GPS Patch Antenna

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Introduction

This application note is one in a series about patch antennas and the subject of patch antennas used in GPS reception is covered. The purpose of this application note is to give the reader an understanding of the basic properties of patch antennas in relation to GPS reception and help in defining the right patch antenna for his or her application.
While a typical GPS antenna has a built in LNA, that subject is covered in a separate application note.

Basic Terminology

Gain: a ratio that indicates how much an antenna radiates energy in a given direction compared to a perfectly omni-directional antenna and expressed in dB. Gain is actually directivity corrected for antenna efficiency. Put differently, an antenna with a lot of gain typically has most of its energy radiated in one direction. This property is not very desirable for a GPS antenna since we wish to receive all spacecraft across the hemisphere.
Gain can be read from a **radiation pattern** plot like the one to the right.

From the radiation pattern one can also read the beamwidth. The beamwidth typically specifies the angle at which the radiated power reaches a level that is 3 dB below the level that is radiated in the main direction. This number will be referenced to as the **-3 dB beamwidth**.

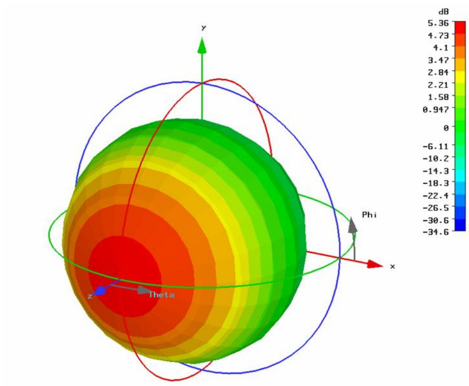

Figure 1: Radiation Pattern Plot

What is the ideal gain for a GPS antenna like the L1 antenna shown in the figure to the left?

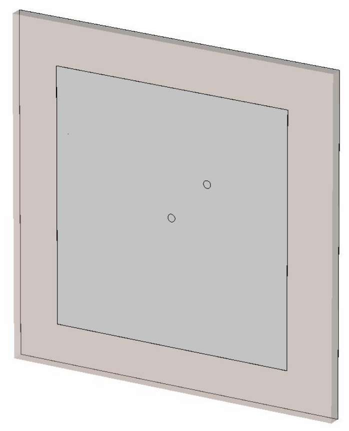

Figure 2: L1 Antenna

A dipole is often used as a reference antenna and we say it has no directivity (there is actually some gain/directivity since a dipole radiates no energy towards both ends of its long axis). If the pattern of a dipole is modified to get the hemispheric coverage we need, we have 'removed' all the energy below the horizon and doubled the energy above the horizon. We say that this new antenna has a directivity of 3 dB over a dipole (because we doubled the energy in the direction we're interested in) and if this is a perfect antenna, gain equals directivity and we now have a 3 dB antenna. The ratio of power radiated to the front of an antenna versus the amount of power radiated to the back of an antenna is called **front-to-back ratio** and is expressed in dB. Front-to-back ratio for this antenna is typically between 10 dB and 20 dB.

Often, we will reference gain of an antenna to an isotropic radiator rather than to a dipole. Now, since an isotropic radiator radiates an equal amount of energy in all directions, it actually has 2.14 dB of gain over a dipole. When we then compare our 3 dB antenna mentioned above to an isotropic radiator, we can say that this antenna has 5.14 dB of gain and since we refer to an isotropic radiator, we will write that as 5.14 dB**i**. Similarly, gain over a dipole is sometimes written as 3 dB**d**.
5 dBi is the typical gain of a GPS antenna; if the antenna has been optimized for size, the gain will be reduced by as much as 10 dB. This is an electrically small antenna, the subject of which is covered in another application note.

Bandwidth: The bandwidth of an antenna is that **frequency range** where the structure meets some requirement. Very often the bandwidth of an antenna is specified as that bandwidth over which the return loss or VSWR is better than a number and while this is absolutely correct, antenna bandwidth can (and probably should) be specified as a combination of the following parameters in addition to the return loss or VSWR:

- Gain bandwidth: the frequency range over which the antenna meets some gain requirement. Typically, we would say the gain is flat to within ±x dB over a specified frequency range.

- Return loss or VSWR bandwidth: this is the frequency range within which the structure has a usable impedance. In a GPS antenna this would be typically 50 Ω but the designer can use other impedances, for example, when the element is used in an array and the element is connected to a feeding network. A typically return loss is -10 dB or a VSWR of 1.9:1.

- Polarization bandwidth: the frequency range within which the antenna maintains its polarization. That would be either horizontal, vertical or circular (left hand or right hand). GPS antennas, and most L and S-Band antennas that receive satellite signals, are right hand circular.

