# The State of GPS In 1995

By James E. Ferguson, O.L.S.

For those of you who actually noticed that the *Geodesy Corner* has been absent from these pages for the past several issues of the Quarterly (hands up you two!), here it is - back! I could give a million and one excuses why it hasn't appeared, but I won't. As with many of you, I confess to often having too little time to entertain family, work and other commitments. We all do our best.

Several columns in the past have dealt with GPS, including the article entitled "What Is It We Obtain From GPS", and two sequential pieces touching on GPS applications. I also promised to continue with the Applications series, and I will do so in the near future.

This current article was inspired by discussions I've recently had with colleagues who have difficulty explaining the true facts about GPS to those who believe that no matter how you use this technology you will always get a perfect answer. It is also the result of my thoughts of writing a review of GPS from its inception to its current state. Each of these subjects by themselves could fill a volume, but I propose to lay out a basic chronology of some of the events that have taken GPS so far so fast and to explain some of the many ways we can interpret and use this technology.

- **The Evolution of GPS**

GPS is not new. Research into the NAVSTAR (Navigation Satellite Timing and Ranging) system began in the early 1970s, and the first GPS satellite was launched on February 22, 1978. Since that time thirty-five satellites have been launched successfully. Of those, all but one had an operational lifespan of some duration. Currently (April 1995) there are twenty-five fully operational satellites in orbit, the oldest having been launched on September 8, 1984 - ten and one-half years ago.

The GPS NAVSTAR system is entirely owned by the United States Department of Defence (DoD), and was primarily intended for navigation. But by early 1984 two or three companies were commercializing the civilian use of the system for more than that. Accurate positioning of survey markers was being done using receivers capable of receiving the signal from the orbiting satellites. Pioneering users of GPS will remember receivers such as the TI4100 developed by Texas Instruments (one of the companies instrumental in developing GPS itself) or the Macrometer V1000, developed at the Massachusets Institute of Technology. Both of these instruments required sophisticated and meticulous operation to achieve success, and had price tags in excess of $250,000 per unit. This high price relegated commercial GPS to be regarded as a very specialized and niche technology at the time. Notwithstanding, it wasn't long before GPS proved itself as a viable method of accurate positioning under unique circumstances. However, as with entry into any uncharted territory, those who initially embraced the technology did so without much support. Utilizing the hardware and software at the outset was often a lesson rooted more in physics than surveying.

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By 1985, the growth potential of GPS was clearly being realized by corporate America, and companies with names like Trimble Navigation sprung from the ranks of military contractors such as Hewlett Packard and JPL (Jet Propulsion Laboratories) - the companies who were at the heart of the research into GPS. In the January 1995 edition of *GPS World*, the magazine dedicated solely to GPS, there are no less than 275 different makes and models of GPS receivers listed, manufactured by fifty-four different companies from the following countries: USA, Canada, Japan, The United Kingdom, Sweden, Switzerland, China, Singapore, Denmark, Spain, France and Germany. This group of companies represents the hardware manufacturers alone and only touches on the number of firms who design and develop software to fuel GPS requirements. The Global Positioning System now truly deserves its name, and could very well be coined the "Global Positioning *Industry*."

- **GPS Policy and Milestones**

The road to what appears to be complete freedom of use of GPS has not been without issue. Even before it was entirely obvious to the DoD that the commercial use would eventually far outweigh the military use of GPS, policy governing the system was quite clear. The general public would, once the system was declared operational, be privy to GPS signals that would allow them to have a 3-dimensional (3-D) position twenty-four hours per day worldwide, to a point accuracy of about 100 metres. The military on the other hand, would be able to use GPS signals that allow them the same 3-D position but to a point accuracy of about 10 metres. I believe that this policy will remain in effect for some years to come, even though there is a substantial US civilian lobby group fighting to have the "10 metres for all" scenario.

Those of you who currently use GPS know that the only cost to the user is the cost of the hardware, software and necessary personpower. Much policy discussion has centred around user fees, or licences for the commercial exploitation of GPS. At some time in the future we may see ourselves paying a fee, through whatever channels, to help support the system. Additionally, as countries throughout the world "officially" begin to embrace GPS (ie. officially sanctioning GPS for stand-alone navigation for their commercial aviation sector), we may also see contributions from various governments to the US. After all, it has cost the DoD over 13 billion dollars to got the system to its current state. And this current state of GPS has some milestones that are worth noting:

* **1984** It is possible to "see" four satellites simultaneously in order to facilitate true 3-D positioning.
* **Spring 1986** The Space Shuttle disaster puts further launches on hold for a period of three years.
* **February 1989** GPS satellites begin launching again via the Space Shuttle and unmanned rockets.
* **December 1993** The Pentagon announces that the GPS has achieved "Initial Operating Capability", meaning that DoD has the inherent responsibility to provide a reliable 3-D positioning service through GPS. Before this date, the GPS was always considered experimental.
* **December 1994** The Federal Aviation Association (FAA) approves the use of GPS as a primary means of commercial airline navigation for oceanic and remote aircraft operation.
* **December 1994** A US Department of Transportation (DoT) report is issued, recommending that the government augment the current GPS structure to provide enhanced positioning to users in the US. It also recommends that the FAA continue to develop its plans to provide GPS landing systems at airports and that this would replace the proposed MicroWave Landing System (MLS) that is currently having development problems. (This report also lists a host of other recommendations, and interested readers can find the complete document on the United States Coast Guard's BBS - (703) 313-5910).

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* **Ongoing 1995** The Canadian Coast Guard will augment its current test bed of differential GPS (DGPS) stations, and install a system of twenty-five by 1998. This system will cover all major southern Canadian waterways and coastal areas. It will also serve land-based users over a large part of the most populated areas of Canada.
* **April 1995** The current GPS satellite constellation is reliable, and there have been no new launches since March 1994. Satellites will be launched on an as-needed basis from now on.
* **Spring 1996** Teleglobe Canada, via the Inmarsat 3 satellite, will be broadcasting GPS integrity messages as well as DGPS corrections.
* **1995** Estimates indicate that the commercial GPS business has become a several billion dollar per year industry, and that it will continue to grow at a steady rate for years to come.

This last "milestone", if you will, clearly illustrates that GPS has taken the world by storm and, if nothing else, shows that there are some astute marketers out there. It also begs the question "What type of GPS hardware/software are people buying, where are they buying it, and how are they using it?" Instead of answering this question - the information can be found in various available market studies/databases - I would like to turn the focus of this article to the building blocks of practical, applied GPS, and to discuss the associated terminology.

- **Whether 100 metres or 1 mm, Think GPS. But Don't Be Fooled!**

If you've ever had the urge to know the approximate location of your automobile while driving across the Prairies, or wanted to position precisely the perspective centre of your aerial photographs over the Amazon jungle, then GPS is for you. The positional requirements for each of these two examples is unique, and that is what makes GPS so special - it can be used for a huge variety of applications.

A note about accuracy and precision before we begin this section. *Accuracy* can be distinguished in two ways. First there is *Absolute Accuracy*, meaning the accuracy of the true values of a position irrespective of any other influences, and second, there is *Relative Accuracy*, or the accuracy of one position relative to another. Unless specifically stated, our discussions will refer to absolute accuracy. Be sure not to confuse accuracy with *Precision*. Precision refers to how precisely an observation was measured and how closely a set of observations or measurements repeats itself. An example illustrating accuracy and precision could be the measuring of a known baseline with GPS. If the line was measured ten times, and the measurements were all within one millimetre of each other, then we can say these measurements are precise. If our measurements reveal the correct distance for the known baseline, then we can also say the measurements are accurate.

***100 Metres, Here's How***

By receiving the GPS signals from at least 4 satellites with your single, autonomous GPS receiver, you will obtain a 3-D position accurate to about 100 metres. This is often referred to as *Point Positioning*, and has the same accuracy whether your receiver cost you $500, $5,000 or $50,000. The reason for this is that the DoD deliberately degrades the GPS signal corresponding to the C/A code (Course Acquisition). True, you might on certain occasions be within 30, or 50 or even 1.5 metres of a true position but the official word is 100 metres! Should you decide to keep your single receiver over the same point for a number of hours (say 6), then the averaged position could be within 15 metres of the true position. Of course, it is impossible to apply this averaging to your car driving across the Prairies. One caveat, if you own a receiver that reads the P-code (Precise Code), and if the DoD happens to have P-Code encryption turned off, then your single stand-alone receiver may give you 10 metres of accuracy, even if you are in a dynamic mode. Today, a low-end C/A code receiver capable of 100 metre accuracy starts at about $500.

