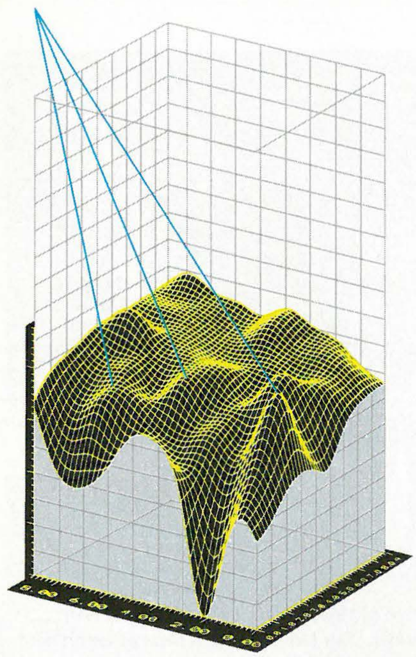

As we become more and more reliant on GPS, it becomes increasingly important to understand its limitations. One such limitation is vulnerability to interference. In this month's column, Rolf Johannessen discusses different kinds of interference, how we may recognize when it occurs, and what we can do to protect ourselves.

Johannessen comes from Norway but studied at the University of St. Andrews in Scotland. He moved to southern England to work on navigation systems, which has been his field of expertise for more than 30 years. He recently returned to Scotland to live and work among its beautiful hills and lochs. Johannessen is the director of Lambourne Navigation Ltd., in Helensburgh, Scotland, a company specializing in navigation and surveillance.

"Innovation" is a regular column featuring discussions about recent advances in GPS technology and its applications as well as the fundamentals of GPS positioning. The column is coordinated by Richard Langley of the Department of Geodesy and Geomatics Engineering at the University of New Brunswick, who appreciates receiving your comments as well as topic suggestions for future columns. To contact him, see the "Columnists" section on page 4 of this issue.

Interference: Sources and Symptoms

Rolf Johannessen

Lambourne Navigation Ltd.

Interference affects everyone's lives in one way or another. Perhaps you have discussed important business while entertaining a client at a nice restaurant. You knew that his or her expressive nuances might reveal how to seal the deal, but a nearby group was talking so loudly that you had difficulties even hearing the words. Interference. Or perhaps you had just purchased a new, high-quality CD player. As you settled down to enjoy a perfect reproduction of your favorite Mahler symphony, your neighbors decided to listen to AC/DC — with the volume up and their windows open. The result? Interference.

Radio communication systems also suffer from interference. This is particularly noticeable when listening to a distant radio station and another spectrum user is on the same frequency or very close to it. A form of deliberate interference was also common during the Cold War. Because the West was transmitting news from the free world to the suppressed East, some eastern countries broadcast noise transmissions on the same radio frequencies to prevent their own people from hearing Western "propaganda."

Interference also affects radionavigation systems. Aviation's Instrument Landing System (ILS), part of which operates in the 108–112-MHz band, provides a well-known example. Spectrum regulators are allowing FM broadcast stations to use frequencies close to the ILS band, and it is feared that interference from those FM transmitters will cause some older ILS receivers to malfunction. Accordingly, the International Civil Aviation Organization has developed a new specification for the filtering now required in ILS receivers.

Interference, therefore, presents a common problem both in our everyday lives and for our communications and navigation systems. And so we need to face the possibility of interference to GPS.

INTERFERENCE SOURCES

Several kinds of interference can potentially disrupt a GPS receiver's proper operation (see the "Problematic Frequencies" sidebar.)

In-band Emissions. Other radio spectrum users, for example, may transmit signals in the GPS bands, with or without permission. Swisscontrol, Switzerland's air navigation service, reported an in-band emitter that caused problems for GPS receivers on an aircraft approaching that country's Lugano airport. Officials found "high levels of interference in the GNSS [Global Navigation Satellite System] band" while flying over southern Europe. The interfering signal and its source were identified as originating in a nearby country.

