Miniaturized Balanced Antenna with Integrated Balun for Practical LTE Applications

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Abstract. *A design of dual-band balanced antenna structure operating in the 700 and 2600MHz LTE bands is studied and investigated. The overall dimensions of the radiator are 50 × 18 × 7 mm3 allowing it to be easily concealed within mobile handsets. A broad-band balun is designed and integrated with the antenna handset in order to provide the feeding network and perform the measurements of the antenna radiation performance. Prototypes of proposed antenna with and without balun are fabricated and verified. The simulated and practical results with and without the hand held effect in terms of reflection coefficient, power gain and radiation pattern show good agreement.*

Keywords

Balanced Antenna, Printed Dipole, Dual-band, LTE, Balun.

1. Introduction

The demand for multisystem handset equipment has increased rapidly in recent years. The design of a wireless transceiver in a smart phone or a portable device must support multisystem operations, since the forthcoming mobile networking ecosystem will constitute legacy and future 5G technology. This raises numerous challenges and requirements for mobile phone antenna designers [1]. Such antenna requirements lie in its incorporation into portable devices, and moreover it is required to be thin, light, compact design, reduced volume size, and low energy. Therefore, to meet these requirements of current mobile phone built-in antenna, several works have been recently dedicated to internal multiband antennas in mobile handset applications. The planar Inverted-F antennas (PIFA) [2-3], microstrip patch antennas [4-5] and monopole printed structures [6-7] have been considered as the most common internal mobile phone antennas. In particular, with the advancement of the LTE technology, smart phones are now broadly used, thus designing new LTE antenna for legacy and future releases of the LTE standard, catering for carrier aggregation and multiple wideband frequency bands are now of much interest in the research community. Numerous miniaturized LTE handset antennas have been reported [8-13].

By examining the work [8-13], one can note that these antennas have only a single terminal and driven against a local ground plane. Having an antenna along with the system ground plane may help in improving the bandwidth and gain performance. These unbalanced antennas have been exploited in commercial handsets, especially as the mobile device is quite small. However, these unbalanced structures are sensitive to user hand held effect, in that the user´s hand covers a large area of the antenna ground plane in which may change the impedance matching requirements of the antenna and lead in performance degradation. This is because the ground plane of the unbalanced antennas is being used as part of the radiator structure in which a large amount of current would be induced on the radiator as well as on the antenna ground. As a result, while the device is being held by the users' hand, the current flows on the human hand/body and lead in depredating the antenna performance [14-16].

To avoid such degradation performance phenomena, a balanced antenna is deemed as a promising candidate for the mobile phone since the current induced on the ground is small or approximately neglected, which leads to minor influences on the performances of the antenna in the scenario of device being held by the user's hand.

To exploit this beneficial property, a number of mobile phone balanced antenna structures operate in dual-band, multiband and wide band have been recently studied [16-29]. Table1 shows the differences between these antennas in terms of operating frequency band, antenna size, power gain and efficiency.

By investigating Table 1, it is clearly noticed that these available balanced antennas can only cover either the major existing mobile bands or/and UWB sepcturm, for example: antenna design in [17] can only cover GSM900, the antenna geometry in [18] is capable to work for GSM1800, fitting together GSM900/1800 was proposed in [19]; moreover, [16, 20-23] proposed to operate in WLAN, joining GSM and UMTS in [24], whilst [25] designed a balanced antenna to operate in GSM and WLAN, and authors in [26] offered balanced antenna that work in the full operation of three mobile radio bands of GSM900/1800, PCS/1900 and UMTS/2200.

On other hand, several work has been reported to operate over the UWB spectrum such as authors in [27] have proposed an antenna design that operates in both lower band of UWB from 2.36 to 2.56 and higher bands of UWB spectrum from 5.13 to 12 GHz. Furthermore, in [28-29] Vivaldi balanced antennas covers the whole range of UWB from 3.1-10.6 GHz have been designed and tested.

Tab. 1. Comparison of the performance of the published balanced antennas.

