Application Note:

Using the WS1357 13 mm GPS Antennas.

Introduction

Thank you for your interest in Wi-Sys Communications' WS1357 active 13 mm GPS antenna products. This brief note is intended to provide accessible guidance with respect to their use, which, depending on your circumstances, may not be as straight forward as might first appear.

As an introductory starting point, antennas are a form of transducer that have the function of transformation of electromagnetic field energy into an electrical signal (or vice versa). The key patch antenna parameters are size, operating frequency, gain, radiation pattern (beamwidth) and bandwidth. This discussion is limited to low cost, single electrode13mm patch elements.

The electrical side of the transducer function is amenable to technology, but the electro-magnetic coupling of the antenna is a function of dimensions and geometry, which are directly determined by the laws of physics based on the signal wavelength in the dielectric material of the patch.

Patch antennas are narrow band electromagnetically resonant devices with a response frequency that is a direct function of the dielectric constant of the fabrication materials and the antenna dimensions. A traditional GPS patch antenna may be considered to be two orthogonal transmission line devices that are coupled with appropriate phasing to yield a circularly polarized receiving antenna. For GPS signals the coupling is configured such that the antenna is right hand circularly polarized.

The transmission lines are formed between a ground plane electrode on the base of the patch and the front face electrode. The dimensions of the patch are such that the front face electrode is approximately lambda/2 on a side, relative to the wavelength of the signal in the dielectric material of the antenna (with a virtual RF ground at the centre). Most usually, this material has a high dielectric constant (Ek) being approximately 20+, 45 and 90+ for 25 mm, for 18mm and 13mm patch antennas, respectively.

In use, patch antennas are typically mounted on a ground plane, such as a PCB or metal bulkhead.

The ground plane may be considered to have two surfaces or "sides". The first is within the patch on the dielectric side, the second is the outside or opposite metal surface of the ground plane. Because of the skin effect, RF signals are not conducted through conductive planes, and electrical connection occurs only at the edges of the plane, where currents may flow from one side to the other.

Necessarily, balanced anti-phase currents are induced on opposing faces of the patch and ground electrodes. The external signal paths (electrode surfaces in air) present reactive shunt connections at the edges of the patch and ground. As the dimensions of the patch are reduced (with increasingly high dielectric materials) , the shunt impedances become smaller, thereby substantially increasing the "Q" and reducing the bandwidth of the resonant structure.

It is also important to preserve the antenna impedance bandwidth through simple matching networks to the LNA.

Circularly polarized RF signals can be considered to be the super-position of two linearly polarized signals in quadrature; with arbitrary axis of decomposition. The relative phase relationship (lead or lag) with respect to the axis of the two linear signals determines if the signal is RHC or LHC.

The ability of the patch antenna to receive circularly polarized signals results from its physical structure. In general, patch antennas are designed such that the resulting terminal voltage of signals received in each of the orthogonal responses are phase shifted so as to sum for the appropriate circular polarization. It follows that the signals will difference for signals of the opposite circular polarization.

For single pin feed antennas, circular polarization is achieved either by a corner cut which couples the response of one orthogonal direction to the other, or by patch electrodes with offset dimensions such that one axis is inductive (with a Q of 1), and the other capacitive. In either case, the impedance is determined by the offset of the pin from the geometric centre of the patch, in the first case, offset in one direction only, and in the second, offset in both. Maximum bandwidth and gain are achieved simultaneously when both antenna orientations are critically coupled, regardless of how this is achieved.

Ground Plane Considerations

Perhaps surprisingly, it is the ground plane size that strongly influences antenna gain, resonant frequency and coupling for any given patch size. Best performance is achieved with a ground plane that is relatively large compared with the patch element above it.

Benefits accrue for any ground size bigger than the patch element, and the maximum ground plane effect is achieved with a ground plane of about 10cm on a side (or circular diameter). Antennas may be optimized for smaller ground planes but this is always at the expense of gain. For comparison, the 13mm patch antenna will typically provide -1dBic gain with a 30mm ground plane, while a 25mm patch will provide 5.5dBic with a 100mm ground plane. Clearly, small size comes at a cost, and optimization is necessary to preserve available performance.

