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Gee, PS!

GPS HISTORY

We have all heard of the Vietnam War. It was in the '60s and '70s, it was very unpopular, and many people will tell you that something called "Vietnam Syndrome" developed within the US government. In addition to all these things, there was a lot going on that most people didn't, and still don't, know about, namely navigation and contact problems among the different sections of the US military. Initiated by large distances and necessary secrecy, and fueled and perpetuated by a harsh jungle terrain, the military was having major problems keeping in contact with all of its parts (Safetrack, 2001). Common sense will tell you that lack of communication is not good for war strategy, and something had to be done. A navigation system called LORAN was in place at first, but it was a slave to nighttime and bad weather. As bad weather is a frequent occurrence in Vietnam, and, surprisingly enough, nighttime came about upwards of once a day, this system became obsolete before its time (Safetrack, 2001). Next up was the TRANSIT system, which, like GPS, used four satellites to gather location data. However, this system was also a bust because it could only receive signals every two hours. Such infrequent measurements resulted in inaccuracy and inconvenience (Safetrack, 2001). After two failed attempts at high-tech, modern navigation and communication systems, the US government needed to get cracking. Its next brainchild, NavStar, was very well designed. Developed in 1986, it took into account and tried to fix all the problems that had previously prevented success, and it might have become a very extraordinary system. I say “might have,” of course, because, due to unfortunate circumstances, the system was not a success. Many people lay the blame for the failure of this project on the Challenger Space Shuttle disaster of 1988. The Challenger Space Shuttle was used to launch NavStar satellites into space, and the events of 1988 notably limited the number of satellites in orbit. Because of the lack of satellites in the sky, people and groups trying to use this system only had about three to four hours per day during which they could receive signals (Safetrack, 2001). Although the NavStar system turned out to be a big flop, it only took the US government two years to develop a new one. In 1990, during the conflict in the Gulf, Global Positioning Systems (GPS) finally arrived. Twenty-one satellites were up and running in the sky, and the program was so successful that it was made available to civilian users that same year. This twelve-year-old system is the same one that is used today (Safetrack, 2001). It is safe to say that GPS was developed because of military problems, and, antiwar as I am, I cannot help but be fascinated by this system. I would definitely classify it as one of the top ten coolest developments of modern (wo)man.

How GPS Works

The GPS network of satellites, or what experts refer to as the GPS Operational Constellation, is made up of twenty-four Space Vehicles (SVs), or satellites, that are 11,000 miles up in the sky and repeat their pattern (with respect to the earth) every twenty-three hours and fifty-six minutes. When authorities are launching new satellites, there are often more than twenty-four satellites in the sky at one time, and although each satellite's pattern is repeated close to once a day, they all actually orbit the earth twice per day (Dana, 1999). (Figure 1 shows a representation of GPS satellites and each one's ground track.) Included in the Operational Constellation are six orbital planes, each containing four SVs. These satellites are strategically placed sixty degrees apart, so that at any given time, anywhere from five to eight satellites are visible from any point on Earth (Dana, 1999). (Figure 2 is an illustration of the GPS Operational Constellation.)

In addition to the satellites in the sky, anyone wishing to use GPS also needs a ground receiver to obtain and put to good use the information available from the SVs. There are several types of GPS receivers, but they all work the same way: each receiver will connect to as many GPS SVs as possible and use the resulting data to compute its position. When a GPS receiver gets a signal from a satellite, it immediately measures how long it took for the signal to reach it, after leaving the satellite. Using this information, the given speed at which the signal travels, and the satellite's precise position in the sky, the receiver can then process its distance from the satellite. When the receiver has gathered all of this information from three or more satellites, it can then calculate its precise position on Earth, using triangulation formulas. Obviously, the more satellites that are connected to the receiver at once, the more accurate the calculations will be (Dana, 1999).

For GPS receivers to be able to get accurate readings, the information they get from the SVs must be accurate first. To make sure the SVs' data is always as correct as possible, control stations must monitor each satellite's orbit. There are five GPS control stations around the world, including the Master Control facility in Colorado, at Schriever

Air Force Base, which used to be Falcon Air Force Base. The other four stations are located in Hawaii, Ascension Island, Diego Garcia, and Kwajalein. (Figure 3 shows the "GPS Master Control Monitor Network.") The computers at these stations calculate each SV's exact time and orbit information and send it to the SVs (Dana, 1999). This way, the SVs have more correct information to begin with, so they can send more correct information to the receivers. (Figure 4 shows the "GPS Control Monitor").

