

Two-Way Satellite Time Transfer: Overview and Recent Developments

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Abstract

The experiment using small earth stations for transatlantic two-way satellite time transfer between the USA (USNO, Washington, DC) and Germany (DFVLR, Oberpfaffenhofen) has had its 10th anniversary this year. Pseudo Random Noise coded time signals were phase modulated and demodulated at each stations using a modem developed by Professor Hartl and his staff.

Recently, during the last two weeks of August 1993, six European time laboratories have used the INTELSAT 307E satellite for line-up tests and preliminary time transfer sessions using the same type of MITREX modem. This opportunity was given by INTELSAT, thanks to the help of Dr. Veenstra.

The need for a uniform format for the exchange of data was felt heavily after these sessions. This problem was foreseen and addressed in international working parties.

During April 1993 in Task Group 7/2 of the ITU Radiocommunication Sector (formerly CCIR), a very intense discussion has taken place about what procedures should be recommended for TWSTFT and what items the header and data lines of the resulting data fields should contain. A difficulty is that two different methods of calibration of the earth station delays exist which results different sets of delay data to be exchanged. Further study and discussions are necessary.

Also, a meeting of the CCDS Working Group on TWSTFT addressed this in October 1993. The outcome of the discussions and the prospect for future developments will be presented.

Introduction

Today the best, that is the most uniform and accurate, time scales are produced by caesium atomic clocks. The unit of time, the second, is defined on the quantum mechanical properties of atoms of Cs-133. Its accuracy and long term stability has not been surpassed yet and for this reason caesium clocks are used by the national timing centres for time scales. These clocks can contribute to the formation of the International Atomic Time (TAI) if a good quality comparison method to the BIPM is used.

The delay calibration for the signal path of the remote clock in the wanted accuracy regions of 10 ns or better for state of the art cesium clocks is a great problem, especially for radio

links which are changing with distance, ionosphere, troposphere, air humidity and air density, temperature, earth conductivity and so on.

To avoid most of these influences by cancelling in first order the Two Way Satellite Time Transfer (TWSTT) scheme has been introduced: at both clock sites the time signals are transmitted to a common satellite at the same instant and on both sides the signal from the other clock is received and measured. After the exchange of the measured data the difference of the two clocks is calculated, and the delays cancel due to the complete reciprocity of the signal paths. The inaccuracy of the result is the departure from the assumption of complete reciprocity.

Two way time comparison equation

From fig 1 we can see that the difference of the clocks at station 1 and 2 can be determined.

$TA(k)$ is the time scale at station k

$TI(k)$ is time interval reading (1 pps TX - 1 pps RX)

$TT(k)$ is transmitter delay

$TR(k)$ is receiver delay

$TU(k)$ is uplink delay

$TD(k)$ is downlink delay

$TS(k)$ is satellite delay

$TCU(k)$ is the Sagnac correction needed in the uplink

$TCD(k)$ is the Sagnac correction needed in the downlink

The time scale difference $TA(1) - TA(2)$ can be obtained from:

$$\begin{aligned}
 TA(1) - TA(2) = & \\
 & 0.5xTI(1) - TI(2) \quad \text{TIC Reading differences(1)} \\
 & +0.5xTS(1) - TS(2) \quad \text{Satellite delay difference(2)} \\
 & +0.5xTU(1) - TD(1) \quad \text{Up/Down difference at 1(3)} \\
 & -0.5xTU(2) - TD(2) \quad \text{Up/Down difference at 2(4)} \\
 & +0.5xTT(1) - TR(1) \quad \text{Transmit/Receive diff. at 1(5)} \\
 & -0.5xTT(2) - TR(2) \quad \text{Transmit/Receive diff. at 2(6)} \\
 & +0.5xTCU(1) - TCD(1) \quad \text{Sagnac effect at 1 (7)} \\
 & -0.5xTCU(2) - TCD(2) \quad \text{Sagnac effect at 2 (8)}
 \end{aligned}$$

The right hand expression items (2) to (6) are 0 when full symmetry is obtained; the accuracy depends on the departures from symmetry and these are discussed below.

Departures from delay symmetry

Satellite delay difference

If in the satellite the same frequency, the same receive antenna, transponder channel and transmit antenna is used, then the delays $TS(1) = TS(2)$. This is not the case when different frequencies, transponders or different spot beams are used for the reception and/or transmissions from each station, i.e. the transatlantic Intelsat satellites. In this case $TS(1)$ and $TS(2)$ or at least the difference $TS(1) - TS(2)$ should be measured before the launch of the satellite. If not available, the difference might be estimated from detailed drawings of the satellite transponders and its wiring.

Another problem is that when the antennas for two different spot beams are not collocated there can be a separation of several meters, and its time difference effect may vary depending on the satellite orientation with respect to station 1 and 2. Every meter difference in separation may cause up to 3 ns non-reciprocity error!

If the signals from both stations cross each other at the satellite at the same moment, or at least the satellite is not moving in the time between the signals pass the satellite, then the up and down path lengths are equal. However, if the satellite is moving at a range rate of i.e. 3 m/s, then the signals experience the double value of 6 m/s, so if the signals pass the satellite within 0.01 s then this correction amounts up to $0.5 \times (6 / c / 0.01) = 100$ ps, where $c =$ speed of light.

Up/Down propagation delay difference

Ionosphere

The up and down link signals differ in carrier frequency and they experience a different ionospheric delay equal to $40.3 * TEC * (1/c) * (1/f_d^2 - 1/f_u^2)$. For $TEC = 1 * 10^{18}$ electrons/m² and for 14.5 /12.0 GHz this ionospheric delay = 0.932 ns - 0.639 ns = 0.293 ns. So the correction for $TU(k)-TD(k)$ is smaller than -0.3 ns.

Troposphere

The troposphere gives a delay depending on the water content of the air, air density and temperature, but this delay is not frequency dependent and its influence on the up and down propagation delay is equal and no correction for $TU(k)-TD(k)$ is needed.

Transmit/Receive Station delay difference

The difference of the transmit and receive section including the up- and down convertors, modulator and demodulator (modem), feeds, wiring, etc. has to be determined at each station. Methods proposed to obtain this have been:

- collocation of both stations
- subsequent collocation of a third (transportable) earth station at both stations
- using a satellite-simulator + calibrated cable.

