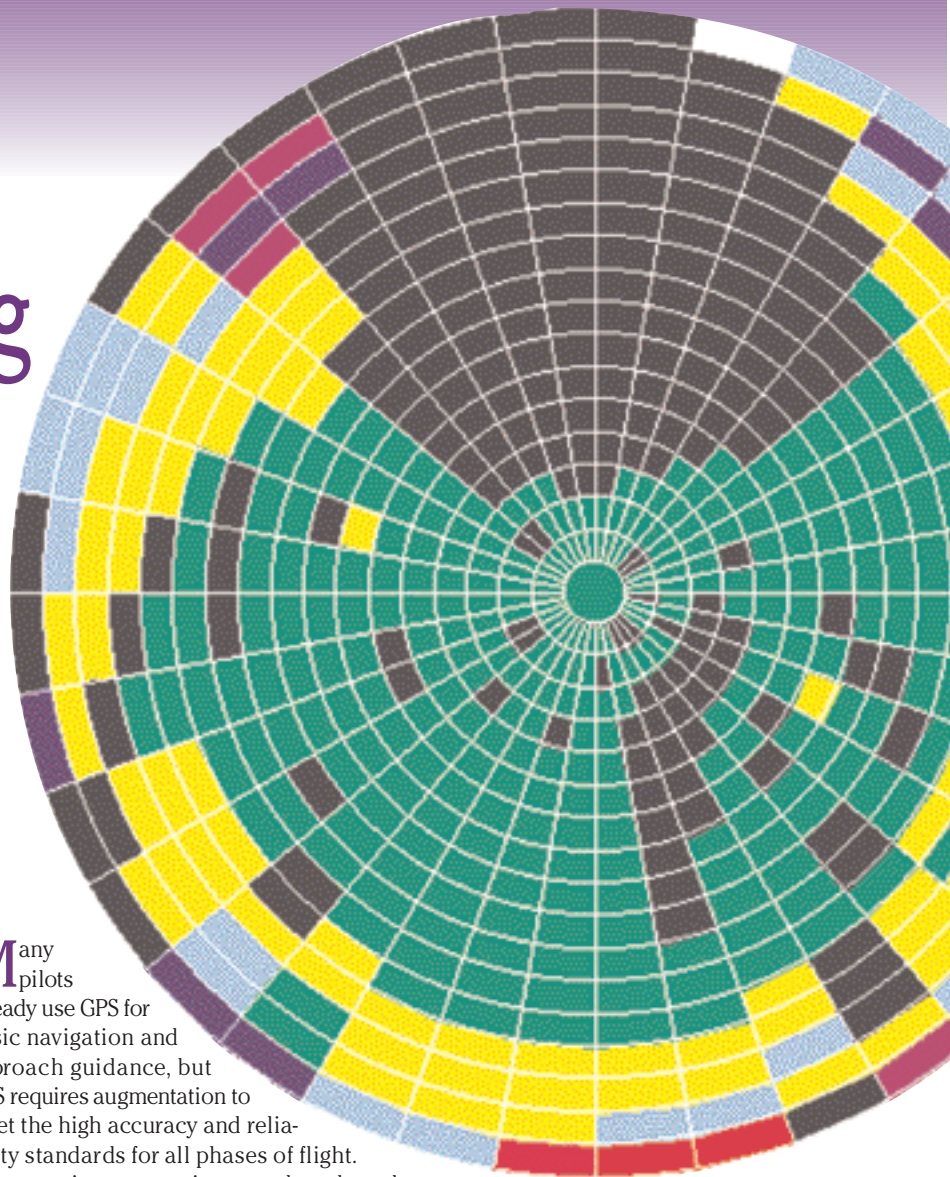# Running Interference

Multipath Detection for GPS Monitoring Sites

by Joe Jaksic

This article reveals . . .

- how multipath assessment software enables quick site evaluation for antenna placement for base station networks

- how the tool records data for detailed off-site analysis

- how engineers on-site can use this data to visually orient towards the multipath source, identify it, evaluate, and recommend ways to avoid it or minimize its effects.

