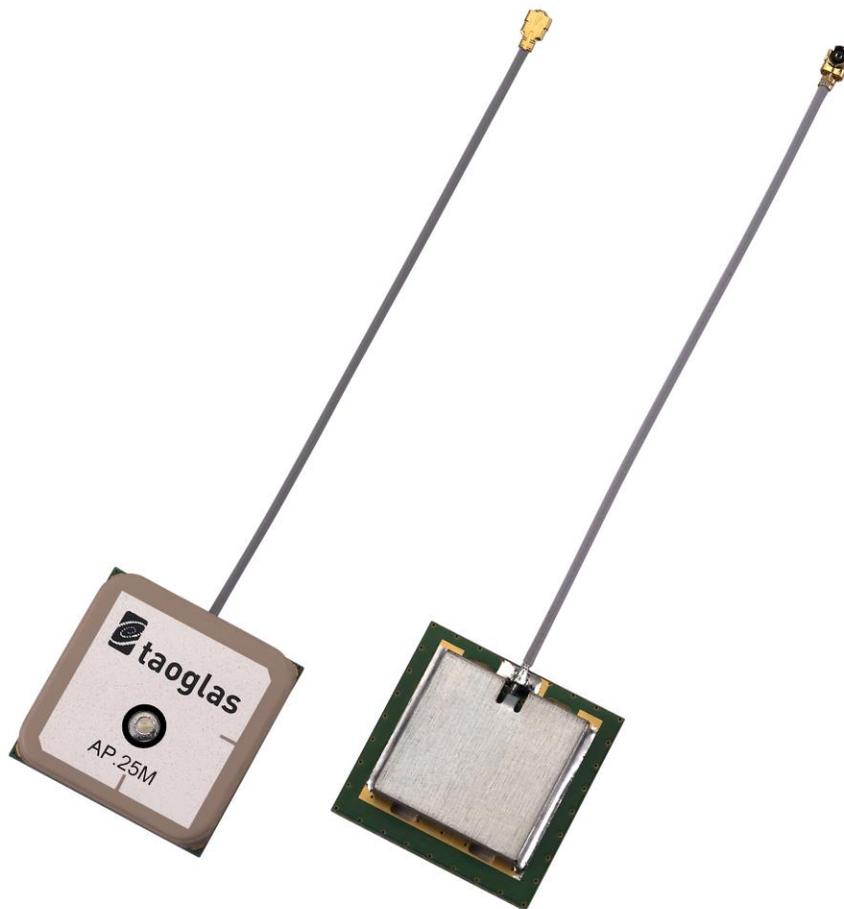


Internal GPS Active Patch Antenna Application Note



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1. BASICS

An internal GPS active patch antenna with cable is used in most mobile devices today that require high signal strength in a small form factor. It is the highest performing solution of all antenna types.

Usually consisting of a specially formulated dielectric ceramic, a trace is printed on the substrate to get the desired right hand circularly polarized patch antenna topology. The patch is mounted on a PCB; underneath the PCB is the Low Noise Amplifier (LNA) which amplifies the GPS signal before being transmitted through the coaxial cable and connector to the receiver.

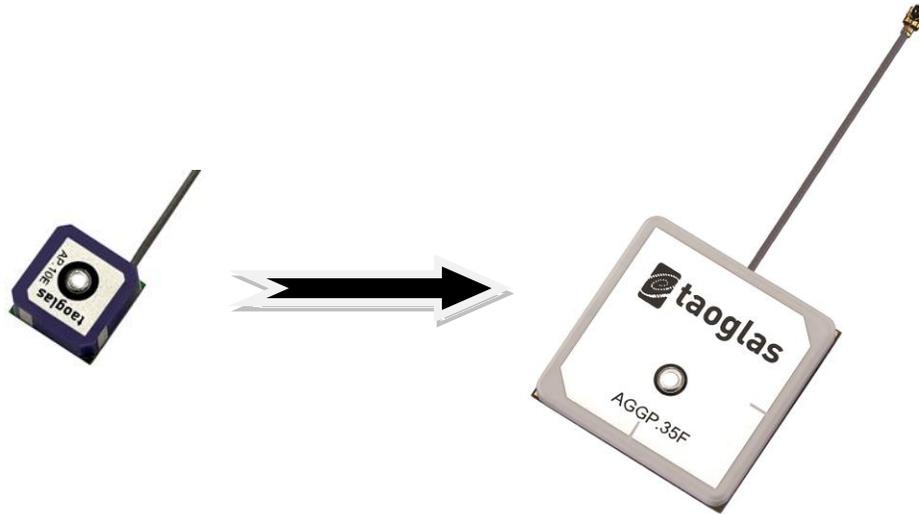
This design application note is intended to help the antenna integrator understand the relevant parameters affecting the antenna performance. Taoglas recommends that the integrator strictly follow the guidelines in this application note. Upon your device prototype completion, Taoglas can provide further optimization by offering custom tuning and testing services for the antenna in your device. (See Section 17 for further info on Tuning.)

