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THE FIRST SATELLITE LASER ECHOES RECORDED ON THE STREAK CAMERA

K. Hamal, I. Procházka

Faculty of Nuclear Science and Physical Engineering, Czech Technical University
Brehova 7, 115 19 Prague 1, Czechoslovakia,
Phone/fax +42 2 848840, telex 121254 fjfi c, E-mail TJEAN@CSEARN.BITNET

G. Kirchner, F. Koidl

Austrian Academy of Sciences, Lustbuenel Observatory
A-8042 Graz, Austria, Phone +43 316 472231

ABSTRACT

The application of the streak camera with the circular sweep for the satellite laser ranging is described. The Modular Streak Camera system employing the circular sweep option was integrated into the conventional Satellite Laser System. The experimental satellite tracking and ranging has been performed. The first satellite laser echo streak camera records are presented.

GENERAL

The laser ranging of the artificial Earth satellites, the Moon and the long ground baselines is an attractive and rapidly developing technique. The laser ranging precision and accuracy is gradually increasing, it reaches one centimeter level at present. The goal for nineties, requested by the data users, is the satellite laser ranging to artificial satellites with millimeter accuracy. The existing pulsed laser ranging systems are using short pulse lasers of 20-200 picoseconds at 532 nanometers as a transmitter, the fast microchannel plate photomultiplier tube along with an appropriate electric discriminator or an avalanche photodiode as a return signal detector reaching a time interval resolution of 30 picoseconds. An electronic time interval unit having a resolution of 20-35 picoseconds is used to determine the interval between the laser pulse transmission and echo signal detection¹.

The limiting factor for the current systems accuracy improvement from centimeter to millimeter level are the currently used detectors and discriminators, time interval meters and the contribution of the target itself. The main contributors to the systematic error and hence limiting the final accuracy is the atmosphere. The existing atmospheric models based on meteorological data permit to predict the atmospheric optical delay with centimeter accuracy. It is expected, that ranging simultaneously on two wavelength and determining the two wavelength propagation time difference, the existing atmospheric models will be improved to millimeter accuracy. However, to obtain the valuable data for atmospheric model improvement, the two wavelength delay must be measured with picosecond accuracy².

The goals of the implementation of a streak camera into a laser ranging system :
The first : the replacement of the existing detectors and discriminators by the streak camera

with and appropriate readout and data processing system. This will increase the time interval resolution of the radar detection chain several times, the echo pulses distortion by the target geometry may be monitored and compensated. The second : the streak camera will be used for two wavelength laser ranging echo signals detection, the two wavelength range delay may be determined with the picosecond accuracy. The third : along with the detector, the streak camera may be integrated into the time interval unit. The picosecond time resolution and a high overall timing accuracy is expected¹.

THE STREAK CAMERA CONSTRUCTION

Designing the streak camera for satellite laser ranging purpose several key problems have to be solved:

- the energy budget of the ranging chain, closely connected to the photocathode and sweep speed used,
- the camera configuration, the type of deflection, input optics configuration,
- the readout system and the output data processing.

Completing the series of indoor and ground target ranging experiments, we have chosen the S25 photocathode, the circular sweep camera setup and a two dimensional TV readout system with a full frame image processing. The linear sweep tube setup reaches higher limiting temporal resolution. However, the necessity of a trigger signal appearing 10-30 nanoseconds prior to the photons to be detected with a subnanosecond jitter and the angular/temporal relation may cause serious difficulties when ranging to satellites. Using the circular sweep tube setup, the trigger signal requirements are moderate : the trigger signal must appear 10-20 microseconds before the optical signal, the jitter of several microseconds is acceptable. The temporal/angular dependence may be monitored, software modelled and compensated.

