Thin Internal Patch Antenna for GSM/DCS Operation in a PDA Phone with the User's Hand

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Abstract

A thin dual-band internal patch antenna for GSM/DCS operation in a PDA (Personal Digital Assistant) phone is presented. The antenna can generate two wide resonant modes for GSM (890~960 MHz) and DCS (1710~1880 MHz) operation, yet it requires an air-layer substrate of thickness 4 mm only. The antenna's top patch comprises a resonant narrow strip supporting a longer resonant path for GSM operation and a resonant subpatch supporting a shorter resonant path for DCS operation. By including a suitable widened end portion for the narrow strip and a suitable tapered end portion for the subpatch, increased bandwidths for the proposed thin internal mobile phone antenna are obtained. Detailed design considerations of the proposed antenna are described. In addition, the user's hand effects on the performances of the proposed antenna are studied.

1. INTRODUCTION

Thin mobile phones or PDA phones with a thickness of about 10 mm are becoming very attractive for wireless users. For this application, several thin internal patch antennas for operating in the 900/1800 MHz bands for GSM and DCS operation have recently been demonstrated [1], [2], in which the thickness of the thin air-layer substrate between the antenna's top patch and the system ground plane is 3 or 4 mm only. Note that this small substrate thickness is only about one half of that of the conventional internal patch antenna. When the conventional internal patch antenna with a larger system ground plane is with such a thin air-layer substrate thickness, the operating bandwidths of the antenna usually cannot cover the required bandwidths of the GSM and DCS systems.

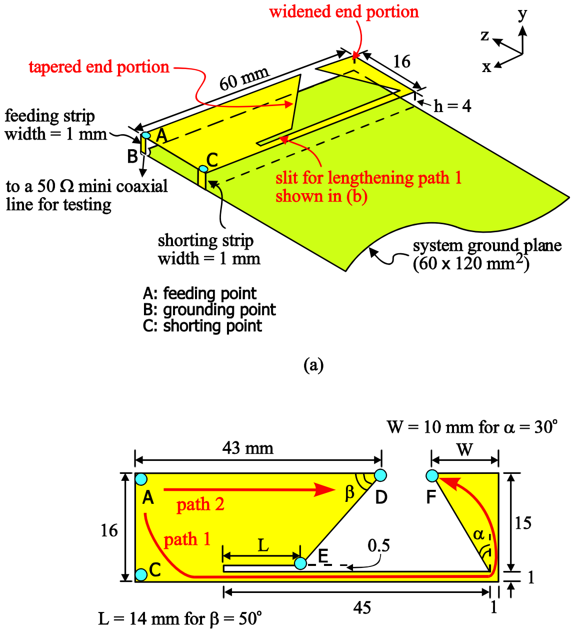
To overcome the problem, the design techniques such as extending a small portion of the antenna's top patch over the top edge of the system ground plane of the mobile phone [1] or using a slotted ground plane [2] have been applied. In this case, it is expected that the quality factor of the patch antenna can be decreased, thus the bandwidths of the antenna will be increased. However, for the case in [1], a longer casing for the thin mobile phone will be required, owing to the antenna' top patch extended over the top edge of the system ground plane. On the other hand, for the case in [2], it will become difficult in arranging the associated electronic components in the mobile phone, owing to the presence of the embedded slots in the system ground plane.

In this paper, we propose a promising design of the thin internal patch antenna, without the need of extending the antenna's top patch over the top edge of the system ground plane or embedding slots in the system ground plane. The proposed antenna requires a small air-layer substrate thickness of 4 mm only, and it can provide wide operating bandwidths covering GSM/DCS operation. The bandwidth enhancement is achieved by using a suitable widened end portion to the antenna's longer resonant path for GSM operation and a suitable tapered end portion to the antenna's shorter resonant path for DCS operation. In this case, it is expected that the excited surface current distributions in the end portions of the longer and shorted resonant paths will become more uniform, which can thus lead to enhanced bandwidths for the proposed antenna. Results of the constructed prototypes are presented and discussed. In addition, the condition of the user's hand holding the PDA phone with the proposed antenna is considered, and effects of the user's hand on the performances of the proposed antenna are analyzed.

2. DESIGN CONSIDERATIONS OF PROPOSED ANTENNA

Fig. 1(a) shows the geometry of the proposed thin internal patch antenna in a PDA phone for GSM/DCS operation. The size of the system ground plane in the study is selected to be 60×120 mm^2. The proposed antenna is mounted at the top portion of the system ground plane, with the top edge of the antenna's top patch flushing with that of the system ground plane. Also note that the thickness h of the air-layer substrate is 4 mm only. Fig. 1(b) shows the detailed dimensions of the antenna's top patch, which was easily fabricated by line-cutting a 0.2 mm thick copper plate in the study.

