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Miniaturization of a CPW-fed Dual-Band Antenna for GSM 1800/1900 and WLAN 5 GHz Applications

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This paper presents a unique and miniaturized dual-band coplanar waveguide (CPW-fed) antenna for modern wireless communication. A new technique of using a modified ground structure (MGS) and frequency shifting strips (FSS) has been employed in the design to achieve dual-frequency operation. The proposed antenna generates two separate impedance bandwidths and covers the minimum required frequency bands of GSM 1800, GSM 1900, and Wi-Fi/WLAN 5 GHz. The proposed antenna is relatively small (17×20 mm^2) and operates over frequency ranges 1.51~2.06 and 4.43~6.70 GHz. The designed antenna was simulated using Ansoft HFSS, a FEM based simulator, and antenna characteristics, such as reflection coefficient, gain, radiation efficiency, radiation pattern, impedance bandwidth, VSWR, surface current, and electric field distributions, are reported in this paper. The effect of the antenna's key structural parameters on its performance is also analyzed.

Keywords: CPW-fed, Dual-band antenna, FSS, GSM, MGS, Wi-Fi/WLAN

1. INTRODUCTION

In the last few years, due to rapid increase in demand for wireless communications, cell phones were evolved, not just for voice communication, but also as a multimedia device with access to the internet and GPS tracking system. To meet the expectations of the end user, and to make the device more compact and stylish, the external antenna was replaced with a miniaturized internal antenna. A wireless device must support applications like mobile communication, high-speed data communication, and tracking systems, but designing such antennas faces great challenges because of the confined space available inside the devices [1,2]. Different techniques have been proposed for designing dual-band WLAN antennas [3–6]. Ali et al. proposed a dual-band/wideband packaged antenna for IEEE 802.11a WLAN band (5.15~5.35 and 5.725~5.825 GHz) applications [3]. Deshmukh et al. presented a technique for increasing bandwidth of microstrip antennas using quarter-wavelength resonant slots [7]. Some methods for designing compact, low profile, and broadband microstrip antennas were discussed in [8]. Most of the planar and coplanar monopole antennas were proposed because of attractive characteristics, such as low cost, light weight, compact size, and multi-resonance modes. The most serious limitations of microstrip antennas are their low gain and narrow bandwidth, since the size, the bandwidth, and the efficiency of an antenna are inter-related [9]. Typically, smaller antennas provide lower gain, so either the bandwidth or the gain of an antenna must be decreased [10]. Therefore, the bandwidth and the efficiency of an antenna have become major concerns for designing smaller antennas for wireless communication. The gains of such antennas are quite important, as they have to operate under hostile environments. Most of the real-time radio devices, such as Wi-Fi/WLAN and cellular phones, benefit from more bandwidth. The bandwidth increment would be achieved at some cost, but it can benefit the users by providing a higher data rate with shorter download time. The various feed structures that can be used for

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bandwidth enhancement, resonance-mode realization, and size reduction of a monopole antenna include the probe [11–14], the microstrip [15–17], and the coplanar waveguide (CPW) [18–20].

In this paper, a relatively small dual-band monopole antenna is presented for GSM and Wi-Fi/WLAN application. The proposed antenna provides two impedance bandwidths of 0.55 and 2.27 GHz with corresponding frequency bands of 1.51~2.06 GHz, centered at 1.702 GHz, and 4.43~6.70 GHz, centered at 5.802 GHz, respectively. A cell-phone antenna must cover and support the other countries GSM and WLAN bands to provide the advantages of roaming facilities during visits [21]. Therefore, several approaches and efforts were taken to improve the bandwidth, so that the proposed antenna offers a high-speed data connectivity and covers the other bands of GSM and WLAN. The proposed antenna meets the minimum required impedance bandwidth necessary for GSM 1800, GSM 1900 and WLAN 5 GHz applications. Moreover, the proposed antenna has pros, such as significantly reduced dimensions, coplanar structure with a simple and effective resonator, less power consumption, and a low-cost FR-4 substrate design. The antenna's performance was simulated using Ansoft HFSS. We achieved wider bandwidth than did other designs presented in [22–24].

