Basic Guidelines For the use of the Ultra-Compact Embedded Antenna

P/N 45336-00

1) Introduction

With the availability of a new generation of miniature, low power GPS modules and antennas, new opportunities are present to integrate GPS into applications that were not possible a few years ago. With these new opportunities also come new challenges facing the product designers that were also not present in earlier generations of GPS products. The purpose of this document is to provide an overview of some of the tradeoffs and challenges faced by the system designers using the current generation of unpackaged patch GPS antennas. Unpackaged antenna is meant antenna element and LNA with no radome and ground plane.

2) Signal to Noise Ratio (S.N.R.)

The primary challenge faced by an engineer who is integrating a GPS antenna into a product is how to maximize the signal to noise ratio (S.N.R.) of the GPS system. The process can be broken into 2 categories:

1) Maximizing the desired signal present at the antenna feed
2) Minimizing the noise present at the antenna feed

Maximizing the desired signal is a process of optimizing the antenna gain for the desired signal. For GPS, this means that an ideal antenna would have a near constant gain with right hand circular polarization for all directions above the horizon, and no reception below the horizon. The goal of all GPS antennas is to get as close as possible to this ideal.

Minimizing the noise present at the antenna feed requires three additional tasks:

1) Minimize the electronic noise present at the input of the LNA
2) Reduce interfering signals outside of the GPS frequency band
3) Reduce interfering signals inside of the GPS frequency band

Typical product constraints are:

1) The antenna needs to be inexpensive
2) The antenna needs to be very small
3) The antenna needs to be very low power

With the customer product constraints in mind, GPS vendors have been hard at work developing new materials, new electronics, new manufacturing processes, etc. to satisfy both the product constraints, and to get as close as possible to an ideal antenna. The Trimble Ultra-Compact Embedded Antenna is a very good example of this generation of new antennas.

The antenna element is manufactured from a high dielectric constant, ultra high Q ceramic material for best performance and small size. The electronics have been designed for very low noise performance with a noise figure less than 1.5 dB. The LNA is very selective with a system bandwidth of only 20 MHz. The antenna has been optimized for good antenna gain and polarization at the zenith.

There are 2 criteria that have to be met for the antenna to operate correctly:

1) The 45336-00 antenna requires a ground plane.

