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PRINTED ANTENNA FOR PENTA-BAND WWAN TABLET COMPUTER APPLICATION USING EMBEDDED PARALLEL RESONANT STRUCTURE

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Abstract—A compact printed antenna for WWAN tablet computer application is proposed in this article. The designed antenna occupies a small area of $35 \times 12\,\text{mm}^2$, which is small enough to be incorporated in a tablet computer, and is placed close to the edge of the shielding wall with a distance of 10 mm. The antenna has a simple structure of comprising a long coupling strip and a feeding strip to capacitively excite the long coupling strip. In this scheme, a chip inductor is loaded on one branch of the feeding strip, which can form a parallel resonant structure to enhance the bandwidth of the lower band. As a result, two wide operating bands to cover GSM850/900 and GSM1800/1900/UMTS2100 operation are obtained with desired 3 : 1 VSWR. The proposed antenna is an all-printing structure with low production cost, which is especially suited for the thin-profile tablet computers.

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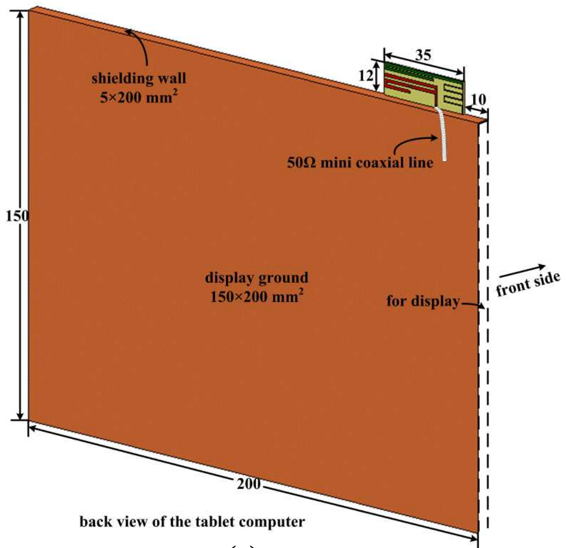
1. INTRODUCTION

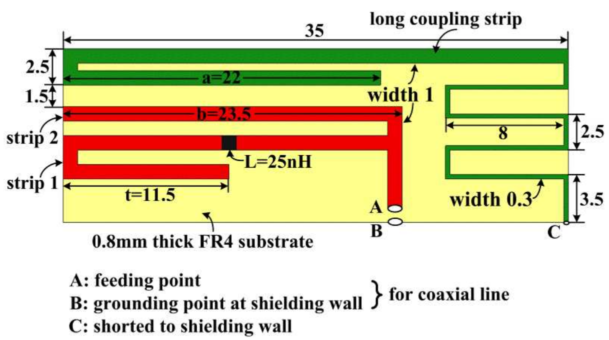
Due to the rapid progress in both wireless communication and chip technology, tablet computers can be developed with a compact size to support more portable requirements. Accordingly, many promising antenna designs to be embedded inside a tablet computer as an internal antenna for WWAN applications have attracted high attention. However, the challenge to designing the antenna for tablet computer is much larger than that for mobile phone [1–6] or the USB dongle [7–11], especially for multi-band application. There are two main reasons for this. Firstly, the system ground plane of the tablet computer is too large to assist in achieving a wide operating band for the embedded internal antenna. Secondly, the antenna must be disposed on the edge of the display ground so that the height of the antenna should be compact for elegant appearance of the tablet computer.

Fortunately, in recent years, extensive research activities have been dedicated toward the development of multiband and wideband antennas for tablet computer applications. The coupling feed structure is used in [12], in which a parasitic element is coupled fed by a meandered feeding part. Because the coupling feed technique can result in the improvement of impedance matching and generate a dual-resonance mode over the desired lower band for the antenna, it is a good choice for wideband tablet computer antenna. As reported in [13, 14], some inverted-F antennas for tablet computers are presented, which have the simple structure and narrow footprint characteristics. Besides, it can be seen some new technologies are applied in the tablet computer antenna, like the parasitic open slot structure in [15], and the parallel resonant structure in [16, 17]. However, most of the existing designs [12–19] are somewhat large and not so suitable for tablet computer use, so it is important to further reduce the size and enhance operating bandwidth of the antenna.

