A NEW PRECISION TIME AND FREQUENCY SOURCE FOR STATIONARY PTTI APPLICATIONS

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ABSTRACT

The highly stable, accurate navigation signals provided by the GPS satellite navigation system are utilized in a new time and frequency source presently in the final stages of development. Integration of the latest technology in component quartz oscillators and digital electronics with a low cost, C/A receiver provides frequency and timing signals with exceptional stability and accuracy at a very cost effective level. A description of the product and results of key performance measurements will be presented in this paper.

INTRODUCTION

The Trimble 5000A GPS Time and Frequency Source is designed to satisfy a broad set of requirements for system time and frequency applications as well as calibration lab and scientific research applications. It is a fully automatic unit with self-test features to ensure proper operation on a continuous basis.

Automatic acquisition and tracking of the optimum satellite provides continuous updates to the frequency and timing outputs without the need for operator interaction. When no satellites are above the horizon, the internal oscillator or externally provided reference will determine the frequency and time based on the last update from the satellite.

The present constellation of satellites provide 14 to 18 hours per day of single satellite coverage. Figures 1-3 show the hours of coverage available at locations around the world. As additional satellites are added, the coverage will approach 24 hours.

In addition to providing a wide variety of frequency and timing signals, frequency and time interval comparisons of other sources are provided to automate calibration.

Accurate position determination capability in WGS-72 coordinates is provided to eliminate any need for precise site survey.

PRODUCT DESCRIPTION

The Trimble 5000A Time and Frequency Source consists of an omnidirectional antenna/preamp assembly, coaxial cable up to 75 meters in length, and a 7" high rack mountable main unit.

The product provides isolated front and rear panel standard frequency outputs at 10 MHz, 5 MHz, 1 MHz and 100 KHz. Timing signals at 1000 PPS, 100 PPS, 10 PPS, 1 PPS and 1 PPM are available to meet most system requirements. Table 1 lists the specifications for these signals.

The main unit can be powered by 110/220 volt AC or external DC from 20-35 volts. An internal standby battery provides one hour of operation. The antenna/preamp power is provided from the main unit via the coaxial cable.

The unit contains a built-in display and keyboard with GPIB (IEEE 488) and RS 422 digital interfaces for system integration.

For those applications that require higher performance during non-tracking intervals, an optional internal rubidium oscillator is available. Also, external sources of frequency and time may be utilized as the reference. Frequency control of the external oscillator is also provided.

Calibration of other frequency and time sources can be accomplished with the time interval counter and frequency comparator built into this unit.

SYSTEM DESCRIPTION

Figure 4 shows the block diagram for the integration of a frequency and time source with a simple C/A satellite receiver. A single channel is dedicated to tracking one satellite for time and frequency transfer. Frequency corrections and time corrections are applied to the component quartz oscillator and digital clock based on range and range rate measurements of the satellite. Frequency control resolution is 1.5 parts in ten to the twelfth and time control resolution is 4 nanoseconds.

Calibration of an external source of time and frequency can be automated with the time interval counter and frequency comparator built into this product. Single shot, 1 nanosecond time difference measurements can be made against the internally generated timing signals. The frequency comparator can resolve two parts in ten to the eleventh in one second of measurement time.

Sequential measurements of four satellites will allow precision position determination necessary for accurate time and frequency transfer when tracking one satellite. Position can be determined within 50 meters after a few hours of averaging when four satellites are available.

Position determination need only be done upon initial installation in order to achieve high accuracy time and frequency transfer.

PERFORMANCE DATA

Stability, accuracy and reliability are the key measures of performance for a time and frequency source. Stability and accuracy measurements have been made on the present prototype. Reliability can be assured with simplified design that minimizes the number of components and interconnections. Component derating is essential to high reliability.

FREQUENCY STABILITY AND ACCURACY

The frequency stability of the 5 MHz and 10 MHz outputs is determined by the component quartz oscillator and output amplifiers for averaging times less than the time constant of the frequency control loop. The stability of the satellite signal plus receiver noise exceeds the oscillator stability for averaging times greater than ten seconds. The control loop has been designed with a time constant of 10-15 seconds in order to not degrade the performance for shorter averaging times, yet still remove any thermal and long term drift of the oscillator. Figure 5 shows the frequency stability for ten second averaging. The "Allan Variance" for 10 second to 300 second averaging times is shown in Table 2.

