INITIAL RESULTS OF THE NAVSTAR GPS NTS-2 SATELLITE

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ABSTRACT

NTS-2 was successfully launched on 23 June 1977 into a near 12-hour circular orbit. Precise frequency and timing signals are derived from the two cesium frequency standards. This paper discusses the launch and preliminary results which include verification of the relativistic clock effect.

INTRODUCTION

The successful launch of the Navigation Technology Satellite No. 2 (NTS-2) marks the beginning of a new era in navigation and timekeeping history. NTS-2 (Fig. 1) is the first NAVSTAR GPS (1) Phase I Satellite, which will provide near-instantaneous navigation and time-synchronization service on a worldwide, continuous basis to the DOD community and a wide variety of commercial users. NTS-2 technological features encompass the world's first orbiting cesium frequency standards, built by Frequency and Time Systems (FTS); nickel-hydrogen batteries (developed by COMSAT); three axis gravity gradient stabilization with momentum wheel unloading; control of the spacecraft orbit; verification of Einstein's relativistic clock shift; time interval measurement precision of 3 nanoseconds; and a worldwide network (GE International Time Sharing) for data acquisition.

NTS-2 is also the fourth in a series of NRL technology satellites (Fig. 2) which have carried quartz (2), rubidium (3) and cesium (4) oscillators into orbit. The NTS-3 spacecraft, now under development at NRL, is scheduled to carry the first orbiting hydrogen maser (5) frequency standard(s). The primary data type for all of the technology satellites has been precise time difference measurements, which have been used for time transfer (6), navigation (7, 8) and orbit determination.

GPS LAUNCH PROCEDURE

The GPS launch procedure (Fig. 3) requires that the spacecraft be inserted into a pre-assigned position in the GPS constellation; first into a high eccentricity transfer orbit (Fig. 4), then into a low eccentricity drift orbit (Fig. 5), followed by final constellation place ment. A set of orbital values and tolerances was specified; the most critical tolerance was for orbital period which was required to be within an accuracy of 1 second of the specified value of 717.973 minutes (nearly 12 sidereal hours).

The NRL built spacecraft was launched into the transfer orbit from Vandenburg Air Force Base on June 23, 1977, at 0817UTC. First acquisition of signal (AOS) was made by the NTS tracking station in Panama. NTS-2 was then acquired and tracked from Blossom Point, Md. Calculations of measurement residuals indicated a nominal transfer orbit. The scheduled apogee kick motor (AKM) burn at the first apogee was deferred in order to allow processing of measurements from the launch tracking network (Fig. 6). The launch tracking network consisted of two of the NTS tracking stations (Panama and Chesapeake Bay, Md.) complemented by Blossom Point, Md.; Millstone, Mass.; the Range Measurements Laboratory, Patrick AFB, Fla. The tracking network is coordinated by the NRL Control Center (NRLCC), which has links (Fig. 7) to the GPS Master Control Station. Transfer orbit solutions were independently made by Bendix personnel at Blossom Point, Md.; RML, Patrick AFB; and Millstone Radar personnel using measurements from the launch tracking network. A merged orbit solution (9) was performed by the Naval Surface Weapons Center (NSWC) which was compared with the independent solutions using various data subsets. The AKM burn was performed at the sixth apogee which resulted in a near circular drift orbit.

The pre-launch drift orbit profile (Fig. 8) was chosen to allow the ascending node of NTS-2 to drift eastwards at a nominal value of 5 deg/day. The actual drift orbit (Fig. 9) had a larger drift rate than expected, resulting in NTS-2 reaching its pre-assigned position in the constellation of 28 ± 2 degrees West Longitude in 5 days. Three velocity increments (Fig. 9) ranging from 1 to 3 feet per second were used to increase the spacecraft period. The final orbit, excepting small microthrusts, was achieved 15 days after launch. Three axis gravity gradient stabilization and solar panel deployment was achieved within 18 days after launch.

The final drift orbit of NTS-2 in the GPS Phase I constellation is given by Figure 10. The locations of the five Navigation Demonstration Satellites (NDS) are possible positions; final satellite positions will be determined later. These six satellites will comprise the GPS Phase I Constellation.

NTS-2 follows a constant ground track orbit with an inclination of 63 degrees. Occasional orbital maneuvers of the spacecraft are performed, as necessary, to maintain the ascending node within the GPS specifications. Figure 11 presents a summary of four of the NTS-2 orbital parameters and the associated GPS specifications.

NTS-2 TRACKING NETWORK

The NTS-2 tracking network (Fig. 12) consists of U.S. stations located in Chesapeake Beach, Md. (CBD), Panama Canal Zone (PMA); overseas stations are located at the Royal Greenwich Observatory (RGO) in England and in Australia (AUS) at a Division of National Mapping site. United States stations are operated by Bendix Field Engineering, the overseas sites are operated by personnel from England and Australia, all under the direction of NRLCC. The NTS-2 measurements are used by these cooperating countries for time comparison with the U.S. Naval Observatory (USNO), independent orbit determination and polar motion studies. The network provides almost complete tracking coverage of NTS-2; Figures 13, 14, 15, and 16 depict the portions of the NTS-2 orbit when the spacecraft is above the horizon from PMA, RGO, AUS, and CBD, respectively. Figure 17 shows that only a small segment of the NTS-2 orbit is not observable from some station in the NTS network. Noteworthy is the coverage obtained from Panama (Fig. 13); NTS-2 is tracked for one complete revolution every day, thus allowing for immediate analysis of any cesium frequency adjustment performed by NRLCC. Each of these stations has at least three cesium standards whose offsets (independent of NTS-2) are related to the USNO Master Clock No. 1 by timing links as detailed in Figure 18.

