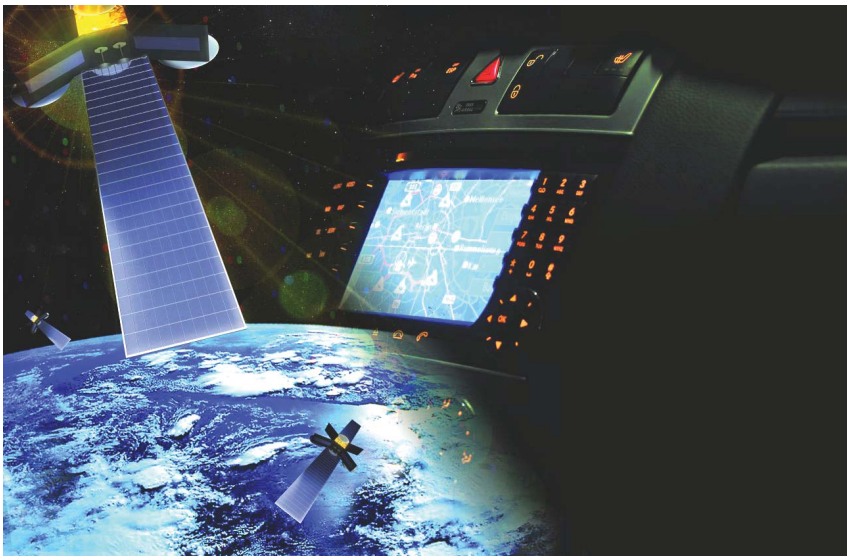
GPS Receiver Testing

Application Note



As GPS technology becomes more common, GPS receiver manufacturers, OEM integrators, and contract manufacturers struggle to determine the appropriate standard tests to verify GPS receiver performance. Verification procedures require a controlled environment that facilitates precise repeatability. In most cases, using actual GPS satellite signals received through an antenna does not provide such an environment. This paper describes the typical GPS receiver tests used today for GPS receiver verification. It also introduces a real-time GPS signal simulation application and platform capable of generating the required GPS signals for a repeatable and flexible test environment.

Agilent Technologies

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Introduction

GPS (Global Positioning System) is a satellite-based technology. It allows users to determine positions at points in time by utilizing navigational signals broadcast by multiple satellites, known as a satellite constellation. Currently, this constellation consists of 24 active satellites, which orbit the earth at an altitude of approximately 11,500 miles. Each satellite completes an orbit every 12 hours. The constellation includes some in-orbit spare satellites which can be activated to replace any satellites which may fail.

The GPS system (also called NAVSTAR) was developed by the United States and is owned and operated by the United States Department of Defense. The initial satellites were launched in 1978, and by 1994 a full constellation of 24 satellites was available. Satellites typically last 8 to 12 years and new satellites are periodically launched to replace older satellites. Enhancements have been made over the years and currently there are a number of new technologies, including new signals, that are being planned.

Navigation signals

In the current GPS satellite constellation, each satellite broadcasts two different navigation signals, known as L1 and L2. The L1 signal is broadcast on a frequency of 1575.42 MHz, and the L2 signal is broadcast on a frequency of 1227.60 MHz. The L2 signal is encrypted and is available only to authorized users – typically military applications. The L2 signal provides a highly reliable and accurate time and location solution. The L1 signal is not encrypted and is available to users worldwide, 24 hours a day, without charge or subscription. GPS navigation signals are broadcast with circular polarization. See Figure 1.

For a given signal (L1 or L2), all satellites broadcast on the same frequency. The signals are differentiated by the different codes that are transmitted by each satellite. This is called "code domain multiple access" or CDMA.

Two different code rates are used. The first code is the Coarse Acquisition code, or C/A code, which has a code rate of 1.023 MHz and it repeats every 1 millisecond. The second code rate is 10.23 MHz, it is called the Precise, or P code and it repeats every week. Typically the P code is encrypted to form a code called P(Y). Each satellite is assigned a unique code sequence for the C/A and P codes, respectively. These sequences are identified by a number called the PRN (pseudo-random) ID.

The navigation signals convey information to the GPS receivers including precise timing information as well as system status, orbit descriptions of each satellite, and satellite health information. Using this information a receiver can determine the distance to each satellite and, using a triangulation approach, a position and time can be determined.

Navigation signals are broadcast with a fairly low power and appear at a minimum level of about -155 dBm at sea level. Signal levels may be even lower inside of buildings or under tree cover. These signal levels are extremely low and require significant amplification and baseband processing to recover.

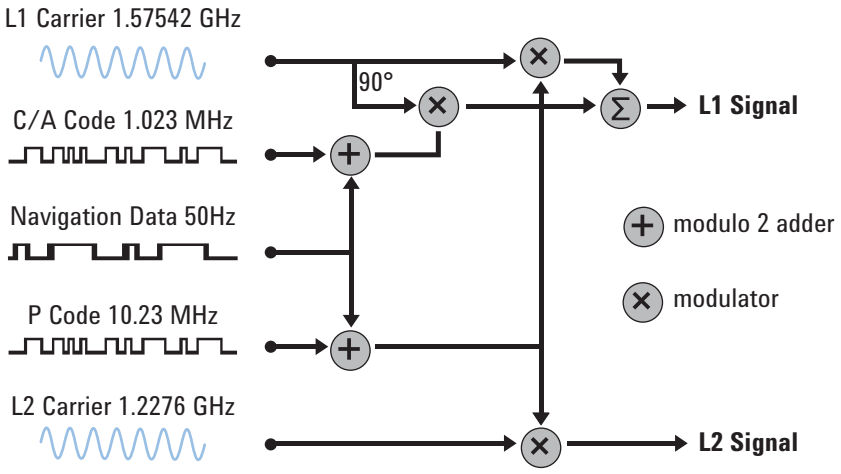

Figure 1. GPS signal structure.