Frequency accuracy maintained by the GPS system is better than 1 part in ten to the twelfth. The quartz oscillator in the Trimble 5000A is locked to the carrier frequency and corrected to a few parts in ten to the twelfth. During non-tracking intervals, thermal and long term drift in the component oscillator may reduce accuracy to one part in ten to the tenth in reasonably controlled environments. For those applications where higher accuracy is required, the optional component rubidium will maintain better than one part in ten to the eleventh during non-tracking intervals.

TIMING STABILITY AND ACCURACY

The stability of the timing signals is determined by the amount of averaging done on the psuedo-random phase modulation. Table 3 shows the stability of the timing signals for averaging times of 10 to 300 seconds. Averaging for 100 seconds will improve the stability to near 1 nano second (one sigma). Figure 6 shows the timing stability for 10 second averaging during part of a satellite pass of satellite tracking.

Time accuracy of the GPS system is specified to be within 100 nanoseconds (one sigma) with respect to USNO (UTC). Receiver delay and position must be accurately determined to achieve this level of accuracy. The Trimble 5000A automatically calibrates the receiver delay and can determine accurate position with respect to WGS-72 coordinate system.

Table 4 shows the results of time comparisons with Hewlett-Packard HP (UTC) via time transfer and portable clock trips. The uncertainty in TV time transfer and portable clock trips amounts to as much as 100 nanoseconds presently. HP (UTC) uncertainty is 200 nanoseconds. A visit to the GPS Master Clock is planned in the near future to eliminate these uncertainties. The day to day variation of these time transfers is less than 50 nanoseconds including the TV time transfer jitter. During non-tracking intervals, the error may increase to one microsecond for eight hours of non-tracking. With the optional rubidium oscillator, this can be held to less than 200 nanoseconds. Utilizing an external cesium beam standard, less than 100 nanoseconds can be assured on a continuous basis.

CONCLUSION

The GPS satellite navigation system provides a very high performance source of time and frequency for 14-18 hours per day and will become continuous within the next few years. It will likely become the most widely used system for time and frequency distribution and comparison during the next decade.

The Trimble 5000A provides a complete time and frequency source referenced to UTC. The stability and accuracy provided by this product without any need for calibration meets most system and calibration lab requirements. Within the next few months, the Trimble 5000A Time and Frequency Source will become available at a price well below the cost of Cesium beam frequency sources. The elimination of recalibration and synchronization costs will make this source an attractive instrument for all precision time and frequency applications.

ACKNOWLEDGEMENTS

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REFERENCES

1. "NAVSTAR GPS Space Segment/Navigation User Interface", ICD-GPS-200.
2. Milliken, R.J. and Zoller, C.J., "Principle of Operation of NAVSTAR and System Characteristics", Navigation, Summer of 1978.
3. Time and Frequency: Theory and Fundamentals, NBS Monograph 140.
4. Characterization of Frequency Stability, NBS Technical Note 394.

SINGLE SATELLITE COVERAGE - Hours Per Day

18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
18	18	18	18	19	18	18	18	18	18	18	18	18	19	18	18	18	18	18	18
19	19	18	18	18	18	18	18	19	18	18	18	18	18	19	18	18	19	18	19
19	19	19	19	19	19	19	18	19	18	18	19	19	18	19	18	19	19	18	19
20	19	19	19	19	18	19	19	19	19	19	18	19	19	18	19	19	19	19	19
19	19	20	19	19	19*	19	19	19	18	19	18	19	19	19	19	19	19	19	19
19	19	19	19	18	17	19	18	18	17	17	19	18	18	18	19	18	18	18	19
19	19	19	19	18	18	18	19	17	16	17	18	18	16	18	18	18	18	18	19
19	18	18	18	17	18	18	18	18	16	17	18	17	16	18	18	18	17	18	19
20	19	18	18	18	17	18	19	18	17	17	18	18	17	18	19	18	17	18	19
19	18	18	18	18	17	18	18	18	17	17	18	18	17	18	18	18	18	18	19
19	17	18	18	18	17	18	19	17	17	18	18	16	18	18	18	17	18	19	18
18	17	18	18	17	17	18	19	17	17	17	18	17	17	18	18	17	18	19	19
18	18	17	19	18	17	18	18	18	17	18	18	17	18	19	19	18	18	19	19
18	18	18	18	18	18	18	18	18	18	18	18	18	18	19	19	18	19	19	19
19	18	18	18	18	18	18	18	18	18	18	18	18	18	19	19	19	19	19	19
18	18	18	18	18	18	18	18	18	18	17	18	18	18	18	18	18	18	18	19
18	18	18	18	18	18	18	18	18	18	18	18	17	18	18	18	19	18	18	18
18	18	18	17	17	17	18	18	17	17	17	17	18	18	18	18	18	17	18	18
18	18	18	17	17	18	18	18	18	17	17	17	18	18	18	17	17	17	18	18

