Miniaturized, Triple Band Microstrip Patch Antenna

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Abstract

This article presents a design of a miniaturized antenna for modern wireless communication, which is emerging for the last couple of decades. Advanced wireless applications, such as wearable devices are using Wireless Fidelity (WiFi), Bluetooth, or Bluetooth Low Energy (BLE) as the key communication techniques. These communication techniques are operating at the Industrial, Scientific, and Medical (ISM radio spectrum) frequency band, 2.4GHz. This frequency band does not need a license and free to use. In this article, the fabricated Triple Band Microstrip Patch Antenna can be used at 2.37, 3.94, and 5.96 GHz frequencies. The proposed antenna is designed, simulated, and fabricated by using multiple slots of different shapes on a single patch, and they are separated by calculated distances. Improvement in Bandwidth, VSWR (Voltage Standing Wave Ratio), Directivity, Efficiency, and Gain can be achieved by using a microstrip patch antenna. The reflection coefficient of the designed antenna is around -35dB, and VSWR is around 1.03 at 2.37 GHz.

***Keywords**: - Triple Band Microstrip Patch Antenna, Wideband Antennas, Multiband Antennas*

INTRODUCTION

Microstrip Patch antennas have many benefits over the usual antenna, and therefore they are used in a variety of applications. Today, rapid growth in the mobile communication industry has fostered the development of antennas [11]. They are widely used for the applications such as Radio Frequency Identification (RFID), broadcast radio, mobile systems, Global Positioning System (GPS), Television (TV), multiple input multiple output systems (MIMO), WANET, SATCOM, remote sensing, missile guidance, security systems, fault detection founding, RADAR systems, and so on.

The need for antennae with small size and multiband operability has risen because these antennas are working with more than one communication techniques to improve the performance of wireless devices [12].

It improves the directivity, efficiency, Gain, and Antenna bandwidth since it does not require additional transmit power. Ideally, to maintain VSWR in between 1:2, the value of the impedance of a transmitter circuitry must equal the approximate value of the impedance of a transmitter antenna element or vice versa; it is referred to as Impedance matching. Impedance matching is necessary between the circuitry and the antenna. The impedance of the transmitter and antenna should match so that maximum power can be transferred through the antenna in the air in the form of electromagnetic waves. If the impedance of the transmitter/receiver does not match with the antenna, then the power radiated will be reflected. Instead, some of the power is reflected in the form of reflected/standing waves. This impedance mismatch is indicated by the voltage standing wave ratio (VSWR), also called SWR. For the higher value of impedance mismatch, the higher will be the value of VSWR. Monopole antennas are well-thought-out to be the best option for multiband use due to their precise properties, such as simple fabrication, compact size, low cost, and lightweight [13]. A major requirement for any vehicular telematics device is the ability to provide universal connectivity with the option to choose a low-cost network in the case of the availability of multiple access points [14].

REVIEW OF LITERATURE

The overall comparison between the proposed work and the other work presented in the literature is shown in table 1. Rahil Joshi et al. [1] reported a dual-band folded shorted patch antenna in which PDMS is used as a substrate material designed for

400 MHz and 2.4 GHz. A bandwidth of 4 MHz is obtained at the desired frequencies.

Ken Paramayudha et al. [2] presented a triple band monopole antenna designed for 2.51, 3.56, and 4.62 GHz by using Rogers Duroid 5880LZ as a substrate material with εr = 2.0.Circular patch with a diameter of 150 mm. Used as a radiating element. Reflection Coefficient is below -10dB.

Da Guo et al. [3] designed a polarized omnidirectional antenna with commercially available deflection material for Four Bands (690 MHz–1.03 GHz and 1.69–3.21 GHz for HP and 770–980 MHz and 1.70–3.75 GHz for VP). The proposed antenna is miniaturized, and the dimensions are 117.5mm X 76 mm. It gives reflection coefficient between -20dB to -30dB and bandwidth 0.69–1.03GHz and 1.69– 3.21GHz.

