PRESENT STATE OF LONG DISTANCE TIME TRANSFER VIA SATELLITES WITH APPLICATION OF THE MITREX - MODEM

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ABSTRACT

The Microwave Time Transfer MODEM MITREX is of particular interest for very precise time transfer over intercontinental distances. It allows the synchronization of atomic clocks to accuracies in the order of a few nanoseconds. The MODEM is compatible with the 70 MHZ-input/output interfaces of standard Intelsat earth stations. After a general description, the results of various tests with existing telecommunication satellites are reviewed.

1. INTRODUCTION

Since the beginning of space telecommunications in the 60's, the distribution of time signals to a large group of users has been tested and practically used with great success. Also many experiments have been performed via satellites in the area of time transfer between time keeping stations for atomic clock comparison.

The broadcast mode of the GEOS geosynchronous meteorological satellites has become of particular interest for a large community with needs for accuracies in the order of a few microseconds. Another interesting "broadcast-mode" system is GPS, where the orbits of the satellites are of 12 hours period. In this GPS-case one can achieve a few tens of nanoseconds or even a few nanoseconds relative accuracy between ground stations, provided that they have common view to the same satellite(s).

For intercontinental distances, where the GPS-satellite signals cannot be received simultaneously, the time synchronization can be of 50 to 100 nanosec accuracy. Such limitations are basically existent for one-way concepts, where the stability of the spaceborne clock and the uncertainties of the propagation time become effective.

For the utmost accuracy achievements, one has to apply the two-way transmission concept, which excludes most of these effects: In a fully symmetric case for two ground stations the effects of uncertainty cancel.

This principle is well-known and has been used experimentally in many ways, with tv-signals, side tone signals, PN-signals etc. See [1] to [5], for example.

MITREX, the MICROWAVE TIME AND RANGING EXPERIMENT system, is also based on this concept and applies PN-codes. Its main advantage over the previous experiments may be the fact, that more than a dozen units of these MODEMs have been produced since the first tests. They have been used in many experiments and demonstrated the feasibility of this hardware for operational application. The MODEMs can be procured and used very easily. In addition, the extremely low transmitter power and the low power spectral density of the time signal are very important features, necessary to get permission from the FCC-administrations. They are needed to avoid radio interference and - in the satellite transponder - intermodulation. The MITREX design is acceptable for the transmission via operational telecommunication satellites, for example INTELSATs. The satellite receives a signal, which is buried below the noise floor.

2. THE MITREX CONCEPT

2.1 General Aspects

The system design is based on the following assumptions:

- Only a two-way time transfer can deliver the utmost accuracy,
- its worldwide application is only achievable, if telecommunication satellites can be used,
- the modulation must therefore avoid intermodulation problems in the transponder,
- the MODEM must be compatible with the standard INTELSAT earth-stations.

These constraints have been met by the MITREX MODEM. It is an interface between the 70-MHz IF of a standard earth station, a Time Interval Counter TIC and the time keeping hardware, i.e. the atomic clock. The hardware is housed in a 19-inch drawer and operates as a pseudorandom noise sequence (PN) encoder/decoder of the time signal. The PN-code is a truncated maximum length sequence of period 10.000, instead of the 16.383 chips. This period of 10.000 eases the overall system design, as it allows the use of even and decimal dividers for signal processing. The correlation features of the maximum length sequence are almost retained.

2.2 PN-Encoding/Decoding

As shown in fig. 1, MODEM 1 (2) is fed by the 5MHz (or 10MHz if desired) standard frequency of the cesium clock cl1 (cl2). The frequency is divided by a factor of two (or four) and used as the PN-clock (the description is true for MITREX 2500, the newer version. In the original MITREX, the clock rate was 2 MHz, and therefore a division of 2.5 or 5 resp. was necessary). This is also called the chiprate. In addition, the 1 pps time tick of cl1 (2) is used for the generation of the 1 sec period phase modulation of the PN-code. The PN-signal consists of "bits" of 10.000 chips and length of 4 msec. 249 such bits are sent before the bit 250 is to indicate the occurance of the 1 pps pulse. The indication is done by delaying the first 5000 chips of this bit 90 degrees and advancing the next 5000 chips by 90 degrees.

After the 250 bits the "normal state" is reconstituted. The whole PN-sequence phase modulates a 70-MHz carrier in PSK and is then fed into the IF-input of the standard earth station transmitter, in order to be sent via the satellite transponder to the earth station 2 (1).

The 1 sec pulse of the clock is also fed into the time interval counter TIC 1 (2) and starts the time counting there.

