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GPSY2: A programmable hardware module for precise absolute time event generation and measurement

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Abstract: We have designed and built a programmable hardware module, dubbed the GPSY2,for TTL pulse generation and capture in absolute time. The time reference is an on-board Global Positioning System (GPS) receiver. Our specific motivation was to trigger flash-lamp pumped lasers at specific times for calibration of cosmic-ray observatories. However, the potential applications are considerably broader. The GPSY2, has 8 independently programmable outputs and 8 independently programmable inputs. The hardware is configured in a standard PC104 layout for use with embedded systems. A Linux software device driver offers an extensive set of user commands. Measurements of the US UTC standard at National Institute of Standards (NIST) found a nominal timing resolution of better than 20 ns.

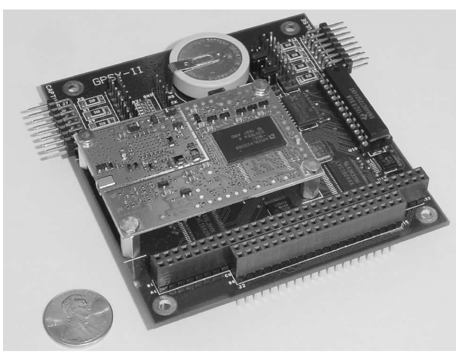

Figure 1: GPSY2 circuit board. This PC104 format board is compatible with the Motorola M12+ (shown) and iLotus M12M GPS engines.

Introduction

Many applications require precise time synchronization between instruments that can not be connected directly. A related requirement is synchronization to an absolute global time standard.

This work was motivated by the need to synchronize the firing times of lasers [1], [2] that calibrate large-aperture cosmic ray detectors [3], [4]. These detectors record the passage of extensive air-showers in the atmosphere [5]. The same detectors can also record tracks produced by light scattered out of pulsed laser beams fired into the sky from remote locations. Distances between lasers and detectors can exceed 40 km. The typical laser used is flashlamp pumped. It requires two precisely timed digital trigger pulses to produce light at a specific time. We needed to generate laser light pulses at specific precise times to distinguish the laser tracks from cosmic-ray candidate tracks with essentially no ambiguity. However, the GPSY2 was designed as a general purpose timing device. The device driver software supports more than 30 user functions to provide considerable flexibility in configuration and operation.

Hardware Description

The GPSY2 (figs. 1 and 2) can measure the time of the rising, falling or both edges of eight separate 5-volt TTL logic inputs with 25nS resolution. The device can also generate pulse-edge sequences on eight separate outputs with the same resolution. The absolute times of the captured and generated pulse edges are continuously calibrated against an on-board GPS receiver. The specified 1-sigma accuracy of these receivers is about 5nS. The GPSY2

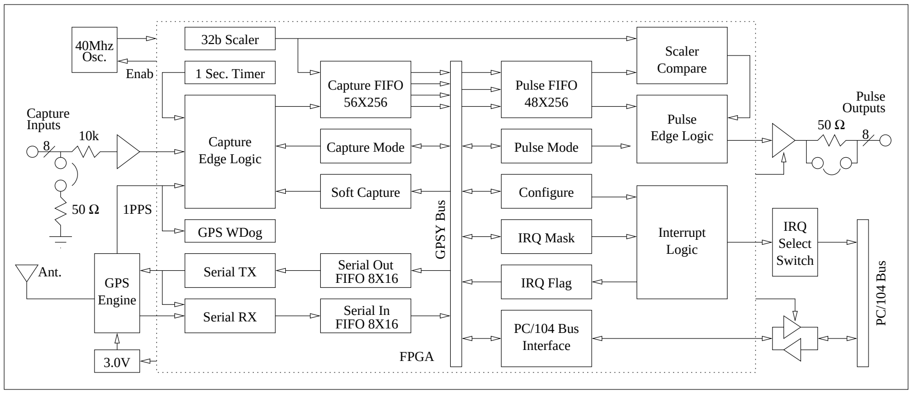

Figure 2: Block diagram of the GPSY2 hardware module.

module relies on a PC/104 host processor and a software device driver for full functionality.