Ref	Operating Frequency Band (GHz)	Size mm³ including ground plane	Peak Gain Range (dBi)	Radiation efficiency %
16	2.4	118x62.5x0.8	NaN	75.3
17	0.9	100x50x10	NaN	NaN
18	1.8	120x50x12	4	NaN
19	0.9 and 1.8	100x50x6.6	NaN	
20	2.4 and 5	90x40x9	2.3 -4.3 and 3.5 -5.3	NaN
21	2.4 and 5	90x40x9	NaN	NaN
22	2.48,5,4 and 6.5	90x40x7	3.5-5.2	NaN
24	0.9, 1.8 and 2.2	120x50x9.5	2.5 -3.5	NaN
25	1.8-2.4	120x50x9.5	2.7-4.2	70-94
27	2.36 - 2.56 and 5.13 - 12	87x35x1	0.7- 5	NaN
28	3.1-10.6	32 x 35 x1.6	-3-5.25	NaN
29	3.1-10.6	123.5x96.7x1.6	NaN	NaN
proposed	0.7-2.6	100x50x7	0.95-1.7and 3.8 -4.9	79-95

In contrast, due to the big demand for higher data rate as well as larger bandwidth in recent network of mobile communication; the new technology of the 4th generation namely long term evolution (LTE) has been developed and newly released. However, none of these balanced antenna designs in [16-29] have the capability to operate in the range of LTE bands and in particular the lower band of 700MHz. To address this, we propose a miniaturized printed folded dipole balanced antenna, which operates at dual-band frequency of LTE, these are 700 and 2600MHz for a mobile communication device.

By compromising the bandwidth, antenna size and frequency bands, some approaches were proposed by previous author's works [18, 20-22,23-24] to enable wide-band and dual-band functional operation, as shown in Table I. In comparison to [16–29], this version of the proposed balanced antenna has come up with such advantage of covering the dual-band of LTE namely 700/2600MHz as well as achieving a size reduction compared to previous work in [16-18,24-25]. Moreover, this version has obtained a better efficiency in contrast to [16,25]. Furthermore, it accomplishes an improved gain compared with works in [18, 24-25,27-28].

2. Proposed Antenna Structure

The full configuration of the present dual-band LTE mobile balanced design is shown in Fig. 1. The present design has a simple structure. The antenna is printed over a FR4 material permittivity of 4.4, tangent loss of 0.025 and with a thickness of 1.6mm. The overall size of the antenna and handheld device is 100 × 50 × $7mm^3$, where the antenna size is 50 × 18 × $1.6mm^3$. A balanced voltage source was used to feed the proposed design. The folded printed arms have a uniform width of 1mm.

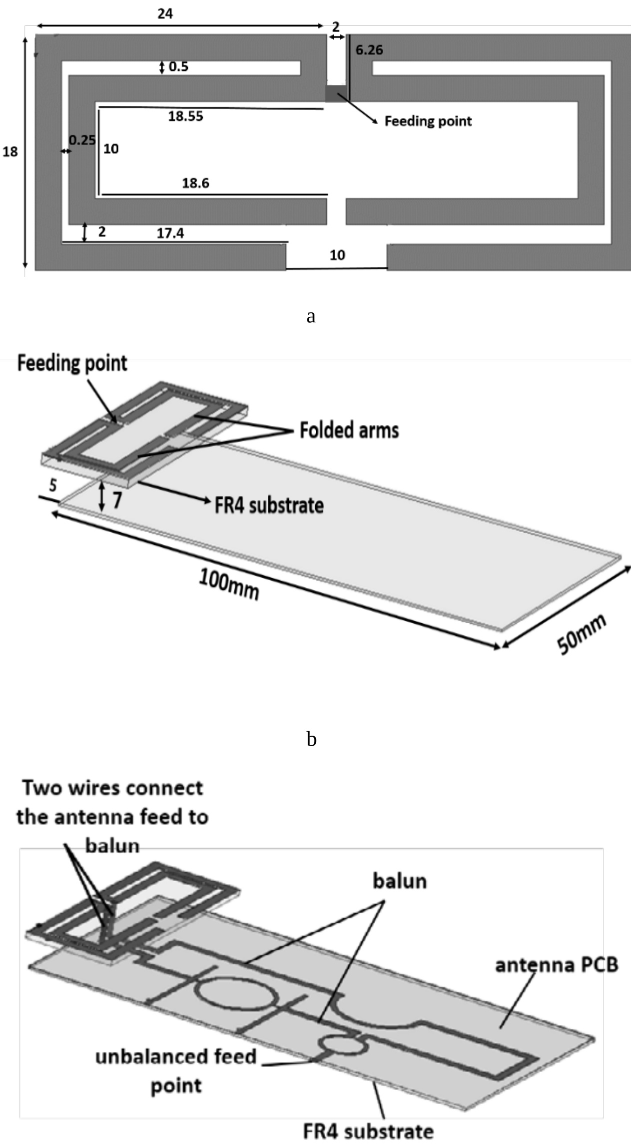

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Fig.1. Antenna structure; (a) Top view (b) antenna without balun (c) antenna with balun. Unit in mm

The ground plane was shifted backward by 5mm. This has created a defected area under the radiator which has contributed to accomplish and improve the bandwidth of the LTE lower frequency of 700MHz The proposed antenna comprises of two printed dipoles arms with separation slot of 2mm width. Each dipole arm is patterned in a way to create two joint U shapes. The formation of such printed dipole shapes has not only contributed towards the antenna miniaturization, but has also effectively achieved the dual-band LTE frequencies defined within this work in particular the lower band of 700MHz. It should be noted that different set/shapes of folded arms were attempted on the top of the substrate in which it can pave the path towards the targeted dual-band frequencies of 700/2600MHz.