The PV-006 streak tube having the S25 photocathode and the microchannel plate image intensifier fiber optically coupled together have been used. The streak tube is equipped with two pairs of deflecting plates acting in the mutually perpendicular direction. Applying the RF signal phase shifted to both deflection plate pairs, the circular sweep may be obtained. The 320 MHz signal, 13 Watts of pulsed RF power is used. The maximal RF power applicable on the deflection system is limited by the internal ionization inside the tube. The diameter of the circle was about 6 mm resulting in 155 psec/mm sweep speed. Due to the imperfect impedance matching of the RF driving circuit to the tube deflection system, the deflection is not perfectly circular. Nevertheless, the complex streak image processing and calibration package is able to compensate for these effects. The temporal resolution of 30-35 psec and the range difference jitter 6 psec have been achieved.

The application of the streak camera for ranging purposes is accomplished by the timing and gating circuitry. The deflection signal is ON for only few microseconds before laser transmission and again few microseconds before expected arrival of the satellite echo. All the remaining time the camera is working in the static image mode and may be used for guiding / alignment purposes, as well. The 320MHz deflection signal is produced by multiplication of the 5 MHz sine wave output of the station Cs beam frequency standard, which is simultaneously acting as an master oscillator for all the station timing electronics. This way, the precise phase synchronism of the radar electronics and the camera circular deflection is maintained. In fact, the camera may be used as a vernier to the time interval unit, rough time interval is derived from the integer number of periods from Start to Stop event, the fraction of the period may be determined from the phase difference of the Start and Stop events⁵.

The microchannel plate intensifier gain is controlled in three steps. During the laser

transmission, the gain is set to minimum to avoid the blinding of the system by the atmospheric backscattered light. Optionally, the mechanical shutter in front of the input photocathode is used. Most of the time the microchannel plate gain is set to 100, a compromise between the static image mode gain and the background noise contribution. At the expected echo arrival time, the gain is set to maximum of 10,000 for 300 microseconds to achieve maximum detection sensitivity.

To readout the tube screen image we use the Silicon Intensified Target (SIT) tube made by Haimann. The output signal was fed to the Visionetics Frame Grabber card (512x512x8bits) inserted in the IBM PC. To solve the problem of a deflection nonsymmetry, the software package³ allows the full frame image processing and accomplishes the software modelling of the image distortion, the sweep nonlinearity, the gain nonuniformity etc. On the end of the image processing procedure the temporal curve consisting of 1000 channels, 8 bits each is generated. Once the center of the deflection circle is identified, for example using the satellite image in the static mode, the temporal/angular effect⁴ may be software compensated.

The compact design of the camera, its rugged construction along with its low mass permitted to install it directly on the moving part of the tracking telescope.

SATELLITE LASER RANGING SYSTEM

The streak camera has been integrated to the Satellite Ranging System of the Lustbuehel Observatory, Graz, Austria. The ranging system consists of a modified Quantel laser, passively mode locked NdYAG with the second harmonic generator, delivering pulses of 10 millijoules, 35 picoseconds in green. Alternatively the semitrain of 5 - 7 such pulses containing totally 60 millijoules may be transmitted. The telescope is a Contraves laser tracking type. The laser output is transmitted by a 10 cm diameter Galileo telescope, the 0.5 meter diameter Cassegrain optics is used for both return photons collection and visual guiding. The streak camera replaced an original ISIT camera attached to the telescope and dedicated for faint objects visual tracking. The dielectric mirror is directing 99% of the returned photons on the streak photocathode the remaining photons enter the standard detector package based on a single photon avalanche photodiode. All the rest of the satellite laser ranging hardware/software remained unchanged. Thanks to the photodiode single photon response capability, the satellite routine ranging capability has been preserved, although with reduced return rate. The streak camera system timing and gating logic has been added.

The streak tube, the image intensifier and the readout have been kept at the temperature + 5 C what resulted in significant dark noise reduction.

