Passive Patch Antenna- Application Note

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The APAE Series is a selection of low profile PATCH ANTENNAS covering a wide range of frequency bands including GPS, GLONASS, SDARS, and RFID. These patch antennas offer small, low-profile, easy to mount PCB solutions; for systems requiring a flat & compact antenna.

The APAE Series is RHCP (Right Hand Circular Polarized) in order to be compatible with the propagated GPS signals. Other key characteristics include narrow bandwidth and high gain, to further improve system performance.

Positioning the patch on the end-product PCB

Electrical connection with the PCB is accomplished by soldering the silver pin through the hole on the PCB. Subsequently, the RF signal propagates through the PCB and excites the patch antenna.

During final board assembly, only the silver pin is soldered onto the PCB, by placing it through the hole and soldering it on the back side of the PCB. The adhesive tape is utilized to ensure solid positioning of the antenna on the PCB. It is not recommended to put the patch antenna through a standard reflow process.

The ideal position for the patch antenna is on top of the GPS receiver in the center of the printed circuit board. This technique eliminates the transmission line on the PCB between the input of the GPS receiver and the feed point on the antenna. Further, it limits the radiation plot distortion caused by the potential impedance mismatch.
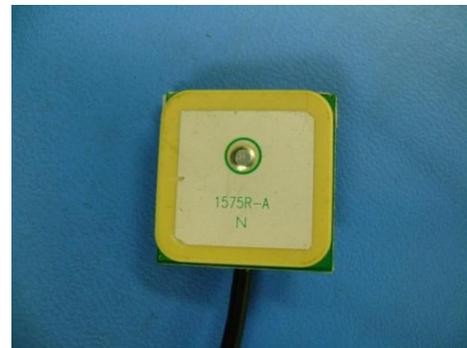
Peak gain and center frequency may significantly vary depending on the position of the patch on the ground plane; while the VSWR and bandwidth is not affected by moving the patch on the ground plane.
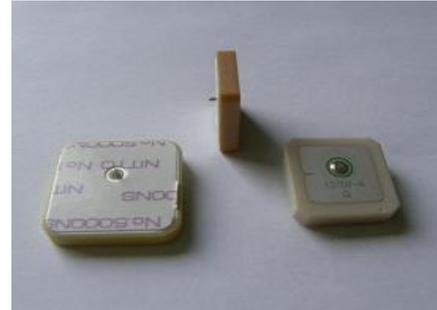
Figure (1); Front, Back, and Side View
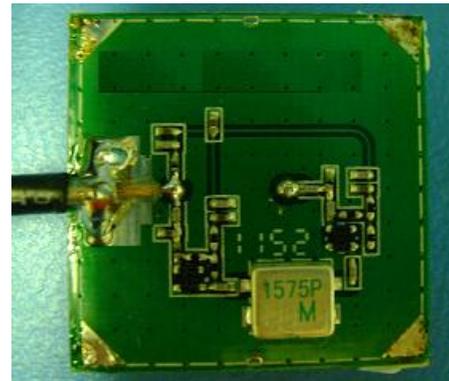
Figure (2); Patch Antenna Module (Back View)

Figure (3); Patch Antenna Module (Top View)

It is recommended to mount the patch on the center of the ground plane. As we move the patch to the edge of the ground plane, the polarization which is ideally circular tends to become elliptical, which is not desired since the propagated GPS signals are circularly polarized.

Impedance Matching

The concept of VSWR (Voltage Standing Wave Ratio) is introduced as a measure of how well-matched an antenna is to the transmission line. If the impedance of the antenna does not match the impedance of the cable, a part of the signal will reflect from the antenna - back to the source.

Standard patch antennas are manufactured by matching to 50Ω input & output impedance on a well-defined Ground plane; on the manufacturers test fixture, in a controlled environment. In real world application when this antenna is placed on the end-product PCB, optimization is required. This optimization involves impedance matching in the end-product PCB to optimize the reflection coefficients. Further, if the end-product is encapsulated or has a metal cover, etc., this optimization accounts for the frequency shift of the patch in the end-product PCB.

Impedance matching may also involve placement of capacitors and/or inductors onto the PCB. It is also helpful to remember that the patch antenna impedance decreases as the feed location approaches the center.

