Eventech Stream Time-Tagger ESTT

Abstract. Eventech Stream Time-Tagger (ESTT) is an event timer distinguished by high precision in recording the moments of events (Single-shot RMS differences 2.1 ps), which is combined with the ability to continuously record a stream of input events with an intensity of up to 25 Mevents/sec. The device has built-in means of automatic stabilization of metrological parameters, ensuring stability in the temperature range of 5-40 °C. For satellite laser ranging (SLR), it is imperative to synchronize the internal time scale with the external time scale using 10 MHz and 1 PPS signals (including the UTC scale using GPS signals).

The precision event recorder ESTT belongs to the time to digital converters (TDCs) and its main function is to register the moments of events that correspond to the appearance of leading edges of the input pulses. Registration results (time-tag) serve as the basis for determining derived time parameters (time interval, period, pulse duration, event flow intensity, temporal correlation between events, etc.).

According to its structure, ESTT belongs to the class of computer-based instruments and consists of a measuring unit and a computer program that implements control and data processing routines. The measuring unit communicates with the personal computer (PC) through a high-speed USB3 port. Structurally, the measuring block has one measuring channel having dead time of about 40 ns with two inputs connected via OR logic. The presence of two inputs (Input A and Input B) is optimal for establishing timing relationships between initiating (start) and second (stop) events. The input signals can arrive at inputs A and B in an arbitrary order. This situation usually occurs in kilohertz SLR stations when overlapping time intervals are measured. For input B, the possibility of external time selection is provided, when the signal at the Gate In input can enable or disable the registration of input events.

The output time tags of an event contain the marker of the corresponding input and are presented with a resolution of 1 ps. The duration of the instrument time scale cycle is 7 days, so if no events have been received by the device during this time, then it is necessary to repeat the time scale synchronization procedure. The output data contains information about the temperature inside the meter body.

A user-friendly C/C++ application programming interface (API) for Windows and Linux allows the user to design various measurement systems for the time analysis of high-speed pulse flows in applications such as kilohertz laser ranging, precision gravimetry, time transfer and data transfer. In addition to API, an example of command-line program is provided to illustrate how to operate the device and access the measurement information. The device software includes self-testing program that allows you to verify the functional and parametric readiness of the device for operation.

The device block diagram is shown in Figure 1.

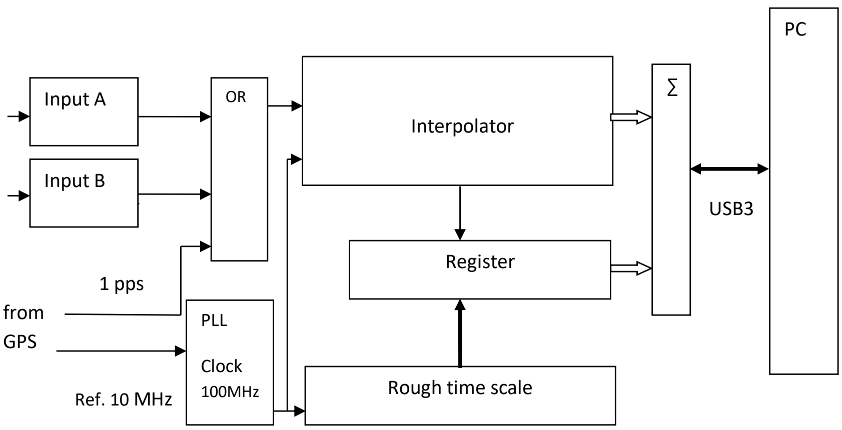

Figure 1. Block diagram of ESTT

The time-tagger is based on a coarse time scale with a resolution of 10 ns and an interpolator, which specifies the phase of the input event within a coarse time quantum (interpolator resolution of approx. 2.7 ps). The input event is sensed by the sensor and is fed to one of the device inputs as a normalized electrical pulse. The input signals are received by a speed comparator whose comparator level can be set by software, including for NIM or LVTTLT signals. The polarity of the working edge of the input signal can be selected by software. Since structurally, the device is a single channel meter, events on inputs A and B are combined by an OR circuit. The moments of their arrival are recorded as coarse scale and interpolator codes. The combined tag is transmitted via an USB3 interface to the PC. The control and data processing software processes the received time tags until the final logging results in time tags. The best possible measurement precision is achieved through calibration, which enables the measurement channel model to be updated to suit the current operating conditions of the device.

