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A Compact Wideband Monopole Antenna using Single Open Loop Resonator for Wireless Communication Applications

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Abstract

A novel single layer, microstrip line fed compact wideband monopole antenna using open loop resonator has been designed and analyzed. The proposed antenna occupies a compact size of only 30×36.5×1.6 mm^3. A partial ground plane is employed to enhance the operating bandwidth and reflection coefficient of the proposed antenna. The variations in operating bandwidth of the proposed antenna can be easily controlled by properly adjusting the position of the gap in the open loop resonator.The antenna prototype is fabricated on FR4 substrate with a dielectric constant 4.2. In this design, the antenna exhibits −10dB wide impedance bandwidth of 61% from 2.0174 to 3.7903 GHz.The antenna can be easily fed using a 50 Ω microstrip feed line and it covers the bandwidth requirements of a number of modern wireless communication systems such as IEEE 502.11b WLAN band (2.4–2.5 GHz), extended UMTS (2.5–2.69 GHz), IMT (2.7–2.9 GHz), and IEEE 802.16 Wi–MAX band (3.3–3.6 GHz) applications. The desired antenna is designed and simulated using Computer Simulation Technology (CST). An extensive analysis of the antenna parameters (reflection coefficient, radiation pattern, directivity, and VSWR) including surface current distributions is presented and discussed in this paper. Good agreement between simulated and measured result is obtained.

***Keywords**: compact, monopole antenna, wideband, loop resonator, wireless communication*

1. Introduction

The wireless communication systems have been developed widely and rapidly during the last decade with an increasing demand for higher data rate and large bandwidth. In recent years, the demand for small antennas has been increased due to the miniaturization of the wireless pieces of equipment [1-2]. So, the design of the compact, efficient and light weight antennas have become a major challenge for the researchers of the antenna community.The microstrip patch antennas are likely to be preferred for their well-known attractive features like the small size, light weight, inexpensive to manufacture using printed circuit technology and compatibility with MMIC designs. Again, the increasing demands for wireless connectivity challenge the design of a single antenna that can cover the bandwidth requirement of several allocated wireless frequency bands for WLAN, IMT, UMTS, WiMAX etc.

The usage of the separate antenna for separate application bands are usually restricted by the size and cost constraints of the systems.Therefore, it is better to use a single antenna with a multiband characteristic than having a separate antenna for each frequency band [3-4]. But, the major problem of the microstrip patch antenna is its narrow bandwidth. The conventional microstrip patch antenna suffers from narrow impedance bandwidth (2-4%) problem [5]. So, bandwidth enhancement of microstrip patch antenna has become another

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important challenge for the researchers in the field of the printed antenna. The bandwidth enhancement of microstrip antenna is usually required for many practical applications [6].

The researchers of the antenna community have investigated and proposed various design techniques to enhance the bandwidth of the conventional microstrip patch antenna [7−14]. Khodaei et al. [7] proposed an asymmetric U-slot patch antenna that can operate from 1.9 to 2.6 GHz with 31% fractional bandwidth but not suitable for IMT and WiMAX systems. In Ref. [8], wideband rectangular patch antenna using L probe feeding has been reported with 35.89% bandwidth ranging from 1.6 to 2.3 GHz but the required dimension of the ground plane for the design is very large (210 mm×210 mm). An inverted E-H shaped antenna has been investigated in ref. [9] for broadband operation (1.76 to 2.38 GHz) but the dimension of the antenna is very large (80 mm×50 mm) and does not cover the bandwidth requirement of 3.5 GHz WiMAX system. Kiran et al. [10] proposed a broadband microstrip patch antenna for the frequency band 0.9575 to 1.3882 GHz using meandering slots in the ground plane but it is not suitable for most of the modern wireless communication systems. Diego et al. [11] employed zig-zag slots and perturbation of E-shaped patch for wideband operation but it is not suitable for 2.4 GHz WLAN and 3.5 GHz WiMAX wireless systems.