The IF-output of the earth station 2 (1) delivers the received signal to the MODEM 2 (1) receiver's input, where it is correlated with the replica of the transmitted PNK-code by means of a delay locked loop. This leads to the optimum PN-signal recovery. The 1 sec pulse, which can be derived from this reconstituted PN-signal is delayed against the transmitted original of clock 1 (2) according to the propagation time. It is used to stop TIC 2 (1). If both propagation times t are identical and if the two clocks 1,2 are synchronized, then both TICs must indicate the same number, which corresponds to t.

3. DESCRIPTION OF EXPERIMENTAL RESULTS

First preliminary functional tests with the French-German experimental telecommunication satellite SYMPHONIE in 1982 already showed excellent reliability and very high precision.

3.1 Measurements Across the Ocean with INTELSAT V

In a common effort between USNO, COMSAT, DFVLR and INS experiments have been performed in July 1983 via the INTELSAT V Atlantic spacecraft's 14/11 GHz transponders. The transportable ground station located at USNO, Washington, D.C., had a parabolic dish of 2.4m and a G/T of 20 dB/K. The German ground station at Oberpfaffenhofen was equipped with a 4.5m dish and had 26dB/K. The rmsstandard deviations were better than 1 ns. The link budget is shown in table 1. The rf transmitter power was 170 mW in Washington and 80mW in Oberpfaffenhofen. The signal was nominally 10 dB below the noise level at the receivers.

3.2 Experiments with OTS

Together with the European Space Agency, ESA, the next series of tests was performed via the OTS-satellite of ESA in February 1984. It is to be mentioned, that this satellite operating at 11/14GHz was at that time already out of preoperational use after 7 years of tests and had only very modest fuel left for position control. Therefore this spacecraft was varying its position considerably. In addition, one of the ground stations had no automatic tracking capability. Elevation varied 1.5 degrees around the nominal value. For this reason, both the signal to noise ratio was varying and the time of actual signal reception was limited. The transportable ESA station at Noordwijk had a 3m dish; [5].

Various tests were performed:

Single carrier interference tests; At 1 MHz frequency offset the interference level had to be as strong as 28dB over the PN-signal level. With 18dB the false lock occurred, when the disturbing carrier frequency was within 1 KHz of the MODEM lock frequency.

- For broadband interference, the disturbing level of 10dB above noise caused an increase of the jitter of the time signals of 0.7 nanosec rms.
- A swept interfering frequency of 4MHz deviation to both sides of the center frequency caused a 0.59 nanosec rms increase, if its power was 16dB above the PN-level.
- Various tests of the ranging capability to the geosynchronous satellite showed excellent performances and the superiority over existing techniques.

3.3 Time Transfer with SIRIO

The Italian Politechnico di Torino (Prof. Leschiutta) and various Chinese Academies of Space Technology applied MITREX MODEMs for tests via the very long distance between China and Italy. The tests were executed with good carrier to noise distance and therefore arrived at rms precision values of about 200 picoseconds, using 60 measurements every second. The absolute accuracy is not known, because the ground station performances were not adequately known.

3.4 TDMA Synchronization

Experiments were performed by use of the European Communication Satellite ECS in cooperation with DFVLR. Further applications and a general description of the synchronization principles are described in [7].

3.5 Multiple Station Synchronization

Presently preparations of experiments are under way to conduct time comparison via OTS and ECS under the participation of the Dutch Dienst van het Ijkwesen, ESA-ESTEC, University Graz, Austria, the German FTZ and INS with MITREX MODEMs. In addition, all stations will be equipped with GPS receivers. This allows to determine deviations of GPS-time from the common time reference of these stations. For all GPS receive stations in Europe with common view to the same GPS satellites, this corrective value could be telexed. This combination of time dissemination and time transfer can improve the overall time distribution considerably.

In the future, such experiments will be extended to Italy and England and later to USA and Canada. This should lead to a demonstration of the improvement possible for the worldwide time synchronization. With this in mind, one should approach the preoperational test of world wide synchronization: Time transfer to the continents via MITREX and correction of GPS-time in regional areas by use of the MITREX-information.

4. CONCLUSION

MITREX seems to be a versatile tool to improve the time synchronization of the GPS system for time dissemination.

