Millimeter-Wave Wideband Circularly Polarized Antenna Array Using SIW-Fed S-Dipole Elements

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***Abstract*—This paper presents a millimeter-wave (mm-wave) wideband circularly polarized (CP) antenna array which is composed of novel SIW-fed S-dipole elements. Each array element consists of two rotational symmetric curved arms which form an "S" shaped geometry. By exciting the element differentially through aperture coupling, the S-shaped element can radiate CP wave within a wide frequency range. A 4 × 4 array is fabricated by cost-effective PCB technology to investigate the performance of the proposed design. Good agreements between the simulation and measurement results are observed and it is noticed that the proposed array achieves a wide impedance bandwidth from 25 GHz to 32.7 GHz (26.7%), a 3-dB axial ratio bandwidth from 24.1 GHz to 34.6 GHz (35.8%) and a 3-dB gain bandwidth from 24.8 GHz to 33.5 GHz (30%). With its planar structure and excellent performance, this antenna is suitable for various mm-wave applications.**

Keywords—antenna array; circular polarization; millimeter wave; wideband array

I. INTRODUCTION

Driven by the 5G deployment, millimeter-wave (mm-wave) antennas received increasing interests recently [1]. Due to the increase of free-space loss at mm-wave bands, antennas working at mm-wave frequencies are always demanded to have high gain, which is normally realized by mm-wave antenna arrays [2]. On the other hand, circularly polarized (CP) antennas are widely employed, especially for the mm-wave satellite communications attributed to their unique features such as the immunity of "Faraday rotation" [3]. MM-wave CP antenna arrays are therefore becoming necessary for a growing number of wireless systems.

As dielectric loss, metallic loss and radiation loss become much more severe at mm-wave frequencies, substrate integrated waveguide (SIW) based antennas that can effectively alleviate these issues are investigated extensively. However, the bandwidth of mm-wave SIW CP arrays is generally inferior to those mm-wave arrays fed by conventional transmission lines because of the limitation of waveguide cut-off frequency and the less flexibility of SIW compared to conventional transmission lines. For this purpose, various SIW CP arrays were proposed to improve the bandwidth of mm-wave CP antenna array [4]-[7]. In [4], an SIW-fed magneto-electric dipole array was presented, which achieved around 16.5% overall bandwidth. SIW based spiral elements were utilized to constitute a wideband mm-wave CP spiral array where sequential rotation feeding network was also utilized for bandwidth improvement [5]. For further bandwidth improvement, SIW-fed stacked patches [6] and curl elements [7] were employed to build large-scale mm-wave antenna array which achieved around 20% and 30% bandwidth, respectively.

In this paper, a 4 × 4 antenna array operating at Ka-band is proposed. The array is constituted by novel planar SIW-fed S-dipole elements which have very simple configuration but excellent performance. Attributed to the good element performance and the low-loss feature of SIW feeding network, the proposed array can operate over a wide bandwidth and realize high antenna gain at mm-wave frequencies.

II. ARRAY DESIGN

The geometry of the proposed array is shown in Fig. 1. As shown, the proposed array is designed on three stacked Rogers RO5880 substrates which all have a thickness of 1.5mm. 4×4 elements are printed the top layer of substrate 1 while four SIW cavities are embedded in substrate 2. Each S-dipole element is excited through aperture coupling which is mainly controlled by the slots carved on the top surface of the SIW cavities. The electromagnetic energy is guided and distributed to the cavities by the SIW power divider in substrate 3. An SIW to coplanar waveguide transition is attached to the input port of the SIW power divider to mount the Southwest connector for measurement purpose. It is worth pointing out that although the proposed array radiates right-hand circularly polarized wave, left-hand circularly polarized array can also be realized by changing the inverted-S shaped elements to S-shaped elements.

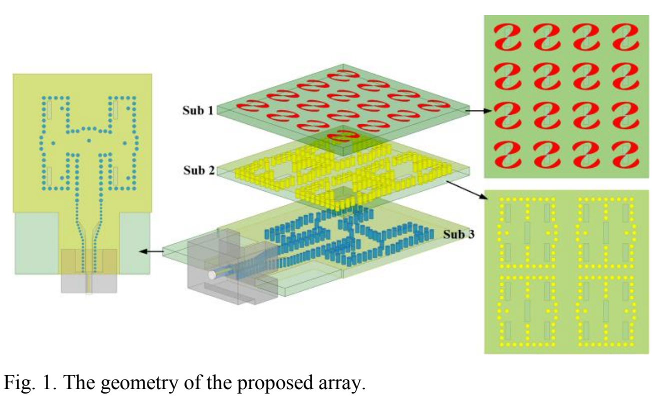


Fig. 1. The geometry of the proposed array.

