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Design, Realization and Measurements of Compact Tetraband PIFA Antenna for Mobile Handset Applications

Mohamed Tarbouch[1], **Abdelkebir El Amri**[2], **Hanae Terchoune**[3]

[1] RITM Laboratory, CED Engineering Sciences, Ecole Supérieure de Technologie, Hassan II University of Casablanca, Morocco
[2] RITM Laboratory, CED Engineering Sciences, Ecole Supérieure de Technologie, Hassan II University of Casablanca, Morocco
[3] RITM Laboratory, CED Engineering Sciences, Ecole Supérieure de Technologie, Hassan II University of Casablanca, Morocco

Abstract. In this paper, a tetraband planar inverted-F antenna (PIFA) for mobile handset applications is studied. The proposed structure covers the GSM (880–960 MHz), DCS (1710–1880 MHz), PCS (1880–1990 MHz), and UMTS (1920–2170 MHz) bands. The miniaturization in the antenna size is achieved by introducing a meandered line design. The antenna has compact size of 40x26x1.7mm3. The radiation patterns in each operating bandwidth are almost the same as the omnidirectional characteristics. Moreover the proposed structure offers remarkable gain in the lower band compared to previous works. The simulation analysis was performed using the CADFEKO software, a Method of Moment (MoM) based solver, and a prototype of this antenna was fabricated, good agreement with the simulation providing validation of the design procedure.

The measurements are done with ANRITSU MS2026C Vectorial Network Analyzer.

1. Introduction

Today, technological advancements in wireless communication and the diversity of needs in this area are leading to the creation of ever smaller, lighter, and more multifunctional mobile handsets [1]. As a result, antennas have gone from external to internal; they have also become subject to numerous constraints in size and function. For antennas to satisfy the requirements of the current market, they must be compact while having multiband capability. Accordingly, attention is being focused on high-performing antennas with simple structures, one of which is the planar inverted-F antenna (PIFA). The PIFA consists in general of a ground plane, a top plate element, a feed wire attached between the ground plane and the top plate, and a shorting wire or strip that is connected between the ground plane and the top plate.

Because it operates at a resonant length of ($\lambda/4$), it is highly conducive to a small and lightweight design, and thus well-suited for use as an internal antenna [2]. The PIFA has the advantage of a low profile, but its narrow bandwidth makes it difficult to realize multiband capability with a single resonator. While this problem can be resolved by using additional resonators [3], such additions tend to increase the size of the antenna. This means that with a PIFA, it is difficult to simultaneously achieve miniaturization and multiband capability.

The miniaturization can affect radiation characteristics, bandwidth, gain, radiation efficiency and polarization purity. The miniaturization approaches are based on either geometric manipulation (the

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use of bend forms, meandered lines, PIFA shape, varying distance between feeder and short plate, using fractal geometries[4-7]) or material manipulation (Loading with a high-dielectric material, lumped elements, conductors, capacitors, short plate [8]), or the combination of two or more techniques [9].

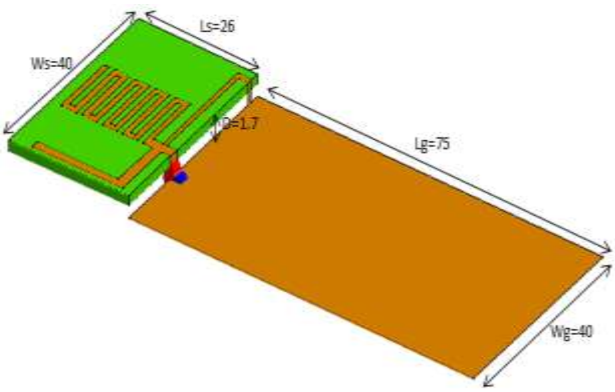
To overcome the problem described, we propose a compact Tetra band PIFA antenna. The proposed structure is composed of two radiators, a meandered patch line radiator and L-shaped line radiator. The first radiator has two resonance frequencies f1 and f2, the frequency f1 covers mainly the lower band (GSM900) with 10.3% bandwidth and f2 covers a small part of higher bands, while the second radiator has one resonance frequency f3. The last resonance frequency f3 when combined with the second resonance frequency f2 allows the structure to covers 30.3% bandwidth which led to cover the three services GSM1800, PCS and UMTS. The design methodology of the antenna is included in section 2. In section 3 the designed antenna is manufactured and measured and results are discussed.

