

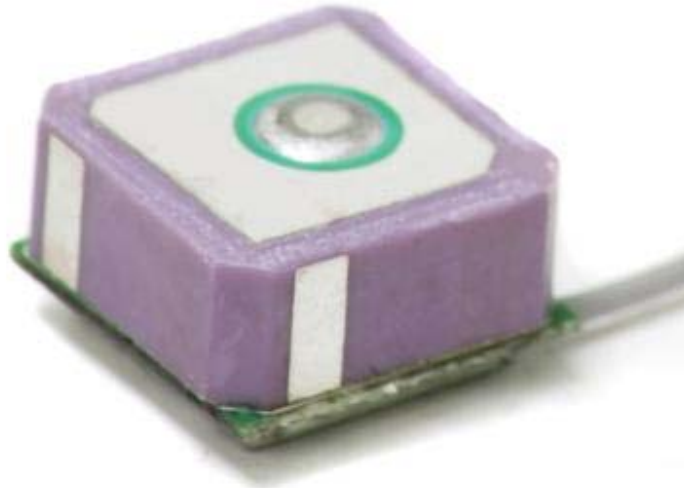
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Which Internal GPS Active Patch Antenna?

Version 1



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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.

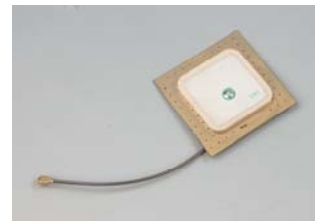
This design application note is intended to help the antenna integrator understand the relevant parameters affecting the antenna performance. Taoglas recommends that the integrator strictly follow the guidelines in this application note, upon your device prototype completion Taoglas offers further optimization by custom tuning and testing service of the antenna in your device.

2. APPLICATIONS

An internal GPS active antenna with cable is suitable for mobile applications or 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

3. SIZE

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



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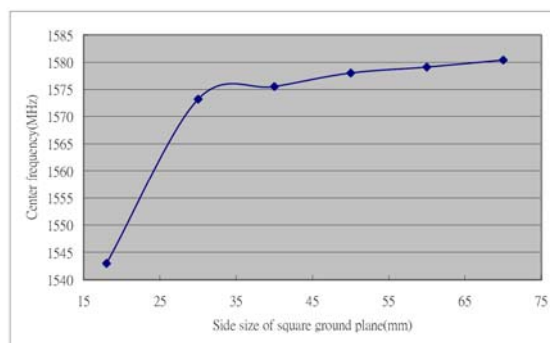
4. SHAPE AND PROFILE

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 gain in general.

Also the centre 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 into account these changes.



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

6. IMPEDANCE

RF circuits in mobile devices should be designed for a 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 a 50 Ohm impedance.

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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 1.5754 GHz frequency.

8. VSWR

In principle the target is to be below 2.0, ideally below 1.5.

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9. LINK BUDGET

We use a table called a link budget to determine what antenna gain we need 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 3.9 km per second and have a circulation time of 12 h sidereal time, corresponding to 11 h 58 min 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 in 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.

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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 canceling 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.

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10. GAIN

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

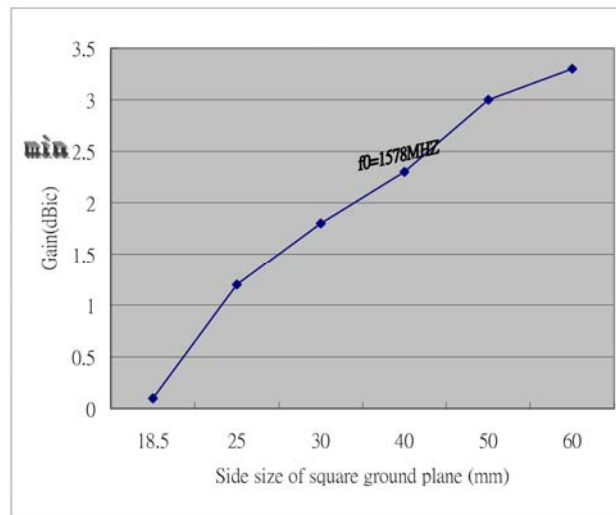
First is the passive gain. This has the most effect on the intrinsic performance of the antenna. The passive gain of the antenna is closely linked to the surface area or volume of the antenna. The larger the surface area or volume of the antenna the higher the gain. Care must be taken that clearances of minimum 4mm are kept from other metal components in the device or metallized 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. As the more omni-directional an antenna, the worse its average gain in any position. The reason patch antennas are most popular than helical or chip antennas is precisely because they deliver maximum gain towards one hemisphere, ie. 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 (in fact it also has areas it has null points), that is a huge drop in overall sensitivity.

Typical peak gain for GPS patch antennas on standardized ground planes are following.

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 LNA's 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 intermodulation products in LNA and receiver. Not enough gain can cause the GPS signal to be below the MDS 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 in-built 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 RG174 cable lengths up to 8M.

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For applications that require longer cable length than 8M, an in-line GPS amplifier is needed every 10 metres 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 Discernable 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 2 mA and 100 mA or more. Keep in mind that a really low current device can sometimes have a poor intercept behaviour of the LNA. Taoglas LNAs typically have a power consumption of 3mA for one stage LNAs and 8~13mA for two stage LNAs.

13. EFFICIENCY

Efficiency is a good overall measurement of an omni-directional antenna for mobile communication systems such as GSM and WLAN. It is less of a good measurement for GPS as ideally the GPS antenna in a device is pointing towards the sky. It is better to look at the actual radiation pattern of the top hemisphere of the patch antenna to understand its true performance characteristics

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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. Our 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 to acquire a GPS lock in urban areas.

