Low SAR, Planar Monopole Antenna with Three Branch Lines for DVB, Mobile, and WLAN

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***Abstract*— In this paper, an open slot antenna fed by a U-shaped monopole is introduced. The slot antenna radiates in the range from 1.6 to 3.44 GHz and from 3.8 to 5.7 GHz. The slot is formed by an open ring of quarter wavelength at 900 MHz. Thus, the ring acts both as a monopole at 900 MHz and as a wideband slot radiator in the high frequency range. In order to serve the LTE 700 MHz band, another monopole ring is added to the antenna to cover DVB-H and T-DMB for mobile broadcasting. The antenna size is 28×38×1.5 mm^3. A prototype of the antenna was fabricated using FR4 substrate. This paper proposes a new mobile handset antenna structure with low SAR and covers most of the mobile operating bands and other wireless applications. The covered bands are the DVB-H, T-DMB, GSM 900, DCS 1800, PCS 1900, UMTS 2100, and most of the LTE bands including the LTE 700 band. Furthermore, it covers the ISM, WIMAX and the WLAN bands. The SAR calculations are done using the CST 2012 commercial package. It is worth mentioning that the antenna has compact size, multiband operation including the low frequency bands, and low SAR radiation. The simulation results are compared to the experimental measurements and a good agreement is observed.**

***Index Term*— Monopole, Digital Video Broadcasting Handheld (DVB-H), Terrestrial Digital multimedia Broadcasting (T-DMB), Long Term Evolution (LTE), Industrial, Scientific and Medical (ISM), Wireless Local Area Network (WLAN), Specific Absorption Rate (SAR).**

I. INTRODUCTION

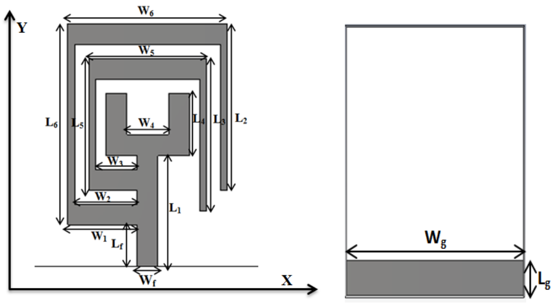
As mobile communication systems support and enhance the multimedia functions, various demands have been expected and increased for mobile phone antenna design. Digital Video Broadcasting-Handheld (DVB-H) and the Terrestrial Digital Multimedia broadcasting (T-DMB) L-band reception are very attractive for many mobile users. Also, the fourth generation of mobile communications, the long term evolution (LTE), is expected to deliver multimedia services anywhere, anytime. The LTE standard is scheduled to operate in different frequency bands that range from 400 MHz to 4 GHz with bandwidths of 1.4 and 20 MHz [1-2]. Currently, the DVB-H service has made it possible to deliver digital broadcasting for a portable device, which operates in the portion of ultra-high-frequency (UHF) band (470 –702 MHz, relative bandwidth of 40%) [1]. Typically, the size of handset is much smaller than a quarter of a wavelength at (470-702) MHz. Thus, it is always challenging to design an antenna that covers all of the above-required bands with good impedance matching while integrating into a mobile handset.

Several studies have been performed to produce an antenna structure able to satisfy the demands of the DVB-H antenna for use in hand-held terminals [2-14]. Miniaturisation techniques with control circuits were introduced [2–5]; however, they had problems such as low antenna efficiency because of insertion loss in lumped elements, as well as an increased cost. Magneto-dielectric materials have primarily been used for the antenna miniaturisation method [6, 7]; however, they have certain disadvantages that cause high loss as well as low radiation efficiency and high cost in comparison with those of a general dielectric material [8].

