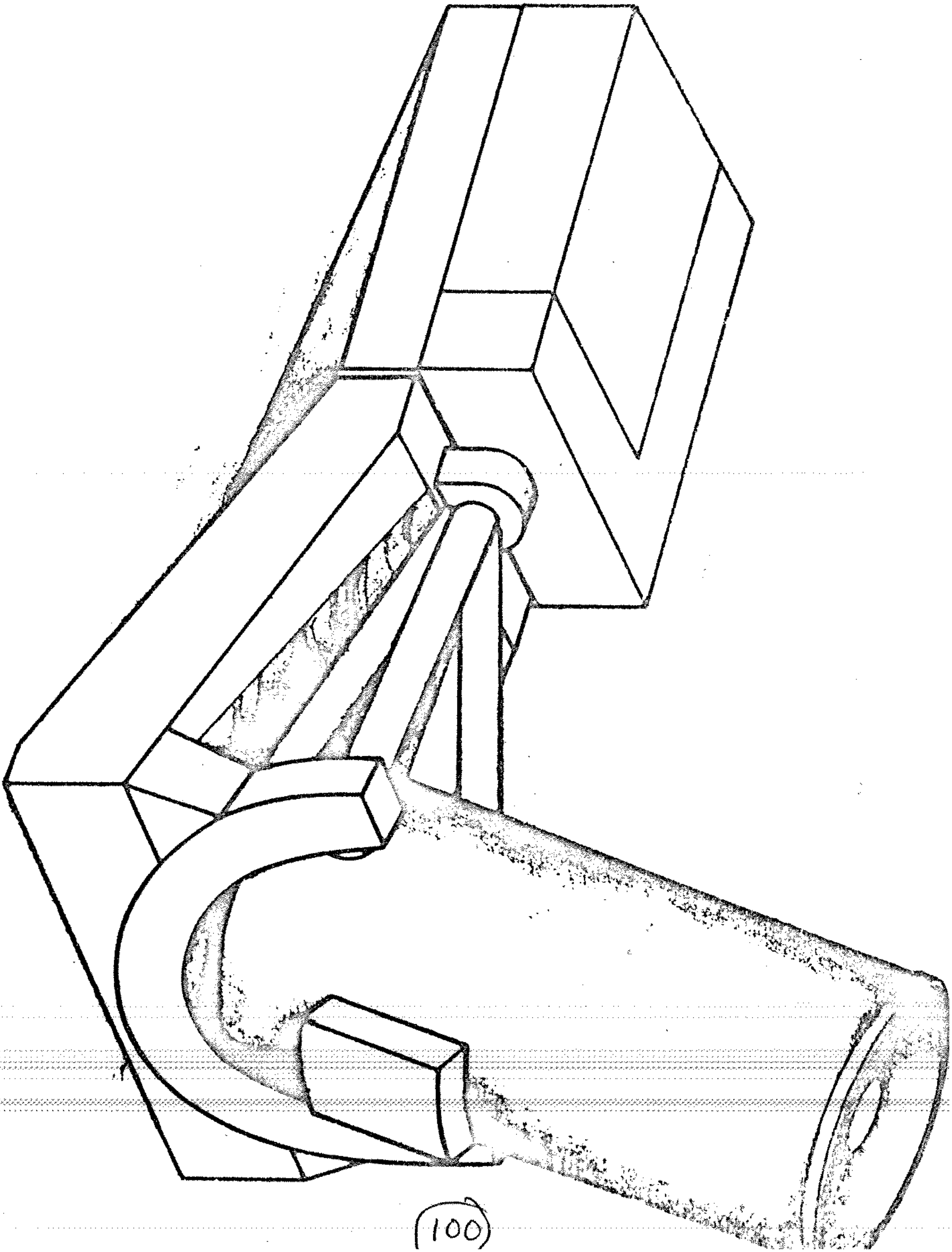
IV. Detector

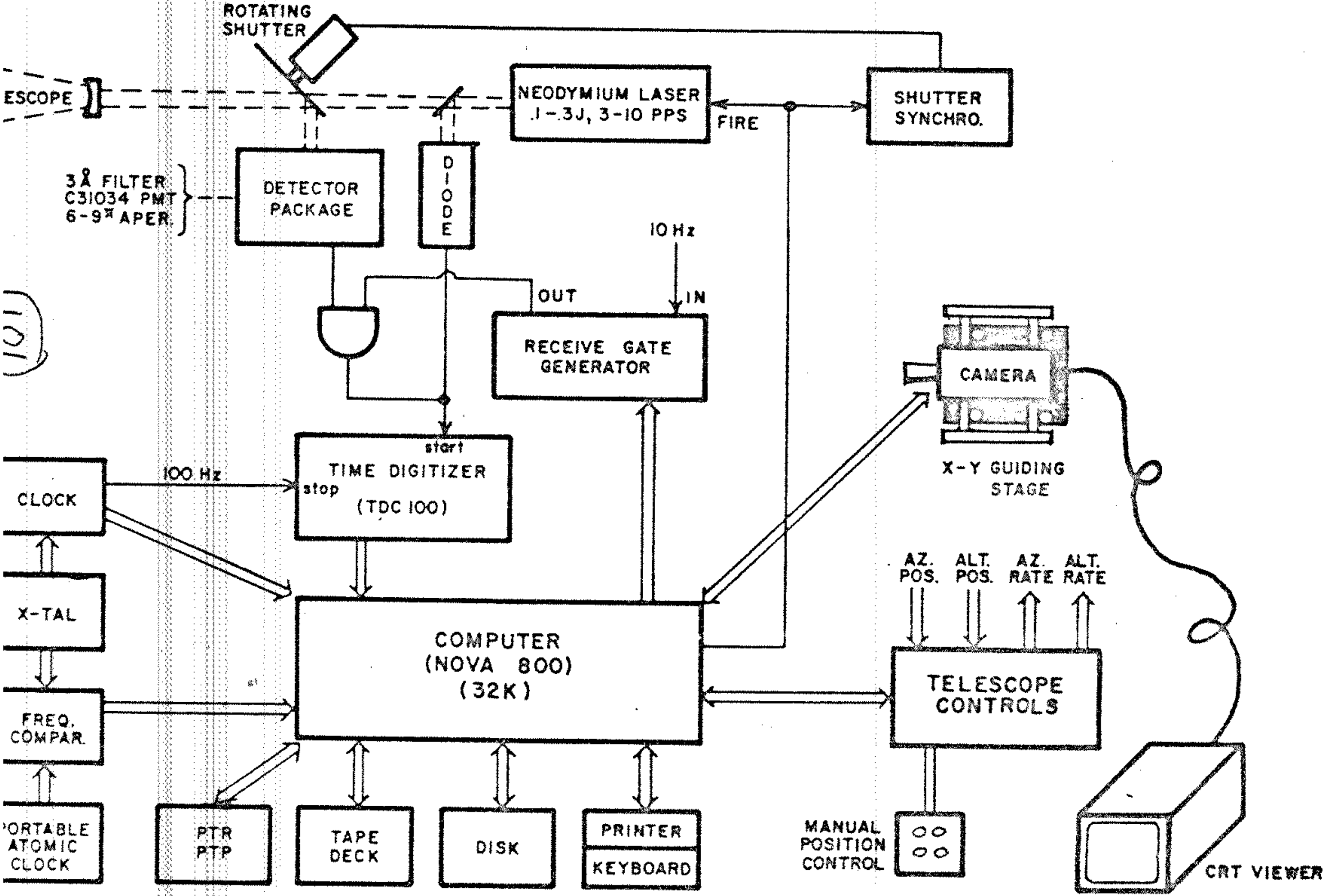
- A. PMT: Ga-As photomultiplier
- B. Spacial filter: approximately 6 arc seconds
- C. Spectral filter: 3 angstrom, conventional interference filter

VI. Single shot uncertainty: approximately 0.7 nanoseconds

VII. Calibration accuracy: better than 100 picoseconds

VIII. Accuracy: 3 centimeter ranging accuracy on the Apollo 15 corner reflector with less than 10 minutes of firing in 5 arc second seeing conditions.