A popular type of matching network is the PI-network, consisting of two shunt components with one series component in the middle. This method provides flexibility for impedance matching. Although only two components are used for matching the load to the source, PI-network allows putting the shunt component either before or after the series component.
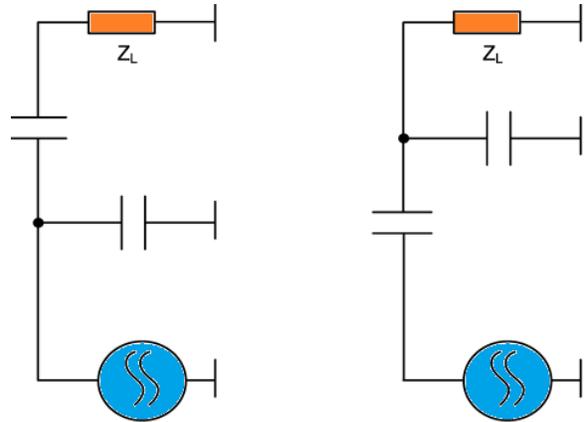

Figure (4): Two Possible Matching Networks

It is recommended to match the entire GPS band as close as possible to 50Ω and therefore, at least three frequency points have to be matched, as shown in figure (5).
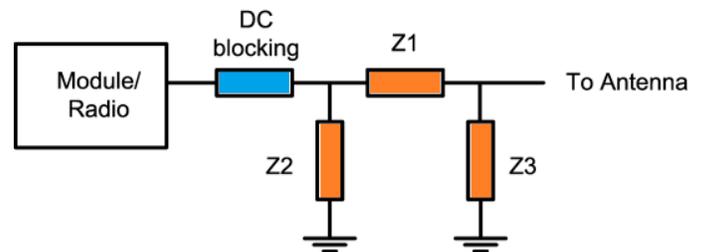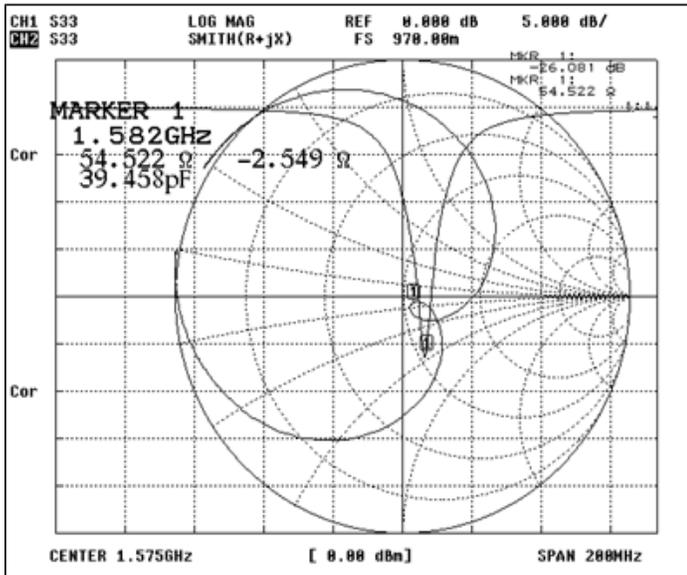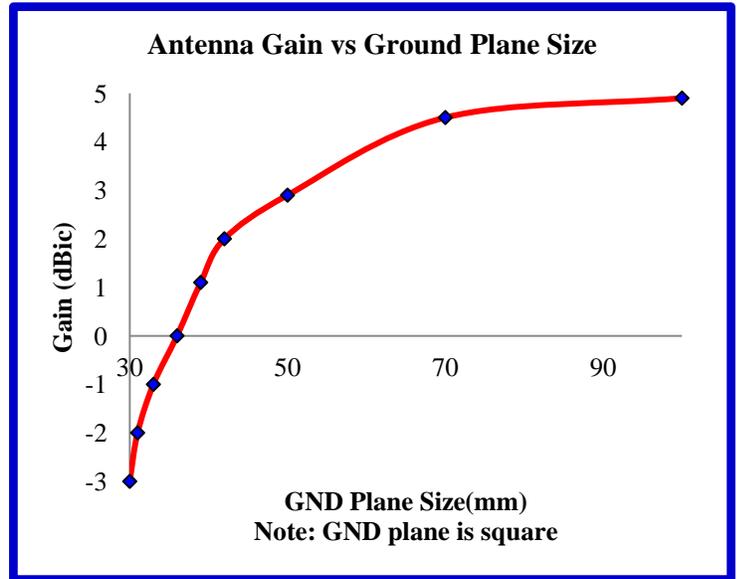