Joe Jaksic *is a project engineer with NAV CANADA's SatNav Program Office. He is responsible for developing the site selection criteria and procedures and identifying the best locations in Canada for GPS augmentation system monitoring stations. He was responsible for fielding three Canadian monitoring stations linked to the U.S. Federal Aviation Administration's National Satellite Test Bed (NSTB), which is used for the development and testing of wide area augmentation concepts.*

Many pilots already use GPS for basic navigation and approach guidance, but GPS requires augmentation to meet the high accuracy and reliability standards for all phases of flight. Augmentation system sites must be selected carefully to meet these standards. Site selection includes verification of existing infrastructure such as space, power, communication circuits, security and maintenance access, and GPS signal reception, which includes verification of satellite visibility, multipath interference and electromagnetic interference (EMI). Satellite visibility can be measured directly for specific azimuth and elevation angles and EMI can be measured using spectrum analyzers.

GPS errors due to reflected signals, commonly referred to as multipath interference, are generally difficult to measure when selecting antenna locations for GPS monitoring stations for augmentation systems such as Wide Area Augmentation System (WAAS) and Local Area Augmentation System (LAAS). It is critical to minimize multipath effects to get maximum performance from these systems.

Two basic methods are used to analyze multipath interference. The first involves GPS signal analysis in the RF domain by measuring direct (desired) and reflected (undesired) signals from each satellite along with phase shift and delay between the desired and undesired signals. The second method, commonly known as code minus carrier method, involves determining the residual pseudorange error from each satellite by differencing the L1 code and carrier pseudorange measurements. In each case, a minimum of 24 hours of data are required to assess the full GPS constellation performance at the selected site.

This article describes a method where the multipath errors are estimated from data provided by special multipath software operating in a 12-channel, dual frequency GPS receiver. This special software uses patented proprietary techniques to output information related to the multipath environment that the receiver is experiencing.

Given its abilities, this receiver software is referred to as the "multipath meter software." Unlike the code minus carrier method, there is no need for additional computations or even the removal of ionospheric effects from the outputs. The software provides accurate measurements of the delay, amplitude, and relative phase of all received satellite multipath signals and also provides information related to its ability to estimate and remove these multipath effects.

The receiver manufacturer in consultation with NAV CANADA's Satellite Navigation Program Office, has developed analysis software suitable for multipath evaluation. The software permits real-time data analysis for a quick site evaluation as well as data recording for any detailed off-site analysis. This software has been developed as a tool for any application — not exclusive to aviation — needing to assess multipath for base station networks.

System Components. The system components comprise a WAAS reference station receiver with multipath meter software in place of normal software, a suitable GPS L1/L2 antenna, a PC or laptop computer running Windows 95,98 or NT, and multipath assessment software. The special version of the software running inside the receiver generates the multipath error logs, and the multipath assessment software in the PC analyzes the logs. A 500 MHz Pentium III or better processor is recommended for post-processing the data. The accompanying photos show the basic hardware components.

Multipath Assessment

The software collects and displays GPS satellite signal data from the WAAS receiver, including carrier-to-noise (C/No) ratio, desired/undesired (D/U) signal ratio, delay and phase shift between desired and undesired signals, and modeled multipath residual errors. Data logging functions are included to support post processing. Because of large volume of data, options are provided to log data to sequential files based on maximum file size or time duration resulting in files that are easier to port and analyze. Post processing options permit playback speed selection as well as fast forward, rewind and pause controls.

This multipath assessment software has the ability to perform numerous calculations and statistical analyses for satellite signals and pseudorange errors. The software can analyze satellites on an individual basis as well as compare them with each other.

The software provides polar plots displaying average or maximum pseudorange errors or desired/undesired signal levels for 0–360° azimuth and 0–90° elevation combinations. It sorts multipath errors from all visible satellites in 10° azimuth by 5° elevation bins and displays them in user selectable colors. These plots characterize the site, providing indications of problem spots including direction and elevation of sources of multipath interference. The software does not determine how far the reflector lies from the antenna. It does determine multipath delay, and from which satellite and in what direction the multipath occurred. From this information we can return to the site and visually orient towards the object causing the signal reflection.

Pseudorange errors and desired/undesired signals can be displayed as histograms, showing maximum errors and error distribution for the site. These displays lend themselves to situations where multipath error specifications must be met. Linear plots of user selected signals can be plotted over user-specified time periods. The user can also select to display in one-plot window similar signals from any number of visible satellites. This plotting capability permits detailed assessment of a site.

The software provides the capability to print any user-selected data display or plot. A capture control can copy screen images to files periodically or on request.

Operating the System

We installed our antenna at a desired test location, with the WAAS receiver and data logging PC located indoors. An RF cable and a DC cable link the antenna and the receiver. The WAAS receiver connects to the PC via a standard serial cable.