A 32-bit scaler clocked with a 40 Mhz oscillator provides the module's timing. For selected input events this scaler is latched into a 256 entry first-in-first-out (FIFO) **capture FIFO** buffer. The triggering capture events (table 1) may be any of the following: rising, falling or both edges of any of the eight capture inputs; the GPS receiver's calibrated one-second pulse output; a uncalibrated one-second timer; 'soft' captures by the host processor. The **capture-mode** register controls which pulse edges for each external input generate a capture. The **configuration register** enables GPS and uncalibrated one-second captures.

To generate pulse-edge sequences, the device driver software on the host processor uses the captured GPS one-second events to compute a list of free-running scaler values for each output pulse rising and falling edge. This list, along with 16-bit control words that define the required rising/falling edge action for each of the eight outputs is written to a 256 entry **pulse FIFO**. When the free-running scaler matches the FIFO output scaler value, the action defined by the associated control-word is performed and the next FIFO entry is read.

The GPS receivers use an RS-232 serial connection for configuration and status messages. The module translates these serial streams via universal asynchronous receiver/transmitter (UART) to a byte stream that the host processor accesses through I/O registers.

The GPSY2 uses one physical interrupt line on the PC104 bus. The **capture input** FIFO, the **pulse output** FIFO, and the **GPS serial receive** and **GPS serial transmit** FIFOs are all interrupt driven. The host processor does not need to poll the FIFO status to find out when a FIFO is ready for reading or writing. Four other 'error' interrupts may also generated: watch-dog timeouts on the GPS one-second pulse; over-run errors on the pulse-edge capture and GPS serial receive FIFOs and framing errors on the GPS serial input. All of these interrupts can be individually enabled with the **interrupt-mask** register and monitored with the **interrupt-flags** register.

The **module configuration** register allows dynamic selection of the interrupt request number and allows various subsections of the module to be enabled or disabled for low power applications. If the GPS receiver is not currently needed, it can be powered off and the serial UART circuit disabled. If the pulse outputs are not needed, the pulse output driver can be disabled with high-impedance outputs. If none of the modules functions are needed, it can be effectively shutdown to a very low power state by turning off the module's clock oscillator. For diagnostics, the serial UART can be put in loop-back mode and the free-running scaler, the **capture-input FIFO** and **pulse-output FIFO** may be cleared individually.

The module uses 16 bytes of I/O space on the PC/104 bus. Jumpers select the following: the GPS antenna preamplifier voltage (3.0V or 5.0V), 50-

Name	Class	Source	Description
1PPS	Reference	GPS Receiver	1 pulse per second
Internal Clock	Reference	40/80 MHz scaler	Pulse every 40/80 million counts
TTL In	External	Input Channels (8)	rising/falling/both edge(s) of TTL pulse
SoftCapt	External	Soft Capture Register (5 bit)	application program writes to register

Table 1: Types of capture events that the GPSY2 can time-stamp

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Ohm termination to ground on each of the eight capture inputs and 50-ohm series termination on each of the eight pulse outputs.

For a test bed we mount the GPSY2 on a Technologic Systems TS5500 x86 single board computer (SBC) running the Linux operating system.

GPSY2 Software Description

The software for the GPSY2 module has three parts: a Linux device driver, a daemon server program and client application programs. Multiple GPSY2s stacked on one SBC are supported.

The device driver is a kernel module providing two character devices nodes for each GPSY2 installed. The device driver handles the GPSY2 device interrupts and transfers data between the GPSY2 hardware and the device nodes. One device node is for control and status message transfer with the GPS engine. The second device node is for transferring event data to the pulse output FIFO and capture data from the capture input FIFO. Device control functions allow reading and writing to the GPSY2 hardware control and status registers.

