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# Design of a Compact ACS-Fed Dual Band Antenna for Bluetooth/WLAN and WiMAX Applications

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**Abstract**—In this paper, a compact asymmetric coplanar strip (ACS)-fed printed monopole dual-band antenna for 2.4 GHz bluetooth, 5.2/5.8 GHz wireless local area network (WLAN) and 3.5/5.5 GHz worldwide interoperability for microwave access (WiMAX) applications is presented and investigated experimentally. The proposed antenna is composed of a ACS-fed monopole, an arc-shaped strip and an omega-shaped strip, which occupies a compact size of $18 \times 22\,\text{mm}^2$ including the ground plane. By properly selecting the positions and lengths of these strips, dual frequency operation with wide impedance bandwidth characterstics can be achieved. The proposed antenna has been validated experimentally and found to have nearly onmidirectional radiation patterns in the $H$-plane, nearly bi-directional behaviour in the $E$-plane and acceptable peak gain across operating bands.

## 1. INTRODUCTION

Nowadays, due to the rapid advancements in wireless communication technology, integration of more than one wireless communication protocol into a single unit is of great interest to designers and researchers. Especially there is a huge demand in developing of multi-band antenna for 5.2/5.8 GHz WLAN IEEE 802.11 a (5.15–5.35 GHz and 5.725–5.825 GHz), 2.4 GHz IEEE 802.11 b/g (2.4–2.484 GHz), 3.5 GHz WiMAX IEEE 802.16 (3.4–3.6 GHz) and 5.5 GHz HIPERLAN2 (5.47–5.725 GHz) due to its wide range of usability in almost all commercial communication devices such as smartphones, laptops, tablets, phablets. etc. Different types of multi-band antennas for various applications have been reported in literature [1–18]. A detailed comparison in terms of parameters like antenna size, antenna purpose, total area occupied by the antenna and its frequency of operation has been given in Table 1. Many of these reported designs are having either complex structures or large size, in addition to the above drawbacks some of the reported antennas are covering only few WLAN/WiMAX operating bands. This makes them difficult to integrate with RF/MIMO circuits as well as gives limited access of service in WLAN/WiMAX frequency bands.

To decrease the overall size of the antenna, some designs have been reported in [19–27] by using the concept of asymmetric coplanar strip (ACS)-fed. In comparison to general coplanar waveguide (CPW)-fed antenna, an ACS-fed antenna structure will consume only 50% area by considering only half of the ground plane of CPW-fed structure. Table 2 shows the comparison of antenna size, operating bands and average peak gain of the proposed antenna with antennas reported in [19–23]. It is found that the proposed ACS-fed dual-band antenna is compact in size and it is covering all 2.4/5.2/5.8 GHz WLAN and 3.5/5.5 GHz WiMAX frequency bands with acceptable peak gain of 2.8 dBi. Recently some other structures of compact ACS-fed antennas have been reported in [24–27]. In [24, 25] a dual-band acs-fed antenna is proposed for 2.4/5.8 GHz WLAN applications by using the concept of loaded capacitance terminations. Though the antenna is compact in size but it is having the drawbacks

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of complex structure, narrow bandwidth and limited/no access of 5.2 GHz WLAN and 3.5/5.5 GHz WiMAX band services. In [26, 27] two different asymmetric antennas are proposed for dual frequency of operation. Both the reported antennas have compact size but again these structures are having limitations of narrow bandwidth and limited frequency of operation of WLAN/WiMAX bands. To overcome these drawbacks, a compact ACS-fed dual band antenna has been proposed and discussed in detail. The proposed design is not only compact in size but also has wider bandwidth along with simple structure and feeding mechanism.