2. Design Methodology

2.1 Antenna Geometry

Fig. 1(a) shows the 3-D geometry of the proposed antenna, which consists of a two radiators, an L-shaped radiator printed in the left of the antenna and a meandered line radiator printed in the center of the antenna. For efficient radiation, the ground (GND) found on the bottom surface of the substrate was turned by 180 degrees. The system GND for the antenna has a dimension of 75 mm length and 40 mm width and it is connected with the top radiators elements using a shorting strip. The volume under the radiating elements is filled by air except a thin region 1.6 mm who is composed of FR4_epoxy substrate with relative permittivity of 4.4.

Fig. 1(b) shows in details the geometry of the printed radiators as seen from above. The antenna takes up an area occupying 40*26 mm on the upper surface of the substrate. The radiators elements are placed at a height D=1.7 mm from the horizontal plan of the ground plane. The height D is composed of 1.6 mm the thickness of the substrate and a 0.1 mm of the Air. The proposed structure is excited with a microstrip feed line of input impedance (Z0= 50 ohms).



(a)

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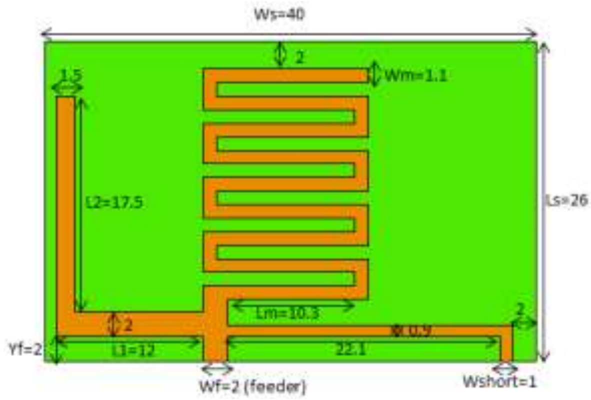

(b)

Figure. 1. (a) 3-D geometry of the proposed antenna. (b) Patch antenna geometry as seen from above in mm

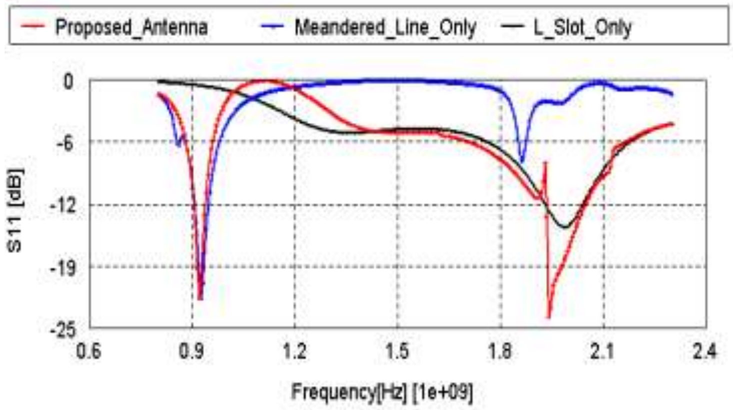

Figure. 2. Simulated reflection coefficients for the proposed antenna, the meandered line radiator, and the L-shaped radiator

Fig. 2 shows the simulated reflection coefficients for the proposed antenna, the meandered line radiator, and the L-shaped radiator. The parameters for the proposed antenna were set as mentioned in Fig. 1(b).

As Fig. 2 shows, the proposed antenna has three resonant frequencies. f1=0.92 GHz and f2=1.908 GHz are the fundamental frequency and the second harmonic component of the meandered line radiator, respectively, while f3 frequency is determined by the total length of the L-shaped radiator, which is 1.944 GHz. Note that the bandwidth used here is -6 dB which is a widely used value for the internal antenna in practical mobile phone applications [10-12]. By combining the resonance frequency f3 of L-shaped resonator with the second harmonic component of the meandered line resonator f2, broadband characteristics encompassing DCS, PCS, UMTS can be easily implemented.

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2.2 The Choice of the Patch parameters

We set Ws= 40 mm, then we change Ls from 24 mm to 26 mm , by varying Ls the S11 parameter of the antenna versus frequency is shown in Fig. 3. Table 1 summarizes the bandwidth obtained by varying the Ls parameter. From TABLE I we note that Ls=26 mm is the most adapted value in term of bandwidth, and will allows to get the lower band to be centered in 0.92 GHz which is the centered frequency of the GSM band. Moreover all other values can be considered not interesting values in term of bandwidth.