ROTATING SHUTTER
ESCOPE
NEODYMIUM LASER .1-.3J, 3-10 PPS
FIRE
SHUTTER SYNCHRO.
3Å FILTER
C31034 PMT
6-9" APER.
DETECTOR PACKAGE
DIODE
10 Hz
IN
OUT
RECEIVE GATE GENERATOR
CAMERA
X-Y GUIDING STAGE
start
TIME DIGITIZER
stop
(TDC 100)
CLOCK
100 Hz
X-TAL
FREQ. COMPAR.
PORTABLE ATOMIC CLOCK
COMPUTER (NOVA 800) (32K)
AZ. POS.
ALT. POS.
AZ. RATE
ALT. RATE
TELESCOPE CONTROLS
PTR PTP
TAPE DECK
DISK
PRINTER
KEYBOARD
MANUAL POSITION CONTROL
CRT VIEWER

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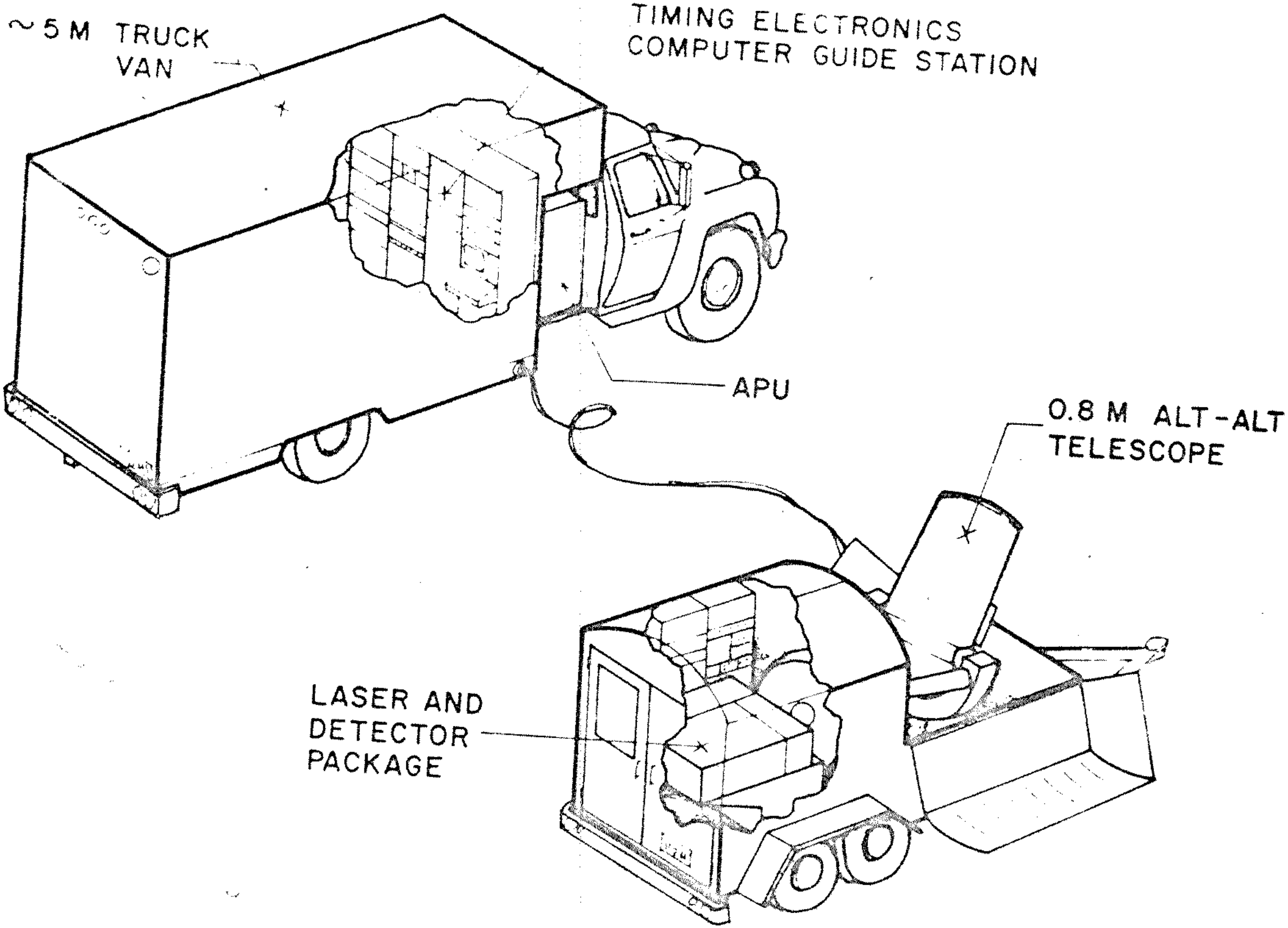


FIGURE 3 : ARTIST'S VIEW OF THE MOBILE LUNAR LASER STATION

ENCOURAGING THE DUAL PURPOSE STATION: AUTOMATED LUNAR GUIDING

by

E. C. Silverberg
McDonald Observatory
Fort Davis, Texas 79734

The Lageos satellite which is to be placed in orbit in 1976 will require the use of techniques which more nearly approach lunar laser ranging than those used for the earlier low altitude satellites. It is our contention that many of the ground stations designed for Lageos can, with minor modification, be also capable of a program of lunar laser ranging. This note is to encourage the development of dual purpose capability wherever possible.

A lunar laser ranging system will have a sufficient signal to noise ratio, even at full moon, if the transmitted energy exceeds approximately 50 millijoules per pulse. Since most satellite systems exceed this criterion very easily we shall continue. Our experience at McDonald Observatory indicates that the return from the Apollo 15 corner reflector averages approximately 6 photons per meter^2 per joule transmitted, under moderately good seeing conditions. Using this empirical criteria we can deduce that a system will have sufficient size to acquire the Apollo 15 corner reflector if the product of its (aperture) x (average power transmitted) x (receiver efficiency) exceeds a certain minimum value. Including the beam divergence (Θ), we get the following formula as an indication of the minimum size laser ranging station which can successfully range the Apollo 15 lunar corner reflector.

$$\frac{A(m^2)\cdot P(\text{watts})\cdot e(\%)}{\Theta^2\ (\text{arc sec})} \geq .03\ m^2\cdot\text{watts}\cdot\%/(\text{arc sec})^2$$

In other words, a 0.6 meter receiver with a 2% overall efficiency, operating in conjunction with a one watt (average power) transmitter, will just qualify as a potential lunar ranging system, if the transmitted beam divergence is approximately 4 arc sec. Many future satellite ranging systems may qualify as potential lunar ranging systems under these criteria. The one major remaining question is whether or not the proper guiding techniques can be developed to hold the narrow divergence beams on the lunar target for a high percentage of the time. The rest of this short note is to present a mode of automatic guiding which can make lunar ranging operationally similar to satellite ranging and, we hope, encourage the consideration of a number of dual purpose ranging installations.

The techniques for guiding differ more than in any other technical area between the lunar and satellite systems. To date, almost all the lunar ranging has been done with manual pointing, relying strictly on an observer's ability to recognize the proper place at which to point the telescope. The satellite guiding, on the other hand, is primarily automatic using precalculated positions. From an operational standpoint it is highly desirable if the lunar guiding could be automated to the extent that extensive personnel training is not required to locate a corner reflector on the lunar surface. The ideal solution would be to be able to rely on absolute pointing. One or two arc second absolute pointing, however, is a very difficult engineering problem which has not (to this investigator's knowledge) become routine on any instrument of 0.5 meter size or larger. It is hoped that a simpler system can be found which uses a closed loop optical feedback from some portion of the lunar image. McDonald Observatory is currently attempting to develop such a mode of operation both for the Fort Davis installation as well as a proposed transportable station.

The lunar surface is an exceedingly difficult object for which to design any automatic guiding system. Since the characteristics of any particular site change considerably from day to day and from night to daylight ranging conditions, it is hard to envision any but the most sophisticated systems using image recognition on the surface itself. The lunar edge, on the other hand, does have sufficient contrast to be discernable, even a few days from new moon, and benefits further from the fact that its simple shape can be recognized by a minimal computer program.

The geometry which we propose for an automatic guider is shown in Figure 1. An area detector is aligned to some zero location relative to the outgoing laser beam and then offset the approximate distance from the corner reflector site from the edge of the moon. The detector beam only covers about one square arc minute of surface area such that arc sec quality resolution can be obtained without necessitating a great deal of information storage. At the edge of the moon the detector is automatically positioned so that the limb bisects its area. The image is now read into a small computer which uses a least squares algorithm to calculate the angle of the limb relative to the orientation of the array (Θ). Knowing this angle, the geometry of your instrument and the lunar attitude at that time you can then deduce the surface coordinates (Xi_E, Eta_E) for the point at which the tangent line is parallel to the edge. Given the surface coordinates of that point on the limb and Xi and Eta of the target, it is then a simple matter to calculate the relative offsets (Δx and Δy) which are required to place the center of field at a corner reflector site.

While the hardware requirements for the scheme are relatively simple, the calculation does require considerable software, particularly for a small computer. We have used a 32 x 32 array of silicon diodes to create a computer-readable image at the edge of the moon. In order to simplify the software calculations we will align the columns of the diode array to true North/South and rotate the camera and X-Y stage at lunar rate. To date we have completed the software for calculating Δx and Δy as a function of x_{IT}, Eta_T and Θ, but have not yet checked out the accuracy of the algorithms for measuring Θ. The angle Θ must be found to about 5 arc minutes to calculate coordinates for that point on the edge which have arc second precision. We hope that such a system will permit us to make a completely automated laser run within about two years, in time to lead to a truly operationally acceptable system for lunar laser ranging.

