GS-AN042

Basic Antenna Guidelines

Introduction

An antenna is a transducer designed to transmit or receive electromagnetic waves (i.e. antennas convert electromagnetic waves into electrical currents and vice versa). Physically, an antenna can be an arrangement of conductors that generate a radiating electromagnetic field in response to an applied alternating voltage and the associated alternating electric current, or can be placed in an electromagnetic field so that the field will induce an alternating current in the antenna and a voltage between its terminals. In other words, an antenna can be any conductive structure that can carry an electrical current. If it carries a time varying electrical current, it will radiate electromagnetic waves, maybe not efficiently or in a desirable manner, but it will radiate. Usually one designs a structure to radiate efficiently with certain desired characteristics.

Considerations for choosing antenna approaches include ease of use, low cost, and conformity with respect to embedded WLAN applications. In order to ease the "RF design" burden for the GS1011MIP, GS1011MIE, GS1011MEP, and GS1011M module solutions, three particular antenna options have been modularly qualified with, and they are as following:

1. On board module PCB antenna
2. External PCB antennas with IPEX/UF. L and cable connections
3. External Dipole antennas with IPEX/UF. L and cable connections

Basic Characteristics Common to All Antennas

Basic Characteristics Common to All Antennas: Reciprocity, Input Impedance, Return Loss, Antenna Radiation Resistance, Antenna Resonance Tuning, Bandwidth, Directivity, Gain, Radiation Pattern, Beamwidth, Side Lobs, Nulls, Polarization Mismatch and Front-To-Back Ratio.

Reciprocity

The Reciprocity Theorem of antennas states the following: If a voltage is applied to the terminals of antenna, A, and the current is measured at the terminals of another antenna, B, then an equal current (in both amplitude and phase) will be obtained at the terminals of antenna A if the same voltage is applied to the terminals of antenna B. The "reciprocal nature of antennas" means that the electromagnetic characteristics of a transmit antenna are equivalent to those of a receive antenna, assuming the antennas are identical in form-factor and orientation.

Antenna Input Impedance and Return Loss

The impedance into the terminals of an antenna is only important for signal power matching relative to the transmission line. Terminal impedance is generally composed of the (real) resistance term plus a reactive term. For an antenna where the radiation losses are much greater than the resistive losses, the resistive term is called the antenna's radiation resistance.

The return loss is a way of expressing mismatch. It is a logarithmic ratio measured in dB that compares the power reflected by the antenna to the power fed into the antenna from the transmission line. The relationship between SWR and return loss, where SWR is the standard wave ratio, is the following:

$$\Gamma = \left| \frac{1 - \text{VSWR}}{1 + \text{VSWR}} \right|$$

$$\text{RL} = -20\log|\Gamma|$$

$$\text{VSWR} = \left[10^{\frac{\text{RL(db)}}{20}} + 1 \Big/ 10^{\frac{\text{RL(db)}}{20}} - 1 \right]$$

For an efficient transfer of energy, the impedance of the antenna drives for the antenna and for the transmission cable connecting them must be the same. Transceivers and their transmission lines are typically designed for 50-Ohm impedance for embedded WLAN environments. If the antenna subsystem has components of differing impedance, then there is a mismatch and an impedance matching circuit is required.

Antenna Radiation Resistance

An antenna's radiation resistance is a measure of ability to radiate an applied signal into space or to receive a signal from space. To calculate the radiation resistance, the antenna is assumed to be lossless. Then, for a given applied signal, the total radiated power *P* is calculated or measured, along with the current *I* in the antennas using the equation, where the preceding is defined as:

- **I** = RMS antenna current (A)
- **R** = antenna radiation resistance (Ω)

$$P = I^2 R$$

We associate the radiated power with the radiation "resistance" *R*. The radiation resistance is not a real (dissipative) resistance, but a measure of the power radiated into free-space for a given input current. The important observation about radiation resistance is that for a given current into the antenna, as radiation resistance increases, so does the antenna's efficiency. It will be established later that, in general, larger antennas are more effective "signal collectors," while also exhibiting higher radiation resistance than smaller antennas. This implies that antenna size should be maximized to the extent possible. Antenna size is generally not as important for the transmitters in low-power applications since regulatory agencies usually limit the allowable effective radiated power or field strength. It is assumed the signal current could be increased, no matter what the radiation resistance, to increase the current to offset antenna inefficiency. However, due to the reciprocity theorem of antennas, higher radiation resistance is desirable at the receiving antenna since efficiency is more important there. The system designer should maximize this parameter to the extent possible at the receiver.

Antenna Resonance Tuning

An antenna is defined as resonant if the terminal impedance is equal to its radiation resistance. This is equivalent to saying that the terminal impedance contains no reactive impedance component. Since the antenna impedance equals the radiation resistance at resonance, it can be said that the antenna is operating at maximum radiating (or receiving) efficiency. An antenna may be "tuned to resonance" at a given frequency by incrementally adjusting the length, form factor of the antenna structure or by adding reactive components. If proper layout guidelines and placements are not followed, the antenna will be detuned.