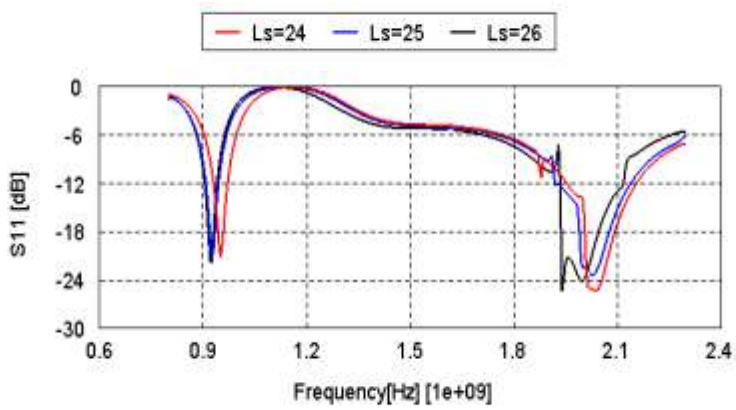

Figure.3. Simulated S11 versus frequency by varying the parameter Ls

Table 1. Bandwidth versus the Parameter Ls

Ls (mm)	Bandwidth(MHz)
24	893-1003 & 1744-2300
25	875-977 & 1722-2300
26	872-967 & 1679-2280

2.3 The Choice of the Height D

The height D is the distance between the top plane of the patch and the horizontal plane of the ground plane. By varying the height D from 1.6 mm to 5.6 mm the S11 parameter of the antenna versus frequency is shown in Fig.4. From the simulation results it’s clear that the height D affect mainly the UMTS band, except for D=1.6 witch affect also to GSM band.

Table 2 summarizes the bandwidth and resonances frequencies obtained by varying the height D. From Table 2 we note that D=1.7mm will allows us to have a good antenna in term of bandwidth. In addition, a low antenna height (1.7 mm) allows us to obtain a small antenna volume, which is 1.768 cm^3.

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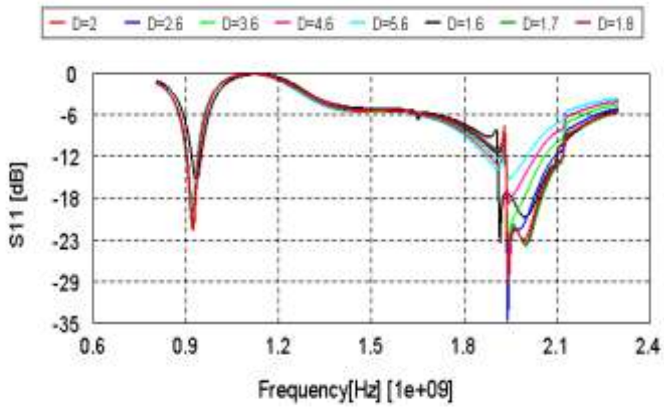

Figure.4. Simulated S11 versus frequency by varying the height D in mm

Table 2. Bandwidth and Resonant Frequency versus the Height D

D(mm)	Bandwidth (MHz)	Resonance frequency(GHz)/S11(dB)
1.6	884-979 1712-2250	N/A
1.7	872-967 1679-2280	0.92/-22.03 1.908/-10.84&1.944/-25.69
1.8	872-968 1700-2272	0.92/-22.01 1.908/10.85&1.940/-26.97
2	871-969 1678-2263	0.92/-22.16 1.910/-11.01&1.942/-29.64
2.6	871-969 1678-2235	0.92/-22.26 1.906/-11.47 & 1.940/-34.89
3.6	870-968 1657-2190	0.92/-22.19 1.907/-12.07 & 1.940/-24.16
4.6	873-963 1642-2149	N/A
5.6	869-963 1625-2130	N/A

2.4 The Choice of the meandered line parameters

The meandered line parameters are Lm and Wm, by varying the parameter Lm from 9.5 mm to 11 mm the S11 parameter of the antenna versus frequency is shown in Fig.5. From the simulation results, we note that the parameter Lm affects mainly the GSM band, while higher bandwidth remains unchanged. In addition from the graph we note that as Lm is increased, the first resonance frequency f1 of the meandered line is decreased while the bandwidth arise from the combination of f2 and f3 remains unchanged.

