SPREAD SPECTRUM TIME TRANSFER EXPERIMENT VIA INTELSAT

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ABSTRACT

A two-way time synchronization experiment was performed in July 1983, between Washington, D.C. and Oberpfaffenhofen, Federal Republic of Germany. The experiment used the 14/11-GHz transponders on the INTELSAT V Atlantic spacecraft. The MITREX (Microwave Time and Ranging Experiment) modem designed, developed, and constructed at the Technical University of Berlin was employed. The experiment was jointly conducted by COMSAT Laboratories and the Institute for Nachrichtentechnik, DFVLR, Oberpfaffenhofen, FRG, in cooperation with the United States Naval Observatory and the Institut für Luft- und Raumfahrt, TU Berlin.

The spread spectrum signal occupied a bandwidth of 4 MHz and used the power normally required by a single-voice carrier. The ground stations involved had parabolic dishes of 2.4 m (G/T = 20 dB/K) and 4.5 m (G/T = 26 dB/K). In the 4-MHz occupied bandwidth, the carrier-to-noise ratio was -11 dB. At this power level, the time transfer performance had rms-standard deviations of better than 1 ns.

The experimental results confirm that an international time transfer and clock synchronization network using communications satellites is economically viable when using a spread spectrum transmission format.

INTRODUCTION

During 1978 and 1979, COMSAT Laboratories participated in an experiment of time and frequency synchronization via the CTS satellite [1],[2]. This experiment demonstrated the use of a conventional PSK data transmission to transfer time between primary standards. These previous experiments used a technique applicable to situations where it was desired to send time or frequency via an existing high speed digital satellite link. The disadvantage of the system was its high link requirements, 75 dB-Hz or more. This generally precluded use of such a system to directly interconnect standards labs with simple low cost small terminals.

In 1983 a new spread spectrum modem, the MITREX, was made available that did not require as much link power as the old PSK system. This unit required a nominal 55 dB-Hz, the same power as that of an SCPC voice channel [3].

The MITREX (Microwave Time and Ranging Experiment) modems, designed, developed, and constructed at ILR*, were originally intended for use with the SIRIO-2 satellite

- to support the LASSO (Laser Synchronization from Stationary Orbit) project with additional ranging information
- for comparison of different time transfer techniques (laser/microwaves) under the same conditions.

The applied concept makes use of the operating transponders in the same way as do telecommunication systems. First modem tests in the laboratory showed a very promising performance; therefore, after the launch failure of the SIRIO-2 satellite, the U.S. Naval Observatory (USNO) arranged with COMSAT for time transfer tests

*ILR = Institut für Luft- und Raumfahrt, the Aerospace Institute of Technical University of Berlin (TUB) with this modem. For the ILR this experiment is part of an experimental study for time and ranging concepts which is sponsored by the German Ministry for Science and Technology (BMFT).

This experiment evaluated the performance of the MITREX modem under simulated and actual satellite links. As part of the experiment, a time transfer between UTC (USNO) and UTC (PTB) was made. The experiment was conducted using the 11/14-GHz spot beam transponders on the INTELSAT primary Atlantic Ocean region satellite (INTELSAT V F3). COMSAT provided a transportable 2.4-m earth station at USNO that was connected directly to the master clock. In Germany, a 4.5-m fixed station at DFVLR* (Oberpfaffenhofen) was used. A portable cesium clock was used to close the time transfer link to the PTB master clock.

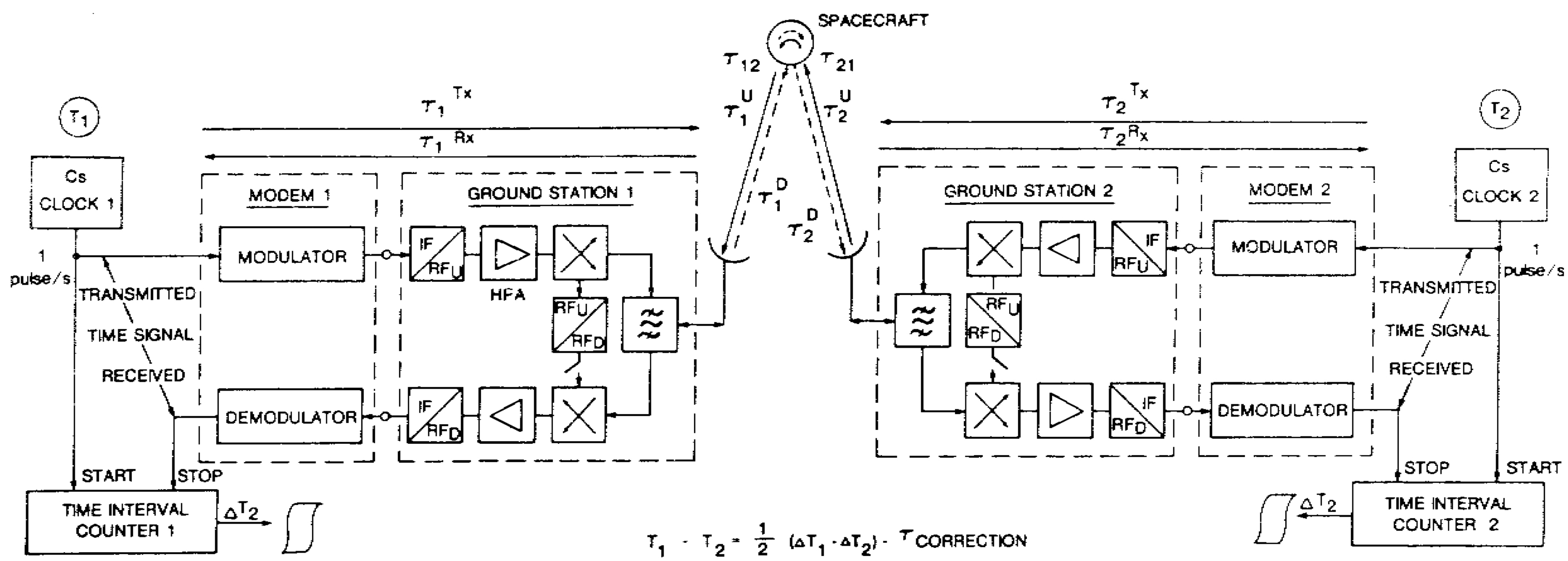
MODEM DESCRIPTION

The time transfer techniques require each station to transmit a "time mark," e.g., a pulse, and to receive the time mark transmitted by the opposite station. The transmitted time mark need not appear periodically; only coordination with the local time scale is necessary. The basic concept for 2-way satellite time transfer is described in Figure 1. Two separated clocks (representing the local time scale) are compared in their time values via the telecommunication channel of a geostationary satellite.

A special unit is needed to interface between the 70-MHz IF of a satellite ground station and the time-keeping hardware necessary to manage and to compare the time scale. This unit is called a modem (modulator/demodulator). It is housed in a 19-in. drawer and operates at the transmit part as a pseudorandom (pn) signal encoder and at the receive part as a corresponding pn signal decoder (Figure 2). The pn sequence which is used to spread the time signal over a large frequency band is of 2-MHz chip rate and has a period of 10^4 chips.

The generation of periodic sequences of the pn-type is accomplished by means of a shift register with prescribed feedback connections. An n-stage shift register is capable of generating a periodic output sequence whose maximum length is $p = 2^n - 1$. These maximal sequences have certain properties which

*DFVLR = Deutsche Forschungs-und Versuchsanstalt für Luft-und Raumfahrt



$$T_1 - T_2 = \frac{1}{2}\,(\Delta T_1 - \Delta T_2) - \tau_{CORRECTION}$$

$$\tau_{CORRECTION} = \frac{1}{2}\left\{(\tau_1^{Tx} - \tau_1^{Rx}) - (\tau_2^{Tx} - \tau_2^{Rx}) + (\tau_{12} - \tau_{21}) + (\tau_1^{U} - \tau_2^{U}) + (\tau_7^{D} - \tau_2^{D}) + \tau_R\right\}$$

