
High-Speed Enhancement to HTSI Event Timer System

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Abstract

HTSI has developed a high-performance Event Timer Controller to pair with the HTSI Event Timer that allows acquisition of UTC tagged event epochs with <2ps jitter and 0.5ps resolution from up to 12 input event channels at continuous asynchronous event acquisition rates of over 50kHz. The increase in sustainable data rate allows easy integration of multiple or arrays of detectors and generation of a single real-time stream of UTC epoch'd event data with associated channel ID flags.

This paper describes the upgrades to the HTSI event timer system that enable the high-speed capability. The content will include a data comparison of ILRS stations utilizing the HTSI event timer as well as a discussion of current usage applications and potentials for future use.

High-Speed Enhancement to HTSI Event Timer System

The HTSI Event Timer was designed and built in the 1990s by Charles Steggerda based on his years of experience designing timing devices. Initial laboratory and MOBLAS-7 test results were reported in July 1998 at the 19th International Laser and Radar Conference in Annapolis, MD in a paper titled *Instrumentation Development and Calibration for the Matera Laser Ranging Observatory*. Today's paper follows up after 8 years of use and describes an important new capability that can be utilized by the current and next generation of high rate laser ranging stations. Figure 1 shows the HTSI Event Timer.



Figure 1: HTSI Event Timer

HTSI Event Timer Description

The HTSI Event Timer (ET) generates precise epoch time-tags ideal for Satellite Laser Ranging, Lunar Laser Ranging, and other precision timing applications. The ET facilitates measurement of delays between one or more pulses without a range/delay

dependant effect on timing error and supports applications with multiple shots in the air required by high laser fire rates or extended time of flight to targets (i.e. geosynchronous, lunar, or beyond). The basic design and capability hasn't changed since that reported in July 1998 at the 19th International Laser and Radar Conference. The ET couples a precise synchronous counter with from 1 to 4 analog verniers and a computer synchronized to UTC. In the single vernier configuration, the ET provides better than 2 ps of resolution and less than 4 ps of Root-Mean-Square (RMS) jitter. In the four vernier configuration, the ET provides measurement redundancy and increases the effective resolution to <500 fs with an RMS jitter of < 2 ps.

Clock Speed (Internal)	500 MHz, Locks to external 10MHz
Input Channels	12 SMA inputs; NIM type; 50 Ohm termination; negative pulses (unused channels do not require termination)
Resolution	Better than 2ps (1 vernier), 500 femtoseconds (4 vernier)
Dead-Time	100 Nanoseconds
RMS Jitter	<5ps for 1 vernier; <2ps for 4 vernier
FIFO Depth	512
Interface	32 bit DIO, Optional computer allows additional interfaces
Software	UNIX (HP-UX, Linux), MS Windows, etc.
Power	Auto ranging (100-240V; 50-60Hz)

Figure 2: Summary of Specifications

Twelve external inputs are provided and events sampled on each channel are tagged with an identification flag in hardware. When coupled with a computer that receives coarse time via time code or GPS, a full event epoch can be generated. Events can be sampled by the hardware at a rate of 10MHz, but are input into a high-speed FIFO buffer that can only store 512 events. Thus the specification of maximum sustainable event sample rate is dependant on the DIO and processing speed of the specific event timer controller.

HTSI Event Timer Past Performance

The initial HTSI event timer development was started in 1995 to support the Matera Laser Ranging Observatory (MLRO). Initial testing of the ET prototype was performed at NASA Goddard Space Flight Center's MOBILAS-7 reference station. Comparison results between the prototype ET and MOBILAS-7 indicated addition of the Event Timer produced an immediate 30-40% improvement in MOBILAS 7 data quality over the existing HP-5370 counter data decreasing LAGEOS range data RMS from 9mm to 5mm.