**Table 1.** Comparison of proposed antenna performance with other compact antennas.

| **S. No.** | **Published literature/ proposed** | **Antenna Size (mm$^2$)** | **Total area occupied by the antenna (mm$^2$)** | **Frequency bands covered** | **Antenna purpose** |
|---|---|---|---|---|---|
| 1 | Ref [1] | 50 × 50 | 2500 | 2.4/5.2/5.8 GHz | Dual-band |
| 2 | Ref [2] | 40 × 35 | 1400 | 2.4/3.0–5.6 GHz | Dual-band |
| 3 | Ref [3] | 40 × 40 | 1600 | 3.4/5.0–5.9 GHz | Dual-band |
| 4 | Ref [4] | 40 × 40 | 1600 | 2.4/5.15–5.825 GHz | Dual-band |
| 5 | Ref [5] | 48 × 30 | 1440 | 2.4/5.2/5.8 GHz | Dual-band |
| 6 | Ref [6] | 60 × 45 | 2700 | 2.4/5.2/5.8 GHz | Dual-band |
| 7 | Ref [7] | 30 × 25 | 750 | 2.4/5.2/5.8 GHz | Dual-band |
| 8 | Ref [8] | 26 × 36 | 936 | 2.4/5.2/5.8 GHz | Dual-band |
| 9 | Ref [9] | 50 × 30 | 1500 | 2.4/5.2/5.8 GHz | Dual-band |
| 10 | Ref [10] | 22 × 26 | 572 | 2.4/5.2 GHz | Dual-band |
| 11 | Ref [11] | 40 × 30 | 1200 | 2.4/5.2/5.8 GHz | Dual-band |
| 12 | Ref [12] | 60 × 70 | 4200 | 3.5/5.2/5.5/5.8 GHz | Dual-band |
| 13 | Ref [13] | 40 × 40 | 1600 | 2.4/3.5/5.2/5.5/5.8 GHz | Tri-band |
| 14 | Ref [14] | 16 × 30 | 480 | 2.4/3.5/5.8 GHz | Tri-band |
| 15 | Ref [15] | 35 × 25 | 875 | 2.4/3.5/5.2/5.5/5.8 GHz | Tri-band |
| 16 | Ref [16] | 25 × 38 | 950 | 2.4/2.5/3.5/5.2/5.5/5.8 GHz | Tri-band |
| 17 | Ref [17] | 22 × 29 | 638 | 2.4/3.5/5.2/5.5/5.8 GHz | Tri-band |
| 18 | Ref [18] | 34.5 × 18 | 621 | 2.4/3/5/5.2/5.5/5.8 GHz | Tri-band |
| **19** | **Proposed antenna** | **18 × 22** | **396** | **2.4/3.5/5.2/5.5/5.8 GHz** | **Dual-band** |

**Table 2.** Comparison of proposed antenna performance with other existing ACS-fed antennas.

| **S. No.** | **Published literature/ proposed** | **Antenna Size (mm$^2$)** | **Antenna purpose** | | **Antenna type** | **Average Peak gain (dBi)** |
|---|---|---|---|---|---|---|
| | | | **WLAN** | **WiMAX** | | |
| 1. | Ref [19] | 31 × 15 | 2.4/5.2/5.8 GHz | --- | Tri-band | ∼ 2.4 |
| 2. | Ref [20] | 35 × 19 | 2.4/5.2/5.8 GHz | 3.5/5.5 GHz | Tri-band | ∼ 2.2 |
| 3. | Ref [21] | 28 × 30 | 2.4/5.2/5.8 GHz | 3.5 GHz | Dual-band | ∼ 2.1 |
| 4. | Ref [22] | 21 × 19 | 2.4/5.2 GHz | --- | Dual-band | ∼ 1.9 |
| 5. | Ref [23] | 37.5 × 24 | 2.4 GHz | --- | Dual-band | ∼ 1.21 |
| 6. | Proposed antenna | 18 × 22 | 2.4/5.2/5.8 GHz | 3.5/5.5 GHz | Dual-band | ∼ 2.8 |

