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BANDWIDTH ENHANCEMENT OF SMALL-SIZE INTERNAL WWAN LAPTOP COMPUTER ANTENNA USING A RESONANT OPEN SLOT EMBEDDED IN THE GROUND PLANE

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ABSTRACT: *A new bandwidth-enhancement method of using a resonant open slot embedded in the ground plane or supporting metal frame of the display panel for a small-size internal wireless wide area network (WWAN) laptop computer antenna is presented. To demonstrate the results, a small-size printed monopole slot antenna with a length of 50 mm only, which is about the smallest among the internal WWAN laptop computer antenna that have been reported, is applied in this study. For such a small-size WWAN antenna, the impedance matching in the 900-MHz band is usually very poor and hence the obtained antenna's lower band cannot cover the desired GSM850/900 operation. By embedding a resonant open slot in the ground plane, which does not increase the size of the internal WWAN antenna, a wideband resonant mode with good impedance matching at about 900 MHz contributed by the resonant open slot can be generated to cover the GSM850/900 operation. Further, a wide upper band for the antenna to cover the GSM1800/1900/UMTS operation can also be obtained. Details of the proposed bandwidth-enhancement method are studied in this article.* © 2010 Wiley Periodicals, Inc. Microwave Opt Technol Lett 52: 1137–1142, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25148

Key words: *mobile antenna; internal laptop computer antenna; WWAN antenna; small antenna; monopole slot antenna*

1. INTRODUCTION

The internal wireless wide area network (WWAN) antenna has been equipped in many modern laptop computers to incorporate with the wireless local area network (WLAN) antenna to provide ubiquitous wireless internet access. As more and more antennas are required to be embedded in the modern laptop computers, it is required that the internal WWAN antenna be with smaller length such that less space is occupied when the antenna is mounted along the top edge of the display panel. However, for the internal WWAN laptop computer antennas that have been reported [1–7], the length of the antenna along the top edge of the display panel is generally required to be at least 60 mm such that a long enough resonant length can be provided to excite the desired resonant mode for the 900-MHz band. When the length of the antenna is decreased, the obtained lowest resonant mode will be shifted to higher frequencies, and the impedance matching for frequencies over the 900-MHz band will be quickly degraded. This behavior makes the obtained bandwidth of the antenna's lower band very difficult to cover the desired GSM850/900 (824–894/880–960 MHz) operation.

In this article, we present a new bandwidth-enhancement method of using a resonant open slot embedded in the ground plane or supporting metal frame of the display panel for the small-size internal WWAN antenna in the laptop computer. The embedded resonant open slot requires no direct feeding and can be treated as a parasitic element of the internal WWAN antenna; further, it does not increase the size of the internal WWAN antenna. The resonant open slot is chosen to have a length of about 70 mm, close to 0.25 wavelength at 900 MHz, and can contribute to the excitation of a wideband quarter-wavelength resonant mode at about 900 MHz for the GSM850/900 operation. To demonstrate the results, a printed monopole slot antenna of length 50 mm (see Fig. 1), which is about the smallest among the internal WWAN laptop computer antenna that have been reported, is applied in this study as the small-size internal WWAN antenna. With the presence of the resonant open slot, the printed monopole slot antenna can provide two wide operating bands at about 900 and 2000 MHz to respectively cover the GSM850/900 and GSM1800/1900/UMTS (1710–1880/1850–1990/1920–2170 MHz) operation. Details of the proposed bandwidth-enhancement method to assist in achieving the GSM850/900/1800/1900/UMTS operation for a small-size internal WWAN laptop computer antenna is presented and studied.

2. INTERNAL WWAN ANTENNA WITH A RESONANT OPEN SLOT

Figure 1(a) shows the geometry of the small-size internal WWAN laptop computer antenna (a printed monopole slot antenna in this study) using a resonant open slot in the ground plane or supporting metal frame of the display panel for bandwidth enhancement. The printed monopole antenna for WWAN