PRECISE TIME AND FREQUENCY TRANSMISSIONS

Precise frequency signals for NTS-2 transmissions are obtained from one of the two spacecraft qualified (4) cesium frequency standards built by FTS. Each cesium standard may also be operated in a quartz oscillator mode which requires less power. The reduced power, quartz only mode was used for the first 15 days after NTS-2 launch. The cesium standard was locked following solar panel deployment which allowed full power operation.

NTS-2 timing information is continuously transmitted in two modes, a side tone ranging system, called the Orbit Determination and Tracking System (ODATS); the other a Psuedo Random Noise Subsystem Assembly (PRNSA). Time difference measurements between the spacecraft clock and ground station clocks are made through special receivers (10, 11) which measure time difference by comparing a waveform similar to that transmitted by the spacecraft. These measurements are then used to determine the spacecraft orbit, clock difference (12), frequency difference and other parameters associated with GPS operation.

FREQUENCY DETERMINATION

GPS requirements for the NTS-2 mission called for cesium controlled frequency operation after full power was available, following solar panel deployment. The first FTS cesium standard to be used, designated as PRO-5, was locked up (Fig. 19) on the first attempt on Day 190, 1977,at 1418 UTC following a frequency tune to bring the PRO-5 quartz oscillator frequency within the VCXO tuning range of the cesium resonance frequency. Figure 19 presents the theoretical range minus the observed range (T-O) values (13) which are calculated from measurements collected at a one-minute interval from the Panama site. These (T-O) values yield a measure of the spacecraft clock offset with respect to the PMA clock. Knowledge of the station clock offset with respect to the USNO Master clock permits the spacecraft to be referenced to USNO. Figure 20 presents a plot of (T-O) values (13) from PMA over a six day span. The (T-O) slope gives the frequency offset of +442.5 pp10^{12} with respect to the PMA clock. Inclusion of the PMA frequency offset of +0.6 pp10^{12} produces an NTS measured value of +443.1 pp10^{12}. Comparison of this value to the predicted value of the relativistic offset of +445.0 pp10^{12} gives a difference of -3.1 pp10^{12}. On Day 215, 1977, the NTS-2 PRO-5 output signal was offset (Fig. 21) through the use of a frequency synthesizer (4). Closer frequency synchronization to the UTC rate is obtainable by use of cesium C-field tuning which provides a resolution of 1.3 pp10^{13}. Before applying the C-field tune, the NTS-2 frequency offset was re-determined using the CBD station. Figure 22 presents a plot of UTC (USNO MC No. 1) - UTC (CBD), where CBD denotes the clock used for the CBD receiver. The slope of this line yields a frequency offset of 18.0 pp10^{13}. Figure 23 presents a plot of (NTS-CBD); a frequency offset of 10.1 pp10^{13} was measured. Combining these results Figure 24 produced a frequency offset of

+7.9 pp10^{13}. On Day 287, 1977 (14 Oct), a C-field tune of 6 bits was applied. Figure 25 presents a plot of the (T-O)'s after the C-field tune; a resultant frequency of -6.6 pp10^{13} was measured. The net measured change was 14.5 pp10^{13} which exceeded the expected value by 6.7 pp10^{13}. Figure 26 presents the preliminary results of the C-field tune; the cause of the small differences are being investigated. A frequency history of NTS-2 since launch is presented by Figure 27, a split logarithmic scale is used so that positive and negative values of frequency offset with respect to UTC (USNO) may be included over a large range.

TIME TRANSFER

Preliminary time transfer results have also been obtained. Figure 28 depicts the technique and the links which are used to relate a time difference, measured with respect to NTS-2, back to UTC (USNO). The time transfer results are of interest to the PTTI community, but also significantly to the GPS community because four simultaneous time transfers measured between a user and four GPS satellites form the basis of a GPS navigation and time synchronization. Figure 29 presents NTS-1 time transfers results between the NASA station located at Cape Kennedy and USNO via the CBD ground station link to USNO. The results in Figure 30 present time transfer results using identical ground station equipment but with measurement obtained from the NTS-2 spacecraft; these results are obtained with a single channel 335- MHZ receiver (14) and are not corrected for ionospheric delay. The NASA laser network which will use these receivers is given by Figure 31.

INTERNATIONAL TIME TRANSFER EXPERIMENT

As a result of the encouraging time transfer results, an international time transfer experiment has been planned in 1978. Figure 32 lists the different participants from seven countries. Extensive use will be made of the single channel 335-MHZ receiver; ionospheric delay will be minimized by using measurements at the time of closest approach of NTS-2. It is anticipated that a worldwide time synchronization accuracy of 100 nsec or less will be achieved by this effort.

LASER ORBIT VERIFICATION PROGRAM

A laser program has been started for the purpose of verification of the GPS orbit accuracy. Initially, laser returns will be used to verify one component of the orbit at the time of the observation; later as more laser stations track NTS-2, an independent orbit will be calculated. An important part of the laser program is to obtain near-simultaneous laser and time difference observations at co-located sites which will be used for precise clock analysis in addition to orbit determination. These and other objectives are summarized in Figure 33.

NTS-2 is equipped with a laser retroflector similar to NTS-1 which also had a retroflector. One element of the retroflector is designed for light emitted in the ultra violet region. Figures 34 and 35 show the retroflector elements for NTS-1 and NTS-2. In addition to the NASA network, the Smithsonian Astrophysical Observatory (SAO) has four stations capable of making laser observations on NTS-2; those stations in the SAO network are detailed in Figure 36. Additional laser observations may be obtained from stations (Fig. 37) located in France, Germany, Holland, and Australia. Figure 38 presents measurement resolutions from some of those stations with NTS tracking capability. Laser returns have already been obtained from the SAO Mt. Hopkins, Arizona, site. Figures 39 and 40 present the residuals referenced to the NTS-2 orbit. The measured biases of 56 and 17 nsec provide preliminary verification of the NTS orbit. The noise levels of 6 and 5 nsec are typical of the expected laser measurement noise level for this laser configuration; implementation of a more accurate laser pulse should improve these results.

