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# High Gain Flexible CPW Fed Fractal Antenna for Bluetooth/WLAN/WPAN/WiMAX Applications

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**Abstract**—A dual-band flexible antenna incorporated with the fractal structure using coplanar waveguide (CPW) is proposed for 2.42 GHz WLAN and 3.78 GHz WiMAX applications. The antenna is printed on a low-cost FR4 substrate having a thickness of 0.5 mm with an overall antenna dimension of $97.48 \times 80\,\text{mm}^2$. Incorporation of fractal geometry leads to improvement in terms of impedance bandwidth and radiation efficiency. The simulated and measured results of the proposed antenna in terms of return loss ($S_{11}$), gain, and radiation pattern are presented here which show great correlation. The measured impedance bandwidth and gain of the flexible antenna are 17.08% (2.20 GHz–2.61 GHz), 16.30% (3.38 GHz–3.98 GHz), 4.56 dBi and 1.09 dBi, respectively. The proposed dual-band antenna shows omnidirectional and bidirectional radiation patterns in $H$ and $E$-planes which makes it suitable for its use in low-cost Bluetooth/WLAN/WPAN/WiMAX applications.

## 1. INTRODUCTION

Due to the development of wireless communication technology, newer devices are coming to the market each and every day which leads to increased demand for latest technologies to be integrated into the devices. The device communication mainly depends upon transmitter and receiver antennas installed in the devices. These antennas play an important role in effective communication. The user demands of various communication services such as IEEE 802.11 WLAN/Bluetooth Wireless Personal Area Networks [WPAN] and IEEE 802.16 WiMAX in a single device are difficult due to the limited availability of space. These constraints can be overcome if the antennas installed in the devices occupy minimum space which demands antennas which are flexible in nature and can work in multi-bands. Thanks to the advent of innovative materials [1–5], recently the efficiency of wireless communications has been increased, and novel devices have been fabricated and introduced to the market. This has implied an increased demand for latest technologies to be integrated into devices.

Antennas' impedance bandwidth and return loss should be at an acceptable level so as to cover the target frequencies with minimum loss of electromagnetic waves. In literature, fractal antennas are widely accepted as a method for increasing the impedance bandwidth of the antennas by using various natural and artificially shaped geometries which are repeated in iterations [6]. In [7], a wideband antenna using fractal geometry is proposed for wireless applications which use hexagonally shaped fractal resonating in the range of (1.31 GHz–6.81 GHz). Another multiband fractal antenna using E shaped fractal is proposed for applications in mobile communication working in LTE/WWAN [8, 9]. A coplanar waveguide (CPW) feed having different features such as uni-planar structure, easy circuit integration and fabrication makes them more suitable for wireless communication devices. A CPW-fed dual wide-band modified Koch fractal slot antenna is proposed in [10] which is applicable to WLAN