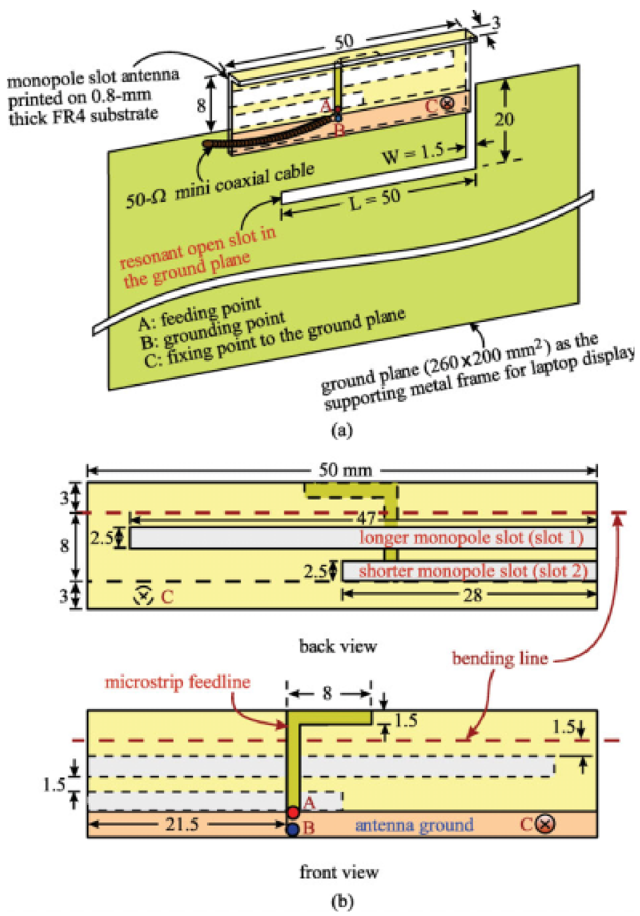

Figure 1 (a) Geometry of the small-size internal WWAN laptop computer antenna (a printed monopole slot antenna here) using a resonant open slot in the ground plane for bandwidth enhancement. (b) Dimensions of the small-size printed monopole slot antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

operation has been applied in the laptop computer [1, 3]. In Ref. 1, three monopole slot elements are required and the antenna length along the top edge of the display panel is required to be 60 mm. While in Ref. 3, only two monopole slot elements are needed; however, the required antenna length is increased to be 75 mm. When the antenna length is reduced to be 50 mm as shown in Figure 1 for the studied small-size monopole slot antenna without the embedded open slot in the ground plane, the obtained bandwidth of the antenna in the 900-MHz band is quickly decreased and cannot cover the desired GSM850/900 operation.

Detailed dimensions of the printed monopole slot antenna as the internal WWAN antenna are given in Figure 1(b). There are two monopole slot elements in the studied WWAN antenna. The longer monopole slot (slot 1) having a small length of 47 mm cannot contribute to a quarter-wavelength resonant mode at about 900 MHz for the GSM850/900 operation; On the other hand, the shorter monopole slot (slot 2) having a length of 28 mm can generate a wideband quarter-wavelength resonant mode at about 2000 MHz for the GSM1800/1900/UMTS operation. The operation principle of both slot 1 and 2 has been extensively discussed in [1, 3, 8–19]. They are excited as quarter-wavelength resonant structures, different from the traditional slot antenna with two closed ends excited as half-wavelength resonant structures [19–22]. Both slot 1 and 2 can be excited in series by using a microstrip feedline of an inverted L-shape. For testing the antenna in the experiment, a 50-Ω mini coaxial cable with its central conductor connected to point A (the front terminal of the microstrip feedline) and its outer grounding sheath connected to point B (the grounding point) in the antenna ground is applied. The antenna ground is electrically connected to the ground plane through a via-hole at point C (the fixing point to the ground plane). The top portion of width 3 mm in the proposed antenna can also be bent in this study to reduce the antenna height to be 8 mm only, which is attractive for practical applications.

To assist in achieving wideband operation in the 900-MHz band of the small-size internal WWAN antenna, the resonant open slot of length 70 mm is embedded in the ground plane as shown in the figure. The open slot is also configured to be an inverted L-shape and to be extended below the antenna to make it easy to implement for practical applications. The open slot is excited indirectly by the 50-Ω mini coaxial cable and is operated as a quarter-wavelength resonant structure, which contributes to the generation of a wideband quarter-wavelength resonant mode at about 900 MHz for the antenna to cover the GSM850/900 operation. That is, with the presence of the resonant open slot, the small-size WWAN antenna can generate two wide operating bands at about 900 and 2000 MHz to respectively cover the WWAN operation in the GSM850/900 and GSM1800/1900/UMTS bands.