Figure 1

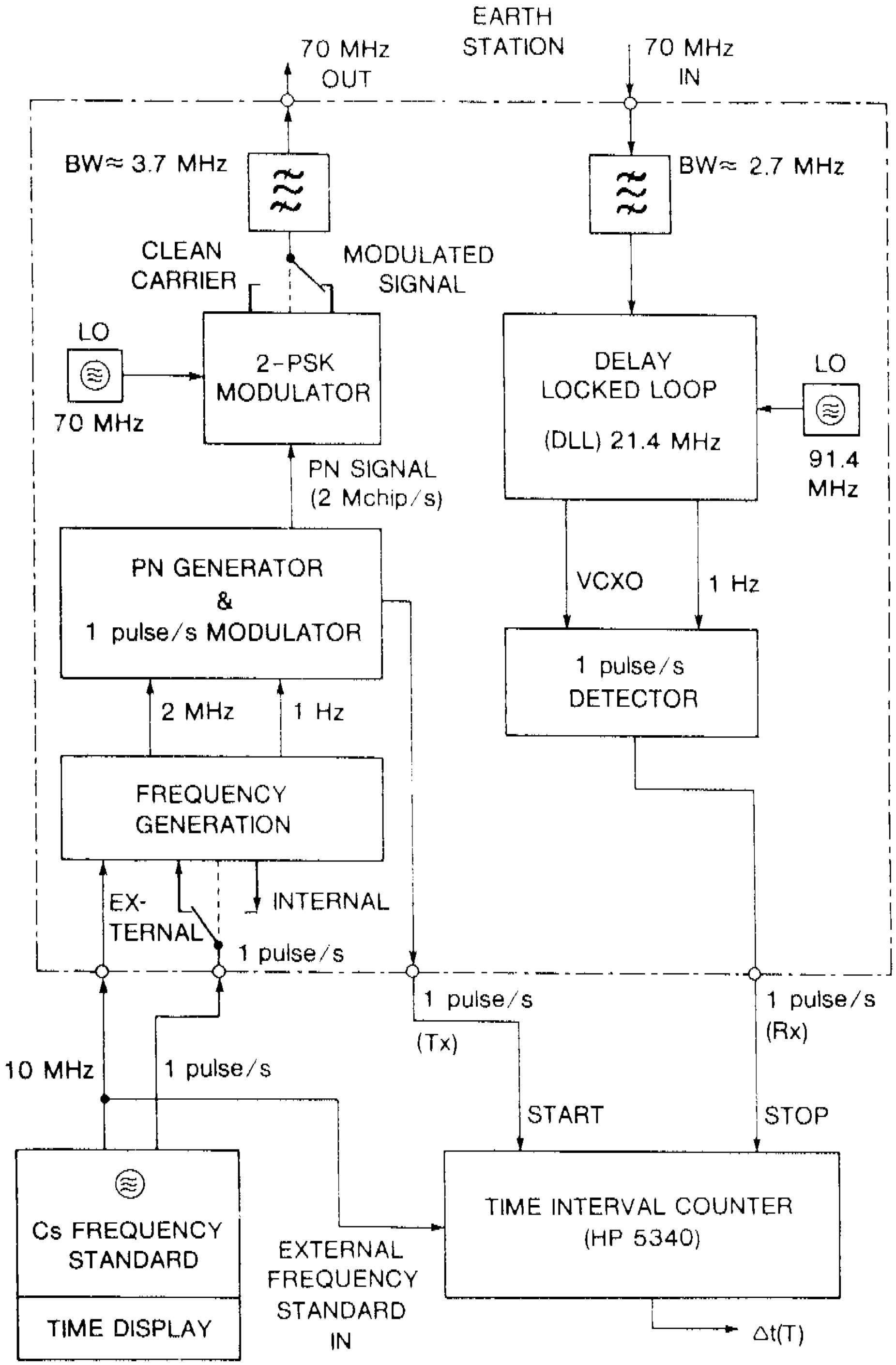

EARTH
STATION
70 MHz
OUT
70 MHz
IN
BW≈ 3.7 MHz
BW≈ 2.7 MHz
CLEAN
CARRIER
MODULATED
SIGNAL
LO
70 MHz
2-PSK
MODULATOR
DELAY
LOCKED LOOP
(DLL) 21.4 MHz
LO
91.4
MHz
PN SIGNAL
(2 Mchip/s)
PN GENERATOR
&
1 pulse/s MODULATOR
VCXO
1 Hz
1 pulse/s
DETECTOR
2 MHz
1 Hz
FREQUENCY
GENERATION
EX-
TERNAL
INTERNAL
1 pulse/s
1 pulse/s
(Tx)
1 pulse/s
(Rx)
10 MHz
1 pulse/s
START
STOP
Cs FREQUENCY
STANDARD
TIME DISPLAY
EXTERNAL
FREQUENCY
STANDARD
IN
TIME INTERVAL COUNTER
(HP 5340)
Δt(T)

Figure 2

make them very useful, especially in ranging systems (see Figure 3). Our basic sequence of 10^4 chips is a truncated part of a maximal sequence of 16 383 chip length. The choice of this length is a weighing between acquisition time which grows with the length and cross correlation which is the smallest for a maximal length sequence. To ease the overall system design, especially the frequency generation, a sequence with a period which is an even number and some decade is used. To get the unambiguous range of 1 s, this basic sequence will be repeated continuously so that 199 times the same sequence is generated before in the period 200, the 1 pps (1 peak per second) is indicated (Figure 4). This indication happened by a sort of phase modulation. At the beginning of the sequence one chip will be deleted and in the middle one additional chip will be inserted. This modulation, called COBIPAM (Coded Bi-Phase Pulse Amplitude Modulation), will be detected in the receiver.

MULTIPLEXING

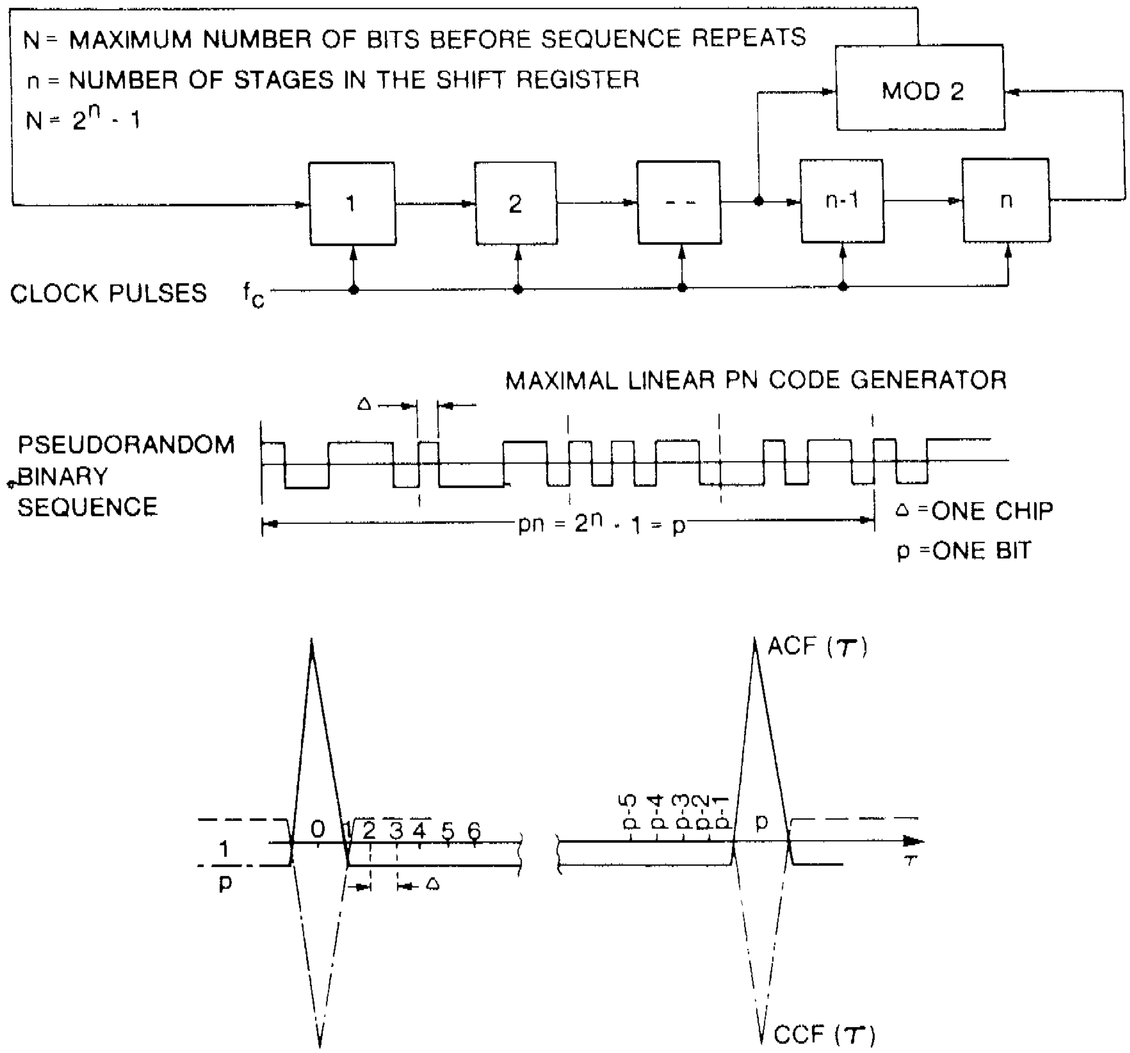
An important feature of pn-sequences is the code, multiplexing property. By using sufficiently orthogonal codes, it is possible to use the same frequency band for different users without disturbing each other. In the current modem, two codes are implemented but a number of 4 or 8 codes (with a sequence length of 10^4 chips) are possible without deterioration of the current modem quality.

TRANSMITTER (Figure 5)

Baseband input signals to the modem are standard frequency and the time tick 1 pps generated by the time standard to be compared, i.e., a cesium clock normally. In the current version, the standard frequency has to be 10 MHz, but with a simple modification, 5 MHz could also be used.