A proposed laser precise orbit tracking network is shown by Figure 41. This proposed network includes possible laser tracking at the operational TRANET sites which are under the direction of the Defense Mapping Agency.

NTS-2 ACHIEVEMENTS

GPS objectives that have been achieved to date are

(1 launch insertion into GPS constellation position

(2 demonstrated orbit stability and controllability

(3) first cesium frequency standard in space

(4) verification of relativity theory

Other GPS objectives that are being pursued are:

(1 satellite clock analysis

(2) error budget determination

(3) navigation with NDS satellite

(4) worldwide timing system synchronization

(5) refine coefficients of geopotential

(6) measure earth rotation rate

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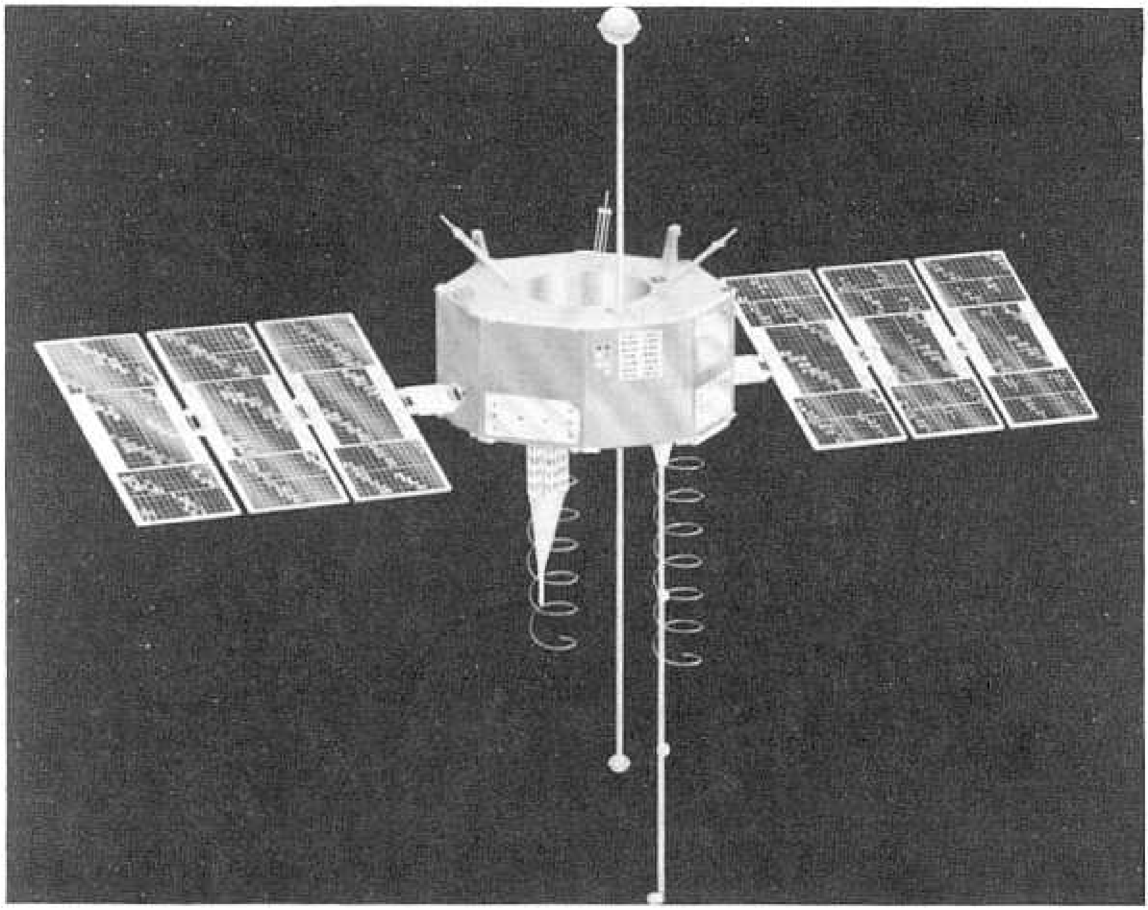


Fig NTS-2

		T-11	T-111 NTS-1	NTS-2	NTS-3
Launch	5/31/67	8/30/69	7/14/74	6/23/77	1981
Alt. (n.mi.)	500	500	7400	10,900	10,900
Incl.	70°	70°	125	63°	63°
Ecc.	.0008	.002	.007	.0004	.001
Wt. (lbs)	85	125	650	950	1080
Power (W)	6	18	100	445 BOL	475 BOL
Freq.	UHF	VHF/UHF	UHF/L Band	UHF/L, L_1, L_2	UHF/L, L_1, L_2
Osc.	Qtz	Qtz	Qtx/Rb	Qtz/C_s	Qtz/H_2
$\Delta f/f$(day) pp10^{13}	300	100	5-10	2	.1
Range Error ft/day	2400	240	40-80		

