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A PLANAR ANTENNA ARRAY WITH SEPARATED FEED LINE FOR HIGHER GAIN AND SIDELOBE REDUCTION

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Abstract—A new antenna structure with lower side lobe pattern and higher gain was designed by combining a microstrip rectangular planar antenna array with the separated feed network technique. In this paper, the side lobe behaviors of two different radiating structures have been studied and compared. The first antenna configuration ("Structure 1") is a 16-element planar antenna array whose feed line is printed on the same plane as the radiating elements. The second one ("Structure 2") is a 16-element planar antenna array whose feed network is separated from the radiating elements by an air gap. This technique enables one to reduce the unwanted spurious effects from the feed line. Both antennas are designed at 5.8 GHz. Compared to "Structure 1" we show that the optimization of "Structure 2" allows reducing the side lobe level and increasing the antenna gain. The experimental results are shown to be in very good agreement with the numerical simulations.

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1. INTRODUCTION

Microstrip antennas have been widely used due to their advantages like low profile, light weight, inexpensive and ease of integration with active components and Radio Frequency (RF) devices [1, 2]. When one considers adding new features to existing antennas, the question arises about the uniqueness and versatility of these configurations. The design of microstrip antennas is strongly related to several characteristics, such as complexity, gain, radiation pattern, side lobe level and bandwidth [3, 4]. Etching the antenna array and transmission lines on the same layer enables one to reduce the manufacturing cost. Unfortunately, this may increase the size of the antenna and, at the same time, could degrade the antenna performance [5, 6]. This performance degradation is attributed to several factors.

Firstly, the transmission line will radiate or receive a signal which indirectly contributes to increase the sidelobe level and decrease the antenna efficiency [7, 8]. Hall [9] estimated that the feed line radiation in a 16-by-16 corporate-fed array could degrade the sidelobe level by 10 dB. Secondly, for reconfigurable antenna designs, the switches integrated within the antenna may alter their fundamental characteristics. However, if these switches are placed in the beam forming network and then fabricated in the same plane as the radiating elements, parasitic interference will be generated [10]. Therefore, to overcome this problem, Das [11] proposed multiple-layers printed antennas. In this paper we introduce a new structure of planar antenna array where the corporate feed network is separated from radiating element plane in order to avoid spurious radiation from the feed network.

The main objective of this paper is to design, investigate and analyze the concept of separated feed network in planar antenna arrays to reduce the side lobe level and increase the antenna gain. In Section 2.1, an analysis of 16-element arrays including feed network is presented, whilst in Section 2.2, a similar 16-element array with separated feed network is discussed. Both antenna structures are analyzed numerically (using the Computer Simulation Technology (CST) Studio Suite 2008) and experimentally.

2. ANTENNA STRUCTURES

Two 16-element microstrip patch antenna arrays have been designed and compared. In both cases, the antenna prototypes were fabricated on a FR-4 substrate with a dielectric constant of $\varepsilon_r = 4.7$ and thickness $h = 1.6\,\mathrm{mm}$.

2.1. Single-layer Planar Antenna Array

The antenna layout is represented in Figure 1. It is similar to the one described in [12]. The size of patches is 17 mm × 12 mm and their inter-element spacing is approximately $\lambda/2$. By optimization of inter-element spacing between patches and size of substrate, the simulated radiation patterns and return loss are given in Figure 2. As can be seen,

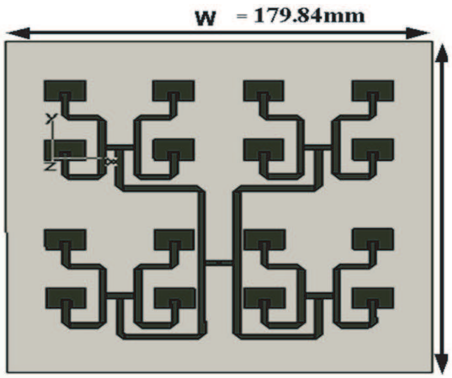


Figure 1. Layout of the single-layer 16-element microstrip patch antenna array ("Structure 1").