This having been said, modern GPS receivers (circa 2006) can acquire and track GPS at extremely low signal levels, so that good GPS navigation performance is achievable even with a 13mm antenna.

A second, concomitant effect of the ground plane is to offset the resonant frequency of the patch element. Over a small range of ground plane size, patch resonant frequency is shifted up with increased ground plane size, in a non-linear relationship. This can be compensated for with antennas manufactured with offset frequencies (by use of different etching masks).

However, because the 13mm patch has a narrow frequency response, being approximately 6MHz wide for a -1dB response, compared with approximately 30MHz for the 25mm patch, the de-tuning effects of the ground plane and housing for 13mm patch antennas must be positively accommodated.

The effects of ground plane size on frequency and gain are shown below.

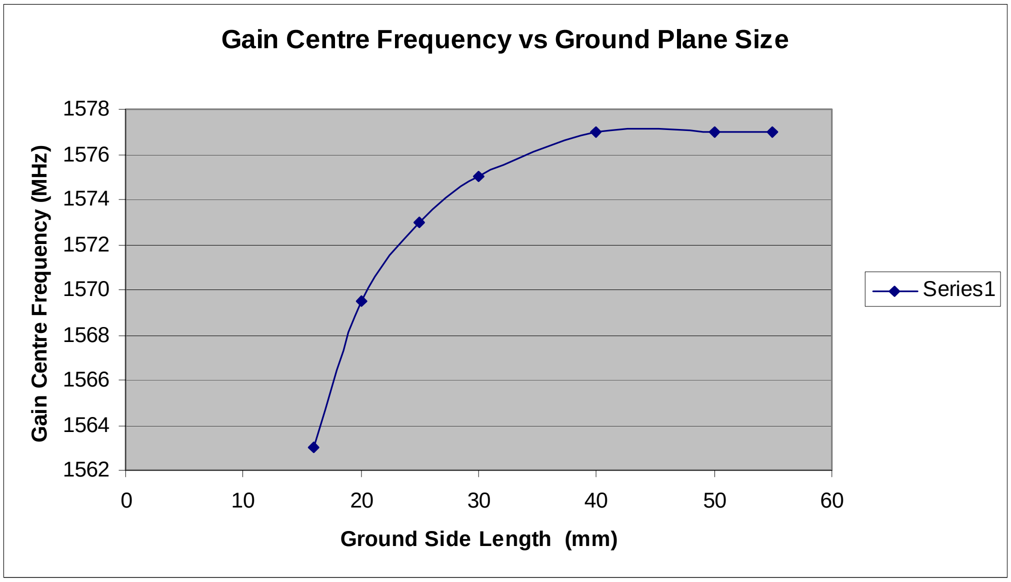

Fig 1 13mm Patch Centre frequency as a Function of ground Plane Size

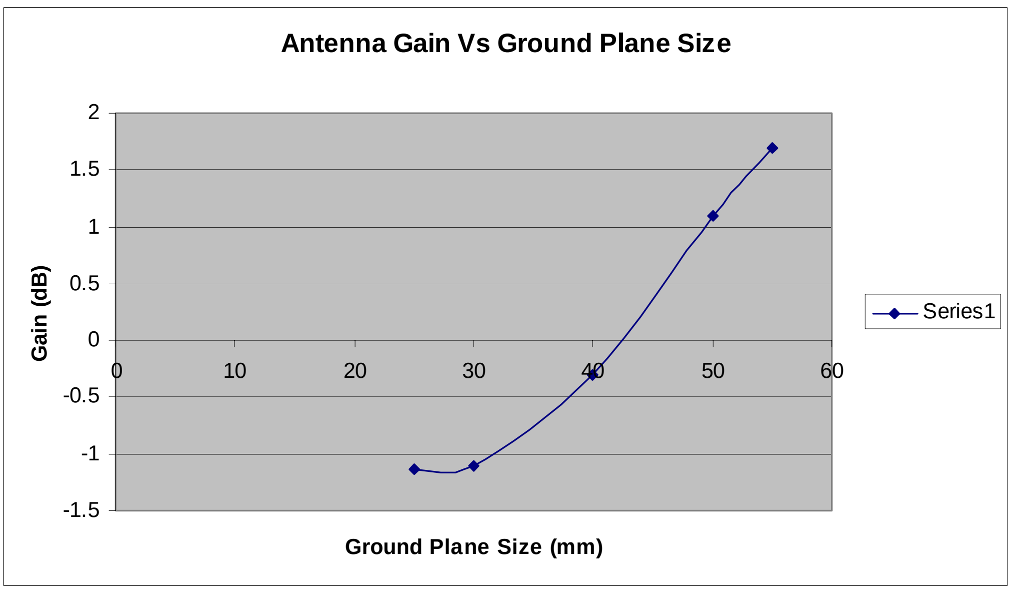

Fig 2 13mm Patch Antenna Gain as a function of Ground Plane Size

It should be noted that it is not necessary for the antenna ground plane to be directly electrically connected to the antenna ground. Indeed, if a ground plane is attached to the antenna (as it is for the WS1357 evaluation samples), an additional (non-connected) ground plane in close proximity “beneath” the circuit ground plane, provides added gain benefits, with relatively minor detuning effects. In this circumstance the added ground plane can be considered to be more of a reflection plane than a formal ground plane.