2. ANTENNA BASIC STRUCTURE

This section presents a study of a basic antenna model with two stages of modifications carried out by varying some parameters, such as feed width and step width, while keeping others constant. Figure 1 describes the geometry of an antenna without step.

The basic CPW-fed antenna (17 × 20 mm^2) with its geometry is shown in Fig. 2. In the first stage, an antenna is designed to study the behavior of feed without using the step (Fig. 1). In the second

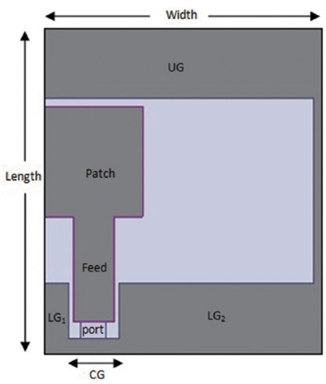

Fig. 1. Geometry of the antenna model without step.

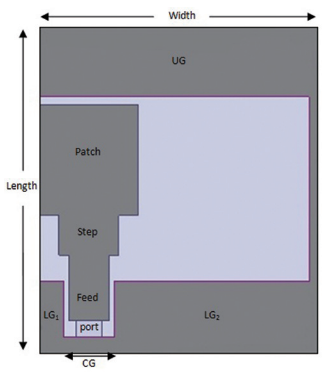

Fig. 2. Geometry of the basic antenna model with step.

Table 1. Parameters for the antennas shown in Figs. 1 and 2.

Parameter			Size(mm) Width	Length	Height
Substrate			17.00	20.00	1.00
Patch			6.00	6.78	0.02
Step (Fig. 2)			3.67	2.43	0.02
Feed (Fig. 1)			2.50	6.43	0.02
Feed (Fig. 2)			2.50	4.00	0.02
Port (rectangular sheet)			1.55	1.04	0.00
Grounds	Upper ground	UG	17.00	4.25	0.02
	Lower ground	LG_1	1.45	4.40	0.02
		LG_2	12.45	4.40	0.02
	Connecting ground	CG	3.10	0.96	0.02

Table 2. Simulated Results for antenna model in Fig. 1.

Feed width (mm)	S_{11}(dB)	Center freq. (GHz)	Freq. band at -10 dB (GHz)	Band-width at-10 dB (GHz)	VSWR
2.5	-9.2316	1.002	0	0	2.0557
2.6	-9.0788	1.002	0	0	2.0846
2.7	-12.4596	0.902	0.856~1.005	0.146	1.6255
2.75	-9.0651	1.002	0	0	2.0872
2.8	-9.0722	1.002	0	0	2.0858
2.9	-8.9933	1.002	0	0	2.1012

Table 3. Simulated results for basic antenna model in Fig. 2.

Step width (mm)	Feed width (mm)	S_{11} (dB)	Center freq. (GHz)	Freq. band at -10 dB (GHz)	Band-width at -10 dB (GHz)	VSWR
3.67	2.7	-9.6707	1.002	0	0	1.9782
3.67	2.5	-9.0955	1.002	0	0	2.0813
4.67	2.7	-9.3760	1.002	0	0	2.0293
6.00	2.7	-9.5953	1.002	0	0	1.9909

stage, a step is introduce in the design antenna and made to work as a reference antenna, as shown in Fig. 2.

Table 1 provides information about the optimized parameters to be considered for the antennas shown in Figs. 1 and 2.

Table 2 presents information about the parametric changes in the design (Fig. 1) needed for different feed widths, keeping its length constant (6.43 mm). Again, the antenna in Fig. 1 is further studied by introducing a step with the feed (Fig. 2). By varying the feed width and step width with a constant length of 4 and 2.43 mm, respectively, antenna characteristics, such as reflection coefficient, center frequency, VSWR, operating frequency bands, and impedance bandwidths, are simulated for Fig. 2; the obtained results are tabulated in Table 3.