GPS satellites must use two different kinds of data to make the system work: almanac and ephemeris. Almanac data is pretty much universal for all satellites and receivers (Dana, 1999). Any GPS SV or receiver can acquire this information from any other SV, as long as the SV is connected to something. Almanac data contains general information: the SV'S last known position in the constellation and how healthy the SV is. Without connecting to the SV itself, a receiver can use almanac data to find out where the SV was last known to be so it knows where to look for the SV in the sky(Dana, 1999).

Ephemeris data carries more recent and specific information and is specific to each satellite. This kind of data tells a receiver exactly where a satellite is in the sky, and the receiver uses this information to compute its own location. To receive ephemeris data, a receiver must be connected to an SV (Dana, 1999).

GPS not only uses two kinds of data, but also two types of signals, although only one type of signal is used in each connection. Coarse Acquisition, or CA signals are the less accurate of the two types. One might say they are a more "coarse" estimation or version of the information being transmitted. The result of using this type of signal, as I said before, is a somewhat accurate, but less-than-perfect measurement. The accuracy of a CA signal is about 15m Root Mean Square (RMS). This means that there is about a 15m radius of error (Dana, 1999). CA signals are fine for user Joe Schmoe, who just thinks GPS is cool and likes to play around and remind himself how many glorious lines of latitude he is away from his dreadful mother-in-law. But when attempting to parachute oneself onto a 2-foot-radius island in the middle of shark infested waters, I would recommend using PPS signals.

Precise Positioning System (PPS) signals are much more high tech than CA signals. The accuracy of this signal is less than 1m Root Mean Square, but there is one drawback: to use it, one must be licensed. It is apparently pretty tough to get licensed to use PPS, and most legal users are experienced military personnel (Dana, 1999). Although I searched and searched, I could not find a reason for this restriction, and I have to say that as of now I do not agree with it. GPS is something that everyone should enjoy, and I really do not see the harm in allowing the general public to compute the precise location of their sleeping cats. For a few minutes, I thought the government might be afraid that if civilians got their hands on GPS, they would find a way to use it to launch missiles or something. But what civilian has the means to do something like that? Furthermore, countries all over the world were doing worse things before GPS even existed. If there is a reason for the restriction of PPS signals, I have yet to find it.

What GPS is Used For

We have already established that GPS was developed for military purposes, and that the military is hogging all the good GPS signals. Therefore, it makes sense that the primary function of GPS is navigation, mostly by the military (Dana, 1999). GPS is successfully used for the navigation of "aircraft, ships, ground vehicles, and hand carrying by individuals" (Dana, 1999). (Figure five shows how GPS helps with navigation). The system is also frequently used for precise position measurements to help with surveying, geodetic control, and plate tectonic studies. Astronomical observatories, telecommunications facilities, and laboratory standards sometimes use GPS satellites to determine accurate time and/or frequency. This information is set and monitored by the control stations and sent to highly accurate clocks on the SVs. Another scientific area in which GPS has been helpful is measuring atmospheric parameters (Dana, 1999).

The area of GPS usage that I find most interesting, and that will be discussed in the next section of this paper, is plate tectonic studies. GPS receivers are set up at precise, strategically placed points and connected to SVs to determine whether or not one point on Earth has moved relative to other points. If there is movement within or among plates, geologists know that some sort of geologic event is taking place. The event could be as insignificant as the tiny shift of a rock or as monstrous as a fault such as the San Andreas in California, which is predicted to eventually make the state break away from the North American continent and fall into the sea. The event could even be as disastrous as a violent volcanic eruption.

Tectonic Applications

To measure plate movement many measurements must be taken over time from the same, extremely precise positions on Earth. For this to happen, the place of measurement must be carefully marked so that qualified scientists can come back again and again and be assured that their measurements actually mean something. In light of this problem, the benchmark was invented. A benchmark, in GPS terms, is a marker with a precise point of measurement that is permanently attached to stable ground, usually bedrock (Owen, 2002).

