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ScienceDirect
Procedia Computer Science 85 (2016) 443 – 450
Procedia Computer Science

International Conference on Computational Modeling and Security (CMS 2016)

Quad Staircase Shaped Microstrip Patch Antenna for S, C and X Band Applications

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Abstract

This paper presents miniaturization by introducing staircase shape at each edge of the patch of Microstrip Patch Antenna (MPA) which operates in S-band (2-4 GHz), C-band (4-8 GHz) and X-band (8-12 GHz). The proposed antenna operates at 2.44 GHz, 5.53 GHz, 7.79 GHz and 9.39 GHz with up to 37% size reduction compared to the basic MPA. Design frequency for the proposed antenna is 2.4 GHz which supports multiband behavior. The Rogers RT/Duroid 5880 with relative permittivity 2.2 and height 1.6 mm is used as substrate material for design of proposed antenna. Transmission line model is applied to calculate the dimensions of the proposed antenna. Coaxial probe feed is used to feed the proposed antenna because this type of feed provides better impedance matching to source by varying the feed position. Ansoft HFSS V13 (High Frequency Structure Simulator) software is used for the design and simulation of the proposed antenna. The results of the proposed antenna are obtained in terms of Return Loss, Voltage Standing Wave Ratio, Gain and Radiation Pattern which have acceptable values of return loss less than -10 dB, VSWR less than 2 at each resonant frequencies and Gain more than 3 dB.

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Keywords: Multiband; Coaxial probe feed; High Frequency Structure Simulator (HFSS); Return loss; VSWR; Gain

1. Introduction

Microstrip Patch Antenna can be used in various wireless communication applications such as satellite, Radar, missile and aircraft. MPAs are called low profile antenna because these can be flush mounted on curved surface and they only require space for the feed line [3]. Microstrip antennas are popular at frequencies above 100 MHz [2]. Improper impedance matching and narrow bandwidth are two main disadvantages of MPA's. There are two techniques to enhance the bandwidth, one is by using thick dielectric substrate and the second is by using slotted

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doi:10.1016/j.procs.2016.05.190

patch. The first technique is limited because the thick substrate require increased length of the probe feed which introduces large inductance and increase only a few percentage of bandwidth. The second technique (slotted patch) increases the bandwidth more than the first method, reduces the size of the patch and also shifts the fundamental resonant frequencies to lower side [7].

MPA consist of a thin metallic patch which is kept on dielectric substrate and below the dielectric substrate there is a conducting ground plane. A microstrip patch is generally of cooper placed on the top of the dielectric substrate. Ground plane is at the bottom side of the dielectric substrate as shown in Fig. 1[4] [5].

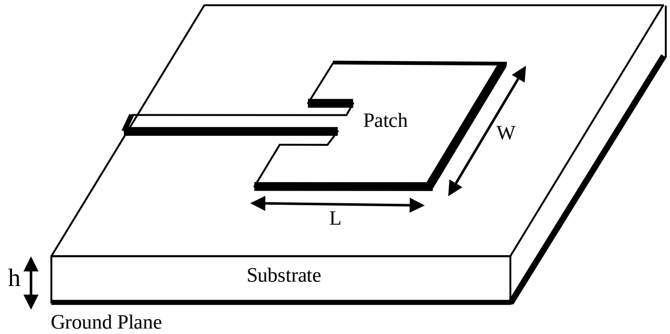

Fig. 1. Microstrip Patch Antenna [1].

2. Antenna Design

The shape of the patch resembles the staircase shape hence the name “Staircase shaped patch antenna” is given. The size reduction of 37% is achieved by cutting the staircase at each side of the patch. Geometry of proposed antenna is shown in Fig. 2.