As illustrated in Table 3, the simulated results do not meet the minimum required frequency and band width for GSM and Wi-Fi/WLAN, so the reference antenna (Antenna i) was further studied with an optimum feed size (2.5 × 4 × 0.02 mm) and step size (3.67 × 2.43 × 0.02 mm) in section 3.

3. EFFECT OF MODIFIED GROUND STRUCTURE AND STRIPS

The section studies and presents the effect of using modified ground structure (MGS) and frequency shifting strips (FSS) on a CPW-fed antenna (Fig. 2). A FSS is formed by combining metallic strips (S_1 to S_6) which surround the patch of the antenna (Fig. 4) and interconnect both the upper and lower ground sections. The FSS structure so formed in the design helps in achieving dual-frequency

Table 4. Parameters of the proposed antenna.

Parameter			Size(mm) Width	Length	Height
Substrate			17.00	20.00	1.00
Patch			6.00	6.78	0.02
Step			3.67	2.43	0.02
Feed			2.50	4.00	0.02
Lumped port (rectangular sheet)			1.55	1.04	0.00
Grounds	Upper ground	UG	17.00	4.25	0.02
	Lower ground	LG_1	1.45	4.40	0.02
		LG_2	12.45	4.40	0.02
		LG_3	8.375	3.60	0.02
		LG_4	2.625	1.60	0.02
		LG_5	1.3125	1.00	0.02
	Connecting ground	CG	3.10	0.96	0.02
Strips	S_1		0.50	6.25	0.02
	S_2		4.175	0.50	0.02
	S_3		0.50	2.00	0.02
	S_4		1.50	0.50	0.02
	S_5		0.50	1.5	0.02
	S_6		0.50	2.5	0.02
Gaps	g_1		0.30		
	g_2		0.225		
	W_s		5.425		

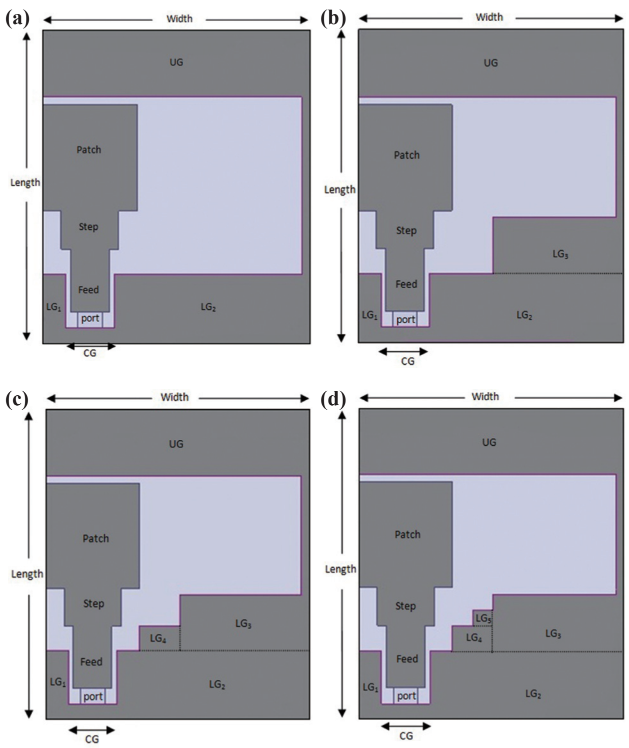

Fig. 3. Evolution of the proposed dual band antenna. (a) Antenna i, (b) antenna ii, (c) antenna iii, and (d) antenna iv.

operation. The effect of using modified ground structures (MGSs) on the same side of the substrate was carried out in detail in our previously studied antenna model [25]. Figs. 3 and 4 presents the stages of modifications being introduced during the evolution of the proposed CPW-fed antenna, and its corresponding simulated reflection coefficients are shown in Fig. 6. Figure 5 gives an idea about a 3D HFSS model of the proposed antenna. The design procedures begin with designing the reference antenna (antenna i or Fig. 1) and lead to a proposed antenna (Fig. 4). The parameters and dimensions considered during the evolution of the design are tabulated in Table 4.