The last method is the least expensive and can be used frequently. This method is explained in the literature and consists of the calibration of a auxiliary cable, measurement of the sum of the transmit and receive delay, measurement of the sum of the auxiliary cable delay and the receive delay and calculation of the receive and transmit delay from the measurements.

The internal transmit and receive delay of the modems have to be determined too. This can be done by collocating the modems and measuring the sum of the transmit delay of one modem and the receive delay of the other; so the difference of the transmit delays of the two modems is found, not the real values. Another absolute method is indicated in the literature, but this requires opening the modem and making a temporary modification. Modem delay $TT(k)$ - $TR(k)$ asymmetries of -526 ns have been measured.

Sagnac effect

Due to the movement (rotation around the centre of the earth) of the earth stations and the satellite during the propagation of a time signal to and from the satellite a correction has to be applied to the propagation time of the signal. This amounts for one way from satellite down to station k :

$$TCD(k) = \Omega/c^2 * Y(k) * X(s) - X(k) * Y(s) \quad (1)$$

where:

$$\Omega = \text{earth rotation rate} = 7.2921 \times 10^{-5} \text{ rad/s} \quad (2)$$

$$c = \text{speed of light} = 299\,792\,452 \text{ m/s} \quad (3)$$

$$r = \text{earth radius} = 6367\,000 \text{ m} \quad (4)$$

$$R = \text{satellite orbit radius} = 42\,150\,000 \text{ m} \quad (5)$$

$$(k), (s) = \text{station } (k), \text{ satellite } (s) \quad (6)$$

$$X(), Y() = \text{geocentric coordinates in meters} \quad (7)$$

$$(8)$$

If only Latitude and Longitude are known, then for geostationary satellites for which $LA(s) = 0$:

$$TCD(k) = \Omega/c^2 \times R \times r \times \cos(LA(k)) \times \sin(LO(k) - LO(s)) \quad (9)$$

where: $LA()$, $LO()$ are the latitude and longitude, respectively.

$X()$, $Y()$ can be calculated from:

$$X(k) = r \cos(LA(k)) * \cos(LO(k)) \quad , \quad X(s) = R \cos(LA(s)) * \cos(LO(s)) \quad (10)$$

$$Y(k) = r \cos(LA(k)) * \sin(LO(k)) \quad , \quad Y(s) = R \cos(LA(s)) * \sin(LO(s)) \quad (11)$$

$$(12)$$

The uplink Sagnac effect $TCU(k)$ is equal to $TCD(k)$ but of opposite sign:

$$TCU(k) = -TCD(k)$$

Total Sagnac correction Two-Way:

$$0.5TCU(1) - TCD(1) - 0.5TCU(2) - TCD(2) = -0.5$$

$$2TCD(1) + 0.52TCD(2) = -TCD(1) + TCD(2)$$

Example:

$$\begin{array}{llll} LA(VSL) = 52 \text{ N} & LO(VSL) = 4 \text{ E} & LO(\text{sat}) = -53 \text{ E} & TCD(VSL) = +112.42 \text{ ns} \\ LA(USNO) = 39 \text{ N} & LO(USNO) = -77 \text{ E} & LO(\text{sat}) = -53 \text{ E} & TCD(USNO) = -68.83 \text{ ns} \end{array}$$

$$\text{link VSL} \rightarrow \text{USNO: } TCU(VSL) + TCD(USNO) = -112.42 + -68.83 = -181.25 \text{ ns}$$

$$\text{link USNO} \rightarrow \text{VSL: } TCU(USNO) + TCD(VSL) = +68.83 + +112.42 = +181.25 \text{ ns.}$$

Achievements and status of TWSTT

The two-way method using microwave carrier frequencies and satellites has been used already in 1962 on the Telstar satellite between the United Kingdom and the USA (Fig.2).

The use of bi-phase modulation with PN code has been reported in 1974 and the use of a dedicated modem (Mitrex) for high precision time transfer has been reported in 1983 giving 0.5 ns precision.

Since August 1987 the time scales of USNO, NIST and NRC are routinely compared using the two-way Mitrex method 3 times per week on a US domestic satellite. Results show a precision of 1 ns at 1 s averaging time.

An excellent result has been reported from TUG, using a EUTELSAT ECS satellite for two-way time transfer between France and Austria during LASSO experiments and also common view GPS measurements were taken in 1990 and 1991. This work included a careful calibration by collocating the French portable station and the Austrian station. The difference between two-way and GPS was 3 ns with a precision of also 3 ns.

Three TWSTT experiments in Japan (CRL) using 1.8 m antenna were conducted: a. ranging in 1989, b. TWSTT over 120 km distance in March 1992 and c. the third experiment TWSTT between Japan (CRL) and Korea (KRISS) in April 1992. The results were: a. precision 0.43 ns @ C/No = 59 dBHz, Allan deviation $3 \times 10^{-10} \tau^{-3/2}$; b. precision 0.94 ns, Allan deviation $2 \times 10^{-9} \tau^{-3/2}$; c. difference GPS-TWSTT 10 ns accuracy level, precision 0.94 ns, Allan deviation $2 \times 10^{-9} \tau^{-3/2}$. A Mitrex 2500A modem was used as well as a Mitrex compatible prototype I-modem (Imamura, CRL).

In Germany a TWSTT between PTB (Braunschweig) and FTZ (Darmstadt) took place starting September 1992 using the German domestic satellite Kopernikus. Both stations were VSAT's from identical design: 1.8 m antenna, EIRP 50 dBW, G/T 22 dB/K, upgraded MITREX 2500A modem. The precision obtained was 300 ps which was consistent with the expected value at C/No between 65 and 70 dB/Hz. The difference with GPS measurements was up to 20 ns (at TZ the GPS receiver coordinates were not highly accurate).

In Italy, an experiment between IEN (Turin) and ISPT (Rome) was performed during March to June 1993 using Olympus satellite and upgraded MITREX 2500A modems; some unexplained periodic instabilities (10^{-15} ns) were observed. Olympus has become inoperative, an other European satellite will be used in the future.

