TV GUIDING FOR SATELLITE AND LUNAR RANGING

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I. INTRODUCTION

Since the first station set up in France (1966), with which only visual tracking was achievable, we felt that we must maintain that possibility.

The main reasons were :

a) To decrease the need of accurate ephemerides when satellites are visible.

b) To make visual checking and eventually to correct the ephemeridis (ΔM or ΔT)

c) To set up the overall optical system

d) To adjust the zeros of the Azimuth-Altitude encoders.

e) To ensure the safety around the laser beam path

As the developments of the stations do not allow direct visual tracking, a guiding telescope coupled with a sensitive TV camera and a remote monitor was chosen.

In addition to the preceding reasons, it was found that the sensitivity was increased, and also the tracking comfort.

II. GUIDING TELESCOPES

II.1. First generation

A . 20m diameter refractor, 1m focal length is coupled with a NOCTICON tube TV camera. The distance between the optical axes of the guiding telescope and the receiver is .60m. The reticle is etched directly on the monitor screen.

II.2. Second generation

The guiding telescope is also a 20cm aperture objective.

An optical relay gives focal lengths of 2m and 5m. The distance between the optical axes of the guiding telescope and the receiver is 85cm.
Five remote controls are located beneath the monitor screen. They are :

a) A luminous projected reticle in which the intensity may be increased from dim during night operation to bright on day time.

b) Variable optical attenuators with a zero attenuation mark (hole in the attenuator disks). They are used for day time operation or for target calibration test and they protect the photocathode.

c) Variable sensitivity of the TV tube.

d) Focusing of the telescope

e) Choice of the focal lenght (2m or 5m)

II.3. Lunar system.

The incoming light in the 1.5m telescope is picked up through a dichroïc splitting mirror. The receiving camera is mounted on a computer-driven setting device which allows the camera to follow a lunar crater while the telescope tracks the retroreflector. Three cameras will be tried : NOCTICON, ISOCON, VIDICON.

III. SPECIFICATIONS

III.1. Satellites stations.

Generations	1rst	2nd
Objective diameter	.20m	.20m
Focal length	1m	2m- 5m
viewing angle	1°	30'
sensitivity(magnitude stars)	12/13	11/12

With these specifications, STARLETT (10/12) Magnitude could be tracked. Due to the blooming effect of the Nocticon cameras, a bright satellite such as GEOS B is seen as a very white spot of 3 to 10mm diameter. The image of the satellite crosses the monitor screen (2nd generation) in approximatively 1s for STARLETT and 30 for GEOS 3 averages times.

In the second generation, two other cameras will be displayed on the same monitor.

a) a wide angle camera viewing the entire mount and telescope system, mainly for safety reasons.

b) a NOCTICON sensitive camera to display dim oscillograms of return or laser pulses. By this means, we will be able, through a digitizer, to check the quality of the laser and study the pulse processing apparatus.

To improve the manual tracking, we plan to introduce added datas on the monitor screen such as, mount position, clock time, range, error messages...

III.2. Lunar ranging system

For satellite tracking the blooming effect of the Nocticon camera is not very important. Men's eyes and brain are able to detect, with a great accuracy, the center of a nearly circular spot.

In the case of lunar tracking there are additional problems.

- On the illuminated moon the light flux is enough to track with a vidicon. The blooming must be eliminated as it masks the details.

- near of the terminator, the effect is even more critical.

- On the earth shine, the contrast is very weak and a sensitive camera is necessary. It has to be improved by contrast-processing of the video signal.

It seems that an ISOCON camera, which is blooming-resistant, could be a good choice.

SESSION 6A - SPECIAL TOPICS IN HARDWARE (MAINLY LASERS)

INTRODUCTORY REMARKS

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THE LASER TRANSMITTER

The first satellite laser ranging systems used Q-switched ruby lasers giving ∿ 1J in a 20-30 nsec pulse with the aim of obtaining a recognisable return pulse which was then analysed to obtain a precision better than that of the pulse width itself. Early lunar laser ranging systems were similar except that they used larger telescopes and operated with single photo-electron (or less) detection.

Many of these systems were later modified to give shorter 2-5nsec pulses, by cavity dumping or pulse-chopping techniques, and hence higher precision, and the majority of systems in use at the moment are of this type producing much valuable information.

It has long been recognised that even better accuracy is possible with mode-locked lasers giving sub-nanosecond pulses, used in conjunction with single photo-electron counting techniques, but technical difficulties have delayed their general acceptance.

Ruby lasers can be mode-locked, albeit with some difficulty, but they have low efficiency, need large power supplies and cannot be used at a high repetition rate because of cooling problems. For mode-locking Nd:YAG is the preferred material, having none of these problems but, because it emits at 1·06μ, the output needs to be converted to the second harmonic for detection purposes.

Nd:YAG lasers can be mode-locked passively, using a bleachable dye, or using an active element such as an acousto-optic modulator. In each case the output consists of a train of pulses,separated by the cavity round trip transit time, one of which can be switched out by an electro-optic (e.g. Pockels cell) switch.

The passively mode-locked oscillator gives a train of about 10-20 pulses each of about 20-30 psec duration, which can be increased up to ∿ 1nsec by choice of dye or by restricting the number of oscillating axial modes with an etalon. The energy in a single pulse is of the order of 1mj and can vary by at least ±10%. About 90% of the trains are well mode-locked but the system needs a skilled operator to keep it working satisfactorily.

Until recently active mode-locking was used only with c.w. systems, producing a continuous train of highly reproducible pulses. The energy in each pulse was very low (of the order of ∿ 1nJ) and a somewhat complex regenerative amplifier system had to be used to bring this up to a usable level, leading to reliability problems.

Now, however, an actively mode-locked pulsed system has been developed, for use in large laser fusion systems, which is very reproducible and yet contains sufficient energy in each pulse. This uses both an acousto-optic modulator and an acousto-optic Q-switch. The laser is pulsed in a quasi-c.w. way for several milliseconds during which the loss in the Q-switch is adjusted so that the laser just exceeds threshold. The modulator is on during this pre-lase period allowing the mode-locking process to reach a steady state so that when the laser is Q-switched at the end of the quasi-c.w. period a transform limited, stable, short pulse exists in the cavity leading to a reproducible Q-switched train of short pulses. The pulse duration depends on the modulation frequency and hence on the cavity length and varies from 50-100psec. The energy in a single pulse is ∿ 0.5mj and the repetition rate 20p.p.s. The reproducibility is ±2% but because such a good value is not required in a laser ranging system some simplification may be possible. The average power is about an order of magnitude lower than the 0.1 - 1.0W required, in the green, for satellites such as Starlette and Lageos and thus amplification will be necessary. It is preferable to increase the energy rather than the repetition rate to avoid problems of stress birefringence and lensing which occur at high thermal loadings.

An alternative, which may be attractive for mobile systems where size, complexity and cost are all important factors, may be to transmit the whole mode-locked burst instead. This creates additional detection and timing problems but these are perhaps acceptable in view of the better reliability of such systems. Further simplification might be possible by the use of new photocathodes which have greatly increased quantum efficiency at 1.06μ which, together with the greater atmospheric transmission at this wavelength, may make second harmonic conversion unnecessary.

Another way of obtaining higher energy might be to use a mode-locked unstable resonator configuration for the oscillator. This uses a larger volume of material and can give up to an order of magnitude increase (up to 10mj) in the energy in a single mode-locked pulse.

Some of these matters, and others, are discussed further in this session.

HIGH ENERGY PICOSECOND PULSES FROM A TWO-MIRROR UNSTABLE Nd:YAG LASER

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1. Introduction

In the operation of conventional mode-locked oscillators, laser beam diameters are of the order of a few millimetres at most in order to achieve diffraction-limited outputs. At the same time, in high gain systems, there is a maximum power density which can be generated before the onset of self-focusing and subsequent damage. These two limits lead to a restriction in the useful energy developed within such resonators. The use of an unstable resonator offers the advantage of obtaining diffraction-limited output from active volumes having larger diameters[1,12]. Increased power and smaller beam divergences can then be obtained.

There are a number of unstable configurations which may be considered (Fig. 1) being classified into n- or p- branch categories. In both cases the active volume of the laser is fully exploited. However, in n-branch resonators the laser cavity is characterised by a focusing point within it and at the high peak powers developed in mode-locked oscillators, gas breakdown or bulk damage in components can then occur and thus p-branch unstable resonators are more suitable for mode-locked unstable laser oscillators.

It is worth noting the unusual characteristics of travelling wave ring resonators when used in unstable configurations; the high magnitude of the losses leads to irreversibility of the path of the light rays and to the possibility of constructing unidirectional ring generators. Fig. 1 shows two types of system of this kind. The first of these, Fig. 1d, utilises a ring resonator with a mirror configuration equivalent to that of Fig. 1b; placing a small aperture in the plane of the real centre of the wave propagating in one of the directions eliminates the appearance of waves travelling in the opposite direction. In the second type, Fig. 1e, the resonator is similar to that shown in Fig. 1c; the unidirectional property is achieved by appropriate positioning of an angular radiation selector. In both cases, introduction of one additional element (aperture or selector) provides simultaneously the unidirectional property and angular selection of radiation.

We have used mode-locked ring resonators in stable configurations[3] in the past but have experienced difficulty in maintaining alignment for more than a few hours. With a ruby rod, Pozzo et al[4] constructed a mode-locked unstable ring laser using prisms. As expected, large intensity discrimination between the two opposite propagating waves was obtained, the intensity ratio being 400:1. The resonator could therefore be said to be operating unidirectionally, giving pulse durations of $\sim$ 100ps. However, since the resonator configuration was n-branch, with the beam focusing in the resonator, such a laser is unlikely to be useful in the generation of very high powers. Experimental work on two-mirror unstable systems has been carried out using CO_2 lasers[5,6](15,16), Nd:glass lasers[2,8], HF/DF lasers[13,14] and Nd:YAG lasers[9,10,11]. However, in all cases the pulsewidths have been of nanosecond duration or longer. We have now examined mode-locking in such a system, generating pulses on picosecond timescales from a p-branch resonator.

2. Experimental Work

Our experimental configuration is shown in Fig. 2. The cavity was designed using the formulations given by Siegman[1,12]. Mirror radii of curvature for the positive confocal cavity are given by

$$R_1 = -\frac{2L}{(M-1)} \quad \text{and} \quad R_2 = \frac{2ML}{(M-1)}$$ where L is the empty cavity length, and M is the magnification, equivalent to the ratio of the rod diameter to the output mirror diameter. The geometrical output coupling is $\delta = 1 - \frac{1}{M^2}$, though in practice diffraction effects reduce this coupling to values slightly less than δ. For approximate correspondence with conventional cavities, the equivalent Fresnel number is

$$N_{eq} = \frac{(M-1)}{2M^2} \frac{D^2}{4L\lambda} ,$$

representing the number of half-periods in the phase change along the mirror for a spherical wave in the geometrical approximation[2]. Transverse modes with least loss have values of N_{eq} = 1·5, 2·5, 3·5 .... $(n + \frac{1}{2})$ .... where n is integer.

As a general rule, the unstable resonator should have the largest possible magnification compatible with output coupling requirements. One of these demands sufficient feedback for stimulated laser action to develop. Since the saturable absorber used for mode-locking, in our case Kodak 9860, is a lossy element, preliminary experiments used a modest magnification of two.

In the final stage of the design it would be necessary to include the effect of thermal lensing in the rod which becomes important for Nd:YAG lasers operating at repetition rates in excess of 1pps but to maintain simplicity and study only the mode-locking capabilities of the laser, we operated at 0·1pps. Our initial design parameters were:

$$M = 2,\quad R_1 = -2\text{m},\quad R_2 = +4\text{m},\quad \delta = 0{\cdot}75,$$

$$L = 1\text{m},\quad N_{eq} = 1{\cdot}2$$

Satisfactory mode-locked trains were obtained, Fig. 3, using a pumping energy of 51J. Peak output energies of ∿ 2mJ in single pulses were recorded, with good shot-to-shot reproducibility.

Since it was possible to increase the pump energy to ∿ 150J, resulting in higher gains within the Nd:YAG rod, the magnification was then increased to M = 3·0 with R_1 = -1·3m, resulting in mode-locked pulses with peak energies of ∿ 11mJ.

Further work is required to improve the spatial structure of the pulse, which can be dependent on the pumping geometry of the laser rod; we used a one flashlamp elliptical system for these preliminary results, but for homogeneous pumping it may be necessary to construct a four flashlamp system. For the same input energy, flashlamp lifetimes would then be greatly lengthened - an important consideration in high-repetition-rate laser ranging systems.

3. Conclusions

We have shown that it is possible to extract 11mj pulses from a mode-locked two mirror unstable resonator, which is considerably in excess of that obtained with a conventional TEM_{00} resonator.

With similar magnifications others have shown that unstable resonator Nd:YAG lasers can be operated with diffraction limited beam outputs of approximately 0.25mrad [9], at repetition rates of 20pps [11]. Combining these characteristics would make the unstable Nd:YAG laser an extremely attractive device for lunar/satellite ranging.

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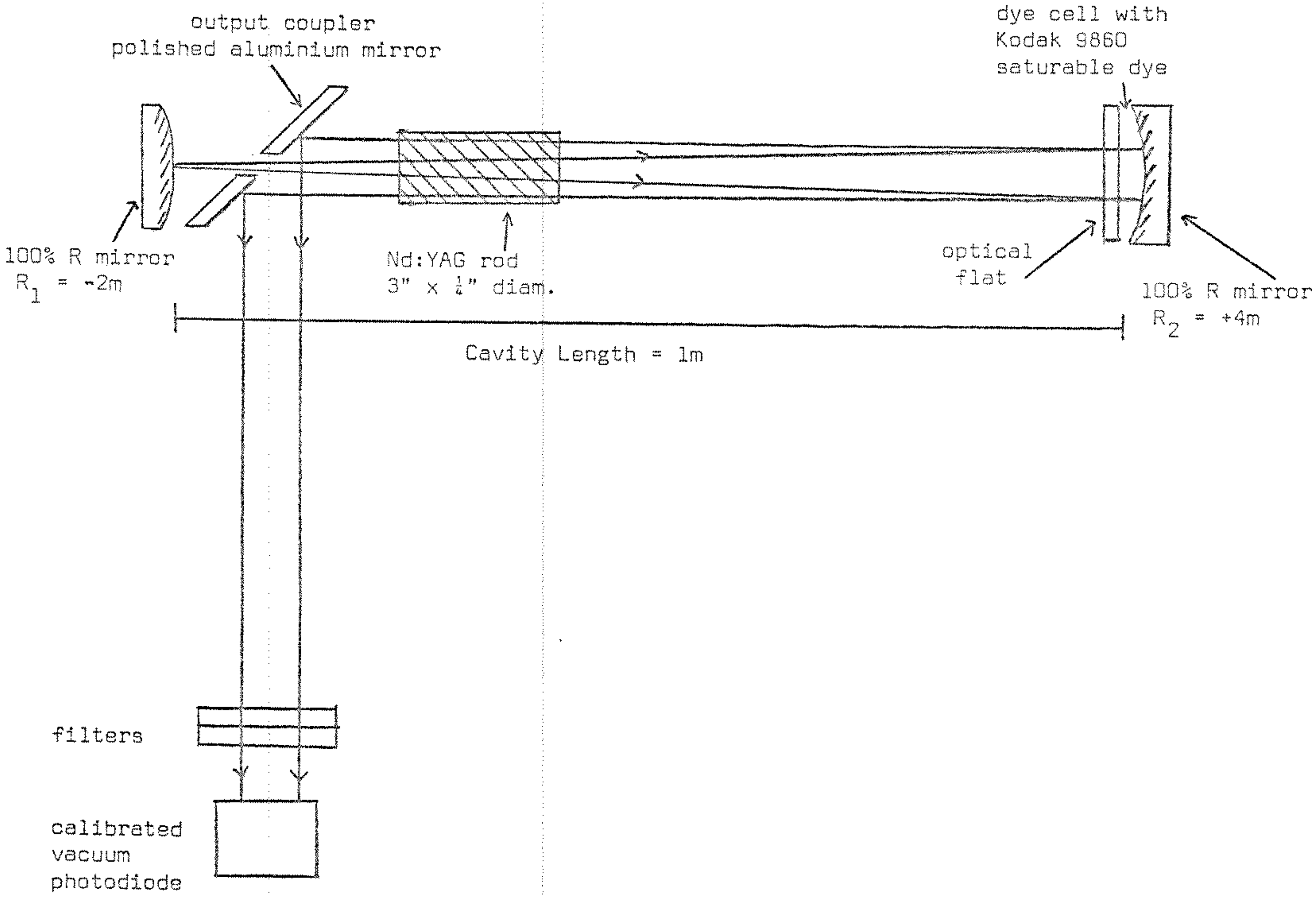

Figure 2 Nd:YAG mode-locked unstable laser

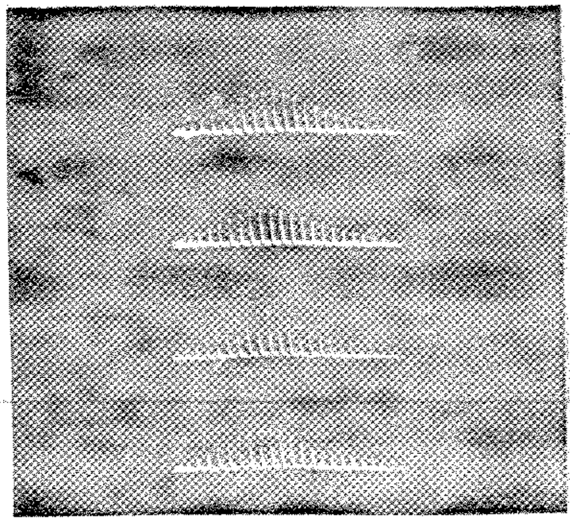

Fig 3 Mode-locked trains from an unstable resonator

Timescale 20ns/div

NEW DEVELOPMENTS ON LASER TRANSMITTERS FOR THE GRGS/CERGA SATELLITE AND LUNAR RANGING SYSTEMS

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Here after is a brief description of the last two laser transmitters used for the GRGS/CERGA ranging systems.

The satellite laser has now been operating since 1976 and we have gained some training through unexpected troubles.

The Lunar laser has been delivered in March 1978 and its simplicity of design and use seems to be good both from the viewpoint of operations and reliability.

I - SATELLITE SYSTEM

I.1. Introduction

When designed in 1974 only a ruby system was able to have the following advantages :

- wavelength 6943 A° where PMT cathodes have an acceptable efficiency
- Good space and time coherence
- Narrow bandwidth
- Short adjustable pulsewidths and mode-locked possibilities
- Mean power important for a Q-Switched laser
- High peak power to allow pulse shape processing
- High degree of reliability

Hoped to be transportable and versatile, the system is rather heavy and complex and needs trained operators.

I.2. Hardware

The ruby laser system shown in fig.1 is built in an oscillator - preamplifier-double pass amplifier - power amplifier configuration.

The oscillator cavity consists of a concave mirror MS immerged in a dye cell (Dicarbocyanine*)and two Fabry-Perrot etalons FP_1 FP_2. The overall assembly is a 1.5m long cavity designed for 23ns pulse width. A pin hole, placed between the output end of the 6.35 diameter 122mm long oscillator rod and the first FP, acts as a selector for a TME_{00} mono-longitudinal mode operation.

By switching the FP etalons it is possible to mode-lock the oscillator.

Through a pulse slicer P,PG the width is reduced to 2ns, 6ns, 10ns. The outgoing beam goes through a divergent lens L_1 to cover the following rods and is amplified by a preamplifier (6,35x122mm), a double pass amplifier (12,7x203mm) and, after a collimating lens, a power amplifier (19,05x197mm).

I.3. Specification

0.2 Hz repetition rate

Energy output	Pulsewidth FWHA
12j	10ns
8j	6ns
3j	2ns

0.5 Hz repetition rate

2j	10ns
12j	6ns
4j	2ns

- 70% of the energy within.25x10^{-3}rad.beam divergence
- 80% of the pulses within ±10% energy stability
- 100,000 shots flash tubes lifetime

In the mode-locked operation the oscillator delivers seven 200ps pulses in 10ns the energy has not yet been tested.

