Unidirectional Low-Profile CPW-fed Slot Antenna Achieved by using Metasurface

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Abstract

Instead of a conducting reflector, this work shows to achieve unidirectional CPW-fed slot antenna by using metasurface as a superstrate. The metasurface comprises an array of square ring cells to reduce the resonant frequency of the conventional CPW-fed slot structure. The proposed antenna gain increased from 1.5 to 8.0 dBi and the radiation patterns are all improved when using metasurface. Moreover, a significant reduction of antenna height from $\lambda_0/4$ (conducting reflector) to $\lambda_0/15$ (metasurface) at 2.45GHz is predicted. Good agreement between measured and simulated results is achieved.

Keywords : Metasureface ,CPW-fed Slot ,Unidirectional, Gain Enhancement

1. Introduction

Coplanar waveguide (CPW)-fed slot antennas are very attractive at microwave and millimetre wave bands due to their low-cost, low profile, light weight and easily integrated with electronic devices. However, a CPW-fed slot antenna is essentially a bidirectional radiator with the back radiation usually undesired. One common technique to redirect the back radiation forward is to place a conducting reflector at a fixed distance away from the antenna. This distance is usually chosen to be a quarter-wavelength so that the reflected back radiation incurs an additional phase of 360° and thus adds in-phase with the forward directed radiation. However, in this case the parallel-plate geometry permits the excitation of the dominant transverse electromagnetic mode, which drastically reduces the overall radiation efficiency.

More recently, metamaterial structures have been proposed to improve the antenna directivity, bandwidth and efficiency [1]-[3]. Especially, use of the metasurface as a superstrate has been studied due to ease to fabricate and take less space than their 3-D metamaterial counterparts. Metasurface is the 2-D planar equivalent of metamaterials that exhibit anomalous values in their constitutive parameters at certain frequencies. However, most of them are designed for directional antenna especially microstrip patch antenna. Consequently, this study is extended to practical bi-directional or omnidirectional antenna operating at WLAN frequency of 2.45 GHz. By adding the metasurface, it is noticeable enhancements in both radiation pattern, which provides unidirectional pattern, and gain can be achieved while maintaining simple, low-cost and low-profile structure. Details of the design considerations of the proposed antenna and the experimental results of the constructed prototype are presented.

2. Antenna Design

Figure 1 shows the configurations and cross sectional view of the proposed antenna. It consists of a CPW-fed slot antenna (Fig. 1(a)) beneath a metasurface (Fig. 1(b)) with the air-gap separation h_a. 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 (L) determines the resonant length, while the slot width can be adjusted to achieve a wider bandwidth. The radiator is printed on 1.6 mm thick (h_1) FR-4 material with a dielectric constant (ε_{r1}) of 4.2. The metasurface comprises of an array 4 × 4 square ring resonators (SRRs). It is printed on an inexpensive FR-4 substrate with dielectric constant ε_{r2}= 4.2 and thickness (h_2) 0.8 mm. The physical parameters of the SRR are given as follows: P = 20 mm, a = 19 mm and b = 18 mm. A detailed explanation of the physical phenomena behind this structure can be found in [1]-[2] and [4].

3. Results and Discussion

The CPW-fed slot antenna without metasurface is also compared. For CPW-fed inductively slot antenna, usually, the length L is approximately one-guide wavelength ($1\lambda_g$) at the slot resonance. It is also noted that the wavelength in the slot, λ_g, is determined to be about $0.86\lambda_0\sqrt{(1+\varepsilon_r)/2\varepsilon_r}$, where λ_0 is free space wavelength [5]. Dimensions of the CPW-fed slot antenna are chosen to be (unit: mm) L = 50, W = 5, W_f = 3 and g = 0.5. For given dimensions, the slot antenna can excite the resonant frequency of 3.75 GHz for calculation. For simulation as shown in Fig. 2, however, the resonant frequency shifted to 3.84 GHz due to the ground plane has a finite size. When the metasurface is placed on top the CPW-fed slot antenna with h_a = 6.0 mm, a resonant frequency shift down to 2.45 GHz is observed due to the loading effect of the metasurface. This means the metasurface can reduce the slot length about 47% compared with the absence metasurface. It is worth remarking that this antenna design has a very low-profile, with a total thickness (h_a+h_1+h_2) of only λ_0 /15 at 2.45 GHz.

