USE OF LIBERIA OMEGA TRANSMISSIONS
for
FREQUENCY CALIBRATION IN EGYPT

Safaa Samuel
National Institute for Standards
Cairo, Egypt

ABSTRACT

The National Institute for Standards (NIS), is maintaining the
Egyptian National Standards. Frequency comparisons with different
transmissions has been going on for several years.

In this paper, the measuring method used for frequency comparison by
means of Omega transmission system between Liberia (12 kHz) and the
NIS is described. The results of continuous phase comparison of the
transmission from Monrovia, Liberia and the HP Cesium frequency stan
dard maintained at NIS, a distance of 5100 km during a 10 month
period (Jan- Oct, 1985) are summarized. Measurements are made on
the phase records at 24 hours intervals at times when the propaga-
tion path is completely sunlit and phase fluctuations are minimal.
A statistical analysis of the propagational phase variations for a
55 day sample is included. A precision of 1.6 pp 10^{13} is achieved
in that period.

I. Introduction

The very low frequency band (3 - 30 kHz) is characterized by its
history of early long distance communication with stable and reli-
able signal propagation. The part of the band between 10 and 14
KHz is allocated to radionavigation systems among which OMEGA is
most generally known. A comprehensive review of the evolution and
current state of VLF techniques has been written by Swanson and
Kugel [1] .

Advantages of VLF include high accuracy and also very long range.
The particular interest is the ability of VLF to readily provide
information for the intercomparison of precision oscillators.
Numerous applications of VLF for comparing atomic frequency stan
dards at global distances, using the band allocated for communi-
cation (14 to 30 kHz), have been described in the literature [2-6] .

The basic method of using VLF transmissions is phase-time compa-
rison of the received signal with the local standard frequency

signal, using a phase tracking receiver [7] . The receiver synthe-
sizes the 100 kHz frequency from the atomic oscillator to that of
the incoming radio transmission. A servomechanism locks the syn-
thesized signal to the incoming. The time difference Δt between
the time marker of the Institute's frequency and the rising slope of
the synthesized signal is measured. The results obtained by means
of an electronic counter is printed as a matter of routine.

This paper summarizes the results of a continuous phase comparison
between Omega standard frequency transmission (12 kHz) of Monrovia,
Liberia and the cesium beam frequency standard of the National Ins-
titute for standards (NIS), Cairo, Egypt for a period of 10 months
(Jan.-Oct., 1985). Measurements are made of the phase records at
24 hours intervals at times when the propagation path is sunlit and
phase fluctuations are minimal.

An estimation of the frequency difference is calculated, as well as
normal phase variation during the different seasons. A statistical
information is obtained to give an insight into the nature of the
perturbations over the path of 5100 km.

II. <u>Omega Navigation System</u>:

This system was originally conceived as a VLF radio navigation
system for ships, submerged submarines, and aircraft. It is expe-
cted that both civilian and military craft of many nations eventually
navigate by Omega. Omega transmitting stations operate in the inter-
nationally allocated VLF navigational band between 10 and 14 kHz.
This very low transmitting frequency enables Omega to provide adequ-
ate navigation signals at much longer ranges than other ground-based
navigation systems. On October 1, 1968 the U.S. Defense Department
approved an eight-station, 10-kW, Omega system with an operational
date in mid 1970 [8] . The eight-station system provides reliable
and near-global coverage. Figure 1 gives the worldwide location of
the eightstation network.

All stations now transmit three basic navigational frequencies
(10.2 kHz, $11\frac{1}{3}$ kHz, 13.6 kHz). In order to prevent interference,
transmissions from each station are time-sequenced as shown in
Figure 2.

This pattern is arranged so that during each transmission interval
(approximately 1 second), only three stations are radiating, each
at a different frequency. The duration of each transmission varies
from 0.9 to 1.2 second, depending on the station's assigned location

within the signal pattern. With eight stations in the implemented system and a silent interval of 0.2 second between each transmission, the entire cycle of the signal pattern repeats every 10 seconds [9] .

Besides the three basic navigational frequencies, other frequencies have been added to the Omega signal format. Original plans were made to transmit two unique frequencies at each station for the purpose of interstation time synchronization but this requirement has been removed through use of highly stable cesium frequency standards. In addition, a unique frequency transmission for each station can be added which will aid in time dissemination by providing a beat frequency and a high duty cycle at that frequency, and hence may be received without commutation.

All Omega transmitting stations are synchronized by means of very stable cesium beam frequency standards. These standards or clocks are referenced to the atomic time scale which differs from Coordinated Universal Time (UTC) more commonly in use. Thus, in 1978, the Omega epoch or time reference is seven seconds ahead of UTC since the yearly adjustments for earth motion have not been made to make Omega Epoch in agreement with UTC.

III. Propagation Measurements:

The standard frequency signal used in this study is the 12-kHz signal from Monrovia, Liberia and the receiver is located in Cairo, Egypt, about 5100 km north east of the transmitter. The signal from this transmitter is continuously monitored at NIS, Cairo, Egypt, to obtain the relative phase of this transmission versus HP 5061 A. Fig.3 gives the typical daily phase record for each month, expanded so that seasonal variation might be seen more clearly. The depth of the diurnal shift of the received signal at Cairo is typically 45 microseconds. This figure displays all the characteristic features of all of the similar records that have been made at Cairo, Egypt. The depth of the trapezoidal pattern is constant throughout the year, being about 45 $\pm$ 1 μs. The only real seasonal change is the ordinary variation in the length of the day and night. The afternoon shift is not so well defined as the morning shift. Generally, the phase stability during the day is much better than during the night.

IV. Frequency Comparison:

The effects of diurnal variations induced by ionospheric changes must be eliminated from phase observations prior to timing application. For frequency comparison, measurements may be restricted to day or

night observations where temporal phase variation may be disregarded. The constancy of the diurnal phase shift is an important factor in the day-to-day intercomparison of frequency standards via Omega signals. From Fig.3, it can be seen that there are hours of the day during which quite consistent results might be expected, for instance 1200 UTC. At that time the whole path is in light in all seasons.

The phase of the received signal can be described as:

$$\phi_{ab} = \phi_{oa} + \phi_{pa} + \alpha_b t - \alpha_a t$$

where:

ϕ_{ab} = phase of signal from point A received at B
ϕ_{pa} = propagation delay of signal from A
α_a = frequency offset of oscillator A from an absolute standard
α_b = frequency offset of oscillator B from an absolute standard
ϕ_{oa} = absolute phase of Omega signal at transmitting antenna A at time t=0

If the phase of the signal from A is measured at times t and t', using the prime marks to indicate quantities measured at the later time:

Then

$$\overline{\phi}_{ab} - \phi_{ab} = \overline{\phi}_{pa} - \phi_{pa} + (\alpha_b - \alpha_a) (t - t')$$

and

$$\alpha_b - \alpha_a = \frac{(\overline{\phi}_{ab} - \phi_{ab}) - (\overline{\phi}_{pa} - \phi_{pa})}{(t - t')}$$

The propagation delay ϕ_{pa} is a variable which, for a given path, varies with the time of day, with season, and with sudden ionospheric disturbances. The greatest variation appears to be the diurnal shift which is cyclic and, to a high degree predictable. The seasonal variations, to the degree that they affect the pattern of day light and dark, are also predictable. Sudden disturbances of the ionosphere which affect the ionization of the reflecting layer involved in VLF propagation are largely unpredictable, but usually of short duration.

