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# Evaluation of timing GPS receivers for industrial applications

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***Abstract-*** Paper deals with accuracy and stability evaluation of PPS signals generated by timing GPS receivers (uBlox LEA-6T and Trimble ICM SMT) using UTC(TP) reference time.

## I. Introduction

Synchronization of measurement and control units (nodes) in large distributed systems is a common problem of industrial automation. Efficient solution is based on using local time bases controlled (synchronized) by timing GPS receivers. For their industrial application, sufficient accuracy and stability of generated synchronization pulses and an acceptable price are required. Modern timing receivers satisfy these requirements.
This paper evaluates two GPS receivers suitable for industrial "online" applications, the uBlox LEA-6T and the Trimble ICM SMT, both priced under $100 USD.

## II. Timing GPS receivers for industrial applications

Global Positioning System (GPS) enables worldwide continuous precise time transfer. Timing GPS receivers differ from GPS receivers intended for navigation in the output of 1 PPS signal (frequency of 1 Hz), which physically represents a second of the GPS time scale synchronized with the UTC(USNO) scale maintained by the United States Naval Observatory. This signal (1 PPS) is therefore commonly used as main synchronization signal of local time bases.
Receivers may have several outputs, which can be set to different output frequency than 1 Hz (within range from 1 Hz up to single digits of MHz). Another useful feature is the "time-stamping input", which enables identification of precise rectangular signal edge time. This input can be used for measurement and calibration of external sources of PPS signal.
PPS signal from timing GPS receiver provides very precise and long-term stable time scale. However, its short-term stability makes it in most cases inadequate for measurement. For that reason, precise GPS disciplined oscillators are sometimes being used. This combination benefits from good short-term stability of the oscillator signal and great long-term stability of the GPS signal.
Another specific feature of timing GPS receivers is the ability to operate in *fixed mode*. This feature improves the quality of synchronization. So called *survey-in mode* serves for getting precise position of the GPS receiver. Time needed for precise positioning of the receiver ranges from 1000 to 86000 s, depending on demanded accuracy and signal quality.

## III. Common sources of errors

Timing GPS receivers automatically apply corrections to the signal reception and processing (processing of C/A code from several satellites, usage of synchronization algorithm for connecting internal oscillator, etc.). It outputs a 1 PPS time signal and an information about time of the rising edge of the pulse included in the respective communication protocol (e.g. NMEA). Still, it is necessary to eliminate some of the common sources of errors, particularly: antenna cable delay, antenna position fix error, quality of output PPS signal, distribution units delay and output cable delay.

## IV. Evaluation of GPS receivers

This section describes test method and test results of GPS receiver evaluation.

### A. Receivers description

Timing GPS receiver LEA-6T by uBlox supports communication via RS232 and USB using NMEA and UBX protocols. The receiver has features important for timing application, such as ability to set the offset of output pulses in terms of ns and ability to record time events. Furthermore, it provides corrections of the time scale (needed to compensate for the granularity of the internal scale).
ICM SMT GPS Disciplined Clock by Trimble supports communication via RS232 using NMEA and TRIMBLE protocols. Receiver also has the ability to set the offset of the output pulses in terms of ns. Table 1 shows the PPS signal parameters as provided by manufacturers.

| | **LEA-6T** | **ICM SMT GPS** |
|---|---|---|
| **RMS** | 30 ns | 15 ns |
| **99%** | < 60 ns | < 50 ns |
| **Granularity** | 21 ns | 10 ns |
| **RMS with corrections** | 15 ns | ------ |

Table 1. Accuracy for 1 PPS of GPS receivers (from official data sheets)

### B. Measurement configuration

The GPS receivers LEA-6T and ICM SMT were measured against precise and stable time scales. In the first case (Fig. 1), the Rubidium standard FS725 synchronized by GPS receiver LEA-6T was used as a source of reference time scale. These measurements have been performed at Faculty of Electrical Engineering, Czech Technical University (FEE CTU).