GPS technology

Although GPS receivers have been available for many years, initial implementations were large, expensive, and consumed considerable power. Because of this, the GPS application was limited to high-end commercial and military applications.

In recent years, the cost for GPS receivers has declined significantly for commercial technology. The result is that GPS receiver technology has recently become increasingly important in consumer products such as handheld receivers, automotive receivers, mobile phones, and other tracking devices.

Assisted GPS (A-GPS)

A-GPS development was driven by a U.S. FCC E911 requirement to quickly provide a cell phone location to emergency call dispatchers. A-GPS greatly reduces Time To First Fix (TTFF) measurements and allows GPS receivers to identify satellites at much lower power levels.

"Assistance data" is provided by the base station to help the mobile phone identify the satellites that are visible. The mobile phone can then quickly find these satellites and calculate it's position. Typical TTFF can be reduced from 60 seconds to under 10 seconds.

There are two methodologies for sending and receiving assistance data. They are control plane and IP data channels (user plane).

GPS Test Requirements

The GPS user experience for commercial applications is affected by several factors. GPS devices which provide an enhanced user experience will sell better, so manufacturers are looking for factors to differentiate their receivers. Typical factors which determine the outcome of the user experience include the following factors:

1) When a GPS device is turned on, how long is it until the position of the receiver is determined?
2) When a weak or poor signal area is encountered, can the receiver still determine its position?
3) If the signal is interrupted and then restored, how long does it take for the receiver to recover and resume calculating its position?
4) Accuracy of the calculated location.

There are of course other factors such as cost, user interface, turn-by-turn navigation, spoken directions, and so forth that are important to users, but these are not so dependent on the GPS receiver performance.

For commercial or military applications, there may be many other kinds of GPS conditions that are important, such as:

1) How accurately can a position or time be determined?
2) How repeatable is the solution?
3) How sensitive is the receiver to interference or jamming?
4) How rapidly can the receiver report its position (if the receiver is moving rapidly – such as in an airplane)?

From this point forward, this application note will focus mainly on testing for consumer GPS applications.

GPS receiver basics

From a high level perspective, the GPS unit appears as an antenna which senses the navigation signals, and has an output of some kind which reports status, positions, and time (via some I/O port or a screen).

A typical block diagram for GPS receivers includes an antenna, an RF front end/down converter, a baseband processing element, and a computation engine. In some cases these elements may be integrated in a single module which can be quite small – on the order of 1 square cm. See Figure 2.

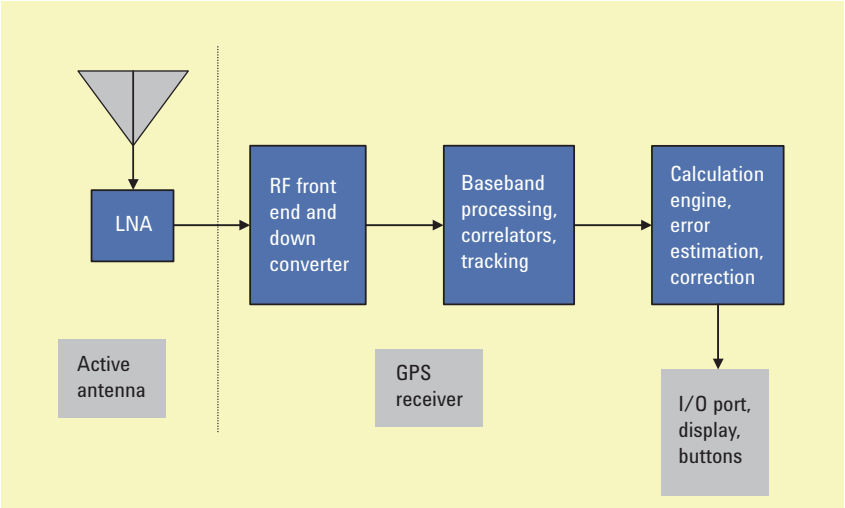

Figure 2. GPS receiver block diagram.

GPS antennas

As previously noted, navigation signals on the earth's surface are quite low in power. In order to recover the navigation signal successfully, active antennas are typically utilized with gains of 20 or 30 dB. For these active antennas, a DC voltage is supplied from the receiver over the same cable that transmits the signal to the receiver. In most commercial implementations the antennas are integrated into the receiver unit. In some cases a port for an external antenna may be provided.

GPS receiver verification

In order to test a GPS receiver, we can use an antenna and try to receive off-the-air signals. However realistic this approach may be, it can only provide limited information because the signals presented to the receiver are highly variable and non-repeatable. In addition, testing under specific conditions such as remote locations or high velocities becomes expensive and impractical.

To address this issue, a GPS signal simulator may be used. These devices produce an output signal that models the signal that would be received by the GPS receiver – a mix of signals from many different satellites at different time delays, Doppler shifts, and power levels. If the proper signal is presented to the receiver, it can perform signal acquisition and tracking and provide a navigation solution (location fix).

Signals can be created by modeling the motions of satellites at a particular point in time. By knowing a specific receiver location (latitude, longitude, altitude), the properties of the navigation signal as it propagates to the receiver location can be modeled and reproduced by a signal generator. These properties can include path losses, distortions due to atmospheric effects, as well as relativistic effects and the effects of transit time as the signal travels from the satellite transmitter to the receiver antenna.

Using a signal simulator with appropriate models, a repeatable, known signal can be presented to the GPS receiver to allow testing to determine the receiver's ability to operate under various conditions, locations, times, and movements.