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Table 3 summarizes the bandwidth obtained by varying the parameter Lm. From Table 3 we note that Lm=10.3mm will allows us to have a good antenna in term of bandwidth for higher bands, and will allows us to get the lower band to be centered at 0.92 GHz.

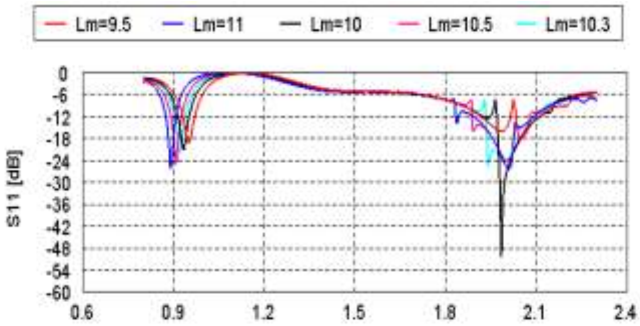

Figure.5. Simulated S11 versus frequency by varying the parameter Lm

Table 3. Bandwidth versus the Parameter Lm

Lm(mm)	Bandwidth (MHz)
9.5	895-1001 & 1698-2280
10	881-983 & 1698-2280
10.3	872-967 & 1679-2280
10.5	859-956 & 1679-2280
11	844-936 & 1679-2280

By varying the parameter Wm from 0.9 mm to 1.2 mm the S11 parameter of the antenna versus frequency is shown in Fig.6. From the simulation results we note that the parameter Wm affects both resonances frequencies f1 and f2, which influence the whole antenna behavior.

Table 4 summarizes the bandwidth obtained by varying the parameter Wm. From Table 4 we note that Lm=1.1mm is the most adapted value in term of bandwidth, and will allows to get the lower band to be centered in 0.92 GHz. In reality, the simulation shows close results for the Wm parameter values 1 mm and 1.1 mm. Also, 0.9 mm and 1.2 can be considered not interesting values.

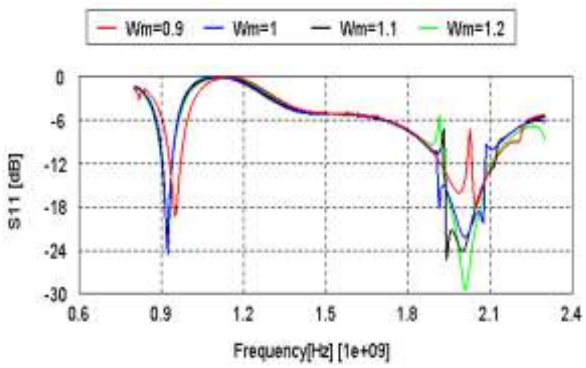

Figure.6. Simulated S11 versus frequency by varying the parameter Wm

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Table 4. Bandwidth versus the parameter Wm

Wm(mm)	Bandwidth (MHz)
0.9	895-1003 & 1706-2256
1	875-968 & 1691-2272
1.1	872-967 & 1679-2280
1.2	871-968 & 1691-1911 & 1924-2200

2.5 The Choice of The L-shaped parameters

We set L1= 7 mm, then we change L2 from 16.5 mm to 18.5 , by varying L2 the S11 parameter of the antenna versus frequency is shown in Fig. 7. Table 5 summarizes the bandwidth obtained by varying the parameter L2. From Table 5 we note that as L2 increased the bandwidth of higher bands decreased while the GSM band remains unchanged. Moreover we note that L2=17.5 mm is the most adapted value in term of bandwidth, and will allows to get the lower band to be centered in 0.92 GHz. Again, the simulation shows close results for most L2 parameter values and L2=16.5 can be considered not interesting value.

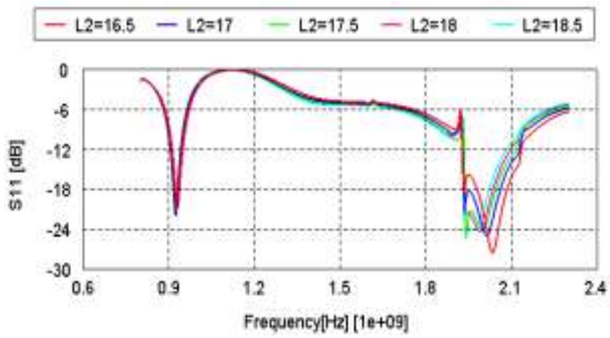

Figure.7. Simulated S11 versus frequency by varying the parameter L2

Table 5. Bandwidth versus the Parameter L2

L2(mm)	Bandwidth (MHz)
16.5	875-977 & 1730-2280
17	873-971 & 1702-2300
17.5	872-967 & 1679-2280
18	879-979 & 1675-2266
18.5	879-979 & 1655-2241

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2.6 The Choice of the ground plane parameters

We set Wg= 40 mm, then we change Lg from 60 mm to 80 , by varying Lg the S11 parameter of the antenna versus frequency is shown in Fig. 8.