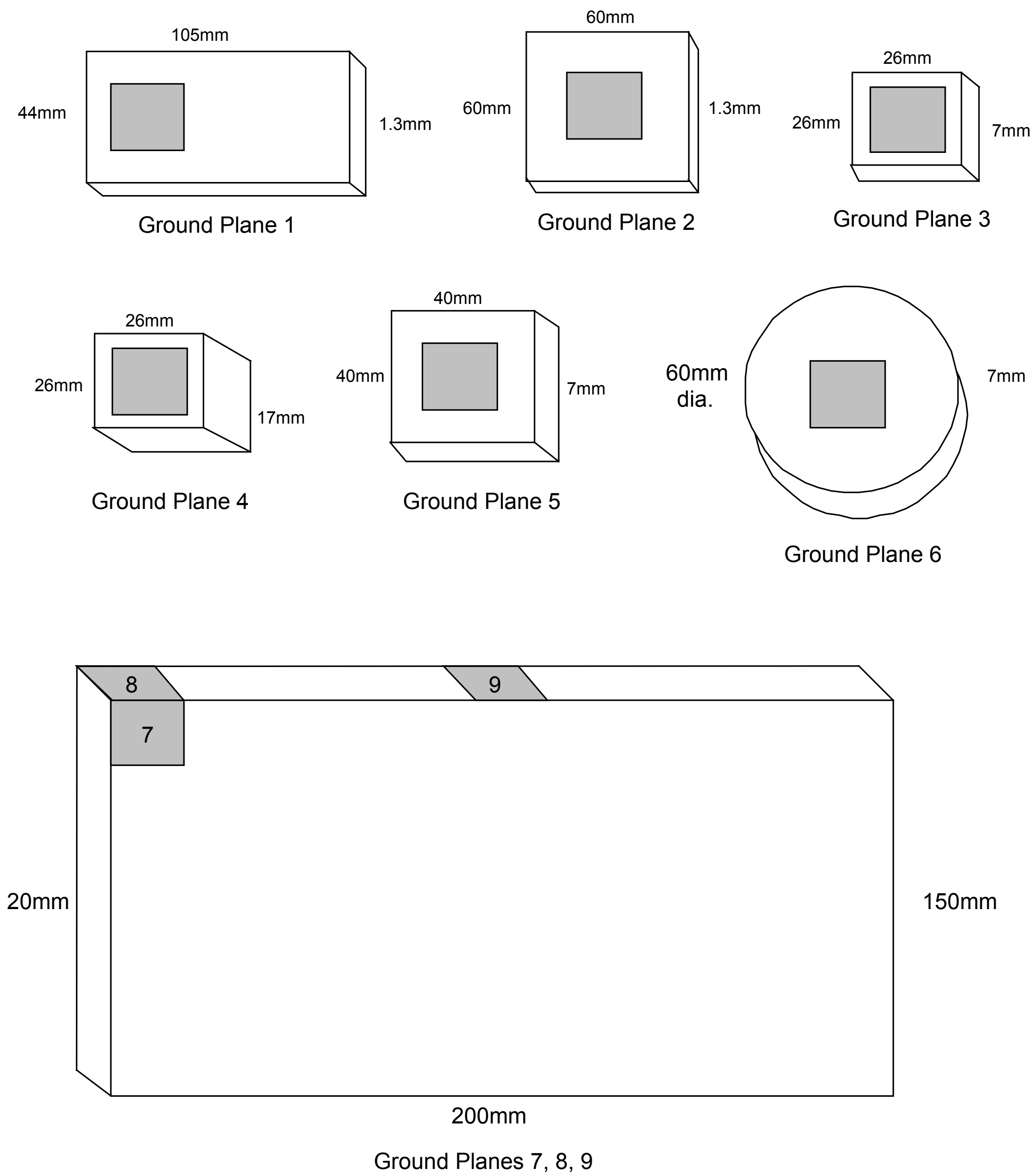
2) The antenna needs a radome in close proximity to the antenna element.

Note: The performance characteristics for the Embedded Antenna, specified in document number 45336-00-SP "Trimble Miniature Antenna Specification", were measured using a 60mm X 60mm ground plane.

What this means is that two antenna design elements, the ground plane and radome, which used to be part of the antenna design are now part of the top-level product design. This provides an opportunity for cost and space savings; however, it also challenges the product designer to be aware of the potential impacts that the product design will have to the antenna in these two areas.

3) The Ground Plane

To assist the system designer, several ground plane shapes and sizes were constructed and tested with the 45336-00 antenna to see what effect ground planes had on the antenna performance. The nine (9) different ground planes are shown in Figure 1. The test ground plane #2 is the manufacturer’s reference ground plane (60mm X 60mm). The test ground planes were included that represented shapes similar to cell phones, notebook computers, and other simple shapes that are smaller than the manufacturer’s reference ground plane (60mm X 60mm). Performance results for all the test ground planes are available in the Appendices.



Ground Planes used in Miniature Antenna Testing

FIGURE 1

4) Antenna Elevation Plots in Appendix A

The antenna elevation plots for the test ground planes can be found in Appendix A. Each ground plane was tested with three different antennas. All plots contain the measured results from 3 antennas. The traces in red are reception of the desired RHCP (right hand circularly polarized) signal. The traces in blue are reception of the undesired LHCP (left hand circularly polarized) signal.

The most striking features from these plots are:

1) The best and most consistent reception is at the zenith for RHCP
2) The best and most consistent reception is directly below the antenna for LHCP

4.1) The Presence of a Ground Plane

The influence of the ground plane on the performance of the antenna has been investigated in this part of the study. Please see Appendix A, Plots GPng-0 and GPng-90. With no ground plane at all, the elevation plots show a severe loss of gain (> 8 dB) and axial ratio (> 10 dB). The antenna is effectively useless with this degradation in performance. The GPS receiver will not be able to track most of the time.

