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Research Article

Dual-Element PIFA Design with Dual Shorting Pins for Multiband Communication Devices

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A low profile multiband resonant, dual-element array antenna is proposed for use in handheld communication devices. The proposed antenna comprises two dual shorting pin planar inverted-F antennas and a folded ground plane which operates as a perfect electric conductor case. The feeding scheme adopted for the proposed design produces a fixed phase difference between two antenna elements of the design to achieve an ultrawide bandwidth and a flexible radiation pattern. The proposed antenna design is simulated with commercially available software, which is based on the finite element method. The resonant frequency bands covered are GSM850/900, DCS1800, PCS1900, UMTS2100, and LTE2300/2600 MHz. Details of the design considerations for the proposed antenna are described and the simulated and measured results are presented and discussed, which are in agreement.

1. Introduction

Recently, as the antenna industry has progressed, the demand for multiband resonant antennas has increased immensely. Presently, antenna designs must be both of low profile and of multiband resonant; they should also offer a wider bandwidth. Antenna designs with lower dimensions may become helpful in reducing the size of the devices that use them. The theoretical performance of the antennas is limited in cases when their overall size is small because the internal mobile antenna must resonate at multiple frequencies.

In pursuit of designing a multiband resonant antenna, a planar inverted-F antenna (PIFA) is a reasonable choice because it offers a better gain over the desired resonant band. Specifically, when the required resonant bands are wider, maintaining the gain and performance becomes critical. In [1–3], the flexibility of different PIFA designs is presented. In [1], the importance of the PIFA design in terms of wide bandwidth and high gain is discussed. In [2], the idea of bandwidth enhancement of a PIFA design by inserting slots in the radiating patch is described. In [3], a method to increase the bandwidth of a PIFA antenna by inserting slots in the ground plane is reported. Additionally, multishorting pins and parasitic patch elements within PIFA design can also be utilized to achieve multiresonant bands with reasonable corresponding gains [4–6].

In [7, 8], a lossy scenario in which metallic objects are in close proximity to the antenna is examined; such scenarios affect the resonant bands and perturb the resonant frequencies of the antenna. A multiband integrated slot antenna that utilizes a metal back cover in its mobile handset design has been reported in [8]. Because of the physical limitations of low-profile antennas, it is not always possible to achieve a wider bandwidth and better gain at the same time, especially at lower resonant frequencies such as GSM850/900 MHz. In [9], the impedance bandwidth and Q factor of the low-profile antennas are discussed; this work provides a better understanding of Q factor evaluation to increase the radiation efficiency of the antenna at its resonant frequencies.

The dual-element antenna design that we propose in this paper has the ability to overcome these problems of the bandwidth and gain relation at GSM850/900 MHz. The proposed design consists of two PIFA antennas excited by a single source. The feeding scheme used produces a difference in phase between the antennas, which enables us to control the radiation pattern of the handheld device at given resonant frequencies for better reception in the worst-case scenario. Both PIFAs (mirrored to each other) have two shorting pins,