II. LUNAR SYSTEM

II.1. Introduction

In order to ut down the expenses for a completely new system, a rebuilding of the old 6ns / 6j multimode las r was achieved. The compoments are now installed on a new granite bench. The higher stability thus achieved, as well the larger dimensions giving better access to the compoments, assures that the settings are less critical than before.

In addition a new arrangements of the ascillator generates 3ns pulses in a TEM_{00} mono-longitudinal mode.

II.2. Hardware

The ruby laser system shown in fig.2 is built in an oscillator-double preamplifier- amplifier configuration.

The oscillator cavity consists of a concave mirror M_1 immersed in a dye cell (Dicarbocyanine*Jelikova, Hamal) and the combination of the output face of the rod with a 1cm Fabry-Perrot etalon.

The overall assembly is close coupled on each side of the 6,35mm diameter 132mm long ruby rod to shorten the cavity as much as possible. The mode selection is a pinhole between the mirror M_1 and the frontface of the ruby.

The outgoing pulse is collimated by two concave mirrors M_3M_4 and travels twice through the preamplifier head H_2(9,52x152mm). A telescope L_1L_2 expands the beam to cover the 14,3mm-diameter,204m-long power amplifier rod.

II.3. Specifications

The tested and guaranteed specifications are :

4j	3ns pulses
0,3 Hz	repetition rate
70% of the energy within 10^{-3}rad beam divergence	
80% of the pulses within ±5% energy stability	
100,000 shots flash tubes lifetime	

II.4 Conclusion

It seems possible to enhance the energy output,as some shots delivered 6j without damage.

The development of the Dicarbocyanine-Methanol dye(Jelikova Hamal) opens the possibility of passive Q-switching with a very high degree of reliability a it seems almost unaffected by temperature (20°C ± 10°C) and time (3 months tests).

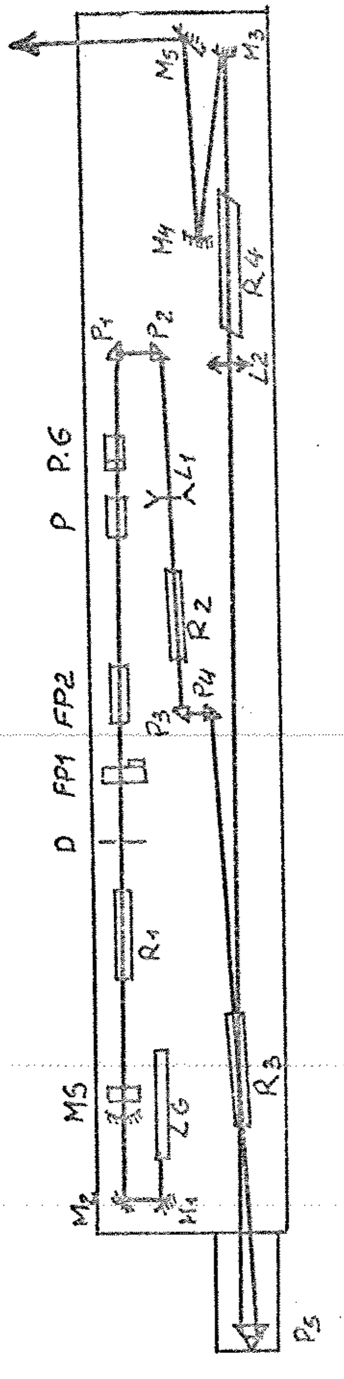

Fig. 1

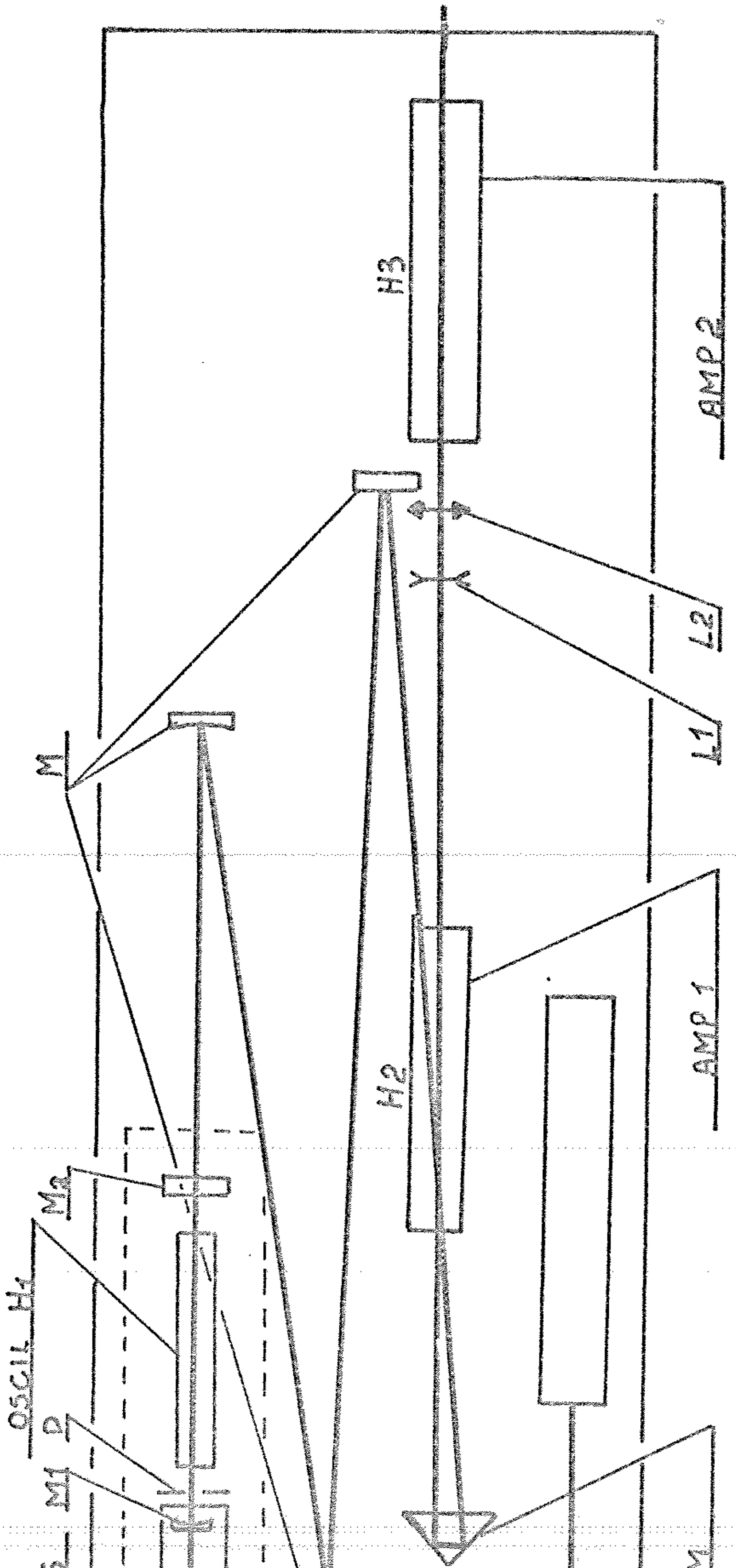

Fig 2

COMPACT SATELLITE RANGING LASER SUBSYSTEM

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The accuracy of 10 cm is expected from the second generation of the satellite laser radar |1|.Except the satellite retroarray and atmospheric transmission there exist also error sources in the laser radar itself,mainly due to finite length of the laser pulse and the jitter of the electronics including the time base.From the point of view of the pulse length,to obtain the required 10 cm noise level, there are in principle two solutions,either using a nanosecond pulse laser together with a centroid detection technique or using a subnanosecond laser.Subnanosecond pulses of the required peak and average power were obtained from the sophisticated YAG oscillator-amplifier system |2| installed at the Coudé focus.However,there are still certain advantages of the simple altitude-azimuth mount with movable laser transmitter.The altitude-azimuth mount gives strong limitations on the size of the laser subsystem.To obtain satisfactory retrosignal from Lageos,the laser transmitter should deliver about one Joule in 5 nsec in multimode regime.The requirements can be fulfilled with the oscillator-amplifier system.The cylindrical arrangement pumping cavity creates inhomogenities which can lead to laser rod distortion.The rotational ellipsoid gives a better inversion distribution |3|,|4|;on the other hand,it requires more space.

We would like to report on the arrangement,where two rubies and two flashlamps are placed symmetrically inside one rotational ellipsoid according to its axis (Fig.1).This arrangement exploits the advantages of the rotational pumping symmetry and saves the space.We were using ruby rods 15 cm long and 10 mm in diameter,and two flashlamps with the inner diameter of 12 mm.Having one ruby and one flashlamp in this pumping cavity,the threshold pumping energy was 1600 Joules.Having two rubies and two flashlamps,the pumping energy decreased by 20% for each flashlamp.

To obtain 4 nsec pulses,we were using PTM technique with $\lambda/4$

voltage.The Pockels cell is driven by two air spark gaps;the first is electrically triggered,the second coaxial optically triggered |5|,both of them at atmospheric pressure.To obtain a short risetime,a new technique was applied |6|.The risetime is less than 0.8 nsec.To obtain a short fall time,the Pockels cell was carefully terminated.It was found that even a little mismatch causes remarcable fall time lengthening and distortions.To avoid postlasing resulting from piezoelectric retardation,two different voltages are applied on Pockels cell.The polarizer P2 in Fig.1 is used to reflect the pulse to the amplifier and to decrease the background as well.To obtain acceptable reliability usually required for ranging at remote observatories,the oscillator is kept at medium values.The output of the oscillator is between 0.2-0.3 Joule.The amplifier gain is about three.Both flashlamps are kept at the same pumping voltage to simplify the power supply.

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Figure Capture

Fig.1. Two rubies pumping cavity

Fig.2. The output pulse.The multiple exposure shows the reproducibility.The time scale is 2 nsec/div.

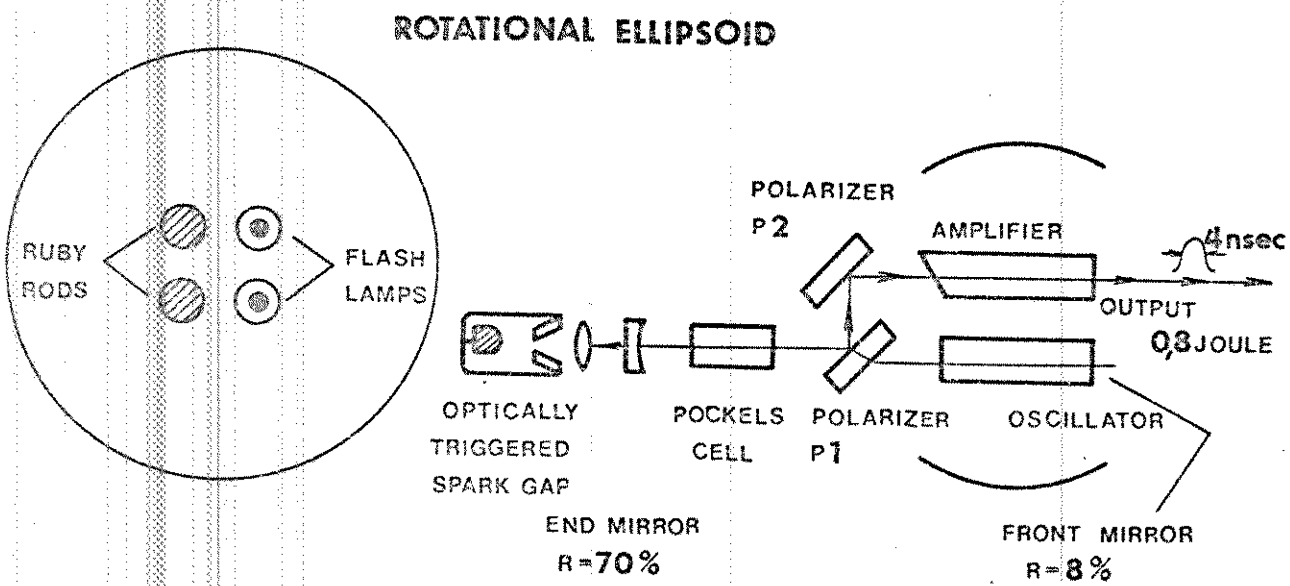
ROTATIONAL ELLIPSOID
RUBY RODS
FLASH LAMPS
OPTICALLY TRIGGERED SPARK GAP
END MIRROR
R=70%
POCKELS CELL
POLARIZER P2
POLARIZER P1
AMPLIFIER
OSCILLATOR
4nsec
OUTPUT
0,8JOULE
FRONT MIRROR
R=8%

Fig.1.

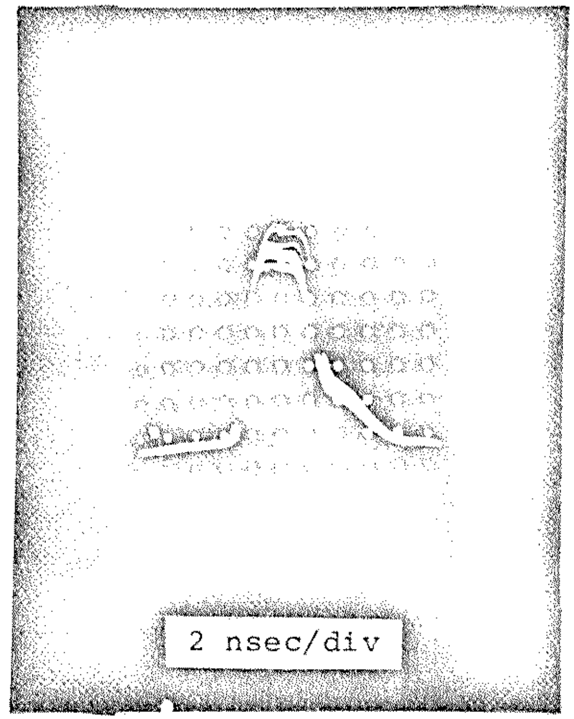
2 nsec/div

Fig.2

EFFICIENCY OF THE RUBY TELESCOPIC AMPLIFIER

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INTRODUCTION

Obtaining laser pulses with duration < 10ns is inevitably connected with the loss in the driving oscillator pulse energy, therefore, ruby laser transmitters of the second generation become significantly complicated by application of the multistage amplifiers /1,2/.

There exist more efficient types of amplifiers, based on multi-pass amplification in a single stage. In /3/ the description of the neodymium multi-pass resonant laser amplifier, which was modified in /4/ for Nd-YAG laser for intermediate amplification of weak light pulses with duration $\sim 10^{-10}$s, is given. We shall turn down to the discussion of the telescopic amplifier, that has been studied in /5/ for glass laser for the first time. Telescopic amplifier has such important advantages, as: 1) high amplification factor; 2) small size; 3) relative simplicity of the optical alingment and maintenance. Moreover, the amplifier can be used not only for intermediate amplification, but as the last amplifying stage.

Schematic Diagram of a Three-Pass Telescopic Amplifier

Schematic diagram of the amplifier (Fig.1a) looks like inverted Mersenne afocal telescopic system /6/, where the space between the mirrors is filled with laser medium. Depending on the parameter of the mirrors, three, five and more passes may be carried out in an amplifying medium. In one of recent papers /7/ a three-pass telescopic amplifier for CO_2-laser system with amplification factor $\simeq 10^3$ was described. The ruby telescopic amplifier has some characteristic features due to filling of the space between the mirrors by the optically heterogeneous medium, which has a refraction factor > 1.

Sufficiently complete consideration of the main characteristics of the telescopic amplifier is based on an unstable cavity theory /8/. In view of a relatively low ruby amplification factor one can confine himself to a geometrical approach, neglecting the problems of stability of the amplifier. A simple calculation for two-mirror telescopic system /6/, that has ruby length 240 mm, gives $R_1 \simeq 800$ mm, $R_2 \simeq 250$mm, where R_1, is a curvature radius of a big mirror, and R_2, is a curvature radius of a small mirror. Diameters of a small mirror and the hole in a big mirror for three-pass amplifier are $\simeq 0.3D$, /6/, where D, is the diameter of the big mirror.

Experimental Results

The telescopic amplifier has been investigated for schematic diagram presented in Fig. 1b. Reflecting prisms were used as mirrors, and a telescopic configuration of beam path was provided by lens with a focal length $\simeq$ 1m.

An entry prism was prepared as a double roof-prism. The top of the prism was cut off to ensure optical coupling of the amplifier with the oscillator. The ruby crystal 16mm in diameter and 240 mm long had tapered edges inclined at 2° angle to the geometrical axis of the rod.

At energy density on the output ruby edge $\simeq 1.3$ J/cm^2 the amplification factor for one pass was $\simeq 5$. Telescopic amplifier for the same conditions had the factor $\simeq 60$.

Divergence of the input beam was 5', and the output divergence was practically the same.

The output mirror of the telescopic amplifier is in the powerful light field, therefore, it is necessary to take measures to avoid optical surface contamination by the vapour of the holder material. One can use Maksutov-Mersenne telescopic system /6/ for the amplifier (Fig. 1c), in this case there are no elements of the mirror holder in the light beam.

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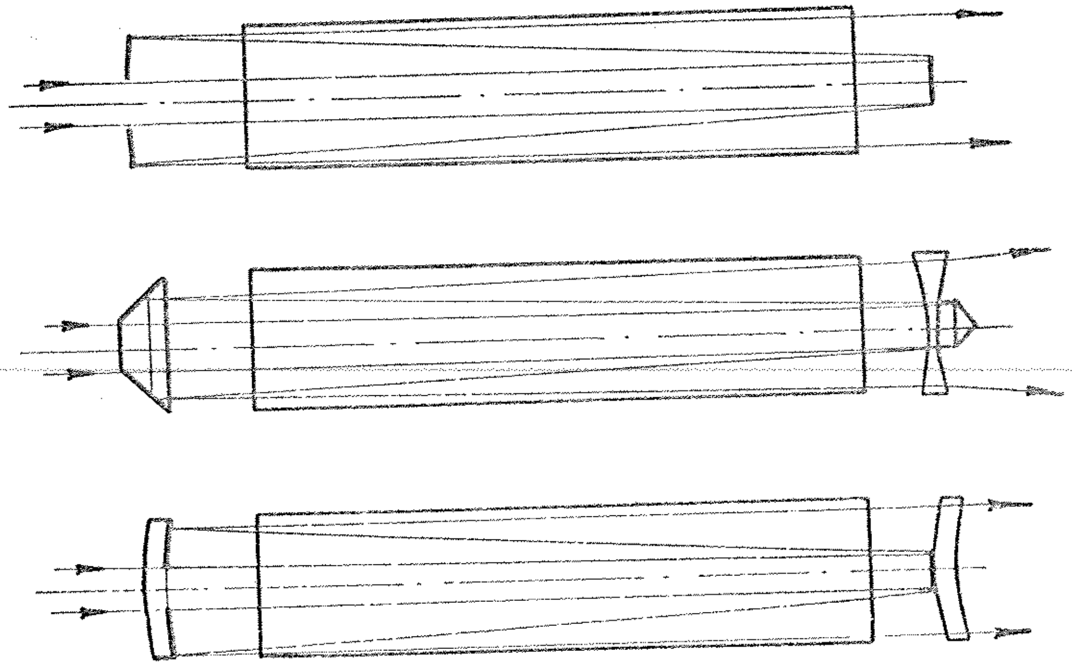
Figure Captions

Fig. 1. Schematic diagrams of the telescopic amplifiers.



