Circularly Polarized Met surface Antenna Excited by Linearly Polarized CPW-fed Slot Antenna

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ABSTRACT
This paper proposes a dual-band antenna designed by combining a linearly polarised coplanar-waveguide-fed (CPW) slot antenna with a circularly polarised metasurface. Preliminary results have shown that circularly polarized (CP) radiation can be obtained from linearly polarized (LP) source antennas with the use of metasurface. The CPW-fed antenna printed on one side of the substrate is used as the source antenna.The metasurface consisting of 16 unit cells in a 4 × 4 arrangement is printed on the other side of the substrate. Two operating bands at around 3.6 GHz and 4.6 GHz are generated, with the radiation patterns in broadside direction. Good agreement between measured and simulated results is achieved. The directivities in operating band is around 6dB and 8dB respectively.

General Terms
Metasurface, Polarization, Slot antenna

Keywords
Coplanar Waveguide, Microstrip antenna, Linear polarization.

1. INTRODUCTION
Planar antennas, such as microstrip and printed antennas, have the attractive features of low profile, small size, and conformability to mounting hosts. Various techniques for reducing its size have been presented in the literatures such as using a substrate with high dielectric constant, incorporating a shorting pin in microstrip patch, employing a dielectric resonator and inverted-F antenna. Another importance candidate which may complete favourably with microstrip for the above applications is coplanar waveguide (CPW) [1-4]. CPW-fed slot antennas also have many attractive features including low radiation loss, less dispersion, easy integration for monolithic microwave integrated circuits (MMICs) and a simple configuration with a single metallic layer. Accordingly, many antenna elements suitable for a CPW-fed configuration have been proposed, the slot antenna being one of the most attractive solutions Metasurface, a two-dimensional equivalent of metamaterial, has been attracting attention for researchers in recent years [5, 6]. Due to its planar structure, metasurface can be easily combined with planar antenna to achieve performance enhancement in terms of bandwidth, gain and radiation pattern. In such application, the original planar antenna is called the source antenna. When the source antenna is combined together with a metasurface, it is called a metasurface antenna. Among the reported metasurface antennas studied the metasurfaces and source antennas were fabricated on different dielectric substrates and placed at a certain distance away from each other [7,8]. Although the distance between source antenna and metasurface was very close, the thickness of metasurface antenna has been increased considerably compared to source antenna. In addition, the complexity of antenna was also increased due to assembly problem. However, this will be different if metasurface is placed the on the other side, the metasurface and source antenna will be combined perfectly as one single antenna. The thickness of the metasurface antenna does not even change at all compared to that of the source antenna.

Circularly polarized (CP) antennas can reduce the loss caused by the misalignment between transmitting and receiving antennas. CP wave in the broadside direction is generated when two orthogonal modes are excited with equal amplitude with quadrature phases. Nowadays, circularly polarized microstrip patch antennas (CP-MPAs) are widely used, particularly in satellite and wireless communications, since they are compact, lightweight and cost-effective. There are two commonly used feeds for circularly polarized microstrip antennas (CP-MPAs), namely a single-feed and a dual-feed. Although the axial ratio (AR) bandwidth of single-feed CP-MPAs is narrow, they are very attractive because they allow a reduction in the complexity and RF loss due to feeding network. There are various methods reports in the literature on single-feed circularly polarised microstrip antennas: square patch with truncated corners [9], U-slotted rectangular patch [10], and circular patch with slits [11]. Yo et al. [12] proposed an interesting method to get circular polarization by embedding two circular slots in the circular patch. A combination of CP-MPAs with the periodic structures including frequency selective surface (FSS) [13] and electromagnetic bandgap (EBG) [14] has been investigated. Using the filtering properties of such structures, it is possible to reduce surface wave, to achieve wide band and high gain. This has motivated us to study a periodic structure superstrate-loaded CP-MPA. This paper proposes a dual-band antenna designed by combining a linearly polarised coplanar-waveguide-fed (CPW) slot antenna with a circularly polarised metasurface The CPW-fed antenna printed on one side of the substrate is used as the source antenna. The metasurface consisting of 16 unit cells in a 4 × 4 arrangement is printed on the other side of the substrate The design objective here is to obtain simultaneous enhancement for antenna directivity, impedance bandwidth and axial-ratio bandwidth and gain bandwidth. The proposed CP antenna has a simple, low profile, and yet a low-cost structure. Nevertheless, it is interesting to know that if CP radiation wave can be achieved when a metasurface is excited by using a LP source. Commercial software IE3D based on MOM has been used to simulate the antenna characteristics followed by experimental verification.