Yingying Yang et al. [4] reported antenna using symmetrical radiating elements connected by neutralizing line.FR4 epoxy substrate with dielectric constant εr = 4.4 and loss tangent tan δ =0.02. A metamaterial is used as a dielectric substrate. The proposed antenna radiates at GSM 900 MHz, DCS 1800 MHz, LTE-E 2300 MHz, and LTE D 2600 MHz and having dimensions 80mm X 60mm.

He Huang et al. [5] designed a Multiband metamaterial-loaded monopole antenna for 2.4-GHz, 4.1 GHz, and 5.2 GHz. Overall dimensions of antenna are 40mm X 45 mm and the reflection Coefficient is between -20dB to -30dB. Bandwidths obtained at those three frequencies are 1.7 GHz (2.3–4 GHz) and 1.6 GHz (5–6.6 GHz).

Yang Ding et al. [6] designed Quasi-Yagi-Type Antenna With CPW-to-CPS Transition for 1.8, 2.4, and 3.5 GHz using FR4 epoxy substrate with dielectric constant εr = 4.4 and loss tangent tan δ =0.02. Bandwidths observed for those frequencies are 1.85–2.00, 2.25–3.05, and 3.35–3.80 GHz.

Di Wu et al. [7] reported an antenna that is compact and low profile with a multiband operation that can be used in ultra-thin phones. But it is observed that the USB connector has little effect on antenna performance. Pedro Cheong et al. [8] presented an article on Yagi Uda Antenna for radar application with multiband operability. They found that front-to-back ratios are 10.8 that makes it suitable for radar application.

Table 1: Overall comparison between proposed work and the other work presented in the literature

References	Technique	Substrate and ε_r	Operating frequency Band(s)	Overall Dimensions	S-Parameters	Bandwidth/ % Bandwidth	Reference Impedance	VSWR	Applications Mentioned
[1]	Dual-Band Folded-Shorted Patch Antennas	Polydimethylsiloxane (PDMS)	Dual-Band: 400 MHz and 2.4 GHz	200mm X 200mm	Around -19 dB	400MHz	50Ω Theoretically	NA	Wearable Applications
[2]	Triple-Band Monopolar Antenna	Rogers Duroid 5880LZ $\varepsilon_r = 2.0$	Triple Band: 2.51, 3.56, and 4.62 GHz	Circular patch with diameter of 150 mm.	Below -10dB	22.8%	50Ω Theoretically	1-2	Not mentioned
[3]	Dual-Polarized Omnidirectional Antenna	diplexer	Four Band: 690 MHz–1.03 GHz and 1.69–3.21 GHz for HP and 770–980 MHz and 1.70–3.75 GHz for VP	117.5mm X 76 mm	Between -20dB to -30dB	0.69–1.03GHz and 1.69–3.21GHz	50Ω Theoretically	NA	horizontal polarization (HP), and vertical polarization (VP)
[4]	Symmetrical radiating elements connected by neutralizing line	FR4 the epoxy substrate with dielectric constant εr = 4.4 and loss tangent tan δ = 0.02.	GSM 900 MHz, DCS 1800 MHz, LTE-E 2300 MHz, and LTE D 2600 MHz	80mm X 60mm	Up to -25dB	NA	50Ω Theoretically	NA	GSM, DCS, and LTE Indoor Applications
[5]	Multiband metamaterial-loaded monopole antenna	Metamaterial	2.4-GHz, 4.1 GHz, and 5.2 GHz.	40mm X 45 mm	Between -20dB to -30dB	1.7 GHz (2.3–4 GHz) and 1.6 GHz (5–6.6 GHz)	50Ω Theoretically	NA	WLAN/WiMAX Applications
[6]	Quasi-Yagi-Type Antenna With CPW-to-CPS Transition	FR4 epoxy substrate with dielectric constant εr = 4.4 and loss tangent tan δ = 0.02.	1.8, 2.4, and 3.5 GHz	50mm X 60mm	Below -10 dB.	1.85–2.00, 2.25–3.05, and 3.35–3.80 GHz	NA	NA	2G/3G/4G cellular
This proposed work	**Slotted Microstrip patch antenna**	**FR4, ε_r = 4.4**	**2.37, 3.94 and 5.96 GHz**	**19mm X 24 mm**	**-34.99dB**	**1080 MHz (30%)**	**56.3 Ω Practically**	**1.03**	**Wireless Fidelity (WiFi), Bluetooth, or Bluetooth Low Energy (BLE)**

