how it works

NEW GOVERNMENT DIRECTIVES AND LOW-COST HARDWARE PROMISE TO SPARK RENEWED INTEREST IN EMBEDDED GPS PRODUCTS OVER THE NEXT FEW YEARS. MAKE SURE YOU UNDERSTAND THE FUNDAMENTALS OF THIS IMPORTANT TECHNOLOGY.

Embed GPS to pinpoint your product's position

By Warren Webb, Technical Editor

DON'T BE SURPRISED if the specification for your next project calls for a sophisticated microwave receiver that can detect faint signals from multiple satellites thousands of miles into space and measure signal-transition times with atomic clock precision. Luckily, the specification probably refers to GPS (Global Positioning System) hardware that you can buy off the shelf for less than $200. And you can expect even lower prices in the near future as embedded GPS volume ramps up to meet government mandates for enhanced 911 services. GPS will also get a boost from the government's decision to end the deliberate degradation of nonmilitary GPS satellite signals.

NAVISTAR (Navigation Satellite Timing and Ranging) GPS is a worldwide navigation system that uses high-altitude satellites as reference points to determine positions near earth. The US DoD (Department of Defense) developed and maintains the GPS, so the military benefits are enormous. Military users can direct and monitor the movement of missiles, mine sweepers, aircraft, ships, and troops. The DoD launched the first GPS satellite in 1978, but it did not declare full operational capability until 1995. Civilian uses of GPS include the obvious navigation, fleet-monitoring, and construction equipment and farm machinery.

GPS is divided into three segments: ground-control stations; satellites; and receivers, which are in the

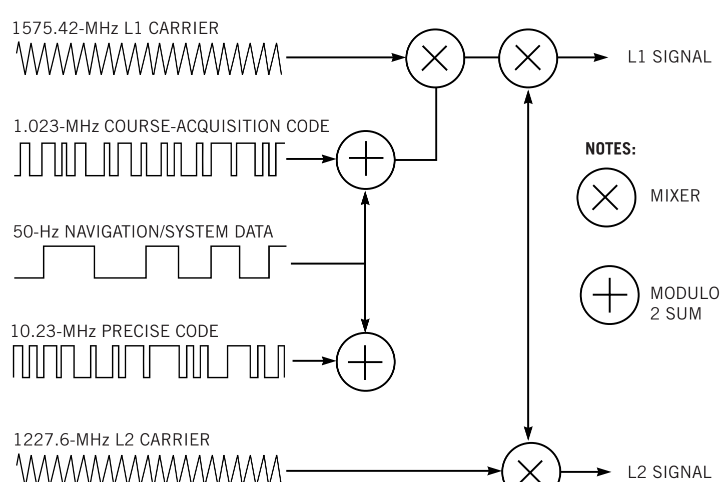


Figure 1 GPS-satellite carrier signals are modulated with multiple pseudorandom-number codes to support civilian and military users.

hands of users. A master station at Schriever Air Force Base in Colorado Springs, CO, controls the GPS system. Four monitoring stations around the world measure the altitude, position, and speed of each satellite using high-power radar and constantly update the navigation data that each satellite transmits.

The celestial portion of the GPS system comprises 24 satellites nearly 11,000 miles above the earth. The satellites are not geostationary and circle the earth every 12 hours. There are six orbits, and each orbit contains four satellites. DoD contractors periodically launches new satellites to replace deteriorating orbits, and, at any one time, more than 24 satellites are aloft. From any point on the earth, as many as eight satellites are simultaneously visible.

GOT THE TIME?

Each GPS satellite packs equipment, including four atomic clocks, several communications transceivers, solar panels, batteries, and a navigation system, that keeps the satellite pointed toward the earth. The clocks are accurate to approximately 1 nsec, which is about the time it takes light to travel 1 ft. The communications power output of each satellite is about 50W.

Each GPS satellite transmits two L-band carrier signals (**Figure 1**). The L1 signal at 1575.42 MHz is modulated with a 1.023-MHz PRN (pseudorandom-noise) code containing course acquisition and navigation information. The PRN code from each satellite is unique, and receivers use the code to identify the signal source. The PRN repeats every 1023 bits (1 msec) and spreads the signal over the full 1-MHz spectrum. The L1 signal is the source of GPS data for most civilian and commercial receivers. GPS satellites also transmit a L2 carrier at 1227.6 MHz, which carries encrypted, precise positioning data for use by the military plus selected government or civilian users.

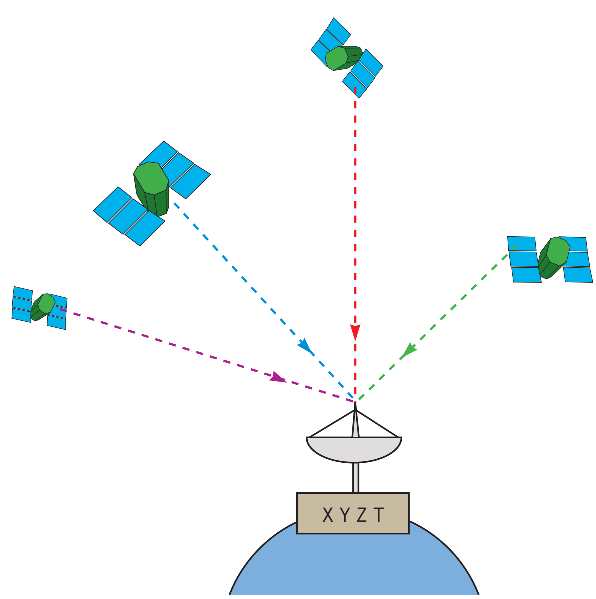
The navigation message is a 50-Hz signal bit stream that describes the GPS satellite orbits, clock corrections, and other system parameters. The orbit information rebroadcast from each satellite consists of almanac data, which gives a rough estimate of the location of each satellite and ephemeris data, which pinpoints the precise coordinates. When you activate a new receiver, it takes about 12 minutes to download the almanac and ephemeris data before you can use it to determine location.