GPS Satellite Simulation

The N5106A PXB baseband generator and channel emulator and the N5182A MXG RF vector signal generator combined with the N7609B Signal Studio for Global Navigation Satellite Systems (GNSS) is a solution capable of generating the GPS signals required for comprehensive GPS receiver testing. The N5106A PXB and N5182A MXG combination is a high performance, general purpose signal generator that can not only create the required GPS signals, but also signals for other wireless standards such as Bluetooth®, WLAN, LTE, and WiMAX™. The N7609B is a software application with the ability to create and generate custom GPS signals for reliable, repeatable, and flexible GPS receiver testing.

Features of the N7609B include:

- 15 satellite simulation (depends on scenario and satellite visibility)
- 24 channels total (satellites + multipath)
- Individual real-time channel power adjustments
- Individual real-time channel on/off
- Scenario generation capability (Option RFP required)
- Moving GPS receiver simulation
- Up to 8 hour scenario playback with 8 channels
- Multipath signal capability
- Ability to select scenario start time
- Static test mode
  - Individual channel Doppler shift adjustments
  - Individual channel delay adjustments
  - Individual power control adjustments for each channel
- Scenario generation and editing
  - A-GPS assistance data for each scenario
  - Scenario generation for static and moving GPS receivers
  - Ionospheric and tropospheric modeling
  - NMEA data input for scenario generation
  - Scenario editor to apply power, delay, and Doppler offset for multipath channels
  - Elevation mask for satellite visibility

N5106A PXB platform capabilities

- Remote capability (control PXB and N7609B from an external PC)
- Summing of baseband signals for interference testing (requires additional baseband generator for PXB)
- Marker output
- AWGN support (requires Option N5106A-JFP Calibrated AWGN on the PXB)
- Digital IQ output (N5102A digital signal interface module required)
- Analog IQ output

Figure 3. N5106A PXB and N5182A MXG RF signal generator.

Types of GPS Tests

Classical receiver testing for digital systems normally involves testing bit error rate (BER, FER, PER, BLER) with of specific power, noise, fading, and interference conditions. With GPS we are not only concerned with the recovery of the digital content of the signal, but the receiver must also track the arrival time of the signal very closely (synchronization).

Correct tracking of arrival times requires tracking the timing of the signal very carefully. In most GPS receivers this is tracked in terms of carrier phase, literally the number of carrier wavelengths and fractions of carrier wavelengths between the receiver and the transmitter. At L1 frequency, this is a resolution of C (the speed of light) divided by the carrier frequency F0 = 1575420000 Hz. This gives a resolution of fractions of nano-seconds.

Tracking is complicated by the relativistic effects of the velocity between the receiver and each of the satellites. This situation causes a phenomenon known as Doppler shift which means that the receiver perceives the frequency of the signal to be shifted by some amount depending on the relative velocity. So, a receiver has to track not only the timing of the signal from each satellite, but also the Doppler shift of each signal. For receivers that are not moving, the Doppler shift can be on the order of ±5000 Hz.

Further, the data rate for GPS signals is only 50 bits per second, so testing for a bit error rate of 1 error in 1,000,000 bits at 95% confidence would mean running a test that would take hundreds of hours. Clearly we must do something different.

In addition, it turns out that for the GPS receiver, the recovery of data bits is only necessary for short time periods – as little as 18 seconds every few hours. During the remaining time, the receiver just has to track the carrier phase.

This means that there are really two sensitivity levels – one for data recovery, and one for tracking.

Time To First Fix (TTFF)

When a receiver is turned on, it must do some searching to find the satellite signals – this process is called acquisition. It must then track the signals, and compute a position. The time from turn on to the availability of the first valid location fix is called Time To First Fix or TTFF. TTFF is a critical parameter for testing GPS receivers. It relates directly back to a user desire which is to have a location fix as soon as possible.

When testing GPS receivers, you'll often hear the terms Hot Start, Cold Start, and Warm Start. These terms refer to the data that is available to the receiver when it is turned on. Most GPS receivers have some persistent memory which stores the time of day and predictions of satellite orbits. When you turn on these receivers, they will use this data as a "hint" to make it easier to search for active satellite signals.

Hot start

If the receiver has been off for a short time (less than an hour or two) and has not moved much (100 meters or less) it will have fairly accurate information on satellites and can typically use this information to acquire satellite signals and compute a position relatively rapidly. This scenario is termed a hot start and may be the case that results from a short power interruption or a battery change.

Warm start

If the receiver has been off for a longer time, or moved farther while it was powered off, it will experience a warm start. With a warm start, the receiver has sufficient data to know what time it is (approximately) but it doesn't really know where it is. One necessary condition for a warm start is that the receiver has what is known as "Almanac Data."

Almanac data is a long-term prediction of satellite orbits and is usually pretty accurate for a 24-hour day and deteriorates over the course of several days. Typically, after 7 days the accuracy becomes very poor. Almanac data is transmitted by each satellite. It takes about 15 minutes of good signals from at least one satellite in order to receive all the almanac data. This data will be good for several days. See Figure 4 for a description of the satellite navigation message.

For a warm start condition, the receiver has to work harder to acquire the signal, and this means that the TTFF becomes longer.