To further understand the contribution of the printed folded arms technique in size miniaturization, different antenna designs with several printed folded arms shapes were modelled. In this analysis, four standard different printed arms including L-shaped, U-shaped, L-U shaped and 2U shaped were studied. The dimensions of L, U and L-U shapes are depicted in Fig.2, while the proposed structure of 2U shapes are already shown in Fig.1. The variation of the printed folded arms against the response of S_{11} was investigated within this study as depicted in Figure 2. The simulated S_{11} of L-shaped, U-shaped, L-U shaped and 2U shaped arms of proposed antenna shown in Figure 2. As can be seen, by implementing L-shape radiator on each arm, the proposed antenna can only operate at 4200MHz, but, when the U-shape was applied, the current path length of the antenna will be changed in which will make the antenna operates at 3500MHz. On the other hand, by joining L and U shapes together on each side of the radiator, the dual-band paradigm started taking a place in which the proposed design will be able to cover the dual-band of 1000/3400MHz. However, by employing 2U shapes configuration on each arm, the present antenna would be tuned to meet the targeted dual-band of 700/2600 proposed within this study.

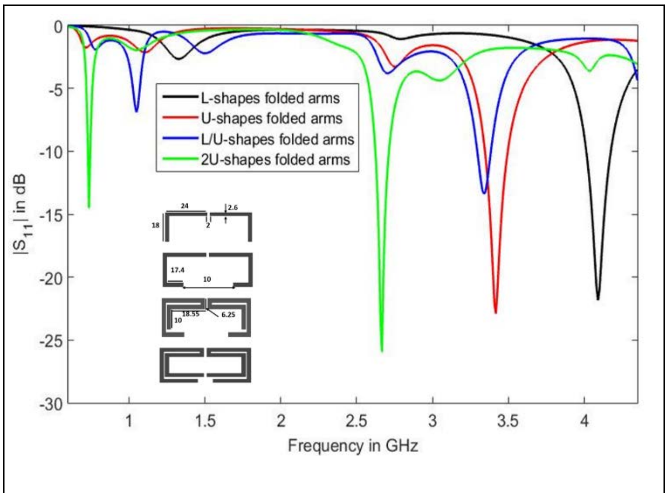


Fig.2.The variation of the printed folded shapes against the response of S_{11}.

Same planar balun as in ref [30] is used and integrated on the handset of proposed antenna to support the balanced feeding network that is fed by unbalanced source, as illustrated in Fig.1c. The full geometry of the used balun is depicted in Fig.3, while the full dimensions are stated in Table 2. One can note that, the ground plane of the antenna was placed on one side of the FR4 dielectric with a thickness of 0.8 mm, permittivity of 4.4, and tangent loss of 0.025, while the planar balun was located on the opposite side as depicted in Figure 1c. The proposed antennas were modeled using HFSS software package [31].

