ABSTRACT SUMMARY

EUROPEAN SPACE AGENCY
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New Methods and Systems for Time and Frequency Distribution Via Satellite

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A wide range of disciplines (from sophisticated bio-medical equipment to digital TV production; from ground network synchronisation to On-Board clock to be used in low-orbit constellation satellites or into scientific satellites) require world wide availability of extremely accurate and stable clocks in real time. These disciplines not only need a good and accurate timing distribution, but are also calling for cheap easy-to-use “User terminals”.

The solutions available today are mostly based on GPS. Some of these solutions offer limited guarantees in terms of accuracy, stability and reliability for many applications. Alternative space based solutions as the Two Way Satellite Time and Frequency Transfer (TWSTFT) method look more attractive in terms of performance, but is more expensive and may have a lack of availability for the measurements.

TFDS (Time and Frequency Distribution via Satellite) is a concept proposed by ESA which aims at reducing the gap between stand alone high precision clocks and methods for communicating this accurate and stable time and frequency information between distant locations. It consists of a new method for time and frequency transfer via satellite between two or more ground based clocks transmitting in TDMA mode. The achieved precision is better than what can be done with state-of-the-art time transfer techniques by two orders of magnitude. Furthermore, this precision is obtained continuously in real-time and with a global world coverage.

This concept makes use of an On-Board Processing (OBP) system to communicate accurate and stable time and frequency information between distant locations. The main idea is to use a communication system technique to synchronise a space clock to a highly stable ground reference clock, which in turn allows the synchronisation of the remote clocks. It offers as main advantage the avoidance of an ”ad hoc” system for synchronisation.

The On-Board Processing Concept dates back to the 80’s; its main difference with respect to a conventional transparent TDMA satellite is the possibility to utilise the on-board generated clock as the system master Clock (MCK). This master clock is provided by an On-Board Clock Module (OBCK) piggy-backed on a regenerative communication satellite, and interfacing with the Baseband modules of the payload. This OBCK provides mainly a Phased-Locked-Loop (PLL) function which steer the satellite’s clock (VCXO) on the clock recovered from the received data which have been modulated with the Ground Reference Clock in the Master Clock Station.

During the start-up, the On-Board Clock Module (OBCK) is free running and working with the low stability clock delivered by the unlocked on-board VCXO. The on-board TDMA Burst Mode demodulator receives the master clock station bursts and delivers the recovered clock to the on-board VCXO which, in a few frames, shall lock to the more stable ground clock.. Once the on-board generated clock is locked to the stable ground clock, a second master clock station with a clock of the same level of stability as the first one can start its synchronisation with the on-board generated clock, which is now acting as the Master Clock (MCK). In addition to the redundancy achieved in the references for the MCK, the comparison of distant on-ground clocks is possible by making use of the stable on-board MCK.

This study TFDS (Time and Frequency Distribution via Satellite) has been contracted by ESA to Alcatel Space Industries as Prime Contractor, with Sofreavia and Thales Detexis as subcontractors.

The main objectives of this study were:

- ✓ End-to-end characterisation of the proposed concept and specification including a field trial specifications.
- ✓ Detailed definition and technical specifications for the following system space and ground elements.
- ✓ Identification and specification of a specific mission profile for future flight opportunity.

The main results of the study are of three orders:

- First the TFDS system has been described, and an error budget associated with the transmission link budgets has been given, leading to the target performances of the system.
- Then a summary of the applications for such a system has been presented as a result of a market analysis performed in the frame of the study.
- Finally a ground system test bed which is scheduled has been presented based on a breadboard model of the OBCK equipment as well as ground clocks, for analysis of the system performances. The effects of propagation will be taken into account by the use of satellite transmissions through a transparent repeater.

It has shown an interesting potential of TFDS for the applications listed from the market analysis. The latter has shown however that to be competitive, TFDS should associate both performance and cost interests with respect to concurrent solutions as GPS for mass market applications, and the TWSTFT method for high precision clock comparisons, whose performances in time transfer are recalled hereafter.

Methods used	**Time transfer accuracy**	**Comment**
GPS Common view	3-10 ns	
TWSTFT	< 1 ns	
TFDS	220 ps / 3.2 ns (TBC)	Two-way / One-way target

Concerning Galileo, three possible applications have been listed for the latter. However, while theoretical assessment of the performance of the TFDS system in time transfer for general users has been done in the frame of this study, **the specific case of Galileo needs to be deeply investigated**, with feedback from the Galileo industrial consortium, in particular :

- ✓ Synthesis of the Galileo needs in terms of clock accuracy and availability.
- ✓ The implementation of the OBCK module on the Galileo MEO Satellites. Synthesis of the available payload units and specification of the interfaces.
- ✓ The available ground network that could offer regular access to the OBCK modules boarded on the MEO Satellites, based on the current Galileo architecture.
- ✓ Assessment of the performance analysis of the Ground to Space synchronisation taking into Galileo MEO Satellites.
- ✓ Comparison of the performances of the on-board recovered clocks with respect to the performances of the on board clocks presently under development.
- ✓ Overall technical impact on the Galileo Architecture (overall performance assessment, technical impact on space segment, Integrity determination segment, etc).
- ✓ Overall programmatic impacts on Galileo (comparison of costs, schedule, risks).