## 2. ANTENNA DESIGN AND CONFIGURATION

The electromagnetic simulation software package CST Microwave Studio (CST MWS) was used to design and analyze the antenna's electrical and radiation characteristics. The configuration of the proposed dual-band WLAN/WiMAX antenna is shown in Fig. 1. The designed is printed on one side of the low cost substrate FR4 having thickness of 1.6 mm with dielectric constant of 4.4 and loss tangent of 0.02. The dimensions of the antenna including substrate is $0.23\lambda \times 0.28\lambda$ with respect to first resonant frequency of 2.4 GHz. The proposed antenna is composed of simple $50\,\Omega$ monopole feeding strip whose width is $L5$ (= 3.3 mm), asymmetric ground plane with a gap distance of 0.5 mm from feed line, two interconnected radiating elements of arc-shape and omega-shape respectively. The dual-band performance of the proposed antenna is obtained from these radiating elements which have different lengths. By choosing the dimensions of the radiating strips to half-wavelength at the desired resonance frequency the working band can be adjusted to cover WLAN and WiMAX bands. The optimized parameter values of the proposed antenna have been found to be: $L = 18$ mm, $W = 22$ mm, $L2 = 5$ mm, $L3 = 3.5$ mm, $L4 = 10.4$ mm, $L5 = 3.3$ mm, $W1 = 7.6$ mm, $W2 = 7.2$ mm, $R1 = 2.1$ mm, and $R2 = 2.9$ mm. The gap between the ground plane and feedline is 0.5 mm.

Figures 2 and 3 show the design evolution and the corresponding simulated return loss characterstics of the proposed dual-band ACS-fed antenna. The antenna — stage 1 (Ant-1) shown in Fig. 2 is the basic ACS-fed monopole structure, which consists of a asymmetric ground plane and a straight vertical rectangular strip. As shown in Fig. 3, with this structure, a resonant frequency at 3.6 GHz is obtained. Next, to this structure a metallic arc shaped stub is attached (Ant-2) which creates an additional resonance near 2.2 GHz. Also the monopole resonance near 3.6 GHz is slightly shifted to the lower side. If instead of the arc shaped stub, an omega shaped stub is attached as in Ant-3, the first resonance appears at 1.9 GHz. This is because of larger length of the omega shaped strip. The resonance near 3.6 GHz shifts to the upper side (4.4 GHz) and an additional resonance appears at 3.8 GHz which can