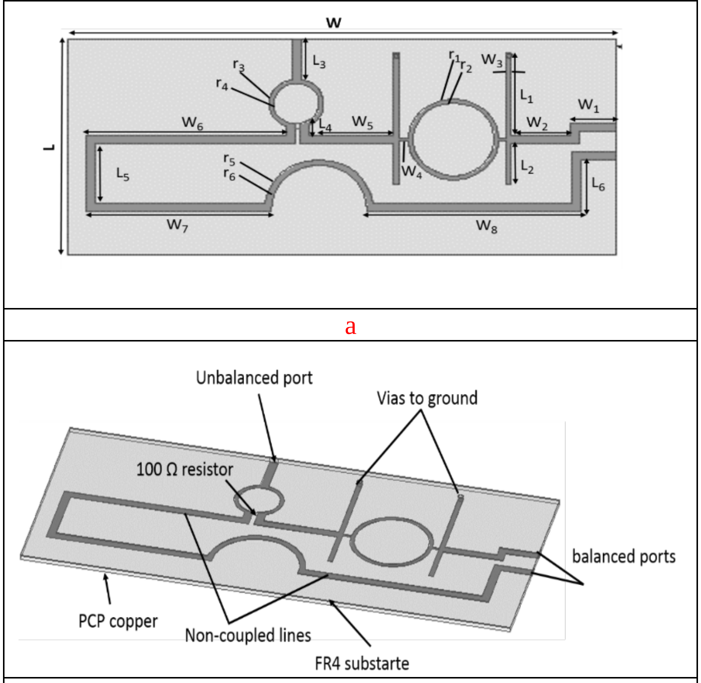


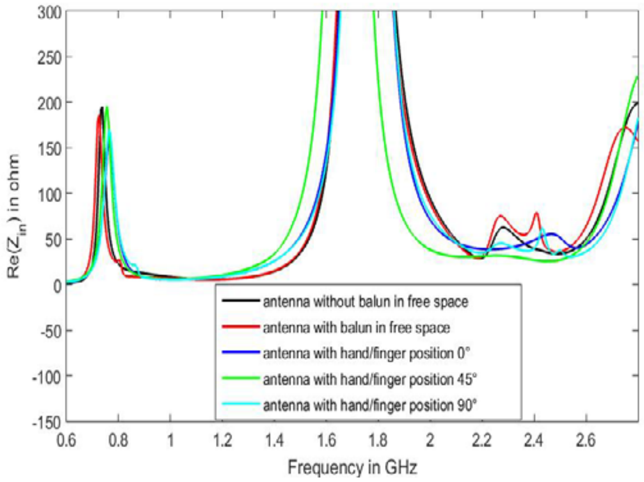
Fig.3. Geometry of proposed balun (a) Top view. (b) 3D View

As depicted in Fig.1c, the location of two balanced ports of the balun were wisely designated to be exactly in direct position underneath the antenna feeding point on the upper sheet of the substrate. Dual thin cables were exploited in order to join the wide band balun to the antenna feeding point via holes. In this manner, the integration of both the antenna and its balanced feeding system were successfully accomplished. The proposed balun operates over a wider frequency range from 700MHz to 3200MHz in which the targeted frequency bands of 700 and 2600MHz proposed in this work can be easily met.

Tab .2. The overall dimensions of proposed balun.

Parameters	Value in mm	Parameters	Value in mm
W_1	10	L_2	10
W_2	13	L_3	10.5
W_3	1.2	L_4	2.25
W_4	2.2	L_5	16
W_5	18.5	L_6	17.75
W_6	43.5	r_1,r_2	10, 9
W_7	40	r_3,r_4	6,5
W_8	44	r_5,r_6	12,11
L_1	21	L,W	50,100

To further investigate the physical behavior of the antenna, the input impedance of the proposed antennas with and without balun in free space and hand held are studied and investigated as shown in Fig.4. The values of the input impedance of the proposed antenna in the above-mentioned five cases were summarized in Table 3. As can be observed in Table 3, the proposed antenna in both scenarios of free space and handheld exhibits a resistance of around 50 Ohm (fluctuated between 46 and 50 Ohm) at 700MHz and 2600MHz.



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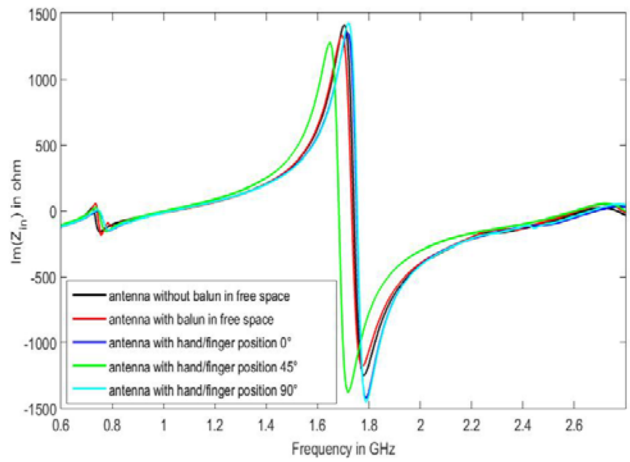

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Fig.4. Input Impedance of the proposed antenna.

The reactance values of the five version for the both scenarios at the dual targeted frequencies of 700/2600MHz were varied between -3 and 0 ohm. In summary, the responses of the present antennas in both scenarios of frees pace and held hand satisfy the good impedance matching condition to a 50 Ohm load.

Tab. 3. Input impedance of the proposed antenna in free space and handheld scenarios.

