Proceedings of the 2003 IEEE International Frequency Control Symposium and PDA Exhibition
Jointly with the 17th European Frequency and Time Forum

DEVELOPMENT OF A TWO WAY SATELLITE TIME AND FREQUENCY TRANSFER STATION AT BNM-SYRTE

J. Achkar, P. Merck
Observatoire de Paris
BNM-SYRTE, CNRS UMR 8630
61, avenue de l'Observatoire F-75014 PARIS, France

Abstract

The national metrology institute BNM-SYRTE has developed an earth station for satellite communications in order to compare, by using radiofrequency link with other earth stations installed in Europe and USA, atomic clocks disseminated in the time laboratories. The goal of BNM-SYRTE is to contribute in the realization of International Atomic Time (TAI) calculated by the BIPM, by using an alternative technique to GPS, denoted TWSTFT (Two Way Satellite Time and Frequency Transfer).

With this particular technique, atomic clocks are compared through a geostationary satellite using microwave links between ground clocks and the satellite, in the frequency bands 13,75-14,50 GHz (up-link) and 10,95-12,75 GHz (down-link). Such comparisons are made using the spread spectrum method with a 70 MHz Intermediate Frequency (IF) carrier modulated by a pseudo-noise (PN) code sequence, at 2,5 MChips/s, generated by a SATRE (SAtellite Time and Ranging Equipment) modem.

1. Introduction

TWSTFT Technique is used in order to compare the time between two clocks. It is based on the transmission of clocks data between two earth stations, using satellite microwave links. The time signals are simultaneously transmitted, the signal of a station is received and measured by the other station. The exchange of measurement data permits the calculation of the difference time between two clocks.

During a measurement session, signal delays vary as a function of physical parameters in the propagation media (troposphere, ionosphere, terrestrial conductivity, distance, temperature, etc.). This technique permits to consider only the variation of these parameters at first order.

The delays are then canceled. This is done to the reciprocity, at first order, of signal ways. Precision of results depends on the non reciprocal residual effects.

The characteristic equation describing the difference time T_1 - T_2 between two clocks located in 1 and 2 (Figure-1) is given by :

$$T_1 - T_2 = \frac{1}{2}(\Delta T_1 - \Delta T_2) + \frac{1}{2}\Delta\tau$$

where,

$$\Delta\tau = \Delta\tau_{TR} + \Delta\tau_{UD} + \Delta\tau_{SAT} + \Delta\tau_{R}$$

ΔT_1 and ΔT_2 are measured with Time Interval Counters (TIC).

$\Delta\tau_{TR}$ expresses the difference of delays on the transmission and reception ways, within earth stations,

$$\Delta\tau_{TR} = \left[\left(\tau_1^{TX} - \tau_1^{RX}\right) - \left(\tau_2^{TX} - \tau_2^{RX}\right)\right]$$

$\Delta\tau_{UD}$ represents the difference of delays related to the atmospheric propagation for up-links (earth – satellite) and down-links (satellite – earth) :

$$\Delta\tau_{UD} = \left[\left(\tau_1^{U} - \tau_1^{D}\right) - \left(\tau_2^{U} - \tau_2^{D}\right)\right]$$

$\Delta\tau_{SAT}$ describes the difference of delays "one way" and "opposite way" in the geostationary satellite repeater :

$$\Delta\tau_{SAT} = \tau_{21} - \tau_{12}$$

$\Delta\tau_R$ gives the difference of spatial delays due the earth rotation (Sagnac effect) and the instability of the satellite position :

$$\Delta\tau_{R} = \left[\left(\tau_{R1}^{U} - \tau_{R1}^{D}\right) - \left(\tau_{R2}^{U} - \tau_{R2}^{D}\right)\right]$$

All the terms in τ are the errors due to non reciprocity effects. Corrections can then be determined. Each station transmits its time scale with appropriate corrections to the other station.