3. RESULTS AND DISCUSSION

The proposed antenna shown in Figure 1 was fabricated and tested. Figure 2 shows the measured and simulated return loss for the fabricated prototype. Two wide operating bands are generated for the proposed antenna. The lower band at about 900 MHz has a measured wide bandwidth (6-dB return loss) of 205 MHz (795–1000 MHz), and the upper band at about 2000 MHz shows a wide bandwidth of 875 MHz (1705–2580 MHz). Note that the 6-dB return loss for bandwidth definition is acceptable for practical application and is generally used for the design of the internal WWAN antenna. The two wide operating bands make it easy for the proposed antenna to cover pentaband WWAN operation. The measured data also agree with the simulated results obtained using the Ansoft HFSS [23].

To analyze the effects of the resonant open slot embedded in the ground plane, Figure 3 shows the simulated return loss and

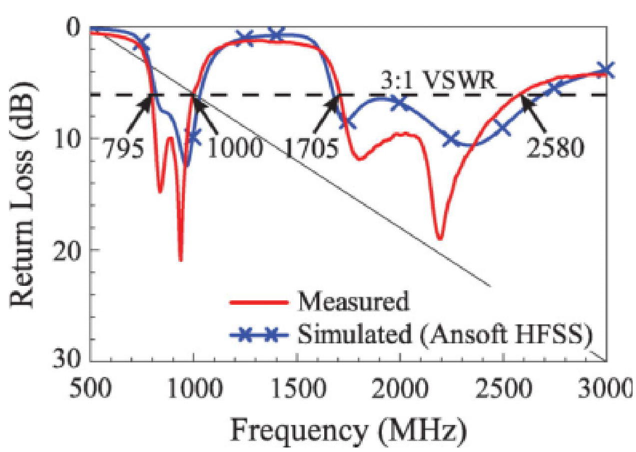

Figure 2 Measured and simulated return loss for the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

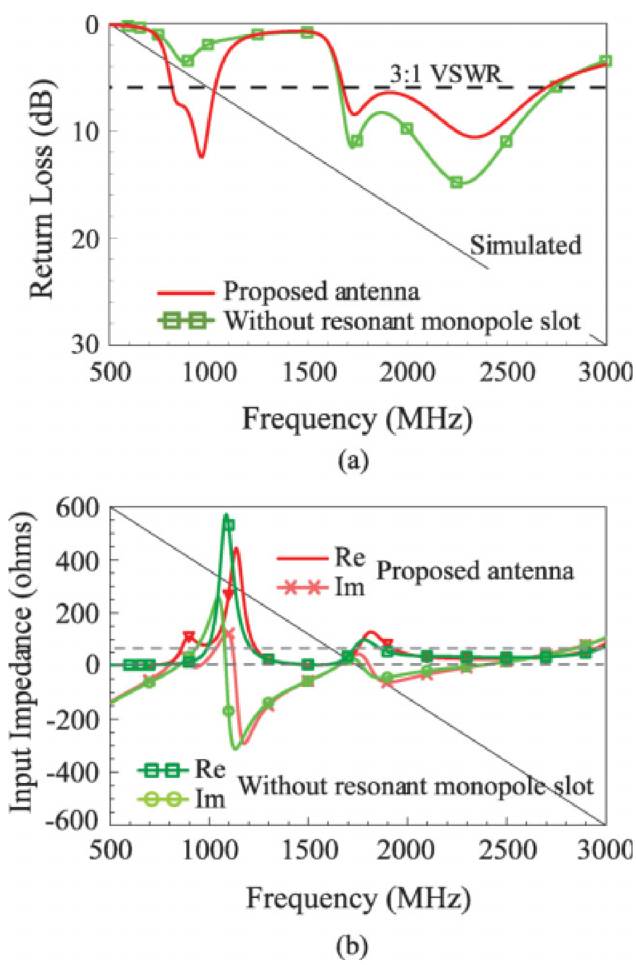

Figure 3 Simulated (a) return loss and (b) input impedance of the proposed antenna and the case without the resonant open slot. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

