Bandwidth and gain enhancement of microstrip antenna by frequency selective surface for WLAN, WiMAX applications

KALYAN MONDAL^{ID}

Department of Electronics and Communication Engineering, Modern Institute of Engineering and Technology, Bandel 712123, India
e-mail: kalyankgec@gmail.com

MS received 21 October 2018; revised 9 September 2019; accepted 6 October 2019

Abstract. The research work presents a broad band with enhanced gain FSS based microstrip patch antenna for wireless communication. Three different antennas results are investigated to obtain proposed antenna. The designed antennas are E shaped patch, combined E and T shaped patch and combined E and T shaped patch with frequency selective surface (FSS). The proposed antenna is obtained by combined E and T shaped radiating patches with FSS under the modified ground plane. U shaped slit with multiple number of slots are loaded on the ground plane. The broad bandwidth of 6.4 GHz (2.9–9.3 GHz) with 8.12 dBi gain is achieved which is 5.12 dBi greater than the proposed E and T shaped patch (without FSS) antenna. The proposed patch antenna without FSS is fabricated and measured to validate the work. The designed antenna is very much applicable in wireless communication systems. It is specially designed for WiMAX (3.5/5.8 GHz) and WLAN (3.6/4.9/5/5.9 GHz) applications.

Keywords. Simple patch; modified ground plane; broadband; FSS; wireless communication.

1. Introduction

In recent times, patch antennas are broadly used because of their inherent advantageous properties like light weight, small size, low cost, etc. The main drawback of the antenna is narrow bandwidth and limited gain. Different shapes of patch antenna were designed to enhance the frequency band. A circular-shaped radiating patch with spiral-shaped slot on the ground plane was presented in [1]. The broadband was obtained by modifying patch and ground plane in reference [2]. The broadband was obtained by multiple number of slots loaded ground plane under the patch. In reference [3], a multi-band microstrip patch antenna was designed for 3.66 GHz, 5.3 GHz, 5.8 GHz, and 7.03 GHz wireless applications. A rectangular microstrip antenna was designed for dual frequency operation in [4]. The optimum frequency bands were obtained by using narrow open rectangular ring slot. It was reported by Sze and Wong in [5] that the bandwidth of the patch antenna can be enhanced by a U shaped slot and pair of L shaped slots at the two opposite edges of the antenna. Triple-band monopole antenna was designed in [6] for WLAN and WiMAX applications. From references [7–18], FSS based microstrip patch antenna was designed for dual band, circular polarized, gain and bandwidth enhancement. In this work combined E and T shaped broadband microstrip patch antenna with patch-type FSS has been designed. The proposed

antenna is simulated using Ansoft designer software. The combined proposed E and T shaped patch is fabricated and verified the results.

2. Antenna design methodology

A rectangular patch of dimensions 20 mm × 19.5 mm is considered as a reference. It is designed on the Neltec NY9220(IM) dielectric substrate. The dielectric constant and thickness of the substrate are 2.2 and 1.6 mm respectively. The reference antenna offers percentage bandwidth of 4.4% (4.67–4.88 GHz) and it is resonating at a single frequency of 4.75 GHz. The obtained peak gain at 4.8 GHz is 6.75 dBi. Ground plane is modified by loaded U shaped slit and others slots at the optimum position on the ground plane to enhance the bandwidth. Finally 21% metal is removed from the ground plane under the patch to design the proposed ground plane. E shaped antenna is designed by cutting slits on the rectangular patch. The E shaped patch offers maximum bandwidth and peak gain are 2.92 GHz (3.2–6.12 GHz) (at G = 13.5 mm) and 2.58 dBi respectively. Further some modifications have been taken on the patch and proposed combined E and T shaped patch are found. From the combined E and T shaped antenna –10 dB impedance bandwidth of 6.55 GHz (3.02–9.57 GHz) with 3 dBi peak gain is obtained.

The *E* shaped patch and proposed patch are given in figure 1. The proposed ground plane and combined *E* and *T* shaped antenna are portrayed in figure 2a, b respectively. The methodology of antenna designed using equivalent circuit is followed by reference [19]. A patch-type FSS (*U* shaped slot loaded) of dimensions

45.8 mm × 55 mm are loaded under the proposed ground plane. The separation between ground plane and FSS is 16 mm. The photographs of the fabricated antenna are demonstrated in figure 2. All the parameters and dimensions of the proposed patch and ground plane are given in table 1.

Figure 1. Design of the patch: (a) *E* shaped patch, (b) proposed combined *E* and *T* shaped patch, (c) proposed ground plane, (d) combined *E* and *T* shaped antenna, (e) equivalent circuit of conventional antenna and (f) equivalent circuit of proposed antenna.

Figure 2. Photograph of the fabricated antenna.

Table 1. Parameters and dimensions of the proposed antenna (all dimensions are in mm).

