Characterization of Delays for Spare SATRE Modems in TWSTFT Stations

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Many timing laboratories are currently employing Two-way Satellite Time and Frequency Transfer technique to compare their respective time scales and contribute to the Coordinated Universal Time calculated monthly by the Bureau International des Poids et Mesures (BIPM). It is not unusual to implement multiple TWSTFT stations or install multiple modems to ensure redundancy. Some SATRE (SAtellite Time and Ranging Equipment) modems, which are widely used in this context, are manufactured with expansion slots for multiple signal receiving (RX) modules, increasing the capability for redundancy. In this case, it would be useful to characterize the different delays introduced between modems and between their RX modules, if applicable, in order to switch devices in the event of a module or system failure while maintaining service continuity and calibration results. This work presents the preliminary measurement results of the delays of various SATRE modems used: #079 and #416 at INRIM and #077 and #321 at LNE-SYRTE (OP).

Currently the SATRE modems #079 and #416 at INRIM (used for nominal station IT02 and back-up station IT01, respectively) are both equipped with two RX modules capable of making TWSTFT measurements in parallel but currently only one module is used on each modem to create time transfer data. A preliminary test was carried out by scheduling both modules of the SATRE #416 to receive the signal of the same laboratory during nominal sessions (every even UTC hour). They are separately used to create quadratic fits and reported in ITU-formatted files. Suppose at epoch t a measurement (quadratic fit) is done by module RX_i regarding laboratory LAB denoted as $TW(t)_{i,\,LAB}$, it is possible to see the difference between a pair of RX modules (i, j) by taking:

$$TW(t)_{i,\,LAB} - TW(t)_{j,\,LAB} \qquad (1)$$

considering that the time and frequency signals supplied to the input of the two modules as well as the signals received by these two modules are identical, the other parameters of the chain of stations are therefore canceled.

Fig. 1 shows preliminary results of this test on the modem SATRE #416 over a measurement period of three days, where a 3 ns difference can be seen (on average) as the difference between time interval measurements done by its RX1 and RX2 modules across European and Transatlantic TWSTFT links. Such difference can be taken into account when switching modules for maintenance activities without affecting the calibration values for each TWSTFT link, by e.g. including this correction in ESDVAR field of the ITU format data files for the station [1].

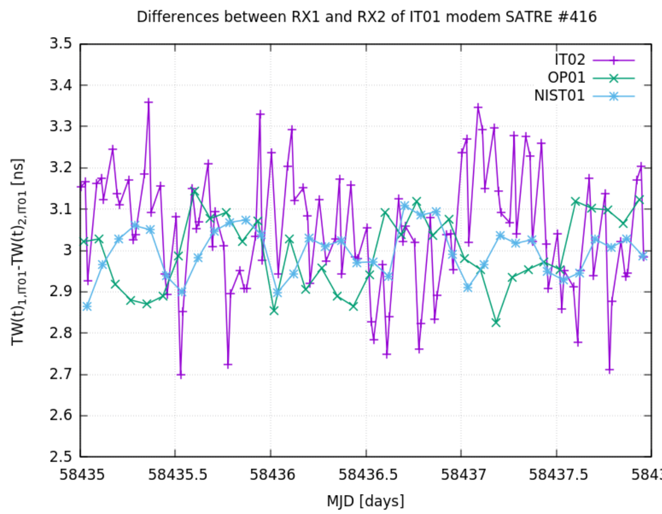

Fig. 1. Difference between time interval measurements of IT01 (modem SATRE #416) RX1 and RX2 modules

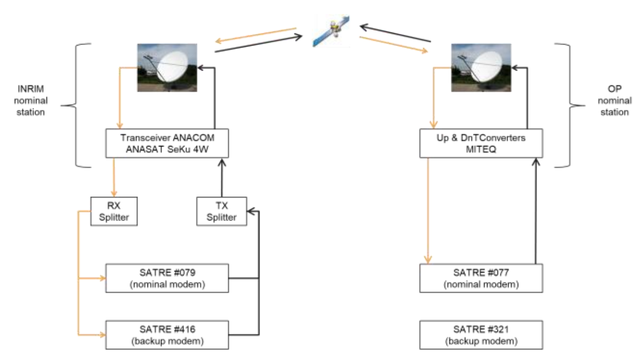

Fig. 2. TWSTFT stations test configuration at INRIM and OP

To validate the relevance of our modems delay characterization method, a comparison of the measurements of time intervals between remote stations can be performed.