In the UK, NPL has studied and measured during 1992 the delays of elements of the NPL TWSTT earth station and their temperature dependence in the 10 ps range. Some interesting typical results: variations of ± 1 ns in the total delay asymmetry during 3 days; ± 2.5 ns uncertainty of absolute delay asymmetry values; Mitrex 2500 delay asymmetry (510.1 ± 2) ns, temperature coefficient -63 ps/ $^{\circ}$ C; satellite simulator mixers TC = 12 & 20 ps/ $^{\circ}$ C, power delay coefficient 20 ps/dB, frequency delay coefficient 5 ps/MHz, uncorrelated changes with time 20 ps.

In 1992 a transatlantic TWSTT line-up test (Fig. 3,4,5) between USNO and TUG (Austria) has been established using the INTELSAT VA (IBS) satellite at 307° E using a VSAT at TUG. The elevation from TUG was only 6° . A precision of 0.7 ns was obtained and a modified Allan deviation of $1.3 \times 10^{-9} \tau^{-3/2}$. The difference between GPS and TWSTT measurements, after applying Sagnac correction and all other known corrections, was about 350 ns; so this is the sum of the unknown non-reciprocity in the satellite delay and in the earth station equipment delay.

Recently, during the last two weeks of August 1993, six European time labs (TUG, NPL, PTB, FTZ, VSL, OCA) have used the same INTELSAT 307° satellite for line-up tests and preliminary TWSTT (Fig. 6). The first results (Fig. 7-10) show a modified Allan deviation ranging from 1 to $3 \times 10^{-9} \tau^{-3/2}$ at an EIRP of 47 dBW from the stations. The possible deterioration with multiple use was tested with clean carriers as well as with PRN coded signals. Also the deterioration as function of EIRP was tested. Not all results are yet fully examined and understood. A three station closure error will be also examined. A longer term test has started in november with sessions 3 times per week. Also a line-up test for a new transatlantic TWSTT including USNO and NIST also using the INTELSAT 307° satellite is foreseen end 1993 and beginning of 1994.

Support from International Organizations

The remarkable results with the TWSTT have been recognized by international bodies that deal with accurate time scales and its dissemination.

In EUROMET (EUROPEAN cooperation of national standards labs on METrology), in the field of time and frequency, a project concerning the use of two-way has been initialized in 1987 and in several European countries steps have been taken to implement two-way at the national standards institutes for time, i.e. Germany, UK, France, Austria, Netherlands, Italy (Fig.11). Bottlenecks were the costs and delivery time of earth stations, the availability of modems and to get the necessary permissions for the transmitting earth stations. Also the national signatories of satellite organizations had to be approached for transponder time.

The Comité Consultatif pour la Définition de la Seconde (CCDS) adopted a Recommendation in 1985 which was confirmed in 1987 by the 18th Conférence Général de Poids et Mesures

(C.G.P.M.) to implement two-way satellite links using PRN-coded signals for the transfer of International Atomic Time.

In 1989 the CCDS asked the Bureau International des Poids et Mesures (BIPM) to establish ad hoc working groups to coordinate activities on such time links (Fig.12). Since then two ad-hoc working-group meetings have been held: in June 1989 in cooperation with the EUROMET Project members at VSL in Delft, Netherlands and in October 1992 at TUG in Graz, Austria. Recommendations were made. In Europe the 12.50 to 12.75 GHz down link and the 14.0 – 14.5 GHz up link would be used on i.e. ECS or Intelsat satellites. The Mitrex coding would be used as a start, and possible shortcomings could be studied. The INTELSAT 307° satellite as proposed by Veenstra was preferred for transatlantic links, and could also be used for US and European regional links.

During the CCDS meeting at the BIPM in March 1993 the ad-hoc working group was transferred into a permanent “Working Group of the CCDS on Two-Way Satellite Time Transfer”. This Working Group has met on 20 and 21 October at the NPL in Teddington (UK). After status reports from the labs, the data-format for the exchange of TWSTT data was discussed in connection with a ITU-R draft Recommendation on TWSTT. A flexible data format was agreed together with designations of labs (Figs. 13–16). Also makers of TWSTT modems (MITREX, SATRE, ATLANTIS, NIST) updated the status of their modems. A report on INTELSAT with respect to TWSTT was given by Dr. Veenstra. Also the calibration of TWSTT earth station delays were discussed. A co-location of European stations with an transportable USNO earth station will be organized in 1994. The goal is to combine this with a VSL satellite simulator to obtain as correct as possible absolute delay measurements. This is expected to solve the problem that even from a visiting third station the individual delay corrections at two earth stations cannot be determined. NPL has offered to edit a TWSTT Newsletter, the first issue has been distributed in October 1993. Contributions can be sent to John Davis, NPL, Teddington, Middlesex, United Kingdom, TW11 0LW.

Also in the International Telecommunication Union (ITU), the ITU-R (the former CCIR) Study Group VII in Geneva has adopted a question to study two way time transfer and for this purpose a Task Group (TG7/2) has been established in 1991 (fig. 17). Its task will be to issue Recommendations about the use of TWSTT (including procedures and data format) and how to avoid or solve encountered problems. This TWSTT question was recently designated urgent by the ITU Radiocommunication Assembly in November 1993.

In April 1993 the first Meeting of TG7/2 was held in Geneva. A very thorough discussion about delay calibration methods and the data format took place. A preliminary draft recommendation was adopted, but the content of two Annexes that will give more details about the calculation and measurement procedures as well as the data format have to be finished by the participants by mail and will then be adopted at the next formal meeting in the fall of 1994. Cooperation and coordination with other Working Groups like the CCDS and EUROMET has been sought; technical matters should be discussed in TG7/2 and organizational matters concerning the contribution to TAI should be discussed in the CCDS Working Group although some overlap may occur. As a consequence, the above mentioned ITU TG7/2 data format document was discussed and a first draft agreed at the CCDS TWSTT meeting in Teddington October 1993.

Conclusion

Very promising results with Two-way Time Transfer have been obtained and interesting experiments are being planned. The use of small earth stations (VSAT's) at the premises of the timing centres has now been achieved. There is still much to do to obtain the inherent good absolute accuracy of TWSTT.