QUANTUM LIMITED 4 NSEC LASER RANGING ACCURACY

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The 4 nsec trapezoidal and gaussian laser pulses of different power level were compared from the point of view of laser radar measurement accuracies. Pulse centroid correction procedure was taken into account. The computer simulation of the detection procedure was done using HP 9830 as reported in [1]. The statistical ensembles of at least 50 stochastic photomultiplier current realizations were compared. Representative results are summarized on Figs.1,2,3.The photomultiplier response time equals 1 nsec. Fig. 1 shows the spreads of ranges in the case when laser pulse shape is gaussian of 4nsec FWHM and the signal level equals 100 photoelectron. The same pulse duration but lower signal level (20 photoel.) leads to the histogram shown as Fig.2. Fig.3 summarizes the simulation results for 20 photoel. trapezoidal pulses of 4 nsec FWHM and 0.5 nsec rise time.

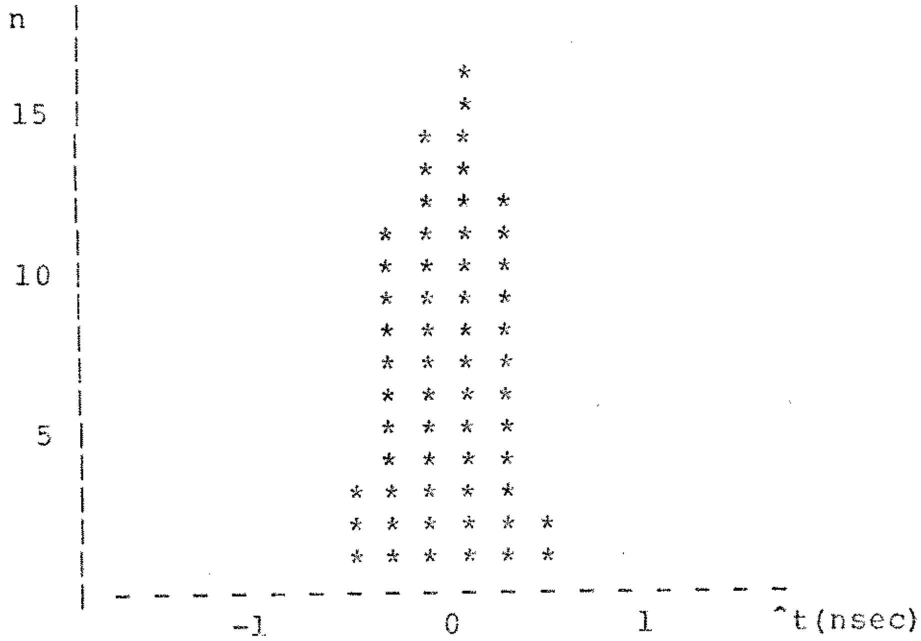

Fig.1: Histogram of the range inaccuracies (quant.limited)
horizontal scale: 0.2 nsec/div
gaussian pulse, power level: 100 photoel.,
FWHM : 4 nsec

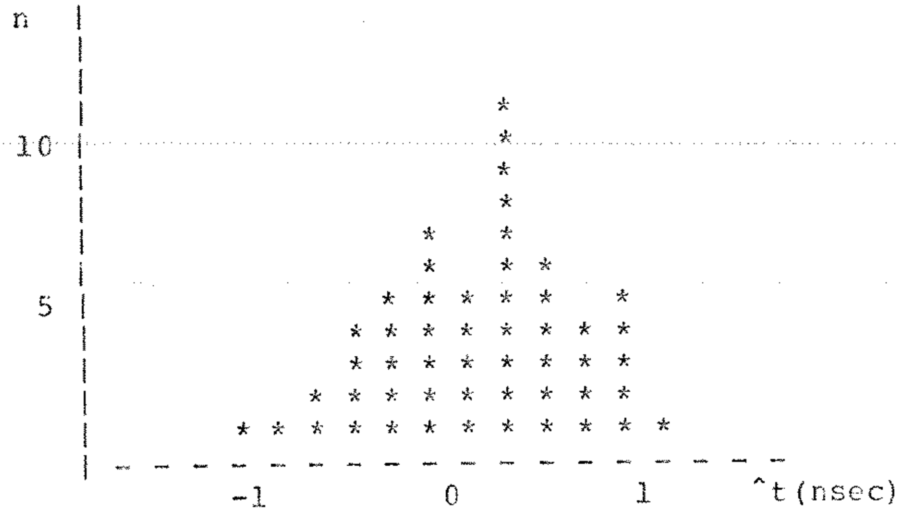

Fig.2: Histogram of the range inaccuracies (quant.limited)
horizontal scale: 0.2 nsec/div
gaussian pulse, power level : 20 photoel.
FWHM : 4 nsec

```
 n |
   |
   |          *
   |        * *
   |        * * *
10 |        * * *
   |        * * *
   |        * * *
   |        * * * *
   |        * * * *
 5 |        * * * *
   |        * * * *
   |        * * * * *
   |        * * * * * *
   |    * * * * * * * *
   |- - - - - - - - - - - - - - - - - -
          -1        0         1        ^t(nsec)
```

Fig.3: Histogram of the range inaccuracies (quant.limited)
horizontal scale: 0.2 nsec/div
trapezoidal pulse, power level : 20 photoel.
FWHM : 4 nsec

In accordance with these graphs we can conclude:

(1) The gaussian pulse shape,100 photoelectron signal, 4nsec and analog pulse centroid correction procedure assure that the quantum limited accuracy is higher then $\pm$half nsec.

(2) Whenever the signal level decreases five times the quantum limited range inaccuracy increases approximately two times (compare Figs.1 and 2).

(3) The trapezoidal pulse with 0.5 nsec rise time,4 nsec FWHM has at the signal level about 20 photoelectron the quantum limited accuracy better then $\pm$0.6 nsec. This value is almost two times higher than that for the gaussian pulse shape of the same width and the same signal level (compare Figs.2 and 3).

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A FAST LASER TRIGGERED SPARK GAP DRIVEN ELECTRO-OPTICAL SHUTTER SYSTEM

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INTRODUCTION

Desirable features of a good laser ranging pulse are a short duration, high power and small beam divergence, i.e. high radiance. The Q-switching lacks the first prerequisite, but fortunately this drawback can be readily remedied by using an external electro-optical shutter to tailor the pulse.

The present paper describes the construction and preliminary test results of an electro-optical shutter intended for use in the Metsähovi satellite laser range finder /1/ to shorten a 20 ns Q-switched ruby laser pulse to 5 ns or less. A more detailed description can be found elsewhere /2/.

APPARATUS

An electro-optical shutter (or slicer) typically consists of a Pockels cell situated between crossed polarizers. The time dependent transmission T(t) of the shutter can be described by the equation

$$T(t) = T_{max} \cdot \sin^2 \left[\frac{\pi}{2} \cdot \frac{U(t)}{V_{\lambda/2}} \right], \qquad (1)$$

where T_{max} is the maximum transmission, U(t) is the applied time dependent voltage, and $V_{\lambda/2}$ is the half wave voltage of the Pockels cell. If the cell is driven via a coaxial cable with the impedance Z_o, the voltage V(t) is ideally given by $V(t) = V_{max} \cdot \left[1 - \exp(-t/\tau) \right]$, where V_{max} is the final value of the voltage pulse and the electrical time constant, τ, is given by $\tau = Z_oC$, where C is the cell capacitance. V_{max} can be selected to be $V_{\lambda/2}$ (= half wave shuttering) or $2V_{\lambda/2}$ (= full wave shuttering). The transmitted optical pulse shapes are shown in Fig. 1.

The schematic diagram of the electro-optic shutter tested is shown in Fig. 2. A high speed, 50 Ω, KD*P Pockels cell of coaxial cylindrical ring electrode structure is used (Interactive Radiation Inc., Model 262-150). The electrical rise time is specified as 550 ps, from which a cell capacitance of 10 pF can be calculated ($T_r = 2.2\tau$, where τ is now 0.5 Z_0C). The N_2-pressurized laser-triggered spark gap (LTSG) employed is a small 50 Ω transversally triggered unit (Lasermetrics, Inc. Model SG-201). A Glan-laser polarizer was used (Lasermetrics Inc.).

The pulse shape was measured by a high speed vacuum photodiode (Instrument Technology Ltd, Model HSD-1850, S-20 photocathode, the nominal rise time 0.1 ns) and a Tektronix Transient Digitizer R 7912 (500 MHz bandwidth). The rise time of the detecting system was 0.7 ns.

RESULTS AND DISCUSSION

The shutter was first tested in the conventional mode, where the cable L_3 was the long terminated cable and the cable L_1 was the charge storage cable of 50 cm length (RG214/U), designed to give a 5 ns electric pulse. The measured rise and fall times of the shuttered pulses were near 1 ns.

The shutter system was also tested in a less common inverted configuration, shown in Fig. 2, where a bias voltage of 2 $V_{\lambda/2}$ was continuously applied to the Pockels cell without the external cable L_3. If the electro-optical crystal is located at the very end of the cable, the bias voltage goes smoothly from $2V_{\lambda/2}$ to zero when the LTSG is switched on and the optical transmission follows the full wave shuttering curve, Fig. 1b. However, in this case, there is a small intrinsic length of transmission line on both sides of the crystal because of continuous 50 ohm coaxial construction, and therefore the ideal pulse shape becomes modified by the voltage reflections. The theoretical transmission curve is shown in Fig. 3a. The estimated optical rise time is 500 ps and the pulse length 2 ns (FWHM). A measured optical pulse shape is shown in Fig. 3b. The front end of the pulse is integrated by the detecting system and the real amplitude is thus not known exactly.

The values measured support the conclusion that the rise time is about 500 ps and the pulse length 2 ns as calculated. This experiment also shows that the rise time of a matched LTSG can be considerably less than 500 ps.

CONCLUDING REMARKS

If the crystal is located at the end of the cable, the theoretical pulse width is 550 ps (FWHM) and the rise time 350 ps, Fig. 1b, with

$C = 10$ pF, $Z_o = 50$ ohm, $\tau = 0.5$ ns. This might be obtainable with some suitably designed capacitive Pockels cells. A faster operation could be obtained using the pulse-on method and the full wave shuttering (two transmitted optical pulses, $\tau = 0.25$ ns), but the charge voltage needed would be $4V_{\lambda/2}$. The use of a double crystal Pockels cell might be profitable in this case. A recent report on optical rise time measurements on KD*P transmission-line Pockels cells /3/ shows that the rise time of a shuttered laser pulse would be restricted to rise times of about 300 ps when half wave shuttering and a spark gap driver is used. Faster operation, to less than 100 ps, could be obtainable with silicon photoconductive switches /4/.

If the Pockels cell is fed by a $V_{\lambda/2}$-voltage instead of the $2V_{\lambda/2}$-voltage, the whole Q-switched pulse is transmitted without shuttering action, Fig. 2. This feature might be useful in a ranging process where the satellite is first detected by a long, higher energy pulse and then the transmitter is switched to a short pulse mode for precise range measurements.

It is a great pleasure to acknowledge the financial aid of the Geographical Survey Office of Sweden, Gävle, in procuring the electro-optic shutter components used. Support from the Academy of Finland is also acknowledged

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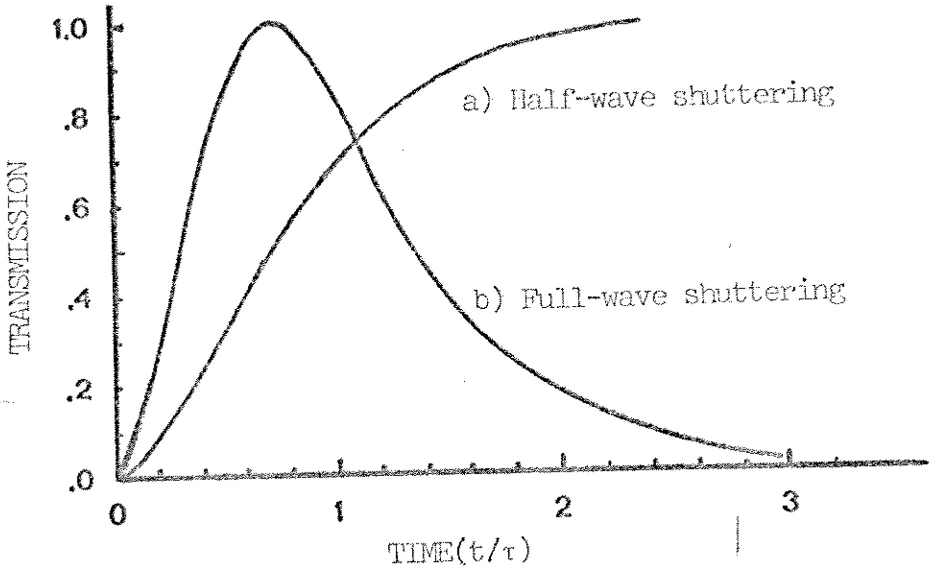

Fig.1. Transmission of the electro-optical shutter.

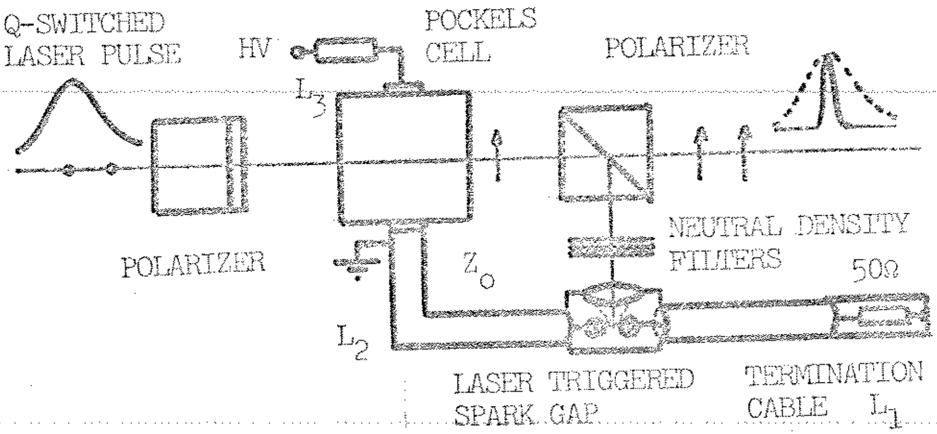

Fig.2. Schematic diagram of an electro-optical shutter.

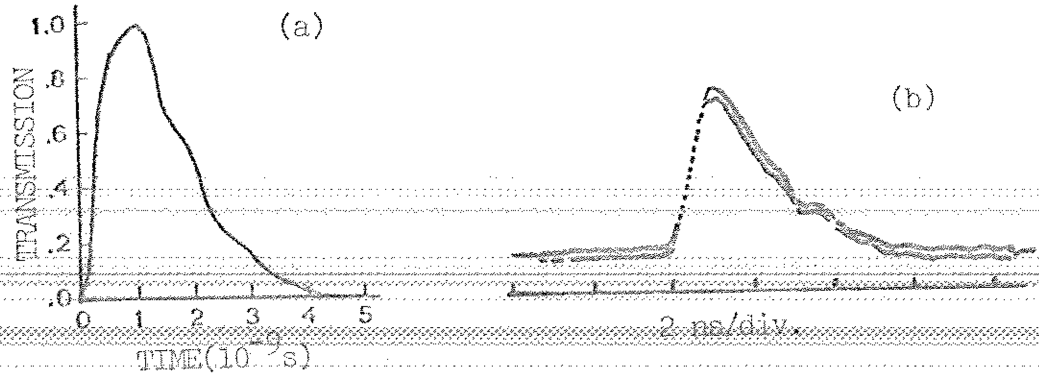

Fig.3. Calculated (a) and measured (b) transmission of the shutter shown in Fig.2.

LASER FOR SATELLITE RANGING

AT QUANTEL

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Today's satellite tracking and ranging laser systems are concerned with two types of satellites :

Geodesic satellites of small size including retroreflecting mirrors that allow for high precision low loss tracking, in the ultimate precision range of 1 to 5 cm when a good atmospheric model is available.

Other satellites of larger size allowing only for high losses, low precision ranging (100 cm).

Geodesic satellites ranging systems can make full use of mode lock lasers. Such lasers tacking advantage of the prelase technic are under development at QUANTEL and are described in paragraph 2. However they are still expensive instruments devoted to very specific experiments and most measurements can be made with pulses a few nanoseconds long.

A new Q-switch system is now available from QUANTEL that can cover in a simple ruggedized unit all tracking needs for both types of satellites since it's pulse duration can be as short as 2.5 to 3 ns.

1/ A simple Q-switch laser for satellite ranging

Let's consider a laser emitting a single reproducible pulse of full width half maximum duration τ.

In the case of high loss tracking at low precision τ must allow for 1 meter ranging precision with no shape analysis (single photon return). Therefore we must have $\tau \leq$ 4 to 6 ns with an energy of the order of 100 mJ or $2{,}5.10^{17}$ photons.

When used on geodisic satellites the collected energy from the same pulse is around 10^4 to 10^5 photons and an increase in ranging precision on a factor 10 is possible using threshold and shape analysis methods.

If a final precision of 5 cm is needed a pulse of duration τ = 3 ns is sufficient. Our present laser emits such pulses with the following characteristics :

- FWHM pulse duration $\leq$ 3 ns
- Diffraction limited beam
- A single amplifier stage for :
- Output energy at 1,06 µ 300 mJ
- Output energy at 0.53 µ 100 mJ
- Repetition rate 1 to 10 Hz.

Higher energy can be obtained with a second amplifier.

The short pulse is produced directly by a short length laser cavity that includes a high gain short YAG rod.

In order to keep a high beam quality the laser oscillator works on a TEMoo mode and uses the Polarex$^{(T)}$ technic described in (1). It's general organization is given on figure 1.

Figures 2 and 3 show the laser bench with the different components in the case of one and two amplifier stages.

Pulses shapes are given on figure 4.

2/ A stable mode lock laser

High energy mode lock laser system are usually very expensive (regenerative amplifier systems) or rather unstable (passively mode lock lasers).

There use in laser ranging is therefore limited and cumbersome.

We have experimented at QUANTEL an actively mode lock laser (Acousto optic modulator) Q-switched by a Pockels cell driven by a D.C. power supply with controlable current.

This system gives stable reproducible pulses with a relatively unexpensive equipment.

It is possible to run this laser in a quasi continuous fashion since the current in the flash lamp is precisely controlable and to have a long period to develop a stable mode lock behaviour (2).

When the laser is then Q-switched with the Pockels cell a stable pulse arrises (Figure 5).

In an other configuration giving similar results a standard pulsed power supply was used and a controle loop was driving the DG voltage on the Pockels cell in order to keep the output power of the laser constant around 10 W.

The same prelase operation was observed with the same type of pulse stability. Figure 6 shows the output pulse of the laser when it is not Q-switched.

This laser is followed by a fast pulse selector working at high repetition rate and by two stages of amplification.

Output energy for 0.3 ns pulse can be 100 mJ at 1,06 μ and 50 mJ at 0.53 μ at a 10 Hz repetition rate.