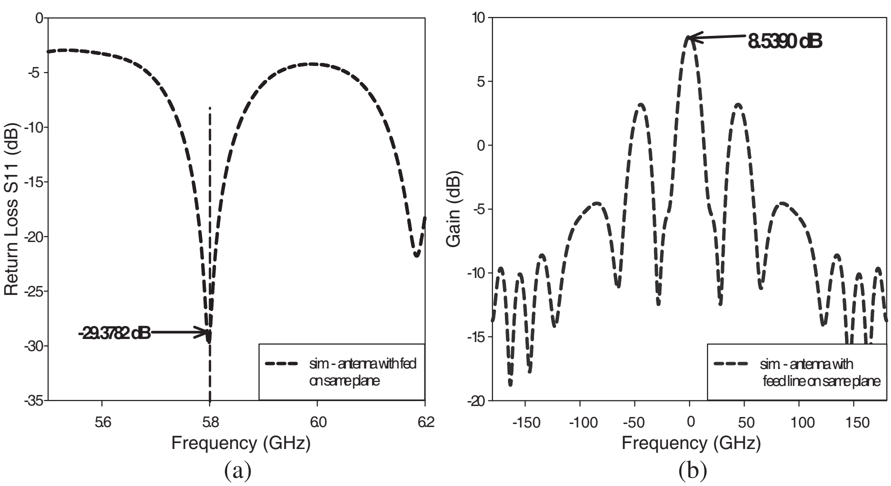


Figure 2. Simulated result for the single-layer 16-element microstrip patch antenna array ("Structure 1"). (a) Return loss (dB). (b) Radiation pattern at 5.8 GHz (H-plane).

for such designs, the side lobe level is rather high (around -6 dB). A rectangular inset patch antenna is expressed as follows in Equations (1) to (6) [2].

$$\text{Width } (w) = \frac{c}{2f_r\frac{\sqrt{(\varepsilon_r+2)}}{2}} \tag{1}$$

$$\text{Length } (L) = L_{eff} - 2\Delta L \tag{2}$$

$$\text{Effective dielectric constant } (\varepsilon_{reff}) = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-\frac{1}{2}} \tag{3}$$

$$\text{Effective length } (L_{eff}) = \frac{C}{2f_r\sqrt{\varepsilon_{reff}}} \tag{4}$$

$$\text{Length extension } (\Delta L) = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{reff}-0.3)\left(\frac{w}{h}+0.813\right)} \tag{5}$$

$$\text{Width of transmission line } (w_t) = \exp\left(\frac{Zc\left(\sqrt{\varepsilon_r+1.41}\right)}{87}\right)\frac{0.8}{5.98h} \tag{6}$$

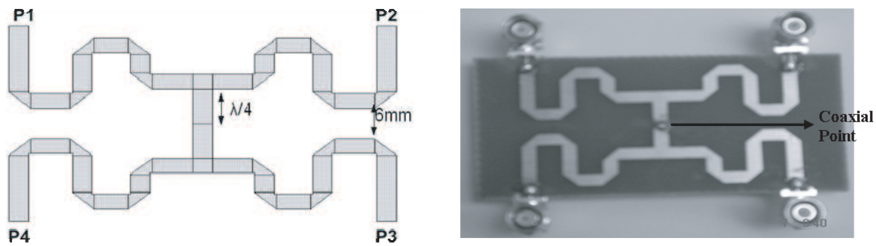
where

f_r = Resonant frequency
h = Thickness of substrate
ε_r = Dielectric constant
c = Speed of light
Zc = Impedence of transmission line