References

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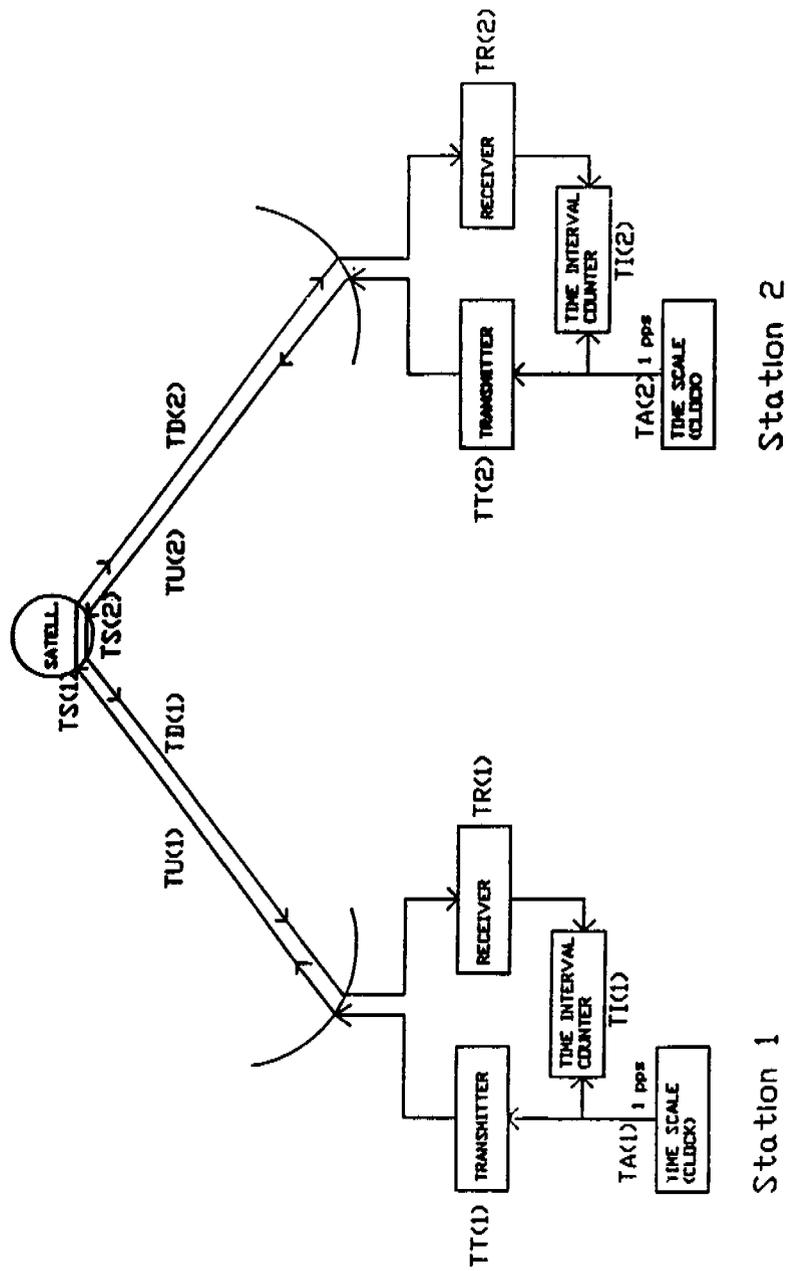


Fig. 1 Basic Two-Way Satellite Time Transfer scheme

- 1962 Telstar UK, USA
- 1974 PN code & BPSK
- 1983 MITREX: Transatlantic USNO, DFVLR; <0.2W, 55 dBHz
small antenna 2.4 m, 1 ns Intelsat 325
- 1985 NAVEX experiment Space Shuttle German DFVLR
- 1987 MITREX NIST, USNO, NRC routinely 3x/week
- 1990 MITREX TUG(A), OCA(F), LASSO & GPS ECS
- 1992 MITREX Transatlantic TUG, USNO Intelsat 307
Japan (CRL) - Korea (KRISS) Intelsat 177
Germany: PTB - FTZ Kopernicus sat
- 1993 MITREX Italy: IEN (Turin) - ISPT (Rome) Olympus
W-Europe: TUG(A), PTB(G), FTZ(G),
NPL(UK), OCA(F), VSL(NL)
- 1994 Plans: long term experiment W-EUR 3x / wk + US

Fig. 2 Progress of TWSTT

INTELSAT V-A(F13) at 307 E (53 W)

Stations: NIST, USNO, TUG, VSL, PTB, NPL, OCA, FTZ
(IEN, LPTF, NRC)

Occasional Use / No full connectivity

Transatlantic

West Spot (USA) Uplink 14.0 GHz

West Spot Downlink 11.7 GHz

East Spot (W-Eur) Uplink 14.0 GHz

East Spot Downlink 12.5 GHz

Useful for transatlantic Time Link for BIPM
International Atomic Time (TAI)

for regional links in USA and W.-Europe
but not coincident any more

(see Veenstra, Proc. PTTI, 1990)

