

## Compact metal-plate slotted WLAN-WIMAX antenna design with USB Wi-Fi adapter application

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**Abstract:** In this study, a compact antenna design, which operates in the 2.4, 5.2, and 5.8 GHz (WLAN) and 3.5 and 5.5 GHz (WiMAX) frequency bands, has been implemented to be compatible with the 802.11.ac/n standards. The proposed metal antenna is made of a copper plate of thickness 0.5 mm with a compact overall physical size of 20 mm × 30 mm. Although it is low-profile, it can work with high efficiency because it has a cheap planar metal structure and it does not contain any expensive dielectric material. The antenna is investigated in terms of S parameters, input impedance, efficiency, surface current distributions, and radiation pattern. The implemented antenna has been used in a USB WiFi adapter design for a desktop computer as an indoor WLAN application. The protector outer jacket of the WiFi adapter has been designed using a 3D printer, and the adapter card and driver are acquired commercially. As a result, the produced WiFi adapter has been realized in a size of approximately 60% smaller than the other modules using commercially available monopole antennas on the market. The WiFi adapter provides IEEE 802.11.n/g/b standards and supports USB 2.0. It has been observed that the speed measurement tests have been performed successfully and that the download-link and upload-link can reach 600 Mbps data rates. In addition, BPSK, QPSK, and 16QAM with OFDM modulation techniques are used.

**Key words:** Planar metal antenna, metal plate antenna, slotted antenna, dual band, triple band, USB WiFi adapter, WLAN application

### 1. Introduction

Due to the growing demand for wireless communication, LTE, WiMax, and WLAN applications with MIMO technology are in need of faster data transfer, more channel capacity, and consequently multiple and wider frequency bands. Therefore, to provide worldwide compatibility in different devices, 2.4 / 5.2 / 5.8 GHz WLAN and 3.5 / 5.5 GHz WiMAX frequency bands are primarily preferred. This requires that the designed antennas evolve into broadband or multiband configurations. Today, in addition to the multiple and wider band properties, cost-effective compact antennas are in demand with versatile integrability, high efficiency, and high gain [1–3].

For many WLAN application, different types of antennas can be used such as microstrip or metal plate. Each antenna type has its own strengths and weaknesses based on the application. In the literature, many microstrip antenna designs can be found [4, 5]. The microstrip antenna structures are used widely

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because of their simple material and structural properties along with the practical design procedure. Also, for these antennas, the dielectric material can have two separate conducting surfaces, and these surfaces can hold independent and discrete different conductive patches on the same plane. Thus, it is easier to obtain compact designs via microstrip structures. However, apart from the design variety, dielectric loss is a critical weakness for microstrip antennas. In particular, low-profile dielectric materials such as FR-4 have high tangential loss and it directly affects the efficiency and gain of the antenna. Unlike microstrip antennas, metal antennas should be implemented on a one-piece metallic layer without any dielectric substrate. Although this seems to be a constraint from the designer's point of view, in fact, with a correct design approach, compact planar metal antenna designs can be realized as practical as in microstrips. Moreover, planar metal type antennas can achieve greater gain values and can radiate more efficiently since they do not suffer from dielectric loss. Additionally, planar metal type antennas are also prone to fast mass production like microstrip antennas. Manufacturing methods such as one-punch, water jet, and wire erosion can particularly provide a great advantage to manufacturing in terms of cost and time.

Over the last decades, metal type antenna configurations have attracted more attention of researchers interested in WLAN applications due to their outstanding properties such as high efficiency. It is possible to classify these configurations into two groups. The most comprehensive group includes 3-dimensional metal antenna structures. To obtain a 3D antenna, either a planar one-piece metal antenna can be bent [6–8] or a planar metal antenna can be combined with another metal plate, which is used as a reflector or protruded ground [9–15]. In one of the most recent studies of 2019 [6], a circularly polarized (CP) dual-layer planar inverted-F antenna (PIFA) was achieved. The proposed antenna is composed of two stacked orthogonal-orientated PIFAs, which can be fabricated by elaborately folding one piece of the metal plate. In another study of 2019 [14], the metal plate is used as a reflector and the antenna does not contain any dielectric substrate. In this study [14], the antenna mainly consists of a rectangular ground plane, a radiation patch with a U-slot, and two short metal cylinders. The effects of the U-slot suppress the high harmonics and cross-polarization. Apart from these antenna structures, some of them can both have a bent design and include an additional metal plate [16–20]. The work in [19] is a good example of this. In [19], a multiple-loop-antenna system was easily constructed from a single metal plate and was able to generate concurrent 2.4 and 5 GHz bands for WLAN operations. The design comprises four one-wavelength loop antennas, arranged perpendicular to and set along a square antenna ground. Although bending operations extend the fabrication process and cause additional cost, it is possible to obtain more compact designs and broader radiating bands with high efficiency. Unlike 3-D metal antennas, 2-D metal antennas are prone to mass-fast production and can be fabricated by stamping a single metal plate at once. Since they do not need any additional fabrication processes they are relatively less costly. They are usually produced from planar metal plates 0.3 to 0.5 mm thick, such as copper or related alloys. As a first study of 2-D metal antennas, Fang et al. [21] presented a dual-band operating antenna in 2.4/5.2 GHz bands. This antenna has two different radiating arms, which are connected to each other by a shorting loop portion. The antenna is fed with a  $50\ \Omega$  mini coaxial cable through initial points of the shorting loop. The next study was presented by Su et al. [22, 23], having an antenna that initially performs as a single band antenna and is then modified into a dual-band antenna by only adding an additional small radiating arm. Among these radiating arms, there is a shorting portion. The shortest radiating arm radiates in lower resonance frequency. The longer arm is utilized for input impedance matching. Adding the third arm, the proposed antenna structure serves as a dual-band antenna. In two successive studies, Chou et al. presented a flat-metal type antenna and one-piece dipole structure, respectively [24, 25]. The first proposed dipole antenna has a form of an “L” structure, which