The interface with the PC enables continuous (skip-free) logging of event arrival times with almost no time limit (but within the available memory capacity of the PC). ESTT provides a maximum event rate of 25 Mevent/sec considering 40 ns dead time of TDC and high-thoughput computer interface.

The 10 MHz and 1 pps signals from the Global Positioning system (GPS) time and frequency standard are used to synchronize the internal time scale with the external UTC time scale, allowing the time tags of input events to be obtained relative to UTC.

An instrument can only be considered precise if its metrological parameters are stable, especially in temperature. Thanks to the interpolator parameter stabilization systems in the ESTT, high-temperature stability of precision is achieved (Figure 2).

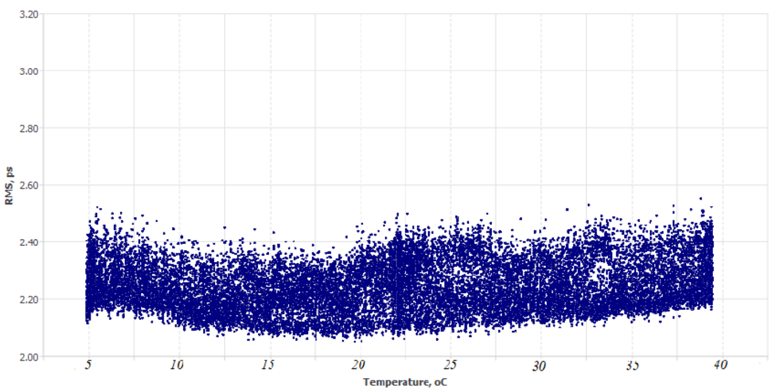

Figure 1. Dependence of ESTT precision from temperature.

The ESTT 704 has a time tag drift stabilization system, which ensures a drift level not exceeding 0.5 - 1 ps/^{0}C (Figure 3).

Deleted: Figure

Formatted: Font: (Default) Times New Roman, 12 pt, English (US)

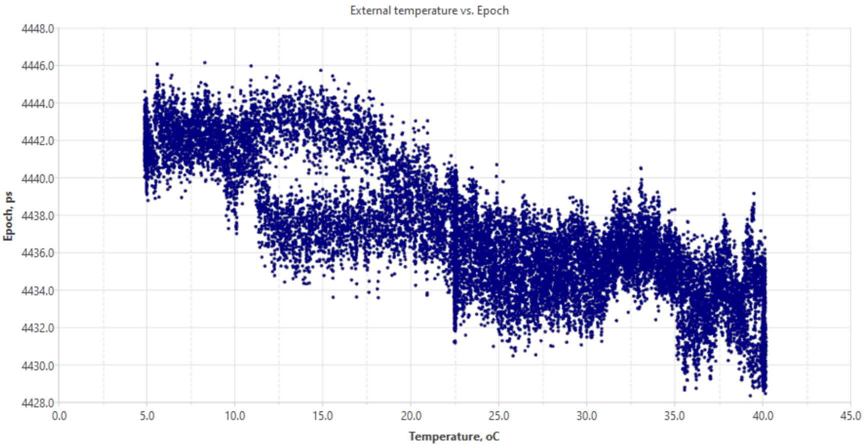

Figure 3. Temperature drift of the systematic error in event time recording

The Figure 4 shows the delay difference between INPUT A and INPUT B (offset) and its drift. A typical offset value is 40-50 ps with a temperature drift of 0.1-0.15 ps/°C.