The idea of stacked patch configuration has been applied by Kiran et al. [12] to achieve broadband frequency response (4.79−5.88 GHz) but it is also not supporting the bandwidth requirement of 2.4 GHz WLAN and 3.5 GHz WiMAX wireless systems. The bandwidth enhancement of microstrip patch antenna upto 27% was achieved by using staggering effect but the large dimension of the antenna (104×46 mm^2) makes it unsuitable for the majority of modern wireless applications [13]. The rectangular gap-coupled microstrip antenna has achieved a fractional bandwidth of 12.7% (3.24 to 3.7 GHz) but at the cost of the large area of nearly 1800 mm^2 [14]. Recently, wide bandwidth of 49.46% (1.444 to 2.393 GHz) has been reported by introducing I-slotted rectangular patch antenna but the size (100×100 mm^2) of the antenna is too large for practical applications [15]. So, the reported antennas in ref. [7-15] are either of very large dimensions or not able to cover the bandwidth requirements of most of the desired wireless applications. Recently, extensive researches in the field of microstrip antennas by using split-ring resonators technique are proposed and discussed by the researchers of the antenna design community [16-18].

This work is also devoted to the design of wideband microstrip patch antenna but the design technique is different compared to the reported techniques in the literature [7-15]. Our aim is to design a small size wideband microstrip patch antenna so that it can fulfill two major needs of today's modern wireless communication systems such as miniaturization and broadband operation. In this paper, a very compact monopole using a single open loop resonator with enhanced bandwidth dedicated to different wireless applications in S-band, like IMT, WLAN, ISM, RFID, Bluetooth, WiMAX and UMTS application is presented. The proposed antenna is novel because the single covers three important design aspects of microstrip patch antennas, such as i) miniaturization, ii) multiband applications and iii) bandwidth enhancement.The novelty of our work is wide operating impedance bandwidth (61%, 2.0174-3.7903 GHz) in a compact size (36.5×30mm^2) without using thick foam substrate, stacked patch, DGS, staggering or modifications in the feed. The proposed antenna is suitable for the maximum number of modern wireless communication systems due to its wider-bandwidth, lowest miniaturized dimension and better working characteristics compared to the antennas reported in [7-15].

2. Antenna Design

The geometry of the proposed monopole antenna is shown in Figure 1. A rectangular patch with an open loop resonator as shown in Figure 1(a) is used on the top face of the substrate. The partial rectangular ground plane of the proposed antenna is shown in Figure 1(b). The proposed antenna is designed using an inexpensive FR4 substrate of thickness 1.6 mm and relative permittivity of 4.2. The finite integration technique (FIT) based electromagnetic simulation software CST is applied for parametric investigation in the proposed design. The top side of the substrate consists of an open loop resonator rectangular patch of size 29×28 mm^2 and a microstrip feed line of width 3.2 mm and length 8.5 mm. The bottom plane of the substrate consists of a ground plane of size 3.7×30mm^2. The overall dimensions of the proposed antenna are only 30×36.5×1.6mm^3. The -10 dB bandwidth of the proposed antenna can be easily controlled by adjusting the gap position 'g' of the loop resonator. The patch is easily fed by using a 50Ω microstrip feed line. The optimal dimensions of the proposed antenna are illustrated in Table 1. The configuration of the presented antenna model is based on improving bandwidth performance of the microstrip antenna because its major disadvantage is having the very narrow bandwidth.

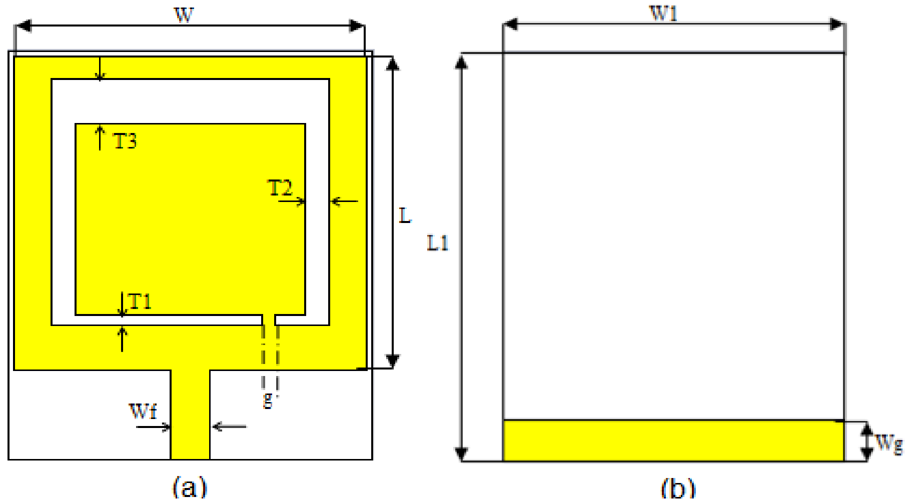

Figure 1. Geometry of the proposed antenna (a) Top view and, (b) Bottom view

Table 1. Dimensions of the proposed antenna in (mm)

