

Basics Of GPS Antennas

Functionality and performance are critical considerations when selecting a GPS antenna. This article provides an overview of the most important specifications.

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In order to select or specify the right GPS (Global Positioning System) antenna, it is important to have a basic understanding of how GPS antennas work and what level of performance is required. This article will provide an overview of the general properties of GPS antennas and briefly compare three common types.

Throughout this article, when we refer to GPS antennas, we should really say Global Navigation Satellite System (GNSS) antennas.

The term GPS literally refers to the U.S. Department of Defense’s NAVSTAR GPS constellation of satellites; however, it is commonly used to describe any of a number of navigation systems that have been and are currently being developed, including the European Galileo and the Russian GLONASS systems.

We will first consider the functionality and performance needed in a GPS antenna.

Properties to consider include:

- Frequency coverage
- Radiation pattern
- Circular polarization
- Multipath suppression
- Phase center
- Impact on receiver system sensitivity
- Interferers handling

Frequency Coverage

GPS receivers brought to market today may include frequency bands such as GPS L5, Galileo E5/E6, and GLONASS, so the antenna may need to cover some or all of these bands. *Table 1* provides an overview of GNSS frequencies currently in use by the various constellations. Keep in mind that you may see slightly different numbers published elsewhere as a function of how the bandwidth is defined.

As the bandwidth requirement of an antenna increases,

System	Frequencies (MHz)				
	L1	L2	L3	L5/E5	E6
GPS	1563-1588	1215-1240	N/A	1164-1189	N/A
Galileo	1554-1596	N/A	N/A	1145-1238	1258-1300
GLONASS	1592-1615	1237-1257	1194-1209	N/A	N/A

Table 1: GNSS frequency allocations

the antenna becomes more difficult to design. Developing an antenna that covers all of these bands *and* is compliant with all the other requirements is a challenge. If small size also is a requirement, some level of compromise may be needed.

Radiation Pattern

The GPS receiver operates best with only a small difference in power between the signals from the various satellites, and, ideally, the antenna covers the entire hemisphere with no variation in gain. This has to do with potential cross-correlation problems in the receiver and the fact that excessive gain roll-off may cause signals from

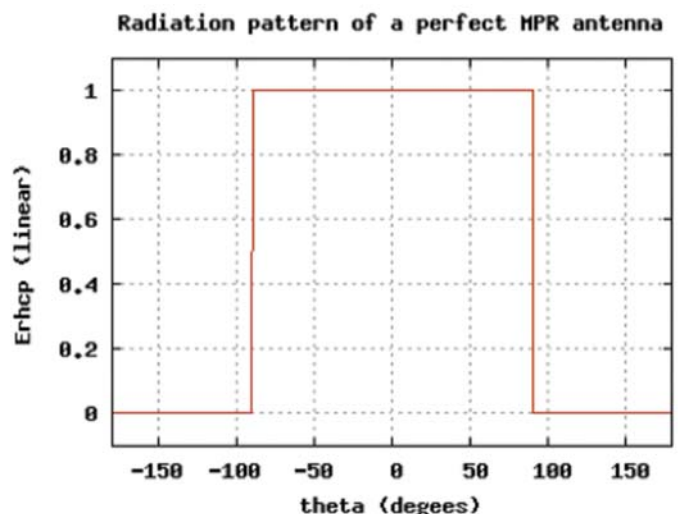


Figure 1: Theoretical antenna with hemispherical radiation pattern

satellites at low elevations to drop below the noise floor of the receiver.

On the other hand, optimization for multipath rejection and antenna noise temperature require some gain roll-off. *Figure 1* shows what a perfect hemispherical radiation pattern looks like.

However, such an antenna cannot be practically built, and real-world GNSS antennas experience a gain roll-off of 10 to 20 dB from broadside to the horizon. *Figure 2* shows a typical radiation pattern.

Circular Polarization

Spaceborne systems at L-band typically use circular polarization (CP). Changing relative orientation of the CP antennas does not cause polarization fading like it does with linearly polarized antennas. In addition, CP does not suffer from Faraday rotation, which causes a linearly polarized wave from space to arrive at the Earth’s surface at a different polarization angle, like it would if the antenna was turned. This leads to signal fading and potentially poor reception. GNSS satellites use right hand circular polarization (RHCP) for these same reasons.

Antennas are not perfect, and an RHCP antenna will pick up some left hand circular polarization (LHCP) energy. Because GPS uses RHCP, we refer to the LHCP part as the cross-polar component (see *Figure 3*).