To measure the frequency offset between the two oscillators considered, one should know or be able to measure each term on the right side of the last equation. The terms of ϕ_{ab} and $\overline{\phi}_{ab}$ are measurable.

The term $(\bar{\phi}_{pa} - \phi_{pa})$ could be made quite small by making observations at the same time of the day, and by using an observation period of such length as to permit the identification and elimination of the effects of sudden ionospheric disturbances.

A considerably large sample is encompassed in Figures 4,5. Fig.4 presents the phase variation, at 1200 UTC, of Liberia (12 kHz) as received at Cairo, Egypt versus HPCS 5061 A located at Cairo for the period March through April. The frequency offsets are plotted for each day of the measurement period in Fig.5.

V. Statistical Representation of Phase Difference Measurements:

The consistency of phase measurements during a given period of the day is indicated by the variance of the measurements at that hour. The part of the fluctuations from day to day of the daily phase measurements (of a transmitted signal) by the receiving laboratory, is characterized by a standard deviation. Phase fluctuations observed at a receiver output result from a combination of effects, due to: (1) he transmitting system; (2) the propagation medium; (3) atmospheric and other types of noise, and (4) the receiving system. Fig.3 includes both propagation and measuring system variations.

The best (least-square-error) straight line fit for the phase record of Liberia (12 kHz) measured at Cairo, Egypt for the period March-April is computed for the set of data taken daily at 1200 UTC. The most significant value is the slope of the line and the variance of measured values with respect to this line. The slope of the straight line represents the estimated frequency difference. For the period March-April slope of 4.6×10^{-13} is obtained; the corresponding variance is 0.6 microseconds.

Having assumed that any slope in the record was due to oscillator frequency discrepancy, the deviations of Fig. 6 represent random variations due to fluctuations in transmission time or noise in the receiving equipment. The important point is that the deviations seldom exceed $\pm$ 1.5 microseconds.

The standard deviation divided by the number of microseconds in the interval gave the standard deviation of the frequency measurement for that period. It is seen that a precision of 1.6 in 10^{13} is achieved in 55 days.

Conclusions

Omega transmissions can be used as sources for frequency comparison of high accuracy at very long distances due to the inherent reliability of VLF propagation and almost continuous signal availability.

A frequency comparison between Monrovia, Liberia and the National Institute for Standards, using the Omega transmitter is possible with a relative measurement uncertainty of approx. 4×10^{-13} with an observation period of 55 days. For better precision, the comparison period should be increased.
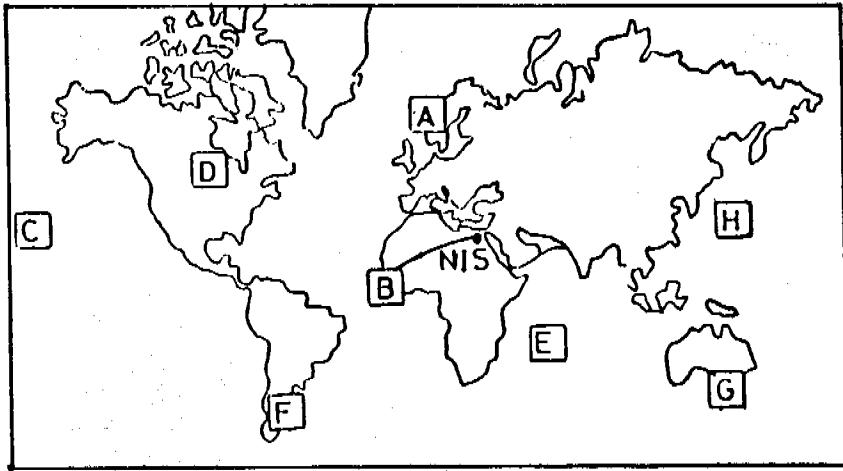
The main disadvantage of this system for frequency comparison is the continuous operation and phase maintenance of the frequency source and the receiver over the total period of comparison.

Another disadvantage is the non-continuity of this type of transmission which reduces the efficiency of the system for frequency comparison. However, receivers using commutators to turn the receiver on and off at the proper times to receive only the desired Omega station, to improve reception was not necessary in this case.

References:

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Fig.1 Location of Omega transmitters and NIS
receiving laboratory

Segment	A	B	C	D	E	F	G	H
Duration (s)	0.9	1.0	1.1	1.2	1.1	0.9	1.2	1.0

Pauses: 0.2 s

Station	A	B	C	D	E	F	G	H
Norway (A)	10.2	13.6	11.33					
Liberia (B)	12.0	10.2	13.6	11.33	12.0	12.0		12.0
Hawaii (C)			10.2	13.6	11.33			
N.DaKota (D)				10.2	13.6	11.33		
La Reunion (E)					10.2	13.6	11.33	
Argentina (F)						10.2	13.6	11.33
Australia (G)	11.33						10.2	13.6
Japan (H)	13.6	11.33						10.2