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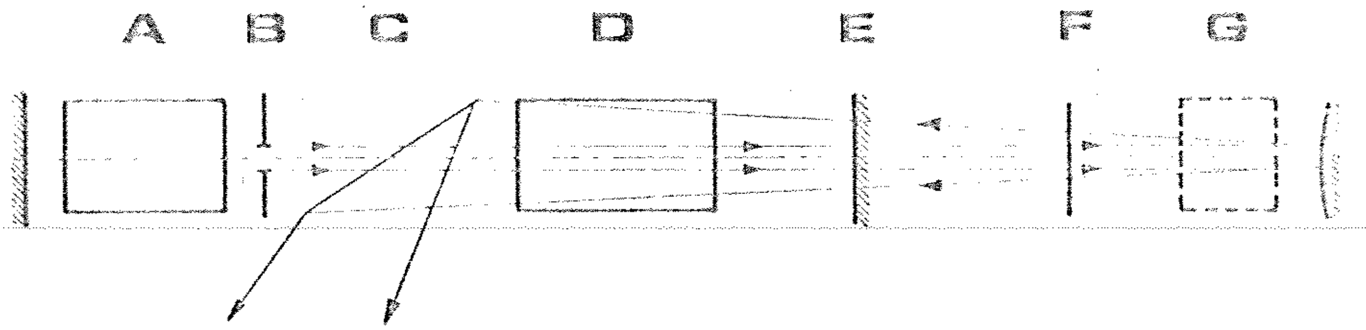


FIGURE I

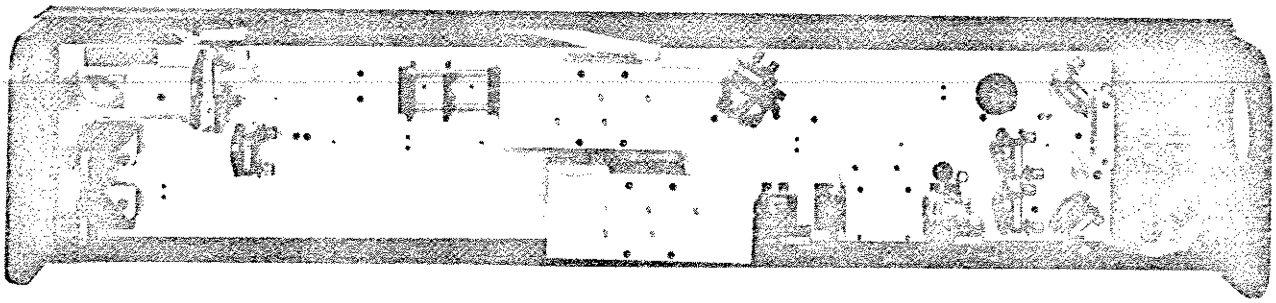


FIGURE 2

View of the short pulse Q-switch YAG laser.

The two laser heads (oscillator + amplifier) are clearly visible.

The second harmonic generation crystal is in its at the far left of the bench.

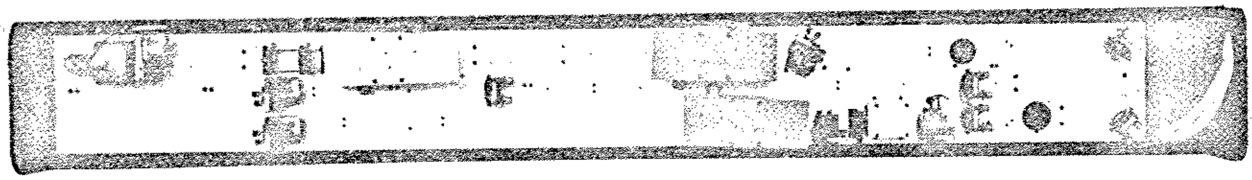
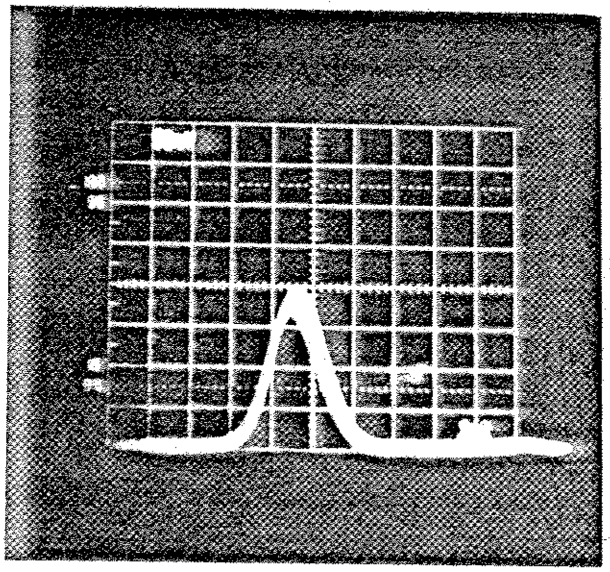


FIGURE 3

View of the short pulse Q-switch YAG laser with two amplifiers.

(A)



(B)

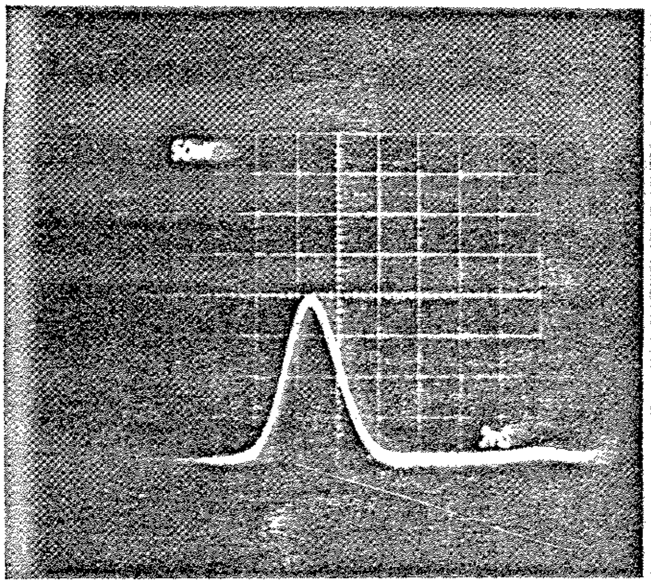


FIGURE 4

Laser pulse (A) and second harmonic pulse (B) from a short pulse Q-switch laser.

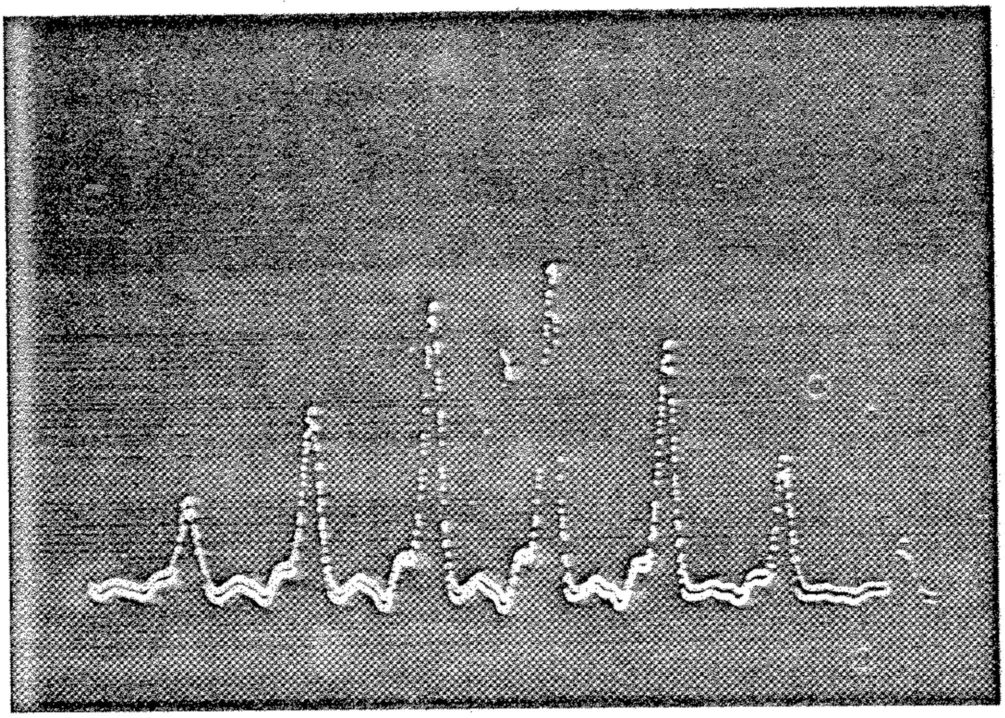


FIGURE 5

Mode lock pulses obtained with the prelase technic.

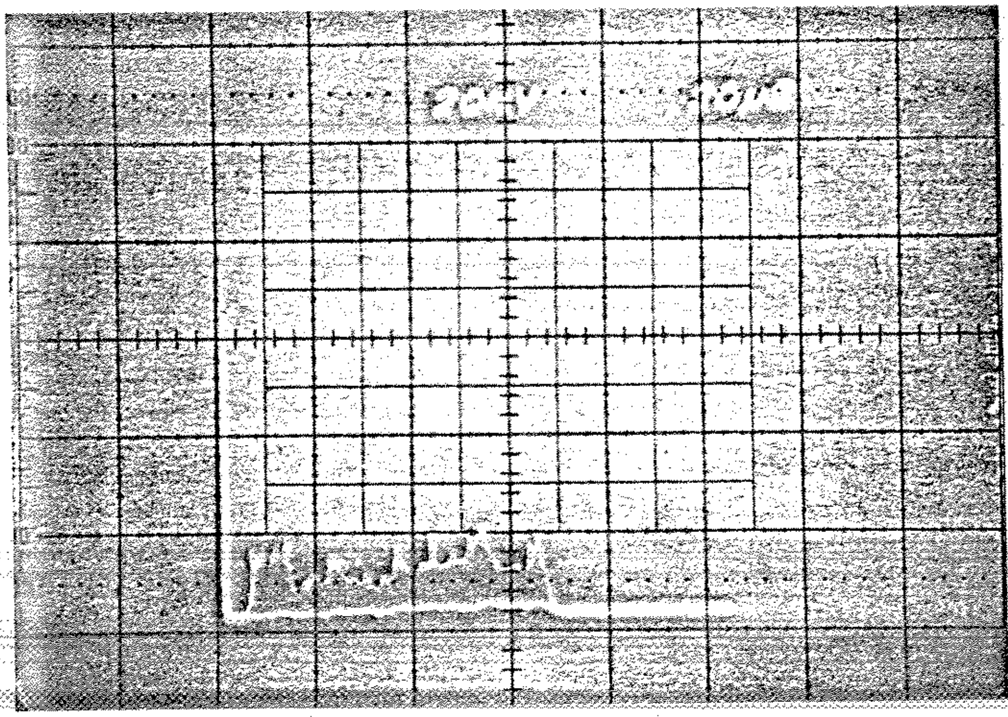


FIGURE 6

Output of a laser in the prelase mode when the Q-switch (a Pockels cell) is not opened.

200 PICOSECOND LASER DEVELOPMENT - A STATUS REPORT

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An important long term goal of the laser ranging R&D program at Goddard has been the achievement of 2 cm overall ranging system accuracy. In order to achieve this goal it has been our consistent belief that the pulsewidth of the laser transmitter must be reduced by approximately an order of magnitude below the 3-5 nanosecond pulsewidth which can be achieved using Q-switched or cavity dump techniques. To this end, we sponsored the development beginning in the early 1970's of a high energy frequency doubled Nd:YAG laser with a cw modelocked oscillator at GTE Sylvania. This laser was intended solely for ground based applications. We have now had an opportunity to gain operational experience with this laser and to make certain improvements in its design. Beginning in 1975, we sponsored the development of a flash pumped modelocked laser transmitter at International Laser Systems. The goal of this development was to develop a laser with a configuration that would permit operation in a spacecraft environment. Obviously, if the laser can be made to operate properly it can be used in ground based systems.

The operational characteristics, performance and status of these developments is the subject of this paper.

THE CW MODELOCKED OSCILLATOR APPROACH

The high energy, short pulse, Nd:YAG laser system manufactured by GTE Sylvania, consists of a cw modelocked oscillator, a regenerative amplifier, three single pass amplifiers, and a type II KD*P second harmonic generator. The laser system is capable of operating at 5 pulses per second emitting a nominal 250 milljoules of energy at .53 micrometers with a pulse width of less than 200 picoseconds fullwidth half max. (FWHM).

In operation, the cw oscillator is modelocked by an acousto optical modulator and generates a continous train of 200 picosecond, 6 nanojoule coherent optical pulses at a 150 megapulse/sec. rate. This train of pulses passes through the selector pockels cell which rotates the polarization of a single pulse by application of a short pulse of halfwave voltage in syncronization with the modelocked output of the cw oscillator. This single seed pulse is directed into the regenerative amplifier by calcite polarizers and passes through the regenerative amplifier "Q" switch pockels cell. The "Q" switch pockels cell is biased at the quarterwave voltage and the seed pulse after reflection from the regenerative amplifier cavity end mirror passes back through the "Q" switch pockels cell. The quarterwave voltage on the "Q" switch pockels cell is then reduced to O preventing any additonal pulses from the cw oscillator from entering the regenerative amplifier and allows the regenerative amplifier circulating energy to remain in the cavity. The initial seed pulse reflects back and forth between the regenerative amplifier cavity end mirrors and is amplified each time it passes through the regenerative amplifier rod. After several round trip passes (typically 10-30) through the amplifier rod the circulating energy reaches a maximum value and the cavity dump pockels cell is operated. This rotates the polarization of the circulating energy by a halfwave and the energy is coupled out of the regenerative amplifier and through the isolator pockels cell to the three single pass amplifiers. The original seed pulse from the cw oscillator is amplified from $6x10^{-9}$ Joules to about 10^{-3} Joules by the regenerative amplifier. The three single pass amplifiers amplify the one millijoule regenerative amplifier output to the 500 millijoule level. The output of the final amplifier is expanded and doubled by the type II KD*P second harmonic generator with a nominal 50% conversion efficiency.

The successful operation of this laser system depends on several factors. Principle among these factors are the maintenance of proper alignment or opto-mechanical stability, the precise and stable control of the optical radiation and switching and the maintenance of good beam homogeneity throughout the system. Except for the question of damage to the various optical components, introduced by beam inhomogeneities, optical instability, dirt or operation at unusually high power levels, the control of the optical radiation throughout the laser effects its performance for the ranging application as much as any other single factor. In fact, proper control of the radiation through stable reliable operation of the drive voltage to the electro optic switches will tend to prevent the destructive effects of changes in alignment and the beam inhomogeneities introduced by these changes. As manufactured, the 4 Kilovolt pulses for the pockels cells were generated by krytron driver boards. The voltage transitions were typically 3-5 nanoseconds in duration with a jitter of 1.5-3 nanoseconds. In addition, the transition risetime and jitter would materially change over both short and long term operation, requiring constant adjustment to maintain operation of the laser. These changes would cause the laser to operate with multiple or long pulse operation, and with a large variation in output energy. Furthermore, the timing between the "Q" switch and cavity dump transitions was fixed by an adjustable delay synchronized to the cw oscillator optical output. Any variations in the Gain of the regenerative amplifier from misalignment or pump energy fluctuations would cause the buildup of the circulating seed pulse to occur at different times with respect to the fixed cavity dump timing. In order to stabilize this buildup time, the regnerative amplifier was usually pumped at a very high level which would give an output pulse with energy close to or exceeding the damage threshold of some of the optical components.

Two modifications have been implemented in one of the laser systems to achieve stable and reliable control of the electro-optical switching. The original pockels cell driver boards were replaced with EG&G (Ortec) HV100/N high voltage pulsers. These pulsers supply the pockels cells with the correct voltages with a risetime of less than 1.5 nanoseconds and a jitter with respect to the input trigger pulse of less than 1.5 nanoseconds over long periods of time. The cavity dump driver trigger was changed from the original fixed timing synchronized to the cw mode locked output to a trigger generated by a radiation detector sensing the buildup in the regenerative amplifier itself. This radiation detector was fabricated from an avalanche mode transistor with the top of the can cut off and the junction illuminated by leakage radiation from one end of the regenerative amplifier. Control of the cavity dump pockels cell driver is better than 1 ns and cavity dumping always occurs at a given energy level within the regenerative amplifier cavity. This allows operation of the regenerative amplifier at a level low enough to preclude the development of any pulse energetic enough to damage any optical components. Furthermore, triggering on the energy buildup itself compensates for minor misalignment changes in the regenerative amplifier which normally manifests itself as a major change in buildup time rather than a large reduction in buildup energy.

Those applications requiring a high energy, short pulse laser can be satisfied under certain limitations with this laser system if the modifications as described are made. However, this laser system does require frequent alignment by highly trained personnel and the lifetime of optical components is directly related to the required output energy.

THE FLASHLAMP-PUMPED APPROACH

The goal of the ILS program is the development of a rugged, frequency doubled, subnanosecond pulse, flashlamp-pumped Nd:YAG oscillator/amplifier system capable of ranging from the Space Shuttle to ground-based retroreflectors with a single shot accuracy of two centimeters. Present ruggedized lasers are Q-switched oscillators having pulsewidths of 10 nanoseconds or more which, with realizable receivers, are not capable of such precise ranging. Flashlamp-pumping the oscillator reduces the system prime power requirements to about 200 watts compared to over 3000 watts for ground-based systems which use CW-pumped, mode-locked, oscillators to generate a subnanosecond seed pulse for the laser amplifier chain.

The ILS system uses an RF-driven, electro-optic KD*P modelocker in combination with a dielectric thin film polarizer to provide a sinusoidal modulation of the cavity loss during the pre-lase period. During this period, which lasts for several microseconds, the laser oscillates at a very low level just above threshold while the modelocker gradually reduces the temporal width of the circulating pulse to its steady state value of approximately 200 picoseconds. A voltage-programmable KD*P Q-switch and a second dielectric polarizer provides a variable loss for three separate cavity conditions: (1) the pre-lase condition (moderate voltage) during which the modelocker acts on the circulating low-level radiation to produce a subnanosecond pulsewidth; (2) the Q-switched condition (zero voltage) during which the subnanosecond pulse builds up rapidly in energy; and (3) the cavity-pump condition (quarter wave voltage) in which the circulating pulse is ejected from the cavity. The pulse is then amplified in a double-pass amplifier and frequency-doubled in a Type II KD*P crystal. The use of a double-sided convex-concave mirror and the crossed TIR prism resonator enhances the mechanical alignment stability while providing a long resonator length for the oscillator within a compact volume. The long resonator length relaxes the switching time requirements for the cavity dump operation and provides large spot sizes within the resonator which in turn improves the mode volume and energy extraction efficiency within the Nd:YAG rod and raises the energy threshold at which optical damge will occur. In addition to providing a subnanosecond pulsewidth, the prelase period also allows the TEM_{00} or gaussian spatial mode to become dominant.

The breadboard consists of four separate units: (1) the transmitter unit; (2) the modelocker driver unit; (3) the power supply unit; and (4) the cooling unit.

Experiments to date have verified the generation of a single subnanosecond pulse (less than 800 picoseconds detector limited) with an energy of 35 millijoules at the 1.06 micrometer wavelength. The output of the oscillator/amplifier exhibits virtually no prepulse although a small postpulse is observed. Efforts are being directed toward an improvement in the postpulse extinction via a reduction in the cavity-dump switching time.

FIGURE OF MERIT OF A LASER FOR RADAR APPLICATIONS

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The applications requirements on lasers can be expressed by a figure of merit.Born and Wolf /1/ separate the brightness and a time bandwidth product of a light source.We examine /2/ some pulse laser applications and demonstrate the ratio of the brightness and the spectral width defined as *the spectral brightness* can be used as a figure of merit for a laser source in most applications including a laser radar.

The radar scheme has a transmitter,target and receiver. The received energy S is determined by the radar equation /3/. Assuming the transmitter terms only

$$S \ \alpha \ \frac{1}{R^4} \frac{E}{\Theta_T^2} \quad . \tag{1}$$

Here E is the transmitted energy,air is the target distance and Θ_T is the beam divergence due to the transmitter.The factor E/Θ_T^2 is controlled by the transmitter.The transmitter beam divergence Θ_T refers to a laser beam collimated by a telescope and can be expressed as

$$\Theta_T = \frac{D_L}{D_T} \ . \ \Theta_L , \tag{2}$$

where D_L is the diameter of the input laser beam,D_T is the diameter of the telescope output beam and Θ_L is the laser beam divergence.Combining (1),(2) we obtain

$$S \ \alpha \ \frac{E}{D_L^2 \ . \ \Theta_L^2} = B \ . \ \Delta\tau \ . \tag{3}$$

where B is the brightness of a laser and $\Delta\tau$ the pulse length. The thermal noise energy N of the detector with bandwidth Δf_G and time gate $\Delta\tau_G$ is proportional to

$$N \ \alpha \ \Delta f_G \ . \ \Delta\tau_G . \tag{4}$$

The figure of merit of a laser radar can be determined by a signal noise ratio SNR.The maximum SNR corresponds to the conditions $\Delta f_G = \Delta f$ and $\Delta\tau_G = \Delta\tau$.$\Delta f$ is the spactral width of a laser radiation.Then

$$\mathrm{SNR}\ \alpha\ \frac{B}{\Delta f}\quad . \qquad (5)$$

Thus the spectral brightness is the figure of merit of a laser for radar applications.