Table 6 summarizes the bandwidth obtained by varying the Lg parameter. From Table 6 we note that Lg=75 mm is the most adapted value in term of bandwidth, and will allows to get the lower band to be centered in 0.92 GHz. Moreover all other values can be considered not interesting values in term of bandwidth and also of compactness.

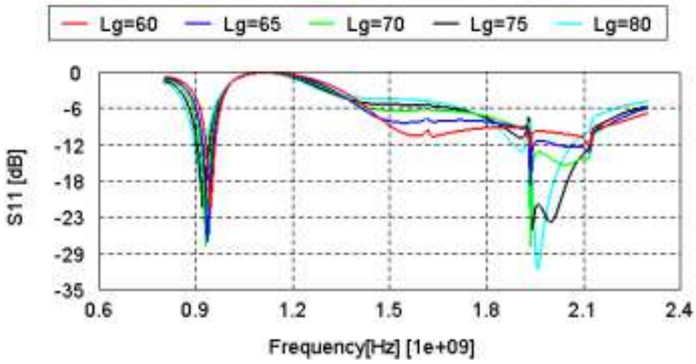

Figure.8. Simulated S11 versus frequency by varying the parameter Lg

Table 6. Bandwidth versus the Parameter Lg

Lg(mm)	Bandwidth (MHz)
60	903-981 & 1425-2300
65	895-977 &1406-2300
70	883-973 & 1623-2308
75	872-967 & 1679-2280
80	861-964 & 1712-2209

3. Antenna Realization: Results and Discussion

From the previous parametric study in section 2 of the proposed antenna, we obtained an optimized structure which has a compact size and an interesting reflection coefficient in the operating studied bands. After good results obtained by simulations, we manufactured the antenna on a PCB (Printed Circuit Board) and we measured the S11 parameter of the antenna, Fig.9 shows a photograph of the realized antenna with the dimensions as found in section 2. (Lg=75 mm, Wg=40 mm, Ws=40 mm, Ls=24 mm, D=1,7 mm, L1=7mm, L2=17,5 mm,Wm=1,1 mm, Lm=10,3 mm).

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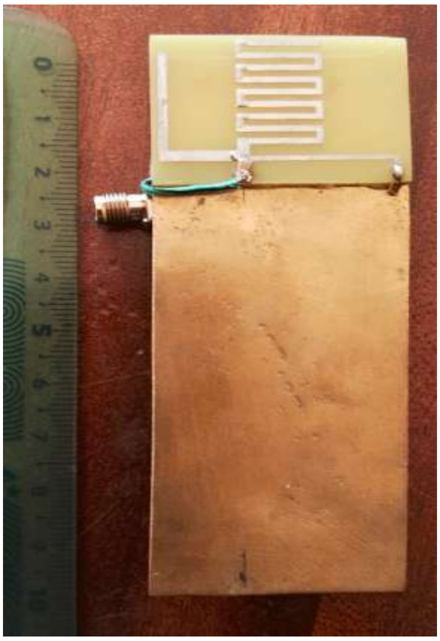

Figure.9.The Realized Antenna

The measured and simulated results for the reflection coefficient of the proposed antenna are shown in Fig.10. The reflection coefficient magnitude was measured using ANRITSU MS2026C Vectorial Network Analyzer.