Wideband noise from electrical devices, such as ignition systems and arc welders, may also be a problem, if strong enough. A receiver's antenna may pick up this noise, or it may be conducted into the receiver through a power supply connection or other wiring.

Nearby-band Emissions. Some emissions radiate at frequencies close to those of GPS in a legal manner but interfere with GPS receivers that incorporate poor filtering designs adopted to achieve a low-cost product. For example, a ship reported that its C/A-code receiver became inoperable in the harbor at Stavanger, Norway. The problem was traced to interference from a microwave link transmitter operating at 1533.005 MHz, about one kilometer away. That signal, however, did not affect other GPS receivers tested at the same site.

Harmonics. Several cases have also arisen in which equipment designed to radiate at a frequency far removed from the GPS bands has a spurious component that encroaches on one of those bands. One aircraft, for example, reported GPS interference from a Distance Measuring Equipment transmitter designed to radiate at 1050 MHz — an output derived by doubling a crystal frequency at 525 MHz. Unfortunately, the circuit used to achieve this also generated the third harmonic (1575 MHz) at a level strong enough to prevent three different GPS receivers from operating.

Jamming. Deliberate interference with GPS signal reception is called *jamming*. This article's author has not heard of it happening yet, except under well-controlled conditions for the purpose of obtaining scientific data. Nevertheless, we should not ignore the potential for jamming any more than we can ignore the possibility that a deranged person could transmit, by very high frequency (VHF), an Air Traffic Control–like clearance that directs an aircraft to fly into a mountain.

HOW VULNERABLE IS GPS?

There are many records of attempts to assess GPS's vulnerability. For instance, the Department of Defense Notice Advisory to Navstar Users (NANU) number 236, issued in 1995, referred to receivers being affected within a 200–nautical mile range of Beatty, Nevada, where the Naval Strike Warfare Center planned testing on November 8, 1995. Such testing has continued with similar warnings.

For various dates between March and June 1997, the U.S. Coast Guard Navigation Center Web site also gave an "affected area" as a 300-nautical-mile circle around the Tonopah, Nevada, VORTAC (a military air navigation system combining VHF Omnidirectional Range [VOR] and Tactical Air Navigation [TACAN] systems). The power of the interference source was not stated, though the transmissions were reportedly to come from an airborne transmitter at 15,000 feet above mean sea level.

Other reports have been more specific. One account described a test using a continuous-wave (cw — an unmodulated carrier wave) transmitter located on a lighthouse 67 meters above sea level. The 1575.36-MHz emission had an effective radiated power of 7.9 dBW vertically polarized. This signal incapacitated three different GPS receivers on a ship 20–30 nautical miles away. The precise distance at which the GPS receivers failed depended on the height of the receiving antennas, which were at elevations from 14 to 28 meters.

In another report, following a series of trans-Europe flight tests to measure interference, the investigators concluded that "standalone GPS navigation is extremely vulnerable to interference." (The "Further Reading" sidebar lists these and other reports.)

GPS and GLONASS Differences. Because all GPS satellites operate on a common frequency, it follows that if interference causes a receiver to lose lock on one satellite, it is probable that it will lose lock on other, if not all, satellites and thus be unable to compute a position fix. GLONASS satellites, however, operate on a variety of frequencies so that if cw or other narrow-band interference affects the signals of one satellite, it will probably affect only that one. This gives GLONASS the advantage of continuous position output despite that interference. On the other hand, a random cw interference source is more likely to affect reception from one GLONASS satellite than from one GPS satellite, because GLONASS has so many vulnerable frequencies. Other GPS/GLONASS differences also affect their relative vulnerability; however, a complete comparison is unfortunately outside this article's scope.

