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ACS-Fed e-Shaped Dual Band Uniplanar Printed Antenna for Modern Wireless Communication Applications

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Abstract—A printed small size (12×16.5 mm) ACS-fed e-shaped uniplanar antenna is proposed for dual band applications. The multiband operating characteristics have been achieved by integrating e-shaped radiating strips to the 50 Ω ACS feed line. Two simultaneously operating wide bands have been generated by using optimized radiating branch strips for the multiband applications. For obtaining size reduction and wider impedance bandwidth, e-shaped meandered elements are chosen in the design. The proposed design features the bandwidth (VSWR < 2, reflection coefficient below –10 dB) of 100 MHz in 2.4–2.5 GHz, and 2100 MHz in 4.0–6.1 GHz. The developed multiband antenna can be useful for several wireless communication applications, such as 2.4 GHz Bluetooth/RFID, WLAN (2.4/5.2/5.8 GHz), WiMAX (5.5 GHz), US public safety band (4.9 GHz), ISM band, radio frequency energy harvesting and internet of things (IoT) applications.

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1. INTRODUCTION

Current generation wireless communication systems demand the integration of multiple communication protocols into a single device within a specified area/volume. In this scenario antenna is a key element that decides not only device capability, but also its size. To address this issue, many researchers focused on the design of small antennas that work simultaniously for multiple frequency bands.

Recently, various antenna designs have been reported by using different structures/geometries and feeding techniques, such as microstrip feeding [1–3], coplanar waveguide (CPW)-feeding [4–8], and asymmetric coplanar strip (ACS)-feeding [9–19] for portable devices. As shown in Table 1, all the structures are complex and large in size; moreover, most of them operate in narrow bandwidth.

To address the above-stated wireless communication device requirements, this paper proposes a small size (12×16.5 mm) uniplanar ACS-fed e-shaped antenna for wideband operation and verifies its performance experimentally. The multiple resonant frequency bands are realized by integrating a half wavelength (λ/2) e-shaped radiating element to the basic 50 Ω ACS structure.

The antenna performance properties, such as return loss S_{11}, bandwidth, parametric studies, radiation patterns and peak gains are simulated and analyzed by using the CST MWS software package. The measured –10 dB impedance bandwidth values of the proposed dual band antenna are about 100 MHz in the range 2.4–2.5 GHz and 2100 MHz in the range 4.0–6.1 GHz, which can be used for 2.4 GHz Bluetooth/RFID, WLAN (2.4/5.2/5.8 GHz), WiMAX (5.5 GHz), US public safety band (4.9 GHz), ISM band, RF energy harvesting and IoT applications.

2. DUAL BAND UNIPLANAR ANTENNA DESIGN WITH ANALYSIS

The compact e-shaped geometry of dual band ACS-fed monopole antenna [15] is shown in Fig. 1 with its optimized parameter values given in Table 2, which comprises meandered rectangular strips in the form of an e-shape structure and a rectangular uniplanar ground plane. The electromagnetic simulation software (CST microwave studio package) is used to quicken the novel design of reported antenna. The uniplanar structure of dual band antenna is designed on a 1.6 mm thick glass epoxy substrate (FR4) having relative permittivity of 4.4 and compact size of 12×16.5 mm. The feedline strip width of 4 mm and the constant gap

Table 1. Published literature devices versus the proposed antenna summary

Ref.	Size, mm×mm	Avg. peak gains, dBi	Area, mm^2	Purpose		Antenna type	Radiation efficiency
				WLAN, GHz	WiMAX, GHz		
[1]	35×30	3.8	1050	2.4/5	3.5/5	Triple	NA
[2]	40×40	2.8	1600	2.4/5	5	Dual	NA
[3]	20×12	1.8	240	2.4/5	3.5/5	Dual	NA
[4]	85×85	NA	7225	5	3.5/5	Single	NA
[5]	30×18	3.6	540	2.4/5	3.5/5	Triple	NA
[6]	23×36.5	2.4	839.5	2.4/5	3.5/5	Triple	NA
[7]	30×25	3.2	750	2.4/5	5	Dual	NA
[8]	17.5×17.5	2.2	306.25	2.4/5	3.5/5	Triple	NA
[9]	37.5×24	1.21	900	2.4	—	Dual	NA
[10]	21×19	1.8	399	2.4/5.2	—	Dual	74%
[11]	14×26	2.7	364	2.4/5	5	Triple	80%
[12]	28×30	2.1	840	2.4/5	5	Dual	NA
[13]	14.75×26	1.4	383.5	2.4	3.5	Dual	NA
[14]	17×12	0.75	204	2.4/5.8	—	Dual	NA
[15]	10×17.5	2.7	175	2.4/5	3.5/5	Triple	NA
[16]	22×12	1.75	264	2.4/5	3.5/5	Triple	70%
[17]	21×7.35	3.3	154.35	—	5.5	Dual	NA
[18]	13.4×22.7	1.8	304.18	2.4/5	5	Dual	NA
[19]	25.5×37.5	3.2	956.25	5	3.5/5	Single	NA
Proposed antenna	12×16.5	3.7	198	2.4/5	5	Dual	69%

