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5.8 NAVSTAR/GLOBAL POSITIONING SYSTEM*

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The Global Positioning System (GPS) has been developed to provide highly precise position, velocity, and time information to users anywhere in the neighborhood of earth and at any time. The GPS, when fully operational, will consist of 18 satellites in six orbital planes. These satellites will be at about 20,000 km altitude with a 12-h period and the orbits will be inclined to 55°. The satellites will transmit L_1 (1575.42-MHz) and L_2 (1227.6-MHz) signals. Navigation information such as the emphemeris of the satellites and satellite clock model parameters and the system data are superimposed on these radio signals. Any GPS user, by receiving and processing the radio signals from the constellation can instantaneously determine navigation information (position and velocity parameters) to an accuracy of about 15 m in position and 0.1 m/s in velocity. This radio navigation system is primarily developed for utilization by the Department of Defense. However, there exists a broad spectrum of civil users who would benefit from this system.

The GPS system has three separate segments. One is the space segment, which is the satellite itself, then what we call a control segment, which is responsible for providing the information to the satellite, and the third is the user segment. The user segment includes individual user MANPAC or automobiles, trucks, ships, aircrafts, and satellites. With regard to program history, originally the Navy was responsible for initiating a navigation system, the TRANSIT program--and it is still operational now. They have five satellites and the accuracy is reasonable. The GPS mission program was a preliminary study which the Navy originated and 621-B was a program the Air Force initiated; they were subsequently combined and became the Global Positioning System. During the program evolution there are three phases: (1) the concept validation phase, (2) the full-scale engineering development and testing (present phase), and (3) full operation capability. In Phase I we had four satellites and two planes; in Phase II we have 6 satellites; however, one of the satellites is not functioning properly because of the on-board clock. It is not giving the accuracy we need. In Phase III we will eventually have 18 satellites and this will be a different satellite than what we have now.

Let's briefly look at the space segment. Once we have 18 satellites, each satellite will be in a 12-hour period at 20,000 km altitude. (Figure 1). Current clock accuracy is about $1{:}10^{-13}$ to $5{:}10^{-14}$. Clock performance is extremely good even though the design specifications show only $2{:}10^{-13}$. We have two L-band frequency signals, L-1 and L-2, at 1.2 GHz and 1.5 GHz, and we also have an L-3 but that's not a user oriented band, it is used for a specific purpose. We may use that L-3 which is a cross-link capability from one satellite to another satellite.

Now the concept of getting navigation information from the GPS satellites. The satellites will provide signals from which you can, if you have a receiver, get range information and simultaneously if you can get full range information properly distributed in the sky, you can determine your own position and the bias in your clock. If your clock is not as precise as the satellite clock, you can determine instantaneously our precision plus the timing bias.

*Edited oral presentation.

If you have the range rate information in addition to the range information you can also determine the velocity if you are a user. The accuracy we are currently broadcasting (Figure 2) we would get is 15 meters of spherical distributed error for all these types of users, whether a MANPAC, an automobile, ship, aircraft or Shuttle. When you deviate from 800-1,000 km altitude, like Landsat, your accuracy will be improved because of some of the errors are associated with atmospheric modeling.

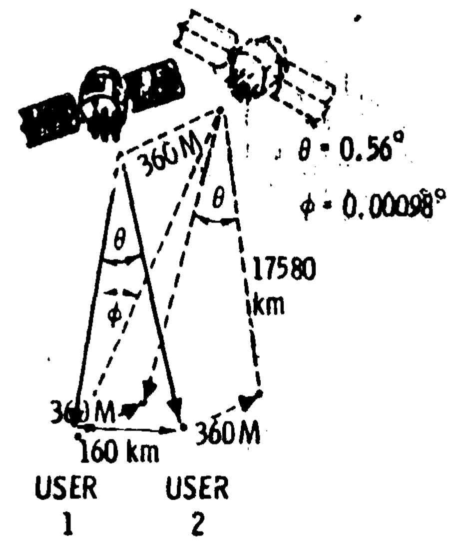
In comparison of navigation systems (Figure 3), the GPS is a navigation system purely based upon radiometric measurements. There are a quite a large number of navigation systems in existence. Currently, LORAN-C, OMEGA, INS, TACAN, TRANSIT—these are all radio based navigation systems. The TRANSIT is probably closer to GPS because it has a global capability; however, the accuracy degrades in between orbits. GPS provides the same accuracy globally everywhere anytime. That's the key point. In other systems the errors are fairly large and obviously there is a lot of lost information you will not receive. GPS is a very simple concept and versatile, and obviously, a very expensive system also. For user equipment, as I said earlier, you need to have four satellites simultaneously visible. Simultaneous in the sense that you don't need to have a four-channel receiver in order to do it; you can do it sequentially. However, the four satellites have to be available to the user and the constellation is designed to be able to achieve at least four satellites at any given time, anywhere near the earth.