can easily be located in wireless communication devices [24]. In the other proposed antenna structure [25], unlike the first, L-type slits were added on the radiating dipole arms to provide radiation at the 5.2 GHz band. Since radiation characteristics of the 2.4 GHz band showed more omnidirectional properties than the 5.2 GHz band, the gain value in the 5.2 GHz band is higher than the value in the 2.4 GHz band. The study published by Su et al. in 2007 described the antenna design to obtain dual-band operation in the 2.4/5 GHz bands [26, 27]. In [26], a dipole antenna design operating at 2.4 GHz was presented. The radiating arms of the antenna are bent into a compact structure. Among these radiating dipole arms, there is a shorting strip, which mainly affects the input impedance characteristics of the antenna. The study was extended in [27] with additional L-type slits, which allow the antenna to resonate in the 5 GHz band also. The study in [27] got attention from researchers working on planar-metal type antennas due to the broader radiating frequency bands, which cover both 2.4 GHz and the whole of 5 GHz for the first time. One of the studies of Su [28] is an outstanding work for researchers interested in planar-metal type antennas due to the detailed analyses of surface current distributions and radiating mechanisms of the antenna. In [28], the antenna has two radiating structures: a loop radiating arm and a larger radiating arm. Through these arms, the antenna operates as a triple band, which includes bands of 2.4 GHz, 5.2 GHz, and 5.8 GHz. In another study by Su [29], a one-piece, coupled-fed, short-circuited monopole antenna was presented for wireless local area network applications in 2.4 GHz. The monopole is in the shape of an inverted hook, and it is short-circuited to a small antenna ground. Many studies in the literature belong to a specific research group that commonly performs studies on metal-based antennas. Members of this research group mainly gathered around Wong, Su, and Liu, who work together at the National Sun Yat Sen University and Lite On Technology Corp., or their partners. Besides this group, Mondal et al. presented a number of studies about planar metal type antennas [30–33]. In these studies, some bulky planar metal antenna geometries such as elliptical or similar curved edges were studied with the purpose of realizing ultra-wideband antenna designs. All of the antennas in those works were fed via SMA connector instead of UFL mini coaxial cable.

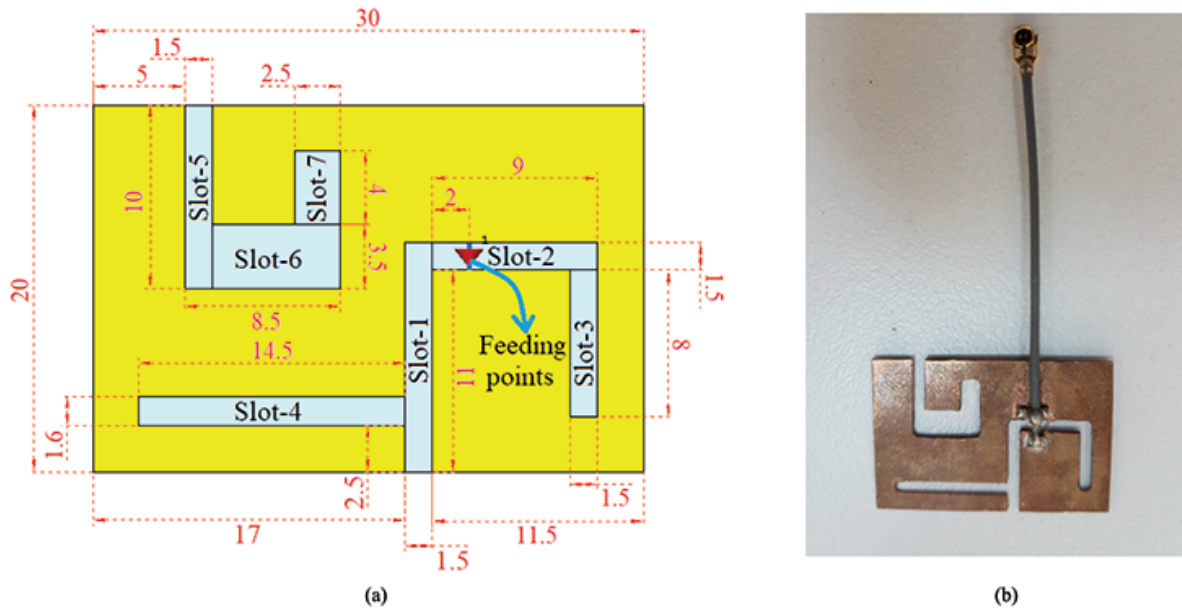
Different from previous planar metal plate antenna studies, the antenna proposed here has three different slit groups, and with these slits, the antenna is optimized to resonate in 2.45 GHz, 3.55 GHz, and 5.5 GHz via some dominant current distributions. Also, as an application, the proposed metal plate antenna configuration is utilized in a compact USB WiFi adapter design for a desktop computer.

The following sections are presented in the manuscript. First, the proposed antenna geometry and some numerical calculations are given. In the same section, S parameter measurement results are discussed. Next, the performance parameters of the USB WiFi adapter design are described. Then a comparison of the proposed design to the commercially available adapter is given to show the performance of the design.

## 2. Antenna design principle and measurements

The proposed metal antenna design has been numerically computed and optimized in CST Microwave Studio 3D electromagnetic simulation software. As a design material a 0.5-mm-thick planar copper plate with the electric conductivity of  $5.8 \times 10^7$  S/m is used. The physical dimensions of the proposed antenna are 20 mm  $\times$  30 mm ( $\lambda_0/6.12 \times \lambda_0/4.08$  at the resonance frequency of 2.4 GHz). The design parameters of the antenna model are shown in Figure 1 along with the fabricated antenna prototype. The fabricated antenna prototype is fed with UFL cable from the specified points in the figure. According to the resonant frequencies of the antenna, it can be accepted as a compact design. For this reason, it is easy to integrate the antenna into any device or application. The proposed antenna design is accommodated with 3 different slot groups and the antenna's feed

point is in one of these slots (Slot-2). The first slot group consists of Slot-1, Slot-2, and Slot-3; the second slot group consists of only Slot-4; and the third slot group consists of Slot-5, Slot-6, and Slot-7 (Figure 1).