Parameters	Dimensions	Parameters	Dimensions
A	20	M	3
B	4	N	9
C	5.5	O	8
D	5	P	1.5
E	16	Q	11
F	10	R	2.5
G	11.5	S	29
H	2	T	3.5
I	6	U	30
J	19	V	13
K	23	W	1
L	7	X	13.5

2.1 Analysis of the antenna with equivalent circuits

Figure 1e, f shows the equivalent circuit of the conventional antenna and proposed antenna. The conventional antenna is represented by parallel combination of R (resistor), L(inductance) and C (capacitance) parameters. The significance of parameters R, L and C is given in [20].

$$C = \frac{\epsilon_r \epsilon_0 L_p \times W_p}{2h} \cos^{-2}(\pi x_0/L_p) \quad (1)$$

$$L = \frac{1}{\omega^2 C} \quad (2)$$

$$Q_r = \frac{v_0 \sqrt{\epsilon_r}}{fh} \quad (3)$$

$$R = \frac{Q_r}{\omega C} \quad (4)$$

Where the velocity of light, the radiating patch length and the radiating patch width are represented by v_0 , L_p , and W_p

respectively [21], f_r is the design frequency, ϵ_e is the effective permittivity of the medium and h is the height of the substrate. The feeding point location is presented by x_0 along the length of radiating patch. The effective permittivity ϵ_e is defined by Garg *et al* [20], where relative permittivity and effective length are presented by ϵ_r and L_{ep} respectively.

The equivalent circuits of the antenna have been changed due to the loaded slot and slits on the antenna. It is modified by introducing additional series capacitance (ΔC) and additional series inductance (ΔL) with the inductance (L) and capacitance (C). The resonance frequency of the antenna is changed for the modified equivalent circuit. The series inductance and capacitance are calculated by Eqs. 5 and 6 in [22].

$$\Delta L = \frac{h \mu_0 \pi}{8} \left(\frac{L_n}{L_p} \right)^2 \quad (5)$$

$$\Delta C = \left(\frac{L_n}{L_p} \right) \times C_s \quad (6)$$

Where length of the patch is 20 mm, $\mu_0 = 4\pi \times 10^{-7}$ H/m, L_n = depth of the slot and C_s = gap capacitance given by Meshram and Vishvakarma [23].

2.2 FSS layer design

An FR4 substrate is considered to design a FSS (Frequency Selective Surface). The dielectric constant and thickness of the substrate is 4.4 and 3.2 mm. First of all a square shaped unit cell of the FSS is designed. The dimensions of the unit cell are 9 mm $\times$ 9 mm. A U shaped slot is loaded on the unit cell patch. All the dimensions of the unit cell patch are given in figure 3a. To design the proposed FSS, five number of unit cells is placed in a row and a row is repeated six times along the column. The gap between two

Figure 3. (a) Unit cell patch, (b) proposed FSS and (c) 3D view of the antenna with FSS.

successive unit cells along the row and column is 0.2. The dimension of the FSS is $45.8 \text{ mm} \times 55 \text{ mm}$. The proposed FSS is loaded under the proposed antenna. The distance between left edge of the FSS and ground plane is 7 mm and top edge of the FSS and ground plane is 10 mm.

3. Results of the designed antennas

The investigations have been done on different antenna properties like reflection coefficient, gain and radiation patterns. Parametric studies and proposed antenna results are demonstrated clearly in this section.

3.1 Parametric studies

3.1a Results for the variation of parameter G The effects of parameter G on frequency band and antenna gain are

presented in figure 4a, b. The results of the antenna for the variation of parameter G from 14.5 mm to 9.5 mm are observed. At $G = 13.5 \text{ mm}$, maximum impedance bandwidth of 2.92 GHz (3.2–6.12 GHz) with 2.58 dBi gain is found.

3.1b Variation of parameter A The reflection coefficient versus frequency response and gain versus frequency response for the variation of parameter A from 18 mm to 12 mm are presented in figure 5. The better simulated results are obtained for the parameter A at 18 mm. The maximum bandwidth and gain obtained are 3.58 GHz (3.08–6.66 GHz) and 2.9 dBi.

3.1c Variation of parameter F The simulated results for the variation of parameter F from 10.5 mm to 6.5 mm are demonstrated in figure 6a, b. From the reflection coefficient results it is found that the number of resonant frequencies is not changed significantly. The maximum bandwidth of 6.55

Figure 4. Results for variation of parameter G . (a) Reflection coefficient versus frequency plot and (b) gain versus frequency plot.

Figure 5. Results for variation of parameter A . (a) Reflection coefficient versus frequency plot and (b) gain versus frequency plot.

Figure 6. Results for variation of parameter F . (a) Reflection coefficient versus frequency plot and (b) gain versus frequency plot.

Figure 7. Results of the proposed antenna. (a) Reflection coefficient versus frequency plot and (b) gain versus frequency plot.