Setting up a GPS satellite over a benchmark can take upwards of several hours and is one of the most frustrating experiences known to woman. But it's worth it. Once that blasted piece of equipment is situated just exactly right, one experiences a kind of joy that has never been felt before (Fonde, 2002). The first step is to set up the tripod over the benchmark. Then an instrument called a tribrach is used to level the apparatus, and an optical plummet is used to pinpoint the bullseye. That is the hard part. Next, the antenna goes on top. Most GPS satellites now use what is called a choke ring antenna because it helps reduce multipath, or static and unclear radio signals. The rings around a choke ring antenna are related to the frequency of the radio waves, similarly to the way an auditorium with good acoustics is related to the sound waves (Owen, 2002).

The battery and GPS receiver are then hooked up to the satellite with cables, and such information as which benchmark is being used and the time of day is entered into the receiver. When entering time into the receiver, the user must remember that GPS time does not mean whatever time it is at the location of whatever benchmark is being used. Rather, GPS time means Universal Time Coordination (UTC), or Greenwich Mean Time (GMT), which is the time in Greenwich, England (Owen, 2002). Why is Greenwich, England so special, you ask? Because it is at zero degrees longitude, which makes it the first time zone (Dana, 1999).

At this point, another question wishes to make itself heard: why all this fuss about exact time? The whole GPS system is actually very dependent on precise time. Without it, the formula it uses to calculate distance (distance = rate * time) would be thrown off (Owen, 2002).

Once the GPS receiver is up and running, it will take many measurements each minute, and because of error, there will be some slight divergence of accuracy in each measurement. Therefore, to get the most accurate results possible, the receiver takes the average of all the measurements to get one measurement. Just as it is better for a receiver to be connected to as many SVs as possible, it is also better for a receiver to take as many measurements as possible to get the best average possible. In order to acquire a very large number of measurements, many geologists will leave an assembled satellite standing over a benchmark for two or three days at a time. This method has proven very effective in obtaining accurate results(Owen, 2002).

Why People Trust GPS

GPS is far from being a perfect system. There are many potential errors that go into every single measurement. However, most people, even members of the science community, who are stereotypically sticklers for proof, hard facts, documentation, and accuracy, routinely rely on GPS for location information. Why is this so? Because GPS acknowledges these potential errors and takes them into account every time it processes information. Consequently, its measurements are more credible (Wormley, 2002).

The total user error for a GPS measurement is referred to as EPE (Estimated Position Error). to get this number, the HDOP (Horizontal Dilution of Precision) is multiplied by the UERE (User Equivalent Range Error). Finally, the resulting number is multiplied by two (Wormley, 2002). This number is very important to GPS because it allows people to make measurements without claiming that they are consistently perfect. When error is incorporated into a calculation, the result is a much more realistic conclusion. To learn more about these errors and how they are incorporated into GPS measurements, visit http:/www.edu-observatory.org/gs/check_accuracy.html.

Another reason GPS is reliable is that it can be checked against strict standards set by a division of the government. There is a lot more to it, but basically a GPS receiver must have a 95% confidence level to meet the standards. The USFS GPS Steering Committee, which makes the standards, states, "These Standards and Guidelines provide guidance to the Government cadastral surveyor and other land surveyors in the use of Global Positioning System (GPS) technology to perform Public Land Survey System (PLSS) surveys of the Public Lands of the United States of America" (USDA, 2002). What this statement means is that most GPS users are not actually required to follow the guidelines set by the Committee, however they had better do it anyway if they want anyone to take their work seriously. Personally, I think that creating a set of non-mandatory standards and guidelines is a good way to go. People who are doing serious work with GPS will have to abide by these suggestions if they want their work to actually mean anything, and people who are doing serious research will know what to look for to make sure their sources are credible. However, people who just like to mess around and experiment with GPS do not need to be made to follow a bunch of rules. If their measurements are inaccurate it does not hurt anyone. And if their results are inconsistent the world is not going to blow up. I think the set of suggestions in place is absolutely perfect for the state GPS is in right now.

Another big reason that I personally trust GPS is reputation. Since I heard about GPS, I have only heard good things. Nobody has ever said to me that they think GPS is a really stupid idea and should be outlawed. Furthermore, although I have searched long and hard, I have not been able to find any published work that talks smack about GPS. I obviously cannot say anything for certain, as I have not read every work ever published, but after doing extensive research I completely believe that there is absolutely no controversy where GPS is concerned. Maybe I am wrong. Maybe there were fifteen different articles right in front of my face stating that GPS is destined to be the instigator of the extinction of life on Earth. But, Sir or Madam, you look for yourself, and you try to find someone out there who is openly against GPS. If you are successful, please let me know. I will be surprised.

