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Biconcave Microstrip Antenna

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***Abstract*: This paper modifies the non-radiation edge of a rectangular microstrip radiator to push the resonant frequency upward and simultaneously increase its gain. The modification of the non-radiating edge increases the physical length of the edge, but reduces the electrical current path length, which is responsible for the push of the resonating frequency. For the change in resonating frequency, the work proposes an empirical formula. The modification of non-radiating edges results in a biconcave shape for the radiator. The push of the resonating frequency results in a decrease of wavelength, which leads to increased electrical size of the patch. Therefore, effective radiating aperture increases leading to improvement in gain and efficiency of the radiator. Simulated and measured results on fabricated prototype follow each other. The realized gain of the fabricated prototype is 5.0 dB at 4.19 GHz. This antenna has potential for use in various C band application areas like satellite communication, automobiles, radar, etc.**

***Index Terms*: Biconcave, microstrip antenna, realized gain, surface current**

I. INTRODUCTION

The patch antenna resonant frequency depends on patch dimensions, substrate permittivity and thickness. Most of the wireless communication systems today prefer microstrip antenna due to technical advantages like MMIC-compatibility, low profile, low cost, and conformability. Despite limitations like narrow bandwidth, low efficiency, low power gain, industry prefers these antennas due to full control over their resonant frequency, radiation pattern and impedance characteristics. Different techniques are continuously evolving for such controls.

Authors in [1] suggested a method of controlling operating frequency by inserting shorting posts at appropriate locations within the antenna's boundaries. Loading of lumped impedances [2] alters the patch antenna radiating characters. Simple cavity model can analyse [3], [4] patch antennas with shorting pins. Shorting pins can also result in design of dual-frequency structures [5], [6]. The suitable modification of the formula for resonant frequency of a probe-fed patch antenna can give the resonant frequency of a patch antenna with shorting posts [7]. Besides, electrostatic force can tune the resonant frequency of a microstrip antenna [8]. A recent paper proposes frequency reconfigurable antennas using pentagon slot resonator [9]. Similarly, electromagnetic band-gap (EBG) principle suggests reconfigurable antennas for frequency diversity applications [10].

It is well known that the physical area of an antenna determines its effective aperture area. The more the effective aperture size, the more is the illumination and hence efficiency. With increase in operating frequency, the size of a microstrip antenna decreases resulting in smaller physical and hence electrical aperture. Therefore, at higher frequencies, the efficiency of microstrip antenna can degrade. It is thus desirable to find out ways of maintaining larger effective aperture size while operating at higher frequencies. To realize this one needs to redistribute the fields. Keeping the overall dimension constant, a perturbation of the original shape can result in such redistribution. This results in reduction of effective current path from that of the physical path. We propose a biconcave patch antenna keeping these in mind. To start with we suggest a closed form expression for the resonant frequency of this antenna. Simulated verification of the above is possible by observing the surface current distribution, radiation pattern, S_{11} plot, etc. using ANSYS HFSS software. Measurements of S_{11}, radiation pattern, realized gain on a fabricated prototype can confirm the simulation.

II. ANTENNA GEOMETRY

Fig. 1 shows the schematic of the proposed antenna and its prototype. To obtain the structure, two symmetrical circular-segmental arch sections are etched from two opposite sides of a rectangular patch with the corresponding side length of the patch being the chord of the arch. The chord length is 'L' and the patch width is 'W'.

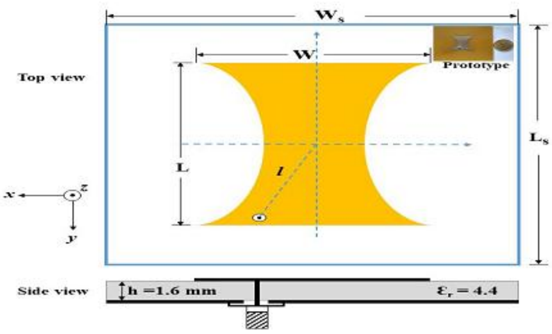

Fig. 1. Schematic structure of the proposed antenna and its prototype

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A 50Ω coaxial feed excites the patch at a distance of ‘l’ from its centre towards the radiating edge along the centre line. The substrate for the antenna is of thickness ‘h’, width ‘W_s’ and length ‘L_s’.

