without any complicated mathematical functions or operations. Thus, the developed equation can be useful for design and development of CAD for E-shaped microstrip patch antennas.

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USER’S HAND EFFECTS ON EMC INTERNAL GSM/DCS DUAL-BAND MOBILE PHONE ANTENNA

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ABSTRACT: User’s hand effects on an electromagnetic-compatible (EMC) internal dual-band mobile phone antenna for GSM/DCS operation are studied. The EMC internal antenna can be placed in direct contact with nearby conducting elements, without degradation in the antenna performances. Experimental and simulation studies are conducted to analyze the user’s hand effects on this EMC antenna. Obtained results indicate that the user’s hand affects not only the impedance matching of the antenna, but also the radiation characteristics including radiation patterns and efficiency. Effects of different positions of the user’s hand holding the mobile phone are also analyzed and discussed. © 2006 Wiley Periodicals, Inc. Microwave Opt Technol Lett 48: 1563–1569, 2006; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21699

Key words: antennas; EMC antennas; EMC mobile-phone antennas; internal mobile phone antennas; GSM/DCS antennas; user’s hand

1. INTRODUCTION
Recently, EMC internal antennas suitable for handheld mobile device applications have been demonstrated [1–5]. The EM-compatible (EMC) internal antenna mainly comprises a top radiating patch and a vertical antenna ground portion functioning as a shielding metal wall. With the presence of the vertical antenna ground portion, the EMC antenna can be placed nearby or in direct contact with the conducting elements or electronic components with very small or negligible effects on the antenna performance. This kind of EMC antenna is thus very attractive to be employed as an internal antenna in mobile phones, so that compact integration of the antenna and the associated electronic components can be achieved. However, reported studies of the EMC antenna applied in the mobile phone are for single-band operation only. In

Figure 1 (a) Geometry of the EMC internal GSM/DCS dual-band antenna in a mobile phone; (b) detailed dimensions of the antenna unbent into a planar structure. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]
a promising design of the EMC internal antenna for GSM (Global System for Mobile Communication, 890–960 MHz) and DCS (Digital Communication System, 1710–1880 MHz) dual-band operation in a mobile phone is introduced.

In addition, as we know, the human hand is one of the most frequent parts that directly touches the mobile phone, even more often than the human head, since some people use an ear phone or a hands-free device while talking, or just hold the mobile phone while waiting for a call. The total effects of the user’s hand and head on a mobile phone have been reported in recent papers [6–9]. However, these papers studied the human effects on conventional mobile-phone antennas. The EMC antenna with the consideration of the user’s hand has not been tested. In this paper, the effects of the user’s hand on the performances of the EMC antenna are studied. Further, by moving the hand from the top to the bottom portions of the mobile phone, the effects of different positions of the user’s hand holding the mobile phone are analyzed and discussed.

2. ANTENNA DESIGN AND USER’S HAND MODEL

Figure 1 shows the geometry of the EMC internal GSM/DCS dual-band antenna in a mobile phone. The EMC antenna mainly comprising a top radiating patch and a vertical antenna ground portion is easily fabricated by line-cutting or stamping a single metal plate (0.1-mm-thick copper plate is used here). The detailed dimensions of the antenna unbent into a planer structure are given in Figure 1(b). The vertical antenna ground portion effectively blocks the possible fringing EM fields from penetrating into the interiors of the mobile phone [1–5]. In this case, the EM compatibility of the antenna with possible nearby conducting elements or electronic components can be obtained. The top radiating patch is mainly with two folded arms of different resonant lengths, both operating as quarter-wavelength structures. That is, their resonant lengths correspond to a quarter-wavelength of the frequency at about 900 or 1800 MHz. The longer one (path 1 in the figure) and shorter one (path 2) of the two folded arms are designed to generate two resonant modes for GSM and DCS operation, respectively. The operating principle is similar to the conventional internal dual-band patch antenna using the design technique of two separate resonant paths [10].

The system ground plane or the main PCB (0.8 mm thick FR4, \(\varepsilon_r = 4.5, \sigma = 0.07 \text{ S/m}\)) is chosen to have dimensions of 40 \(\times\) 120 mm\(^2\), which is a reasonable size of the practical mobile phone. In addition, a RF shielding metal case of dimensions 40 \(\times\) 40 \(\times\) 7 mm\(^3\) is considered as a possible conducting element placed nearby the antenna, which is electrically connected to the ground plane for shielding and protecting the associated electronic components in a mobile phone. Note that the distance \(g\) between the

![Figure 2](image-url) Photograph of the experimental model of the studied mobile phone with the user’s hand. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

![Figure 3](image-url) The hand model comprising muscle and bones in the simulation study. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]
RF shielding metal case and the vertical antenna ground portion is defined for testing the EMC property of the antenna in the next section. Also note that there is a 1-mm-thick plastic housing (\(\varepsilon_r = 3.5, \sigma = 0.02 \text{ S/m}\)) enclosing the antenna, RF shielding metal case, and main PCB in order to avoid direct contact of the user’s hand with the interior elements of the mobile phone in the experiment. The antenna attached to the plastic housing is tested by using a 50Ω mini coaxial cable with its central conducting core connected to point A (the feeding point) and its outer shielding braid connected to point B (the grounding point).