We can describe the quality of the CP by specifying the ratio of this cross-polar component with respect to the co-polar component (RHCP to LHCP), or by specifying the axial ratio (AR). An AR close to 1 is best (indicating a good CP). The relationship between co-/cross-polar ratio and AR is shown in *Figure 4*. *Figure 5* shows the co- and cross-polar components ratio and the AR versus elevation for a typical GPS antenna.

For high-end (geodetic/choke ring) GPS antennas, the typical AR in broadside (looking straight up from the antenna) should be around 1 dB. AR increases toward the lower elevations, and you should look for an AR of less than 3 to 6 dB at 10° elevation for a high-performance antenna. Expect to see small (<1 dB) variations of AR versus azimuth at low elevations. Maintaining a good AR over the entire hemisphere and at all frequencies requires a lot of real estate in the antenna and only can be accomplished in high-end antennas, such as base station and rover antennas.

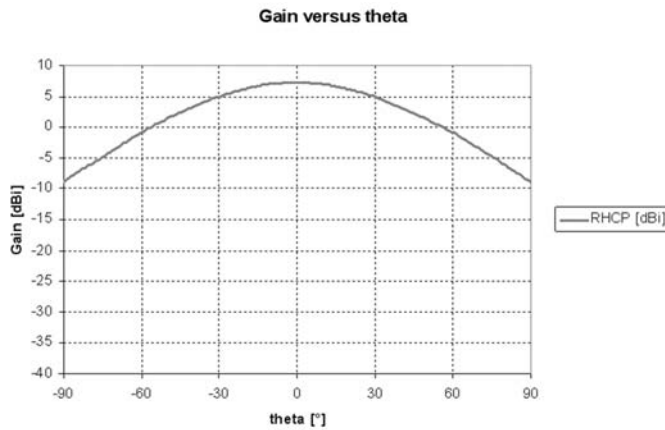


Figure 2: Real-world radiation pattern

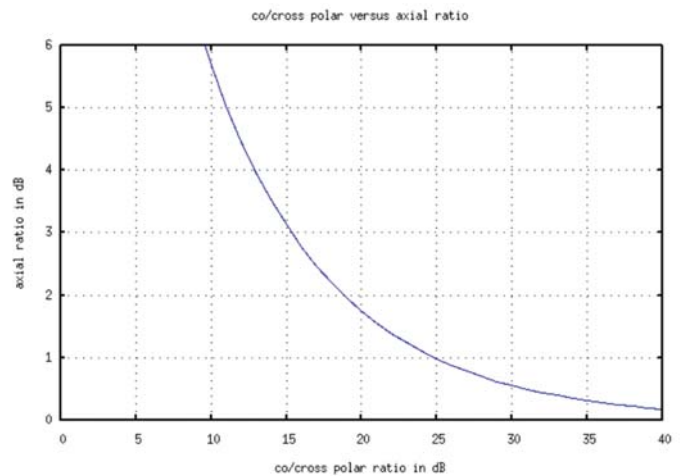


Figure 4: Converting AR to co-/cross-polar ratio

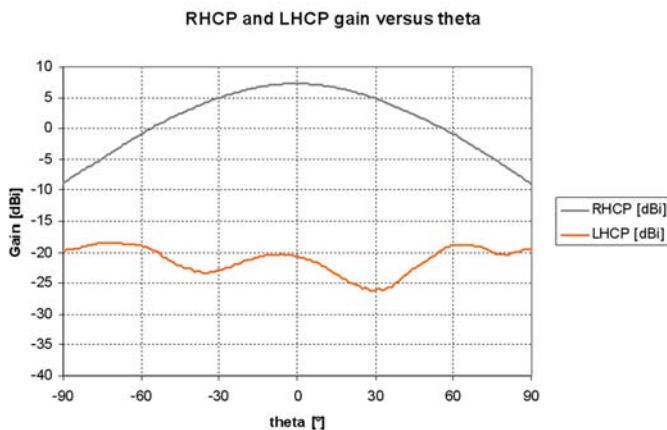


Figure 3: Co- and cross-polar radiation pattern versus elevation of a rover antenna