Bandwidth

The bandwidth of an antenna refers to the range of frequencies of which the antenna can operate correctly. The antenna's bandwidth is the number of Hz at which the antenna will exhibit an SWR less than 2:1. The bandwidth can also be described in terms of percentage of the center frequency of the band. This is the definition of "fractional bandwidth":

$$BW = 100\frac{F_M - F_L}{F_C}$$

F_H is the highest frequency in the band, F_L is the lowest frequency in the band and F_C is the center frequency in the band. In this way, bandwidth is constant relative to frequency. If bandwidth is expressed in absolute units of frequency, it would be different depending upon the center frequency. Different types of antennas have different bandwidth limitations.

Directivity and Gain

Directivity is the ability of an antenna to focus energy in a particular direction when transmitting; or to receive energy focused from a particular direction. In a static situation, it is possible to use the antenna directivity to concentrate the radiation beam in the wanted direction. However, in a dynamic system where the transceiver is not fixed, the antenna should radiate equally in all directions. This is known as an Omni-directional antenna.

Gain is not a quantity that can be expressed in physical terms in the same manner as the Watt or the Ohm, but rather is a dimensionless ratio. Gain is given in reference to a standard antenna. The isotropic antenna radiates equally in all directions. Real isotropic antennas do not exist, but they provide useful and simple theoretical antenna patterns with which to compare real antennas. Any real antenna will radiate more energy in some directions than in others. Since it cannot create energy, the total power radiated is the same as an isotropic antenna. The gain of an antenna for a given direction is the amount of energy radiated in that direction compared to the energy an isotropic antenna would radiate in the same direction when supplied with the same input power. Usually we are only interested in the maximum gain defined as the gain in the direction in which the antenna is radiating most of the power. An antenna gain of 2 dB compared to an isotropic antenna would be written as 2 dBi. Since a passive antenna cannot create or generate energy, a 2dBi antenna also would have at least a corresponding loss of 2dBi in a volume not considered its radiating pattern. The method for measuring gain is to compare the antenna, under test conditions, against a known standard antenna with calibrated gain. This is technically known as the gain transfer technique.

Radiation Pattern

The radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenna at a constant distance. The radiation pattern is a reception pattern as well by defining the receiving properties of the antenna. The radiation pattern is three-dimensional, but usually the measured radiation patterns are the two-dimensional slices examining just the horizontal or vertical planes.

There are two kinds of radiation pattern: absolute and relative. Absolute radiation patterns are presented in absolute units of field strength or power. Relative radiation patterns are referenced in relative units of field strength or power. Most radiation pattern measurements are relative to the isotropic antenna where the gain transfer method is then used to establish the absolute gain of the antenna. The radiation pattern in the region closest to the antenna is not the same as the pattern at larger distances. The term “near-field” refers to the field pattern that exists close to the antenna, while the term “far-field” refers to the field pattern at large distances. The “far-field” is also referred to as the “radiation field”.

Ordinarily, it is the radiated power that is of interest, and so antenna patterns are usually measured in the far-field region. For pattern measurement it is important to choose a distance sufficiently large to be in the far-field scope, well out of the near-field parameters. The minimum permissible distance depends on the dimensions of the antenna in relation to the wavelength. The accepted formula to calculate this distance is:

$$r_{\min} = \frac{2d^2}{\lambda}$$

Considering $r_{\min}$ as the minimum distance from the antenna, d is the largest dimension of the antenna, and λ is the wavelength.

Beamwidth

An antenna's beamwidth is understood to refer to the half-power beamwidth. The peak radiation intensity is found and the distance then to measured points on either side of the peak that represent half the power of the peak intensity. The angular distance between the half power points is defined as the beamwidth. Half the power expressed in decibels is -3dB, so the half power beamwidth is sometimes referred to as the 3dB beamwidth. Both horizontal and vertical beamwidths are usually considered. Assuming that most of the radiated power is not divided into sidelobes, where the directivity is inversely proportional to the beamwidth: as the beamwidth decreases, the directivity increases.

Side Lobs

Simple antennas are not able to radiate all energy in one preferred direction. The peaks are referred to as side lobes, commonly specified in dB down from the main lobe.

Nulls

In an antenna radiation pattern, a null is a zone where the effective radiated power is at a minimum. A null often has a narrow directivity angle compared to that of the main beam. Thus, the null is useful for several purposes, such as suppression of interfering signals in a given direction.

Polarization Mismatch

Polarization is defined as the orientation of the electric field of an electromagnetic wave. Polarization is generally described as an ellipse. Two special cases of elliptical polarization are linear polarization and circular polarization. The initial polarization orientation of radio waves is determined by the antenna. With linear polarization, the electric field vector stays in the same plane all the time. Vertically polarized radiation is somewhat less affected by reflections over the transmission path. Omni-directional antennas always have vertical polarization. Horizontal antennas are less likely to pick up man-made, vertically polarized interference.

With circular polarization, the electric field vector appears to be rotating with circular motion about the direction of propagation, making one full turn for each RF cycle (either to the right or left). Choice of polarization is one of the design choices available to the RF system designer.