The incoming standard frequency is divided down to 2 MHz and then fed to the clock input of the pn-generator where the 1 pps is used to synchronize the generator with the atomic clock. This synchronizer provides also the pulse for starting the time interval counter.

Output signal of the pn-generator is the continuously repeated code pattern with a chip rate of 2 Mchip/s which is applied on the data input of a double balanced mixer to spread the spectrum of the 70-MHz carrier to the RF-bandwidth (2 PSK modulation). The RF spectrum has a $(\sin x/x)^2$ characteristic



ACF (τ) = pn (τ) $\oplus$ pn (t - τ) AUTOCORRELATION FUNCTION

CCF (τ) = pn (τ) $\oplus$ $\overline{\text{pn}}$ (t - τ) CROSS-CORRELATION FUNCTION

pn = pn SEQUENCE $p = 2^{n} - 1$

$\overline{\text{pn}}$ = THE SAME AS pn, BUT INVERTED

Figure 3

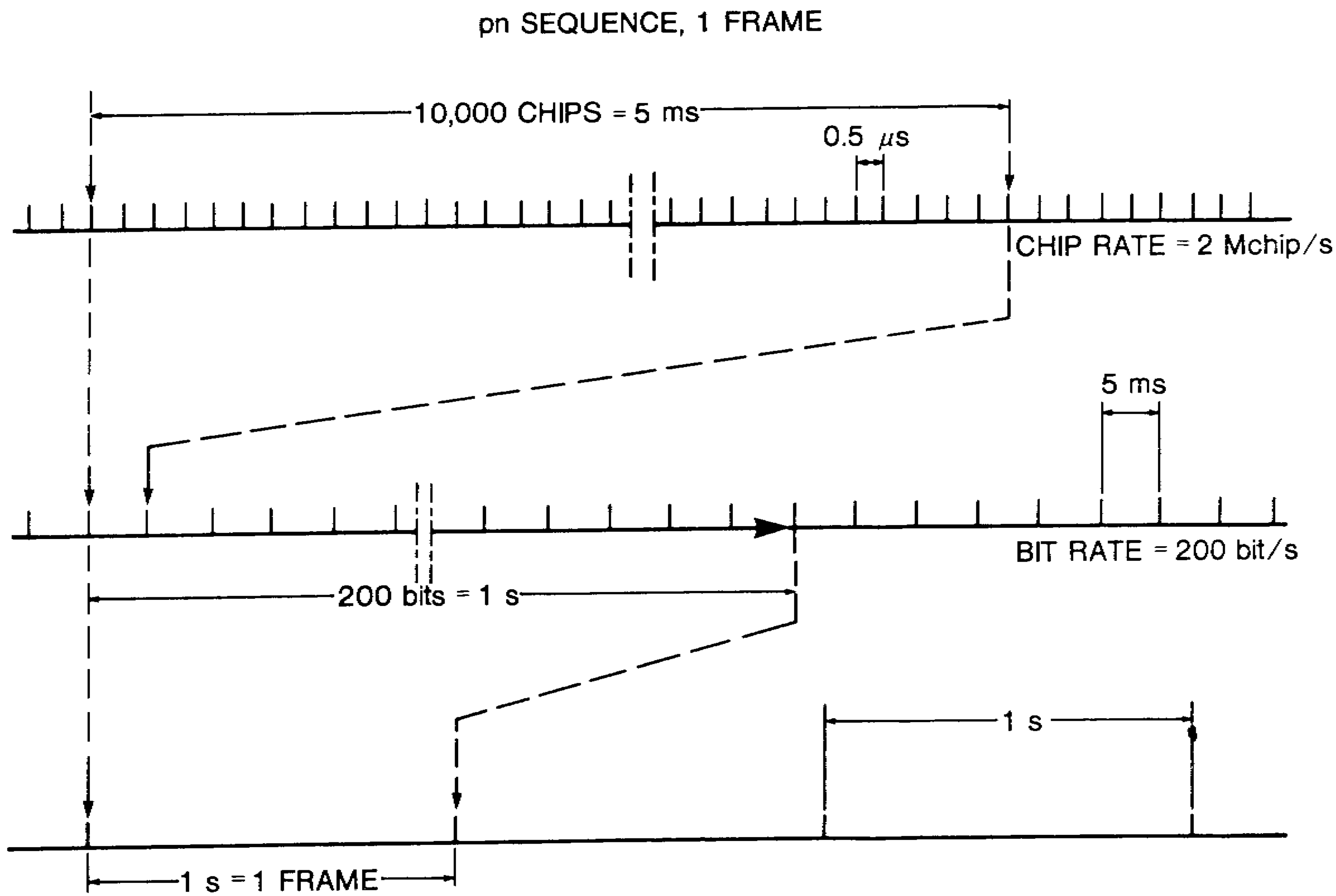
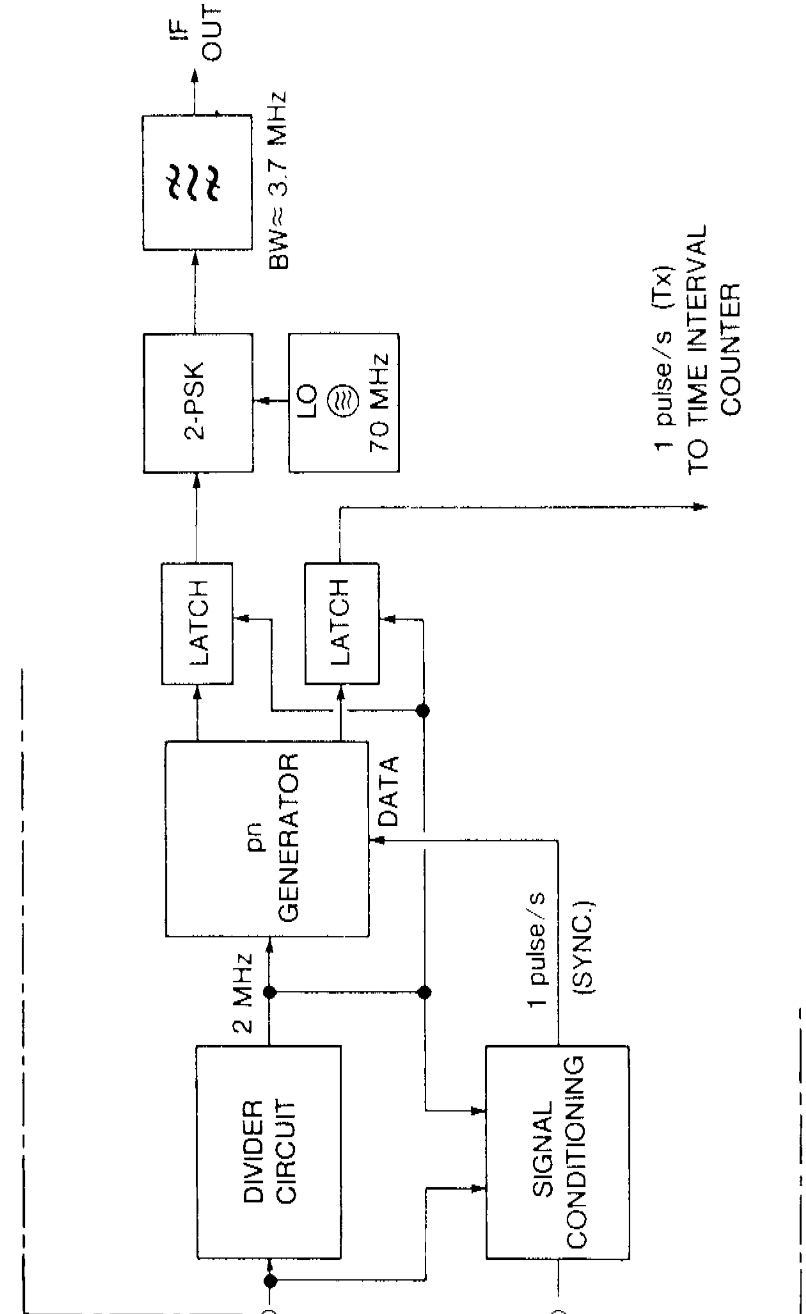

pn SEQUENCE, 1 FRAME
10,000 CHIPS = 5 ms
0.5 μs
CHIP RATE = 2 Mchip/s
5 ms
BIT RATE = 200 bit/s
200 bits = 1 s
1 s
1 s = 1 FRAME

Figure 4



IF OUT
BW≈ 3.7 MHz
2-PSK
LO
70 MHz
1 pulse/s (Tx) TO TIME INTERVAL COUNTER
LATCH
LATCH
pn GENERATOR
DATA
2 MHz
1 pulse/s (SYNC.)
DIVIDER CIRCUIT
SIGNAL CONDITIONING
10 MHz
FROM TIME STANDARD
1 pulse/s

Figure 5

with a bandwidth of about 4-MHz (main lobe) and is suitable for satellite transmission (Figure 6).

Whereas a truly random chip stream has a continuous spectrum, this chip stream generates a spectrum with a fine structure of separate lines whose spreading is determined by the sequence repetition rate (200 Hz).

