Design Verification Testing of GPS Receivers

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Modern GPS receivers are extremely sensitive signal detection devices. With tracking sensitivity’s below -160dbm, they can detect signals at 50dB below the ambient thermal noise in the channel. However, modern digital electronics are required, by governmental regulations, to limit their radio emissions or electro-magnetic interference (EMI) to below -100dB when measured a few inches away from a device.

The reality of this is that, anyone can sell a GPS receiver product that would be unable to “hear” any signals and be completely non-functional. It could be a product that works most of the time, just not all the time and not in any predictable way. We have seen this with some of the lower cost and short life cycle consumer GPS devices.

If you want to avoid those situations, proper design verification testing and debugging is required to bring device EMI emissions down to where the GPS receiver functions properly. In this article, I will discuss the steps needed to do just that, and outline how to test GPS receivers to make sure they work effectively. Here are five steps to testing GPS receivers. These steps need to be completed in the sequential order as listed. Not following the numbered sequence will often force you to repeat tests in the event changes are made to the system.

### Design Verification Test

As the name suggests, design verification testing (DVT) is carried out in order to verify that a design actually works to the required and targeted specification. It is different to production testing, quality testing or anything associated with production because DVT for a radio receiver creates a controlled repeatable radio environment and tests a receiver in a useful and realistic way. Testing the whole radio system is the responsibility of the hardware integrator. The actual hardware suppliers will have tested the antenna or radio module performance. However, the performance of these individual system elements depends on the test scenario, factors such as the location, test set up, mounting, test equipment and so on. Using an external GPS antenna is in most cases, pretty simple. Follow the datasheet or application note guidelines as it was designed and it should operate in the manner specified. For instance, if you use a magnetic mount GPS antenna on the roof of a car, it will work great. Use that same antenna on a non-metallic surface like glass or plastic and it will not work as well because that antenna was tuned assuming it would be used on a metallic surface.

While antenna testing is the responsibility of the system integrator, many antenna vendors will assist in this effort to ensure a customer has the best experience with their product.

### Step 1: Antenna Testing
The first step in receiver testing is to ensure your antennas work properly. This consists of ensuring the antennas are tuned on-frequency, in-situ. If your product is a GPS wristwatch for example, you have to test the performance of the antenna in the enclosure with the other electronics boards, battery and strap, strapped on an arm. Real enclosures are best and failing that a rapid-prototyped enclosure is better than nothing. For accuracy, you should test on a phantom, a fake plastic arm or leg-sized container filled with a salt-water solution to simulate the electro-magnetic absorption properties of the human body.

**Tuning**

The passive element of an antenna needs to be tuned to the correct operating and center frequency. The passive element needs to show a good return loss with the unit assembled and in-situ. 7dB is good enough; 5dB is acceptable for certain applications. Other components, enclosures, screens, batteries and different ground-plane shapes and sizes can all contribute to frequency shifts and antenna detuning.

Many GPS antennas are active - they have a filter and LNA combination right after the antenna element. These are less prone to detuning effects but still need to be checked.

A word about testing in a parking lot: This location testing gives a false result, because in general under open sky is as strong as a real GPS signals ever gets. Your product may work fine in this situation, but when presented with an impaired signal such as seen in urban canyons or inside structures, if your receiver is impaired you won’t get a fix, where a properly tested product will. That means in field performance comparisons against competitor products your product will be inferior. Testing should be done in a controlled and repeatable environment. An anechoic chamber, a GPS constellation simulator, a network analyzer and several copies of your device are all needed to do this testing correctly.

Your antenna vendor or integrator can help you achieve this level of testing. Typically for a small internal antenna an initial prototype is sent to the antenna vendor for tuning and optimization. GPS antennas can be tuned with external passive components but these parts add extra costs to the BOM and take up more space on the main PCB. In some cases, these extra components can add to losses and actually can negate receiver performance rather than helping.

**Radiation Pattern**

Radiation pattern is the direction the antenna receives radio energy from most efficiently, at a chosen frequency. This is controlled by the selection of antenna type. An antenna, mounted in a product will develop a particular radiation pattern. Other components, metal, the size of the antenna and the ground plane all have a bearing on the radiation pattern. It is important that the radiation pattern for a GPS antenna correlates with the direction from which the GPS signals are travelling. Think of a vehicle satellite navigation device, it is located in a car, which is outside most of the time, and obviously the roof is facing towards the sky. Patch antennas have hemi-spherical radiation patterns, the bigger the patch, the more directive or focused it is along the center axis of the antenna. This means in a car, a bigger patch works more efficiently because it is always in the optimal orientation - perpendicular to the earth’s surface.

In portable devices that are often used indoors, there is no control over orientation. A linear
polarized omnidirectional antenna can be more effective in these cases as a patch would never get a clear view of the sky. The omni antennas are not reliant on direction so they may pick up more reflected signals.

**Conducted Receiver Sensitivity Efficiency**

Efficiency is a complete measure of an antenna’s performance and a 360-degree measure of how much energy is transferred to a system or lost into the air depending on if you are considering transmit or receive. It includes things like return loss and directivity/radiation patterns and it varies with direction and frequency. In general, antennas need to be at a minimum of at least 10% efficiency. 30% efficiency is good, 50% is great and counter-intuitively, anything over 50% is not actually helping you much because the link budget difference between 50% and 90% is only 3dB, which is a relatively negligible amount out of a typical 180dB link budget. Also, the effort to go from 50% to 90% is considerable and would often force the product to be much larger without a user perceptible performance gain. The antenna integrator and supplier are again responsible for meeting this performance target.