The performance of the user system depends upon several things (Figure 4). The vehicle environment -- of concern in particular to defense related problems and constellation geometry -- is very geometry dependent and dependent on the dynamics of the vehicle and the way the ionosphere and troposphere are modeled. The ionosphere can be monitored better if you have a two-channel receiver because you have two frequencies going in and separated in frequencies so we can calibrate real time. For a single receiver, we have provision in the navigation message which will provide some kind of table for modeling the ionospheric effects. It may not be very accurate, but sufficient for that type of user.

Reviewing the error budget (Figure 2), true navigation error is a product of what we call GEODOFF, that is, geometry delusion of precision. If you multiply the GEODOFF times the user equivalent range error component you get the navigation error. The GEODOFF data varies from one place to another place and the best GEODOFF is 2 or 2.2. So if the satellite dependent range error is multiplied by 2.2, it would give you around 15-meter accuracy, which is the total of the various error sources. The satelite clock is minus 13 over a 24-hour period and we update once in 10-hours. Each clock will have a different elapsed time because the update time will be different for each satellite. A single satellite will be visible once or twice a day from a given ground control station. Another interesting element is that if you use GPS in a relative mode for a relative navigation, all these errors tend to cancel out. So the only error you will be left with is a user related error of approximately 2 meters. Most of the civilian types of purposes can be used in a relative mode depending on what your particular application is. For that reason, we have what we call for security purposes selective availability, so we cannot guarantee any user the real accuracy the system would provide. However, the degraded accuracy would be available to everyone. We don't know what the degraded accuracy is or whether it will be opted; those decisions are to be made at a much higher level, but we have the ability to introduce whatever error we want. However, that will not affect a user using a relative mode.

- USERS NAVIGATE IN RELATIVE COORDINATES USING THE SAME SATELLITES

	NORMAL THREE SIGMA	THREE SIGMA WITH *
• ERRORS THAT DISAPPEAR		
• IONOSPHERIC	6.9	6.9
• TROPOSPHERIC	6.0	6.0
• EPHEMERIS PREDICTION	7.5	353.0
• CLOCK STABILITY	8.1	353.0
• SV PERTURBATIONS	3.6	3.6
RSS	14.85	500
• REMAINING ERRORS		
• RECEIVER NOISE	4.5	4.5
• MULTIPATH	3.6	3.6
• OTHER	1.5	1.5
RSS	6.0	6.0