- Axial ratio bandwidth: related to the polarization bandwidth and this number expresses the quality of the circular polarization of an antenna. In GPS antennas we are interested to know how well the antenna suppresses the unwanted left hand circular polarization. This is particularly important if you need multipath suppression: when a GPS signal reflects off a near by object, the first reflection will have its polarization inverted (from right hand circular to left hand circular). When the left hand circular suppression of the antenna is poor (and at low elevations it will at least degrade to some extent), the reflected signal will cause interference in the receiver. The ratio by which a polarization is suppressed vs. another polarization is referred to as cross polar suppression.

- Efficiency bandwidth: the frequency range over which the antenna has a reasonable radiation efficiency.

Antenna size: a typical patch antenna has half wave sides. That is a half wave in whatever substrate the antenna is built of. The higher the dielectric constant of the substrate the smaller the antenna: the side of a patch equals a half wavelength divided by the square root of the dielectric constant. As you make the antenna smaller, other properties change with it and not for the better. Please refer to OMP's application note 'Basics of Patch Antennas' for more details.

Antenna efficiency: Efficiency of the antenna is a number that indicates how much of the RF energy fed into the antenna is actually radiated. In reception we can say that efficiency is the number that indicates how much of the incident RF energy into the structure is actually coming out of the connector. Since antennas are passive and therefore reciprocal structures, efficiency –and all other parameters– are identical in receive and transmit.
Here is an example to demonstrate the issue of efficiency. This antenna was designed to cover a specific set of cellular frequency bands.

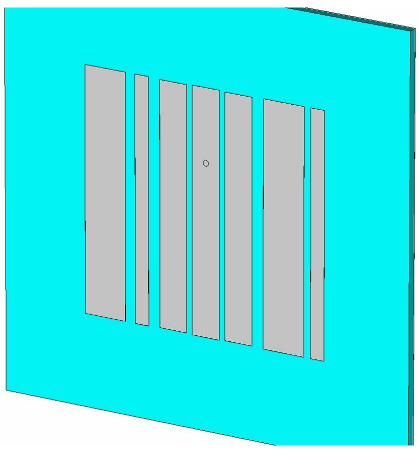

Figure 3: Cellular patch antenna

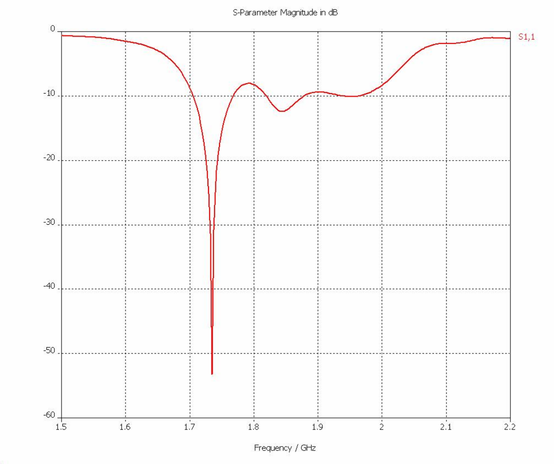

Figure 4: Return loss bandwidth of cellular patch antenna

The return loss bandwidth is acceptable and meets the requirement.

The efficiency shows a very different picture though: while the return loss is good, the efficiency is only a couple % at the high end of the passband rendering this antenna pretty much useless.

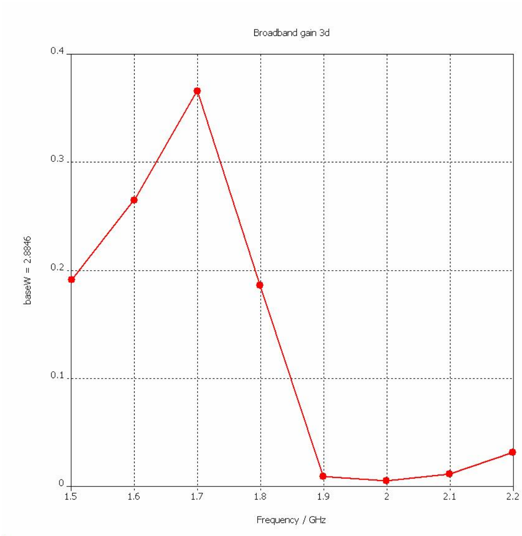

Figure 5: Efficiency of cellular patch antenna

The **noise temperature** defines how much noise power is captured by the antenna. This subject is covered in our application note 'Noise in antennas'.

The **electrical phase center** of an antenna represents the theoretical point in space where the carrier phase of one band (L1 for example) is fixed and where the carrier phase of another band (L2 for example) is received on average.

The electrical phase centre of a GPS antenna is not equal to its **physical phase centre** and using the correct phase centre offset is important: the spatial relationship between these points is provided as calibration data with your antenna and should be used when processing your GPS data.

