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A Compact Millimeter Wave Polarization Reconfigurable Double Patch Antenna

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***Abstract*— A polarization-reconfigurable single-fed patch antenna loaded with a smaller parasitic stacked bandwidth-enhancing patch are reported in this letter. The antenna system is optimized to operate at 29 GHz with three polarization modes that can be reconfigured electronically. The structure consists of two Rogers 3003 substrates of thicknesses of 0.25 and 0.50 mm for the driven antenna and the parasitic one, respectively. The main antenna's ground layer has four square loops etched out to excite the current paths on the driven patch needed for circular polarizations. These four slot loops are placed in the driven patch's four corners and are controlled with four P-I-N didoes. By shorting two diagonally placed slot loops, a circular polarization (CP) mode is created while shorting all of them will result in linearly polarized (LP) radiation. The measured gain and relative impedance bandwidth (BW) of the left-hand circular polarization (LHCP) are 3.1 dB and 5.4%, respectively. Similar results are obtained for the RHCP due to symmetry in structure and biasing conditions. The LP case reached a gain of 4.0 dB and a relative impedance BW of 5.45%. The overall size of the antenna system is 10.2x14.1x0.784 mm^3 with a radiation efficiency above 90%. Measurement results are compared and validated with simulations.**

I. Introduction

Motivated by an addition of another order to spatial multiplexing, researchers started building antenna systems that support both senses of circular polarizations (CP) and linearly polarized ones. Combining CP with LP in a single-fed antenna is a complex task that leads to either complex feeding network or compromised performance in terms of bandwidth, gain, and axial ratio. A single-fed monopole antenna operating at 2.4 GHz that could radiate in LP and CP modes was reported in [1]. Impedance BW was 70% for the LP and 22% for the CP case and the ARBW was 4.2%. However, as expected, the gains reported were 1.2, 0.6 and 0.5 dBic for the RHCP, LHCP and LP modes, respectively. Another multi-polarized antenna with better performance was presented in [2] that operated at 2.4 GHz. The antenna utilized two loop slots under the top two corners of the patch antenna to stimulate the polarization mode required. Across each loop slot, a pin diode was placed to control the current path on the patch above. CP modes were activated when one of the loop slots was shorted, while LP radiations happened when both slots were shorted.

In this work, a three-polarization-reconfigurable patch antenna is introduced with four loop slots in the ground under each corner. The addition of two more slots compared to [2] increases the cross-polarization levels for the CP modes but will increase the difference between the resonance frequencies of the LP and CP modes as inserting slots in the ground will change the effective dimensions of the patch antenna and, hence, change the operating frequency. To increase the BW, another thicker substrate with a parasitic patch that is 16% smaller in surface area is mounted on top of the driven antenna. Furthermore, as an extension, this work and its measurements are validation of a previous paper [3] with slight modifications in the design. The fabricated mm-wave tri-polarized single-fed antenna had up to 1.6 GHz of BW, CP gain of 3 dB, LP gain of 4 dB, an ARBW of 370 MHz and a total size of 112.75 mm^3.

II. Polarization Reconfigurable Patch Antenna

The antenna system consists of two elements; a driven patch antenna on a Rogers (RO3003) substrate with a thickness of 0.25mm, and a smaller parasitic one mounted on a thicker substrate of the same material and positioned centrally above the active patch. Both of the driven patch antenna and the parasitic one are squares with side lengths of 2.83mm and 2.264mm, respectively. Shown in Figure 1, the overall size of the antenna system is 14.1×10.2×0.784 mm^3 that corresponds to 1.4×1×0.8 λ^3. Four square slots are placed under each corner of the driven patch with a side length of 1.5 mm and a slot width of 0.25 mm. They are useful in stimulating the current paths on the active patch needed to achieve CP modes. The inner corner of each square slot is located 0.707mm toward the projection of the driven patch's center point on the xy-plane. A microstrip line is etched out from the ground with a width of 0.31mm having an impedance of around 50Ω to accommodate the feeding probe (Pasternack port PE44489), through which the antenna will be connected later to a VNA. This feeding line is connected to a via with a diameter of 0.4mm and optimally positioned $\lambda/3$ from the edge for matching purpose. The presence of these four slots is controlled by four P-I-N diodes connected across them that have their cathodes shorted with the grand ground plane. These mm-wave MACOM beamlead P-I-N diode, are modeled as 10 kΩ resistors in parallel with 28 pF capacitors when the forward voltage drop is less than 1.2V and modeled as 4Ω resistors when forwardly biased. The addition of the parasitic element increased the impedance BW and increased the antenna's system gain, but the cross-polarization levels between LHCP and RHCP were reduced. Operating in the transverse magnetic mode, when all loop slots are shorted, the antenna produces linearly polarized radiations since the tip of the surface current vector on the driven patch is oscillating in the ± y-axis. Introducing loops slots diagonally placed across the patch would add some phase difference between the maximum current in the upper edge with respect to the maximum current on the lower edge, creating rotational resultant current that produces CP radiations. The slots' dimensions and positions are optimized to produce highest cross-polarization levels possible while maintaining high gain and wide BW.