Sultan Shoaib et al. [9] reported an article on the study of the dual-element multiband antenna with printed monopole in the form of an array. A rectangular slot with one circular end etched on the ground plane and two inverted L shaped branches are introduced to improve isolation.Viet-Anh Nguyen et al. [10] reported an article on dipole antenna for multiband systems with self-balanced impedance. It is designed to resonate at LTE bands at 1.7-1.8 GHz and 2.3-2.6 GHz; WLAN bands at 5.2 and 5.8 GHz. But the major problem is S11 is less than-7dB, whereas it is supposed to be less than -10dB.

Surwase et al. [15], The Antenna that has 4 elements of microstrip patch is designed. The antenna is fabricated using dielectric substrate material of flame retardant (FR4 material) of a dielectric constant of $\varepsilon = 4.4$, with the thickness of FR4 that hs = 1.6 mm and the thickness of the patch is hp = 0.035 mm.

From the practical results of Yadav et al. [16], it is observed that the increase in the number of patches on the substrate, data rate, and radiation pattern gets increased. The Proposed design gives VSWR in the range of 1 to 2 and the values of S Parameters which are less than -10 dB.

Gaikwad et al. [17] demonstrated, For Wi-Fi (wireless fidelity) and LTE (long term evolution), a two-element slotted patch antenna that operates on the frequency 2.4GHz and 2.6GHz.

Jadhav et al. [18], a Comparison of various methodologies of antenna design and different software tools used for simulation is made to propose powerful techniques to proceed in the field of Microstrip Patch Antenna design. Multiple inputs multiple-output antenna systems can also be used for the next generation of wireless communication, i.e. 5G and beyond. In [19], parameters of antenna which are well suitable for applications, using which high efficiency can be obtained are focused. We can further improve the gain and directivity by employing more number of antennas elements in the communication. The performance of the communication system can be improved with an increase in the number of elements. In [20], authors have proposed an inverted U-shaped microstrip patch antenna that produces double band frequency radiating at 2.8GHz and 6.4GHz with a return loss of less than -25dB. Hence it is well suited for wireless (WLAN) and satellite communications.

METHODOLOGY

The microstrip patch antenna is a very popular type of printed antenna. It plays a vital role in today's world of advanced wireless communication. The microstrip patch antenna is very simple in construction using a conventional photochemical machining technique. As shown in Fig. 1, the Microstrip patch antenna consists of a dielectric substrate (FR4) that has a ground plane of copper (Cu) on one side, and on the other side, there is a radiating patch.

The microstrip patch is of a conducting material such as copper or gold, and it may take any possible shape like triangular, elliptical, rectangular, and circular or any other commonly used shape. The radiating microstrip patch and the feed lines are usually etched using photochemical machining on the dielectric substrate material such as FR4.

