# AN IMPROVEMENT OF THE SATELLITE CAMERA

Fusakichi Ono

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**Abstract**

From several field observations the following improvements have been made to the satellite camera designed by the author in 1966.

(1) As driving mechanism of equatorial mounting a kind of D. C. motor is designed to obtain facilities for field operations.

(2) Number of the travelling slits is increased to 8 with equal interval.

(3) Slits can move 3 times along the surface of photographic plate according as the apparent angular speed of the satellite.

(4) Flashing times are controlled by the pulse from a quartz clock calibrated by the time signal of the standard frequency, enabling accuracy of the flash time to the order of $\pm 5$ microseconds with respect to the clock.

(5) Number of flashing is unified to 32 or 64 pps.

(6) Calibration of the quartz clock is made by photographing the dual-beam synchroscope, with the use of a time selector which was especially designed for this purpose. In the original design the calibration of flashing time were made by an electro-magnetic oscillograph.

## 1. Introduction

A timing device for satellite camera was designed by the author (1966) employing travelling slits and multiple flash light, and the camera has been used for observation of satellite triangulation practically. Mainly from the experience of practical use of this device, some modifications has been done to improve the accuracy and operational handiness.

In the present report the construction of the modified device is described.

## 2. Principle of the device

This timing device, to be mounted on conventional astrograph, was developed with the aim of determining exposure time of satellite in an accuracy of better than 1 msec.

The principle of this device is illustrated in Fig. 2. A metal plate having several slits (denoted by $a$) and pinholes (denoted by $b$) is located in front of photographic plate. Both upper and lower margins of the plate are bored pinholes, the positions of which relative to the slits should be calibrated beforehand.

During a satellite passage in the camera field, the metal plate moves along the surface of the photographic plate with a speed faster than the apparent angular speed of the satellite. The trail image of the satellite is thus chopped

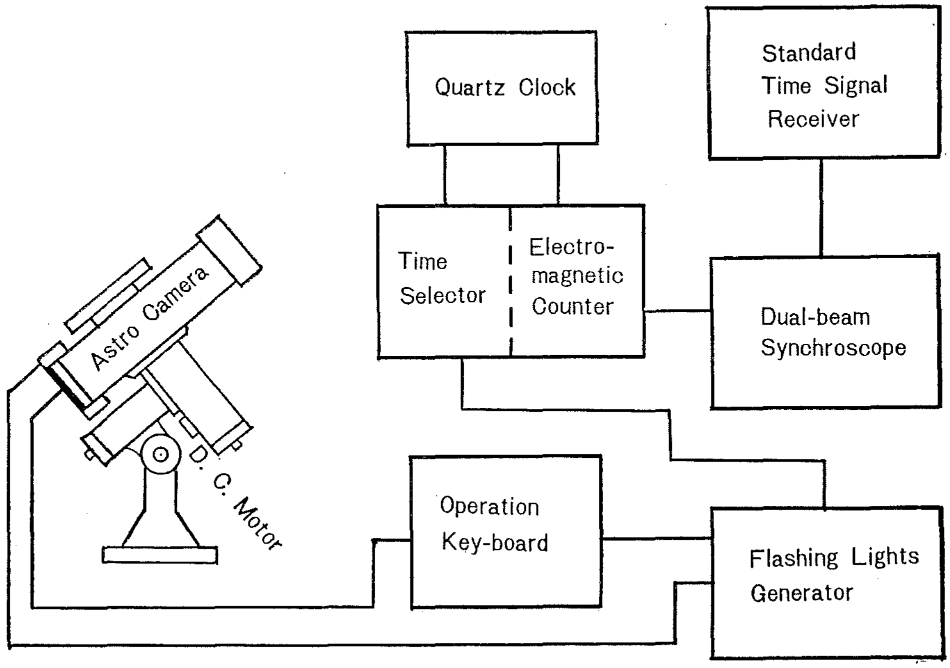


Fig. 1. Block diagram of observing equipments.