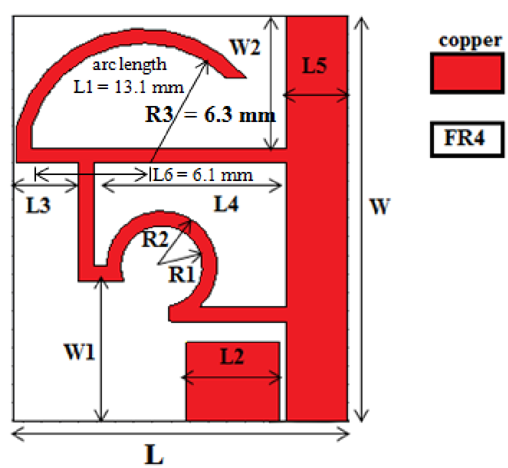


**Figure 1.** Geometry of the proposed ACS-fed dual-band antenna.

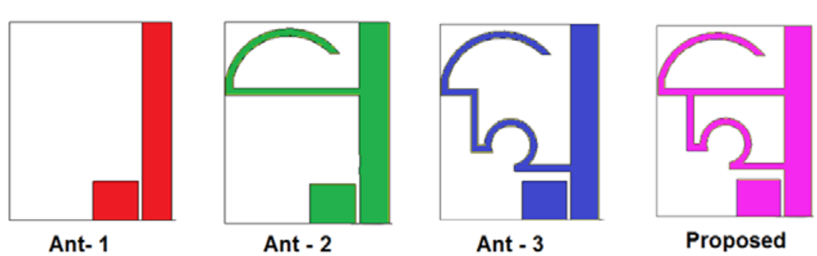


**Figure 2.** Evolution process of the dual-band monopole antenna.

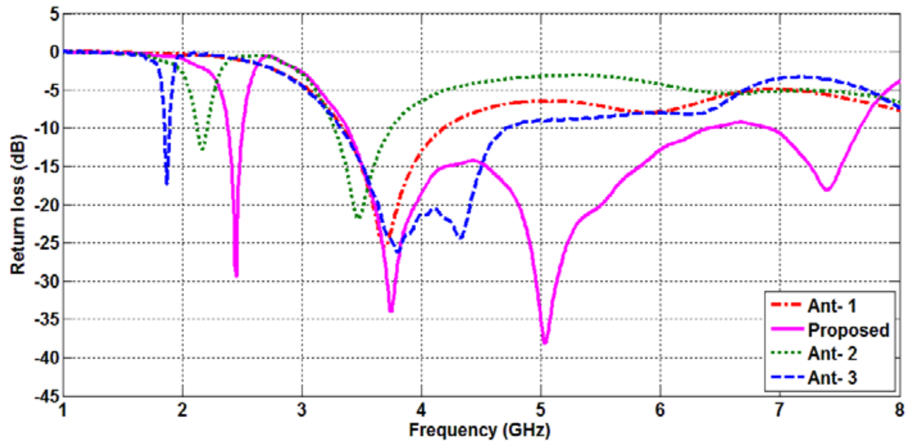


**Figure 3.** Simulated return loss curves of various ACS-fed structures in the design evolution process.

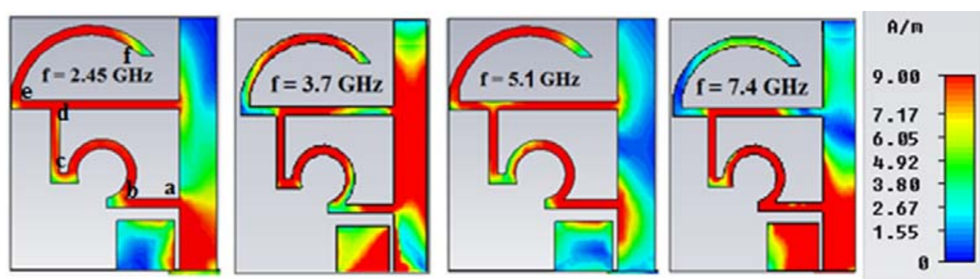


**Figure 4.** Simulated surface current distributions of the antenna at 2.45 GHz, 3.7 GHz, 5.0 GHz and 7.4 GHz.

be said to be the second harmonic of the resonance at 1.9 GHz. Finally, in the proposed antenna when the arc shaped strip and the omega shaped strip are combined, the second harmonic of the monopole resonance near 3.8 GHz becomes prominent because of loading effect due to the formation of the metallic loop comprising the vertical monopole and the two strips. Also the first resonance increases to 2.45 GHz due to the coupling between the arc shaped strip and the omega shaped strip. Its harmonic appears at 5.1 GHz. Finally, due to the combined effect, the impedance matching improves and in overall, the desired dual band characteristics are obtained.

In order to understand the dual-frequency operation of the proposed ACS-fed antenna, the current distribution at the various resonance frequencies, i.e., at 2.45 GHz, 3.7 GHz 5.0 GHz are shown in Fig. 4. From Fig. 4, at frequency 2.45 GHz the maximum current is along the arc shaped strip and omega shaped strip connected to the monopole structure and it also shows two maxima. This indicates that the first resonant frequency at 2.45 GHz corresponds to the $\lambda_g/2$ length of the strip ($L7$ = path length 'abcdef' shown in Fig. 4 = 37.6 mm) attached to the monopole and the expression for the same is given in Equation (1). From the return loss characteristics given in Fig. 3, we can also observe one more resonance at 5.0 GHz which is the harmonic of 2.45 GHz resonance. Similarly from the Fig. 4, we can observe that at 3.7 GHz, maximum electric current is concentrated on the asymmetric monopole straight strip. So the resonance at 3.7 GHz is due to the straight strip. The resonance at 7.4 GHz is the harmonic of the resonance at 3.7 GHz as indicated by the presence of minima at that frequency on the vertical monopole strip.

In the design, the resonant lengths of the arc-shaped monopole '$L7$ = path length '$abcdef$' shown in Fig. 4' and the straight monopole '$H$' are set close to half-wavelength of the fundamental resonant frequencies which they are supposed to excite. The lengths can be calculated from the desired resonance frequencies from Equations (1) and (2). All the resonant frequencies can be tuned independently by varying the lengths of the individual radiating strips.

$$L7 = \frac{c}{2f_1\sqrt{\epsilon_{r,eff}}} \tag{1}$$

$$H = \frac{c}{2f_2\sqrt{\epsilon_{r,eff}}} \tag{2}$$

$$\epsilon_{r,eff} = \frac{\epsilon_r + 1}{2} \tag{3}$$

Here $c$ stands for the velocity of light in free space, and $\varepsilon_{r,eff}$ is the effective relative permittivity of the substrate which can be calculated from Equation (3). For calculating the effective relative permittivity,