W1	L1	W	L	Wf	Wg	T1	T2	T3	g
30	36.5	29	28	3.2	3.7	1	2	4	1

3. Parametric Study of the Proposed Antenna

The structural effect of the design parameters on the performance of the proposed antenna is investigated through parametric study. The effects of the structural design parameters of the loop resonator and partial ground plane are analyzed by changing only one structural parameter at a time while all other parameters remain fixed at the time of simulation. The simulated results of the parametric study of the proposed antenna are shown in Figures 2-3. The important criteria in the design of the desired monopole antenna are adjusting the impedance bandwidth and the desired center frequency of each resonant frequency band. The effect of the parameter 'T2' on the variations of reflection coefficients and frequency of the proposed antenna is shown in Figure 2. It is clearly seen from Figure 2 that the parameter 'T2' does not have a major impact on the operating bandwidth of the antenna and the fractional bandwidth (61%, 2.0174 to 3.7903 GHz) remains unaltered with further change in 'T2' parameter than the proposed value. However, reflection coefficient of the antenna is maximum for the proposed value of T2=2 mm.

Similarly, the effect of the parameter 'W_g' is depicted in Figure 3. It can be observed from Figure 3 that there is a slight variation in -10 dB operational bandwidth due to change in 'W_g' parameter. If the dimension of 'W_g' is decreased from the proposed value (3.7 mm) to 3 mm, the proposed antenna shows dual band behavior for $S_{11} \leq -10$ dB. Further increase in 'W_g' from 3.7 to 4.6 mm, provides slight less fractional bandwidth of 54% (2.2-3.7903 GHz) and the reflection coefficient (S_{11} parameter) is decreased to -21 dB for center frequency (3.5 GHz) of Wi-MAX compared to proposed dimension (W_g=3.7 mm). So, it can be concluded that the parameters 'T2' and 'W_g' do not have the major influence on the operating bandwidth i.e., wideband characteristics of the proposed antenna.

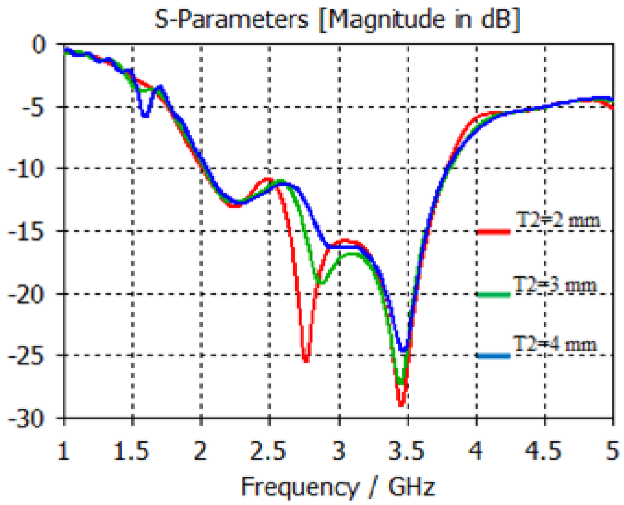

Figure 2. Simulated S_{11} of the proposed antenna for various values of T2 parameter

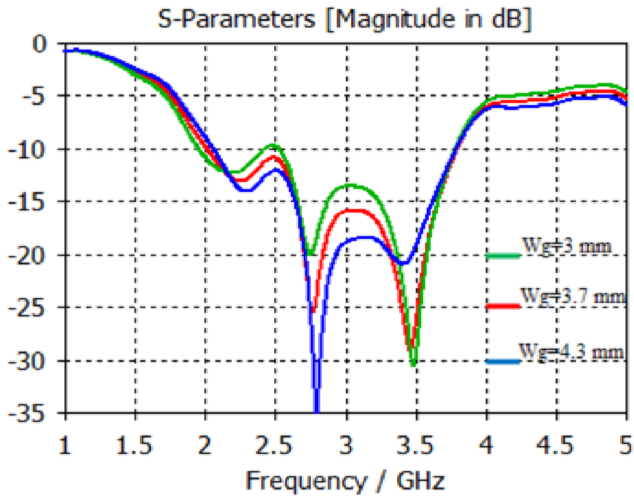

Figure 3. Simulated S_{11} of the proposed antenna as a function of W_g parameter