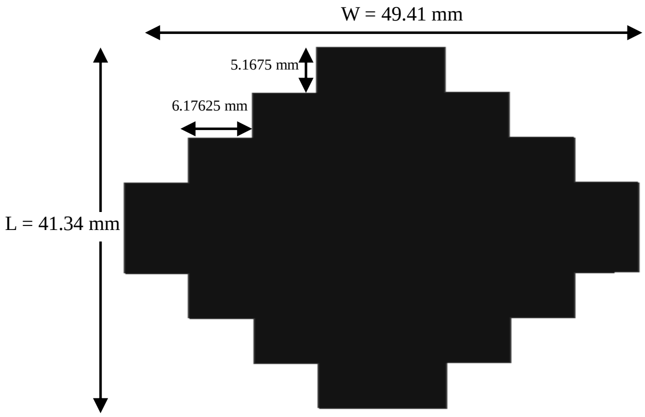

Fig. 2. Geometry of Quad Staircase Shaped MPA

2.1. Rectangular Patch Design

Frequency, thickness and material of the substrate are three necessary parameters for designing the MPA. The resonant frequency 2.4 GHz is chosen, because this frequency locates in ISM band, low atmospheric attenuation and low cost components. This frequency is used in RFID, WLAN and Bluetooth based wireless systems [6] [9]. The Rogers dielectric material with relative permittivity 2.2, height 1.6 mm and loss tangent 0.0009 is taken as substrate material. Coaxial probe feed is employed to feed the proposed antenna in which the inner conductor is

soldered to the patch and outer conductor is soldered to the ground plane. Coaxial probe feed has low spurious radiation and easy to fabricate [10]. Dimensions of proposed antenna are calculated by as follows:
Patch width of MPA is determined using equation (1) as given below [11]

$$W = \frac{c}{2 f_r \sqrt{\frac{(\epsilon_r + 1)}{2}}} \tag{1}$$

An effective dielectric constant is introuced due to fringing effect because some waves travel in the air and some in the substrate as follows (2).

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{\frac{-1}{2}} \tag{2}$$

Due to the fringing effect the dimensions of the patch are extended by ΔL on both sides according to equation (3).

$$\Delta L = 0.412h \frac{(\epsilon_{eff} + 0.3)(\frac{w}{h} + 0.264)}{(\epsilon_{eff} - 0.258)(\frac{w}{h} + 0.8)} \tag{3}$$

The final or actual length of the patch is calculated by the equation (4) as follows:

$$L = \frac{c}{2 f_r \sqrt{\epsilon_{eff}}} - 2\Delta L \tag{4}$$

Table 1 shows the design parameters of the antenna which are calculated by using the equations 1-6 as follows:

Table 1.Performance parameters of the antenna

Antenna Parameter	Size
Width of the patch (W)	49.41 mm
Effective dielectric constant (ϵ_{eff})	2.11
Extension in length (ΔL)	0.84 mm
Length of the patch (L)	41.35 mm
Ground plane width (W_g)	59.01 mm
Ground plane length (L_g)	50.95 mm

2.2. Dimensions of the Ground Plane

The transmission line model can be applied to infinite ground plane only, but infinite ground plane is not possible for practical use [8]. So the dimensions of the ground plane are calculated by the following formula (5) and (6) :

$$L_g = 6h + L \tag{5}$$

$$W_g = 6h + W \tag{6}$$

3. Results And Discussions

Ansoft based HFSS V13 software is used to simulate the proposed antenna. Probe feed position is optimized by changing feed position along the x-axis and y-axis. The best results are obtained at position x=18 mm and y=17 mm. Return loss Vs frequency plot of the proposed antenna are shown in Fig. 3 shows the. The proposed antenna resonates at four different frequencies 2.44 GHz, 5.53 GHz, 7.79 GHz and 9.39 GHz.

