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NAVSTAR : GLOBAL POSITIONING SYSTEM (GPS)

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ABSTRACT

The principle of operation and characteristics of the NAVSTAR GPS system is discussed . The system will provide extremely accurate three-dimensional position and velocity information to users anywhere in the world . The measurement is based on receiving the R.F signal from four satellites of a total constellation of 18 . Accuracies on the order of 10 meters may be anticipated . This paper discusses also the possibility of implementation of the system in Egypt with the modification suggested to acquire the national conditions .

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INTRODUCTION

As currently planned, the operational NAVSTAR GPS will consist of 18 primary satellites deployed in six orbital planes.These will be augmented by three-on orbit spares to insure a high degree of system availability[1] .The baseline constellation of 18 satellites operates in 12-hour orbits at an altitude of 20,183 Km (10,898 nmi) [2] .

Signals are transmitted at two L-band frequencies (1227 and 1575 MHz) to permit corrections to be made for ionospheric delays in signal propagation time. The signals are modulated with two codes : P,which provides for precision measurement of time,and C/A,which provides for easy lock-on to the desired signal .

The satellites employ a shaped-beam antenna that radiates near-uniform power to system users of at least -163 dBW for the L1 P-code and -158.2 dBW for the L1 C/A code .The corresponding L2 power level carrying only the P code is at least -166 dBW .

Navigation fixes can be made in a time interval of from tens of seconds to several minutes, depending on the sophistication of the receiver .

There will be produced 28 NAVSTAR GPS satellite (including spares). The first four of these satellites are to be delivered in 1986; eight more in 1987; nine in 1988; and the remaining seven in 1989. The planned launches aboard the shuttle follow the satellite delivery schedule .

NAVIGATION TECHNIQUE

The 18-satellites are deployed in six orbital planes, which will be equally spaced 60° apart in longitude and inclined to the equator at 55° as shown in Fig.1 .

Fig.1 Satellites orbital planes

Three satellites will be deployed in each of the six orbital planes with equal spacing of 120° between satellites in plane. Satellite phasing from plane to plane will be 40° [1] .Each satellite completes exactly two orbits while the Earth turns one complete revolution on its axis .

The choice of satellites' orbits and speed is to allow the possibility of receiving the signals transmitted from at least four satellites to users anywhere in the world at any time and eliminating or at least minimizing dependence on control stations outside of the direct control of the united states .

A GPS use three-dimensional navigation fix requires pseudo-range measurements from four space vehicles, with time being the fourth solution variable .These concept is simplified and illustrated in Fig.2 .Using GPS time as a reference [3] , the true transit times are those between the GPS transmit times and the GPS receive times. They represent the true slant range except for propagation delays , described by :

$$R_i = c\ (\ t_R - t_{Ti}\ ) - c\ \Delta t_{Ai} \quad ; \ i=1,\ldots,4 \qquad (1)$$

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$$t_{Tsi} = t_{Ti} + \Delta t_{si} \quad ; \; i=1,\ldots\ldots,4 \qquad (4)$$

The user must solve for four unknowns. These are his position co-ordinates X,Y,and Z (earth-fixed earth-centered) and his clock offset Δt_u . Expanding equation (2) in terms of these unknowns yields

$$R_i = \sqrt{(X_{si} - X)^2 + (Y_{si} - Y)^2 + (Z_{si} - Z)^2} + c\,\Delta t_{Ai} + c\,(\Delta t_u - \Delta t_{si}) \; ; \; i=1,\ldots\ldots,4 \qquad (5)$$

There are twenty other unknowns in these four equations that must be defined before X,Y,Z and Δt_u can be found .

The Δt_{Ai} are estimated by the user by measuring the pseudo-ranges at two frequencies (ionosphere delay corrections) and estimating troposphere delays based on geometry and altitude . The X_{si}, Y_{si}, Z_{si}, and Δt_{si} must be computed by user from information provided to him via the GPS navigation message. The velocity estimates are made by measuring the Doppler shift in the carrier frequency of the navigation signal from the satellites .