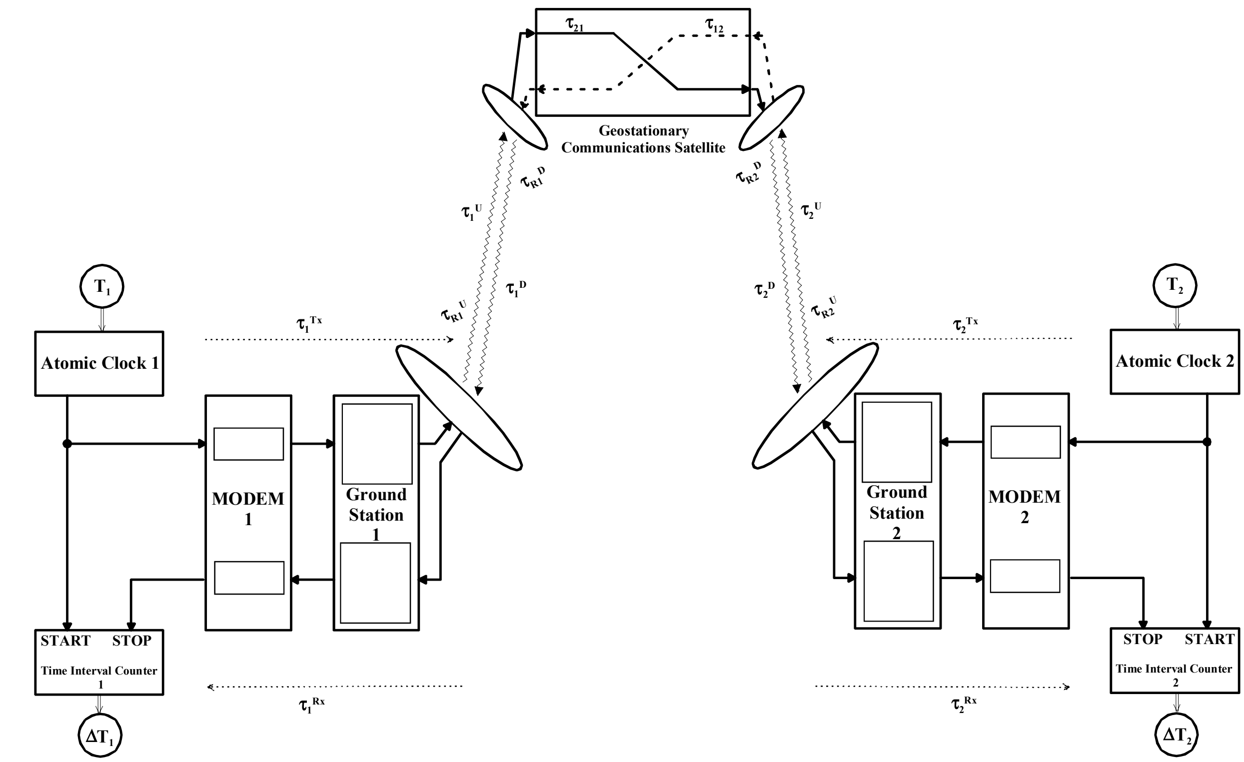

Figure-1 : TWSTFT technique for atomic clock comparisons

2. TWSTFT station of BNM-SYRTE

The TWSTFT station developed at BNM-SYRTE is composed from the following main equipments :

- a modulator - demodulator SATRE-077 generating the PN code at 2,5 MChips/s and realizing the spread spectrum modulation at 70 MHz IF. It is equipped with an internal TIC ;
- an up-converter Miteq U-176-3 with a local oscillator piloted in frequency by UTC(OP) : frequency band 13,75-14,50 GHz, gain 25 dB, IF attenuator 30 dB ;
- a solid state power amplifier Miteq BA-8 : frequency band 13,75-14,50 GHz, gain 42 dB, output power 8 W at 1 dB compression ;
- A Vertex DPVK asymmetric Gregory antenna with linear orthogonal polarization : diameter 2,40 m, frequency band 10,70-14,50 GHz, gain 48 dB, noise temperature 50 K @ 10 °EL ;
- A low noise amplifier Miteq AMFW : frequency band 10,95-12,75 GHz, gain 60 dB, noise temperature 70 K ;
- A down-converter Miteq D-128-3 with a local oscillator piloted in frequency by UTC(OP) : frequency band 10,95-12,75 GHz, gain 45 dB, IF attenuator 30 dB ;
- An external time interval counter SR620 ;
- A computer to control the whole of station equipments, to make data acquisition and to process time data.

