A Circularly Polarized Multimode Patch Antenna with Full Hemispherical Null Steering for GPS Applications

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1. Introduction

Pattern reconfigurable antennas offer an additional degree of freedom in the design of communications systems with which to mitigate potential threats in the electromagnetic environment. GPS receivers for example are notoriously susceptible to low power jammers and benefit from the use of reconfigurable null forming antennas. A common implementation consists of a patch array of N elements fed by a beamforming network to generate $N - 1$ scannable nulls. Active and switched parasitic beamforming array approaches can require sophisticated algorithms to compute the required complex weighting at each antenna element. Another approach is to excite N orthogonal radiating modes on the same element or collocated elements and use phase and amplitude weighting to scan $N - 1$ beam peaks and nulls. The approach taken in [1] realizes a circularly polarized (CP) directional mode and a linearly polarized (LP) omnidirectional mode excited on the same rectangular patch. However, only low elevation azimuthal jammers can be effectively nulled while maintaining CP in the main beam. collocated patch antennas in [2] produce CP directional modes capable of azimuthal ring nulls. An LP multimode antenna using amplitude weighting and switched phase to achieve full hemispherical beam peak and null steering was reported in [3]. We propose a novel multimode patch antenna capable of both low axial ratio main beam and full hemispherical null steering. All results are based on full wave simulations performed using Ansoft's High Frequency Structure Simulator (HFSS).

2. Antenna Geometry

The novel single layer multimode microstrip antenna in Fig. 1 consists of a TM_{11} patch embedded in a TM_{21} shorted annular patch. Shorting vias are used both to isolate the modes and to create a good impedance match for the feed points on the outer patch. This is in contrast to the multimode circular patch antenna of [4], which requires m ports at m points of rotational symmetry in a TM_{mn} mode. For low axial ratio, each antenna is fed in quadrature at two points whose angular spacing is given by $\pi/2m$, where m is mode number associated with TM_{mn}. The angular separation between each pair of ports is 90° (TM_{11}) and 45° (TM_{21}) in accordance with the azimuthal boundary condition for each mode. The antenna was designed to operate over the L1 GPS band (1565 MHz - 1585 MHz). Rogers 5880 ($\epsilon_r = 2.2$) substrate was chosen with a 60 mil thickness, which has reasonable loss characteristics and stable permittivity within L-band. The geometric parameters of the patches were optimized to achieve a low reflection coefficient over the L1 band as follows: $a = 36.3$ mm, $b = 75.1$ mm, $r_{12} = 10.5$ mm, $r_{34} = 52.0$ mm and $g = 3.0$ mm. Shorting vias were chosen to be 1 mm in diameter, spaced 6° apart and located at a radius of 14.0 mm.

3. Theory of Operation

As stated in [1], the phase shift between modes changes the azimuthal location of the null while the null elevation is controlled by the mode amplitude ratio. The phase difference between modes is specified by $\beta = P_1 - P_3$, where P_2 and P_4 are known by the additional 90° phase shift required for CP.

Similarly, the amplitude ratio between modes is denoted by $\alpha = A_1/A_3$. Fig. 2 illustrates mechanism for this behavior by plotting the complex radiation pattern for a port amplitude ratio of 0 dB and a phase difference of 0° at 1575 MHz. There is a wide range of elevation angles where the amplitudes are approximately equal and an overlapping narrow range of azimuthal angles where the modes differ by 180°. Based on this observation, we can expect a null to form with narrow azimuthal beamwidth near ϕ = 45° and with wide elevation beamwidth.

4. Results and Discussion

The feed network shown in Fig. 3 is composed of low noise amplifiers (LNA) for stable input impedance, a single variable gain amplifier (VGA), a single phase shifter (PS), and one hybrid coupler for each pair of ports. This feed architecture was not implemented in simulations, rather each port was independently excited in HFSS. The resulting reflection coefficient for ports 1 and 3, and the worst case mutual coupling (between ports 3 and 4) are plotted in Fig. 4. The antenna is well matched at each pair of ports and the mutual coupling is less than -20 dB across the L1 band.

Azimuthal null and beam steering are accomplished only by changing the phase difference between pairs of ports. This effect is shown for 4 values of phase difference in Fig. 5, which verifies the anticipated shape and location of the null from section 3. One complete rotation of the null in azimuth requires a phase shifter range of 0° to 360°. Fig. 6 plots the null and beam peak elevation pattern characteristics as a function of port amplitude ratio. The null can be continuously scanned from broadside to endfire with a port amplitude ratio ranging from -15 dB to 5 dB, respectively, while maintaining a null depth less than -15 dB. Finite ground plane effects limit the scan range of the beam peak to approximately 40° off broadside. Polarization purity is maintained within the vicinity of the main beam for any null scan angle. A particular case is shown in Fig. 7, where the main beam is located at $\phi = 90°$, $\theta = -30°$ with a null depth of less than -10 dB from $\theta = 20°$ to 90°. An axial ratio less than 3 dB is maintained from $\theta = -63°$ to +24° , which is well beyond the HPBW of the main beam.