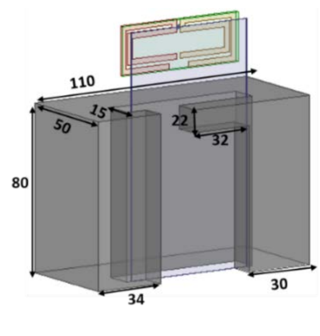
Input Impedance	**Antenna without balun in free space**	**Antenna with balun in free space**	**Antenna with hand/finger position at 0°**	**Antenna with hand/finger position at 45°**	**Antenna with hand/finger position at 90°**
Resistance 700MHz	50 Ohm	50 Ohm	46 Ohm	47 Ohm	49 Ohm
Reactance 700MHz	0 Ohm	0 Ohm	-3 Ohm	-3 Ohm	-2 Ohm
Resistance 2600MHz	46 Ohm	49 Ohm	47 Ohm	46 Ohm	48 Ohm
Reactance 2600MHz	-2 Ohm	-3 Ohm	-3 Ohm	-3 Ohm	-3 Ohm

3. Measurement and Simulation Results

The simulated reflection coefficient of proposed designs was studied and investigated in the free space and close vicinity to human hand scenarios. The hand model that includes the proposed antenna has the dimensions of 50 × 80 × 110 mm^3. The antenna and hand model are illustrated in Fig.5. For simplicity and reasonable estimation, the proposed hand model is considered to be a muscle tissue of only a single layer, having a relative permittivity material of 54 and a conductivity of 1.45 S m-1 [24-25].

As depicted in Fig.5, the hand model takes three typical different methods of holding the handset, while taking the finger positions into account, i.e., 0° (Left), 45° (middle), and 90° (Right) which are the most common talk positions.

Fig.6 depicts the computed S_{11} for the balanced antenna (i.e., the antenna with/without balun) in free space scenario and including the human hand effect. Observing Fig.6 plots, it is obviously seen that the $|S_{11}|$ remains below -10 dB over the targeted operational dual-band of 700/2600MHz for the analyzed antenna in free space scenarios.



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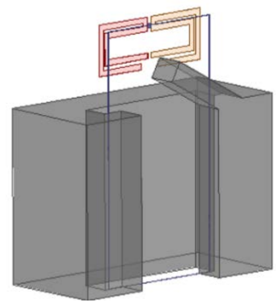

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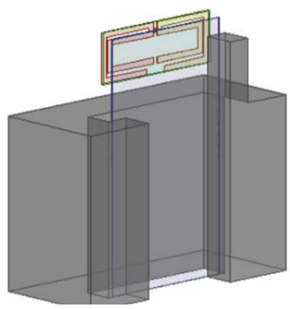

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Fig.5.Simulated hand model, with finger positions, 0° (a), 45° (b), and 90° (c).

On the other hand of Fig.6, the S_{11} of the antenna in hand effect paradigm in the three positions shows approximately a stable performance in term of S_{11} and in good agreement with the free space scenario. This proves that such a balanced antenna is ground plane independent and can be a good candidate for practical mobile applications.

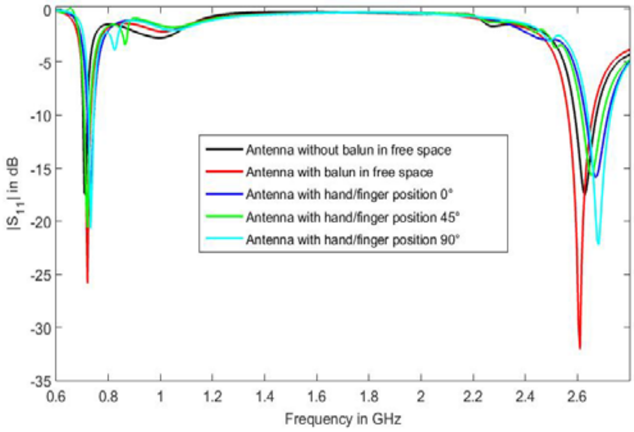
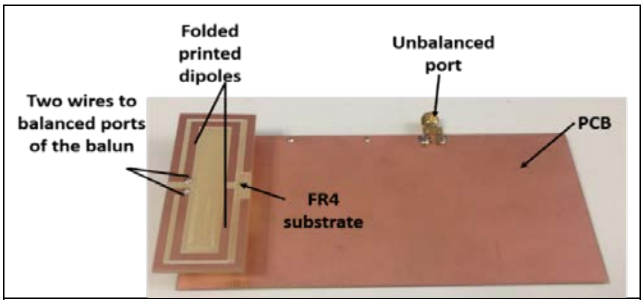


Fig.6.Simulated reflection coefficients $|S_{11}|$ of proposed antennas.