Examples

Example Number 1:

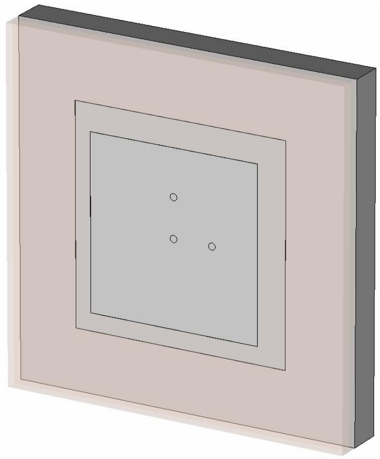

Figure 6: L1/L2 antenna

This is an example of a classic L1/L2 GPS antenna. Two elements are vertically stacked and the smaller (top) element is the one that covers the higher (L1) frequency band.

The return loss plot shows the dual band behavior of this structure.

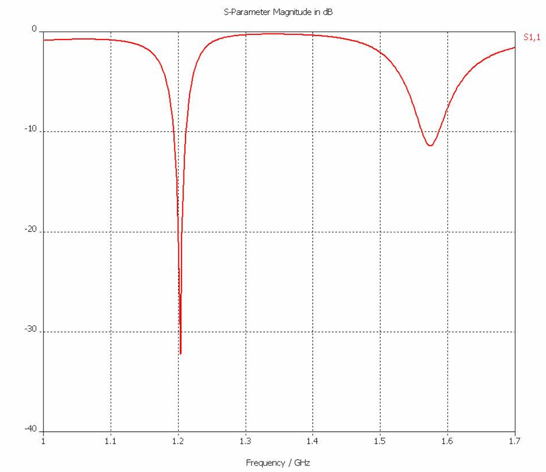

Figure 7: Return loss plot of L1/L2 antenna

Example Number 2:

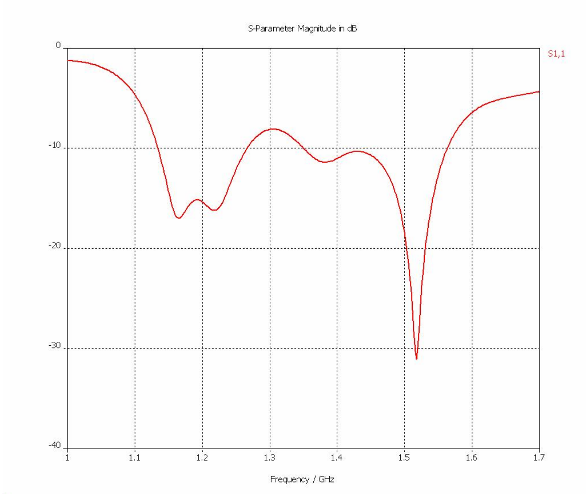

Figure 8: Return loss plot for L1/L2/L5 antenna

This structure was designed and optimized to yield a good hemispherical coverage. The figure shows a return loss for this structure that covers the L1, L2 and L5 frequency bands and the 1.545 GHz L-Band segment.

The radiation pattern of this right hand circularly polarized radiating element is optimized to yield the best possible hemispheric coverage: that would be minimal gain roll-off and best possible axial ratio from zenith down to 5° elevation.

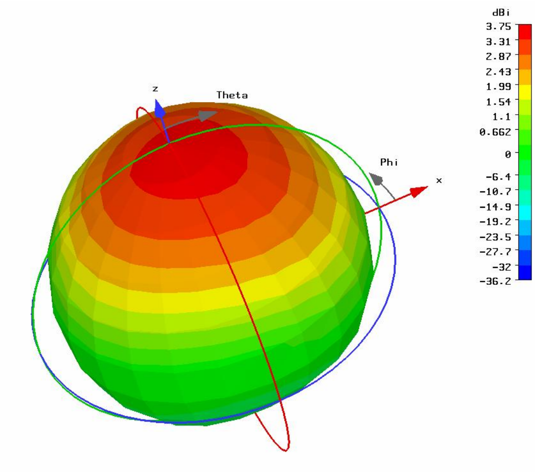

Figure 9: Radiation plot of L1/L2/L5 antenna

If you need more information about this structure, please contact an OMP agent.

Conclusions

In this article we have covered the most important technical aspects of radiating elements used in GPS antennas. Other aspects like the LNA are covered in different articles.

We have tried to keep this discussion simple and we have avoided the inclusion of too much technical detail. There are many excellent textbooks that cover the subject of patch antennas and antennas in general.
For those that wish to learn more about patch antennas, please refer to our application note 'Basics of patch antennas'.

Based on this text, the user should be able to understand and define his requirements and write initial specifications that form the basis of a to be designed antenna.

The Authors

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Orban Microwave Products (OMP) *designs and produces a wide range of RF and microwave modules and antennas for both the commercial and high end markets. The company was established in 1996 as an independent RF and microwave design house. OMP offers the unique advantage of not only just designing products but also overseeing production and providing engineering support throughout the entire product's life cycle.*
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