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INRIM and OP have joined together to carry out a test during odd UTC hours to have a flexible test schedule and to minimize effects from other signals (Fig. 2). Each remote laboratory transmits and receives clock signals using the same two-way station and swapping between different local modems to better understand the contribution of each SATRE modem in the two-way link studied. At INRIM, modem SATRE #079 and #416 were connected to the nominal TWSTFT station via a couple of splitters for TX and RX path, which introduced a negligible non-reciprocity with respect to the nominal operations. These modems during test hours transmitted the same signal configuration, one after another each 2-min session; all RX modules were programmed to perform the same measurement at the same time. Modem SATRE #077 at OP was used during the major duration of the test, except for some sessions being switched out for SATRE #321. Then the baseline UTC(OP) – UTC(IT) from various measurement combinations is analyzed.

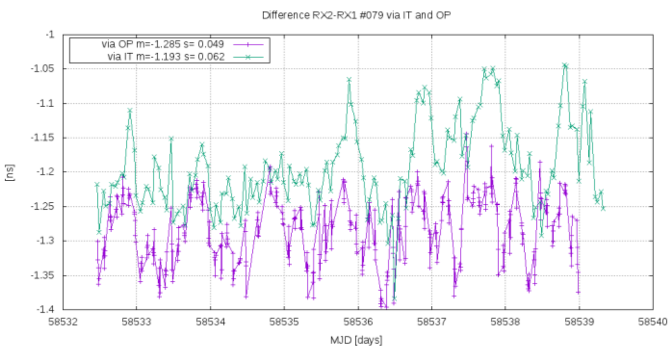

Fig. 3. Difference between time interval measurement of SATRE #079 during test period

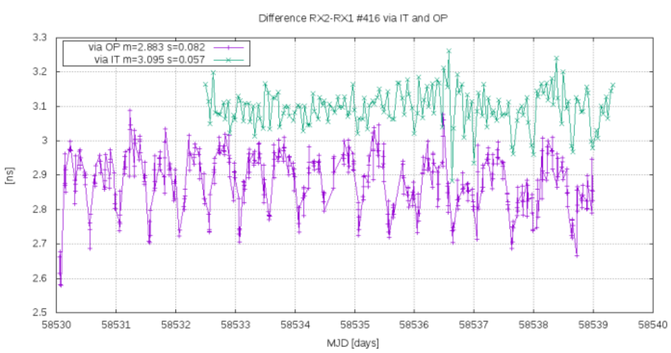

Fig. 4. Difference between time interval measurement of SATRE #416 during test period

First it is possible to validate previous results (Fig. 1) by calculating the differences between RX modules of SATRE #079 and #416 via their measurements of OP signal and via ranging sessions. It can be seen with Fig. 3 and Fig. 4 that these differences agree with past data and agree with each other within uncertainty. In case of single RX module failure, these values can be taken into account for ESDVAR (doubling the absolute measured value, Table I).

TABLE I. ESDVAR to be used when replacing RX1 module by RX2 module at INRIM SATRE modems

Modem	ESDVAR	ESIG
SATRE #079	2.600	0.300
SATRE #416	- 5.800	0.300

Then by examining UTC(OP) – UTC(IT) during SATRE #079 transmission, we can see the difference between SATRE #079 and #416 in reception. Fig. 5 shows this quantity to be stable at around -244.800 ns. While Fig. 6 shows the difference between the two modems in transmission at about -28 ns. The sum of these quantities gives us the value to compensate for when SATRE #079 is replaced by SATRE #416, which is verified by performing a physical switch in an even hour measurement session, applying the calculated ESDVAR in Table II. It can be seen from Fig. 7 that the difference between the modems are properly compensated resulting in continuity for the tested links i.e. UTC(OP) – UTC(IT), UTC(SP) – UTC(IT) and UTC(VSL) – UTC(IT).