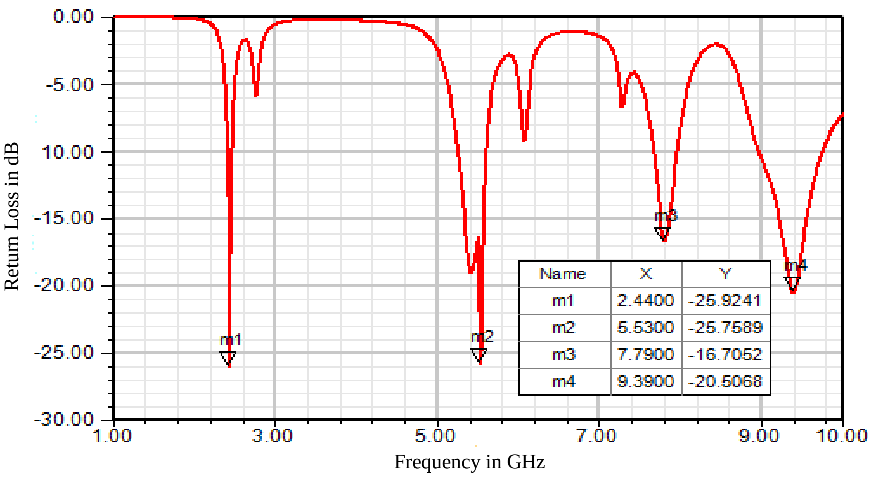

Fig. 3. Return Loss Vs Frequency Plot

3.1. VSWR

The most important property of antenna is VSWR. It represents the impedance matching of the antenna. The value of VSWR should be less than 2 for good antenna performance [2]. The proposed antenna operates at four frequencies with VSWR of 1.10, 1.10, 1.34 and 1.20 respectively. Fig. 4 shows the VSWR Vs frequency plot of the proposed antenna.

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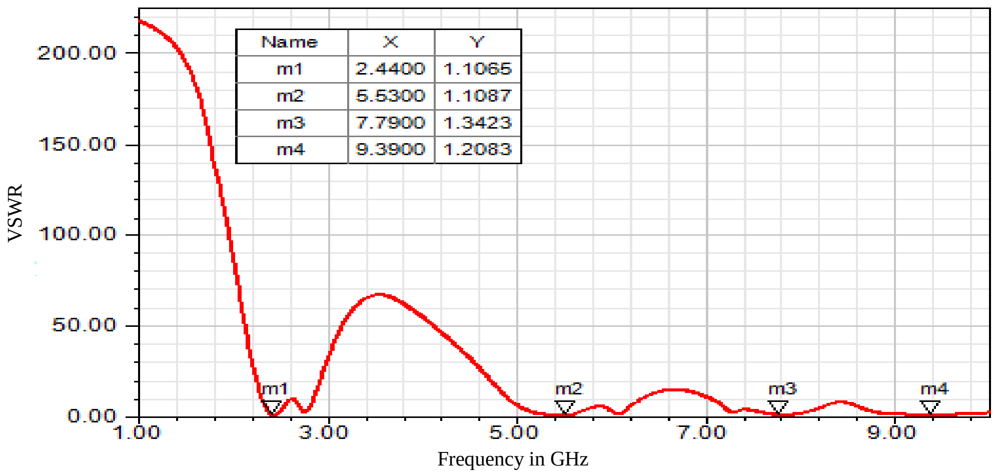

Fig. 4. VSWR Vs Frequency Plot

3.2. Radiation Pattern

Fig. 5 shows the Radiation pattern of the proposed antenna at resonant frequency 2.4 GHz for Phi equals to 0 degree and 90 degree.

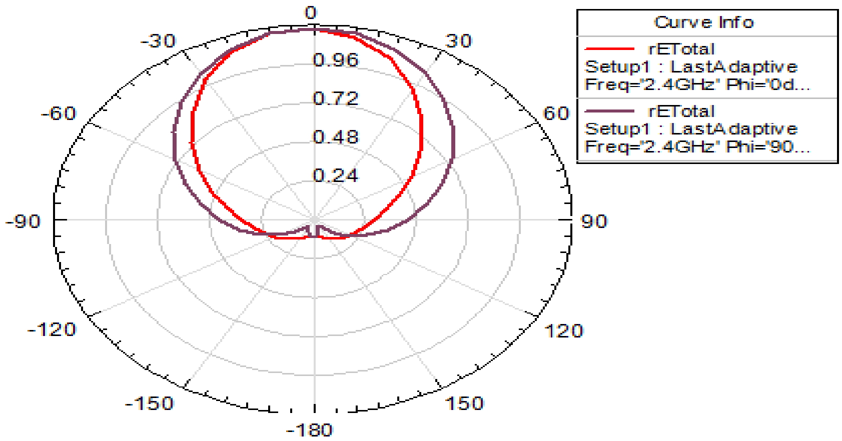

Fig. 5. Radiation pattern of antenna in E and H planes at 2.4 GHz

The radiation pattern at four resonant frequencies 2.44 GHz, 5.53 GHz, 7.80 GHz and 9.38 GHz is shown in Fig. 6, Fig. 7, Fig. 8 and Fig. 9 respectively.