*Degraded clock and ephemeris

Figure 1. Relative Navigation

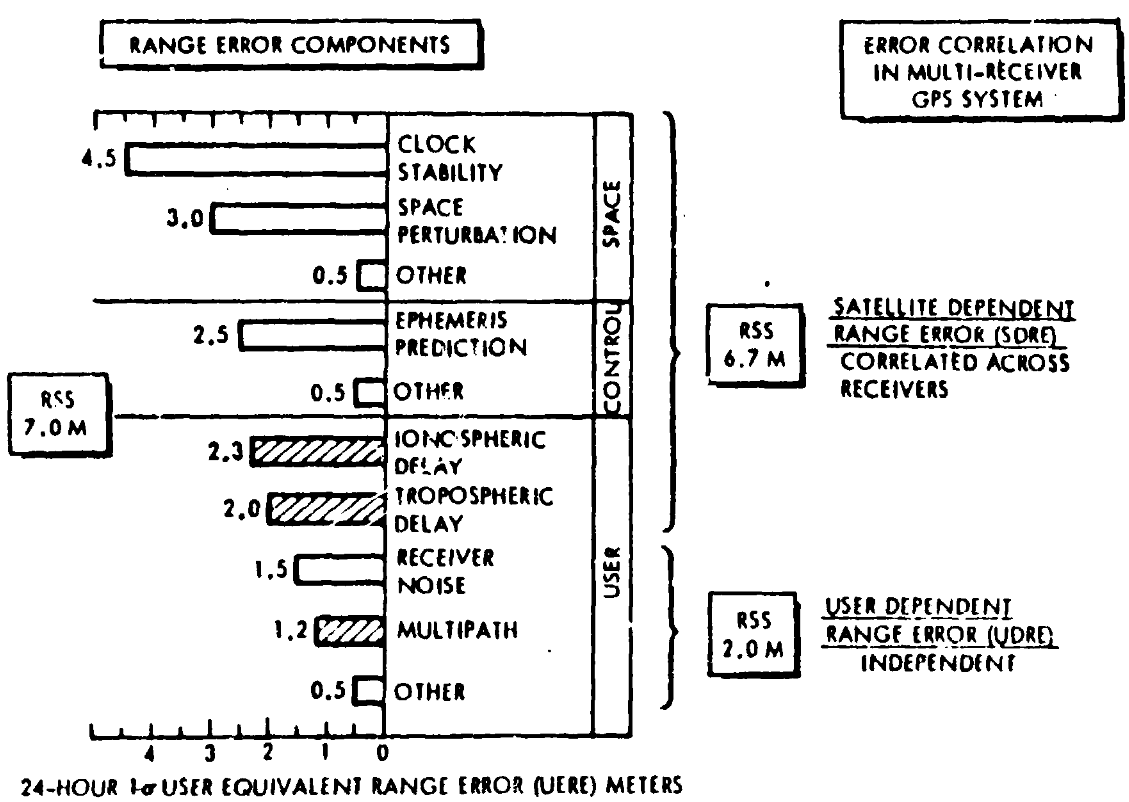


Figure 2. User Equivalent Range Error Budget

System	Position Accuracy (m)	Velocity Accuracy (m/sec)	Range of Operation	Comments
GPS	15 (SEP) 3-D	0.1 (RMS per axis)	Worldwide	Operational worldwide with 24-hour all-weather coverage.
Loran-C (Note 1)	180 (CEP)	No velocity data	U.S. Coast, Continental U.S., Selected Overseas areas	Operational with localized coverage. Limited by skywave interference.
Omega (Note 1)	2,200 (CEP)	No velocity data	Near global (90% coverage)	Currently operational with localized coverage. System is subject to multi-path errors.
Std INS (Note 2)	1,500 max after 1st hour (CEP)	0.8 after 2 hr (RMS per axis)	Worldwide	Operational worldwide with 24-hour all-weather coverage. Degraded performance in polar areas.
TACAN (Note 1)	400 (CEP)	No velocity data	Line of sight (present air routes)	Position accuracy is degraded mainly because of azimuth uncertainty which is typically on the order of ±1.0 degree.
Transit (Note 3)	200 (CEP)	No velocity data	Worldwide	The interval between position fixes is about 90 minutes. For use in slow moving vehicles

NOTES:
1. Federal Radio Navigation Plan, July 1980
2. ENAC-77-IV, Characteristic for a Moderate Accuracy Inertial Navigation System, August 1979
3. Journal of the Institute of Navigation, Volume 27, No. 2, Summer 1979

Figure 3. Navigation System Comparison

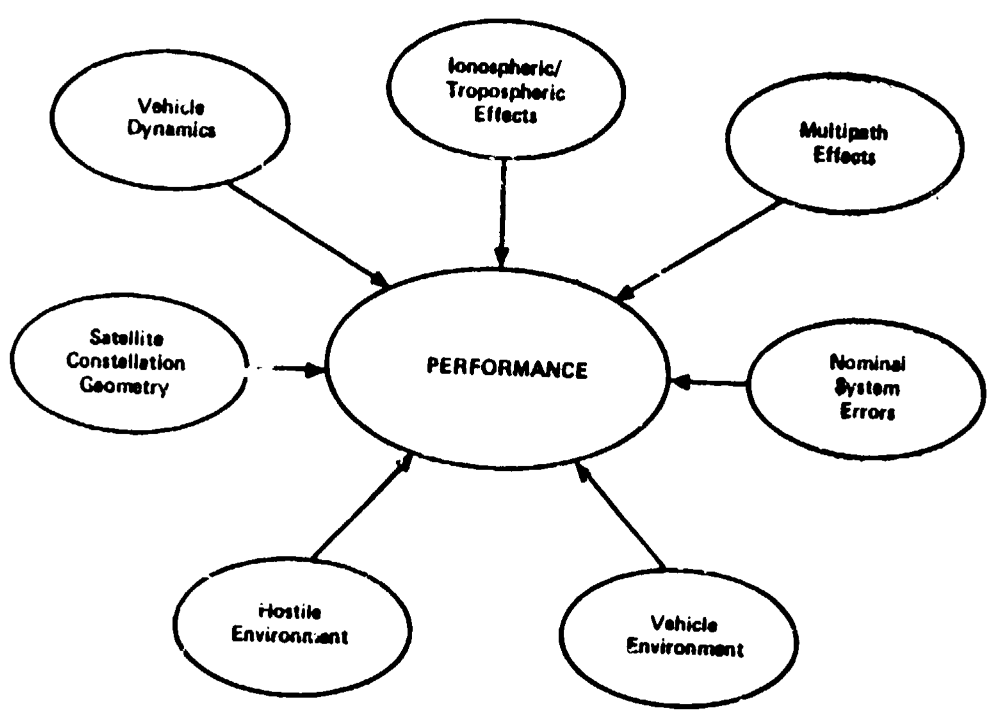


Figure 4. UE Set Performance