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A Millimeter Wave Tri-Polarized Patch Antenna with a Bandwidth-Enhancing Parasitic Element

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***Abstract*—In this work, a multi-polarized patch antenna operating at 28 GHz is presented covering two senses of circular polarizations (CP) and a single linear polarization (LP). Four loop slots are introduced in the ground plane under the corners of the square driven microstrip patch antenna. These loop slots can be shorted with the aid of 4 p-i-n diodes controlled via external DC biasing lines. Diagonal loop slots guide the formation of circularly rotating current on the driven patch activating one CP mode, while the other diagonal pair activates the opposite CP mode. Shorting all slots results in an almost plain ground plane making the antenna radiates LP waves. To enhance the bandwidth (BW), another square parasitic element on a thicker substrate is mounted on top. For the LP, a 10-dB impedance BW of 1.88 GHz is reported with a gain of 5.8 dB. While the CP's 10-dB BW is 2.07 GHz with a gain of 4 dB and axial ratio BW (ARBW) around 430 MHz. Radiation efficiency for all three modes is above %95.**

Keywords—mm-wave antenna; Polarization-reconfigurable radiator; multi-polarized antenna.

I. Introduction

Interest in multi-polarized antennas started long time ago with numerous papers reporting dual circularly polarized (CP) antennas or multi linearly polarized (LP) antennas. Applications such as localization and using different polarizations in spatial duplexing incentivized researchers to build multi-polarized antenna systems including both LP and CP. Building such radiators is strenuous and requires complex biasing networks. Due to that, two prototypes, instead of one, were reported in [1]. Two pin diodes were placed across both arms of a u-slot patch antenna and by alternating their biasing, one arm would be longer than the other; exciting two orthogonal modes necessary for the CP case that have the proper quadrature phase difference at the resonance frequency, and by identical biasing an LP case was achieved. Centered at 5.9 GHz, the impedance BW for the LP and CP modes were 6.1% and 13.5%, respectively, and the ARBW ranged from 5.725 to 5.85 GHz with a maximum gain of 7 dBic. Operating at 2.4 GHz, a single antenna was reported in [2] which could radiate in both LP and CP by controlling connecting strips that would make the current's path follow circular patterns or linear ones when turned off. The printed monopole antenna had a BW of 70% and 22% for the LP and CP, respectively, while the axial ratio spanned from 2.34 to 2.44 GHz (4.2%) with a gain of around 0.6 dBic. The advantage of this design was the use of reconfiguring elements(strips) on the ground plane instead of the antenna itself which mitigated the effects on the antenna. Up in the mm-wave spectrum, an array of four small patches which were fed through a complex feeding network, resulting in a radiation efficiency of 51%, was illustrated in [3]. The ARBW ranged from 27.2 to 28.35 GHz and a maximum gain of 6 dBic. Switching between left to right hand circular polarization (LHCP, RHCP) was achieved via the feeding network that consisted of a coupler and 4 PIN diodes. The LP-lacking antenna array had an impedance BW from 27 up to 29 GHz. Similar to [2], slots and diodes were only placed in the ground plane to have minimal effect on the patch antenna resonating at 2.4 GHz and reported in [4]. Two loop slots were introduced in the ground across which two diodes were placed to control the polarization state of the antenna. The patch antenna had an impedance BW of 60 MHz and 30 MHz, and a gain of 6.4 and 5.83 dB for the CP and LP cases, respectively, while the 3-dB ARBW was 20 MHz.

In this paper, based on the 2.4 GHz design reported in [4], a modified mm-wave multi-polarized patch antenna is presented operating at 28 GHz. To increase cross-polarization levels, four loop resonators are introduced in the ground plane, instead of only two. In order to widen the impedance BW, another parasitic patch of different size etched on a thicker substrate is mounted on top of the main driven patch antenna. Next section explains the design and geometry of the antenna's structure followed by results and discussion before concluding this work.

II. Tri-Polaried Antenna Design

A. The Main Driven Antenna Element

The microstrip patch antenna is designed on a Rogers (RO3003) substrate that has a thickness of 0.25mm, a relative permittivity of 3.0 and a loss tangent of 0.0013. The overall design has a size of $8.18 \times 8.18 \times 0.784\ mm^3$ with extra area in the xy plane to account for the spacing needed to mount the two substrates on top of each other using silver epoxy. The square patch's length is optimized to 2.83 mm and the loop slots in the ground shifted 0.707 mm diagonally inward the patch's corners. The gaps of the slots have a thickness of 0.25mm to fit the MACOM beamlead PIN diode (MA4AGBL912) [5], that has a parallel combination of a high resistance of 10 kΩ and a capacitance of 28 fF when OFF and a low resistance of 4 Ω when ON. The feeding location is shifted one sixth of the patch's side toward the center for matching purposes as detailed in Fig. 1.

