International Journal of Microwave and Wireless Technologies, 2017, 9(9), 1877–1881. © Cambridge University Press and the European Microwave Association, 2017
doi:10.1017/S1759078717000617

RESEARCH PAPER

SIW-fed microstrip patch antenna array for circular polarization

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A new single-feed aperture-coupled, X-band microstrip patch antenna array with circular polarization (CP) is designed. CP is achieved using indented microstrip patches fed through the slots on a substrate integrated waveguide. The antenna has the high radiation efficiency more than 90% over the operating frequency. Impedance bandwidth (VSWR < 2) and axial ratio bandwidth (AR < 3 dB) of 11.8, and 10.9% is attained, respectively. Good agreement is achieved between simulated and measured results.

Keywords: Antenna Design, Modeling and Measurements, EM Field Theory, Substrate Integrated Waveguide

Received 14 January 2017; Revised 2 May 2017; Accepted 7 May 2017; first published online 13 June 2017

I. INTRODUCTION

Microstrip antennas have been used in microwave application due to their well-known features of low cost, low profile, and light weight. However, their performance is limited by narrow impedance bandwidth, low efficiency, and poor polarization purity. Many works, such as stacking the patches [1], using metamaterial [2], loading by electromagnetic band gap (EBG) [3], and many other techniques, have been done to resolve some of these limitations.

On the other side, waveguide slot antennas with high gain, high efficiency, and low cross-polarization level are interesting structures in radar applications and communication systems; but the waveguide structures are bulky, expensive to produce, and hard to integrate with the planar components. Substrate integrated waveguides (SIWs) can be used as the alternative structures to eliminate some deficiencies of the waveguides. It is implemented by low-cost printed circuit board (PCB) technology without manufacturing difficulties of the waveguides.

Slot radiators can be used as the feeding structures for some antennas. In this case, the antenna can be considered as the series-fed structure with high radiation efficiency. Unlike corporate networks, series-feeding technique minimizes the insertion and radiation loss of the feeding line by reducing length of it [4]; therefore, the antenna has high radiation efficiency.

The circular polarized antennas can give better performance against reflection, absorption, penetration, and bending effects as compared with the linearly polarized antennas. The multipath fading effects due to the phase difference are also less destructive in circularly polarized antennas. Circular polarization (CP) in microstrip antennas can be accomplished by using single-, double-, or multiple-feed structures. The single-feed structure reduces the complexity, weight, and loss of the antenna, but it could not provide wide axial ratio bandwidth as much as double-feed networks.

Using the advantages of series-feeding and SIW structures, a new synthetic circular polarized antenna, consisted of microstrip patch and slot on the SIW, is proposed. The similar design is accomplished in [5] for linear polarization in two distinct bands. In this paper, it is shown that the large CP bandwidth can be achieved by single feeding. To get high gain and wide impedance bandwidth, the resonance frequencies of the slot and the patch, as the first and second radiators, respectively, are set near to each other. An indented-shaped patch is used to achieve CP [6]. A 1×4 linear array with CP and simple single-fed structure is designed and fabricated, which increases the radiation efficiency of the antenna. As the antenna works in *X*-band, it can be used in earth-satellite communication, which needs CP antennas due to their immunity to Faraday rotation. Since CP antennas can filter out the reflected signals, they are appropriate for satellite-based navigation system [7].

II. ANTENNA DESIGN

The antenna consists of microstrip patches that are loaded on SIW-based slot radiators. Schematic of the antenna is illustrated in Fig. 1. SIW is implemented on Rogers 4003 with $\varepsilon_r = 3.55$, loss tangent of 0.0027, and thickness of 1.32 mm. The end of the SIW is closed to block slant pattern for a frequency change, so it is a resonant array. Vias have the distance of 1.5 mm in side walls and 1.6 mm at the end wall with the common diameter of 0.8 mm. Slots on SIWs are half a wavelength apart to feed the patches in-phase. Distance of the last