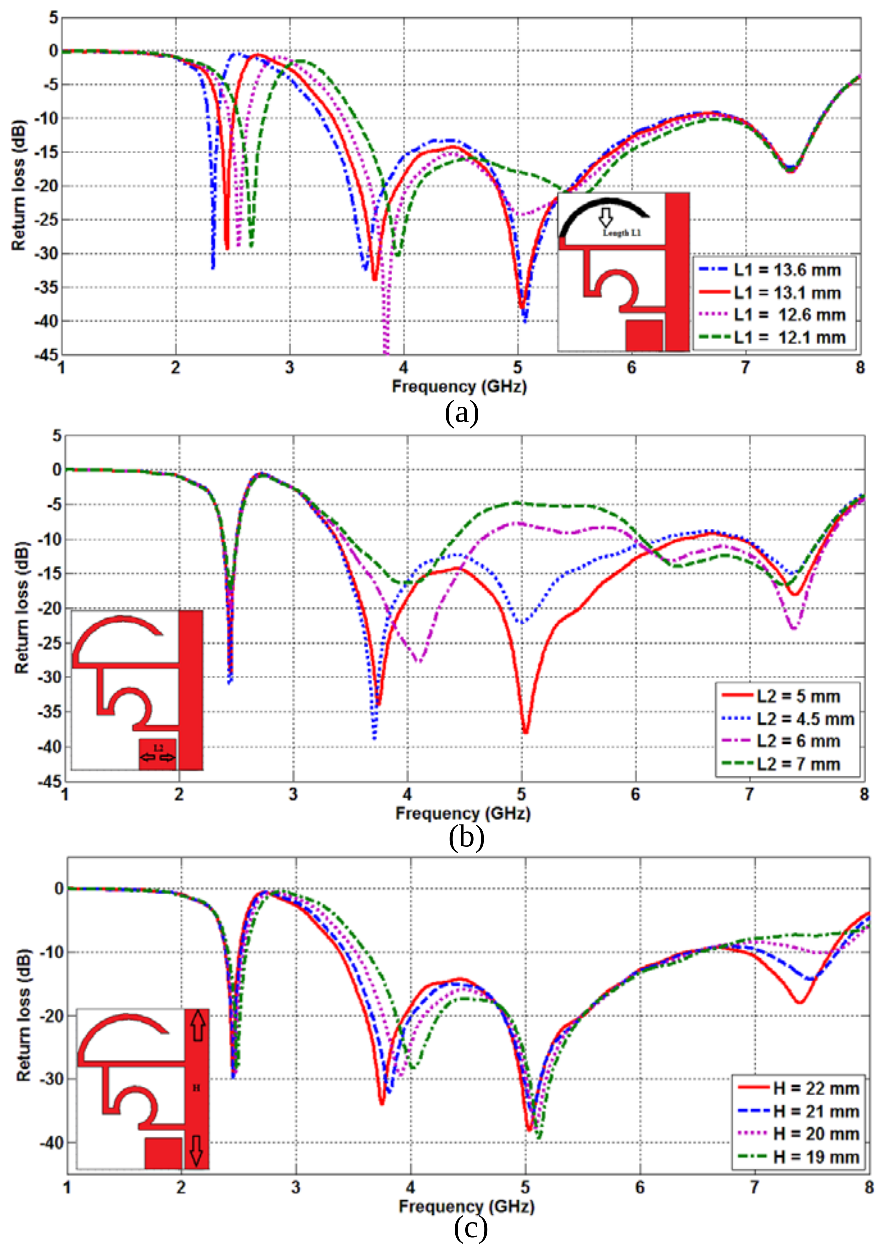


**Figure 5.** (a) Simulated return loss characterstics of the proposed antenna with varied $L1$. (b) Simulated return loss characterstics of the proposed antenna with varied $L2$. (c) Simulated return loss characterstics of the proposed antenna with varied $H$.

it is assumed that for a ACS-fed monopole, half of the established field lies in air while the remaining half is distributed in the substrate.