RESULTS

The retroreflectors equipped satellites at the distances of 1,000 to 2,300 kilometers have been ranged. The first satellite laser ranging echoes recorded by a streak camera have been obtained January 18, 1991 at 21:37 UT from the AJISAI satellite at the distance 2000 km, see **Figure 1**. In this stage, the semitrain of pulses separated by 8.557 nanoseconds has been transmitted. On the image the time interval of 40 milliseconds covering the laser pulse transmission to echo detection is integrated. The transmitted laser beam backscattered light image is near the center of the pattern displayed in the static image. At this moment the satellite was not illuminated by the Sun. On **Figure 2** there is a streak camera record of the AJISAI satellite echo obtained transmitting single picosecond pulse containing 10 mJ of energy. The temporal profile of the first part of the trace is included. Please, note the streak camera receiver system saturation by the strong echo signal coming from the first rows of the

corner reflectors. The satellite is a sphere of diameter exceeding two meters covered with retroreflectors. According to numerical simulations, the returned pulse should be spread over the time interval about one nanosecond depending on the satellite orientation. The separate echoes coming from various retroreflectors may be clearly distinguished. The sweep speed nonlinearity has not been compensated on this display. The central spot is an static image of the satellite illuminated by the Sun, thus marking the center of the sweep. The atmospheric backscattered light has been blocked out by the mechanical shutter. The STARLETTE satellite echo record is on Figure 3. Single picosecond pulse has been transmitted. The satellite is a sphere covered with retroreflectors of the diameter of about 25 centimeters at a distance about 1,000 kilometers. The echo signal time spread is significantly smaller in comparison to the AJISAI satellite. The temporal profile of the echo is included, as well. The detector saturation may be seen. The system temporal resolution may be demonstrated on the not saturated response from a single corner reflector resulting in a pulse width of 25-30 picoseconds.

CONCLUSION

The first satellite laser echoes have been recorded on the streak camera to our knowledge for the first time. The applicability of a Modular Streak Camera system employing the circular sweep for satellite laser ranging has been demonstrated. The sensitivity of the streak camera has been confirmed to be satisfactory for the purpose : for standard geodetic satellite ranging employing available laser ranging technology.

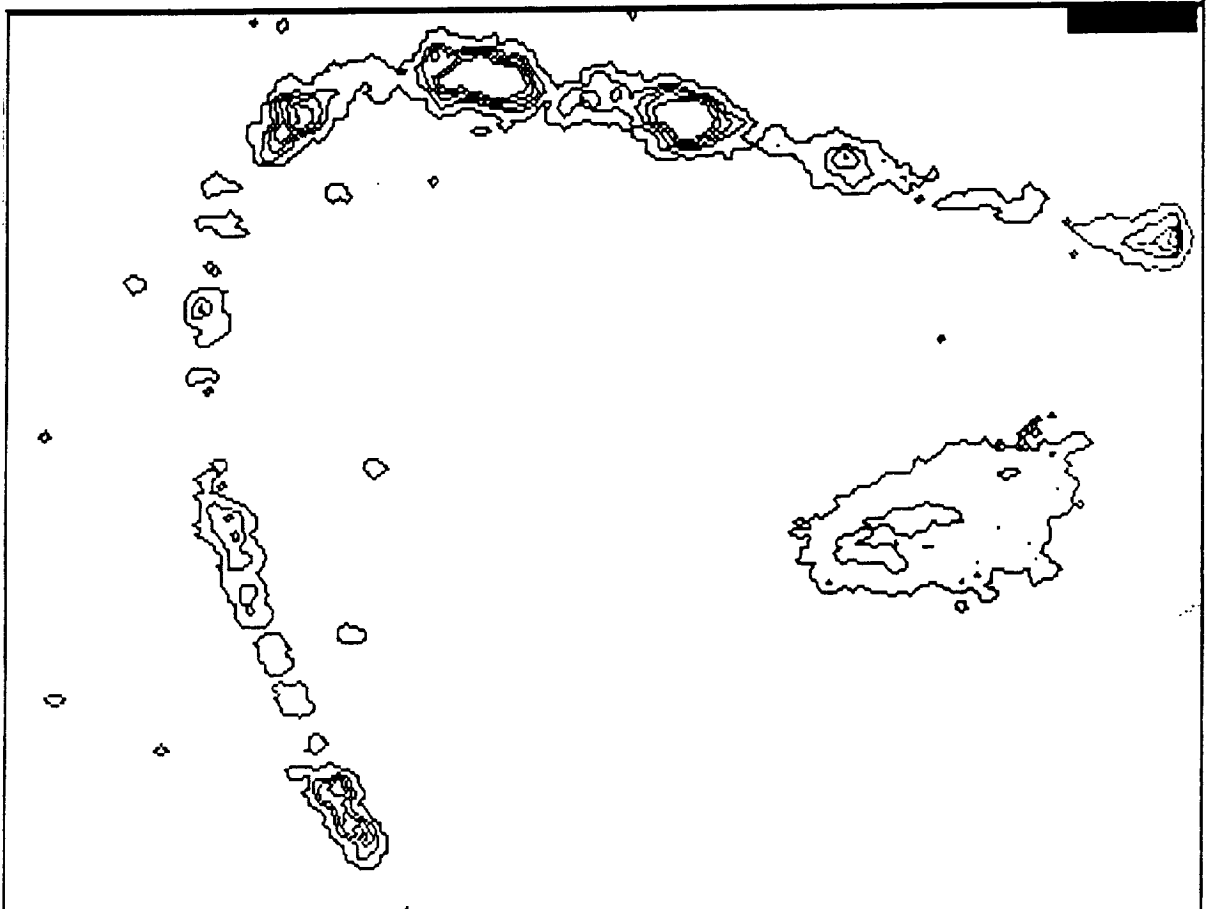
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SATELLITE LASER RANGING

