4.4 TIMING SYSTEM

By
Jun AMAGAI, and Hiroo KUNIMORI

(Received on)

Keywords: Satellite laser ranging, Geodesy, Timing measurement, Calibration.

Running Title: Timing System

A BSTRACT

The timing system is one of the most important hardware components of the satellite laser ranging (SLR) system that is used in the Key Stone Project (KSP). It measures the event epochs such as laser firing and return pulse detection. This section describes principles of timing measurement and some additional functions of the timing system.

1. Introduction

The SLR system measures the traveling time of a laser pulse that makes a round trip between a telescope and a satellite equipped with corner cube reflectors. The ranges between the station and the satellite are calculated from the observed traveling time. We can estimate the three-dimensional position of an observation station or a satellite orbit using these ranges. The timing system measures the time interval of electric signals that are converted from transmitted and received optical pulses. A highly accurate and reliable timing system which is accurate to milimeters, is required in the KSP SLR system. This system is dedicated to monitor crustal deformation in metropolitan areas of Japan. In this paper we describe the KSP SLR timing system which uses extremely accurate vernier and calibration system.

2. Timing system

Fig. 1 shows the configuration of the timing system. A portion of a laser pulse is fed to a photo diode just after it is transmitted. The output from the photo diode is used as a start pulse, which is called the T1 event. Highly sensitive detectors such as multi cannel plate (MCP) and single photon avalanche diode (SPAD) detect the optical signal returning from a satellite or ground targets. The output of the detector is used as a stop pulse, which is called the T2 event.

The start pulse and the stop pulse are fed into the timing system and the epoch of the events are precisely measured by the timing system. The timing system obtains the round trip time of the laser pulse by calculating the time difference between the start pulse and the stop pulse epochs. The round trip time data is sent to a file server. A 10 MHz reference signal generated by a hydrogen maser or a GPS time receiver is used as the reference clock for the timing system.

3. Timing measurement

Timing measurement is carried out by a master ranging control system (MRCS). The MRCS controls the laser and measures each epoch. It also controls the aircraft detection laser system. Timing measurement and control are done by referring to pre-set timings and events that are stored in the part of the system's memory called the event latch. The time of an internal clock and the epoch data stored in the event latch memory are compared and when they agree, the event is executed.

Measured data (event epoch) are stored in on-board memories and can be accessed by a computer via dual port RAM without disturbing an observation. Along with the ranging data, the statuses of the ranging and the control conditions are also sent to the computer. The buffer, which stores commands and data, has a capacity to store the data for 200 ms at a laser repetition rate of 1000 pulses per second (PPS).

1) Internal clock

An 80 MHz signal, which is generated by a multiplier using a 10 MHz tone signal from a hydrogen maser or a GPS time receiver, is used as an internal reference signal. An internal clock uses a 68 bit counter to count the reference signal. The clock time is set by referring to the time code of the GPS clock and is synchronized by using a 1 pps signal. Both operations are done by commands from a host computer.

2) Timing measurement procedure

Firstly, an event epoch is roughly measured using an internal reference signal with a resolution of 12.5 nsec. Then fraction of the event epoch of less than 12.5 nsec is measured by a timing vernier with a resolution of 2 psec. The vernier consists of a ramp circuit and a 14 bit AD converter. The AD converter measures the output voltage of the ramp circuit which is a capacitor that is charged during the fraction time (Fig. 2). Because the precision of the timing measurement depends on the precision of this vernier, the vernier calibrated by measuring the inclination of the ramp wave form. This is done by using test pulses which simulate start and stop pulses, generated by the internal reference signal (Fig. 3).

The event timings measured by the MRCS are the start pulses (T1 event) and the stop pulses (T2 event) from a ground target and a satellite. Four verniers are used in the MRCS. The same vernier is used for measuring the two stop pulses to avoid the influence of any characteristic difference between the verniers (see section (6)). Input gates (calibration window and range gate) are used for stop pulses to avoid trapping undesired noise. The width of the calibration window can be set within a range of 25 ns and 3.2 μs, while the width of the range gate can be set within 25 ns and 819.2 μs.

3) Detector gate

Optical signals sent to the highly sensitive detector include undesired background noise along with the signal from a satellite. A gate in the detector is opened to reject this noise for a time period which is an estimation of a timing of an arrival of a returning signal. The width of this detector gate can be set between 25 nsec and 819.2 µs. There is a dead time of a few micro seconds after the gate opens and before the detector is ready to detect the signal. The calibration and the range gates are opened after this dead time has passed.