Based on the above discussion, in this article, a compact printed antenna with a parallel resonance structure for penta-band WWAN tablet computer application is presented. The proposed antenna has a small size of $35 \times 12\,\mathrm{mm}^2$ with a rather simple structure comprising of a long coupling strip and a feeding strip. The parallel resonant structure as a new effective technology is used to widen the lower operating band in the proposed antenna. The proposed antenna is an all-printing structure with a small size, which is easy to be fabricated and is very suitable to be applied in the modern tablet computer. Detailed configurable illustrations and radiation characteristics of the proposed antenna are given in the next sections.



(a)



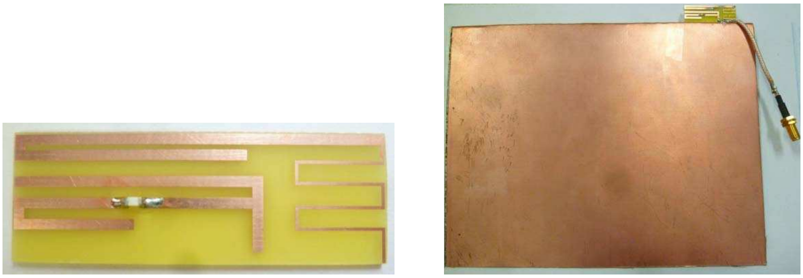
(b)

Figure 1. Proposed antenna configuration. (a) Geometry of the compact printed antenna for penta-band WWAN operation in the tablet computer. (b) Detailed dimensions of the metal pattern in the antenna area (unit: mm).

2. PROPOSED ANTENNA DESIGN AND PARAMETRIC STUDY

Figure 1(a) shows the arrangement and geometry of the proposed antenna for WWAN tablet computer application. In this study, the tablet computer with a $150 \times 200\,\text{mm}^2$ display is considered, which is currently commercially available size for tablet computer. The designed antenna is printed on a 0.8 mm thick $35 \times 12\,\mathrm{mm}^2$ FR4 substrate of relative permittivity 4.4 and loss tangent 0.02 and is placed close to the edge of the shielding wall with a distance of 10 mm. The shielding wall of size $5 \times 200\,\mathrm{mm}^2$at the top edge of the display ground can be used to accommodate the embedded antenna and may also provide some isolation between the antenna and the display, but it usually results in some degrading effects on the impedance matching of the internal antenna. By including the shielding wall, the proposed antenna can still generate two wide operating bands to cover the desired penta-band WWAN operation.

The detailed dimensions of the metal pattern of the proposed antenna are given in Figure 1(b). Seen from the figure, the antenna comprises of a long coupling strip and a feeding strip. The feeding strip also includes two parts: strip 1 and strip 2. Strip 1 having an total length of 39 mm can generate a parallel resonance at around 1 GHz with the help of the loaded chip inductor of $L = 25\,\mathrm{nH}$ in the antenna's lower band. Strip 2 of the feeding strip having a length of about 30 mm which is about 0.20 wavelength at 1900 MHz, can generate a quarter-wavelength resonant mode at about 1900 MHz. The long coupling strip is capacitively excited by strip 2 of the feeding strip, providing a resonant path of about 98 mm which is about 0.27 wavelength at 840 MHz and 0.69 wavelength at 2150 MHz, can produce a quarter-wavelength resonant mode at about 840 MHz and a high-order resonant mode at about 2150 MHz. Notice that in this design, the front section of the long coupling strip is very narrow and the end section is relatively wide. The narrow front section of width 0.3 mm functioning like a printed distributed inductor can adjust the input



(a) (b)

Figure 2. (a) Photo of the manufactured antenna for penta-band WWAN operation in the tablet computer. (b) Overall photo of the fabricated antenna attached to a tablet computer.

impedance of the antenna's lower band to produce resonances. Hence, two wide operating bands of the 824–960 MHz and 1710–2170 MHz can be obtained respectively, which indicate that the proposed antenna can cover the GSM850/900 and GSM1800/1900/UMTS2100 operations. The proposed antenna is fabricated and measured, as shown in Figure 2. In the experiment, a 50 Ω mini coaxial line is used to feed the antenna.