To investigate the effect of the various parameters on antenna performance, simulation studies using CST MWS have been carried out and reported in Fig. 5. It has been found that the parameters $L1$, $L2$ and $H$ mainly affect the resonant frequencies and bandwidth of the proposed antenna. Fig. 5(a) show the effect of varying the parameter $L1$ on the return loss characteristics. As the arc-shaped strip length $L1$ decreases, the first resonant frequency shifts towards higher frequency side. This clearly indicates that the first resonance frequency at 2.45 GHz can be tuned and controlled by the parameter $L1$. It is also found that the parameter $L1$ not only affects first resonant frequency but also affects the lower frequency limit of second operating band due to the coupling between the arc-shaped strip and the monopole strip. Fig. 5(b) shows the return loss curves for different values of the length $L2$ of the ground plane when the other parameters are kept constant. It can be observed that the return loss characteristics of the second operating band are strongly affected when $L2$ increases from 4.5 mm to 7 mm, which means that the antenna impedance bandwidth is depending on the asymmetric ground plane. This is because as the ground plane length increases more coupling area will be developed between omega-shaped strip and ground plane. This increased coupling leads to poor return loss characteristics. The optimized value considered for $L2$ for the proposed antenna is 5 mm.

Figure 5(c) shows the return loss characterstics when the parameter $H$ varies from 19 mm to 22 mm. As the parameter $H$ decreases, the lower limit of the second operating band shifts towards higher frequency side without disturbing first operating band properties. This clearly indicates that the parameter $H$ plays key role in the choosing of lower limit of the second operating band. Similar conclusion can be drawn from Fig. 2 and Fig. 4.

## 3. RESULTS AND DISCUSSION

The proposed ACS-fed dual-band antenna is fabricated and its return loss characterstics are measured by using Rohde & Schwarz Vector Network Analyzer (ZVA-40). Fig. 6 shows the simulated and measured return loss ($S_{11}$) of the dual-band antenna and its fabricated photograph. The measured $-10$ dB impedance bandwidths are about 400 MHz (1.8–2.2 GHz) with a resonance at 2.0 GHz, 4600 MHz (3.0–7.6 GHz) with resonances at 3.8 GHz, 5.0 GHz and 7.4 GHz. The operating bands of the proposed antenna make it suitable for the 2.4 GHz Bluetooth, 3.5/5.5 GHz WiMAX and 5.2/5.8 GHz WLAN applications. The difference between simulated and measured results is probably due to manufacturing tolerances, uncertainty of the thickness and/or the dielectric constant of the FR4 substrate and quality of SMA connector used. Also, the shift seen in both the bands to the lower side in case of the measured $S_{11}$ is due to the small size of the antenna and connector effects. In case of measuring small monopoles, at low frequencies where the electrical size of the antenna ground plane becomes relatively small compared to the wavelength, the SMA connector and a part of the connecting cable of the VNA act as an additional