5. Conclusions and Future Study

A novel multimode element was proposed based on concentric circular patch antenna elements supporting TM_{11} and TM_{21} modes. Using shorting vias, the need for symmetric feed arrangements are eliminated. This antenna maintains excellent CP within the main beam while supporting a null that can be scanned anywhere in the upper hemisphere. We are currently researching wideband implementations of this antenna and the use of additional patch modes. Additional results and related work will be presented during the symposium.

Acknowledgments

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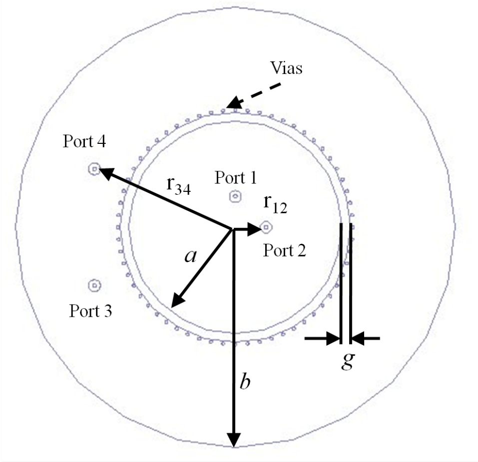
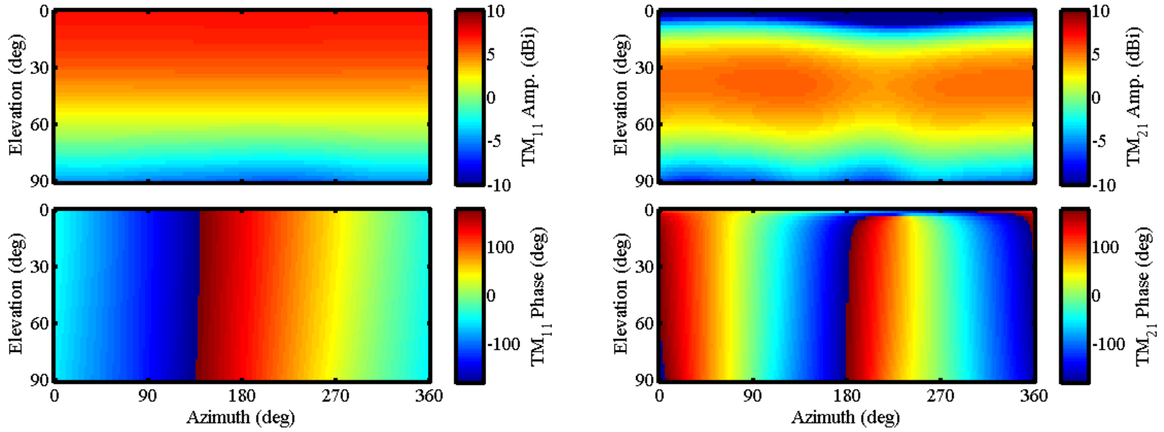


Figure 1: CP multimode antenna geometry.



(a) TM_{11} mode

(b) TM_{11} mode

Figure 2: Amplitude and phase of far-field patterns at 1575 MHz for $\alpha = A_1/A_3 = 0$ dB and $\beta = P_1 - P_3 = 0°$

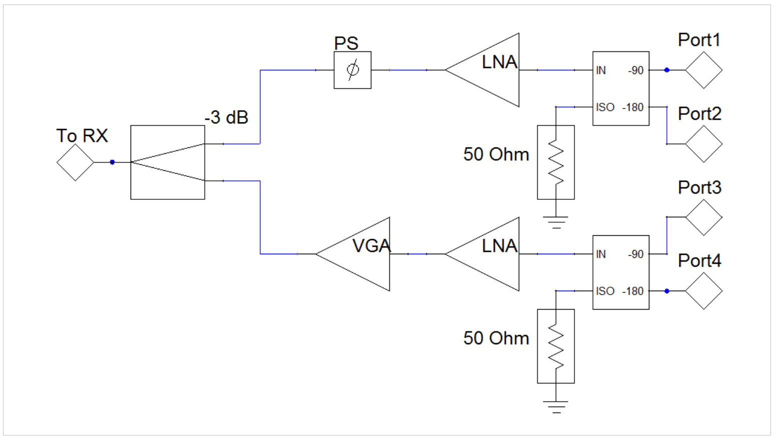


Figure 3: Proposed receiver feed network composed of low noise amplifiers (LNA), variable gain amplifier (VGA), phase shifter (PS), hybrid couplers and power combiner.