References

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2. K.Hamal,"Figure of merit for some pulse laser applications", *IEEE J.Quantum Electron.*,vol.QE-14,June 1978.
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session 6B laser safety

chairman F. Nouel /co-chairman F. Zeeman

Nouel
Thorp /Pearlman
Visser /Zeeman
McGunigal /Bebris
Hatat

LASER SAFETY

F. Nouel
Groupe de Recherches de Géodésie Spatiale, Toulouse, France

INTRODUCTION

During the two previous workshops, the problems of laser safety have been talked about and some major ideas or actions were developped :

- we are responsible by our vocabulary (fire the laser, shot, target) for maintaining the reactions of authorities to the laser ranging systems which are different from those for military applications.

- the standards in most of the countries are either not yet defined or under consideration.

- besides injuries that concerned people at the laser station which still keep, in most cases, the character of laboratory, aircraft safety is a problem as far as concerns us.

At the workshop hold in Prague, it was decided to make literature readily available by sending documents or biographies to Dr. M. Pearlman from SAO. He would distribute copies to requesting individuals. This action will be looked at as far as its result is concerned and further developments given if necessary or wished.

1. Evaluation and control of Laser hazards

In U.S.A., since 2 years a national standard list is used. It was defined by the Bureau of Radiations Health.

In other countries, it seems that utilisation conditions are under investigation (R.F.A., Australia) or not existing (France except for medical use of laser).

A NATO Standardisation Agreement (STANAG 3606) has been written. The issue should be finalised in the near future.

On the other hand, the International Electrotechnical Commission (CEI) has a technical Committee (N° 76) on Laser equipment that defined standards and publishes security levels for the parameters.

The Société Française de Radio Protection organized an international congress at Corbeil (near Paris) in May 1978 and where a special panel is devoted to laser.

2. Parameters in Laser hazard evaluation

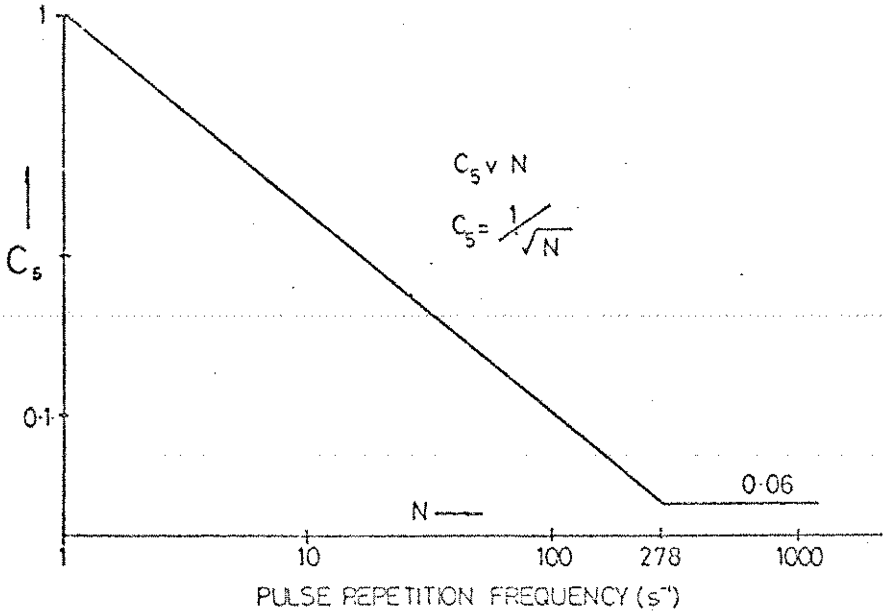
These parameters are :

- the wavelength,
- the pulse duration,
- the pulse energy,
- the natural beam divergence,
- the emergent beam diameter,
- the pulse repetition frequency.

Laser are grouped in four classes which correspond to output of these parameters. Then a Nominal Ocular Hazard Distance (N.O.H.D.) can be computed. It corresponds to the distance where safety for the eyes or skin is respected with respect to the appropriate Protection Standard.

However, factors are affecting this distance, such as atmospheric effects, magnifying optical instruments, reflection hazards, beam pointing accuracy, pulse repetition frequency.

All these parameters are important in order to choose the appropriate attenuating glasses to wear.



For example, it is specified that with repetitively pulsed lasers, it is appropriate to reduce the standard values for maximum permissible exposures of individual pulses, using the correction factor C_5 .

$$C_5 = 1/\sqrt{N} \quad \text{for} \quad 1 \leqslant N \leqslant 278\ s^{-1}$$

$$C_5 = 0.06 \quad \text{for} \quad N > 278\ s^{-1}$$

3. Aircraft safety

Several devices are used by the groups for aircraft safety. It can goes from a permanent watching by radar for example to simplier systems which operate almost automatically by stopping laser emition when a plane is coming too closely to the laser beam. Such systems should be developped because they require less personnal contribution when operating the stations.

The device used at Kootwijk station is operating since the last workshop and reliability will be examined.

The autorities might become more conservative as they already were after reading the paper on "Laser Satellite Ranging as a Hazard to Overflying Aircraft" published by G.J. Pert in Optics and Laser Technology - April 78 -. As it is often the case, the reader looks through the abstract only and he will find that "application of the formula to a typical case shows that one such incident (causing eye damage to an occupant of the aircraft) might occur every year.

CONCLUSIONS

The issue of the work initiated by Dr. M. Pearlman should be a kind of "booklet" where parameters and cautions would be summarized in table easily readable as soon as the international community will have establish their propositions which are now studied.

Moreover an easy system for detecting aircrafts should be installed in stations which are mobile or semi-mobile in order to facilitate their installation in a new site.

LASER SAFETY AT SAO STATIONS

J. M. Thorp and M. R. Pearlman
Smithsonian Astrophysical Observatory
Cambridge, MA

Several safety measures have been taken at the Smithsonian Astrophysical Observatory laser stations. Warning signs have been installed at all exposed accessible places. In addition, red area lights at exposed locations flash when the capacitors are charged and lasing is possible. All electronics for the laser transmitter and charging are enclosed and shielded; all chassis have safety interlocks. A STOP button to discharge the system is located on the laser transmitter head, with a second one near the operator. A discharge hook built into each system allows manual discharge to a ground rod in case of an emergency. Each observer has an eye examination once a year to evaluate any change in the retinal appearance. Records are kept at each site and passed on to new sites when an observer is transferred. To date, no tests have shown any eye damage.

Aircraft safety procedures vary from site to site, depending on traffic density and scheduling. Orroral Valley is near a highly traveled air corridor, but traffic is restricted to specific, predictable hours. For each operating shift, the air-traffic controllers for the region are given a laser pass schedule that includes the time of day and the sectors of the sky. Sector plot information, in eight sectors with high and low subsectors, is produced routinely by the station's prediction software. A direct telephone line between the site and the controllers is used to warn the station of airplane-sector conflicts. The sites at Mt. Hopkins, Arizona, and Arequipa, Peru, are located in mountainous areas, over which air traffic is light. Commerical flights above these sites are closely scheduled. At Mt. Hopkins, private flights are usually below the minimum elevation of the laser; in Arequipa, they are essentially nonexistent. In Natal, Brazil, air traffic is also very light and scheduled. Visual spotters are used at all three sites.

When observers are in a potentially exposed area during calibration, they are required to remain in contact with the laser operator by two-way radio. Targets are located at remote locations, which have been marked as dangerous areas. Pulsing below the horizon is prohibited except at calibration targets.

LASER SAFETY AT THE KOOTWIJK OBSERVATORY

H.Visser, Institute of Applied Physics, Delft (The Netherlands)
F.W.Zeeman, Delft University of Technology, Delft

INTRODUCTION

Apart from legally dictated safety measures (warning signs, goggles, optical and electrical shielding, etc.) there are three area´s of special importance for a laser tracking station:

a. the control system and lay-out of the installation

b. calibration measurements to ground targets

c. overflying aircraft

In this paper the solutions for problem area´s b. and c. at the Kootwijk observatory will be described.

CALIBRATION MEASUREMENTS

For this activity we have two arrangements available:

1) Ranging to a fixed target at 1 km distance.

Instead of the common practice to fire with full power to a diffuse reflective target, we attenuate the beam directly at the laser to a level in agreement with the safety standards. This implies the use of a retroreflective target in order to get returns of the desired signal level. We use 1 m^2 of plastic reflectors (as used for traffic signs). The properties of the reflected light, as seen by the receiver, are similar to diffuse reflection because of the bad quality and the amount of retroreflectors. This retroreflective target is also very useful for alignment of the transmitting optics to the receiving optics with a HeNe laser, especially at daytime.

Using this set-up there is no danger for operating personnel or people outside the station when firing in horizontal directions.

The beam attenuator used for this purpose is of a special design to avoid any chance of damaging neutral density filters with the full output power of the laser (figure 1.)

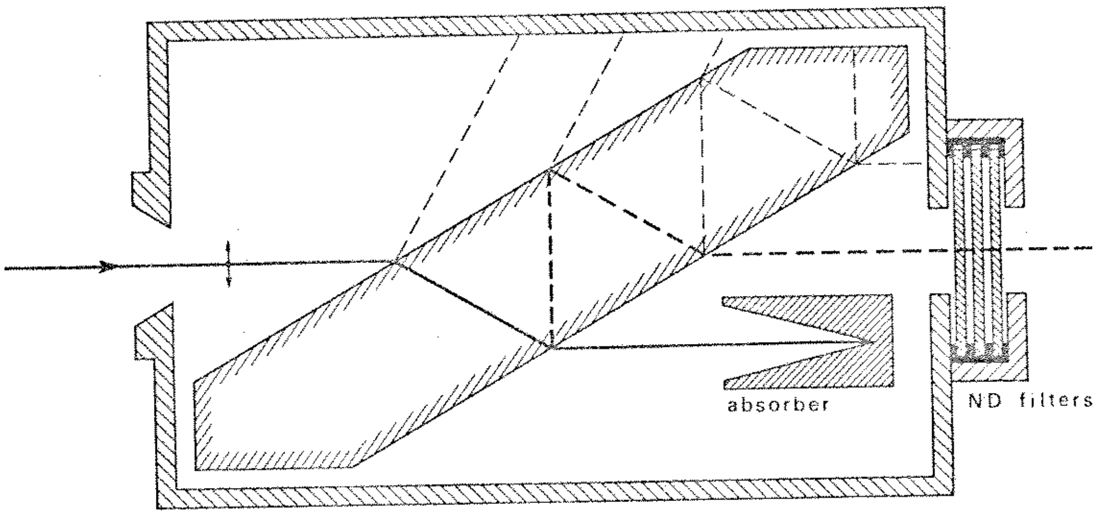


figure 1

The major part of the incident energy is dumped into the cone shaped absorber. The energy left over 2 internal reflections is used for the measurements (after extra attenuation with normal ND filters). The attenuation of this plane parallel plate of glass can be adjusted by turning it around the axis of the incident beam. If the polarization of this beam is in the plane of the drawing,as indicated,the attenuation has a maximum value. When the complete attenuator structure is turned 90° around its axis the transmittance (for vertically polarized light) increases to a maximum of a few percent.

2) Ranging via an internal light path.
For routine calibration of the ranging system the light from the total cross-section of the attenuated outgoing beam is reflected via a secondary light path and an extra optical step attenuator directly to the photomultiplier.

AIRCRAFT SAFETY

Althoughthe total risk for an airline passenger will not be significantly increased by the operation of a laser ranging system at Kootwijk (conclusion of a thorough study) we have established two independent safety measures:

- a look-out near the mount. The protective glasses in his safety goggles are made out of interference filters giving minimum attenuation in the visible part of the spectrum, especially in the red part, in order to have a maximum visibility of the red running lights and anti-collision lights.

- a passive optical airplane detector with automatic laser disabling (fig.2).

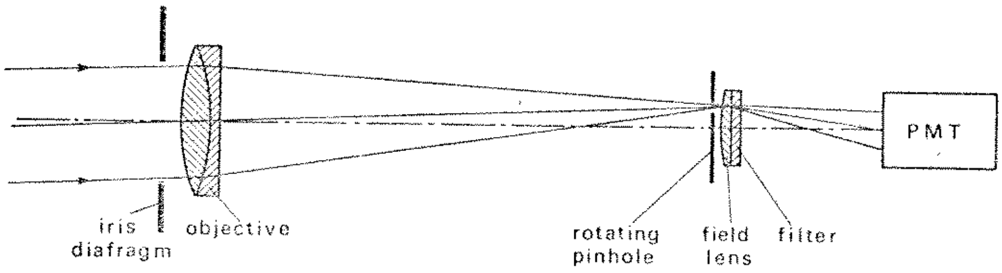


figure 2

For daytime and nighttime operation two different detection techniques are used:

Daytime Detection

The instrument measures the contrast of an airplane, or any other object) against the uniform background of the blue sky. A small off-axis field of view scans continuously around the axis of the transmitted laser beam (fig.3a). The field of view is smaller than the apparent size of an airplane, therefore a good on - off ratio is obtained.

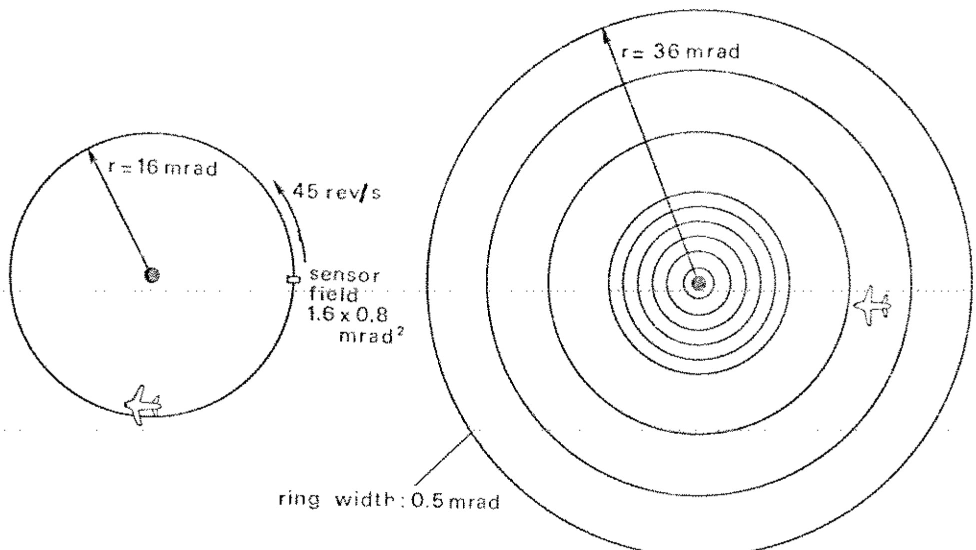


fig. 3a

fig. 3b

When the AC signal from the photomultiplier exceeds a fixed discrimination level the firing of the laser is interrupted for 5 seconds. This gives ample time for any airplane to fly out of the danger area. The scanning rate has been adjusted in such a way that no airplane can enter the danger area undetected.

Because the contrast over great distances through the atmosphere is best in the red part of the visible spectrum, a blue absorbtion filter (Schott type GG 475) has been placed near the field lens. A RCA 8852 photomultiplier has been chosen as detector because of its good red and near-infrared sensitivity.

The average light level is reduced to an acceptable level by means of the iris diafragm in front of the objective.

Nighttime Detection

During the night when only the running lights and anti-collision lights of the airplanes are visible, the field of view of the daytime system is inadequate.

Instead a static pattern of concentric transparent rings is placed in the focal plane of the objective (fig. 3b.). When an airplane light passes a ring the AC coupled photomultiplier will produce an electrical pulse that will inhibit laser firing for 5 seconds.

Measurements of the brightness of airplane running lights on the ground and comparisons of running lights against stars have shown that the great majority of airplanes above 30^{o} elevation can be seen with a visual magnitude between +4 and 0.

The main problem of this detection system is to avoid false triggerings from stars. To reduce the chance of false alarm to a level of about 1% the following three provisions have been made:

- the effective area of the field of view has been reduced to 1 degree square by using very narrow rings
- the photodetector is sensitive mainly in the red part of the spectrum (as for daytime detection) in order to favour the incandescent lamps of the running lights above stars
- the detector is effective only one second before firing when the mount has already been positioned.

THE USE OF THE AIR TRAFFIC CONTROL RADAR BEACON SYSTEM (ATCRBS) FOR LASER GROUND STATION RANGE SAFETY

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INTRODUCTION

A continuing concern in the operation of high energy laser ranging systems is the avoidance of accidental illumination of overflying aircraft by the laser. The generally accepted standard for maximum permissible exposure in the visible and near visible regions of the spectrum widely used by pulsed laser ranging systems is $5X10^{-7}$ Joules/cm^2 (Ref.1). The irradiance from most laser systems currently in use exceeds this level by a substantial margin and because of the use of highly collimated beams, the danger zone may extend for many miles. The use of a safety observer is a substantial help at very close ranges but even the optically aided human eye cannot reliably spot aircraft under hazy conditions at distances corresponding to the danger zone. Radar systems can be quite useful but large and expensive systems are necessary if ranges out to 50Km are required. The system suggested here is one that takes advantage of the fact that all aircraft flying in controlled aerospace (i.e. over 3800 m in altitude or under instrument flight rules) must carry a transponder. The transponder can be interrogated with a relatively simple ground system compared to a radar. The two main elements of this ground system are a phased array antenna with eight elements and a interrogator/amplifier system. The system uses a sidelobe suppression system which produces an effective beam width of $\pm 6^{\circ}$ in azimuth and approximately 29° (Half Power) in elevation. When it is boresighted with the laser ranging system's telescope, it can easily detect the presence of transponder equipped aircraft nearing the laser beam at ranges in excess of 100Km in sufficient time to permit stopping the laser radiation. Closein aircraft which are not transponder equipped can be detected with a relatively simple skin tracking radar.

DETAILED SYSTEM DESCRIPTION

Since the late 1950's, the ATCRBS has become the primary means of air traffic surveillance, with the radars to which it was added assuming a backup role.[2]

The ATCRBS consists of airborne transponders, a ground interrogator-receiver processing equipment, and an antenna system. The antenna may or may not be associated with, or slaved to, a primary surveillance radar. In operation, an interrogation pulse group is transmitted from the interrogator-transmitter unit via an antenna system triggers each airborne transponder located in the direction of the main beam, causing a multiple pulse reply group to be transmitted from each transponder. These replies are received by the ground receiver and, after processing are displayed to the controller.

The ATCRBS has a number of interrogation modes to accommodate its various uses. EAch interrogation consists of a pair of 0.8 s pulses (P1,P3) transmitted on 1030 MHz carrier. An additional pulse, the P2 pulse, is transmitted 2 s after the initial (P1) pulse from interrogators equipped with sidelobe suppression.

The mode is designated by the P1-P3 interpulse spacing. Modes 1 and 2 are used only by military interrogators. Mode 3/A is the basic air traffic control (ATC) identity mode, common to both civil and military systems.

The transponder reply consists of a sequence of up to 15 pulses on the 1090 MHz carrier, each of nominal duration 0.45 s and with an interpulse period a multiple of 1.45 s. Each reply includes the two bracket or framing pulses F1 and F2, spaced by 20.3 s. Thirteen uniformly spaced pulse positions are defined between the bracket pulses.

The Federal Avaiation Regulation, General Operating and Flight Rules require that after July 1, 1975, all aircraft in controlled airspace above 3810 meters must be equipped with an operable coded radar beacon transponder having a Mode3/A 4096 code capability.

1. <u>A Simple Interrogator Ground Station:</u>

For the purpose of laser ground station range safety we will use a narrow beam interrogator antenna boresighted with and slaved to the laser tracking telescope. An Air Force airborne AN/APX - 76A or equivalent interrogator set can serve as a convenient ground station.