The top patch occupies an area of 60×16 mm^2, and mainly comprises a resonant narrow strip supporting a longer resonant path (path 1) for GSM operation and a resonant subpatch supporting a shorter resonant path (path 2) for DCS operation. Note that, with the top patch short-circuited to the system ground plane through a shorting strip at point C, both paths 1 and 2 are operated as quarter-wavelength structures. As shown in Fig. 1(b), path 1 starts at point A, then follows the narrow strip of length 45 mm, and finally ends at point F. The narrow strip has a uniform width of 1 mm, and at its end portion, it is widened to have a width of *W*. This end portion is also bent to be perpendicular to the narrow strip such that a compact size of the top patch can be achieved. Also, the width *W* is controlled by the angle α; when α is increased from 0° to 30°, *W* is increased from 1 to 10 mm. It is found that, when the angle α is properly chosen to have a suitable width *W*, enhanced lower-band bandwidth of the proposed antenna for GSM operation can be obtained.



(a)

(b)

Fig. 1: (a) Geometry of the proposed thin internal patch antenna in a PDA phone for GSM/DCS operation. (b) Detailed dimensions of the top patch of the antenna.

For the resonant subpatch, it is roughly of a rectangular shape with a tapered end portion. The edge between points A and D has a fixed length of 43 mm, and the tapered end portion is controlled by the angle β. When β is decreased (point D is fixed), the edge between points D and E is inclined toward the edge between points A and C. In this case, a tapered end portion for the resonant subpatch is obtained. This tapered end potion is found to be very helpful in enhancing the upper-band bandwidth of the proposed antenna for DCS operation. Detailed effects of the angle β on the operating bandwidths of the proposed antenna will be analyzed in Fig. 4. Also note that, in between the narrow strip and the subpatch, there is a narrow slit, whose length *L* is controlled by the angle β. This narrow slit is used to lengthen the effective length of path 1, such that with a fixed size of the top patch, large decreasing in the center frequency of the lower resonant mode of the antenna can be obtained.

For testing the proposed antenna, a 50 Ω mini coaxial line is used. The coaxial line is connected to the feeding strip placed in between points A and B. Notice that the feeding point is selected to be at the corner of the top edge of the system ground plane. In this case, it is helpful in efficiently exciting the internal patch antenna with a low quality factor. That is, wider bandwidths can be achieved for the proposed antenna.

Furthermore, for testing the antenna with the presence of the user's hand, the simulation hand model (shown in Fig. 7) provided by SPEAG simulation software SEMCAD [3] is used. The hand model mainly comprises the skin, muscle and bones, and their relative permittivity and conductivity at 925 and 1795 MHz are obtained from Ref. [4].

3. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed thin internal patch antenna with dimensions given in Fig. 1 was constructed and tested. The angles α and β are first selected to be 30° and 50°, respectively. Fig. 2 shows the measured and simulated return loss of the constructed prototype. The simulated results are obtained using Ansoft simulation software HFSS (High Frequency Structure Simulator) [5]. Good agreement between the measurement and simulation is seen. From the measured results, with the bandwidth definition of 2.5:1 VSWR, the excited lower resonant mode has a bandwidth of 72 MHz, which covers the required bandwidth of the GSM system. For the excited upper resonant mode, it shows a bandwidth of 180 MHz, also covering the required bandwidth of the DCS system.

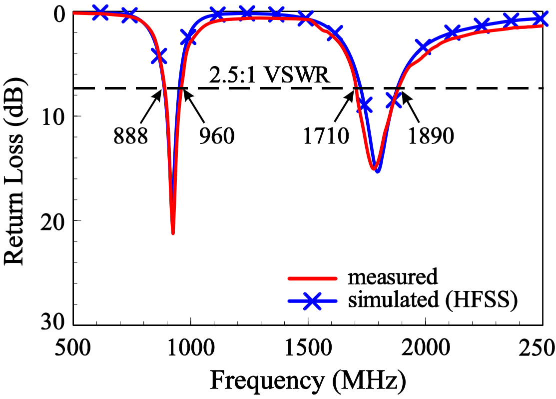


Fig. 2: Measured and simulated (HFSS) return loss; α = 30°, β = 50°, *h* = 4 mm.

The radiation patterns at 925 and 1795 MHz were also measured. It is revealed that dipole-like radiation patterns at 925 MHz are obtained, and more variations in the radiation patterns at 1795 MHz are observed. These radiation patterns showed no special distinctions compared to those of the conventional internal PIFAs for mobile phones. Therefore, they are not shown here for brevity.

To study the effects of the angle α of the widened end portion of path 1 on the bandwidths of the proposed antenna, a parametric study using Ansoft simulation software HFSS was conducted. Results of the simulated return loss obtained for α varied from 10° to 40° and β fixed at 50° are shown in

Fig. 3. It is seen that, with an increase in the angle α, the lower mode is shifted toward lower frequencies. This behavior is expected, since a larger angle α will lead to a widened end portion for path 1, which in turn can lengthen the effective length of path 1. However, it is noted that for α = 30°, a maximum bandwidth of about 8.2% is obtained. This suggests that by selecting a suitable angle α, the bandwidth of the lower mode of the proposed antenna can be greatly enhanced. Also note that some effects of the angle α on the bandwidth of the upper mode are seen. This is probably owing to the coupling effect between the widened end portion of path 1 and the tapered end portion of path 2. This coupling effect is expected to increase, when the angle α increases. When the angle α is too large, the coupling effect will lead to a decreased bandwidth for the upper mode.