2. APPLICATIONS

An internal GPS active antenna with cable is suitable for mobile applications or other areas where internal antennas are required, or where not much space or volume is available. It is ideally affixed to the plastic housing of a device directly by double-sided adhesive, screw-mounting, or slot. Taoglas internal GPS active patch antennas come in a range of sizes from 10mm to 35mm.

3. SIZE

The larger the antenna surface area (or volume), in general, the higher the performance in terms of gain and radiation characteristics.



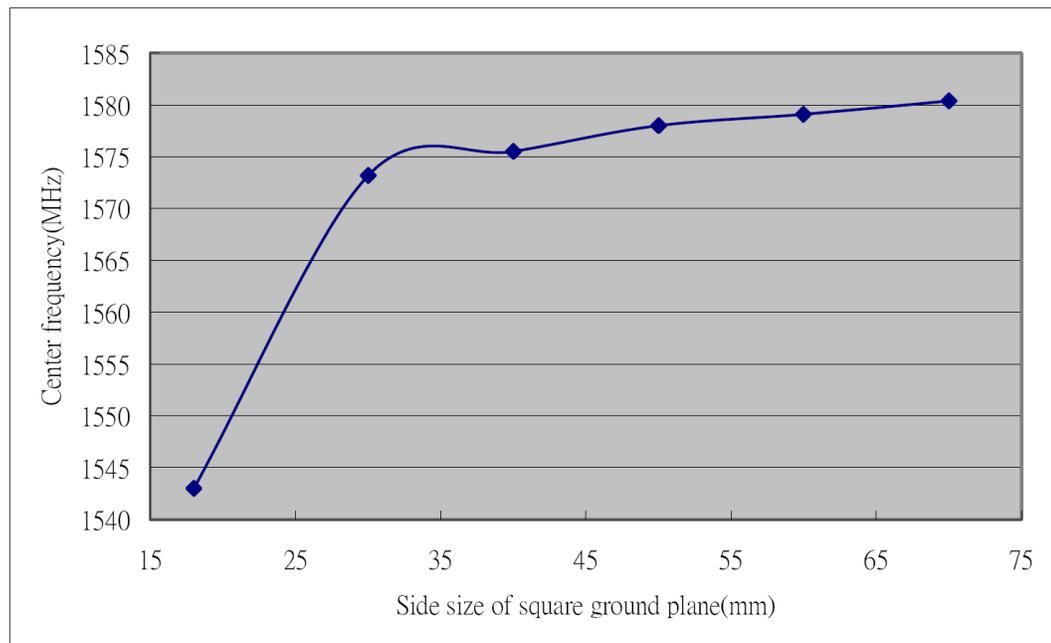
4. SHAPE AND PROFILE

GPS internal active patch antennas are usually square in dimension. Overall height profiles range from 4mm for our slimmest, to 7mm for bulkier designs.



5. GROUND PLANE EFFECTS

The larger the ground-plane, the higher the antenna gain in general. Also the center frequency of the antenna will change depending on the size of the ground-plane. The individual patches on Taoglas active patch antennas can be tuned to take these changes into account.



Graph of 18.5mm Patch Center Frequency shift with Ground-plane size

6. IMPEDANCE

RF circuits in mobile devices should be designed for 50 Ohm characteristic impedance at the source (RF module), transmission line (PCB trace or coax cable) and load (antenna). So we will usually match the antenna for 50 Ohm impedance.

7. BANDWIDTH

The effective bandwidth of a GPS antenna is usually measured by the frequency band below -10dB return loss. A GPS ceramic patch bandwidth narrows with size.