RECEIVER (Figure 7)

The received signal, after down-conversion to 70 MHz, will be applied on the IF input of the modem and will then pass a predetection filter with a bandwidth of about 2.7 MHz (3 dB). The choice of this bandwidth gives an additional receiver gain of about 1.5 dB (the noise contribution is proportional to the bandwidth while the correlation loss depends on the $(\sin x/x)^2$ shape) but the additional signal delay (and therefore the delay variations by ambient effects) are relatively small. The main part of the receiver is the delay-lock loop (DLL) which is a tracking loop with two separate correlators driven by identical, but delayed in time by one chip, code reference signals. The code itself is identical to the transmitter code. The correlator output signals, the auto correlation function (ACF) between local and transmitter code, are used to control the clock oscillator (VCXO) of the receivers pn-generator in such a way that the ACF is at the maximum level. Now, because the transmitter code reaches the receiver delayed by the transmission time, a reference mark generated at the local pn-generator can be used to stop the time interval measurement. The counter output is therefore proportional to the transmission time with some additional equipment delays which have to calibrate out.

The actual implementation of the tracking loop is shown in Figure 7. It is an IF correlator (IF frequency = 21 MHz) with phase detector for generating the VCXO control voltage. The 1 pps signal is detected by an amplitude discriminator of the auto correlation function. The jittered demodulated one pulse per second signal is used to gate out a single pulse of the VCXO clock; therefore, the resulting measurement jitter is that of the VCXO clock that is in turn used to generate the PN receive sequence.

In order to achieve the minimum of tracking jitter, the tracking loop is a modification of the "delay locked loop" [4]. In the MITREX modem, it is not the classical design of the DLL

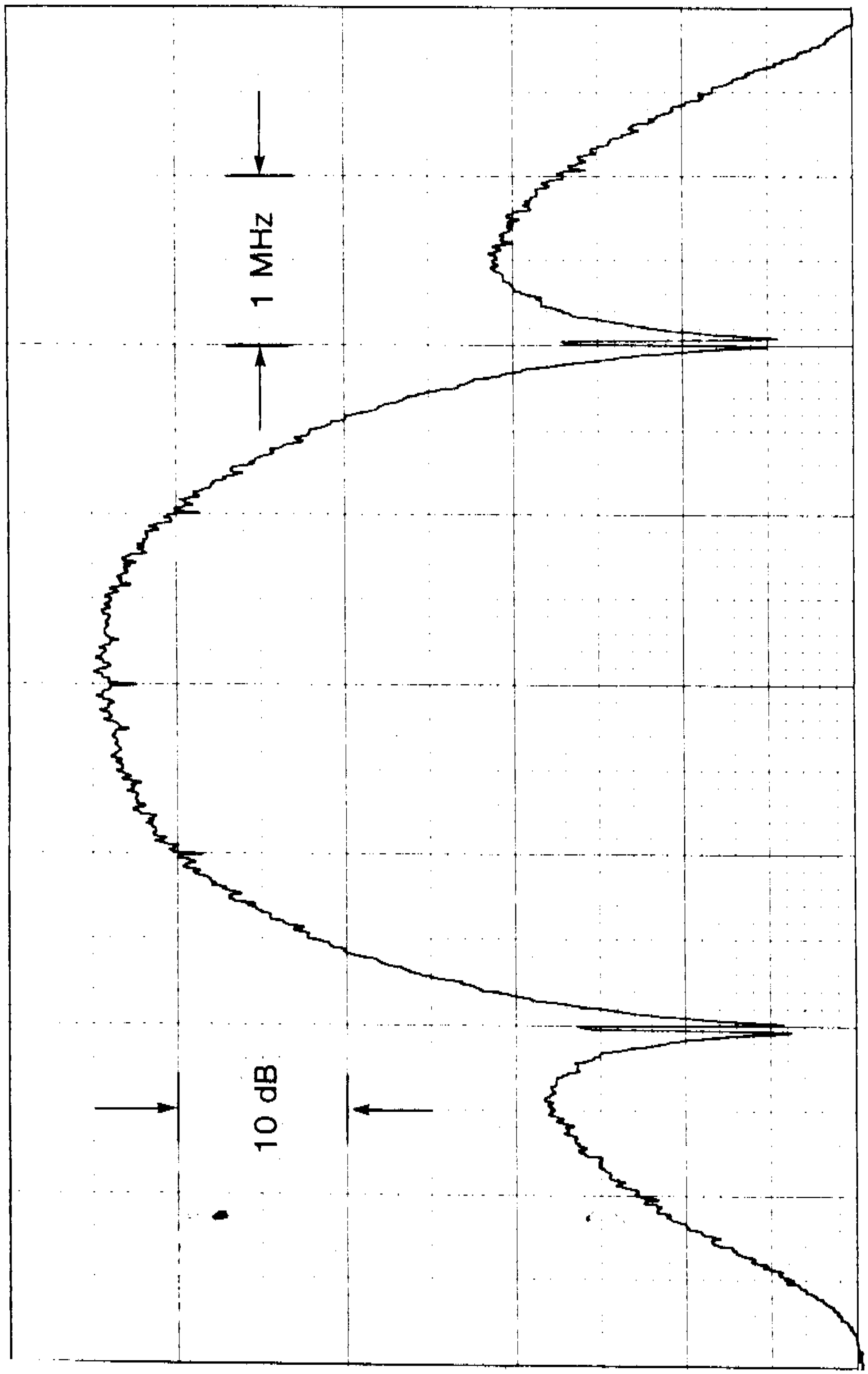
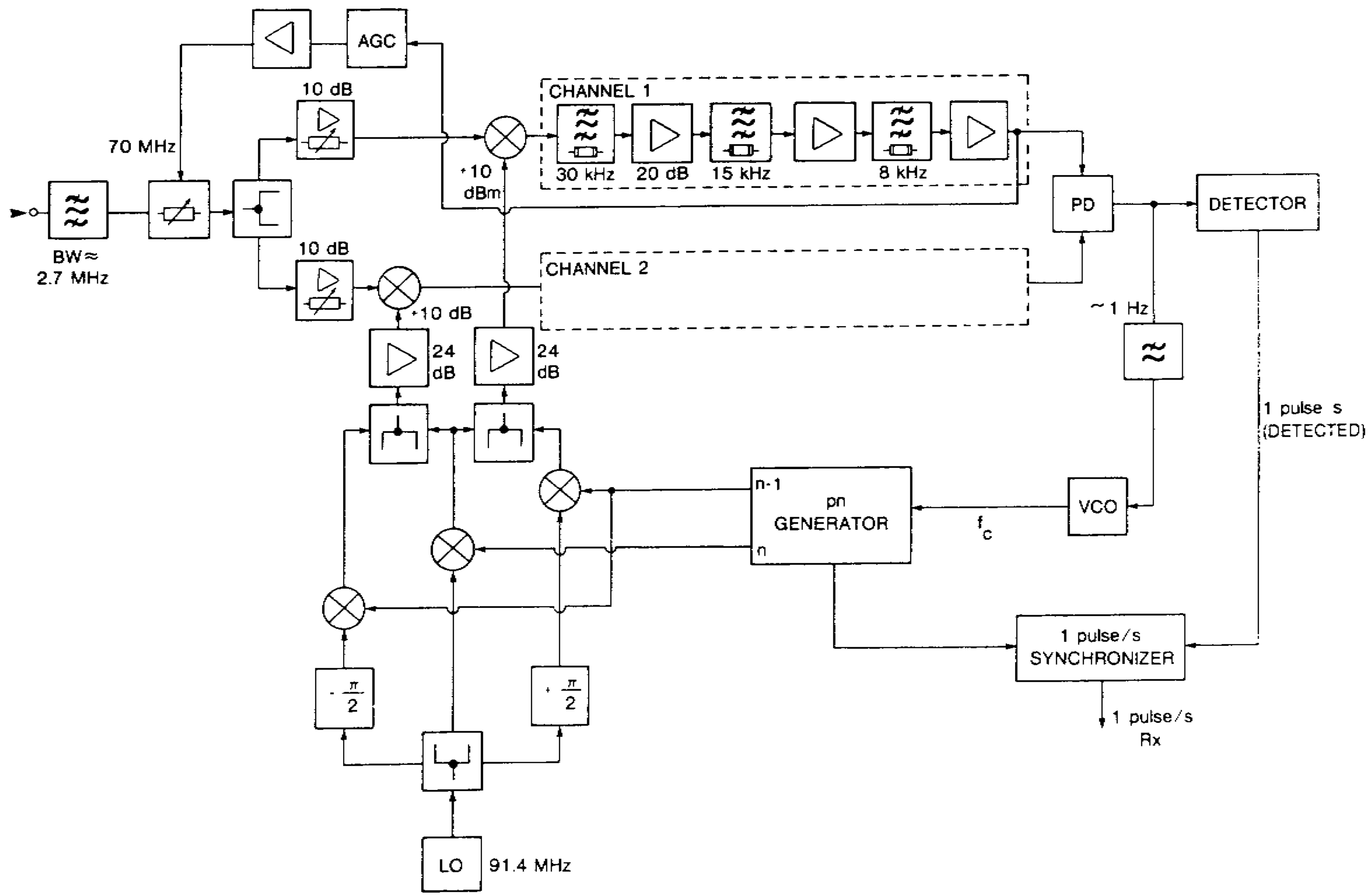


Figure 6



AGC
10 dB
70 MHz
BW≈
2.7 MHz
10 dB
+10
dBm
+10 dB
24
dB
24
dB
CHANNEL 1
30 kHz
20 dB
15 kHz
8 kHz
CHANNEL 2
PD
DETECTOR
~1 Hz
1 pulse s
(DETECTED)
n-1
pn
GENERATOR
n
f
c
VCO
1 pulse/s
SYNCHRONIZER
1 pulse/s
Rx
-π/2
+π/2
LO
91.4 MHz

Figure 7

which is used, but rather a modified one, the idea of which goes back to Osborne [4].