In order to transfer maximum power between the transmitting and receiving antennas, both antennas must have the same spatial orientation, the same polarization sense and the same axial ratio. When the antennas are not aligned, or do not have the same polarization, there will be a reduction in power transfer between the two. This reduction in power transfer will reduce the overall system efficiency and performance. When transmitting and receiving antennas are both linearly polarized, physical antenna misalignment will result in a polarization mismatch loss. This mismatch loss is measured in dB where ϑ is the misalignment angle between the two antennas and is defined as:

$$ML = 20\log(\cos\vartheta)$$

For 15° we have a loss of 0.3 dB, for 30° we have 1.25 dB, for 45° we have 3 dB and for 90° we have an infinite loss. If polarizations are coincident, no attenuation occurs due to coupling mismatch between field and antenna. If not, then the communication is reduced and takes place in worst case conditions.

Front-To-Back Ratio

It is useful to know the front-to-back ratio that is the ratio of the maximum directivity of an antenna to its directivity in the rearward direction. For example, when the principal plane pattern is plotted on a relative dB scale, the front-to-back ratio is the difference in dB between the level of the maximum radiation, and the level of radiation in 180 degrees. However, for embedded WLAN applications, omni-directional antennas are normally used.

Antenna Options for GS1011Mxx Solutions

If a designer truly needs to design an antenna for its embedded WLAN solution, the above guidelines must be followed, and the designer needs to regulatory qualify the antenna with the designed radio; thus, critical engineering time and effort must be spent on the antenna design alone. In order to ease the "RF design" burden for the GS1011MIP, GS1011MIE, GS1011MEP, and GS1011M module solutions, three particular antenna options have been modularly qualified with, and they are as following:

1. On board module PCB antenna
2. External PCB antennas with IPEX/UF. L and cable connections
3. External Dipole antennas with IPEX/UF. L and cable connections

In general, the radio range, with above antennas and from lowest range to highest range is option 1, 2 and 3 respectively.

Antenna Options for GS1011MEP and GS1011MIP Solutions

The onboard GS1011MEP and GS1011MIP module antenna topology is used because it is reasonably compact and meant to have a fairly omni-directional radiation pattern and good efficiency. The antenna radiation patterns are dependent upon the carrier board that the module is placed. The environment that the module is placed in will dictate the range performance. For onboard module PCB antenna placement, refer to Figure 1.

It is also best to keep some clearance between the antenna and nearby objects. This includes how the module is mounted within the product enclosure. Unless the items on the following list of recommendations are met, the radiation pattern can be heavily distorted.

- Never place ground plane or copper trace routing underneath the antenna (refer to Figure 1)
- Never place the antenna very close to metallic objects.
- In the final product, ensure that any wiring or other components do not get too close to the antenna or run parallel to the length of the antenna trace.
- The antenna will need a reasonable ground plane area on the mother board area to be efficient.
- Do not use a metallic or metalized plastic for the enclosure.
- Plastic enclosure keep away dimension should be 1 cm in every direction, while maintaining the keep-out area, as shown in Figure 1. At the bottom of the antenna a minimum of 5mm can be tolerated.

The antenna peak dBi and efficiencies, in free air, are as following:

Total (V + H); refers to the combined data for the test fixture receiving antenna polarization

	2.40 GHz	2.44 GHz	2.48 GHz
Azimuth Pattern Peak Gain (dBi) =	-1.95	-2.56	-1.13
Elevation1 Pattern Peak Gain (dBi) =	1.23	0.15	0.97
Elevation2 Pattern Peak Gain (dBi) =	2.26	1.03	1.69

Estimated Efficiency (%)

	2.40 GHz	2.44 GHz	2.48 GHz
Azimuth	39.8	38.3	47.4
Elevation1	67.5	62.3	64.2
Elevation2	45.9	40.1	41.3
Average	51.1	46.9	51.0

Figure 2 shows the antenna patterns in free air.