2 - Technology satellites

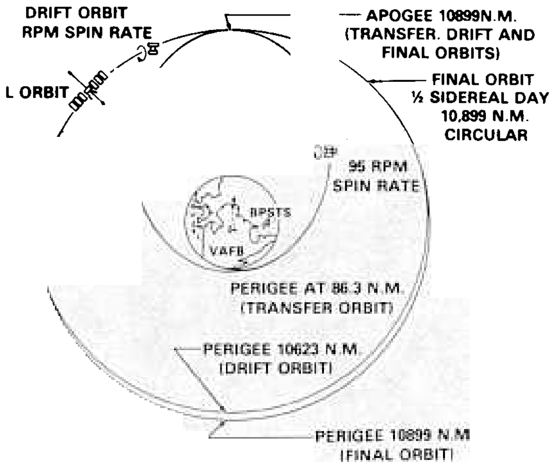
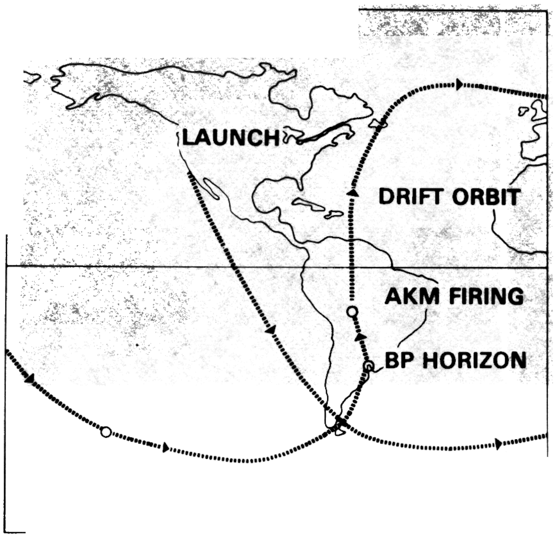


Fig. 3 - Mission sequence of NTS-2 events



4 - NTS-2 transfer orbit

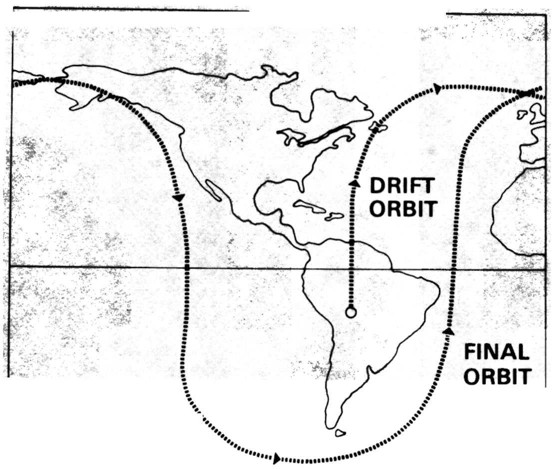


Fig. 5 - NTS-2 drift orbit

TASK: DETERMINE ORBIT TO 1SEC PERIOD

DATA TYPE	STATION LOCATION	ANTENNA APERTURE
1. AZ EL TRACK		
BLOSSOM POINT,	MD.	(20 FT)
SUGAR GROVE,	W.VA.	(150 FT)
RANGE MEASUREMENTS LAB,	FLA.	(48 FT) OPTICALLY
2. RANGE AND DOPPLER		
BLOSSOM POINT,	MD.	(20 FT)
SUGAR GROVE,	W.VA.	(150 FT)
CBD,	MD.	(4 FT)
PANAMA,	CZ.	(4 FT)
3. RADAR RANGE		
MILLSTONE,	MASS.	(85 FT)

Fig. 6 - NTS-2 launch tracking network

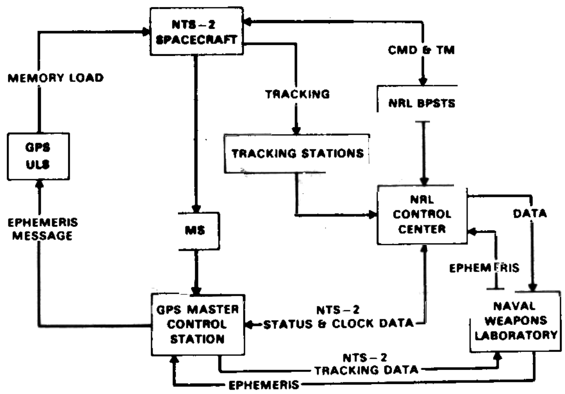
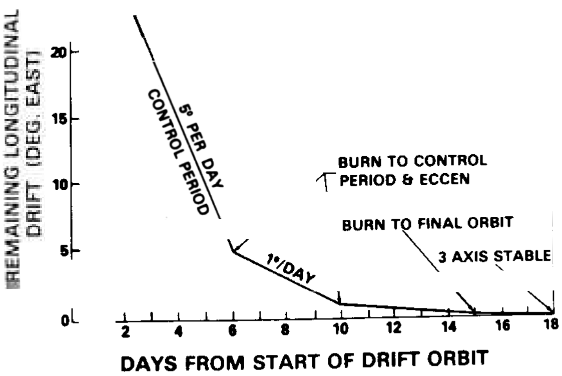


Fig. 7 - NTS-2 command and telemetry links



8 - Pre-launch NTS-2 drift orbit profile

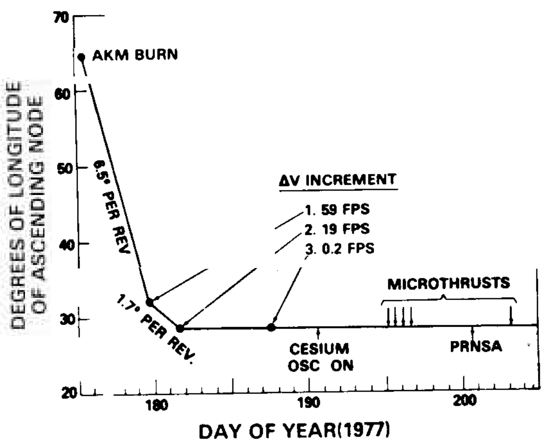


Fig. 9 - NTS-2 drift orbit adjustments

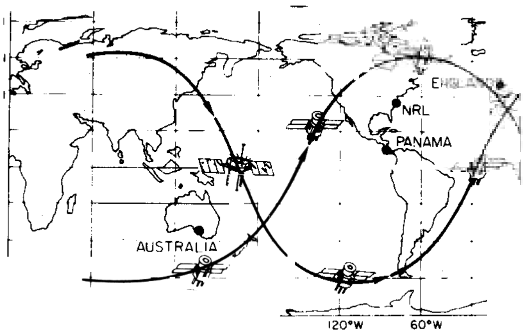


Fig. 10 - NAVSTAR GPS Phase I orbit traces

DAY (1977)	PERIOD (MIN.)	ECCENTRICITY	INCLINATION (DEG.)	LONGITUDE OF ASCENDING NODE (DEG. W)
177	704.9	.012	63.4	
ADJUST				
180	714.5	.002	63.4	
ADJUST				
184	717.94	.0003	63.3	
ADJUST				
192	718.04	.0004	63.3	
ADJUST				
202	717.984	.0004	63.3	
ADJUST				
230	717.967	.0002	63.4	
273	717.956	.00032	63.43	28.35
295	717.946	.00034	63.44	28.10