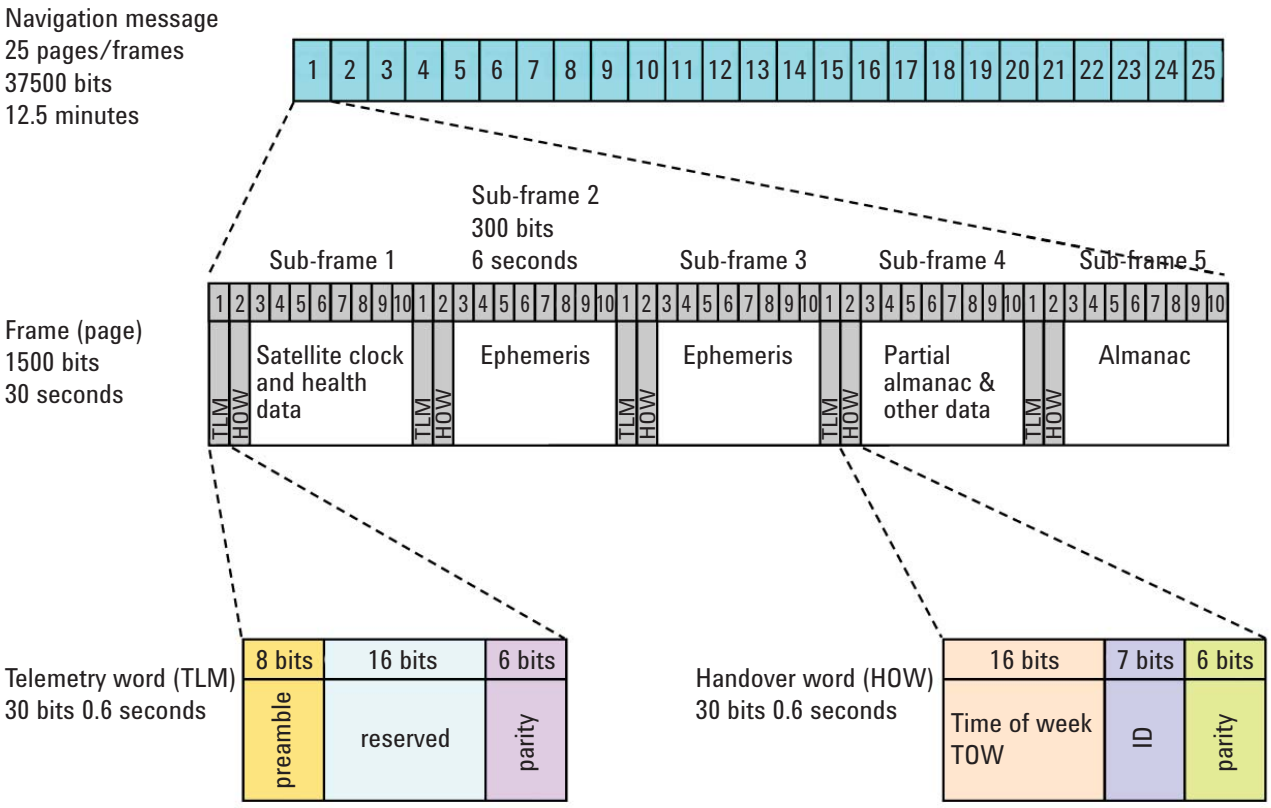

Figure 4. Satellite navigation message.

Cold start

GPS receivers that are started up with no data as to what time it is or where the satellites are located are said to be in cold start mode. In this mode, the receiver's first job is to acquire satellite signals. In order to do this, it must search each of the available CDMA codes, as well as the frequency space over a range of ±5000 Hz of Doppler shift. This is a fairly difficult task which requires signals of relatively strong amplitude and may take quite a long time. In older receivers it may take several minutes. In newer receivers, the timeframe has been reduced so that it is on the order of 10 to 20 seconds.

With a cold start, the receiver must receive at least 18 seconds of good data from each satellite in order to receive an accurate description of the satellite's orbit (known as ephemeris data). Once done, the receiver will have sufficient information to compute its first location fix. TTFF for cold start conditions are typically longer than either hot start or warm start conditions. Modern receivers can achieve the TTFF in less than a minute. Cold start TTFF is an important parameter for GPS receivers and is typically one of the first parameters to test in a GPS receiver.

Connecting GPS receivers to a GPS signal generator

Presenting signals to a GPS receiver can present several challenges. The factors involved are:

1) Receiver may not have an external antenna connection
2) RF power to the receiver is very low
3) Power to the receiver must be known accurately to make good measurements
4) Receivers tend to have active antenna connections
5) Some receivers automatically switch between internal and external connections

Receivers with no external connections

For receivers with no external connections, a radiated signal must be presented. This is called radiated testing or over-the-air (OTA) testing. It involves connecting the signal generator to some kind of antenna that radiates the signal to the receiver antenna. Since these radiated signals may interfere with the real GPS signals, this radiated testing should only be done inside an RF chamber to prevent interference.

This scenario presents some additional problems:

1) Calibration of power to the antenna can be difficult
2) The external antenna expects a circularly polarized signal – it's best to use helical or stacked dipole antennas to generate circularly polarized signals
3) The distance between the transmitter and the receiver should be at least several wavelengths to avoid "near field" couplings

Receivers with external connections

Receivers with external connections present somewhat fewer problems. They require what is called "conductive" testing, which involves no radiation of signals over the air. See Figure 5. The signal generator usually cannot be directly connected to the receiver due to several problems:

1) Most GPS receivers expect ACTIVE antennas – this means they supply a DC voltage to the antenna connector. The DC voltage may damage the signal generator, so it must be blocked. In-line DC blocking devices are commercially available.
2) In addition, some receivers "sense" current draw on the DC supply. If there is no current drawn, they may assume that no antenna is connected. In such cases, the current draw must be simulated by some resistive load and perhaps a series inductor between the signal line and the ground. Such a device may need to be custom built, depending on receiver requirements.
3) Signal generators typically cannot generate the low level signals required directly. In some cases, a signal level as low as -155 dBm could be required, which means that an external attenuation device will likely be needed.