2.2. Planar Antenna Array with Separated Feed Line

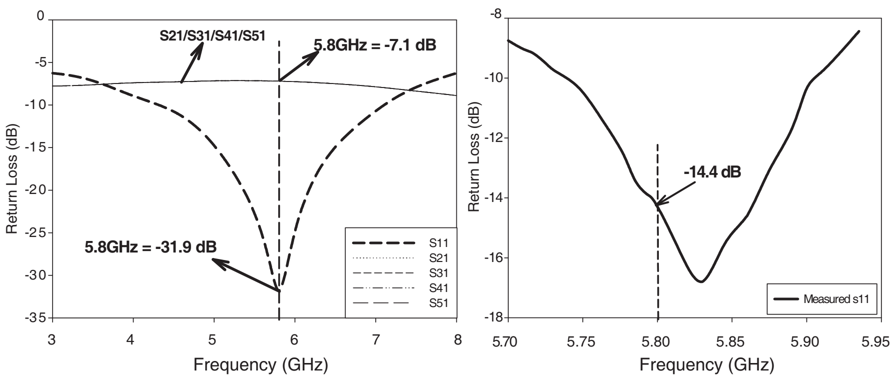
2.2.1. Feed Network

The feed network configuration proposed here is shown in Figure 3. Quarter wavelength transformers are used in the corporate feed network to maintain the input impedance at 50 Ohm. A coaxial probe is located at the center of the feed network (Figure 3(b)). The simulated and measured results for this corporate feed network at 5.8 GHz are given in Figure 4. The minimum simulated and measured return loss is -31.9 dB and -14.4 dB at the operating frequency, respectively. From the results, the frequency shifted is clearly shown. We believe the slight shifted is due to inexact modeling of the Sub Miniature version A (SMA) connector during CST simulation.



(a) (b)

Figure 3. Feed network. (a) Layout. (b) Fabricated prototype.



(a) (b)

Figure 4. Simulated and measured results of return loss. (a) Simulation. (b) Measurement.

2.2.2. Construction of the Planar Antenna Array

The basic structure of the proposed antenna is constructed using multiple 2×2 sub-array modules, as shown in Figure 5. In this structure, the antenna is fed by a 50 Ohm coaxial probe. The size of each patch is 16 mm × 11.15 mm and their inter-element spacing is approximately $\lambda_o/2$. The feed network is conventional [13].

The 16-element array comprises four sub-arrays of 4-elements. Figure 6 shows the structure of the separated feed antenna was proposed in this paper. The input ports on the antenna board are labeled as P1 to P4. The top antennas are fed by a vertical coaxial probe connecting the feed network to eauc sub-array. The gap height h_1 has been optimized to achieve a good return loss at 5.8 GHz.

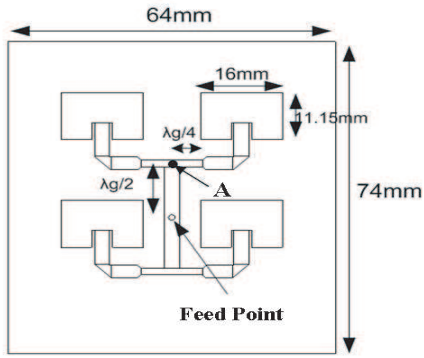


Figure 5. Schematic diagram of the 2 × 2 antenna sub-array.

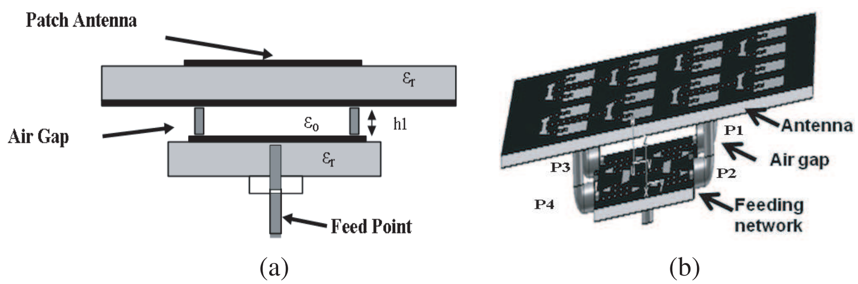


Figure 6. Separated feed antenna through an air gap structures.

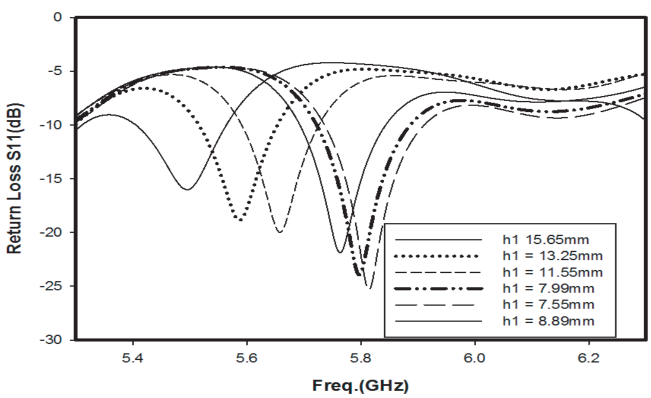


Figure 7. Return loss computed for different air gap heights.