SIGNAL STRUCTURE

The navigation signal transmitted from the space vehicles consists of two RF frequencies,L1 at 1575.42 MHz and L2 at 1227.6 MHz. The L1 signal is modulated with both the P(precise positioning service) and the C/A(standard positioning service) pseudo-random noise code in phase quadrature. The L2 signal is modulated with the P code. Both the L1 and L2 signals are also continuously modulated with the navigation data bit stream at 50 bps [4].

The function of the codes are twofold: (1) identification of space vehicles,as the code patterns are unique to each space vehicle and are matched with like codes generated in the user receiver, and (2) the measurement of the navigation signal transit time by measuring the phase shift required to match the codes .

The P code is operating at 10.23 Mbps but difficult to acquire. The C/A code is a short code, readily acquired, but operating at 1.023 Mbps, which provides a grosser measurement of time . The C/A code is normally acquired first and a transfer is made to the P code by the use of the handover word (HOW) contained in the navigation data stream(see the navigation message) .

The P code generated in each space vehicle is a pseudo-random noise chip sequence of seven days in length. All the space vehicles employ the same P code generator, with each one assigned and generating a unique and mutually exclusive seven-day long code-phase segment of the 267 day code .

The C/A code is a pseudo-random noise chip stream unique in pattern to each space vehicle that repeats every millisecond.

After lock-on to the C/A code, the receiver-generated P code is shifted in phase to synchronize with the designated point in the incoming P code when triggered by the change in the HOW. The total phase shift required for lock-on is the measured pseudo-range time. The P code frequency affords the degree of accuracy required for the measurement of signal transit time that the C/A code frequency could not .

THE NAVIGATION MESSAGE

Fig.3 summarizes the GPS signal parameters and data formats. The navigation message contains the data that the user's receiver requires to perform the operations and computations for successful navigation with the GPS .

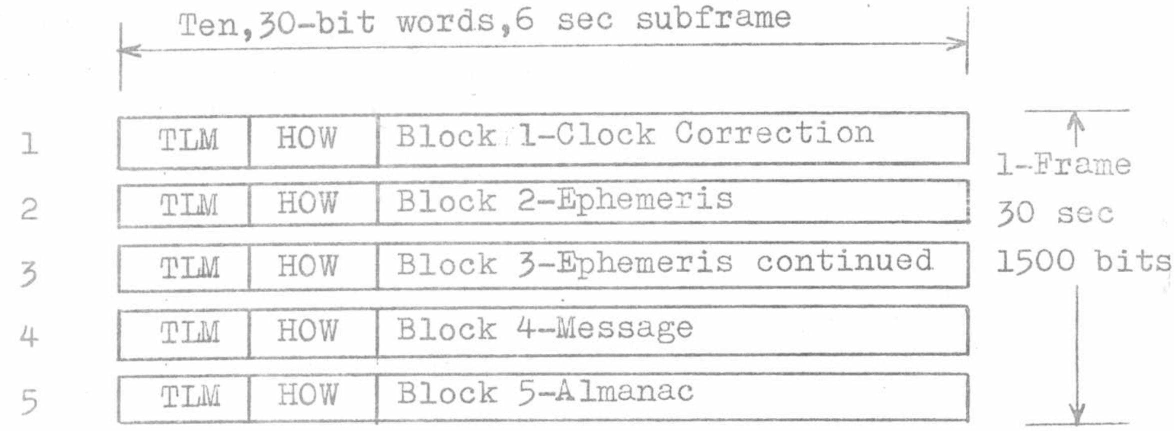

Fig.3 Data Format-Frame and subframe structure

The data include information on the status of the space vehicle; the time synchronization information for the transfer from C/A to the P-code; the parameters for computing the clock correction; the ephemeris of the space vehicle, and the correction for delays in the propagation of the signal through the atmosphere. In addition, it contains almanac information that defines the approximate ephemerides and status of all the other space vehicles, which is required for use in signal acquisitions. The data format also includes provisions for special messages.

CONTROL SEGMENT

The operational NAVSTAR GPS control segment performs the tracking,computation,up dating,and monitoring functions needed to control all of the satellites in the system on a day-to-day basis. This involves several(nominally five) monitor stations,a master control station, and three upload stations. Fig.4 shows the operational concept.

