A Miniature Dual-band GPS Antenna with Slot Loading

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Abstract: A miniature dual-band GPS antenna is proposed for compact GPS arrays or portable GPS devices. Slots are cut on the patch to further reduce the antenna size to one inch ($\lambda/10$ at the L2 band). A single-fed quadrature-phase splitter is designed to reduce the array electronics. Design concepts and procedures are presented along with performance assessment using FEKO.

Keywords: compact GPS array, dual-band GPS, stacked patch antenna, slot-loading, single-fed

1. Introduction

Recent GPS antenna developments have focused on miniaturization of the GPS arrays for anti-jamming purposes (adaptive nulling and beam-forming [1]). The prevailing controlled radiation pattern antenna (CPRA) GPS array has one reference element at the center and six auxiliary ones arranged along the circumference of a 14-inch aperture. However, its large size limits the application of CPRA on small vehicles. It is therefore of interest to design compact and closely-packed GPS arrays for anti-jamming applications.

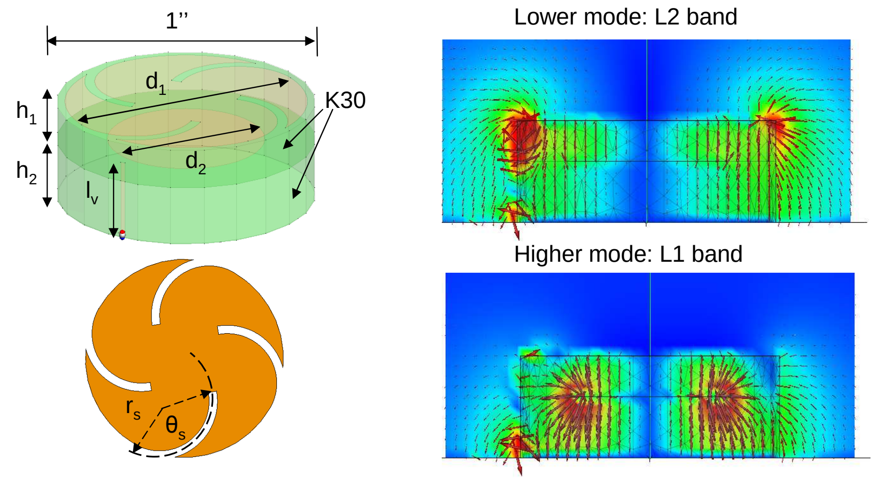
A 1.2-inch GPS antenna was already reported for a 6-element compact GPS array [2]. In this paper, we further miniaturize the antenna size to one inch ($\lambda/10$ at the L2 band) by cutting slots on the patch, which effectively introduces inductive loading for the patch mode. To reduce the feeding electronics for compact GPS arrays, the GPS antenna is fed through a single coaxial cable connected to a quadrature-phase splitter for right-hand circularly polarized (RHCP) operation. A 3.5-inch 4-element GPS adaptive array can thus be designed using the proposed one-inch dual-band (L1: 1575.42 MHz and L2: 1227.6 MHz) GPS antenna. The small size and single-fed property also makes the proposed GPS antenna very attractive for portable GPS devices. In the next sections, we begin with the design concept and procedures, followed by performance assessment using FEKO. The measurement results will be presented at the conference.

2. Design Concept and Procedures

A. Antenna miniaturization by slot-loading

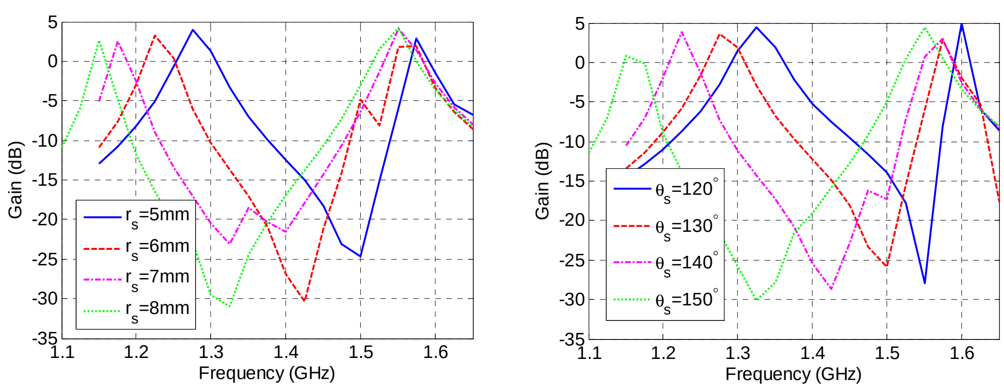
The proximity-fed stacked patch (PFSP) antenna has been reported [2-3] to operate in dual mode, covering all three GPS bands. However, to further reduce the antenna size to 1 inch, more aggressive dielectric loading is needed, but this results in narrower bandwidth and lower antenna efficiency. An alternative to dielectric loading is to employ inductive loading. For example, zigzag dipoles [4] are reported to have longer resonance paths, implying a smaller electrical size. Spiral antennas have been miniaturized in the past by coiling the spiral arms to introduce series inductance [5]. In the similar way, we can perturb the current flow by cutting slots on the patch, effectively increasing the resonance path length and introducing inductive loading.