Fig. 11 - NTS-2 orbital parameters

CBD, MD	BENDIX
PANAMA, C.Z.	BENDIX
AUSTRALIA	AUSTRALIAN (LUNAR LASER, DNM)
ENGLAND	BRITISH (ROYAL GREENWICH OBS.)

Fig. 12 - NTS-2 tracking network

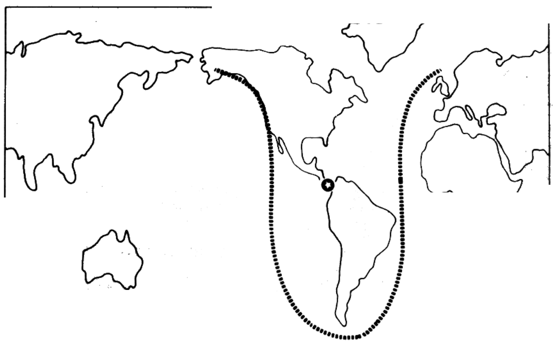


Fig. 13 - Panama NTS-2 coverage

Fig. 14 - Royal Greenwich Observatory NTS-2 coverage

Fig. 15 - Australia NTS-2 coverage

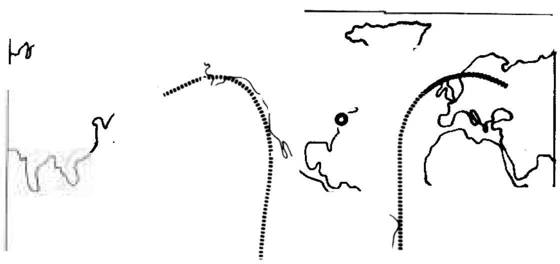


Fig. 16 - Chesapeake Bay Division NTS-2 coverage

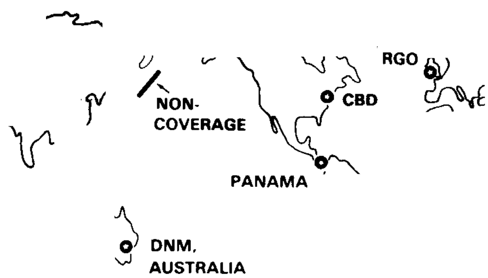


Fig. 17 - NTS-2 orbital non-coverage

CBD
- 3 CESIUMS
- TV (DAILY)
- PORTABLE CLOCK TRIP TO USNO (1X/Week)

PANAMA
- 3 CESIUMS
- PORTABLE CLOCK (1X/YEAR)

AUSTRALIA
- 5 CESIUMS
- PORTABLE CLOCK (2X/YEAR)

ENGLAND
- 3 CESIUMS
- LORAN C
- PORTABLE CLOCK (2X/YEAR)