With the addition of a very small ground plane for example test ground plane # 3 with the size of 26x26x7 mm (0.25" larger than the antenna), the situation improves significantly. Please see Appendix A, GP3-0 and GP3-90. The antenna loss is not as severe (3 dB), and the axial ratio only degrades to 6 dB. While not ideal, this antenna performance will allow the receiver to track under most circumstances. As the ground plane gets larger, the antenna gain at zenith improves, and the undesired antenna gain below the horizon diminishes.

The major point is that the 45336-00 antenna needs a ground plane. It does not to be large, but it does need to be symmetric.

4.2) Multipath Signals

The reception of signals below the ground plane is caused by the relatively small size of the ground plane relative to the wavelength of GPS (31% of the wavelength). This is a parameter that GPS antenna designers are concerned about because GPS (or other signals) can bounce off the ground and arrive at the antenna from a direction below the horizon. This can cause a reduction in the SNR because a signal that has bounced off of anything is the wrong signal, and becomes a type of interference. One of the design tradeoffs we look at is how to minimize the antenna gain in the LHCP signal range.

4.3) Low Elevation Signals

Another characteristic that is visible is the antenna performance near the horizon. As you can see from the plots in Appendix A, the antenna gain is reduced near the horizon, and the reception between RHCP and LHCP is not very different. This means the antenna polarization is now almost linear. This is also a characteristic of patch antennas. Maintaining gain at low elevation angles is a big challenge for system designers.

In addition, if you look at the sensitivity of this antenna to being rotated off of a position where the antenna z-axis is at the zenith, you will see that the antenna will lose gain very fast near the horizon. This will cause problems for reception of low elevation satellites.

5) Antenna Return Loss Plots in Appendix B

We also looked at the frequency response of the antenna P/N 45336-00 as a function of frequency and presence of a radome. The return loss plots (Smith Charts) of the Ultra-Compact Embedded Antenna on the test ground planes 1 to 9 can be found in Appendix B.

The Smith Charts in Appendix B have been labeled using the following format:

GPn-R or GPn-NR

GP Ground Plane

n The test ground plane number.
Please refer to Figure 1 for the shape and size of each test ground plane

R with radome

NR without radome

NOGP no ground plane and no radome

The Blue Dot represents the impedance of the antenna at the GPS center frequency (1575.42 MHZ). The entire plot covers a 100 MHZ (6.5%) frequency range. These plots help explain the effect of size and shape of a ground plane and the effect of a radome on the performance of the GPS system.

5.1) The Presence of a Radome

If you look at the design of a single feed point circularly polarized patch antenna, you will find that there are 2 resonant circuits that are slightly offset in frequency. This creates the 90-degree phase difference between the 2 resonators at the center frequency of the antenna. It also creates a distinctive plot on the Smith Chart. The return loss plot has a very distinctive cusp or very small loop at the center frequency of the antenna. This can be seen in all of the presented plots in Appendix B.

At the point 1.7 +j0.5, you can see the cusp of the return loss. This is a positive aspect. If the center frequency of GPS (blue dot) is not located at the cusp, then the antenna is not centered on frequency. This degrades the antenna axial ratio and the user will experience the performance degradation.

The objective is moving the center frequency of GPS, the Blue Dot, toward the cusp of the return loss plot. As you can observe on all of the Smith Plots in Appendix B labeled as GPn-R, the addition of a plastic radome 0.020 inches (0.5 mm) from the patch had the result of shifting the center frequency of the antenna lower. It means that the cusp of the antenna return loss plot moved to the center frequency of the antenna.

The center frequency of the antenna element is influenced by several factors. In the above example you saw that bringing a radome close to the antenna element lowered the center frequency by 5-6 MHZ.