The station is powered, through its modem, by UTC(OP), itself made with a Caesium atomic clock HP5071A associated with a microphase stepper TST6490 (10 MHz) and a digital clock TST6460 (1 pps). The transmitted and received signals, are controlled by a spectrum analyzer, connected continuously to the station.

In the site of the Observatoire de Paris, the building in which the atomic clocks and the operational time service are installed, receives also on its top roof the antenna system, as it is shown in Figure-2 :

Joseph Achkar

Figure-2 : TWSTFT station of BNM-SYRTE

2.1 Characterization of modem

The characterization of modem has been done using a digital oscilloscope. One issue was to measure the delay between 1 pps Tx *[time rise of 1 pps Tx coming from 1 pps UTC(OP)]* starting the count of TIC, and the 70 MHz IF carrier, available at the output of the modem, modulated by the PN code at 2,5 MChips/s *[at the 1st bit code phase change]* (Figure-3). The knowledge of this delay is useful for one of the correction terms given by the characteristic equation (§.1).

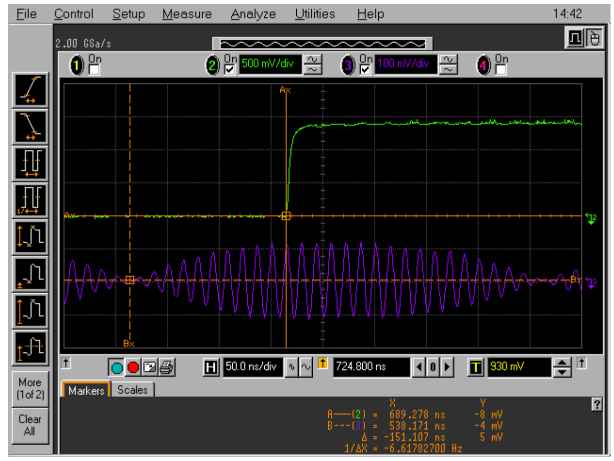

Figure-3 : delay *1pps TX – 70 IF MHz output*

The calculated delay corresponds to the difference between the specific offset of SATRE-077 modem (400 ns) and the measured value at the oscilloscope (-151,107 ns), as 248,893 ns.

2.2 Characterization of the station

One time the installation of the station done, we have evaluated its technical performance. Table-I reports the main characteristics of the BNM-SYRTE station, determined either by calculation, or during effective measurements :

Observatoire de Paris Site : LA LO	48°50' N 02°20' E
Intelsat 706 orbital location	307 °E
Azimuth angle of antenna, AZ	242,5 °N
Elevation of antenna, EL	13,5 °
Equivalent Isotropic Radiated Power, E.I.R.P. max.	57 dBW
'Signal to Noise' ratio calculated, at the input of low noise amplifier, G/T min.	26,5 dB/K
Translation frequency of satellite, for Europe ←→ Europe links	3,5 kHz
Translation frequency of satellite, for Europe ←→ USA links	5,5 kHz
'Carrier to Noise' typical ratio detected, at the input of modem, C/N_0	58 dBHz
Delay interval measured by TIC, 1 pps Tx – 1 pps Rx	260 – 270 ms

Table-I : characteristics of BNM-SYRTE TWSTFT station

The different parameters described in Table-I are given with respect to the following items :

¤ Pointing of the antenna on Intelsat, by considering the terrestrial parameters of the site ;
¤ E.I.R.P and G/T characterizing the station, in transmission and in reception, respectively ;
¤ Translation frequencies of the geostationary satellite are determined by receiving clean carriers transmitted from the different stations ;
¤ C/N_0 and the delay (1 pps Tx - 1 pps Rx) are determined during regular TWSTFT links between stations.

3. Clocks comparison : preliminary step

The time laboratories equipped with TWSTFT stations, in Europe (PTB, VSL, NPL, IEN, ROA, OCA) and in the United States (NIST, USNO), are comparing their atomic clocks through the INTELSAT 706 geostationary satellite, by using microwave links in the Ku band. BNM-SYRTE recently equipped with a TWSTFT station will contribute in the near future to these comparisons.