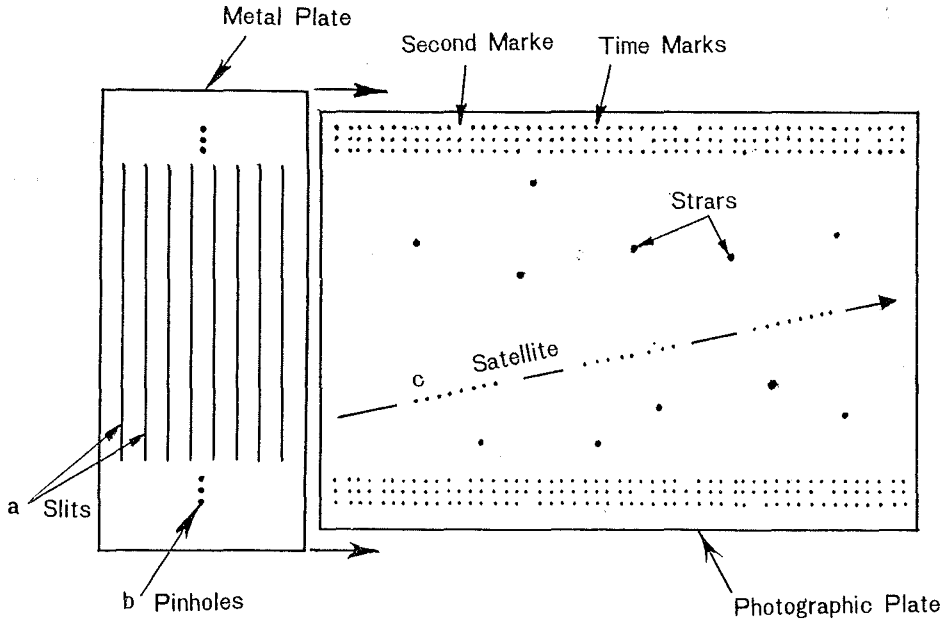


Fig. 2. Principle of the timing device.

by the slits, and a series of dot images is produced on the photographic plate, i. e. $c$ in Fig. 2. During the exposure a series of flashing lights with duration of 5 $\mu$s each controlled by pulses from a precise quartz clock is emitted onto the photographic plate through the pinholes of the metal plate. Then, a series of dot images thus photographed at upper and lower sides on the photographic plate can be used as "time marks", showing every flashing times.

Hence, the exposure time of each satellite dot image can be obtained from the movement of the metal plate through the relation between the positions of slit and pinholes.

(1) Correction for interstice between slit and photographic plate

Owing to the travelling mechanism of the metal plate, it is practically inavoidable to afford a finite distance $d$ between the metal plate and the focal plane. The effect of this distance to the images on the photographic plate should be considered. The displacement of the satellite's dot image due to this effect increases in proportion to the distance from the image to the optical center on the photographic plate, and is given by

$$\Delta r = d \cdot \tan\theta,$$

where $\theta$ denotes angular distance of satellite from the optical axis. See Fig. 3.

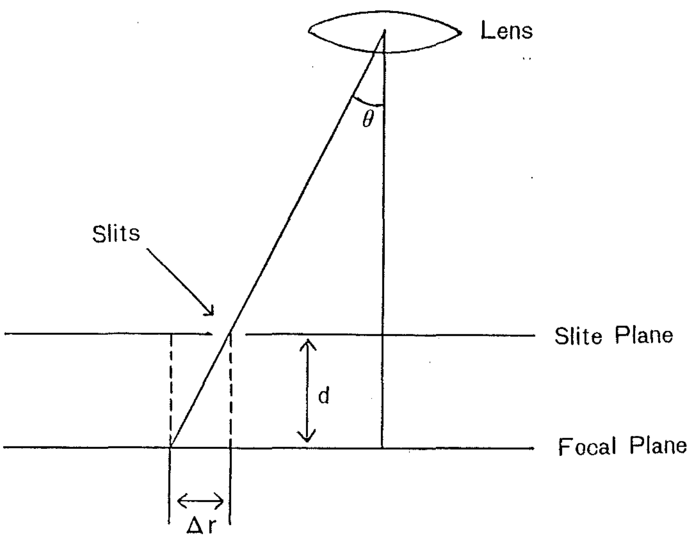


Fig. 3. Correction for interstice.

If we take 0. 2 mm as the minimum possible value of $d$ so as to move the metal plate smoothly, the correction value reaches to 10 $\mu$ at the distance of 50 mm from the optical center with focal length 1000 mm.

The corresponding timing correction depends on the travelling speed of the metal plate. Assuming this speed to be 30 mm/sec, the timing correction for the present case is 0. 3 (=0. 010/30) ms.