In order to include DVB, Kim et al. [3] proposed a new compact antenna that consists of a printed rectangular monopole with a U-shaped slot, an extended ground stub and a folder-type chassis. The antenna occupies an area of only 50×27 mm^2 to cover DVB-H, T-DMB, and GSM900. Other antennas were designed to include mobile bands with DVB, e.g. Liu et al. [12] introduced a compact multiband tunable PIFA system using a varactor as an active tuning component is presented to cover the mobile telephone bands (GSM850,900,1800,1900,UMTS) by controlling the value of the capacitance across the gap in the slotted PIFA and two broadcast bands, FM radio (76-108 MHz) & mobile television DVB-H (470 – 702 MHz) with size of 40×15×8 mm^3. Recently, Zuo et al. [13] proposed a new antenna that consists of a planar meander monopole. By using parasitic strips and a sleeve feed, wideband impedance characteristics are achieved from 440 to 1350 MHz. It is very suitable for DVB-H, LTE 13, GSM850, and GSM900 applications in the mobile phone with dimensions of 40x100 mm^2. Elsheakh and Abdallah [14] introduce compact multiband coplanar waveguide-fed L-loaded printed inverted-F antennas (printed-IFAs) with multiple-folded-slots (MFS) transmission line to cover DVB-H, DVB-L, GSM 850/900, most bands of LTE, ISM, Wi-Max, WLAN and other wireless communication applications with dimensions of 38x43 mm^2 .

In this paper, a novel internal antenna consisting of a monopole with three branch lines to cover multibands including the DVB, LTE bands are introduced. The proposed antenna has a -6 dB bandwidth which extends from 470 to 750 MHz, from 872 to 976 MHz, from 1.6 to 3.44 GHz, and from 3.8 to 5.7 GHz., which means that it supports the following operating bands; GSM 900, DCS 1800, PCS 1900, UMTS 2100, ISM 2450, most LTE bands (FDD-LTE band 1-4, 7-12, 15-17, 23-25 and TDD-LTE band 33-41), WiMAX (2.3-2.4 GHz, 2.5-2.69 GHz, 5.1-5.7 GHz), and WLAN(2.4 -2.5 GHz, 4.8-5 GHz, and 4.825-5.515 GHz), with a size of 28×38×1.5 mm^3.

The paper is organized as follows: section II explains the antenna design, describes the antenna performance and shows the antenna performance together with a comparison between the simulated and the experimental results. In section III, the SAR results are introduced. Section IV presents the conclusions for this research. Finally, Section V introduces the acknowledgment.



(a) Front (b) Back
Fig. 1. Geometry of the proposed antenna

II. Antenna Design

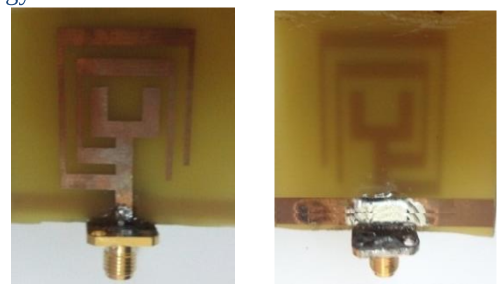
A. Antenna Design With Two Branch Line

The proposed antenna is a planar printed antenna with compact dimensions of (23x31x1.5) mm^3. The antenna can be easily integrated in small and sleek mobile device. Fig. 1 shows the geometry of the proposed antenna. All the labeled dimensions are tabulated in Table I. The antenna is fabricated over FR4 substrate (ε_r=4.5) with 1.5 mm thickness and loss tangent of 0.025 as shown in Fig. 2.

The proposed antenna is composed of a planar U-shaped monopole and two branch lines. The first branch line acts as a monopole radiator at the 900 MHz and at the same time acts as a cavity resonator fed by the U-shaped monopole that radiates in the upper frequency bands. The two branch lines increase the path over which the surface current flows and that eventually results in lowering the resonant frequency. The electrical length of the first line with 62 mm is optimized to resonate at 900MHz (872-976 MHz), while the electrical length of the second line is optimized to resonate at 700MHz (674-750 MHz) with length 82 mm.