LAT

LON

LONDON

WASHINGTON D.C.

*SAN FRANCISCO

*TOKYO

*BUENOS AIRES

*SYDNEY

FIGURE 1

SATELLITE VISIBILITY - WASHINGTON D.C. - 11/30/83

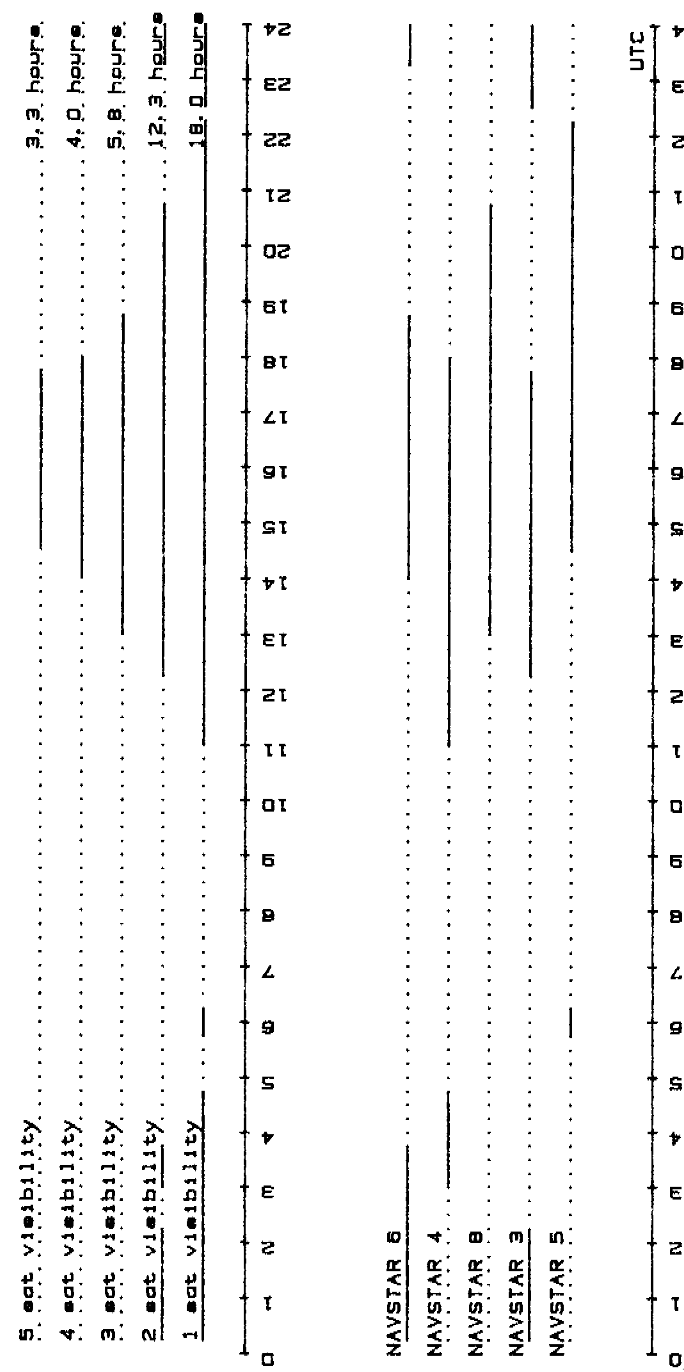

FIGURE 2

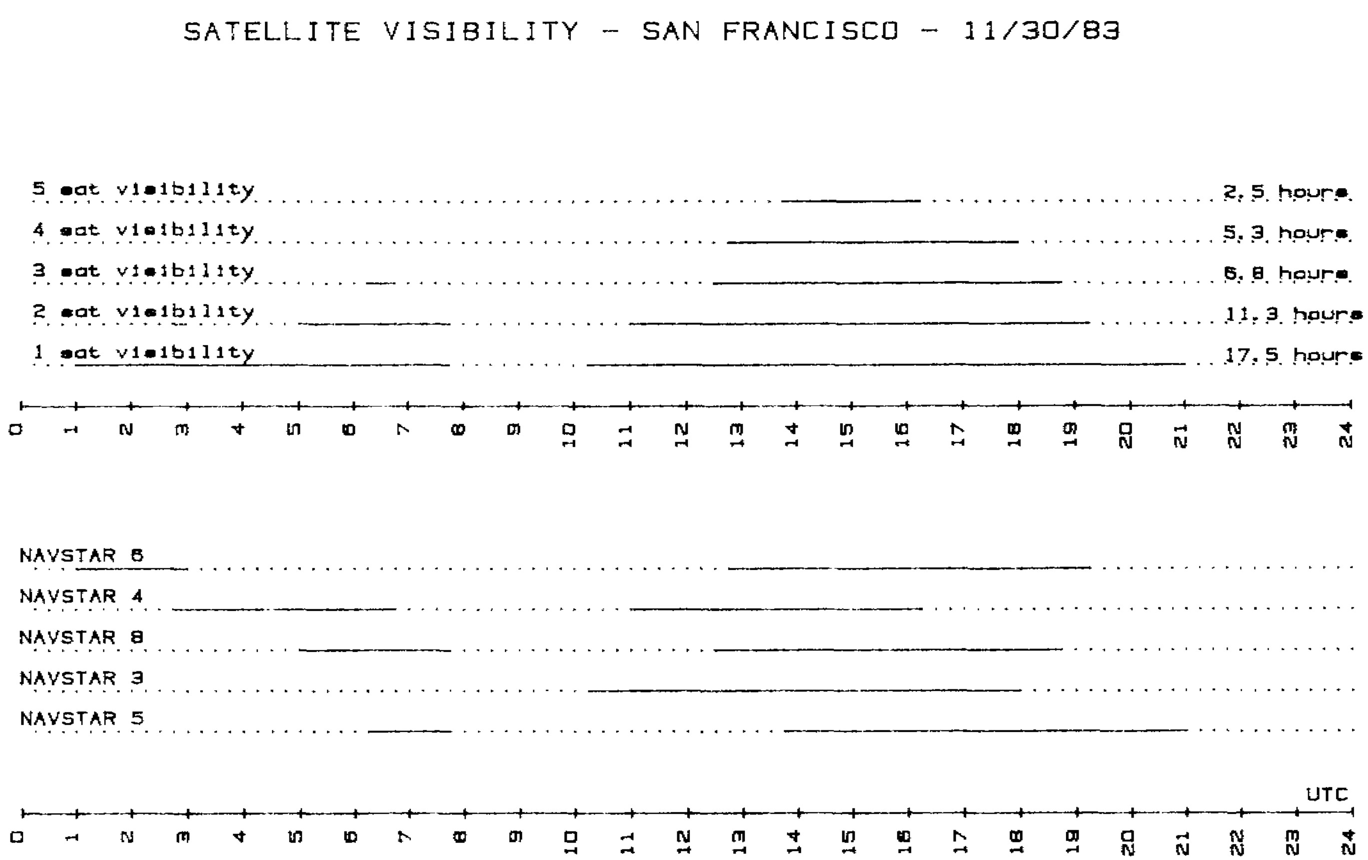
SATELLITE VISIBILITY - SAN FRANCISCO - 11/30/83
5 sat visibility
4 sat visibility
3 sat visibility
2 sat visibility
1 sat visibility
2.5 hours
5.3 hours
6.8 hours
11.3 hours
17.5 hours
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
NAVSTAR 6
NAVSTAR 4
NAVSTAR 8
NAVSTAR 3
NAVSTAR 5
UTC
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