**Figure 1.** Proposed metal antenna geometry: a) design parameters (all dimensions are in mm), b) fabricated prototype.

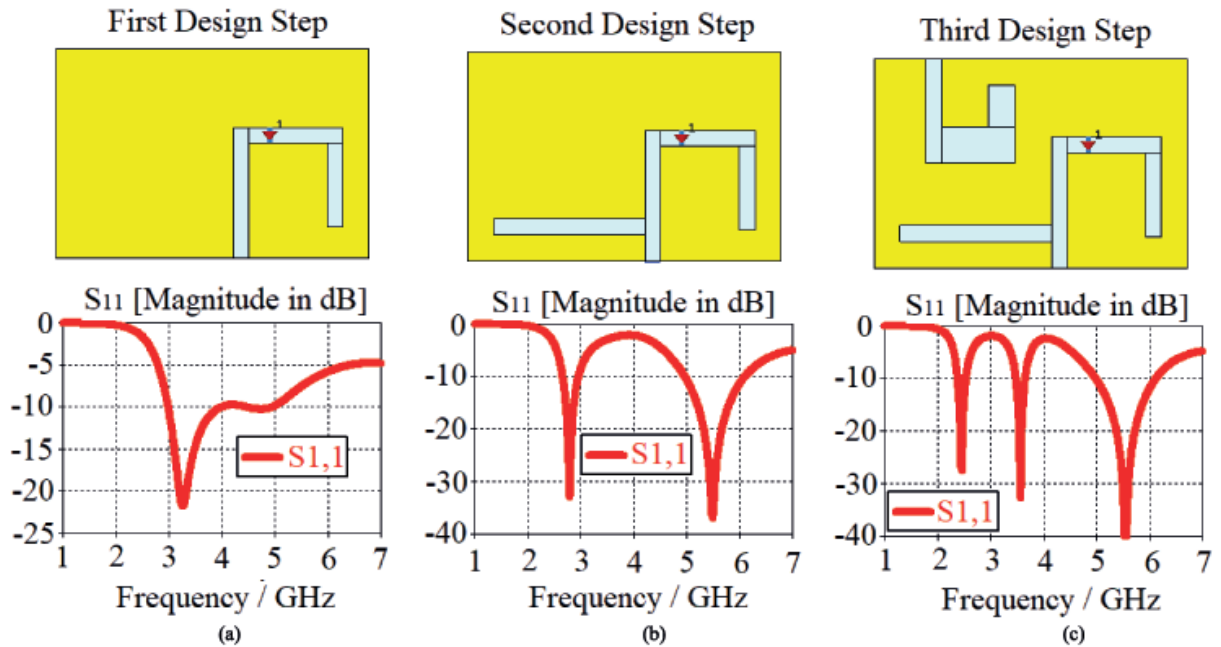
### 2.1. Design steps

The proposed antenna design is obtained by positioning some slits at different positions on a metal plate and optimizing the effects of these slits via CST Microwave simulation software. In the literature, there are similar antenna studies with the positioning and optimizing of different slits on metal plates [21, 25–28, 31, 33]. In each design step, the position of the next slit is determined by analyzing the current distributions of the current design step, and the slit lengths are optimized according to the return loss values. Also, the production process and the fabrication limits have been taken into account in each design step.

In the first design step (Figure 2a), only the first slot group is located on the antenna. By this configuration, a radiation band from 3 GHz to 5 GHz is obtained, and the input reflection coefficient graph is presented in the same figure. The radiation principle of this configuration is based on half-wave resonant modes with the capacitive effects around the slit because of the surface current distributions around feeding points, some part of Slot-2, and all around Slot-1.

The second design step (in Figure 2b) is obtained by combining slot groups 1 and 2. With this configuration, the antenna undergoes behavior modification as dual-band radiation whose central resonance frequencies are 2.8 GHz and 5.5 GHz. For these frequencies, it can be seen that return loss values are very low due to the perfect impedance matching of this antenna configuration. The antenna radiates with a half wave  $\lambda_0/2$  resonant mode for the low resonance band. This radiation is generated by the current distributions around some part of Slot-2 and almost all around Slot-1 and Slot-4. On the other hand, the surface current distributions around Slot-1/2/3/4 provide full wave  $\lambda_0$  resonator behavior for the upper resonance band. Thus, a wide bandwidth is obtained from 5 GHz to 6 GHz.

Finally, for the third design (in Figure 2c), the third slot group is added to the antenna structure with a combination of the other two slot groups. This configuration provides additional radiation in 3.5 GHz and the



**Figure 2.** Design steps of the proposed antenna model with the reflection coefficient simulation results in CST.

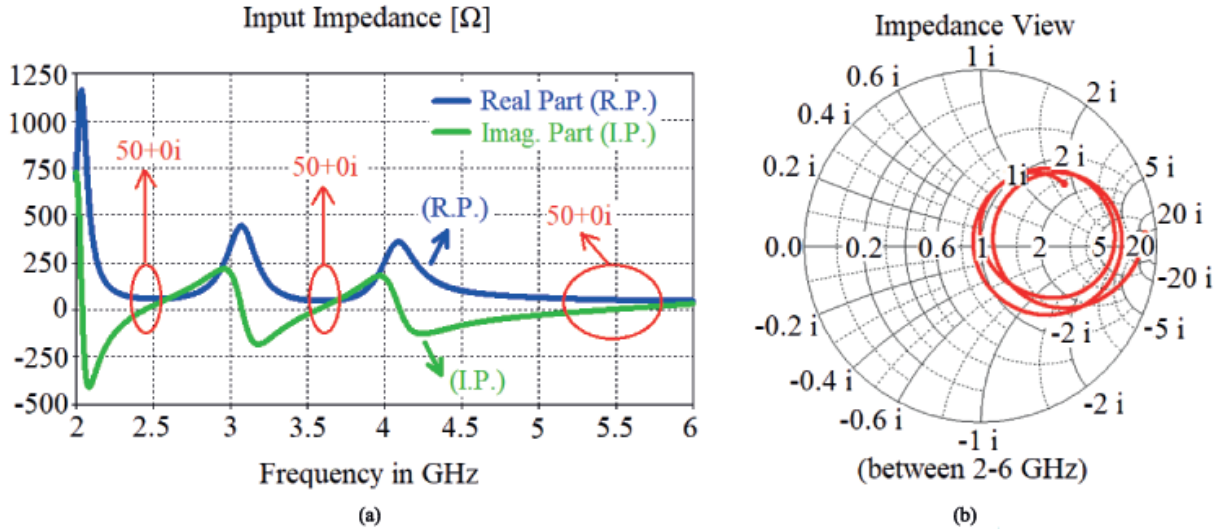
antenna turns into triple band radiation in 2.4, 3.5, and 5.5 GHz. The first two slot groups determine the lower (2.4 GHz) and higher (5 GHz) radiation bands, respectively, while the third slot group provides the middle (3.5 GHz) radiation band. The radiation in 3.5 GHz is generated by three separated surface current loops on the antenna. The first current distribution is produced around Slot-5/6/7 as a half wave  $\lambda_0/2$  resonator configuration. The second and third current distributions occur around Slot-4 and some parts of Slot-2 and Slot-1. It is seen that these current distributions are interfering at the intersection point of Slot-1 and Slot-4. The main reason for this intersection is that one of these current distributions mainly flows in the x-axis direction around Slot-4 and the other current distribution mainly flows in the y-direction around Slot-1, and also the intersection point comes across one of the corners of the antenna. In the current configuration, the presence of Slot-5/6/7 does not cause any significant change for the 5 GHz band in terms of the input impedance and the current distributions. Meanwhile, it leads to the decrease of the resonant frequency to 2.45 GHz, which is the most desired for WLAN applications.