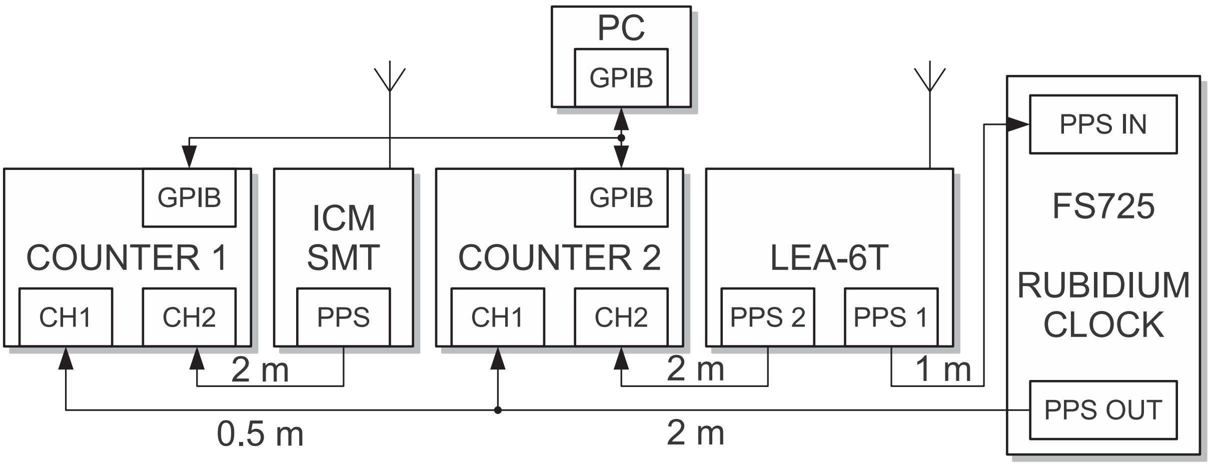



Figure 1. Block diagram of GPS receiver measurement system at FEE CTU

In the second case (Fig. 2), the UTC(TP) (Tempus Pragense) time scale was used as a reference. Measurements were performed at Laboratory of the National Time and Frequency Standard, Institute of Photonics and Electronics AS CR (IPE).

### C. Measurement results

Measurement results of LEA-6T and ICM SMT GPS receivers are presented and compared in Tab. 2 and Figures 3, 4 and 5.

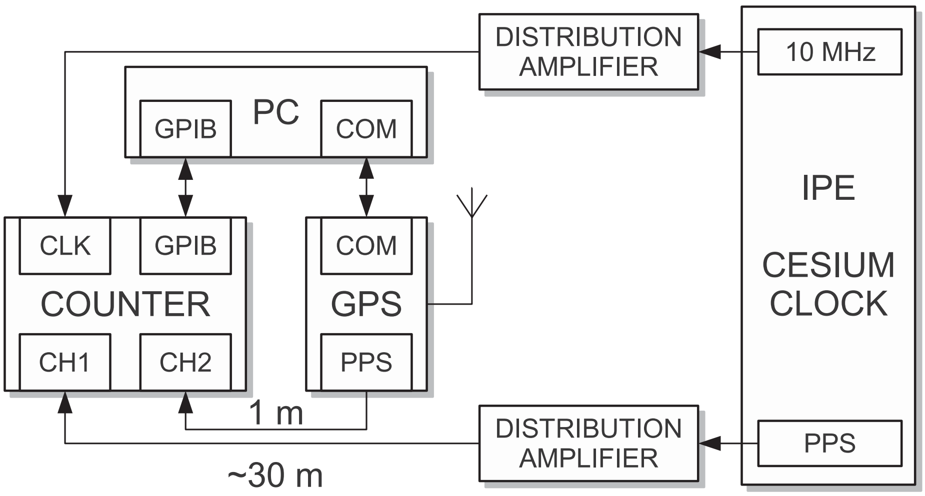
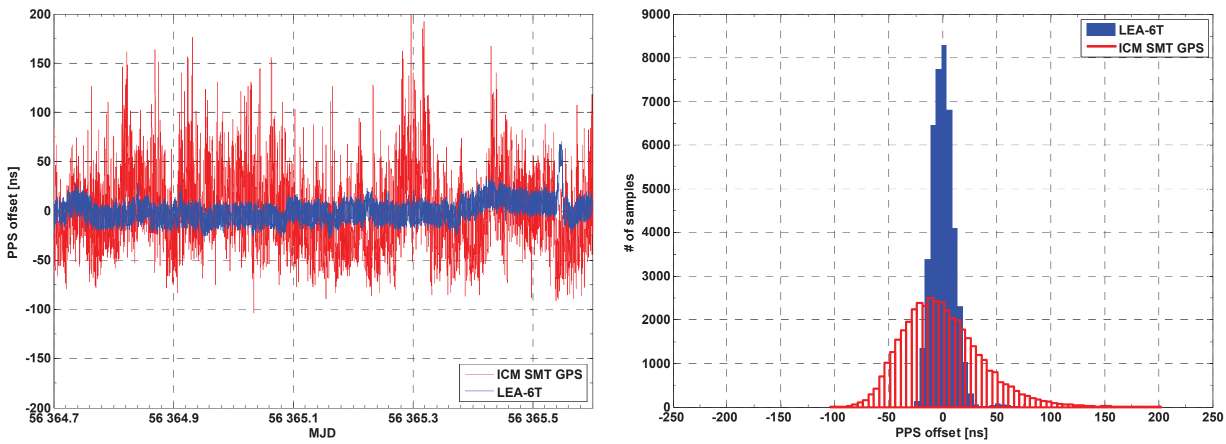