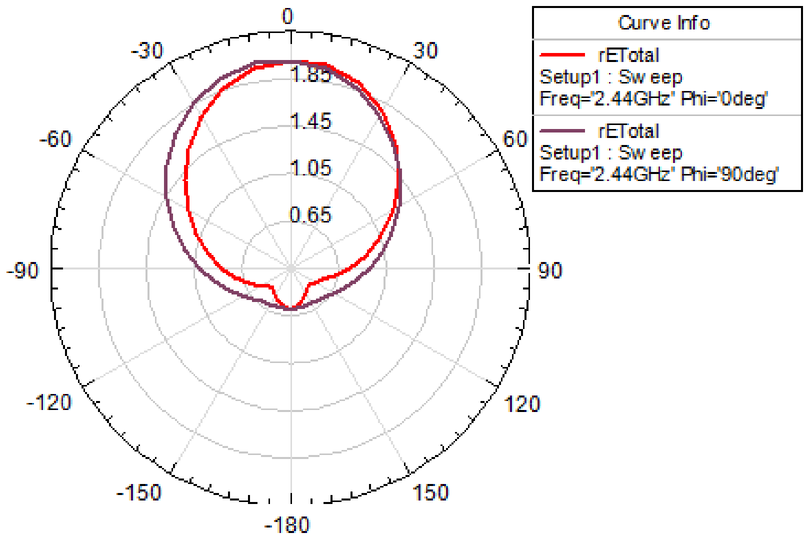

Fig. 6. Radiation pattern of antenna in E and H planes at 2.44 GHz.

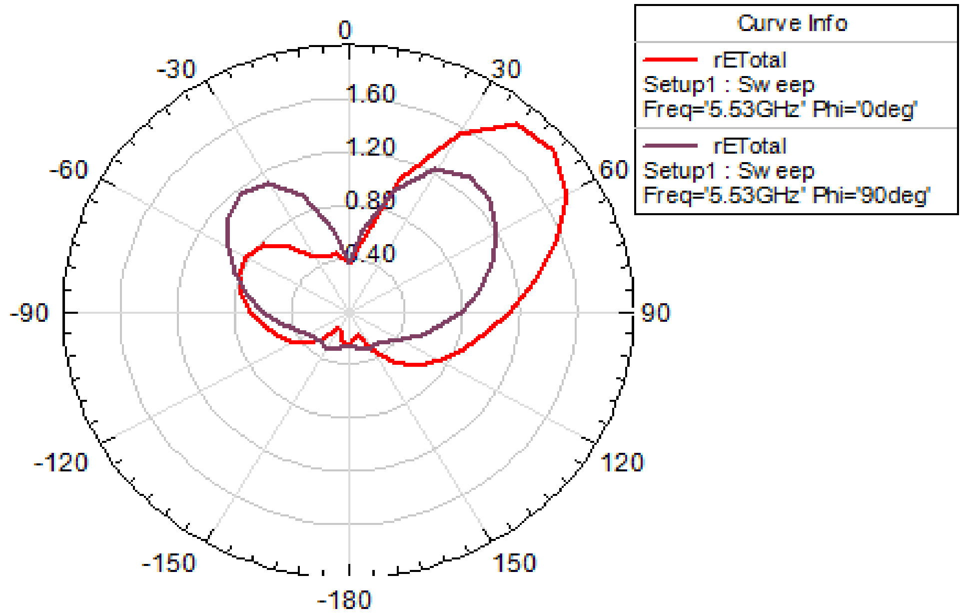

Fig. 7. Radiation pattern of antenna in E and H planes at 5.53 GHz.