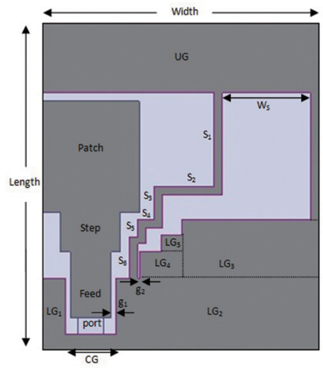

Fig. 4. Geometry of the proposed dual band antenna of dimension (17 × 20) mm^2.

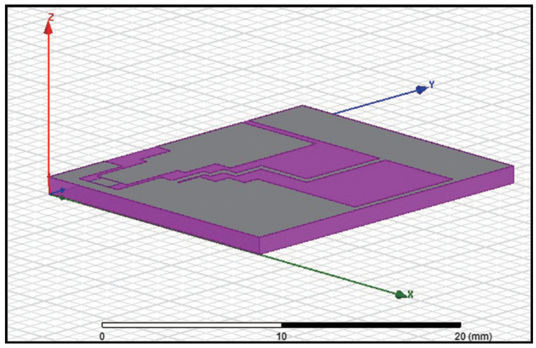

Fig. 5. 3D HFSS model of proposed dual band antenna.

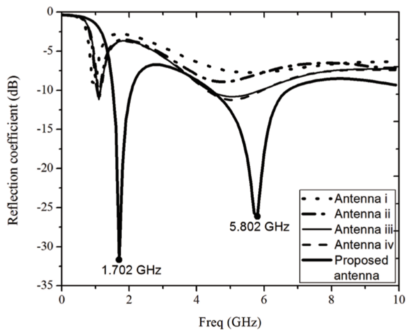

Fig. 6. Simulated reflection-coefficients of the proposed dual band antenna.

The effects of using MGS and FSS on the same side of a substrate during the evolution of the proposed antenna are explained below.

3.1 Effect of LG_{1-2} and UG

As shown in the graph in Fig. 6, the antenna i is confined to a resonant frequency of 1.002 GHz with a reflection coefficient ≤ -5 dB (-9.0955 dB).

3.2 Effect of LG_{1-3} and UG

The antenna ii, in Fig. 3 shows resonating at a frequency of 1.102 GHz with a reflection coefficient ≤ -10 dB (-11.2018 dB).

3.3 Effect of LG_{1-4} and UG

It is seen from Fig. 3 (antenna iii), by adding grounds LG_3 and

LG_4, the antenna starts exciting with two resonant modes: the first with a resonant frequency of 1.102 GHz with reflection coefficient ≤ -10 dB (-11.1761 dB), and the second with a resonant frequency of 5.102 GHz with reflection coefficient of -10.8226 dB.

3.4 Effect of LG_{1-5} and UG

The geometry of antenna iv (Fig. 3) and Fig. 6 describes the frequency behavior with two resonant modes, i.e., resonating frequencies of 1.102 and 5.002 GHz with reflection coefficients of -10.9230 and -11.2176 dB, respectively.

3.5 Effect of LG_{1-5}, UG, and frequency shifting strip (FSS)

The simulated result in Fig. 6 depicts that, by adding a step shaped FSS connecting both UG and LGs, distinct resonant modes are obtained. The proposed structure improves impedance matching and reflection coefficients of -31.6752 and -26.1299 dB are achieved. FSS shifts both the resonant frequencies from 1.102 to 1.702 GHz and 5.102 to 5.802 GHz with improved frequency bands of 1.51~2.06 and 4.43~6.70 GHz at -10 dB.