FIGURE 3

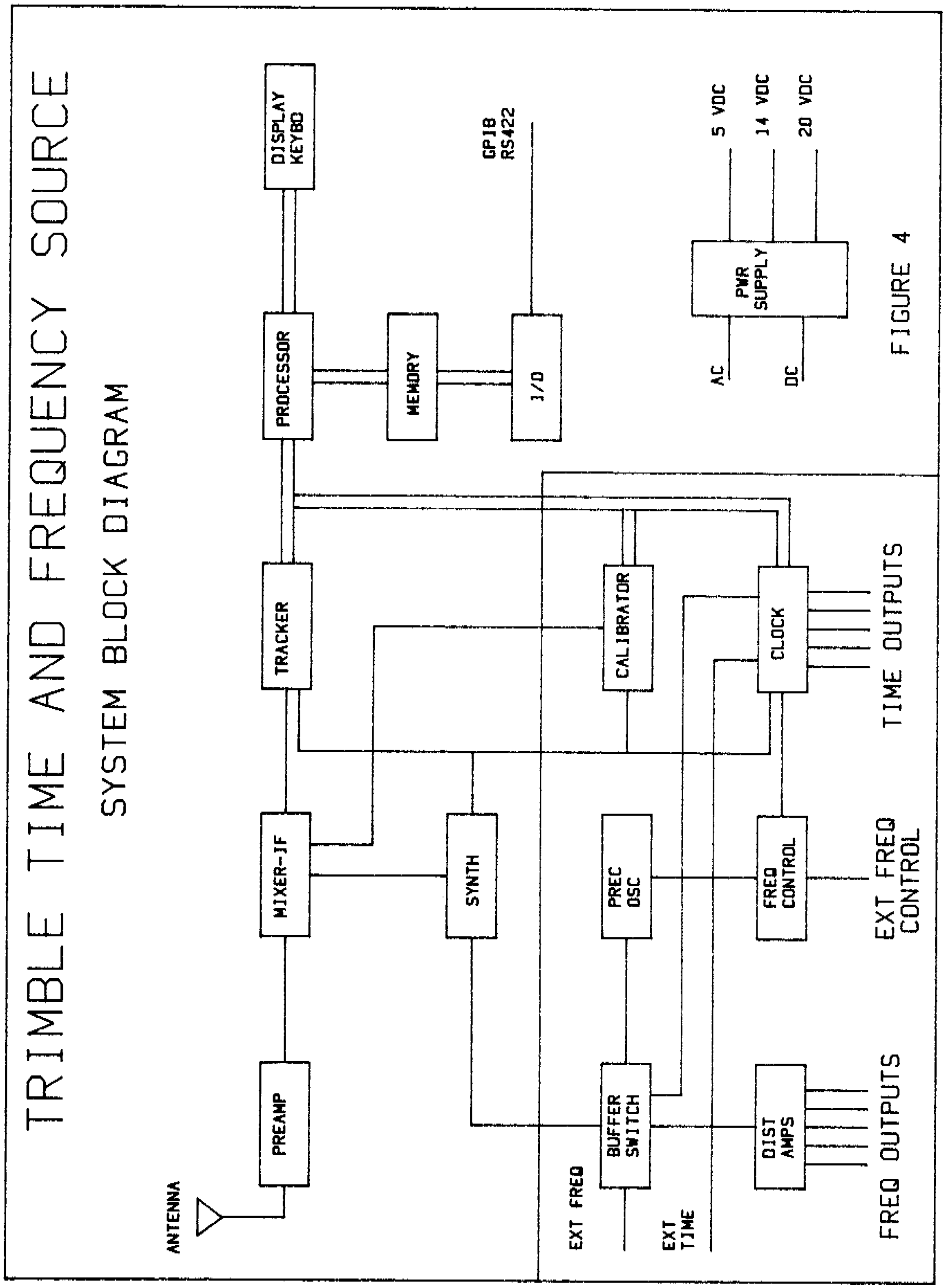
TRIMBLE TIME AND FREQUENCY SOURCE
SYSTEM BLOCK DIAGRAM
ANTENNA
PREAMP
MIXER-IF
TRACKER
PROCESSOR
DISPLAY KEYBD
MEMORY
I/O
GPIB RS422
PWR SUPPLY
5 VDC
14 VDC
20 VDC
AC
DC
SYNTH
CALIBRATOR
CLOCK
TIME OUTPUTS
PREC OSC
FREQ CONTROL
EXT FREQ CONTROL
BUFFER SWITCH
DIST AMPS
FREQ OUTPUTS
EXT FREQ
EXT TIME