Comparative Antenna Ground Plane effects, 13mm vs 25mm Patches.

It is useful to compare the performance of 13mm and 25mm patch antennas. For a 13mm patch, the -1dB bandwidth is 6MHz compared with approximately 30MHz for the 25mm patch antenna. Similarly, a 13mm antenna with a 30mm (square side) ground plane will provide a gain of approximately -1dBic, while a 25mm patch has a gain of is about +2.5dBic without a ground plane, increasing to about 5.5dBic with a 100mm ground plane.

However, if the 13mm patch is situated on a large ground plane (100mm) the small antenna will provide about 3dBic, or just 2.5dB below that achieved with a 25mm patch.

The Effects of Plastic Housings in Close Proximity.

The presence of a plastic radome, or cover, over the patch antenna element can also cause the antenna to be detuned. In this case, as might be expected, plastics in close proximity de-tune the antenna downward by several MHz. While this effect can, to some extent, be used to offset the upward detuning effects of the ground plane, optimization is complex and not recommended. The housing detuning effects are more critical at the patch antenna edges, and ideally, the plastics should not be closer than 2mm to the edges of the ceramic patch.

Evaluation Samples - Ground Plane Issues

Since the ground plane environment for the evaluation units cannot be anticipated, these are supplied with a small 23 mm “evaluation ground-plane” attached to the LNA PCB plane. Fig 3 (a) shows an isometric view of the basic 13mm active antenna, and 3 (b) shows a side view with the “evaluation ground-plane” attached.