Figure (5): PI Network

Plot (1) depicts measured impedance for a GPS patch antenna in end-customer's application. In case of an exact match, the measured impedance is a real 50Ω with no imaginary part. In this example the impedance is 54.522Ω - j2.549Ω.

Passive Patch Antenna- Application Note

Plot (1): Smith Chart

Plot (2)

Ground Plane effect on Gain for APAE Series

Patch antenna is a passive component and therefore, its gain is defined as {antenna directivity times the radiation efficiency}. The antenna efficiency is defined as the ratio of the radiated power to the input power.

In general, the larger patches have higher gain than the smaller patches and even choosing a large ground plane for a small patch will not make its gain comparable to the gain of a larger patch. A GPS patch antenna has its highest gain when placed horizontally on a surface, facing the zenith since it can receive all propagated GPS signals. The gain will be lower if the patch is mounted on a surface that makes an angle with the horizon.

Typical peak gains for Abracon's patch antennas on standardized ground planes are as following.

| Antenna Type	Patch Size	Gain
GPS	25x25x4mm	4.5dBic
Glonass	25x25x4mm	4.5dBic
GPS	25x25x2mm	4.3dBic
RFID	25x25x4mm	4.5dBic
SDARS	25x25x4mm	5.0dBic
GPS	20x20x4mm	3.8dBic
GPS	18x18x4mm	3.3dBic
GPS	18x18x2mm	1.4dBic
GPS	15x15x4mm	1.2dBic
Glonass	13x13x4mm	-2dBic
Glonass	13x13x5mm	-2dBic
GPS	13x13x4mm	0.6dBic

Ground Plane effect on Center Frequency

The center frequency of the patch antenna varies proportionally with the size of the ground plane and can be approximated by equation (1):

$$fc \approx \frac{c}{2L\sqrt{\varepsilon_r}} = \frac{1}{2L\sqrt{\varepsilon_o \varepsilon_r \mu_o}} \quad \textbf{(1)}$$

L :   Size of the Ground Plane
C :   Speed of the electromagnetic wave
ε_o: The Vacuum Permittivity
         8.854187817* 10-12 F/m
ε_r: Relative Permittivity of the Dielectric Material
μ_0:   1/(c2ε0)=1/(299,792,4582(8.854*10-12)) =1.26x10-7 H/m