The FEKO model of such a slot-loaded stacked patch antenna is shown in Figure 1. As can be seen from the electric fields plot, the patches are arranged in such a way that the higher frequency (L1 band) is supported in the lower substrate and the lower frequency (L2 band) is supported in the upper substrate. As compared to [2-3], this arrangement has the advantage of less inter-element coupling in an array setting and is necessary for smaller array sizes. Since the patch mode in the upper substrate requires more miniaturization, slots are cut in the upper patch to force meandering of the electric currents along the slots, which results in a longer resonance path for the lower frequency mode. A parametric study on the slot length (associated with slot radius, r_s, and slot angle, θ_s) is shown in Figure 2. It can be seen that smaller antenna size can be realized with longer slot loading.



(a) FEKO model and parameters (b) Electric fields at resonances

Figure 1: FEKO model of a slot-loaded proximity-fed stacked patch antenna



(a) Adjust slot radius (r_s) (b) Adjust slot angle (θ_s)

Figure 2: Parametric study on slot length

B. Single-fed excitation by quadrature-phase splitter

We now proceed with the design of a single feed to realize circularly-polarized (CP) operation. As shown in the inset of Figure 3, a printed quadrature-phase splitter is proposed to achieve CP excitation with a single feed. Specifically, the input power is divided equally by the Wilkinson power divider and one of the outputs has additional 90° phase delay due to the microstrip delay line. Note that the Wilkinson power divider is bent into a S-shape to reduce the footprint of the feeding network. The widths of the microstrip lines (w_1 and w_2) are adjusted for impedance matching. The other design parameters are chosen as follows: $l_1 \cdot \sqrt{\epsilon_{eff}} = \lambda_0/4$ for the Wilkinson power divider (ϵ_{eff} is effective dielectric constant of the PCB: Duroid 6010LM, $\epsilon_r = 10.2$ & 0.635mm thick); and $[r_1(\pi/2 - \theta_1) - r_1\theta_1] \cdot \sqrt{\epsilon_{eff}} = \lambda_0/4$ to realize a 90° phase delay between the output ports. Figure 3 shows the simulated performance of the quadrature-phase splitter with the following parameters: $r_1 = 16.5$ mm, $l_1 = 22.4$ mm, $\theta_1 = 81°$, $w_1 = 0.25$ mm and $w_2 = 0.58$ mm. As seen, the return loss (S11) and isolation (S23) are below -20 dB for both GPS bands. Also the insertion loss (S21 and S31) is nearly -3 dB, indicating equal power splitting. The phase delay between ports 2 and 3 is 80° for the L2 band and 102° for the L1 band, acceptable for CP excitation.

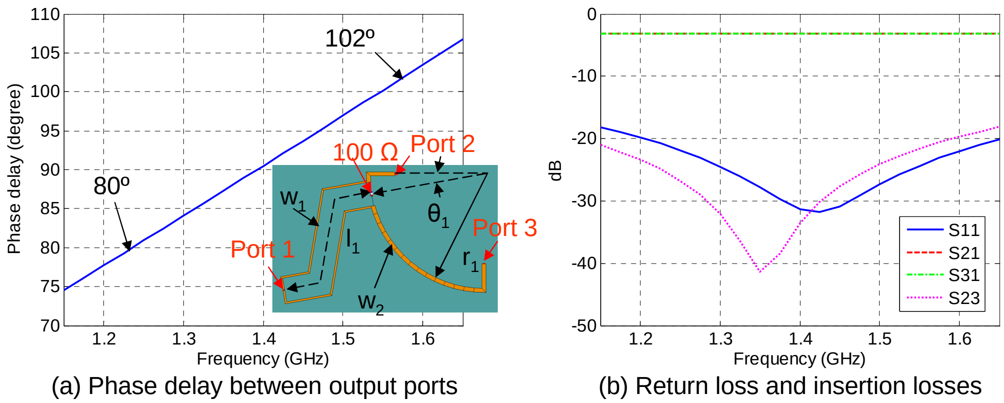
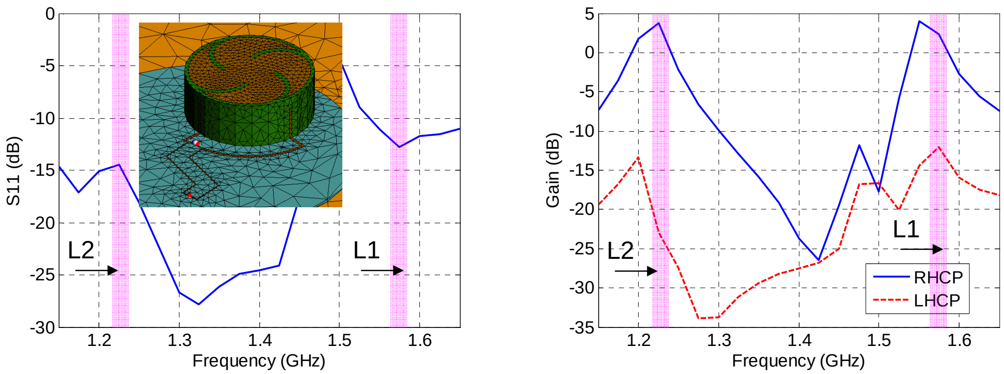