input impedance of the proposed antenna and the case without the resonant open slot. It is clear to see that with the presence of the resonant open slot, the impedance matching for frequencies over the 900-MHz band is greatly improved [see Fig. 3(a)]. This behavior is mainly owing to occurrence of a new resonant mode at about 890 MHz contributed by the resonant open slot [see Fig. 3(b)]. Notice that there is also a resonant mode occurred at about 1100 MHz, which is contributed by slot 1 whose length is selected to be small to achieve a small-size WWAN antenna with a length of 50 mm only. These two resonant modes lead to a wideband lower band for the antenna to cover the GSM850/900 operation. On the other hand, as seen in Figure 3(b), the resonant mode at about 1800 MHz is contributed by slot 2 in the proposed antenna. Small variations in the impedance matching owing to the presence of the open slot are seen. This causes small effects on the obtained bandwidth of the antenna's upper band at about 2000 MHz as shown in Figure 3(a). In this case, the wideband operation of the antenna's upper band can still be achieved.

Figure 4 shows the simulated return loss for the proposed antenna as a function of the length *L* and width *W* of the resonant open slot. Other parameters are the same as given in Figure 1. In Figure 4(a), results for the length *L* varied from 40 to 50 mm are presented. Large effects on the impedance matching over the antenna's lower band are observed. Results for the width *W* varied from 0.5 to 2.0 mm are shown in Figure 4(b), and similar large effects on the antenna's lower band are seen. While for the antenna's upper band, there are small effects because of the variations in the length *L* and width *W*. This is mainly because the open slot is not at resonance for frequencies over the antenna's upper band, thus showing small effects on the impedance matching over the upper band.

Figure 5 shows the simulated E-field distributions in slot 1, slot 2, and open slot at 890, 1100, and 2000 MHz, respectively. At 1800 MHz shown in Figure 5(a), strong E-field occurs at the open end of the open slot, indicating that the open slot in the ground plane is exited and is at resonance. Also, slot 1 is excited, while slot 2 is not. At 1100 MHz in Figure 5(b), only slot 1 is at resonance. Figure 5(c) shows the case at 1800 MHz, and slot 2 is seen to be excited and is at resonance. The observed behavior agrees with the observations in Figure 3(b) for the occurrence of the resonant modes at about 890, 1100, and 1800 MHz.

The measured radiation patterns are plotted in Figures 6 and 7. At 859 and 925 MHz shown in Figure 6, similar radiation patterns are seen, and the vertical-polarized radiation E_θ in the azimuthal plane (*x*-*y* plane) shows no nulls, which is advantageous for practical applications. At 1795, 1920, and 2045 MHz

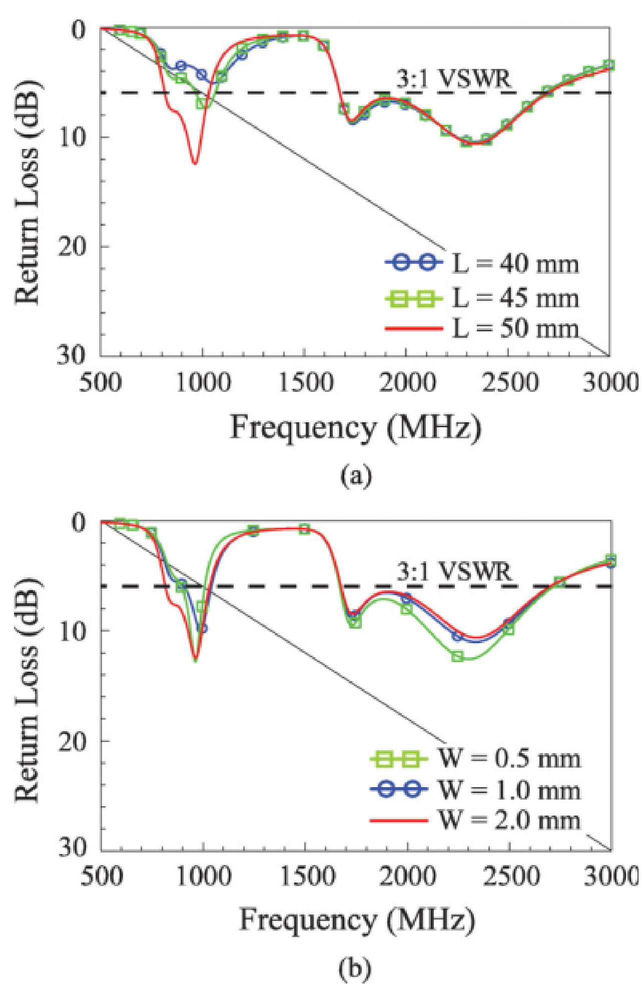

Figure 4 Simulated return loss for the proposed antenna as a function of (a) the length *L* and (b) the width *W* of the resonant open slot. Other parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