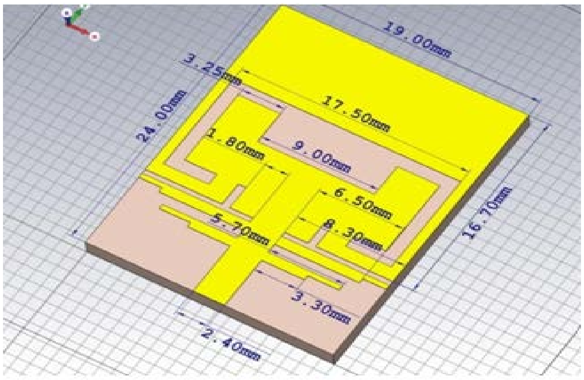

Fig. 1: Triple Band Microstrip Patch Antenna

DESIGN STEPS

For 2.4 GHz frequency, sample design steps are given below; similarly for other frequencies calculations are made.

1	Resonating Frequency	$f_r =$	2.4×10^9 Hz
2	Permittivity	$\varepsilon_r =$	4.4
3	Speed of Light	$C =$	3×10^8 m/s
4	Substrate Height	$h =$	1.6×10^{-3} m
5	Calculation of W (Width of Patch 2)	$W =$	$\dfrac{C}{2fr\sqrt{(\varepsilon_r+1)/2}}$
		$W =$	38.04 mm
6	Calculation of ε_{reff}	$\varepsilon_{reff} =$	4.09
7	Calculation of L (Length of Patch 2)	$L_{eff} =$	$\dfrac{C}{2fr\sqrt{\varepsilon_{reff}}}$
		$L_{eff} =$	9.78 mm
	And	$\Delta L =$	$0.412 \times h \dfrac{(\varepsilon_{reff}+0.3)(W/h+0.264)}{(\varepsilon_{reff}-0.258)(W/h+0.8)}$
		$\Delta L =$	0.74 mm
		$L =$	Leff - 2 ΔL
		$L =$	29.44 mm
8	Calculation of Lg (Length of Ground)	$Lg =$	(6xh)+L
		$Lg =$	39.04 mm
9	Calculation of Wg (Width of Ground)	$Wg =$	(6xh)+W
		$Wg =$	47.64 mm
10	Calculation of Fi (Length of Fed Line)	$Fi =$	$\dfrac{6h}{2}$
		$Fi =$	4.8mm

Calculated dimensions of Patch for resonating at 2.37GHz, 3.94GHz, and 5.96 GHz frequencies are as shown in Table-2.

Table 2: Dimensions of Microstrip Patch

Sr. No.	Dimension	Length(mm)
1	Width of Substrate	19
2	Length of Substrate	24
3	Thickness of Substrate	1.6
4	Thickness of Patch	0.035
5	Thickness of Ground Plane	0.035
6	Width of Patch	19
7	Length of Patch	16.7
9	Width of Ground Plane	19
10	Length of Ground Plane	4.5
11	Width of feedline	2.4
12	Length of feedline	5.2

Other dimensions of the Microstrip patch are mentioned in Fig.1. The fabricated antenna is shown in Fig. 2, which is resonating at three frequencies and that are 2.37, 3.94, and 5.96 GHz frequencies, and it gives VSWR in the range of 1 to 2.FR4 material is used as a dielectric substrate between the ground plane and the patches. The dielectric constant of the substrate is εr = 4.4, and thickness is hs = 1.6mm.

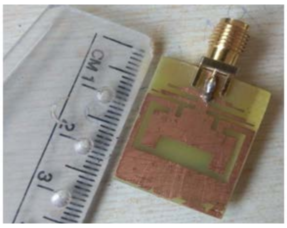

Fig. 2: Fabricated Triple Band Microstrip Patch Antenna

The Ground Plane of the Fabricated Triple Band Miniaturized Antenna for three different bands of frequencies is shown in Fig. 3. A partial ground of 20% is provided to widen the bandwidth of the antenna at different frequencies.