**2.2. Antenna input impedance characteristics**

In Figure 3, computed input impedance values are presented. Real and imaginary parts of the proposed metal antenna are shown in Figure 3a. A Smith chart view of the antenna input impedance is demonstrated in Figure 3b. The proposed antenna shows great wideband impedance matching around  $(50 + j0 \Omega)$  in the 2.4, 3.5, and 5.5 GHz operating bands.

In a free space environment, the proposed antenna does not need any external or additional impedance matching circuit. However, some input impedance distortions or some resonance frequency shifts can be observed when the proposed antenna is integrated into a device for an application. These distortions can be fixed by adding an external matching circuit with lumped elements. The impedance matching configuration can be straightforward for single-band antennas. However, for dual-band or triple-band antennas, impedance matching is much more complicated or even impossible in practice. On the other hand, if a dual/triple-band antenna

shows a similar graphical representation in the Smith chart for the free space environment, it is more simple to fix impedance distortions of a wireless application for a designer. Although the results of the impedance matching circuit and the effects of input impedance distortions mainly depend on the frequency, it is an important advantage that positioning occurs in the same region of the Smith chart for all resonance frequencies with similar graphical representation. At this point, the proposed antenna shows outstanding properties in terms of showing similar graphical representation in the Smith chart as three overlapping circular loops for all resonance bands in 2.4, 3.5, and 5.5 GHz. (Figure 3b).



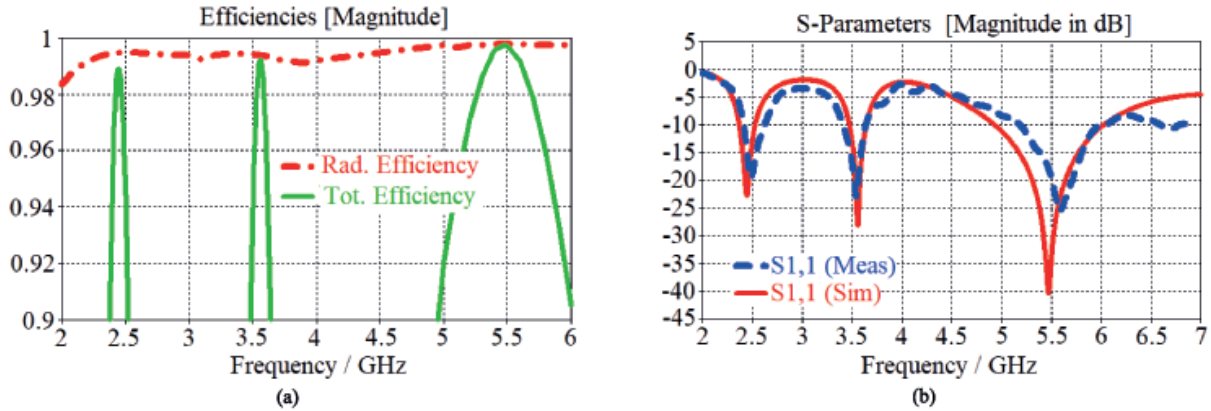
**Figure 3.** Antenna input impedance graphs of a) real and imaginary parts, and b) Smith chart (normalized to 50Ω).

### 2.3. Computed efficiency and reflection coefficient ( $S_{11}$ ) measurements

As mentioned earlier, since there is no dielectric loss, the radiation efficiency values of the proposed antenna are much higher than those of other antennas that contain dielectric materials. With advanced design, reflection loss values also can be decreased, and thus improved total efficiency values can be obtained. Higher total efficiency and directivity are critical parameters for achieving higher gains. For the proposed metal plate antenna, the graphical representation of the compared radiation efficiency and total efficiency is depicted in Figure 4a. Like other metal antennas, its radiation efficiency is nearly 100%. The radiation losses result from low ohmic or conducting losses. As can be seen from the green line in Figure 4a, the total efficiency is above 90% for all radiation bands and it can achieve 99% in the center frequency of bands. High total efficiency values are also dependent on low return loss or good impedance matching. This can be seen from simulated and measured  $S_{11}$  results in Figure 4b.

The measured results of the fabricated prototype were obtained using the MS4640 Series 20 GHz Microwave Vector Network Analyzer. According to Figure 4b, the frequency shift between the  $S_{11}$  measurement and simulation is more apparent, especially in higher frequencies. For the 5 GHz band, the critical -10 dB value for  $S_{11}$  measurement starts at 5.19 GHz and continues until 6 GHz. The main reason is the precision errors in fabrication techniques, which have less effect at low frequencies. Other negligible differences between the results are caused by cable losses and soldering. As deduced from Figure 4b, the resonance frequencies are numerically computed to be 2.44 GHz (with return loss of 23 dB and 10 dB bandwidth of 150 MHz), 3.56 GHz (with return loss of 27.5 dB and 10 dB bandwidth of 160 MHz), and 5.47 GHz (with return loss of 41.2 dB and

10 dB bandwidth of 1080 MHz). The proposed metal antenna can be used as a triple band, and bandwidths are wide enough to provide IEEE 802.11.ac/n standards.



**Figure 4.** Antenna performance parameters: a) total and radiation efficiency, b) simulated and measured  $S_{11}$  results.

#### 2.4. Surface current distributions

The surface current distributions of the proposed triple-band antenna is presented in Figures 5a–5c at the resonance frequencies (2.45, 3.5, 5.5 GHz). Based on these results, the radiation principle of the antenna is analyzed according to maximum and null points, and electrical lengths of dominant current paths.

In Figure 5a, the surface current distribution at 2.45 GHz shows that the antenna's working principle is based on  $\lambda_0/2$  half-wave resonant mode because of surface current distributions around feeding points, some parts of Slot-2, and all around Slot-1. In a free space environment, the half wavelength of 2.45 GHz is 6.12 cm. On the antenna, the current loop length through the feeding points, some part of Slot-2, and all around Slot-1 is also 6.1 cm. Besides, the position of maximum current points and null points verifies that the antenna's radiation configuration is as given in Figure 5a. The effects of Slot-1, Slot-3, and Slot-4 lengths for the 2.45 GHz resonant band are presented in Figures 6a–6c. The length of Slot-3 can be used for minor adjustments for input impedance matching, and it does not affect the resonant point, which is shown in Figure 6b.

In Figure 5b, the surface current distribution shows that three separated surface current loops generate the radiation at 3.55 GHz. The first loop stands around Slot-5/6/7. Around these slot groups, a  $\lambda_0/2$  half-wave resonant mode is generated for 3.55 GHz. The length of this current loop is 4.1 cm, which is very close to the free-space half wavelength in 3.55 GHz. The effects of Slot-7's length on the 3.55 GHz resonant band is presented in Figure 6d. The second loop is around Slot-4 and some parts of Slot-1. The last loop becomes visible around some parts of Slot-2 and Slot-1. Also, the surface current distribution shows that current loop-2 and loop-3 intersect each other at common points. For all the current loops, the maximum current points and null points are presented on the antenna in Figure 5b.