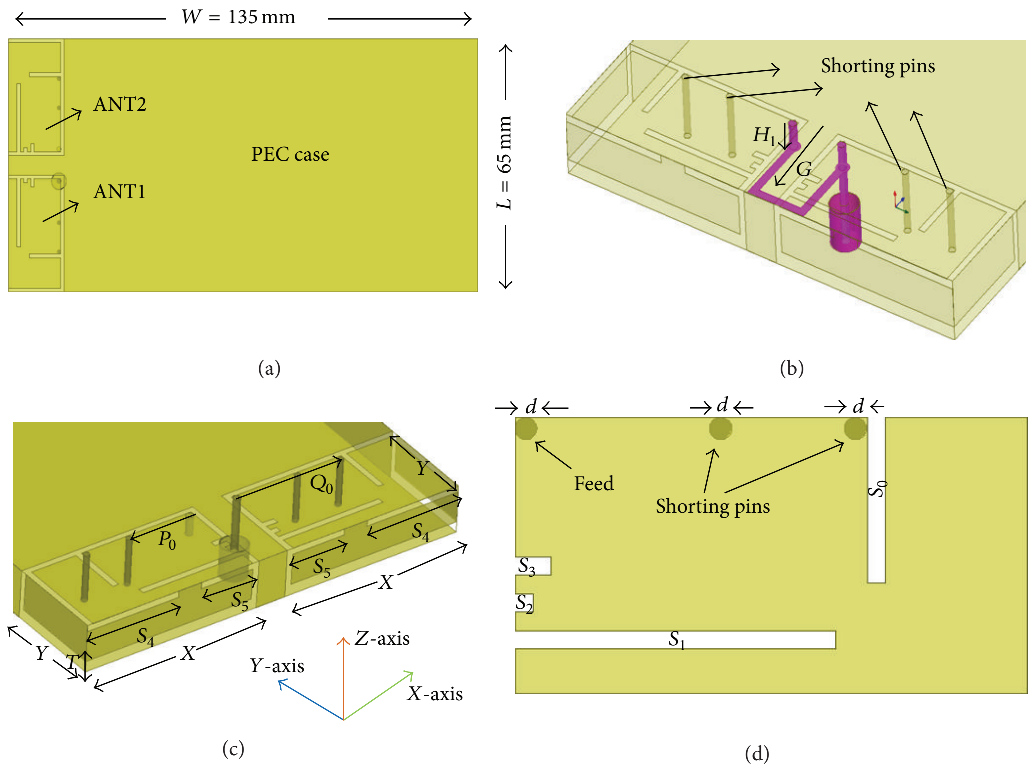


Figure 1: Proposed antenna design: (a) top view of the model, ANT1, ANT2, and PEC case, (b) feeding scheme, (c) antennas with parametric labels, and (d) antenna slot description.

which play an important role in providing the multiband resonance and wider bandwidth required in many cases.

2. Antenna Configuration

Figure 1(a) shows the basic configuration of the design which consists of two identical but mirrored antennas excited with a single feed and a PEC case. 3D views of the design are shown in Figures 1(b) and 1(c). The design consists of two planar inverted-F antenna elements, that is, ANT1 and ANT2 and a perfect electric conductor (PEC) case. Both the antenna elements are identical and symmetric with respect to their respective feeding points. The length and width of the slots and position of the shorting pins in both antenna elements are the same. The substrate used inside the PEC case is FR-4, which has a dielectric constant of $\varepsilon = 4.4$. The dielectric material is sandwiched between the radiation patch and the ground plane; it may provide mechanical strength to the designed prototype and the radiating patches can adhere to it.

Two shorting pins are used in each antenna element, ANT1 and ANT2. The feeding mechanism is shown in Figure 1(b). The electrical length of the PEC stripe used to excite the two antenna elements produces a fixed phase difference between the two antenna elements. The parametric description of the radiating patch is shown in Figures 1(c) and 1(d); details are provided in Table 1. A 50 Ω coaxial feeding is used as an excitation source.

The position and length of the slots S_0 and S_1 have a major effect on all resonant bands. Additionally, by adjusting the positions of shorting pins and the gap between shorting pins P_0 and Q_0 as shown in Figure 1(c), we may control the lower resonant frequency and the bandwidth of the higher resonant bands, respectively. The lengths of the slots S_2 and S_3 are used as the tuning slots to tune all the resonant bands (as their impact on the resonant frequencies is very small). The slots S_4 and S_5 in Figure 1(c) are inserted to obtain the minimum electrical length that is required to obtain the lowest resonant band, that is, GSM850/900. The parameter G in Figure 1(b) is used to change the electrical length of the feeding stripe and therefore can be useful to adjust the phase difference between ANT1 and ANT2. The diameter of all the shorting pins is 1 mm and that of feeding pins is 1.2 mm. However, the width of all the slots is 1 mm.

3. Antenna Design Procedure

As shown in Figure 1, the antenna design consists of two dual-shorting pin PIFAs, a ground plane, and a PEC case. The dimensions of the proposed design are $65 \times 135 \times 7.25\ \text{mm}^3$. Inside the PEC case and the ground plane is the FR-4 substrate, which adds strength to the prototype. FR-4 is used as the dielectric material in the proposed design because of its higher dielectric constant and acceptable low loss tangent. Unfortunately, the use of this low-cost substrate introduces additional complexities into the traditional antenna designs.