distance of 0.5 mm between the ground plane and feedline were used to achive the characteristic impedance of 50 Ω.

The evolution of the presented antenna fed by ACS is illustrated in Fig. 2a, and the curves obtained for the corresponding reflection coefficients are presented in Fig. 2b along with the surface current distribution plots presented in Fig. 2a. Antenna #1 (Fig. 2a) is the orignal ACS-fed structure, in which a rectangular stub is attached on the top of basic monopole structure with the ground plane separated by gap distance *G* (0.5 mm) from the signal feedline. As can be seen from Fig. 2b, antenna #1 excites the centric resonant frequency of 5 GHz (Fig. 2a) and covers the operating band from 4.2 to 6.1 GHz. Thereafter an e-shaped radaiting branch is inserted into antenna #1 for generating a lower resonant mode at 2.4 GHz, which is longer as compared to all the other radaiting branches. Antenna #2 in Fig. 2b has two independent operating bands from 2.4 to 2.5 GHz and from 3.9 to 6.1 GHz.

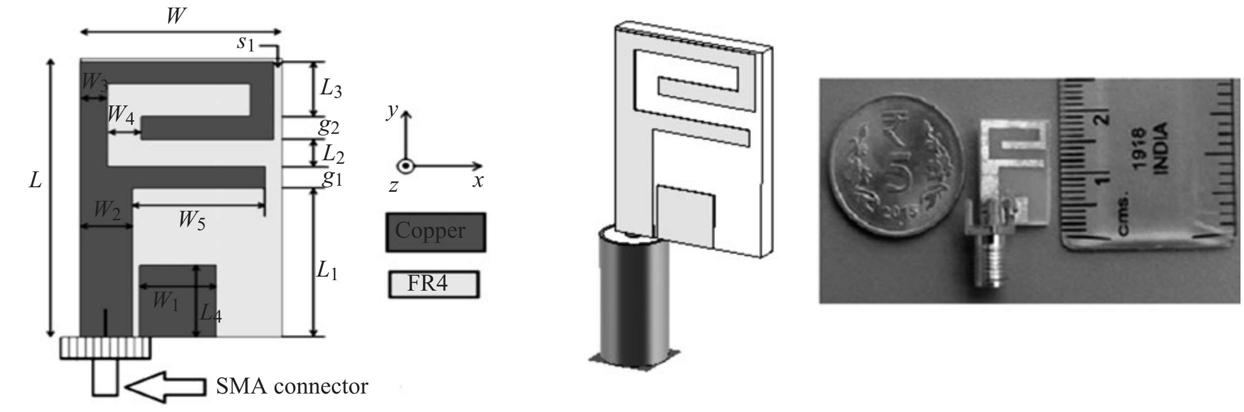

Fig. 1. Uniplanar e-shaped antenna design (a), 3D layout (b), and photograph (c).

Table 2. Uniplanar e-shaped antenna values

L	W_2	g_1	W_3	L_3	g_2	s_1	W_1	W	L_2	W_4	W_5	L_1	L_4
16.5	3.1	1.3	1.6	3.3	1.4	0.5	4.6	12	1.6	2.0	7.9	8.8	4.3