In Figure 5c, the surface current distribution confirms that the radiation principle is based on  $\lambda_0$  half-wave resonant mode in 5.5 GHz. The loop current covers some part of Slot-2 and almost all around Slot-1 and Slot-4. The null point and maximum current point are also shown in Figure 5c. The free-space wavelength for 5.5 GHz is 5.5 cm, which is approximately equal to the total length of the radiating geometry around Slot-1,2,4. The effects of Slot-1 and Slot-4 lengths on the 2.45 GHz resonant band are presented in Figure 6a–6c.

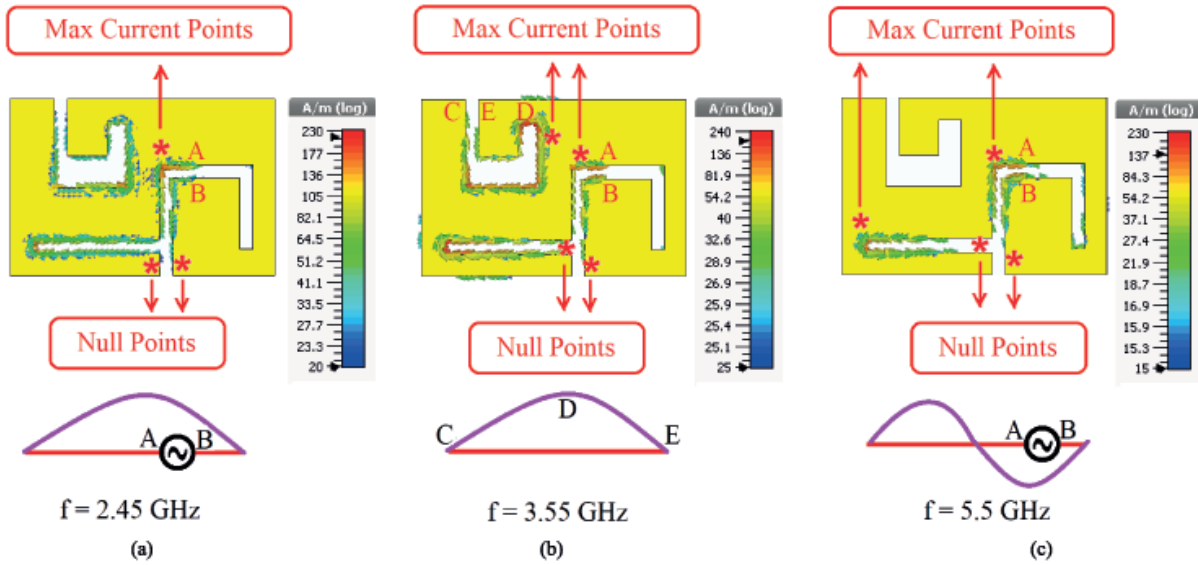


Figure 5. Surface current distributions of proposed metal antenna at a) 2.45 GHz, b) 3.55 GHz, and c) 5.5 GHz.

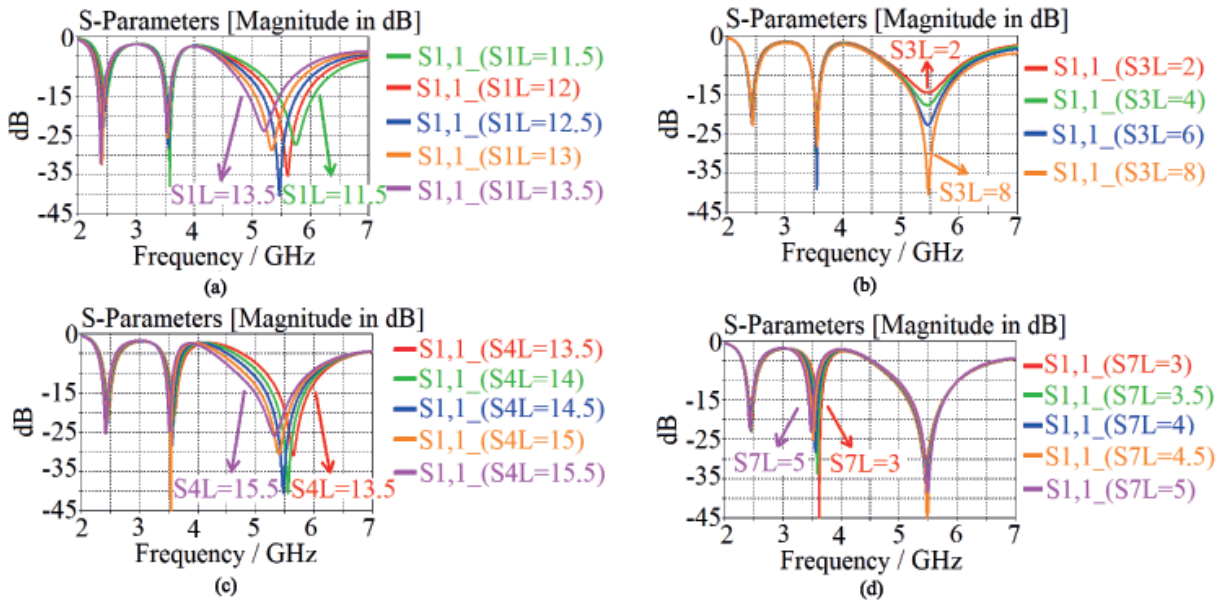
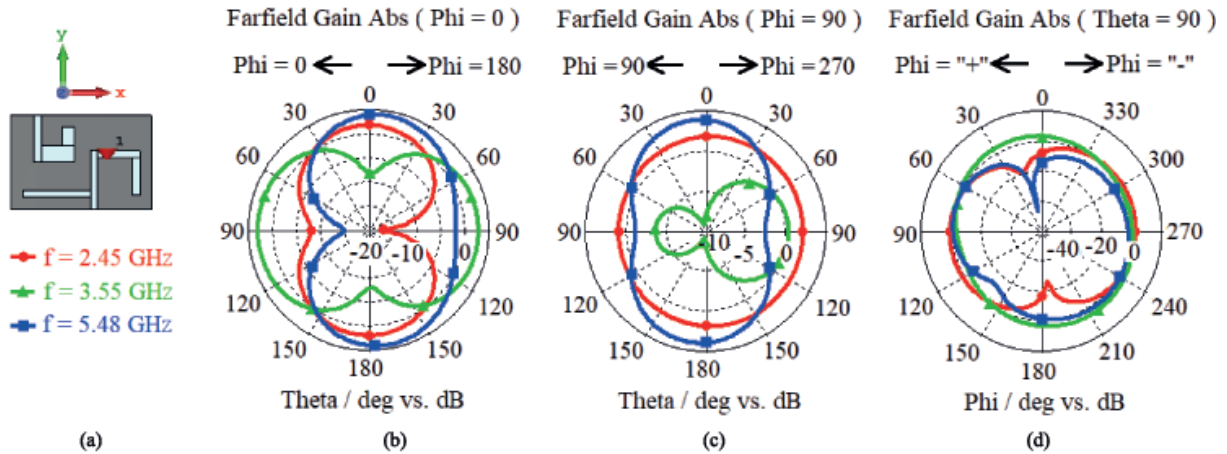