If a transponder equipped aircraft, either civil or military, flew into the microwave antenna pattern, its presence would be detected and laser firing would cease until the aircraft was clear. The maximum range of interest for this application is 50 kilometers although the system is effective at ranges up to 200 kilometers.

2. Subsystem Description

The AN/APX - 76A interrogator set consists of the following subsystems:

1. Interrogator Set Control
2. Receiver - Transmitter
3. Switch - Amplifier
4. Synchronizer

A. Interrogator Set Controls. Each AN/APX - 76A interrogator set controls contains five thumbwheel switches to select the desired interrogation mode or standby and the desired code. A momentary two-position toggle switch (TEST/CHAL CC) permits loop testing the interrogator set or providing a correct code challenge.

B. Receiver - Transmitter. The assembly consists of: a receiver module, a pressurized transmitterpower supply module and four plug in printed circuit boards. The printed circuit boards mount on a "mother" board which provides the necessary board interconnections. The power supply operates from a nominal 115-volt, 400 Hz source. The transmitter module contains five coaxial tube amplifier stages and operates at a fixed frequency of 1030 MHz with three possible power outputs (high, medium, or low) selectable by a front panel switch. Cooling air must be provided to insure safe operating temperatures within the unit.

C. Switch - Amplifier. The switch - amplifier implements switching of the interrogator system R-F output from the sum antenna channel to the difference antenna channel for the duration of the interrogator side lobe suppression (P2) pulse. The assembly consists of three printed circuit board assemblies: a coaxial cavity tube amplifier; a high power, high speed solid state R-F switch; and a diplexer. The unit has a self-contained power supply which is operated from a nominal 115-volt, 400 Hz source. Performance monitoring circuitry samples all critical operating parameters and signals a failure by a front panel fault indicator.

D. Synchronizer. In itsintended application as part of an airborne interrogator system, the synchronizer uses the main surveillance radar trigger pulses to generate the various signals necessary for initiation of an interrogation cycle. In our application, appropriate external trigger pulses are provided.

E. Antenna. An effective beamwidth of about 12^o is achieved with an array of eight (8) L-band dipoles mounted on 46x66 cm ground plane. By radiating the required interrogation signal and the control pulse signal on the sum and difference patterns, (see Fig.1) respectively, of a dual feed L-band antenna array, responses to sidelobe interrogation are supressed at transponders equipped with interrogation side-lobe suppression (ISLS) circuitry for all angles beyond about ± 6 degrees from the center of the antenna main beam (sum pattern).

F. Interrogator System Size, Weight and Power. The AN/APX-76A interrogator system was developed for airborne application. Its size and weight are minimized. The largest unit, the Receiver Transmitter, has the dimensions of 19.4x12.7x44.5 cm and weights 8.6 kg. The total weight of the four (4) units is 16.8 kg. Input power - 115V, 400 Hz, 230 volt - amperes; 28 Vdc, 1.3 amperes.

CLOSE-IN RANGE SAFETY

Because not all low flying (less than 3810 m) aircrafts are equipped with operable coded radar beacon transponders, we must provide close-in safety by other techniques.

The Goddard ranging stations do not operate below 20^o in elevation. Therefore, the maximum distance from the station a low flying aircraft may be in the pass of a laser beam is 11Km.

Our calculations show that for 35.DB X-band antenna gain, a 10 KW LN66 Radar Set, manufactured by Canadian Marconi Company, will provide the required additional protection. This radar set has been specifically designed to serve as a shipboard navigator aid for reliable detection of surface obstacles or other vessels. The LN66 radar is being extensively used by the U.S. Navy.

In our experiment, we need employ only the LN66 transmitter - receiver, control unit and the A/C power supply with no need for the PPI display.

I. LN66 Radar System"

Description

A. Receiver - Transmitter Unit. The Receiver - Transmitter Unit contains the transmitter and the receiver circuitry, and the power supply for the

Radar Set. The transmitter circuitry generates the high power 9,375.MHz pulses which are fed to the Antenna Unit via a waveguide. The time interval between any two transmitted pulses is used by the receiver circuitry to process the signal reflected back by the targets.

B. AC Power Unit. The primary power required by the LN66 Radar Set is 26.4 Vdc. However, in situations where a 26.4 Vdc power source is not available, the Radar Set is supplied with the AC Power Unit which is a simple power supply to convert the 115. Vdc primary power into the 26.4 Vdc.

C. Antenna Unit. The Antenna Unit transmits the high power RF pulses and receives the signal reflected back by the target.

We are employing Scientific - Atlanta, Inc. Series 22 Reflector (1.22m dia.) and the Model 23 - 8.2/4 Feed. The nomial beamwidth is 2^{o} and 39.DB gain. The 4.ft reflector with the x-band feed and the L-band dipole array are mounted on an Azimuth/Elevation mount which is slaved to the laser tracking telescope.

D. Size, Weight and Power.

Unit	Dimensions (cm.)	Weights (kg.)
Receiver - Transmitter	47x31.75x21.6	20.4
AC Power Unit	21x34.8x18.9	13.6

The Receiver - Transmitter unit require 26.4 Vdc, 10. amps. The AC Power Unit converts the 115 Vdc primary power into 26.4 Vdc.

Theory of Operation

Transmission

The transmission from the Radar Set is in the form of narrow, high power RF pulses which ar radiated by the Antenna Unit. Depending upon the range selected and mode of operation (narrow or wide pulse), either 2500, 1250, or 800 pulses per second are transmitted.

Reception

Because the antenna in operation is following the tracking telescope in azimuth and elevation, and the transmitter PRF is relatively high, the LN66 Radar transmitter pulses strike all targets within the main antenna beam. Immediately after transmission of each pulse, the antenna acts as a receiving antenna and picks up the signal reflected back by the low flying aircraft target.

STATUS

The Interrogator - Transponder link has been exercised with excellent results. The observed antenna patterns were very nearly as expected. The range is more than adequate for the present and expected future laser transmitter power.

The LN66 radar subsystem is not yet completed and no experimental results are available. We expect to complete the full system evaluation by September 1978.

ACKNOWLEDGMENT

The authors wish to acknowledge the excellent technical and administrative assistance and cooperation of: Martain Natchipolsky, Donald Asker, Richard Haskin and Gerry Markey of Federal Aviation Administration; Joe E. Smith of Department of Defense; Donald Brennon of Westinghouse Corporation; Dwight Pasek of Hazeltine Corporation and Calvin Rossey and James Scott of Goddard Space Flight Center. Also, we wish to extend a special acknowledgement to David Grolemund of Bendix Corporation who performed the integration of the AN/APX-76 interrogator subsystem.

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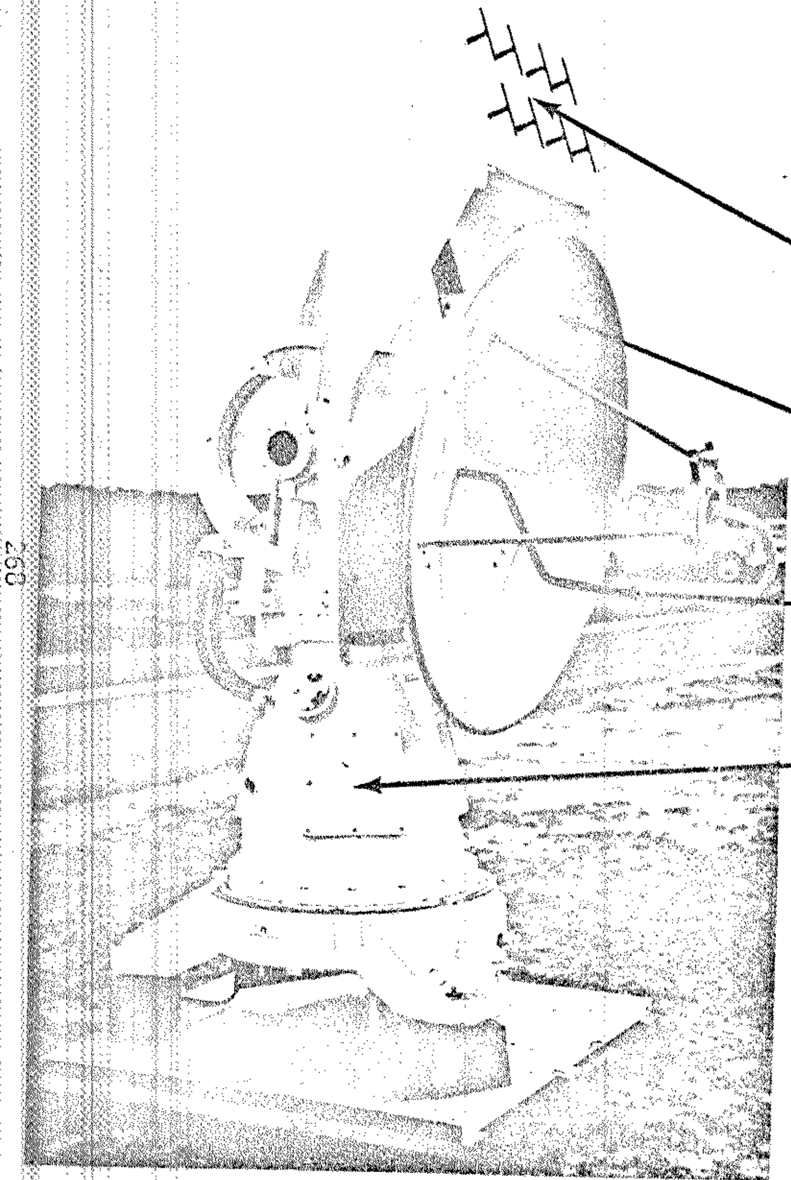
1. American National Standard for the Safe Use of Lasers, ANSI Z136.1-1976.

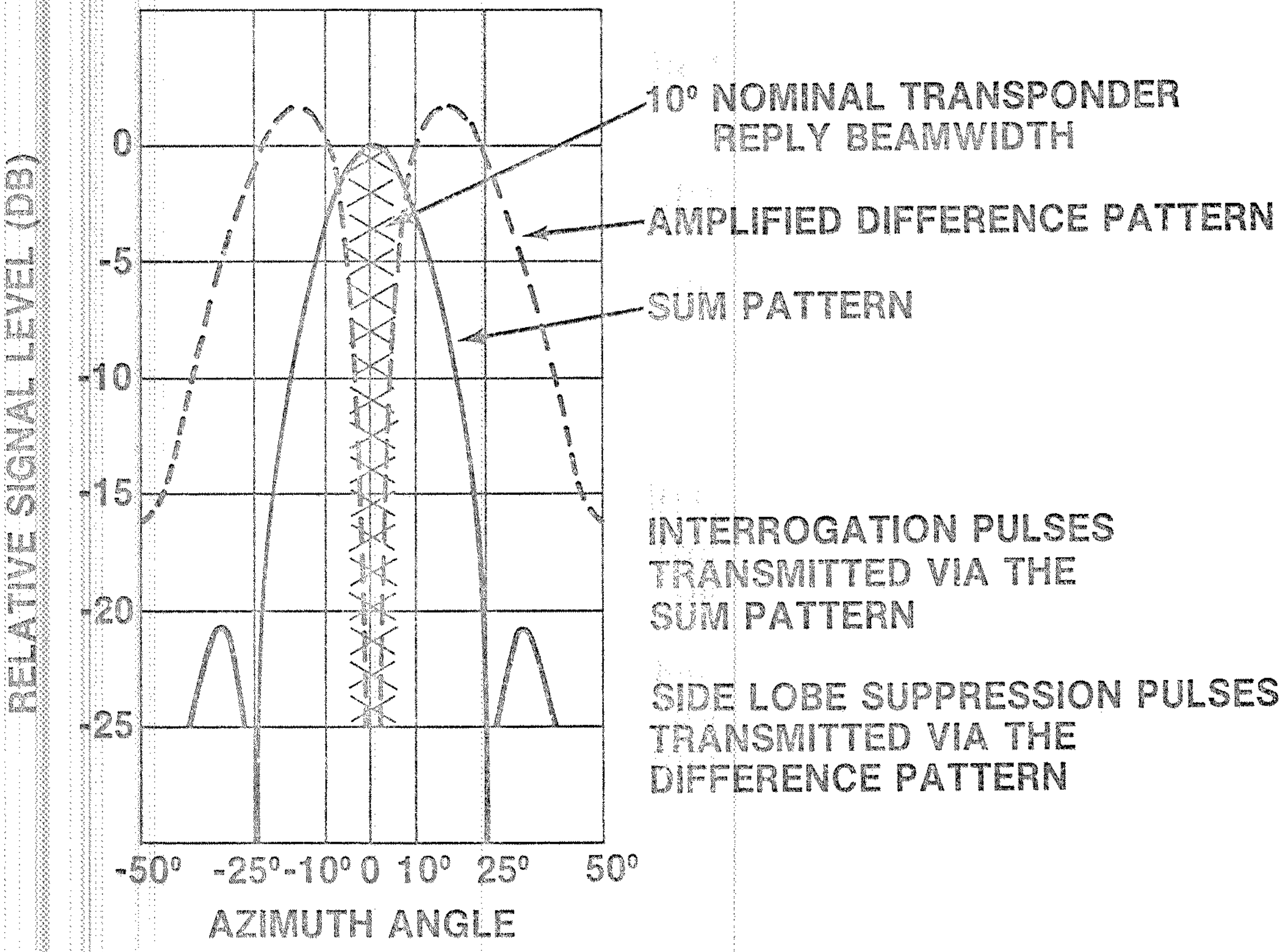
2. Drouelhet, Paul R. Jr., "The Development of the ATC Radar Beacon System: Past, Present and Future," IEEE Transactions on Communications, Vol. Com 21, No. 5, May 1973.

AIRCRAFT SURVEILLANCE SYSTEM
ANTENNA SYSTEM

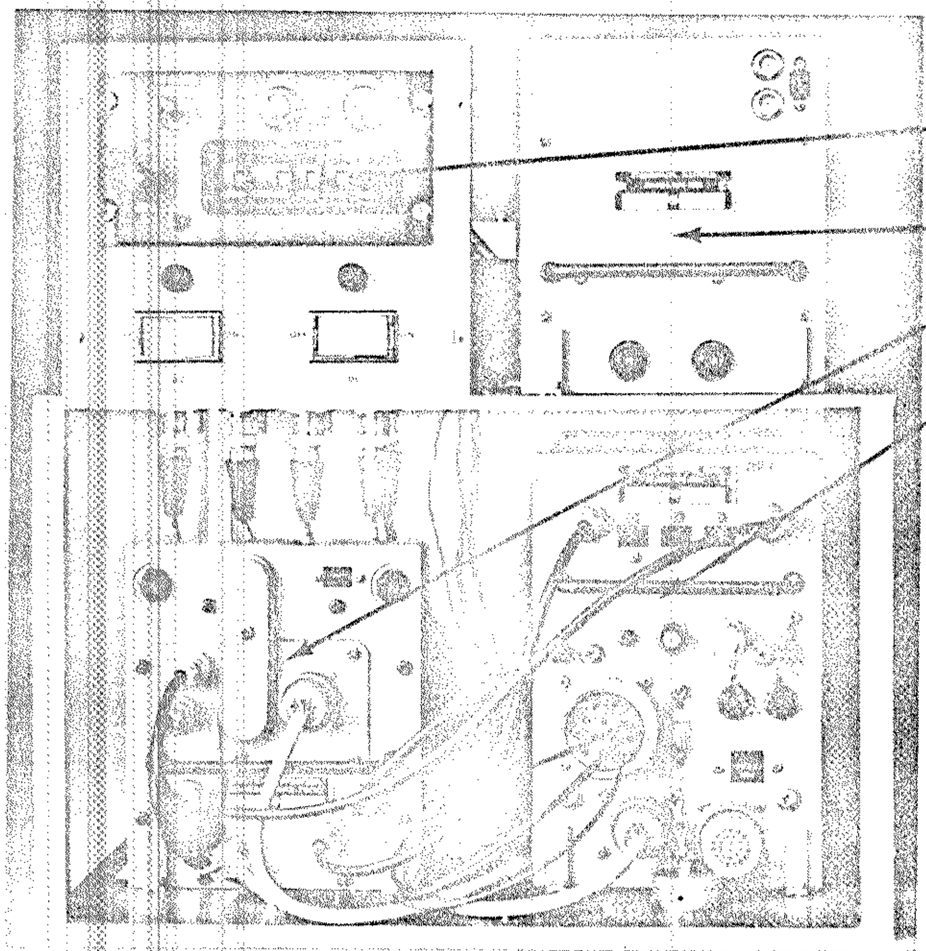


NASA G - 78 - 02276

ANTENNA PATTERNS



AIRCRAFT SURVEILLANCE SYSTEM
GROUND INTERROGATOR-RECEIVER



NASA G-78-02280

RECEIVER: FREQUENCY- 1090MHz
SENSITIVITY - -83dBm

TRANSMITTER: FREQUENCY-1030 $\pm$ 0.2 MHz
HIGH POWER - 2 KW
(33dBW) PEAK

INPUT POWER: 275 WATTS

CONCLUDING SUMMARY OF LASER SAFETY SESSION

Most of the stations have taken the necessary measures for preventing laser damages.

It most of the sites, there are local agreements to avoid striking aircrafts during tracking of satellites. The two papers presented at the session concerned that subject :

one, typically a radar system, is still experimental and requires the agreement from air traffic control authorities.

the other one has been experienced for two years now, and is used at Kootwijk station, on an optical basis.

Furthermore for some calibration methods requiring the use of a near target, a special component was designed for attenuating the beam.

Some discussions then occured and were devoted to probabilities of striking an aircraft : it seems that the chances can vary tremendously from an author to another and will bring more confusion than efficiency.

THE SATELLITE LASER RANGING STATION AT SAN-FERNANDO, SPAIN

J.L.HATAT : Centre d'Etudes et de Recherches
Géodynamiques et Astronomiques.

INTRODUCTION

The satellite ranging station at San-Fernando is the mobile station of the G.R.G.S.(Groupe de Recherche de Géodesie Spatiale).
It is in routine night time operation, in this site, since the summer of 1975.
It is an improved first generation laser station. The staff is formed by French and Spanish technicians.
The co-operation agreements between the G.R.G.S./C.N.E.S. and the Instituto y Observatorio de Marina de San-Fernando will permit a full management of this station by the I.O.M. by 1979.
The observing conditions at the present location are now threatered by construction of high buildings in the proximity. The station will be moved to the dome on the observatorio's main building.