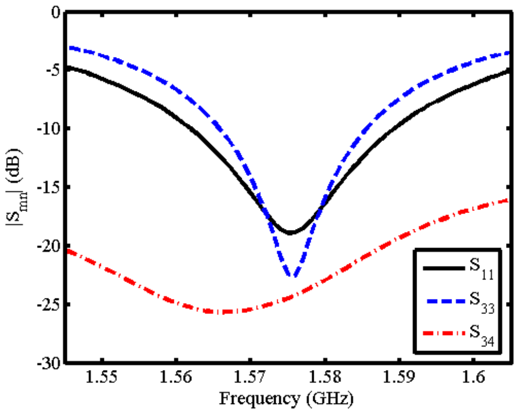


Figure 4: Port reflection coefficients and worst case mutual coupling.

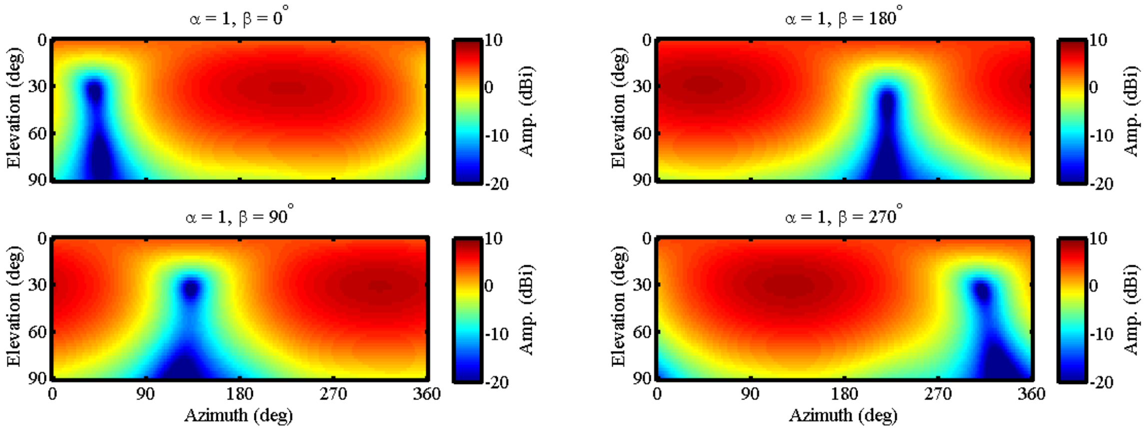
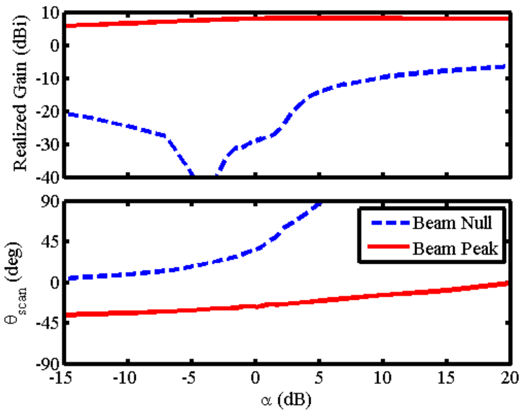


Figure 5: Azimuthal null scan as a function of mode phase difference β.



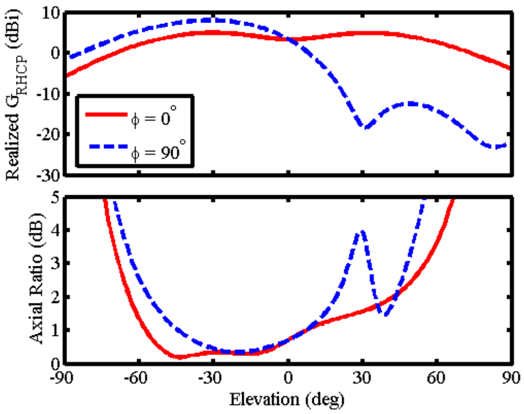


Figure 6: Elevation beam peak and null scan properties as a function of port amplitude ratio α.

Figure 7: Co-pol gain (top) and axial ratio (bottom) for $\alpha = 1$ and $\beta = 45°$.