4) Two color ranging

The timing system is designed for two color ranging (1). In two color ranging, a laser beam with a shorter wavelength than is usual for SLR observations is used to compensate for excess atmospheric delay caused by light dispersion. The delay is estimated by measuring the difference between the ranges of the two wavelengths. The MRCS is designed to accept plural start pulses and plural stop pulses in order to do this.

5) Control of the aircraft detection laser

In the KSP/SLR system, the laser is fired into the sky at an elevation angle higher than 15 degrees to avoid damaging human eyes. When the laser is fired at ground targets, power is limited to the maximum permissible level as defined by Japanese Industrial Standard C-6802. The peak power of the laser pulse transmitted to the sky, however, is more than 1 GW, and injury to the eyes of pilots or passengers of aircraft s possible. Therefore, we use an aircraft detection laser (ADL) which monitors aircraft by radar using an eye-safe laser with a wavelength of 1.5 µm. The ADL transmits eye-safe laser pulses and inhibits the transmission of the SLR laser if a pulse returns within 300 µs, which corresponds to a range of 45 km. The ADL is not operated, however, when the repetition rate of the SLR laser is higher than 1000 pps and its power is weak enough not to be dangerous to eyes.

6) Calibration

The range which is measured by the SLR system is a distance between the satellite and a reference point or the telescope (the intersection of the axes of the telescope). However, this cannot be done without including system delay. Therefore a system-delay-calibration target is mounted inside the telescope. By ranging this target simultaneously with a satellite and subtracting the target range from that of the satellite and then correcting the distance between the target and the telescope reference point, we can get the correct range between the telescope reference point and the satellite. This technique provides real-time compensation for any system delay (Fig. 4).

4. Conclusion

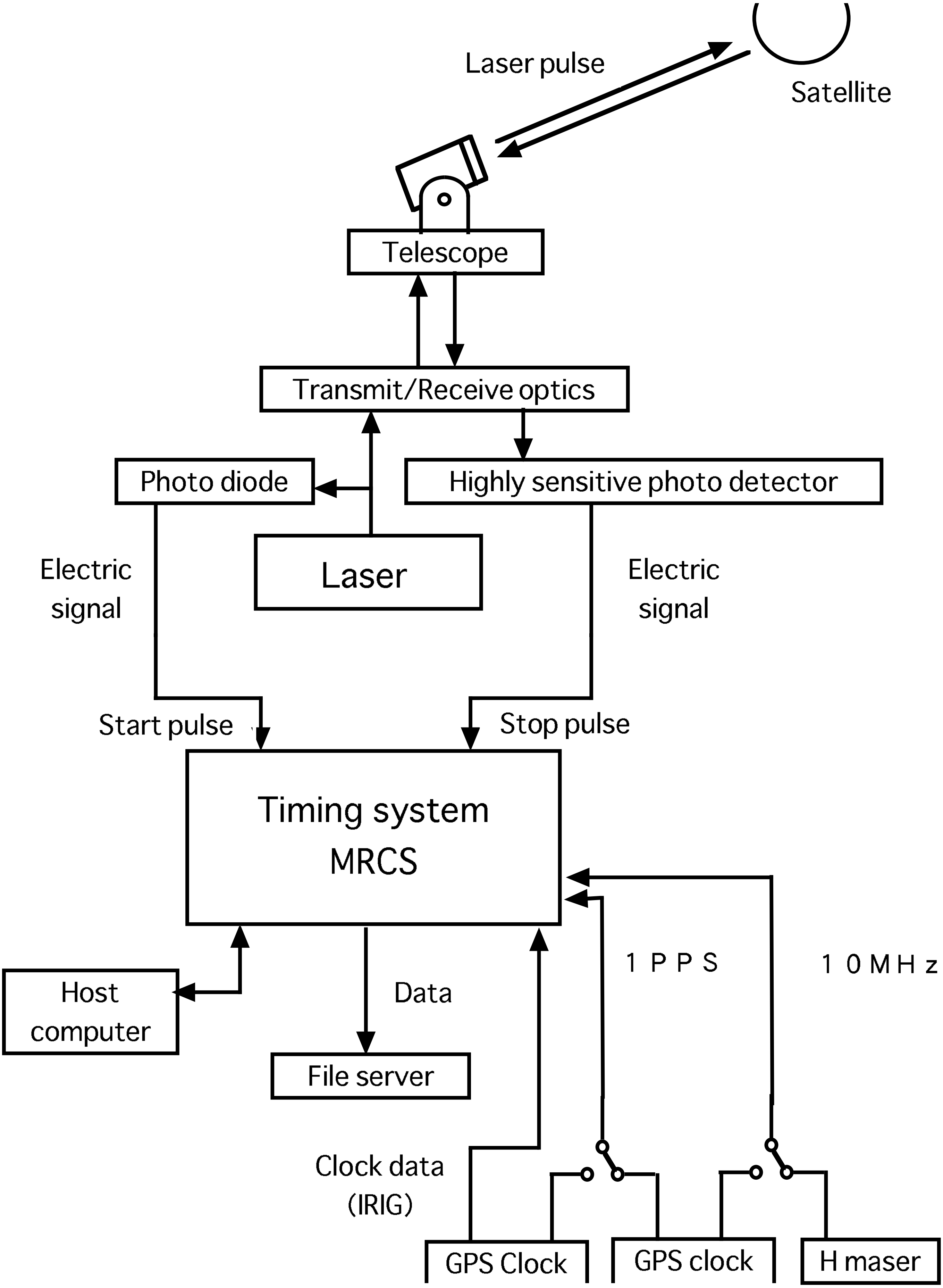
The KSP SLR timing system, which uses a vernier with 2-psec resolution and calibration system, enables crustal deformation to be monitored to within a few millimeters. We can monitor crustal deformation extremely accurately by using this system, which is extremely sensitive to vertical changes in the position of a station, together with the VLBI system, which is sensitive to horizontal changes.