Typical bandwidths for GPS patches are as follows

25*25*4 mm	20 MHz
18*18*4 mm	10 MHz
15*15*4 mm	8 MHz
12*12*4 mm	7 MHz
10*10*4 mm	5 MHz

Therefore the smaller the antenna, the more chance it will have that frequency shifts in the device will cause it to perform very poorly, thus necessitating that the antenna bandwidth be retuned to have the effective bandwidth at the GPS 1575.42 MHz frequency.

8. VSWR

VSWR (Voltage Standing Wave Ratio) is a function of the return loss, which describes the power reflected from the antenna. A lower VSWR means the antenna has a better match to the transmission line and more power is delivered to the antenna. A VSWR of 1.0 represents an ideal match. In practice, a VSWR below 2.0 will still allow for very good performance.

9. LINK BUDGET

A link budget is used to determine what antenna gain is needed for a given application.

GPS Link Budget Analysis - Example

	Inputs	Power Levels
Transmitter (i.e Satellite)	Gain/Loss (dB)	Sig. (dBm)
Transmitter Power (based on 15W Tx Power)	41.76	41.76
RF Component Losses	-1.0	40.76
Transmission Line Loss	-1.5	39.26
Transmit Antenna Gain	1.0	40.26
Effective Radiated Power (ERP)		40.26
Channel		
Free Space Loss	-165.51	-125.25
Rain + Cloud + Atmospheric Loss	-0.3	-125.55
Multipath Loss	-20.73	-146.28
Receiver Ant Gain (Taoglas AP-17A Active Antenna)	15.00	-131.28
RF Component Losses	-1.00	-132.28
SiRFstarIII Receiver Noise Level		-159
Fade Margin		26.72

Where do we get this from? We need to discuss the GPS system attributes

The GPS satellites orbit the earth with a speed of 3.9km per second and have a circulation time of 12 h sidereal time, corresponding to 11h 58min earth time. This means that the same satellite reaches a certain position about 4 minutes earlier each day. The mean distance from the middle of the earth is 26560 km. With a mean earth radius of 6360 km, the height of the orbits is then about 20200 km. Orbits at this height are referred to as MEO – medium earth orbit. In comparison, geostationary satellites like ASTRA or Meteosat – satellites orbit the earth at 42300 km, which is about twice the distance of GPS satellites.

This long distance creates multipath issues. Multipath occurs when waves emitted by the transmitter travel along a different path and interfere destructively with waves travelling on a direct line-of-sight path. This is sometimes referred to as signal fading. This phenomenon occurs because waves travelling along different paths may be completely out of phase when they reach the antenna, thereby cancelling each other.

So the amount of extra RF power radiated to overcome this phenomenon is referred to as fade margin. The exact amount of fade margin required depends on the desired reliability of the link, but a good rule-of-thumb is 20dB to 30dB. This is the number we always want to reach and which we work backwards from when calculating the link budget.

We can see that the three controllable variables in this budget are the RF component losses, the antenna gain, and the receiver sensitivity or “noise level”. By manipulating these three variables we can preserve the total fade margin to enable a strong GPS signal lock. A lower gain antenna would need a higher receiver sensitivity, conversely a low sensitivity receiver would require a higher gain antenna.

10. GAIN

We can separate the gain of an active GPS antenna into two parts.

First is the passive gain. This has the most effect on the intrinsic performance of the antenna. The passive gain of the antenna is closely linked to the surface area or volume of the antenna. The larger the surface area or volume of the antenna, the higher the gain. Care must be taken that clearances of minimum 4mm are kept from other metal components in the device or metallised substances which will obstruct the electro-magnetic radiation, substantially reducing the gain. Also, the larger the ground-plane of the antenna, the more the gain.