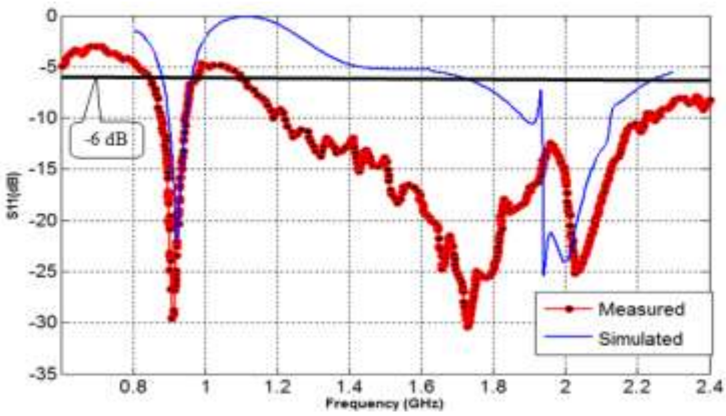

Figure.10. Simulated and measured S11 versus frequency of the realized antenna

Due to manufacturing imperfections, the measurement results are not exactly similar to the simulated results. Some measured resonant frequencies are shifted from those simulated. For example, as shown in Fig. 10, the first measured resonant frequency (f1) of the GSM900 band is 912MHz while the simulated one is 920MHz. Also the measured bandwidth of GSM900 [849-977 MHz] is large than the simulated one [872-967].

The same for the second resonant frequency (f2) of the meandered line, the measured resonant frequency is 1728MHz while the simulated one is 1908MHz. Also the obtained bandwidth around the resonance frequency f2 is very large than simulated one. In addition measurements show that the total

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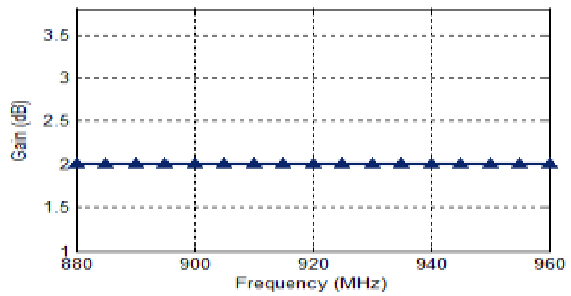
obtained bandwidth when combining the resonant frequency f2 and f3 is very large than simulated one. Also, some differences between measured and simulated S11 are observed. For example, as shown in Fig. 10, the measured S11 corresponding to the resonant frequency f1 is very low (-30dB) compared to the simulated one (-22.03dB). Table 7 summarizes the comparison between simulated and measured S11 and (-6dB) bandwidths.

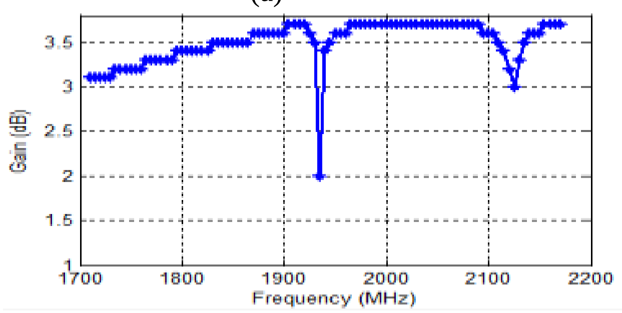
Table 7. Comparison between Simulated and Measured Results

Simulated Results		Measured Results	
Resonant frequencies (GHz)/S11(dB)	(-6dB) bandwidths (MHz)	Resonant frequencies (GHz)/S11(dB))	(-6dB) bandwidths (MHz)
0.92/-22.03	872-967	0.912/-30	849-977
1.908/-10.84	1679-2280	1.728/-30.39	1097-2430
1.944/-25.69		2.027/-25.13	

Fig.11 shows the maximum gain of the proposed antenna. At the GSM band, the maximum gain is stable and it is equal to 2 dB in the whole band. At the DCS band, it varies from 3.1 to 3.6 dB, while it varies from 2 to 3.6 dB at the PCS/UMTS bands.



(a)



(b)

Figure.11. Maximum gain of the proposed antenna: (a) GSM900 band, (b) GSM1800, PCS and UMTS bands

Figures 12, 13 and 14 show the 3D radiation patterns of the proposed antenna for the three resonances frequencies f1=0.92GHz, f2=1.908 GHz and f3=1.944 GHz respectively. As shown in figure 12, the radiation pattern for the f1 frequency is nearly omnidirectional for three planes, while it's omnidirectional in the XZ plane for the two others resonances frequencies.