Later in 1998, the final 4-vernier MLRO and 1 vernier SLR2000 event timers were built. In 2002, a dual vernier model was built for the Global High Accuracy Trajectory Station (GUTS) to be located in Tanegashima, Japan. The MLRO and GUTS event timers supported both stations in achieving best case performance of 2mm ground calibration and 5mm LAGEOS RMS. Both stations utilized the multiple inputs to support fire, dual color PMTs (MLRO), amplified channels for Lunar (MLRO) and Geosynchronous ranging (GUTS), system calibration inputs, on-time pulses, etc. And in 2006, an Event Timer is being built for the US Naval Research Laboratories (NRL)

- **MOBLAS 7** – (Prototype Event Timer; 1998; 3ps RMS)
 - 5 Hz fire, 2 events per frame
 - Use of the HTSI Event Timer produced an immediate 30-40% improvement in MOBLAS 7 data quality over the HP-5370 TIU (Lageos-1 data improved from 9 mm RMS to 5 mm RMS).
- **SLR2000 Prototype** – (Delivered in 1998; 4ps RMS)
 - 2 kHz fire, multiple events per frame, quad PMT
- **MLRO** – (Used in Greenbelt, MD in 1998 and Matera, Italy since 2000; 2ps RMS)
 - 10 Hz fire, 8 events per frame
 - Multiple laser & PMT detection path signals sampled by one event timer.
 - Supported station in achieving 2 mm calibration and 5 mm LAGEOS RMS.
 - Supported station in acquiring two-color and lunar data.
- **GUTS** – (Used in MD in 2002 and Tanegashima, Japan since 2004; 4ps RMS)
 - 10 Hz fire, 4 events per frame
 - Supported station in achieving 2 mm calibration and 5 mm LAGEOS RMS.
 - Supported station in acquiring data from geosynchronous targets.
- **NRL** – Being developed as a stand alone ET for delivery in 2006/2007
- **GUTS Spare** – Being developed for delivery in 2007

Figure 3: HTSI Event Timer Past Performance

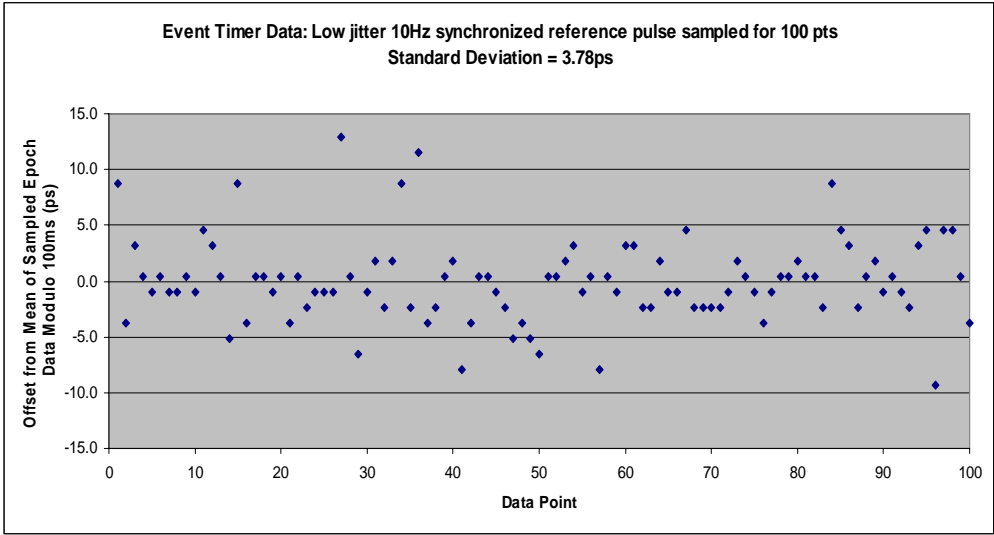


Figure 4: Event Timer Accuracy

HTSI Event Timer Data

Figure 4 demonstrates typical Event Timer Accuracy / RMS when configured with a single vernier. To generate this graph, a precise 10Hz electrical reference pulse was sampled 100 times by the event timer. The epoch data was then normalized to the mean repetition frequency. The graph shows raw, unfiltered offset data that demonstrates a 3.78ps RMS jitter. If you look closely, you can see data banding demonstrating that the single vernier bit resolution is <2ps.

Figure 5 demonstrates the potential single shot RMS of stations that utilize the HTSI event timer showing the MLRO and GUTS stations as having the lowest reported LAGEOS single shot RMS in the ILRS network. Note that the event timer, while crucial, is coupled with excellent optics and low-noise optical detection to produce these results.