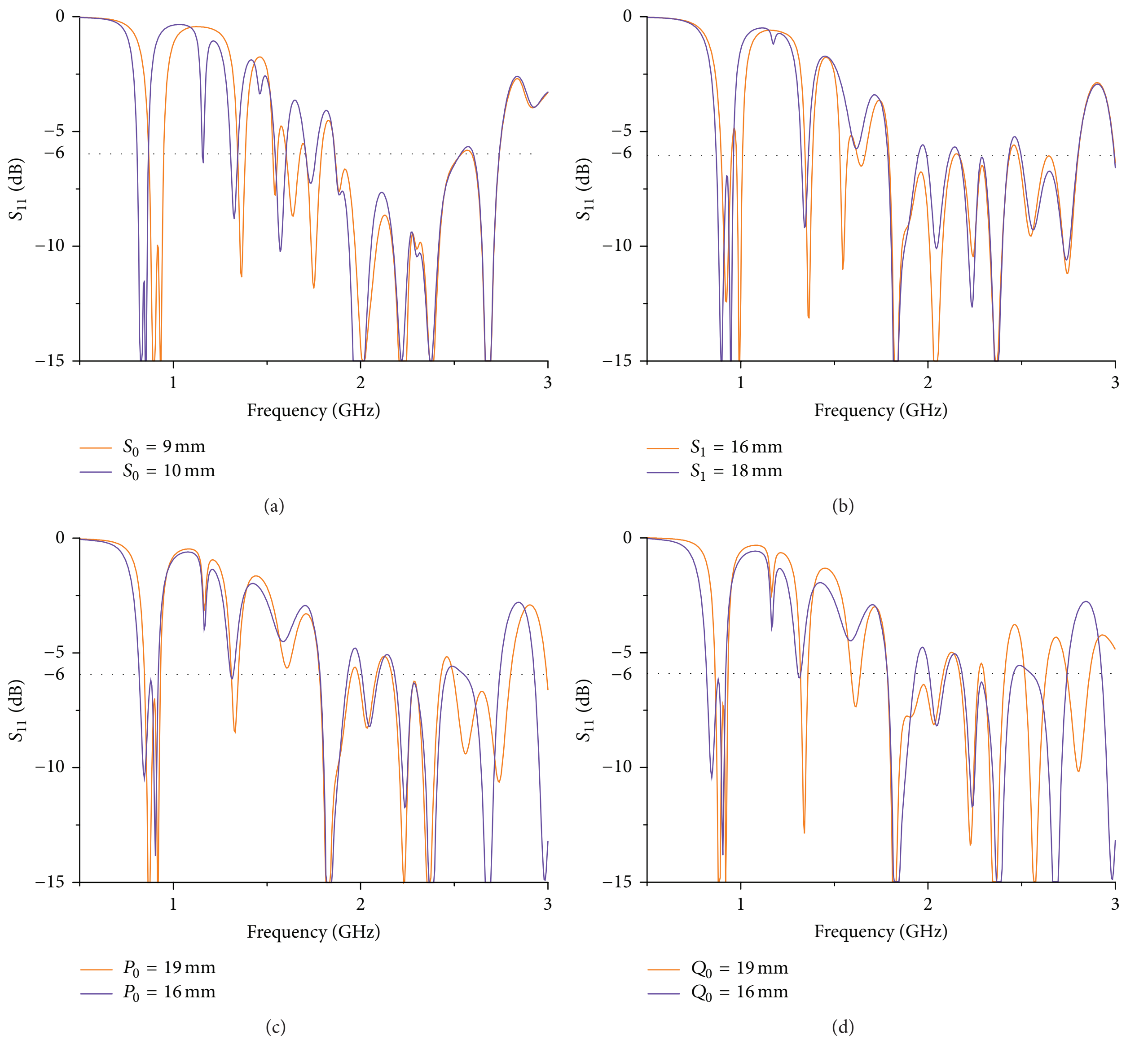


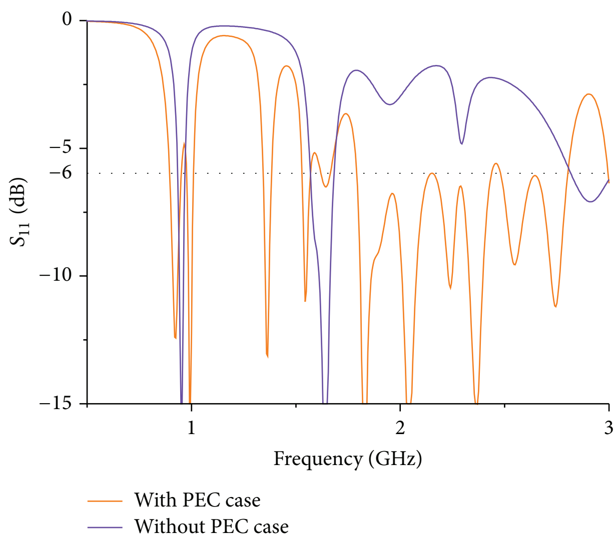
FIGURE 2: Effects of changing the lengths of (a) S_0 and (b) S_1 on S_{11} and also the effects of the change in the positions of (c) P_0 and (d) Q_0 on S_{11}.