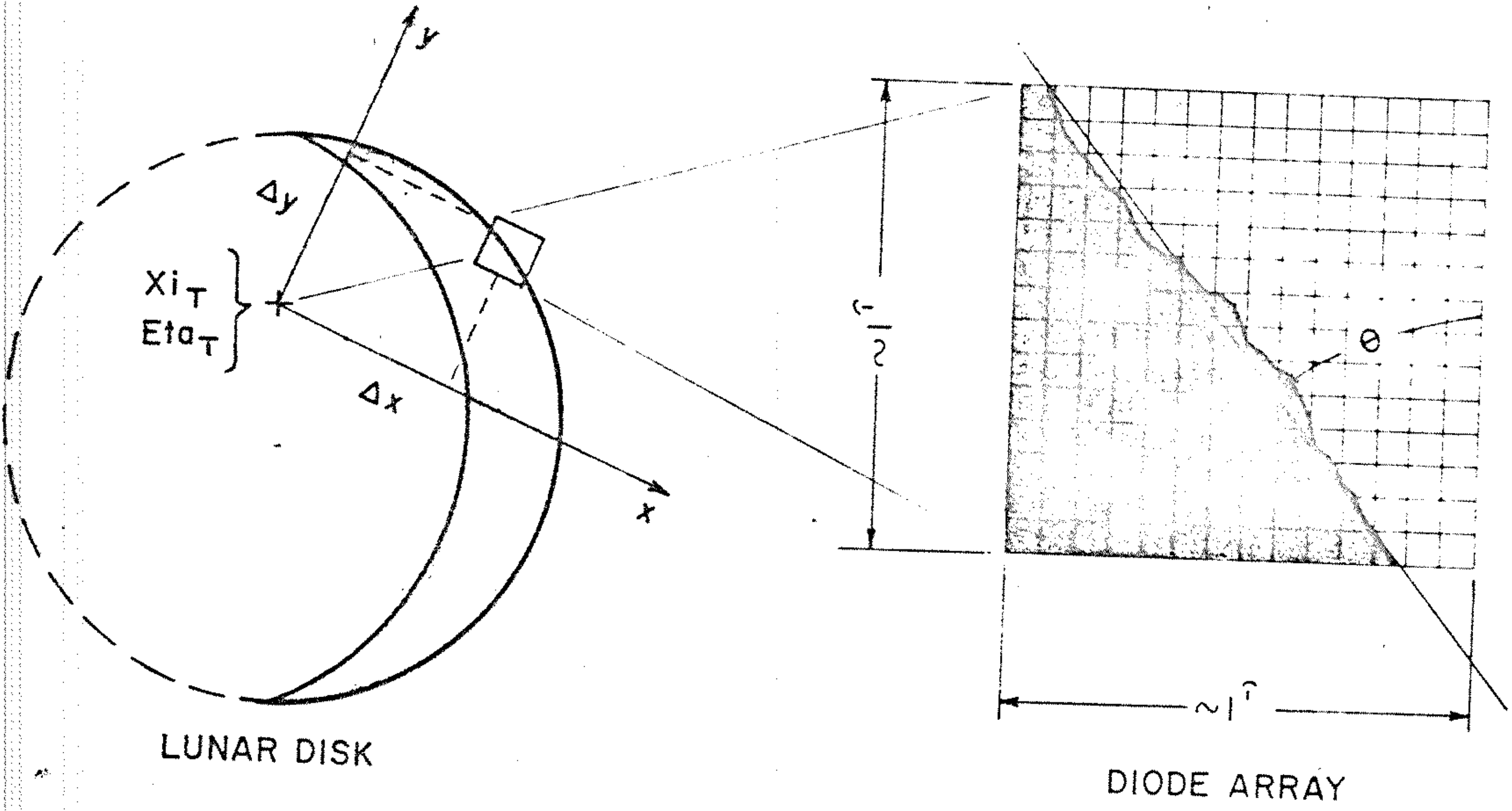


FIGURE I: GEOMETRY OF THE PROPOSED AUTOMATIC GUIDING SCHEME

Preliminary Plan of the Earth Satellite Tracking Station at the Mizusawa Latitude Observatory

Sigetugu Takagi
The International Latitude Observatory of
Mizusawa

1. In consideration of the recent development of new techniques of observation in the field of geodynamics, the Mizusawa Latitude Observatory decided to make a plan to establish a satellite tracking station at or near the Observatory.

Our works based on this tracking station will be chiefly to promote investigations of the pole motion obtained from results of observation independent of the astronometric method.

2. Doppler Satellite Station.

We have started a test program of pole coordinate determination based on the Doppler satellite observation since February 1974. We are making studies on the pole motion by means of results obtained from the Doppler satellite observations. We have two kinds of data , that is, pole coordinates and the latitude and longitude at the Doppler station.

A merit of Doppler satellite observations is in the point that we can obtain results of observation with accuracy of ± 50 cm in all weather. A new Doppler station are now under investigation sponsored by the Defense Mapping Agency of U. S. A. We have an intention to settle an up-to-date s station to make studies on the pole motion at our Observatory in the near future.

3. Laser Ranging Station.

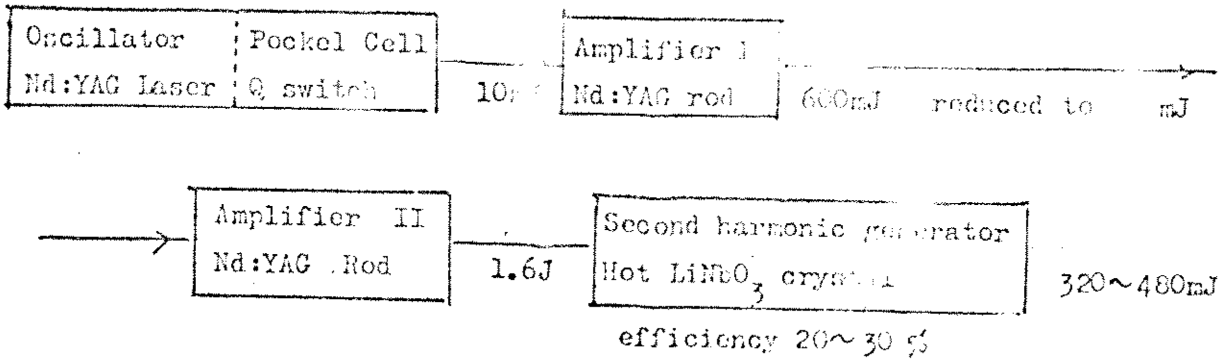
In Japan, several Institutes and Laboratories have [illegible]led the Laser Ranging system for scientific and geodetic purpose. The accuracy of Laser ranging is expected to be improved to about ± 10 cm in the near future. After we attain this goal, we will be able to develop our studies on the pole motion with more accurate data based on the satellite observation. It will be desireable for us to establish a Laser ranging station near the Mizusawa Observatory simultaneously with the Doppler satellite and astronomical observations. We have many advices and informations on the Laser techniques from the Tokyo Astronomical Observatory. We have a future plan of a Laser ranging station. The Laser tracking system will be almost the same with those of the Tokyo Astronomical Observatory, but we have an idea to replace Ruby laser in the emitter by a Nd:YAG laser.

4. Block Diagram of the emitter.

Data for Nd.Yag laser:

Wave length	0.53 micron (second harmonics of 1.06 micron)
Output energy	more than 200 mJ (TEMoo mode)
Pulse duration	5 ns
Repeating frequency	10 pps
Beam divergency	0.5 mrad.

Block Diagram



We compared the returned signal from GEOS-C for emitters with Ruby-Laser and Nd:YAG Laser by the foumulae given in H.H.Plotkin's paper.

$$S_0 = \frac{P_T G_T G_R \lambda^2 \sigma L_S}{(4\pi)^3 R^4}$$

		Ruby Laser		Nd:YAG Laser	
		DB	Value	DB	Value
P_T	Power Transmitted	0.	1J	- 5.2	0.3J
G_T	Transmitt er Gain	81.1	$\Theta_r = 5\times10^{-4}$		
G_R	Receiver Gain	127.1	$D_R = 0.5$m		
λ^2		-123.2	$\lambda = .6943$	-130.7	$\lambda = .53$
σ	Radar Cross Section				
	$\sigma = N\frac{\pi}{36}\frac{A^2}{2}$	82.5	$D_C = 3.5$ cm N = 270		
$(1/4\pi)^3$		-33.0			
$1/R^4$	Range	-238.7	$R = 9.27\times10^5$ m		
L_S	System Losses	-11.1	$\rho = 7.8$ %		
S_0	Received Signal	-115.3	2.95×10^{-12}J	-122.8	5.25×10^{-13}J

$$Ns = \eta \frac{S_0}{H\nu}$$

		Ruby Laser		Nd:YAG Laser	
		DB	Value	DB	Value
η	Quantum Efficiency	- 17.0	0.02	- 10.0	0.10
$(H\nu)^{-1}$	Photon Energy	185.4			
N_S	Received Photonelectrons	53.1	2×10^5	52.8	1.9×10^5
N'_S	G EOS-C Array = 0.05 N_S		10^4p.c.		9.5×10^3 p.e.