Fig.2 Omega Signal Transmission Formats
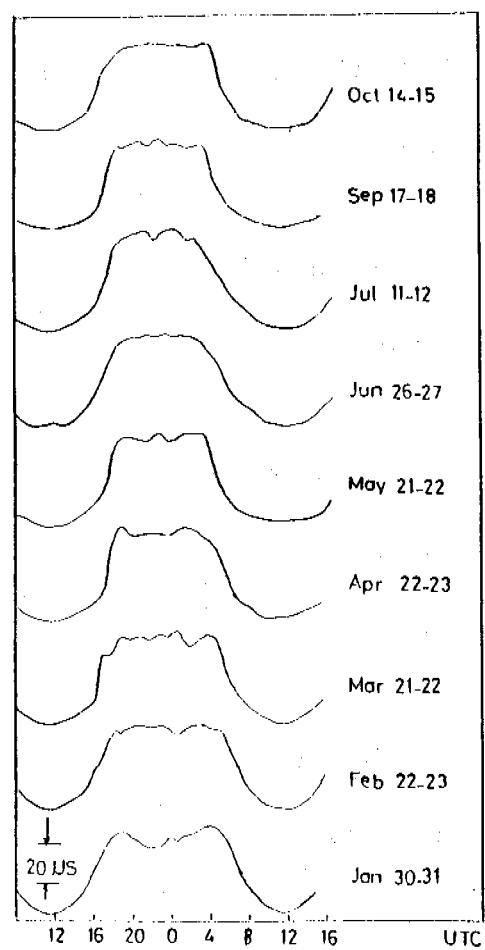
Fig. 3   30-hour diurnal phase variation
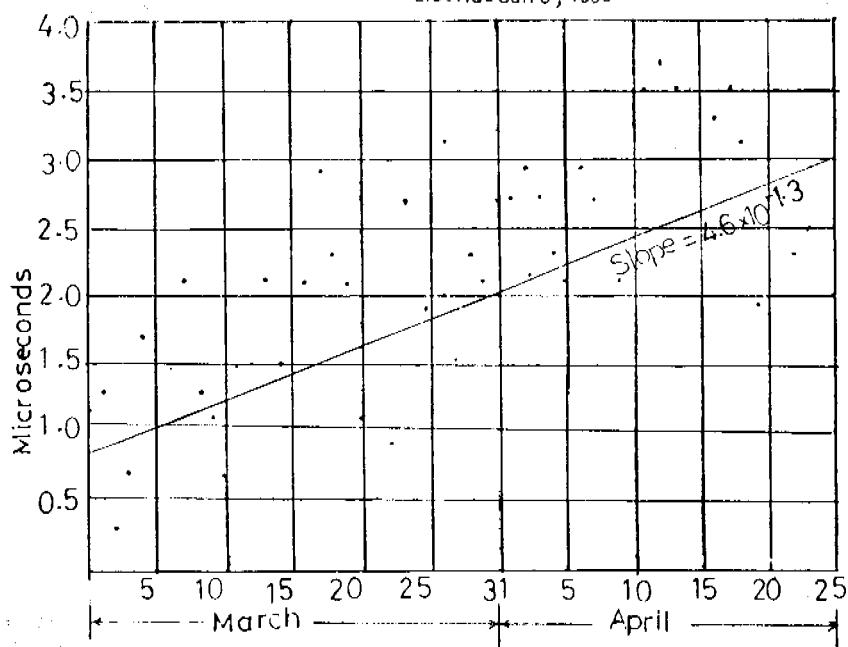Liberia–Cairo, 1985
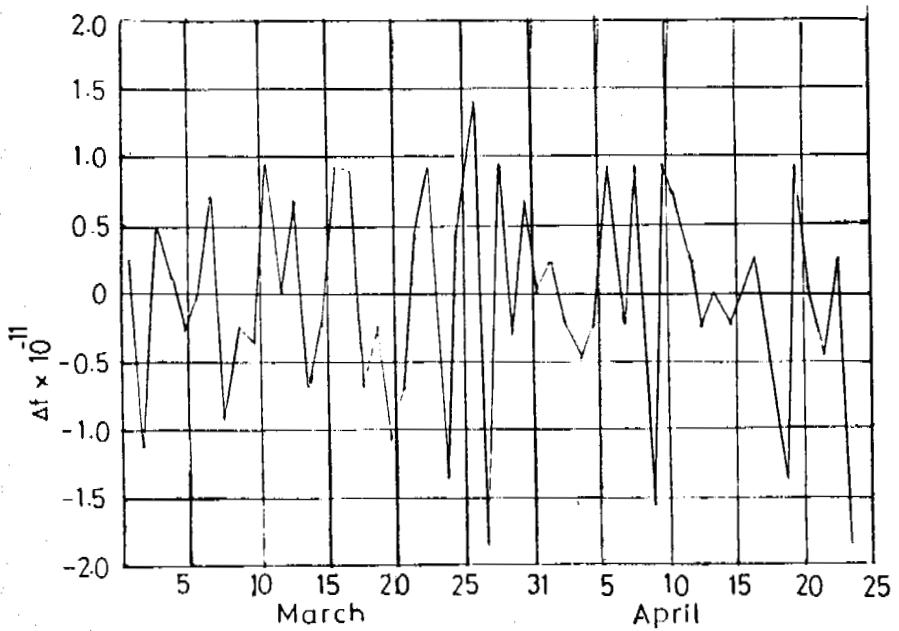

Fig. 4. Phase record of Liberia at Cairo, Egypt.
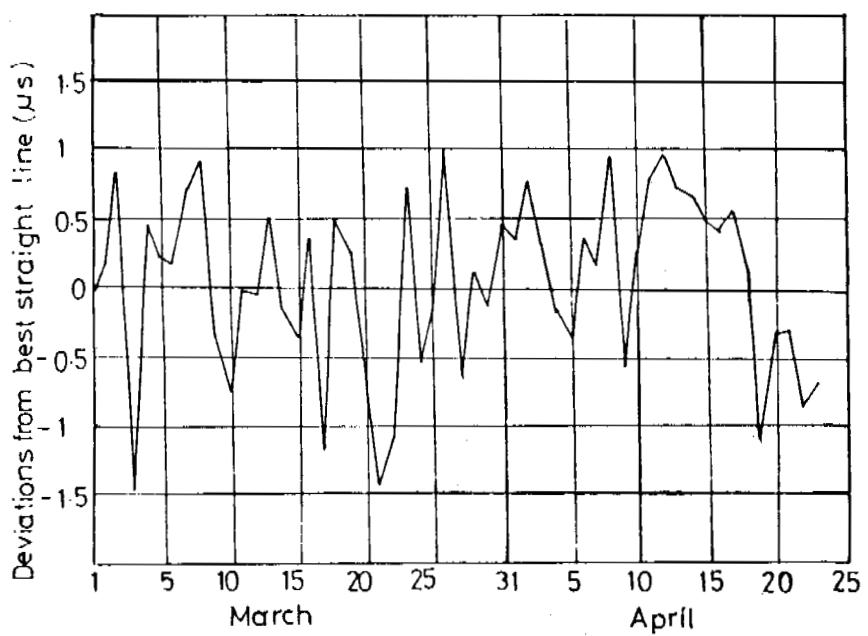
Fig.5 Frequency offset vs Hp 5061A Cs

Fig 6. Fluctuations in the time of arrival of the 12 KHz
unique frequency from Liberia received at Cairo

NAVSTAR GPS PROGRAM STATUS AND PHASE III GPS USER EQUIPMENT

LCDR (RNoN) PER W. NIEUWEJAAR
Norwegian Representative to the Navstar GPS Joint Program Office
USAF/Space Division - YEU
P.O. Box 92960 WWPC, Los Angeles, CA 90009-2960