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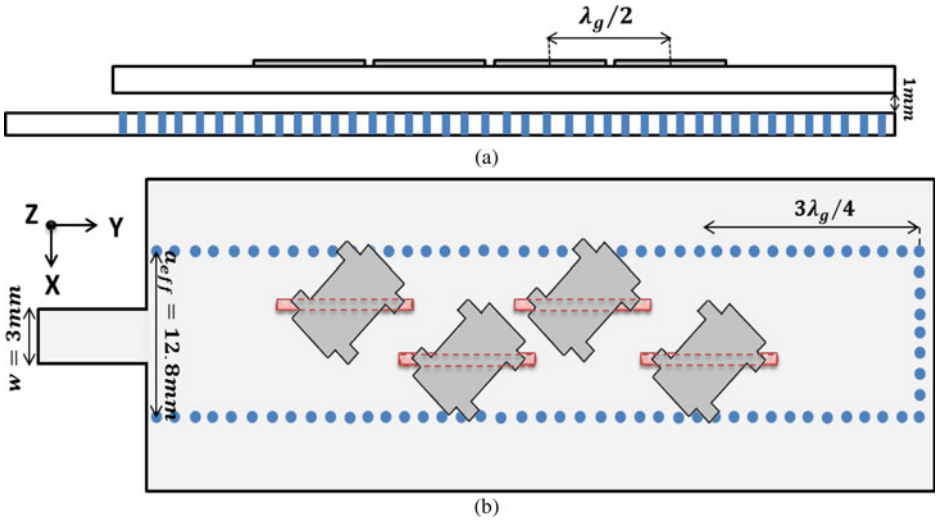


Fig. 1. (a) Side and (b) top view of the antenna.

slot from the short wall of the SIW is $3\lambda_g/4$ to put the slots at the peaks of standing waves, where λ_g is the wavelength inside the SIW.

Microstrip patches are etched on Taconic TLY with dielectric constant of 2.17 and loss tangent of 0.0027 and thickness of 1.5 mm. They are fed by slots on the SIW. This kind of feeding network for microstrip antenna not only makes it have a higher gain and wider impedance bandwidth but also makes it easy to control the dielectric constant of the feed line and radiating patch, separately. Thus, the unwanted radiating field is reduced by choosing high permittivity substrate for the feed line. Waveguide-fed microstrip antennas benefit from the high efficiency, and choosing the low permittivity substrate for patches increases the radiation efficiency more. There is an air gap between patches and SIW to match the loaded slots with the characteristic impedance of the SIW and provide wide impedance bandwidth [8].

A 45° rotated square patch on a longitudinal slot can excite two orthogonal modes with equal amplitude. These modes should be 90° out of phase to obtain CP. This can be achieved by shifting the resonance frequencies of two modes; the phase difference between two modes can be provided by a time delay in their excitation signal or changing the resonance frequency of each mode (since $\Delta\phi \propto \omega\Delta t$). The side of the patch is lengthened by indenting to lower the resonance frequency and the other side is truncated to raise the resonance frequency. This configuration is illustrated in Fig. 2. Increasing the length of the l_y makes the array to have a good axial ratio bandwidth in exchange of lowering the impedance bandwidth. It seems that varying the dimensions of the patch changes its resonance frequency, which is no longer matched with resonance frequency of slot, but it regulates the phase difference to have a wider CP bandwidth. Increasing the length of slot rectifies this deficiency and

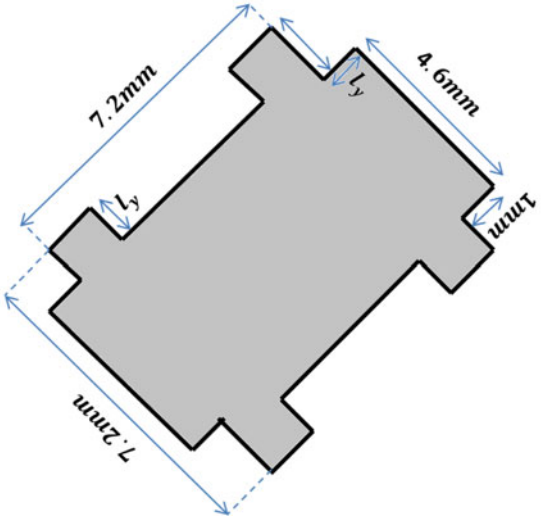


Fig. 2. Configuration of the designed patch to produce circular polarization.