The radiation efficiency, axial ratio, and antenna gain are disturbed by the imperfect permittivity distribution and higher loss tangent of this substrate. However, these problems can be addressed and the radiation efficiency of the design can be increased by utilizing a comparatively thick substrate [10]. The higher dielectric constant and loss tangent of this substrate make it possible for antenna designers to achieve wider bandwidths and miniaturization of the antenna designs. Furthermore, FR-4 may reduce the overall size of communication devices. Antenna designs are complicated, especially when their resonant frequencies depend on several parameters.

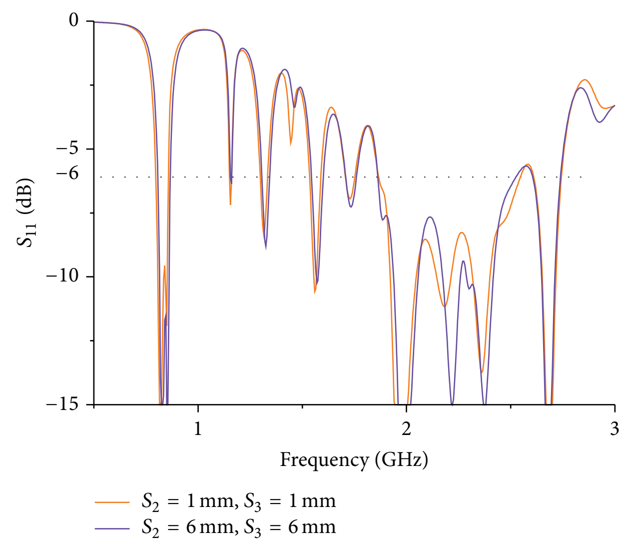
In our proposed design, a change in the position of the shorting pin or a change in the position or length of a slot will change the resonant frequencies and their corresponding bandwidths. However, parametric analysis of these variables (in terms of sensitivity towards S_{11}) makes it easy to divide all these parameters into groups, that is, which parameters affect S_{11} more than the others and help optimizing the specific resonant bands of the proposed design.

The basic purpose of the slots is to adjust the resonant bands of the S_{11}. The impact of slots with different lengths and shorting pins with different positions on S_{11} is shown in Figure 2. In Figures 2(a) and 2(b), it is shown how the change in lengths of slots S_0 and S_1 affects the S_{11} in the proposed design. The change in this slot's length has an effect on the lower resonant bands, whereas the resonant band around 2.5 GHz observes very minor effect. The simulation shows that changing the length of the parameter P_0 or Q_0 slot adjusts the position and bandwidths of the resonant frequencies.

The position and diameter of the shorting pins P_0 and Q_0 affect the bandwidth and gain of the resonant bands.



(a)



(b)

FIGURE 3: Effects on S_{11} parameter: (a) PEC case and (b) variation in the lengths of S_2 and S_3.

TABLE 1: Parameters used in the design.

Parameter	Length (mm)
L	65
W	135
H	7.25
S_0	19.5
S_1	11.5
S_2	0.5
S_3	1
S_4	15
d	1.2
S_5	8
P_0	14
Q_0	19
X	30
Y	16
T	1.5
G	10
H_1	3.19
H_2	4.06