3.1. Effect of Gap Position 'g' of the loop resonator on the Bandwidth of the Antenna

The most important consideration in this design is to control the position of the gap 'g'. It has a strong effect than other parameters on controlling of the operational bandwidth of the proposed antenna. The effect of different positions of the gap in the resonant characteristics of the proposed antenna has been investigated and analyzed. The different positions of the gap are depicted in Figure 4 and the corresponding variations in S_{11} parameter and frequency of the proposed antenna are shown in Figure 5. As shown in Figure 5, it is obvious that the gap positions have a dominant effect on the operating bandwidth of the proposed antenna. For the gap position (c) placed along the length of the patch, the antenna exhibits narrow dual band resonance characteristics below -10 dB level and there exists a notch frequency band ranging from 2.3 to 4 GHz. The antenna also shows broad frequency response for the gap positions (b), and (d), but the fractional bandwidth is less than the proposed antenna. The antenna provides a highest operating bandwidth of 1.7729 GHz (2.0174-3.7903 GHz) for $S_{11} < -10$ dB for the proposed position (a) of the gap parameter. So, the optimum resonance behavior with best impedance matching is achieved for the proposed position of the gap 'g' in the loop resonator of the antenna.

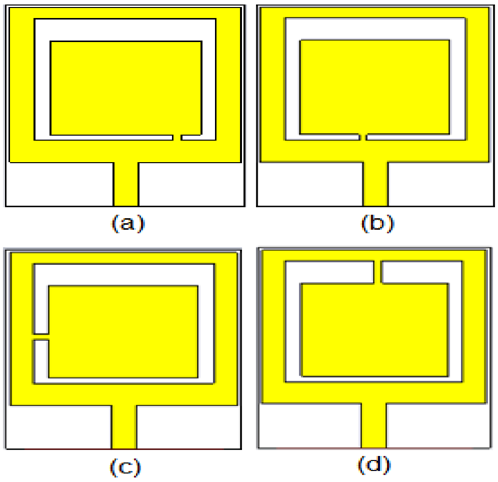

Figure 4. Structure of the proposed antenna with different gap positions

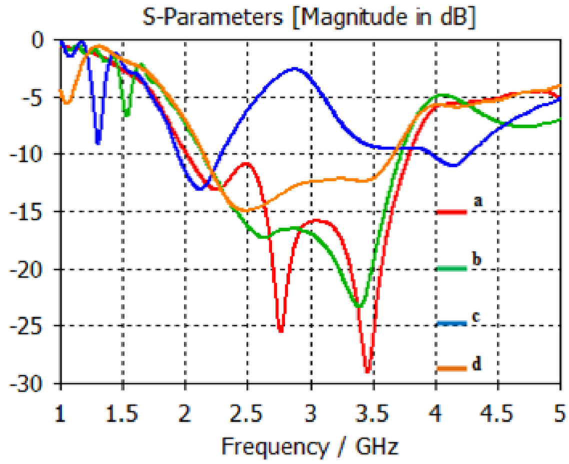

Figure 5. Simulated S_{11} parameter of the proposed antenna for different gap positions

4. Surface Current Distribution of the Proposed Antenna

In order to understand the behavior of the band characteristics, the simulated current distributions of the proposed antenna are shown in Figure 6. The simulated surface current distributions of the proposed antenna at different frequencies (2.77 GHz, and 3.46 GHz) are shown in Figures 6(a) and 6(b). As shown in Figure 6, the current is mainly concentrated at the upper side of the loop resonator. It is observed from Figure 6(a) that for 2.77 GHz operation, the surface current is mainly concentrated at the right side of the loop resonator. For 3.46 GHz operation, the current is mainly concentrated at the left side of the resonator loop Figure 6(b).