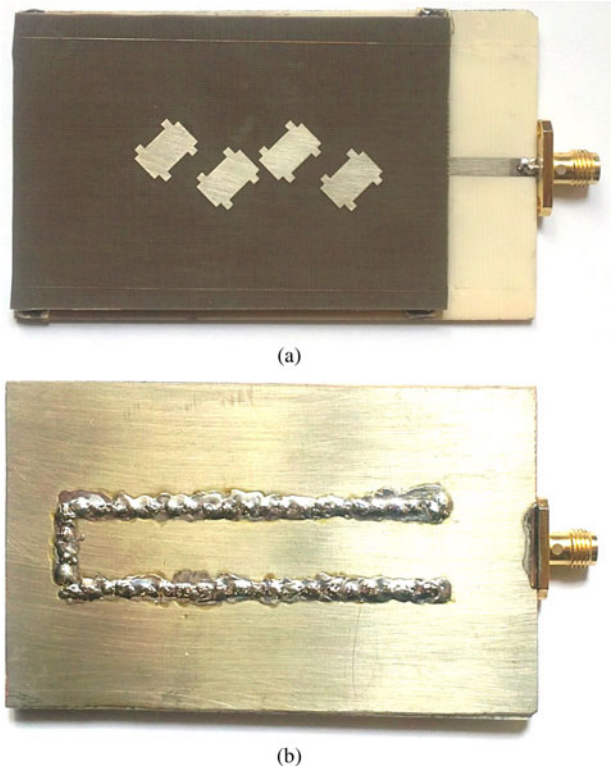


Fig. 3. (a) Top and (b) bottom side of the fabricated antenna.

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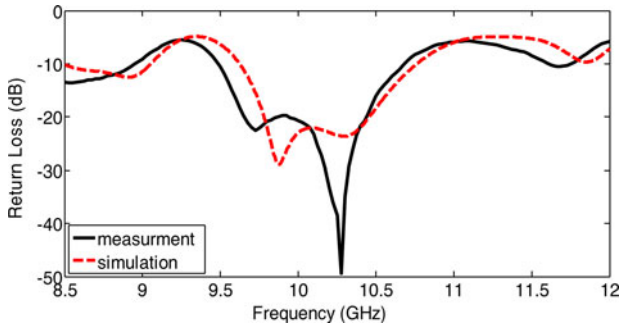


Fig. 4. Simulated and measured return loss of the antenna.

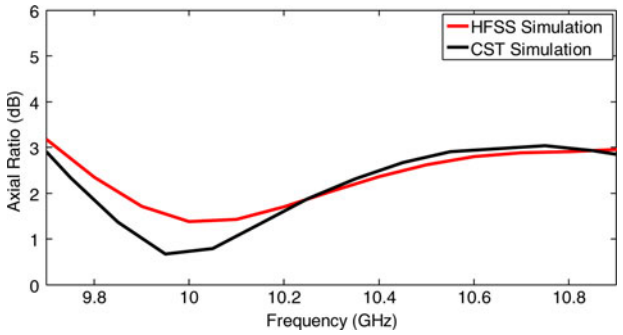


Fig. 5. Simulated axial ratio of the antenna.

increases the impedance bandwidth. The appropriate length of slots on the SIW, for efficient radiation to the free space, is $\lambda_o/\sqrt{2(\varepsilon_r+1)}$ [9]. Here, the slots are radiating to an effective media, free space, and substrate beneath the patches, so the effective permittivity is larger than free space and the slot length needs to be smaller than what is stated in formula. As the shaped patches disturb the scattering parameter of the antenna, the length of the slots is optimized (12 mm) to provide an acceptable return loss and axial ratio bandwidth at the same time.

