FLEXIBLE ENERGY SYSTEMS - FLEXe
Deliverable D2.1-3

UTC time synchronization methods for power digitizer

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1. Introduction

IEC 61850 is a design standard for automation within digital substations in electric power systems. It contains rules for e.g. substation device models, data communication and real-time data transmission in a substation LAN. One aspect of the standard is “61850-9-2: Sampled values (SV) over ISO/IEC 802.3”, i.e. transmission of VT and CT data over Ethernet. An implementation guideline, with “LE” extension after the name, is available from a group of stakeholders. It contains clearly defined sample data profiles to be used in transmitting voltage and current samples over Ethernet.

Usually substation devices receive time synchronization from a PTP (IEEE1588-2008) master clock, which in turn is often synchronized to GPS and therefore produces PPS edges, which are tied to UTC. Viable methods for synchronicity in an embedded device aimed as a NMI-level reference source for SV data are considered in this report. The device doesn’t need to comply with any other part of IEC 61850 except for the “9-2 LE” profile “MSVCB01”.

The target platform is Analog Devices ADSP-BF537, which forms the backbone of the digitizer developed in the SGEM program. The processor board has a 100Base-TX full duplex RJ-45 Ethernet port, which is one of the possible interfaces suggested in IEC61850-9-2 LE. The processor doesn’t run an operating system, which guarantees fast and low-jitter interrupt handling. This is a key feature for developing IEC 61850-9-2 LE extension for the digitizer. The processor has several timer modules, which can be clocked by outside sources.

1. Time Synchronization Methods

1.1. Requirements

IEC 61850-9-2 LE states that sample time stamping accuracy shall be better than ±4 µs. A reference SV data source should therefore reach sub-microsecond accuracy, which should preferably have low jitter and therefore be easily compensated for. As the device would be used in remote areas, the synchronization method should be available regardless of location.

1.2. Available Methods

DCF77 — German radio broadcast timecode, which is in theory accurate enough and available in Finland. Low cost receivers reach an accuracy of around 100 ms. High quality receivers are hard to find. Propagation delay from Maintflingen, Germany to Finland should also be compensated.

GPS — Atomic clock derived timing is available anywhere on the globe via GPS, and is accurate enough even when using low-cost receivers. Some receivers output a stable 10 MHz frequency reference in addition to the standard PPS (pulse per second) clock signal. This adds significant value to the system, since the digitizer sample clock should be derived from a stable source. GPS does, however, require a clear view of the sky to be able to track satellites, so indoor use is not possible.

IRIG — Often used in installation, where a single clock master delivers sync to IEDs. IRIG carries UTC PPS information and thus is a valid choice. A transmitter needs external synchronization. Many COTS devices use GPS as a clock source, which means that implementing IRIG would just add another layer of hardware into the system without any benefits.

PPS + freq.reference — The standard does not care about *which* UTC second is used for time-tagging the data as long as all devices do it on the *same* second edge. A PPS signal and preferably a reference frequency signal are available from the PTP clock master inside a substation. This would be the most straightforward solution and guarantee a constant synchronicity to other substation hardware regardless of clock master losing UTC sync.

PTP (IEEE1588v2): The method most often used inside a substation and therefore most likely available in all conceivable locations. It requires a special Ethernet PHY, where hardware time stamping occurs as close to the transmit media as possible. The PHY on BF537 processor board does not support this. A sister processor, BF518 implements IEEE1588 on hardware level, including a compliant PHY. This can be reconsidered in the future.

Due to ease of implementation and high accuracy along with the possibility to get a stable 10 MHz reference frequency, GPS is selected as a timing source for the digitizer. Inputs for PPS and reference frequency signals are added, since they add no significant overhead to the design. They enable using an external source for synchronicity.