Application environment such as size of the ground plane, proximity to other components and a dome will affect stated performance. Fine tuning of the patch antenna is required in end-customer's application in order to achieve the desired center frequency.
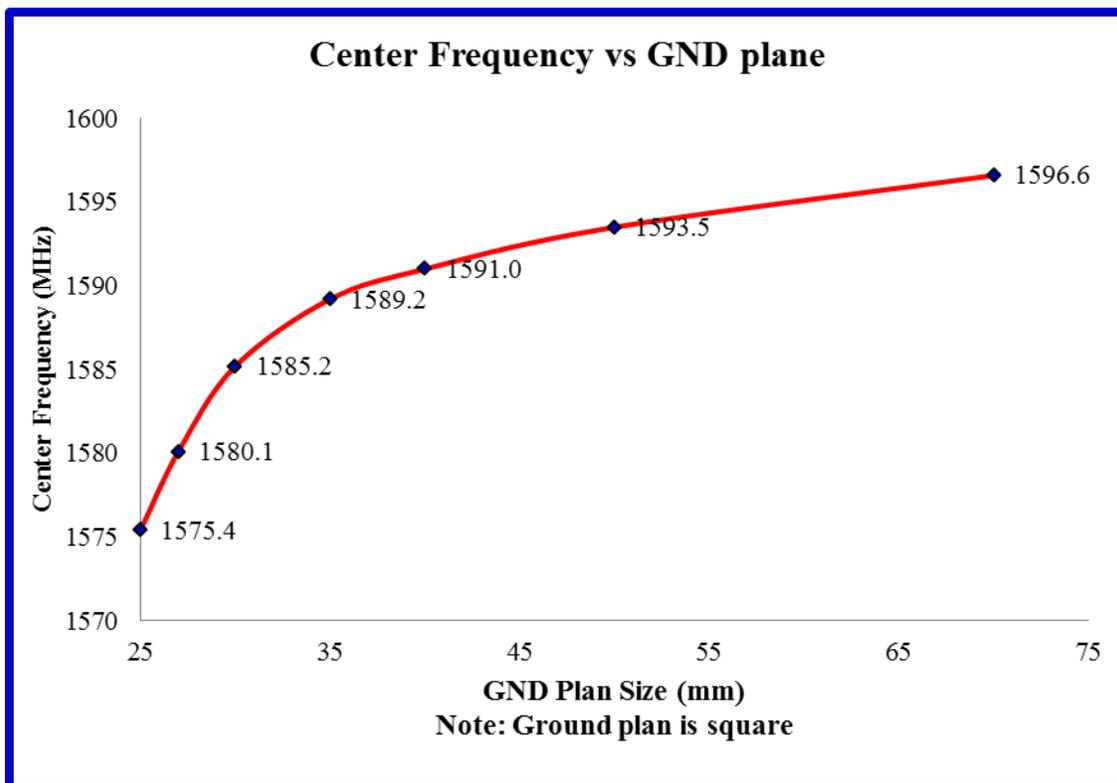
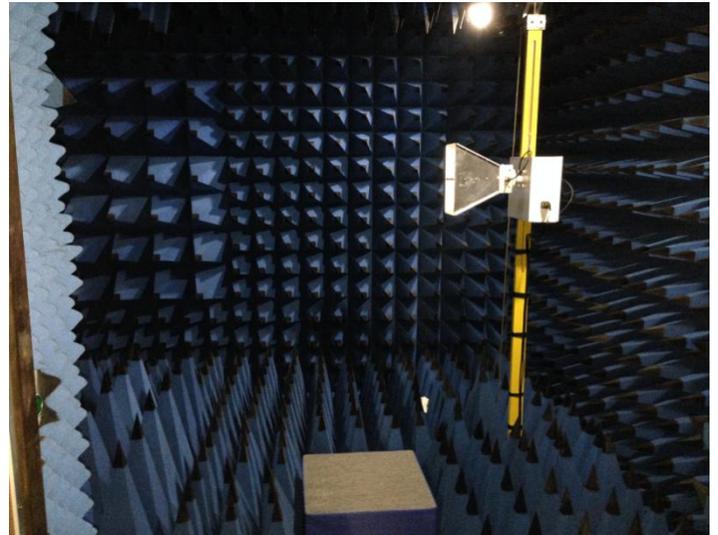**Plot (3)**

Tuning (Optimization)

Antenna's performance is affected by the environment such as its proximity to other components or to the dome. Almost in all cases, tuning is required after the patch antenna is mounted in the end-application.

There are several methods to tune the antenna such as moving the feed point, changing the shape of the top silver electrode, and scratching the corners or sides of the top silver plate.

Per Abracon's standard procedure, customers purchase standard products from our distribution channel and try them in their application. Almost in all cases, the patch needs to be tuned to account for overall environmental effects in the end-application. At this point, our customer sends us their PCB, three samples of patch antenna, and any additional coverage (such as Dome, cover, etc.) for fine tuning. One patch is tuned exactly to the desired frequency, one patch to a slightly higher, and one patch to a slightly lower frequency.

Figure (6): Radiation Chamber

Figure (7): Optimized Patch

Test data is provided for before and after tuning for comparison purposes. Once the customer receives the tuned patches, these devices are tested in the end-application and if the performance is deemed satisfactory, a custom part number is issued for the patch with the best performance {from the (3) supplied samples}. A custom data sheet is created based on the tuning results for mass production. Subsequent orders are manufactured in accordance with the custom data sheet.

Passive Patch Antenna- Application Note

Radiation Pattern

Patch antenna's radiation pattern shows that the antenna radiates more power in a certain direction than other directions. This characteristic in antennas is called directivity which is measured in dB.