Receiver connection to signal generator – General

In both radiated and conductive testing, the power delivered to the receiver must be carefully calibrated if meaningful, repeatable results are to be obtained. For a typical signal with 8 active satellites, the net power delivered to the receiver will need to be between -125 and -150 dBm.

Typical GPS Receiver Tests

The following are representative of the tests performed on GPS receivers. Most receivers will not be subjected to all of these tests, or perhaps will be subjected to them only during some design verification stage. Other tests might be done at a manufacturing level to determine if the receiver is responding according to desired or specified parameters.

Perhaps the most common tests are cold start TTFF and location accuracy. Other tests becoming more popular include sensitivity and multipath testing, which are built on top of TTFF and location accuracy.

One general note for all of these tests is that they are sensitive to the exact positions and movements of satellites. This means that the results are going to be variable unless the tests are repeated with exactly the same time in the same scenario. Furthermore, such a "repeatable" number may not be representative of the receiver's performance in general. Typical measurements must be performed under different start times, dates, and locations. These measurements are then averaged to provide a meaningful value.

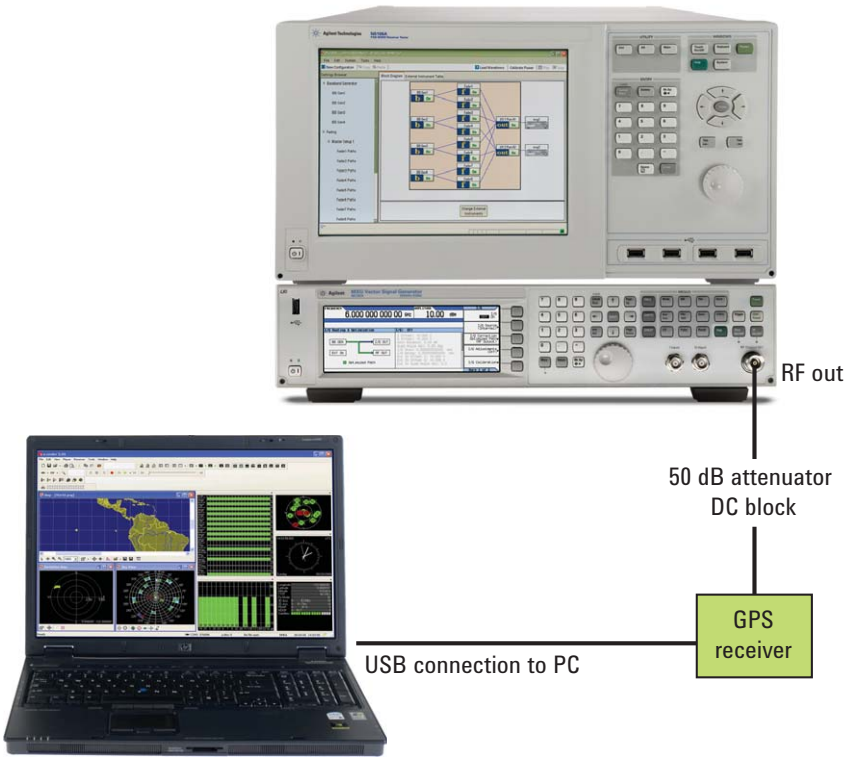

Figure 5. Typical GPS receiver test setup.

TTFF tests

1. Cold start TTFF

In this test, the receiver is placed into a cold start state – usually by some command sent to the receiver through a test connection – and then a fairly strong signal is sent. The time it takes for the receiver to determine its first good location fix is recorded. Typical figures quoted by modern chip sets are in the 40 to 50 second range. This is perhaps the most common type of testing done for GPS receivers. Normally, this test is done many times over many conditions and the results are averaged.

Cold start TTFF times may vary depending on the scenario and the time into the scenario due to the different numbers and positions of satellites in different scenarios and even during different times of the same scenario. Most repeatable results will be obtained if the TTFF measurement is taken at the same time in the same scenario. However this repeatable time may not be representative of all scenarios.

A good design characterization test (evaluation, design verification) would do many hundreds of cold start TTFF tests at different locations.

A good manufacturing variation test would do several tests of cold start TTFF with the same time, same scenario (restart scenario at same time for each test).

2. Warm start TTFF

Warm start TTFF testing is less commonly done than cold start TTFF testing. The test is usually conducted by sending a "warm start" command to the receiver. This type of testing is more difficult because the receiver must first be exposed to the scenario for about 15 minutes so that it can receive the complete almanac data.

Other characteristics are virtually the same as for cold-start TTFF testing. To repeat this test at the same scenario time (15 minutes or so into the scenario) may take a long time unless the signal generator can restart 15 minutes into the scenario.

3. Hot start TTFF

Hot start testing is less commonly done than cold start TTFF testing, but it is perhaps a bit more common than warm start testing. The test is usually conducted by sending a "hot start" command to the receiver. This type of testing is more difficult because the receiver must first be exposed to the scenario for about 15 minutes so that it can receive the complete almanac data.

Other characteristics are virtually the same as for cold-start TTFF testing. To repeat this test at the same scenario time (15 minutes or so into the scenario) may take a long time unless the signal generator can "time-warp" to restart 15 minutes into the scenario.

Location accuracy (predictable, repeatable, relative)

Location accuracy refers to the ability to achieve a location fix that is as close as possible to the desired position, both in repeatability and accuracy. There are several variations of location accuracy testing, as follows:

1. A Relative Location Accuracy test refers to comparing the location fixes obtained by cold/warm/hot starting, while at the same locating and comparing the variation between fixes. A low variation means that the receiver can achieve a relatively accurate location fix, which is good if you want to return to the same location, using the same receiver – but don't care too much about how close the longitude/latitude/altitude numbers are to the actual location.

