A Compact Microstrip Patch Antenna for Mobile Communication Applications

A. Sanega and P. Kumar

Abstract In this paper, the design and fabrication of a compact rectangular microstrip antenna (RMSA) are presented. The defected ground structure (DGS) along with *T*-shaped slots in patch is utilized to reduce the size of the antenna. The designed patch antenna with optimized dimensions is fabricated using FR4 substrate. Using the aforementioned methods, the antenna patch size is reduced by 25% when compared to a conventional rectangular microstrip patch antenna. The designed antenna is operating at mobile communication frequency band. The designed antenna is simulated and the simulation is performed using computer simulation technology microwave studio software. The presented antenna is compact in size and suitable for mobile devices.

Keywords Microstrip antenna (MSA) · Size reduction · Defected ground structure (DGS) · Reflection coefficient (RC)

1 Introduction

The size reduction is a key requirement in modern wireless systems to accommodate more applications in a compact device. The compact size of MSA makes these antennas suitable for modern wireless communications. However, the size of these antennas becomes large at low frequencies [1, 2]. The size of the MSA can be decreased by size reduction techniques such as shorting post loading [3, 4], using slots [5], using metamaterials [6], and DGS [7].

In the shorting post-loading technique, the patch is shorted with the ground. The shorting post behaves like an inductor between the patch and the ground plane. Due to the inductance behavior of shorting post, the resonant frequency of the MSA is shifted and the size of the MSA can be reduced [3]. Mazumdar et al. [8] have proposed slits loaded compact MSA. The presented compact MSA resonates at four different frequencies. In [9], a MSA is designed and analyzed for array application. The

A. Sanega · P. Kumar (✉)
EECE, School of Engineering, University of KwaZulu-Natal, Durban 4041, South Africa
e-mail: pkumar_123@yahoo.com

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numerical models for calculating resonant frequency, input impedance, and radiation patterns of the MSA are given. In [10], a slot loading technique is used to reduce the size of the MSA. Slots along with conducting strips give multi-frequency operation. In [11], a compact MEMS switches-based reconfigurable MSA is designed. The MSA can radiate in different twelve directions in different states. In [12], slots-based compact MSA is designed. The slots loaded MSA operates at multi-bands. Thabet and Hassan [13] have proposed the design of a compact MSA by changing the substrate material. A nanocomposite material having RT Duriod 5880 with nanofillers is used in the design. Bharti et al. [14] have proposed a compact MSA for triple-band applications. Fractal elements are used in the MSA structure which decreases the resonant frequency of the MSA. Monti et al. [15] have used fractal technique and shorting post to reduce the size of the MSA structure. Using fractal technique along with shorting posts, a compact MSA for RFID applications is designed.

Kumar [16] has designed various shaped compact MSAs for 2.4 GHz applications. The MSAs are designed on a flexible substrate and suitable for wearable applications. Barad and Behara [17] have proposed the design of a compact MSA. The MSA resonates at 2.8 GHz have the beam steering capability. Xiong et al. [18] have presented a compact metamaterial-based MSA for wideband applications. The minimum gain and maximum gain of the designed MSA are 2 dB and 6 dB, respectively. Chatterjee et al. [19] have proposed the design of a compact MSA which is suitable for mobile communication applications. The unequal rectangular slots have been used to reduce the size of the proposed MSA. Wei et al. [20] have proposed a MSA with enhanced bandwidth which is compact in size. The fishnet metasurface is used in the ground plane of the MSA. Gunesar and Seker [21] have proposed the design of a compact MSA which operates in triple bands. *E* shaped and cylindrical slots are used to achieve triple-band operation. The MSA operates at resonant frequencies 1.8, 2.1, and 3.5 GHz, which makes MSA suitable for GSM, UMTS, and WiMAX applications. Anitha et al. [22] have designed a compact MSA for Ku band applications. *U* shaped patch and a slot at center are used in the structure. The MSA is fabricated on FR4 substrate. Alam et al. [23] have designed a compact fractal MSA for 2.4 GHz applications. Roy and Thomas [24] have designed a compact MSA for high-performance wireless network applications. The structure utilizes proximity coupled rectangular slot loaded patch and *V*-shaped slot loaded patch. Kumar and Singh [3] have reviewed the shorting post loaded MSAs and suggested that the size of the MSAs can be reduced by shorting the patch. Singh and Kumawat [25] have proposed a compact *E* shaped wideband MSA for wireless local area networks applications.