Fig. 18 - NTS-2 ground timing links

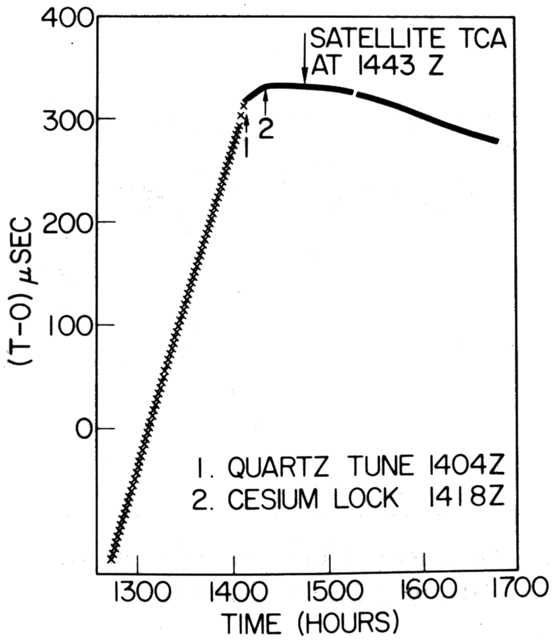


Fig. 19 - Cesium frequency standard lock up, 1977 day 190, 1418 UTC

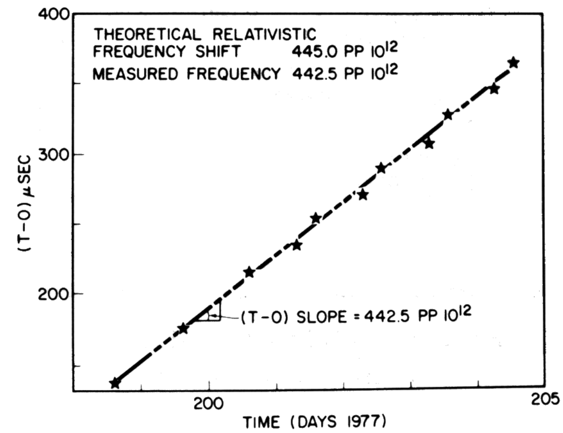


Fig. 20 - Cesium frequency via (T-O) slope

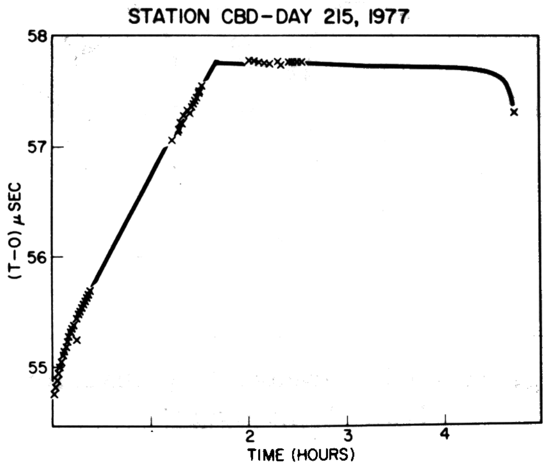


Fig. 21 - Effect of relativity correction

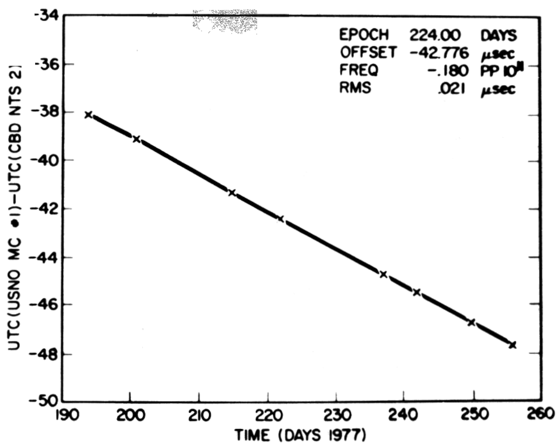


Fig. 22 - Frequency, USNO-CBD

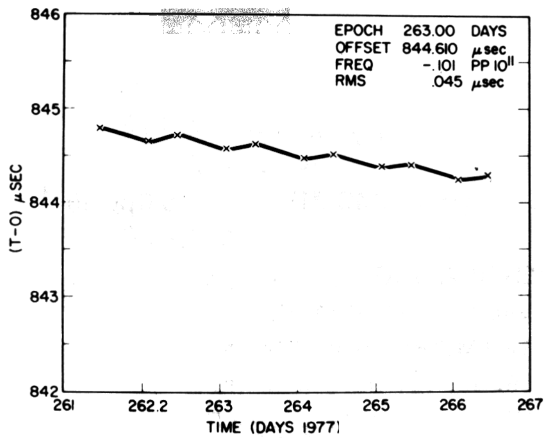


Fig. 23 - Frequency, NTS-CBD

CBD – USNO (MC#1) VIA PORTABLE CLOCK TRIPS	$1.80PP10^{12}$
CBD – NTS 2 VIA SATELLITE RANGE OBS.	$1.01PP10^{12}$
NTS 2 – USNO (MC#1)	$7.9PP10^{13}$
NTS 2 CESIUM OSCILLATOR C FIELD ADJUSTED 14 OCT 77	$7.8PP10^{13}$