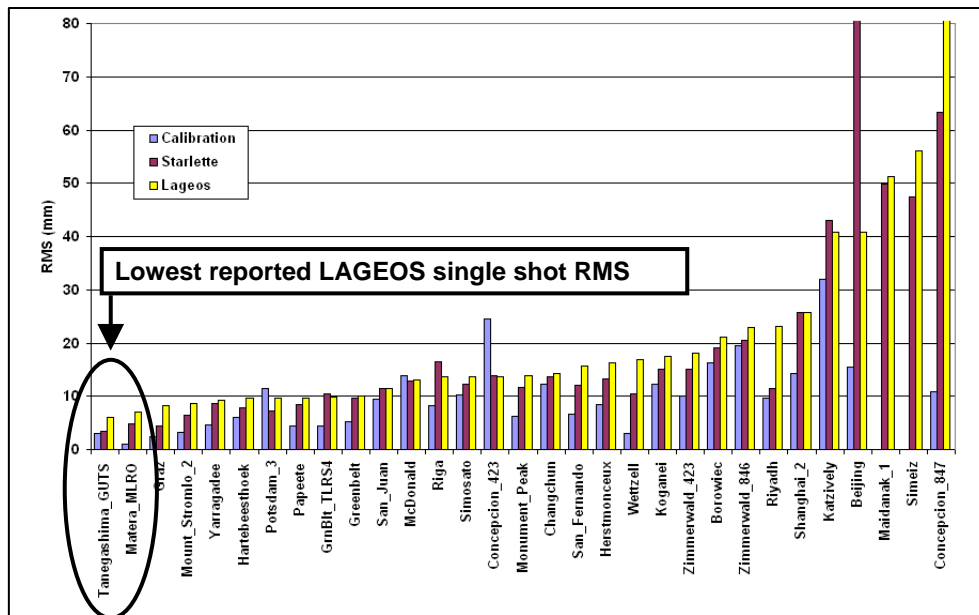


Figure 5: ILRS Station Single Shot RMS Data for 2Q 2006

HTSI Event Timer Controller High Speed Enhancement

The HTSI ET has always supported Mega-event per second sample rates, but has been limited by the speed of its control computer in emptying the 512 event deep hardware FIFO. The GUTS and MLRO ET controllers used non-DMA DIO to communicate with the ET at a maximum event rate of approximately 200 events per second (while also performing tracking and controlling other equipment). Counter and verniers were manually addressed by the controller. For SLR2000, HTSI converted the ET to use a high-speed DIO card. In addition, the counter and vernier became auto-addressed allowing for DMA transfer operations. The ultimate data rate was still limited from sharing control computers with other tasks, 10Mbps Ethernet speeds and generation of individual event interrupts.

The advances in computer processing speeds and network bandwidth since 1998 have allowed the design of a high-performance controller to utilize the hardware to its full potential. This high-performance controller enables the HTSI event timer to immediately gain a factor of 10 in sustainable rate (from multi-KHz samples per sec to at least 50ksamples/sec) and promises to allow for further growth in the future as the world transitions to dual core processors and 10GB Ethernet. In addition, the enhanced controller removes the complex issue of DIO interface, driver, and data handling replacing them with a simplistic network accessible design. The enhanced Event Timer controller provides a real-time stream of epoch'd ET data across a dedicated LAN to a station tracking computer. DIO transfer rate is maximized by allowing the ET FIFOs to buffer data. Data is immediately calibrated, combined with UTC coarse time, sent to Ethernet, and received on the tracking computer. A prototype of the enhanced controller has been built in Greenbelt, MD, and is still in the process of software development and testing.

Figure 6 shows the block diagram of the Event Timer Controller that has been built in our integration lab. Notice that all components exist to produce high accuracy time epochs referenced to UTC.