Table I
Geometrical dimensions of the proposed antenna (all dimensions in mm)

Parameter	L1	L2	L3	L4	L5	L6	Lf	Lg
Value	14	23	21	7	18	25	6	6
Parameter	W1	W2	W3	W4	W5	W6	Wf	Wg
Value	10	9	6	6	17	23	2.8	23



(a)Front (b)Back
Fig. 2. A photo of the fabricated antenna

The proposed antenna is simulated using the CST Microwave Studio 2012. Fig. 3 shows a comparison between the simulated and measured results of the return loss. The simulated and the experimental results ensure that the antenna covers all the aforementioned mobile and wireless applications bands. Taking the -10 dB return loss reference, the antenna operates in the four bands (674-750 MHz), (872-976 MHz), (1.6-3.44 GHz), and (3.8–4.7 GHz). The first and the second resonant frequency are controlled by adjusting the total length of the second and first lines and the third and fourth resonances are controlled by adjusting the dimensions of monopole radiators and branch lines.

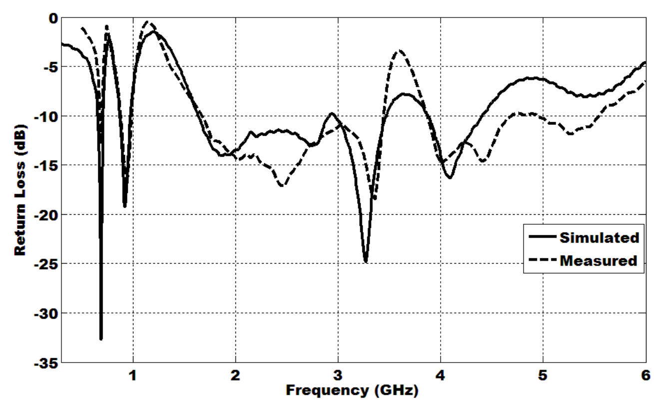
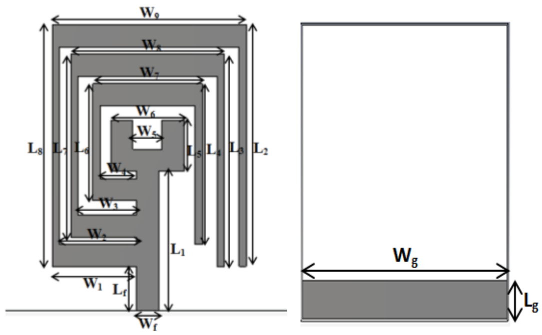


Fig. 3. Simulated and measured return loss of the proposed antenna.

B. Antenna Design with Three Branch Lines

In order to include the DVB band, the proposed antenna is redesigned with three branch lines as shows in Fig. 4 and all the labeled dimensions are tabulated in Table II. The third branch line increases the path over which the surface current flows and that eventually results in lowering the resonant frequency. The length is optimized at 500 MHz to include DVB bands where the new dimensions of antenna become (28x38x1.5) mm^3. Also, the DVB antenna is fabricated using FR4 substrate (ε_r=4.5) with 1.5 mm thickness and loss tangent of 0.025 as shown in Fig. 5.

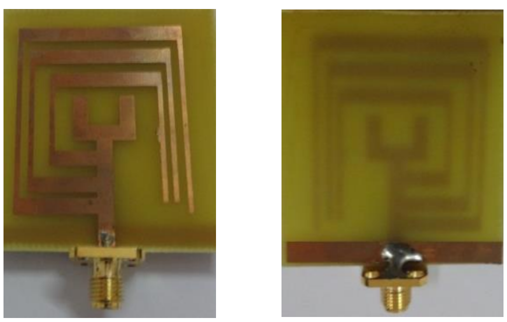


(a)Front (b)Back

Fig. 4. Geometry of the DVB antenna

Table II
Geometrical dimensions of the DVB antenna (all dimensions in mm)

Parameter	L1	L2	L3	L4	L5	L6	L7	L8	Lf
Value	19	34	30	25	8	18	28	34	6
Parameter	Lg	W1	W2	W3	W4	W5	W6	W7	W8
Value	6	15.5	14.5	12	8	6	12	21	27
Parameter	W9	Wf	Ws						
Value	30	2.8	36						