For validation purposes of the simulated S_{11} results of the antenna system without balun, a prototype of the antenna without the inclusion of balun is shown in Figure 6a and b. It was initially fabricated based upon on the structure and dimensions as clarified in Figure 1b, and then tested. Fig.7e shows the measured S_{11} of the present balanced antennas. The S_{11} of the antenna without balun was achieved by utilising the method of two port network analyser whereby the integrated balun is not needed.

a

b



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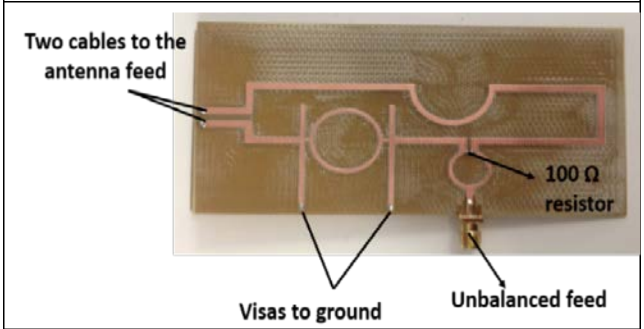

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Fig.7.The antenna prototypes, (a) 3D without balun (b) bottom without balun (c) 3D view with balun, (d) bottom view with balun.

Practically, this would be accomplished by direct connection of the balanced antenna two ports into the two inputs ports of a calibrated vector network analyser. One can clearly observe that, the experimental results of S_{11} are said to be in fair agreement with the computed results presented in Fig.6, where the targeted LTE dual-band, namely 700/2600MHz was accomplished.

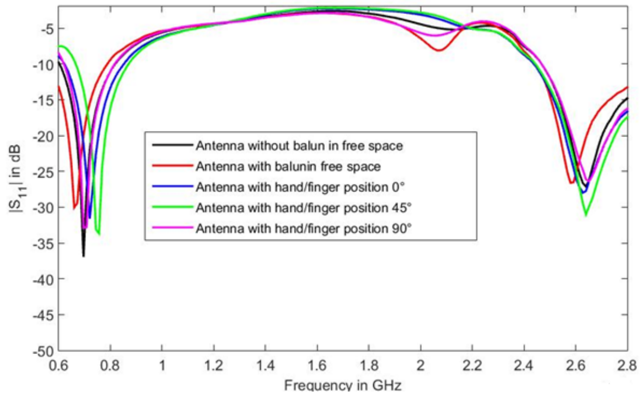


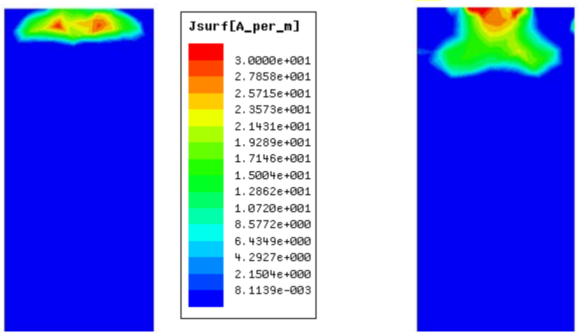
Fig.8. Measured reflection coefficients $|S_{11}|$ of proposed antennas.

For verification purposes, the full antenna prototype assembly (antenna & balun) has been also manufactured and measured as depicted in Fig.7c, d. The measured S_{11} of the antenna with the integrated balun is indicated in Fig.8.

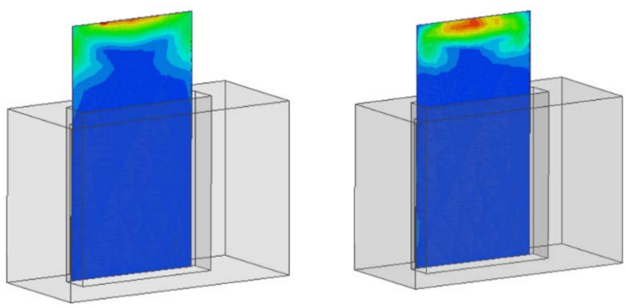
As can be observed, the measured S_{11} of the full antenna assembly shows a good result that covers the suggested dual-band frequency spectrum. The results agree well with the computed results as demonstrated in Figure 5.

The effect of hand holding scenario on the S_{11} performance of the prototype antennas was also studied and investigated in which the ground plane was considered as being held in a hand and positioned in the above-mentioned “talk” positions, shown in Fig.5. It was found that, from Fig.8, slight discrepancies were noted on the antenna S_{11} compared to the measured S_{11} of the antenna in free space cases within the envisioned operating bands.