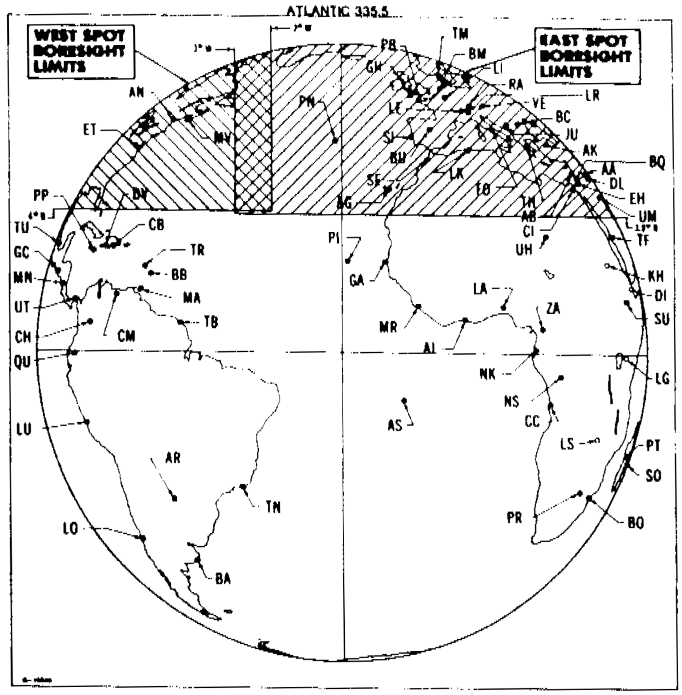
EARTH TERMINALS AND SATELLITE LINK

Two earth terminals that employed different antenna diameters were used in the experiment. The USNO site had an Advanced Communications Terminal (ACT) with a 2.4-m diameter antenna. The DFVLR used a roof-mounted 4.5-m antenna. Table 1 gives the details on the stations. Both stations were equipped with TWT amplifiers of the 200-W class although less than a watt was used. In fact, the exact transmit power was difficult to measure at this low level because of the broadband noise generated by the TWTA.

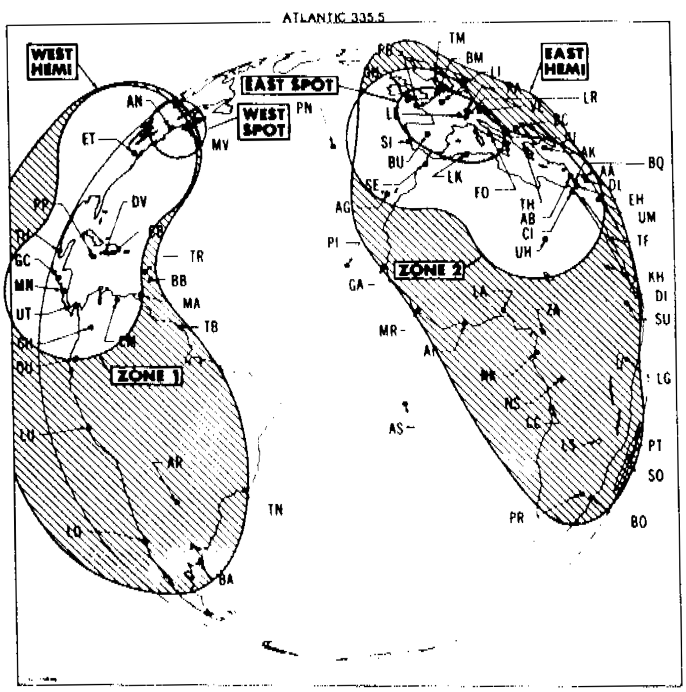
Table 1. Earth Station Parameters

	USNO ACT	DFVLR Oberpfaffenhofen
Antenna		
Diameter	2.4 m	4.5 m
Type	Prime Focus Parabolic	Prime Focus Parabolic
Polarization	Dual-Orthogonal Linear	Dual-Orthogonal Linear
Receive System Figure of Merit (G/T)	20 dB/K	26 dB/K
Maximum Possible e.i.r.p.	69 dBW	75 dBW

The satellite used was one of the new Atlantic region INTELSAT V spacecraft [6]. These are the first INTELSAT satellites to include 11/14-GHz transponders. The 11/14-GHz service is provided via spot beam antennas. There spots have limited steerability and coverage area, Figure 8. This restricts the service area that they can provide to the time transfer community. However, within the service area, the high gain resulting from the narrow spot beam antennas provides an excellent transponder for small terminal use. The link budget and the operational satellite specifications are shown in Tables 2 and 3. The low powers required in this experiment, 80 mW from the DFVLR transmitter and 170 mW from the USNO transmitter, are a function



Spot-Beam Steering Capabilities
INTELSAT V Coverages



Atlantic Ocean Region
INTELSAT V Coverages

Figure 8

Table 2. Transponder Characteristics

IS-503	
West Spot	
Flux to saturate	-79.1 dBW/m^2
G/T	9.0 dB/K
e.i.r.p.	50.0 dBW
East Spot	
Flux to saturate	-77.6 dBW/m^2
G/T	6.5 dB/K
e.i.r.p.	46.5 dBW
Path Loss	
Up-Link	-207.9 dB
Down-Link	-205.9 dB

Table 3. Link Budget

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

of the low requirements of the MITREX modem and the gain of the INTELSAT V transponders. This means that modest solid state amplifiers on 3.5-or 4.5-m antennas could support an operational link. The link does, however, have to be between areas served by the spot beams. This means for the normal antenna pointing, the north east United States, down to the D.C. area, and up to the Canadian maritime provinces, as well as Ontario and Quebec. In Europe, most countries, except northern England and Scandinavia, are served.

Figure 9 shows the signal and noise spectrum at a station receiving a 55-dB-Hz MITREX spread spectrum signal. At this level, the signal is just obvious above the noise by about 1 dB. This means that if this signal were being used in a system where all stations had the same G/T (25 dB/K for Class E1 stations) and other stations were using narrowband signals at the same frequency, those other narrowband stations would receive a degrading interference of 1 dB. It is likely that the time transfer system will share transponders with normal traffic between much higher G/T stations. For example, INTELSAT Class C stations, with a G/T of 39 dB/K, would see the time transfer signal as 10-11 dB higher than the noise. This clearly would not be tolerated in a frequency reuse situation. Thus, it is clear that a network of INTELSAT Class E1 stations (3.5-4.5-diameter antennas G/T greater than 25 dB/K) used for time transfer would not be transparent to other users of the transponder.

In this experiment, the east-to-west and west-to-east transponders were used. This enabled both stations to use the same frequency and the same PN code sequence. Service within a spot beam, say west to west, would require different codes to reuse the frequency. The frequency reuse is desirable in time transfer to minimize any differential time of transmission effects in the link.

MODEM PERFORMANCE

In laboratory tests using noise generators at 70 MHz, the modem performance is close to that expected [3],[5]. Figure 10 indicates the one sigma jitter in the time transfer performance of a single link for each one second data point. This indicates that at the nominal 55-dB-Hz operating point, an uncertainty of 700 ps can be expected. Prior to the link with Germany, the USNO modem was tested in a ranging mode looped back to itself via a transponder on the domestic SBS satellite (12/14 GHz). These tests achieved the same one pulse per second