(a) Front (b) Back

Fig. 5. A Photo of the fabricated antenna

Fig. 6 shows a comparison between the simulated and measured results of the return loss. The simulated and the experimental results ensure that the antenna covers all the previous bands plus the DVB band. Taking the -6 dB return loss reference, the antenna operates in the five bands from 470 to 750 MHz, from 872 to 976 MHz, from 1.6 to 3.44 GHz, and from 3.8 to 4.7 GHz.). Table III shows the gain and the radiation efficiency of the proposed antenna. The current distribution on the antenna is simulated as shown in Fig. 7. It is seen that the current distribution is concentrated consecutively on the branch lines at 0.5GHz, 0.7 GHz and 0.9 GHz frequencies, respectively and on the monopole at 2.3 GHz. These phenomena mean that the position of the first, second and third resonant frequencies are controlled by adjusting the total length of its corresponding line while the fourth band from 1.6 MHz to 3.44 GHz is controlled by adjusting the dimensions of monopole radiators. Fig. 8 shows a comparison between the measured and simulated radiation pattern of the proposed antenna at 0.9 GHz, 1.8 GHz, and 2.1 GHz. Radiation pattern measurements were carried out using SATIMO Anechoic antenna chamber where the available frequency range starts from 0.8GHz.

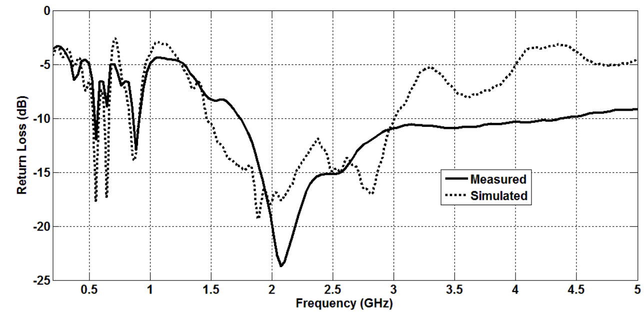


Fig. 6 Simulated and measured return loss of the DVB antenna.

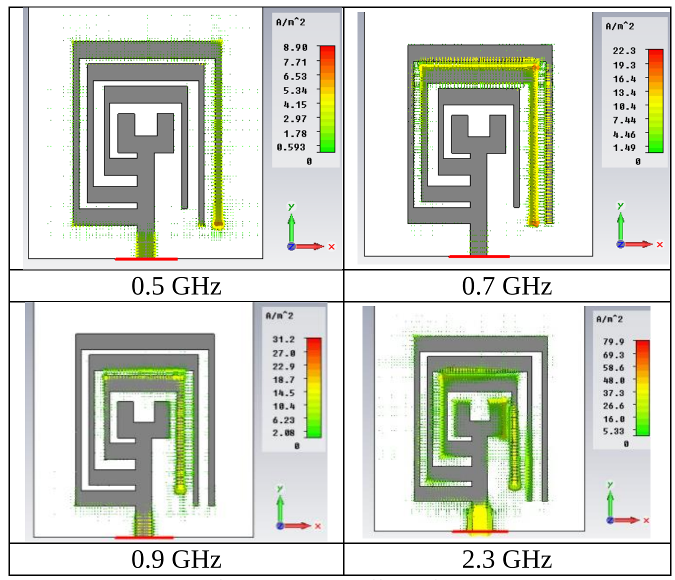


Fig.7. Current distribution of the antenna at different frequencies. 0.5 GHz, 0.7 GHz, 0.9 GHz, and 2.3 GHz.

Table III
Gain and the radiation efficiency of the proposed antenna.

F(GHz)		0.5	0.7	0.9	1.8	2.1
Gain dBi	Simulated	1.9	2.3	2.4	3.2	3.6
	Measured	-	-	1.9	2.9	3.1
Radiation Efficiency %	Simulated	69	71	82	77.2	82.6
	Measured	-	-	75.6	69	76.4