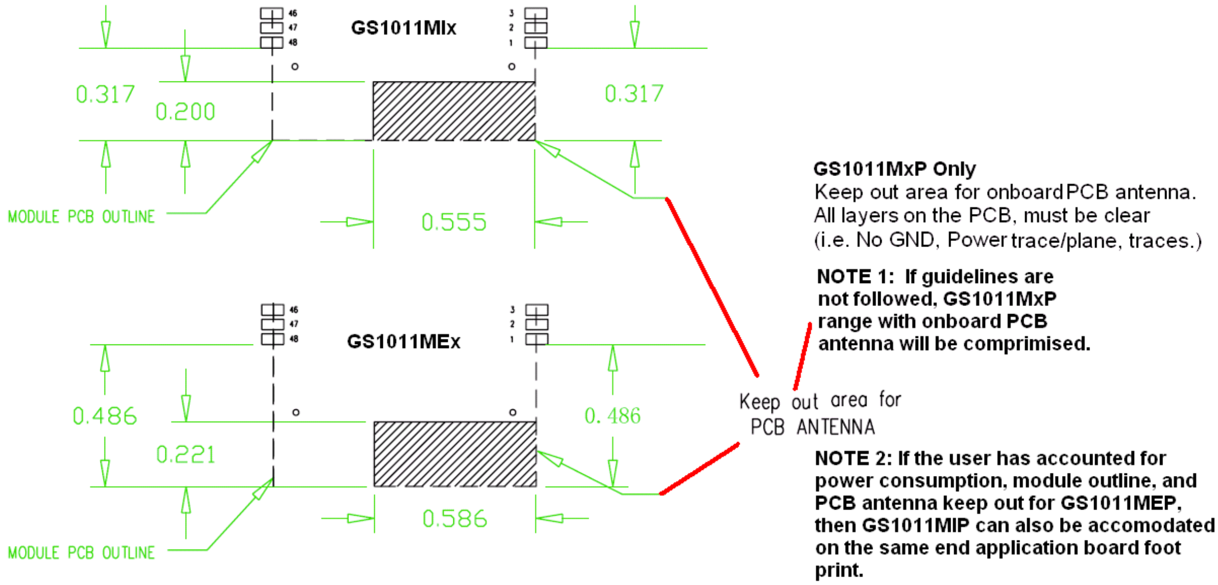
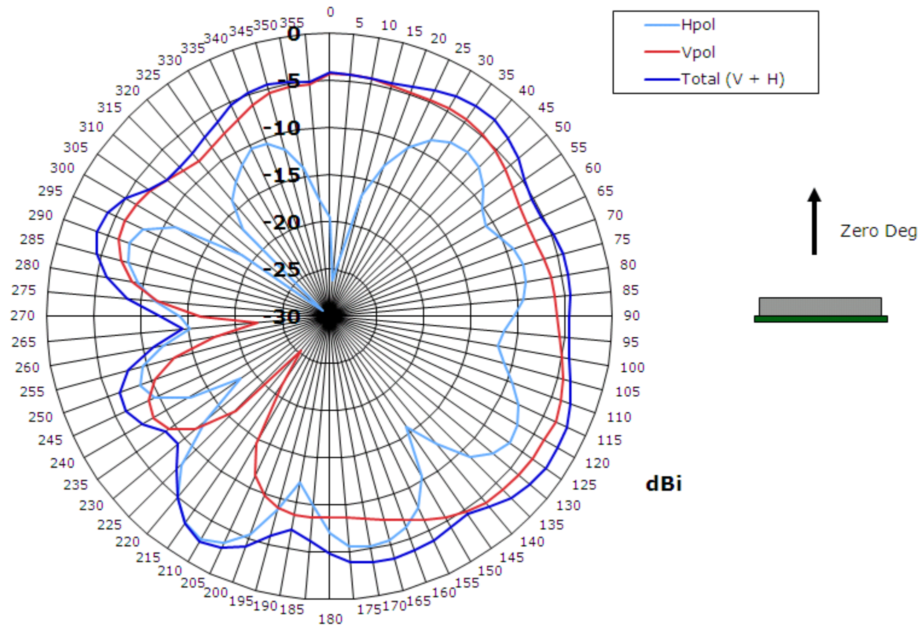
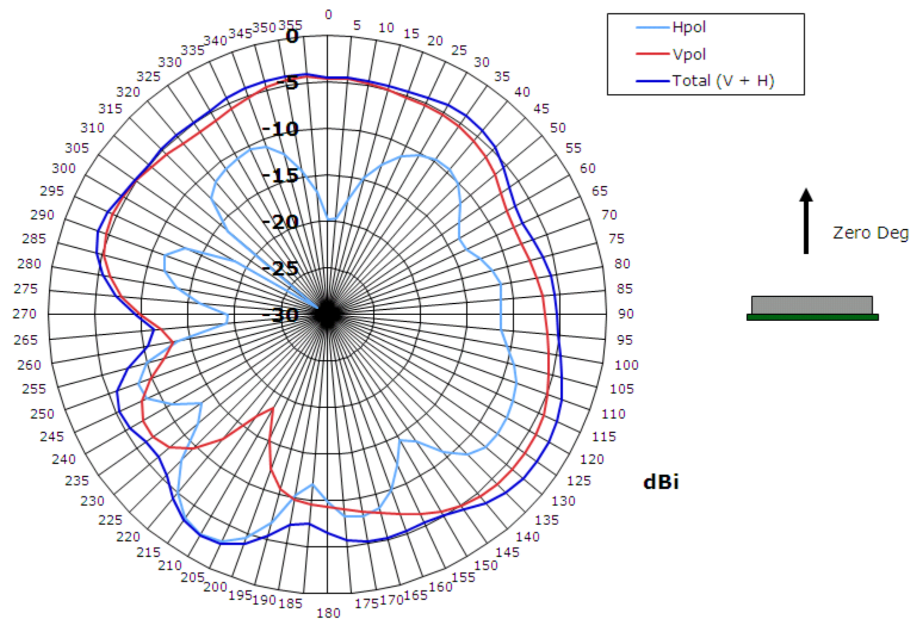


Figure 1: GS1011MIP and GS1011MEP Modules Onboard Antenna Board Layout Guidelines