Fig. 3 Transatlantic link USA-Europe

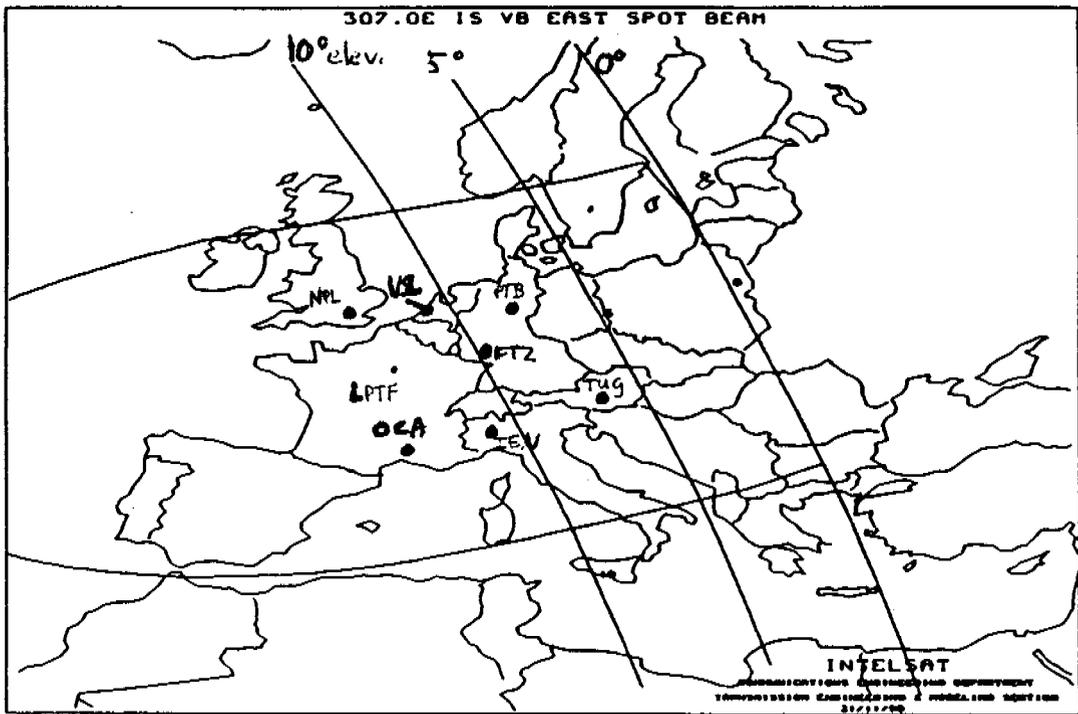


Fig. 4 Footprint Europe East Spot INTELSAT 307

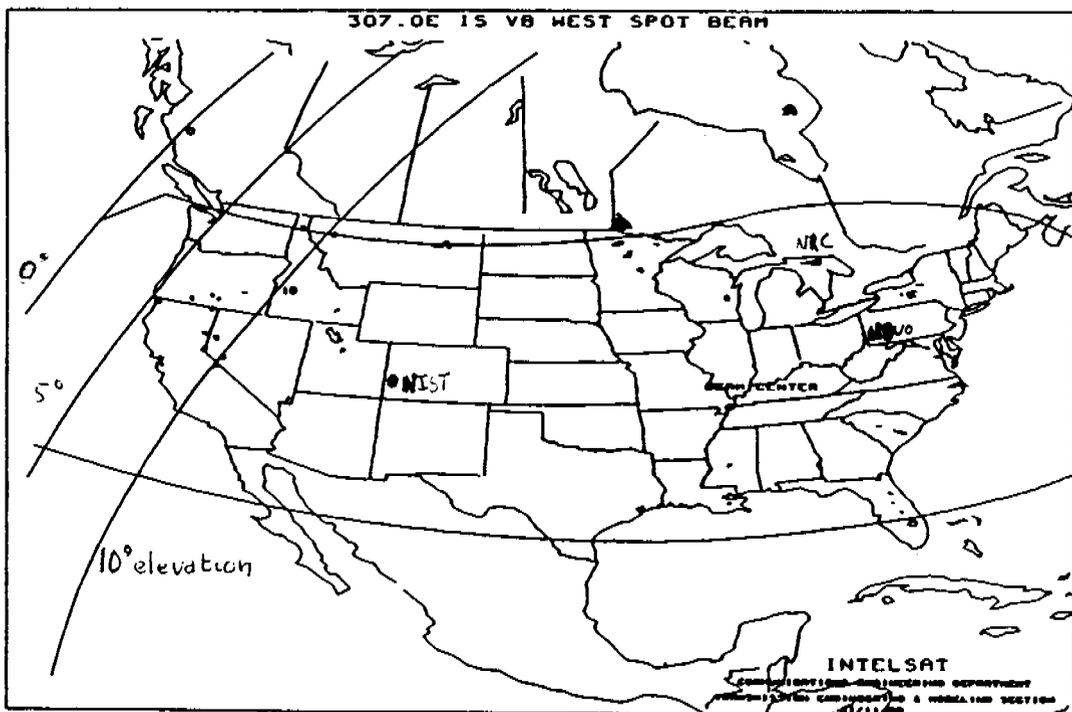


Fig. 5 Footprint North America West Spot INTELSAT 307