5.2) The Shape of a Ground Plane

If you look at the basic physics of the patch you will discover that a large amount of energy is stored near the 4 edges of the antenna element. Any material that you bring near the edges of the element will influence the center frequency and impedance of the 2 resonators in the antenna element. This includes plastic near the element, and the shape of the ground plane.

If the ground plane shape does not look the same to the 2 resonators in the element or the plastic is not symmetric with respect to the 2 resonators, then the center frequency of one antenna will shift with respect to the other antenna. In this case the antenna axial ratio will degrade and you will see performance degradation.

This is also visible in the Smith Charts of the asymmetrical test ground planes number 8 and 9:

- Appendix B_SC_GP8-NR
- Appendix B_SC_GP8-R
- Appendix B_SC_GP9-NR
- Appendix B_SC_GP9-R

As you can notice from the plots, the cusp now looks like a large loop, and the impedance of the antenna has changed significantly.

In Appendix A, the following Antenna Elevation Plots of the asymmetrical test ground plane # 9 reveal the same aspect:

- Appendix A_AE_GP9-0
- Appendix A_AE_GP9-90

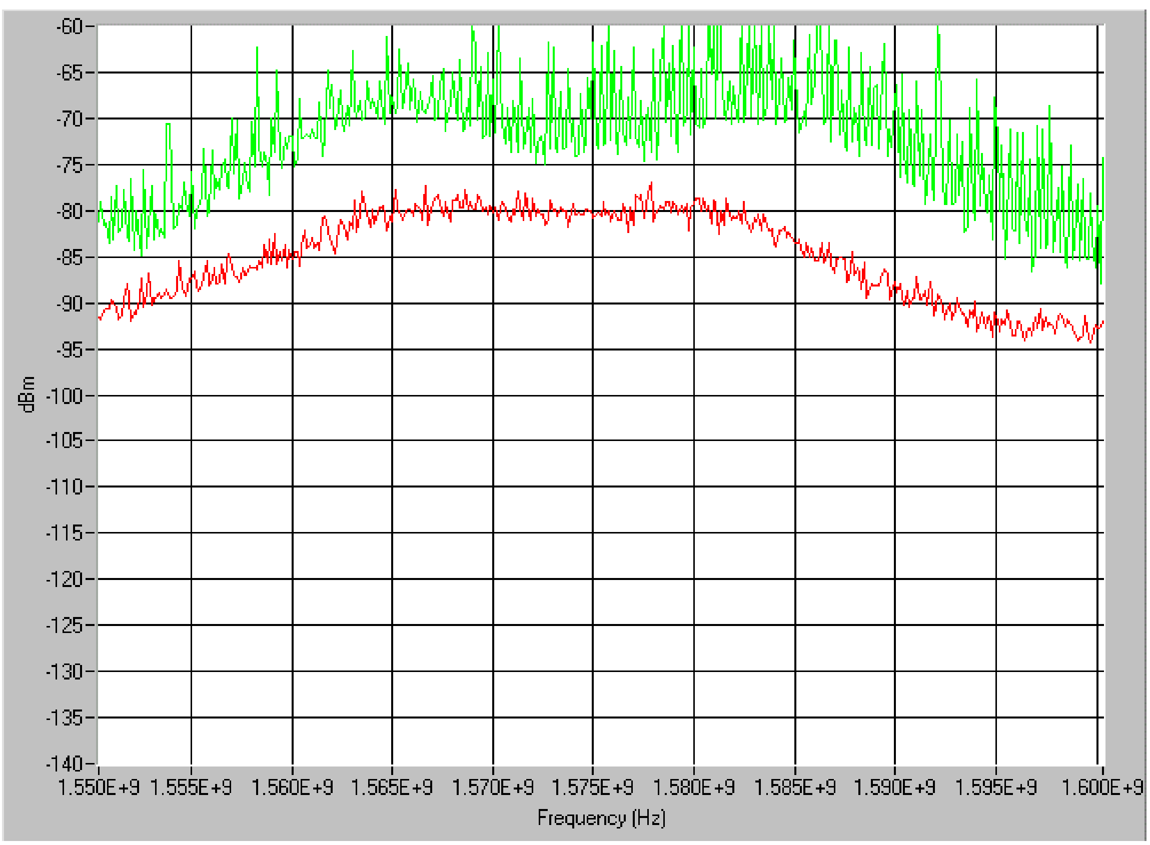
In these plots, you can observe that the LHCP reception near the zenith is only a few dB less than the RHCP. This indicates that the axial ratio is severely degraded (close to 15 dB). The system performance of this antenna was poor.