The fluctuation of the distance $d$ during travel of the slits should also be considered. If we can keep the fluctuation within $\pm 0.05$ mm under careful construction, this effect can be disregarded, because it only corresponds to the timing error of $\pm 0.08$ ms for the above case.

(2) Determining the exposure time of time mark

If the time marks are photographed as a series of dot images they stand, we can not get any information on the epoch of time. This problem was solved by employing the following method.

By means of omitting each first one of 32 or 64 pps of the quartz clock, the time marks corresponding to every right seconds are discriminated from the others. In order to give numbers to the seconds corresponding to these omitted time marks, the number of seconds from any time to the starting time of the flashing lights is counted by a electro-magnetic counter. Here, a series of flashing lights is always started at such time when the pinholes for time mark arrive at a definite position onto the photographic plate by means of electric contacts attached to the metal plate.

(3) Pulse frequency necessary for time marks

In order to know accurately the motion of the slits, the number of flashings per one second should be selected according as the linearity of the slit motion. If we increase the number of flashings, the labour to measure them also increases. In the present device 32 and 64 pps can be taken at the choice and practical experience shows these values to be good enough for determining the plate motion.

## 3. Improvement of the device

(1) Mounting

For the driving mechanism of the equatorial mounting, synchronous motor has been generally employed as its electric power source. Such mechanism necessitates electric power considerably, and is unsuitable for the observation at an offshore island, in which we can not take commercial electric sources unlimitedly. Then, in the new design a driving mechanism developed by the author is adopted. This mechanism is drived by D. C. motor and can be operated under a few consumption power.

In general, D. C. motor has been regarded to be unsuitable for precise driving with constant speed. The author has broken down this superstitution and has found that D. C. motor is also capable of synchronization with A. C. frequency as same as a synchronous motor. The principle is very simple as explained below.

The switch of D. C. motor is closed by every pulses of an A. C. standard oscillator and is opened by every synchronized pulses which are obtained by transforming the rotation of the motor's rotation axis into the A. C. frequency. While the motor is rotating with slow speed, the pulses of the oscillator exceed the synchronized pulses in frequency. Then, a mean electric current is in a high level, the rotation of the motor being continued to rise. When the number of the motor rotation reaches to a definite value, the frequency of the pulses of the A. C. oscillator and that of the synchronized pulses of the motor become equal each other or in a commensurable relation. In this situation a synchronization force acts on the motor. Under this condition, if a large load is imposed on the motor, a force acts on the motor in such a way to conserve the speed of rotation, due to the increase of current accompanied by the phase lag of switch-off of the motor.

On the contrary, if the load decreases a force acts similarly on the motor to conserve the rotation speed, because of the decrease of current accompanied by the phase advance of switch-off of the motor.

Then, in case the frequency of the pulses of the oscillator consists with the frequency of the synchronized pulses of the motor, the numbers of switch-on and off of the motor are equal with each other, and transmissibility of electric current is changeable from 0 to 100 % in response to the load fluctuation. As a result, the motor will not escape from the synchronized state to which the motor arrives once.

As it is easy to raise the frequency of pulses developed from the rotation of the motor to 10~100 times of the rotation speed of its shaft, we can take the frequency of the standard oscillator so high as several kHz.

The driving method is much superior to the case of a conventional synchronous motor in stability of synchronized phase. We can thus succeed to reduce the electric power consumption to 1/60 or less of that of a conventional synchronous motor which necessitates power amplification.

(2) Timing device

The travelling slits are actuated ab means of a synchronous motor with double speed which is given by switching over between 2-poles and 4-poles. By combining sets of gear heads to this motor, moreover, it is possible to acquire various speed reductions, 4~35 mm/s in practice, according as the apparent angular speed of the satellite.

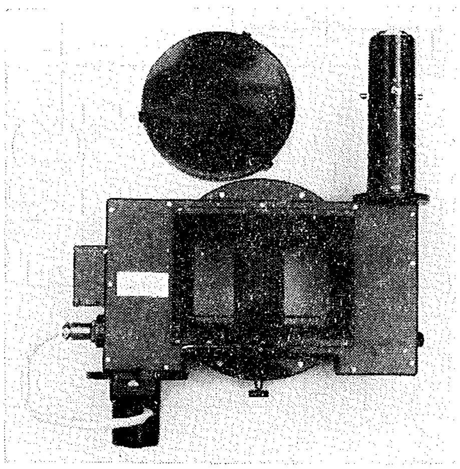

Fig. 4. Timing device.