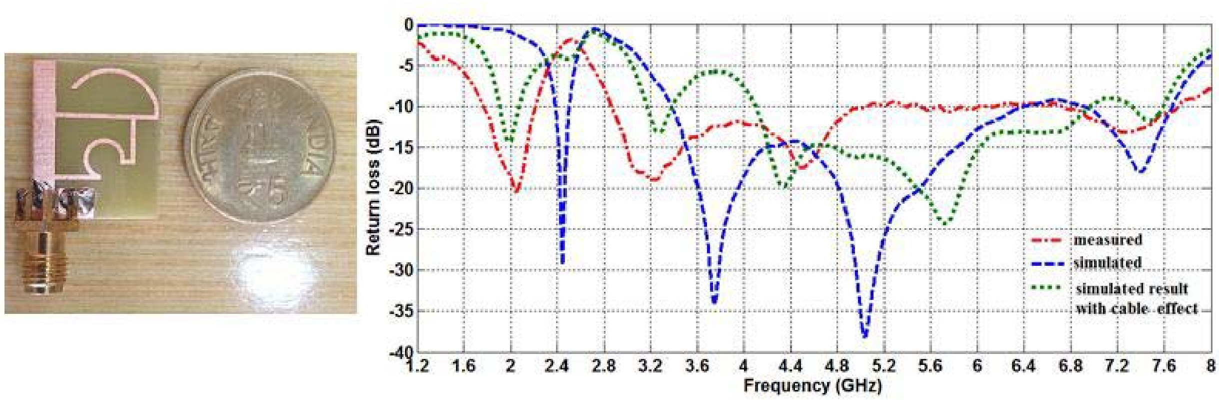


**Figure 6.** Fabricated prototype photograph and its simulated and measured return loss against frequency.

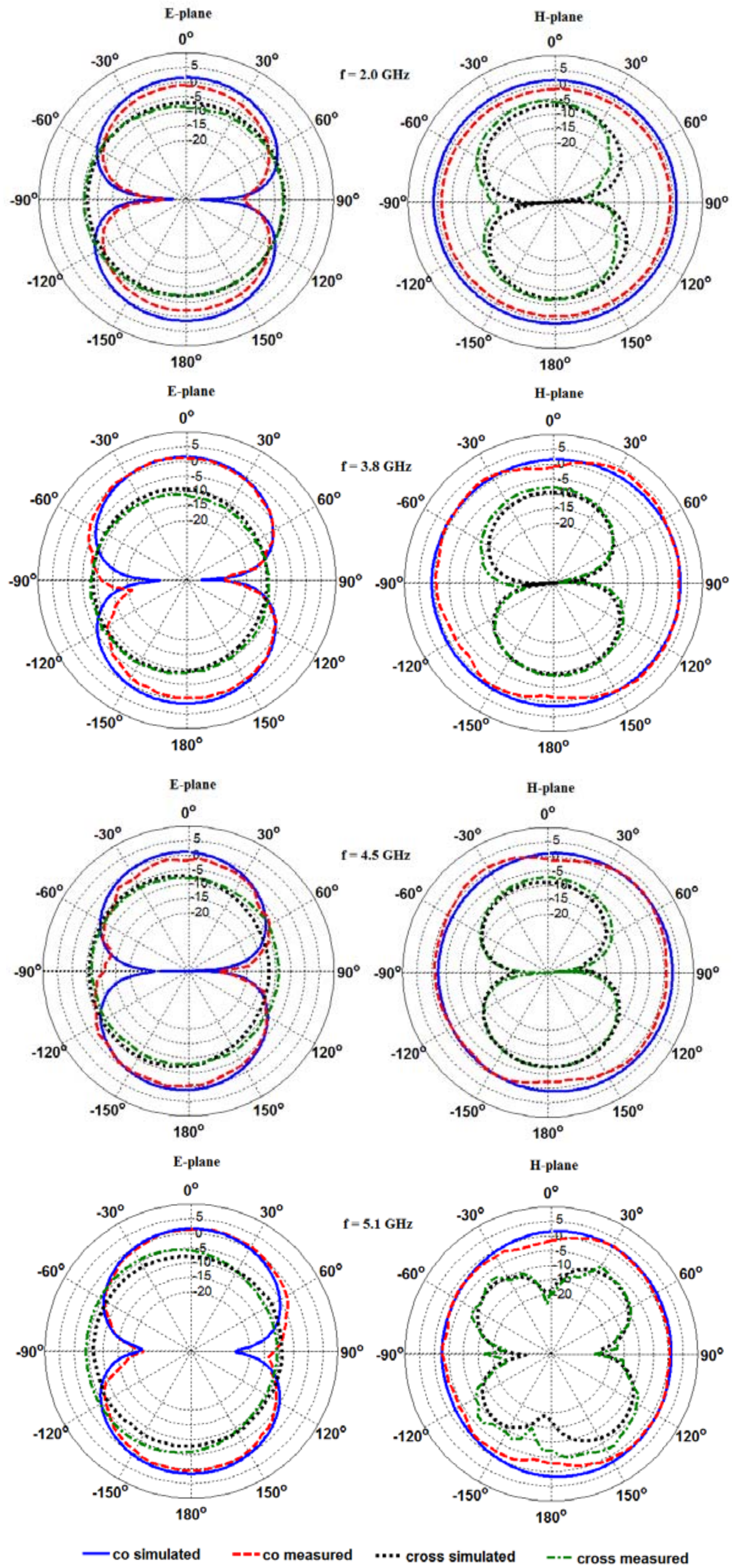


**Figure 7.** Simulated and measured radiation patterns of the proposed ACS-fed dual-band antenna at 2.0 GHz, 3.8 GHz, 4.5 GHz and 5.1 GHz.