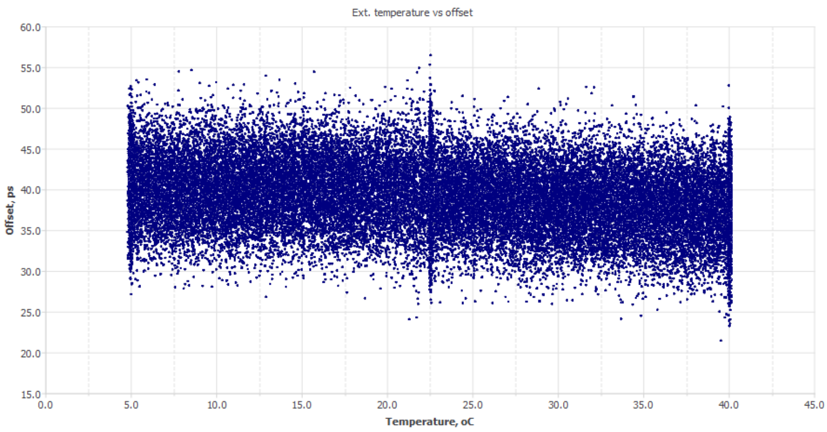

Figure 4. Temperature stability of offset

The front panel of the ESTT and corresponding notations are shown below (Figure 5):

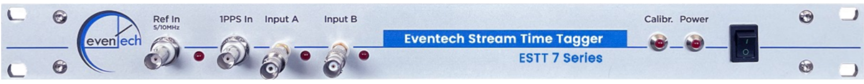

Figure 5. Front panel of ESTT measuring unit.

INPUT A and INPUT B (SMA connectors, 50 Ohm load) are inputs for measured events.
REF IN (BNC connector, 50 Ohm load) - external reference oscillator input (5/10 MHz, >0.5 Vp-p). The connection of an external reference oscillator is automatic when a signal appears on the **REF IN** input and is indicated by the LED on the front panel. Frequency switching of the input signal is also automatic.
1PPS IN (BNC connector, 50 Ohm load) - TTL second time stamp input from external reference oscillator (assumes that the reference oscillator signal and 1 pps pulses come from the same source and are synchronous). The presence of the 1PPS IN signal is indicated by the flashing of the LED located near the connector on the front panel.
Calibr. - The flashing LED indicates that the calibration procedure is in progress.

The rear panel is shown in (Figure 6):

Figure 6. The rear panel of the ESTT measuring unit

TRIG IN (BNC connector, 50 Ohm load) - LVTTL pulse input to implement external triggering of the current measurement. The triggering is done on the rising edge of the trigger pulse.
USB3 (B type connector) - connector for connection to USB3 PC. It is recommended to use the cable provided.
GATE IN (BNC connector, 50 Ohm load) - LVTTL pulse input enables or disables registration of signals coming to **INPUT B.** With the cable on the **GATE IN** input disconnected, measurements on **INPUT B** are enabled.
AUX OUT (BNC connector, 50 Ohm load) - LVTTL pulse signals output with a programmable period. These pulses can also be used as device test inputs.

The main parameters of the device are presented in the Table 1.

Table 1. Parameters of ESTT 704

Event inputs (SMA, 50 Ω)	
INPUT A: Pulse > 0.5 ns width, max -2.0 V to +3.0 V	
Level of comparison -2.0 V to +3.0 V, step 1.2 mV	
INPUT B: Pulse > 0.5 ns width, max -2.0 V to +3.0 V	
Level of comparison -2.0 V to +3.0 V, step 1.2 mV	
Choice of operating edge: positive, negative, positive&negative	
Inputs (BNC, 50 Ω)	
GATE IN: Pulse LVTTL level ("LOW" enables Input B)	
TRIG IN: Pulse TTL/LVTTL level (rising edge)	
REF IN: 5 or 10 MHz (>0.5 V p-p)	
1 PPS IN: Pulse TTL/LVTTL level (rising edge)	
Output (BNC, 50 Ω)	
AUX: Pulse LVTTL level	
Single-shot RMS (differences):	2.1 ps typically, 2.5 ps maximum
Single-shot RMS (time-tags):	1.5 ps typically, 1.8 ps maximum
Dead time:	40 ns (35 ps minimum)
Measurement rate **Typically average rate:**	25 MEPS
Interval non-linearity:	±1 ps maximum (for time intervals greater than 100 ns)
Single-input time tag drift:	<1 ps/°C
Input-to-input offset: **Offset drift:**	40 ps <0.15 ps/°C
Synchronization error of input signals and signal 1 pps	± 15 ps maximum
Operation mode	continuous measurement of events occurring at the inputs
Gating of "Input B"	by external pulses at the input "GATE IN"
Internal clock:	100 MHz, locked external reference frequency (REF IN)
1 PPS pulse:	synchronisation precision ± 20 ps