The above data are taken from the paper "Plotkin, H.H. ; Laser Technology for High PRECISION Satellite Tracking. Proc. Symposium on Earth's Gravitational

LASER-RANGING AT THE SATELLITE OBSERVATION STATION IN WETTZELL /BRD/

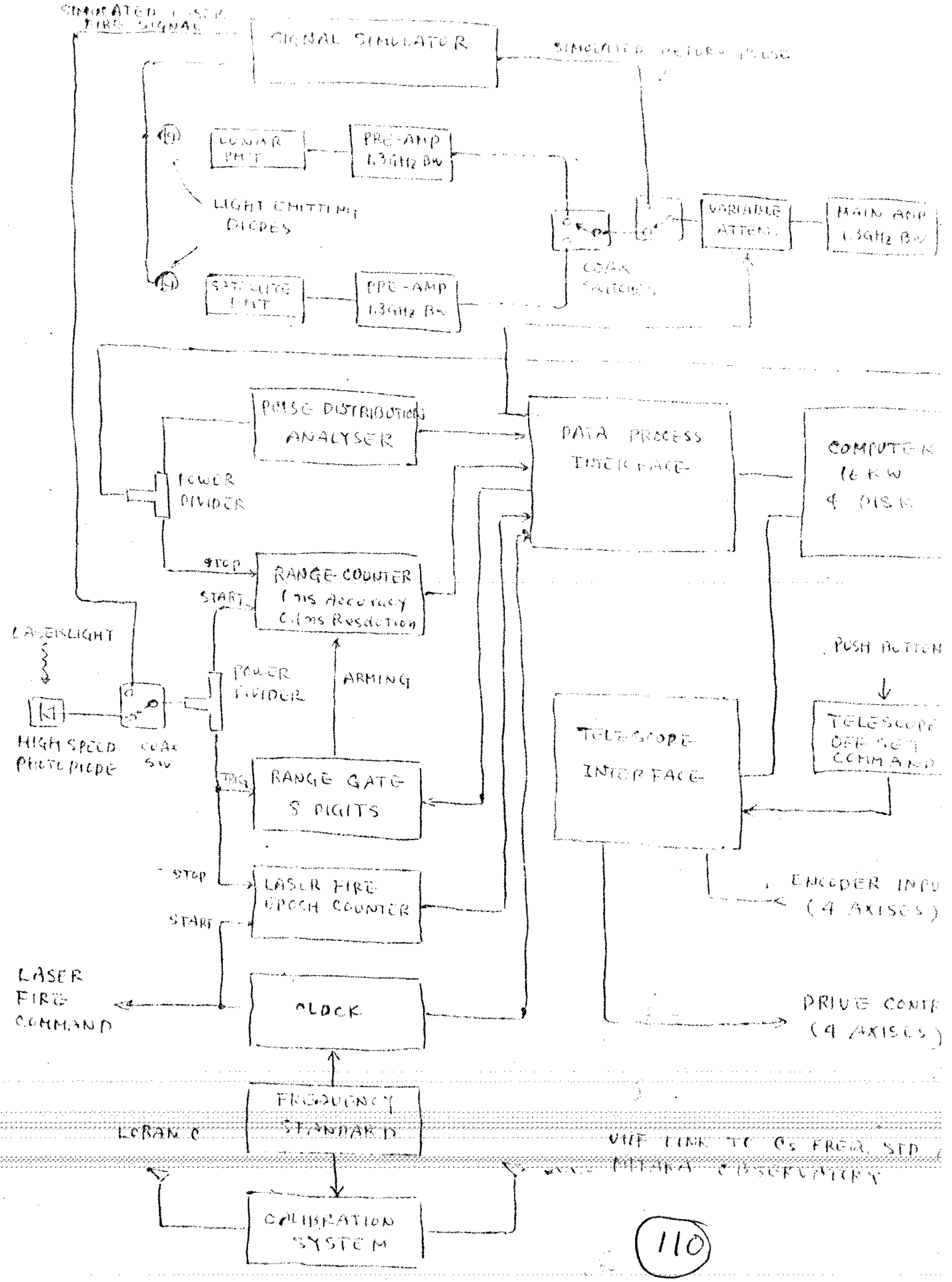
Peter Wilson, Hermann Seeger, Klemens Nottarp

1. The current system

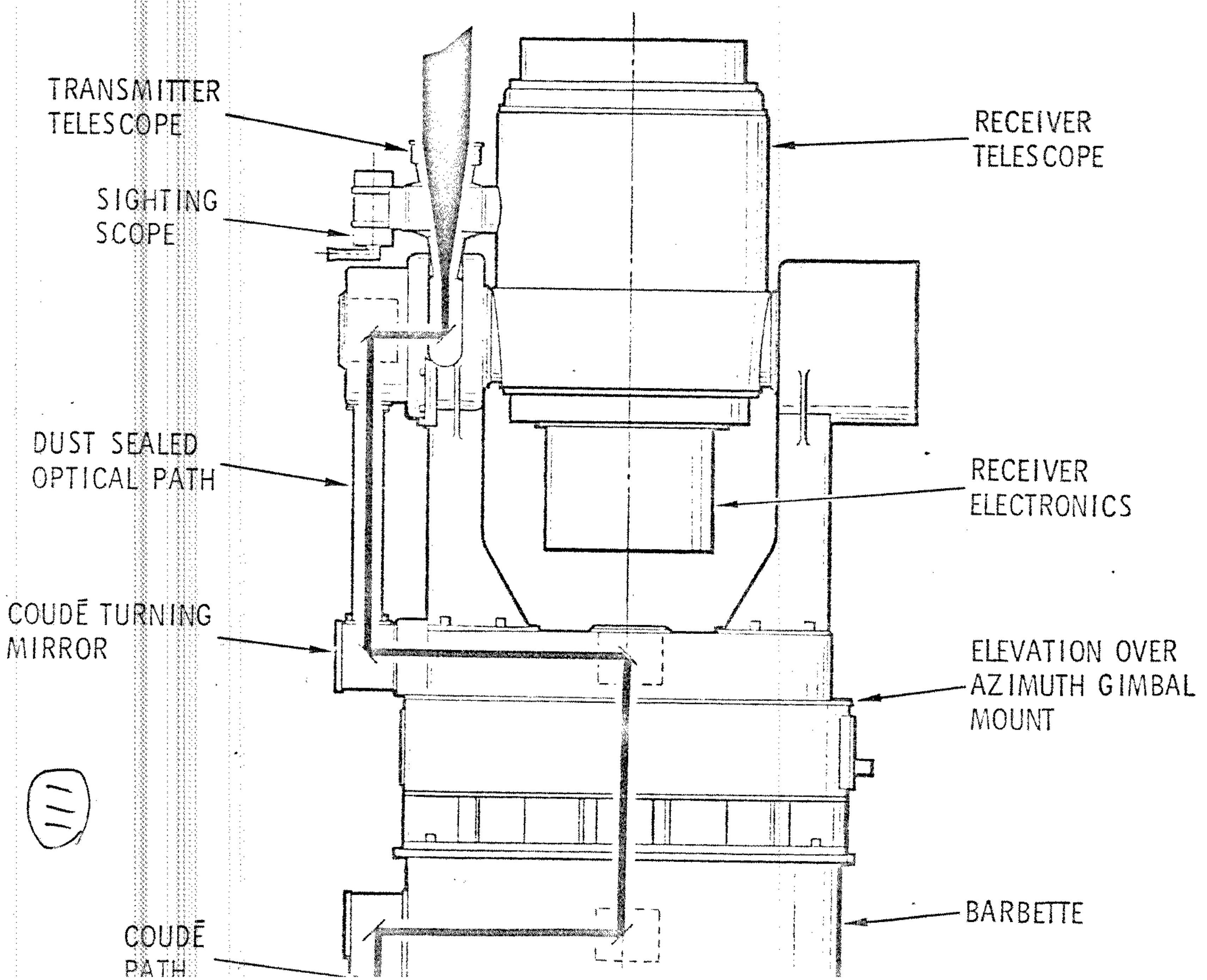
The unit currently operating in Wettzell /fig. 1/ was developed originally by the "Institut für Flugführung" at the "Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt" in Braunschweig. It incorporates certain components, such as the interface to the station timing system and the device for switching between giant pulse and relaxed mode operation, which were designed, built and supplied by the IfAG. First trials of the system occurred in the autumn of 1972 and first returns were obtained in April 1973. Since September 1972 the equipment has undergone major modification. The laser has been largely reconstructed, the power unit improved and new Galileian transmitting optics have been substituted for the original Cassegrain system. Furthermore, the telescope provided to perform the manual tracking has been replaced by a more effective combination comprising a larger field scan-telescope and a high-power small-field tracking unit. The cooling-system of the laser has been redesigned.