1. Introduction

The Navstar Global Positioning System is now in the production and deployment phase or the so called phase III. This paper will give an overview and current status of the three segments of the GPS system. It will present the User Equipment (UE) with emphasis on their precise time dissemination capabilities, test plans for the UE time interfaces and delivery schedules for User Equipment. Some applications of Precise Time and Time Interval (PTTI) in military operations will also be discussed.
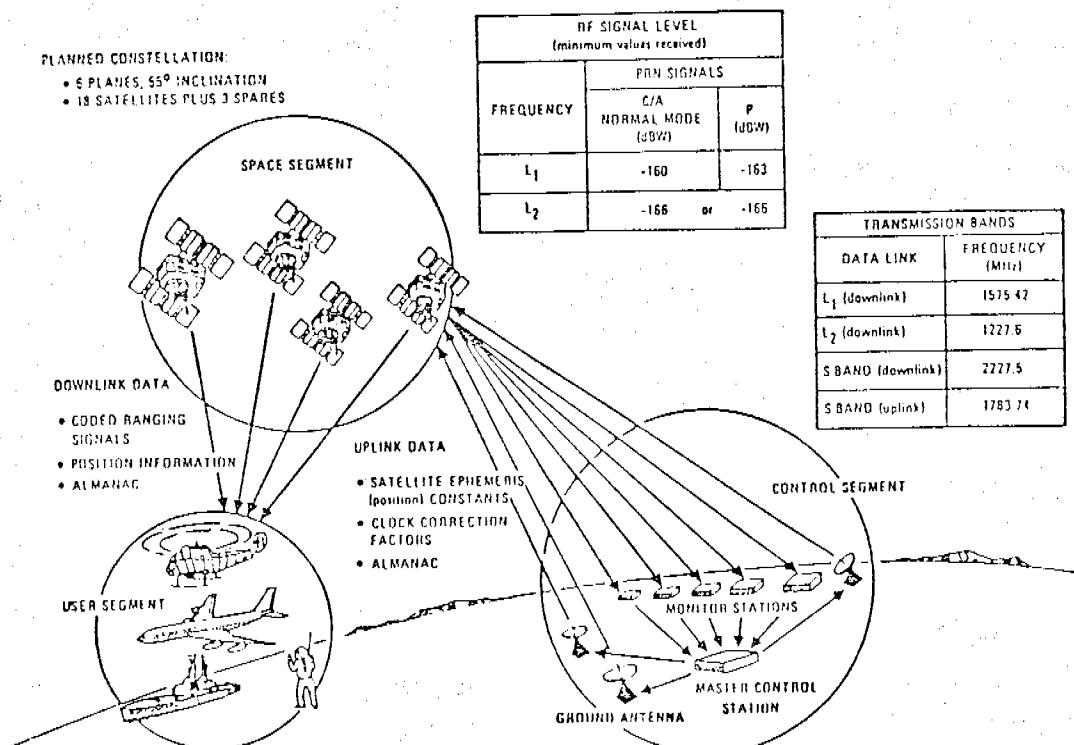
Navigation Mission

Figure 1 Navstar GPS Major Segments
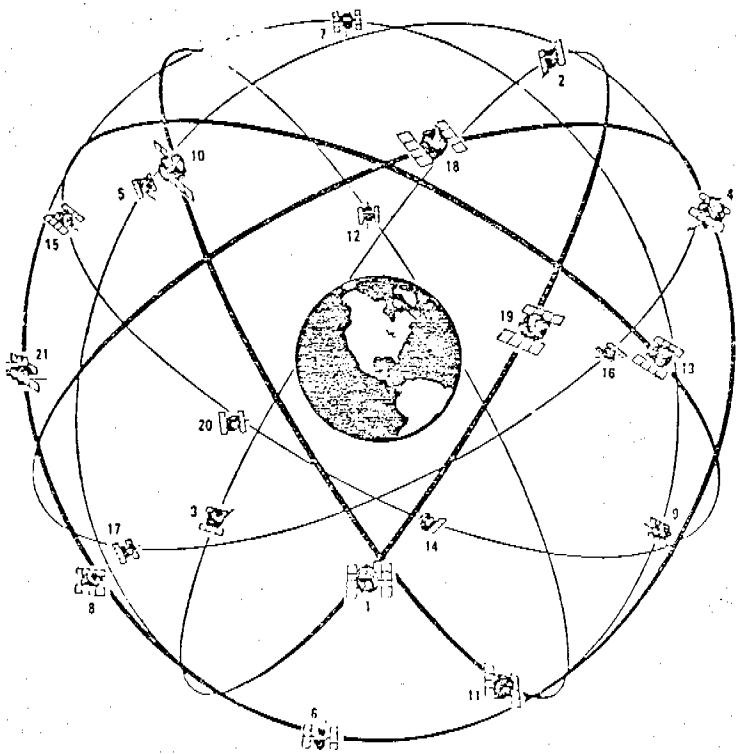
2. GPS System Overview

The NAVSTAR GLOBAL POSITIONING SYSTEM (GPS) is a space based radio navigation system which provides a global, continuous position, velocity and time capability. The GPS system is comprised of three major segments: Space-, Control- and User-, see Figure 1. The GPS development and production program for all three segments is managed by the US Air Force Systems Command / Space Division, Navstar GPS Joint Program Office (JPO) at Los Angeles Air Force Station, CA. The JPO is manned by personnel from: US Air Force, US Navy, US Army, US Marine Corps, US Coast Guard, Defense Mapping Agency and NATO.

2.1 Space Segment

The GPS space segment, when fully operational, will consist of 18 operational satellites and 3 active spares. The satellites will be placed in 6 orbital planes with 3 operational satellites in each plane and an active spare in every other plane, see Figure 2. The satellite orbital planes will have an inclination relative to the equator of 55° and a circular orbit height of 20,200 km, which dictates that the satellites will have an orbital period of approximately 12 hours. The satellites are developed and are being produced by Rockwell International Incorporated, Seal Beach, California. The satellites will be positioned such that a minimum of 4 satellites are always visible to a user anywhere on earth. The satellites transmit on two frequencies L_1 = 1575.42 MHz and L_2 = 1227.6 MHZ. The satellites transmit their signals using spread spectrum techniques and two types of spreading functions: the C/A-code and the P-code on L_1 and the P-code only on L_2. The C/A-code or the "Coarse/Acquisition"-code is available to any GPS user, military or civilian, but the P-code, or the "Precision"-code, is only available to US military users, NATO military users and other military and civilian users authorized by the US Department of Defense. The codes are used to lock on to the satellite signals and to determine the range between the satellite and the user. Since only the P-code is on both frequencies, only authorized users can make dual frequency comparisons to compensate for ionospheric delay errors. The C/A-code user has to use a model of the ionosphere which gives a lower navigation accuracy. Superimposed on both the P-code and the C/A-code is the NAVIGATION-message, containing satellite ephemeris data, atmospheric propagation correction data and satellite clock bias information.

2.2 Control segment

The Control segment has been developed and built by International Business Machines (IBM), Gaithersburg, Maryland and consists of one Master Control Station (MCS) at Falcon AFS in Colorado Springs, Colorado and monitor stations at Hawaii, Kwajalein, Diego Garcia and Ascencion. See figure 3. All monitor stations except Hawaii are also equipped with ground antennas for communication with the GPS satellites.

Figure 2 Operational Satellite Constellation
18 Operational Satellites Plus 3 Active Spares

The monitor stations passively track all GPS satellites in view, collecting range and clock data from the satellites. This information is passed on to the MCS, where it is compared against predicted ephemeris and clock drift data. Corrected navigation message information is uploaded to the satellites via one of the ground antennas, and the information is then made available to the user via the satellites NAV-message.