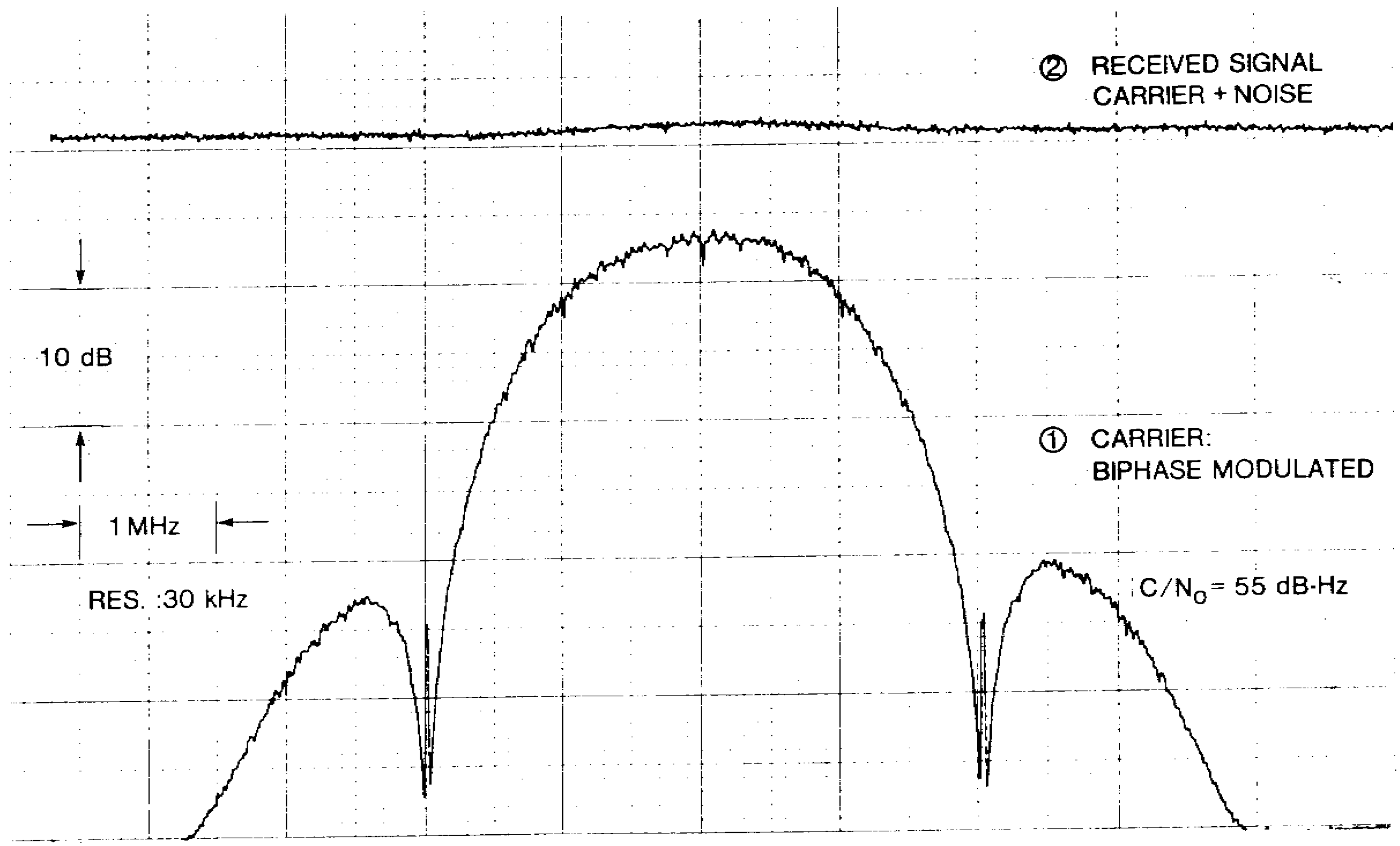


Figure 9. Signal Spectrum at Receiver Input

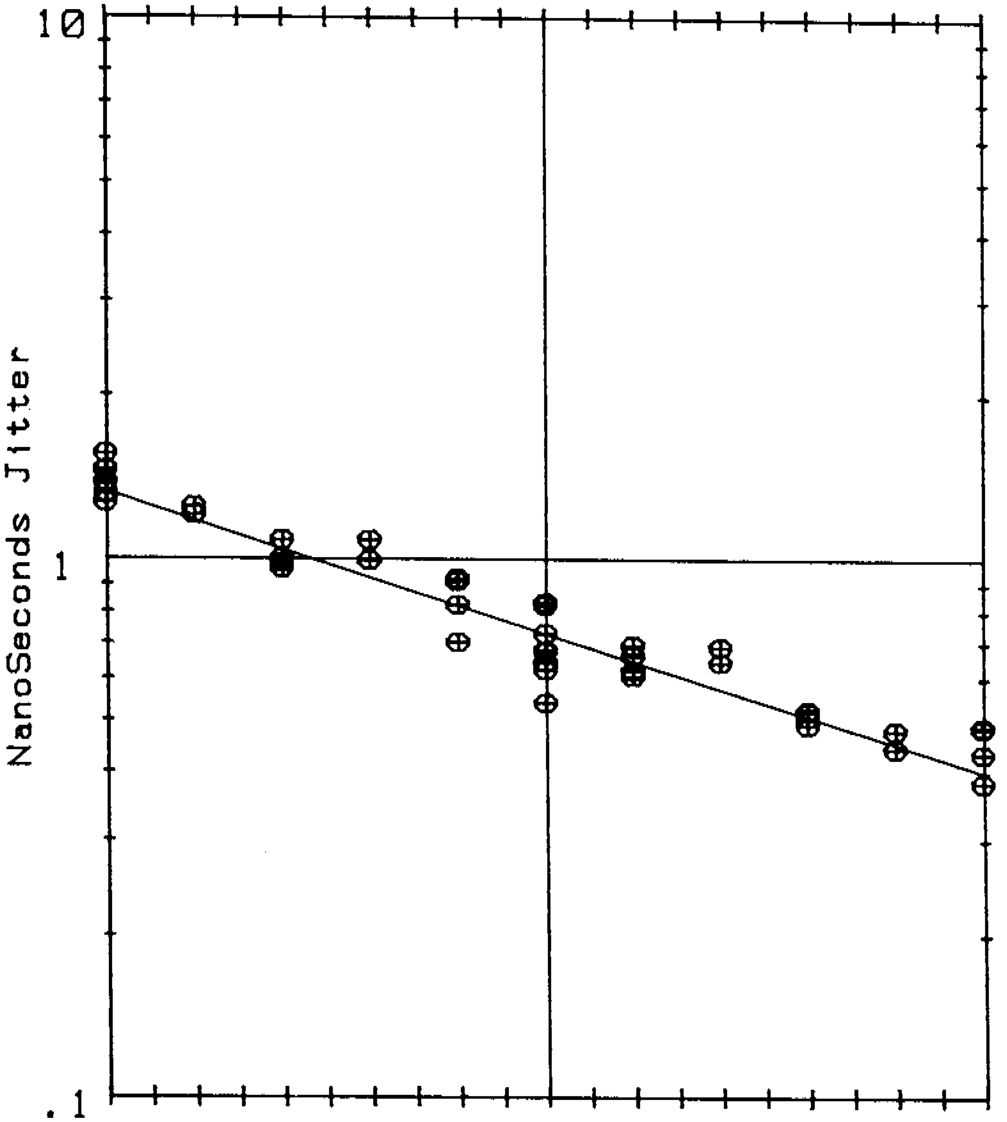

10
1
.1
50
55
60
NanoSeconds Jitter
C/No Carrier To Spectral Noise Density

Figure 10

jitter at a given C/N_0 as was observed in the laboratory 70-MHz IF loop tests. This would indicate that for the particular frequency converter chains used and for the satellite transponder, the oscillator noise was not significant at this C/N_0. The modem's performance is self limited by internal noise after about 90 dB-Hz. The limit is about 10 ps in the absence of noise.

The model used for these tests had two code sets available. This allows two spread spectrum signals to reuse a common frequency without interference due to the orthogonality of the selected codes. At the nominal links tested, 50-60 dB-Hz, the addition of the second signal caused no degradation in the performance.

The internal time delay of the modem between the 1 pulse per second pps input from the local clock and 1 pps (Tx) output that is used to start the time interval counter is not fixed. The synchronization process with 10 MHz also from the standard causes an uncertainty in the internal time delay each time the system is turned on. This uncertainty is in the form of some integer number of 50 ns steps (2-MHz internal clock). Table 4 shows the delays measured on the unit at DFVLR.

Table 4

Day	Internal Delay 1 pps IN/TX(1 pps) (ns)	Internal Delay Modulo 50 (ns)
11 July	980.6	30.6
12 July	781.5	31.5
14 July	978.9	28.9
18 July	734.9	34.9
19 July	634.6	34.6
20 July	733.0	33.0
26 July	1078.3	28.3
27 July	973.6	23.6

For time transfer this internal delay as well as the time delay to the master clock reference must be known.

EXPERIMENTAL TESTS

During the month of July 1983, the MITREX modem was used in a time transfer experiment between USNO, Washington, D.C. and DFVLR, Oberpfaffenhofen, Germany. The two sites were linked via the INTELSAT V primary path satellite at 11/14 GHz for eight days, one hour per day. The satellite transponders used were simultaneously carrying commercial FDM/FDMA traffic of about 1500 two-way voice circuits between INTELSAT class C stations (18-m diameter) located in the United States, France, and Germany. The spread spectrum signal frequency did not overlap with the frequency used by the FDM carriers. There was no detectable crosstalk to the FDM service from the 2 MCPS spreading signal.

The data in the form of the time delay between the local transmit pulse and the received pulse from the opposite station was recorded along with the time of day at the start pulse. These data were recorded in files of 100 points, one point per second. The data were reduced offline with each day's data for the satellite link combined into one file and the third order regression coefficients calculated. To evaluate the quality of the link the residuals were plotted as a scatter diagram as well as used to calculate the standard deviation.