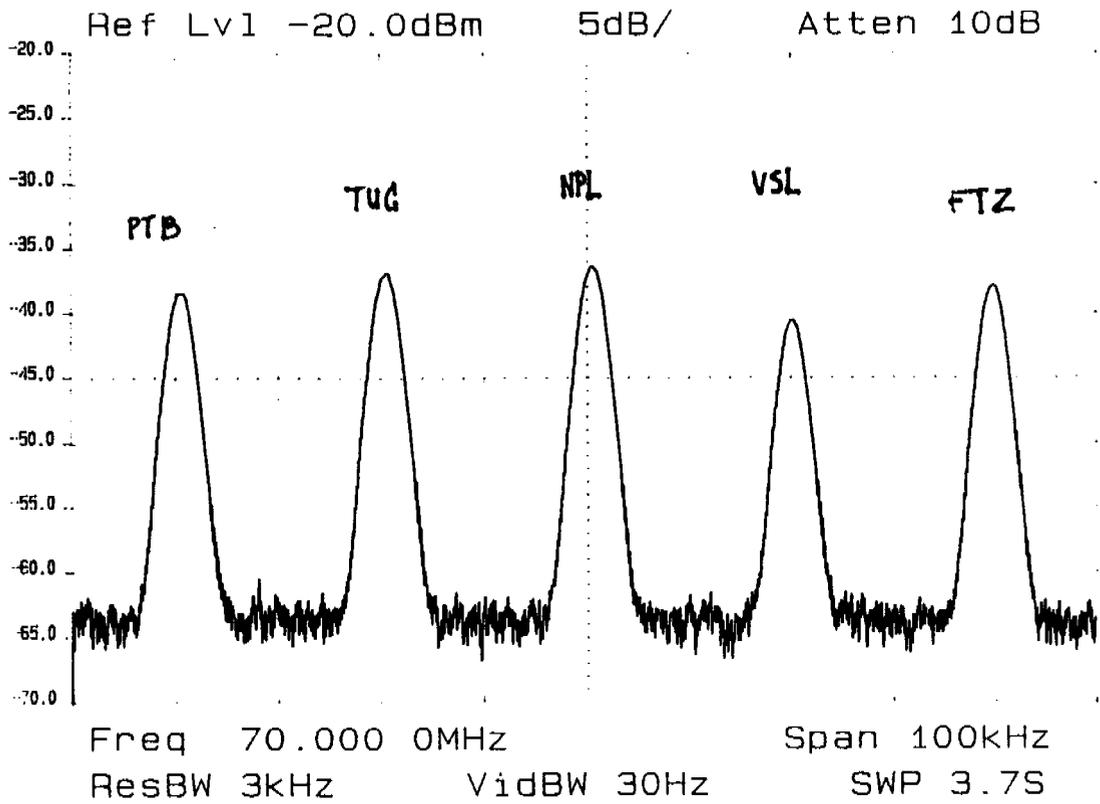


Fig. 6 Clean Carriers of the European Labs offset by $n * 20$ kHz

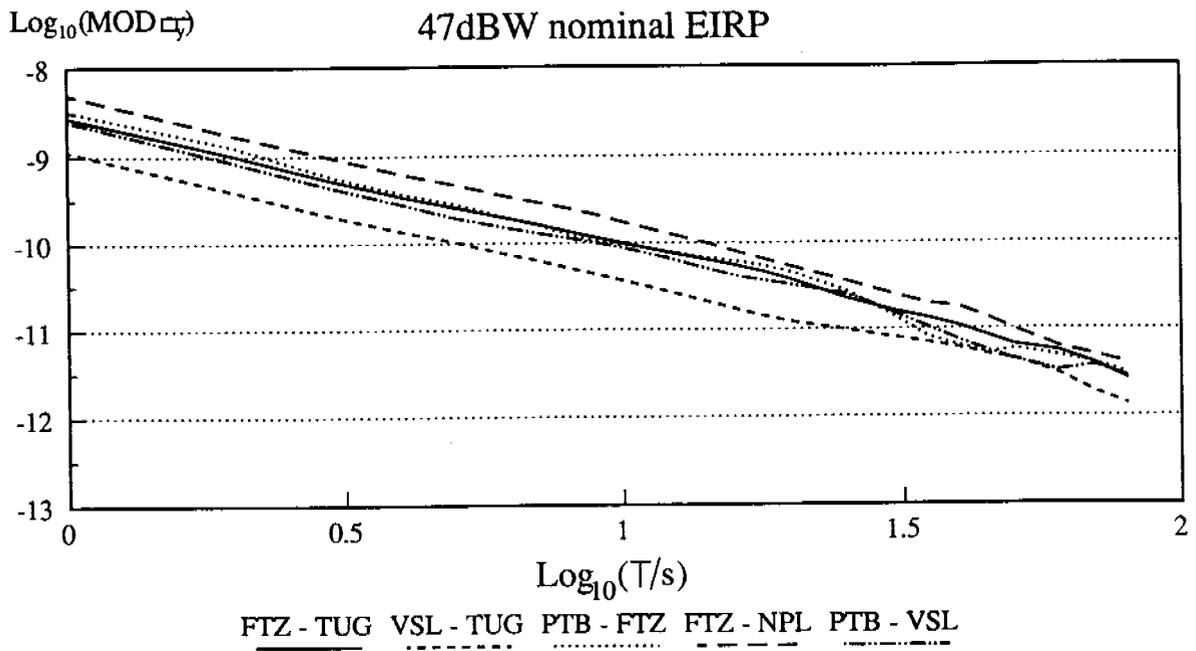
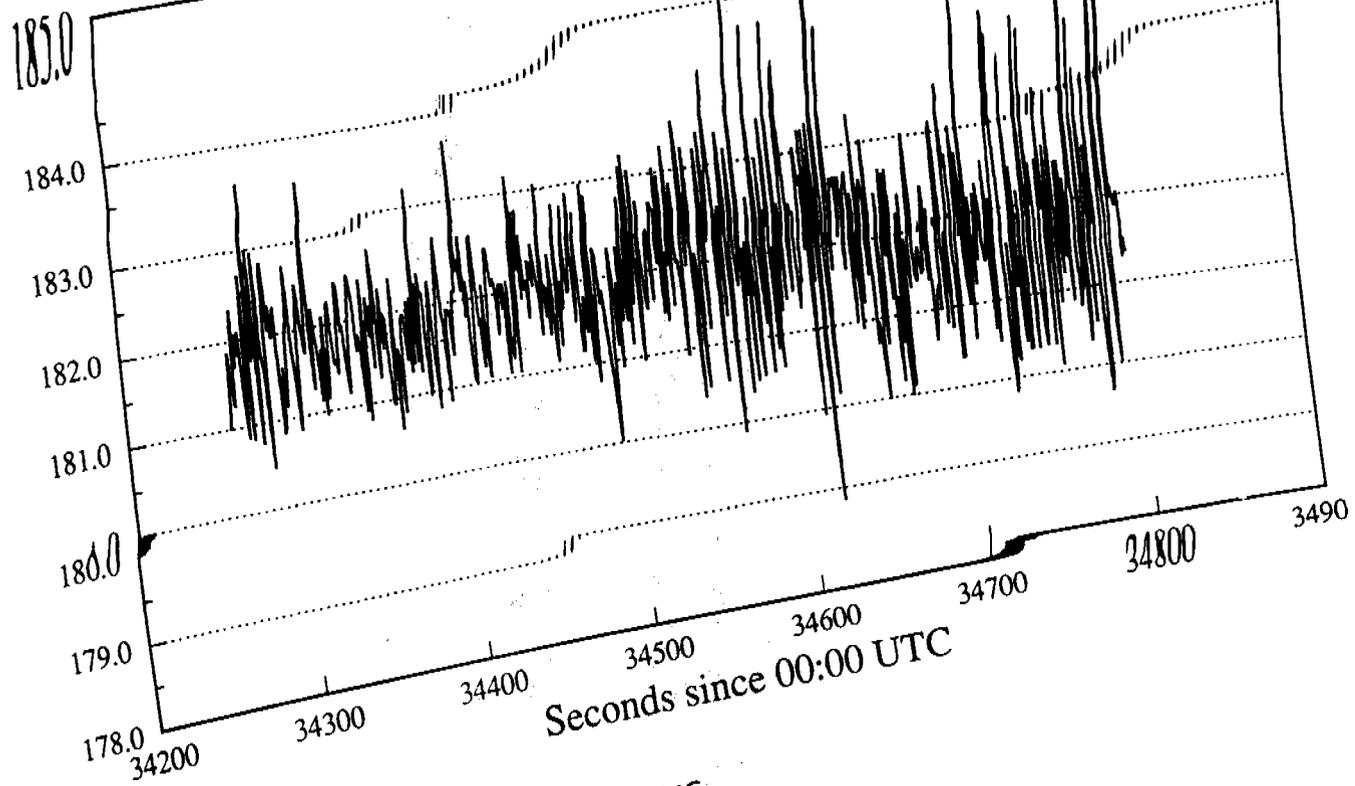


