Compact slot based triangular multiband microstrip patch antenna for C and X band applications

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ABSTRACT

Modern portable communication devices require a compact antenna with superior performance and lower weight and size. The design and development of such a compact size antenna is a major challenge for the researchers. In this proposed work compact slot based triangular patch antenna to work at the multiple resonance frequencies from 5 GHz to 10 GHz using FR4 substrate is presented. Proposed antenna is simulated using High Frequency Structural Simulator (HFSS 2020R1). Simulated and fabricated antenna test results shows that proposed antenna can be suitably employed for the portable wireless transceivers in C and X band. Proposed slot based triangular patch antenna achieves the peak gain of 8 dBi and has the good impedance matching properties such that return loss S11is less than -10 dB and VSWR value is very closer to 1 at all the resonance frequencies.

Key words: Microstrip patch antenna, FR4 substrate, C and X band, return loss, VSWR, Peak gain.

Introduction

The evolution of wireless technology has been increased in recent years. The technology reached 5th Generation (5G) by the way of 3G/4G. At the earlier years, for 2G application such as Global System for Mobile communication (GSM) prefers planar narrow band microstrip patch antennas for transmitting and receiving voice signal at desired center frequency. Dimension of the antenna depends upon the operating frequency of the wireless system. For 3G and 4G applications, such as transmitting multimedia and image file through the Radio Frequency (RF) channel, Long Term Evaluation (LTE) system prefers high frequency carrier wave. For such
applications, Antenna becomes more and more compact and occupies very less space, can be mounted easily. Such compact antenna is also preferred for low power transceiver applications in modern wireless networks. As internet technology developed, spectrum allocation of cellular band over crowded. Increase in demand for the wireless service causes the development of compact and multiband communication devices in modern wireless communication systems. Present 4G cellular communication system occupies the 2.7 GHz frequency band of the spectrum. 5G cellular frequency band may shift slightly higher than the present 4G frequency band. A wireless antenna is the central component of electron devices may play an important role in the miniaturization of total unit size. It is also required to develop an antenna to work at multiple frequency bands. Further antenna plays vital role in mobile communication system to improve the coverage area and to increase the capacity of the cellular system and to decrease the network complexity. Significant amount of improvement done by many researchers by modifying the shape of the radiating element from simple rectangular, circular and square to complicated fractal based shape to obtain the desired impedance matching and radiation characteristics. size of the antenna naturally depends on the dielectric constant of the substrate used in patch antenna design[1]. Dielectric constant of the material should lies between 2 to 12 in order to achieve the acceptable performance of the antenna. Many researchers have been proposed different substrate materials for antenna miniaturization and acceptable radiation characteristics. A low cost frequency agile antenna on ferroelectric substrate was proposed by V.Furlan et.al. and proved that developed antenna achieves elliptical polarization for the tunable frequency from 6.895 GHz to 7.050 GHz [1]. Miniaturization of microstrip patch antenna is achieved by using ceramic substrate material with high dielectric constant [2, 3, 4]. It is also proved by researchers that simple FR4 substrate can be suitable for patch antenna at high frequency application with enhanced gain, impedance matching and other radiation characteristics of the patch antenna. In this proposed work FR4 material is used as substrate for desired shape of the radiating patch.

Zhenya Li et.al developed Co-Planar Waveguide (CPW) fed ultra wideband slot antenna using FR4 substrate for achieving broadband dual circular polarization [2]. The authors proved that developed antenna achieves ultrawide band characteristics by optimizing the radiating patch and achieved the peak gain of 3 dBi. Nadeem ashraf et.al done a research on optimized broadband and dual band printed slot antennas for future millimeter wave mobile communication [3].
Authors developed two different slot antennas to work at Ka band using Rogers RT5880 substrate. They proved that that developed antenna achieves the peak gain of 5.6 dBi and radiation efficiency of 94%. Devesh et. al developed modified square sierpinski based microstrip patch antenna and achieved multiple resonance frequency at Ku and K band [4]. Authors proved that developed antenna achieves peak gain of 8.89 dBi at third iteration. Manisha gupta and vinita mathur developed Ultra Wideband patch antenna using FR4 substrate [5]. In their research work they modified the radiating element and achieved circularly polarized antenna. Authors proved that developed antenna achieves better miniaturization and peak gain of 7.1 dBi and bandwidth of 267 MHz. Ajay Kumar Gangwar et.al [6] developed A miniaturized Quad-band antenna with slotted patch using FR4 substrate for WiMAX/WLAN/GSM applications. Authors achieved desired performance by using slot and slit method and proved that developed antenna achieves good resonance at four different frequencies in GSM, WiMAX and WLAN frequency band. Ashok kumar et. Al developed CPW fed monopole antenna for wireless applications using FR4 substrate [7]. They proved that developed antenna resonates at 2.45 GHz and 5.5 GHz and achieves the return loss of -20 dBi and achieved the peak gain of 7.2 dBi at the frequency of 4.8 GHz. Authors also proved that good discrimination between co and cross polarization. While the characteristics of broadband dual band and multiband characteristics are studied in above literature, antenna still faces large size problem, complex design and relatively narrow axial bandwidth ratios. This paper presents a compact slot based triangular microstrip patch antenna with multiple frequency band between 5GHz to 10 GHz.