The GPSY daemon program interfaces between the GPSY device driver and applications that require GPSY2 services. This daemon acts as a TCP/IP server program to client applications and interprets ASCII text commands to device I/O and control functions. The GPSY daemon calibrates the 40MHz (80MHz) clock oscillator against the GPS 1PPS signal and translates the hardware FIFO scaler values to and from Universal Coordinated Time (UTC). Captured event are translated into text messages and sent to client applications. The GPSY daemon maintains a list of high level pulse sequence descriptions and computes pulse edge

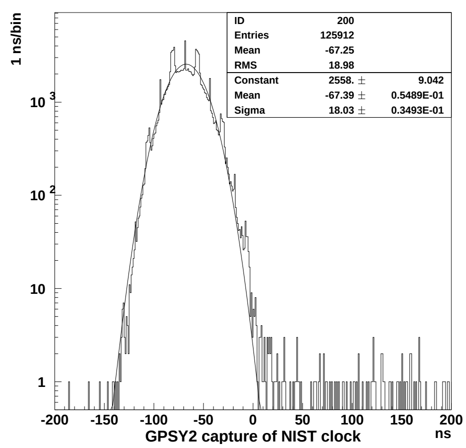

Figure 3: GPSY2 measured times relative to the NIST UTC clock (1 pulse per second)

control data to be written to the GPSY2 pulse output FIFO on a second-by-second basis.

For interactive sessions with the GPSY2, the standard telnet program works well as a client application. Two simple utility programs have been written. Gpsycmd reads commands from a text file, sends the commands to the GPSY daemon program and prints the command replies to standard output. Gpsylog connects to the GPSY daemon and logs to file selected data messages.

Tests at NIST

In July 2006 a GPSY2 configured with a 40 Mhz oscillator and an M12+ receiver, and mounted on a x86 SBC, was tested at the NIST Timing and Frequency Standards division in Boulder Colorado, USA ([6]). This GPSY2 measured the times of the 1 pulse per second output of the US UTC stan-

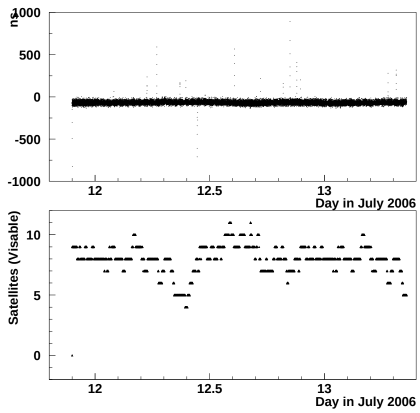

Figure 4: 30 hours of GPSY2 measurements of the NIST US standard UTC clock (top panel). and the number of visible GPS satellites (lower panel.)

dard clock. This clock is derived from MASERS that are calibrated periodically against the NIST-F1 cesium fountain atomic clock which is the US primary frequency standard. The time stability of the NIST UTC clock is many orders of magnitude better than commercial GPS receivers.

Thirty hours of measurements are shown. Over this period the measured resolution was 19 ns (fig. 3). The -67ns offset is under investigation. The spikes in the distribution (fig. 3) are formed by the superposition of the GPS receiver +/-15ns correction on the GPSY2 40 Mhz scaler. The number of satellites varied from 4 to 11 during these tests (fig. 4). The measured resolution varied between 16 and 19 ns, and the offset varied between -70 and -64 ns. We observed 14 transient periods when the time offset drifted by more than 100 ns. These represent 0.2% of the total test time. Most of these drifts appear to correlate with changes in the number of received satellite signals. (example in fig. 5).

Future Plans

We have doubled the GPSY oscillator rate to 80 Mhz. The Motorola M12+ receiver is no longer manufactured. We have confirmed the GPSY2 is compatible the iLotus M12M. We have also configured the software driver to record real-time satellite information to further study the time-drift effects.

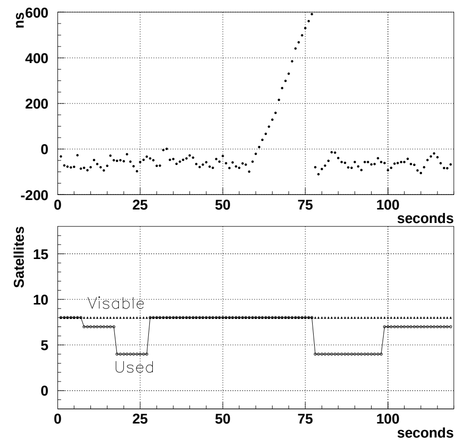

Figure 5: Occasionally the GPSY2 times drift. The drift often correlates with a change in the number of satellites used in the time calculation.

In house tests are in progress. We intend to conduct a second round of tests at NIST with a GPSY2 in the 80 Mhz/M12M configuration.

Acknowledgments

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