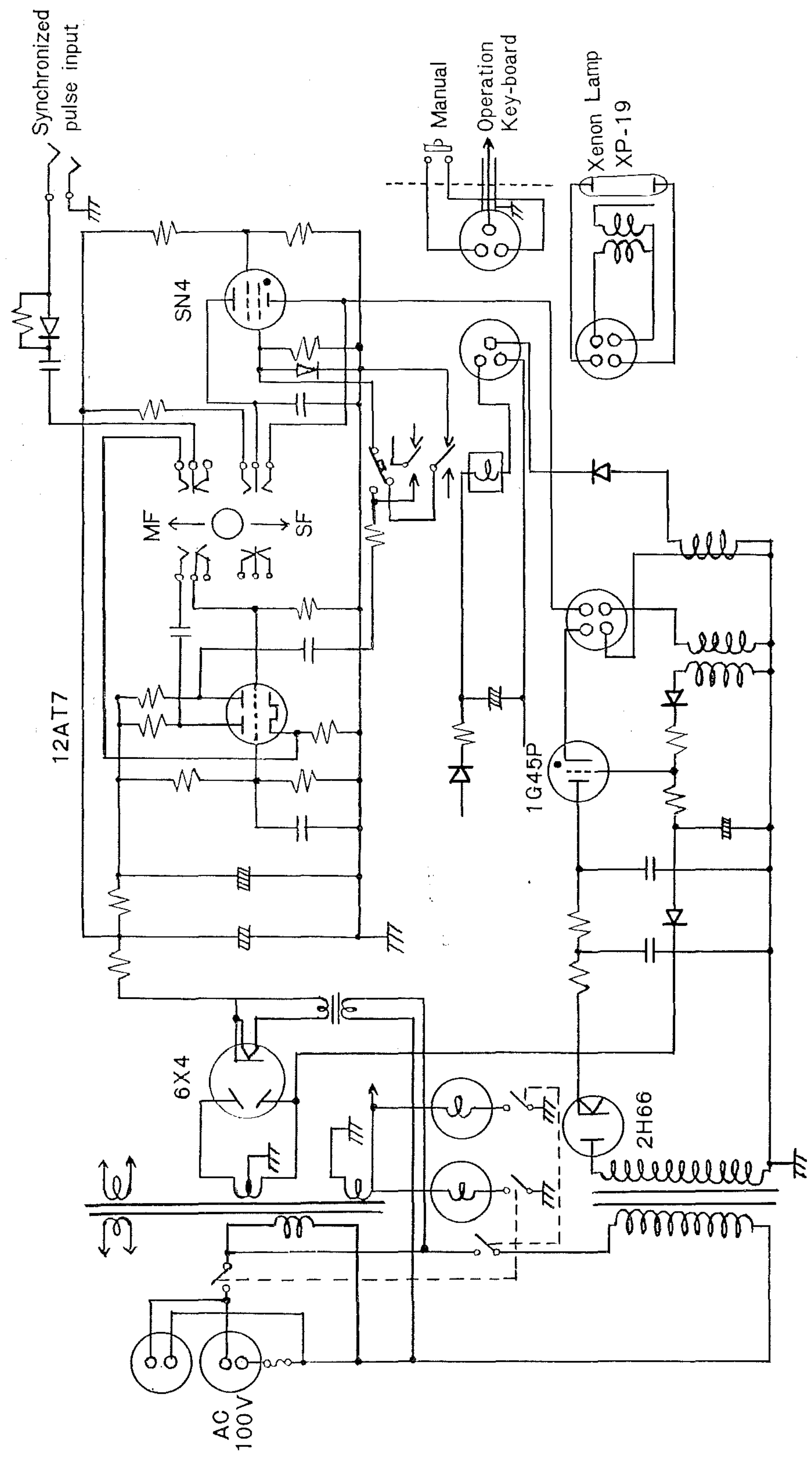


Fig. 5. Circuit diagram of flashing Light generator.