The resonant frequency and bandwidth of the lowest resonant frequency, that is, GSM850/900 MHz, depend on the position of the shorting pins and the width between the shorting pins, as shown in Figures 2(c) and 2(d). The relation between input impedance and the distance between the feed point and the shorting pin has been evaluated and reported in many previous studies. In [10–12], the input impedance of the PIFA was shown to be tunable by controlling the distance between the feed point and the shorting pin. As we move the shorting pin closer to the feeding point, the input impedance decreases. The worst case scenario for antenna designers is an antenna working in close proximity of the metallic bodies or scatterers as it increases complexities in antenna operations. The fact that this situation affects not only the resonant frequency bands but also their corresponding gains makes it an even less desirable situation. The lossy nature of metallic bodies causes the loss in the Q factor. In [13, 14]; the authors show that Q factor varies as the antenna moves closer to the metallic body. It is also explained that Q factor and impedance bandwidth of an antenna are approximately inversely proportional. In our design, the effect of the PEC case on the proposed antenna's S_{11} is shown in Figure 3(a). The antenna design is optimized so as to achieve a wider bandwidth at the desired resonant frequencies. To tune the S_{11} of the proposed antenna, S_2 and S_3 shown in Figure 1(d) are adjusted. The effects of the lengths of these two slots can be observed in Figures 3(a) and 3(b).

4. Measurement and Verification

A comparison of the simulated and measured S_{11} of the proposed antenna design is shown in Figure 4(a). A comparison of the simulated and measured gain of the corresponding resonant bands is presented in Figures 4(b) and 4(c). Despite the small shift in the lower resonant frequency band and on S_{11} around 2.2 GHz (which is the result of the fabrication tolerance), the resonant bands and the gain of the antenna within those bands are found to be in agreement and acceptable.

The resonant bands and their corresponding gain are suitable for those devices that operate in these resonant bands. The measured resonant bands are GSM850/900 (845–967 MHz), DCS1800 (1726–1880 MHz), PCS/WCDMA (1850–2073 MHz), UMTS (2.0 GHz), WLAN/WiMAX (2.3 GHz/2.5 GHz), WIFI (2.4 GHz), and LTE (2.6 GHz). The proposed design is suitable for handheld communication devices such as smart phones and tablet PCs.