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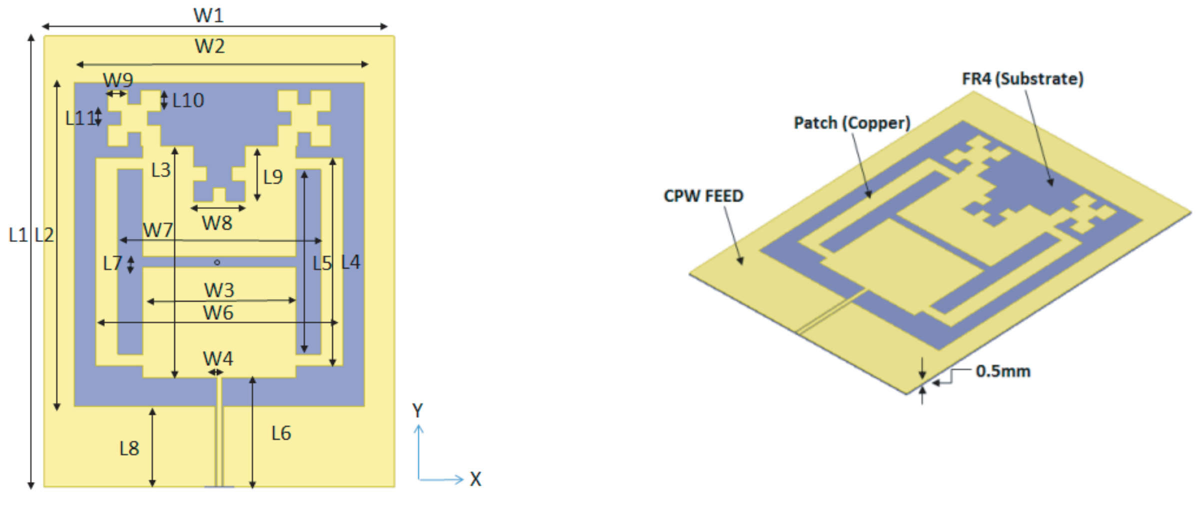
and WiMAX operation having gain above 2 dBi. With increasing demand for inculcating more features in the same device, the board space needs to be utilized carefully. Conventional antennas occupy more space due to their solid structures, so to overcome it there is need of antenna which is either transparent, electrically small or flexible. Transparent antennas can be accommodated anywhere as they will not affect the aesthetics of the device. A dual-band transparent antenna useful for wireless applications is proposed in [11–13] which resonates in WLAN and WiMAX frequency bands. Electrically small antennas have low gain, and narrow bandwidth [14]. A flexible antenna has leverage due to its bending nature which allows it to be interfaced easily without any need of extra space. A single band antenna operating at 2.45 GHz based on Kapton polyamide substrate is proposed in [15] which is made up using inkjet printing and tested under various bending conditions. In [16], the authors test the effect on $S_{11}$ due to deformation and crumpling effect using a coplanar fed flexible dual-band antenna built substrate made of Kapton polyimide applicable for ISM bands. A liquid crystal polymer (LCP) based CPW fed flexible antenna is proposed for breast cancer detection in [17]. CPW fed bow-tie antennas for wireless applications are proposed in [18, 19] which use Rogers RO4003C and FR4, respectively. Various other CPW fed flexible antennas are proposed for UWB systems [20] and Dual band applications [21].

In this article, a CPW fed flexible fractal slot antenna based on an FR-4 substrate is presented. The flexible antenna resonates at 2.4 GHz and 3.8 GHz which makes it suitable for low-cost WLAN/Bluetooth Wireless Personal Area Networks and WiMAX applications where available board space is small. The antenna design geometry, simulation, and testing results are presented in Section 2 and Section 3 followed by concluding remarks.

## 2. STRUCTURE OF PROPOSED ANTENNA

The flexible antenna printed on an FR-4 flexible sheet has a thickness of 0.5 mm as shown in Figure 1. The substrate in the form of FR-4 is used with a dielectric constant of 4.4 and loss tangent of 0.02. The antenna uses Coplanar Wave (CPW) Structure which acts as a ground plane. The flexible antenna is fed by a 50 Ω SMA connector which is connected to the patch and CPW feed for maximum power transfer. Therefore, patch and ground are placed on the same plane on the FR-4 sheet.

The slot in the middle of the patch gives rise to electromagnetic coupling. This is due to the capacitive effect created by the slot, and it helps in achieving dual frequency bands. Minkowski type



(a) (b)

**Figure 1.** Proposed antenna geometry, (a) top view, (b) side view. Antenna dimensions after optimization: Substrate Height: 0.5 mm, Substrate length ($L1$): 97.48 mm, Substrate Width ($W1$): 80 mm, Patch length ($L3$): 50 mm, Patch Width ($W3$): 35 mm, $W4$: 1 mm, $L5$: 40 mm, $W2$: 66.5 mm, $L2$: 70 mm, $W6$: 56.5 mm, $L3$ and $L4$: 45 mm, $W7$: 46.5 mm, $L6$: 38.74 mm, Origin ($O$): 0 mm, $W8$ and $L9$: 12 mm, $L11$: 3 mm, $L8$: 17.48 mm, $L10$ and $W9$: 4.5 mm and $L7$: 2.3 mm.