2. ANTENNA DESIGN
The configuration of the proposed dual-band metasurface antenna is shown in Fig. 1, which was designed using planar technology. This arrangement is different from others where different substrates are used for the antenna and metasurface.The source antenna was a CPW-fed antenna

consisting of two identical slots etched on one side of the substrate as shown in Fig. 1(a). The two slots were mirror images of each other along the CPW-fed line which was at the center line of substrate. The metasurface consisting of 16 unit cells in a 4 × 4 arrangement was printed on the other side of the substrate as shown in Fig. 1(b). Each unit cell had single square ring with a diagonal-strip (SQR-DS) implemented using microstrip lines as shown in Fig. 1(d). The metasurface antenna was designed on substrate, having the thickness of t = 1.6mm and area of $G_L \times G_W = 60 \times 60 mm^2$, with a dielectric constant of $\varepsilon_r = 3.48$ and a lost tangent of $\tan\delta = 0.003$.

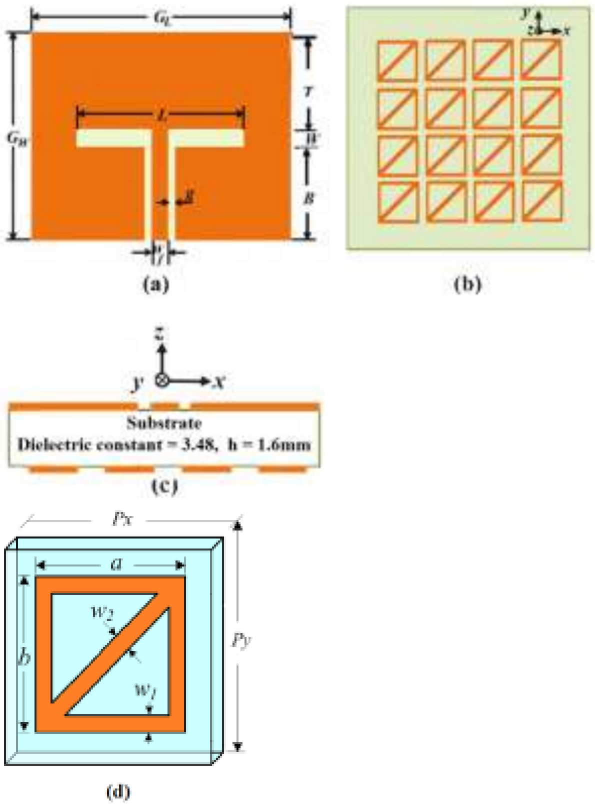


Fig. 1: Configuration of the CPW-fed slot antenna with metasurface (a) the CPW-fed slot antenna, (b)metasurface (c) the cross sectional view and (d) single square ring with a diagonal-strip (SQR-DS) unit cell.

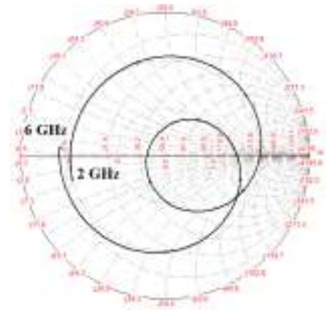
The radiator is center-fed inductively coupled slot, where the slot has a length ($L-W_f$) and width W. A 50 Ω CPW transmission line, having a signal strip of width W_f and a gap of distance g, is used to excite the slot. The slot length determines the resonant length, while the slot width can be adjusted to achieve a wider bandwidth. The dimensions of the CPW-fed slot antenna are chosen to be (unit mm) L = 48.4, W = 3.5, W_f = 3, T = 28.25, B = 28.25, g = 0.5 and the ground plane size G_w= 60 and G_L= 60.

The physical parameters of the SQR-DS are given as follows: P_x = 14 mm, P_y =14 mm a = 12.8 mm, b = 12.6 mm, w_1 =1mm, w_2 =1.2mm. A detailed explanation of the physical phenomena behind this structure can be found in [15]. The performance of the antenna with and without metasurface are presented in the following section.