In this paper, the concept of DGS along with *T*-shaped slots in the patch [5] is used to decrease the size of the MSA. The design is simulated and optimized using CST microwave studio. The presented MSA is compact and suitable for mobile applications. The rest of the paper is organized in three sections as follows. Section 2 discusses the MSA design and configuration. Simulated results, fabricated MSA, and measured results are given in Sect. 3. Section 4 presents the conclusion of the work.

2 Antenna Design and Geometry

Figure 1 shows the geometry of the proposed compact rectangular MSA with DGS and *T*-shaped slots in the patch. The top and bottom views of the proposed MSA depict the combination of two methods which include the methods of using *T*-shaped slots [5] in the patch and the use of slots in the ground plane. The size of the MSA is reduced by incorporating *T*-shaped slots in the microstrip patch as shown in Fig. 1a and incorporating slots in the ground plane as shown in Fig. 1c. Figure 1b shows the side view of the MSA configuration. The MSA is fed by a coaxial connector as

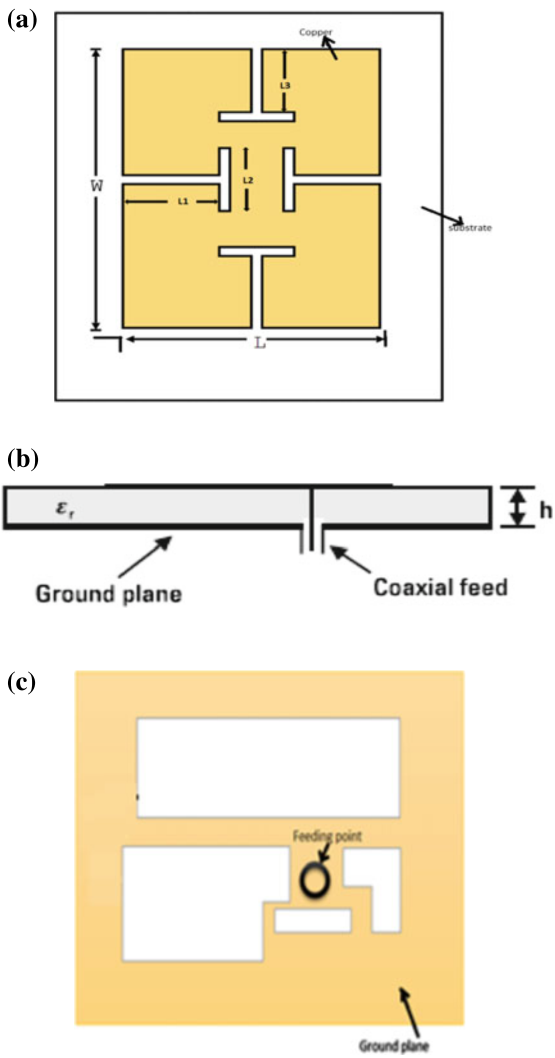

Fig. 1 Structure of the proposed MSA **a** top view of the MSA, **b** side view of the MSA, **c** bottom view of the MSA

shown in Fig. 1. The MSA is designed using FR4 substrate with dielectric constant of 4.3 and thickness of 1.5 mm. The MSA dimensions are computed by utilizing the transmission line method [1, 2]. The width (W) of the patch is calculated using the following expression [1, 2]:

$$W = \frac{c}{2 f_0 \sqrt{\frac{(\varepsilon_r + 1)}{2}}} \tag{1}$$

where 'c,' 'f_0,' and 'ε_r' are velocity of light, resonant frequency of the MSA, and dielectric constant of the substrate, respectively.

The effective dielectric constant ($\varepsilon_{\text{reff}}$) of the MSA is computed by [1, 2]:

$$\varepsilon_{\text{reff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12\, h/w}} \tag{2}$$

where 'h' is substrate thickness.