III. RESONANT FREQUENCY

The resonating frequency of the proposed biconcave radiator is higher than that of the generating rectangular antenna. Therefore, it will be in the form of

$$f_{bc} = f_{re}\{1+g(r)\} \quad (1)$$

Where, f_{bc} is the resonant frequency of biconcave radiator. f_{re} is the resonant frequency of the generating rectangular antenna and $g(r)$ is a function of radius (r) of the circular segment etched out from the generating antenna. For the generating antenna radius approaches infinity. After neglecting higher order terms, $g(r)$ will be of the form

$$g(r) = \frac{1}{a_0 r + a_1 r^2 + a_2 r^3} \quad (2)$$

Using numerical techniques [11], [12] and simulations (Algirothm 1), we found

$$a_0 = -0.27$$

$$a_1 = 0.05$$

$$a_2 = -1.44\times10^{-3}$$

Simulations validated these values. Using equation (1) the value of resonant frequency of test antenna is 4.15 GHz.

Algorithm 1:
Derivation of resonating frequency formula:
STEP 0: Begin.
STEP 1: Determine resonating frequencies for three different radii.
STEP 2: Substitute the above values in equation (1) to obtain three simultaneous equations with a_0, a_1 and a_2 as unknowns.
STEP 3: Solve these equations to obtain values of a_0, a_1 and a_2.
STEP 4: End.

IV. SIMULATION AND MEASUREMENT

Table 1 shows the physical dimensions of the considered antenna on FR4 substrate of permittivity (ε_r) 4.4, loss tangent (tan δ) 0.002. ANSYS HFSS simulation of the antenna is for the band of 3.0 to 6.0 GHz. The simulation gives the variation of S_{11} over the above frequency band. The S_{11} plot indicates the resonant frequency of antenna. We also obtain the surface current distribution, radiation pattern and realized gain at this frequency.

Table 1: Dimensions of the proposed antenna (in mm)

Parameter	Value	Parameter	Value
L	24	h	1.6
W	23.57	W_s	50
l	9.84	L_s	50

The prototype fabrication is on a FR4 substrate with the given dimensions indicated in Table 1. The vector network analyser (Agilent N5247A) measured the value of S_{11}. Measurements of pattern and gain have been done in anechoic chamber using horn antenna as transmitter.

A. S_{11} Characteristics

Fig. 2 compares simulated and experimental values of S_{11}. They indicate close resemblance. The curves show strong resonances around 4.1 GHz and weak resonances around 4.8 GHz, 5.25 GHz and 5.6 GHz. The simulated resonant frequency is 4.07 GHz with -32 dB S_{11} and bandwidth 0.23 GHz (5.63%). In addition the measured resonant frequency is 4.19 GHz with -34 dB S_{11} and bandwidth 0.15 GHz (3.63%).

Fig. 2. Measured and simulated S_{11} of proposed antenna

B. Surface-current Distribution

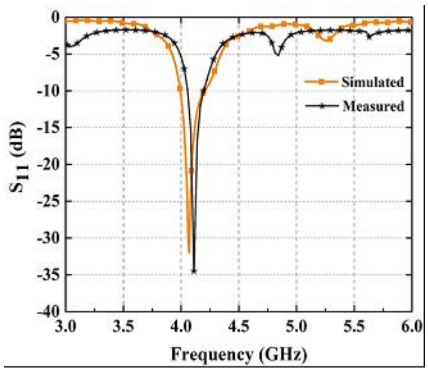

Fig. 3 shows surface current distribution at the resonant frequency for the antenna. The non-radiating edge has an effective current along it which is smaller than the physical length. The effective current length is responsible for the resonant frequency. A smaller effective current length pushes the resonant frequency upward.

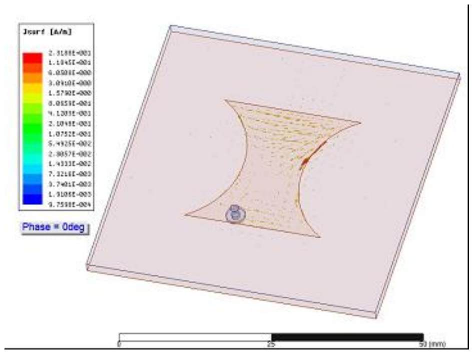

Fig. 3. Surface current distribution of proposed antenna

C. Realized Gain Characteristics

Fig. 4 shows the simulated and experimental plots of realized gains. At simulated and measured resonant frequencies, the realized gains are 5.3 dB and 5.0 dB respectively. There is a small separation between the plots though the nature of the plots remains the same. The maximum shift of measured gain from the simulated gain is 0.21 GHz to right at the second resonant peak. Table 2 summarises both simulation and experimental results of the investigation.