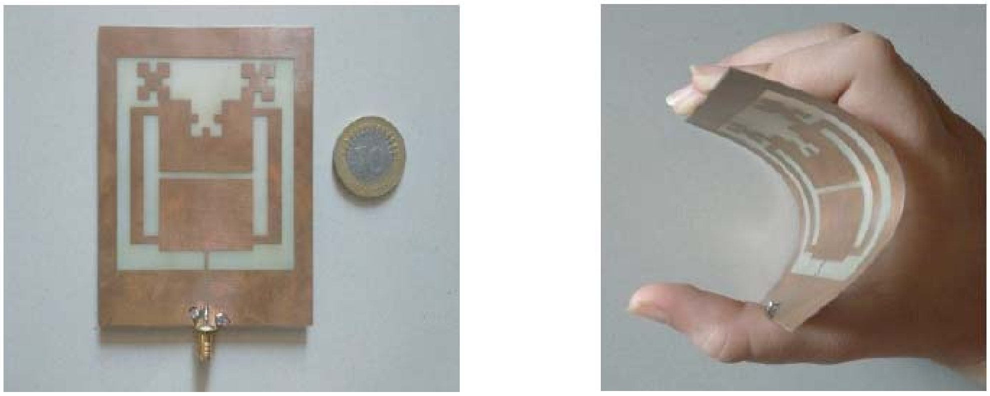

(a) (b)

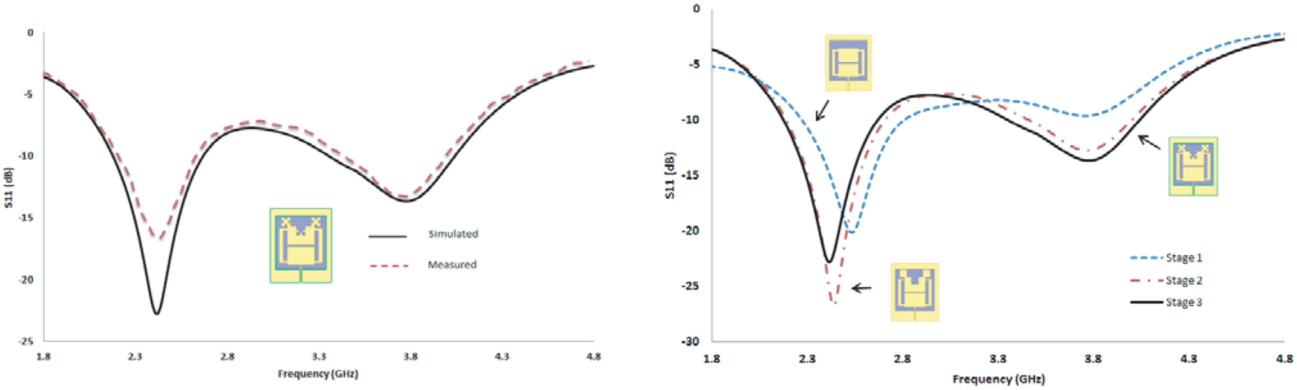
**Figure 2.** Fabricated antenna, (a) top view, (b) bending.

fractal geometry [22] is introduced which helps in improving the return loss and impedance bandwidth. C shaped branches protruding on both sides of the center patch help in achieving the proposed frequency bands of operation. The proposed flexible antenna has an overall dimension of $97.48 \times 80\,\text{mm}^2$ with the thickness of 0.5 mm which makes it easily bendable. The size of the antenna is slightly bigger than other antennas proposed in the literature; however, the promising results achieved using this design compensate the size. The fabricated antenna is shown in Figure 2(a). The flexibility of the antenna is visible from Figure 2 where antenna bending is along the $Y$-axis.