Recognizing Interference. Receivers differ in the way they react to interference. Sometimes, a unit simply ceases to display position information, or maybe the display freezes, or perhaps the device enters a dead-reckoning mode. Whatever the final outcome, and depending on the equipment, users can look for early warning signs of impending failure. A receiver's displayed measure of signal level or signal-to-noise ratio, for example, will indicate a deterioration in trustworthiness when an interference signal increases in intensity. The number of satellites tracked may also begin to decline. Some receivers will draw the user's attention by whistling or beeping. However, others may give no warning whatsoever. Users should therefore become familiar with the symptoms of possible interference and should ask the receiver's manufacturer what signs to watch out for.

GPS PROTECTION

Pressure on the radio spectrum will always exist, as long as people can make money using the frequencies for their own purposes.

Further Reading

For a wide-ranging assessment of GPS interference including user experiences and studies, see

- *GPS Interference — Is It a Problem? Workshop Notes.* A collection of notes and visual aids from the Royal Institute of Navigation workshop on GPS interference held in London on October 12–13, 1995.

The following workshop presentations are mentioned in this month's column:

- "GPS Interference Search Around the Swiss Lugano/Agno Airport," by M. Schulte-Elte, pp. 151–165.
- "Electro Magnetic Interference Observed with a GPS Receiver in Stavanger Harbour," by Ø. Berggraf, pp. 113–122.
- "GPS Interference on Approach to Edinburgh Airport," by A. Moore, pp. 167–174.

For additional GPS interference reports, see

- "Practical Measurements of Radio Frequency Interference to GPS Receivers and an Assessment of Interference Levels by Flight Trials in the European Regions," by P. Nisner and J. Owen, published in the *Proceedings of ION GPS-95, the 8th International Technical Meeting of The Institute of Navigation*, held in Palm Springs, California, September 12–15, 1995, pp. 1373–1382.
- "Overcoming Interference to Reception of GPS at Sea," by N. Ward and R. Johannessen, published in the *Proceedings of ION GPS-94, the 7th International Technical Meeting of The Institute of Navigation*, held in Salt Lake City, Utah, September 20–23, 1994, pp. 1421–1427.

For thorough technical discussions about how interference affects GPS signal tracking, see

- "Interference Effects and Mitigation Techniques," by J.J. Spilker, Jr., and F.D. Natali, Chapter 20 in *Global Positioning System: Theory and Applications*, Vol. I, edited by B.W. Parkinson and J.J. Spilker, Jr., published as Vol. 163 of *Progress in Astronautics and Aeronautics*, American Institute of Aeronautics and Astronautics, Inc., Washington, D.C., 1996.
- "Effects of RF Interference on GPS Satellite Signal Receiver Tracking," by P. Ward, Chapter 6 in *Understanding GPS: Principles and Applications*, edited by E.D. Kaplan, published by Artech House, Inc., Norwood, Massachusetts, 1996.

For a discussion about interference to GPS and GLONASS from an aviation viewpoint, but also of interest to other users, see

- *Assessment of Radio Frequency Interference Relevant to the GNSS*, RTCA/DO-235, published by RTCA, Inc., Washington, D.C., 1997.

The U.S. Coast Guard maintains Web pages devoted to GPS spectrum issues. See

- <http://www.navcen.uscg.mil/radionav/ spectrum/>.

Problematic Frequencies

Signals on certain frequencies are more prone to cause interference to GPS than others. Certainly, signals whose fundamental frequencies lie within the bandwidth of a GPS receiver may cause problems, if strong enough, despite the fact that the spread-spectrum nature of the GPS signals affords them some degree of interference immunity compared with other signal types.

The GPS satellites have an internal filter that reduces out-of-band emissions to a very low level so that the signals are essentially confined to the ITU-registered bandwidths of ±12 MHz.

Although the bandwidth of the C/A-code modulation's central lobe is about ±1 MHz, there is spectral power in secondary lobes that extend many megahertz to either side of the central lobe. Some GPS receivers make use of this wider signal bandwidth to improve pseudorange measurement precision and to reduce the effects of multipath. P(Y)-code correlating and codeless civilian receivers use the full P-code bandwidth of about ±10 MHz. A signal with sufficient power on a frequency within this band will decrease the GPS signal carrier-to-noise density ratio, thereby decreasing measurement precision. It may even cause the GPS receiver to lose signal lock.