Figure 4  (a) Front view and (b) top view of the simulation model of the studied mobile phone in the handheld position. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

A photograph illustrating the mobile phone with the user’s hand in the experiment is shown in Figure 2. Note that the user’s hand in the experiment is the right hand, which holds the mobile phone from the back side. The mobile phone with the user’s hand model in the simulation study is shown in Figures 3 and 4. The hand model with the consideration of the forearm used here is provided by the commercial EM simulation software, SEMCAD [11]. Note that this right hand model in an encircled pose to hold the mobile phone consists of muscle and bones, and the muscle is in translucency (in Fig. 3) for clarifying the relative positions of the bones. The related material parameters of muscle and bones of

Figure 5  Measured return loss for the EMC internal antenna with a nearby RF shielding metal case. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

Figure 6  Simulated surface current distributions at (a) 925 MHz and (b) 1795 MHz for the EMC internal antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]
the hand model at different frequencies (925 and 1795 MHz in this study) are obtained from [12]. In Figure 3, notice that the distance from the top edge of the mobile phone housing to the top edge of the thumb is defined as \( d \) (in Fig. 3, \( d = 60 \) mm, and in Fig. 4, \( d = 0 \)). Since the tested EMC internal antenna is on the top portion of the mobile phone in this study, the antenna is overlaid with the user’s hand from the outside of the housing when \( d \) is equal to or less than 30 mm. In this study, mobile phone held by the user’s hand for \( d \) varied from 0 to 100 mm is analyzed, and the results are discussed in the next section. In Figures 4(a) and 4(b), how the user’s hand holds the mobile phone in the simulation study is shown, and the related parameters in the simulation are given.

3. RESULTS AND DISCUSSION

Figure 5 shows the measured return loss of the tested EMC internal mobile phone antenna for GSM/DCS operation. From the results, two resonant modes excited with good impedance matching in the GSM and DCS bands are observed. In addition, when a RF shielding metal case is placed nearby the antenna, the results show small or negligible effects on the impedance matching of the antenna. Even when the distance \( g \) decreases to 0, indicating that the RF shielding metal case is in direct contact with the tested EMC antenna, there is almost no difference between the results of the antenna with and without the RF shielding metal case. The explanation is because the vertical antenna ground portion functioning as an effective shielding wall to block the EM fringing fields from penetrating into the interiors of the mobile phone [1–5].

The surface-current distributions of the system ground plane, antenna’s vertical ground portion, and antenna’s top radiating patch are shown in Figure 6. Relatively very small surface currents distributed on the portion of the system ground plane near the antenna’s vertical ground portion are observed, which indicates that the EM fringing field does not penetrate into this region. Therefore, the possible coupling induced between the RF shielding metal case and the tested EMC antenna is greatly suppressed, leading to the phenomenon of very small variations between the curves shown in Figure 5.

Figure 7 presents the measured return loss of the handheld mobile phone shown in Figure 2. Two resonant modes excited at about 900 and 1800 MHz are seen, and some variations in the resonant modes are observed when the distance \( d \) changes. Especially in Figure 7(a), large-frequency detuning is seen when the distance \( d \) is varied from 0 to 30 mm. In this study, the lower mode for GSM operation affected by the user’s hand has smaller frequency shift compared to that of the higher mode for DCS operation. This is largely because the index finger is much closer to the resonant path (path 2) of the higher mode than to that (path 1) of

![Figure 7](image-url)
the lower mode [see Fig. 1(b)]. Also note that in Figure 7(b), probably because the user’s hand does not directly cover the tested EMC antenna in the mobile phone ($d$ larger than about 40 mm), the results show very small differences to the curve of the mobile phone in free space (without the user’s hand). Figure 8 shows the return loss obtained from the simulation model for the mobile phone in handheld position described in Figures 3 and 4. The simulated results show similar tendencies to the measured data shown in Figure 7. This also ensures the accuracy of the simulation results. Generally, if the antenna has more overlaid portion with the user’s hand, larger effects on the impedance matching of the antenna in the operation band will occur.