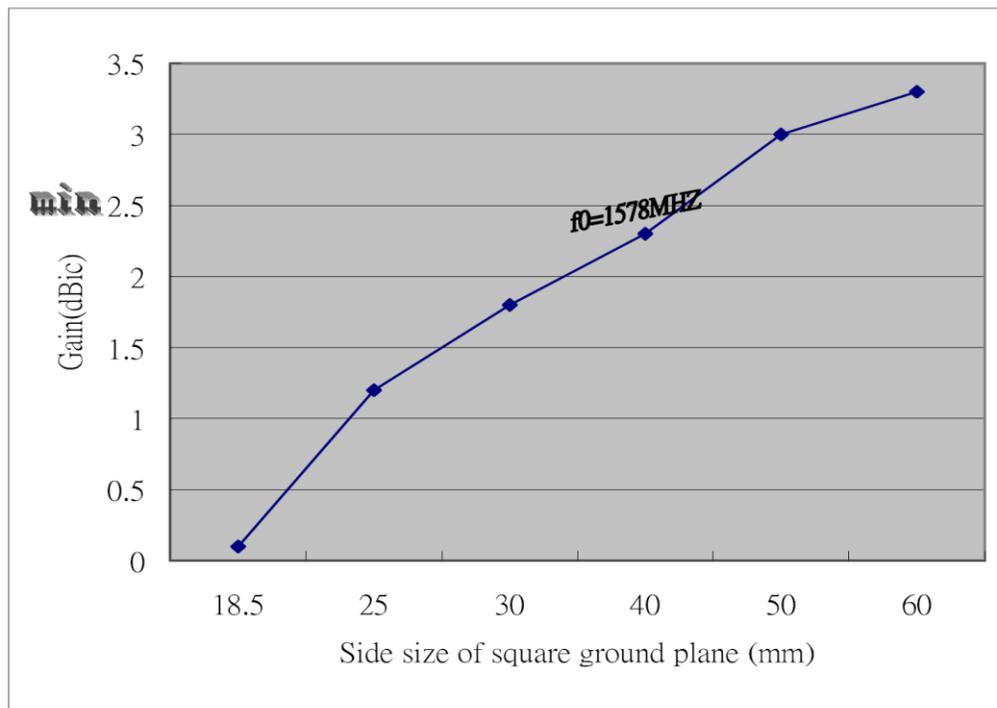
Gain of the antenna is chiefly determined by the directionality of the antenna and the surface area.

A GPS patch antenna has high gain towards the zenith (highest point in the sky), and gradually decreasing gain towards the horizon. This is actually an advantage compared to antennas that have their gain distributed in a fully Omni-directional pattern. The more Omni-directional an antenna, the worse

its average gain in any position. The reason patch antennas are more popular than helical or chip antennas is precisely because they deliver maximum gain towards one hemi-sphere, i.e. the sky, up to 5dBi towards the highest point of the sky. Whereas a helical or chip antenna will deliver something like -3~-5dBi in most directions, which is a huge drop in overall sensitivity.

Typical peak gain for GPS patch antennas on standardized ground planes are as follows:

25mm Patch	5 dBi
18mm Patch	2dBi
15mm Patch	1dBi
12mm Patch	0.5 dBi
10mm Patch	-2 dBi



Graph of 18.5mm Patch Gain vs. Size of Ground Plane

A larger ground plane will increase the gain of the antenna. Conversely, longer cable lengths or more lossy cables will decrease the gain of the antenna.

Second is the active gain. In this sense, gain is the ratio of input to output power. Typical GPS LNAs use two or three gain blocks and yield 25 dB to 50 dB of gain depending on the user's requirement. Unlike NF, a low or high gain does not indicate a good or bad LNA. It is important to specify the amount of gain that is required rather than to go for the highest available gain. More gain will produce more inter-modulation products in the LNA and receiver. Not enough gain can cause the GPS signal to be below the MDS (Minimum Detectable Signal) level of the GPS receiver.

One-stage LNA active antennas are enough for most GPS applications nowadays that use the latest generation GPS receivers.

Two-stage LNA active antennas are usually used where the cable is relatively long, longer than 200mm, to compensate for attenuation in the cable and effects of noise in the environment or with older GPS receivers with less sensitivity or no integrated LNA. Even when a two-stage LNA active antenna is used with the latest receivers, it will usually not saturate the signal as most of the latest receivers have automatic gain control.

Three-stage LNA active antennas are used for longer RG-174 cable lengths up to 8M.

For applications that require a cable length longer than 8M, an in-line GPS amplifier is needed every 10 meters or so to boost the signal.

11. NOISE FIGURE (NF)

Noise Figure is a ratio that indicates how much noise power the LNA will contribute to the total receiver noise. The Minimum Detectable Signal (MDS) is the weakest signal a receiver can decode. The more noise the LNA contributes, the higher the noise floor and the less sensitive the receiver is.