***Want 3-10 Metre Accuracy You Say?***

To get this level of accuracy you have several options, but there is one constant - you must have at least two GPS receivers operating simultaneously, or have access to data that emulates a two receiver scenario. Let me explain. In the most basic case, you need to have a *Base Station Receiver*, one which is set up over a previously defined point, such as a geodetic control point. This receiver is recording and/or transmitting data at the same time the second receiver, *The Rover Receiver*, is recording and/or receiving data. If the receiver *Records* the data, then it can be *Differentially Post Processed* to obtain the 3-10 metre accuracy. Using this technique, the inherent errors in the GPS system are cancelled out between the two data sets and we obtain a more accurate answer. This method is referred to as *Differential GPS* or *DGPS*. If the Base Station receiver is transmitting data, then it is capable of what we term *Real Time DGPS Transmission*, or *RDGPS*. RDGPS eliminates the need to Post Process the data, and gives you roughly the same accuracy. The transmitted data is received by the Rover Station, which has to be capable of RDGPS *Reception*. The transmitted data is not the raw GPS data, but rather it is the result of the receiver's internal computations, and is termed the *Differential Corrections*. In simple terms, the differential corrections are derived by subtracting the known coordinates of the base station from each successive position calculated by the base station receiver using the GPS satellites.

If the base station receiver computes its satellite-based position every second, then we can compute a differential correction every second as well. Once computed, it is transmitted to the rover station receiver at the same rate. The underlying principle of using the differential corrections assumes the positional errors at both the base and rover stations are roughly the same. Thus, the rover station's true position can be obtained by applying the same corrections as were computed at the base station. In practice, there are several ways to compute the differential corrections, but let's leave that for another time.

Note that if you are doing RDGPS, then you will also need a means of transmitting/receiving the data, either using HF radios, UHF radios or Cellular phone technology.

Now let's look at the situation where you don't actually operate the Base Station receiver, but your Rover Station is capable of RDGPS reception. You must then rely on an external source of differential corrections. At present, there are a number of available sources, from both the private and public sectors. For each of the following data sources the user must have an extra piece of hardware to receive the differential corrections and, for all of the private sources, a license fee applies. In no particular order, differential corrections can be obtained from, among others, US and Canadian Coast Guard DGPS Beacons, DCI which broadcasts on FM sidebands and communications satellites, OMNISTAR which broadcasts using communications satellites, STARFIX (similar to OMNISTAR), and Racal DGPS which broadcasts using communications satellites. Several current initiatives in RDGPS that will be available in the very near future include the FAA's *Wide Area Augmentation System (WAAS)*, the Inmarsat 3 transmissions mentioned earlier, joint efforts between the US DoT and US Coast Guard to implement over 60 land-based DGPS Beacons, and the Canadian Coast Guard's expanded DGPS project. More sources will surely crop up domestically and globally. A receiver capable of receiving/transmitting DGPS data can be bought for under $1,500, but this is a very basic model. Of course the communication link and/or autonomous differential correction hardware is an additional cost.

***How About Sub-Metre Accuracy?***

Sub-metre accuracy can be obtained using the same principles that apply to the 3-10 metre problem, but using slightly more sophisticated GPS hardware. Whereas we can get our 3-10 metre accuracy with a receiver that essentially deals only with the C/A code, sub-metre positioning requires that the receiver use the GPS signal's *Carrier Wave* in a method known as *Carrier Phase Smoothing*. This smoothing of the C/A code eliminates more of the inherent error sources in the GPS system. It is still necessary to have our base station receiver, or differential correction source, to function in this mode, but by using more sophisticated receivers we can raise our accuracy to the sub-metre level. Note, however, that both the differential source (or base station receiver) and the rover station must be capable of performing the Carrier Phase smoothing. Otherwise, the anticipated accuracy will not be achieved. Several of the differential sources mentioned above have the capability to provide differential corrections based on this method. However, some increase the price of the license fee for this service. To get a basic sub-metre system, you'll probably have to spend a ballpark figure of $10,000 per unit.

***So You're a Preciophiliac (i.e. you want lots of accuracy)....***

Many of us in the survey business deal daily with the requirement to have accuracy of a centimetre or less. This level of accuracy is really a continuation of the forgoing method but using slightly different techniques and more sophisticated receivers yet again. Most important of all, it is the method of processing the raw GPS data that gains us the increased accuracy.