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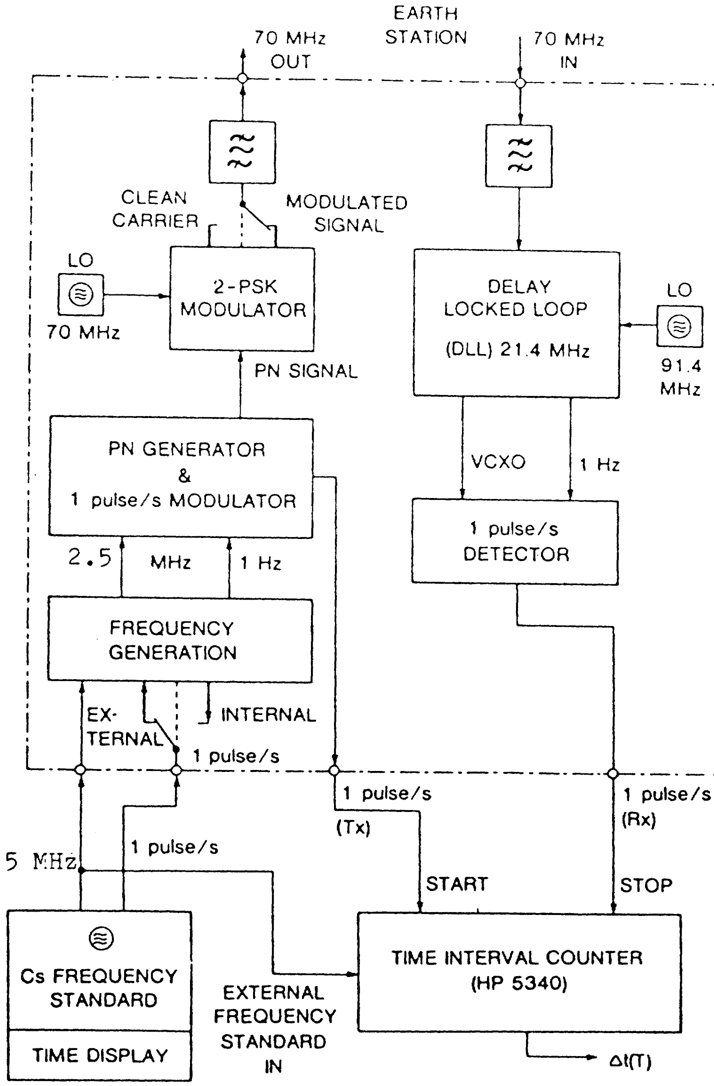

Figure 1: Time Comparison with MITREX

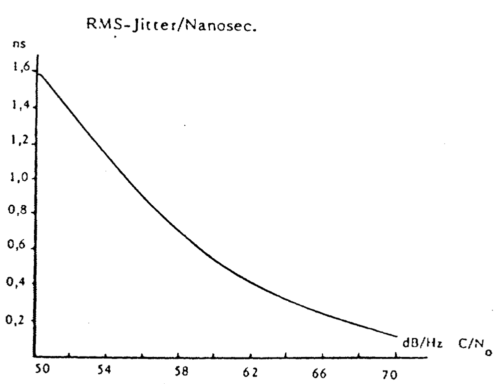

Fig. 2a:

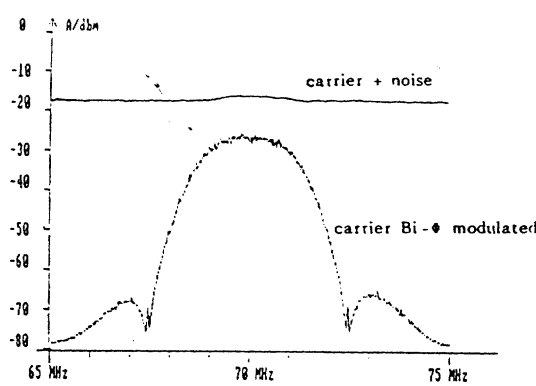

Fig. 2b:

Table 1: Link Power Budget for the Intelsat V Experiment

From To	U.S. DFVLR	DFVLR U.S.	
Transmitter Power	0.17	0.08	W
Transmitter Power	-7.7	-10.8	dBW
Transmitter Gain	46.9	54.0	dBi
e.i.r.p.	39.2	43.2	dBW
PL Up	207.9	207.9	dB
S/C G/T	9.0	6.5	dB/K
C/T Up	-159.7	-158.2	dBW/K
e.i.r.p.	39.2	43.2	dBW
PL Up	207.9	207.9	dB
Gain $1m^2$	44.5	44.5	dBi
Flux at Satellite	-124.2	-120.2	dBW/m^2
Flux to Satellite	-79.1	-77.6	dBW/m^2
Input Backoff	-45.1	-42.6	dB
Output Backoff	-40.1	-37.6	dB
Maximum e.i.r.p.	46.5	50.0	dBW
S/C e.i.r.p.	6.4	12.4	dBW
PL Down	205.9	205.9	dB
G/T	26.0	20.0	dB/K
C/T Down	-173.5	-173.5	dBW/K
C/T Up	-159.7	-158.2	dBW/K
C/T Link	-173.6	-173.6	dBW/K
C/N_o Link	55.0	55.0	dB-Hz