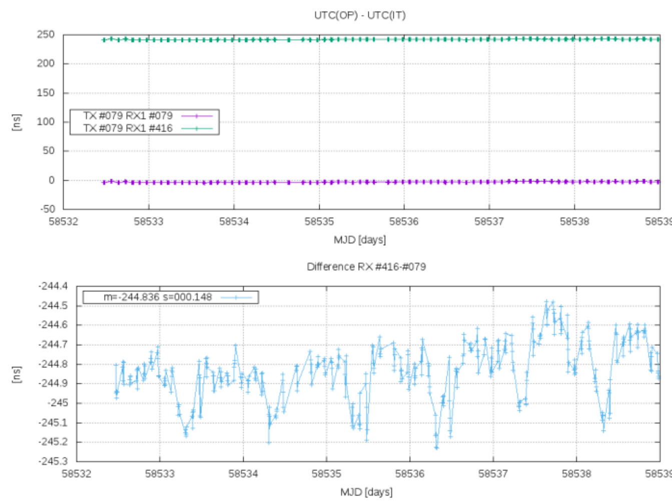

Fig. 5. Difference between SATRE #079 and #416 – RX

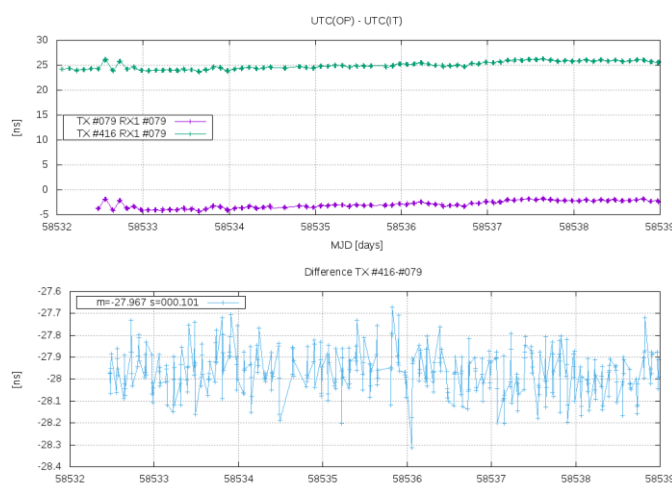

Fig. 6. Difference between SATRE #079 and #416 – TX

Table II. ESDVAR to be used when replacing SATRE #079 by SATRE #416 at INRIM nominal TWSTFT station

ESDVAR	ESIG
(244.800 + 28.000) x2 = 545.600	0.300

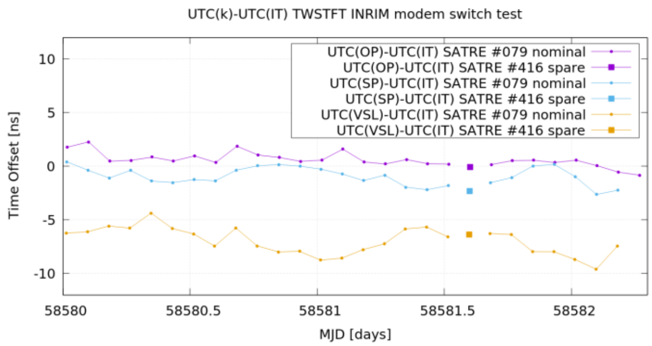

Fig. 7. Test switching nominal modem by spare modem at INRIM

Additional tests were performed locally and independently, in OP, by connecting directly the two involved modems (SATRE #077 and #321) plus an intermediate modem (SATRE #503) without passing by the geostationary satellite. In this case, the delay measurements of each modem was free of contributions from external influence parameters and the differences in delays between the modems can be extracted, which can then be taken into account in the case of replacement of a modem by another. These additional tests allowed us first to determine the delay introduced by a light change of adequate wiring performed in the OP01 station (Table III) enabling to use the OP satellite simulator coupled with the SDR receiver implemented in OP01.

TABLE III. A corrective value of -3.53 ns taken into account in the ESDVAR field of the ITU format data files of OP

	RX (#077)	**OP01**
TX (#321)	TX-RX (ns)	ESDVAR (ns)
Before MJD 58535	14 227,660	0,000
After MJD 58535	14 231,190	**-3,530**

And then, a preliminary offset value introduced by switching between the two modems (SATRE #077 and #321) was determined with a standard deviation of few hundred picoseconds (Table IV).

TABLE IV. A correction can be taken into account when switching modems without affecting the calibration values for each TWSTFT link with OP

SATRE #503	**SATRE #077**		
TX-RX (ns)	REFDELAY (ns)	TX-RX (ns)	ESDVAR (ns)
57,250	826,040	14 225,000	0,000
SATRE #503	**SATRE #321**		
TX-RX (ns)	REFDELAY (ns)	TX-RX (ns)	CORRECTION (ns)
5,200	771,630	28,900	**14 252,870**

As for the corrective value given in Table IV obtained by considering the REFDELAY values determined separately for the modem SATRE #077 and the modem SATRE #321, it can be taken into account when switching modems without affecting the calibration values for each TWSTFT link, by e.g. including this correction in ESDVAR field of the ITU format data files for the OP01 station. The two additional measurements carried out locally in OP were validated remotely on the OP-IT link using the two remote modems of INRIM.

REFERENCES

[1] Recommendation ITU-R TF.1153-4 (08/2015) "The operational use of two-way satellite time and frequency transfer employing pseudorandom noise codes", ITU-R Radiocommunication Sector of ITU.