Furthermore, the characteristics of radiation patterns are expected at 2400, 2450 and 2500 MHz. The radiation patterns simulated are shown in Fig. 3 in the *E*- and *H*-planes for the antenna with and without the metasurface. It is observed that the CPW-fed slot antenna without metasurface has a dipole-like radiation pattern, which is barely omnidirectional in *H*-plane. In *E*- plane, it radiates bi-directionally with equal power or the front-to-back ratio (FBR) is 0 dB. Placing the metasurface atop the antenna plays a key role in order to reduce the back radiation. It can be seen that the back-lobe level decreases and the front-lobe increases when the metasurface is presented. When placed antenna beneath the metasurface, the gain increases in the forward direction by about 7.5 dB at boresight. The FBRs at 2300, 2450, and 2500 MHz for antenna with the metasurface have improved by approximately 9.0, 10, and 10 dB, respectively.

To validate the proposed concept, a prototype of the CPW-fed slot antenna with metasurface was designed, fabricated and measured as shown in Fig. 4 (a). The metasurface is supported by four plastic posts above the CPW-fed slot antenna with h_a = 6.0 mm, having dimensions of 108 mm×108 mm ($0.86\lambda_0 \times 0.86\lambda_0$). Simulations were conducted by using IE3D, a full-wave moment-of-method (MoM) solver, and its characteristics were measured by a vector network analyzer. The S_{11} obtained from simulation and measurement of the CPW-fed slot antenna with metasurface with a very good agreement is shown in Fig. 4 (b). The measured impedance bandwidth ($S_{11} \leq$ -10 dB) is from 2350 to 2600 MHz (250 MHz or 10%). The obtained bandwidth covers the required bandwidth of the WLAN system (2400-2485 MHz). Some errors in the resonant frequency occurred due to tolerance in FR-4 substrate and poor manufacturing in the laboratory.

Corresponding radiation patterns and realized gains of the proposed antenna were measured in the anechoic antenna chamber located at the Rajamangala University of Technology Thanyaburi (RMUTT). The measured radiation patterns at 2400, 2450 and 2500 MHz with both co- and cross-polarization in *E*- and *H*- planes are given in Fig. 5 and 6, respectively. Very good broadside patterns are observed and the cross-polarization in the principal planes is seen to be than -20 dB for all of the operating frequency. The FBRs were also measured. From measured results, the FBRs are more than 15 and 10 dB for *E*- and *H*- planes, respectively. Moreover, the realized gains of the CPW-fed slot antenna with and without the metasurface were measured and compared as shown in Fig. 7. The gain for absence metasurface is about 1.5 dBi, whereas the presence metasurface can increase to 8.0 dBi at the center frequency. An improvement in the gain of 6.5 dB has been obtained. It is obtained that the realized gains of the present metasurface are all improved within the operating bandwidth.

4. Conclusion

The use of the metasurface for redirect radiation pattern of the CPW-fed slot antenna has been presented. The broadside gain of the CPW-fed slot antenna with the metasurface is 6.5 dB higher than that of the absence metasurface. When the metasurface is added, the back radiation is effectively reduced to -10 dB in broadside direction. Moreover, the proposed antenna presents a low cost and very low-profile, since the whole antenna thickness is of $\lambda_0/15$ at the center frequency.