At the systems level, a poor LNA degrades the MDS. While LNA NF is not the only factor that drives the MDS, it is an important consideration since the noise figure of the first stage in a receiver chain is the single largest contributor to the system noise figure. A typical state of the art, single-stage, commercial-grade LNA at LBand (GPS) has a noise figure between

0.5 and 1 dB. A multistage GPS LNA with filtering has a noise figure between 1.0 and 2.5 dB. Taoglas active patch antennas have a noise figure between 1.0 to 1.5dB.

12. POWER CONSUMPTION

Power consumption is the current flowing through the LNA multiplied by the voltage coming out of the coax line. LNAs typically have their current specified. For a typical single-stage LNA, the current is between 2mA and 100mA or more. Taoglas LNAs typically have a power consumption of 3mA for one-stage LNAs, and 8~13mA for two-stage LNAs.

13. EFFICIENCY

Antenna efficiency is the ratio of the total power radiated by the antenna to the power accepted by the antenna. Efficiency is a good overall measurement of an omni-directional antenna for mobile communication systems such as GSM and WLAN. It is less useful for highly directional antennas such as the ones used for GPS. It is better to look at the actual radiation pattern of the top hemisphere of the patch antenna to understand its true performance characteristics.

14. POLARIZATION

Polarization describes the orientation of the wave oscillation. The radiation transmitted from GPS satellites is circularly polarized. An antenna designed for GPS reception should always be circularly polarized. Taoglas internal GPS active patch antennas are circularly polarized. The reason other competing technologies like chip, metal, or printed PCB circuit antennas have such poor GPS performance is they are all linearly polarized. In effect their sensitivity is reduced by 50% compared to a GPS active patch antenna, which causes major difficulty in acquiring a GPS lock in urban areas.

15. MOUNTING

Taoglas internal GPS active patch antennas, like all GPS antennas, should be placed with a line of sight to the sky. The antenna should be placed on the top of the device below the plastic housing, without metal nearby. The antenna cable should not be more than 200mm so as to minimize attenuation to the receiver. The cable should not be bent more than 30 degrees and should be routed away from noisy components such as ICs.

16. ENVIRONMENTAL CONSIDERATIONS

Close proximity to components or housing affects the electrical performance of all antennas. When placed within the enclosure, in most cases, there should be a clearance of 5mm in all directions from the housing, metal, or other components for maximum efficiency. A reduction in antenna efficiency and a shift in tuned frequency will be observed if these clearances are not maintained. Proximity effects will also have an adverse effect on the radiation pattern of the antenna. Device housings should never be metal or have metal materials when using internal antennas. Also note that some housing colorants, such as carbon black, have RF absorptive properties and can severely degrade antenna performance. Housing materials that absorb moisture, such as nylon, are also not recommended.

17. TUNING

GPS Patch antennas should be tuned to the ground-plane on which they are mounted. The specific device environment, such as the housing and surrounding components also impacts radiation pattern and can result in slight frequency shifts. Tuning is required to overcome these issues. This is done in our state of the art laboratories and anechoic chambers.

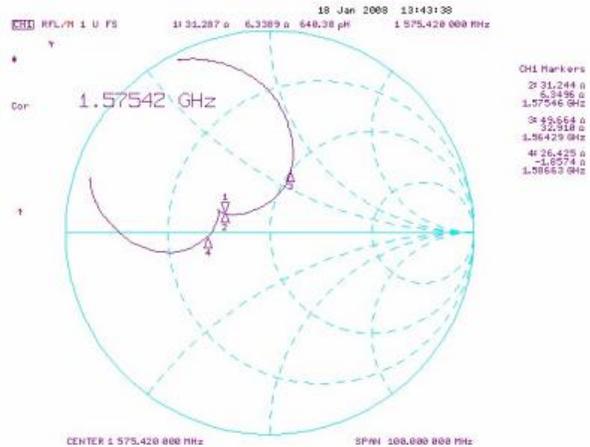
17.1 Impedance matching

The antenna will be tuned to get close to 50 Ohm match. The S11 return loss magnitude is also analyzed. The industry standard is <10dB across the bandwidth.

It is also important to check the radiation pattern and gain at in-bandwidth frequencies to understand the real performance of the antenna in the device.