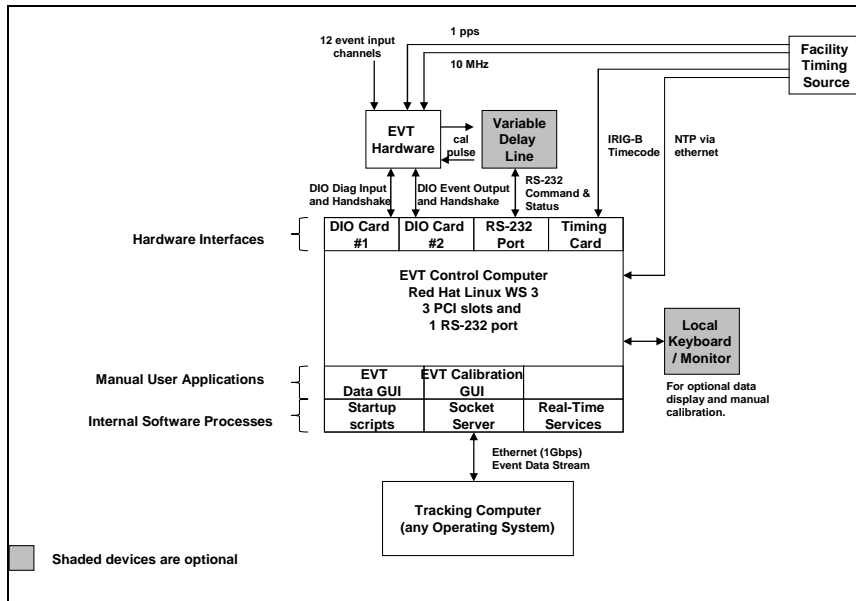


Figure 6: Enhanced Event Timer Controller: Block Diagram

Figure 7 shows the internal software architecture and data flows within the Enhanced Event Timer Controller. The Event Timer Software architecture is based on modular C++ UNIX processes inherited from the MLRO and GUTS software heritage. Event Data moves from right to left in this figure. Event Timer and Time Code Generator data is merged to produce a real-time stream of event epoch data. Vernier non-linearity's are then removed via calibration in real-time. The event data is then distributed to client tracking computers via a network socket server.

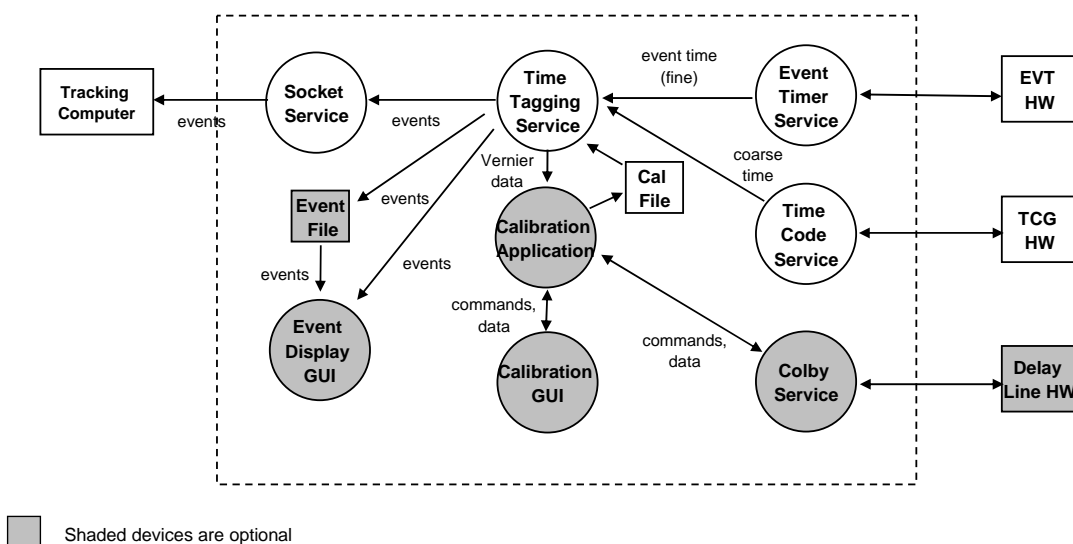


Figure 7: Enhanced Event Timer Controller Software Architecture

Optional software modules allow for local calibration of the event timer or independent use of the ET controller by storing event data in a file. Optional modules include a delay line interface, a calibration process and GUI, and an event display GUI.

HTSI Enhanced Event Timer Controller: Initial Results

DIO Performance

Figure 8 shows initial results of high speed testing with the Enhanced Event Timer Controller. Initial DIO laboratory performance tests were able to read reference pulse event times from the ET FIFO buffer at a sustained rate of 5Msamples/sec or **1.25 Million events per second** with a 3 vernier + 1 counter ET. DIO card specifications indicate that the maximum continuous handshaking I/O rate for the DIO-6533 is 17.3 Msamples/sec potentially enabling the reading of **4.3 Million events per second** with a 3 vernier + 1 counter event timer.