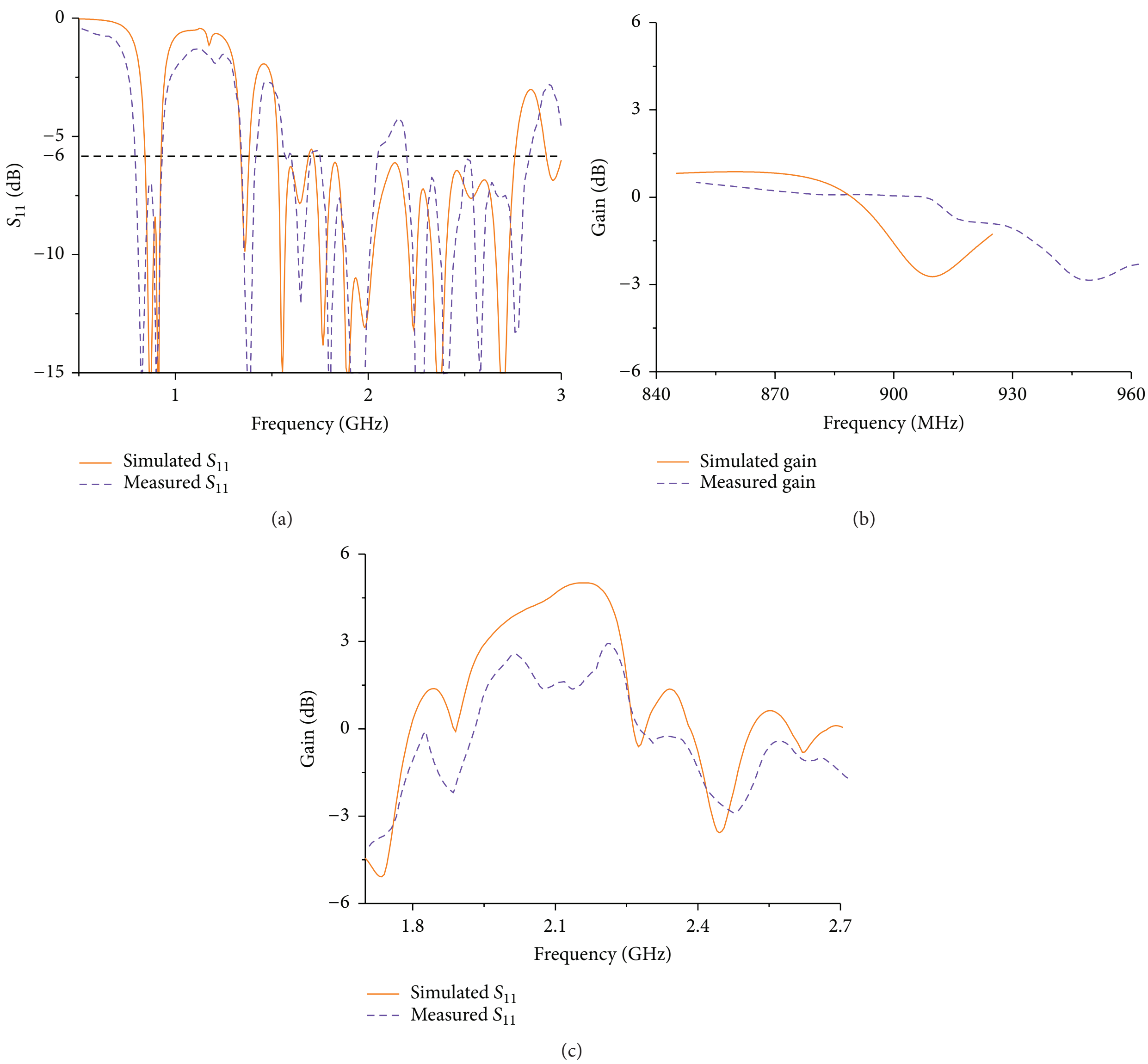


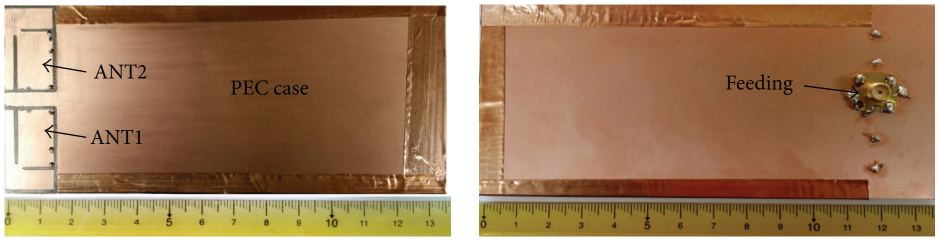
FIGURE 4: Comparison of simulated and measured characteristics of the proposed antenna: (a) S_{11}, (b) gain at lower resonant frequency band, and (c) gain at higher resonant frequency band.

In Figure 5, the prototype of the proposed design is shown. Two sheets of substrate FR-4 were used to imprint the feeding stripe (used to create the fixed phase difference between two antennas). Top sheet has the thickness of H_1 and the bottom sheet has thickness of H_2 which is mentioned in Table 1.

In radio communication, control over radiation pattern can help in antenna's reception quality and may provide better spectral efficiency. The cost of this efficiency can be the extra set of antennas. The basic requirement is to choose a design configuration that makes it possible for the model to receive and transmit an electromagnetic wave in different ways. A well-known way to improve the reception is to introduce more than one antenna element, as reported in [15, 16].