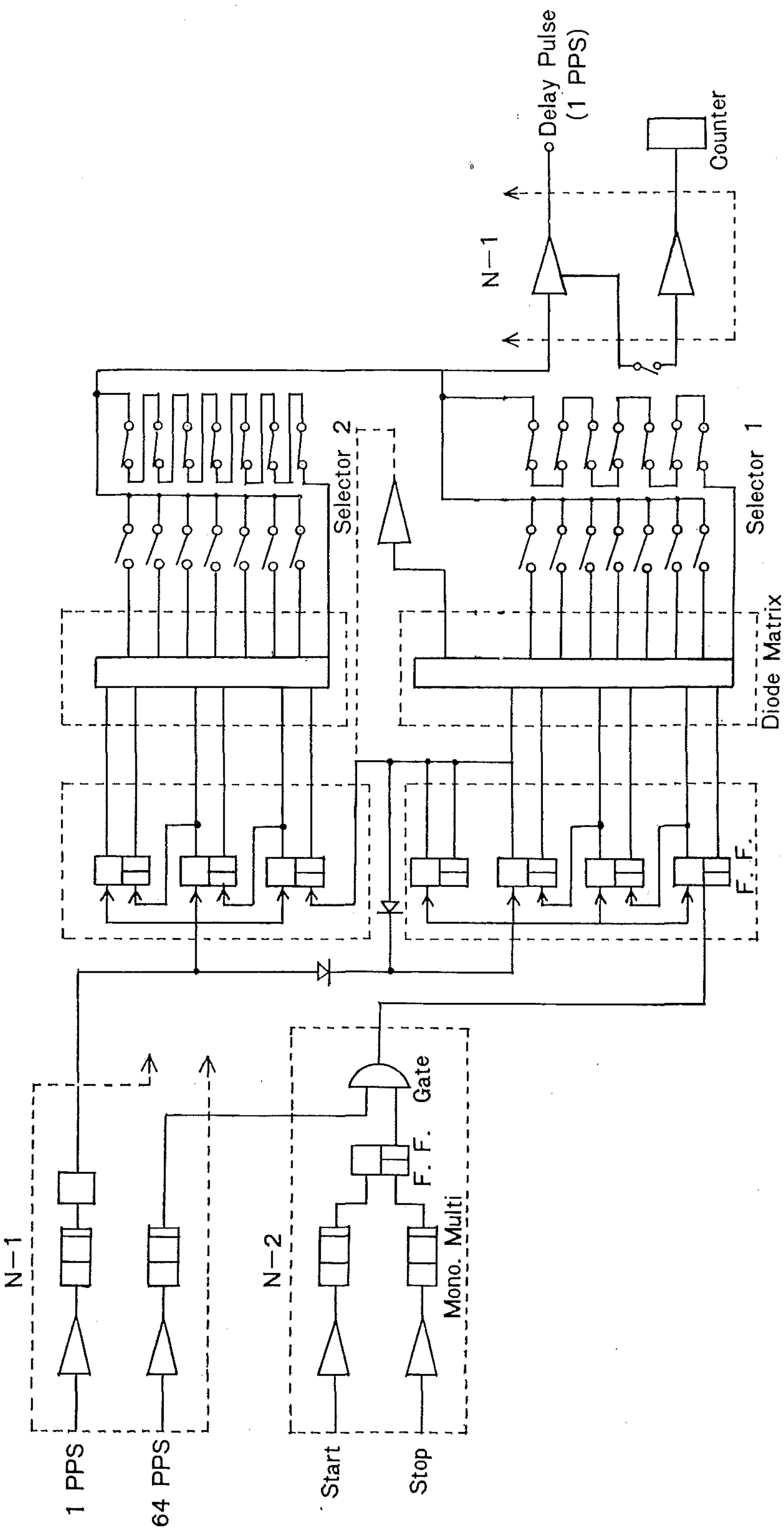


Fig. 6. Block diagram of time Selector.

In order to guide the flashing light to the pinholes on the metal plate, the following optical system is employed.

The light emitted from Xenon lamp after passing through a condenser lens becomes a parallel ray with diameter of about 10 mm. After successive reflections at several small prisms, this parallel ray falls on the photographic plate through the pinholes on the metal plate.

Driving mechanism for the slits are modified to travel succesively in three times along the surface of photographic plate. Then each three pinholes are bored at upper and lower margins of the metal plate.

The number of the slits increases to 8 with equal interval from 3 with unequal interval of the original design, and 24 dot images divided into three groups are then photographed for one exposure.

In order to set the photographic plate to the focal plane of the camera as closely as possible, a special plate holder has been designed, which make possible operations of the photographic plate from the outside by a rubber sucker.

(3) Flashing lights

In order to know precisely the movement of the slits relative to the photographic plate, it is desirable that the duration of a flashing light is enough short. In this modification, 5 $\mu$s $\pm 2$ $\mu$s is chosen for the duration.

