Wideband Proximity-Fed Low Profile Circularly Polarized Patch Antenna

Christian Cavalier and Brad R. Jackson
Department of Electrical and Computer Engineering
California State University, Northridge
Northridge, CA, USA
christian.cavalier.141@my.csun.edu, bradley.jackson@csun.edu

***Abstract*—This paper presents a low profile, circularly polarized patch antenna using proximity coupled feeds. A wide bandwidth was achieved by exciting the patch antenna with four proximity coupled feeds from a wideband phase shifting network. The simulated -10 dB $|S_{11}|$ bandwidth was from 1480 MHz to 2730 MHz (58.4%) and the simulated 3 dB axial ratio bandwidth was from 1650 MHz to 2820 MHz (52.4%). The peak gain of the antenna was simulated to be 4.4 dBi at 2000 MHz in the broadside direction. This was achieved while maintaining a very low profile of 0.05λ, where λ is the wavelength corresponding to the lowest operating frequency. The overall antenna dimensions were 75.0 mm $\times$ 75.0 mm $\times$ 9.2 mm.**

I. Introduction

With the increasing popularity of small satellites, such as CubeSats, the need for low profile antennas to be used for this application has increased. The antennas used on these small satellites typically must be low profile, have a small footprint, a large bandwidth (BW), and have circular polarization (CP). Traditional patch antennas, however, often exhibit narrow bandwidths. To improve the bandwidth of the patch antenna, proximity coupling may be used in lieu of a direct connection of the feed network to the patch. This technique is explored in [1]–[4]. The gain and bandwidth of these antennas is good, however, these designs require a relatively large footprints. The designs in [1]–[4] utilize air gaps and large ground planes to increase their gain whereas the antenna proposed in this paper uses a smaller ground plane to make a very compact, low profile, broadband, CP antenna.

The antenna design proposed in this paper aims to employ the bandwidth-increasing technique of proximity coupling while maintaining the advantage of the patch antenna's low profile in a CP design. A circular patch was chosen because it can be easily used to achieve CP by exciting it with multiple ports with appropriate phase shifts. In the proposed antenna, a compact multilayered design was used to implement the phase shifting feed network in order to keep the antenna footprint and height to a minimum.

II. Antenna Design

The circular patch was first optimized with an ideal feed network and the optimal patch radius was determined to be 21.5 mm for the desired center frequency of 2 GHz. Four proximity feeds connect to the centers of rectangular proximity patches located on the substrate beneath the antenna patch as shown in Fig. 1. The antenna was driven with one input port that connects to a phase splitting network. This phase splitting network creates relative phases of 0°, 90°, 180° and 270° for the four proximity patches. A perspective view of the antenna with semi-transparent substrates can be seen in Fig. 1.

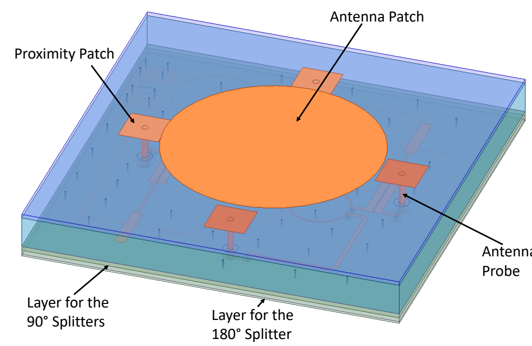

Fig. 1. Diagram of the proposed antenna with semi-transparent substrates.

The middle substrate was made of a 6.4 mm Rogers 5880 layer with a relative permittivity (ϵ_r) of 2.2, which was used to maximize antenna efficiency. The top substrate layer contains a thin 0.8 mm FR4 layer with an ϵ_r of 4.3. This top FR4 layer keeps manufacturing costs to a minimum and does not introduce signifcant losses since it is relatively thin. The bottom substrate layer was a 2.1 mm thick FR4 layer which contained the phase splitting network. Again, FR4 was chosen to keep manufacturing costs to a minimum.

To achieve phase differences of 0°, 90°, 180° and 270°, one 180° hybrid and two 90° hybrids were used. To ensure the design of the feed network could fit beneath the antenna element and be very compact, the PCB area was limited to 75 mm $\times$ 75 mm. To achieve this, the feed network was designed using four conducting layers in a stacked configuration.

To implement the 90° hybrids, stepped impedance open stubs [5] were used with Wilkinson power dividers using striplines. The characteristic impedances and lengths of the striplines were designed for a center frequency of 2 GHz.

To complete the feed network, the 180° phase splitter was designed based on the approach in [6]. As with the 90° phase splitter, the characteristic impedances and electrical lengths of the transmission lines were designed for 2 GHz, but used

TABLE I
COMPARISON OF CIRCULARLY POLARIZED PATCH ANTENNAS

Reference	Center Frequency (GHz)	Peak Gain (dBi)	Axial Ratio BW	Impedance BW	Footprint Area (λ^2)	Height (λ)
This Paper	2.00	4.4	52.4%	58.4%	0.17	0.05
[1]	1.84	8.6	81.6%	73.0%	1.73	0.09
[2]	1.40	5.0	29.0%	43.0%	1.08	0.07
[3]	5.80	10.1	13.4%	27.0%	1.18	0.11
[4]	2.25	6.8	38.0%	61.0%	0.69	0.10

microstrip lines. For both the 90° and 180° hybrids, the 50 Ω transmission lines leading into and out of the splitters were placed such that the splitters could fit in the antenna footprint while making necessary connections to the vias that connect to the proximity patches. The feed network of the antenna can be seen in Fig. 2 with a semi-transparent substrate. The overall dimensions of the antenna are 75.0 mm × 75.0 mm × 9.2 mm.