Again we must use at least two receivers, or have, one receiver and a source data to act as a base station receiver. Very often, the term *Relative Positioning* is used to describe the positioning of one receiver with respect to another. This term could also be applied to the DGPS and RDGPS methods as well. To obtain centimetre level relative positioning, each of the GPS receivers must be able to track at least one of the two GPS carrier waves and its associated data. These receivers are termed *Single Frequency Receivers*, and are the most common type used for "traditional" high accuracy positioning as well as for the above DGPS methods. Many of the receivers used today to provide this level of accuracy actually track the two available carrier waves and are termed *Dual Frequency Receivers*. The terms *L1* for single frequency and *L1/L2* for dual frequency are common. In general, it is possible to compute more accurate answers more quickly using dual frequency receivers. It is also generally accepted that it is possible to measure longer lines using dual, as opposed to single, frequency equipment. In the list to follow describing the different methods of obtaining centimetre level accuracy, I will indicate whether it requires single or dual frequency receivers.

There are a number of ways in which we can produce positional information to the centimetre level of accuracy. Some of the methods require *Post Processing*, while others are possible using *Real Time* techniques. Here is a list of the methods and a brief description of each.

* *"Traditional Static"* positioning is the art of using two or more receivers to simultaneously record raw GPS data over a relatively long period of time, say one hour. The GPS data is then downloaded onto a computer and post processed using any one of a variety of software packages specially designed for this purpose. The results are the positions of where the receivers were installed relative to each other. Single or dual frequency receivers can be used, depending on the distances between stations. For distances of over forty or fifty kilometres, dual frequency receivers may be preferred.
* *"Rapid Static or Fast Static"* positioning provides identical results to the static method, but is done using much shorter observation times. Typically, for distances under ten kilometres a fifteen minute recording session is sufficient. The exact amount of recording time is determined from a wide range of factors including: the number of visible satellites, the geometric strength of the satellite constellation, or *PDOP*, where the station is located, the type of receiver being used etc. I know of only one receiver type that is capable of performing the rapid or fast static technique using a single frequency model. Most receivers used for this technique are dual frequency. Although it varies between receiver types, this method yields slightly less accuracy than does the static method. (But you'll still get "several" centimetre level accuracy.)
* *"Kinematic"* positioning uses roughly the same processing techniques (post processing required) as the two static methods, but this technique allows you to obtain centimetre level accuracy in a dynamic fashion. Thus, if you require an accurate position every second as you drive down the road, then this is possible using the kinematic method. Typically, using the kinematic method requires an initialization process between the base station receiver and the rover. Once this has been carried out, the signal must be recorded at each receiver uninterrupted (maintain *Lock* on each satellite) so that the centimetre accuracy is maintained. Many receivers capable of static positioning are also able to record data for a kinematic survey but more and more manufacturers are concentrating on dual frequency units for kinematic applications.
* *"Real Time Kinematic, or RTK"* positioning allows you to perform a kinematic type survey but in real time. Again, this means that you don't require post processing to achieve your answer. Surveyors and road construction crews are beginning to use this technique for real time layout in the field. In addition to the appropriate GPS hardware requirement, you must also have a dedicated data transmission system. Depending on the RTK system you choose, you may or may not be required to maintain lock on the satellites at all times. All of the RTK systems that I've seen on the market are dual frequency.
* *"On The Fly or OTF Kinematic"* positioning takes the kinematic bundle one step further. Unlike the straight-forward kinematic method which requires constant lock on the satellites, OTF does not. This technique allows you to lose lock on a satellite (while sitting still or moving), reacquire its signal again and maintain centimetre level accuracy. There are, however, some limitations. If all of the satellites being recorded drop out at once, it may take some seconds to bring the positional solution in line with its true value. Some RTK systems use the OTF technique for real time data processing. Currently, most OTF is post processed. On the price side, a basic unit for static applications may start at about $10,000, while a fully loaded unit capable of OTF Kinematic may run as high as $50,000.

- **Conclusion**

After reading this, I hope you will agree with me that GPS is a mature technology. Ongoing refinements and developments to the system and its applications will only enhance the use of GPS. Every day there are new hardware and software products available to tackle a new task or put a new twist on an old one. Concerns over the current policies in place to regulate GPS may be easing as more of the world community increasingly embraces the system. We can only wait and see. One thing is for sure, major departments of the United States government have committed themselves to the furtherance of GPS. If this commitment is backed by a clear policy statement from the President, then GPS could go ballistic.

In conclusion, this paper grew larger than I had anticipated, and I really only scratched the surface of the topics I presented. I hope reading this will clear up any misconceptions you may have had and I hope that it encourages you to delve deeper into the world of GPS.

Thanks for reading. Don't forget to write me care of the AOLS if you have any queries.

The next issue of the *Geodesy Corner* will be a surprise... even to me!

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***Author's Bio***

*James eats, sleeps and breathes GPS, and he can automatically receive GPS signals by affixing an antenna to the bicycle helmet perched on his head!*