**Step 2: Conducted Receiver Sensitivity Testing**

The next step in system testing is conducting receive sensitivity testing, and it is the first time you actually test the receiver itself. There are a number of problems that can impact receiver performance such as conducted power supply noise, power supply errors (such as voltage or current problems), firmware setup, and module management errors. Conducted receive sensitivity testing is the responsibility of the radio integrator.

The performance of the receiver is impacted almost entirely by hardware and firmware implementations. This testing should be done with the device under test in a chamber, screen room, or otherwise shielded from the signal generator and other equipment to prevent unanticipated coupling between the test equipment and device under test. The testing also requires a GPS signal generator. These multi-channel generators are required to do tracking sensitivity tests. You cannot do this testing with a real-live GPS constellation as the satellites are constantly moving and there is no way to control signal strength.

**Acquisition sensitivity**

With acquisition sensitivity, this will check that the physical implementation of a receiver is performing as per the specification, and that the module can achieve the stated sensitivity. If there are problems with conducted RF signals, these are fixed in a different way to radiated problems. The solution here is to get the GPS running with a good strong signal, let it run for some time, then reduce the signal down beyond where the GPS can track it. Force the GPS to do a cold start, or warm start depending on what you are testing, and set the signal generator to just below the stated acquisition sensitivity. Gradually increase the signal on the signal generator in 1dB increments, waiting about 60 seconds at each level to see if the receiver gets a fix. Losses in cables and connectors also need to be included.

Note that acquisition time with the same signal strength varies, depending on several timing factors. Remember that acquisition times shown in GPS receiver data sheets are statistical representations,
not absolute promises - your GPS vendor can elaborate further on how they arrived at the numbers given.

**Tracking sensitivity**

Tracking sensitivity is basically the opposite of the acquisition test; you start out with a good solid signal and keep turning the signal down until the module loses the signal.

**Step 3: Residual Error Test**

With residual error, a conducted RF test is done with signal levels turned up so a signal is strong. It should not be so strong that it might impact the linearity of the receiver. It should be sufficiently strong so there is no ambiguity that the signal the receiver is seeing is well within the sensitivity range. For most modern GPS modules a number of approximately -100dBm seen at the RF input of the module would be a good starting point. Set the GPS signal generator up, let the GPS get a fix and then start examining the test cases.

It is pretty common that there are firmware errors within the code. That is more prevalent if the engineers do not have a lot of experience with that particular radio device. This is common in cases where an interrupt is not effectively handled properly and/or consistently or where receive serial data is lost. For instance, GPS reception is fine most of the time but when a button is pressed on a device some of the GPS data is lost. That would be a typical and relevant example of what to look for - problems that show up even when the RF signal is perfect. Residual error testing is effectively showing that the device behaves as intended across the full set of firmware use-cases.

If you add use-case factors such as button presses, cellular activity or battery charger activation ensure they do not impact on the installed application.

**Step 4: Radiated receiver sensitivity testing**

With radiated receiver sensitivity testing the entire receive system is being tested, as it would work in the field, with the exception that it is being done in a controlled and repeatable RF environment. Testing of this kind is done in an anechoic RF chamber with a GPS signal generator. It cannot be done using the real satellite constellation because you cannot control the signal levels of the satellites. In order to know the path loss of the test setup, typically a network analyzer is used to measure this.

On the device side, this normally means having a copy of your product (often the same one used to verify antenna tuning) where the connection between the antenna and receiver is broken out so the network analyzer can see what the GPS receiver would normally see. It is important to note that the extended coax cable from the network analyzer can affect the antenna tuning. This can be minimized with a clamp on ferrites on the coax feed to the antenna. At this stage, the conducted sensitivity of the device has already been measured, and the test setup path loss including the device’s antenna. By substitution, you can do the same acquisition and tracking sensitivity tests you conducted. When you subtract out the path loss for the radiated test setup, you should get exactly the same values that were conducted.
Step 5: Self-quieting

All wireless devices emit radio energy. The amplitude and frequency of these emissions are directly related to the circuitry chosen and how it is implemented. Because a GPS receiver is so sensitive, it takes deliberate attention to noise suppression to have a chance of keeping the rest of your electronics quiet enough, from a radio standpoint, so that they do not interfere with the GPS receiver. The further the antenna is away from your electronics the less trouble you will have.

In vehicle navigation when antennas are placed on a roof that is three feet or more away from the electronics, you are probably far enough away from any potential emissions that could cause issues. We have seen cases in certain markets where cheap consumer electronics, namely FM MP3 players, saturate the GPS receiver. What is more common however is that the GPS antenna is actually mounted on, or near, the PCB containing the main electronics. Obviously the RF noise is much louder when your antenna is right on top of noise source.

There are only two ways to fix self-quieting. The first is to move the antenna away from the noise source and the second is to alter the amplitude or frequency of the noise source so it does not impact the GPS. Typically this involves suppressing the RF emissions’ amplitude, as there is usually little control over the frequency.

The Best GPS Receivers in the Market

The demand for GPS continues to grow. If you have a product that includes GPS, the bottom line for GPS receivers is to ensure that noise, emissions or other radiating parts in devices do not impact them. The steps above will certainly guide you in the right direction. But the best option is to have an RF expert involved in the process to ensure you get the most out of your product and ensure a smooth swift route to market.