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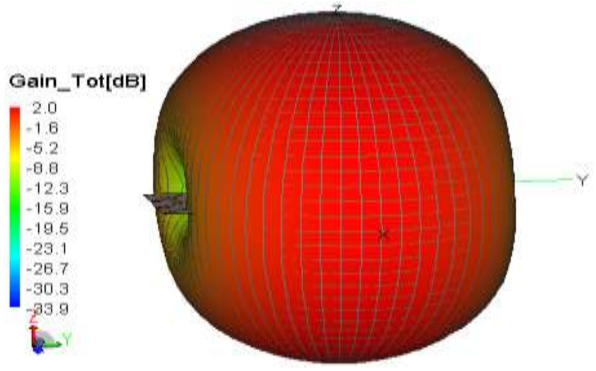

Figure.12.The 3D total gain pattern of miniaturized antenna at f1=0.92 GHz

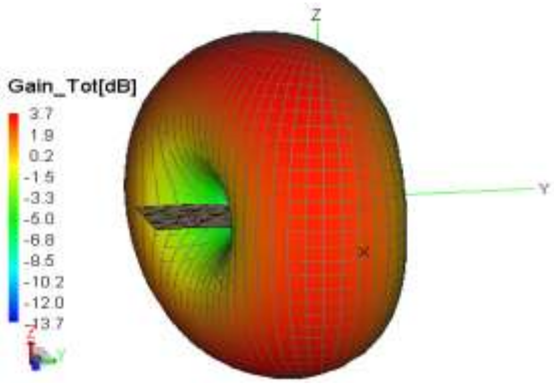

Figure.13.The 3D total gain pattern of miniaturized antenna at f2=1.908 GHz

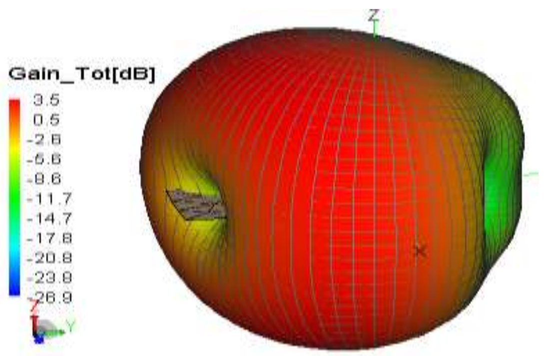

Figure.14.The 3D total gain pattern of miniaturized antenna at f3=1.944 GHz

Also, comparison between several different multi-bands antennas for handset applications is illustrated in Table 8. From this table it's clear that our structure has a miniaturized design compared to most other antennas. Moreover the proposed antenna has the best and stable gain in the GSM900 band, which is 2 dB. Moreover the proposed antenna has reasonable gain in the three other bands.

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Table 8. Comparison of the proposed Antenna to Other antennas for Handsets Applications

Ref.	Dimension (mm3)	Volume (cm3)	Bands	Gain (dB)
Our work	40*26*1.7	1,768	GSM900	2
			DCS1800	3.1 to 3.6
			PCS1900	2 to 3.7
			UMTS	2 to 3.7
[10]	48*16*1.6	1.229	GSM900	0.3 to 1.3
			DCS1800	0.9 to 4
			PCS1900	0.9 to 4
			UMTS	0.9 to 4
			WiBro/Blutooth	4.1 to 5.1
[11]	30*16*9	4.32	GSM900	1.19
			DCS	2.93
			DMB	1.48
[13]	40*8*7.8	2.496	GSM850	1 to 1.8
			GSM900	1 to 1.8
			GSM1800	3.2 to 3.7
			GSM1900	3.2 to 3.7
			UMTS	3.2 to 3.7
[14]	36*15*6	3.24	GSM900	-0.37 to -0.78
			DCS1800	1.24 to 1.78
			UMTS	1.78 to 3.12
			WiBro	2.73

4. Conclusion

In this paper, a tetra band PIFA for mobile handset applications was proposed. Because the proposed antenna is a flat structure, it is simple and easy to manufacture. The antenna has a small volume of 1.768 cm3, which makes it suitable for use as an internal antenna. By combining the second resonance frequency of the meandered line radiator with the resonance frequency of the L-shaped radiator, it was possible to implement broadband characteristics in the higher band. The radiating element of the proposed antenna is manufactured on a (40x26mm2) FR-4 substrate and the S11 is measured and shows a good agreement with the simulated one. The obtained results show that the bandwidth of the proposed antenna covers GSM900, DCS1800, PCS, and UMTS bands. Moreover the antenna has remarkable gain for GSM band compared to several other works, and reasonable gain for other bands. Therefore, the proposed antenna exhibits great potential for multiband mobile communication applications.

In the next work, more refinement should be done to cover the 2.6GHz LTE band and to change the shape of the radiation patterns to protect user's heads against electromagnetic radiation.

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