that the effects of the user’s hand on the performances of the antenna
the system ground plane of the mobile device. Hence, it can be expected
design, the shorted patch antenna is isolated from the two side edges of
nearby electronic components. In addition, with the proposed integration
thus, in this case, the shorted patch antenna can operate as an internal
coupling-free space for accommodating electronic compo-
within the dented portion of the U-shaped shielding metal case, which
EMC internal patch antenna is integrated with a U-shaped shield-


dimensions of the shielding metal case and the system ground plane on
performances of the antenna are also studied.


coupling between the antenna and the nearby electronic components will occur, thus resulting in degrading effects on the performances of the antenna. To reduce this degrading coupling effect, an isolation distance of about 7 mm or larger between the antenna and the nearby electronic components is usually required for practical applications [2, 3]. This isolation distance leads to an inefficient usage of the valuable board space of the system circuit board of the mobile device.

To overcome this problem, the internal patch antenna with an EMC property with nearby electronic components has been demonstrated [2–4]. In addition to the use of the system ground plane as the bottom ground plane of the antenna, this kind of EMC internal patch antenna has an additional vertical ground plane arranged at the antenna’s side surfaces. This vertical ground plane not only functions as part of the antenna’s ground plane, but also as an effective shielding wall to suppress or eliminate the possible coupling between the antenna and the nearby electronic components [2–4].

In this paper, we propose another promising EMC internal patch antenna suitable to be applied in a mobile communication device such as a smart phone or personal digital assistant (PDA) phone for UMTS (1920–2170 MHz) operation. The proposed EMC internal patch antenna is integrated with a U-shaped shielding metal case, which provides a coupling-free space for accommodating the electronic components such as the RF modules/circuitry and battery in the mobile device [5–8]. This proposed integration design allows no isolation distance required between the internal patch antenna and nearby electronic components. In addition, the proposed U-shaped shielding metal case is different from the simple shielding metal case reported in [5–8]. The internal patch antenna fits well within the dented portion of the U-shaped shielding metal case. That is, the internal patch antenna is encircled by the U-shaped shielding metal case, and is thus isolated from the two side edges of the system ground plane of the mobile device. In this case, it can be expected that the effects of the user’s hand on the performances of the antenna will be suppressed. Details of the design considerations of the proposed integration design are described, and the experimental results of the constructed prototype are presented. The technique used in this study to enhance the impedance bandwidth of the antenna to cover the UMTS band is also discussed. The effects of varying the dimensions of the shielding metal case and the system ground plane on the performances of the antenna are also studied.

2. ANTENNA DESIGN

Figure 1(a) shows the geometry of the proposed EMC internal patch antenna integrated with the U-shaped shielding metal case
for application in a mobile device such as a smart phone or PDA phone. The U-shaped shielding metal case is mounted at the top portion of the system ground plane, with their top, left, and right edges flushed to each other. Also note that the system ground plane is printed on the front side of a 0.8-mm-thick FR4 substrate, which is treated as the system circuit board of a practical smart phone or PDA phone. The size of the system ground plane is first selected to be 100 × 60 mm^2 (L × W) in this study, and the effects of other possible dimensions of the system ground plane on the performances of the antenna are analyzed in section 3.

Note that the width W of the shielding metal case is the same as that of the system ground plane, and the length of the shielding metal case, denoted as D, is first chosen to be 70 mm. The thickness h of the shielding metal case is first selected to be 7 mm; in this case, the shielding metal case can provide a sufficiently large space for accommodating the electronic components such as the RF modules/circuitry and battery in the PDA phone. The effects of varying the length D and the thickness h on the performances of the antenna are discussed in detail in section 3.

The internal patch antenna is mounted within the dented portion (10 × 36 × 7 mm^3) of the U-shaped shielding metal case. The antenna mainly comprises a rectangular top patch of 7 × 34 mm^2 and a triangular feeding patch, and can be easily fabricated from bending a single flat metal plate (a 0.2-mm-thick copper plate is used in this study), whose detailed dimensions are shown in Figure 1(b). Notice that the length t of the top patch is 34 mm, which is close to a quarter-wavelength of the frequency at 2045 MHz, the center frequency of the UMTS band. With one of the shorter edges of the rectangular top patch short-circuited to the shielding metal case, the patch antenna is firmly integrated to the shielding metal case. In this case, the shorted patch antenna is expected to operate as a quarter-wavelength resonant structure; thus, by tuning the length t, the center frequency of the excited resonant mode of the antenna can be effectively adjusted. The related results will be analyzed in more detail below.