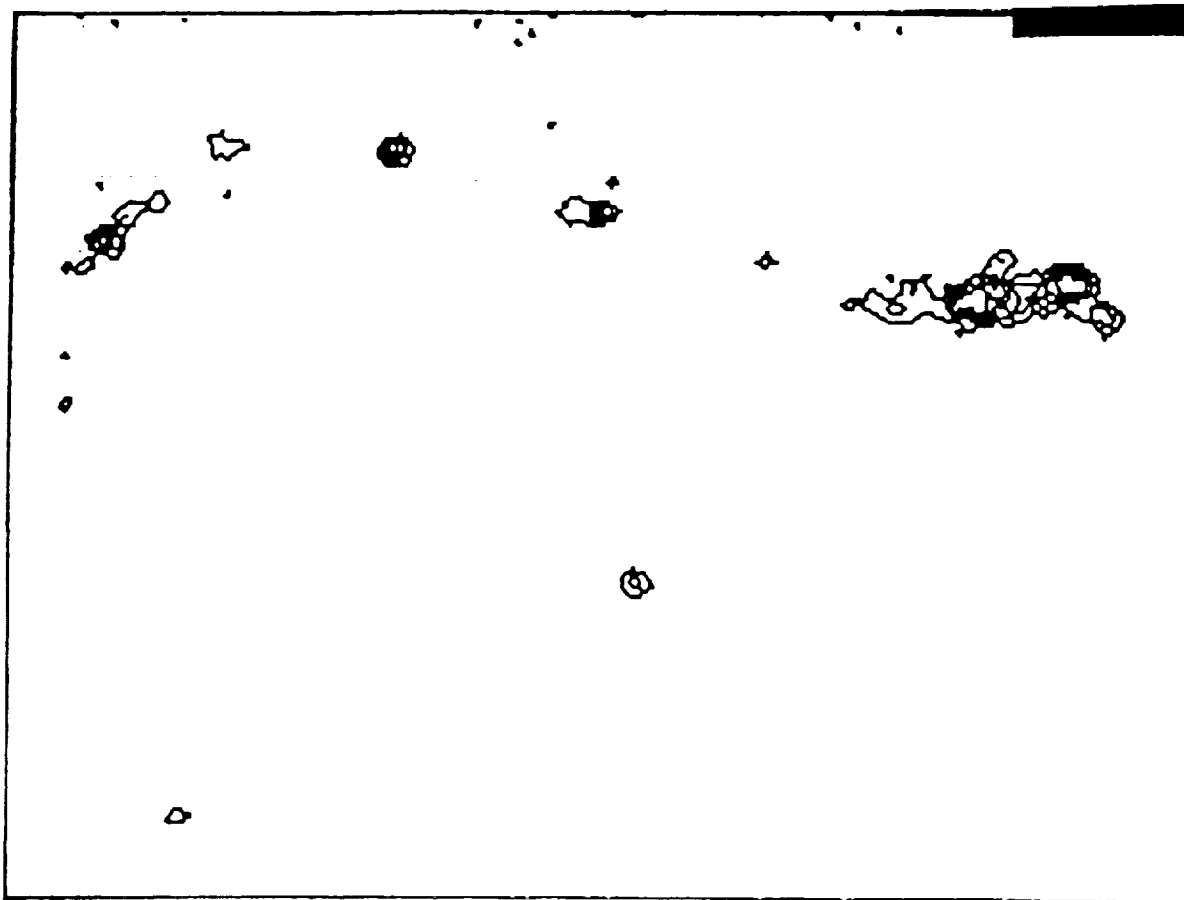
FIRST STREAK RECORDS

AJISAI satellite , diameter 2. meters
range 1 500 km
January 19, 1991 , UT 21:37

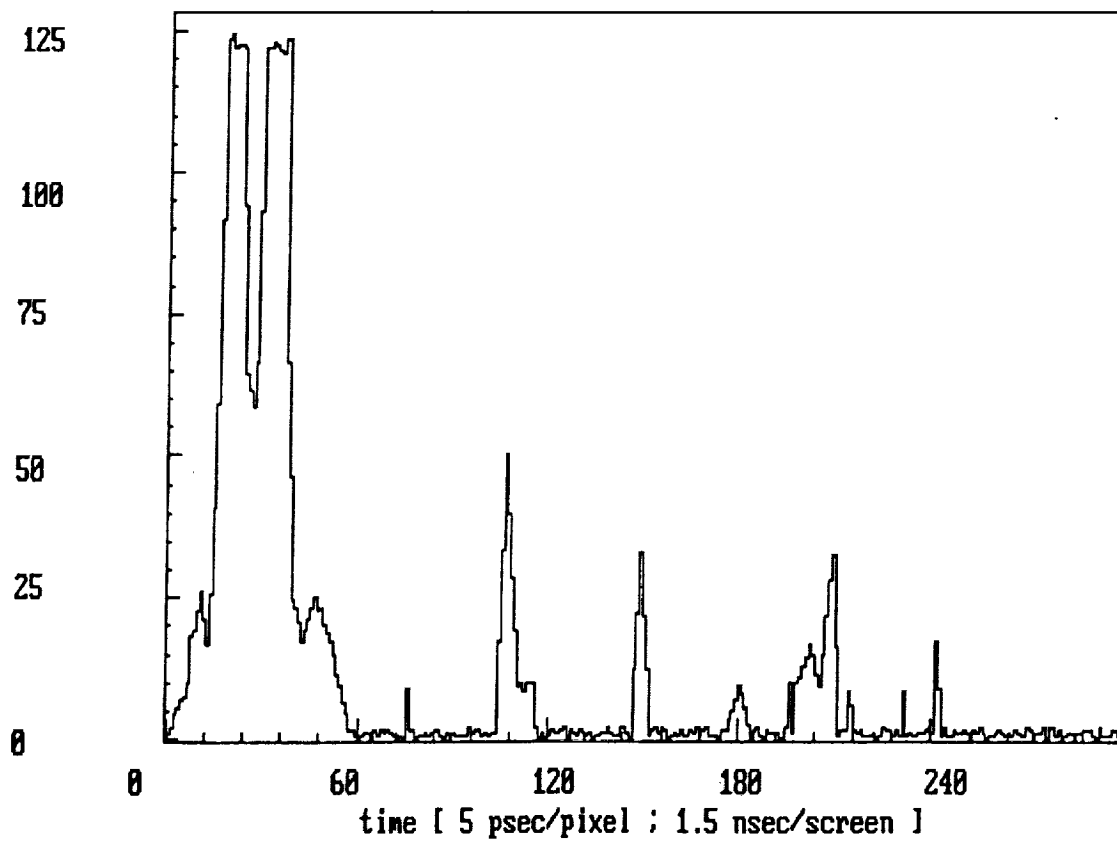