Figure 2. Block diagram of GPS receiver measurement system at IPE

| | uBlox LEA-6T | Trimble ICM SMT |
|---|---|---|
| **Hour** | 6.3 ns | 21.0 ns |
| **Day** | 7.1 ns | 26.9 ns |
| **Week** | 7.7 ns | 24.4 ns |
| **Month (30 days)** | 8.0 ns | 26.2 ns |

Table 2. RMS of PPS signals from GPS receivers

Figures 3a) and 3b) show the phase plot and histogram, respectively, of PPS signals measured during 24 hours using measurement system at FEE CTU.

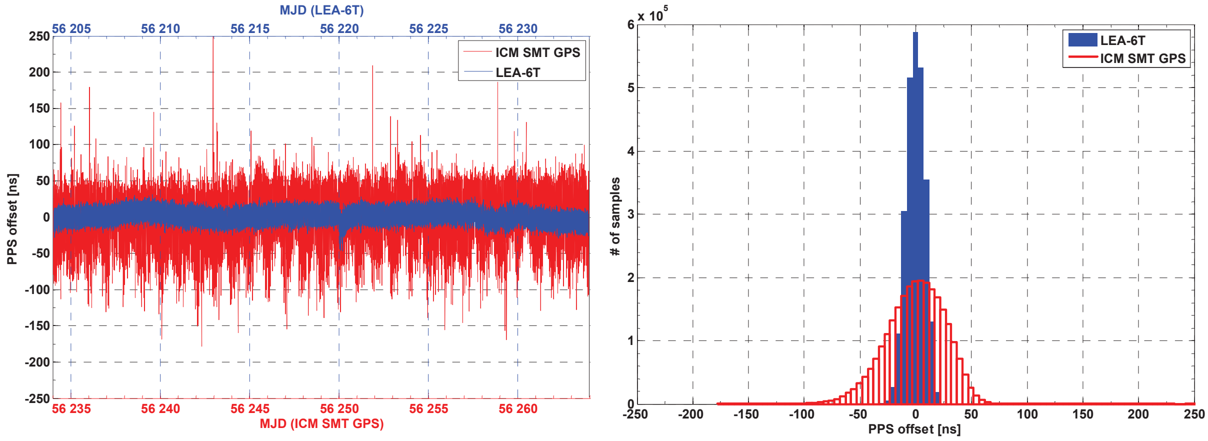



a) Data obtained by comparing the 1 PPS output from GPS receiver to Rb local time scale

b) Histogram calculated from a)

Figure 3. Short-term measurement (24 hours) at FEE CTU

Figures 4a) and 4b) show the phase plot and histogram, respectively, of PPS signals measured during 30 days using measurement system at IPE.




a) Data obtained by comparing the 1 PPS output from GPS receiver to UTC(TP)

b) Histogram calculated from a)

Figure 4. Long-term measurement (30 days) at IPE

Fig. 5 shows Allan deviations of PPS signals generated by GPS receivers.