Figure-4 and Figure-5 show the clean carriers received at BNM-SYRTE (the one from BNM-SYRTE is identified by OP). From these detected signals, we determined the translation frequencies of the satellite, in order to specify within the modem the dynamic range in which PN codes can be locked during TWSTFT links, and then to measure the related delays between clocks.

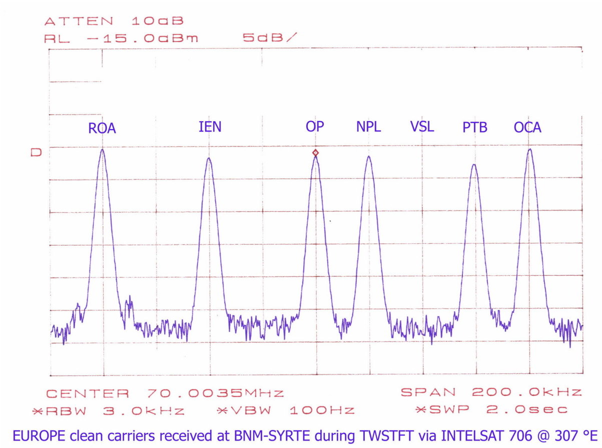

Figure-4 : clean carriers received at BNM-SYRTE,
On May 23, 2003.

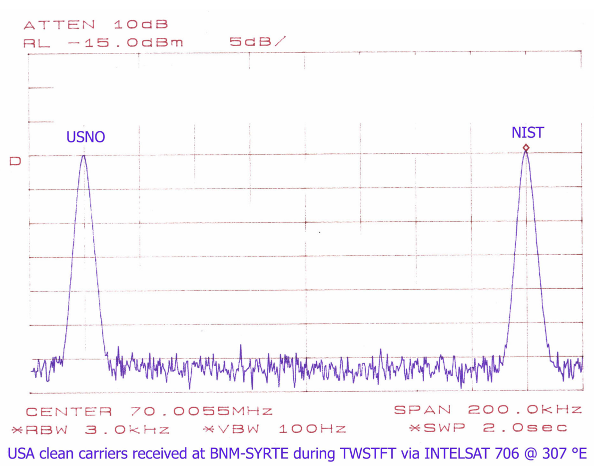

Figure-5 : clean carriers received at BNM-SYRTE,
on May 21, 2003.

4. Conclusion

Since March 2003, Observatoire de Paris is equipped with a TWSTFT station running in Ku band and dedicated to ground atomic clocks comparisons using microwave links with a geostationary satellite. It is also holder a permission from the Autorité de Régulation des Télécommunications (October 2002) to transmit to the satellites, and the station has received its Intelsat type approval in April 2003.

A software has been developed to control the station, to make data acquisition and to process time data.

The research and development work will continue in the following technical investigations :

- Clocks comparison during regular two way sessions with the contribution of BNM-SYRTE besides time laboratories, in Europe and in the United States ;
- To analyze and to validate the measurement results for the calculation of TAI ;
- To be actively involved in the calibration process using a portable station ;
- To develop a satellite simulator in order to determine the internal time delay of the station.

5. Acknowledgment

BNM-SYRTE thanks the following bodies for their fruitful cooperation in this project : CCTF/TWSTFT working group, *FRANCE TELECOM*, *Autorité de Régulation des Télécommunications*, INTELSAT, *Mairie de Paris* and the technical services of the *Observatoire de Paris*.

References

[1] Télécommunications spatiales : Tome I, II et III, Collection CNET-ENST, 1983.

[2] P. Hartl, L. Veenstra, N. Gieschen, K. M. Mussener, W. Schafer, C. M. Wende, W. Klepczynski, H. H. Nau, R. Stoiber, "Spread spectrum time transfer experiment via Intelsat", 15th PTTI, 1983, pp. 331-356.

[3] "The operational use of two-way satellite time and frequency transfer employing PN codes", Rec. ITU-R TF.1153, 1995, pp. 42-50.

[4] J. A. Davis, P. R. Pearce, D. Kirchner, H. Ressler, P. Hetzel, A. Soering, G. De Jong, P. Grudler, F. Baumont, L. Veenstra, "European two-way satellite time transfer experiments using the Intelsat (VA-F13) satellite at 307 °E", IEEE Trans. Instr. & Meas., Vol. 44, No. 2, pp. 90-93, April 1995.