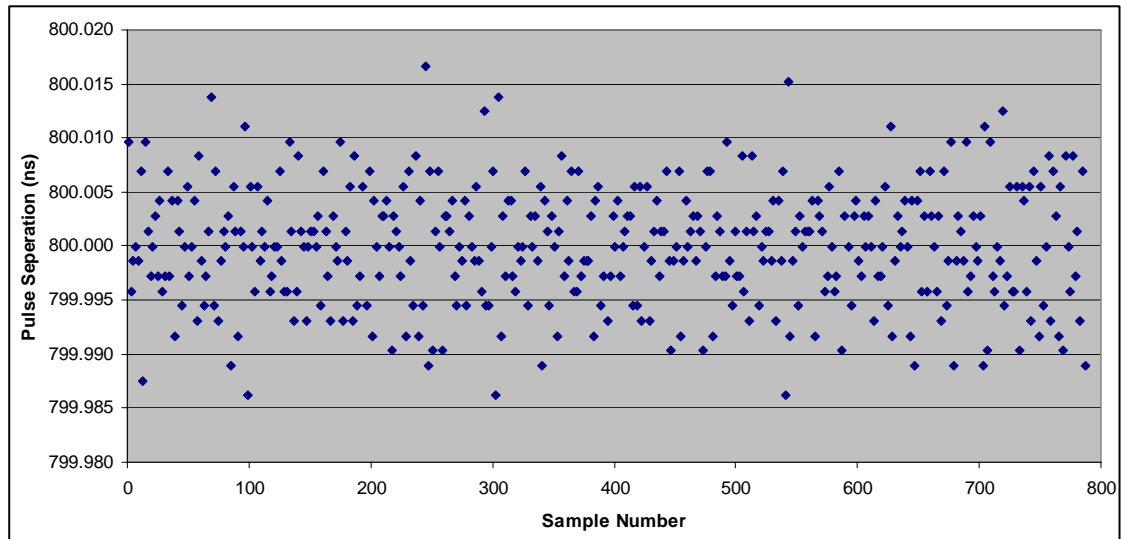


Figure 8: Initial Enhanced Event Timer Controller High Speed DIO Test Data

LAN Performance

Preliminary tests demonstrate that it is possible to sustain network transfer rates of **61,035 events per second** on our current 100Mbps testing LAN (no network traffic analysis tool was available to determine actual network bandwidth usage). Further increase in speed is theoretically possible after tuning of packet sizes and enhancing our laboratory with a 1Gbps network switch. These results match initial computations to first order predicting that 50,000 events per second requires a minimum of 25Mbps dedicated network bandwidth on an isolated LAN (assuming 1,024 bit packets holding (8) 112 bit events or 896 bits of user data each and a factor of four compensation for traffic).

HTSI Event Timer: Future Applications

The newly developed HTSI High-Speed Event Timer Controller when combined with the HTSI Event Timer produces a system that can enable many future applications in addition to those currently being supported. Currently the HTSI Event Timer has been used to support:

- 10Hz single and dual laser fire and return with station calibration events (single and multi-wavelength)
- 10Hz geosynchronous and lunar laser ranging (multiple shots in the air)
- 2kHz tracking with 3 high-rate event inputs (6KEvents/sec)

The Enhanced HTSI Event Timer System meets the needs of the SLR data community to acquire data at higher and higher repetition rates with more detectors and enables the design of the next decade of forward reaching experiments. A few of the additional potential applications that can be extrapolated includes:

- 2kHz operations with multiple fire and detection events (i.e. for multiple wavelengths / dual PMTs)
- 2kHz operations with additional station delay diagnostic event inputs
- Use of arrays of detectors at 2kHz (3x3; 3x4; 4x4 would require external event coupling)
- Recording of high rate event epoch data approaching 1 Million events per second
- Laser fire and return pairs several orders of magnitudes faster than 2kHz
- Time transfer experiments (ground and on-orbit)
- Station construction with reduced event timer integration time
- Station construction with reduced real-time tracking controller complexity and cost (ethernet vs. DIO)

References:

- [1] *Instrumentation Development and Calibration for the Matera Laser Ranging Observatory*, July 1998, 19th International Laser and Radar Conference in Annapolis, MD, C. Steggerda, M. Selden, C. B. Clarke, R. Stringfellow, J. M. Heinick, D. McClure, Dr. G. Bianco
- [2] Time of Flight Devices Manufacturer Specifications Comparison Table, ILRS Web Site, http://ilrs.gsfc.nasa.gov/engineering_technology/timing/tof_devices/manufacture_spec/index.html
- [3] SLR Global Performance Report Card 2Q 2006, ILRS Web Site, http://ilrs.gsfc.nasa.gov/stations/site_info/global_report_cards/perf_2006q2_wLLR.html

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