<u>GPS Future</u>

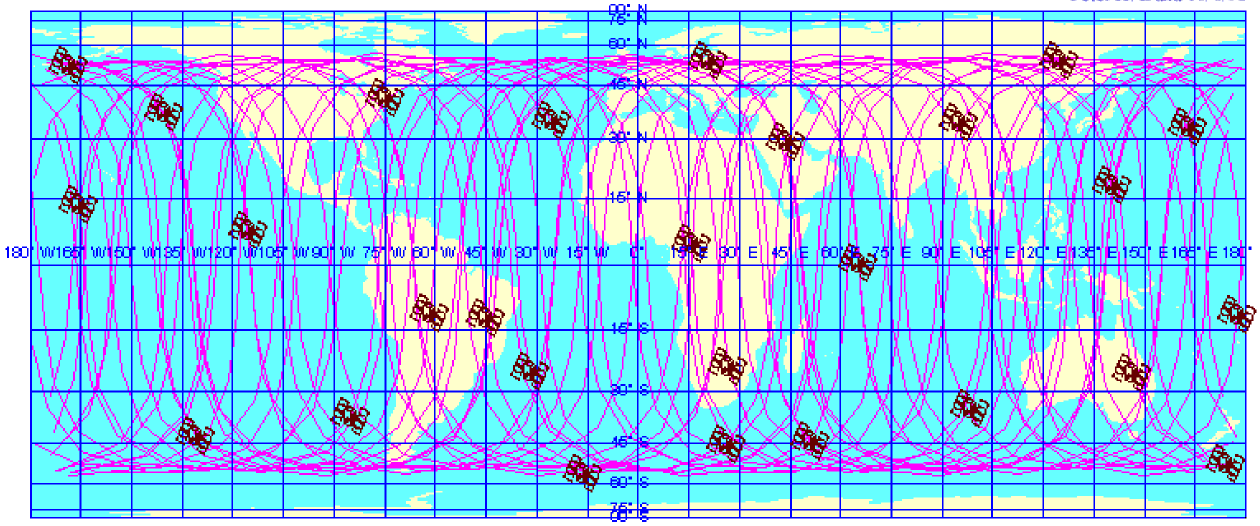
Currently, the military accounts for the largest sector of the GPS market. However, according to Safetrack, "The US GPS Industry Council recently announced that the world-wide market for GPS receiver equipment is expected to grow to over $8 billion by the year 2002, with most growth in the commercial and consumer sectors, which will eventually account for 60% of the market"

(2001). Apparently, the GPS civilian consumer market is booming, and it is no mystery why. Those GPS thugs have been hard at work making systems for cellular phones, emergency services, roadside assistance companies, and luxury cars (Safetrack, 2001).

Also, a slightly improved system called Differential GPS (DGPS)
is becoming more and more popular around the world. States Safetrack, "A series of land-based beacons transmit exact position information to an optional radio beacon receiver attached to the GPS receiver, thus enabling the receiver to give a position fix accurate to less than fifteen meters" (2001). How is this system different and/or better than using PPS signals? It is available to the public and free of charge in the US. (Figure six shows how Differential Navigation works).

So far, the history of GPS does not take too long to recap. However, just taking a glance at the future of this incredible system makes me feel safe in saying that its history will continue to grow more and more complex for many years to come.

Figure 1: GPS SATELLITES AND GROUND TRACKS



Global Positioning System Satellites and Orbits
for 27 Operational Satellites on September 29, 1998
Satellite Positions at 00:00:00 9/29/98 with 24 hours (2 orbits) of Ground Tracks to 00:00:00 9/30/98