Basic Windows knowledge suffices to operate the software. Drop-down menus and iconized functions help perform desired tasks. Logged data can reach up to 10 Mbytes per hour depending on the number of visible satellites and selected options. A file management plan is recommended to port and store the large volume of data collected over 24-hour periods.

Potential antenna site assessment typically starts with the software automatically requesting the necessary data from the receiver. We open a polar plot and a histogram window to display multipath information in real-time and choose to log the data to file(s) for post processing. The software will plot the pseudorange error and D/U signal as the satellites pass overhead. After 24 hours, the GPS constellation repeats itself, so we save the plots and halt data collection. At this point, the polar plots show the multipath environment for the current antenna location including which satellite signals experienced multipath and what part of the sky the satellites were in when the multipath occurred. This information may lead to identification of potential reflectors. The histogram indicates the statistical behaviour of the multipath signals for each satellite or for all satellites at this antenna location. Real-time data collection and

WAAS receiver and PC display
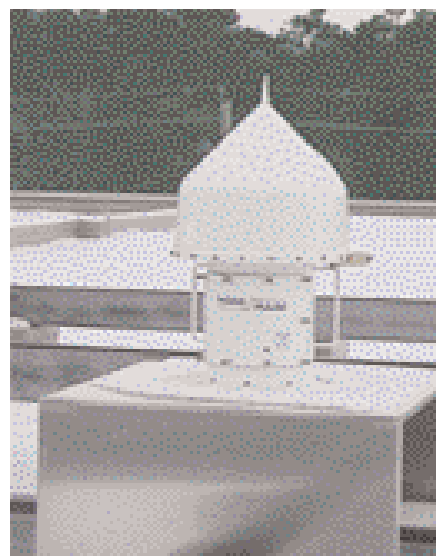
WAAS antenna

display allows us to examine the plots at any point during the 24-hour period to see if the antenna location has already exceeded site specifications.

We can move the antenna or remove the reflectors and repeat the steps. Comparison of two 24-hour sets of data (from each antenna location) will reveal if one antenna location experienced fewer multipath induced errors than the other. This comparison is best done in post processing mode. We can also examine plots for worst-case multipath errors in terms of pseudorange or D/U signals and then assess compliance to site multipath requirements.

Results to Date

NAV CANADA performed an initial evaluation of the multipath analysis software on the rooftop of our Technical Systems Centre
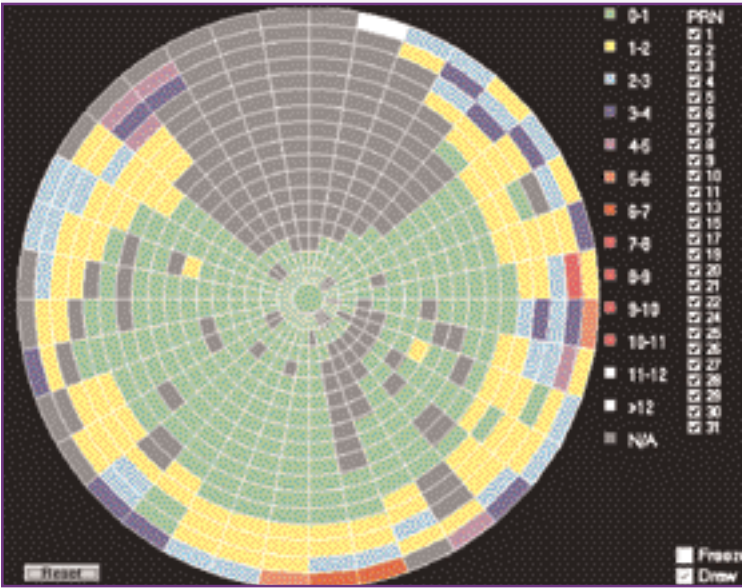
FIGURE 1 Polar plot of maximum pseudorange errors

FIGURE 2 PRN 26 Multipath Desired/Undesired signal levels

FIGURE 3 PRN 26 Pseudorange errors

FIGURE 4 PRN 26 Elevation plot

FIGURE 5 PRN 26 Azimuth plot

(TSC). We positioned the WAAS antenna in low and high multipath environments, with several potential reflectors nearby. We chose this location to validate the assessment software's ability to detect and quantify multipath errors.