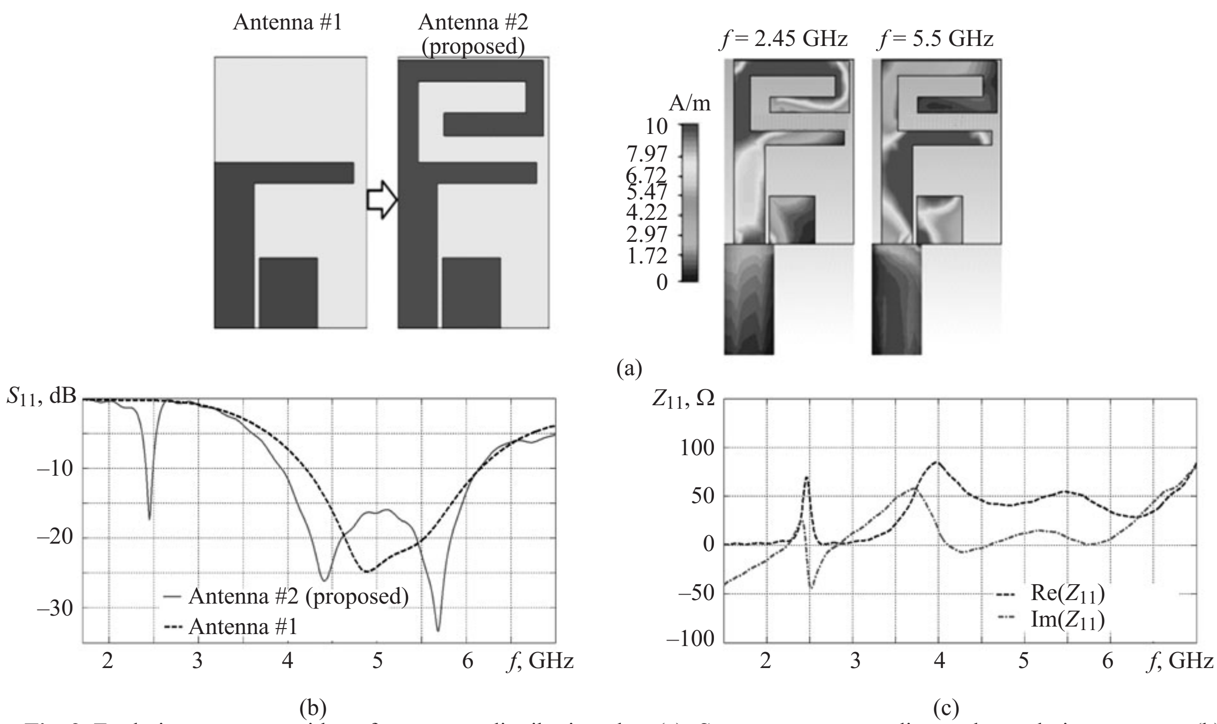

Fig. 2. Evolutionary stages with surface current distribution plots (a); S_{11} curves corresponding to the evolutionary stages (b); and the real and imaginary parts of input impedance Z_{11} (c) of the proposed antenna.

It is perceived that due to electromagnetic coupling, the impedance bandwidth of the second band becomes wider changing from 1900 MHz (4.2–6.1 GHz) to 2200 MHz (3.9–6.1 GHz). It happens because of the close arrangement of both radiating branches and the surface current distritribution, which leads to the center frequency of all resonant modes. Hence, the current distribution is responsible for a little shifting in resonant frequency. The proposed antenna (Fig. 2a) is obtained with three independent resonant frequencies and with a wider impedance bandwiths to cover several wireless communication applications, such as 2.4/5 GHz WLAN, 3.3/5 GHz WiMAX, RF energy harvesting and IoT applications. For better understanding of