The currents along the edges of the loop resonator introduce additional resonance, in conjunction with the resonance of the patch produce an overall broadband frequency response characteristic. Thus by obtaining multiple resonant frequencies radiating very close to each other under -10 dB levels, and overall their resonance envelopes provide the enhanced bandwidth.Again, Due to modifications in the ground plane, a parasitic field or fringing is created and this creation of fringing field increases the coupling between the conducting patch and ground plane. This increased coupling enhances the bandwidth of operation of the proposed antenna.

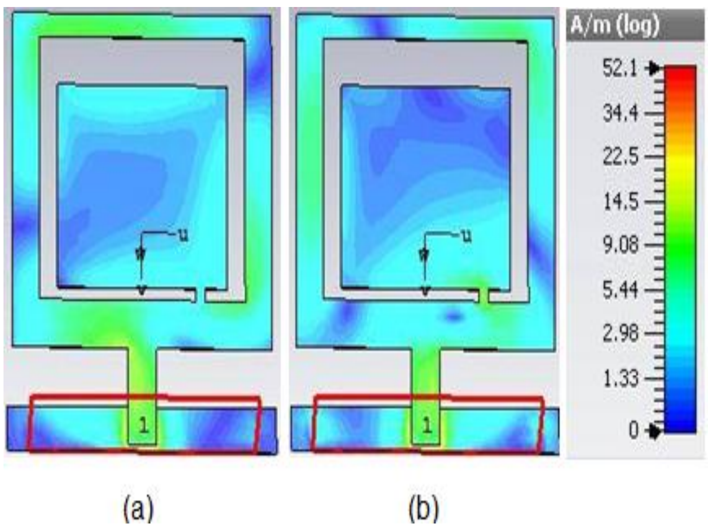

Figure 6.Current distribution of the proposed antenna at (a) 2.77 GHz and, (b) 3.46 GHz

5. Simulation Results and Discussion

The simulated reflection coefficient curve of the proposed antenna is shown in Figure 7. The simulated results indicate a wide impedance bandwidth of 1772.9 MHz (2.0174-3.7903 GHz) under -10 dB level. The simulated VSWR of the proposed antenna is shown in Figure 8. The values of VSWR of the proposed antenna are within 1.5:1through out the operating band.The very low value of VSWR signifies very less miss match loss throughout the operating bandwidth of the proposed antenna. The proposed antenna shows a very low value of VSWR of 1.076 at 3.4676 GHz, which indicates less reflected power and better impedance matching. The mismatch loss (ML) can be calculated from the values of VSWR using the expression