Figure 1 shows a polar plot of maximum pseudorange errors derived from 1-second data logs recorded over a 24-hour period at the above location. The color scale to the right of the plot depicts the pseudorange error in meters as displayed in each 10° azimuth by 5° elevation slot. The PRN column displays all the satellites visible during the 24-hour period. Errors of up to five meters are found at all azimuths for elevation angles below 15°. For elevation angles above 30° errors are typically in the 0–2 meter range. A hot spot is visible around 320° azimuth, most likely due to the satellite dish antenna positioned within 10 meters of the test antenna. The lack of data around ±30° of North is due to lack of GPS satellite tracks at these azimuths in the Ottawa area.

The polar plot provides an overview of the site which in some cases may be sufficient to identify interference sources. In most cases it points to areas that should be analyzed in more detail using time-scale plots.

Figures 2 and 3 show typical desired/undesired signal levels and pseudorange error time plots for PRN 26 for a 15-minute (900 one second measurements) duration. Figures 4 and 5 show corresponding satellite azimuth and elevation plots over the same time period allowing for a visual determination of exactly where and when multipath interference occurred.

Good receiver performance can be expected with D/U signal ratios greater than 20 dB. In Figure 2, the lowest D/U signal levels appear around the 262826 and 263276 times, indicating more multipath signals for PRN 26 during those times. The pseudorange plot in Figure 3 shows increased pseudorange errors during the same times. More importantly, we must determine the exact azimuth and elevation path between the satellite and antenna. We can easily obtain this information from the elevation and azimuth plot in Figures 4 and 5 respectively by noting the angles at corresponding times. We could generate similar plots for other satellites for the same path to see if their signals also experienced multipath reflections. If so, we would look for reflecting objects in a very specific area.

The above antenna location would not be suitable for most GPS augmentation purposes. The test antenna could be raised using a suitable mount to clear the obstacles. In our case, the WAAS antenna was installed on the upper roof, which provided an interference-free environment. The software reported significantly improved performance, with errors less than one meter for all elevation angles above 10°.
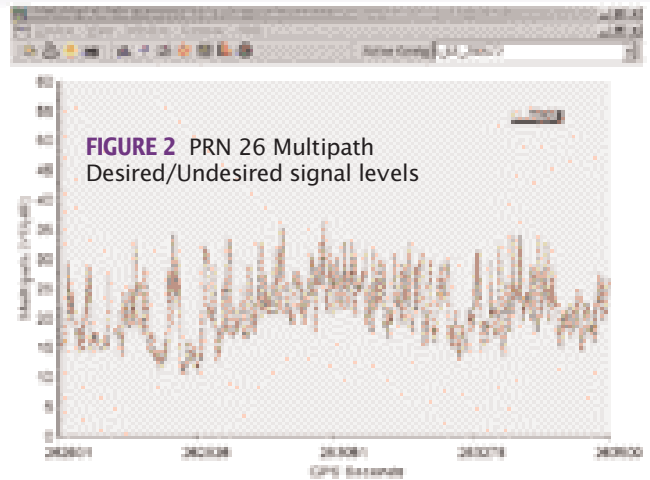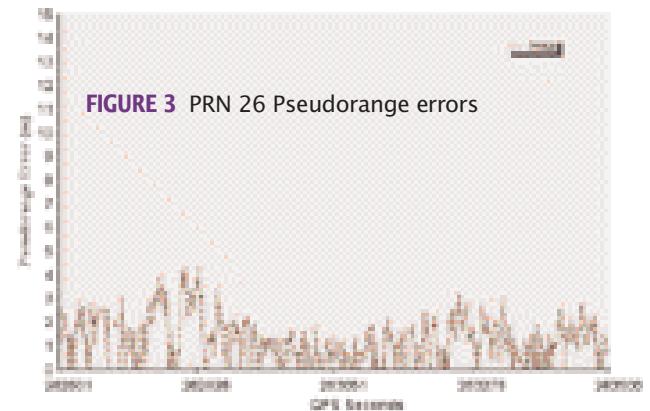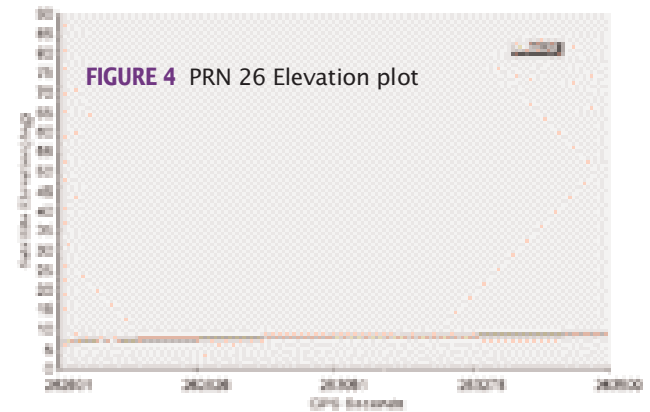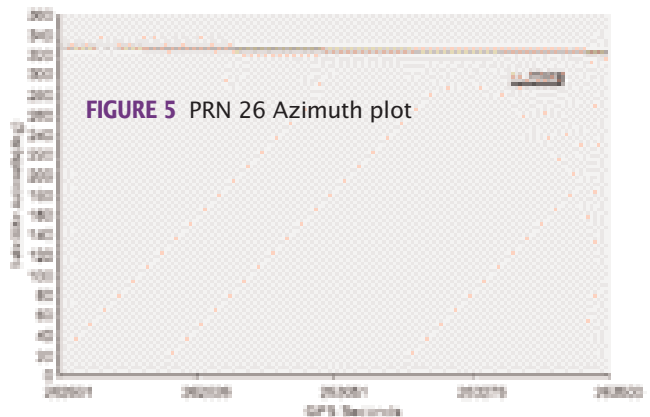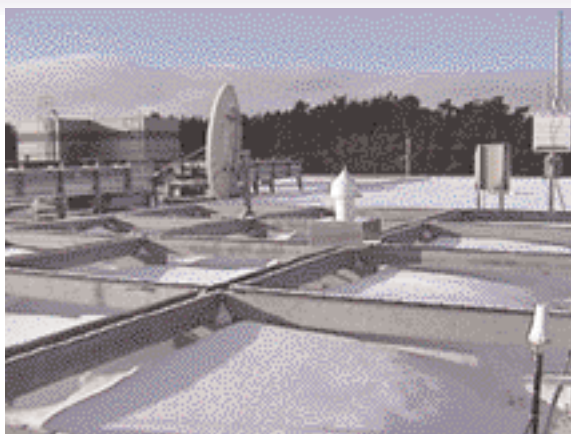
WAAS antenna rooftop placement for testing with several potential reflectors nearby.