To effect a time transfer the regression coefficients at each site were used to calculate the time interval observed at some point of time common to both data sets. The difference in the time intervals observed at each site is the difference in their clock times after the clock to start pulse time delays are accounted for. Unfortunately, the necessary modem delay times were not recorded each day at the USNO site. Without this correction, the data is unusable due to the random multiple 50-ns jumps in the interval. However, the nature of the scatter diagrams, Figure 11 and 12, show a good agreement with a Gaussian or normal distribution. There are some wild points associated with the start of each one hundred point file but they do not affect the regression coefficients. Figure 13 shows this data set before and after removing all points more than three sigma from the regression curve. The resulting change in the time interval is only 0.013 ns.

CONCLUSION

The MITREX spread spectrum modem is an efficient time transfer system. Its low-link power and lower flux density allow it to be used via communication satellite transponders with a

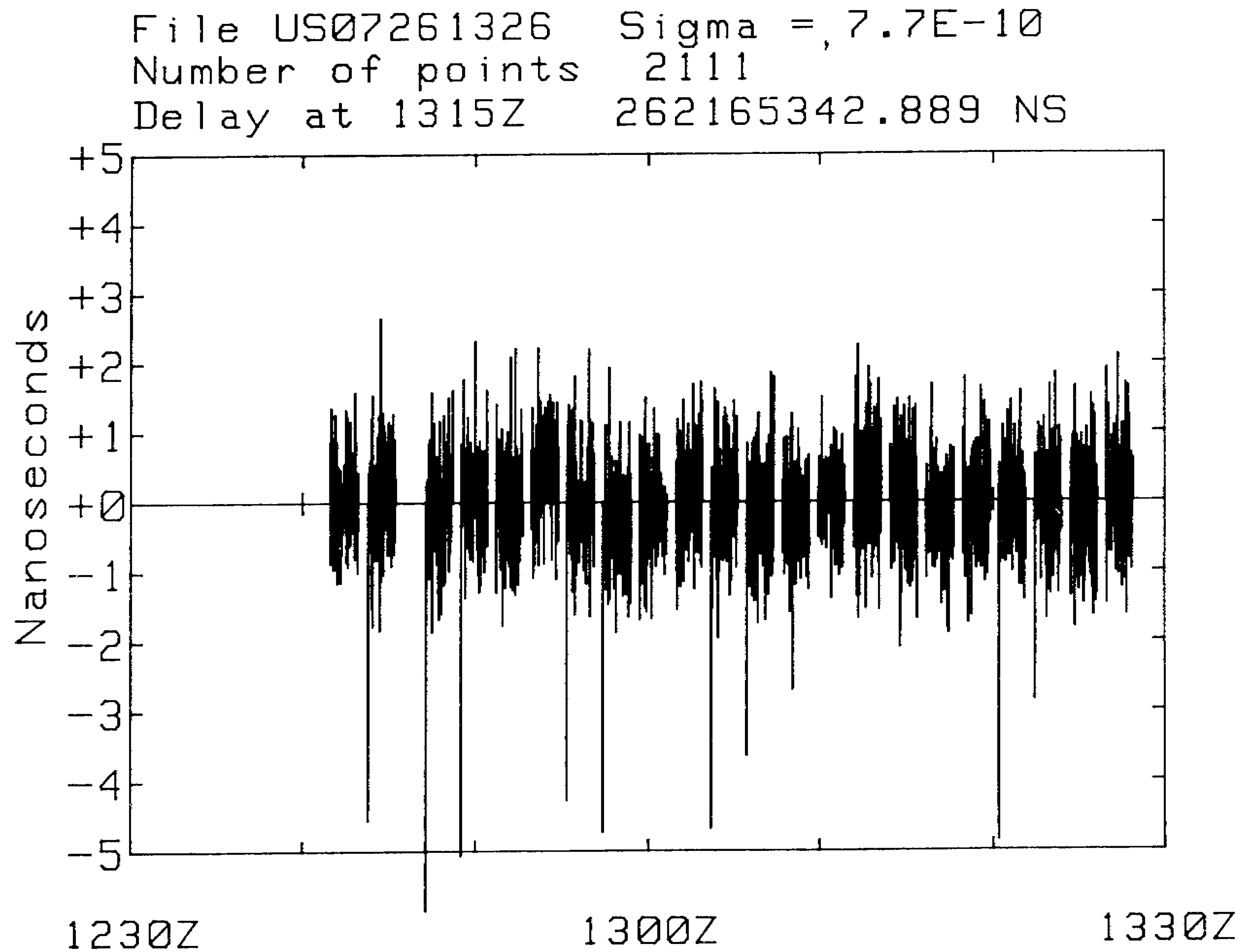

File US07261326   Sigma = ,7.7E-10
Number of points   2111
Delay at 1315Z   262165342.889 NS
Nanoseconds
+5
+4
+3
+2
+1
+0
-1
-2
-3
-4
-5
1230Z
1300Z
1330Z

Figure 11

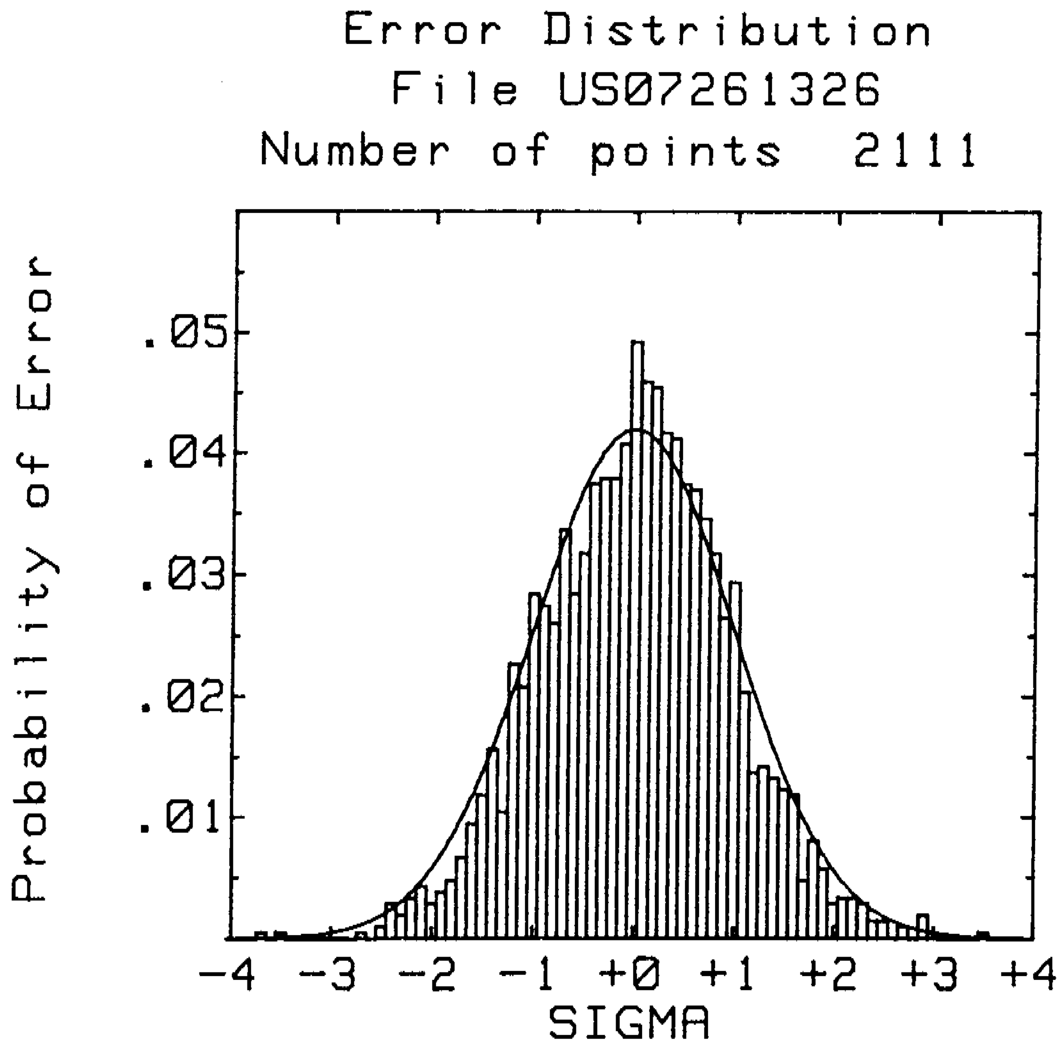
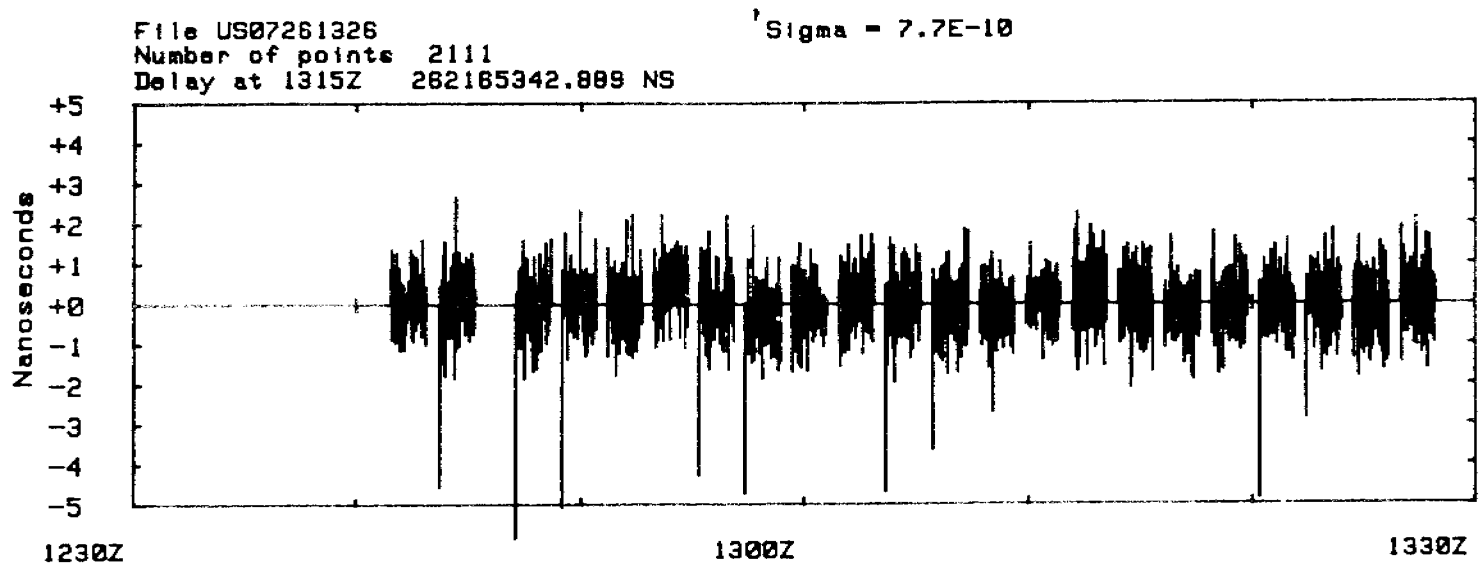