It should also be noted that in order to achieve a resonant mode with good impedance matching for this kind of shorted patch antenna, the optimal feeding point is usually located close to the shorting point or edge [9]. In this case, the optimal feeding point is point A, as shown in Figure 1(b), which is 6-mm away from the shorting edge. However, when a small-size feeding patch or a simple feeding strip is used at point A to feed the top patch, the obtained bandwidth is usually too small to cover the UMTS band. By using a large triangular feeding patch, that is, a large tuning angle α (75° in this study) in the feeding patch shown in Figure 1(b), the obtained bandwidth can be greatly enhanced. This bandwidth enhancement is achieved mainly because the feeding patch functions as a smooth transition region between the feeding point and the top patch [10], thereby leading to a wider operating bandwidth. The effects of varying the tuning angle α on the bandwidth enhancement will be discussed in more detail below.

Also note that the tip of the triangular feeding patch is connected to the feeding pad printed at the top edge of the front side of the system circuit board. This feeding pad is isolated to the system ground plane through a 1-mm-wide slit encircling the feeding pad, and through a via-hole, the feeding pad is connected to a 50Ω microstrip feed line printed on the back side of the system circuit board.

Figure 1  (a) Geometry of the proposed EMC internal patch antenna integrated with the U-shaped shielding metal case for a mobile device (patent pending); (b) detailed dimensions of the patch antenna unfolded into a planar structure. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

Figure 2  Measured and simulated return loss of the preferred prototype with parameters given in Fig. 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]
3. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed design was constructed and tested. Figure 2 shows the measured and simulated return losses of the constructed prototype. The simulated results obtained using Ansoft simulation software High-Frequency Structure Simulator (HFSS) are also shown, and the simulated results are observed to agree well with the measured data. A resonant mode centered at about 2045 MHz is excited with good impedance matching, and a wide bandwidth of 262 MHz (1912–2174 MHz) covering the UMTS band is achieved. Note that in this study the bandwidth definition adopts 2.5:1 VSWR (7.3-dB return loss), which is a higher bandwidth definition for general portable mobile phones. In general, mobile phones are usually designed based on the bandwidth definition of at least 3:1 VSWR (6-dB return loss).

To study the effects of the length $t$ of the top patch on the antenna performances, several prototypes with various values of $t$ were constructed and studied. Figure 3 shows the measured return loss as a function of $t$. The other dimensions are the same as those given in Figure 1. Three cases of $t = 33$, 34, and 35 mm are shown. It is clearly seen that the excited resonant mode is shifted to higher frequencies when $t$ is decreased. This behavior indicates that the length $t$ effectively controls the resonant length of the antenna as a quarter-wavelength resonant structure. Hence, by adjusting the length $t$ of the top patch, the center operating frequency of the antenna can be effectively controlled.

Figure 4 shows the measured return loss as a function of the tuning angle $\alpha$ in the triangular feeding patch. We note that different angles of $\alpha$ lead to different sizes of the triangular feeding patch and also affect the effective resonant length of the antenna. Thus, in order to make it easy to compare the obtained bandwidths, the length $t$ for each $\alpha$ is adjusted such that the center frequency of the excited resonant mode is about the same. From the results, it is observed that the obtained bandwidth increases with an increase in $\alpha$. For the cases of $\alpha = 0^\circ$ and 75°, a large increase of the obtained bandwidth (2.5:1 VSWR) from 158 MHz (1913–2071 MHz) to 262 MHz (1912–2174 MHz) is obtained.

The effects of parameters $L$ and $W$ on the performances of the antenna are studied in Figures 5 and 6. Note that in this study the width of the shielding metal case is the same as that of the system ground plane. From the results shown in Figures 5 and 6, it is first observed that the center frequency of the excited resonant mode is

**Figure 3** Measured return loss as a function of the length $t$ of the top patch of the proposed antenna (other parameters are as given in Fig. 1). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

**Figure 4** Measured return loss as a function of the tuning angle $\alpha$ in the triangular feeding patch; the length $t$ for each $\alpha$ is adjusted such that the center frequency of the excited resonant mode is about the same (other parameters are as given in Fig. 1). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

**Figure 5** Measured return loss as a function of the width $W$ of the system ground plane and the shielding metal case (other parameters are as given in Fig. 1). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

**Figure 6** Measured return loss as a function of the length $L$ of the system ground plane (other parameters are as given in Fig. 1). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]
varied only slightly. On the other hand, a relatively large effect on the impedance matching level of the frequencies near the center frequency is seen. However, the obtained bandwidths (2.5:1 VSWR) for all the studied cases are about the same, except for the case of $W = 55$ mm in Figure 5. This behavior is largely because, when the width $W$ is decreased, the width of the two outer arms of the U-shaped shielding metal case surrounding the patch antenna will become too small; in this case, the effect of the variation of $W$ on the antenna performances cannot be ignored.

Figure 7 shows the effects of the length $D$ of the shielding metal case. The measured return-loss results for possible lengths of $D = 30, 50, 70$, and $90$ mm are presented. Very small variations of the measured return loss are observed. The results suggest that the proposed internal patch antenna can integrate with the U-shaped shielding metal case with various lengths, without considering its effects on the antenna performances.