Fig. 24 - NTS-2 cesium frequency

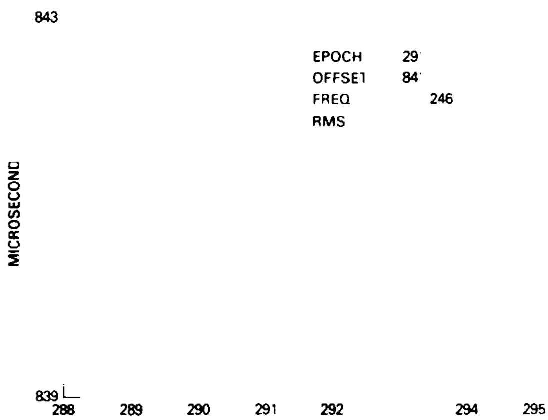


Fig. 25 - Frequency, NTS-CBD after C-field adjustment, 1977 day 287

NOV. 10, 1977

NTS-2 USNO(MC #1) -6.6pp 10^{13}

INVESTIGATING

1. VALUE OF BIT CHANGE
2. TELEMETRY BIT INSERTION
3. FREQUENCY DETERMINATION
4. USNO (MC #1) UNCERTAINTY

Fig. 26 - Preliminary NTS-2 C-field adjust results

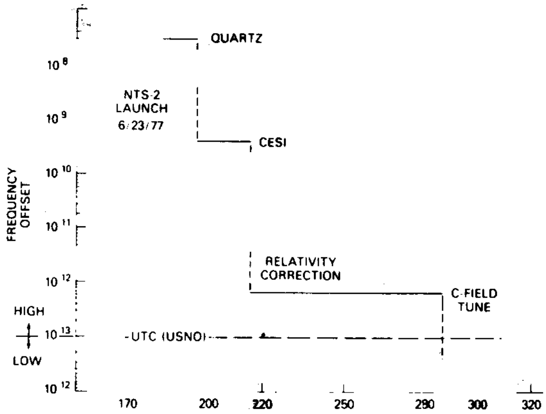


Fig. 27 - Frequency offset summary

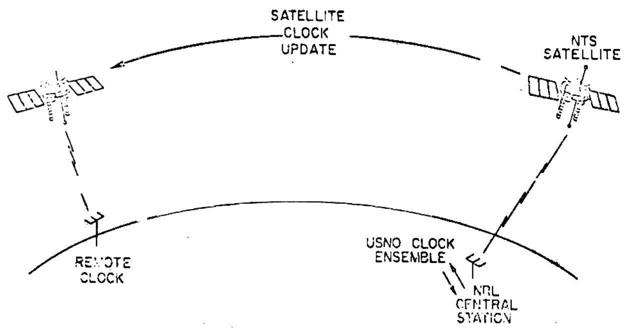


Fig. 28 - Time transfer, NAVSTAR GPS, navigation technology segment

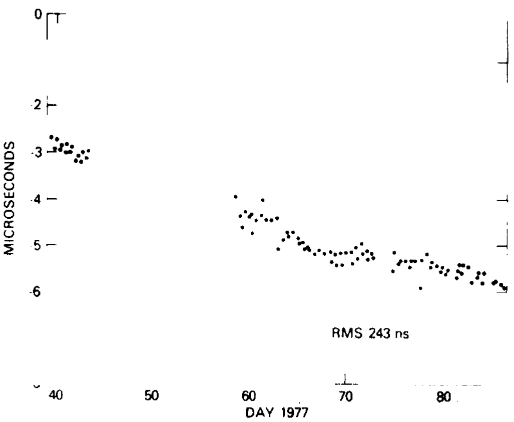


Fig. 29 - NTS-1 time transfer NASA Cape Kennedy Station

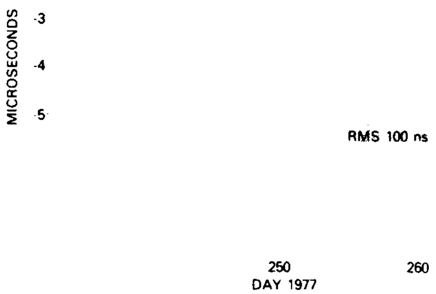


Fig. 30 - NTS-2 time transfer, NASA Cape Kennedy station

STALAS
- GODDARD

RAMLAS
- PATRICK AFB

MOBLAS
- HAYSTACK
- OWENS VALLEY
- GOLDSTONE
- 5 ADDITIONAL

Fig. 31 - NASA laser network

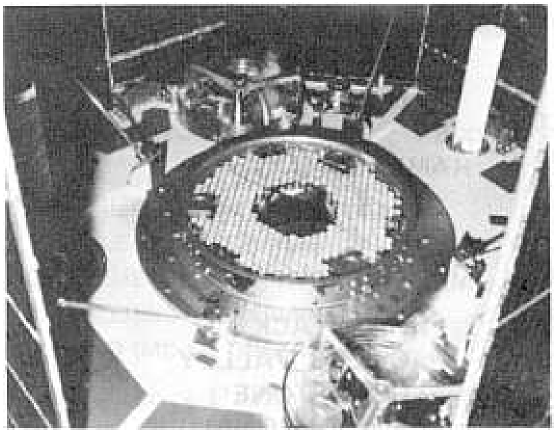
ORGANIZATION	COUNTRY
NASA GODDARD SPACE FLIGHT CENTER	USA
U.S. NAVAL OBSERVATORY	USA
NAVAL RESEARCH LABORATORY	USA
NATIONAL BUREAU OF STANDARDS	USA
THE BUREAU OF INTERNATIONAL DE L'HEURE (BIH),	FRANCE
THE ROYAL GREENWICH OBSERVATORY (RGO),	ENGLAND
THE DIVISION OF NATIONAL MAPPING (DNM),	AUSTRALIA
THE NATIONAL RESEARCH COUNCIL (NRC),	CANADA
THE RADIO RESEARCH LABORATORIES (RRL),	JAPAN
THE NATIONAL RESEARCH LABORATORY OF METROLOGY (NRLM),	JAPAN
THE INSTITUT FUR ANGEWANDTE GEODASIE,	GERMANY

Fig. 32 - International time comparison experiment

OBJECTIVES:

- RESOLVE SCALE BIAS PROBLEM
- LONG RANGE STATION POSITION STABILITY
- LASER NET OBSERVATION
- REFINE COEFFICIENTS OF GEOPOTENTIAL
- PRECISE GPS ORBITS
- HYDROGEN MASER EVALUATION

Fig. 33 - Laser orbit program objectives



34 - NTS-1 laser retroflector

Fig. 35 - NTS-2 laser retroflector

- AREQUIPA, PERU
- NATAL, BRAZIL
  SAN FERNANDO, SPAIN
  ATHENS, GREECE
- ORRORAL VALLEY, AUSTRALIA
- MT. HOPKINS, ARIZONA
- NTS-2 CAPABILITY

Fig. 36 - SAO network

WETZELL, GERMANY
DELF, HOLLAND
TOKYO, JAPAN
GRASSE, FRANCE

Fig. 37 - Cooperating laser sites

DATA TYPE	STATIONS	
TIME DIFFERENCE	NTS TRACKING NETWORK	48 CM
LASER	NASA; SAO; GERMANY; AUSTRALIA	15 CM
OPTICAL	PATRICK AFB	1-2 ARC SEC