The influence of h_1 on the antenna return loss is illustrated in Figure 7. This figure shows that increasing the air gap height induces a decrease of the resonant frequency. The best result providing a good impedance matching at 5.8 GHz is obtained for $h_1 = 7.99$ mm. Hence, this height has been chosen in the final design.

3. MEASUREMENT AND DISCUSSION

3.1. Fabrication of "Structure 1"

Structure 1 has been manufactured (Figure 8). An open stub of 20 mm length and 1 mm width with 100 Ohm impedance is added at the feed point to improve the input impedance at resonance, as shown in Figure 9. The measured radiation patterns at 5.8 GHz are shown in

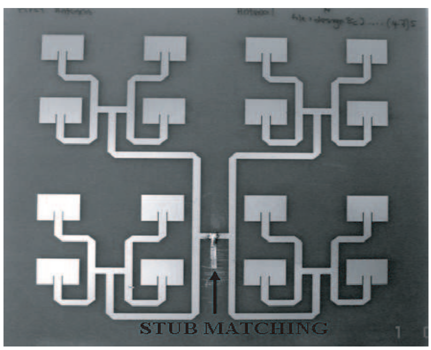


Figure 8. Fabricated prototype ("Structure 1").

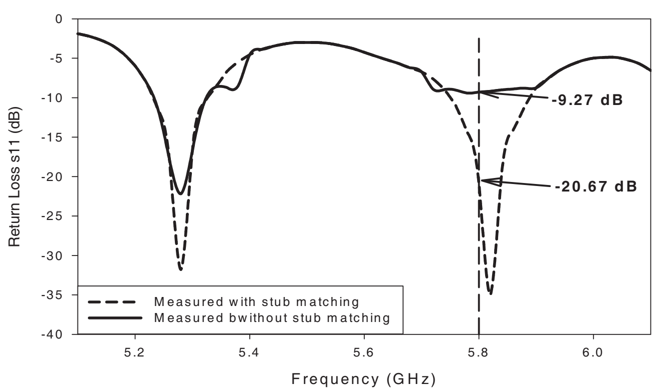


Figure 9. Measured return loss with and without the matching stub.

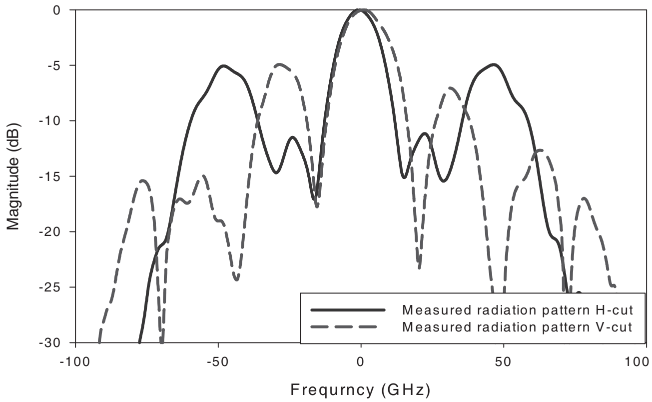


Figure 10. Measured radiation patterns plotted in V- and H planes at 5.8 GHz.

Figure 10. As mentioned in Section 2, the high side lobe level mainly originates from spurious radiation from the feed network.

3.2. Fabrication of "Structure 2"

One fabricated 2×2 sub-array antenna is shown in Figure 11. The simulated and the measured return loss and radiation patterns of this structure are shown in Figures 12(a) and 12(b), respectively. A satisfactory agreement between measurements and simulations has been obtained.