FIGURE 4

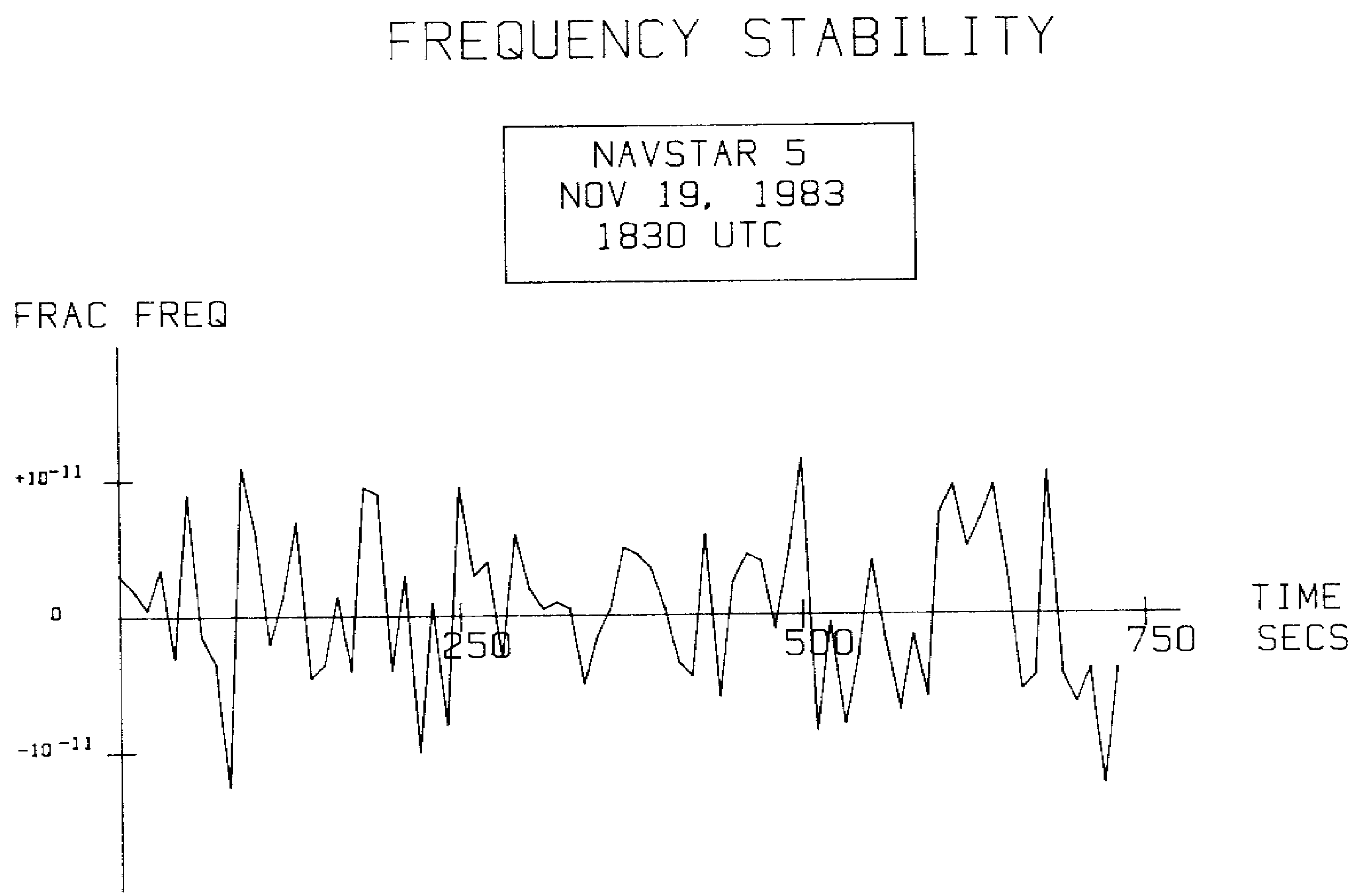
FREQUENCY STABILITY
NAVSTAR 5
NOV 19, 1983
1830 UTC
FRAC FREQ
$+10^{-11}$
0
-10^{-11}
250
500
750
TIME
SECS