2.3 User Segment

The Phase III User Equipment (UE) is developed by Rockwell/Collins Government Avionics Division, Cedar Rapids, Iowa. The UE will be used by USAF, USN, USA and USMC. The most common use of GPS will be for navigation purposes, and the design of the UE reflects that use. The majority of military vehicles will have GPS installed and will use it for many different applications, some of them shown in figure 4. However, the equipment can also meet most requirements for precise time dissemination for many military users.

3. Space Segment Status

3.1 Block I Satellites

Currently 6 out of the 10 Block I development satellites on orbit are functioning satisfactorily. Navstar 3 is nearing the end of its useful lifetime due to solar array degradation. Navstar 4 lost its last atomic clock and is currently running on a crystal oscillator which provides reduced pseudorange accuracy. Due to these problems Navstar 4 was set unhealthy and cannot be used by Rockwell-Collins UE. To back up Navstar 3 and 4, Navstar 11 is being rephased to improve the constellation coverage time over Yuma Proving Ground, Arizona, where JPO's GPS field test facilities are located. The rephasing of Navstar 11 started in October – 86 and is scheduled to be completed in April – 87. Old, current and new position of Navstar 11 are shown in Figure 5.
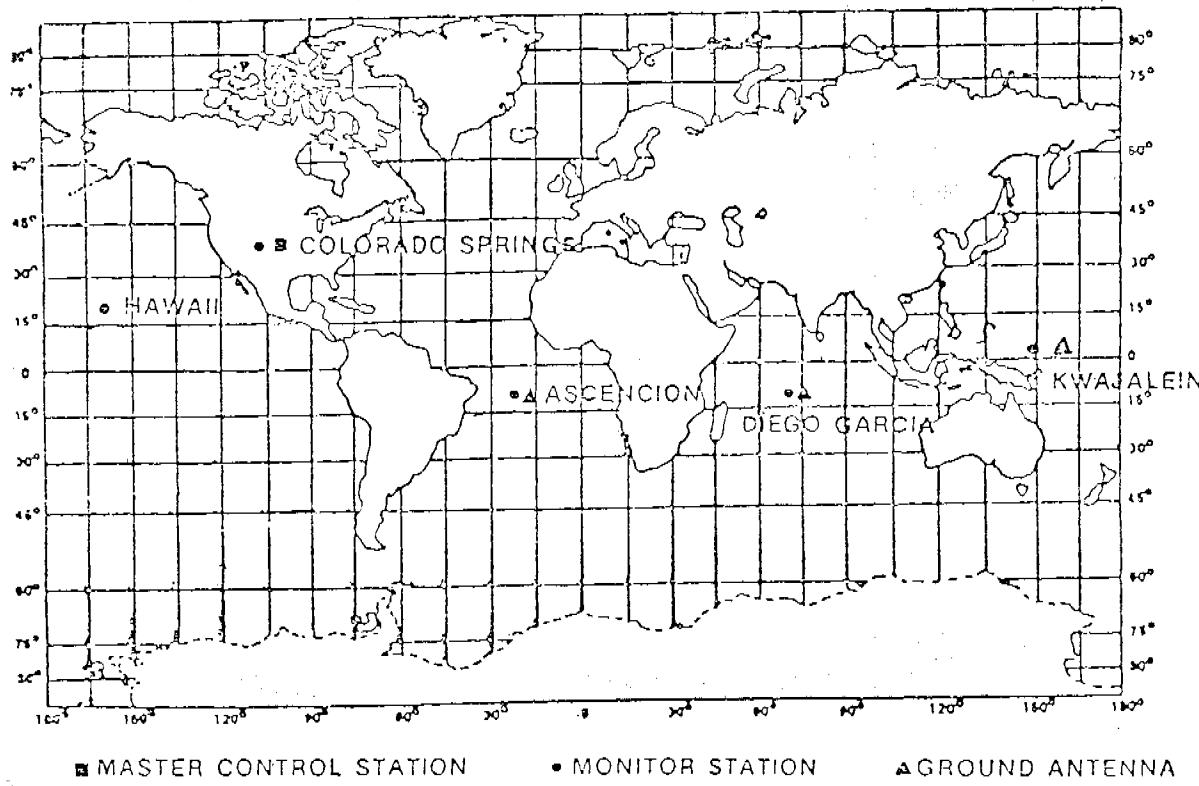