The widely dispersed monitor stations employ extremely stable GPS receivers to gather transmitted navigation data from each of the GPS satellites as they pass overhead. The location of each monitor station is precisely surveyed and the navigation measurements are combined with additional data on atmospheric conditions, etc. This information is transmitted back to the master control station where precise predictions of satellite ephemerides and clock offsets are made .

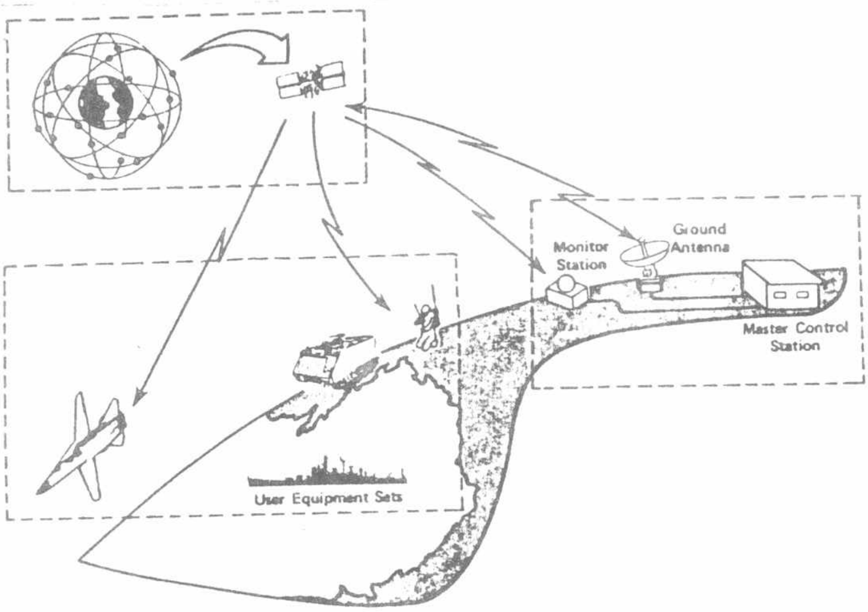

Fig.4 NAVSTAR GPS operational concept

The master control station, to be colocated in Colorado springs, CO [1] , will process the data received for all of the monitor stations to determine the predicted satellite ephemeride and clock bias parameters for each satellite in the system . These data are then used to generate upload messages for each satellite to correct the satellites' navigation messages describing those parameters to the users. In this manner, each satellite in the system is provided with refreshed navigation and timing data at least once a day to maintain the entire system in peak operating conditions .

TEST RESULTS

To provide the necessary navigation signals over a suitable test area,a series of self-contained,solar-powered ground-based transmitters was installed at Yuma,AZ,to simulate the actual satellite navigation signals. A network of precision laser tracking devices was established to provide near real time test results to within 1-m accuracy over the test area. The testing became more sophisticated as satellites of phase I were launched,each satellite taking the place of one of the ground-based transmitters .

The tests were performed with a variety of user equipment models,ranging from a "low cost" unit designed to operate only on the C/A code to competing designs of single and multiple channel units and finally to man-portable unit .
Over all test results demonstrated acheivable system accuracies of 7m(50%) and 17m(90%) with correspondingly similar results for each type of equipment tested.Fig.5 shows that results.