Fig. 7 Stability plot of different TWSTT pairs

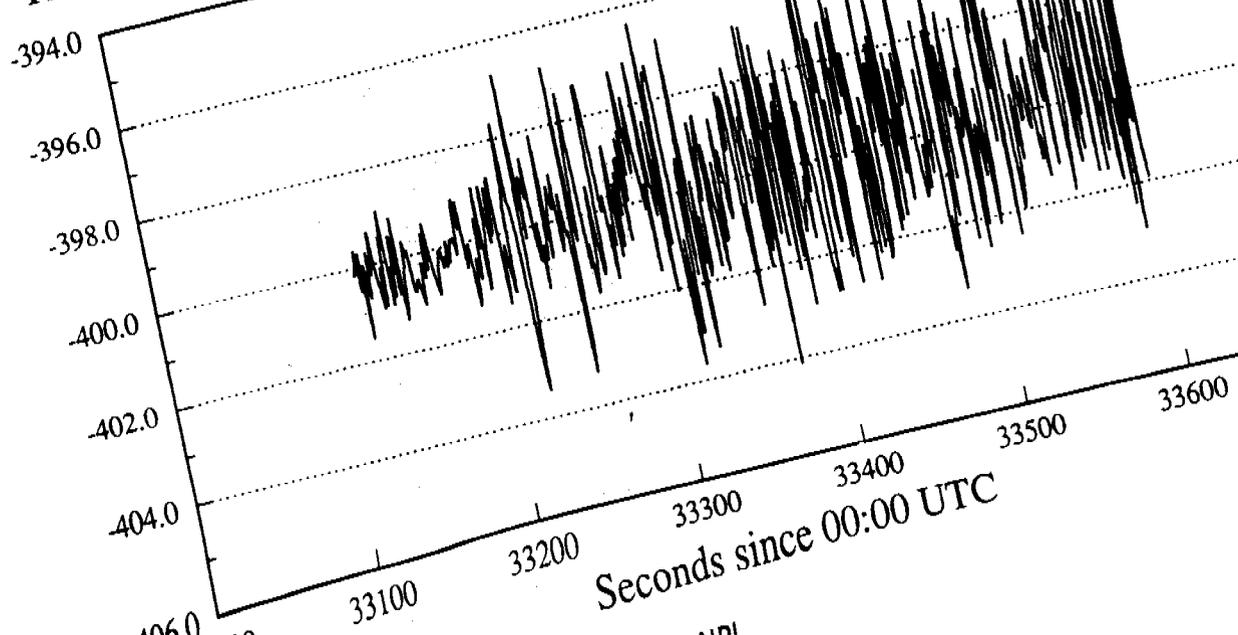
Time Transfer (ns)

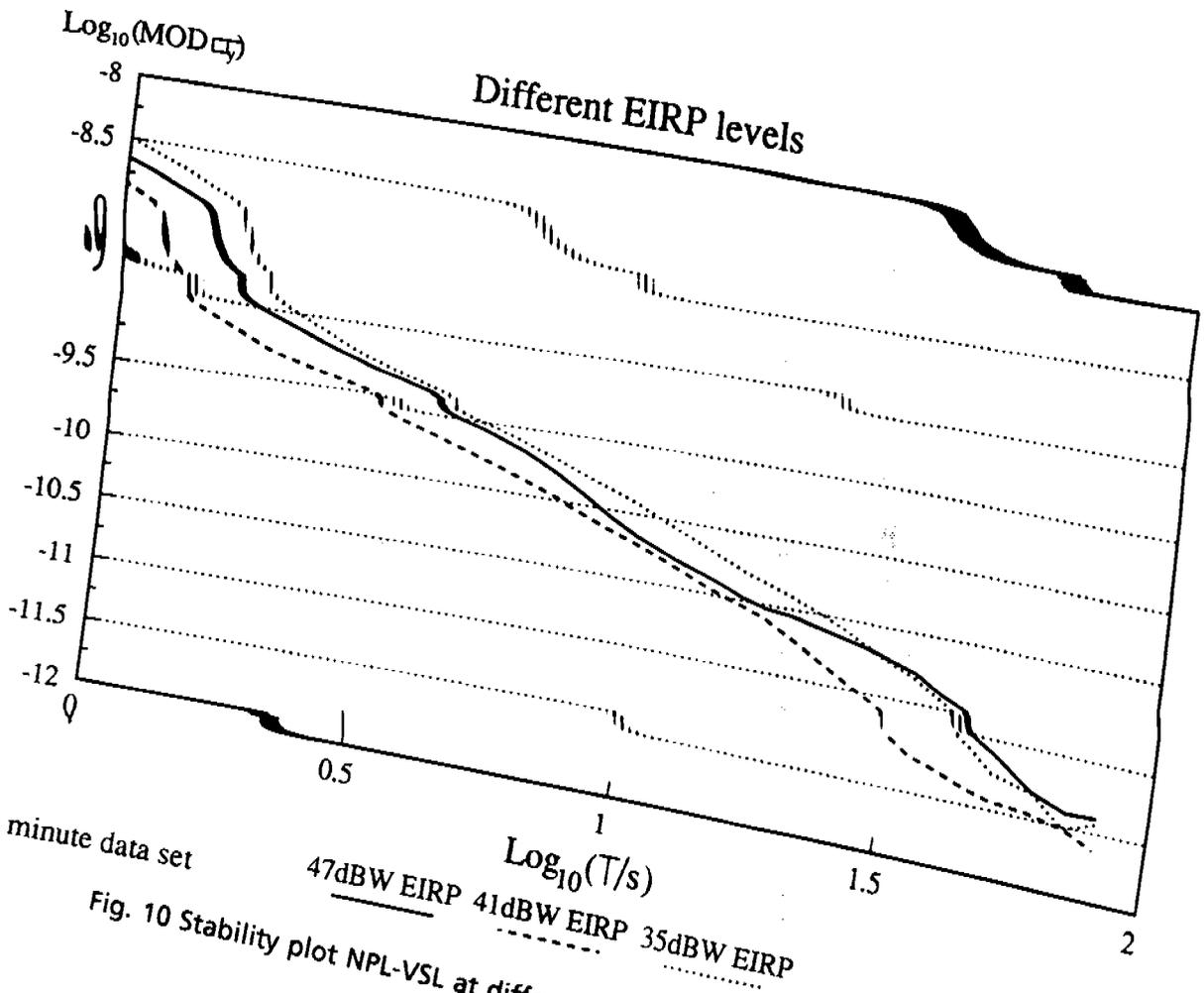


27/8/93

Fig. 8 Run of TWSTT data VSL-TUG

Time Transfer (ns)