The main characteristics of the equipment as it is now in use have been summarized in the following table:

Laser energy /maximal/	7 J
Half-energy impulse width	30 nsec
Impulse power /maximal/	240 MW
Repetition rate	0,14 Hz
Natural divergence of beam	5 mrad
Effective divergence of beam	1 mrad
Receiver objective	320 mm
Counter resolution	1 nsec
Mount	2-axes
Tracking telescope field, resolution	3
Gating	≤ 1 msec
PMT	Philips 56 TVP


SIMULATED LASER FIRE SIGNAL
SIGNAL SIMULATOR
SIMULATED RETURN PULSE
LUNAR PMT
PRE-AMP 1.3GHz BW
LIGHT EMITTING DIODES
SATELLITE PMT
PRE-AMP 1.3GHz BW
COAX SWITCHES
VARIABLE ATTEN.
MAIN AMP 1.3GHz BW
PULSE DISTRIBUTION ANALYSER
POWER DIVIDER
DATA PROCESS INTERFACE
COMPUTER 16 KW 4 DISK
STOP
START
RANGE COUNTER (1ns Accuracy 0.1ns Resolution)
LASERLIGHT
HIGH SPEED PHOTODIODE
COAX SW
POWER DIVIDER
ARMING
PUSH BUTTON
TRIG
RANGE GATE 8 DIGITS
TELESCOPE INTERFACE
TELESCOPE OFFSET COMMAND
STOP
LASER FIRE EPOCH COUNTER
START
ENCODER INPU
(4 AXISES)
LASER FIRE COMMAND
CLOCK
DRIVE CONTR
(4 AXISES)
FREQUENCY STANDARD
LORAN C
VHF LINK TO Cs FREQ. STD
MITAKA OBSERVATORY
CALIBRATION SYSTEM

MOUNT GROUP


TRANSMITTER TELESCOPE
SIGHTING SCOPE
DUST SEALED OPTICAL PATH
COUDĒ TURNING MIRROR
COUDĒ PATH
RECEIVER TELESCOPE
RECEIVER ELECTRONICS
ELEVATION OVER AZIMUTH GIMBAL MOUNT
BARBETTE

ADP & CONTROL/DATA PROCESSING

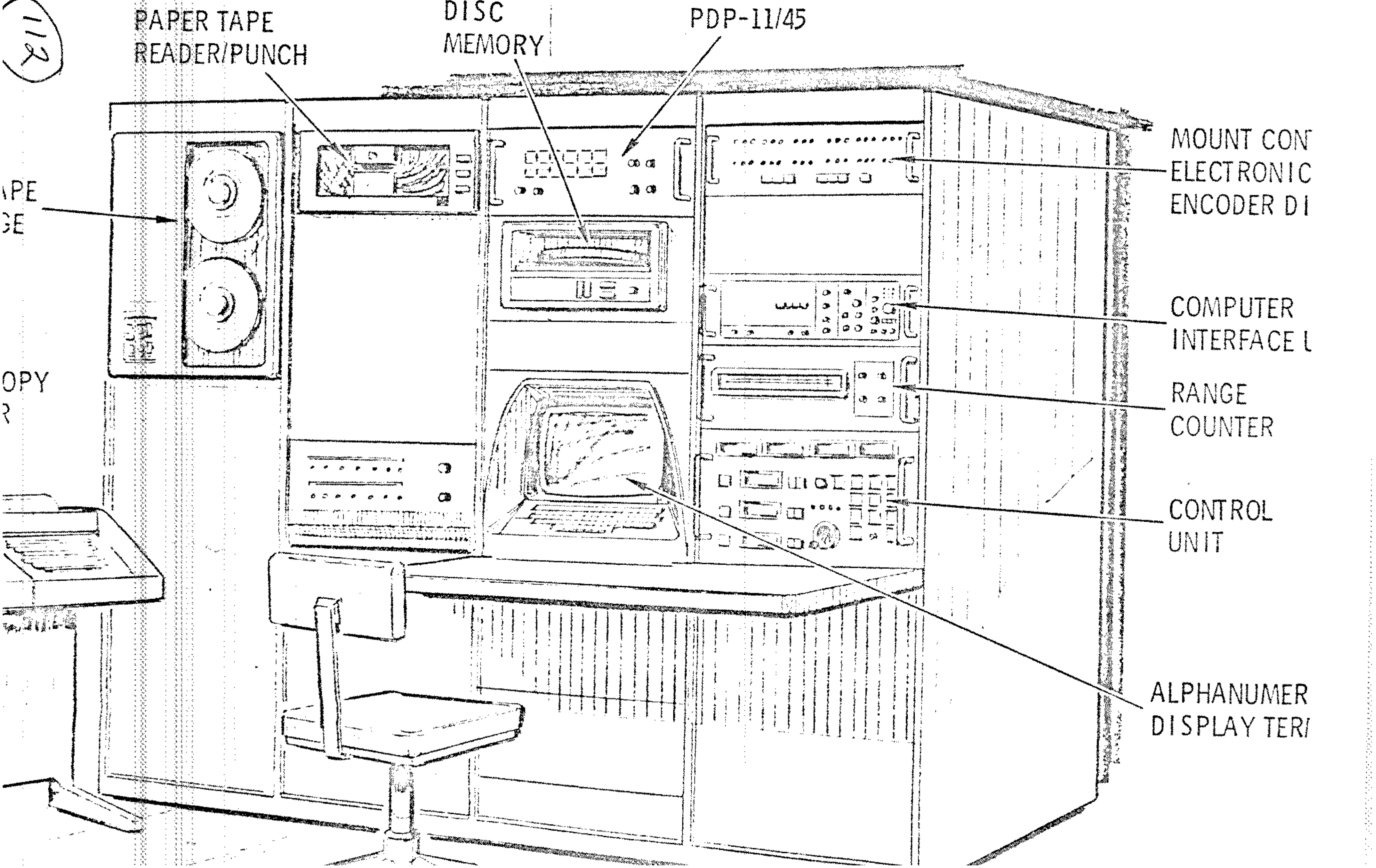


Table 2. The System to be installed in 1976

Peak Power Output:	1.25×10^9 watts at approximately 0.53 μm or 3.0×10^9 watts at approximately 1.064 μm
Energy Output:	0.25 joules per pulse at approximately 0.53 μm or 0.5 joule per pulse at approximately 1.064 μm
Output Stability:	±5%
Pulsewidth:	Less than 0.2 nanoseconds
Repetition Rate:	Up to 3 pulses per second external or internal command, and at least 1 pulse per second by manual control
Beam Divergence: (Full width containing > 90% of the energy)	Not greater than 10 times the diffraction limit from the final amplifier assembly.
Spectral Linewidth:	Less than 0.2 Å
Spectral Line Stability:	Better than 1Å
Spectral Line Position:	Repeatable to better than 1Å from one operational cycle to another
Physical Characteristics:	The following nominal dimensions apply: 1. Laser Transmitter – 1.23 meters long x 63 cm wide x 30 cm high 2. Power Supply – Self-contained cabinet 1.6 meters high x 60 cm wide x 80 cm deep 3. Cooling System – Cabinet mounted 1.6 meters high x 60 cm wide x 80 cm deep
Operational Parameters:	1. Operational Cycle Time – No intrinsic limit 2. Operational Life Time – Greater than 2×10^5 pulses for all components
Equipment Operation Mode:	1. Remote or local operation 2. Cooler located up to 7.5 meters from laser and power supply 3. Control Console – Control console has six switched functions including: power on/off, start (standby) charge, auto/manual fire control, manual fire, and emergency stop. In addition, provisions are made for mode-locked frequency adjustment, high-voltage adjustment, and trigger voltage adjustment 4. Electromagnetic interference control requirements, as per principles outlined in U.S. Government Standards
Environmental Conditions:	1. Operating: Altitude – 0-4.2 km Humidity – 0-49% relative Temperature – +40° to +125°F 2. Storage and Shipment: Altitude – 0-12.2 km Humidity – 99% relative Temperature – -30° to + 150°F
Primary Power:	Less than 8 kVa, 240/380V, 50 Hz, 4 pole, 5 wire, wye connected

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SYSTEM/SUBSYSTEM SPECIFICATIONS

The following is a summary of SLRS system and subsystem performance specifications. General specifications relate to system performance, operating environments, and facility requirements. The other specifications refer to specific subsystems.

General

Range Limit – 350 Km to 36,000 Km
Range Accuracy – Better than 10 cm
Range Resolution – Better than 2 cm
Data Rate – 0.5 to 5.0 PPS
Operational Time – 24 hours per day except during inclement weather

Environment
Temperature – +18°C to +23°C
Mount -40°C to +50°C
Humidity – 0 to 49% RH
Mount 0 to 100%
Altitude – 0 - 14,000 ft.