These examples of asymmetrical ground planes indicate that the antenna expects to see a symmetrical ground plane and a symmetrical radome in order to not be detuned.

6) Additional Sources of Interference

The final point that we looked at involves additional sources of interference. Figure 2 is a spectrum analyzer plot of the 45336-00 antenna when it is placed near a PDA. The red trace is the plot when the PDA is turned off; the Green trace is the plot when the PDA is active. As you can see, there is a significant amount of energy both inside the GPS band, as well as outside that is being generated by this PDA. It is enough that a GPS receiver will not track reliably.

For getting reliable GPS performance, the interference from the other electronic units needs to be shielded by roughly 20 dB.

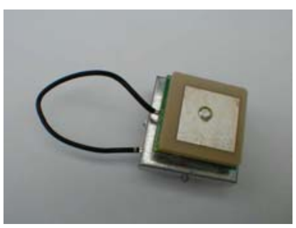


Interference from a PDA
FIGURE 2

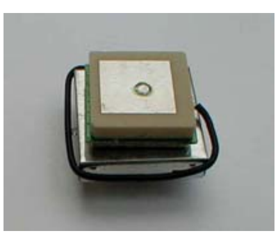
7) Conclusion

In conclusion, the system designer needs to consider the following points when integrating small unpackaged GPS antennas:

- The antenna P/N 45336-00 requires a ground plane.
- The ground plane that the antenna is connected to needs to be symmetrical.
- The Z-axis of the antenna should point near the zenith for best performance.
- When using the shield of the Lassen® SQ or M-Loc GPS receivers as the ground plane, the antenna cable must be kept in very close proximity to the module. Please see Photographs 3 and 4.



Wrong: Loose cable can act as an antenna and pickup interference.
FIGURE 3



Right: Keep cable close to the antenna and the GPS module to minimize interference.
FIGURE 4

- The radome needs to be designed symmetrical so that the antenna is not tuned off frequency.

- The radome spacing used in the tests, described in this guideline is 0.020 inches (0.5 mm). Radom spacing is the free space between the plastic radome and the antenna patch. In order to determine the optimum radome spacing in your application, you could run the frequency response for your GPS system. Frequency response shows the antenna gain as a function of frequency for both RHCP and LHCP signals.

- Other electronics can interfere with the antenna. Shielding must be adequate.
  It is a good idea to look at the output of the active antenna with the GPS and other electronics in the system turned on using a spectrum analyzer, to verify that there is not significant energy being radiated into the antenna. It is also a good idea to look at the antenna gain and axial ratio at zenith as a function of frequency to confirm that there is not a significant loss of gain and that the antenna is still tuned on frequency. You might also need to consult someone experienced in RF design and layout.

APPENDIX A
ANTENNA ELEVATION PLOTS

Please see the following Antenna Elevation Plots:

Appendix A_AE_GP1-0	…..	Ant. Elevation Plot Ground Plane 1, Azimuth at 0 deg
Appendix A_AE_GP1-90	…..	Ant. Elevation Plot Ground Plane 1, Azimuth at 90 deg
Appendix A_AE_GP2-0	…..	Ant. Elevation Plot Ground Plane 2, Azimuth at 0 deg
Appendix A_AE_GP2-90	…..	Ant. Elevation Plot Ground Plane 2, Azimuth at 90 deg
Appendix A_AE_GP3-0	…..	Ant. Elevation Plot Ground Plane 3, Azimuth at 0 deg
Appendix A_AE_GP3-90	…..	Ant. Elevation Plot Ground Plane 3, Azimuth at 90 deg
Appendix A_AE_GP4-0	…..	Ant. Elevation Plot Ground Plane 4, Azimuth at 0 deg
Appendix A_AE_GP4-90	…..	Ant. Elevation Plot Ground Plane 4, Azimuth at 90 deg
Appendix A_AE_GP5-0	…..	Ant. Elevation Plot Ground Plane 5, Azimuth at 0 deg
Appendix A_AE_GP5-90	…..	Ant. Elevation Plot Ground Plane 5, Azimuth at 90 deg
Appendix A_AE_GP6-0	…..	Ant. Elevation Plot Ground Plane 6, Azimuth at 0 deg
Appendix A_AE_GP6-90	…..	Ant. Elevation Plot Ground Plane 6, Azimuth at 90 deg
Appendix A_AE_GP7-0	…..	Ant. Elevation Plot Ground Plane 7, Azimuth at 0 deg
Appendix A_AE_GP7-90	…..	Ant. Elevation Plot Ground Plane 7, Azimuth at 90 deg
Appendix A_AE_GP8-0	…..	Ant. Elevation Plot Ground Plane 8, Azimuth at 0 deg
Appendix A_AE_GP8-90	…..	Ant. Elevation Plot Ground Plane 8, Azimuth at 90 deg
Appendix A_AE_GP9-0	…..	Ant. Elevation Plot Ground Plane 9, Azimuth at 0 deg
Appendix A_AE_GP9-90	…..	Ant. Elevation Plot Ground Plane 9, Azimuth at 90 deg
Appendix A_AE_GPng-0	…..	Ant. Elevation Plot <u>No</u> Ground Plane, Azimuth at 0 deg
Appendix A_AE_GPng-90	…..	Ant. Elevation Plot <u>No</u> Ground Plane, Azimuth at 90 deg

APPENDIX B
ANTENNA RETURN LOSS PLOTS

Please see the following Antenna Return Loss Plots:

Appendix B_SC_GP1-NR	**…..**	Smith Chart Ground Plane 1, No Radome
Appendix B_SC_GP1-R	**…..**	Smith Chart Ground Plane 1, with Radome
Appendix B_SC_GP2-NR	**…..**	Smith Chart Ground Plane 2, No Radome
Appendix B_SC_GP2-R	**…..**	Smith Chart Ground Plane 2, with Radome
Appendix B_SC_GP3-NR	**…..**	Smith Chart Ground Plane 3, No Radome
Appendix B_SC_GP3-R	**…..**	Smith Chart Ground Plane 3, with Radome
Appendix B_SC_GP4-NR	**…..**	Smith Chart Ground Plane 4, No Radome
Appendix B_SC_GP4-R	**…..**	Smith Chart Ground Plane 4, with Radome
Appendix B_SC_GP5-NR	**…..**	Smith Chart Ground Plane 5, No Radome
Appendix B_SC_GP5-R	**…..**	Smith Chart Ground Plane 5, with Radome
Appendix B_SC_GP6-NR	**…..**	Smith Chart Ground Plane 6, No Radome
Appendix B_SC_GP6-R	**…..**	Smith Chart Ground Plane 6, with Radome
Appendix B_SC_GP7-NR	**…..**	Smith Chart Ground Plane 7, No Radome
Appendix B_SC_GP7-R	**…..**	Smith Chart Ground Plane 7, with Radome
Appendix B_SC_GP8-NR	**…..**	Smith Chart Ground Plane 8, No Radome
Appendix B_SC_GP8-R	**…..**	Smith Chart Ground Plane 8, with Radome
Appendix B_SC_GP9-NR	**…..**	Smith Chart Ground Plane 9, No Radome
Appendix B_SC_GP9-R	**…..**	Smith Chart Ground Plane 9, with Radome
Appendix B_SC_NOGP-NR	**…..**	Smith Chart NO Ground Plane, No Radome
Appendix B_SC_NOGP-R	**…..**	Smith Chart NO Ground Plane, with Radome