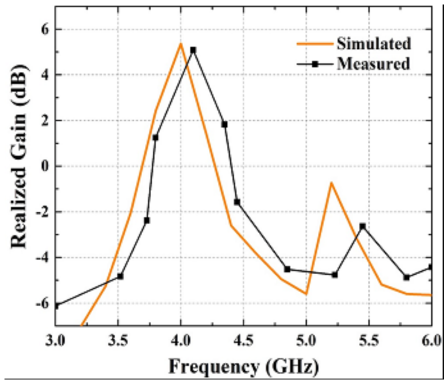

Fig. 4. Measured and simulated realized gain of proposed antenna

Table 2: Summary of simulation and experimental results

Parameter	Resonant Frequency (GHz)	S_{11} (dB)	Gain (dB)	Bandwidth (GHz)
Simulation	4.07	-32	5.3	0.23
Experiment	4.19	-34	5.0	0.15

D. Radiation Pattern Characteristics

Fig. 5(a) and (b) shows the simulated and measured radiation pattern results of the proposed patch at resonating frequency 4.19 GHz in E-Plane ($\Phi = 0^0$) and H-Plane ($\Phi = 90^0$) respectively. The difference between measured values of Co-Pol and X-Pol are respectively around 15 dB and 20 dB. In both E and H-plane the difference between Co- and X-Pol is around 25 dB. The pattern shape indicates a broadside radiation.

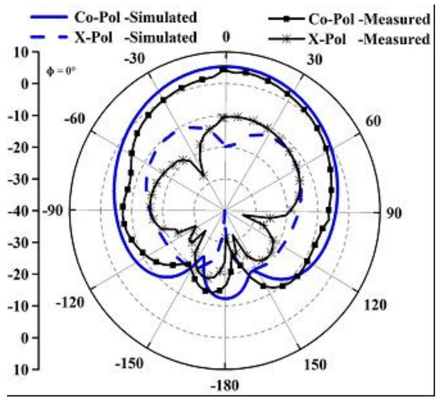

Fig. 5. (a) E-plane Radiation pattern

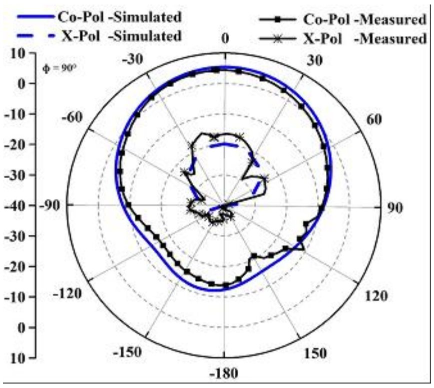

Fig. 5. (b) H-plane Radiation pattern

V. DISCUSSION

The sources of mismatches between simulated and measured results might be lying in fabrication tolerance, measurement errors in the available laboratory and equipment therein with rudimentary facilities. The second simulated resonant peak may be due to the non-adaptive meshing adopted by the ANSYS HFSS engine over a broadband which affects the modelling of the coaxial probe as well as edge effects of the antenna. A major cause of the second and third resonant peaks of the measured values might be the protruding feed probe soldered to the patch.

Etching out portions along the length of a rectangular patch antenna elongates its physical path for the current between the radiating edges. As a result, the resonant frequency should shift downward from that of the parent antenna. However, in the present case the resonant frequency of the resulting structure shifts upward compared to its generating patch. The reason for this lies in the fact that after removal of conducting portions, the fields between the patch and ground plane redistribute. This redistribution obeys the principle of least action. Therefore, the effective current path decreases compared to the path in the generating patch; and it results in upward shift of the resonant frequency. Further removal of the conducting portion reduces the conductor loss. Therefore, the realized gain of the suggested antenna should exceed that of the parent antenna. Simulations conform this with realized gains of 5.3 dB and 2.91 dB respectively. The radiating edge maintains its shape in the proposed antenna. Therefore, the radiation pattern of the proposed antenna should match that of a rectangular patch antenna without much degradation. This is evident from the simulated and measured radiation plots which indicate at least 15 dB difference between Co-Pol and X-Pol. The simulated radiation efficiency of the proposed antenna is 58% while that of the parent rectangular antenna is 48%.

VI. CONCLUSION

The authors argued that it is possible to enhance efficiency and gain of a rectangular microstrip radiator by modifying its non radiating edges which changes its resonating frequency.

It is also said that though the modification increases physical length, through approximate design, the electrical length reduces. Thus, in terms of electrical size the effective antenna aperture increases enhancing efficiency and gain.

Thus the paper proposed generation of a biconcave patch antenna from a parent rectangular patch antenna with a higher realized gain and upward shift in resonant frequency while maintaining radiation characteristics. It also suggested a closed form expression for the resonant frequency of the biconcave patch antenna. Simulations and measurement on prototype verified the claims for biconcave patch antenna. The potential application of this antenna is in C-band for WiFi, disaster management, weather radar system, etc.

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