Following equation gives the effective length (L_{reff}) [1, 2]:

$$L_{\text{reff}} = \frac{c}{2 f_0 \sqrt{\varepsilon_{\text{reff}}}} \tag{3}$$

The length extension (ΔL) due to fringing field is given by [1, 2]:

$$\Delta L = 0.412h \frac{(\varepsilon_{\text{reff}} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{\text{reff}} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{4}$$

The actual length (L) of the patch is obtained as [1, 2]:

$$L = L_{\text{reff}} - 2\Delta L \tag{5}$$

The dimensions of the ground plane are given by [1, 2]:

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

$$W_g = 6h + W \tag{7}$$

The coaxial connector location (x_f, y_f) is calculated using the following equations [1, 2]:

$$x_f = \frac{L}{2\sqrt{\varepsilon_{\text{reff}}}} \tag{8}$$

$$y_f = \frac{W}{2} \tag{9}$$

Table 1 Comparison of size of the designed MSA with conventional MSA

S. No.	Parameter	Dimensions of the conventional MSA (mm)	Dimensions of the proposed compact MSA (mm)
1	Length of patch	36.6	27.5
2	Width of patch	46.7	35
3	Length of ground plane	45.6	34.2
4	Width of ground plane	55.6	41.8

The comparison between the dimensions of the conventional MSA and the MSA with *T*-shaped slots and DGS is shown in Table 1. From Table 1, it can be observed that the size of the proposed MSA is reduced significantly. The size of the patch is reduced by approximately 25%.

3 Results and Discussion

For simulations and optimization of the MSA structure, CST microwave studio is used. After carrying the simulations in CST microwave studio, the RC of the proposed MSA is shown in Fig. 2. Figure 2 shows that the RC of the MSA at resonant frequency of the MSA is approximately −11.4 dB. The bandwidth of the MSA is approximately from 1.95 to 1.97 GHz that is approximately 40 MHz. The two-dimensional and three-dimensional radiation patterns of the MSA are depicted in Fig. 3a, b, respectively. The radiation pattern of the MSA in $\emptyset = 90°$ plane shows that the shape of the pattern is approximately figure of eight and the main lobe direction is toward 5° with 3 dB angular beam width of 114.8°. From the three-dimensional radiation pattern of the MSA, it is observed that the major lob of the proposed MSA is toward positive *z*-axis. The maximum gain, maximum directivity, and efficiencies of the designed MSA are