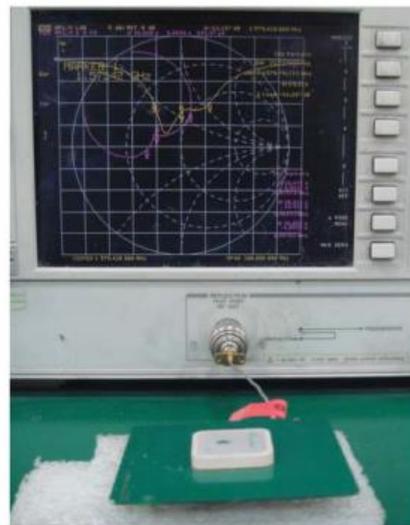
Return Loss : -12.43 dB



Impedance : 31.28+j6.33 Ohm



VSWR : 1.63@1575.42MHz



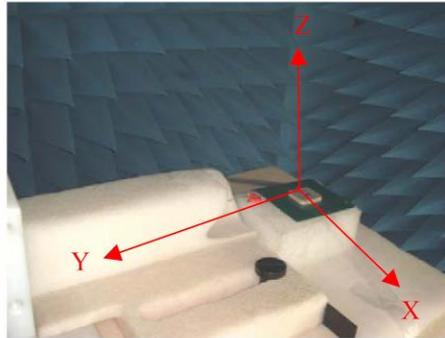
The antenna is physically tuned a number of ways. The shape of the top silver electrode can be changed or the feed-point can be moved.



17.2 Radiation Pattern and Gain Testing

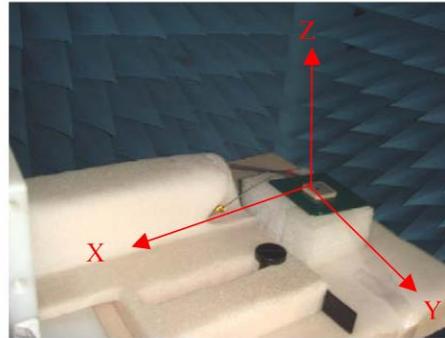
Radiation patterns of the antennas X-Y and Y-Z planes are taken in the device. These radiation patterns tells us the most important information about the real-life antenna performance in the field such as the antenna's ability to receive signals from satellites at low altitudes, or to be able to compare relative performance of one antenna against another. The below patterns are taken from scans of a 25mm*25mm*2mm patch on an extended 35mm ground-plane.