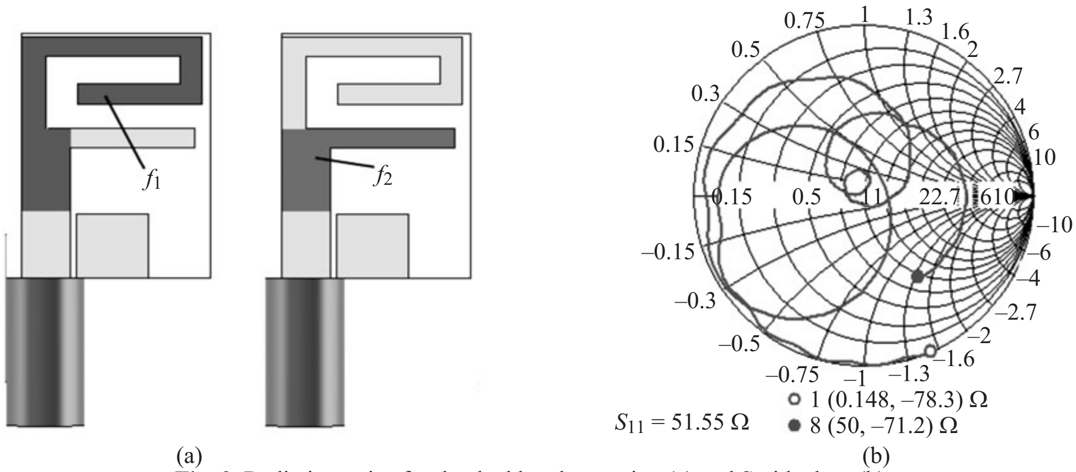

Fig. 3. Radiating strips for the dual band operation (a) and Smith chart (b).

the behavior of the proposed ACS-fed e-shape monopole antenna, the real and imaginary parts of the input impedance of the antenna are shown in Fig. 2c. It can be seen that the real part and imaginary parts are closer to 50 and 0 Ω, respectively. Both these observations indicate perfect impedance matching.

The targeted dual operating bands are achieved owing to the excitation of resonances by attaching two λ/2 length e-shaped and L-shaped radiating strips to the 50 Ω ACS feed line (Fig. 3a). The corresponding desired resonant frequencies f_r for a monopole antenna can be calculated by using the following relationships:

$$f_{\rm r} = c / \sqrt{\varepsilon_{\rm eff}}, \tag{1}$$

$$\varepsilon_{\rm eff} = \frac{\varepsilon_r + 1}{2}, \tag{2}$$

$$Z_0 = K(k) / K(k_1), \tag{3}$$

where $k = a / b, k_1 = \sqrt{1 - k^2}$, and $K(k) / K(k_1)$ is the elliptical integral of the first kind given by expression:

$$\frac{K(k)}{K(k_1)} = \begin{cases} \dfrac{\pi}{\ln \dfrac{2(1+\sqrt{k_1})}{(1-\sqrt{k_1})}}, & 0 \le k \le \dfrac{1}{\sqrt{2}}, \\ \dfrac{1}{\pi \ln \dfrac{2(1+\sqrt{k})}{(1-k)}}, & \dfrac{1}{\sqrt{2}} \le k \le 1. \end{cases} \tag{4}$$

The corresponding impedance characteristics in the form of a Smith chart are shown in Fig. 3b. Since both the CPW and ACS feeding techniques are working on the same principle [20]. The characteristic impedance of the proposed uniplanar e-shaped ACS-fed printed antenna can be calculated by using the equations (3) and (4), respectively.

3. PARAMETRIC STUDIES OF DUAL BAND ANTENNA

In the proposed design, several key parameters play an important role in improvement of antenna performance. So a detailed study has been carried out and the relevant explanations are provided in this section. The proposed antenna geometry implies that the L-shaped strip, e-shaped strip, and ACS-fed ground plane influence the antenna performance by varying the length and width of the above parameters