III. FABRICATED PROTOTYPE AND RESULTS

To verify the design concept, the proposed 4×4 array is fabricated, which is shown in Fig. 2. As traditional low-cost multi-layer PCB process is utilized, four small holes are placed at the four corners of the substrate for better alignment.

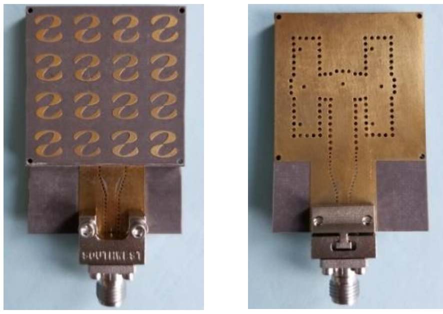


Fig. 2. The fabricated prototype of the proposed array.

The simulated and measured reflection coefficients of the proposed array are shown in Fig. 3. As can be seen, relatively good agreement between the measurement and simulation results is observed. The measured impedance bandwidth ($|S_{11}|$<-10 dB) is from 25 GHz to 32.7 GHz, equivalent to a fractional bandwidth of 26.7%.

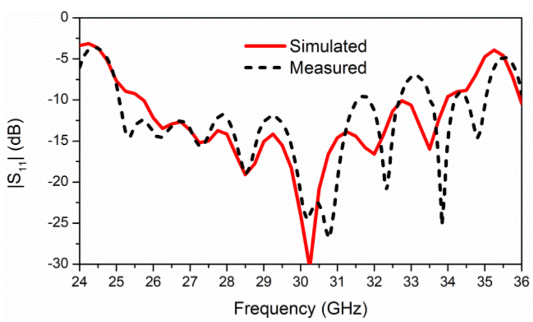


Fig. 3. The reflection coefficients of the proposed array.

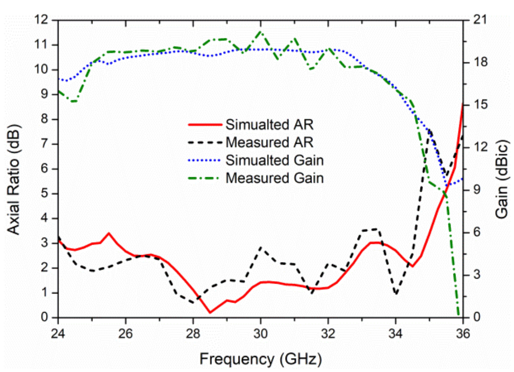
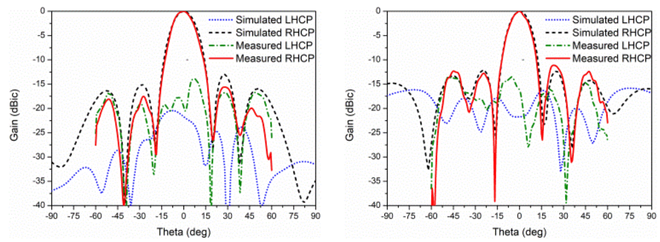


Fig. 4. The simulated and measured AR and gain of the proposed array.

The performance of the proposed array in terms of axial ratio (AR) and gain are plotted in Fig. 4. As shown in the figure, the measured 3-dB AR bandwidth is from 24.1 GHz to 34.6 GHz (35.8%) and the measured 3-dB gain bandwidth is from 24.8 GHz to 33.5 GHz (30%). The measured peak gain is around 20.2 dBic at 30 GHz. Considering all the measured results, the proposed array can achieve an overlapped bandwidth from 25 GHz to 32.7 GHz while keeping a high gain within this frequency range.

The simulated and measured radiation patterns at 30 GHz are shown in Fig. 5. Due to the limitation of measurement facilities, the radiation pattern can only be measured in the angle range of -60° to 60°. As shown, the proposed array achieves good beam shape, low sidelobe, and low cross-pol radiation.



(a) (b)

Fig. 5. The radiation patterns at 30 GHz. (a) *xz* plane, (b) *yz* plane.

IV. CONCLUSION

A wideband planar CP array based on the SIW technology has been proposed in this paper. The presented array is composed of novel SIW aperture coupled CP S-dipole elements which have a simple configuration. By feeding the S-dipole elements corporately using a stacked low-loss SIW feeding network, a wideband highly efficient CP array is implemented. Attributed its wide bandwidth, high gain, low-profile, and low-cost features, the presented array would be a promising candidate for various mm-wave applications.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China under Grants 61801299 and 61372077, and also by the EPSRC grants EP/N032497/1, EP/P015840/1, and EP/S005625/1.

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