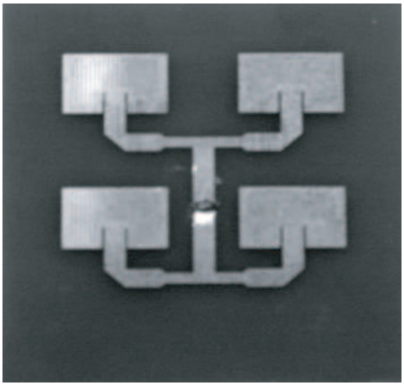
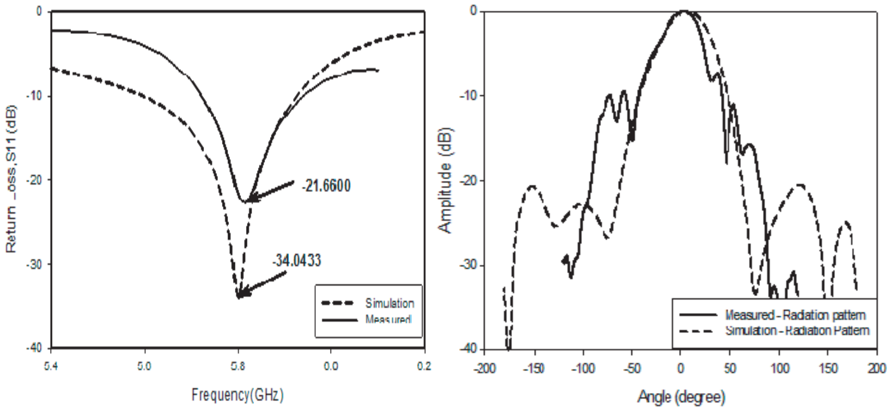
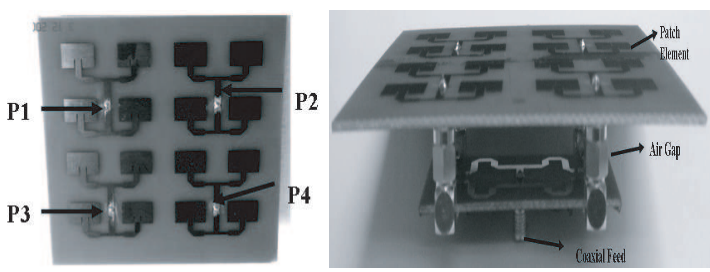


Figure 11. Prototype of the 2×2 sub-array structure.



(a) (b)

Figure 12. Comparisons of simulated and measured results for the 2 × 2 sub-array structure. (a) Return loss. (b) Radiation pattern (H-cut-plane).



(a) (b)

Figure 13. Prototype of the separated feed antenna. (a) Top view. (b) Overall antenna structure.

Figure 13 shows the final structure after assembly. It is constructed from four sub-array elements. The measured and computed return loss and radiation pattern given in Figure 14. The reflection coefficient is smaller than $-21\,\mathrm{dB}$ at resonance and the experimental and predicted patterns have nearly the same half power bandwidth (HPBW).

3.3. Comparison between Both Structures

A comparison is made with the radiation pattern and return loss of antenna between "Structure 1" and "Structure 2". The simulation

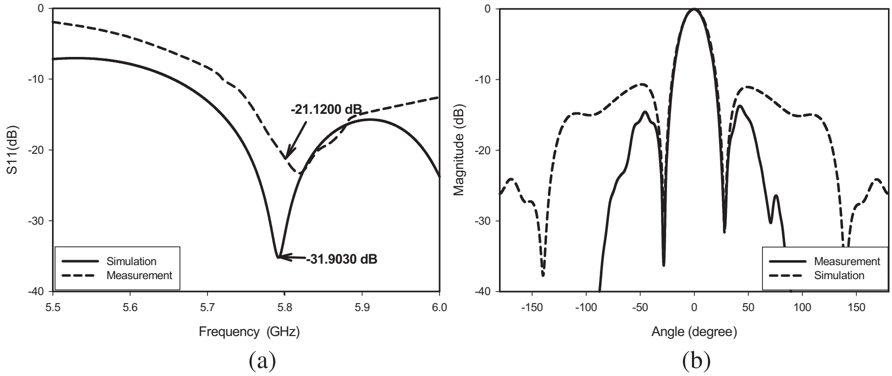


Figure 14. Measured results compare to simulated result of "Structure 2". (a) Return loss. (b) Radiation pattern.

Table 1. The comparison simulated result between two structures.