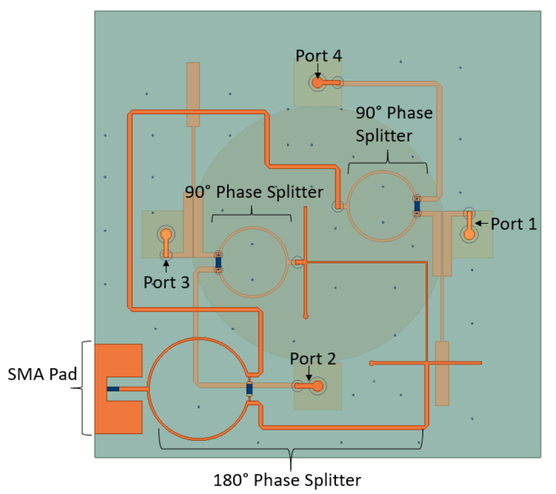

Fig. 2. Bottom view of the proposed antenna with semi-transparent substrates.

III. ANTENNA PERFORMANCE

The antenna was simulated with HFSS and the results can be seen in Figs. 3 and 4. The simulated 3 dB axial ratio bandwidth was from 1650 MHz to 2820 MHz (52.4%), as shown in Fig. 3. The simulated -10 dB $|S_{11}|$ bandwidth (Fig. 4), was from 1480 MHz to 2730 MHz (58.4%). The peak gain of the antenna was simulated to be 4.4 dBi at 2000 MHz in the broadside direction as also seen in Fig. 4.

Table 1 compares the antenna presented in this work to other wideband circularly polarized antennas, where λ is the wavelength corresponding to the lowest operating frequency. As seen in Table 1, the antenna presented in this paper has similar or greater bandwidth to the other antennas while achieving a smaller size. For example, the antenna presented in this paper has a footprint area of $0.17\lambda^2$ while the antenna in [1] has an area of $1.73\lambda^2$.

IV. CONCLUSION

A wideband low profile circularly polarized antenna was presented in this paper using a proximity coupled design. The main advantage of the presented antenna is its low profile design (0.05λ) and its compact footprint area (0.17λ), where λ corresponds to the wavelength at the lowest operating frequency. The simulated impedance bandwidth ($|S_{11}| \leq -10$ dB) was from 1480 MHz to 2730 MHz (58.4%) and the 3 dB axial ratio bandwidth was from 1650 MHz to 2820 MHz (52.4%). The peak gain of the antenna was simulated to be 4.4 dBi at 2000 MHz.

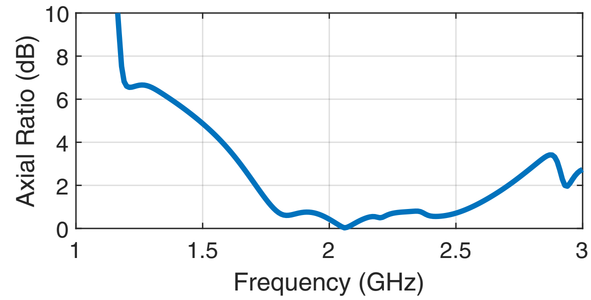

Fig. 3. Simulated axial ratio at broadside.

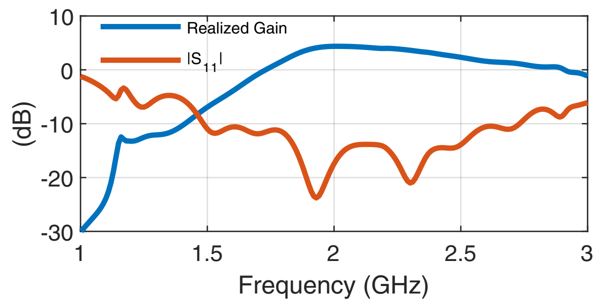

Fig. 4. Simulated realized gain and reflection coefficient.

REFERENCES

[1] Y.-X. Guo, S. M. IEEE, K.-W. Khoo, S. M. IEEE, L. C. Ong, and S. M. IEEE, "Wideband circularly polarized patch antenna using broadband baluns," *IEEE Trans. Antennas Propag.*, vol. 56, no. 2, 2008.

[2] D. Li, P. Guo, Q. Dai, and Y. Fu, "Broadband capacitively coupled stacked patch antenna for GNSS applications," *IEEE Antennas Wirel. Propag. Lett.*, vol. 11, 2012.

[3] R. Theunis, M. Baert, P. Leroux, and W. Dehaene, "Highly broadband circular polarized patch antenna with 3 phase feed structure," *11th European Conference on Antennas and Propagation*, 2017.

[4] I. Sipili and B. Jackson, "A circularly polarized microstrip antenna using an open stub coupled-line phase shifter," *IEEE AP-S/URSI*, 2020.

[5] Q. Liu, Y. Liu, J. Shen, S. Li, C. Yu, and Y. Lu, "Wideband single-layer 90° phase shifter using stepped impedance open stub and coupled-line with weak coupling," *IEEE Ant. Wirel. Propag. Lett*, vol. 24, no. 3, 2014.

[6] Z.-Y. Zhang, Y.-X. Guo, L. C. Ong, and M. Y. W. Chia, "A new wide-band planar balun on a single-layer PCB," *IEEE Antennas Wirel. Propag. Lett*, vol. 15, no. 6, 2005.