The effects of thickness $h$ of the shielding metal case on the antenna performances are also analyzed. Figure 8 shows the measured return loss for the thickness $h$ varied from 5 to 8 mm. Note that in the proposed design the internal patch antenna and the shielding metal case has the same thickness. The results indicate that when the thickness $h$ increases, a larger bandwidth in general can be obtained. However, for the cases of $h = 7$ and $8$ mm, the obtained bandwidth and the impedance matching level are almost the same. For this reason, the thickness $h$ in the proposed design is selected to be 7 mm for the preferred prototype studied in Figure 2.

Finally, radiation characteristics of the proposed design were studied. Figure 9 plots the measured radiation patterns at 2045 MHz for the preferred prototype studied in Figure 2. Note that the measured results for the design with various dimensions of the shielding metal case are about the same; thus, only the results for the preferred prototype studied in Figure 2 are shown. From the measured radiation patterns, the comparable $E_{\theta}$ and $E_{\phi}$ components are seen. This property is advantageous, because the practical wave propagation environment is usually complex for mobile communications. The radiation patterns for other frequencies over the UMTS band were also measured, and similar radiation patterns as plotted here are observed. Figure 10 shows the measured antenna gain and simulated antenna efficiency over the UMTS band.

**Figure 7** Measured return loss as a function of the length $D$ of the shielding metal case (other parameters are as given in Fig. 1). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

**Figure 8** Measured return loss as a function of the thickness $h$ of the shielding metal case and the internal patch antenna (other parameters are as given in Fig. 1). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

**Figure 9** Measured radiation patterns at 2045 MHz for the antenna studied in Fig. 2. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

**Figure 10** Measured antenna gain and simulated antenna efficiency over the UMTS band for the antenna studied in Fig. 2. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]
for the preferred prototype studied in Figure 2. An antenna gain level of about 2.4–3.0 dBi over the UMTS band is obtained. Good radiation efficiency is also obtained, and it is found to be in the range of about 74% to 90% from the simulated results obtained from Ansoft simulation software HFSS [11].

4. CONCLUSION
A shorted patch antenna integrated with a U-shaped shielding metal case for operation as an internal mobile phone antenna having an EMC property with nearby electronic components has been proposed and studied. The proposed design applied to a smart phone or PDA phone has been successfully implemented, and the EMC property was obtained due to the presence of the U-shaped shielding metal case, in which the nearby electronic components can be accommodated. Good radiation characteristics of the proposed EMC internal antenna have also been obtained.

REFERENCES

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DESIGN OF MICROWAVE LUMPED AND TRANSVERSAL BANDPASS FILTER WITH NOISE REDUCTION

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ABSTRACT: A simple design technique for a microwave lumped and transversal filter using constant-k filter sections is presented. The noise figure can be suppressed by source degeneration inductors, which are added to the transversal element. The filter elements are analytically derived based on the specification and the noise minimization. © 2006 Wiley Periodicals, Inc. Microwave Opt Technol Lett 48: 1161–1164, 2006; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21551

Key words: transversal filter; noise reduction; constant-k filter, source degeneration inductor

1. INTRODUCTION
For dynamic-range improvement in modern communication transceiver, noise analysis for RF/MW active bandpass filter has been studied recently [1–3]. In fact, the noise figure of an active inductor active filter can be as high as 9.1 dB, as reported by Adams and Ho [4]. The negative-resistance-based active filter and recursive ones have reported 7.5- and 5.5-dB in-band noise figures, respectively [5, 6]. But the noise-figure reduction approach is still rare. Recently, Cheng et al. have analyzed the noise of the negative-resistance-based active filter and derived its reduction scheme [3], but the filter stability concerns the above active filter architectures. To tackle filter instability, the lumped and transversal filter can be used, but it also exhibits poor noise performance [7]. In order to elevate the dynamic range of the above transversal filter, its noise performance was studied in [8], and a suppression scheme based on source-degeneration inductors was proposed in [9]. However, a filter systemat design which considers noise reduction is not yet developed. In this paper, we determine the filter’s basic elements by its specifications, such as center frequency $f_0$, bandwidth $B$, and so forth. To facilitate the above study, this work presents a design methodology for the lumped and transversal bandpass filter using a constant-$k$ filtering structure.

2. DESIGN OF MICROWAVE LUMPED AND TRANSVERSAL FILTER
Figure 1 shows the basic structure of the conventional lumped and transversal bandpass filter; it consists of a low-pass filter section and a high-pass filter section. The bandpass response is achieved by the cascade of these two filter sections, which act like the delay and advance lines, respectively. Then, the filter band-edges are sharpened by the signal cancellation resulting from transversal elements ($M_n$, $n = 1, \ldots, N$) [7]. These transversal elements are generally designed with weighted gains.

![Figure 1 Conventional lumped and transversal filter](image-url)