Output pulse signal AUX	The programmable period is from 40 ns to 1 ms, step 10 ns, duration 10 ns
Signal AUX jitter RMS	< 4 ps
Warm-up time:	0.3 hours
Hardware interface:	via PC USB3 port, connector type B
PC Requirements	8 GB RAM, 4 cores (for maximum measurement rate)
Software:	Win 7-11 (64bit) or Linux (64bit) based OS
Accessory software:	Program API, Sample program in C++
Hardware dimension and weight:	RACK 19", 1U; 2.5 kg Can be rack-mounted or used as a desktop
EMC	EMC shielding of approx. 30 dB(A) at 1 GHz
Operating temperature range	5-40 °C
Hardware power supply:	100-240 VAC, max 25W

Full recording technology.

The high-speed communication interface between the measuring unit and the PC in combination with the large memory capacity of modern PCs allows ESTT to implement the “full recording” mode with continuous registration [1,2] for all input signals for several days.

In classical laser location, signal extraction from noise is performed using hardware time selection of reflected signals in real time of the experiment. The full registration mode allows transferring the operation of signal extraction from noise to the software level in the post-processing mode of the registered signals. Full recording significantly simplifies the implementation of the bi-static mode, it becomes possible to locate objects whose orbit is known with low accuracy or is unknown at all (for example, space debris), and it is also possible to obtain operational information about the state of the atmosphere (atmospheric lidar mode of SLR).

A significant limitation of the full recording mode is the need to use sensors that allow high-intensity input signals (for example, photon multiplier tube – PMT). There are also certain limitations associated with the presence in ESTT of only one measuring channel with a relatively large dead time of registration (40 ns), which in some situations leads to the loss of reflected signals. Modeling of the ranging process in full recording mode and the results of real experiments at the RIGA-1884 station show that the loss of useful signal at night (at a noise intensity of 20-200 kHz) is several percent, which is quite acceptable. However, these limitations are compensated by the simplicity of implementation and a significant expansion of functional capabilities. It seems

Optimal to select both the classic ranging mode with time selection of reflected signals and APD-type sensors, and the full recording mode with PMT-type sensors, depending on the goals of the location experiment. In the most optimal case, depending on the goals of the location experiment, the operator could select the classic location mode with time selection of reflected signals and APD-type sensors, and the full recording mode with PMT-type sensors.

In general, continuous logging of all received signals opens broad opportunities for monitoring the atmosphere and space, using post-processing and the correlation of the records from several instruments. It is possible to reconstruct past events in the SLR station's monitored area and predict observed bodies' trajectories using various techniques, including machine learning.

Data communication

Considering the high-speed computer interface, ESTT can be successfully employed for energy-efficient data communication, such as TDC on the receiver side. The pulse position modulation (PPM) transceiver prototype [3] allows data to be received at up to 149 Mbit/s rate, and the average power is thousands of times lower than in classical modulation types such as on-off keying (OOK). Such systems are helpful in deep-space communication where power is limited, and distance is very large. Data communication can be combined with SLR and other sensing applications [2], leading to novel concepts of integrated systems that exploit reflected data communication signals for space awareness and atmospheric measurements.

1. K.Salmins, V.Bespalko, V.Stepanov, R.Sūna. First results with Eventech Stream Time Tagger in full record mode. Twenty-third International Workshop on Laser Ranging, October 16-20, 2023.
2. Aboltins A., Bespal'ko V., Kurtenoks V. (2024). Continuous event recording technology for integrated sensing and communications in space. IGARSS 2024 - 2024 IEEE International Geoscience and Remote Sensing Symposium.
3. P. E. Sics, N. Tihomorskis, S. Migla, J. Ratners, V. Kurtenoks and A. Aboltins, "Implementation of Reconfigurable 149Mbps TDC-Based PPM Transceiver," 2024 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit), Antwerp, Belgium, 2024, pp. 706-710, doi: 10.1109/EuCNC/6GSummit60053.2024.10597124.