Operating Staff – 2 operators
Input Power – Either 220V 60 Hz or 380V 50 Hz 3ϕ, 16 kW Max.

Absolute Pointing Accuracy – ±3 arc seconds
Pointing and Tracking – Computer Controlled
Site Facilities Required – Concrete pad for mount/laser support
– Pre-surveyed terrestrial targets for range offset calibration and mount level correction.

(114)

Mount Subsystem

Configuration – Elevation over azimuth

Transmitter System – Laser stationary - two axes Coudé, dust-free path of transmitter

Range of Travel – ±270° in azimuth; ±100° about zenith in elevation

Tracking – Continuous, under computer control, from elevation angles of 10 degrees to within 2 degrees of zenith

Tracking Rates (in plane of orbit) – From sidereal to 1° per second

Orthogonality – ±1 arc second

Wobble – ±1 arc second

Angular Accuracy – Optical encoders with 18 bit (24 microradians) absolute accuracy and 20 bit (6 microradians) resolution

Transmitting Optics

Location – Elevation Axis

Type – Galilean

Effective Beam Divergence – 50 microradians to 1 milliradian normal

Divergence Control – Motor driven, computer controlled, to correspond to desired divergence

Diameter of Exit Beam – 160 mm

Magnification – 10X

Alignment – Within 5 microradians of reference line of sight

Alignment Stability – Less than 10% of divergence

Optical Damage Criteria – 2 GW/cm^2 max at input

Optical Coating – .10% per surface maximum loss

Receiving Optics

Type – Cassegrain

Diameter – 0.6 meter (24 inches)

Effective Focal Length – 440 cm

Focus – Fixed, temperature compensated over -40°C to +50°C

Field-of-View – Continuously variable, computer controlled, from 100 microradians to 1.1 milliradian

Receiving Optics (continued)

Sun Protection Shutter – Mechanical shutter protects PMT photocathode when sun within 2 degrees of optical axes
Alignment – Within 15 microradian of transmitter line of sight
Spectral Filter Bandpass – Available bandpass between 10Å and 25Å, temperature stabilized
Attenuation Control – Optical attenuation of received signal; continuously variable from 0 to 40 dB; computer controlled.

Laser

Type – Nd:YAG - Frequency Doubled, single transverse mode
Operation – Mode Locked/Cavity Dumped
Energy – 0.25 Joule
Half-Energy-Pulse-Width – 200 picosecond nominal
Pulse Repetition Rate – 0.5 to 5.0 PPS
Spectral Output – 0.532 μmeter
Wavelength Stabilization – Not required
Dust and Humidity Protection – Closed compartment around laser pressurized with filtered, dehumidified air or inert gas.

Receiving Electronics

Detector

Type – Static Crossed Field Photomultiplier
Quantum Efficiency – 10% @ 0.532 μmeter
Rise Time – 140 picoseconds
Photosurface – S-20
Refrigeration – Not required
Range Gate – Computer controlled gate width and gate centering about return pulse
Start Pulse Detector – Common with receiver detector; fiber optics pick off transmitted pulse; leading edge threshold detection
Epoch Signal – Coincident with start signal
Threshold Detection – Leading edge detection; threshold level computer controlled
Tolerable Pulse-to-Pulse amplitude variation – ±10 dB (optical)

Guidance and Data Processing

Time Interval Counter Resolution – 100 psec

Time Standard (Station Clock) – Rubidium frequency standard

  Resolution - Timing – ±10 μsec

  Stability of Clock – 1.5×10^{-10}/10 msec (5 MHz Ref. Frequency)

Data Flow Rate - Max. – 5 measurements/second (epoch, travel time, range)

Information Storage Medium – Magnetic Tape - Permanent Storage

– Magnetic Disc - Temporary Storage

Output – Alphanumeric Terminal

Computer Memory – 16 K words

Mangetic Tape Type – 9-channel IBM standard

Paper Tape Reader – 5-channel - for program loading

Programming Language – Fortran

System Control – Operator control three system control unit and alphanumeric terminal

Computer Interface – Through computer interface unit and alphanumeric terminal.

System Control Unit

The controls, meters, and indicators of the System Control Unit are listed below. Refer to Figure 10.

Controls (Manual or Computer Control Selectable from Front Panel)

	Computer	Manual
Attenuation, Receiver Optical	INC/DEC	INC/DEC
Field-of-View	INC/DEC	INC/DEC
Divergence	INC/DEC	INC/DEC
Start Threshold Level	INC/DEC	INC/DEC
Stop Threshold Level	INC/DEC	INC/DEC
Time Slew (Acquisition)	No	Yes
Open/Close Sun Shutter	No	Yes
Track Mode Controls	No	Yes
Laser Mode Controls	No	Yes
System Mode Controls	No	Yes

Panel Meters

Divergence, milliradians
Field-of-View, milliradians
Attenuation, dB
Transmitted Power, GW
Received Power, dB
Start Threshold, mV
Stop Threshold, mV

Indicators

Start Pulse Light
Stop Pulse Light
False Alarm Light
Sun Presence Light
High Background Light

Joystick

Manual Mount Position/Velocity Control

Computer Interface Unit (Refer to Figure 10)

- Handles all interfaces between system control, encoders, interval counter, computer, peripherals, and time (frequency) standard
- Controls data flow
- Displays encoder angles in binary
- Controls display of Alphanumeric Terminal (see Figure 11).

Software Control

Initialization Mode

- Calculation of Ephemerics
- Optical Controls
  - Field of View
  - Divergence
  - Start/Stop Thresholds
  - Attenuation Control
- Initial Mount Positioning

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Software Control (continued)

- Site Calibration - Leveling, Star Tracking
- Initialization Displays

Execute Mode

- Initiation of Tracking
- Epoch Pointing
- Epoch Data Collection
- Epoch Data Recording
- Non-Epoch Mount Control
- General Laser Control and Firing
- Dynamic CRT Display
- Timing Control

Processing Mode

- Tape Handling Routines
- Data Location on Tapes
- Data Analysis
- Data Display

Playback Mode

- Mission Data Playback

Utility Programs

- Encoder Test
- Loop Checks
- Optical Gain System Tests
- Pseudo Pointing

Workshop on Laser Tracking Instrumentation, Prague, August 1975

THE FINNISH-SWEDISH LASER PROJECT

S. Johansson, M. Paunonen, A. Sharma

The Finnish Geodetic Institute and Helsinki University of Technology have since 1971 collaborated on the project to construct a satellite laser rangefinder. In 1973 the Swedish Geographical Survey Office joined the project. The satellite laser is expected to be operational in 1975 and will be used alternately in Finland and Sweden.

Design parameters of the system are:

- Ruby laser, wavelength 694,3 nm
- Pulse energy 1...2 J
- Pulse length 5 ns, nearly rectangular
- Pulse repetition rate at least 6 per minute
- Transmitter beamwidth 0,5 ... 5 mrad
- Receiving telescope 0,6 m parabolic mirror, f.l. 1,73 m
- Filter bandwidth 2 nm
- Pointing accuracy 0,3 mrad
- Output data in digital form, displayed and recorded

The transmitter is based on a Pockels cell Q-switched ruby laser configuration followed by pulse slicing and amplifier stages. The oscillator ruby is 100 x 10 mm, select quality, flat/flat cut, AR-coated and cooled by deionized water. The helical flash lamp is energised by a maximum of 5 kJ. The oscillator yields a 20 ns pulse of at least 0,7 J when Q-switched and is expected to yield 0,2 J when clipped to 5 ns. Slicing circuit and amplifier are under construction.

The receiver consists of an astronomical telescope with a parabolic mirror and an RCA 31034 photomultiplier installed at the prime focus. The mirror has been made in the Institute for Astronomical Research of Turku University and it was coated with aluminium layer in the Uppsala University. The mount of the telesco is an equatorial one equipped with semi-automatic pointing faciliti

The optical input to the PMT is shuttered to improve average anode current capability, as well as eliminate backscatter. The shutter has a minimum opening delay of 1,5 ms and openin rise time of less than 30 pF introduced by a MOSFET amplifier and the PMT itself, and an introduced leakage resistance of about 1 Mohm. The amplifier thus behaves as an integrator and using a half-max time interval counter, centroid detection is essentially achieved. This method provides a larger signal voltage, and relative design simplicity.

Timing is based on a Hewlett-Packard quartz clock system synchronised to the Universal Time Scale (UTC) using a LORAN phase-locked frequency comparison receiver. The pulse propagation time will be measured using a 0,1 ns accuracy counter (NANOFAST,Inc, model 536 B),equipped with M/2 half-max detection unit.