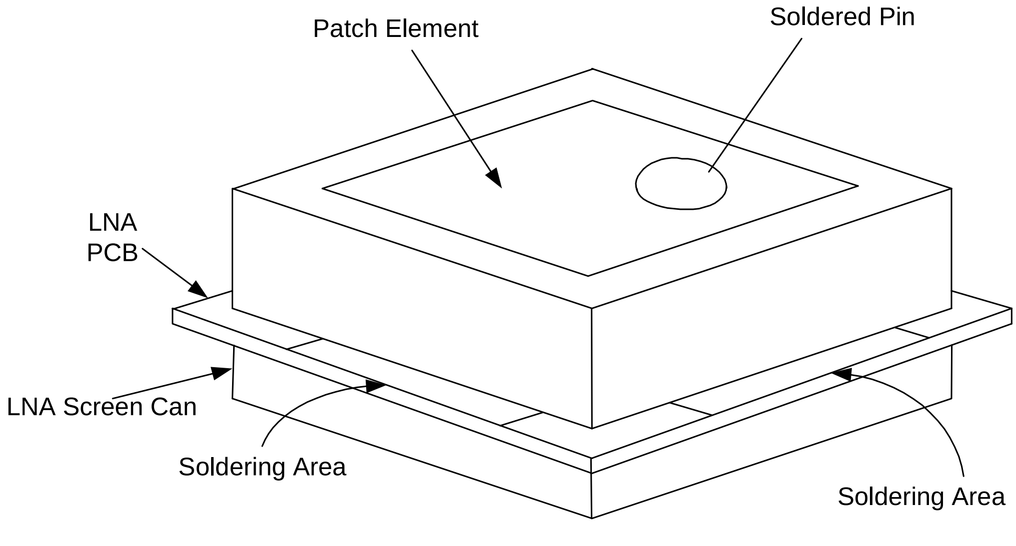

Fig 3(a) Active 13mm Antenna Construction (excluding flying connector)

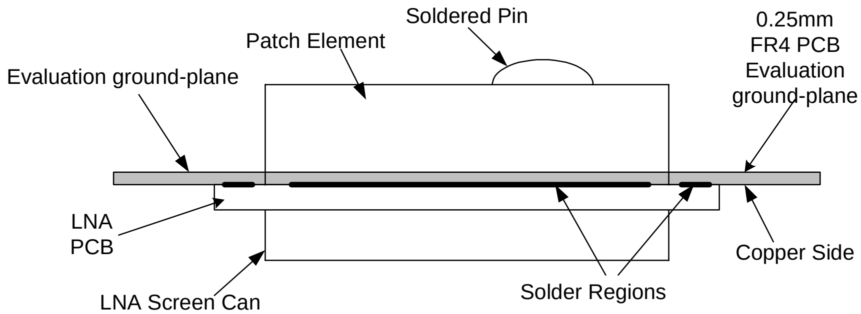

Fig 3(b) Side-view of 13mm Antenna with attached "Evaluation ground-plane"

The purpose of the "evaluation ground-plane" is to tune the antenna close to resonance, without the use of an additional ground plane. However, an additional ground plane in close proximity beneath the LNA screen-can will considerably raise the antenna gain while simultaneously slightly increasing the resonant frequency of the patch element. The size of the "evaluation ground-plane" has been chosen as a compromise, so that reasonable results can be obtained without the need to specifically tune these devices.

Production antennas are available with pre-determined ground configurations, and customisation is available for high volume applications.

Means of Attachment

We recommend two means of attachment for production versions of the WS1357 13 mm antennas.

In the first, the antenna assembly is attached adhesively to the substrate with double sided tape attached to the base of the LNA screening can. This is shown in figure 4. The coaxial feed cable should be strain relieved to remove any constant force on the adhesive attachment.

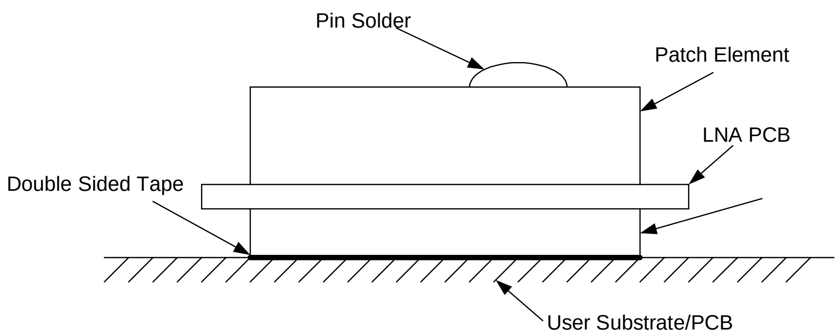

Fig 4, Adhesive attachment of the 13mm Antenna

A ground plane so situated will considerably improve the gain, and is recommended, especially since the frequency up-shift effect of the ground plane is significantly reduced because of the distance between the patch ground and the substrate ground. A simple housing/ground plane optimization review will then be required to select the appropriate production version of the WS1357.