III. RESULTS

Figure 3 shows the prototype of the fabricated antenna. Two 20 and 32 mil layers of Rogers 4003 with overall dimension of 4×8.5 cm^2 are glued to each other to get the desired thickness of 1.32 mm. Both patch and feed network are fabricated with low-cost PCB process. Slots are etched on SIW, fed by a 3 mm width microstrip line that connects the 50 Ω subminiature version A (SMA) to the SIW. The substrate of the patches with overall size of 4×7 cm^2 is placed above the SIW using four stands. These stands are away from the radiation slots of the antenna and do not cause significant effect on the antenna performance. The effect of stands is considered in simulation results. The measured and simulated return loss of the antenna is depicted in Fig. 4. It is shown that wide impedance bandwidth of 11.8% is obtained in *X*-band. The measured bandwidth of the antenna is greater than the simulated one since the fabricated antenna is radiated in an unbounded space. Antenna has the axial ratio <3 dB over the wide frequency range of 1.12 GHz with the center frequency of 10.3 GHz as depicted in Fig. 5. It is much more

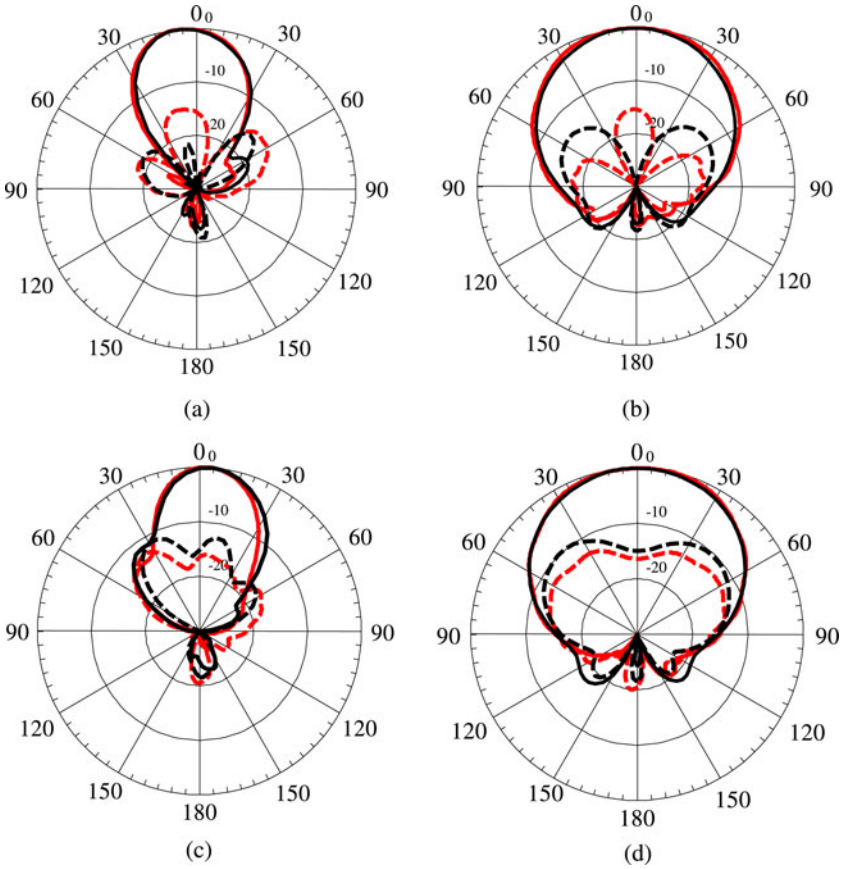


Fig. 6. Simulated co-polarization (solid line) and cross-polarization (dash line) pattern of the antenna in *YZ*-plane of the (a) 9.72 GHz and (c) 10.5 GHz, and *XZ*-plane of the (b) 9.72 GHz and (d) 10.5 GHz. CST and HFSS simulations are shown with black and red colors, respectively.

