Results of a Software Defined Radio (SDR) implementation of Two Way Satellite Time and Frequency Transfer (TWSTFT) emitter and receiver system

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Spectrum spreading of the carrier of an ultrastable clock using pseudo-random sequence generators implemented in a Field Programmable Gate Array (FPGA) is broadcast after bandpass filtering as a Binary Phase Shift Keying (BPSK) modulated signal towards a geostationary satellite using a commercial upconverter to the 14-GHz Ku band. The 70 MHz Intermediate Frequency (IF) numerically controlled oscillator, BPSK modulation and digital information carrying the timestamp of the second in the emitter are implemented as software in the FPGA gateware.

The IF signal output from the downconverter is recorded by an Ettus Research X310 SDR coherent dual-channel A and B receiver, with channel B recording the loopback signal transmitted locally for timing reference. Post-processing involves identifying (correlating) the local copy of the pseudo random sequence in the received and loopback signals, and oversampling by fitting the correlation peak in order to improve the timing resolution with respect to the sampling period by a factor equal to the signal to noise ratio.

A major challenge when developing the processing algorithm is the slow motion of the satellite with a speed up to a few ns/s, well below the sampling period. While a frequency offset is readily simulated by offsetting the driving clock, such slow time delay variations are challenging to simulate in the digital domain. An high thermal sensitivity Surface Acoustic Wave (SAW) analog delay line operating at 70 MHz IF was designed and manufactured to act as a laboratory simulator of this slow drift of the time delay of the received signal with respect to the loopback signal.

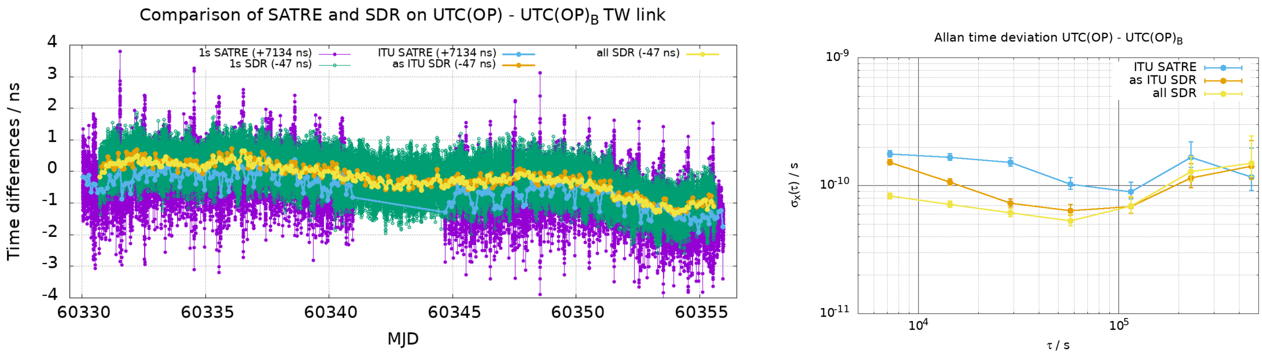

Figure 1: Evolution of time differences (left) and corresponding time instabilities (right) of the two-way link OP-LTFB equipped with SATRE modems and SDR Tx/Rx platforms over a 3.5-week measurement. The "all SDR" measurement includes all SDR measurements at begining and end of odd UTC hours, "ITU SDR" only uses 2-minute records once every odd UTC hour similar to SATRE schedules.

The TWSTFT measurements carried out with SDR Tx/Rx platforms developed in OP and LTFB, over a period of more than 3 weeks, with two 5-min measurement sessions during each odd UTC hour, lead to initial results already slightly better than those obtained with commercial modems, as shown in Fig. 1. This validates the developments obtained in laboratory, as well as their robustness. The next objective is to work on performance and its improvement, including implementing Delay Locked Loop and Phase Locked Loop tracking.

All development software and gateware is available from `https://github.com/oscimp/amaranth_twstft` for analysis and reproduction of the setup as well as experimenting with different modulation schemes (QPSK) and pseudo-random sequences.