Application Note

GPS Antenna Considerations for Automotive Applications

GPS01

The design of active GPS antennas involves essentially three components: a patch element, filter, and low noise amplifier (LNA). Each of these components forms an important part of the overall antenna assembly and is critical to performance.

Antenna Element

Microstrip patch technology is often used to create the antenna element for automotive GPS applications. Sizes have been reduced to a 1 inch square puck, with thicknesses from 0.16 to 0.25 inches. The dielectric constant of the ceramic material in these cases is approximately 20. Several different techniques are used to generate Right Hand Circular Polarization (RHCP) from a patch element, including use of a polarization slot, offset feed points, and polarization tabs. The choice is at the discretion of the designer.

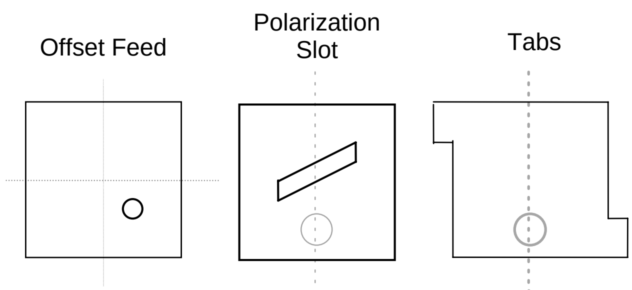

Figure 1: Techniques used to generate RHCP

Axial Ratio

Regardless of the design approach, there are common design parameters that are essential to the performance of the antenna. To provide an antenna that exhibits good performance with respect to RHCP, the axial ratio (a measure of the antenna's polarization purity), is critical. The higher the axial ratio, the more elliptical the polarization, and the lower the gain with respect to RHCP. This parameter is the result of design and process control. A measurement of the VSWR alone does not guarantee the antenna's axial ratio performance.

The correlation between axial ratio and circular gain is shown in the following formula, which provides a gain correction factor (GCF) in transitioning from measured linear gain and axial ratio to circular:

$$GCF\ (dB) = 20 \log [(1/\text{Ö}2)\ (1 + 10^{-(AR/20)})]$$

where AR is the antenna axial ratio in dB.
It can be seen from this formula that an antenna with an axial ratio of 0 dB has a GCF of +3.0 dB. This means that the circular gain of the antenna will be 3.0 dB higher than the peak linear gain of the antenna. An antenna with an 8 dB axial ratio will have a GCF of -0.1 dB, and be 3.1 dB lower than the 0 dB axial ratio antenna.

M/A-COM has developed a measurement process that allows us to verify axial ratio and VSWR in a single measurement. We impose strict requirements on the axial ratio of the ceramic patch antennas fabricated for us, and verify them prior to integration of the patch element into the antenna assembly. We have evaluated the antennas of several other manufacturers and repeatedly found that these parameters significantly deviate from optimized. M/A-COM GPS antennas provide boresight axial ratios of 2.0 dB or better typical on boresight. At 2.0 dB, the deviation in RHCP gain due to polarization inefficiency is only 1.0 dB from a perfect antenna. Other antennas we have measured have specified boresight axial ratios of 4.0 dB, but actually exhibit boresight axial ratios from 6 dB to 13 dB, a gain degradation of 2.5 to 4.5 dB from optimal. It is clear in this case that the controls imposed in M/A-COM designs are not in place elsewhere.

A secondary benefit to the control of axial ratio is multipath rejection. RHCP signals from the satellite that reflect off the sides of buildings, etc., will experience a polarization flip with the first bounce and become LHCP. If the path of the reflected signal is still in the main beam of the GPS antenna, then the only method for rejection of the multipath is polarization purity. An antenna with good axial ratio performance and therefore good polarization purity will have a better response to the direct RHCP signal than an antenna with poor axial ratio, and will also provide for better rejection of the reflected LHCP signal.

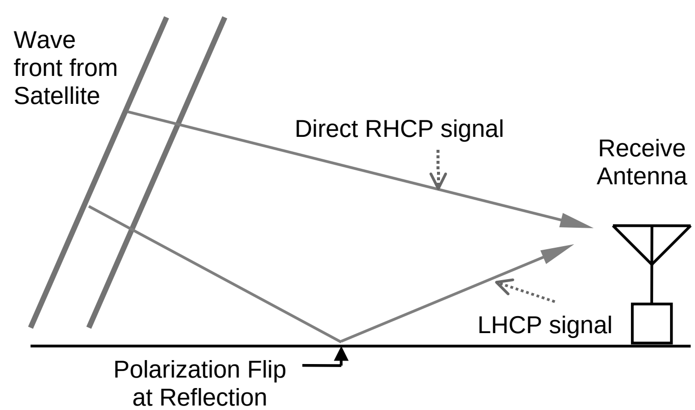

Figure 2: Polarization flip to LHCP

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Resonant Frequency

Equally important in the fabrication of GPS antenna elements is the control of resonant frequency. M/A-COM has a thorough understanding of the effects of radomes on the antenna resonant frequency. The packages we use for GPS antennas were considered in the specification of the resonant frequency performance of the patch antenna itself. As such, the VSWR and axial ratio requirements discussed earlier are set at a specific frequency range. This range is set higher than the final operating frequency band of 1575 MHz ± 3 MHz to assure the final assembly obtains optimized operation over the correct frequency band. These characteristics are verified on each antenna element and the final operating parameters are verified on the finished assembly.