$$ML = -10\log\left[1-\left[\frac{VSWR-1}{VSWR+1}\right]^2\right]$$

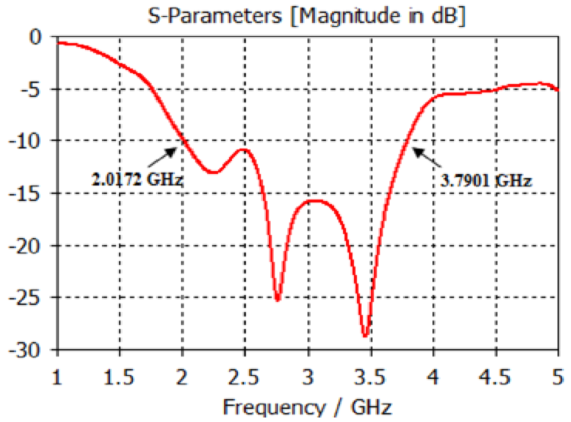

Figure 7. Simulated S_{11} parameter of the proposed antenna

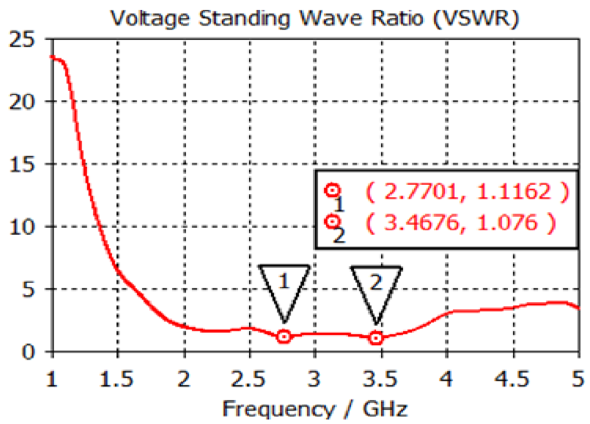

Figure 8. Simulated VSWR of the proposed antenna

The simulated radiation patterns of the proposed monopole microstrip antenna are presented in Figure 9. The radiation patterns of the proposed antenna in the E-plane and H-plane at the frequencies of 2.77, and 3.46 GHz are shown in Figures 9(a) and 9(b), respectively. The proposed antenna shows almost stable bidirectional radiation patterns with acceptable 3dB beam-widths at respective frequencies in both E and H planes. The bidirectional radiation patterns are due to partial removal of conducting material below the radiating patch.

The area of the ground plane is only 6.42% of the total dimension of the antenna. The presence of partial conducting material at the ground plane disturbs the surface current distribution which results in a controlled excitation of the EM waves through the substrate layer. This may cause a change in the radiation characteristics of the proposed antenna. The proposed antenna may also be used in microwave S band RADAR due to its bidirectional radiation characteristics. The S band is a frequency band that uses short waves in the range 2 to 4 GHz. This band is mainly useful for RADAR and communication.The gain of the proposed antenna at the frequencies 2.77 (IMT) and 3.46 GHz (Wi-MAX) are 2.65 and 3.42dBi, respectively. Hence, the proposed antenna can provide sufficient gain and stable radiation patterns, which make it a suitable and important choice for applications in various wireless communication systems.

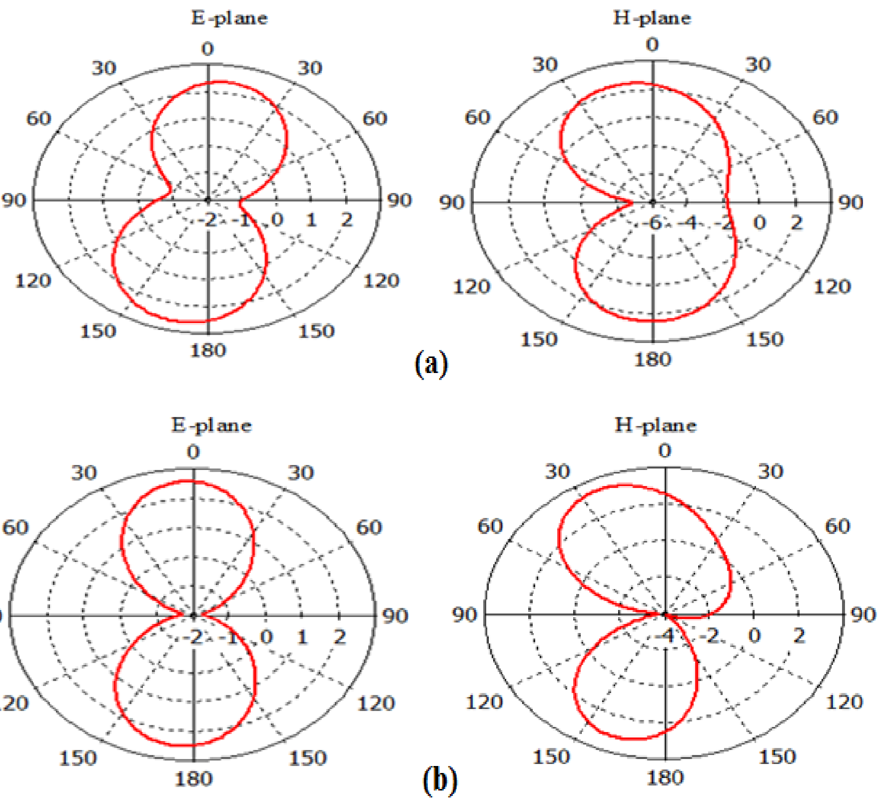

Figure 9. Radiation patterns of the proposed antenna at (a) 2.77 GHz, and (b) 3.46 GHz

6. Fabrication and Measurement Results

To confirm the design concept, the wideband monopole antenna has been fabricated and tested. The proposed structure was fabricated on FR4 dielectric material with ε_r=4.2, and thickness of 1.6 mm and measured using the Rohde and Schwarz vector network analyzer. The photograph of the fabricated antenna is shown in Figure 10. The comparison between measurement and simulation results is illustrated in Figure 11. It can be observed that the agreements between the simulated and measured results are reasonably good. The small discrepancy between the simulated and measured results may be due to the effect of improper soldering of SMA connector at the microstrip feed line or tolerance in the fabrication process. The measured impedance bandwidths for 10 dB return loss covers a bandwidth between 1.93 to 3.62 GHz, which is 60.90% fractional bandwidth. So, the fractional bandwidths of the measurement result (60.90%) and simulation result (61%) are in close agreement.