FIGURE 5

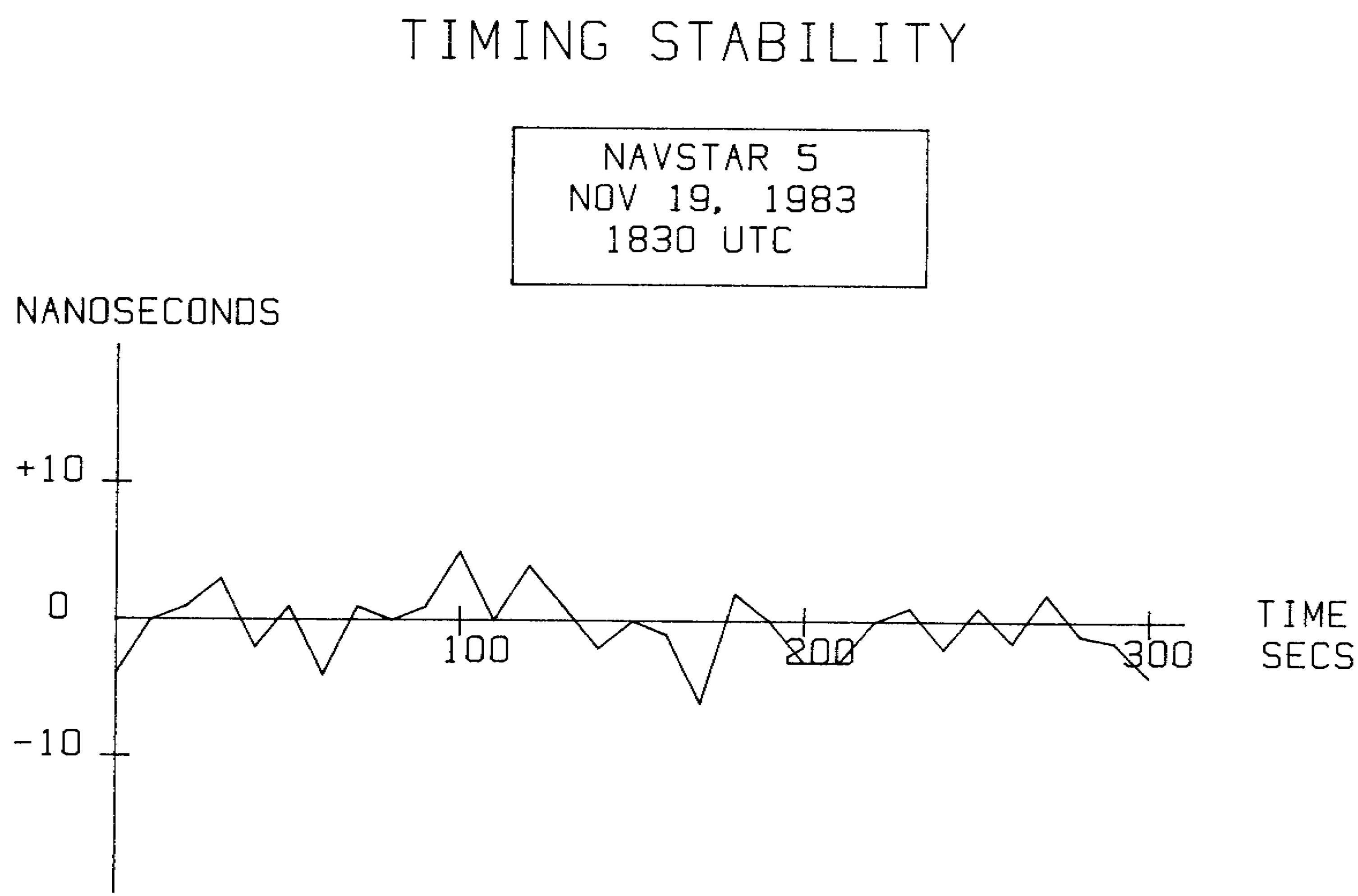
TIMING STABILITY
NAVSTAR 5
NOV 19, 1983
1830 UTC
NANOSECONDS
+10
0
-10
100
200
300
TIME
SECS