## 3. RESULTS AND DISCUSSION

The proposed antenna design is simulated in FEM (Finite Element Method) based HFSS software. The antenna is fabricated, and results in terms of return loss, radiation pattern and gain are measured using MS2037C (up to 15 GHz) Vector Network Analyzer and an anechoic chamber. Simulated and measured return losses are shown in Figure 3(a) which shows that the measured return loss of the proposed flexible antenna is 16.82 dB and 13.37 dB at 2.39 GHz and 3.77 GHz. The results are in great correlation. The slight variation in return loss is due to fabrication errors, losses due to SMA connector and soldering. At this point, the simulated and measured results by bending the antenna are not presented; however, the antenna fabricated using FR4 is flexible enough and has low cost to achieve promising results.

The evolution process of the proposed dual-band antenna is illustrated in Figure 4. The return

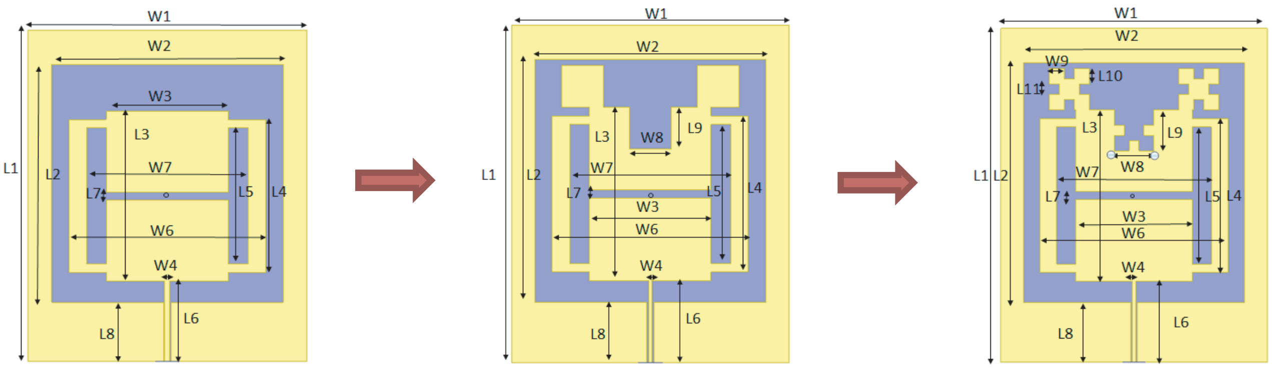


(a) (b)

**Figure 3.** $S_{11}$ (dB), (a) proposed antenna, (b) comparison of iterative stages.

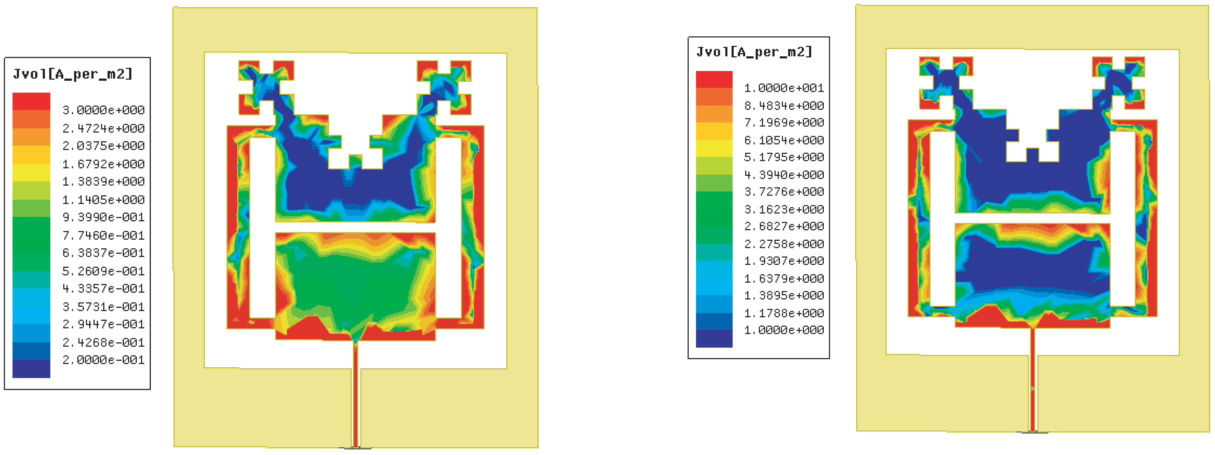
loss comparison plot of three stages is shown in Figure 3(b). Stage 1 is the basic structure of the patch with CPW feed which is achieved by adding a simple H shaped slot at the middle of the patch. Only one resonant mode is achieved using stage 1.