Several main design parameters of the presented antenna are studied and discussed in the following sections. First of all, to further analyze the operating principle of the antenna, Figure 3(a) shows the simulated return loss for the proposed antenna, strip 2 of the feeding strip only (Ref. 1), and the feeding strip only (Ref. 2). For the Ref. 1 case, there is only one resonant mode at about 2000 MHz, and this case can be explained in Figure 3(b), which plots the simulated input impedance of Ref. 1 and Ref. 2. It can be seen that the impedance matching for the frequency range of 500–3000 MHz is poor and there is only one null point of the imaginary (Im) part of the input impedance

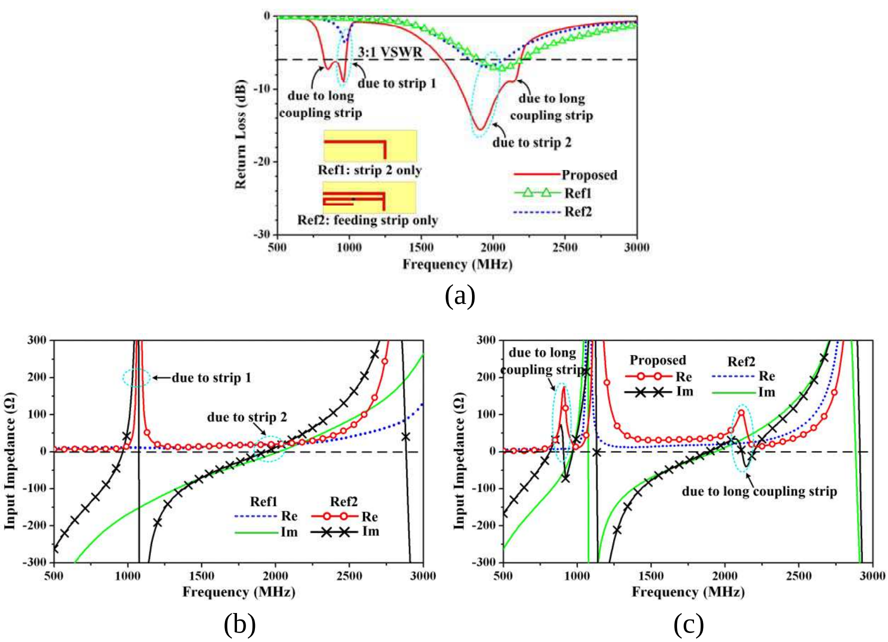


Figure 3. (a) Simulated return loss of the proposed antenna and the reference antennas, (b) simulated input impedance of Ref. 1 and Ref. 2, and (c) simulated input impedance of the proposed antenna and Ref. 2 (other dimensions are the same as given in Figure 1).

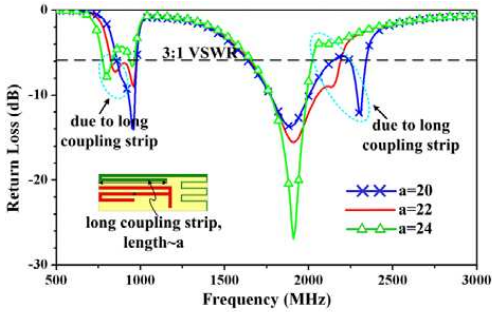


Figure 4. Simulated return loss as a function of the length $a$of the long coupling strip (other dimensions are the same as given in Figure 1).

at about 2000 MHz. After add the parallel resonance structure to form Ref. 2, a new resonance (zero reactance) generated in the lower band. This can be seen more clearly in Figure 3(b), in which Ref. 2 has a large resonance peak and only a null point of the imaginary part in the lower band of the antenna. Hence none of the desired lower and upper bands is obtained for the case of Ref. 2 in this study. Figure 3(c) shows the input impedance of the proposed antenna and Ref. 2 for comparison. Then after add the long coupling strip, which can generate a new zero reactance point in the lower band and a new zero reactance point in the upper band, to form the proposed antenna, two double-resonance modes at 840, 950, 1900, and 2150 MHz can be seen. In this case, the proposed internal tablet computer antenna can achieve the desired lower band of GSM850/900 (824–960 MHz) and the upper band of GSM1800/1900/UMTS2100 (1710–2170 MHz) in order to cover the penta-band WWAN operation.

Some main design parameters are studied and discussed in the next few paragraph. Firstly, Figure 4 shows the simulated return loss as a function of the length a of the long coupling strip and other dimensions are the same as given in Figure 1. Results for the length a varied from 20 to 24 mm are shown, it is clearly seen that large effects on the impedance matching of the resonant mode at about 840 and 2150 MHz are observed. With increasing the length a, the two resonant modes are lowered, which indicates that the long coupling strip can control two resonant modes at 840 and 2150 MHz.