Figure 3 GPS Control Segment Locations

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EN ROUTE NAVIGATION

LOW-LEVEL NAVIGATION

TARGET ACQUISITION

CLOSE AIR SUPPORT

MISSILE GUIDANCE

COMMAND & CONTROL

ALL-WEATHER AIR DROP

SENSOR EMPLACEMENT

PRECISION SURVEY

SPACE SHUTTLE
NAVIGATION

INSTRUMENT APPROACH

RENDEZVOUS

COORDINATE BOMBING

REMOTELY PILOTED
VEHICLE OPERATIONS

BAREBASE OPERATIONS

SEARCH & RESCUE

PHOTORECONNAISSANCE

PASSIVE ELINT

SATELLITE TRACKING
& NAVIGATION

RANGE
INSTRUMENTATION
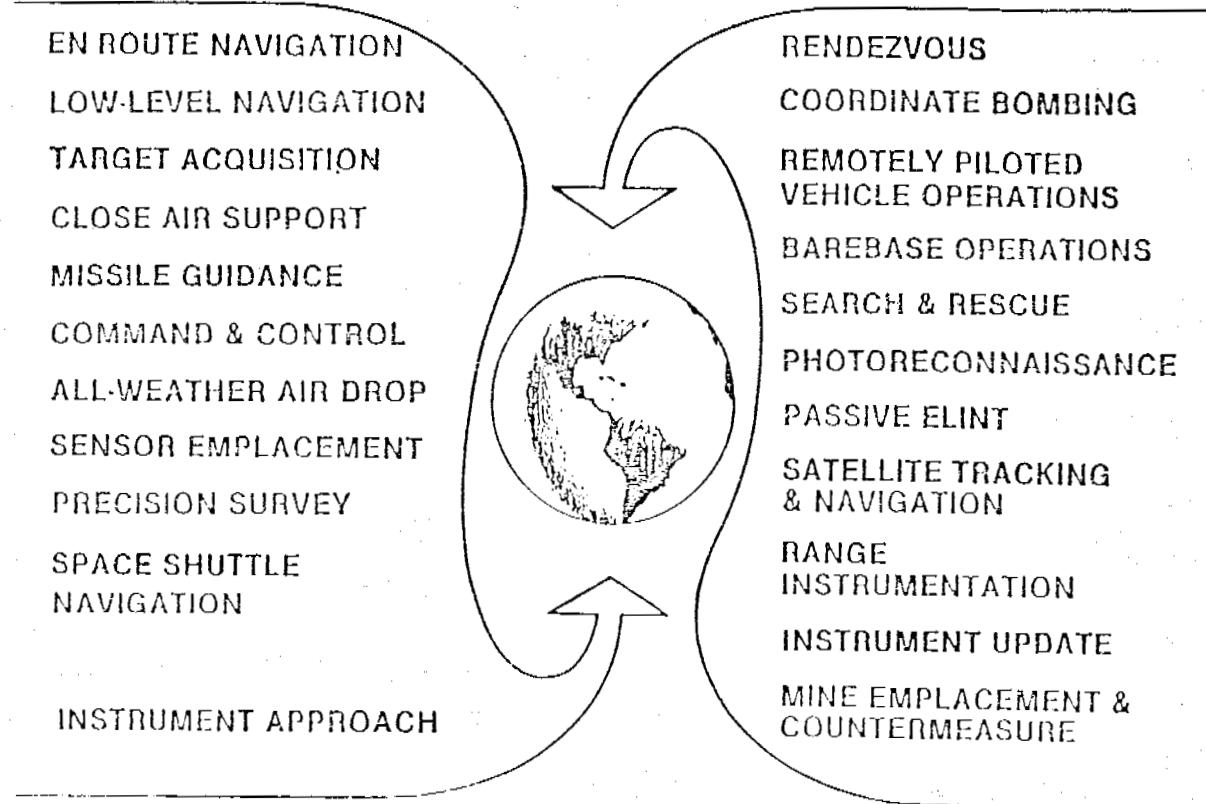
INSTRUMENT UPDATE

MINE EMPLACEMENT &
COUNTERMEASURE

Figure 4 Some GPS Applications

3.2 Block II Satellites

The development of Block II operational Navstar satellites is completed,
and production had already started when the Challenger accident happened.
The Block II satellites were designed to be launched from the shuttle only,
so the accident created three major problems:

1) Storage of already built Block II satellites
2) Change of production schedule for the remainder of the satellites
3) Redesign of some satellites to allow launching on Expendable Launch
   Vehicles (ELVs).

3.2.1 Storage of Satellites

The first two Block II satellites, Navstar 13 and 14 were already so close
to completion at the time of the shuttle accident that the JPO decided to
go ahead and complete assembling and testing them. Navstar 13 will be
shipped to Cape Canaveral for system and compatibility testing. This
operation will give valuable experience and knowledge to support later
shuttle-launch operations of Navstar satellites. Storage of the subsequent
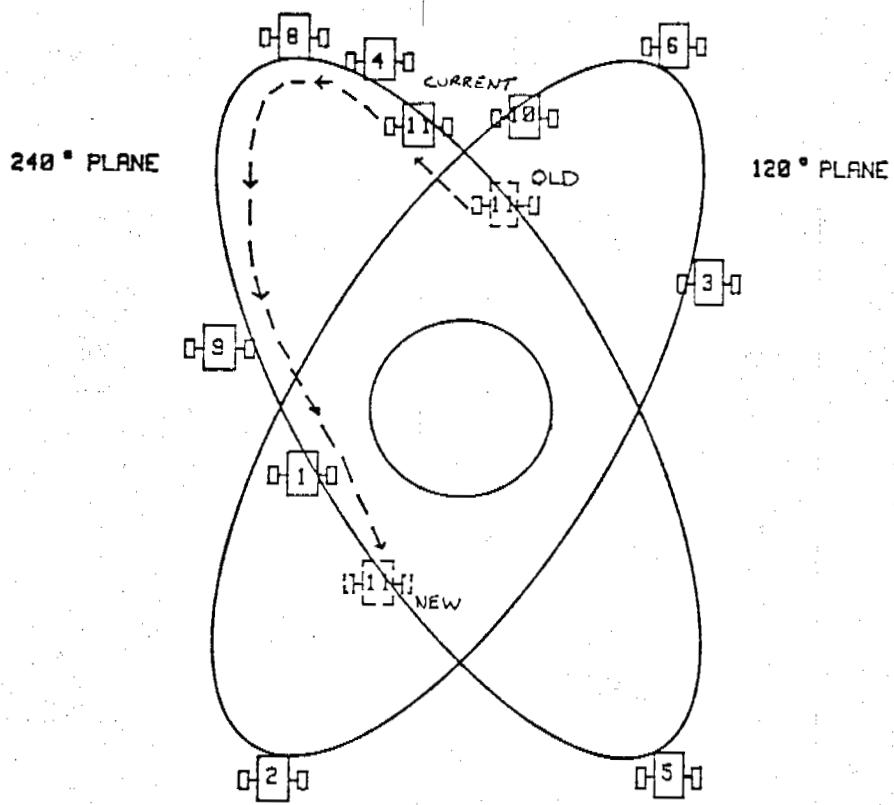satellites has not yet been determined.

Figure 5 Block I Satellite Constellation

3.2.2 New Production Schedule

Due to the launch delay, the production schedule for the satellites had to be modified. The new schedule that JPO is working on will match the new launch schedule. The satellites will be assembled and tested such that they are ready shortly before launch, since long term storage of satellites is very expensive. The current schedule calls for the first GPS launch in early 1989, although the potential exists for one more launch in 1988, depending on ELV contractor selection and national priorities.

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3.2.3 Satellite Launch on ELV's

Because of the shuttle delay, the JPO plans to launch some of the satellites on ELVs to have the operational constellation on orbit as soon as possible. The JPO supported a competitive procurement by Space Division of 12 Medium Launch Vehicles (MLVs) in the summer of 1986. Source selection will take place in February 1987. The four bidders and their candidate MLVs are:

McDonell-Douglas	—	"Stretched Delta"
General Dynamics	—	Atlas Centaur
Martin Marietta	—	Titan 34D
Boeing-Hughes	—	New design

The US DoD has also considered the possibility of using the European Ariane booster to launch some of the satellites.

3.2.4 Launch Schedule for the Satellites

The overall delay in deployment of Navstar satellites due to the Shuttle accident is expected to be approximately two years. Figure 6 shows the original launch schedule and the current plans for launches using both the Shuttle and MLVs.

	FY87	FY88	FY89	FY90	FY91	FY92
Original schedule	6	7	7	4	4	
New shuttle schedule			4	6	6	
MLV launch schedule			3	4	4	1
Shuttle and MLV total			7	10	10	1

Figure 6 Launch Schedules

The new dates for 2 – Dimensional and 3 – Dimensional capability compared to the original planned dates are shown in figure 7.

	2-D Capability	3-D Capability	21 Satellites
Orig. Schedule	June 88	June 89	October 89
New schedule	April 90	October 90	January 91
	(October 89)	(September 90)	

Figure 7 Schedule for 2-D and 3-D Coverage

The dates in parenthesis indicates 2-D and 3-D capability with 4 Block I satellites still operational through 1989.