In stage 2, two square-shaped conducting boxes are added and a slot in the form of the square near the upper side of the center patch due to which the antenna starts radiating at two resonating modes.



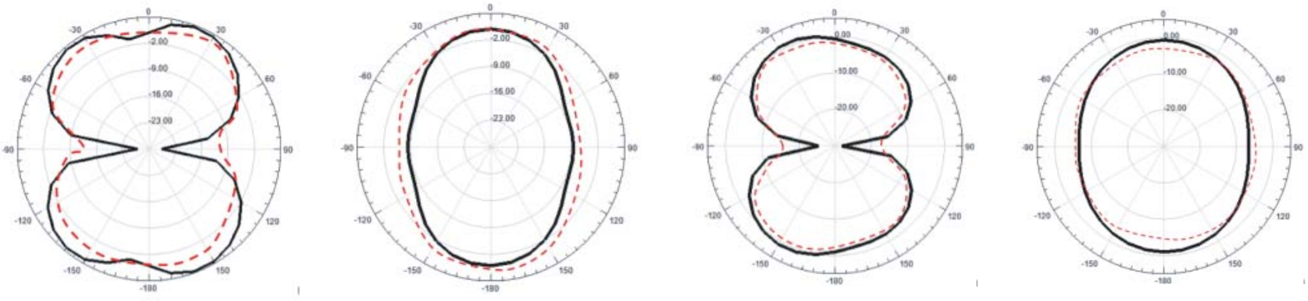
Stage 1 Stage 2 Proposed Antenna

**Figure 4.** Evolution process of the dual-band flexible antenna.



(a) (b)

**Figure 5.** Current distribution pattern at (a) 2.42 GHz and (b) 3.78 GHz.



*E* Plane *H* Plane *E* Plane *H* Plane

2.39 GHz 3.77 GHz

**Figure 6.** Simulated (solid) and measured (dashed) radiation pattern.

In stage 3, Minkowski fractal geometry up to the first iteration is introduced in square boxes which lead to increase in the bandwidth as well as return loss at higher resonance frequency with minor change in bandwidth and return loss at the lower resonance frequency. However, the targeted frequency bands are achieved with acceptable bandwidth and return loss by the introduction of fractal geometry.

Figure 5 indicates the current distribution for the flexible antenna. Maximum and minimum current densities are shown with red and blue colors respectively. A large surface current is concentrated near the center of lower conducting patch, feedline and on edges of the antenna at 2.4 GHz frequency. At 3.8 GHz, the current is distributed on the edges, center of the patch and feedline.

The *E* and *H* plane radiation pattern at 2.39 GHz and 3.77 GHz is shown in Figure 5. The radiation has a dipole-shaped pattern for *E* plane and omnidirectional pattern with no null for *H* plane in both the frequency bands.