5 minute data set

Fig. 10 Stability plot NPL-VSL at different EIRP levels

Project 93

EUROMET

Satellite Time and Frequency intercomparison
using PRN codes (Two-Way method)

Participants:

- NL (VSL)
- AT (BEV, TUG)
- DE (PTB, FTZ)
- FR (LPTF, OCA)
- GB (NPL)
- IT (IEN)

- G. de Jong
- D. Kirchner
- P. Hetzel, A. Söring
- P. Urich, F. Baumont
- J. Davis, P. Pearce
- F. Cordara

- get earth stations ready
- select satellite, get transponder time
- measurement schedule

Fig. 11 EUROMET TWSTT Project

Convention of the METER

CCDS - Comité Consultatif pour la Définition de la Seconde

CGPM - Conférence Générale des Poids et Mesures

BIPM - Bureau International des Poids et Mesures, Sèvres (F)

1985 CCDS, 1987 CGPM: Recommendation to support the use of PRN on Two Way for International Atomic Time

1989 CCDS: Recommendation that the BIPM establish and coordinate (regional) ad-hoc working groups for Two Way

1993 CCDS Working Group on Two-Way Satellite Time Transfer
How to use TWSTT for TAI formation
Chaired by: Cl. Thomas (BIPM)
Secretariat: W. Levandowski (BIPM)

Fig. 12 CCDS Working Group

TWSTFT DATA FORMAT

LAB Designations

LAB	DESIGNATION (ASCII char)	TX CODE (MITREX)	FREQ. OFFSET (kHz from center)
TUG	A	0	-20
NPL	B	1	0
VSL	C	2	+20
FTZ	D	3	-40
PTB	E	4	+40
OCA	F	5	+60
NIST	G	6	+80
USNO	H	7	-80

Fig. 13 Agreed TWSTT data format: Lab designations

TWSTFT DATA FORMAT

Legend

jjjj = Modified Julian Date
hh = UTC hour
mm = UTC minute
ss = UTC second
L = designates the LOCAL lab. by an ASCII char.
R = designates the REMOTE lab. by an ASCII char.
* = indication at the start of a line of text
[] = designates an option
| = designates a choice
0.nnnnnnnnnnnn =
time interval in seconds to 12 decimals (res. 1 ps)

Fig. 14 Agreed TWSTT data format: Legend

TWSTFT DATA FORMAT

Data file format

FILENAME = Ljjjjhh.mmR where jjjj, hh, mm give
the nominal start date of the TWSTFT session

HEADER:

* Ljjjjhh.mmR
* UTC(LAB) - CLOCK = 0.nnnnnnnnnnnn [jjjj hhmmss]
* CLOCK - 1PPSREF = 0.nnnnnnnnnnnn [jjjj hhmmss]
* 1PPSREF - 1PPSTX = 0.nnnnnnnnnnnn [jjjj hhmmss]
* DATA = [1PPSREF - 1PPSRX][1PPSTX - 1PPSRX][TESTLOOP][.]

DATA:

jjjj hhmmss 0.nnnnnnnnnnnn
| | |
| | |
jjjj hhmmss 0.nnnnnnnnnnnn

Fig. 15 Agreed TWSTT data format: Data Format

TWSTFT DATA FORMAT

EXAMPLE of Data file format

Contents of File A4926610.56B of data measured at TUG from a TWSTFT session with NPL on MJD 49266 scheduled at 10h 56 min :

```
* A4926610.56B
* UTC(LAB) - CLOCK = 0.000000123456 49266 101000
* CLOCK - 1PPSREF = 0.000000012345 49266 101500
* 1PPSREF - 1PPSTX = 0.000000001234 49266 102000
* DATA = 1PPSREF - 1PPSRX
49266 105616 0.270924666406
49266 105617 0.270924663805
49266 105618 0.270924660170
49266 105619 0.270924657628
49266 105620 0.270924654270
```

Fig. 16 Agreed TWSTT data format: Example

ITU - International Telecommunication Union

ITU-R - Radiocommunication Sector, (formerly CCIR:
Comité Consultatif International de Radio)

SG7 - Study Group 7, Science Services

WP7A - Working Party 7A, Time and Frequency

TG7/2 - Task Group 7/2, Standard T/F from Satellites

1991 New Question to Study Two Way Time Transfer
through Communication Satellites:

- long-term stability
- time accuracy
- frequency comparison capability
- performance compared to other methods
- causes & cures systematic delay variations
- standard data (exchange) format for comparisons

Fig. 17 ITU-R Task Group 7/2 on TWSTT

QUESTIONS AND ANSWERS

J. Levine, NIST: Have you looked at the correlations between the station data and the remote monitoring data?

Lt. Norm Mason: We have not done that yet, mainly because we haven't taken the data and refined it. Part of the problem is that we also want to look at the time of transmission and that has given us some problems. The data is not really valid enough to do a real hard look correlation.

Christine Hackman, NIST: You mentioned briefly that you had tried using two-way satellite time transfer. But you didn't say much more than that, except for it worked. Could you just expand a little bit more on what you tried?

Charles Justice: Basically we had a two-way transfer antenna set up at Seneca, New York. We had personnel from USNO helping us to install this. Then they used their two-way satellite van up there to collect the data. And it was just about that simple. I think we were only there a day or two. And from the data that they got, as short as it was, it showed that we got excellent measurements; and they were 1 below 10 ns. I can't remember exactly the level. If you are interested, we could send you the printouts of the charts that we got. But that was it. We had hoped to put these in at all of our master stations because we were pretty certain from those results, and also from two-way work at NIST and USNO being done for several years at least. I know it goes back at least a few years. We were pretty sure that it would more than meet the 100 ns requirement that the public law stated. But that is when we found out that our source of funds was going to dry up; we then had to drop the project because we couldn't do anymore. We were originally going to set up the antennas at all the master stations and get the modems and everything else necessary. But that is as far as we could take it.