A thorough understanding of the effects of the dielectric loading of radomes is essential to consistently produce hardware. Measuring frequency vs. axial ratio, we have seen shifts in resonant frequency from 1535 MHz to 1595 MHz in antennas produced elsewhere.

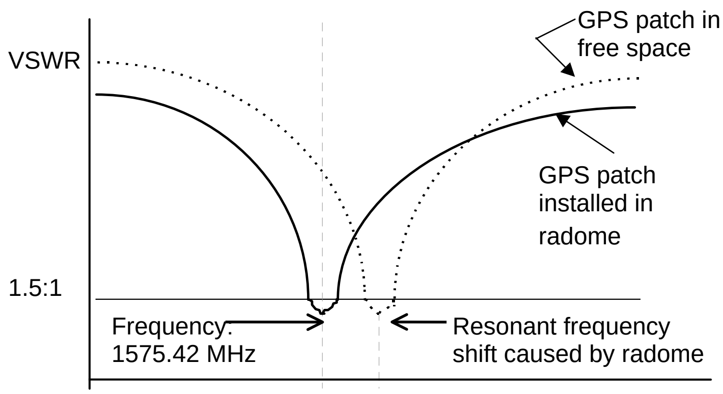

Figure 3: Randome effect on resonant frequency

M/A-COM carries this understanding of dielectric loading into the unpackaged active and passive GPS antennas. We often test antennas in our customers radomes and determine for them the required distance between the antenna face and inner radome to ensure optimized performance.

Ground Plane Size

The resonant frequency performance of each patch antenna will vary based on the ground plane size. The designer must minimize the effect of ground plane size on the antenna by achieving the smallest size point where further changes will have negligible effect on antenna performance.

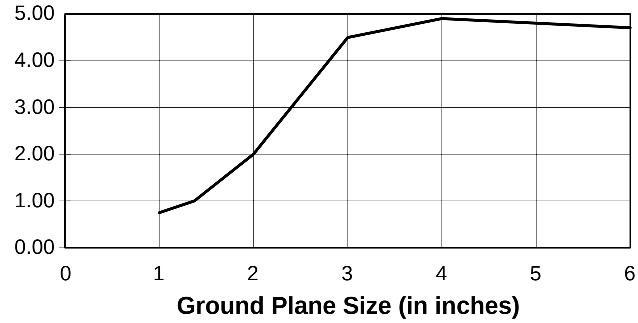

Figure 4: Antenna Zenith Gain vs. Ground Plane Size

M/A-COM has set the resonant frequency and bandwidth of the patch design to accomplish this task. Changes to performance from no ground plane to 3 inches in diameter have a known and balanced effect on the performance of our patch designs. This change reaches a constant at approximately 6 inches in diameter. Increases in the ground plane size beyond that have negligible effect on antenna performance. Without this design control, significant differences in radiation pattern performance will occur.

Bandwidth

Bandwidth is a key parameter to the antenna. It is important to provide as wide a bandwidth (both VSWR and CP purity) as possible to increase production yields and lower costs. It is also important to provide a relatively narrow bandwidth to optimize out-of-band rejection due to the antenna element alone. This helps in the rejection of signals that could be imposed on the LNA, and reduces the requirements on the bandpass filter to achieve overall antenna rejection.

The design of the patch antenna utilized by M/A-COM optimizes CP bandwidth over the VSWR band. The range of frequencies over which the antenna exhibits acceptable CP performance is only somewhat less than the VSWR bandwidth, and the rejection characteristics outside the bandwidth are maintained. The choice of a thin (0.160 inch) dielectric aids in accomplishing an antenna design that extends CP bandwidth performance.

Voltage Standing Wave Ratio

While the VSWR measurement of the patch element itself will not stand as satisfactory, it cannot be ignored. Poor VSWR results in poor gain due to signal lost to mismatch reflection. The antenna elements designed by M/A-COM have in-band VSWR of 1.5:1 or better. This translates to a mismatch loss of only 0.28 dB.

The formula for relating mismatch loss to VSWR is:

$$\text{Mismatch Loss (dB)} = 10 \log [1 - \{(VSWR - 1)/(VSWR + 1)\}^2]$$

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LNA

The LNAs used in M/A-COM's active antennas are high performance GaAs MMICs in low cost SOIC 8-lead surface mount plastic packages. These LNAs employ monolithic 3 stage self-bias designs and a simple external matching network (PC board), to obtain a minimum noise figure. The LNA is ideally suited for use where low noise figure, high gain, high dynamic range, and low power consumption are required. The LNA is fabricated using a mature 0.5-micron gate length GaAs process which features full passivation for increased performance.