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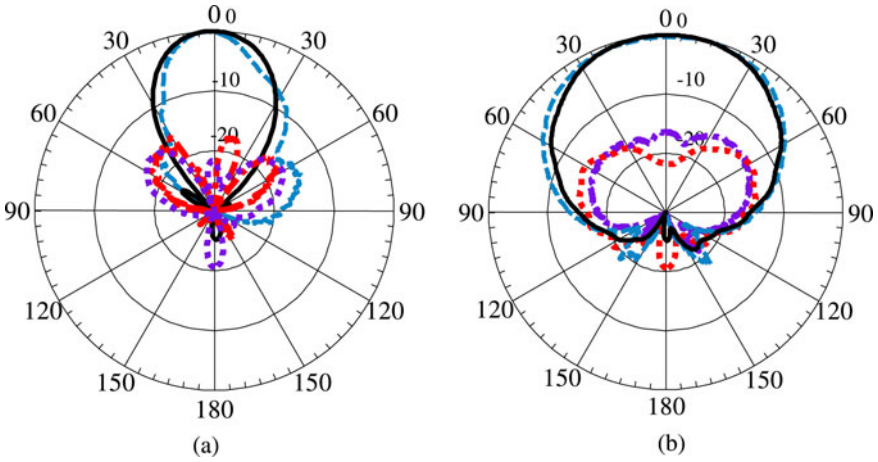


Fig. 7. Simulated co-polarization (solid line), simulated cross-polarization (dot line) and measured co-polarization (dash line) and measured cross-polarization (dash-dot line) pattern of the antenna at (a) *YZ*-plane, and (b) *XZ*-plane in 10.1 GHz.

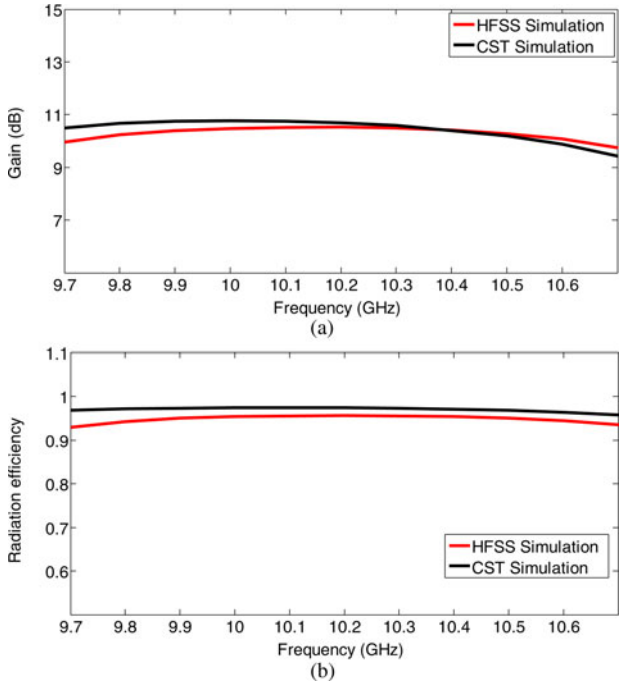


Fig. 8. Simulated (a) gain and (b) radiation efficiency of the antenna.

than the typical axial ratio bandwidth for single-fed circular polarized microstrip antenna. The simulation results of two commercial softwares (CST and HFSS) are compared to confirm the accuracy of results. The simulated radiation pattern of the antenna with co- and cross-polarization is represented at different frequencies in Fig. 6. The measured pattern at the center frequency is similar to the simulated one as shown in Fig. 7. Good cross-polarization level more than 15 dB is achieved in both cutting planes of each frequency. It is seen that the sidelobe level at the end of the frequency band is changed, but still the main lobe direction of the antenna is at boresight. The simulated gain and radiation efficiency of the antenna are illustrated in Fig. 8. It is shown that antenna has the maximum gain of 10.5 dB and high radiation efficiency more than 90% in its operation bandwidth.

Several techniques have been done to attain CP in single-fed microstrip antenna. *C*- [10], *F*- [11], and *S*-shaped slots [12] are used to give the microstrip patches the proper perturbation, but only a few percentage of axial ratio bandwidth is achieved. In [13], stacking method has been used to obtain CP, but only 2.5% axial ratio bandwidth with low radiation efficiency of 40–50% are achieved. The purposed antenna at this paper provides good performance in terms of bandwidth and radiation efficiency compared with the above mentioned works.

IV. CONCLUSION

A 1 × 4 series-fed microstrip antenna array for CP is purposed. The patches are fed through slots on the SIW. Wide impedance bandwidth of 11.8% and axial ratio bandwidth 10.9% are achieved by adjusting adjacent resonance frequency for the slots and microstrip patches. Series-feeding technique makes the antenna have high radiation efficiency over 90%, while the shaped patches cause CP.

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