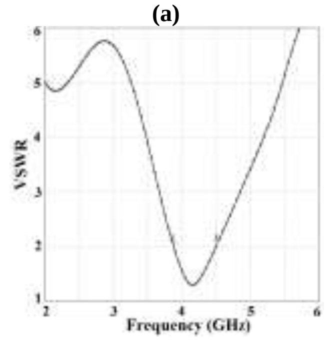
3. SIMULATION AND MEASUREMENT RESULTS

3.1 CPW-fed slot antenna without metasurface

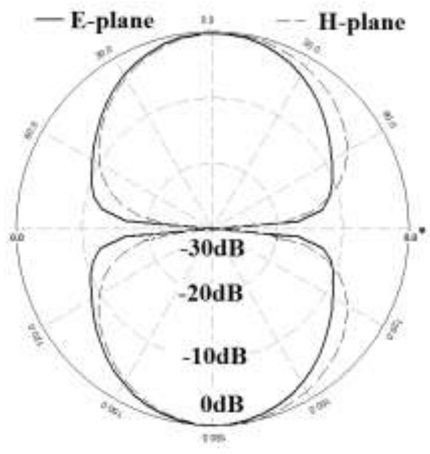
The CPW-fed slot antenna without metasurface has been also studied for comparison. Usually, the length L is approximately one-guide wavelength (λ_g) at the slot resonance. It is also noted that the wavelength in the slot, λ_g, is determined to be about $0.78\lambda_o\sqrt{(1+\varepsilon_r)/2\varepsilon_r}$, where λ_0 is free space wavelength [16]. For given dimensions, the slot antenna can excite the resonant frequency of 3.9 GHz for calculation. For simulation as shown in Fig.1, however, the resonant frequency shifted to 4.15 GHz due to the ground plane has a finite size. The VSWR ≤ 2, BW for the reported configuration was found to be 626MHz at center frequency of 4 GHz which gives total bandwidth of 16%. The simulated results of impedance loci and VSWR are in close agreement as shown in fig. 2 (a) and (b).The simulated radiation patterns at resonant frequency 4.15GHz is shown in figure 2 (c).The radiation pattern is bidirectional.



(a)



(b)



(c)

Fig 2: (a) Impedance loci and (b) VSWR plot for CPW-fed slot antenna without metasurface and (c) radiation pattern of the CPW-fed slot antenna at f = 4.15GHz.

3.2 CPW-fed slot antenna with metasurface

The CPW fed slot antenna with SQR-DS is fabricated and tested. At this proof of concept stage, the aim is merely focused on the possibility of polarizations conversion and the circular polarized directive enhancement in the broadside direction using simple linearly polarized source antenna. The fabricated structure of the antenna is shown in figure 3. The VSWR was measured with an R&S vector network analyzer (ZVH-8). Figure 4 shows the measured VSWR of the proposed antenna, together with the simulated one.

(a) (b)

Fig 3: Photograph of CPW-fed slot antenna with metasurface (a) Top View and (b) Bottom view

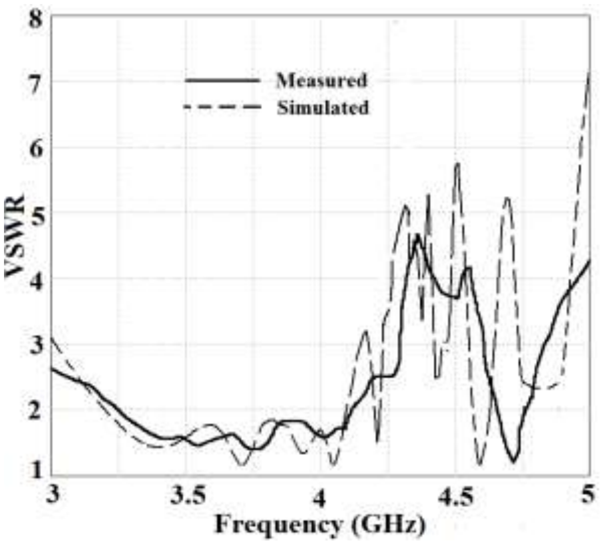


Fig 4: Simulated and Measured VSWR plot for CPW-fed slot antenna with metasurface

As can be seen, there is a reasonable agreement between the measured and simulated results. The lower-band resonant frequency is located at about 3.65 GHz, with VSWR $\leq$ 2 bandwidth from about 3.2 to 4.15 GHz. The second band resonant frequency is located at about 4.65 GHz, with -10 dB impedance bandwidth from about 4.58 to 4.7 GHz. Some errors in the resonant frequency occurred due to tolerance in FR-4 substrate and poor manufacturing in the laboratory. In the lower band, the broadside ($\Phi = 0^o$, $\theta = 180^o$) axial-ratio versus frequency is plotted in Fig. 5. The AR $\leq$ 3 bandwidth is from 3.86 to 3.92 GHz.