Effects of strip 1 of the feeding strip are studied in Figure 5. The simulated return loss results for the length t of strip 1 varied from 9.5 to 13.5 mm are plotted in Figure 5(a). Results show that the resonant mode at about 950 MHz shifts to higher frequencies with the length t decrease and other dimensions fixed, that's because variations in the

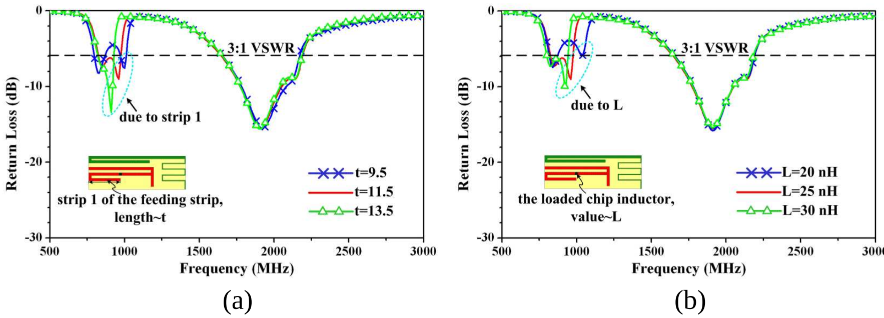


Figure 5. Simulated return loss as a function of (a) the length t of strip 1 and (b) the loading chip inductor L in strip 1 of the feeding strip (other dimensions are the same as given in Figure 1).

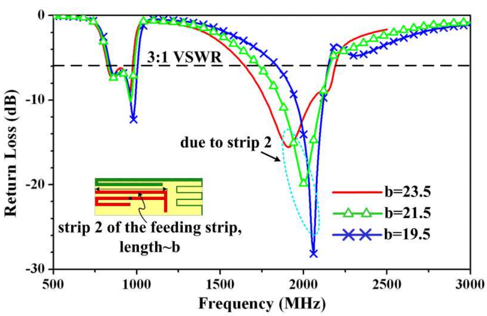


Figure 6. Simulated return loss as a function of the length b of strip 2 of the feeding strip (other dimensions are the same as given in Figure 1).

length t will change the resonant path of strip 1. To form a double-resonance mode and cover the desired lower band of GSM850/900 (824–960 MHz), the length t is chosen as 11.5 mm in the design. Figure 5(b) shows the influence of varying the loaded chip inductor L in strip 1 of the feeding strip. Large effects on the impedance matching of the second resonant mode in the lower band are seen when the inductor L varied from 20 to 30 nH, and little influence on the antenna's upper band. This again shows that strip 1 of the feeding strip generate the resonant mode at about 950 MHz and can increase bandwidth of the lower band. When $L = 25$ nH, the improved impedance matching can cover the desired operating band of 824–960 MHz.

Effects of the length b of strip 2 of the feeding strip are analyzed in Figure 6. Results indicate that the resonant mode contributed by strip 2, which is the first resonant mode in the upper band, shift to higher frequencies with the length b decrease from 23.5 to 19.5 mm and other dimensions fixed. As the long coupling strip is capacitively excited by strip 2, variations in the length b leads to some effects on the resonant modes related to the long coupling strip. Hence, by appropriately adjust the length b, the desired two wide operating bands can be achieved.

Figure 7 shows the simulated surface current distributions on the proposed antenna's metal pattern at 840, 950, 1900 and 2150 MHz. It is clearly seen from Figures 7(a) and (d), the strong surface currents show that the long coupling strip is excited at both 840 and 2150 MHz.

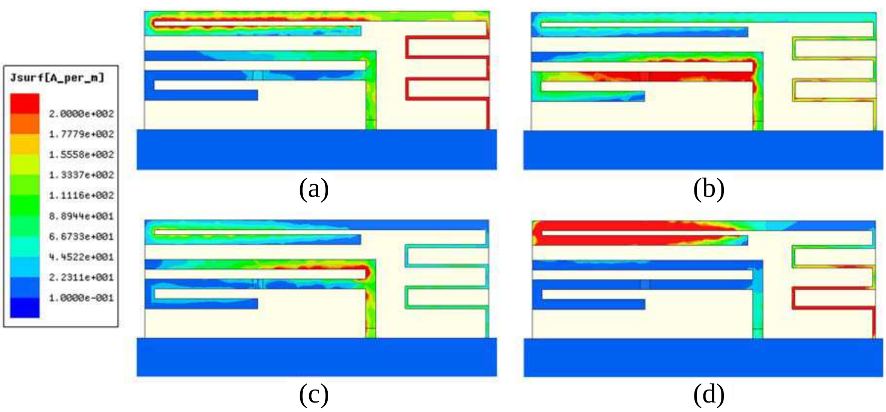


Figure 7. Simulated current distributions on the metal pattern and display ground of the proposed antenna at (a) 840 MHz, (b) 950 MHz, (c) 1900 MHz, and (d) 2150 MHz.