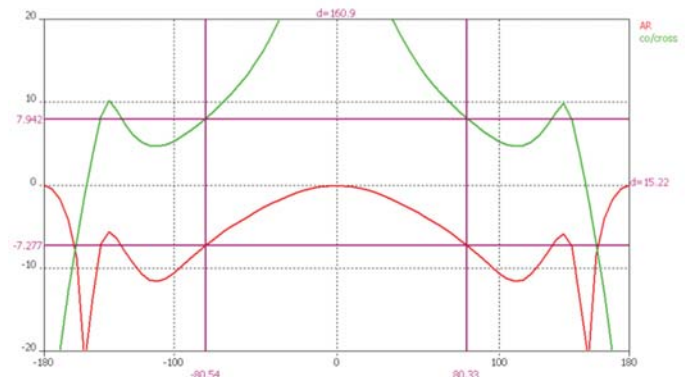


Figure 5: Co-/cross-polar components ratio and the AR versus elevation for a typical GPS antenna

Multipath Suppression

Signals sent from satellites arrive at the GPS receiver's antenna directly from space, but they also may be reflected off the ground, buildings, or other obstacles, arriving at the antenna multiple times and delayed in time.

This is multipath; it degrades positioning accuracy and should be avoided. High-end receivers are able to suppress multipath to a certain extent, but it is good engineering to suppress multipath in the antenna as much as possible.

A multipath signal basically can come from three directions:

- The ground, hitting the back of the antenna
- The ground or an object, hitting the antenna at a low elevation
- An object, hitting the antenna at a high elevation

The technique to mitigate each of these situations is different. As an example, we will describe suppression of multipath due to ground and vertical object reflections.

Ground Reflections

The multipath susceptibility of an antenna can be quantified with respect to the antenna's radiation pattern characteristics by the multipath ratio (MPR). *Figure 6* sketches the multipath problem due to ground reflections.

We can derive this MPR formula:

$$MPR = \frac{E_{RHCP}(\theta)}{E_{RHCP}(180^\circ - \theta) + E_{LHCP}(180^\circ - \theta)}$$

The MPR for signals that are reflected from the ground equals the RHCP antenna gain at an elevation (θ) divided by the sum of the RHCP and LHCP antenna gains at the supplement of that angle.

Reflections Against Vertical Objects

Similarly, an MPR formula can be written for signals that reflect against vertical objects. *Figure 7* sketches the multipath problem due to reflections against vertical objects.

The formula looks like this:

$$MPR = \frac{E_{RHCP}(\theta)}{E_{RHCP}(\theta) + E_{LHCP}(\theta)}$$

The MPR for signals that are reflected from vertical objects equals the RHCP antenna gain at an elevation (θ) divided by the sum of the RHCP and LHCP antenna gains at that angle.

LHCP reflections that hit the antenna at high elevations are not a problem, because the AR tends to be quite good at these elevations and the reflection will be suppressed. Signals that are reflected from the ground, on the other hand, require the antenna to have a good front-to-back ratio if we want to suppress them.

Also, a good front-to-back ratio minimizes ground noise pickup.

Multipath signals from reflections against vertical objects such as buildings can be suppressed by having a good AR

at the elevations from which most vertical object multipath signals arrive. This AR requirement is readily visible in the MPR formula, considering these reflections are predominantly LHCP. In this case, MPR simply equals the co-/cross-polar ratio.

It makes sense to have some level of gain roll-off toward the lower elevations to help suppress multipath signals. However, a good AR always is a must, because gain roll-off alone is insufficient.

Phase Center

A position fix in GNSS navigation is relative to the phase center of the antenna. The phase center is the point in space from which all the rays appear to emanate (or converge on) the antenna. Put another way, it is the point where the fields from all incident rays appear to add up in phase. Determining the phase center is important in GPS systems, particularly when millimeter positioning resolution is desired.

Ideally, the phase center is a single point in space for all directions at all frequencies. A real-world antenna often