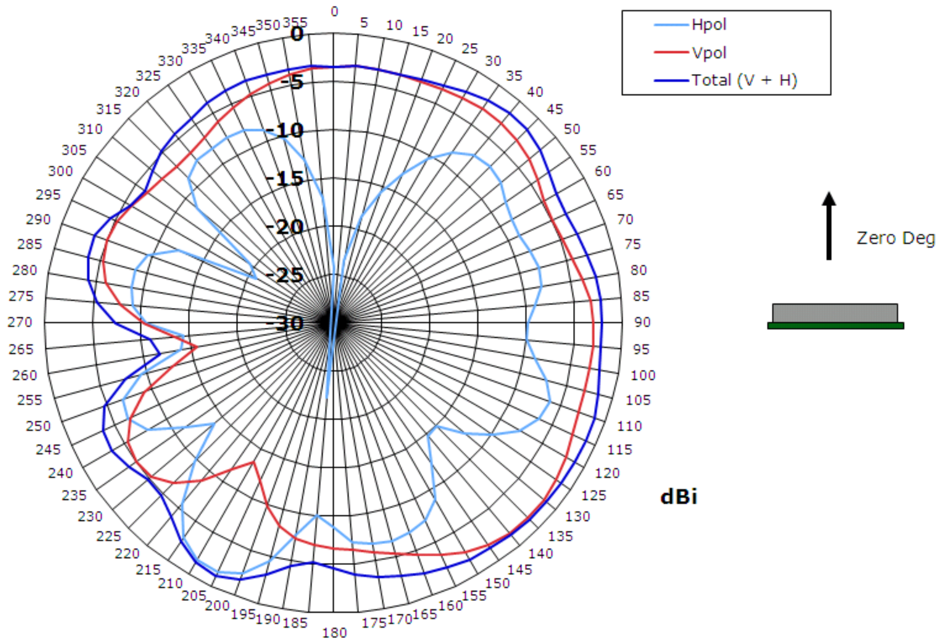
Azimuth Pattern; 2.40 GHz



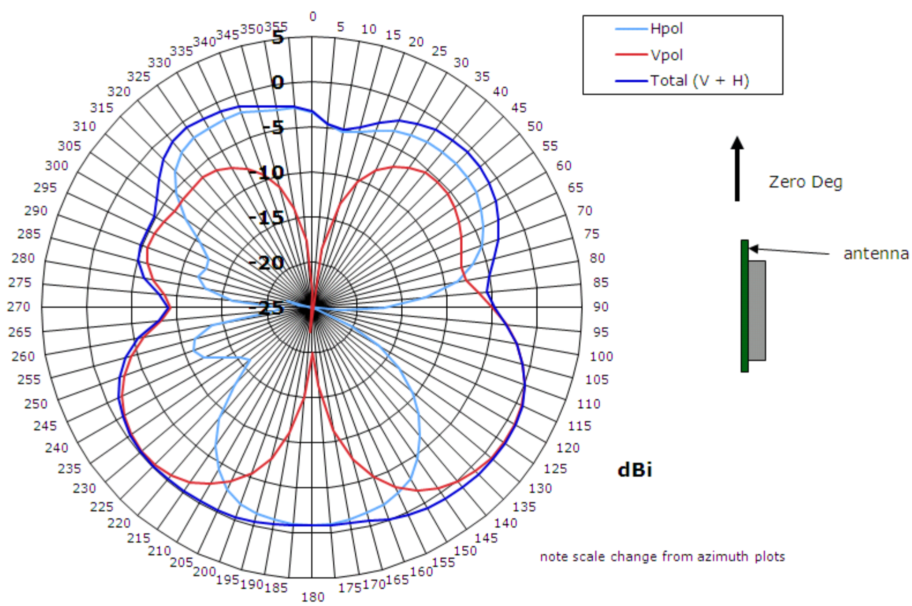
Azimuth Pattern; 2.44 GHz



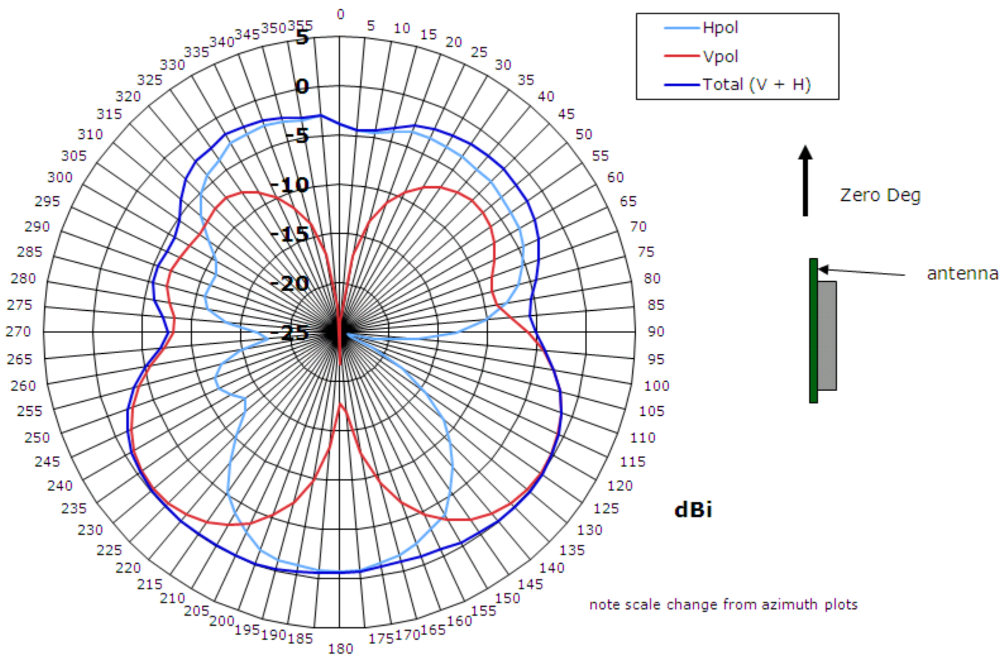
Azimuth Pattern; 2.48 GHz



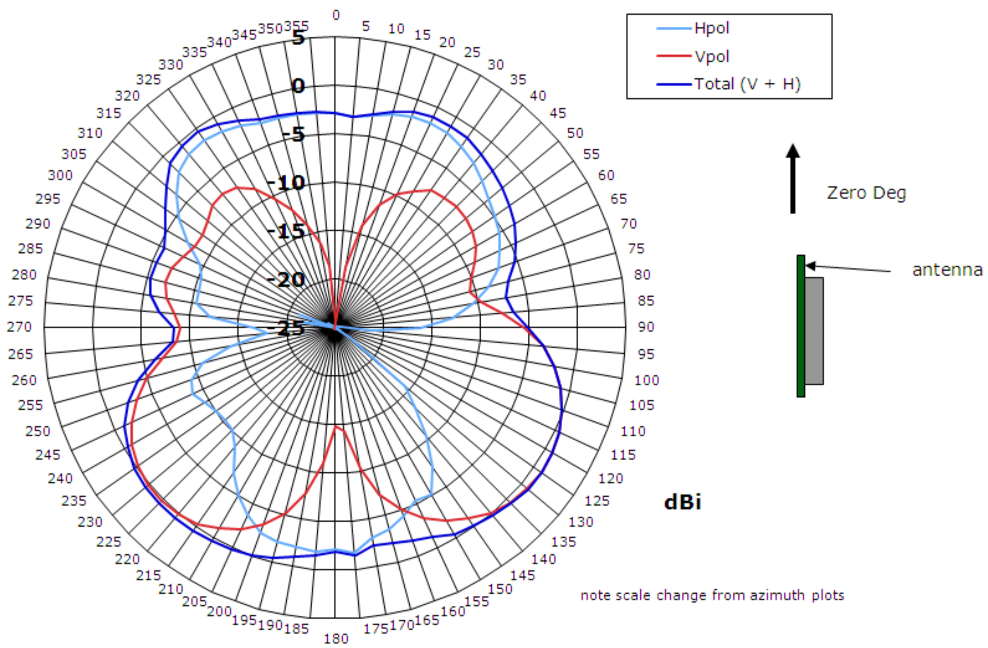
Elevation1 Pattern; 2.40 GHz



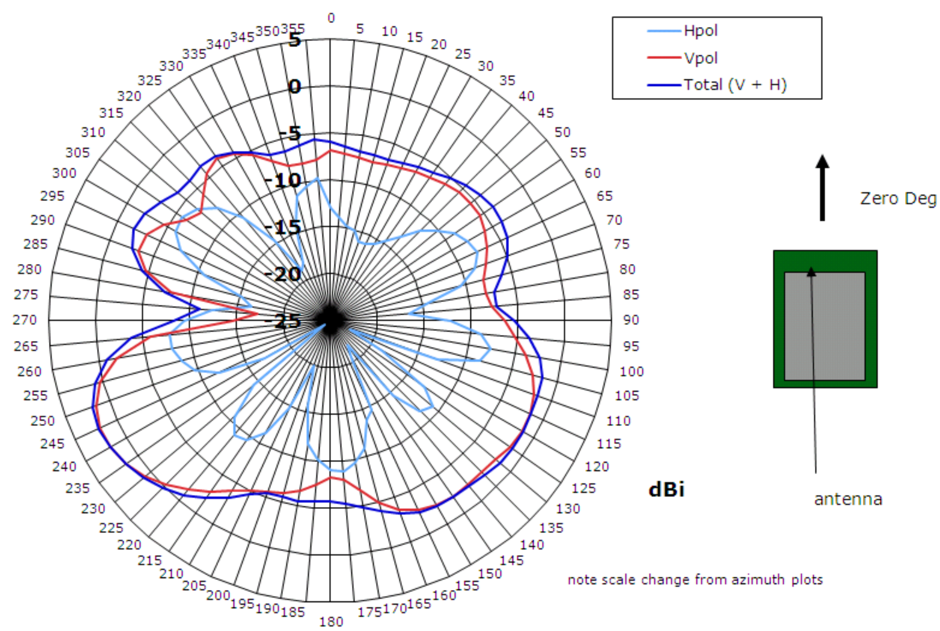
Elevation1 Pattern; 2.44 GHz



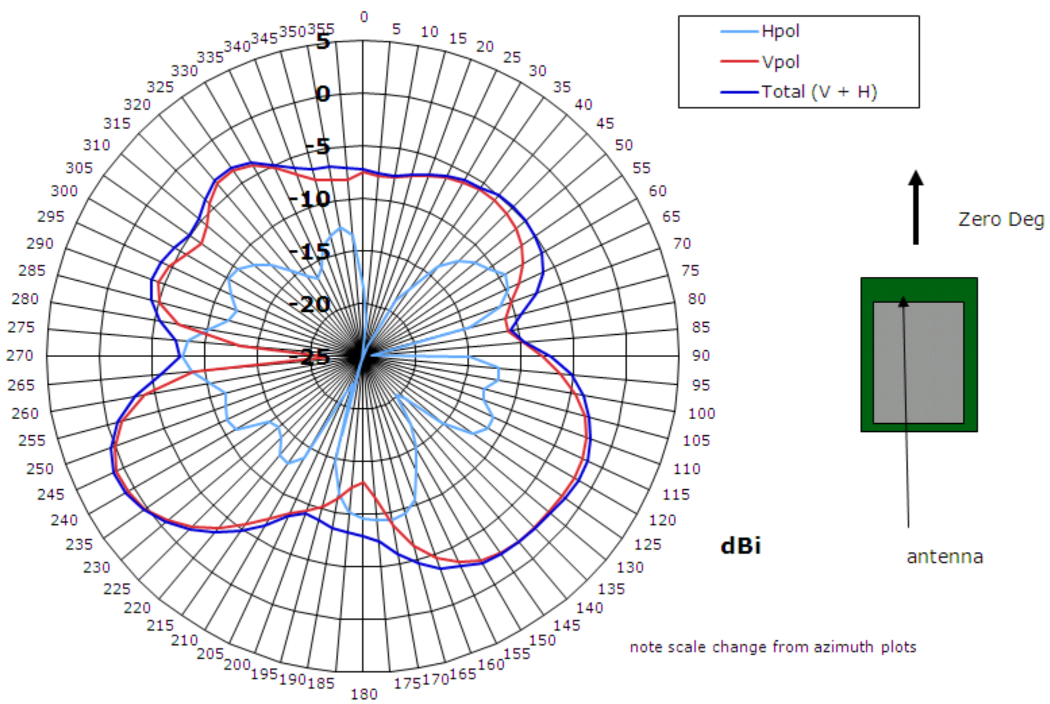
Elevation1 Pattern; 2.48 GHz



Elevation2 Pattern; 2.40 GHz



Elevation2 Pattern; 2.44 GHz



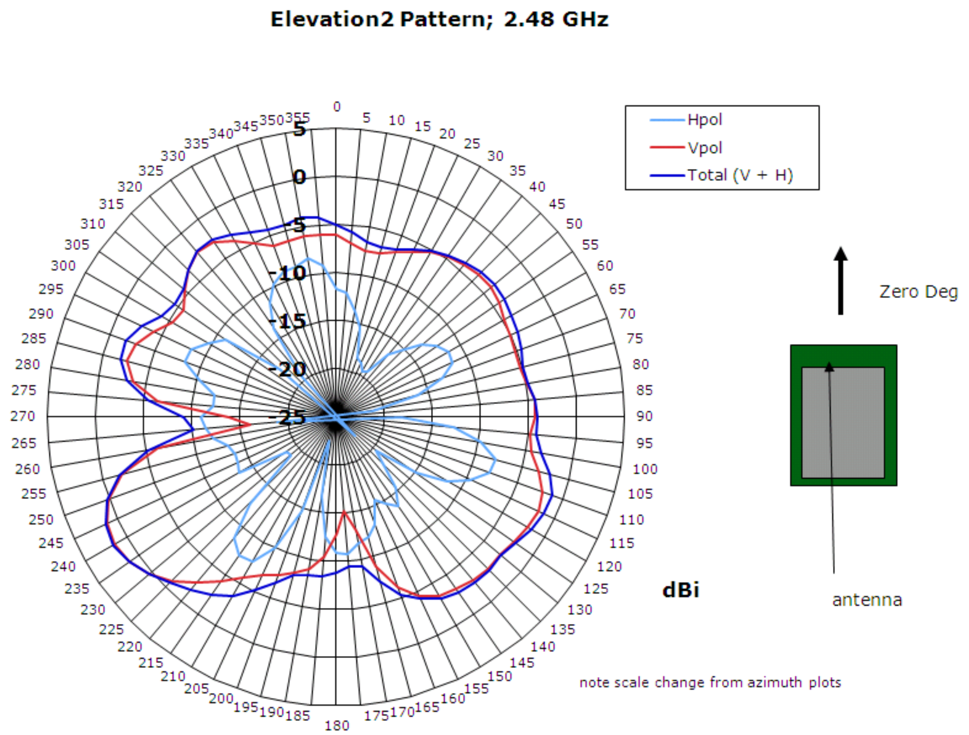


Figure 2: GS1011MIP and GS1011MEP Modules Onboard Antenna Patterns in Free Air (Note: Hpol and Vpol refer to the test fixture receiving polarization.)

External PCB and Dipole Antennas with IPEX and Cable Connections

GainSpan external PCB and dipole antenna options will provide better performance than the onboard PCB antenna, but they require more mechanical real-estate. In order to tune per the customer's specific plastic enclosure, some additional tuning procedure maybe necessary (adding plastic tapes with different heights on the back of PCB antenna, etc.). Never place the antenna very close to metallic objects. Also, in the final product, ensure that any wiring or other components do not get too close to the antenna or run parallel to the length of the antenna trace/antenna wiring. Do not use a metallic or metalized plastic for the enclosure. Modularly qualified external Antenna options, with IPEX and cable connections (refer to Figure 3), is available, and it can be easily used with GS1011MEE and GS1011MIE modules.