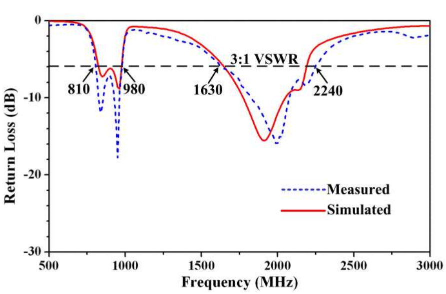


Figure 8. Measured and simulated return loss of the proposed antenna.

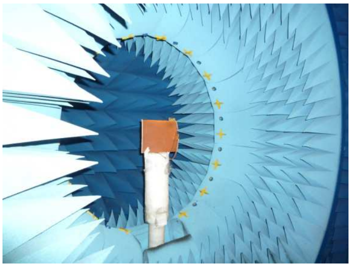


Figure 9. Photo of the proposed antenna measured in SATIMO microwave chamber.

On the other hand, strong electric fields are seen in strip 1 of the feeding strip at 950 MHz shown in Figure 7(b), which confirms that a parallel resonance is generated by strip 1 at 950 MHz. The surface currents on strip 2 of the feeding strip are much stronger at 1900 MHz shown in Figure 7(c), which confirm that the resonant mode at 1900 is mainly contributed by strip 2. Of course, as the proposed printed antenna is an over-all structure formed by the radiating strips and the system display ground, the whole antenna configuration fabricates an effective radiating system.

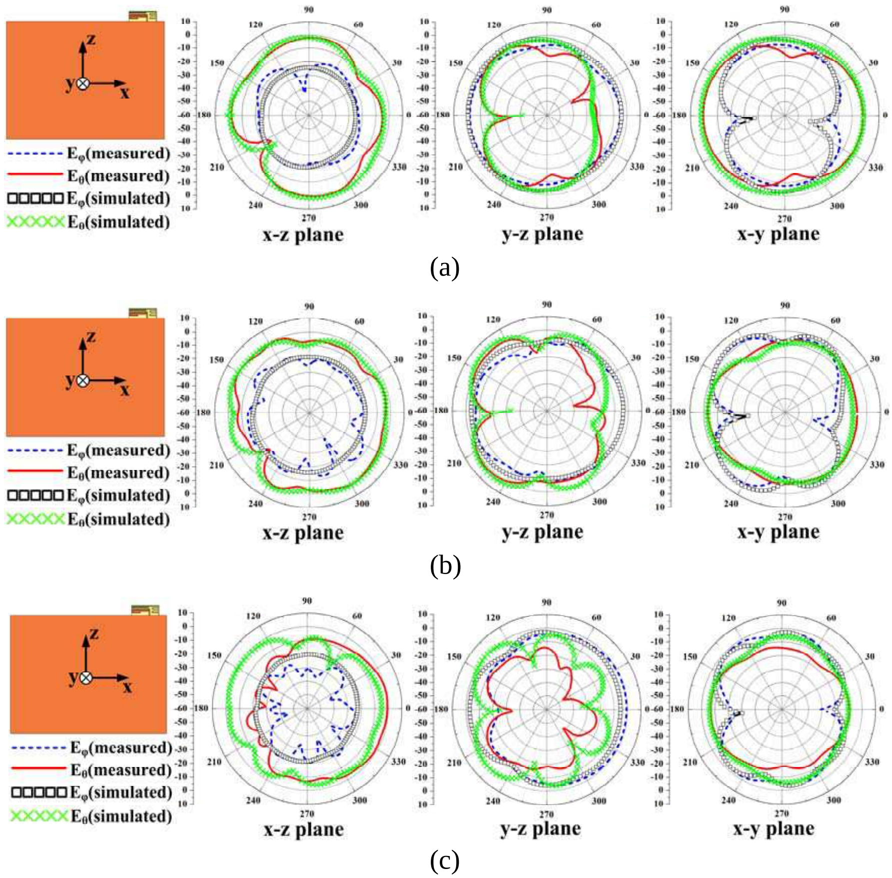


Figure 10. Measured and simulated 2D radiation patterns at (a) 890, (b) 1900, and (c) 2150 MHz of the proposed antenna.