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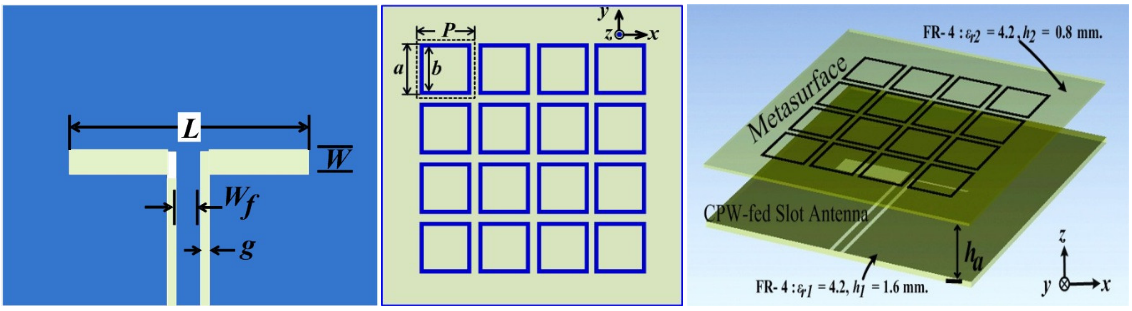


(a) (b) (c)

Figure 1: Configuration of the CPW-fed slot antenna with metasurface (a) the CPW-fed slot antenna, (b) metasurface and (c) the cross sectional view.

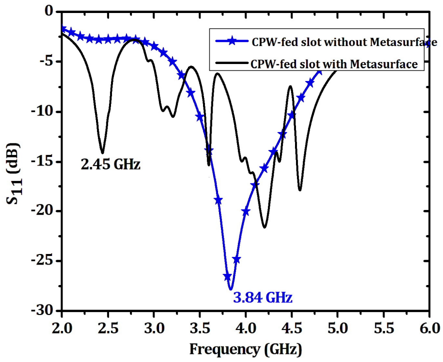
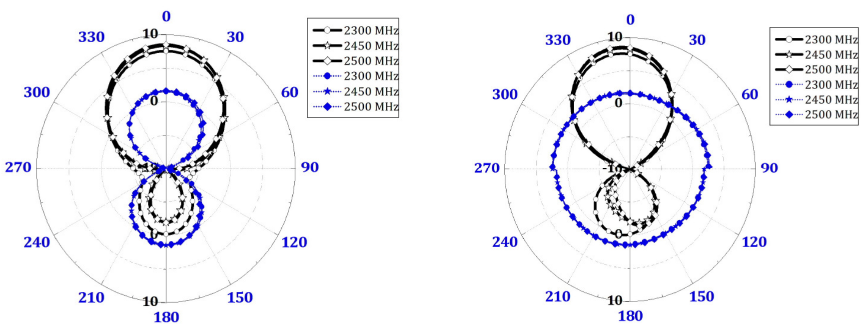
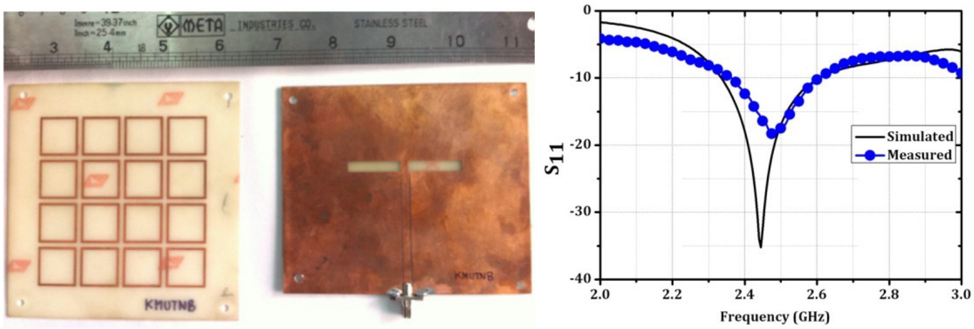


Figure 2: Simulated S_{11} of the CPW-fed slot antenna with and without the metasurface.