Control logic and the data processing system has been construct and tested. Pointing of the telescope is by means of two stepper motors. Calibration of the direction is by means of pointing the telescope towards a known star and programming the coordinates of the star into the logic. Steps of each motor are then counted and thus, because of the equatorial mount, the actual direction is always known. The motors are stopped, when this direction is equal to the required direction set automatically or by thumb wheels. Air temperature,air pressure and relative humidity are measured sim taneously with the fire pulse. The weather data, firing time, pulse propagation time and direction coordinates are punched on a paper tape for further treatment. The outgoing and return laser pulses will be digitized by a Tektronix transient digitizer type R 7912, and the matrix information will be recorded on a cassette recorder for further processing.

The satellite laser rangefinder described will be situated in Finland at the Kirkkonummi Observatory of the Finnish Geodetic Institute. Field test measurements will be initiated there next September.

Session 2: System Errors

12 August AM

Chairman : C.O.Alley

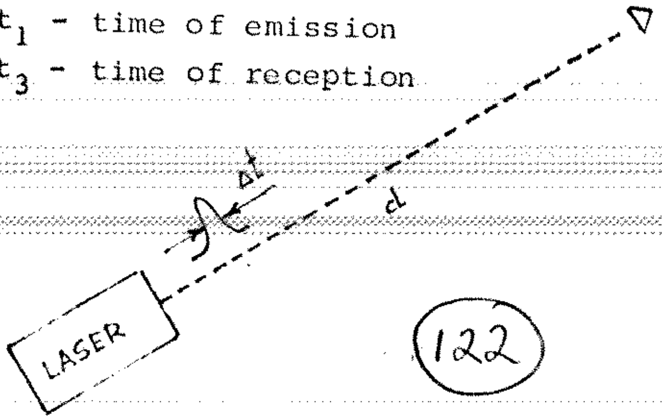
Summary

I. Introduction

The interest in laser ranging is based on the wide bandwidth of laser amplifiers which allows a very short pulse of radiation whose round trip time to a target can be measured with high precission and accuracy. Another product of quantum electronics research, the atomic clock, provides a time base for world wide distribution of epoch of sufficient accuracy (1us to 5 μs) for the most demanding geophysical application-ranging to artificial earth satellites. In contrast, ranging to the moon requires less accurate knowledge of epoch since the velocity of the moon is less. However, the time base needed for the range time interval measurement needs a better fractional stability for moon than for the artificial satellite, since the 2.5 sec range time is much longer. For both, the stability of a good crystal oscillator is sufficient. For 0,1 ns timing $\Delta f/f = \Delta\tau/\tau \sim 4 \times 10^{-11}$ over 2.5 sec is needed for the moon .

A schematic diagram of a ranging system is shown below:

t_1 - time of emission
t_3 - time of reception



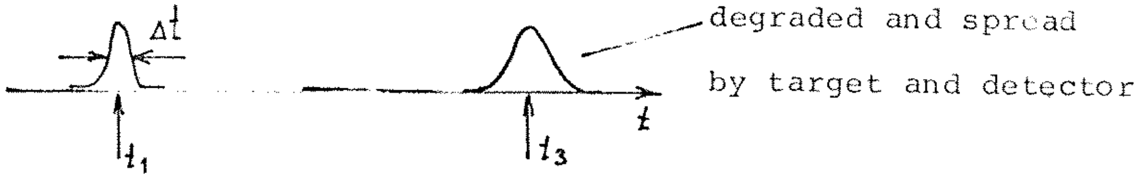
$t_2 = \frac{t_1 + t_3}{2}$ time of reflection

$d = c\frac{(t_3 - t_1)}{2} = c\frac{\tau}{2}$

$\Delta d = c\frac{\Delta\tau}{2}$

c ≈ 30 cm/ns in free space

The basic problem is to derive as accurately as possible the time of the laser pulses in the given time base



This requires a light detector with fast response and low jitter, a method of deriving a time signal from some characteristic of the pulse-eg. leading edge amplitude discriminator, zero crossing discriminator, constant fraction discriminator or centroid determination or swept tube. The difference between the derived signal for the times t_1 and t_3 must be related to the time base by a counter, augumented in the most accurate systems by a vernier to go beyond the 1 ns limit of present counter resolution, perhaps time to pulse height conversion or a dual slope integrator. The entire system must be carefully calibrated and the calibration monitored for changes in delays and otherparameters with temperature and other environmental conditions.

The velocity of light in affected by the atmosphere, but it seems likely that the delay can be determined to <1 cm equivalent range by monitoring local barometric pressure and using an algorithm of Helen Hopfield. This needs to be verified by two-color range measurements which are different due to the dispersion of the atmosphere. For an absolute measurement good to 100 ps, the range time diference between 5321 Å and 3500 Å light must be determined to ~ 5 ps, which can be done with a streak tube.

The following table may be useful in summarizing system errors.

II. Specific Questions

A. Multimode Lasers

Pearlman (SAO) discussed timing problems associated with multimode lasers. The radiation is emitted into different ang at different times. See SAO report.

Ramsden (Hull) pointed out the ease of generating single mode radiation.

B. Atmospheric Delay Corrections

Weiffenbach (SAO) discussed the atmospheric delay correction of Hopfield using local barometric pressure. It seems to work well but needs two-color verification. Problems are associated with winds and horizontal gradients in weather conditions when laser ranging stations do not normally operate.

C. Distribution of Epoch

Morgan (Australia) discussed problems of epoch distribution. The Timation III satellite will allow distribution in the future to 20 ns. Now a $14,000 receiver allows 1 microsecond accuracy from the transit satellites. LORAN-C is maintained to 0.5 microsecond with respect to the U.S. Naval Observatory clocks. VLF reception plus occasoinal clock trips will allow epoch to be maintained to 5 microseconds. The Omega system is good to 5 microseconds.

D. Calibration of Systems

1. Pearlman discussed the procedure of SAO. See SAO report.

2. Silverberg described the procedure used for lunar ranging with short (2 m) path on each shot with attenuation to give the same signal as a lunar return. Statistics give the outgoing pulse shape. The calibration is extended to lunar range times with a diode light pulser.

3. Veret (ONERA) discussed a method of rotating the beam splitter 90 degrees to allow calibration of start and stop detectors with the same strength pulses, and without measuring the distance to the target.

4. Gegnebet (CERGA) discussed the timing correction needed as a function of the intensity of returned pulses as measured for his system.

5. The calibration pricedure for the Goddard Space Flight Center stations can be found in the paper by McGunigal, et. al., in these proceedings.

	First Generation ~100 cm	Second Generation ~10 cm	Third Generation ~1 cm
Laser Pulse Duration	10 - 30 ns (Q-switched)	2 - 5 ns (PTM Pulse slicing)	0.1 - 0.3 ns (Mode locking)
Time Base Epoch	Atomic Clock → e.g. Loran C	→	→
Time Base Interval	Crystal Oscillator →	→	→
Detector	Photomultiplier →	→	→
		Single p.e. →	→
		Crossed Field →	→
Discriminator	Leading Edge	Zero Crossing	
		Constant Fraction →	→
		Centroid →	→ Streak tube
Atmospheric delay Correction	—	Local Barometric Pressure Monitor →	→ Two-color
Target Structure	—	Modeling of C.M. →	→
		Lunar Reflectors →	→ LAGEOS Starlette Shiny Ball

Summary of Session 4: Pulse Detection and Processing

Detectors: An ideal detection system employing the qualities of good efficiency, low timing jitter, high gain and capable of a high count rate is difficult to realise. Some of the new photomultipliers are good in many categories but fail in others. The RCA 31034, for instance, has excellent efficiency but requires care in operation due to stringent limitatinns on the average current. Crossed field tubes are available which have excellent timing characteristics but are quite costly. Future work can be expected in the areas of channel plate photomultipliers and streak tube systems.

Pulse Processing: The length of many current laser pulses favors some degree of pulse processing over simple edge detection or constant fraction discriminators. Pulse digitizing techniques used at SAO and NASA have proved quite successful. Analog techniques have been modeled in CSSR to evaluate their usefulness. Processing techniques to handle the wide dynamic range and variable shape of the return pulse appear, at present, to be limited by wave front distortions from the laser transmitter.

Timing: A number of timing systems, both for satellite and lunar work, are in operation or under construction employing the time-domain streaching technique. Single and multiple stop devices have been developed with accuracy capability well below 1 nanosecond.