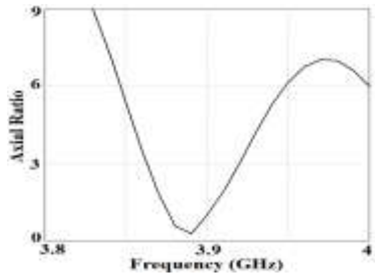


Fig 5: Axial-ratio versus frequency for CPW-fed CPW-fed slot antenna without metasurface in lower band

In the higher band, the broadside ($\Phi = 0^o$, $\theta = 0^o$) axial-ratio versus frequency is plotted in Fig. 6. The AR $\leq$ 3 bandwidth is from 4.61 to 4.64 GHz.

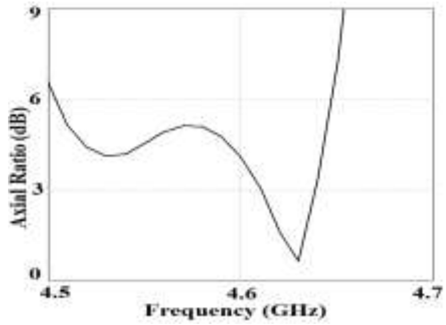


Fig 6: Axial-ratio versus frequency for CPW-fed CPW-fed slot antenna without metasurface in higher band

The directivity of the two configurations namely CPW patch without metasurface and with metasurface in the broadside direction ($\Phi = 0^o$, $\theta = 180^o$) is shown in figure 7. It is seen that in the operating bands the directivity of the CPW fed slot antenna with metasurface is more than that of without metasurface. The directivity in the broadside direction ($\Phi = 0^o$, $\theta = 180^o$) for absence metasurface is about 5.0 dBi, whereas the presence metasurface can increase to 7.0 dBi at the center frequency. An improvement in the directivity of 2.0 dB has been obtained. It is obtained that the directivity of the present metasurface are all improved within the operating bandwidth.

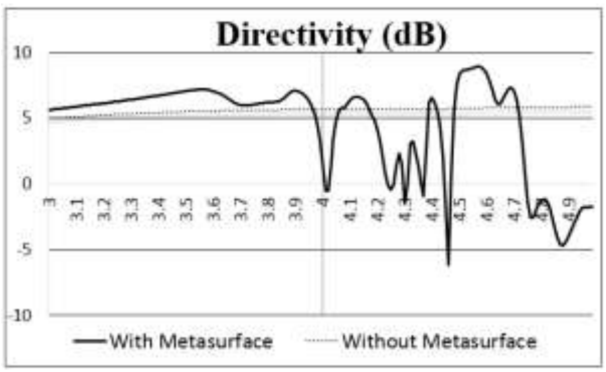


Fig 7: Comparison of directivities for the CPW-fed slot antenna with and without metasurface

Figure 8 shows the simulated radiation patterns in the $\Phi = 0^o$ and $\Phi = 90^o$ planes for the CPW fed slot antenna with SQR-DS at 3.88 GHz.

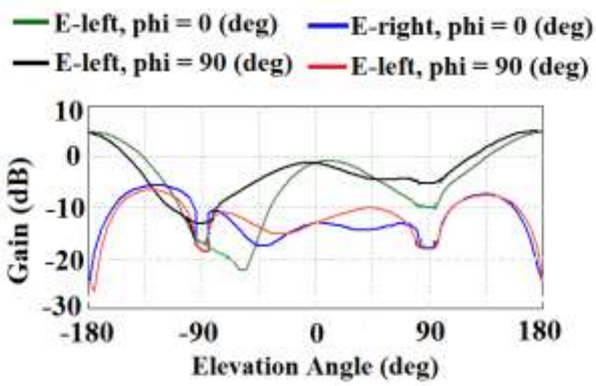


Fig 8: Simulated radiation patterns in the Φ = 0^o and Φ = 90^o planes at 3.88 GHz.

For both planes, the left-hand (LH) circularly polarized fields are stronger than the right-hand (RH) circularly polarized fields, (more than 25 dB), in the boresight direction (θ =180^o). The front-to-back ratios of the left-hand polarization in both the Φ = 0^o and Φ = 90^o planes are more than 9 dB and 10 dB, respectively.

4. CONCLUSIONS

A dual-band antenna designed by combining a linearly polarised coplanar-waveguide-fed (CPW) slot antenna with a circularly polarised metasurface is presented in this paper. Two operating bands at around 3.6 GHz and 4.6 GHz are generated, with the radiation patterns in broadside direction. The directivity in the broadside direction (Φ = 0^o, θ =180^o) for absence metasurface is about 6.0 dBi, whereas the presence metasurface can increase to 8.0 dBi at the center frequency. The proposed metasurface can be regarded as a polarizer for the microwave antennas.

5. REFERENCES

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