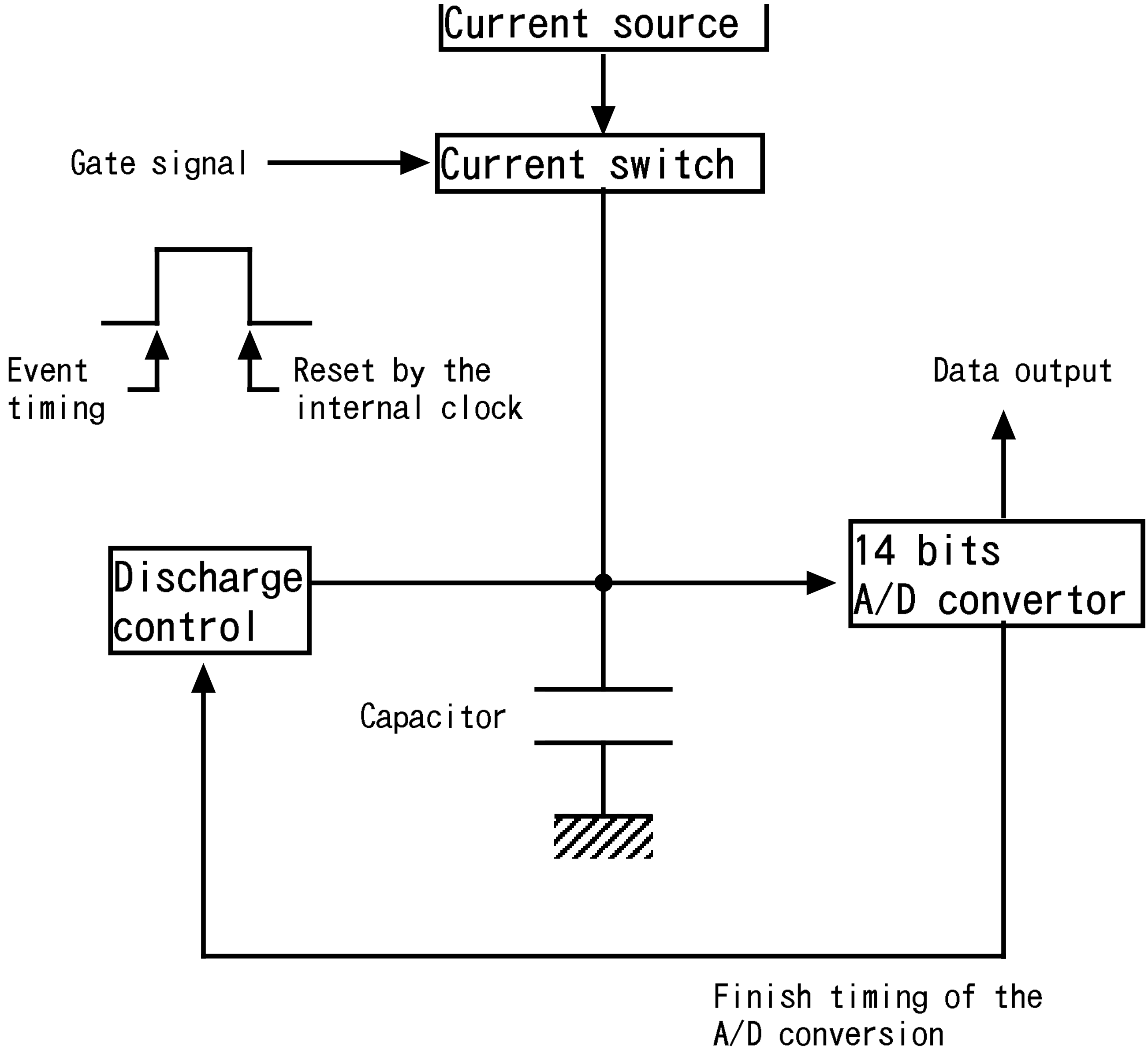
References

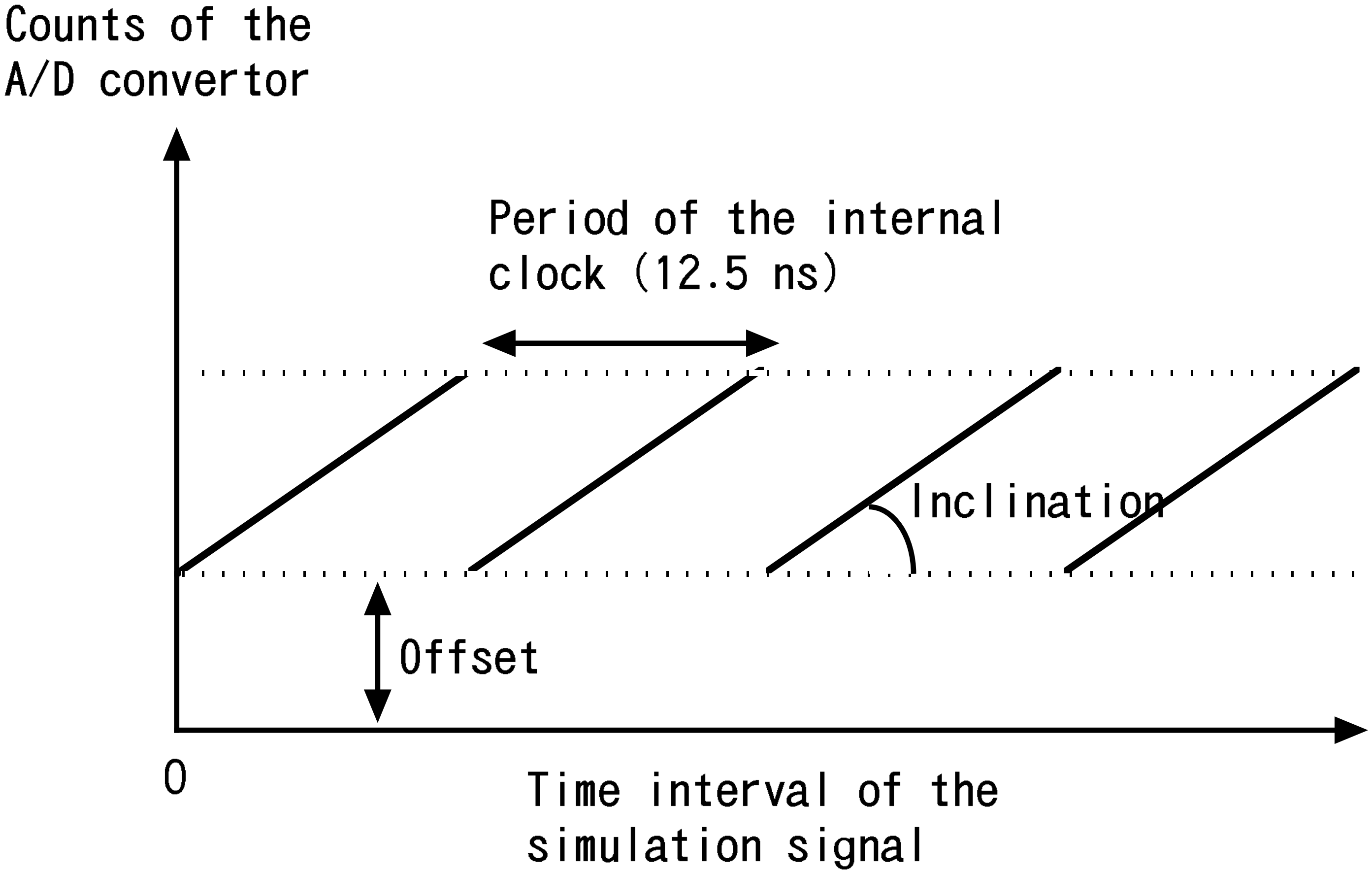
(1) Abshire, J.B., “Pulsed Multi-wavelength Laser Ranging System for Measuring Atmospheric Delay,” Appl. Opt., 19, 3436, 1980.