Figure 8. E plane radiation patterns of the proposed antenna at (a) 3.68 GHz, (b) 4.46 GHz and (c) 5.6 GHz.

Figure 9. Surface current distribution of the fabricated antenna at (a) 3.68 GHz, (b) 4.46 GHz and (c) 5.6 GHz.

Figure 10. Reflection and transmission coefficient of the FSS.

GHz (3.02–9.57 GHz) is obtained at $F = 9.5$ mm. Similarly the gain response for the variation of parameter F (10.5 mm–6.5 mm) is almost the same. The obtained peak gain is 3 dBi for the variation of parameter F .

3.2 Proposed patch antenna results (without FSS)

The simulated and measured results of the proposed patch antenna without FSS are presented in figures 7 and 8. The simulations have been done from frequency 2 GHz to 10 GHz. Within the proposed simulated frequency band, a broad frequency band of 6.55 GHz (3.02–9.57 GHz) is obtained as shown in figure 7a. Four resonant frequencies at 3.68 GHz, 4.46 GHz, 4.94 GHz and 5.6 GHz are obtained. The peak gain of the proposed antenna is reduced from 6.75 dBi to 3 dBi with the enhanced frequency band as shown in figure 7b. The measured bandwidth and peak

Figure 11. (a) Reflection coefficients versus frequency plot and (b) gain versus frequency plot.

Figure 12. E and H plane radiation patterns of the proposed antenna at 3.8 GHz with FSS.

gain are 6.80 GHz (2.86–9.66 GHz) and 3.4 dBi (at 4.7 GHz) achieved. E plane radiation patterns of the proposed antenna at 3.68 GHz, 4.46 GHz and 5.6 GHz are demonstrated as shown in figure 8. Simulated and measured results of the radiation patterns are in good parity. The surface current distributions of the combined E and T shaped antenna are demonstrated in figure 9. Maximum current density of 111 A/m is obtained at 3.68 GHz. Multiple number of slots and slit on the ground plane and patch are disturbed the normal surface current behavior of the antenna. Multiple number of current paths are developed due to the modified structure. Each path is responsible to generate the resonant frequency. The nearby resonant frequencies are combined by staggering effects and broadband is achieved. From the analysis, it is clear that the frequency band is very large but the antenna gain and radiation

patterns are not satisfactory. So, a Frequency Selective Surface (FSS) is used to enhance the antenna gain and other antenna parameters further.

3.3 Proposed antenna results (with FSS)

The Frequency Selective Surface (FSS) behaves as a band stop filter. The band stop filter is used at 16 mm away from the back side of the antenna. The variation of transmission coefficient and reflection coefficient of the FSS with frequency is presented in figure 10. The simulated reflection coefficient and gain of E shaped antenna, proposed combined E and T shaped antenna and proposed antenna with Frequency Selective Surface (FSS) are portrayed in figure 11. For the E shaped patch, two frequency bands of

2.92 GHz (3.2–6.12 GHz) and 1.95 GHz (7.45–9.4 GHz) are obtained. A *T* shaped patch is combined with the *E* shaped patch and a broad frequency band of 6.55 GHz (3.02–9.57 GHz) is obtained. Further to enhance the antenna characteristics, a patch-type Frequency Selective Surface (FSS) is used. The broad frequency band of 6.4 GHz (2.9–9.3 GHz) is achieved. So the bandwidth is not significantly enhanced by the FSS. The simulated peak gain is gradually increased for the incorporation of FSS on the proposed antenna. The achieved peak gain is 8.12 dBi which is 5.12 dBi more than that of the proposed combined *E* and *T* shaped antenna (without FSS). The average simulated efficiency of the proposed antenna within the operating band is found 91%.

The *E* and *H* plane radiation patterns of the proposed FSS based antenna at 3.8 GHz are presented in figure 12. The co- and cross polarization of the *E* and *H* plane at 3.8 GHz are demonstrated clearly. The co-polarization is much better than cross polarization and front to back ratio of the co-polarization radiation pattern is improved significantly. The difference between co- and cross polarization is always maintained 15 dB along the broadside side direction.

4. Conclusions

The complete simulation of broadband microstrip patch antenna has been done using Ansoft designer software. A patch-type Frequency Selective Surface (FSS) is used to enhance the antenna gain with broad bandwidth. The simulated broad frequency band of 6.4 GHz (2.9–9.3 GHz) and 8.12 dBi gain is achieved. The bandwidth is enhanced from 4.4% (reference antenna) to 105% (proposed antenna with FSS). The achieved gain of the proposed patch antenna (With FSS) is 5.12 dBi greater than that of the combined *E* and *T* shaped patch antenna. The front to back ratio of the radiation patterns is improved. From the investigation results, broadband, improved gain and good radiation patterns characteristics antenna is achieved. This antenna covered ISM band 5.8 GHz, WiMAX (3.5/5.5 GHz) and WLAN (3.6/4.9/5.2/5.8 GHz) for wireless communications.

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