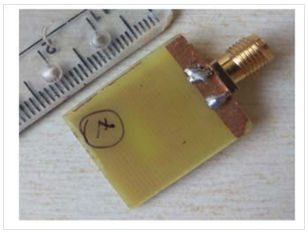

Fig. 3: Ground Plane of Triple Band Microstrip Patch Antenna

RESULTS AND DISCUSSIONS

S-Parameter

Microstrip antenna patch design resonates at 2.37, 3.94, and 5.96 GHz frequencies. Values of S-Parameters at these radiating frequencies are -34.99, -26.85, and -19.42dB, respectively. The simulation result of the 3-Band miniaturized antenna for the S-Parameter is shown in Fig. 4. S-Parameter of the fabricated antenna is observed on VNA and shown in Fig. 5.

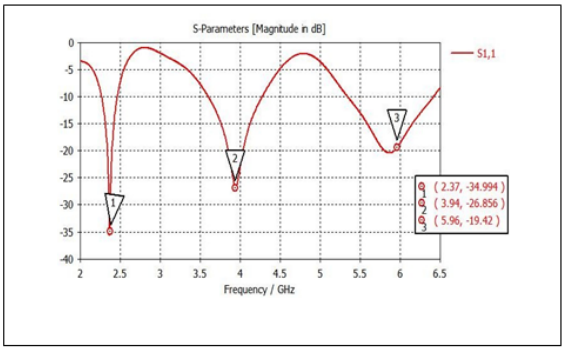

Fig. 4: Simulated S- Parameter of Triple Band Miniaturized Antenna

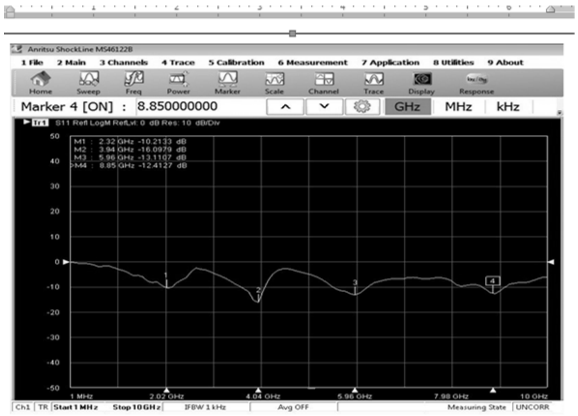

Fig. 5: VNA Testing of S- Parameter of Triple Band Miniaturized Antenna

Comparison between S-Parameter of simulated results and testing results is shown in Table 3, and it is found that there is a reasonable trade-off between S-Parameter of simulated results and testing results at 2.37, 3.94, and 5.96 GHz.

Table 3: Comparison of S-Parameter

Frequency(GHz)	S-Parameter (dB) Simulated	S-Parameter (dB) Practical	Reason for variation
2.37	-34.99	-10.21	Designed antenna has undergone manufacturing simulated results
3.94	-26.84	-16.09	
5.96	-19.42	-13.11	

Bandwidth Enhancement

The patch resonates at three different frequencies with three wide frequency bands. Microstrip antenna patch design resonates at 2.37GHz (from 2.267 to 2.463 GHz, Bandwidth: 196 MHz), 3.94GHz (from 3.6015 to 4.2751GHz, Bandwidth: 674 MHz), and 5.96GHz (from 5.3336 to 6.4147 GHz, Bandwidth: 1080 MHz) as shown in Fig.6.

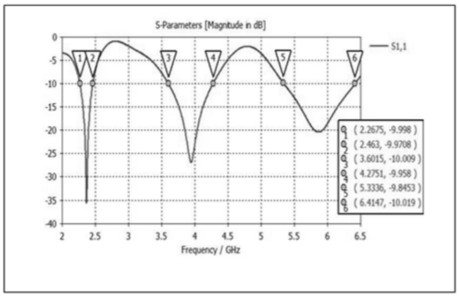

Fig. 6: Bandwidth measurement of Triple Band Miniaturized Antenna

Reference Impedance

The reference impedance of the Triple Band Miniaturized Antenna is shown in Fig.7. If the reference impedance of the circuitry of the transmitter, and antenna does not match, then the power will not be transmitted effectively and some of the radiated power will be reflected in the form of reflected/standing waves.