FIGURE 6

TABLE 1

TRIMBLE 5000A SPECIFICATIONS

TIMING ACCURACY:	100 nanoseconds (one sigma) with respect to USNO (UTC) during satellite tracking. * 1 microsecond with respect to UTC (USNO) during non-tracking intervals up to eight hours with controlled environment.
TIMING STABILITY:	Better than 20 nanoseconds (one sigma) during satellite tracking.
FREQUENCY ACCURACY:	1 part in ten to the eleventh during satellite tracking. * 1 part in ten to the tenth during non-tracking intervals with controlled environment.
FREQUENCY STABILITY:	Better than 1 part in ten to the eleventh for 1 second and greater averaging times. * Optional rubidium oscillator provides better than 1 part in ten to the eleventh and less than 200 nanoseconds during non-tracking intervals up to eight hours.
SIGNAL OUTPUTS:	5 and 10 MHz sine wave outputs. Two channels at each frequency. 0-3 volts rms into 50 ohms. Harmonic distortion -30 dB. Nonharmonic distortion -60 dB. Phase noise -140 dBc @ 1 KHz. 1 MHz and 100 kHz sine wave outputs. Two channels at each frequency. 1 volt rms into 50 ohms. Harmonic disortion -25 dB. 1, 10, 100 millisec, 1 PPS, 1 PPM pulses. 3 volts into 50 ohms. Positive pulse, dc coupled.

	10 microsecond pulse width minimum. 10 nanosecond rise time minimum. Programmable phase, 4 nanosecond steps.
SIGNAL INPUTS:	10 MHz, 5 MHz, 1 MHz sine waves. .3-3 volts rms into 50 ohms.
	1 PPS, 1 PPM pulses. 3 volts into 50 ohms. Positive pulse, dc coupled. 10 microseconds pulse width minimum. 10 nanosecond rise time minimum.
COMPARISONS:	Frequency comparator - Two parts in ten to the eleventh in one second.
	Time interval - 1 nanosecond, single shot.
I/O:	RS 422 GPIB (IEEE 488)
POWER SOURCES:	90/130, 180/280 v ac, 45-440 Hz, 150 va 20-35 v dc, 60 watts Internal battery, 1 hour standby
DIMENSIONS:	Coaxial Cable - 20 to 200 feet Receiver/Source - 7" x 17" x 17"

FREQUENCY STABILITY

τ(secs)	$\sigma_y(\tau)$
10	6.7×10^{-12}
30	3.6×10^{-12}
100	1.6×10^{-12}
300	7.1×10^{-13}

TABLE 2

TIMING STABILITY

τ(secs)	$\sigma_t(\tau)$
10	2.9×10^{-9}
30	2.1×10^{-9}
100	1.4×10^{-9}
300	1.1×10^{-9}

TABLE 3

NAVSTAR 5
NOV 19, 1983
1600-1900 UTC

TIME COMPARISON

WITH HP

DATE	TIME	SAT #	TV TIME DIFF	TV DELAY [1]	HP-USNO [2]	TRIMBLE-USNO [3]
11-23-83	16:51	5	51.10	49.72	1.45	70
11-28-83	16:51	3	51.09	49.72	1.45	80
11-29-83	16:51	3	51.10	49.72	1.45	70
11-30-83	16:51	3	51.12	49.72	1.45	50
12-01-83	16:51	6	51.09	49.72	1.45	80
			μsec	μsec	μsec	nsec

1 - UNCERTAINTY OF 100 NANOSECONDS

2 - UNCERTAINTY OF 200 NANOSECONDS

3 - UNCERTAINTY OF 225 NANOSECONDS RSS

TABLE 4

QUESTIONS AND ANSWERS

DR. REINHARDT:

How big is this going to be?

MR. HYATT:

The main unit is packaged in a seven-inch high-rack mount. So it's like seventeen wide, fifteen deep and seven inches high. And of course, there is an antenna unit which is a 3x6x4 assembly that goes on the roof.

DR. REINHARDT:

It's still not the cigarette pack unit, that's a part in 10^{11} but we are getting there.