2. The Absolute Location Accuracy test refers to the process of comparing the location fixes obtained by cold/warm/hot starting, while at the same locating and comparing the variation between the location fixes and the ideal location provided by the scenario.

3. Moving or Dynamic Location Accuracy tests – these refer to a scenario that simulates movement of the receiver while conducting the accuracy tests described above.

Reacquisition time

In this test we characterize the performance of the receiver in a scenario where the signal is greatly reduced or interrupted for some short period of time and is then restored. An example of this would be a vehicle going through a tunnel or under some heavy tree cover. In this case the receiver is briefly unable to track most or all of the satellites, but must re-acquire (track) the signal when "visibility" is restored. This scenario can be simulated by briefly reducing or turning off the signal generator power and then restoring it without restarting the scenario.

A related test would involve interrupting the signals from only a subset of the satellites. An example of this would be driving behind a building or hill which temporarily blocks out the signals from part of the sky.

The results from this test will usually be compared with signals above the minimal sensitivity levels (good signal conditions).

Sensitivity

A GPS receiver really has two different sensitivity levels – acquisition sensitivity and tracking sensitivity.

Acquisition sensitivity

Acquisition sensitivity refers to the minimum signal level that allows the receiver to successfully perform a cold start TTFF within a specified timeframe. During the signal acquisition process the signal level must be higher than during the tracking process because the time synchronization is not known. An example of this may be identified as the minimum power level to allow a successful cold start TTFF of 100 seconds or less.

One type of acquisition sensitivity test is the single-satellite sensitivity test. In this test a signal with a known amplitude and static Doppler shift are presented to the receiver. A receiver cold start is performed, and the time to acquisition is measured. Power levels are then decreased until the receiver can no longer acquire the signal.

This test can be repeated at several different Doppler shifts, and a set of curves depicting the power vs. acquisition time at various Doppler shifts can be prepared. Such curves can be used to characterize the acquisition sensitivity of a receiver under various Doppler conditions.

Tracking sensitivity

Tracking sensitivity refers to the minimum signal level that allows the receiver to maintain a location fix within some specified degree of accuracy. This is generally a much lower signal level than the acquisition sensitivity level. As the signal level is reduced, the ability of the receiver to recover the navigation message data stream will decrease, and bit errors will be induced. However, since the Doppler frequency and the timing of the signal are known, the tracking loops can still operate successfully. As signal levels continue to decrease, eventually the noise will be so great that it will introduce noise into the tracking loops and the time and/or frequency synchronization will degrade. These conditions will begin to impact the accuracy of the location fix. As the signal level continues to decrease, the system will incrementally lose the ability to track satellites until eventually the receiver is not able to compute a location fix.

Typically the tracking sensitivity is measured as the minimum power to maintain specific location accuracy. Again, this measurement is highly

dependent on the scenario, and the time into the scenario, so the only meaningful measurement is an average obtained over many tests conducted at different times in different scenarios.

Interference testing

Interference is a common problem affecting GPS receivers. Interference can come from classical sources such as RFI, receiver desensitization due to strong out-of-band signals, intentional jamming transmissions, or intentional spoofing transmissions.

Interference testing is a type of meta-test, in that some of the above tests such as location accuracy or TTFF are done with the addition of some kind of interfering signal.

Multipath testing

In some cases the signal from a single satellite arrives at the receiver via two or more paths. One path is typically a direct path, "line of sight," to the satellite. Other paths result from reflection of the same signal from some obstruction such as a building or mountain.

Multipath causes problems because the signal arrival time at the receiver is different for each path because the path length from receiver to transmitter is different for each path. Longer paths caused by reflections arrive at the receiver later than the direct path.

Multi path conditions can cause problems with receivers such as degraded location accuracy, degraded TTFF, or degraded reacquisition time. Multipath testing is a kind of a meta-test in that some of the above tests are done with the addition of multi-path simulation of one or more satellites by the GPS signal simulator.

Other errors

Atmospheric conditions in the ionosphere or troposphere can cause additional errors in time of arrival and signal strength. Typically these errors lead to degraded location accuracy.

Antenna testing

Since there are no ideal antennas in the real world, real antennas will not have an isotropic response pattern. This means that the same signal coming to the antenna from different points in the sky can result in stronger or weaker signals and different signal phases being presented to the receiver front end.

Some GPS signal simulators can simulate this situation in conductive testing by allowing users to input an antenna response pattern and modifying the signal strength from satellites accordingly. This, again, is a meta-test done by repeating some of the above tests using a different antenna pattern.

GPS Receiver Tests using the N7609B Signal Studio for Global Navigation Satellite Systems

As mentioned previously, the N7609B, with the N5106A PXB and N5182 MXG, is capable of creating the GPS signals required to test GPS receivers. For GPS satellite signal creation, the N7609B will provide the following benefits.

- Reliability and repeatability in GPS signal simulation
- Ability to perform standard GPS receiver tests
  - Time to First Fix (TTFF)
    - Cold, warm, or hot start conditions
  - Location accuracy
    - Relative location accuracy
    - Absolution location accuracy
    - Moving receiver accuracy
    - Satellite tracking accuracy
  - Sensitivity
    - Acquisition sensitivity
    - Tracking sensitivity
    - Interference testing (requires 2nd RF source)
    - Reacquisition time
- Flexibility in configuring standard GPS receiver tests
  - Stationary or moving GPS receiver conditions
  - Introduction of multipath signals
  - Reduced satellite visibility (partial or complete loss of visibility)
  - Capability to turn satellite channels off and on in real time
  - Capability to adjust satellite channel power in real time
  - Ionospheric and tropospheric modeling capability
  - Adjust the start time of the scenario playback to a specific timeframe
- User scenario generation capability to create custom scenarios
  - Stationary or moving GPS scenarios
  - NMEA input mode for moving GPS receiver scenarios
  - Scenario editing capability for multipath creation and other impairment situations
- Test GPS tracking capability for any satellite PRN under varying Doppler shift, power, and delay settings (Static test mode)
- Ability to integrate into A-GPS test solution with the 8960
- Ability to create additional wireless test signals

Setting up the tests

The test setup for these examples is shown in Figure 5. Specific test scenarios were created by the N7609B, and the real-time baseband GPS signal is created by the N5106A PXB with RF upconversion by the N5182A MXG.