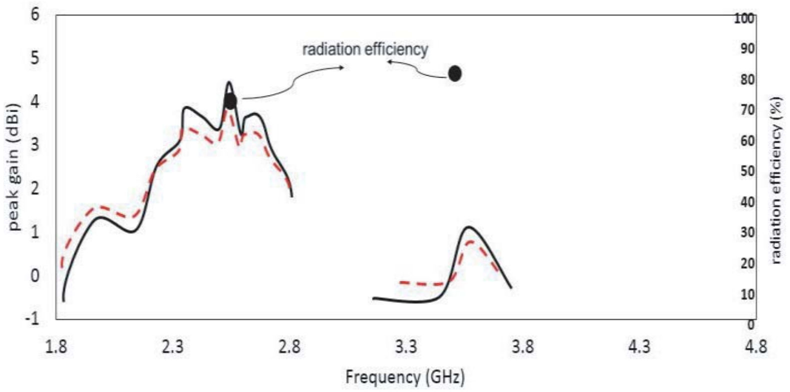


**Figure 7.** Gain (simulated: solid, measured: dashed) and efficiency of antenna at 2.39 GHz and 3.77 GHz.

**Table 1.** Flexible antenna characteristics.

| **Characteristics** | **Flexible Antenna Simulated/Measured** | |
|---|---|---|
| Resonance Frequency (GHz) | 2.42/2.39 | 3.78/3.77 |
| Return Loss (dB) | 22.75/16.82 | 13.40/13.37 |
| Gain (dBi) | 4.8/4.56 | 1.2/1.09 |
| Impedance Bandwidth (%) | 19.83/17.08 | 18.37/16.30 |
| Efficiency (%) | 86.25/82.54 | 78.54/75.11 |

**Table 2.** Comparison of flexible antenna with other flexible antennas from literature.

| **Ref** | **Size (mm)** | **Thickness (mm)** | **Material** | **Gain (dBi)** | **Frequency (GHz)** |
|---|---|---|---|---|---|
| [10] | 33.5 × 28.5 | 1.6 | FR4 | Less than 4.5 | 2.4/5.2/5.8,2.5/3.5/5.5 |
| [16] | 57 × 31 | 0.085 | Kapton polyimide | Not mentioned | 2.45, 5.8 |
| [17] | 30 × 20 | 1.6 | Liquid crystal polymer | Not mentioned | S-Band (3 GHz) |
| [18] | 80 × 60 | 0.2 | Rogers RO4003C | 6.20 | 2.4/3.65, 2.3/2.5/3.5 |
| [19] | 60 × 45 | 1.6 | FR4 | 3.65 | 2.4–2.48, 5.15–5.35, and 5.725–5.852 |
| Proposed Antenna | 97.48 × 80 | 0.5 | FR-4 | 4.56, 1.09 | 2.39, 3.77 |

The simulated and measured gains, as well as the efficiency of flexible antenna, are at a satisfactory level which is shown in Figure 7. At 2.42 GHz, the gain is 4.8 dBi, which is a higher value than that at 3.78 GHz about 1.2 dBi. The measured values of efficiency for the proposed flexible antenna are 82.54% and 75.11% at the lower and higher resonance frequencies. The antenna characteristics in terms of return loss, gain, impedance bandwidth, and efficiency are presented in Table 1.

Table 2 shows a comparison of the proposed CPW fed flexible fractal slot antenna with other CPW fed flexible antennas in the literature, which shows that the proposed antenna achieves higher gain with good impedance bandwidth using low-cost FR4 material due to fractal geometry, slotted structure, and CPW feed.

## 4. CONCLUSION

A dual-band flexible fractal slotted antenna is presented. The antenna radiates omnidirectionally and in a dipole-shaped pattern at higher and lower resonant frequencies. The measured impedance bandwidths of the antenna are 17.08% and 16.30% at 2.39 GHz and 3.77 GHz, respectively. The flexible antenna is fabricated and characterized experimentally and theoretically, which show good agreement. The measured gains of the antenna are 4.56 dBi and 1.09 dBi with the efficiency of 82.54% and 75.11% occurring at 2.39 GHz and 3.77 GHz which makes the antenna suitable for low-cost Bluetooth/WLAN/WPAN/WiMAX applications.

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