A second method of attachment is to "insert" the ceramic patch element through a matching hole (square, to accommodate the patch) in the user PCB. The user PCB should have a suitable ground plane connected via the solder regions to make an electrically contiguous ground. This is shown in figure 5.

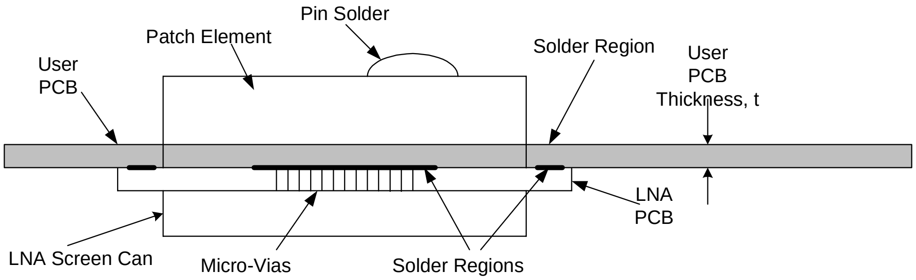

Fig 5, Soldered attachment with 13mm antenna “Inserted” into the User PCB

It should be noted that there are two effects on the antenna tuning in this configuration. Firstly, the antenna resonance is up-shifted by the ground plane effect according to the graph in fig 1, with concomitant improvement in gain. Secondly, the close proximity of the high dielectric constant PCB substrate material to the edges of the patch element (FR4 has a dielectric constant of about 4.5) causes a small frequency downshift. Assuming the user PCB has copper only on the lower side (with reference to fig 5) the patch downshift is about 2.5MHz for a 1.5mm PCB substrate. A reasonable approximation is to assume the downshift is proportional to the PCB thickness.

Production Configurations, and Engineering Solutions

Wi-Sys is happy to offer application assistance, and for high volume applications, we will be glad to review your specific requirements with an eye to customization of a patch antenna for your product. However, this typically is an iterative process to ensure that the patch element is optimally tuned in the product environment and involves a minimum purchase requirement. It is also not usually economic to undertake this activity for product runs of less than 10, 000 pieces.

Standard Products

A very effective alternate, that is usually possible, is to adapt the product (ground) environment to fit the available patch designs. To facilitate this approach Wi-Sys offers the WS1357 13mm antenna in several “standard” tuning configurations (by implication, “standard” ground plane environments).

WS1357-A

The WS1357-A is designed to operate with just its 16mm LNA PCB (embedded ground plane) with no other ground plane. The antenna is tuned on frequency with this small ground plane, which, precisely because it is small, is also the minimum gain configuration.

WS1357-B

The WS1357-B is designed to be incorporated, with a soldered ground plane connection, into a user PCB that extends the ground plane to 30mm square.

WS1357-C

The WS1357-C is designed to be incorporated into a large (80+mm) ground plane. This is the maximum gain configuration.

WS1367

The 13mm product is also offered in a WS1367 format, which includes an embedded 30mm square ground plane (incorporated into the LNA PCB).

Conclusions

This application note has briefly discussed the limitations of small patch antennas and the effect of the ground plane in the immediate vicinity of the antenna.

While the small size of the 13mm GPS antenna comes at the price of diminished antenna performance, it is clear that this can largely be accommodated by the increased sensitivity of modern GPS receivers.

While the larger antenna formats will always provide better performance as antennas, the 13mm antenna opens up new product format possibilities and is an appropriate choice where form factor is critical.

About Wi-Sys Communications

Wi-Sys Communications Inc. is a leading provider of premium performance wireless products for a wide range of mobile applications. Wi-Sys Communications' core competencies include antenna design, RF systems and digital wireless networks. Wi-Sys manufactures a range of products for GPS and satellite communications systems, as well as high performance antennas for the Telematics, mobile radio, and precision GPS markets. In addition, Wi-Sys Communications provides custom antenna and RF system design services, and custom Timing and Telematics solutions.

Wi-Sys Communications Inc
Rev 2.0
19 July 2006