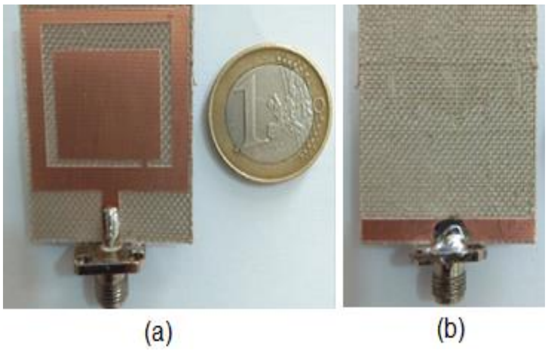

Figure 10. Photograph of the fabricated proposed antenna (a) Top view and, (b) Bottom view

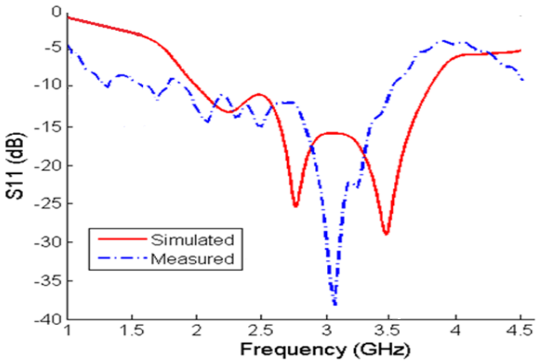

Figure 11. Reflection coefficient of the proposed antenna

7. Performance Comparison of the Proposed Antenna with other Reference Works

The performance comparison of the proposed antenna with some other broadband antenna [7-15] is shown in Table 2. It is clear from the table that the proposed antenna exhibits better impedance bandwidth and covers the bandwidth requirement of a large number of modern wireless communication applications bands such as IEEE 502.11b WLAN band (2.4-2.5 GHz), extended UMTS (2.5-2.69 GHz), IMT (2.7-2.9 GHz), and IEEE 802.16 Wi-MAX band (3.3-3.6 GHz). The dimension (36.5x30 mm^2) of the proposed antenna is also smallest compared to reported broadband antennas in the literature.

Table 2. Performance comparison of the proposed antenna with other broadband antennas in literature

Works	Antenna Dimension (mm)	−10 dB bandwidth (GHz)	Bandwidth (MHz)	Bandwidth (%)
Ref.[7]	55×52	1.9−2.6	700	31
Ref.[8]	210×210	1.6−2.3	700	35.89
Ref.[9]	80×50	1.76−2.38	620	29.95
Ref.[10]	38×38	0.9575−1.3882	430.7	36.72
Ref.[11]	42×42	4.96−6.69	1730	29.8
Ref.[12]	38×38	4.79−5.88	1090	27
Ref.[13]	104×46	4.6−5.45	850	27
Ref.[14]	60×30	3.24−3.7	460	12.7
Ref. [15]	100×100	1.444−2.393	949	49.46
Proposed	36.5×30	2.0172−3.7901	1772.9	61

8. Conclusion

An optimal 50Ω microstrip-fed monopole antenna using single open loop resonator is proposed. The simulated reflection coefficient showed that the proposed antenna can be used for IMT, WLAN, Extended UMTS, and WiMAX applications. The simulated result shows a wide Bandwidth of 61.0%, ranging from 2.0172 to 3.7901 GHz, with respect to the center frequency at 2.9036 GHz. The Experimentally measured result shows satisfactory agreement with the simulated results. The stable radiation patterns and good antenna gain over the operating bands have been obtained. Besides its wideband characteristics, the proposed antenna remains compact and light weight with very small volumetric size, which makes it a good candidate for wireless communication systems.

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