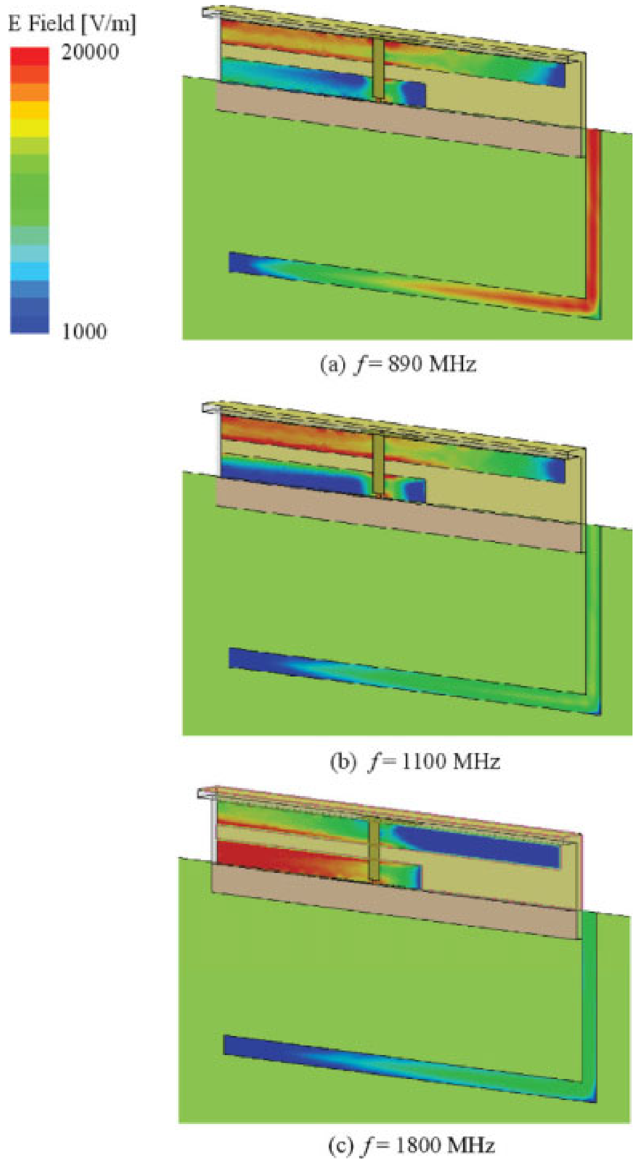

Figure 5 Simulated E-field distributions in slot 1, slot 2 and open slot at (a) 890 MHz, (b) 1100 MHz, and (c) 2000 MHz. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

shown in Figure 7, stable radiation patterns over the antenna's upper band are obtained, and there are also no nulls in the E_{θ} radiation in the azimuthal plane.

Figure 8 shows the measured antenna gain and simulated radiation efficiency of the proposed antenna. The measured antenna gain is about 0.6–3.3 dBi over the GSM850/900 bands [Fig. 8(a)] and about 1.1–3.1 dBi over the GSM1800/1900/UMTS bands [Fig. 8(b)]. The simulated radiation efficiency is all about 64–90% over the GSM850/900 and GSM1800/1900/UMTS bands.

Finally, the three-dimensional (3-D) average antenna gain, defined as the average of the antenna gain over all of space and required for practical applications of the internal WWAN laptop computer antenna [1], is studied. Results of the simulated 3D average antenna gain for frequencies over the five operating bands are given in Table 1. Results for the proposed antenna are seen at the feeding point, while those for the antenna with 70-cm cable loss consider the practical condition in which a long