Fig. 38 - Typical measurement resolution

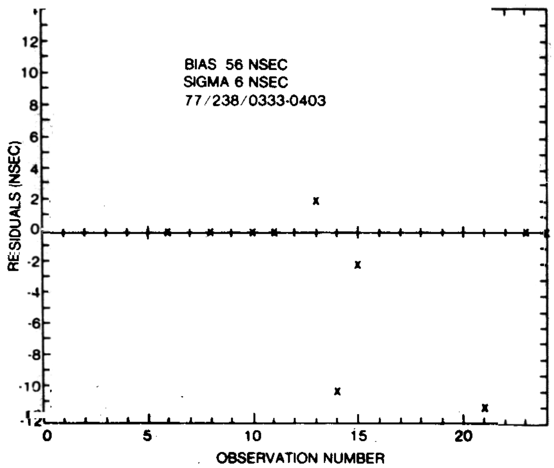


Fig. 39 - Laser residuals, Mt. Hopkins, 1977 day 238

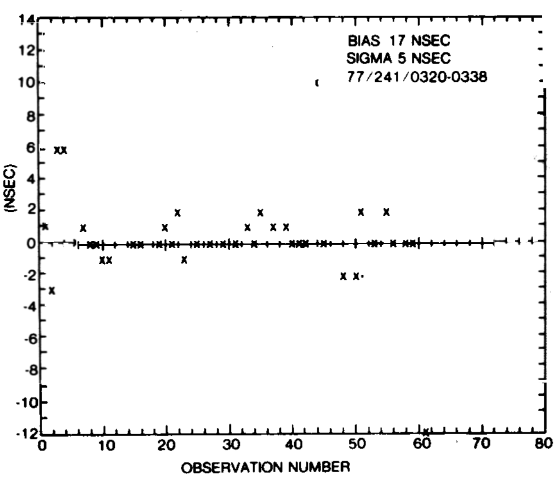


Fig. 40 - Laser returns, Mt. Hopkins, 1977 day 241

Fig. 41 - Proposed precise laser orbit tracking network

QUESTIONS AND ANSWERS

DR. VICTOR REINHARDT, NASA Goddard Space Flight Center:

When you load the C-field adjustment into the cesium, is there a possibility of glitching due to the serial-loading procedure that could have given you hysteresis?

MR BUISSON:

I guess the possibility exists, but we don't think so. We were there when the load occurred, and it was a very clean load. There was no uncertainty in the bit change whatsoever. We got immediate acknowledgement of the numbers that were sent up.

DR. REINHARDT:

My question is not quite the same. Do you latch in the data after it is loaded, or is it loaded as it serially comes in so there could be a large C-field change during loading time?

MR. BUISSON:

It is a two-step process. It is an immediate load, which takes microseconds to do.

MR. LAUREN RUEGER, Johns Hopkins University Applied Physics Lab:

Would you be able to operate this in the timing mode when you are working with the GPS program? Or is that sort of a temporary thing? Or do you use them simultaneously?

MR. BUISSON:

This satellite will be operational. It is designed for a three-to-five year lifetime, and we would expect to be using it right up through NTS-3 launch in 1981.

MR RUEGER

No, I mean the side-tone ranging. Is that what you're receiving? You will be able to operate them simultaneously?

MR. BUISSON:

Yes, it is being operated simultaneously right now t has been since we turned on around day 200 of this year.

DR. HELMUT HELLWIG, National Bureau of Standards

Back to the C-field problem. We have done some measurements at the Bureau that indicate that in cesium, the magnetic shielding properties may be responsible for not producing the calculated values from the C-field adjust in the output frequency. In this case, I think the reason is that you have put the cesium standard in a totally different magnetic environment--actually a very low magnetic field without degaussing--and now any touching of the C-field will relax the magnetic stress in the shielding material.

MR. BUISSON

That is correct. Bob Kern mentioned that yesterday

DR. GERNOT M. R WINKLER, U. S Naval Observatory

I completely agree because the same thing happens to portable clocks, for instance, when you make adjustments. Am I correct that during the tests of that satellite timing equipment, you did check the C-field adjustment but only for small steps? You did not go through such a large adjustment. Is that correct?

MR. BUISSON:

Well, a paper was presented by Joe White, I think, at the Frequency Control Symposium. And I think it was done. I know it was done at 100 to 200-bit changes. I don't know if it was done individually, one bit at a time. We did a 6-bit change, and possibly there is some uncertainty. The hysteresis is unknown on a single 1,2,3-bit change.

DR. ROBERT H. KERN, Frequency and Time Systems:

We have been speculating on what is taking place. It is my understanding that the cesium was launched, turned on, and no C-field adjustments were made. Is that true? The 6-bit change was the first time the C-field was touched?

We were indeed very fortunate, as it came up, to come within about 7 parts in 10^{13} of the USNO clock. What Dr. Winkler has suggested is the hysteresis effect which we have all come to know anytime you put a perturbation (mechanical, thermal, or magnetic) into the C-field of the cesium standard. I think the one thing that amazes me is the stability of the data over the first 50 days or so where we did not see any aging in the C-field. And yet, upon the impact of the 6-bit load, something dramatic certainly happened, whether the loading was correct or.... But the stability that we see over time is not characteristic of a thermal environment change. Jim (Buisson) showed us 30 degrees, I guess, change in the bird.

So it still remains to be determined what actually happened and further tests should bring it out nicely.

MR. WOLFGANG BAER, Ford Aerospace:

I notice you have very low eccentricity numbers. Do you plan to maintain that orbit as close to circular as possible and if so, do you require continual orbit adjustments?

MR. BUISSON:

We will maintain the period so that we have a constant ground track. And in doing that, whenever we do a period adjust, we have the capability of doing an eccentricity adjust also. Right now we are quite satisfied with 0003. The specs were something like 01 or 001. But whenever we do a period adjust to keep it on station, yes, we will hope to keep the eccentricity as circular, if not more circular.

MR. DAVE DOUGLAS, University of Rochester:

In one of the plots in which you showed microseconds versus time, I thought I saw a periodicity. What was that? The oscillation with time?

MR. BUISSON:

A lot of this is due to the uncertainty of the orbit determination at present. You are looking at one side of the orbit and then the other side of the orbit, and it could occur in the order of 0.5 microsecond or less. And I think that is what you are referring to on one of the long-term slides.

DR. HELLWIG

Going back to the C-field problem. It is important to state again that these effects, like magnetic hysteresis and large external magnetic field changes, are common to all present atomic clocks and are generic; that is, it is a magnetic shielding problem. We see that even in our primary standards, so it should not be held against a particular standard.

DR. MULHOLLAND, University of Texas:

Commenting on the previous remark about the periodicity in the residuals, that in fact occurred on two slides in which you had plots of normal points--essentially one point for each pass: It looked as though the periodicity was about half a day which would have to be the orbit.

MR BUISSON:

Yes, we agree. That is being actively pursued now by Naval Surface Weapons Center