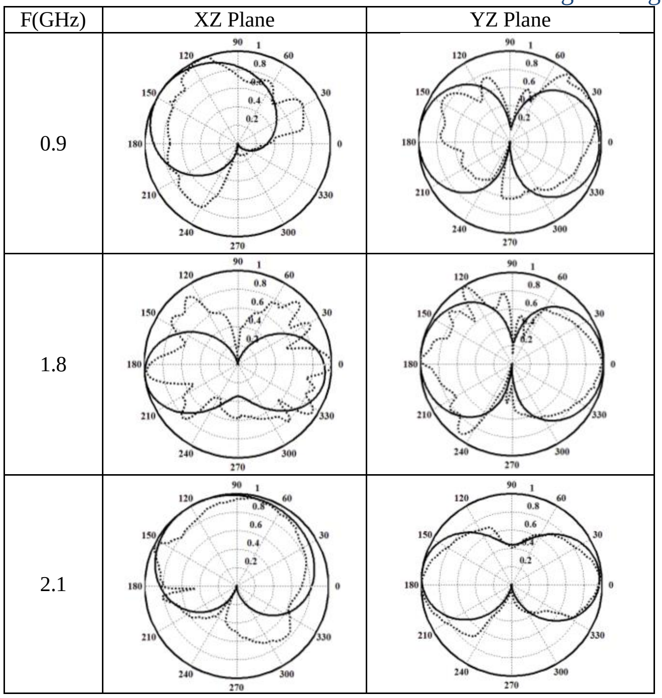


Fig. 8. The Radiation pattern in the XZ and YZ planes. The antenna is in the XY plane. Simulated (solid line) – Measured (dash line)

III. SAR CALCULATIONS

As the use of the mobile phone is increased, the research on the health risk due to the electromagnetic (EM) fields generated from wireless terminals is widely in progress. Many factors may affect the EM interaction while using cellular handset in close proximity to head and hand. One of the most widely used parameters for the evaluation of exposure is SAR, specific absorption rate. Therefore, some regulations and standards have been issued to limit the radiation exposure from the mobile handsets not only to decrease the SAR but also to increase the antenna systems efficiency.

The SAR limit specified in IEEE C95.1: 2005 has been updated to 2 W/kg over any 10 g of tissue [15], which is comparable to the limit specified in the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines [16]. The output power of the cellular phone model need to be set before SAR is simulated. In this paper, the output power of the cellular phone is set to 500 mW at the operating frequencies of 0.5, 0.7, 0.9, 1.8, and 2.1 GHz. Fig. 9 shows the antenna structure in the vicinity of the human head model (Hugo Voxel model). The SAR values are calculated according to the 10 gram standard of the human tissue mass. The SAR calculations are done using the CST 2012 commercial package with Hugo model CST Microwave Studio [17]; the tissues that are contained have relative permittivities and conductivities, according to [18-19]. The tissues frequency dispersive properties are taken into consideration. Table IV shows the averaged 10g SAR at the aforementioned operating frequencies when the antenna is in close proximity to the body.

It is noticed that, the antenna fulfills the IEEE C95.1: 2005 and the ICNIRP standards. Due to the results scalability when the power level changes, the SAR values could be controlled by adjusting the separation between the antenna and the head.

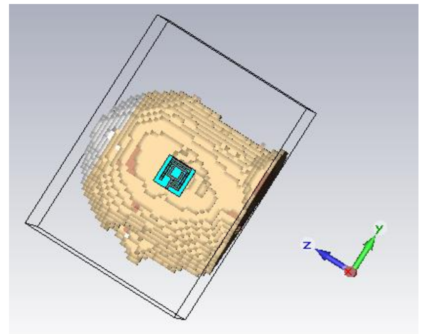


Fig. 9. Antenna structure with the human head model (Hugo voxel model)

Table IV
SAR values and the effects of human model on antenna properties.

F(GHz)	SAR (W/kg) (10g)	In free space		With human model	
		S11 (dB)	Radiation efficiency (%)	S11 (dB)	Radiation efficiency (%)
0.5	1.02	-12	69	-11	62.5
0.7	1.07	-23.1	71	-18.9	67.5
0.9	0.93	-14.7	82	-12.5	69.6
1.8	0.80	-13.5	77.2	-12.6	63
2.1	1.6	-12.5	82.6	-17.4	71.3

IV. CONCLUSION

A new compact planar antenna design that supports all of the operating mobile services, DVB, ISM applications, and wireless communication services is introduced. The SAR values of the antenna satisfy the standard safety guidelines. The antenna has more compact size when compared to other published antennas. The antenna was simulated using the CST simulator and fabricated using photolithographic technique. Very good agreement is obtained between the simulated and the experimental results.

V. ACKNOWLEDGMENT

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