For the purposes of this paper, the GPS receiver used for these tests is the u-blox EVK-5P evaluation kit with U-center software from u-blox AG.

Basic TTFF, sensitivity, and location accuracy results can be derived from typical GPS receiver evaluation software, as shown in Figure 6. In this figure we see that the TTFF is calculated, the calculated location is given (latitude, longitude, and altitude), satellites are identified, and the C/No (dB-Hz) for each satellite is given. For TTFF calculations, warm, cold, and hot start conditions can be created by manipulation of the GPS receiver. This can be done either through direct commands to the receiver to put it in one of these states or by turning off the GPS receiver for a specific period of time. Sensitivity tests can be derived from the GPS receiver's ability to attain and maintain a navigation fix from the GPS signals. The total RF power level of the GPS signal can be varied up or down to measure this sensitivity as well as the power levels of individual satellites during the scenario playback period. This can be done in real time as the scenario is playing from the user interface of the N7609B. Location accuracy is also derived from the GPS receiver. The location fix, usually longitude, latitude, and altitude information, can be converted to Earth-centered, Earth-fixed (ECEF) Cartesian coordinates for evaluation of the simulated, versus calculated, GPS receiver locations.

The signals for these basic tests are easily set up using the N7609B user interface as shown in Figure 7.

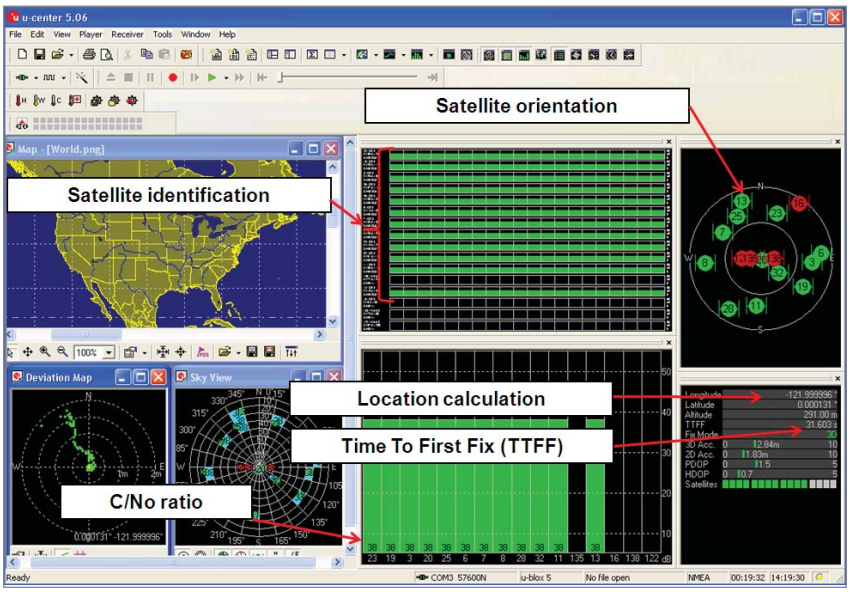

Figure 6. U-center software, printed with written permission from u-blox.

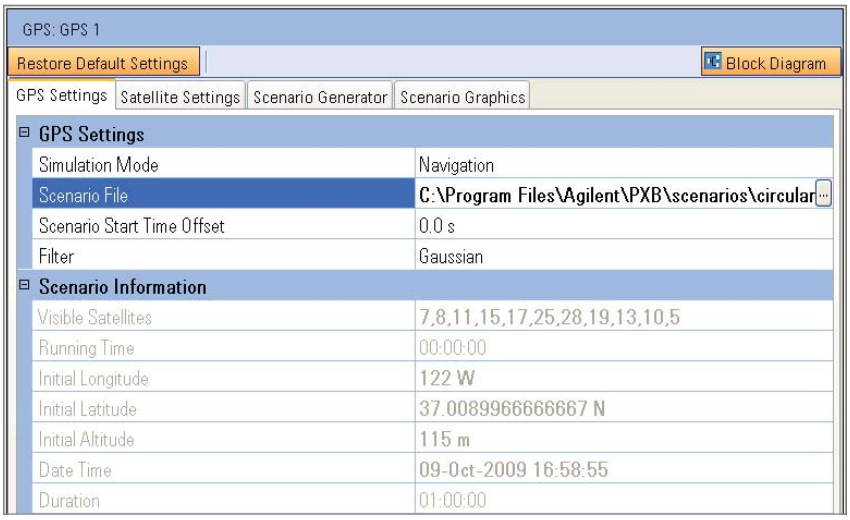

Figure 7. N7609B GPS settings tab.

Dynamic or moving GPS receiver scenarios are also important in characterizing GPS receivers. Figure 8 shows the GPS receiver, tracking a signal created by the N7609B, that provides a 1 km radius circular path at 100 km/hr speed.

To fully characterize and verify GPS receiver performance, impairments must be introduced into the GPS test signals. Impairments such as multipath signals, satellite visibility (obstruction of visibility due to objects such as trees and tall buildings that reduce the number of visible satellites), satellite power level variation, and ionospheric and tropospheric attenuation must be introduced into the GPS signal. This capability must allow for repeatability and reliability in the accuracy of the impairments.