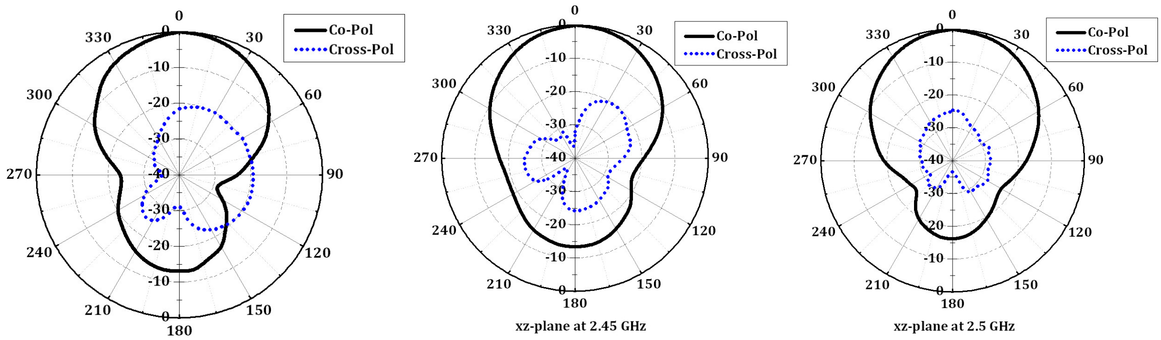
(a) (b)

Figure 3: Comparison of the simulated radiation patterns for the CPW-fed slot antenna with and without the metasurface. (a) *E*-plane and (b) *H*-plane.



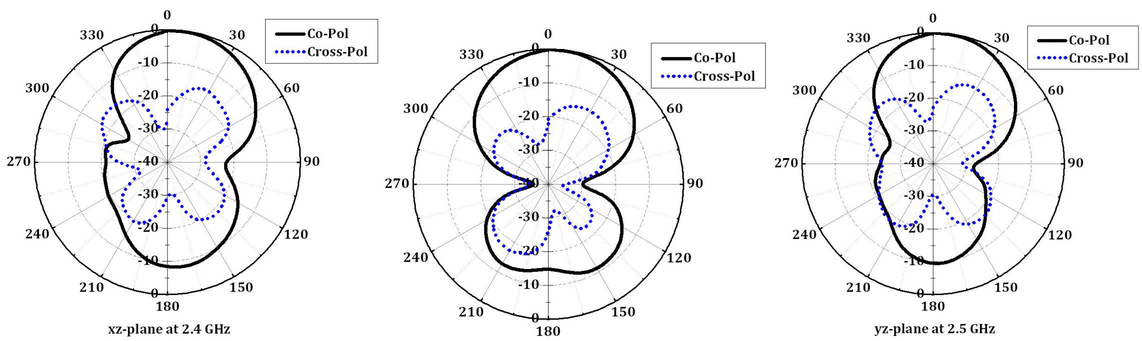
(a) (b)

Figure 4: (a) Photograph of the prototype antenna and (b) simulated and measured S_{11} of the CPW-fed slot antenna with the metasurface.



(a) (b) (c)

Figure 5: Measured radiation patterns for the CPW-fed slot antenna with the metasurface in *E*-plane. (a) 2400 MHz, (b) 2450 MHz and (c) 2500 MHz.



(a) (b) (c)

Figure 6: Measured radiation patterns for the CPW-fed slot antenna with the metasurface in *H*-plane. (a) 2400 MHz, (b) 2450 MHz and (c) 2500 MHz.

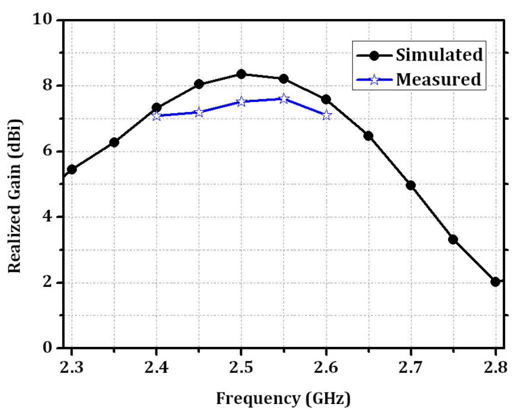


Figure 7: Simulated and measured realized gains of the CPW-fed slot antenna with the metasurface.