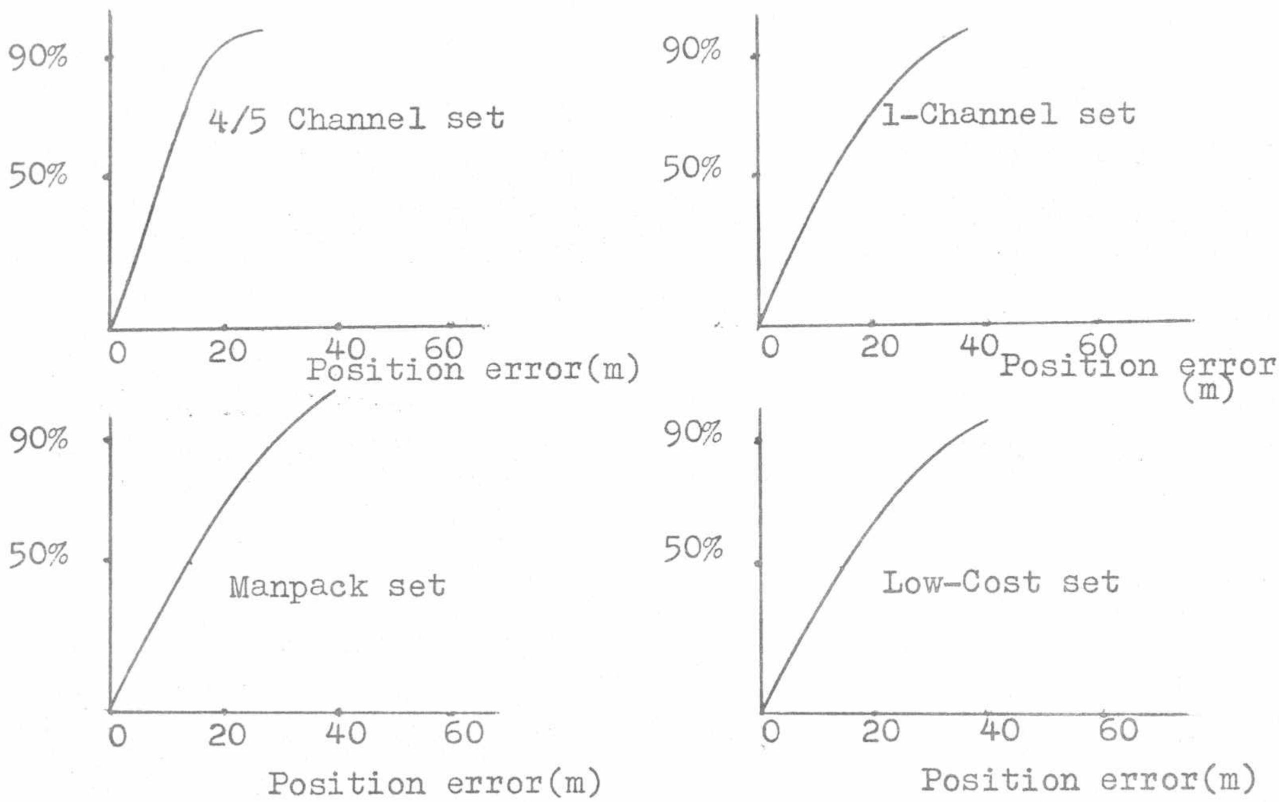

Fig.5 GPS Phase I test results

The low-cost version,proved to be far more accurate than expected,achieving accuracies measured in tens of meters rather than the predicted 100m. Since the C/A code on which this equipment operated is to be generally available to anyone in the world who had access to the technology required to build a suitable receiver,a decision was made to intentionally degrade the accuracy from the C/A code. The American department of defence has announced that the standard positioning service (C/A code) will be made available at an accuracy of 100m(95%). Access to the precise positioning service (P code) will still be limited to US and allied military units and to carefully selected US nonmilitary users .

CONCLUSION

All position-determination schemes can be classified as either dead reckoning or position fixing .

Dead reckoning consists of extrapolation of a known position to some future time [5] .It involves measurement of direction of motion and distance traveled. Examples of the system are airspeed meter with gyromagnetic compass,Doppler navigation system,Inertial navigation system(INS),..etc. Dead reckoning has been characterized as the basis of all navigation with position fixing constituting a method of updating it since the position information degrades with time(INS),or with distance traveled(Doppler) .

Position fixing is the de[illegible] of the position of the craft (a fix) without ref[illegible] to any former position. The common intersection of tw[illegible] nonparallel lines of position constitutes the fix. [illegible] of the system are VOR, TACAN,Omega,LORAN,..etc. [illegible] fixing is either intermittent with relatively long inte[illegible] fixes or continuous where the navigation in b[illegible] is possible only at the service areas of the grou[illegible] .