The N7609B has the functionality to create these custom scenarios. Given a location, date, and time, the scenario generator will create the GPS signals that existed at that time. Moving GPS receiver scenarios, as described previously, can also be created through the input of an NMEA (GGA format) output file that has been collected from a previous GPS receiver experiment. Ionospheric and tropospheric models can be turned on as well as an elevation mask that selects satellite visibility according to a selected elevation.

A powerful capability built into the N7609B is the ability to edit scenarios. Once the specific scenario is created, it can be modified to include multipath signals, apply power offsets to specific channels, delete channels, trim the selected scenario to a shorter length, and equalize the power levels for all satellites. The user interface for this editing capability is shown in Figure 9. A simple graphical display helps to keep track of the edits and allows visualization of the changes that have been made to the scenario. See Figure 10.

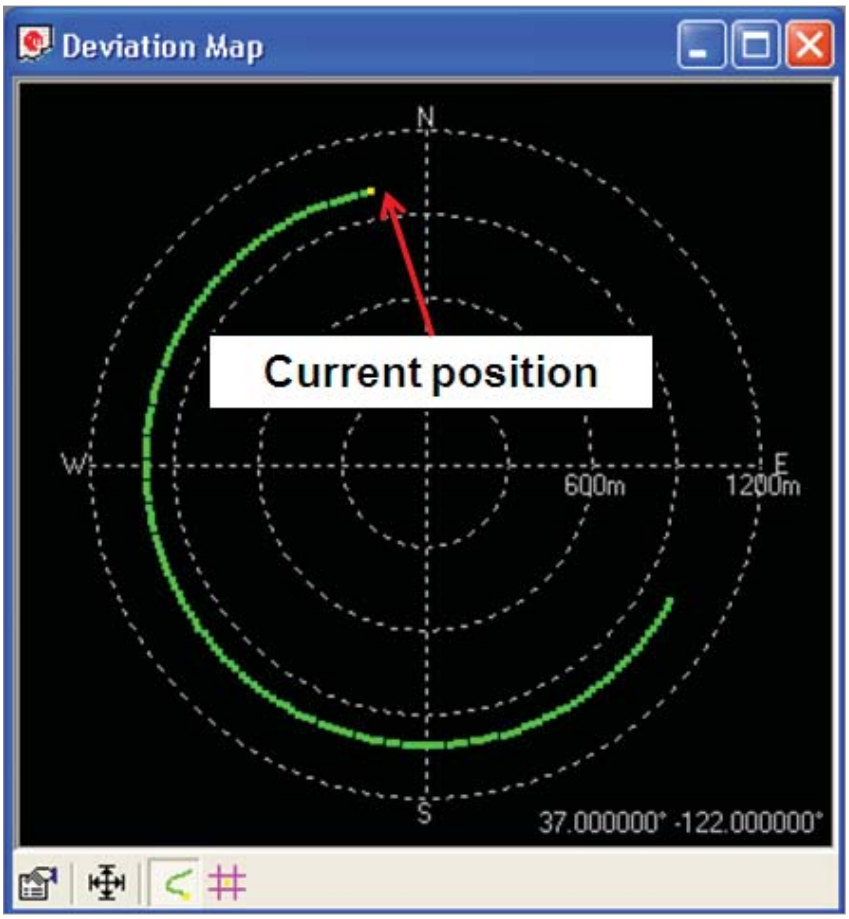

Figure 8. Moving GPS receiver scenario.

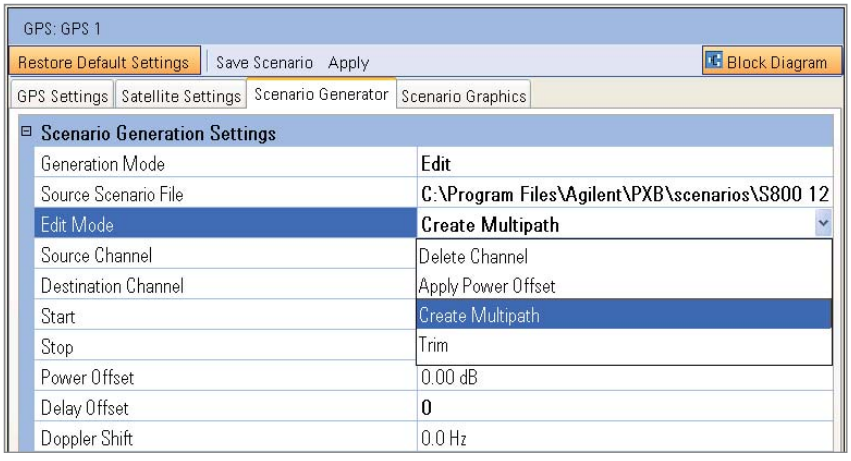

Figure 9. N7609B user interface for editing scenarios.

Figure 10. N7609B graphical overview of edited scenario.

Summary

We have described the basic tests used in verification of GPS receivers. Although the fundamental types of tests are few (i.e. TTFF, sensitivity, and location accuracy), the variations and introductions of impairments to the GPS signal quickly expand the comprehensive list of tests required to completely verify GPS receiver functionality. The ability to recreate these signals in a reliable and repeatable manner requires the use of an RF GPS simulator. The simulator must be able to simulate real-world scenarios and have real-time signal generation capability for maximum flexibility in test signal creation. The Agilent N7609B Signal Studio for GNSS, in conjunction with the N5106A PXB and N5182A MXG, is capable of providing this functionality. The general-purpose nature of the PXB/MXG platform also provides the flexibility to create not only GPS test signals but other wireless standards as well.

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