ITEM	DESCRIPTION	
BPC2J2	joint	joint
BPC2J4	joint	joint
RFA-02-L2H1-70B-150	Frequency range: 2400 MHz – 2500 MHz Antenna gain: 2 dBi / VSWR: 2.0 : 1 Max. Connector: I-PEX / Cable: 1.13	dipole
RFA-02-L6H1-70-35	Frequency range: 2400 MHz – 2500 MHz; Antenna gain: 2 dBi / VSWR: 2.0 : 1 Max.; Connector: I-PEX / Cable: 1.13	dipole
RFA-02-3-C5H1-70B150	Frequency range: 2400 MHz – 2500 MHz Antenna gain: 3 dBi / VSWR: 2.0 : 1 Max. Connector: I-PEX / Cable: 1.13	dipole
RFA-02-5-F7H1-70B150	Frequency range: 2400 MHz – 2500 MHz; Antenna gain: 5 dBi / VSWR: 2.0 : 1 Max.; Connector: I-PEX / Cable: 1.13	dipole
RFA-02-5-C7H1-70B150	Frequency range: 2400 MHz – 2500 MHz; Antenna gain: 5 dBi / VSWR: 2.0 : 1 Max.; Connector: I-PEX / Cable: 1.13	dipole
RFA-02-P05-70B-150	Frequency range: 2400 MHz – 2500 MHz; Antenna gain: 2 dBi / VSWR: 2.0 : 1 Max.; Connector: I-PEX / Cable: 1.13	embedded

RFA-02-P33-70B-150	Frequency range: 2400 MHz – 2500 MHz; Antenna gain: 2 dBi / VSWR: 2.0 : 1 Max.; Connector: I-PEX / Cable: 1.13	embedded
RFA-02-P50-70B-150	Frequency range: 2400 MHz – 2500 MHz Antenna gain: 2 dBi / VSWR: 2.5 : 1	embedded
RFA-02-C2M2-03	Frequency range: 2400 MHz – 2500 MHz Antenna gain: 2 dBi / VSWR: 2.5 : 1	dipole with R SMA PLUG
BTC013-1-70B-150	Jump-cable , R SMA JACK to IPEX,L=150mm	Jump cable

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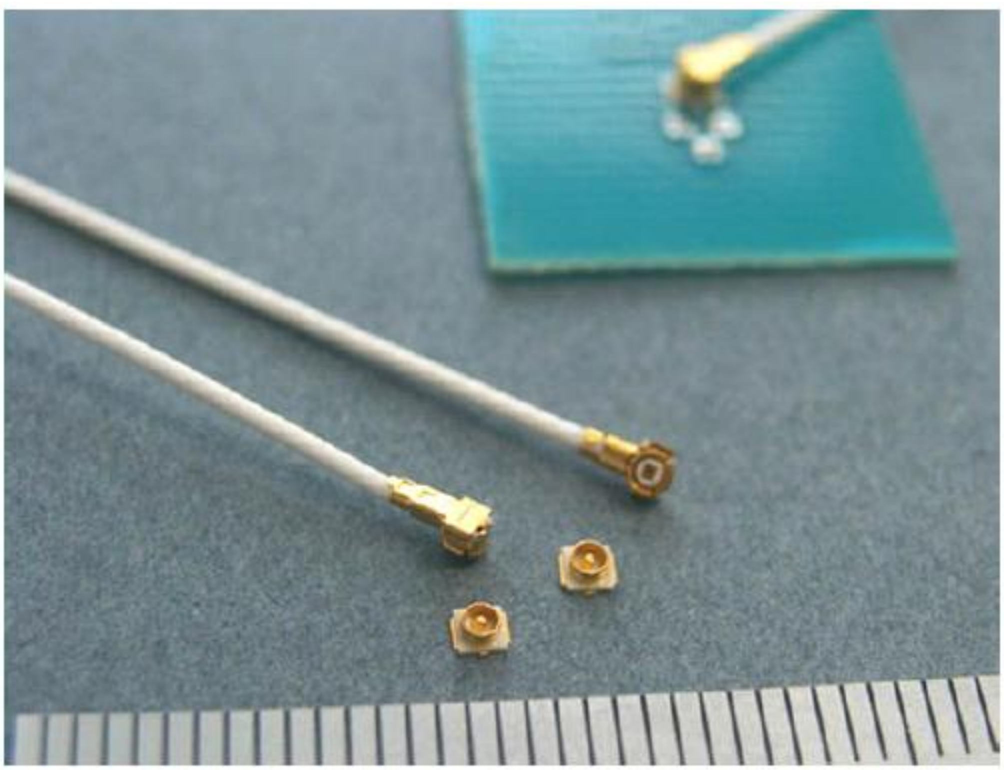

Figure 3: A list of modularly qualified antennas for GS1011MIE and GS1011MEE

Version	Date	Remarks
1.0	(pending)	Initial release.

SP-0.2

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