Figure 3: Simulated performance of the quadrature-phase splitter

3. Performance Assessment Using FEKO

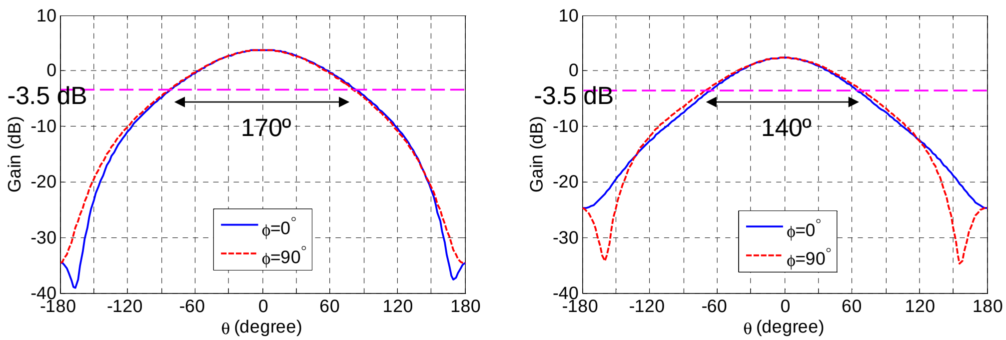
We then proceed to integrate the quadrature-phase splitter with the slot-loaded stacked patch antenna. Two PEC strips are connected to the outputs of the quadrature-phase splitter to excite the patch modes. The FEKO model of the proposed 1"-wide, slot-loaded and single-fed GPS antenna on a 5" ground plane is shown in the inset of Figure 4. The dielectric cylinders are modeled as polygons so that the metal strips are conformal to the boundary of the substrates. The FEKO simulation is implemented via the Surface Equivalent Principle (SEP) using 3176 metallic and 1655 dielectric triangles.

Referring to Figure 1, the design parameters are as follows: $d_1 = 24$ mm (upper patch diameter), $d_2 = 15.6$ mm (lower patch diameter), $h_1 = 4$ mm (upper substrate thickness), $h_2 = 6$ mm (lower substrate thickness), $\epsilon_r = 30$ (dielectric constant of K30), $r_s = 6$ mm (slot radius) and $\theta_s = 140°$ (slot angle). The simulated return loss and gain performances are depicted in Figure 4. We observe that the proposed 1"-wide GPS antenna has a RHCP gain greater than 3 dB at the L1 and L2 GPS bands with CP isolation larger than 15 dB (viz. well above the required minimum specs of 1 dB gain). The simulated radiation patterns on the two principle cuts ($\phi = 0°$ and $\phi = 90°$) are also plotted in Figure 5. These patterns exhibit broad beamwidth at both GPS bands (gain > -3.5 dB for elevation angles > 20°).



(a) Return loss (S11) (b) Gain

Figure 4: Simulated performance of the one-inch GPS antenna



(a) L2: 1227 MHz (b) L1: 1575 MHz

Figure 5: Simulated radiation patterns on the two principle cuts

4. Conclusion

In this paper, we proposed a miniature dual-band GPS antenna for compact GPS arrays or portable GPS devices. Slot-loading was employed to further miniaturize the antenna size down to 1" aperture ($\lambda/10$ at the L2 band). The antenna and the feeding network were modeled in FKEO and exhibited desirable performance for GPS operation.

References

[1] G. F. Hatke, "Adaptive array processing for wideband nulling in GPS systems," in *Proc. 32th Asilomar Conf. Signals, Syst., Comput.*, pp. 1332-1336, 1998.

[2] Y. Zhou, C.-C. Chen and J. L. Volakis, "A single-fed element antenna for tri-band anti-jamming GPS arrays," *IEEE APS/URSI Symposium*, San Diego, CA, July 2008.

[3] Y. Zhou, C.-C. Chen and J. L. Volakis,"Dual band proximity-fed stacked patch antenna for tri-band GPS applications," *IEEE Trans. Antennas Propagat.*, Vol. 55, No. 1, pp. 220-223, 2007.

[4] H. Nakano, H. Tagami, A. Yoshizawa and J. Yamauchi, "Shortening ratios of modified dipole antennas," *IEEE Trans. Antennas Propagat.*,Vol. 32, No. 4, pp. 385-386, 1984.

[5] B. A. Kramer, C.-C. Chen and J. L. Volakis, "Size reduction of a low-profile spiral antenna using inductive and dielectric loading," *IEEE Antennas and Wireless Propagation Letters*, Vol. 7, pp. 22-25, 2008.