GPS is unique among all other positioning and navigation systems.Providing unprecedented accuracy in real time on a global scale. In addition to three-dimensional position determination,GPS also provides three-dimensional velocity accurate to better than 0.1m/s and system time to better than 100ns as byproducts. Applications range from time transfer to autonomous positioning of satellite on-orbit,from geodetic survey and off-shore oil exploration to tracking of trucks carrying high-value cargo,from enroute navigation to passive rendezvous, from precision,all weather,day-night weapons delivery to real time range instrumentation,and the list keeps growing daily .

In 1983,during the Paris airshow,a USAF aircraft has crossed the Atlantic with GPS as sole navigation aid and has stopped 8m short at the predetermined parking place [6] .

During the discussion of supplying Egypt air force with the NAVSTAR GPS system,we should take in consideration the local conditions such as: Egypt airforce is equiped now with aircrafts which are able to fly long distances specially with refueling in air like Phantom F-4,F-16,and Mirage 2000 besides the transporters C-130 and bombers of type TU-16 ; there are a wide undeveloped areas around the country specially in the west and south west direction which is in the favour of accurate self-contained system;need for accurate geodetic survey and off-shore oil exploration besides other pure military functions,and the experience of combat operation in the presence of strong jamming signals .

Therefore,when the NAVSTAR GPS system will be used in Egypt, we would suggest first the integration of the system with the inertial navigation system which is the most accurate existing self-contained system and is already available in the modern aircrafts stated above,if the feasibility study permits. The block scheme of such integrated system(sometimes called aided inertial system) may be drawn as shown in Fig.6 .

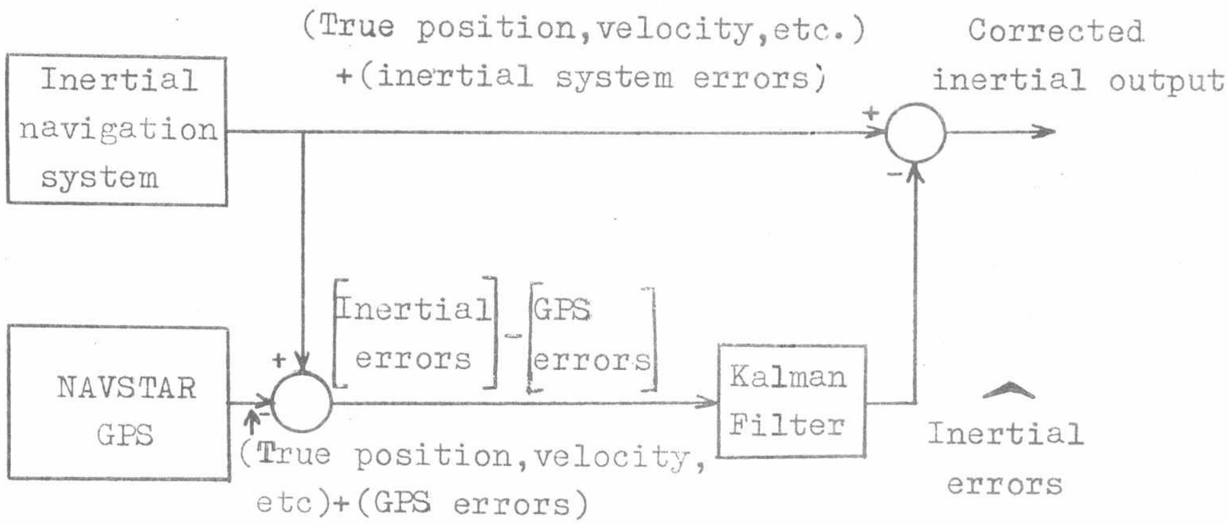

Fig.6 Aided inertial navigation system

The inertial navigation system have drift characteristics that cause the system errors to grow with time. They also exhibit undamped oscillatory errors that are undesirable [7] .
Philosophically,we think of the inertial

functions on a single radio electric support, is feasible . This is one of the main directions of our research at the mean time .

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