B. *The Parasitic Patch Antenna*

To widen the impedance BW, another parasitic patch antenna is etched on a thicker RO3003 substrate and mounted on top of the driven antenna. This addition also contributes to increasing the gain of the antenna but at the expense of reducing the cross-polarization levels for the CP cases. The square parasitic element has a side length of 2.26mm.

III. Results and Discussion

Simulation and optimization have been conducted using ANSYS Electronics 2020. The Linear case is activated when all the four diodes are in forward biasing state such that all slots are shorted. The -10dB impedance BW starts from 27.6 up to 29.48 GHz with a cross-polarization levels below -30 dB as illustrated in Fig. 2 and Fig. 3(c). When two diagonally opposed loop slots are introduced in the ground, a CP case is achieved. When D1 and D3 are activated, their corresponding slots are shorted leaving the other slots present activating the RHCP case. Similarly, when D2 and D4 are ON, LHCP case is activated. The CP impedance BW spans from 27 up to 29.07 GHz. The gain in the LP case reaches 5.8 dBi while it reaches 4 dBi in the CP case and all cases achieve radiation efficiency above 95%. Radiation patterns in the XZ-plane of all cases are presented in Fig. 3. Table I shows a comparison between this design's performance and the aforementioned works.

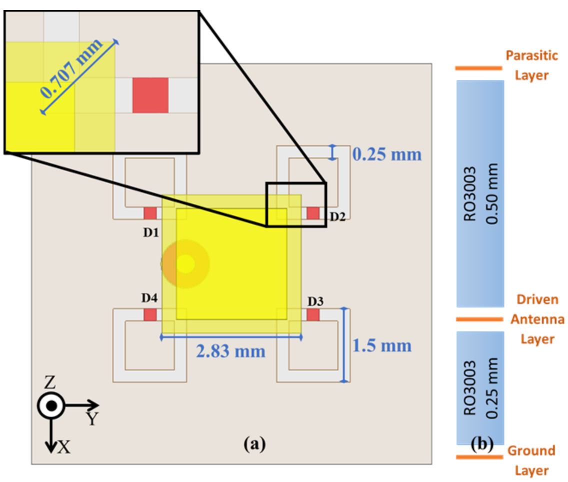

Fig. 1 (a) Layout's top view. (b) Illustrative side view.

TABLE I. COMPARISON

#	Spectrum	# of diodes	Pol. Modes	Gain	FBW
[1]	sub-6GHz	5	Linear & LHCP	6~7 dB	6.1% and 13%
[2]	sub-6GHz	2	Linear, LHCP, RHCP	0.5, 0.6 & 1.2 dBic	70, 23 and 23%
[3]	mm-wave	4	LHCP & RHCP	6 dBic	7.14%
[4]	sub-6GHz	2	Linear, LHCP, RHCP	5.8, 6.4 and 6.4 dB	2.40%
T. W.	**mm-wave**	**4**	**Linear, LHCP, RHCP**	**5.8, 4 and 4 dBi**	**6.6, 7.4 and 7.4%**

Measurements will be added upon presenting in the conference

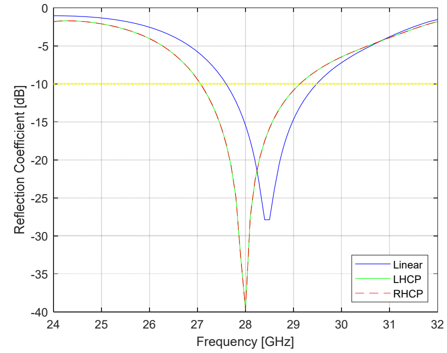

Fig. 2 Reflection coefficients for the LP and CP cases

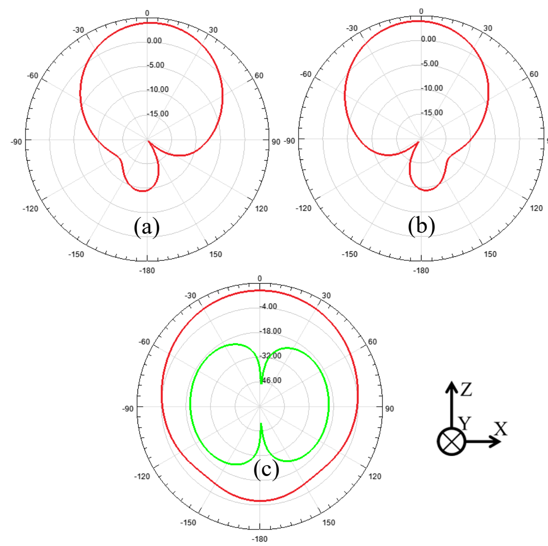

Fig. 3 Radiation patterns for (a) LHCP, (b) RHCP and (c) LP (and its x-pol)

IV. Conclusion

A single-fed single element tri-polarized mm-wave antenna has been presented in this paper. It had a BW of 1.9 GHz and 2.07 GHz and a gain of 5.8 dBi and 4 dBi for the LP and CP modes, respectively. The antenna achieved a radiation efficiency above 95% for all three cases.

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