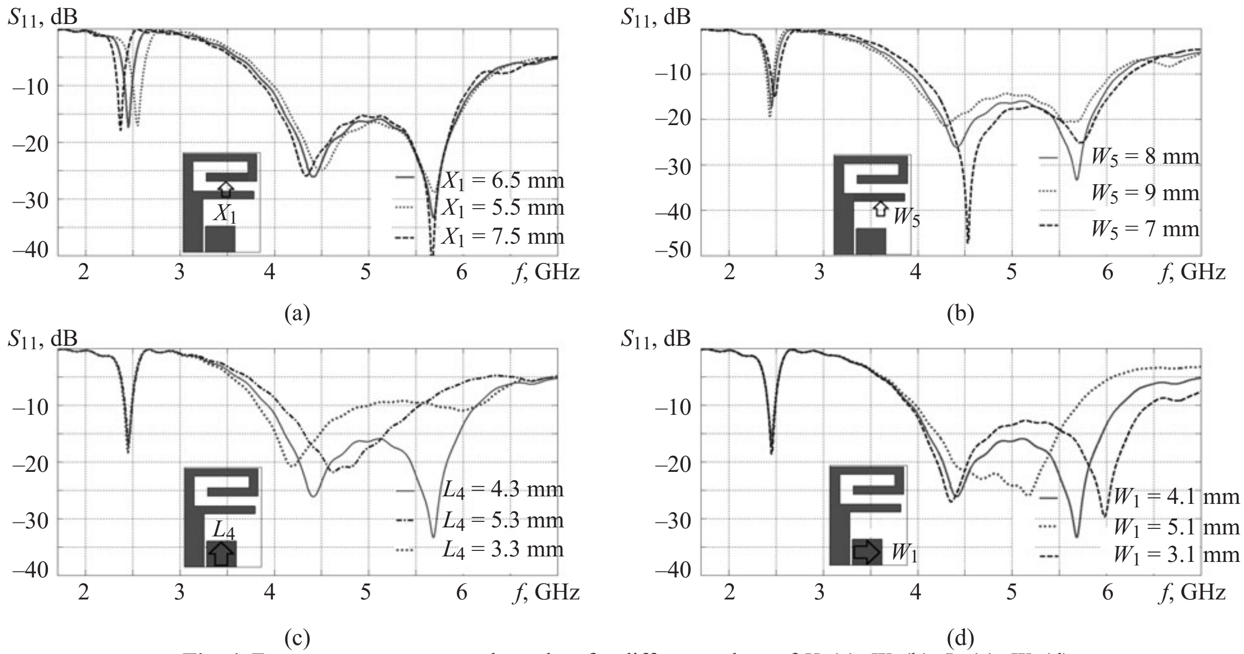

Fig. 4. Frequency versus return loss plots for different values of X_1 (a), W_5 (b), L_4 (c), W_1 (d).

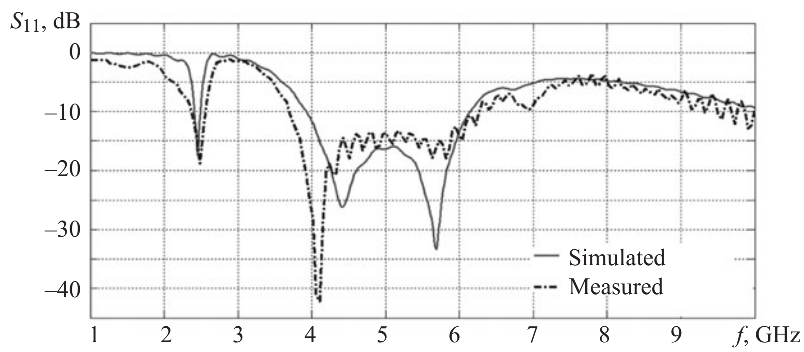

Fig. 5. Measured and simulated return losses.

individually. Fig. 4a presents the simulated results of the relationship of the reflection coefficient as a function of frequency, while varying the length of X_1 (radiating branch) from 5.5 to 7.5 mm. As can be seen from Fig. 4a, a decrease in length of X_1 shifts the resonant frequency of 2.45 GHz towards higher values and vice versa. In the process of generating the first resonant mode, the second resonant frequency is not affected. It is observed that the length of X_1 (radiating element) is responsible for the excitation at 2.45 GHz operating band.

Fig. 4b illustrates the effect of a change in the length of L-shaped radiating branch from 7.0 to 9.0 mm horizontally. As can be seen from the figure, the alteration in length of strip W_5 effects the second resonant frequency with a little change in the first operating band due to coupling. In Fig. 4c, the simulated return loss curves S_{11} are analysed that were obtained by modifying the length of radiating branch L_4 from 3.3 to 5.3 mm vertically. As can be seen from this figure, a change occurs in the second operating band, but it does not affect the excitation at 2.45 GHz operating band. In order to understand better the effect of the ground plane on the antenna performance, a study of variations in the width of W_1 has been carried out, and the salient results are shown in Fig. 4d.

4. MEASURED AND SIMULATED RESULTS

The electromagnetic simulator ‘CST Microwave Studio package’ was used for the simulation of the proposed uniplanar e-shaped antenna. Next, this antenna was fabricated, and the e-shaped ACS-fed antenna performance was used by using an R&S ZVA40 vector network analyzer. A photograph of the fabricated