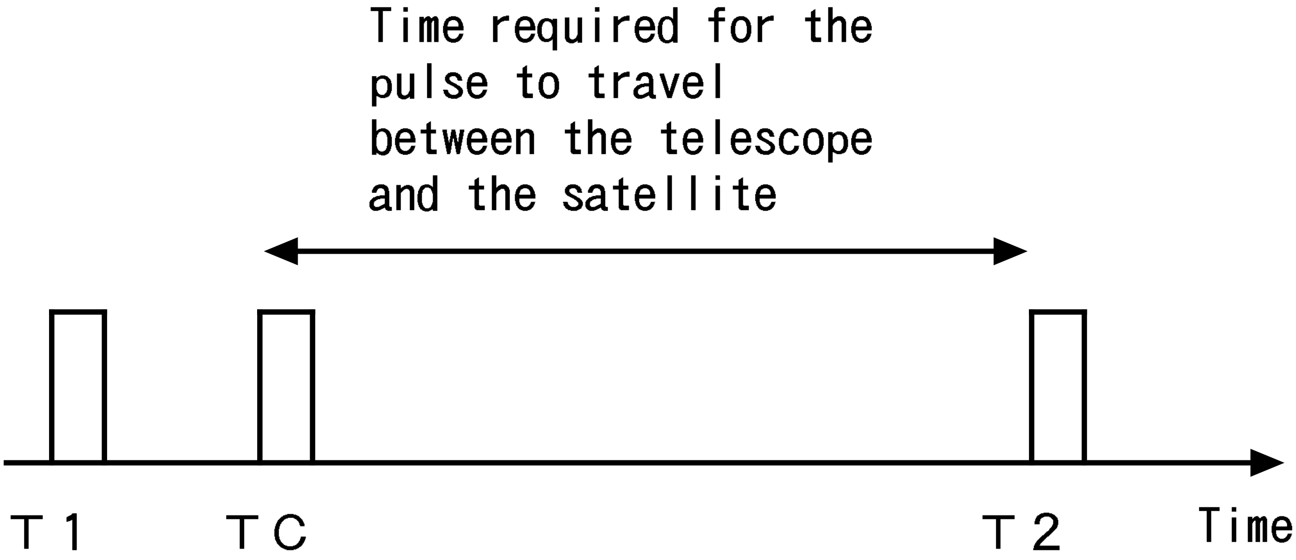
Figure captions

Fig. 1. Configuration of the timing system
Fig. 2. Timing vernier
Fig. 3. Timing vernier calibration
Fig. 4. Calibration of the system delay


Laser pulse
Satellite
Telescope
Transmit/Receive optics
Photo diode
Highly sensitive photo detector
Laser
Electric signal
Electric signal
Start pulse
Stop pulse
Timing system MRCS
1 PPS
10MHz
Host computer
Data
File server
Clock data (IRIG)
GPS Clock
GPS clock
H maser


Current source
Gate signal
Current switch
Event timing
Reset by the internal clock
Data output
Discharge control
14 bits A/D convertor
Capacitor
Finish timing of the A/D conversion


Counts of the A/D convertor
Period of the internal clock (12.5 ns)
Inclination
Offset
0
Time interval of the simulation signal



T1 : Epoch when the start pulse is detected

TC : Epoch when the reflected pulse from the ground target is detected

T2 : Epoch when the stop pulse is detected