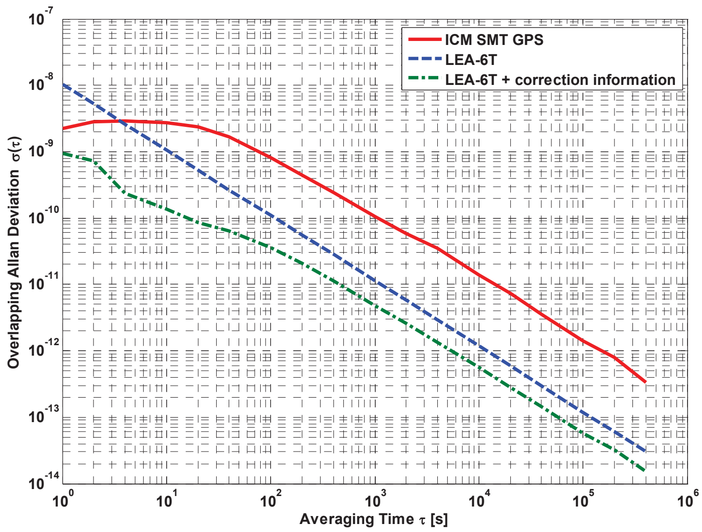
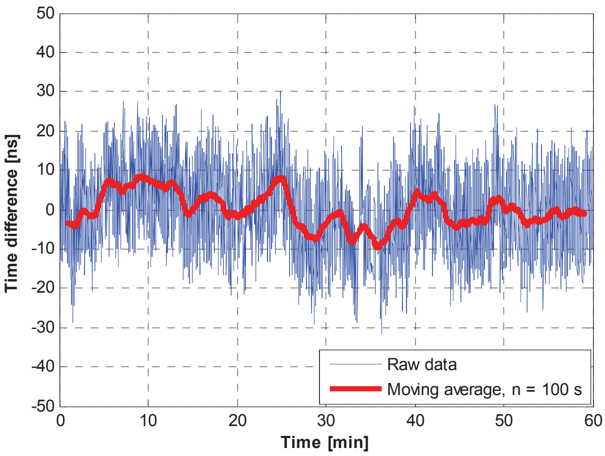



Figure 5. Comparison of Allan deviations of the time scales generated by GPS receivers

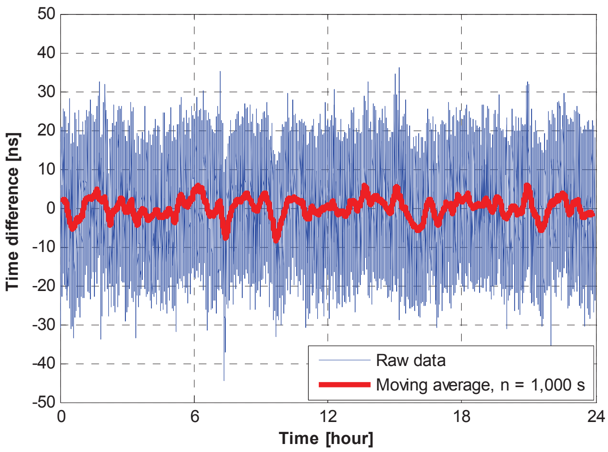
The follow-up research was focused on the LEA-6T GPS receivers.

Two separate receivers were simultaneously measured against precise Rb time scale (measurement set-up was the same as in Fig. 1, only the ICM SMT receiver was replaced by the LEA-6T receiver). Time differences between the two receivers are presented in Figure 6. Smoothed results were obtained by the central moving average. The RMS difference (for n=1000 s) is less than 3 ns, peak-to-peak range is better than 20 ns .

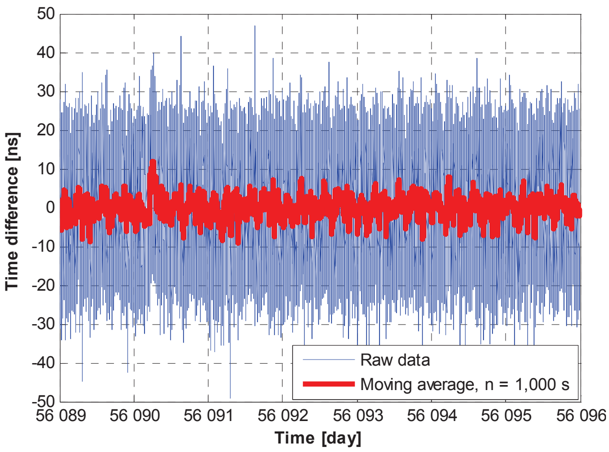
Other long-term measurements were performed in collaboration with the Institute of Photonics and Electronics (see Fig. 2). The 1 PPS signal from LEA-6T receiver was compared to the UTC(TP) time scale. A bias caused by delay from the antenna cable and GPS receiver was removed from measured data.
Time differences were recalculated to the UTC time scale using the BIPM Circular UTC-UTC(TP). LEA-6T time scale bias (PPS offset) from UTC is shown in Fig. 7.