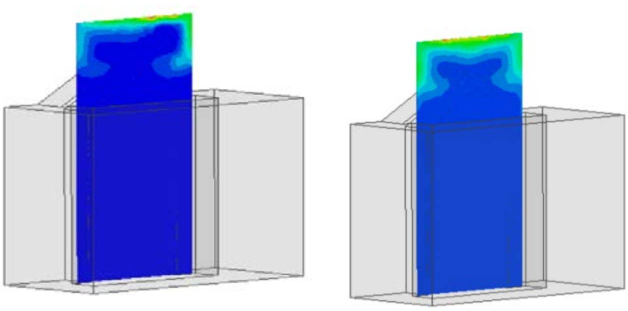
To further explain how the balanced antenna is a ground plane independent, a study of the current intensity of the present design in both free space and hand holding scenarios are shown in Fig.9. The current surface of this antenna in free space was demonstrated and analyzed over the dual-band of 700/2600MHz. In this circumstance, the surface current induced on the antenna ground plane is strong in the area exactly underneath the feeding point for both frequency bands, while it is neglected over the rest of ground plane as indicated in Fig.9a, which is comparable to the results obtained from [21]. It also shows some advantages comparable to the current in which induced on the ground of the unbalanced antenna in [32].



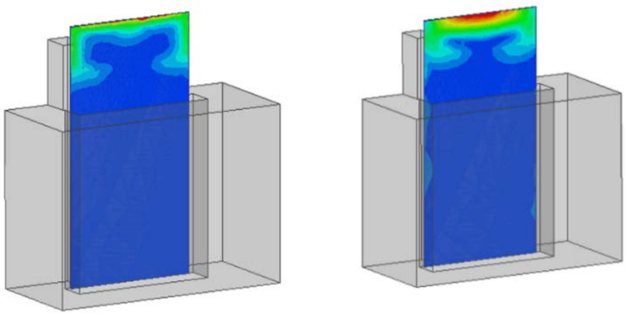
700MHz a 2600 MHz



0° finger position @700MHz b 0° finger position @2600MHz



45° position @700MHz c 45°position @2600MHz

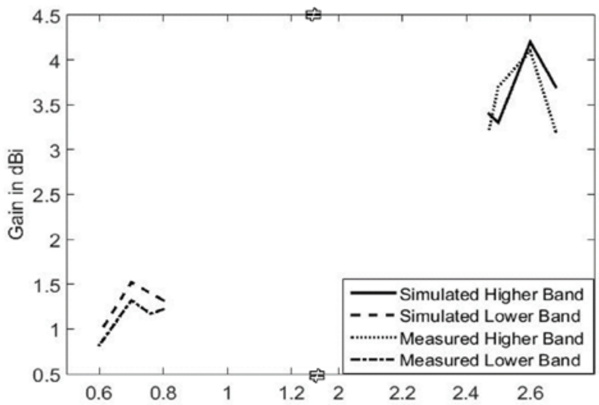


90° position @700MHz d 90°position @2600MHz

Fig.9. Current surface for (a) antenna in free space, (b) antenna with hand finger 0° position (c) antenna with hand finger 45° position (d) antenna with hand finger 90° position.

In the hand model scenario for all finger/talk positions, 0°, 45° and 90°, the major current appears around more or less the same area in the example of free space, whereas the current only exists in the area below the antenna and gradually tapers as we head further away over the whole ground as shown in Fig.9b, 9c and 9d. From the above-mentioned scenarios, this antenna proves the fact that the balanced antenna is ground plane independent. This also suggests that the antenna design has an advantage of being insensitive when it is held by the hand user.

Fig.10a illustrates both computed and measured gain of full assembly antenna for the 700/2600MHz of LTE frequencies. The computed antenna gain varies from 0.9 dBi and 1.62 dBi over the lower band of 700MHz and between 3.5 dBi and 4.4 dBi over 2600MHz band. On other hand, the measured gain fluctuated roughly between 0.85 dBi and 1.4 dBi over the bandwidth of 700MHz, and fluctuated from 3.45 dBi to 4.3 dBi over the band of 2600MHz as observed in Fig.10a. These minor variations may be attributed to the introduction of the physical integration of the balun with ground of the device, and moreover the existence of the connector pin during the fabrication and testing procedure has not been taken into account in the simulation steps.



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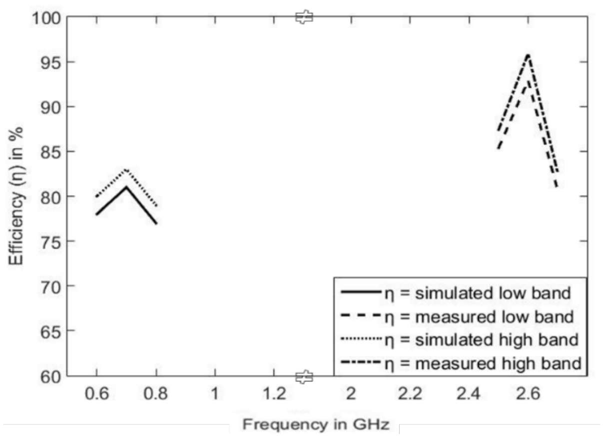

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Fig.10. (a) Simulated and measured gain of the proposed antenna, (b) Simulated and measured radiation efficiency of the proposed antenna.