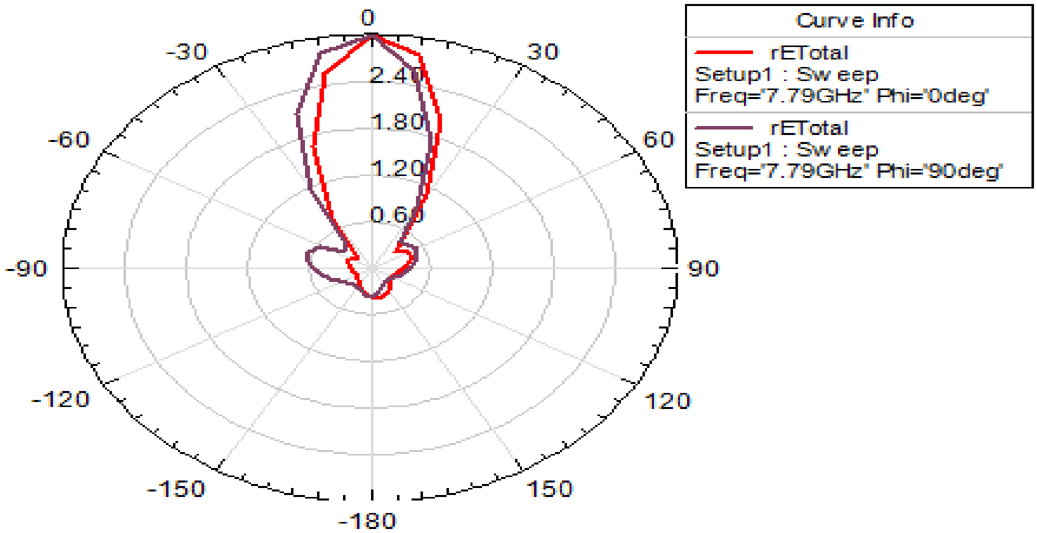

Fig. 8. Radiation pattern of antenna in E and H planes at 7.79 GHz.

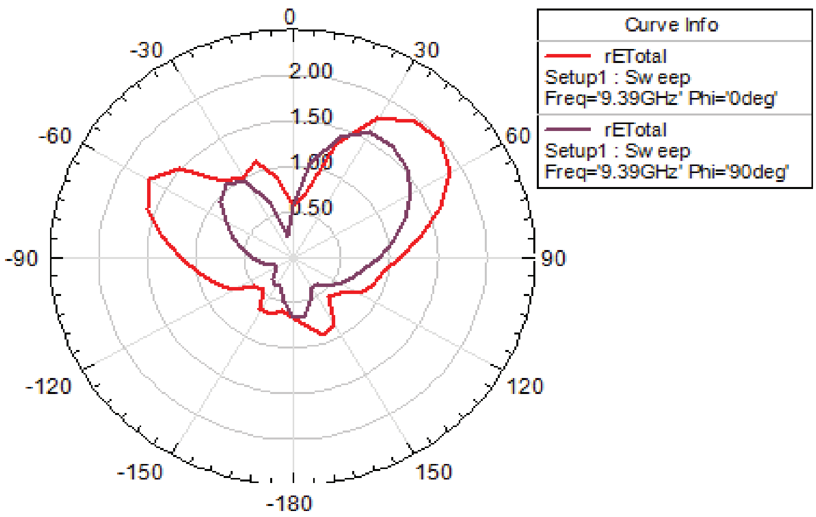

Fig. 9. Radiation pattern of antenna in E and H planes at 9.39 GHz

Table 2 shows the performance parameters of the antenna in terms of resonant frequency, return loss, lower frequency, upper frequency, gain, voltage standing wave ratio and bandwidth.

Table 2.Performance Parameters of the Antenna

Frequency (GHz)	*RL (dB)*	*Lower Freq. (GHz)*	*Upper Freq. (GHz)*	*Gain (dB)*	*VSWR*	*Bandwidth (MHz)*
2.44	-25.9	2.4102	2.4690	6.49	1.10	58.8
5.53	-25.7	5.2542	5.5980	6.05	1.10	343.8
7.79	-16.7	7.6685	7.95	9.98	1.34	281.5
9.39	-20.5	8.96	9.7396	8.55	1.20	779.6

4. Conclusion

The proposed antenna is designed at frequency 2.4 GHz and fed by the coaxial probe feed. The results show that the feed position is accurate because there is good impedance matching between the feed and the antenna. The proposed antenna operates in triple band S, C and X band of frequencies. Patch size reduction of 37% is achieved without affecting the performance of the antenna. The proposed antennas have achieved good impedance matching, stable radiation patterns and high gain.

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