a) 1 hour data record




b) 1 day data record




c) 1 week data record

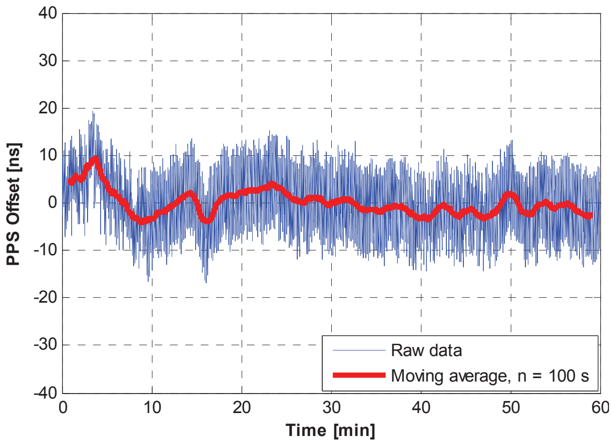
Figure 6. Time differences between two separate LEA-6T receivers
(start of measurement 56 089 MJD = 00:00 UTC, June 11, 2012)

## V. Conclusions

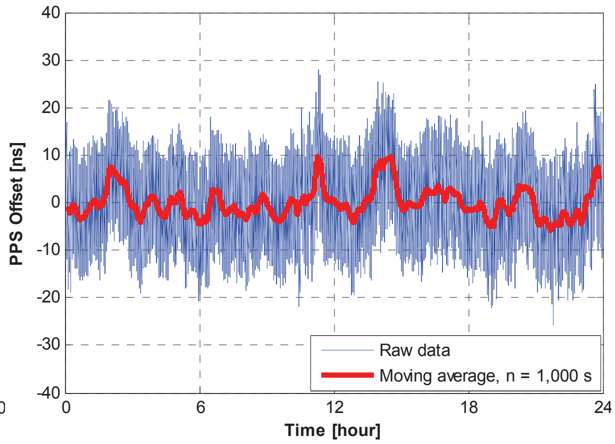
Two low-cost timing GPS receivers for industrial applications were evaluated. The results of measurements using the uBlox LEA-6T GPS receiver proved to be within parameters stated by the manufacturer, with accuracy better than 10 ns in terms of an RMS value. Second receiver, Trimble ICM SMT, despite its better proposed parameters had measured accuracy worse than 20 ns in terms of an RMS value.

Simultaneous measurements of two separated LEA-6T receivers proved very good synchronicity of time scales generated by receivers (the RMS difference is less than 10 ns).

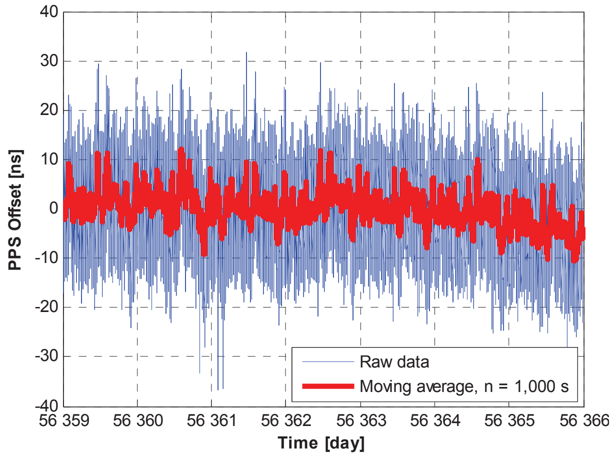
A bias (=time offset) of PPS signal (from LEA-6T receiver) to UTC was obtained from measurements of time differences between PPS signal and the UTC(TP) time scale.



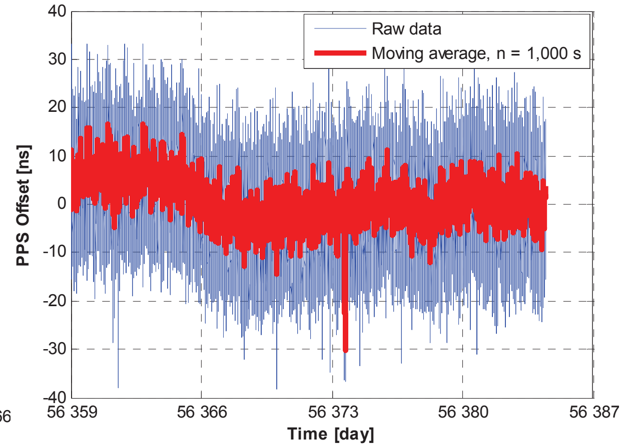

a) 1 hour data record




b) 1 day data record




c) 1 week data record




d) 4 weeks data record

Figure 7. Comparison of LEA-6T PPS signal to UTC
(start of measurement 56 359 MJD = 00:00 UTC, March 8, 2013)

## References

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