GPS receivers are also susceptible to interference from spurious signals. Such signals result from poorly filtered transmitters and include harmonics — signals radiated at integer multiples of the intended or fundamental frequency. These signals may be strong enough to interfere with GPS signal reception, especially if the transmitter is in the immediate vicinity.

The GPS L1 signal, for example, is susceptible to second harmonics from transmitters operating in the 781–794-MHz range, third harmonics from transmitters operating in the 521–530-MHz range, and so on. This includes, for instance, second harmonics of North American television transmitters on channels 66 and 67 (as well as corresponding channels in other regions); third harmonics of television channels 22 and 23; 10th harmonics of marine very-high-frequency (VHF) communications channels between 156.3 and 157.9 MHz; and 12th and 13th harmonics of aviation communications frequencies in the vicinity of 131 and 121 MHz respectively, including the 13th harmonic of the 121.5-MHz emergency and distress frequency. — R.B.L.

Safety-of-life applications, though, demand that international radio regulations protect the satellite navigation frequency bands. All other users must be kept out of those bands — an arrangement that requires international cooperation. (See the "Regulating the Spectrum" sidebar.)

Manufacturer Influence. GPS equipment manufacturers respond to the consumer's desire for low prices. To achieve a lower price point, they often omit components and functions they consider unnecessary. This is generally not a problem, because in many applications, the probability of interference is extremely low and the consequence of encountering it negligible. For instance, a terrestrial television transmitter is unlikely to interfere with a GPS receiver on board a tanker in the mid-Atlantic. And if a car traveling from Colorado Springs to Albuquerque suffers interference over a one-mile stretch of that road, the driver may not even notice. But in some circumstances, interference is more serious. If a narrow harbor's entrance frequently suffers from poor visibility, constant GPS interference could be disastrous. Manufacturers could do more to increase the user community's awareness of potential problems by stating the degree of protection provided by their equipment.

Regulating the Spectrum

In 1865, representatives from 20 European countries established the International Telegraph Union to govern the countries' telegraph relations, which included standardizing equipment and operating practices. With the development of the telephone and subsequently radio, the union expanded its role and, in 1934, was renamed the International Telecommunication Union (ITU).

In 1947, following its own creation, the United Nations took over responsibility for the ITU, which exists today to promote worldwide cooperation in all aspects of telecommunications, including radio-frequency regulation. Through its Radiocommunication Bureau and its World and Regional Radiocommunication Conferences, the ITU strives to achieve international consensus on radio-frequency allocation to the various radio spectrum users, thereby preventing unnecessary mutual interference.

The spectrum is divided into frequency bands, with different radio services assigned to particular bands. Within a band, a service may be granted primary, secondary, or permitted status. A station in a primary service may not cause harmful interference to stations in the same, or another, primary service and may claim interference protection from all other stations. A secondary service may not interfere with stations in a primary or secondary service and may not claim protection against interference from stations in an existing or subsequently installed primary service. A permitted service station may not cause interference to primary or secondary service stations and is afforded no interference protection.

The ITU classifies the navigation signals transmitted by the GPS and GLONASS satellites as part of the Radionavigation-Satellite Service (RSS). Other ITU service categories include, for example, Radionavigation (for terrestrial radionavigation systems), Aeronautical Mobile (for communication between ground stations and aircraft or between aircraft), and Broadcasting (covering transmissions intended for the general public). Formally, a radionavigation-satellite service is defined as one that uses radio signals transmitted from satellites for the purpose of determining position, velocity, and/or other characteristics of an object for the purposes of navigation.