The high voltage circuit for Xenon lamp is shown in Fig. 5.

Trigger pulses for emitting the flashing lights are controlled by pulses from a quartz clock, and delay time from the pulse input to the light emission is about 50 $\mu$s $\pm 5$ $\mu$s.

(4) Calibration of quartz clock

The quartz clock is actuated by the divided frequency secured from a quartz oscillator having original frequency of 160 kHz.

For the frequency of the trigger pulses of the flashing lights, 32 and 64 pps

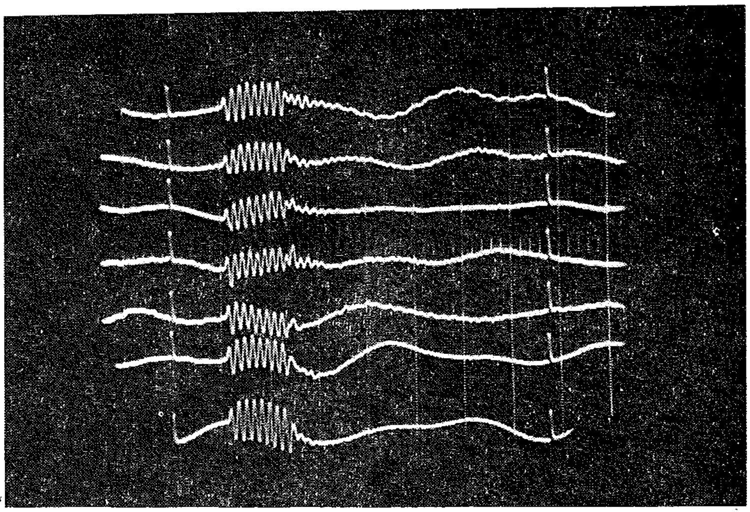

Fig. 7. Comparison between quartz clock pulse and JJY standard time signal.

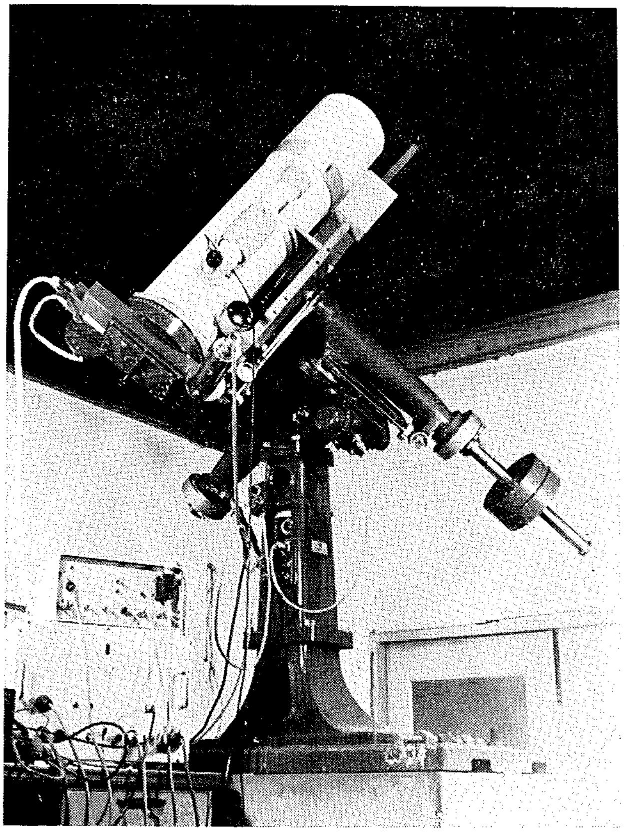

Fig. 8. Satellite tracking camera with timing device.

are adopted, one puls of which is omitted every one second as described above. The clock has also a out-put terminal of 40 kHz for monitoring by the LF standard frequency.

The time difference $\Delta t$ between the quartz clock and the JJY standard time signal are evaluated by photographing the face of dual-beam synchroscope. To do this easily, a time-selector, which consists of flip-flop and diode-matrix mainly, was designed.

By employing this device, the signal of time second for time-axis trigger of the synchroscope can accuratly be shifted by each 1/64 second, and fine comparison between both can easily be performed even if $\Delta t$ takes a large value.

(Astronomical Section)

## Reference

Ono, F. 1966, *Report of Hydrographic Research* No. 1, P. 63.