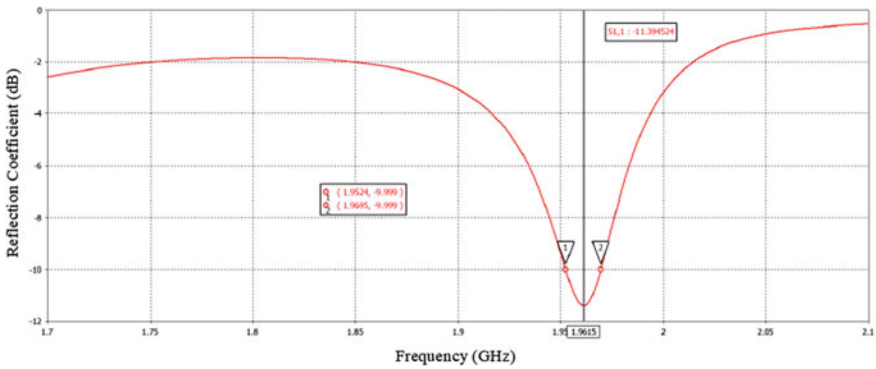

Fig. 2 S_{11} of MSA with inserted *T*-slots and DGS

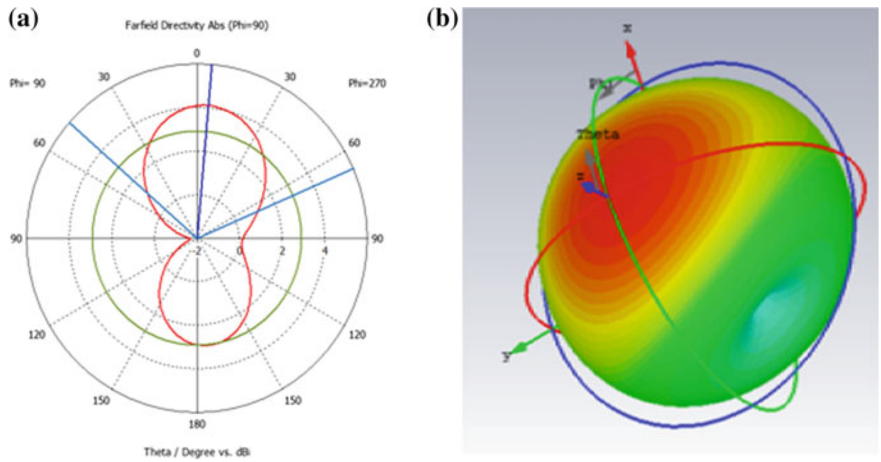

Fig. 3 Radiation pattern of reduced MSA **a** 2D pattern, **b** 3D pattern

Table 2 Directivity, gain, radiation efficiency, and total efficiency of the MSA

S. No.	Parameter	Value
1	Max. directivity	4.101 dBi
2	Max. gain	3.675 dB
3	Radiation efficiency	−1.835 dB
4	Total efficiency	−5.662 dB

presented in Table 2. The maximum directivity, maximum gain, total efficiency, and radiation efficiency are 4.101 dBi, 3.675 dB, −5.662 dB, and −1.835 dB, respectively. For further validation of the proposed MSA structure, the MSA is fabricated. The fabricated MSA is shown in Fig. 4. The RC of the fabricated MSA is measured using network analyzer and it is shown in Fig. 5. Little deviation between simulated and measured RC can be observed and it may be due to connector losses, fabrication errors, soldering errors, etc. The maximum directivity and maximum gain of the MSA are reasonable good and the RC of the MSA is less than −10 dB. So, the designed and presented MSA is suitable for mobile devices.

4 Conclusion

A compact MSA utilizing *T*-slots and DGS has been presented. The design is simulated using CST microwave studio and for further validation of the design, MSA is fabricated and measured. The size of the MSA is reduced by incorporating *T*-shaped slots in the patch and making ground defected. The size of the MSA is reduced and the size of the patch is reduced approximately by 25%. The maximum directivity

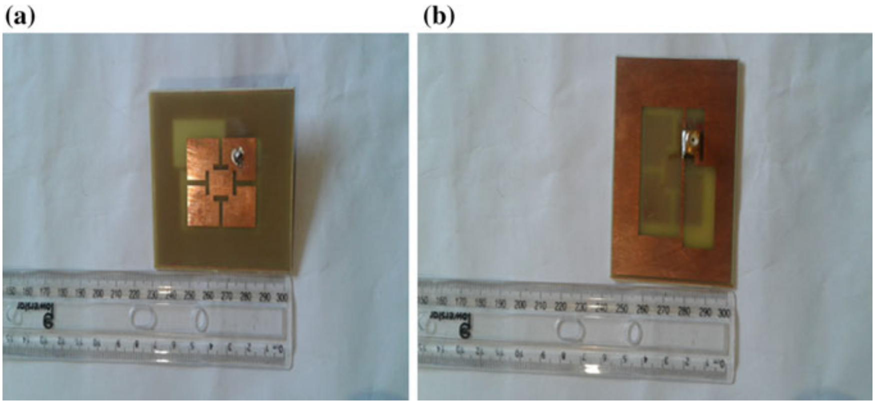

Fig. 4 Fabricated compact MSA

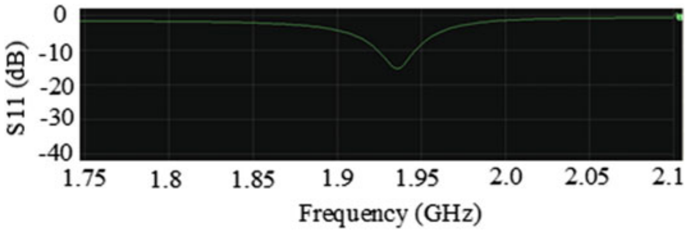

Fig. 5 Measured S_{11} for the compact MSA

and maximum gain of the proposed MSA are 4.101 dBi and 3.675 dB, respectively. The proposed MSA is suitable for compact mobile devices.

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