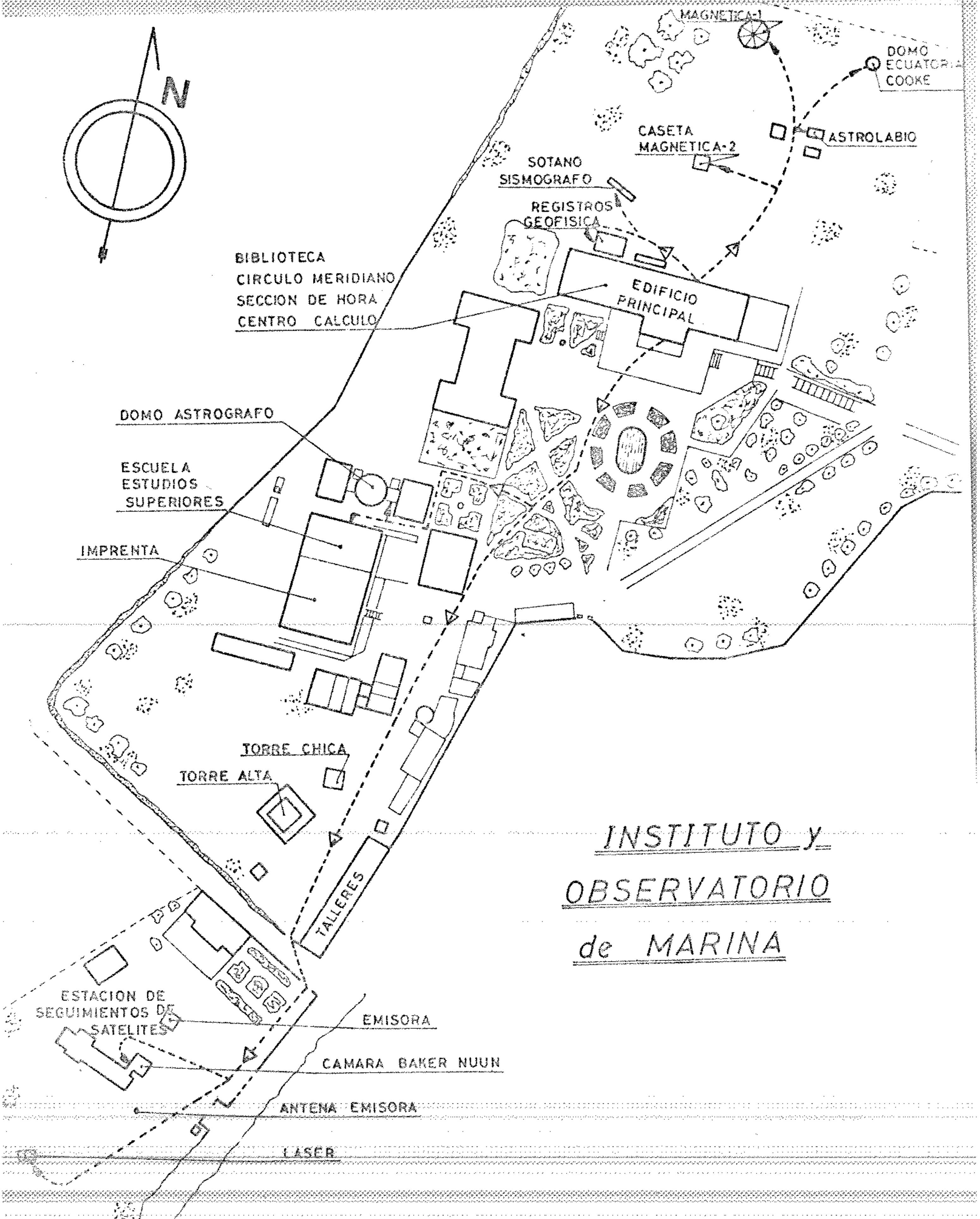
At the present time, the capabilities of this station are the following :

- Blind tracking by night.

- Visual optical tracking by television. (Both systems on GEOS I, GEOS 3, BEC and STARLETTE satellites.

- Ranging accuracy I - I,5 metre.

- Range capability 3800 Kms on GEOS I satellite type. Terrestrial ranging 200 Kms on retroreflectors.

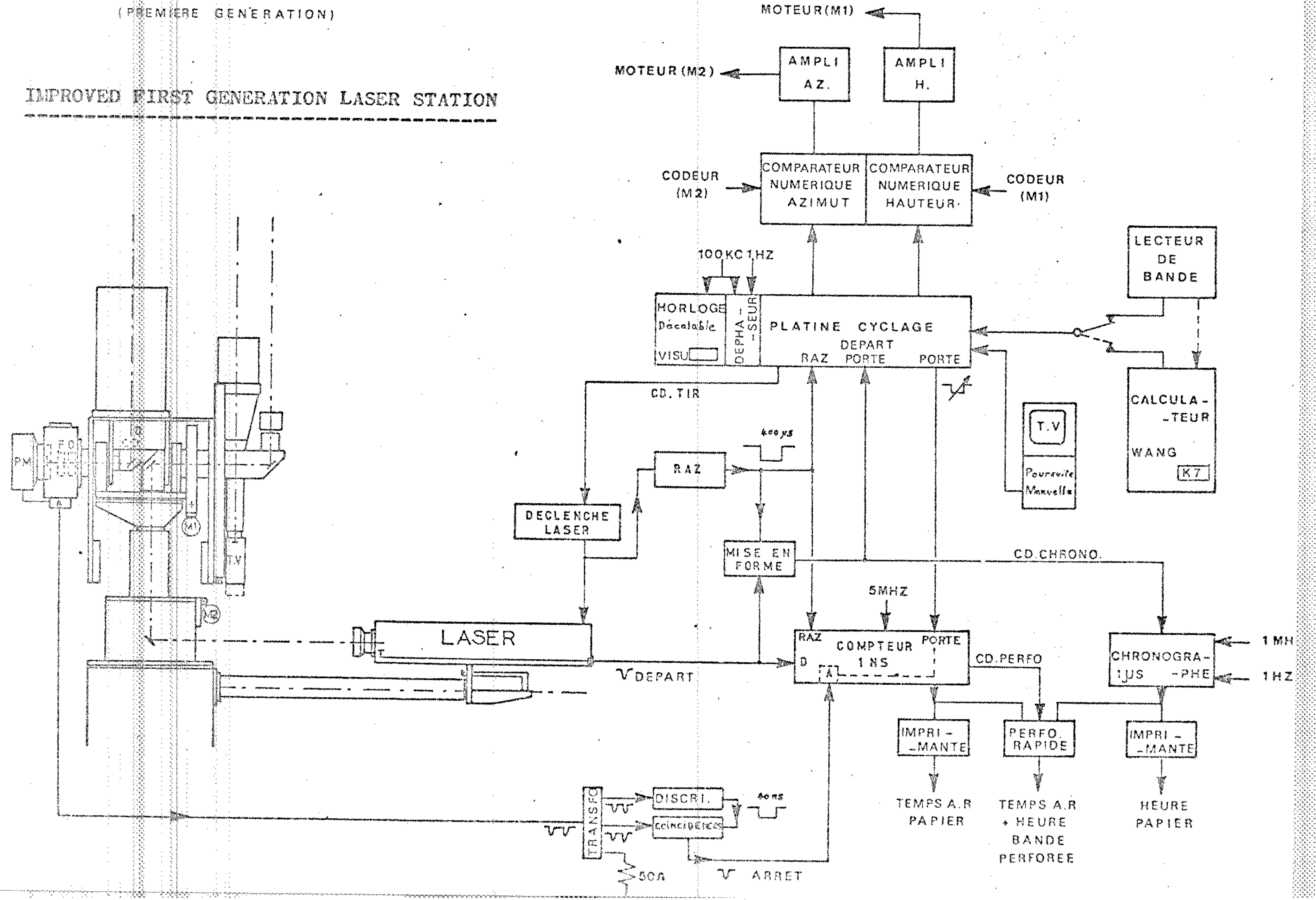


Location of the instruments

STATION DE TELEMETRIE LASER

(PREMIERE GENERATION)

IMPROVED FIRST GENERATION LASER STATION



Technical characteristics are the following :

LASER SYSTEM

Type rubis Compagnie Generale d'Electricité.
Pulse 27 ns 0,5 - 0,6 joule.
Repetition rate : max 60 ppm.
Beam divergence :4 mRad. With transmitting optic : 0,5 mrad.

Receiving telescope
Type cassegrain.
Aperture 36 cm F/IO

Visual tracking system

Television camera SOFRETEC type CF I22.Furnished with a Noticon tube.
Lens 200mm F/5
Limiting magnitude I3 - I4.
With this system,it is possible to track also STARLETTE and LAGEOS.

Detection PMT : R.C.A. model 3I034 A.

Amplifier : Avantek AV 9T, ampl.30 db.

Optical filters : 3 Å,7,5Å,I8 Å.

Range gate generador : GRGS design.

Time interval counter : Model CC 20,Ins. Centre de recherche de la C.G.E.

Receiving coincidences system (I) figure I
Discrimination : type VDI/II ref. SAIP DA/I2I.
Coincidences : type VC 4 V /II ref.SAIP CR I33.

Epoch clock : GRGS design I µs.

Timing UTC : VLF (Baker-Nunn).

The positionning of the mount is performed in real time by a mini-computer WANG 2200 which uses magnetic cassettes.
Repositionning : I point every six secondes.

The mount is driven in both azimuth and altitude by two 250 W D.C motors.
Pointing accuracy : about 30 arcsec.

Optical coders are type MCB GI 076 B . 500 pts resolution.

The final results are punched on a paper tape ready for transmission by telex.
Tape punch : Tekelec airtronic model 34.
Punching speed : approx 70 ch/sec. Synchronous.

Aircraft detection,at this moment,is guaranted by visual television system.

The present staff is 6 persons operating only by night,7 days a week.

(I) R.BIVAS Thése de doctorat es sciences physiques : Télemetrie spatiale par laser.

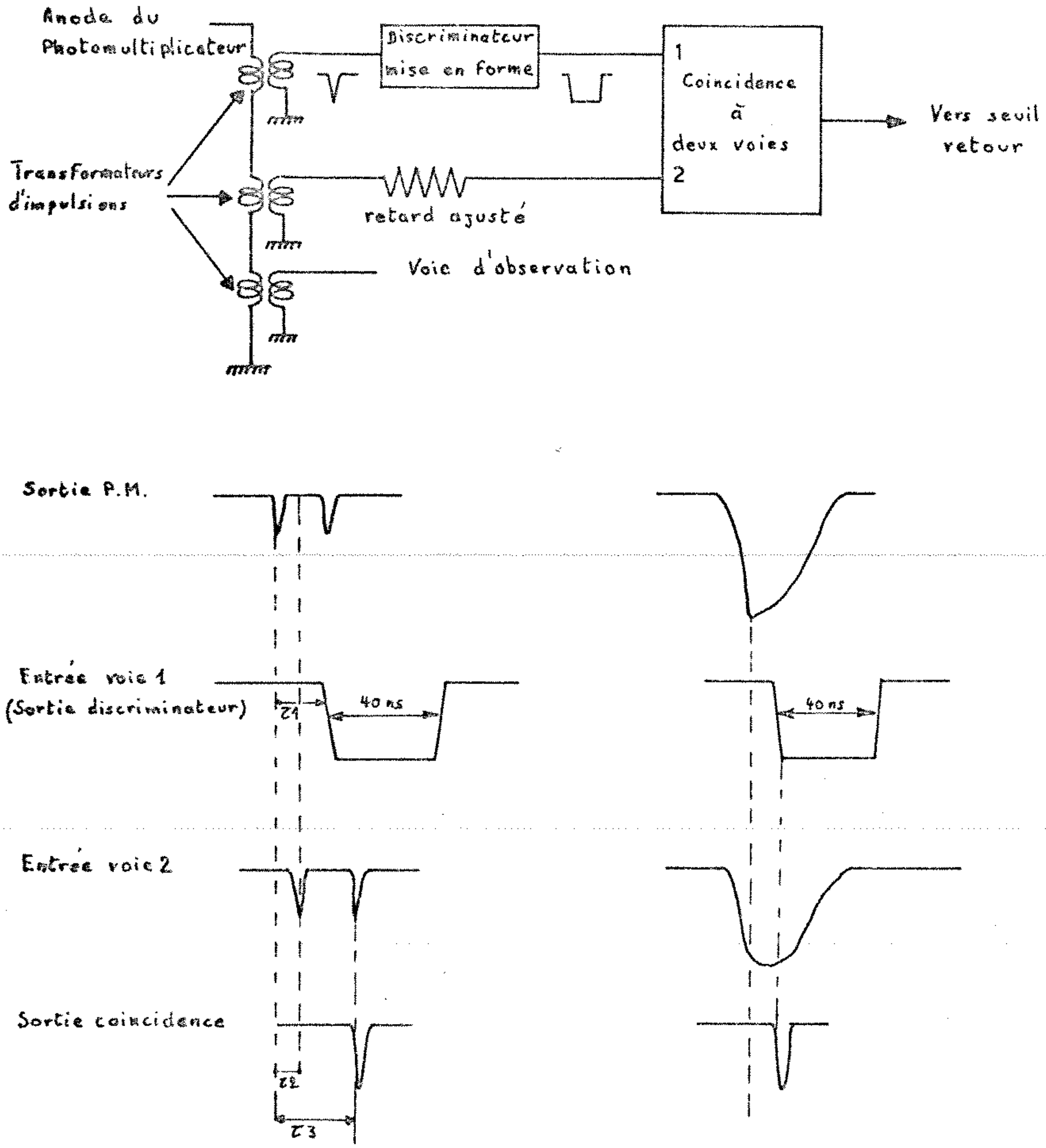
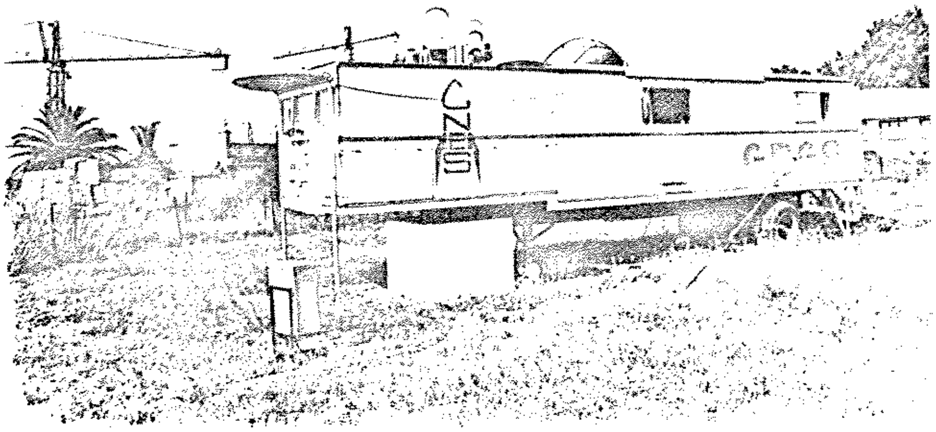
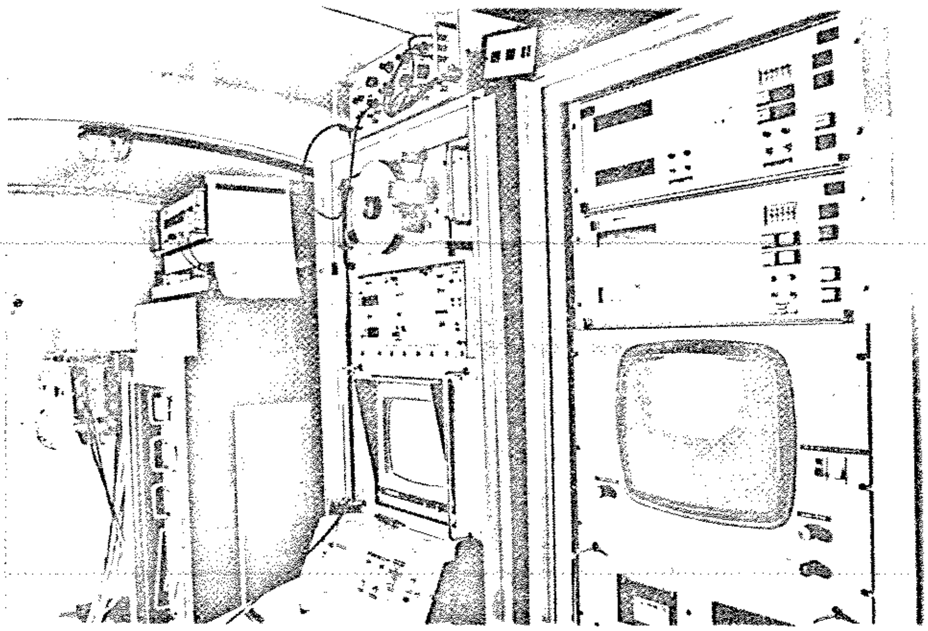


Schéma de principe du discriminateur de coïncidences.

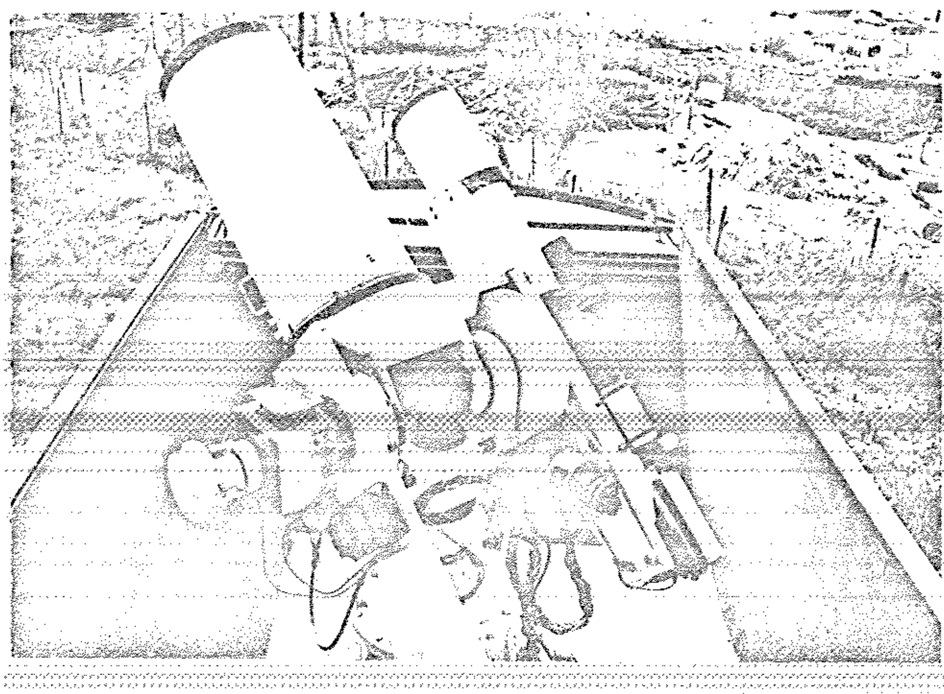
figure I



General view of the station

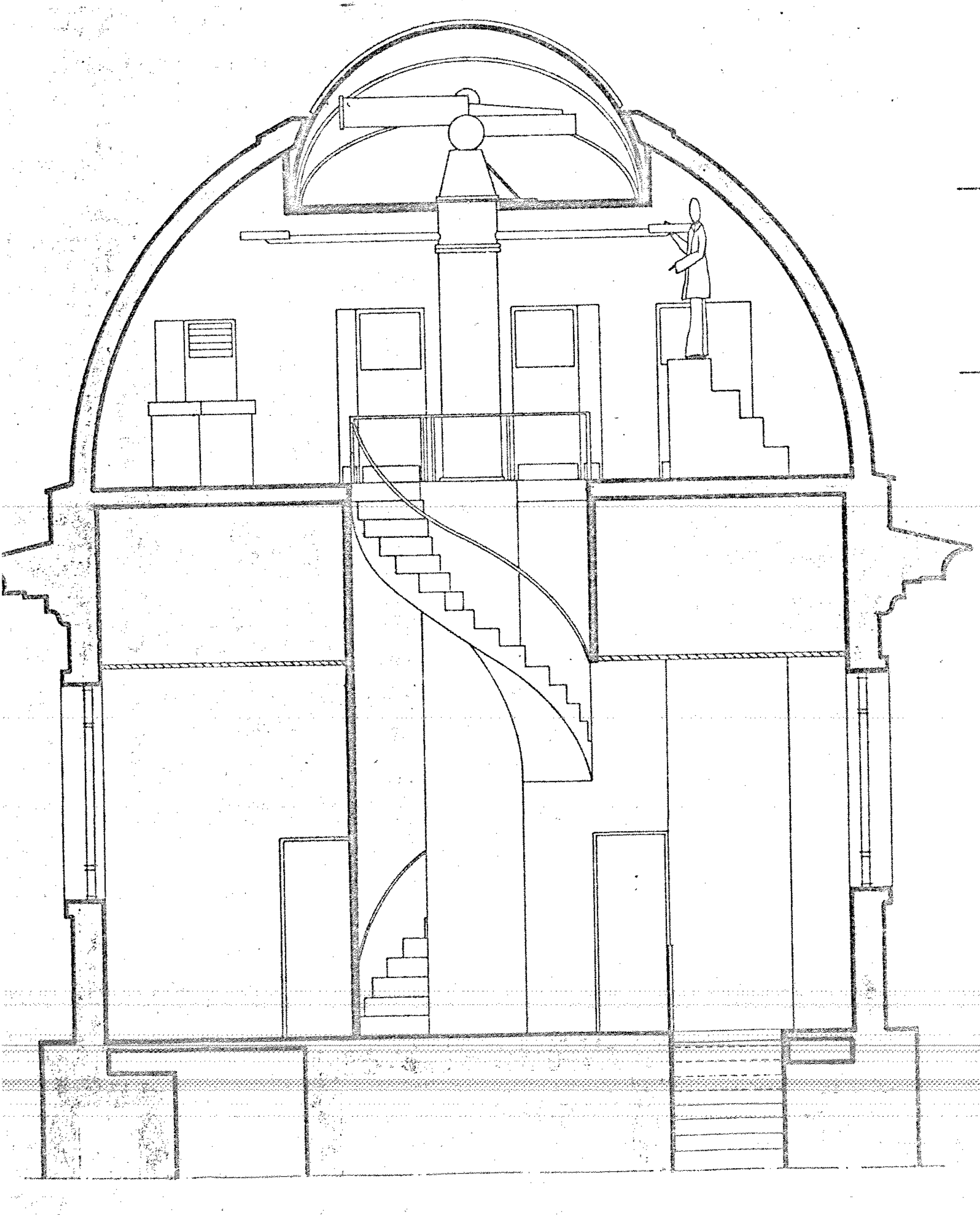


- The electronics



The laser mount

Architect plan project of the new laser site



SECCION-X X'

CALIBRATION

The calibration of the system is by using one ground target at 830 m. This calibration, approximately 60 points of range data, is performed before and after each satellite pass.
It was impossible to find another farther target.