2. Implementation

2.1. UTC sync and sample clock derivation

The digitizer has a built-in DDS-based sample clock, which is used in normal operation. For deriving a PPS-aligned sample clock at 4 kSPS (MSVCB01 profile, 50 Hz mains frequency) it is easier to use a counter inside the BF537. Dividing down from a 10-MHz reference frequency equals an integer division by 2500 cycles. The counter is thus set to roll over after 2500 external events and to create an interrupt to toggle the sample the clock pin. PPS input can simply be used to create a single interrupt to start the sample clock at a UTC edge. For MSVCB02 operation the sample clock derivation is more complicated, since there is no integer divider from 10 MHz to 12.8 kSPS. That is, however, beyond the scope of this work, since only MSVCB01 will be supported.

Figure 1 shows the system design approach. GPS timing module is built around Connor-Winfield Wi125 GPS timing receiver. Manufacturer promises less than 25 ns RMS error to UTC and phase alignment between PPS and 10 MHz outputs. The module is shown in Fig. 2.

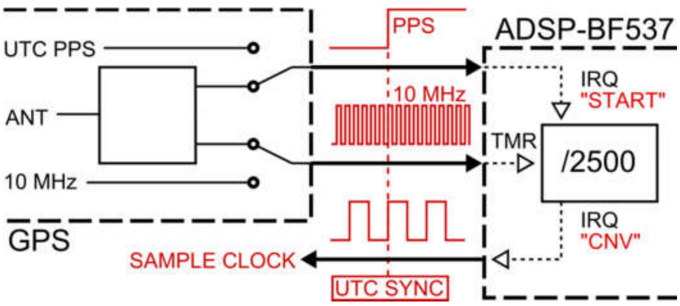

Figure 1. Time synchronization of digitizer

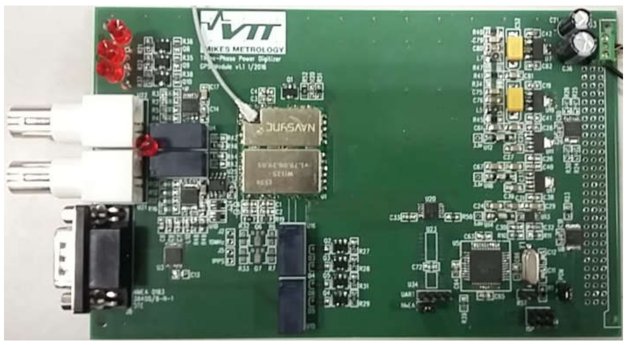

Figure 2. GPS module. Receiver located in the middle.

3. Test Results

The timing was tested against “UTC MIKE” PPS pulse, which is the national time standard in Finland. Jitter properties are orders of magnitude better than what was expected from the GPS receiver. A frequency counter with 0.1 ns resolution was used for measuring the delay between UTC MIKE and the GPS outputs.

Figures 3 and 4 show the difference between PPS and 10 MHz outputs of the receiver vs. reference PPS output from UTC MIKE over three days. A low-bandwidth phase-locked loop built around a 10-MHz crystal oscillator is locked to the 10 MHz output of the receiver. The 10-MHz results show some phase wrapping around 100 ns, which has not been completely cleaned from the result. It manifests itself as spikes in the graph, which are clearly outside the deviation of single measurement results.

It can be seen that both outputs follow a daily cycle around their mean values. The reason for this is unclear. However, the variation is quite small, only roughly twice the short term variation and does not contribute significantly to timing uncertainty. The respective RMS errors (standard deviations) of PPS and 10 MHz signals are 13.5 ns and 17.2 ns. The outputs are also significantly correlated. Pearson correlation between the two signals is 0.74. Timing accuracy is three orders of magnitude better than what is required. It is thus clear that a GPS timing reference is more than adequate for IEC 61850-9-2 LE as long as cable delays are carefully measured and compensated