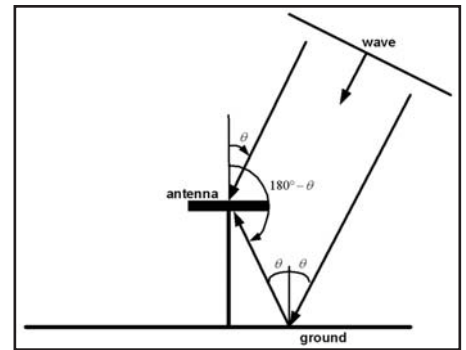


Figure 6: Quantifying multipath caused by ground reflections

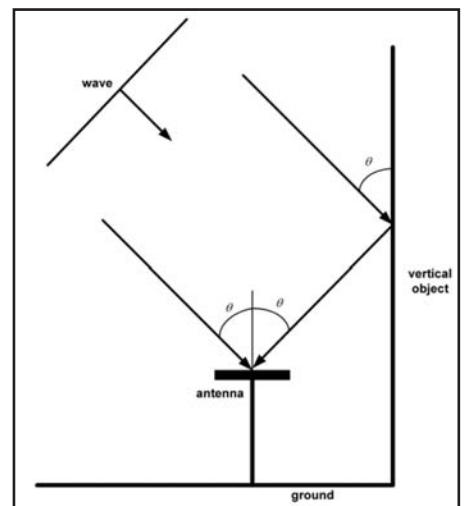


Figure 7: Quantifying multipath caused by vertical object reflections

will possess multiple phase center points (for each lobe in the pattern, for example) or a phase center that appears “smeared out” as frequency and viewing angle varies.

The phase center offset can be represented in 3-D, where the offset is specified for every direction at every frequency band. Alternately, we can simplify things and average the phase center over all azimuth angles for a given elevation and define it over the 0° to 90° elevation range.

For most applications, even this simplified representation is overkill, and, typically, only a vertical and a horizontal phase center offset are specified for all bands in relation to L1.

For well-designed high-end GPS antennas, phase center variations in azimuth are small and in the order of a couple of mm. The vertical phase offsets are typically 10 mm or less.

Impact On Receiver System Sensitivity

The strength of GPS signals from space is on the order of -130 dBm, and we need a very sensitive receiver if we want to be able to pick up these signals. For the antenna, this translates into the need for a high-performance, low-noise amplifier (LNA).

The total (cascaded) noise figure of a receiver chain can be calculated as follows:

$$NF = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2} + \dots$$

The total receiver noise figure (NF) equals the sum of the NF of the first stage (NF₁) plus that of the second stage (NF₂) minus 1, divided by the total gain of the previous stage (G₁). So the total NF pretty much equals that of the first stage plus any losses ahead of it, like filters. Expect to see total LNA noise figures in the 3 dB range for high-performance GNSS antennas.

Another requirement for the LNA is for it to have sufficient gain to minimize the impact of long and lossy coaxial cables. Typically, 30 dB should be sufficient. Keep in mind that it is important to have the right amount of gain — too much gain may drive your receiver into compression. Receiver manufacturers typically specify the required LNA gain.

Interferers Handling

Even though GPS receivers are good at mitigating interference, it is essential to keep unwanted signals out of receivers as much as possible. Careful antenna design can help, especially by introducing some frequency selectivity against out-of-band interferers. The mechanisms by which in-band and out-of-band interferers can create

trouble in LNAs and receivers and the approach to dealing with them are somewhat different.

An out-of-band interferer generally is an RF source outside of the GNSS frequency bands — cellular base stations, cell phones, broadcast transmitters, radar, etc. When these signals enter the LNA, they can drive the amplifier into its nonlinear range, and the LNA starts to operate as a multiplier or comb generator. This is shown in *Figure 8*, where a -30 dBm interferer at 525 MHz generates a -78 dBm spur in the GPS L1 band.

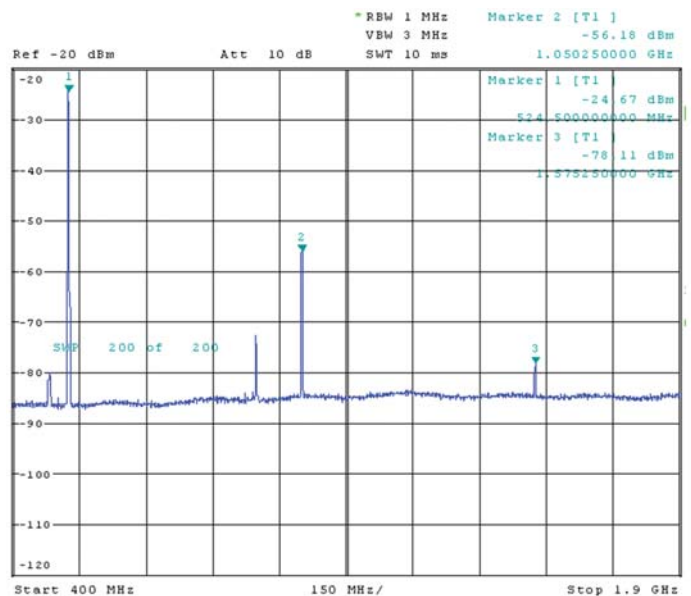


Figure 8: Strong out-of-band interferer and third harmonic in the GPS L1 band

Through a similar mechanism, third-order mixing products can be generated — a signal is multiplied by two and mixes with another signal. As an example, take an airport where radars are operating at 1275 and 1305 MHz. Both signals double to 2550 and 2610 MHz. These will, in turn, mix with the fundamentals and generate 1245 and 1335 MHz.