Major Contributors to Session 4:

D. G. Currie - Description of the streak-camera timing system and description of a multistop epoch timing system

Suchanovskij - Discussion of the Soviet experience with photomultiplier quantum enhancement techniques

J. Gaignebet - Description of the CNES system for reducing the effects of sky background

M. Pearlman - Discussion of the U.S. experience with pulse digitizing systems

M. Vrbova - Computer simulation of analog pulse centroid correction procedures

Veret - Description of the channel plate photomultiplier tube

Billiris - Discussion of the measurements of laser wave front distortion

Hirsl - Interkosmos timing system using the time expanding technique

submitted 13 Aug.
E. C. Silverberg

SESSION 6. SATELLITES IN ORBIT - PREDICTIONS

F. Nouel

1. Satellites

Among the satellites in orbit or planned, we found:

1 - the old satellites

BEACON B and C; GEOS A and B; D1 C and D; PEOLE

2 - the new generation, for which sophisticated design were made in order to

i/ get better response from the satellite through all the pass

ii/ minimize non gravitationnal forces acting on the sat. and make them as constant as possible

D5B - STARLETTE - GEOS C - TIMATION III

3 - The "near future" satellites

LAGEOS - AUOS-Z - TIMATION IV

4 - The "others"

- SHINY BALL with no Laser corner cubes
- Laser Reflectors on the moon.

SOME CHARACTERISTICS - which were pointed out during the session

GEOS III

Tracking down to 15° due to sloped mounting of the reflectors -

$e = 0$

$i = 115^{\circ}$

altitude 850 km

It has a CO_2 corner cube

STARLETTE

- purpose of gravity studies
- Very small Area/Mass ratio
- 60 corners cubes - At least 6 of them are visible in any configuration

perigée - apogée 800 km - 1100 km

inclination 52°

magnitude 11

LAGEOS

- Altitude 5900 km
- inclination 110°
- weight 400 kg
- sphere of 60 cm diameter
- 440 corner cubes of 3.8 cm aperture
  one CO_2 corner cube

Launch planned for March 74 and magnitude will be 12.

AUOS-Z

Launch: end of 76
13 corners cubes.
They are put on a satellite which is part of the Interkosmos project and the primary mission of which is cosmic ray studies.
altitude 500 km on a circular orbit
inclination 83°.

TIMATION III

altitude 14000 km on a circular orbit
inclination 115°
Magnitude is going from 11 to 14 depending on altitude.
GSFC had successful laser echos on it.

D5B Satellite equipped with a micro-accelerometer to study atmosphere density
$i = 30°$
perigée 200 km
apogée 1100 km

LUNAR REFLECTORS

Appolo 11-14-15 caracterised by $\frac{d\Omega}{d\omega} = 50 \text{ km}^2/\text{strd}$.
Lunarod was mentioned.

SHINY BALL

It has no corner cube but expected returns of 5 photos using 1 J laser and 1 meter telescope.
Sphere of 1 m^2 radar cross section
magnitude 6
Polar circular orbit at 500 nautical miles.

II. Predictions

1/ SAO made a report on how predictions are computed. They provide currently ephemeris on GEOS A - B - C - - BEC and STARLETTE.

It was interesting to hear that for STARLETTE, predictions over a period of one or even two months could be possible. This suggests that the earth model is known enough, but non gravitational forces limited computations so far. The same remark applies to the Drag free satellite TRIAD.

2/ Lunar predictions are sent to the station on a daily basis on a polynomial form. JPL can provide them.

FUTURE SYSTEMS

Douglas Currie

During this session we wish to consider an overall view of the future possibilities of the tracking of satellites by lasers. We now wish to gather data to determine the future capabilities and to evaluate questions of future. Thus we wish to provide a framework to permit a detailed comparative discussion.

Detailed discussion and value judgements should be reserved for the programmatic and the open discussion period. This later discussion may then provide data for future planning of the various groups. A large amount of the information on future systems has already been discussed.

Four areas which we shall consider are:

I FUTURE TECHNIQUES
II FUTURE STATIONS
III SATELLITES, CURRENT AND FUTURE
IV NETWORKS, CURRENT AND FUTURE

I. FUTURE TECHNIQUES

In this section we shall receive those technical areas which shall be of critical importance over the next few years. We hope to concentrate on the parameters and techniques which are most important in meeting the basic program goals and leave for another time those techniques which are important in order to reduce cost, increase convenience, or increase reliability.

A. RANGE ACCURACY

There are several sub-systems which are most critical in order to improve range accuracy. These are:

1. The Laser System

   To improve the laser performance as related to in the range accuracy, the important points are:

   a. Studies of multimode structure
   b. Improvement in centroid determination of long pulses

c. Develop methods to obtain short pulses from the laser system by:
   i. active mode locking
   ii. pulse slicing or chopping
   iii. passive mode locking

2. The Photodetection System

The various procedure to improve the detection timing are:

a. Photomultipliers
   i. conventional multipliers may be used in a better fashion to obtain their full capability of a r.m.s. jitter of 0.1 to 0.25 nanoseconds.
   ii. Channeltrons and channel plate tubes appear to have a performance which may be better than the conventional photomultiplier.

b. Crossed-field photomultiplier

These devices, when combined with a wideband width, low-noise preamplifier may yield time resolution at the 0.1 nanosecond level.

c. Streak tube

These detectors, which are currently used in laser fusion work, will give a time resolution, for single photo electrons or for a many photoelectron pulse of 0.001 to 0.01 nanosecond. This accuracy seems of interest only for two color systems which require a range accuracy better than two centimeters.

3. Interval Timing Electronics

Equipment to perform interval timing with an r.m.s. width of 0.04 nanosecond has already been described in the literature and has been used in field operations so will not be considered further.

4. Epoch Determination

   Equipment /1/ necessary to perform this function is available and has been described in the literature.

B. IMPROVED DETECTION THRESHOLD

1. Laser system

   Improvements in the laser system will be of interest in the area of:

   a. higher average power
   b. continuous-wave laser systems

2. Receiver Apertures

   In addition to normal receiving apertures, there are several new techniques which may provide significantly larger receiving apertures.

   a. Multi-aperture receivers

      These are currently being built in France and USA

   b. Large metal mirrors

      These are currently being built in Japan.

3. Reduced Beam Divergence

   a. Orbit predetection

      Better orbit predetections are required but seems to be available

   b. Tracking

      i. improved mounts
      ii. auto tracking techniques on sunlit satellite or on laser returns
      iii. absolute providing capability at the arc second level.

II. <u>FUTURE STATIONS</u>

Discussion of new stations by various workers has been given. The details of these discussions appear in other sections of this workshop. The new stations discussed were:

A. Mt. Haleakala Station /USA/

   by Eric Silverberg

B. Orrora Valley Station /Australia/
by Peter Morgan

C. Dodaria Station /Japan/
by T. Atsushi

D. Crimea Station /USSR/
by A.M. Suchanovskij

E. Greenbelt Station /USA/
by C.O.Alley

F. Netherlands Station
by F.W. Zeeman

G. Cagliari Station /Italy/
by L. Cugusi

H. LURE Mobile Station /USA/
by E.C. Silverberg

I. French Station
by Claude Veret

J. German Station
by Peter Wilson

III. SATELLITES CURRENT AND FUTURE

Some of the current and future satellites are discussed. The parameters define the problems with satellites on which stations are expected to range in the near future.

The relative return is the relative signal level when the laser energy and beam divergence of the stations are held fixed.

IV. NETWORKS, CURRENT AND FUTURE

In this section, we consider the networks of laser tracking stations.

In total, there are now 11 orbital satellite tracking stations which enter data in the SAO prediction program, and by 1977-80, there are expected to be 22. Including the Intercosmos stations and the Lunar stations, there are expected to be 35 stations by 1980 which shall need good intercomparisons of epoch.

Satellite Name	Relative Return	Visual Magnitude	Tracking Rate	Orbit Stability
High Return				
BE-B	2.9	Bright	Fast	Fair
BE-C	4.6	Bright	Fast	Fair
GEOS - A,C	4.0	Bright	Fast	Fair
GEOS B	18.0	Bright	Fast	Fair
AUOS-Z	1300.0	Bright	Fast	Fair
Medium Return				
STARLETTE	800×10^{-3}	11	Fast	Fair
LAGEOS	9×10^{-3}	12	Medium	Good
TIMATION	3×10^{-3}	11-14	Medium	Good
Low Return				
A 11	2.4×10^{-8}	-	Slow	Excellent
A 14	2.4×10^{-8}	-	Slow	Excellent
A 15	5×10^{-8}	-	Slow	Excellent
L 1	6×10^{-8}	-	Slow	Excellent
L 2	6×10^{-8}	-	Slow	Excellent
SHINY BALL	100×10^{-8}	-	Fast	Fair

	Current Number of Stations	Expected Number of Stations by 1977-80	Capability of all Satellites brighter than	Capability by 1977-80	Planned Colocation Experiments	Pointing and Tracking
Inter cosmos	4	8	BE-B	LAGEOS	Yes	visual
SAO	4	4	LAGEOS	LAGEOS	/tri-lateration/	absolute
GSFC	3	7	LAGEOS	TIMATION	Yes	absolute
CNES	1 - 2	3	STARLETTE	STARLETTE	Yes	absolute
ONERA	1	1	STARLETTE	STARLETTE	Yes	absolute
LUNAR	1 - 2	8	all lunar arrays	all lunar arrays	Yes	visual and for some absolute
	16	31				

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