FIGURE 2: GPS CONSTELLATION

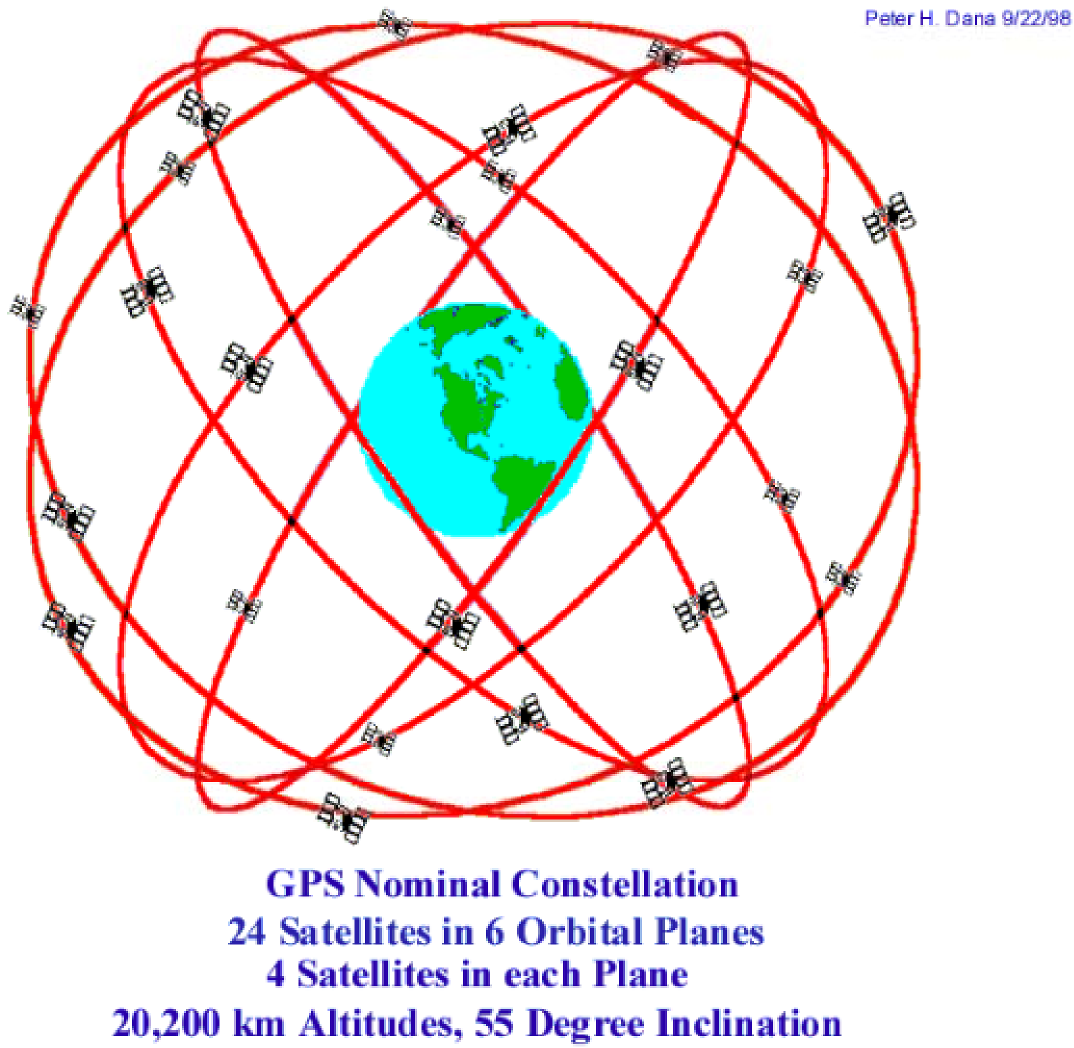


FIGURE 3: GPS MASTER CONTROL AND MONITOR NETWORK

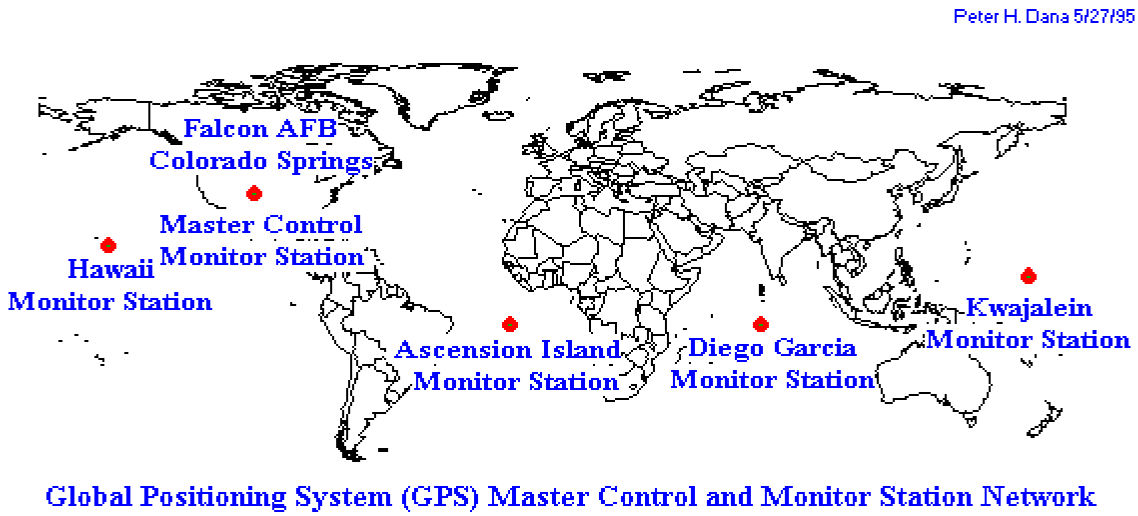


FIGURE 4: GPS CONTROL MONITOR

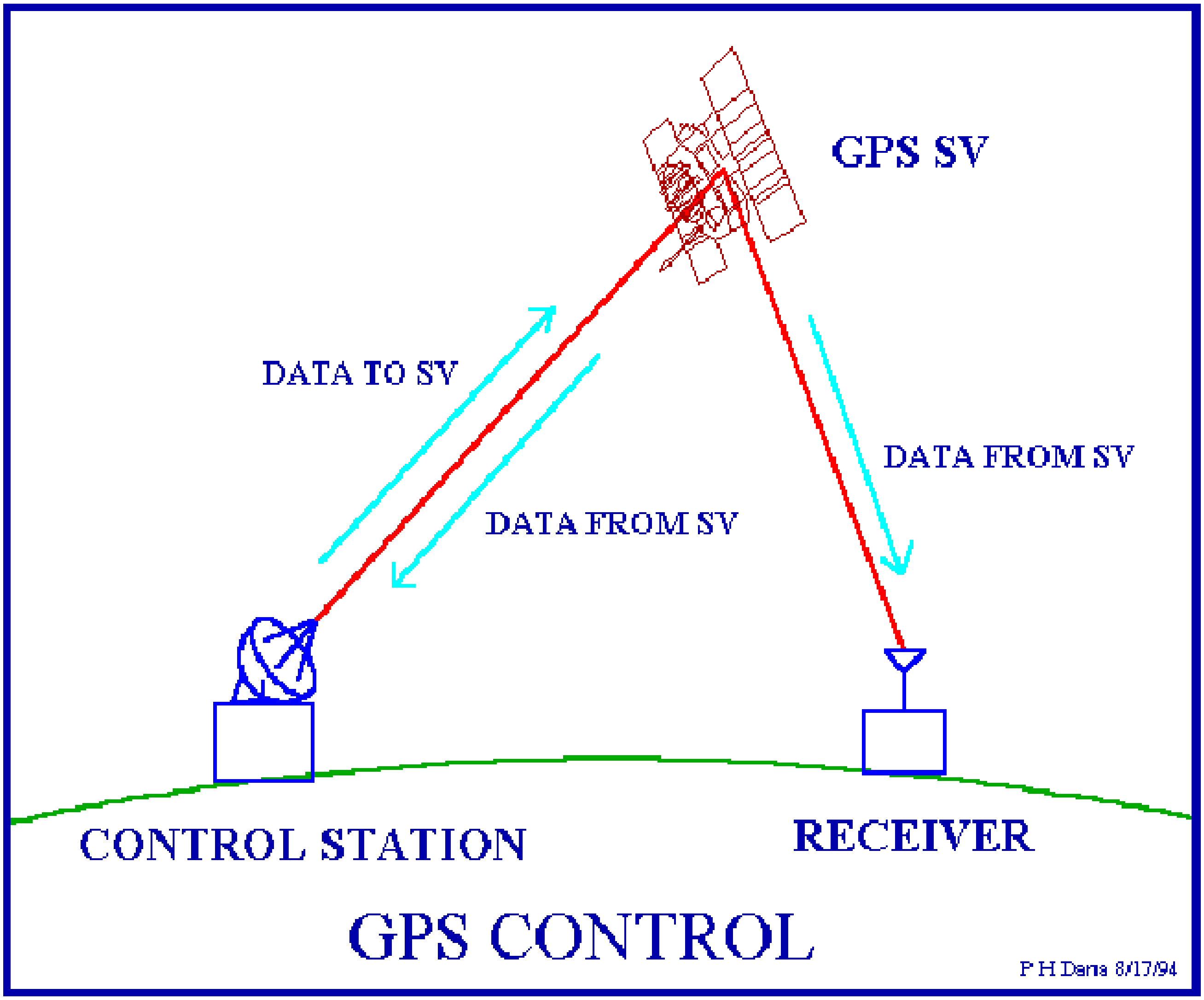