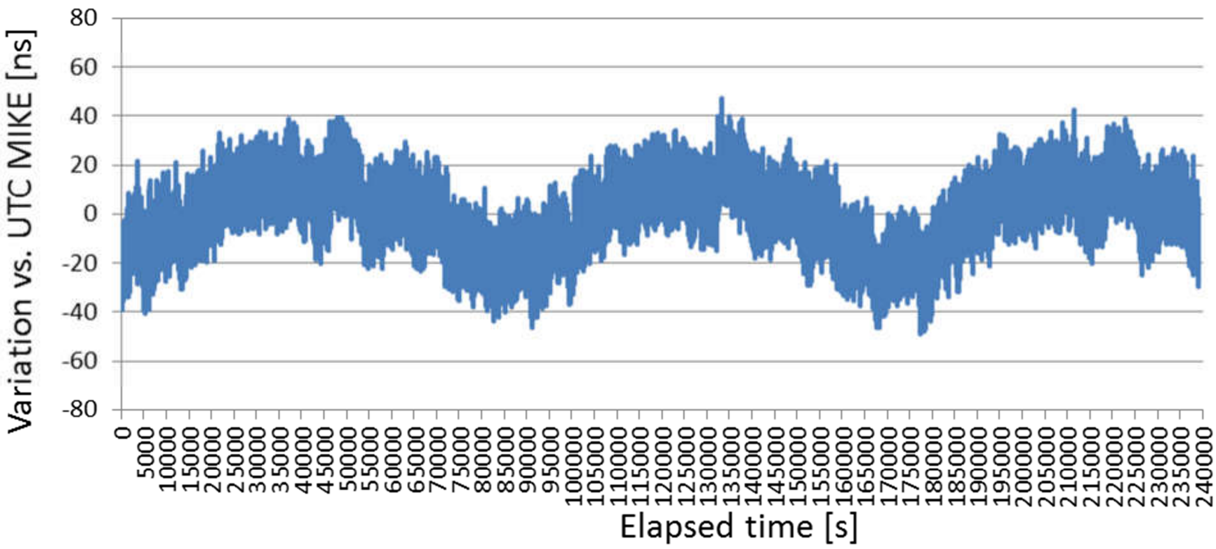

Figure 3. PPS output variation vs. UTC MIKE over three days

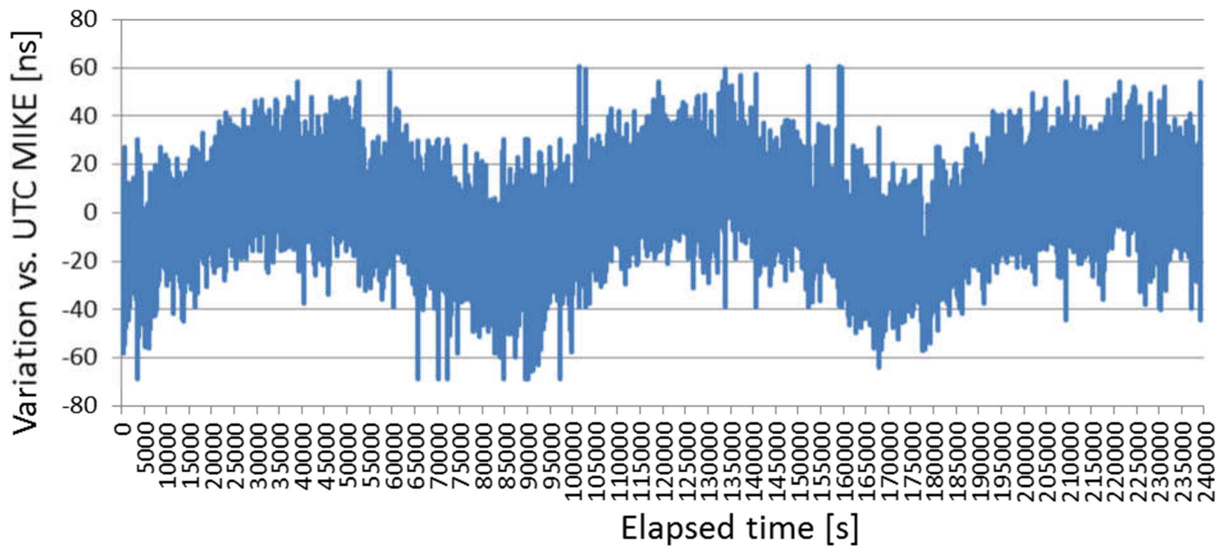

Figure 4. 10 MHz output variation vs. UTC MIKE over three days