XZ-Plane

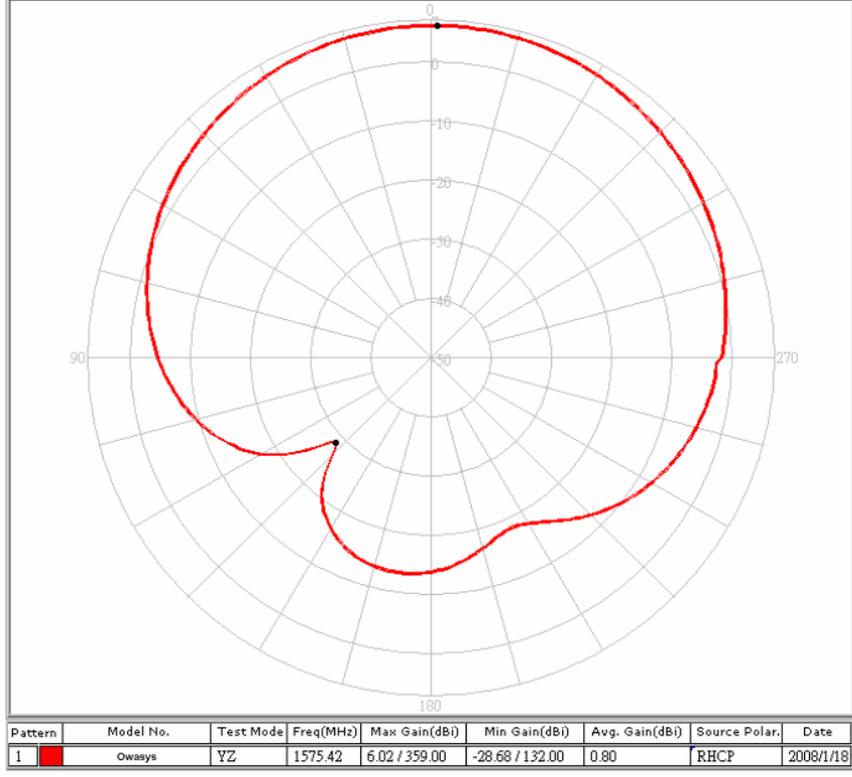
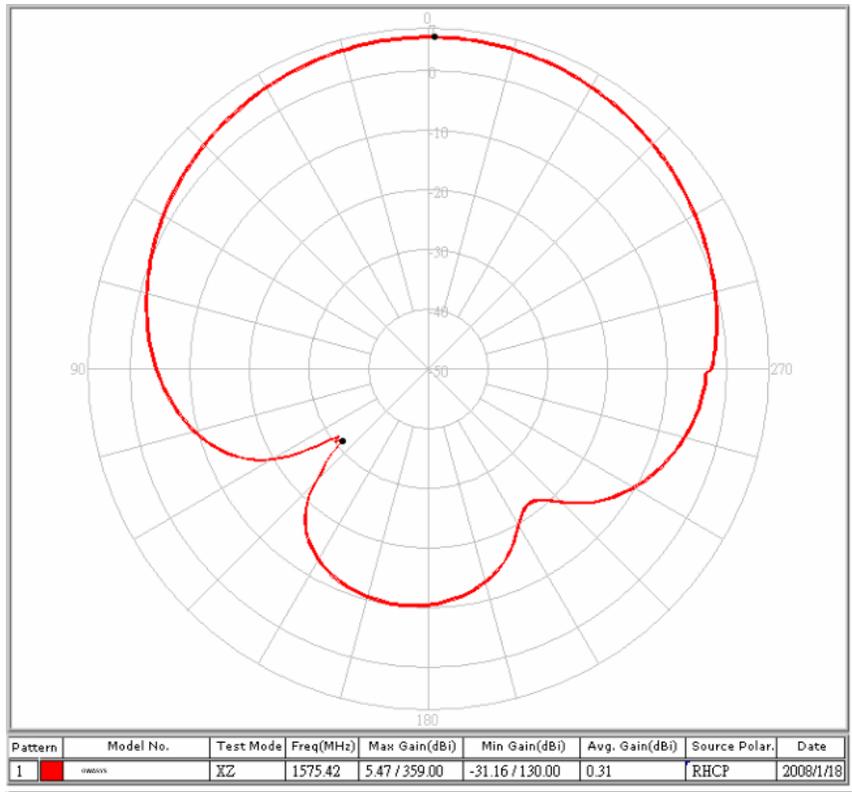


XZ Plane 1575.42 MHz

YZ-Plane



YZ Plane 1575.42 MHz



18. ISOLATION

Isolation is a measure of coupling between two different antennas. The inherently low power GPS signal is susceptible to interference from much higher power cellular or Wi-Fi radiation in the device. Therefore, GPS antennas should be placed as far as possible away from the other antennas in the device.

The antenna cables should not cross over or come close to the other's antenna.

Isolation testing is performed by sending a signal in one antenna and measuring the power of the signal at the other antenna. There should be at least 10dB difference between the transmit and the receive signal. The easiest method is to keep increasing the distance between the two antennas until the target isolation is achieved.

19. CABLE & CONNECTOR

A 1.13mm diameter micro coax cable is preferred in most GPS antenna projects as most economical solution. Cable loss is not a big factor if cable length is kept below 150mm.

The cable needs a good ground. Try to route the cable as close to the device ground as possible.

The cable should not be looped because it will cause frequency shifts and create magnetic fields which will interact with the main antenna magnetic field.

The cable should be kept away from emitting components such as LCD driver chips or CPUs.

It is preferred to use connectors on the cables for higher connection reliability, as opposed to solder. The most economical connector solution is the IPEX line of connectors which is compatible with Hirose U.FL and W.FL industry standards. Taoglas offers any cable and connector solution for the

customer. Taoglas also offers the on-board mating connector and cable jumpers.

20. SMD

Taoglas now offers the industry's first SMD internal GPS active patch antennas. These provide the lowest loss solution and enable automated assembly, increasing accuracy and reliability of integration and eliminating labour costs of mounting and connection.