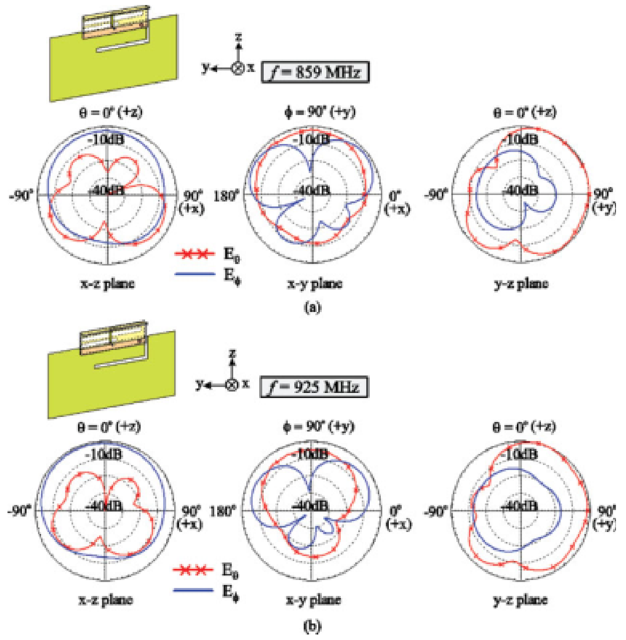

Figure 6 Measured radiation patterns at (a) 859 MHz and (b) 925 MHz for the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

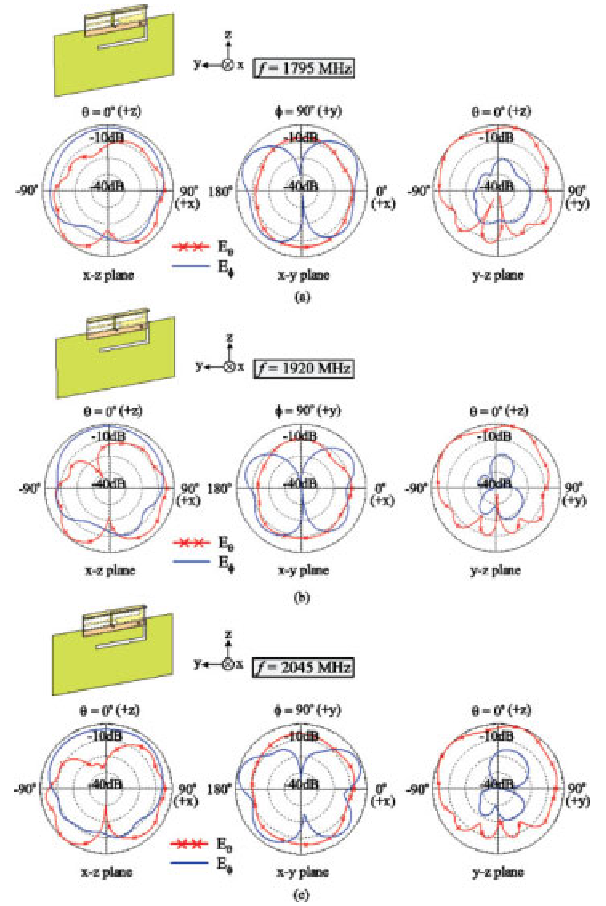

Figure 7 Measured radiation patterns at (a) 1795 MHz, (b) 1920 MHz, and (c) 2045 MHz for the proposed antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