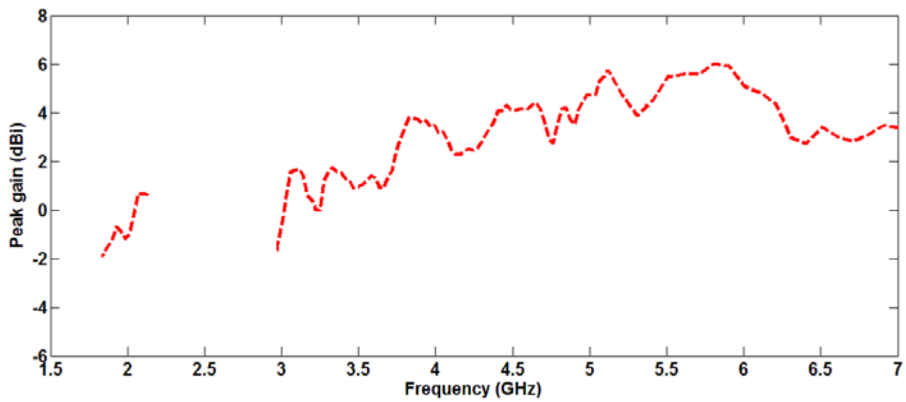


**Figure 8.** Measured peak gain of the proposed ACS-fed dual-band antenna.

ground for the antenna so some current will flow back from the antenna to the feeding cable. This alters the current distribution and shifts the lowest resonance. To verify it, simulated result by approximately modeling the connector is shown in Fig. 6. Almost, a similar shift can be observed.

The radiation patterns of the proposed dual-band antenna are simulated in the $E$ and $H$ planes using CST Microwave Studio and measured in an in-house anechoic chamber using antenna measurement system. A standard double ridged horn antenna is used as reference antenna. The simulated and measured radiation patterns at different frequencies are shown in Fig. 7. The $H$-plane radiation patterns are seen to be omni-directional in nature while the $E$-plane radiation patterns are bidirectional (dumb bell shaped). Further, the simulated and measured results are found to be in close agreement with a little difference due to measurement and alignment errors. At higher frequencies, the radiation patterns deteriorate because the equivalent radiating area changes with frequency over the operating band. Increase in the magnitude of higher order modes at higher frequencies also plays a part in the deterioration seen at higher frequencies. The measured peak gain of the proposed ACS-fed tri-band antenna across the operating bands is shown in Fig. 8. The measured peak gain remains between 1–5 dB in the operating band. The gain increases in the high frequency region due to an increase in the effective area of the antenna at shorter wavelengths.

The radiation efficiency characteristics of the proposed antenna was calculated by using CST Microwave Studio and also achieved efficiencies are compared between proposed antenna and recent published work as given in Table 3. Along with the good radiation efficiency, the proposed antenna has the smallest size, wide operating band, acceptable gain, which can meet the standards of Bluetooth, WLAN/WiMAX applications.

**Table 3.** Comparisons of radiation efficiency of the proposed antenna with other compact antennas.

| **S. No** | **Published literature** | **Radiation efficiency in 2.4 GHz band** | **Radiation efficiency in 3.5 GHz band** | **Radiation efficiency in 5.2/5.5/5.8 GHz band** |
|---|---|---|---|---|
| 1. | Ref [5] | 90% | 75% | 75% |
| 2. | Ref [6] | 80.27% | --- | 75.54% |
| 3. | Ref [11] | 62% | --- | 85% |
| 4. | Ref [22] | 74% | --- | 74% |
| 5. | Ref [23] | 83% | --- | --- |
| 6. | **Proposed antenna** | 80% | 89% | 89% |

## 4. CONCLUSIONS

A compact ACS-fed dual-band printed monopole antenna is proposed and experimentally demonstrated. The radiating element is a combination of an omega shaped strip and an arc-shaped strip attached to a narrow rectangular monopole. The target applications of the antenna as seen from the impedance bandwidth are the 2.4 GHz bluetooth, 5.2/5.8 GHz WLAN and 3.5/5.5 GHz WiMAX. The position and bandwidths of the two bands can be adjusted by tuning the lengths of the attached strips. The radiation characteristics of the antenna are found to show omnidirectional nature in the $H$-plane and nearly bi-directional behaviour in the $E$-plane along with a moderate peak gain.

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