For an ideal patch antenna, all radiation is received in one half of the hemisphere which means 3dB directivity. In this scenario, all radiation is towards the front and no radiation is towards the back of the antenna.

However, in real world applications, a portion of the radiation is towards the back of the antenna. The front to back ratio is very much contingent upon the size and shape of the ground plane.

A patch antenna has a maximum directivity in the direction perpendicular to the patch. This directivity decreases as the patch is moved towards the horizon. The 3 dB bandwidth is twice the angle of the maximum directivity. In another words, the 3dB bandwidth is where the directivity has dropped by 3dB; with respect to the maximum directivity.

As part of the optimization service, Abracon provides radiation plot for each patch antenna, before and after the tuning process, for comparison purposes.

Impact of Adjacent Antennas

GPS signal is of low power and is vulnerable to interference from higher power cellular or Wi-Fi radiation in the end-application. Therefore, the GPS antenna should be placed as far away as possible from other antennas, such as Bluetooth or WWAN, in the end-application.

In order to make sure that the signals from other antennas don't interfere with the GPS signal, validation is conducted 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 transmitted and the received signal. The easiest technique is to continue moving the two antennas farther away from each other and keep measuring the sent and received signals; until the desired isolation is achieved.
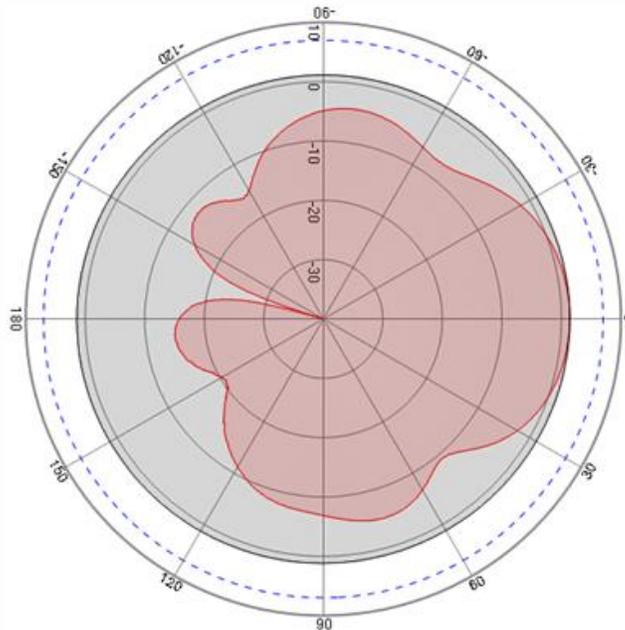
Plot (4): Radiation Pattern

Impact of surrounding Components

Performance of patch antennas is affected by proximity of adjacent components, housing, display, etc. These surrounding components influence the center frequency of the antenna, as well as, cause variation in the radiation pattern. It is recommended that a clearance of 4~10mm is maintained in all directions from adjacent components including housing; in order to ensure maximum efficiency from the patch antenna. The cable between the feed-line and the power source should not be bent more than 30 degrees and should be routed away from any noisy components such as Digital Integrated Circuits.

If Radom is used to protect the patch antenna and the LNA, frequency will be shifted down. If the PCB material thickness is 1 mm and the distance to the patch is 8 mm, frequency will shift down approximately 2.0MHz. It is reasonable to expect a center frequency shift of 1 ~ 4 MHz, depending on this distance.

Design Recommendation

The most important point to consider when drafting a design containing a GPS passive patch is that the GPS signal is below the noise floor. We are surrounded by digital noise and the best solution to avoid it is isolation.

The first stage in the GPS receiver is the LNA. A low-noise power source is required for LNA to properly function.

To improve noise isolation, reactive filtering using an inductor, a bead and/or a capacitor is recommended between the LNA and the bias stage.