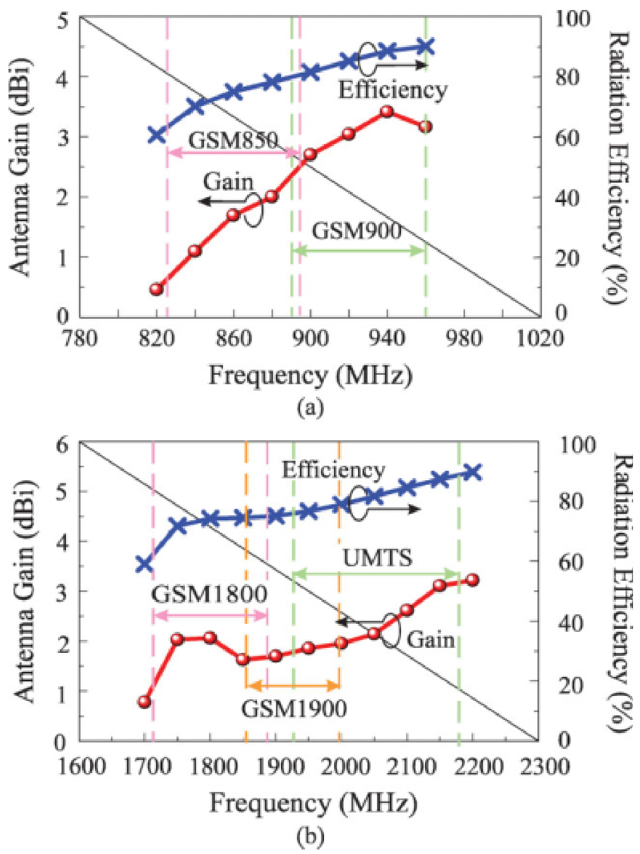

Figure 8 Measured antenna gain and simulated radiation efficiency of the proposed antenna. (a) The GSM850/900 bands. (b) The GSM1800/1900/UMTS bands. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

mini coaxial cable (generally about 70 cm) is connected to the internal antenna in the laptop computer. The 70-cm long cable loss is reasonably estimated to be about −1 dB over the lower band and about −2 dB over the upper band. The specification in the table is the minimum 3D average antenna gain required for

TABLE 1 Simulated 3D Average Antenna Gain for the Proposed Antenna at About the Central Frequencies of the Transmitting (Tx) and Receiving (Rx) Bands in Each Operating System

3D Average Antenna Gain (dBi)			Proposed Antenna (dBi)	Antenna with 70-cm Cable Loss (dBi)	Specification (dBi)
GSM850	Tx Band	836 MHz	−1.6	−2.6	−3.3
	Rx Band	880 MHz	−1.1	−2.1	−4.0
GSM900	Tx Band	900 MHz	−0.9	−1.9	−4.0
	Rx Band	940 MHz	−0.5	−1.5	−6.0
GSM1800	Tx Band	1750 MHz	−1.3	−3.3	−4.0
	Rx Band	1840 MHz	−1.3	−3.3	−6.0
GSM1900	Tx Band	1880 MHz	−1.1	−3.1	−3.3
	Rx Band	1960 MHz	−1.1	−3.1	−4.5
UMTS	Tx Band	1950 MHz	−1.2	−3.2	−4.5
	Rx Band	2140 MHz	−0.6	−2.6	−6.0

The specification is the minimum 3D average antenna gain required for practical applications of the internal WWAN antenna in the laptop computers [1]. The cable loss is evaluated by assuming a 70-cm long mini cable connected to the antenna.

practical applications of the internal WWAN antenna in the laptop computers [1]. The results shown in Table 1 indicate that the proposed antenna meets the 3D average antenna gain requirement for practical laptop computer applications.

4. CONCLUSIONS

Using a resonant open slot in the ground plane or supporting metal frame of the display panel has been shown to be an effective method in enhancing the bandwidth of the small-size internal WWAN antenna in the laptop computer. With a small length of 50 mm along the top edge of the display panel, the WWAN antenna can achieve two wide operating bands at about 900 and 2000 MHz to respectively cover the GSM850/900 and GSM1800/1900/UMTS operation, owing to the presence of the resonant open slot. Good radiation characteristics over the antenna's two wide bands have also been observed, making it promising for the proposed small-size WWAN antenna for practical laptop computer applications.

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SIMPLIFIED DESIGN OF MULTILAYERED SUBSTRATE-INTEGRATED WAVEGUIDE RIBLET–SAAD COUPLERS

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ABSTRACT: *A simplified design procedure for dual- and triple-layered Riblet–Saad directional couplers in substrate-integrated waveguide (SIW) technology is presented. Emphasis is placed on a design that considers ease of fabrication and includes interface ports such as microstrip-to-SIW transitions with straight, bent, and mitered microstrip lines. Designs are performed in an HFSS environment, which is verified by comparison with an independent field-solver simulation.* © 2010 Wiley Periodicals, Inc. Microwave Opt Technol Lett 52: 1142–1144, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25149

Key words: *substrate-integrated waveguide; multilayered E-plane couplers; Riblet–Saad directional couplers*

1. INTRODUCTION

Substrate-integrated waveguide (SIW) technology has found many applications in the millimeter-wave frequency range, for example [1, 2], because it presents a reasonable compromise between microstrip and rectangular-waveguide circuitry. One of the advantages for the design of SIW components is that after dispersion characteristics and via hole dimensions have been related to all-dielectric-filled rectangular waveguides [3], traditional waveguide design strategies, for example, [4], can be used. Moreover, tapers to microstrip technology [5] provide an interface to measurement equipment.