Fig.10b shows the radiation efficiency of full assembly antenna. It is observed that the results of the efficiency are in good correspondence with the gain results which obtained in Fig.10a. The Wheeler Cap method [33] is used to evaluate the radiation efficiency of the present antenna. The Wheeler Cap method is considered as a practical method to test efficiency [34-36].

The basic concept about Wheeler's method is to use the "radiansphere" which is the boundary between the near field and the far field of any small antenna to measure the radiation efficiency of antenna under test. The simulations will be separated into two procedures that the radiation efficiency can be evaluated from the S11 magnitude with and without Wheeler cap by using the following equation [36].

$$\eta = \frac{P_{Rad}}{P_{Rad}+P_{loss}} = \frac{(1-\Gamma_1^2)-(1-\Gamma_2^2)}{(1-\Gamma_1^2)} = \frac{\Gamma_2^2-\Gamma_1^2}{1-\Gamma_1^2} \quad (1)$$

where ,Γ_1 is the S_{11} in free space (without Wheeler cap) ,Γ_2 is the S_{11} with Wheeler cap, P_{Rad} is radiation power of antenna and P_{loss} is loss power.

To verify the Wheeler cap method, the prototype model of the cavity model in Figure was used, in which the fabricated antenna was place inside it. Again, the measured radiation efficiency is obtained by performing measurement in two steps i.e. measuring the antenna under test (AUT) without and with conducting radiation Wheeler cap metal shield.

One can obviously note that, the simulated efficiency varies from 76 to 81 % over the lower band of 700MHz and from 81 to 91 % over the 2600MHz. On the other hand, the measured efficiency over the 700MHz fluctuates from 80 to 83.6%, while it varies from 85 to 95% over the higher band of 2600MHz.

The far-field radiation patterns of both simulated and fabricated full antenna assembly (antenna & balun) were presented in Fig.11. Two pattern planes at xz and yz were taken at 700/2600MHz, respectively. The computed patterns were produced from HFSS software for the aforementioned planes. The normalized two patterns were considered and the fabricated antenna was measured in a far-field anechoic chamber. From Fig.11, a reasonable agreement was observed between computed and measured ones. The accomplished results indicate that the radiation patterns are nearly omnidirectional.

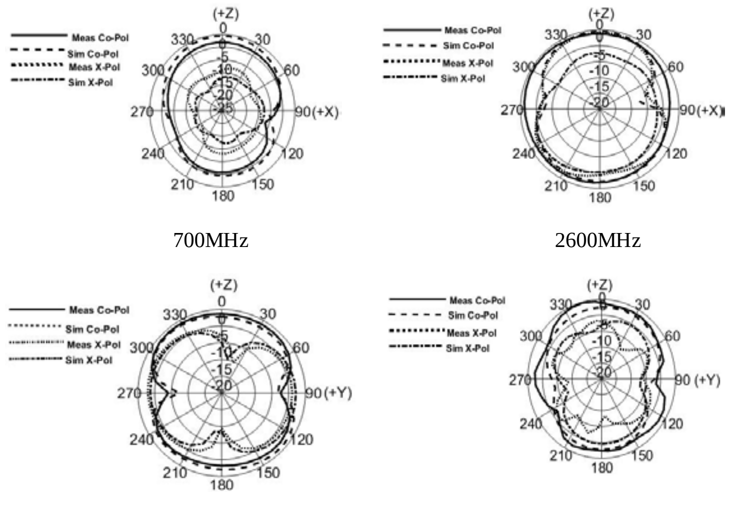

Fig.11.Normalized antenna radiation patterns for two planes (left: xz, right: yz) at 700MHz, 2600MHz, '____' measured co-polarisation '– – –' simulated co-polarisation '------' measured cross-polarisation '.......' simulated cross-polarisation

4. Conclusion

A design of dual-band balanced antenna has been designed and presented. The proposed design was operated in the required LTE dual-band of 700/2600MHz with sufficient impedance matching (S11 ≤ -10 dB). Computed and measured results of S11 showed good agreement for free space and hand held (with/without balun) scenarios. Furthermore, the antenna was demonstrated near-omnidirectional radiation features over the two operating bands. The surface current of the proposed antenna proves that the currents are diminished over the entire ground plane, except underneath the feeding point where there is improved immunity to the hand-held in which can enhance the stability of the present mobile antenna in real operating environments. This makes the present antenna as desired candidate for practical applications in mobile phones.

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