4. RESULTS AND ANALYSIS

The proposed CPW-fed antenna and its geometry is shown in Fig. 4, with a frequency shifting strips (FSS) structure (S_1 to S_6) which connects the upper ground (UG) and lower ground (LG_1 to LG_5) and provides the dual-frequency operation. The antenna is made such that a modified ground with CPW-fed structure is obtained and etching can be done on the same side of a FR-4 substrate with dielectric constant 4.4 and thickness 1 mm. The proposed antenna has a dimension of 17×20 mm^2 and shows two impedance bandwidths of 0.55 and 2.27 GHz at center frequencies of 1.702 and 5.802 GHz between operating bands of 1.51~2.06 and 4.43~6.70 GHz respectively with a reflection coefficient ≤ -10 dB, making it suitable for GSM 1800, GSM 1900 and Wi-Fi/WLAN 5 GHz.

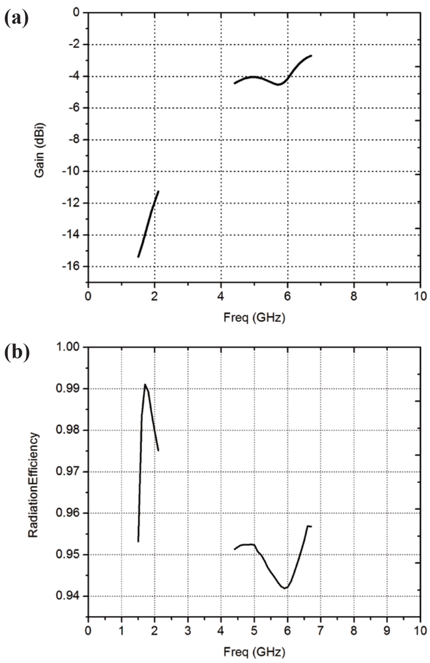

Fig. 7. Simulated (a) gain response and (b) radiation efficiency of the proposed antenna.

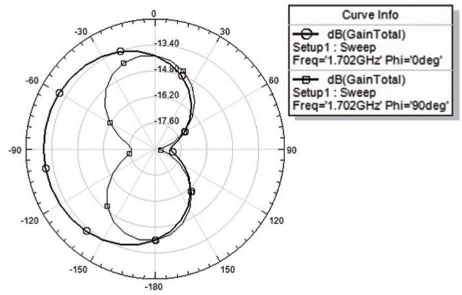

Fig. 8. Simulated radiation patterns of the proposed antenna at 1.702 GHz in the yz-plane (E-plane) and xz-plane (H-plane).

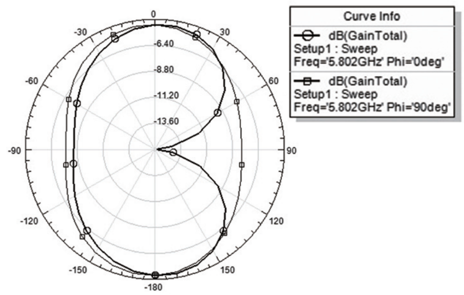

Fig. 9. Simulated radiation patterns of the proposed antenna at 5.802 GHz in the yz-plane (E-plane) and xz-plane (H-plane).

Table 5. Simulated results for the antennas shown in Figs. 3 and 4.

Antenna	S_{11}(dB)	Center freq. (GHz)	Freq. band at -10 dB (GHz)	Impedance bandwidth at -10 dB (GHz)	VSWR
Antenna i	-9.0955	1.002	0	0	2.0813
Antenna ii	-11.2018	1.102	1.10~1.13	0.03	1.7600
Antenna iii	-11.1761	1.102	1.06~1.14	0.08	1.7631
	-10.8226	5.102	4.37~5.89	1.52	1.8076
Antenna iv	-10.9230	1.102	1.07~1.14	0.07	1.7947
	-11.2176	5.002	4.30~5.94	1.64	1.7581
Proposed antenna	-36.6752	1.702	1.51~2.06	0.55	1.0535
	-26.1299	1.1039	4.43~6.70	2.27	5.802