Because of its planar nature, SIW applications are preferably fabricated in H-plane circuitry. Filters, diplexers, power dividers, and H-plane couplers are some of the preferred components, for example, [1, 6–8]. To integrate this technology with two-dimensional antenna arrays [9], however, coupling between stacked SIW components must be facilitated. Attempts to incorporate multilayered SIW circuits for antenna feed networks have been made in [8, 10] in the form of an E-plane directional couplers.

This article presents simplified design guidelines for dual- and triple-layered Riblet–Saad SIW E-plane couplers. The designs include tight coupling and interface ports with straight, bent, and mitered microstrip transitions.

2. DESIGN

Figure 1 shows an eight-section dual-layer [Fig. 1(a)] and two triple-layer [Figs. 1(b) and 1(c)] Riblet–Saad couplers in SIW technology with straight, bent, and mitered microstrip ports. Note that a coupling aperture is represented by a slot pair—one in longitudinal and the other in transverse direction.

For the design of the SIW components, the substrate material as well as the placement, dimensions, and shapes of via holes must be selected. These parameters are usually dictated by the fabrication process involved. We assume standard printed-circuit board facilities and select RT Duroid with $\varepsilon_r = 2.2$, height $b = 0.508$ mm, and metallization thickness $t = 35$ μm as substrate

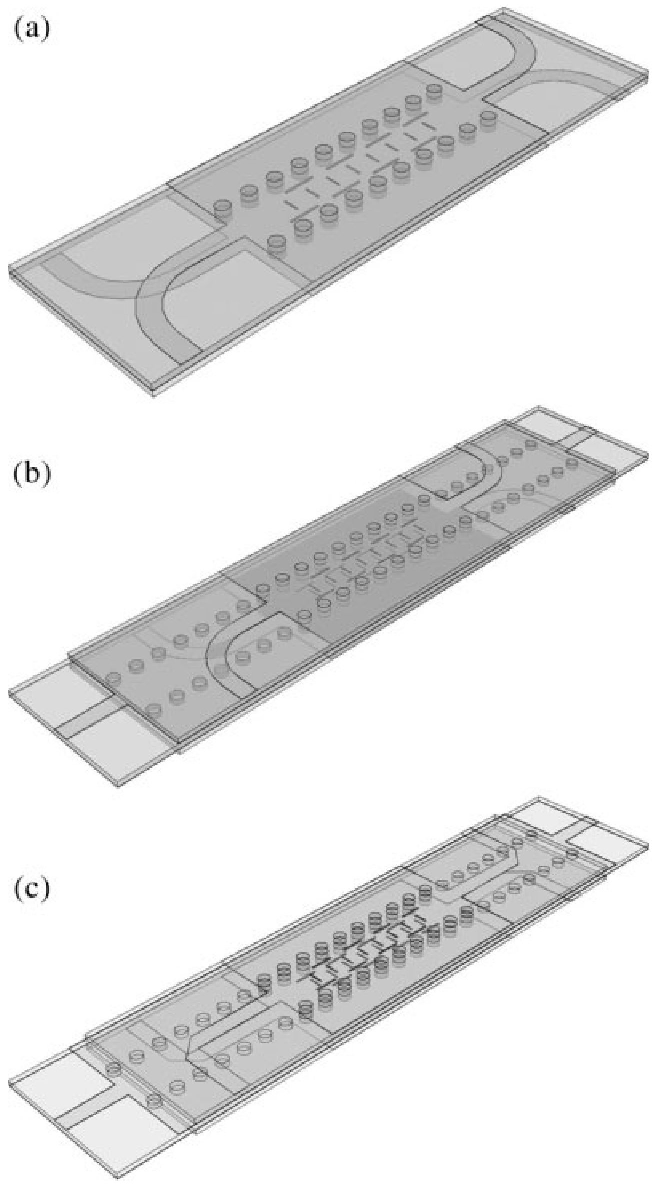

Figure 1 Eight-section Riblet–Saad couplers in SIW technology: (a) dual-layer with bent microstrip ports, (b) triple-layer with straight and bent microstrip ports, (c) triple-layer with straight and mitered microstrip ports