Of the 12 bands now allocated to RSS, seven are above 14.3 GHz and probably not operationally used for the service. Of the others, two are currently used by the Russian Federation's Tsikada and Parus Doppler navigation systems and, until the beginning of this year, the former U.S. Transit System (which, incidentally, continues to operate as an ionospheric research system). GPS and GLONASS use three of the RSS bands: 1215–1240 MHz (for the GPS L2 signal at a center frequency of 1227.60 MHz); 1240–1260 MHz (for the GLONASS L2 signals at center frequencies that now span 1246–1256.5 MHz but will shift to 1242.9375–1247.75 MHz by 2005); and 1559–1610 MHz (for the GPS L1 signal at a center frequency of 1575.42 MHz and the GLONASS L1 signals at center frequencies that span 1602–1615.5 MHz but will shift to 1598.0625–1604.25 MHz by 2005). RSS has primary status in these bands. That status and its status as a safety service affords it protection from other users of these frequencies, such as those of the Fixed Service (for transmissions of data, voice, or other signals between fixed points) in certain countries.

Recently, however, the international communications satellite operator Inmarsat, with the apparent backing of the European Radiocommunications Office, has proposed that ITU reallocate part of the 1559–1610-MHz RSS band to the Mobile Satellite Service (MSS). The proposal, which should be strongly opposed by the GPS community, would assign 1559–1567 MHz for MSS use, resulting in a 3.6-MHz direct overlap with the GPS signal bandwidth. Current civil GPS receivers may not operate to specifications, if MSS makes full use of the requested band. The proposal is scheduled to be discussed at the ITU World Radio Conference '97 in Geneva this month. — R.B.L.

CONSUMER ADVICE

Users, too, can help protect themselves from unnecessary mishaps caused by unexpected interference. Before purchasing a GPS receiver, ask your friends whether they have experienced disruptions with that model in the area where you will use it most. Ask your supplier what his or her customers have said. Request a demonstration or a loan of the unit to test it at your most important sites.

Search Out the Source. What should you do if you experience interference? The first step is to determine whether the interference source is in your own equipment. If you are in a car, try switching off the radio or CD player, as they might cause disruptions. Also, switch off any portable computers. Try turning off the window wipers, air conditioning, and any other electrical system that is on. Such experimentation is best done when the car is stationary, of course!

If you are on a ship or other vessel, try the same procedure. Perhaps high energy from a nearby transmitter is saturating your GPS receiver's front end. Or maybe a harmonic from one of your other systems is getting into the GPS unit. If you are using a handheld device, you may be able to reduce the problem by moving it to a different part of the car or ship, or you may simply need to make sure you use the GPS receiver only when that other interfering system is off.

On a small airplane, interference sources are less likely, because specifications better regulate aircraft systems. But there is no guarantee. Again, the first step is to try to determine whether the disturbance is linked to the operation of some other onboard system.

If you can determine that the interference does not come from your own systems, your next step is to see whether it is a very local problem. In the case of in-car GPS reception, the interference might arise from another car (perhaps using Citizens Band radio or another communications device with poor spurious signal suppression). Try slowing down and letting the other cars around you move away. If the interference does not come from other cars, it may be from a nearby factory or laboratory, in which case you will be able to use your receiver again once you move beyond that area.

In marine use, there may well be interference in an area caused, for instance, by a local TV station or microwave link. Again, you need to try using the system when you think you have moved away from the problem area. If you ever experience an interference problem, make a mental note of the locality and check whether you experience it again the next time you pass that way.

IN CONCLUSION

Most navigation systems are susceptible to interference and can be severely and dangerously compromised if affected in critical situations. Users should protect themselves by becoming familiar with interference symptoms and by retaining human skepticism about any navigation system. A navigator should frequently ask: "Why should I believe this position output?" Compare positions with other systems whenever possible. When the GPS receiver is working correctly, use its high level of accuracy to obtain a reliable position fix and plot it on a map or chart so that you have a reliable point from which to apply dead reckoning, should a problem arise.

The greatest interference danger to GPS is not interference itself, but those who believe that interference will not occur. ■