Error Distribution
File US07261326
Number of points 2111
.05
.04
.03
.02
.01
Probability of Error
-4 -3 -2 -1 +0 +1 +2 +3 +4
SIGMA

Figure 12


File US07261326
Number of points 2111
Delay at 1315Z 262165342.889 NS
Sigma = 7.7E-10
Nanoseconds
+5
+4
+3
+2
+1
+0
-1
-2
-3
-4
-5
1230Z
1300Z
1330Z

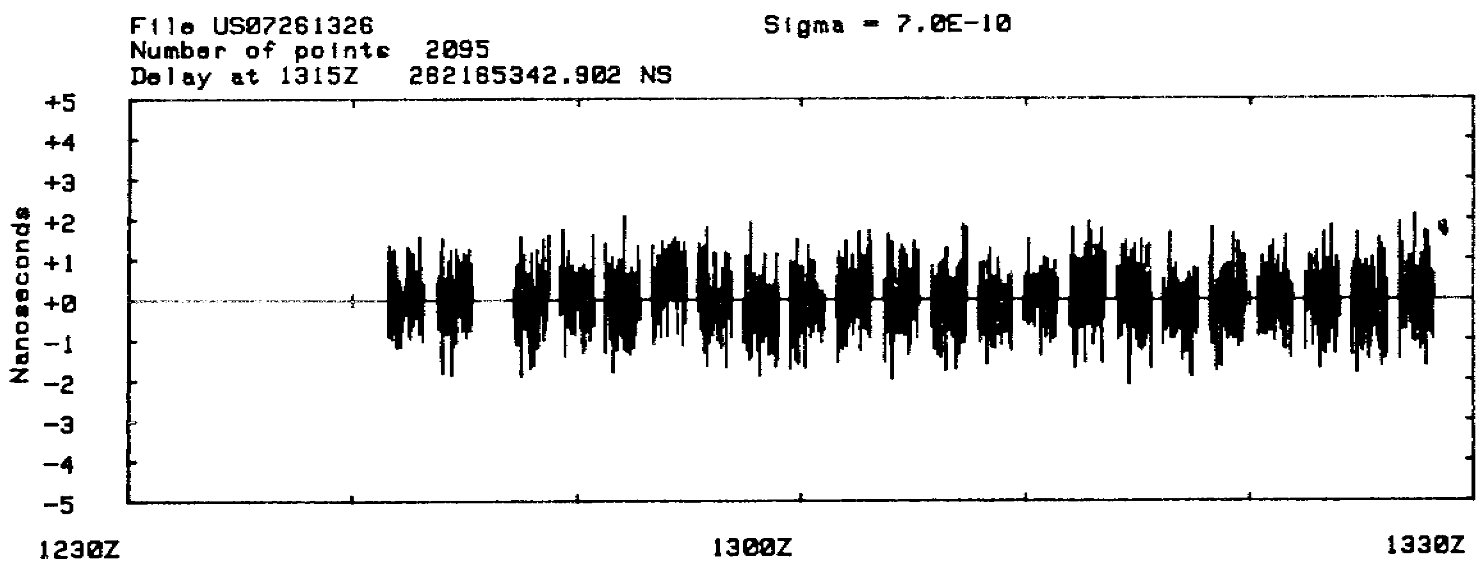

File US07261326
Number of points 2095
Delay at 1315Z 262165342.902 NS
Sigma = 7.0E-10
Nanoseconds
+5
+4
+3
+2
+1
+0
-1
-2
-3
-4
-5
1230Z
1300Z
1330Z

Figure 13

minimum of impact on other users. The sub-nanosecond accuracy of the transfer and the modest earth station requirements make it possible to locate the station directly at the master clock site. The accuracy of the link exceeds that of conventional means, loran, clock carry, GPS. Therefore, work is needed to verify the absolute error caused by earth station path length differences. In addition, the interface with the local clock needs additional work with respect to the use of 5 MHz and the internal time delay stability. It is clear that the experimental results confirm that an international time transfer and clock synchronization network is practical using this spread spectrum implementation.

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QUESTIONS AND ANSWERS

MR. ALLAN:

David Allan, National Bureau of Standards. A question, and a comment or two before you answer the question. The question is, do you have a feeling for how well, in fact, you can calibrate the transmit and received delays, and then I would like to clarify, as compared to G.P.S. common view? In this case, all that is important for time transfer is to know the differential delay between two receivers and then you can transfer time in an absolute sense per what we have described earlier. In this case we are talking about time stability, not time accuracy, and there's quite a difference. So one has to calibrate the delay, and I am curious about the kinds of numbers you anticipate, or maybe it's premature to say that.

MR. VEENSTRA:

Time accuracy is very difficult because it's very hard to separate time delays out between seventy megahertz and fourteen gigahertz. That is the transmit only, twelve gigahertz back to seventy megahertz the receive only chain. However, we do have a pretty good idea of what the stability of the earth station is, because at the beginning and end of every day, we did make loop back measurements via local loop back, that is; satellite simulators. These showed at U.S.N.O. stabilities, and this was stabilities on a day-to-day basis, in the order of one to two nanoseconds.

We say stabilities between the end--between the beginning and end of each day's trial in the order of a half nanosecond.

In other words, if you are willing to calibrate your station each day, you could get well below a nanosecond. If you want to forget about calibrating the earth station, and assume it stayed constant, you could assume two or three nanosecond accuracy in the small terminals that we were using.

Incidentally, the small terminal we were using at U.S.N.O. had about a two-hundred foot run of coax going and coming between the modem and earth station; and that sitting out in the grass, taking the ambient temperature variations of July.

DR. DETOMA:

It's true what you said, that if you make a loop measurement you can go down to one to two nanoseconds, but this is not very important in a two-way time transfer, in the sense that you don't need to sum the delays, but you need the difference and that is much harder; and you are usually not able to measure that at the one or two nanosecond levels like you mentioned.

MR. VEENSTRA:

It's very difficult, particularly in the typical international situation, where you can never get the two earth stations together to try to make these measurements. It's very difficult to try to separate receive and transmit time delays; and this really has been traditionally, and I see no solution, short of spending lots of money. If it's worth it, it could be done. To attempt to calibrate half of the earth stations as far as time delay stability, we make the assumption that both earth stations have comparable delays, split it between them, and then they solve out of the equation. But that is really an assumption born by a lack of any better information, not very rigorously justified.

MR. ALLAN:

David Allan, N.B.S. again. Mr. Beehler was mentioning to me a suggestion, I think it was made by Dr. Costain, N.R.C., that perhaps one could use a transportable calibrator and go from one site to another and perhaps accomplish the mission that's needed here to do absolute time transfer.

MR. VEENSTRA:

The question is, you have to build the transportable calibrator, and I feel it can be done. I have had some thoughts of how it could be done, but you need money to build things like this and prove it can be done; and this has not been done at this point. So all we can do is make a guess as to what the stability is, based on what the round-trip delay of the earth station is. Based on that guess, we'll say that if you had a calibrator we might be able to achieve this kind of accuracies.