Figures 9 and 10 show the simulated 3D radiation patterns obtained from SEMCAD at 925 and 1795 MHz, respectively, the center frequencies of the GSM and DCS bands. In Figures 9(a) and 10(a), where the distance $d = 0$, it is observed that the radiating power seems to be greatly absorbed by the user’s hand in the forearm direction. Thus, there is a null seen in the $x$–$y$ plane or the azimuth plane, and the radiation patterns are greatly distorted to be far from omnidirectional or near-omnidirectional like the ones of the mobile phone in free space shown in Figures 9(d) and 10(d). Similar effects of the user’s hand are seen in Figures 9(b) and 10(b), but the results show only dips or indistinct nulls, different from the case of $d = 0$ due to the smaller overlaid portion of the antenna with the user’s hand. On the other hand, results in Figures 9(c) and 10(c) with $d = 100$ mm show near-omnidirectional radiation patterns. However, even at the position where the user’s hand holds the mobile phone is far away from the antenna, the

![Figure 9](image-url)
antenna radiation patterns are still affected by the user's hand, which is quite different from the user's hand effects on the characteristics of the impedance matching demonstrated in Figures 7 and 8.

The radiation efficiency is illustrated in Figure 11. Note that there are two groups of curves. One is considered with the mismatching loss (return loss included) and the other is considered with perfect matching. The original radiation efficiencies of the mobile phone in free space are marked as dashed lines in the figure (54.1% and 69.5% at 925 and 1795 MHz). By comparing these two groups of curves to the original efficiencies of the mobile phone, the efficiency decrease due to the power absorption of the user's hand or the frequency shifting of the resonant mode because of the user's hand can be easily identified. First note that the differences (the efficiency drops) between the perfect matching curves and the original efficiencies of the mobile phone are contributed from the power absorption by the user's hand. Hence, the additional efficiency loss contributed from the mismatching loss owing to the frequency detuning can then be calculated from the two groups of curves. It is seen that the smaller distance \( d \) leads to larger efficiency loss because the mobile phone has more overlaid portion with the user's hand, which results in more radiated power absorption by user's hand. Further, when \( d \) is less than about 30 mm, additional mismatching loss is seen in the figure, especially in the DCS band, which can be expected from the results shown in Figure 7(a). For the case of \( d = 0 \), the radiation efficiency is decreased to a minimum, about 9.1% and 18.4%. This corresponds to a power loss of about 7.7 dB (from 69.5% to 18.4%) and 5.8 dB (from 54.1% to 9.1%) for GSM and DCS operation, respectively.

Figure 10    Simulated 3D radiation patterns at 1795 MHz: (a) \( d = 0 \); (b) \( d = 30 \) mm; (c) \( d = 100 \) mm; (d) in free space. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]
Figure 11  Simulated radiation efficiency as a function of $d$. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

4. CONCLUSION
The user’s hand effects on the EMC internal GSM/DCS dual-band antenna embedded in the mobile phone have been presented. Although the tested EMC antenna is promising to be integrated into a mobile phone with nearby conducting elements or electronic components, the performance of the antenna is still greatly affected when the user’s hand holds the mobile phone. Results have shown that, even when the mobile phone is handheld at the bottom ($d = 100$ mm in this study), there are large efficiency drops for the tested EMC antenna, especially for GSM operation (from 54.1% to 32.9% or about 2.2-dB drop).

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A NOVEL VARACTOR DIODELESS PUSH-PUSH VCO WITH WIDE TUNING RANGE
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ABSTRACT: A Ku-band push-push VCO for low-cost applications is proposed. The proposed push-push oscillator achieves wide tuning range in the Ku-band by the collector bias tuning instead of varactor tuning. The designed Ka-band VCO shows a wide tuning range of 900 MHz, excellent fundamental suppression of $-30$ dBc, and good phase noise of $-115$ dBc at 1-MHz offset. © 2006 Wiley Periodicals, Inc.
Microwave Opt Technol Lett 48: 1569–1572, 2006; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21726

Key words: VCO; oscillator; push-push; varactor diode

1. INTRODUCTION
Although push-push oscillators have the drawbacks of fundamental spurious signal and circuit complexity in implementation, they have been widely used in microwave applications due to their effectiveness as follows. Push-push oscillators offer the extension of the usage-oscillation frequency limitation [1] and a more wider tuning range compared to fundamental oscillators [2]. Additionally, push-push oscillators show good phase-noise performance compared with solutions using frequency doublers [3] and their pulling-figure characteristic is excellent, since two identical oscillators operate in odd-mode which makes a virtual ground at output port at fundamental frequency.

In this paper, a new wideband VCO topology for a low-cost radar detector is proposed. The proposed VCO adopts the push-push topology. The frequency tuning is achieved by using the collector bias instead of extra varactor diodes. The frequency-tuning mechanism of the proposed topology will be explained through a linear oscillation model.

2. VARACTOR DIODELESS PUSH-PUSH VCO
2.1. Configuration
The schematic of the proposed VCO is shown in Figure 1. It consists of two identical oscillators which operate in 180° out of phase with each other. The gate port of the individual VCO is implemented with a hair-pin resonator which can achieve a low-phase noise characteristic. Short-circuited impedance at the fun-