FIGURE 5: GPS NAVIGATION

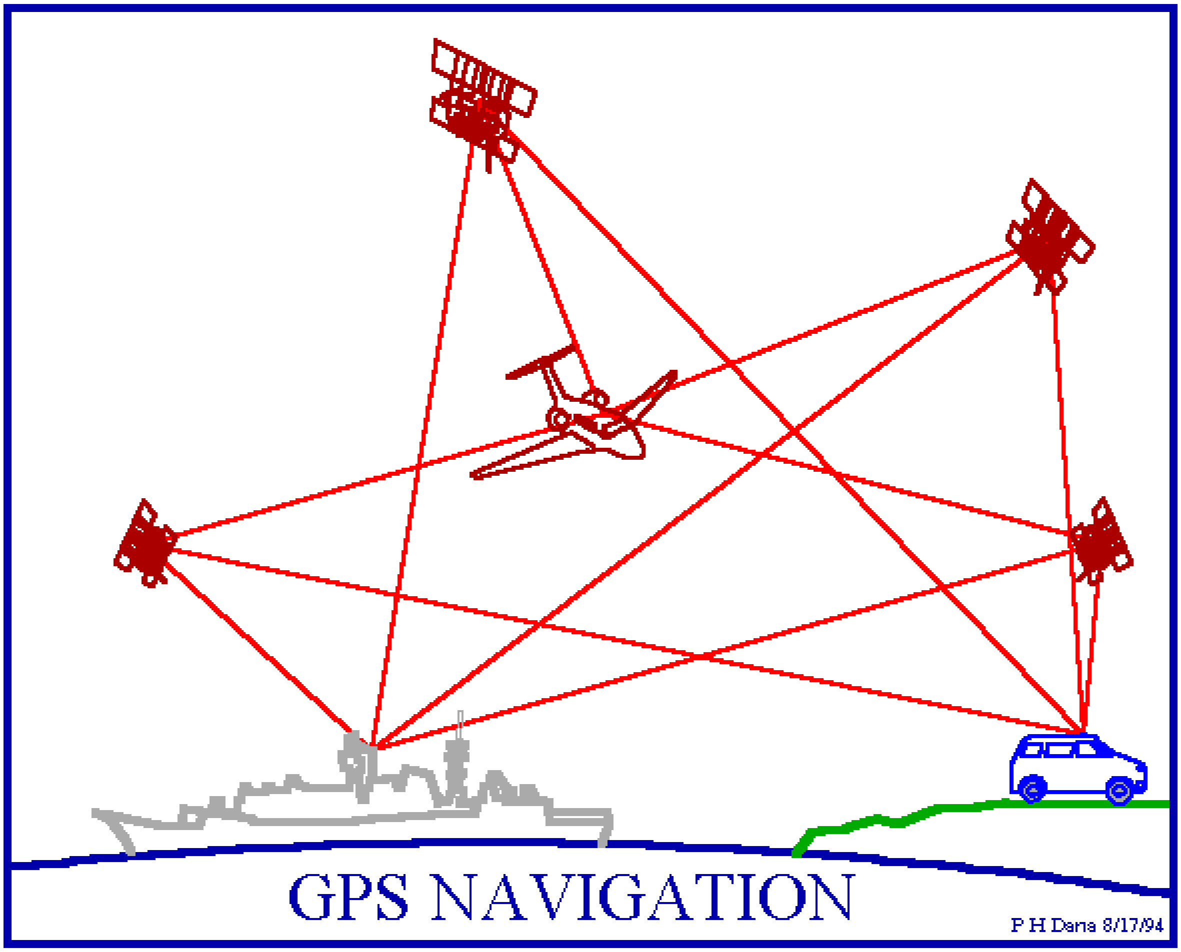


FIGURE 6: DIFFERENTIAL CODE-PHASE NAVIGATION

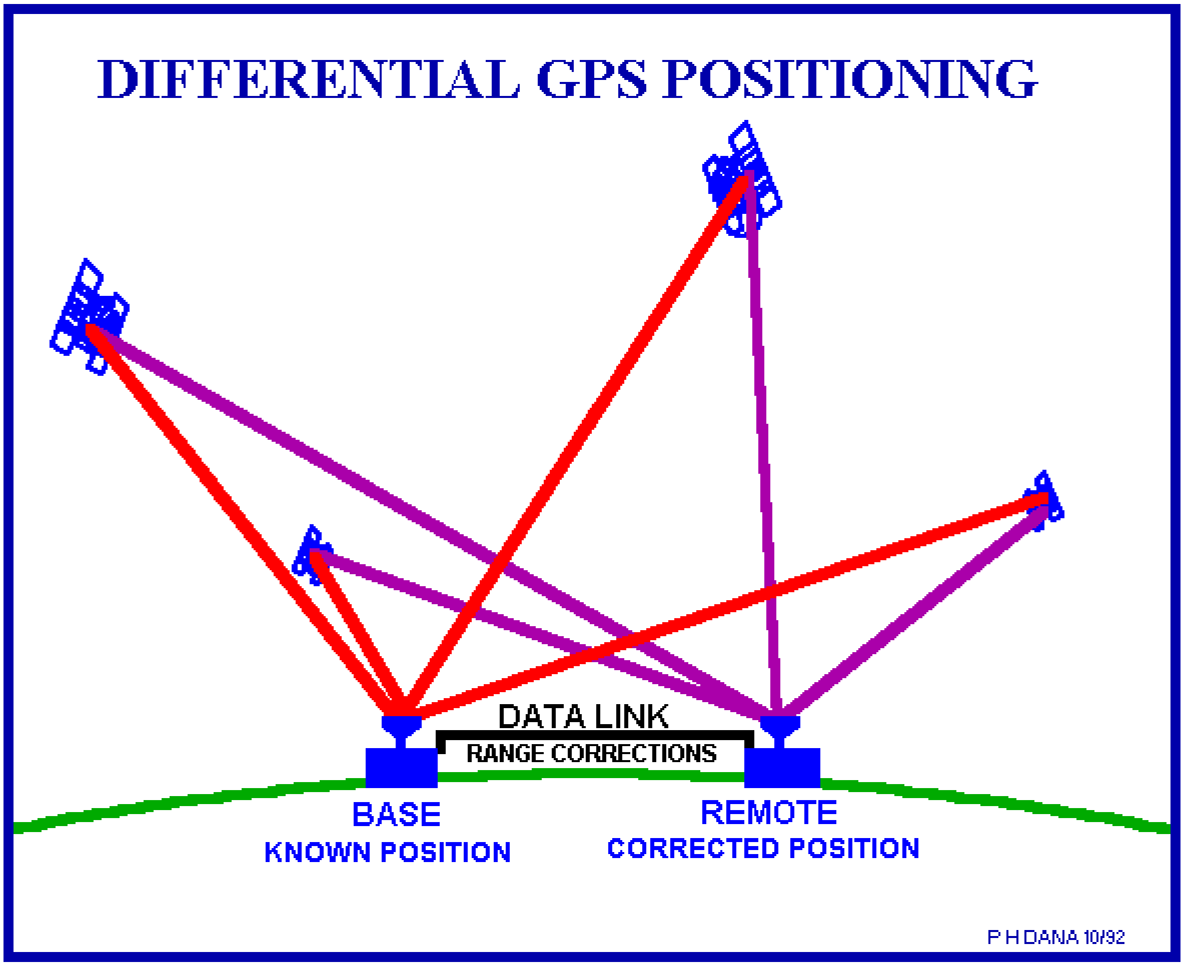


FIGURE 7: GPS ACCURACIES, COSTS, AND SIGNALS

GPS ACCURACIES, COSTS, AND SIGNALS

GPS APPROACH	ACCURACY ESTIMATE	RECEIVER COST ESTIMATE	GPS SIGNALS				
			L1 C/A CODE	L1 P-CODE	L1 CARRIER	L2 P-CODE	L2 Y-CODE
SPS NAVIGATION	100 M	$1,000	X				
SPS DIFFERENTIAL >30KM	10 M	$5,000	X				
SPS DIFFERENTIAL <30KM	1 M	$5,000	X				
PPS NAVIGATION	10 M	$10,000	X	X		X	
ANTI-SPOOFING NAVIGATION	10 M	$20,000?	X	X	X	X	X
L1 CARRIER PHASE SURVEY	0.1 M	$10,000	X		X		
L1 L2 CARRIER PHASE SURVEY	0.01 M	$15,000	X	X	X	X	

Peter H. Dana 8/28/94

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