sweep period 3.125 nsec, displayed part 1 nsec

Fig. 1



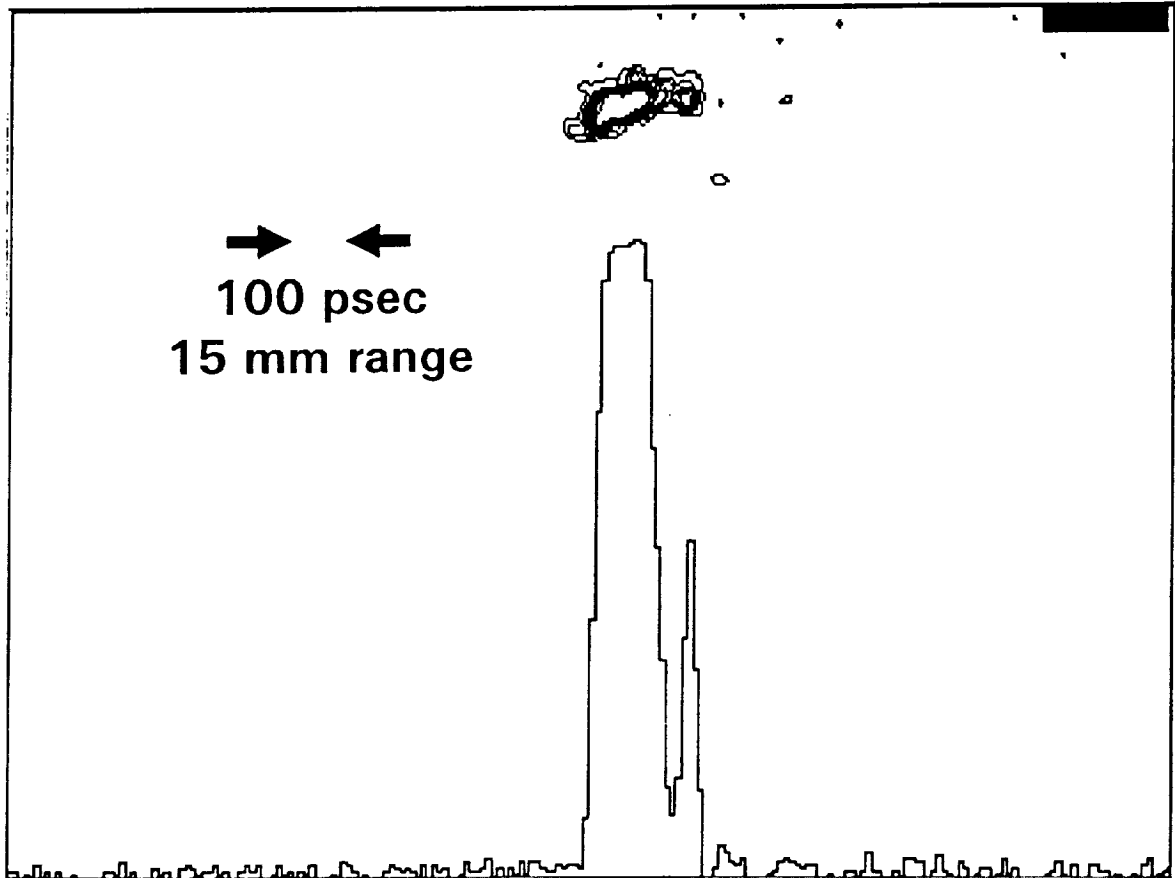
amplitude AJISAI satellite picosecond laser pulse response on streak



SATELLITE LASER RANGING

FIRST STREAK RECORDS

STARLETTE satellite , diameter 0.3 meter
range 1 000 km
January 24, 1991 , UT 21:59



echo signal temporal profile 8 psec / pixel

Fig. 3

Calibration

Techniques/Targets