Future Plans

So far we have had a very positive experience with the multipath assessment software. We plan further testing to prove its accuracy and repeatability before specifying detailed procedures for its use in evaluating prospective sites for augmentation system antennas.

We don't expect the TSC facility to host an operational monitor station, but it offers test locations which provide high or low multipath interference errors. We will perform measurements at each of these locations over several 24-hour periods to determine the repeatability of results and establish baselines for expected results at other sites. Based on these results, we will develop specific procedures for site testing. These guidelines will focus on key issues such as how to include/exclude potential antenna locations quickly and how much data collection is necessary to be sure that a site meets the specifications.

Typical multipath interference mitigations include moving or raising of the GPS antenna to clear obstacles, and removal or relocation of obstacles where possible. Raising antennas typically results in more complex mounts and more difficult maintenance. Relocation of existing obstacles can be costly. Each site must be assessed individually. Finding suitable antenna locations generally involves tradeoffs between system performance and cost of implementation.

Manufacturers

The "multipath meter software" used for the testing described in this article was developed by **NovAtel Inc.** (Calgary, Alberta, Canada). The software operates in a NovAtel WAAS receiver, using NovAtel's *Multipath Estimating Delay Locked Loop* (MEDLL®) to output information related to the multipath environment that the receiver is experiencing. The receiver uses a proprietary coupled correlator sampling technique combined with "maximum likelihood estimation" techniques to break down the received signals into direct path and reflected path components. The software determines the amplitude, delay, and phase angle of both the direct and multipath signals and analyzes the signal with the least delay to determine the direct path. All other signals with greater delay are considered to be multipath components and are removed.

The WAAS receiver has three sub-receivers within it. One ,called a MEDLL receiver, is composed of eight *OEM2* (L1 only) receivers; one is the master and the others are slaves. Two NovAtel *Millennium* receivers also operate, independently of each other, within the WAAS receiver. MAT only makes use of the MEDLL receiver portion of the WAAS receiver.

NovAtel Inc. developed the *Multipath Analysis Tool (MAT)* software for multipath evaluation in consultation with **NAV CANADA**'s (Ottawa, Ontario, Canada) Satellite Navigation Program Office. The software permits real-time data analysis for a quick site evaluation as well as data recording for any detailed off-site analysis.

NAV CANADA, the country's provider of civil air navigation services, is a non-share capital, private corporation with operations coast to coast, providing air traffic control, flight information, weather briefings, airport advisory services, and electronic aids to navigation.