A GPS grade **TCXO** with an initial tolerance of no worse than ±2.5 ppm is required for fast time-to-first-fix (TTFF).
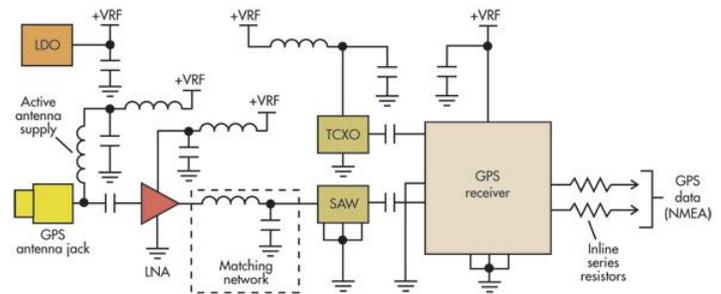

Figure (8): Schematic of a Typical GPS receiver

For proper GPS operation, much tighter stability TCXO's are needed having ~1ppb short term stability. Thermal transients due to heat generating components like PA or LNA could have profound impact on the short term TCXO stability. Additionally, switching components like regulators can also influence the TCXO performance.

To create some degree of isolation, TCXO's are shielded and thermal isolation is achieved with careful PCB design and physical placement of the TCXO, away from the aforementioned components.

SAW BandPass filters can be employed to further improve the overall system performance. Abracon also offers GPS frequency **SAW BPF's** in 1.4x1.1mm, 2.0x1.6mm, 2.5x2.0mm and 3.0x3.0mm footprints.

Figure (9): Layout of a simplified GPS-receiver
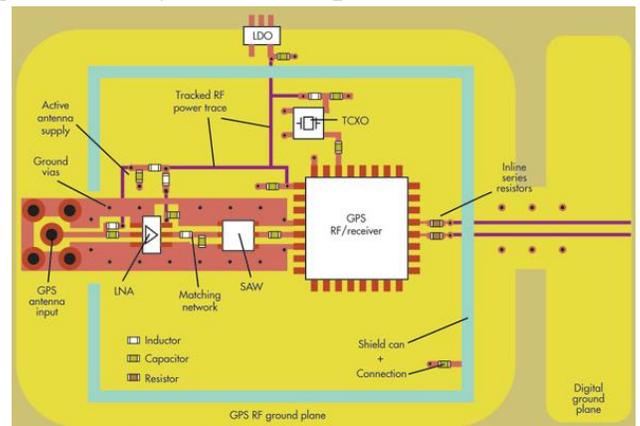
Passive Patch Antenna- Application Note

Noise Control

In order to optimize noise suppression, additional considerations need to be taken. For instance, some frequencies are not compatible with a GPS receiver. Common interfering frequencies are 4 MHz and 19.2 MHz (1575.42 MHz is a multiple of 19.2MHz). It is suggested to change the reference frequency to 24, 25, or 26 MHz.

In order to control impedance and reduce transients, calculate the capacitance of the inputs and then insert a resistor in series to set the edge rate (Figure 10). To calculate the edge rate, either a charging curve is used or the value is approximated using Equation (2) below, representing a 10%/90% switching point.

$$R = 3t/C \quad \ldots\ldots\ldots\ldots (2)$$

As an example, if 10%/90% switching point is needed with 10-ns rise/fall time for a clock line at 10 MHz and a IC input load capacitance of 10pF:

$$R = 3t/C$$

$$= 3\text{x}10^{-8} / (1\text{x}10^{-11})$$
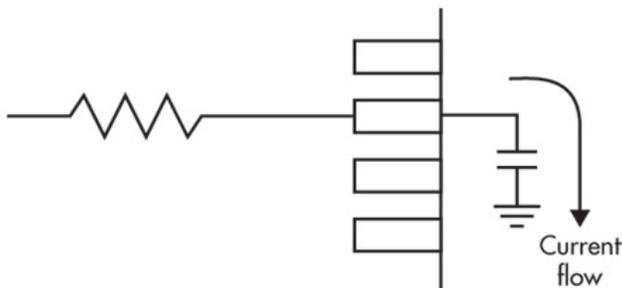
$$= 3 \text{ k}\Omega$$

Current flow

Figure (10): Insert a resistor in series to set the edge rate.

Customization

For customization of a standard Abracon Patch Antenna, in order to optimize in-circuit performance; please contact us at:

tech-support@abracon.com

Stocking Distributors' Links:

- **Digikey**
- **Mouser**

Author:

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References:

- Jeff Wilson (Electronic Design, Aug-2011). Adding a GPS Chipset to your next design is easy
- Texas Instruments, Application Report March-2008; AN-1811 Bluetooth Antenna Design