Figure 6. The 2D polar radiation patterns of the antenna on different planes at resonance frequencies: (a) plot legend and coordinate system demonstration, (b) X-Z plane ( $\phi = 0$ ), (c) Y-Z plane ( $\phi = 90$ ), and (d) X-Y plane ( $\theta = 90$ ).

### 2.5. Radiation pattern characteristics and gain

The 2D polar radiation patterns of the proposed antenna on different planes (X-Y, Y-Z, and X-Z) at different resonance frequencies (2.45, 3.55, and 5.5 GHz) are shown in Figure 7 along with the antenna positioning. The directional antennas can radiate higher gains and omnidirectional antennas can achieve relatively lower gains. From the figures, it can be deduced that the antenna radiation shows quite a similarity to the omnidirectional characteristics around the “x” axes.





**Figure 7.** The 2D polar radiation patterns of the antenna on different planes at resonance frequencies: (a) plot legend and coordinate system demonstration, (b) X-Z plane ( $\phi = 0$ ), (c) Y-Z plane ( $\phi = 90$ ), and (d) X-Y plane ( $\theta = 90$ ).

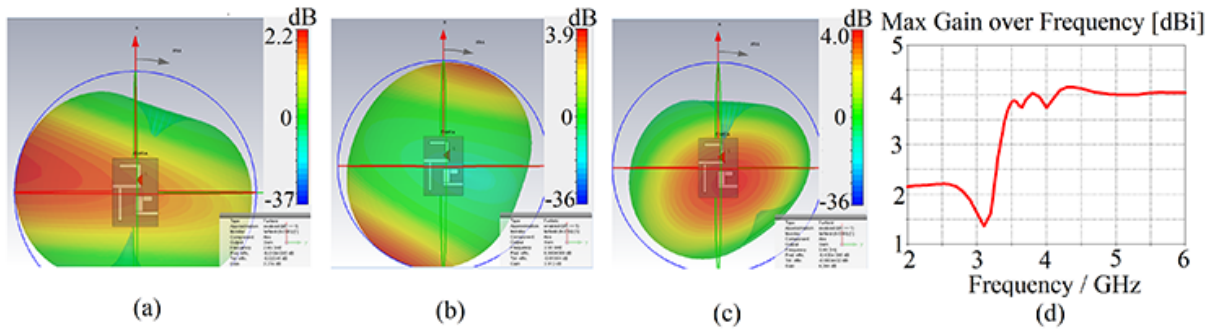
The 3D radiation patterns of the proposed metal antenna at different resonance frequencies are presented in Figure 8. In Figure 8a, the computed max gain in the 2.4 GHz band is around 2.22 dBi. This result can be regarded as a high gain for an omnidirectional antenna. In Figure 8b, the antenna mainly radiates through the “x” axes due to the dominant current distributions in 3.55 GHz and the gain is 3.91 dBi. In Figure 8c, the main radiation direction is through the “z” axes with the gain value of 4.04 dBi.

In Figure 8d, the maximum gain over the frequency graph is presented. The total efficiency is higher than 90% in all operating bands; thus, the max gain values’ differences are directly related to directivity values. Regarding this, the antenna behaves with more directional characteristics in higher frequencies. Alternative metal antenna designs in the literature are listed in the Table to demonstrate the comparatively improved simulated RF performance of the metal antenna designs.

As it can be seen from Figures 8a–8c, due to the resonance modes caused by dominant current distributions in the proposed antenna design, the radiation characteristics at frequencies above 3.5 GHz, directivity, and gain are increased, and the omnidirectional property is lost in parallel. A decrease in the omnidirectional property is not generally desirable for WLAN antennas. On the other hand, the individual performance of the antennas in the free space is increasingly less valuable nowadays. The main reason for this is the increase in compact device designs and the sensitivity of high-frequency electromagnetic waves to environmental factors in these compact devices. Consequently, the radiation performances or characteristics of an antenna should be examined together with the whole device it is designed to benefit. Ultimately, a directional antenna can be transformed to have a more omnidirectional character or vice versa, with adequately designed environmental factors such as reflectors or a metallic chassis. A case in point is presented in Section 3 with a USB WiFi adapter design with the proposed metal antenna. In this situation, applying metallic computer boxes, the 3D farfield radiation characteristic behavior of the adapter is altered drastically according to the proposed metal antenna’s.

### 3. USB WiFi adapter with proposed metal antenna

The proposed planar metal plate antenna has many outstanding features. One of them is having a compact design of 20 mm × 30 mm and it can be fed via flexible mini UFL cable, which provides easy integration within the device. Besides, due to three separate resonance frequencies, the ISM band includes all the necessary



**Figure 8.** The 3D farfield radiations for (a) 2.45 GHz, (b) 3.55 GHz, and (c) 5.5 GHz, and (d) max. gain over frequency.

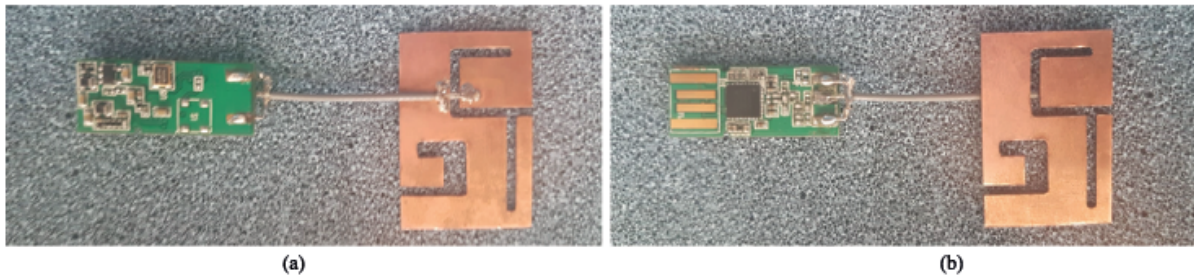
**Table 1.** Planar metal plate antenna performance comparison from the literature.