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4. Control Segment status

The transition from the Initial Control System (ICS) at Vandenberg AFB, California to the Operational Control System (OCS) at the Consolidated Space Operations Center (CSOC) at Falcon AFS, Colorado Springs, Colorado is completed. On-orbit operations are being performed from CSOC. Five crews of operators have been trained so far, and additional training is continuing. The transition of logistics support operations from Space Division to Space Command is in progress and will be completed by 1988. Three hydrogen maser clocks will be placed at CSOC together with a couple of cesium clocks and they are expected to give the CSOC a Universal Time Coordinated (UTC) time accuracy capability in the order of 10 ns. The Interface Control Document, ICD-GPS-202, between US Naval Observatory (USNO) and CSOC for UTC time control has been signed off by USNO and JPO.

5. User Segment Status

The Joint Requirements and Management Board (JRMB) approved a Limited Rate Initial Production (LRIP) program for GPS UE on 16 June 1986. The first production standard sets for test purposes will be delivered in late 1987, and during the next two years, around two hundred sets will be delivered each year. The LRIP currently only involves Fiscal Year (FY) 1986, 87 and 88, but FY 89 might be added later. The JPO has also started a second source program which will have full effect for the recompetition of the UE production contract in 1989 or 1990. Selection of the second source competitors is planned to take place in 1987. The overall plan is to buy some 27,000 sets between 1989 and 1999. The quantities and the procurement schedule are shown in figure 8. Actual delivery is 18 – 30 months after any order is placed.

6. User Equipment Time Interfaces

The DoD's GPS RCVRs will have three different interfaces that output precise time. Also one of these interfaces will receive precise time inputs from an external source. The interfaces are :

Interface	Document
Instrumentation Port	(ICD-GPS-215)
Precise Time and Time Interval	(ICD-GPS-060)
Have Quick	(ICD-GPS-060)
MIL-STD-1553 data Bus	(ICD-GPS-059)

The overall plan is to buy some 27,000 sets between 1989 and 1999. The quantities and the procurement schedule are shown in Figure 8. Actual delivery is 18 - 30 months after any order is placed.
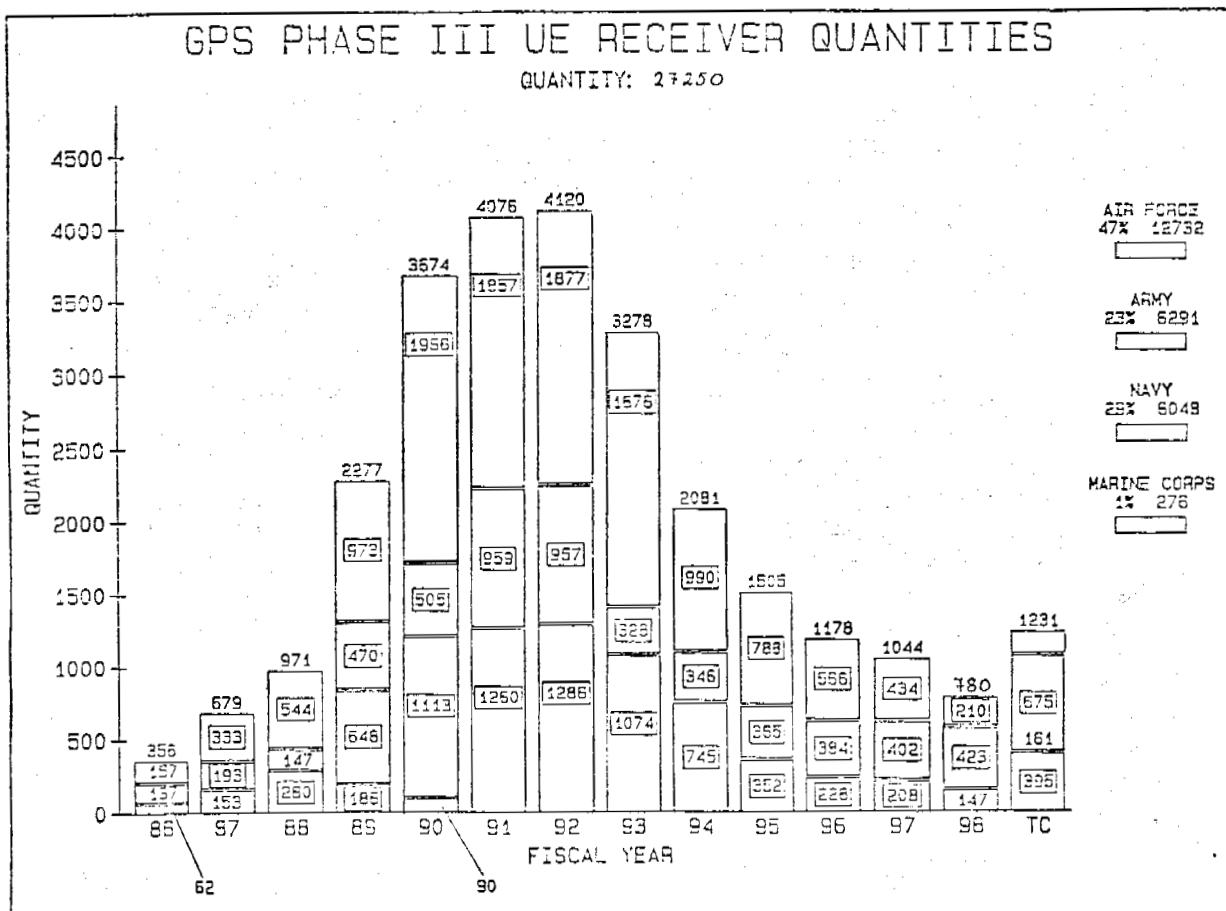

Figure 8 GPS UE Quantities and Procurement Schedule

6.1 Instrumentation Port (IP)

The IP is designed for test and maintenance purposes, but it will have some operational data blocks available. One set of operational data consists of a sharp rise time pulse (called a Time Mark) and an associated Time Mark data block. The Time Mark and the associated Time Mark data block are output once per second and give UTC and GPS time information. The Time Mark does not represent UTC one second rollover.

6.2 Precise Time and Time Interval (PTTI)

The PTTI interface is a two-way interface for precise time input and outputs.