Specifications	**Structure 1**	**Structure 2**
Antenna Gain	8.537 dB	11.7853 dB
Side lobe to main lobe ratio	−5.35 dB	−11.9 dB
Antenna Size, $W \times L$ (mm)	179.84 × 185	119.2 × 121.7
Return Loss S_{11}	−29.3782 dB	−31.9 dB

observation has been done in term of the size of the antenna, the sidelobe level, the antenna gain and the return loss. Figure 15 shows the comparison of simulated return loss for both structures, which it is have good impendence matching of −29.3782 dB and −31.9 dB, respectively. Figure 16 presents the comparison of simulated radiation pattern for H-cut-plane at 5.8 GHz. It can be seen that the magnitude of the side lobe level for "Structure 1" is clearly higher that "Structure 2", −5.37 dB and −11.9 dB respectively. It is also noted from Figure 16(a), the antenna gain generated by "Structure 2" of 11.78 dB is higher compared to 8.539 dB generated by "Structure 1". Since some of the transmission line is placed to another board, the size of the antenna become smaller as shown in Table 1. All the comparison parameters are listed in Table 1.

Figure 17 to Figure 18 present the measured radiation pattern results at 5.8 GHz for normalized and non-normalized value of H-cut plane and V-cut plane, respectively. An important feature that is highly observed of proposed antennas are the sidelobe level produced

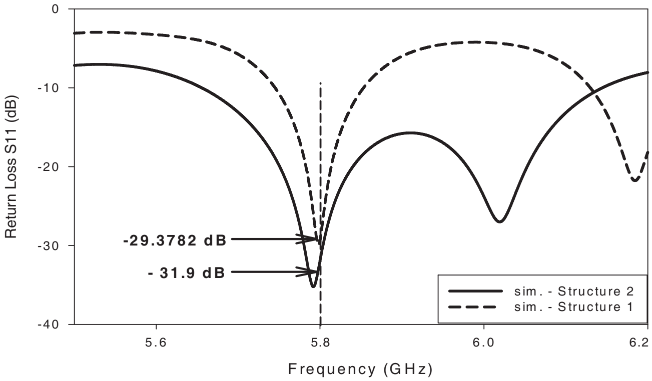
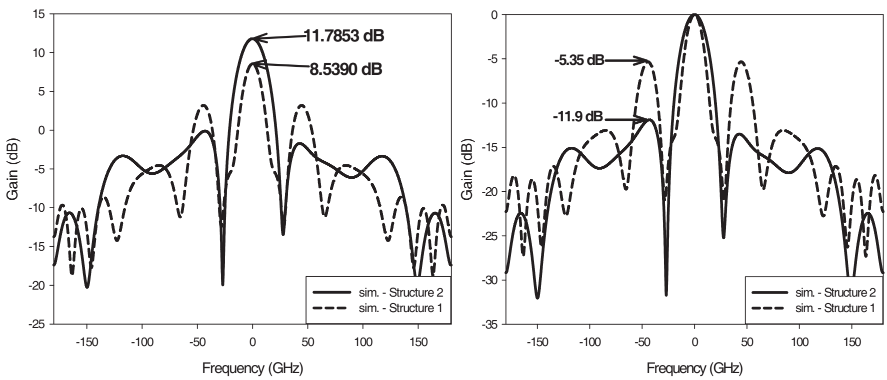


Figure 15. Comparison of simulated result for return loss.

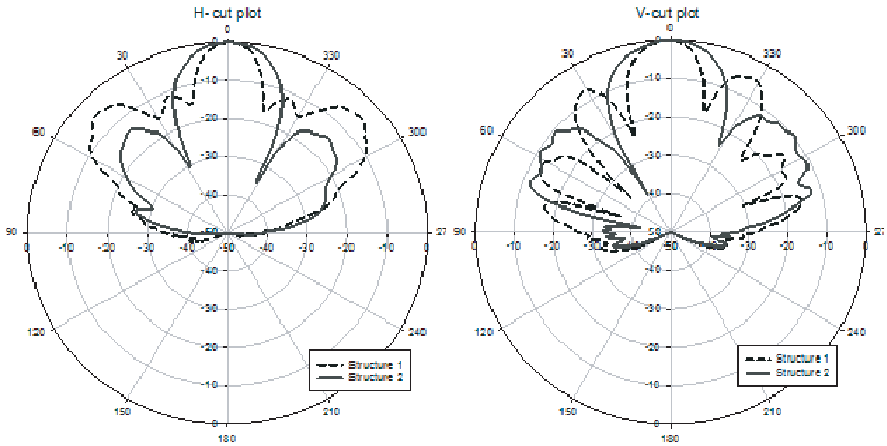


(a) (b)

Figure 16. Comparison of simulated results between "Structure 1" and "Structure 2". (a) Non-normalized radiation pattern. (b) Normalized radiation pattern.