Design	Area [mm×mm]	Band number	Resonance freq. band [GHz]	Bandwith [MHz]	Gain [dBi]
[21]	6×45	Dual	2.4 & 5.2	192 & 507	3.2 & 4.3
[22]	3×60	Single	2.4	400	3.9
[23]	5×60	Dual	2.4 & 5.2	340 & 270	3 & 3.4
[24]	30×30	Single	2.4	389	5
[25]	29×29	Dual	2.4 & 5.2	289 & 472	3.3 & 4.9
[26]	10×38	Single	2.4	250	3.9
[27]	10×37	Dual	2.4 & 5 (includes 5.2, 5.5, 5.8)	100 & 700	3.3 & 4.7
[28]	10×38	Dual	2.4 & 5 (includes 5.2, 5.8)	250 & 1700	2.4 & 3.2
[29]	10×38	Single	2. 4	200	3
[30]	110×110	UWB	0.8 to 40	39200	-2 to 12
[31]	55×65	UWB	2 to 9	7000	-3 to 5
[32]	100×110	UWB	2 to 25	23000	-4 to 8
[33]	85×40	UWB	3.1 to 10.6	6500	-2 to 5
Proposed ant.	20×30	Triple (multiple)	2.4 & 3.5 & 5 (includes 5.2, 5.5, 5.8)	158 & 170 & 1080	2.2 & 3.9 & 4

bands for personal use in 2.4/ 3.5/ 5.2/ 5.5/ 5.8 GHz. The antenna can be easily manufactured with different production techniques such as one punch, water jet, or wire erosion. It does not contain any dielectric material; therefore, it can operate with very high efficiency without suffering from dielectric losses. When all these superior features are combined, the proposed antenna is a great candidate for a USB WiFi adapter.

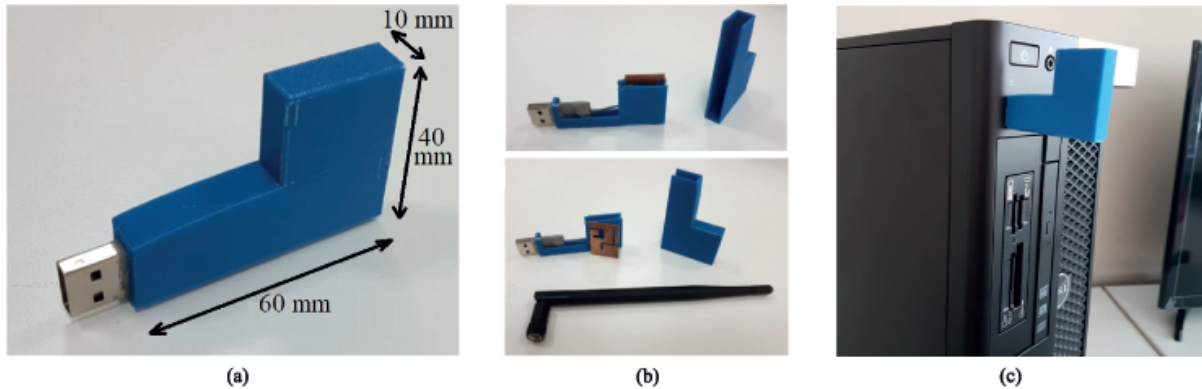
In order to investigate the usefulness of the proposed metal antenna, a commercially available USB WiFi adapter is used. The traditional adapter’s antenna is monopole type and fed by SMA coaxial connector. The traditional adapter has a size of 1 × 5 × 15 cm, which is bulky and noninnovative. The nondirectional monopole antenna and its SMA connector have been removed from the adapter, and instead of them, the proposed compact metal antenna is mounted to the main circuit board via mini UFL coaxial cable (Figure 9).

Integration of the developed USB WiFi adapter with the desktop computer is examined using CST simulations. The dimensions of proposed adapter are 10 mm × 60 mm × 40 mm with a stylish and compact adapter jacket. As can be seen from Figure 10, the designed device is approximately 60% smaller than the traditional one. In the simulations for the outer protector case, ABS polymer composite having a dielectric



**Figure 9.** USB adapter's main circuit board and proposed metal antenna: (a) front view, (b) back view.

constant of 2.57 and loss tangent of 0.0015 is used [34]. The electromagnetic compatible design has been fabricated with a 3D printer as shown in Figure 10. Zortrax-ABS polymer composite has been used to fabricate the case.



**Figure 10.** (a)USB WiFi adapter design, (b) adapter's components and traditional antenna, (c) desktop comp. app.

For the simulated desktop computer the dimensions are assumed as 42 cm × 47 cm × 17 cm as an average value. In Figure 11 the computed reflection coefficient values of -28 dB, -20 dB, and -20 dB for the frequencies of 2.45 GHz, 3.55 GHz, and 5.5 GHz are depicted, respectively. The input impedance of an antenna highly depends on the material properties of the surrounding medium. Therefore, the presence of a computer case would be expected to change the simulated results in this respect significantly. However, for the proposed USB WiFi adapter design, the length between the computer box and antenna is around the half wavelength in concerned resonance frequencies. Consequently, in Figure 12, for the proposed USB adapter design, radiation performances are greatly increased in terms of gain such as 6.8 dBi at 2.45 GHz, 7.1 dBi at 3.55 GHz, 8.2 dBi at 5.2 GHz, 8.8 dBi at 5.5 GHz, and 8.2 dBi at 5.8 GHz, while the traditional design can only radiate in 2.45 GHz with 5 dBi gain. Through this antenna modification, the USB adapter radiation standards are upgraded from IEEE 802 n/g/b to IEEE 802 a/n/g/b/ac. With the installation of necessary drivers, the implemented USB-WiFi adapter is tested successfully with a desktop computer.