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The inputs/outputs are as shown in Figure 9.

```
_____
|                               |_____ 1 PPS
|                               |_____ BCD TIME CODE
|          GPS RCVR             |
|                               |_____ 1 PPS
|                               |_____ 1 PPM
|                               |_____ BCD TIME CODE
|_____|
```
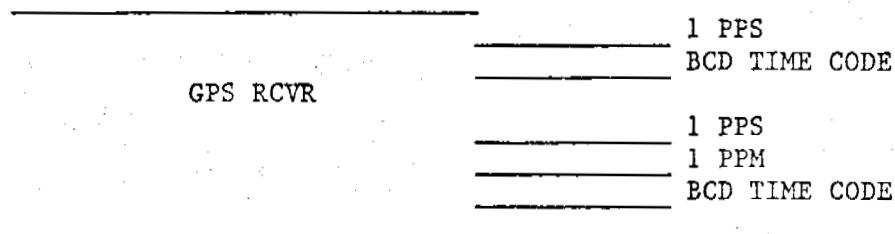
Figure 9 PTTI-interface

6.2.1 1 PPS Input and BCD Time Code

The one Pulse Per Second (1PPS) input pulse to the GPS RCVR represents the UTC one second rollover as determined by an external time standard. In conjunction with the 1 PPS is a BCD time code that identifies the UTC time of the previous time pulse. The BCD time code format consists of hours, minutes, seconds, day of year and a Time Figure Of Merit (TFOM). The BCD time code is transferred with a bit rate of 50 bps. The 1 PPS input is only used to initialize the GPS RCVR and cannot be used instead of a satellite if only 3 satellites are visible.

6.2.2 1 PPS/ 1 PPM Output

The 1PPS output pulse represents the UTC second rollover as determined by the GPS RCVR. A one Pulse Per Minute (1 PPM) pulse that represents the UTC minute rollover is also available. The same BCD time code format as described in 7.2.1 is also output.

6.3 Have-Quick (H-Q)

The H-Q interface is designed specifically for the Have-Quick II anti-jam communication system and is an output only time port. The HQ data message consists of hours, minutes, seconds, day of year, year and TFOM. The HQ data are transferred using a diphase Manchester II transmission at 1667 bps.

6.4 MIL-STD-1553 Data Bus

The 1 PPS pulse and the 1553 I/O port available on RCVR 3A may be used in combination to exchange precise time information between the UE and the Host Vehicle systems. The 1 PPS pulse will mark the precise time of the one second roll over, and the 1553 data bus is used to describe that time in a message transfer following the one second pulse.

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7. GPS RCVR's and Their Interfaces

The JPO has developed a family of GPS RCVR's to be used by all military services. The different types of GPS sets and their time interfaces that will be available are shown in figure 10.

RCVR	NO.OF CHANNELS	HOST VEHICLE	SERVICE	TIME PORT
Manpack	1	Man/Low dynamic vehicle	USA/USN/ USAF/USMC	IP, HQ
RCVR UH RCVR OH RCVR C4	2	Helicopter Helicopter Airplane	USA USA USA	IP
RCVR 3A	5	Aircraft	USAF/USN	IP,HQ,PTTI
RCVR 3S	5	Ships/submarines	USN	IP,HQ,PTTI

Figure 10 Types of GPS sets and their time interfaces

8. Time Accuracies for the Time Interfaces

The time accuracies expected to be available from the different GPS RCVR's and their respective interfaces are shown in figure 11. All time accuracies in the table are absolute time accuracies referenced to UTC.

OUTPUT PORTS RCVR	IP	HQ	PTTI
Manpack	1 microsec (Notes 2,5)	10 microsec (Notes 2,5)	N/A
RCVR OH/UH/C4	1 microsec (Notes 2,5)	N/A	N/A
RCVR 3A	57 nanosec (RMS) (Notes 1,3,5)	10 microsec (Notes 2,5)	57 nanosec (RMS) (Notes 1,3,5) 63 nanosec (RMS) (Notes 4,5)
RCVR 3S	57 nanosec (RMS) (Notes 1,3,5)	10 microsec (Notes 2,5)	57 nanosec RMS (Notes 1,3,5)

Figure 11 GPS time port accuracies

Note 1) 57 nanosec accuracy presumes total user network referenced to UTC and stationary/low dynamic environment.

Note 2) The IP and the HQ time accuracies on the Manpack and the IP time accuracy on the RCVR OH, RCVR UH and RCVR C4 are expected to be obtainable even if only 3 satellites are available.

Note 3) The IP and PTTI time accuracies on RCVR 3A and RCVR 3S are expected to be several times poorer if only 3 satellites are available.

Note 4) RCVR 3A PTTI time accuracy is expected to be 63 nanoseconds in a state 3 (code tracking only), INS aided, 1.5 g situation.

Note 5) All numbers are based on simulations and analysis and not on actual performance results.

9. Test Plans for GPS UE Time Capabilities

The Naval Research Laboratory (NRL) is assisting the JPO in the planning of time accuracy testing and they will also conduct the testing of the production sets. The JPO will provide NRL with a full scale development model GPS RCVR in the near future to be used by NRL to familiarize themselves with the Collins design. Production model RCVRs will not be available for time testing before early 1988, but in the interim NRL will develop detailed test plans and act as consultants to JPO on precise time related issues.

10. PTTI Applications

Very few programs have stated any timing requirements or informed the JPO about their potential interest in the precise time capabilities of the UE. The Have-Quick program office and the Navy (represented by SPAWAR, NADC and NRL) have been active participants in the working process of defining the time interfaces for the Phase III User Equipment, and Tactical Air Command has stated the requirement for time accuracy for JTIDS, Regency Net, and Mark IV IFF. No other programs/agencies requirements are known to the JPO today. The list of candidate programs for using the GPS precise time capabilities as seen by the JPO consists of:

- JTIDS
- Have-Quick
- Mark XV IFF
- Regency Net
- Atomic clock calibration
- Milstar

The GPS system will soon be operational and serve a variety of users. The JPO is eager to ensure that they do as much as possible for the precise time community and their needs and therefore encourage anyone with a need for better, new or other precise time dissemination capabilities to make

their needs or concerns known to the Navstar GPS Joint Program Office through the proper channels.

11. Summary

The Navstar GPS program is in the production and deployment phase and will become operational in a few years. The US DoD will procure some 27000 GPS UE, all with some sort of precise time dissemination capabilities ranging from 10 microseconds to 57 nanoseconds. It is therefore very important that users of precise time in the military services make their precise time requirements known to the JPO.

QUESTIONS AND ANSWERS

DAVID ALLAN, NATIONAL BUREAU OF STANDARDS: Can you comment on the plans for testing degradation and what impact that will be to the civilian sector?

LCDR NIEUWEJAAR: As a foreigner, I am not invited to anything that deals with degraded accuracy so I do not know much more than you do about it. All I know is what is stated in the Journal of Navigation. You know the 100 meters, so you can work backwards to see what sort of time accuracy that will give you.

MR. BUISSON: I might be able to answer that. There has been a cancellation of paper number 27 and we are replacing it this afternoon with Mike Ellett, who is the DMA representative at JPO on Civil Access for NAVSTAR-GPS Precise Positioning Service. I think that Mike will be able to give you some information on that.

MR.BUISSON: If there are no other questions, I have one myself. On NAVSTAR 11, when you reposition it, is this a continuous micro-thrust or will it be discrete jumps in the orbit?

LCDR. NIEUWEJAAR: As far as I know, they will just give it a little boost and it will go along with a little higher speed than normal until it reaches the proper point. This uses the least fuel and that is why it takes a long time to make the change.