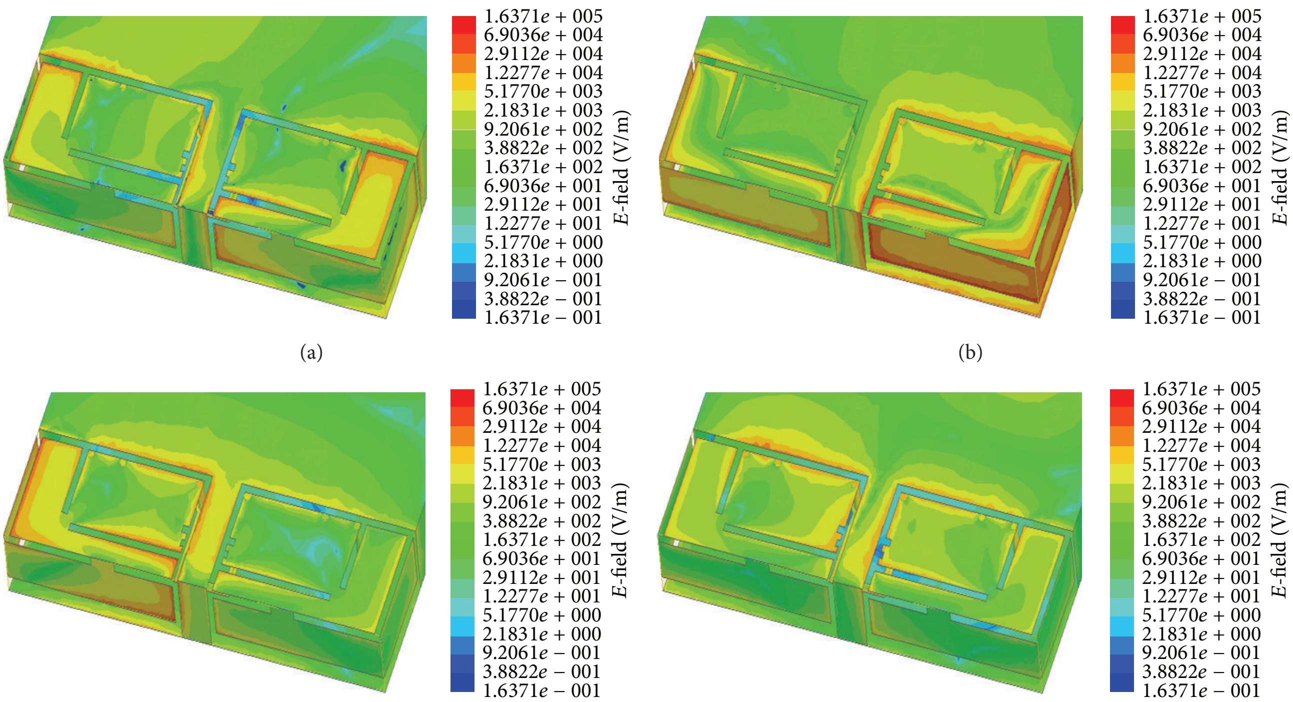
In Figure 6, the distribution of the magnitude of the E-field over the PEC case and antenna elements at resonant frequencies is shown. The phase difference between the two antennas can be calculated for every resonant frequency to establish a balance in the radiation pattern. Moreover, the dual shorting pins in antenna elements ANT1 and ANT2 provide multiple paths for current to flow, resulting in multiple resonances and wider bandwidths at all resonant frequencies.

Simulated 3D far-field patterns at resonant frequencies of the proposed design are shown in Figure 7. The design is optimized to achieve a dipole shape radiation pattern at 0.92 GHz as shown in Figure 7(a) and the radiation pattern at other resonant frequencies is close to omnidirectional patterns as shown in Figures 7(b), 7(c), and 7(d). The radiation pattern specification is due to the need for an omnidirectional pattern to minimize signal variations as handset is moving along a path. This requirement is well



(a) (b)

Figure 5: Fabricated antenna.



(a) (b) (c) (d)

Figure 6: Simulated magnitude of E-field distribution: (a) 0.92 GHz, (b) 1.8 GHz, (c) 2.1 GHz, and (d) 2.6 GHz.

satisfied for the lower band and loosely satisfied for the higher bands as shown in Figure 7. Moreover, another reason to produce omnidirectional radiation pattern at higher resonant frequencies in most proposed designs is due to the fact that the omnidirectional antennas have the ability to radiate and receive electrical energy equally well in all directions; the gain of such antennas can be increased by narrowing the beam widths. It is clear from Figure 7 that the feeding scheme utilized in the proposed design has capability to exhibit the same properties as the other conventional antennas do. Moreover, the benefits of this feeding scheme are wider bandwidths at resonant frequencies and acceptable gain over the resonant frequency bands. The parametric analysis of the parameter G shown in Figure 1(b) plays a vital role in optimizing the design for a reasonable gain, acceptable radiation pattern, and wider bandwidth at resonant frequencies to meet the communication standards through simulations.

5. Conclusion

In this paper, a multiband resonant and low-profile handset antenna with a metal cover, with GSM850/900 (845–967 MHz), DCS1800 (1726–1880 MHz), PCS/WCDMA (1850–2173 MHz), UMTS (2.0 GHz), WLAN/WiMAX (2.3 GHz/2.5 GHz), WIFI (2.4 GHz), and LTE (2.6 GHz) bands, is presented.

In this proposed antenna design, two mirrored PIFAs with dual shorting pins and a PEC case were utilized. A single RF excitation source was used to produce a fixed phase difference between the two antenna elements. The far-field pattern at resonant frequencies can be controlled by changing the phase difference between the two antenna elements. Results show that the metal cover may allow wider bandwidths and sufficient gain when designed smartly.