The proposed USB WiFi adapter and commercial adapter are driven with the same circuit board; thus, some specifications are the same, also. Both adapter designs use the same modulation techniques for 11n: BPSK, QPSK, 16QAM, 64QAM with OFDM; 11g: BPSK, QPSK, 16QAM, 64QAM; 11b: DQPSK, DBPSK, DSSS, CCK with up to 600 Mbps data rate. They have the same data security such as 64/128 bit WEP encryption, WPA, WPA-PSK, WPA2, WPA2-PSK, TKIP/AES. Finally, their operating systems are XP/ Vista/ WIN7/ WIN8.1, Linux, and MAC OS X. The adapter is connected to a desktop by way of a USB 2.0 connection after

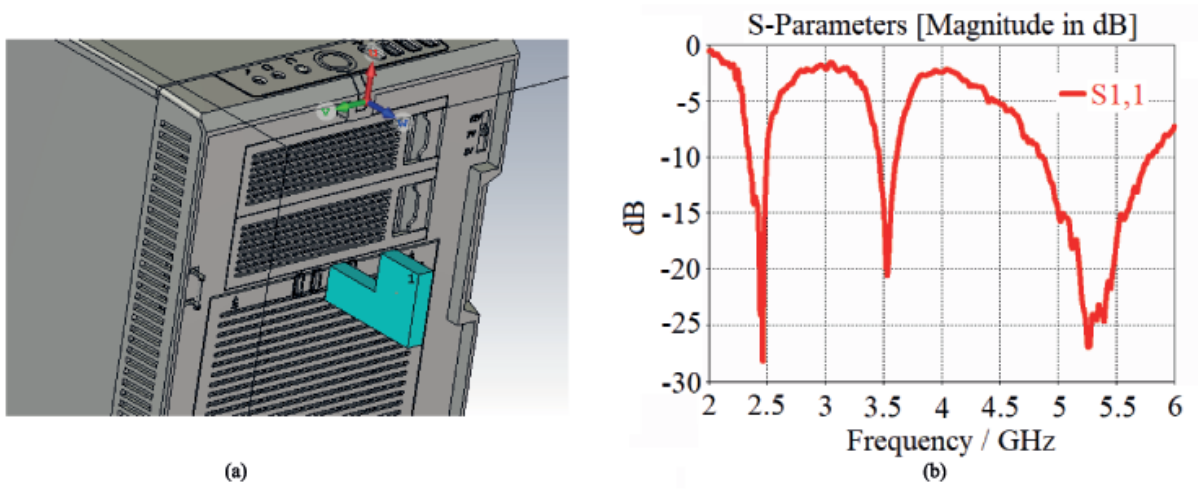


Figure 11. USB WiFi adapter design with computer box: (a) simulation view, (b) computed reflection coefficient.

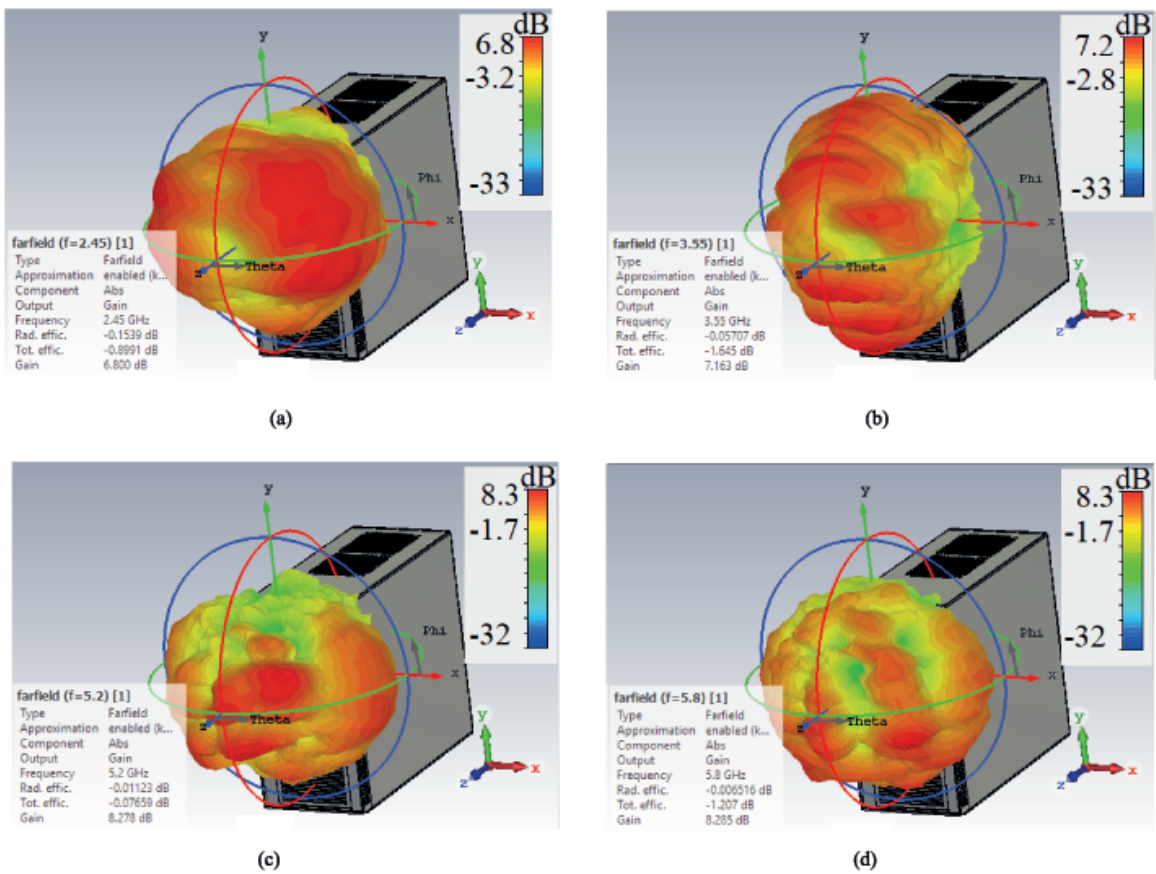


Figure 12. 3D farfield patterns for (a) 2.45 GHz, (b) 3.55 GHz, (c) 5.2 GHz, and (d) 5.8 GHz.

installation of the adapter’s software. Compared to commercial one, the proposed adapter is very compact and radiates in multiple frequencies with broader bands.

#### 4. Conclusion

In this paper, we present a low-cost compact antenna design that works in WLAN and WiMax frequency bands for personal wireless communication applications. The antenna is made of a copper plate with dimensions of 20 mm × 30 mm and a thickness of 0.5 mm. The proposed antenna can provide a significant advantage to the manufacturing process in terms of cost and time. Moreover, since it does not contain any dielectric material, its radiation efficiency is high. The designed antenna has been examined using simulations and measurements for S parameters. The results showed that the proposed antenna radiates at more frequency bands and has broader bandwidth according to previous antenna designs in the literature. When all these outstanding features are combined, the proposed antenna has become an ideal candidate for designing a USB WiFi adapter as an indoor WLAN application for a desktop computer. To create a design example, a commercially available USB WiFi adapter has been purchased and the proposed antenna is mounted to the main circuit board via mini UFL coaxial cable. The adapter with the proposed antenna design is much more compact and functions very well when integrated with a computer.

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