Another mechanism is desensing. As the interference is amplified further down the LNA's stages, its amplitude increases. At some point, the GPS signals get attenuated, because the LNA goes into compression. The same thing may happen down the receiver chain. This effectively reduces the receiver's sensitivity, and in some cases, reception will be lost completely.

RF filters can reduce the out-of-band signals by 10s of dBs, and this is sufficient in most cases. Of course, filters add insertion loss, amplitude, and phase ripple, all of which we don't want, because they degrade receiver performance.

In-band interferers can be the third-order mixing products we mentioned above or simply an RF source that

	Geodetic	Rover	Handheld
Frequency bands	Single to multiband Broadband	Single to multiband Narrow to broadband	Single band Narrow band
Radiation pattern	Controlled	Controlled	Not controlled
Multipath suppression	High	Medium	None
Sensitivity	High	Medium to high	Low
Interferers handling	High rejection	Good rejection	Minimal rejection
Phase center	Very important	Important	Not important
Dimensions	Large	Portable	Very small
Weight	Heavy	Portable	Lightweight
Cost	High	Medium	Low

Table 2: Summary of GNSS antenna classes

transmits inside the GNSS bands. If these are relatively weak, the receiver will handle them. From a certain power level on, however, there is just not a lot that a commercial receiver can do about them.

The LNA should be designed for a high intercept point (IP) so compression does not occur with strong signals present at its input. On the other hand, there is no requirement for the LNA to be a power amplifier. For example, let's say we have a single strong CW (continuous wave) interferer in L1 that generates -50 dBm at the input of the LNA. A 50 dB, high-IP LNA will generate a 0 dBm carrier in L1, but the receiver will saturate.

LNAs with a higher intercept point tend to consume more power, and in a portable application, such as a rover antenna, that may be an issue. In a base station antenna, on the other hand, low current consumption should not be a requirement, since a higher intercept point is probably more valuable than low power consumption.

Types Of GNSS Antennas

In this section, we provide a brief comparison of three common types of GNSS antennas — geodetic, rover, and handheld. *Table 2* is an overview of the most important properties of these three antennas. The sections below describe each type in further detail.

Geodetic Antennas

High-precision, fixed GNSS applications require geodetic class receivers and antennas. These provide the user with the highest possible position accuracy. At a minimum, typical geodetic antennas cover L1 and L2. Coverage of L5 is found in some newer designs, as well as coverage of the Galileo and GLONASS frequencies and L band.

The use of choke rings is common in geodetic antennas. Choke rings allow good radiation pattern control, excellent multipath suppression, high front-to-back ratio, and good AR at low elevations. Plus, they contribute to a stable phase center. The phase center is documented, and high-end receivers allow the antenna behavior to be taken

into account. Combined with a state-of-the-art LNA, these antennas provide the highest possible performance.

Rover Antennas

Rover antennas typically are used in land survey, forestry, construction, and other portable applications. They provide the user with good accuracy despite being optimized for portability.

Horizontal phase center variation versus azimuth should be low because the orientation of the antenna is unknown and cannot be corrected in the receiver. A rover antenna typically is mounted on a handheld pole close to the ground. This means that a good front-to-back ratio is required to avoid ground noise pickup. Rover antenna applications require high precision and good phase center stability. However, since a choke ring cannot be used because of its weight, a higher phase center variation compared with that of a geodetic antenna is inherent to the rover antenna design. A good AR and a decent gain roll-off at low elevations ensures good multipath suppression.

Handheld Receiver Antennas

These antennas are single-band L1 structures optimized for size and cost. They are available in a range of implementations, such as surface-mount ceramic chip, helical, and patch antenna types. Their radiation patterns are quasi-hemispherical. AR and phase center performance are a compromise because of their small size. Because of their reduced size, handheld receiver antennas tend to have a negative gain of about -3 dBi, but this is mostly masked by an embedded LNA. The associated elevated noise figure is typically not an issue in these applications.

Conclusion

Before selecting a GPS antenna for your application, it is important to first understand how these antennas work and to what level they must perform. This article provided an overview of the specifications you should consider and how these properties can impact system performance. Several GPS receiver-antenna classes were introduced based on their typical specifications, and the resulting specification compromises were discussed. ■

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