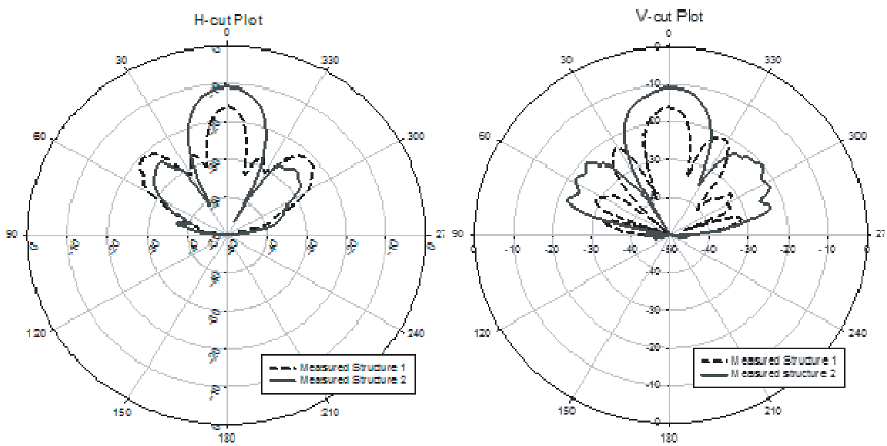
from the "Structure 1" is clearly higher than the "Structure 2". It is can been seen by comparing these characteristic radiation pattern in normalize format as shown in Figure 17.

The comparison of measured gain between both structures are obtained by plotted radiation pattern as in Figure 18. It is observed from the results, the Structure 2 has 2 dB to 3 dB differents higher gain compared to "Structure 1". Figure 19 shows a photo of the both fabricated antennas. The size of "Structure 2" is smaller than "Structure 1", due to some of feeding line is removed to other board. It is proof that from simulation and measurement result shows the "Structure 2" prototypes antenna given advantages compare to "Structure 1" in term of sidelobe level, antenna gain and size of antenna.



(a) (b)

Figure 17. Normalized radiation pattern for the "Structure 2". (a) H-cut-plane. (b) V-cut-plane.



(a) (b)

Figure 18. Non-normalized radiation pattern for the "Structure 2". (a) H-cut-plane. (b) V-cut-plane.

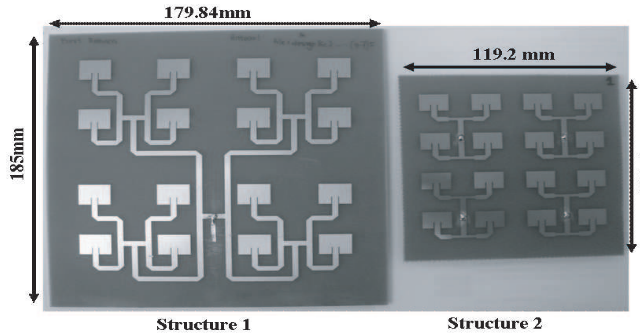


Figure 19. The photo of fabricated antenna for both structures, "Structure 1" and "Sructure 2".

4. CONCLUSION

The microstrip planar antenna array with the separated feed line technique concept is studied in this paper with the objective to reduce the sidelobe level and increasing the gain. The unique property of this antenna design is that instead of fabricating all together in the same plane, the antenna's feeding network is separated from the antenna radiating elements (the patches) by an air gap distance. This allows reducing spurious effects from the feed line. The experimental radiation patterns show very good agreement with simulations which the sidelobe level was suppressed. From the comparison results, it obviously shown that the "Structure 2" is given better sidelobe to mainlobe ration of −11.9 dB while "Structure 1" only −5.35 dB. In this structure, not only improvement is achieved in the sidelobe reduction pattern, but also better performance in term of the antenna gain. The advantage of this design is that the radiation arising from the feeding line cannot interfere with the main radiation pattern generated by the antenna. This antenna is also suggested for reconfigurable antenna which integrated with RF switching at feeding line applications. Finally, in order to proof the validity of the antenna design, the simulation results have been compared with measurements, and good agreement has been found.

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