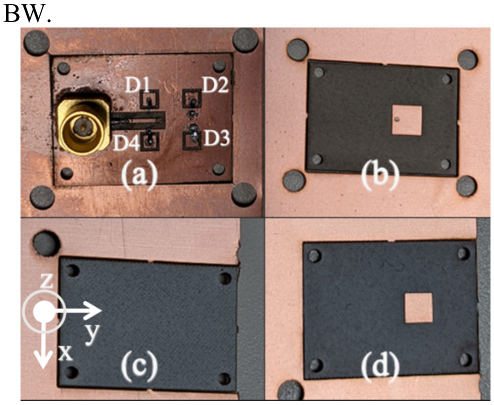

Figure 1 Fabricated prototype; (a) bottom, (b) top view of the driven antenna, and (c) bottom and (d) top view of the parasitic element

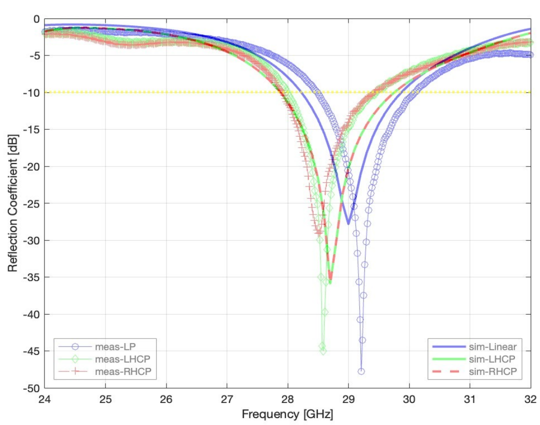

Figure 2 Simulated and Measured Reflection Coefficients

III. Computer Modeling and Simulation Results

The antenna system has been designed and optimized using ANSYS Electronics Suite 2020. Simulating the diodes were done through creating RLC objects that change their values depending on the biasing states. When D1 and D3 are set in forward biasing, their corresponding slots are shorted and only the top right and bottom left slots are present. As a result, RHCP mode is activated and an impedance BW from 27 to 29 GHz with respect to the -10 dB line is achieved. Simulated axial ratio spans below the 3dB line from 27.78 up to 28.15 GHz while the RHCP gain reaches 3.2 dB over a wide BW from 25 up to 30.5 GHz. Similarly, when D2 and D4 are forwardly biased, LHCP mode is activated, and identical results are acquired due to structural symmetry. In the case of linear polarization, all slots are shorted creating an LP microstrip patch antenna with an impedance BW of 1.9 GHz and a gain of 4 dB centered at 28.5 GHz. The simulated reflection coefficients for the three polarization modes are plotted in Figure 2.

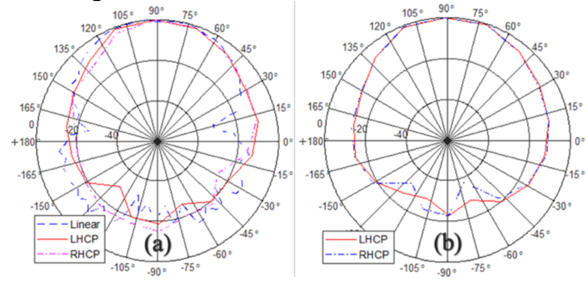

Figure 3 Measured normalized radiation patterns in (a) YZ- and (b) XZ-planes

IV. Measurement and Discussion

Using a vector network analyzer (Anristu MS46522B), the input reflection coefficients for the antenna system were measured. The measured impedance BW spanned from 28 up to 29.5 GHz for the CP cases while it spanned from 28.5 up to 30.1 GHz for the linear one as shown in Figure 2. The ARBW was slightly above 300 MHz around 28.5 GHz. The shift in the operating frequency could be attributed to several factors. While simulating a 0.2mm increase in the antenna's side length, a downward shift of 1 GHz is obtained. When soldering the DC lines into the antenna systems, excess solder could lead to some changes in the geometry of the system that could lead to a different resonant frequency. The antenna system had measured gains of 4, 3.1 and 3 dB for the LP, LHCP and RHCP, respectively. Their normalized radiation patterns are shown in Figure 3. To the author's best knowledge, the antenna system presented here is the most compact single-fed multi-polarized solution in the mm-wave spectrum that has been fabricated and tested.

V. Conclusion

In this work, a compact single-fed multi-polarized mm-wave microstrip patch antenna, operating at 29 GHz, was designed, simulated, fabricated and measured. A secondary parasitic patch was added to enhance the BW that was found to be 5.22% for the LP case and 5.56% for the CP modes. Gains achieved for the three polarization cases ranged from 3 to 4 dB. Polarization reconfigurability was achieved using 4 PIN diodes with a total size of $14.1 \times 10.2 \times 0.784$ mm^3.

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