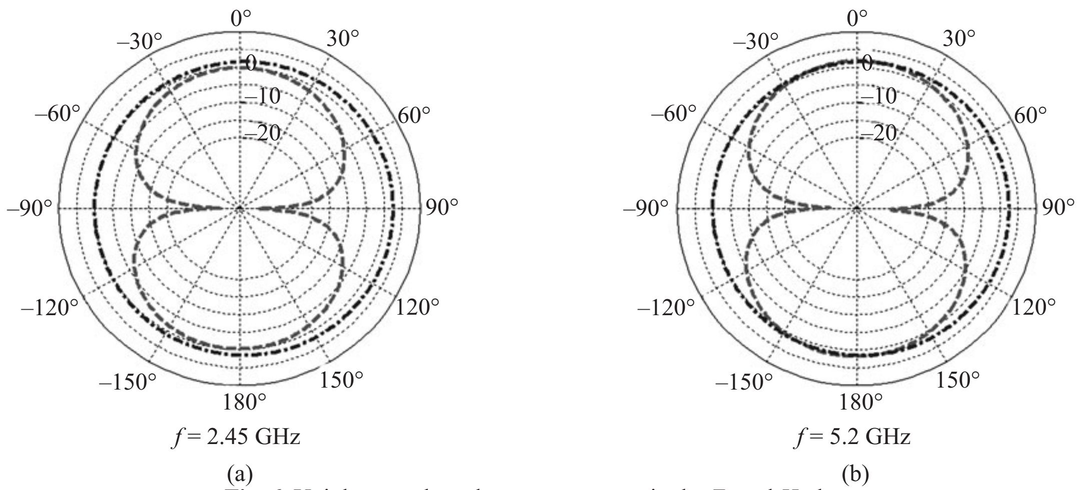

Fig. 6. Uniplanar e-shaped antenna patterns in the *E*- and *H*-planes.

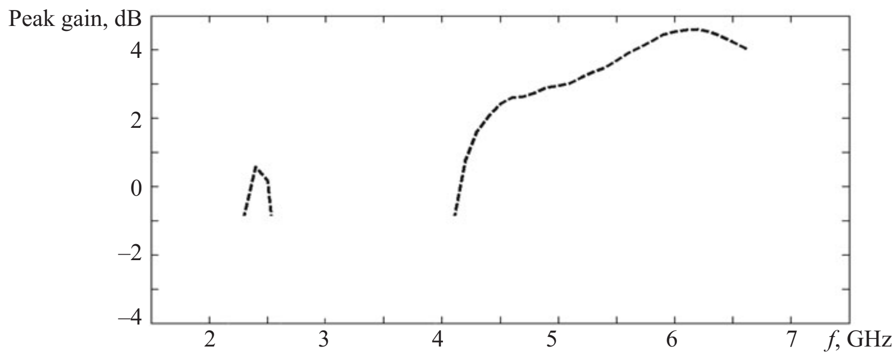

Fig. 7. Peak gains of the uniplanar e-shaped antenna.

antenna is shown in Fig. 1c. The measured and simulated return losses are compared in Fig. 5. As can be seen from this figure, the measured and simulated results are in good agreement.

The proposed dual band design features the bandwidths (reflection coefficient below –10 dB) of 100 MHz in the band from 2.4 to 2.5 GHz and 2100 MHz in the band from 4.0 to 6.1 GHz that meet the requirements of various bands, in particular the US public safety band and WLAN/WiMAX/Bluetooth/RFID/ISM bands. The simulated radiation patterns obtained by using the CST Microwave Studio are presented in Fig. 6. The radiation patterns are calculated at selected frequencies (2.45 and 5.2 GHz), which are in the middle of two operating bands. As can be seen from Fig. 6, while the *H*-plane (*YZ*-plane) patterns are circular in shape, the *E*-plane (*XZ*-plane) patterns have dumb bell shape.

Fig. 7 presents the simulated plots of the antenna peak gain. The average peak gain remains between 1 to 4.5 dBi over both operating bands. The efficiency characteristics of the developed uniplanar e-shaped antenna were simulated in CST MWS, and the peak gains were as high as 70 and 68% in the two respective working bands.

5. CONCLUSIONS

A novel technique for achieving the multiple frequency band operation at with compact size of antenna has been presented and developed in this paper. The targeted multiband operating characteristics are achieved by integrating e-shaped radiating strips to the 50 Ω ACS feed line. The proposed design features the bandwidths (reflection coefficient below –10 dB) of 100 MHz in 2.4–2.5 GHz and 2100 MHz in 4.0–6.1 GHz.

The developed structure can be useful for several wireless communication applications such as 2.4 GHz Bluetooth/RFID, WLAN (2.4/5.2/5.8 GHz), WiMAX (5.5 GHz), US public safety band (4.9 GHz), ISM band, RF energy harvesting and IoT applications.

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