The design was fabricated and the S_{11} and gain results were measured and compared with the simulated ones;

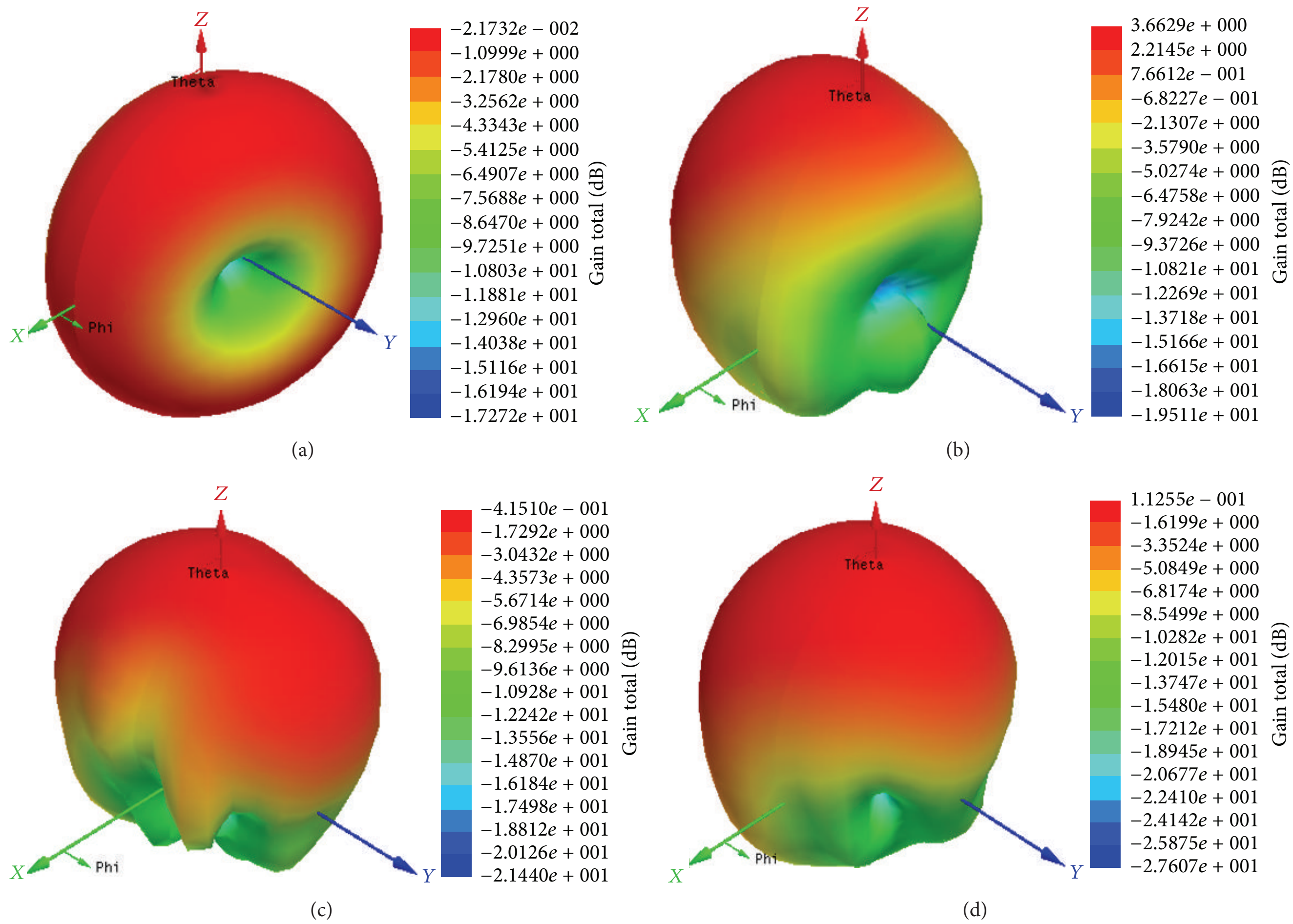


Figure 7: Simulated 3D Gain: (a) 0.92 GHz, (b) 1.8 GHz, (c) 2.1 GHz, and (d) 2.6 GHz.

the S_{11} and gain at the resonant bands were in good agreement. Because of the wideband and high gain characteristics in the desired operating bands, the proposed antenna design may be a good choice for handheld communication devices including smart phones, tablet PCs, and other multiband handset applications that operate in these frequency ranges.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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