These parts are individually tested for gain and noise figure before being supplied to M/A-COM. The excellent NF of these devices allows us to provide an antenna assembly with an outstanding and reliable noise figure. The LNAs are PC board matched to the operating band of 1575 MHz. The consistent center frequency of the antenna element, coupled with an LNA that is also optimized to 1575 MHz, results in a very efficient device.

The use of M/A-COM MMIC amplifiers significantly reduces the parts count normally associated with a discrete FET device. The result is a measurable increase in the MTBF of the antenna assembly.

M/A-COM LNAs also provide excellent RF performance over a range of DC biasing. They are capable of specified operation at a bias voltage as low as +3 VDC. Even at this low voltage, current draw is not increased.

Filter

The bandpass filter used in an active GPS antenna is an important component. Out-of-band rejection can be a critical factor in determining whether the GPS system will continue to operate in the presence of interfering signals such as a cellular car phone.

M/A-COM provides two levels of filtering in its active GPS products. Both are ceramic bandpass devices, one a two-pole and the other a three-pole. In each case, the individual filters are tested to the requirements of center frequency, insertion loss, and rejection at ± 50 MHz (or other), before being integrated into the assembly. This, like the LNA, assures that all three individual components are optimized at the desired frequency of 1575 MHz, providing an efficient antenna assembly.

The positioning of these three elements is important to the overall noise figure (NF) of the assembly. By placing the LNA directly after the antenna element, and before the filter (in a receive direction), the NF of the antenna assembly will be essentially that of the LNA. In this case, it is important that the rejection of the patch element be maintained to reduce the level of out-of-band signals on the LNA.

PCB Design

A poor PCB layout can destroy what may otherwise be a good design. The PCB must be laid out to assure that no RF coupling between the line exists to compromise performance. DC bias lines must have adequate RF chokes at all key locations. RF lines must have good DC blocks to assure that each LNA is biased properly. The PCB must provide the required matching input and output to the LNA(s).

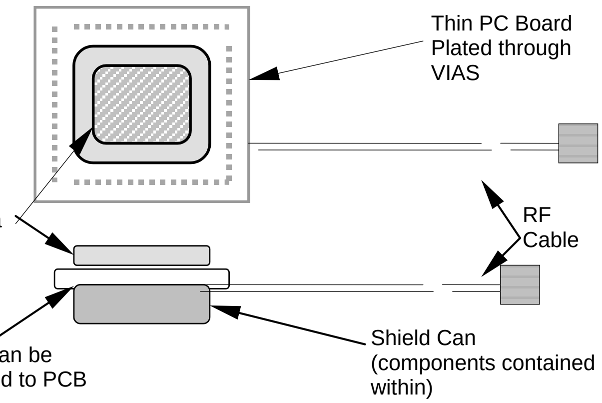

Figure 5: RF Shielding for Active GPS Antennas

M/A-COM has thoroughly evaluated each PCB used for our active GPS antennas. RF chokes and DC blocks are located as required to maintain RF performance. Additionally, M/A-COM's active antennas are the only ones that use an RF shield to assure performance. A metal shield encases the component side of the printed circuit board, eliminating RF coupling and re-radiation from the patch element.

Testing

M/A-COM maintains rigid testing requirements to ensure that all components are performing to specifications. The patch element, low noise amplifiers, and filter are individually tested against specific RF requirements, either by M/A-COM or by our supplier. The final antenna assembly is then tested for RF performance. Typical final testing consists of VSWR, swept gain, and out-of-band rejection.

Summary

Overall gain alone is not the true indicator that a GPS antenna is suitable for an automotive environment. The quality of the product starts with the performance of the patch element. Proper design assures consistency of the axial ratio performance, both at the specified level and the actual variance from part to part. If this parameter shows poor performance, it is safe to assume that the resonant frequency is not well controlled; the overall design is not optimized for efficiency and out-of-band rejection.

Swept gain data can be an indicator of a less than optimized design. The LNA and filter will each have their own pass bands

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(which should be centered on 1575 MHz). If the antenna element is not centered here, then the gain data will have an asymmetrical response around 1575 MHz. Rejection out-of-band will not be optimized.

M/A-COM has paid very close attention to all the details that make an active GPS design an excellent one, and we have incorporated them into our design.

Test Type	Method
Thermal Shock	-40°C to +85°C ; 10 cycles; 1 hour each hour
Moisture Susceptibility	-20°C soak; 45°C 95% relative humidity; 4 hours
Random Vibration	3 axes of 10 Hz/.04 GG/Hz to 1000 Hz/.002 GG/Hz
Salt Fog	Unit sprayed with salt solution; temperature soak at 49°C and 60°C for 16 hours
Mechanical Shock	3 axes; 20 G's peak 6 times per axis
Drop Test	1 meter height onto hard concrete surface; 6 times
Power Temperature Cycling	1000 hours of temperature with 5V bias cycle
Low Temperature Endurance	-40°C with cycled 5 V bias
Biased Humidity	call for test procedure
Electrostatic Discharge	call for test procedure
Immunity to Radiated Electromagnetic Fields	call for test procedure

Figure 6: Environmental Tests for GPS Patch Antennas

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