Figure 2

This cart-based information system uses differential GPS to give the golfer real-time distance-to-the hole data.

GPS receivers calculate their position by measuring the distance to multiple satellites. It takes a little less than 100 msec for the carrier signal modulated with the PRN code to travel from the satellite to the receiver. On Earth, the GPS receiver generates an identical PRN code and compares the two signals to determine how much delay to add to match up the PRN signals. The delay roughly determines the distance between the satellite and the receiver. Similar measurements from two other satellites theoretically create enough data to determine the receiver's position. The problem is that the receiver clock is inaccurate. An error of just 1 msec can introduce almost 200 miles of position error. To solve this problem, receivers are programmed to take a fourth measurement from another satellite and then adjust the receiver's clock until the distances to all four satellites pass through the same point in space. The receiver basically solves four simultaneous equations with four unknowns. This measurement technique not only gives an accurate reading of the receiver's position, but also calculates time to atomic-clock precision.

Even with an accurate clock, other errors in the system can still degrade the accuracy of GPS location measurements. Ephemeris data, the difference



GPS uses measurements of code-arrival times from four satellites to determine the receiver's position in x,y,z space and time.

between a satellite's actual location and its reported location, introduces errors. Even variations in the speed of light as it passes through portions of the Earth's atmosphere create inaccuracies. Receivers can also lock onto multipath signals that are reflected from nearby surfaces to affect distance measurements.

PREMEDITATED ERRORS

Until recently, the largest GPS error was intentionally introduced. The DoD introduced SA (selective-availability) errors into GPS signals to reduce the accuracy of civilian receivers. By intentionally varying the time signal transmitted from each satellite, you could increase a receiver's effective accuracy from 30 to 100m. The government intended SA to prevent enemy use of our signals for terrorist activities or even missile guidance. In May of this year, President Clinton signed an order ending SA while retaining the ability to regionally degrade GPS signals when national security is threatened.

Another government ruling by the FCC (Federal Communications Commission) will also kindle GPS activity. The FCC has given wireless carriers until October 2001 to start reporting the location of 911 callers. The original idea was to determine the caller's location by triangulation from the cellular base stations, but low-cost modules and chip sets have now pushed handset GPS into the favorite position. Volume production of GPS elements will not only reduce prices, but also drive new communications services, such as pedestrian navigation and location-based advertising.

SA prompted clever designers to devise differential-GPS techniques to remove the intentional errors. By installing a fixed GPS transceiver at a known location, users can monitor and transmit the SA timing errors for each satellite. Then mobile differential GPS units can receive the error signals along with the satellite signal and incorporate the correction in to their calculations to provide a much more accurate position. Differential GPS units not only eliminate the SA errors, but also reduce ephemeris and atmospheric delay errors. The golf-course management system from Parview (www.parview.com) is an example of a differential system that includes a cart-based GPS receiver and an LCD to give golfers precise real-time distances to the hole along with electronic scoring and communications features (**Figure 2**).

EXTREME ACCURACY

In addition to differential measurements, other techniques allow you to gain even greater position accuracy from GPS signals. Land surveyors now use L1 carrier-phase tracking to fix positions within centimeters. At least two receivers measure the differences in carrier-phase cycles and fractions of cycles over time from one or more GPS satellites. You can measure positions as far as 30 km from a reference point without intermediate measurements.

This $150, matchbook-sized, 12-channel GPS receiver from Pharos (www.pharosgps.com) has a built-in patch antenna and connects to your system through a standard serial data port.

Although the GPS is in place and fully operational, the United States continues to schedule upgrades to enhance civilian use. Two additional GPS signals will come online over the next five years to reduce errors and improve position accuracy. Starting next year, the military plans to gradually upgrade the entire fleet of GPS satellites with more advanced hardware.

Surprisingly, the European Space Agency and European Union are evaluating plans to launch a competing, fee-based GPS system by 2008. Some Europeans are worried that they will become dependent upon a system operated by the US military and that regional conflicts may force the local reintroduction of SA.

You can expect plenty of new embedded-GPS applications to surface in the next few years. As an electronic-systems designer you will have new opportunities, but as a member of society you may feel that Big Brother is watching. GPS systems in cell phones and vehicles allow employers to check on employees, parents to monitor kids, and insurance companies to extract your driving record. For example, Progressive Casualty Insurance (www.progressive.com) is testing a program using GPS to automatically adjust auto-insurance rates. Drivers who obey speed limits, minimize their vehicle usage, and stay away from dangerous routes get lower monthly bills. Are you ready?□

References

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