15. MOUNTING

Taoglas internal GPS active patch antennas like all GPS antennas should be ideally 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 close to it. 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 on a non-conductive area of the board, in most cases ideally there should be clearance of 5mm in all directions from the board/housing for maximum efficiency. A reduction in the gain of the antenna efficiency and shift in tuned frequency will be observed if these clearances are not adhered to. 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

17. TUNING

GPS Patch antennas should be tuned to their ground-plane that they are mounted on and taking into account the frequency shifts due to the specific

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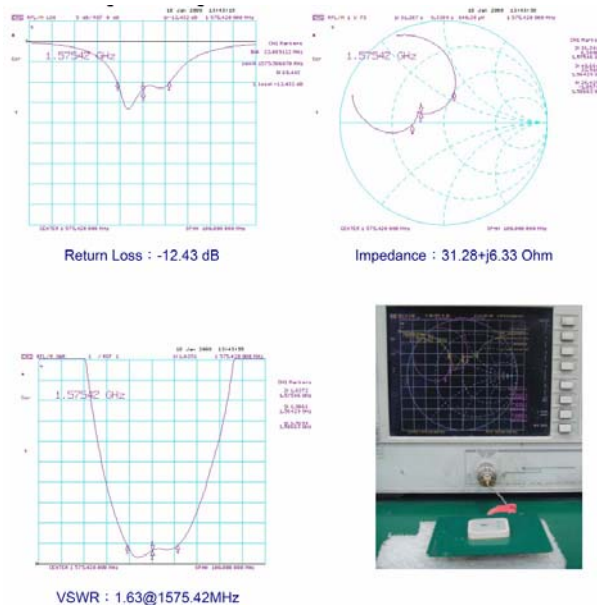
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device environment the antenna finds itself in. This is done in our state of the art laboratories and anechoic chambers

1. Impedance matching

The antenna will be tuned to get close to a 50 Ohm match on the Smith Chart when in the device. The S11 return loss magnitude is also looked at and the industry standard is <10dB across the bandwidth.

But it can be more important to check the radiation pattern and gain at in-bandwidth frequencies to understand the real performance of the antenna in the device



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.



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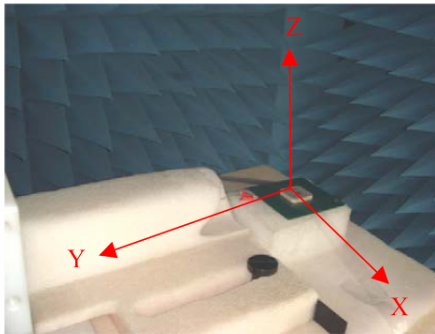
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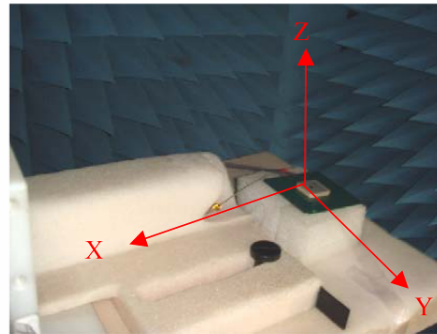
2. Radiation Pattern and Gain Testing

Radiation patterns of the antennas X-Y and Y-Z planes are taken in the device. This corresponds to two vertical cuts of an “apple” type pattern which is the typical pattern of a GPS patch antenna at cross angles to each other. Where they intersect we can then take their point readings at 0deg/180 deg horizontal to have four points of reference for the horizontal radiation pattern and drawing a line through them we can now solve to produce the horizontal radiation pattern of the radiation thereby giving us a 3D view of the radiation pattern. 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.

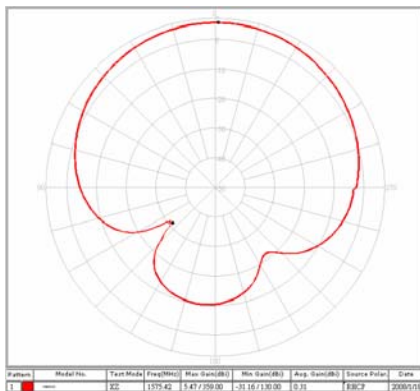
XZ-Plane



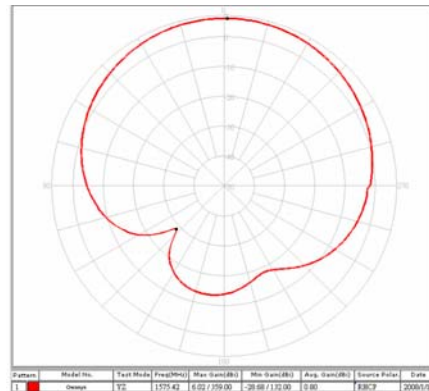
YZ-Plane



XZ Plane 1575.42 MHz



YZ Plane 1575.42 MHz



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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 wifi radiation in the device. Therefore GPS antenna should be placed as far as possible away from the other antennas in the device.

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

Testing is carried by sending a signal in one antenna and measuring the power of the signal at the other antenna. There should be a 10dB or more difference between the transmit and the receive signal. The easiest method is to keep moving the two antennas farther from each other until the target isolation is achieved.

19. CABLE & CONNECTOR

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

The cable needs good grounding. If the body of the cable is near the ground of the device the cable should be as near as possible to the device ground.

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

The cable should be kept away from emitting components such as LCD driver chip or CPU.

It is preferred to use connectors on the cables for higher reliability in connection over solder. Most economical connector solution is Ipex line of connectors which is compatible with Hirose industry standards U.FL and W.FL. Taoglas offers any cable and connector solution for the integrator. Taoglas also offers the on-board mating connector and cable jumpers.

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20. SMD

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

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