3. RESULTS AND DISCUSSION

The proposed antenna was fabricated and studied. Figure 8 shows the measured and simulated return loss for the fabricated antenna. It is noticed that the experimental results done on an Agilent N5247A vector network analyzer agree with the simulated results using Ansoft HFSS. Some discrepancies were found due largely to the antenna manufacture tolerance and the effects of coaxial cables as well as the hand soldering that was performed. All measured impedance bandwidth of the proposed antenna meets the required bandwidth specification from 810 to 980 MHz and 1630 to 2240 MHz with VSWR below 3 : 1, which satisfies the demanded bandwidth specification for the GSM850/900 and GSM1800/1900/UMTS2100 operation. Notice that 3 : 1 VSWR is widely accepted as the design specification for the internal WWAN tablet computer antennas [15–17, 20].

The radiation characteristics of the proposed antenna are measured and studied. The radiation efficiency and antenna gain of the proposed antenna were measured in the SATIMO microwave anechoic chamber shown in Figure 9. Figure 10 plots the measured radiation patterns at 890, 1900, and 2150 MHz, respectively. At 890 MHz, central frequency of the 824–960 MHz, similar half-wavelength dipole-like radiation pattern is observed in the azimuthal plane (xy-plane) shown in Figure 10(a), which indicates that stable radiation characteristic is obtained over the antenna's lower band. The other resonant frequencies at 1900 and 2150 MHz are plotted in Figures 10(b) and (c). The measured radiation patterns show several nulls in the azimuthal plane, which are owing to the length of the ground plane is comparable to the wavelength for the upper band operation and their higher-

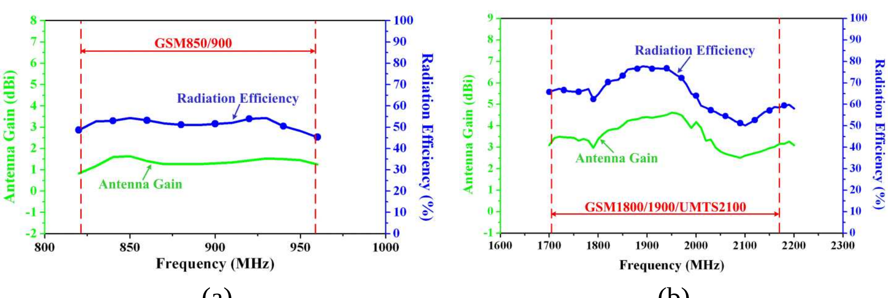


Figure 11. Measured antenna peak gain and radiation efficiency of the proposed antenna. (a) The lower operating bands (GSM850/900). (b) The upper operating bands (GSM1800/1900/UMTS2100).

order resonant modes. Comparable E_φ and E_θ components in the three principal planes are seen, and the radiation patterns also show no special distinction compared to those of the conventional internal antennas [20–24].

Figure 11 shows the measured antenna peak gain and radiation efficiency for the proposed tablet computer antenna. Over the desired lower band of GSM850/900 (824–960 MHz), the antenna gain is varied from about 0.8 to 1.6 dBi, and the radiation efficiency is generally larger than 45%. For the desired upper band of GSM1800/1900/UMTS2100 (1710–2170 MHz), the antenna gain is varied from about 2.5 to 4.6 dBi, and the radiation efficiency is varied from about 50 to 77%. The measured radiation characteristics of the proposed antenna are acceptable and suitable for the practical WWAN internal tablet computer applications.

4. CONCLUSION

In the article, a small printed tablet computer antenna has been presented. A detailed description and discussion of the operating principle of the proposed antenna in exciting these resonant modes have been presented and studied in depth. The proposed antenna is disposed close to the edge of the shielding wall and is easily printed on the 0.8 mm thick FR4 substrate with a very small area of $35 \times 12\,\text{mm}^2$ only. Owing to using a parallel resonance structure, the proposed antenna satisfies the return loss requirements for the GSM850/900 and GSM1800/1900/UMTS2100 operations, with VSWR lower than 3 : 1. The obtained measured results including return loss, antenna peak gain, and radiation efficiency are presented, which indicate that the proposed antenna is promising for tablet computer applications.

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