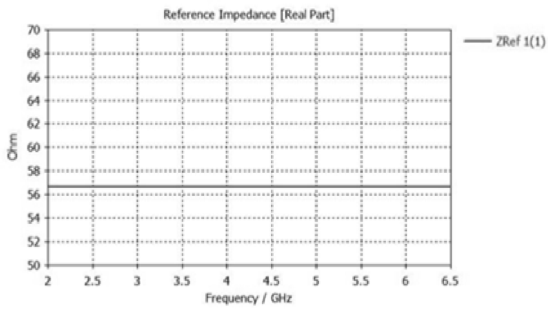

Fig. 7: Reference impedance of 3 Band Miniaturized Antenna

Voltage Standing Waves Ratio (VSWR)

The voltage standing wave ratio is defined as the ratio of maximum voltage to the minimum voltage of the standing wave. If impedance mismatch occurs, some power is wasted in reflected waves, and some of the power is returned in the form of reflected/standing waves. VSWR indicates an impedance mismatch, also called SWR.

The simulated antenna for 3 different frequencies is having VSWR between 1 and 2, as shown in Fig. 8.

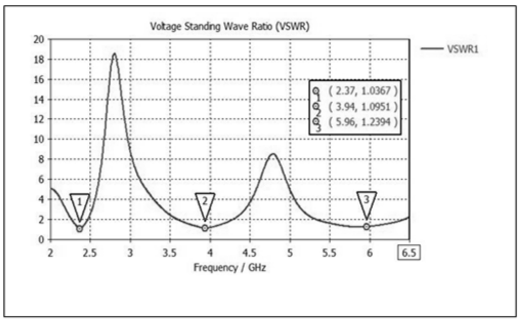

Fig. 8: Simulation results for VSWR of Triple Band Miniaturized Antenna

VSWR of 3 Band Miniaturized Antenna observed on VNA is shown in Fig. 9.

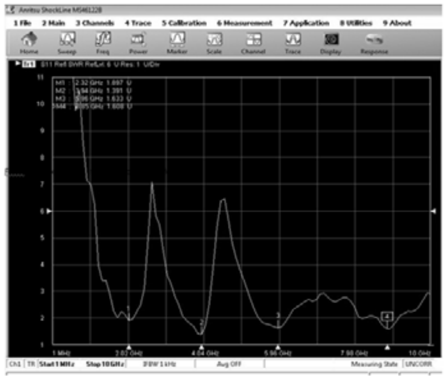

Fig. 9: Simulation results for VSWR of 3 Band Miniaturized Antenna

Comparison between VSWR of simulated results and testing results is shown in Table 3, and it is found that there is a reasonable trade-off between VSWR as per simulation results and testing results at 2.37, 3.94, and 5.96 GHz.

Table 4: Comparison of VSWR

Frequency (GHz)	VSWR (Simulated)	VSWR (Practical)	Reason for variation
2.37	1.03	1.89	The designed antenna has undergone manufacturing deformity because of which observed VSWR values are slightly different from simulated VSWR results.
3.94	1.09	1.39	
5.96	1.23	1.63	

CONCLUSIONS

This paper presents a triple Band Miniaturized Antenna to resonate at 3 different frequencies (2.37, 3.94, and 5.96 GHz frequencies). S-Parameters at those frequencies are less than -10dB (-35dB for 2.37 GHz frequency), and VSWR is between 1 and 2 (1.03 for 2.37 GHz frequency). The average bandwidth obtained at all the 3-Bands of operating frequency is 750 MHz (from 5.3336 to 6.4147 GHz, Bandwidth: 1080 MHz). This Triple Band Miniaturized antenna is fabricated by using slots of various shapes on a single radiating patch, and it can be used in advanced wireless applications such as Wireless Fidelity (WiFi), and Bluetooth, or Bluetooth Low Energy (BLE).

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