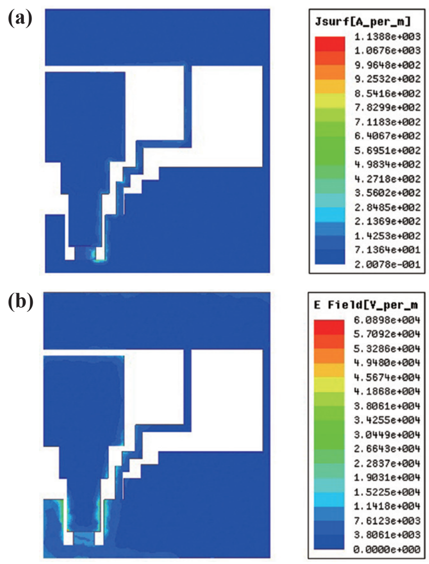

Fig. 10. Simulated (a) surface current distribution and (b) electric field distribution of the proposed antenna.

Table 6. Comparisons with other dual-band antennas.

Antenna	Substrate dimensions (mm)	Freq.band at -10 dB (GHz)	Center freq. (GHz)	Impedance bandwidth at -10 dB (GHz)	Application
Moghadasi et al. model	17 × 20 × 1	1.60~1.85	1.72	0.255	GSM 1800
		4.95~5.80	5.30	0.850	Wi-Fi/ WLAN
Liang et al. model	29 × 15 × 1.5	2.15~2.66	2.40	0.51	WLAN
		5.04~6.00	5.50	0.96	2.4, 5 GHz
Gao et al. model	35 × 35 × 1.25	2.30~2.70	2.40	0.40	WLAN 2.4, 5.2/ 5.8 GHz
		5.12~6.05	5.60	0.93	
Proposed antenna	17 × 20 × 1	1.51~2.06	1.702	0.55	GSM 1800/ 1900
		4.43~6.70	5.802	2.27	Wi-Fi/ WLAN 5.2, 5.5 & 5.8 GHz

The simulated gain response (in dBi) and radiation efficiency as a function of frequency are plotted in Fig. 7 (a) and (b) respectively, which shows the relationship between the gain and efficiency performance of the proposed antenna. It is well noted from Fig. 6 and Fig. 7 (a) that the bandwidth of the proposed antenna was increased, which decrease gain to an extent. The simulated radiation patterns at 1.702 and 5.802 GHz in the yz-plane (E-plane) and xz-plane (H-plane) are plotted in Figs. 8 and 9, respectively.

Table 5 presents the simulated results of the antennas shown in Figs. 3 and 4, such as reflection coefficient (S_{11} in dB), VSWR, operating frequency bands, center frequencies, and impedance bandwidths. The simulated surface current and electric field distributions for the proposed antenna are shown in Fig. 10 (a) and (b), respectively, where strong surface currents can be seen over the antenna's feed line and step-shaped grounds.

The comparison of the proposed antenna with other reported CPW-fed monopole antennas presented in [22–24] is summarized in Table 6. It is seen that the proposed structure shown in Fig. 4 results in better and wider bandwidth than that of other models cited in this paper and can be a good approach for GSM 1800, GSM 1900, and WLAN 5 GHz applications.

5. CONCLUSION

Using a modified ground structure and high-impedance frequency-shifting strip, we designed a small dual-band antenna. The obtained center frequencies are 1.702 and 5.802 GHz between operating bands of 1.51~2.06 and 4.43~6.70 GHz, respectively. The overall technique of CPW-feed thus enables the creation of a dual-band antenna by maintaining the required dimensions of a mobile antenna. The proposed antenna exhibits two resonant modes with improved impedance matching and has various pros, such as compactness, light weight, low cost, and wide bandwidth, as well as the fact that it can be integrated with small devices, which make the proposed antenna well-suited for GSM 1800, GSM 1900, and Wi-Fi/ WLAN 5 GHz applications.

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