**Description of the proposed antenna**

Geometry of the proposed slot based triangular patch antenna shown in figure 1. Antenna is designed using FR4 substrate with thickness of 1.6 mm with dielectric constant of 4.4. Proposed multiband microstrip patch antenna consists of two numbers of triangular sections with slots. Antenna geometry is optimized for desired frequency band with acceptable return loss. Optimized structure of the proposed antenna resonated at 5.16 GHz, 6.6 GHz 7.211 GHz, 8.32 GHz and 9.96 GHz with miniature size of 40 mm X 35 mm. proposed antenna is much suitable for C and X band applications.
**Dimensions in mm**

| Dimension | Value |
|-----------|-------|
| A         | 35    |
| B         | 35    |
| C         | 17    |
| D         | 17    |
| E1        | 20    |
| E2        | 20    |
| E3        | 10    |
| E4        | 10    |
The proposed antenna is evolved from conventional rectangular microstrip patch antenna to achieve multiband operation. Dimension of the proposed triangular slot based patch antenna is determined using transmission line model [1]. The antenna is designed for the resonance frequency of 5 GHz with FR4 substrate with $\varepsilon_r=4.4$. Length and width of the patch antenna is calculated as 40 mm X 35 mm.

**Results and Discussion**

Designed antenna using transmission line model is simulated with the help of High Frequency Structural Simulator (ANSYS HFSS 2020R1) and S-parameters of the proposed antenna are measured using Vector Network Analyzer (Keysight N9917A). Performance of the proposed slot based triangular patch antenna is evaluated using Return loss (S11), Voltage Standing Wave ratio (VSWR), smith chart, and other important radiation characteristics.

Measured and simulated impedance matching characteristics (return loss) shown in figure 2. From the figure it is concluded that proposed antenna achieves resonance at four different frequencies such as 5.7 GHz, 7.48 GHz, 8.13 GHz and 8.84 GHz with return loss of -9.5 dB, -18 dB, -15 dB and -32 dB respectively in simulated case. Experimental results of the proposed slot based triangular patch antenna
shows that antenna achieves resonance at 5.16 GHz, 6.6 GHz, 7.21 GHz, 8.32 GHz and 9.96 GHz with return loss of -16 dB, -12.5 dB, -15 dB, -24 dB and -15.5 dB respectively. From the measured and simulated results it is concluded that there will be a good agreement in terms of resonance frequency of the proposed antenna. It is also concluded that our proposed antenna achieves good impedance bandwidth from 5.6 GHz to 11 GHz and has multiple frequency band in the same frequency band. International Telecommunication Union (ITU) done a preparatory studies for WRC-23 and reported that more spectrum band is required for maintaining 5G high quality of service and to satisfy the growing demand in the frequency band of 3 GHz – 24 GHz [11]. Our proposed antenna resonating multiple frequency band in the above mentioned frequency band. Voltage Standing Wave Ratio (VSWR) measurement of the proposed antenna shown in figure 3. VSWR was used to measure the degree of impedance matching between antenna and feed line. VSWR value obtained from the experimental result is closer to 1 for all the resonance frequencies. The VSWR value is basically appropriate for an antenna up to 2 and hence it is concluded that our proposed antenna achieves good impedance matching characteristics. Comparisons of return loss of different radiating element structure are given in table – 1.

Fig.2 Simulated and measured return loss of the proposed slot based triangular antenna
Fig. 3. Measured VSWR of the proposed slot based triangular patch antenna

Table 1

| References          | Substrate Material | Resonant Frequency (GHz) | Return Loss (dB) | Dimensions |
|---------------------|--------------------|--------------------------|------------------|------------|
| Manisha Gupta and Vinita Matur [5] | FR4                | 4.3 GHz, 5 GHz, 6.1 GHz, 7.4 GHz, 8.9 GHz and 9.2 GHz | < -10 dB | 60 X 55 mm |
| Ajay Kmar Gangwar et al. [6] | FR4                | 1.6, 2.5, 3.5 GHz and 5.5 GHz | < -10 dB | 40 X 32 mm |
Gehan sami et al. [8]  
FR4 3 -25 50 X 60 mm

Sachin Kumar et al. [9]  
FR4 3.8 -32.5 40 X 70 mm

Osama W. Ata [10]  
FR4 1.8, 2.4 and 3.5 < -10 dB 30 X 40 mm

Zeny Li et al. [2]  
FR4 UWB < -10 dB 48 X 48 mm

Proposed antenna  
FR4 5.16 GHz, 6.6 GHz, 7.211 GHz, 8.32 GHz and 9.96 GHz < -10 dB 40 mm X 35 mm

Table 2

| Resonance frequency in GHz | Achieved gain in dBi |
|---------------------------|----------------------|
| 5.16                      | -1.8                 |
Fig. 4 Radiation pattern of the proposed antenna in E–Plane simulated at 5.2 GHz

Fig. 5 Gain characteristics of Proposed patch antenna
Conclusion

A compact slot based triangular multiband patch antenna using FR4 substrate is designed, simulated, and fabricated. A simulated and experimental test result shows that there will be a good agreement between them. Size of the antenna is 16.2 mm X 4.75 mm and achieves the peak gain of 8 dBi and moderate gain at all the resonance frequencies. Proposed antenna can be suitably employed for the compact wireless receivers to work at the frequency of 5.16 GHz, 6.6 GHz 7.211 GHz, 8.32 GHz and 9.96 GHz.

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Conflicts of interest

The authors declare no conflict of interest.

Availability of data and material

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Code availability

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Authors' contributions

Co-author contributed in this study and commented on previous versions of the manuscript. Co-author read and approved the final manuscript.

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