FUTURE IMPROVEMENTS

- A new laser will be fitted. Possibility to operate with pulses of 5 - IO ns and 2 - 3 joules.

- Increased ranging accuracy.

- Blind tracking by day.

- Possibility to get regular ranging data on LAGEOS.

COMMUNICATION INFORMATION

The postal adress of San-Fernando is :

Station Laser

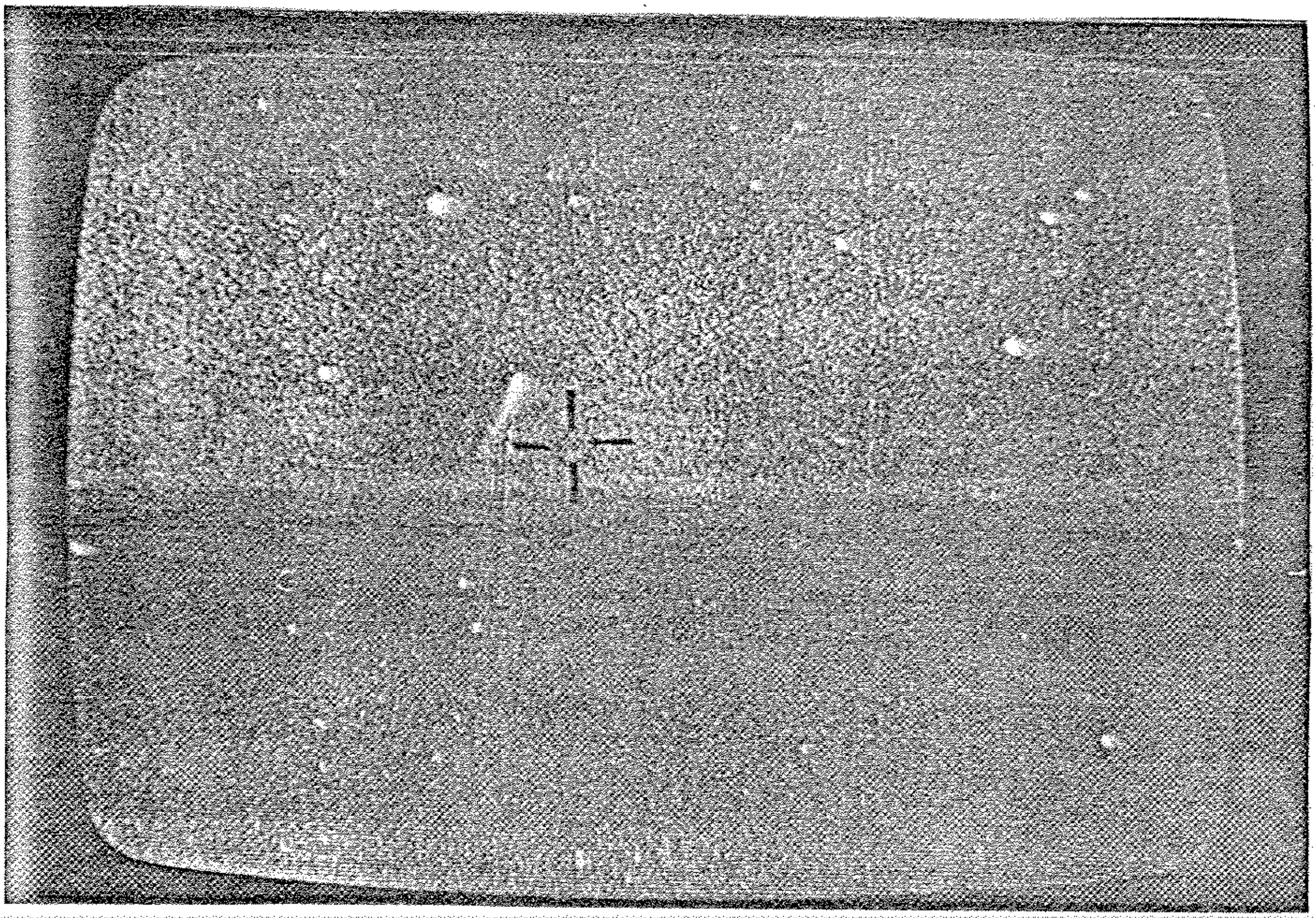
OBSERVATORIO DE MARINA

SAN FERNANDO

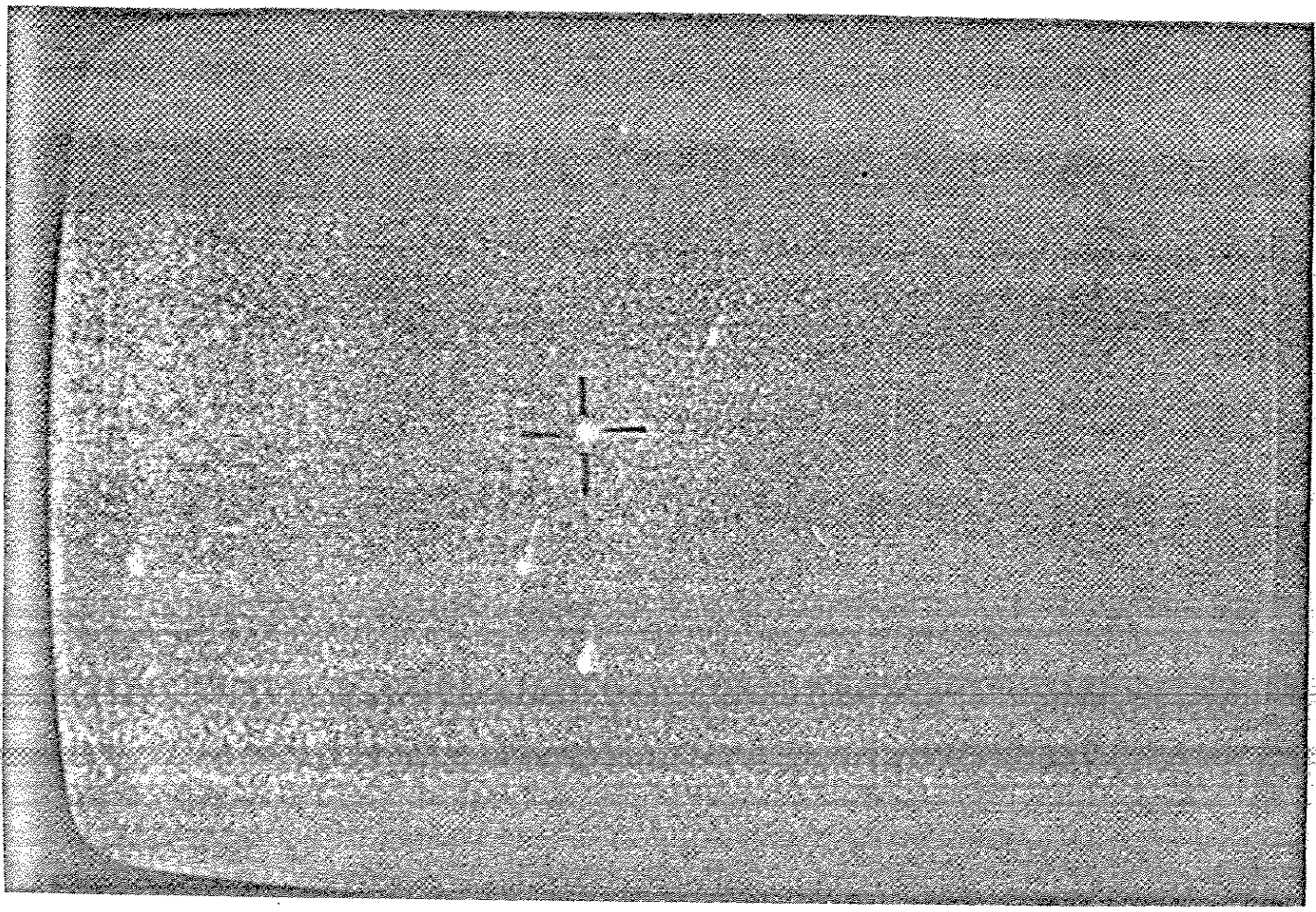
CADIZ (España)

Telex number :

76I08



I - Stars are fixed. The satellite pass on the left of the reference reticle. Film 400 ASA - 1/30 sec.



II - Manual tracking. The satellite is kept in the reticle.

SUMMARY STATISTICS STATION - 7804 SAN-FERNANDO YEAR I977

	GEOS I (650890I) OBS	PAS	GEOS 2 (680020I) OBS	PAS	GEOS 3 (750270I) OBS	PAS	BEACON C (650320I) OBS	PAS	STARLETTE (750I00I) OBS	PAS	TOTAL OBS	PAS	BAD WEATHER CONDITI (lost pass. percenta
AN	0	0	0	0	54	5	0	0	0	0	54	5	90 %
EB	I08	4	75	3	24	3	48	3	0	0	255	I3	77
AR	5I	3	284	9	52	3	93	5	I3	I	493	2I	52
PR	48	4	0	0	I9	I	0	0	0	0	67	5	--
AY	I45	8	0	0	67	2	I24	5	0	0	336	I5	3I
UN	227	8	0	0	78I	2I	837	24	284	I6	2I29	69	39
UL	499	I6	0	0	560	2o	I7	I	5	I	I08I	38	20
UG	348	8	0	0	884	I9	685	23	I85	I0	2I02	60	I0
EP	I78	3	0	0	39	5	47	2	I49	I4	4I3	24	I4
CT	0	0	0	0	I46	4	8I	3	2I	4	248	II	42
OV	84I	I9	0	0	25I	4	I35	4	48	II	I275	38	44
EC	80	2	0	0	I73	4	I3	I	25	I	29I	8	84
OT	2525	75	359	I2	3050	9I	2080	7I	730	58	8744	307	

- Time interval counter failure in april.

- Total blind tracking : '696 returns.

SUMMARY STATISTICS STATION 7804 SAN-FERNANDO, YEAR I978

(For the first four months)

	GEOS I		GEOS 3		BEACON C		STARLETTE		BAD WEATHER CONDITIONS (lost passages percentage)
	OBS	PAS	OBS	PAS	OBS	PAS	OBS	PAS	
JAN	I24	3	0	0	68	2	I9	2	78 %
FEB	429	7	0	0	76	2	I03	8	65
MAR	703	22	776	I3	458	I4	49	5	35
APR	240	5	I9	2	III	4	3I4	I6	6I
TOT	I496	37	795	I5	7I3	22	485	3I	

- NUMBER OF RETURNS 3489
- MANUAL TRACKING 25I9
- BLIND TRACKING 970

session 7

ranging software and data preprocessing

chairman P. Wilson /co-chairman R. Schutz

Wilson

Thorp /Latimer /Campbell /Pearlman

Novotny

Greene

Nouel /Brossier

Vermaat

Carpenter

Sinclair

Shelus /Ricklefs

Schutz

Ranging Software and Data Pre-processing

Chairman's Summary

The primary purpose of this session was to delineate software characteristics and needs at various levels, particular emphasis being placed on the relationship between software and hardware. The pre-processing of data by various organisations was reviewed; the main features of both satellite and lunar software were dealt with and the corrections applied to the data were identified by each group.

Discussions centred mainly on the following topics:

- data compression and data handling, with particular reference to possible implications on system (hardware) design;
- the weighting of observations;
- look angle computations and satellite ephemerides;
- the modelling of systematic errors;
- data filtering and corrections.

A lively discussion followed the provocative statement that 50 error-free measurements would contain all the information on the orbit and related field parameters that can currently be modelled.

The diversity of the software described reflects on the one hand the various levels of sophistication of the hardware in use, and on the other, the need for a standardisation of concepts, particularly with respect to the quantities of data now being accumulated. Although no agreement could be reached on the best ways of dealing with the masses of data which can be foreseen with the developing systems, it was recognised that this question impacts data management at all levels from collection through analysis and archiving. Some agreement was reached on the need for a central data bank and the need was expressed to identify the appropriate parameters which can lead to a compaction of the data and can effect overall system design.

SOFTWARE IN THE SERVICE OF THE LASER RANGING MEASUREMENT PROCESS

INTRODUCTORY REMARKS TO SESSION 7

Peter Wilson
Institut für Angewandte Geodäsie (Abtlg.II, DGFI), Frankfurt and Sonderforschungsbereich 78, Satellitengeodäsie, der TU München
Fed. Rep. of Germany

This is the first session of a Laser Workshop designed to address software problems. In proposing the framework of the papers and discussions which will follow, I have tried to direct the attention of the speakers towards software considerations directly associated with the measurement processes. However, since with improved accuracies it becomes increasingly important for the observer himself to make a preliminary assessment of the relevance of his observations and the degree to which his equipment is performing satisfactorily I have also suggested that on-site postmission analysis and the preliminary off-site screening of the observations be considered. At this point however I consider that we enter the realms of other users and the subject-matter to be addressed in the following symposium. To summarise then, I propose to restrict the discussions here to subjects pertaining directly to

a) range and look-angle predictions
b) system and data flow control during the measurement process
c) on-site post mission analysis
d) initial screening of the observational data.

It is my hope and anticipation that this session will serve not only as a record of the current status of software application , but will also demonstrate the trends and provide useful reference information for those groups updating or introducing automated tracking procedures as well as cataloguing the scope of these problems for newcomers to the laser tracking community. Whereas not all stations are similarly equipped with respect to computer hardware, it is worth bearing in mind that the computer is the most versatile and compact-major hardware component of the ranging system and the software the cheapest to duplicate, an important consideration for the design of future systems, for which the advent of micro-processors may have a significant impact.

SAO RANGING SOFTWARE AND DATA PREPROCESSING

J. M. Thorp, J. Latimer, I. G. Campbell, and M. R. Pearlman
Smithsonian Astrophysical Observatory
Cambridge, MA

MINICOMPUTER FIELD PROGRAMS

The SAO laser stations have a software package to handle satellite ranging from input quick-look orbits to final data preprocessing. The former system of paper-tape recording of data has been eliminated except for quick-look elements and quick-look data for orbital maintenance.

1. Prediction Program

A compact Fortran program that produces pointing predictions from Keplerian elements, rates, and long-period perturbation terms has been developed for use in the field. This software, which is based on the SAO Aimlaser program, operates with the standard SAO laser orbital-element messages, which are sent out each week. Using an abbreviated gravity-field model selected for each satellite, the program generates geocentric vectors 2 min. apart for those periods in which the satellite is visible at the station. The program then interpolates between these vectors to produce topocentric predictions at the laser firing rate and stores them on magnetic tape for use during operation. A short summary of the passes for each day is printed during the prediction calculation.

2. Pulse-Processing Program

The pulse-processing program receives the incoming laser data, including the reference pulses, the precalibration and postcalibration data, and general housekeeping information, in real time. The pulse centers for both the calibration and the satellite data are calculated by means of the cross-correlation technique. Start- and stop-channel calibrations are determined for each return, including the influences of internal system settings. The data are then written on a reduced data tape for shipment to SAO.

This work was supported in part by Grant NGR 09-015-002 from the National Aeronautics and Space Administration.

3. Calibration Programs

Programs to calibrate the system electronics (start calibration) and to process extended target calibrations are available on the field minicomputers and are used routinely. These programs calculate all necessary corrections and apply them to the data, giving the field station a fully reduced analysis. From these calibration analyses, start-calibration parameters are determined and electronic and optical system response is examined.

4. Quick-Look Program

The quick-look program scans the reduced data file and prepares a quick-look message of 12 to 15 points for each satellite pass to be teletyped to SAO for orbital maintenance. The program disregards low-level returns in this process in an attempt to eliminate noise stops. The 12 to 15 points are chosen uniformly over each pass.

5. Direct-Connect Program

The direct-connect program provides the interface between the laser equipment and the minicomputer. The program is interrupt-driven with core-memory buffers assigned to each device. Prediction information stored on magnetic tape is read into the core buffers, where it is available for delivery to the laser on demand every 7.5 sec. Incoming raw data are recorded on magnetic tape and also sent to the pulse-processing software for on-line reduction. In addition, the program provides real-time data for the operator, including a graphic display of the return-pulse shape, the satellite and calibration range data, and general housekeeping information.

The process described above takes 3 to 4 sec to accomplish. At the end of each pass or calibration sequence, a summary of the data is printed for the operator.

DATA PROCESSING

1. Final Data

Raw laser data are received from the four SAO field stations on block-addressable magnetic tape. In addition to the range, epoch, system calibration, and housekeeping information, the raw data also include predicted range, azimuth, and elevation to permit geometry-dependent correction and screening to be carried out before orbital analysis is undertaken. The pass constants, such as temperature, atmospheric pressures, humidity, electronic and optical system settings, and calibration data, are examined immediately. Then the system calibration constant is computed from the average of the pre- and postcalibrations by using tabulated values of surveyed target-calibration distances corrected for atmospheric refraction. The calibration constant is applied to the data, along with the atmospheric refraction (Marini and Murray, 1973) and center-of-mass reductions (Arnold, 1972, 1974, 1975a, b, 1978 a,b).

The data are next screened on the basis of internal consistency by using observed-minus-predicted range differences. The technique "tentatively" selects good points by examining the consistency of slopes between each point and its seven predecessors and seven successors. By including only the good points, a least-squares solution for range and time offsets is obtained, and the slope-clustering screening is repeated. Overlapping 12-point local least-square fits are performed to eliminate the occasional bad points still present. Finally, least-square fits are done for the pass by using serial correlation coefficients to control the degree of the polynomial employed. The root-mean-square residual from this fit is used to characterize the data noise component.

Next the epoch of the observation goes through a sequence of steps: 1) conversion to the time of return-signal reception, 2) correction for station-clock offsets to United States Naval Observatory time, and 3) conversion to the International Atomic (A1) time scale.

Following this, the data are pooled and processed through a differential orbital improvement (DOI) program to determine the orbital elements and to check for systematic time and range biases. In order to save computation time, the DOI program uses an abbreviated gravity field specifically selected by sensitivity analysis for each satellite. A post-DOI processor explicitly computes the best-fit epoch timing error and range bias for each pass. Any significant values obtained are used as flags to indicate possible systematic errors for further examination.

2. Quick-Look Data

A selection of 10 to 15 observations per pass is transmitted from the laser sites to SAO for ephemeris updating on a weekly basis. The process is similar to the final data processing, except that the screening and precise timing reductions are omitted and a simplified version of the DOI program is employed. Orbital elements are generated weekly for a complex of retroreflector satellites and distributed to the laser ranging community for predictions.

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