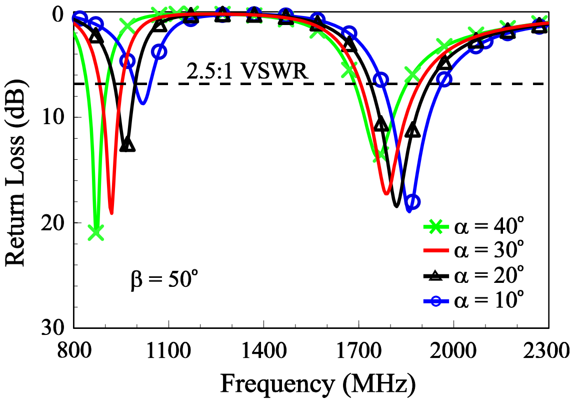


Fig. 3: Simulated (HFSS) return loss as a function of angle α; β = 50°, *h* = 4 mm.

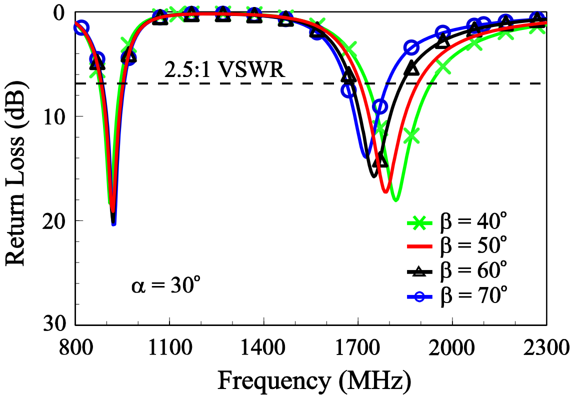


Fig. 4: Simulated (HFSS) return loss as a function of angle β; α = 30°, *h* = 4 mm.

For the effects of the angle β of the tapered end portion of path 2, the results are shown in Fig. 4. In this case, there are large effects on the bandwidth of the upper mode. It is first observed that, with an increase in the angle β, the upper mode is shifted to lower frequencies. This behavior is because a larger angle β will lead to a lengthened effective length of path 2, which in turn results in a lowered center frequency for the excited upper mode. It is also noted that, with a decrease in the angle β, the obtained bandwidths for the upper mode are increased. However, for the case of β = 40°, the upper mode is shifted to higher frequencies that cannot cover the DCS band. Thus, from the results obtained in Figs. 3 and 4, the angles α and β were, respectively, chosen to be 30° and 50° for the constructed prototype in this study. For the reason of the wider bandwidths obtained, it is largely because the excited surface current distributions in the end portions of paths 1 and 2 will become more uniform when proper angles of α and β are chosen, which in turn leads to enhanced bandwidths for the proposed antenna. The antenna gain and radiation efficiency of the proposed antenna in free space were also studied. For the lower mode, the antenna gain varies in a range of about 0 ~ 1.7 dBi, and the radiation efficiency is all larger than 50% over the GSM band. For the upper mode, the antenna gain varies from about 1.7 to 3.3 dBi, and the radiation efficiency is larger than 70%. It indicates that good radiation characteristics are obtained for the proposed antenna.

Effects of the user's hand on the proposed antenna were also studied. The experimental photo and simulation model are shown in Fig. 5, in which the parameter *d* indicates the distance from the top edge of the PDA phone to the top of the user's thumb portion. From the simulated and measured return loss for the cases without and with (*d* = 0, 40 and 80 mm) the user's hand shown in Fig. 5(a) and (b), agreement between the measurement and simulation is generally obtained. This agreement ensures reliable simulation results obtained from the simulation software SEMCAD [3]. Note that, in the experiment, the proposed antenna and the system ground plane are enclosed by a thin plastic housing to avoid their direct contact with the user's hand. Also, the relative permittivity of the plastic housing is chosen to be small or close to that of air such that the antenna performances are very slightly affected by the presence of the plastic housing. From the results obtained, it is seen that the frequency detuning is larger for the case of *d* = 0 (the antenna is completely overlaid by the user's hand) than for the cases of *d* = 40 and 80 mm.

Fig. 6 shows the simulated radiation efficiency as a function of *d*. Note that there are two curves shown in the figure for 925 and 1795 MHz. One curve considers the mismatching loss, while the other one considers no mismatching loss or the perfect matching condition. The difference between the two curves thus can indicate the contribution of the frequency detuning caused by the user's hand to the antenna's radiation efficiency. From the results, owing to the presence of the user's hand, large decrease in the radiation efficiency is seen. The efficiency decrease is also larger when *d* is smaller. Since the two curves are about the same in the figure, it indicates that the efficiency decrease is mainly owing to the radiation power absorption by the user's hand. When *d* = 0, the antenna's radiation efficiency is decreased to be about 20% for both 925 and 1795 MHz. The effect of user's hand on the three-dimensional total-power radiation patterns at 925 and 1795 MHz will be presented.

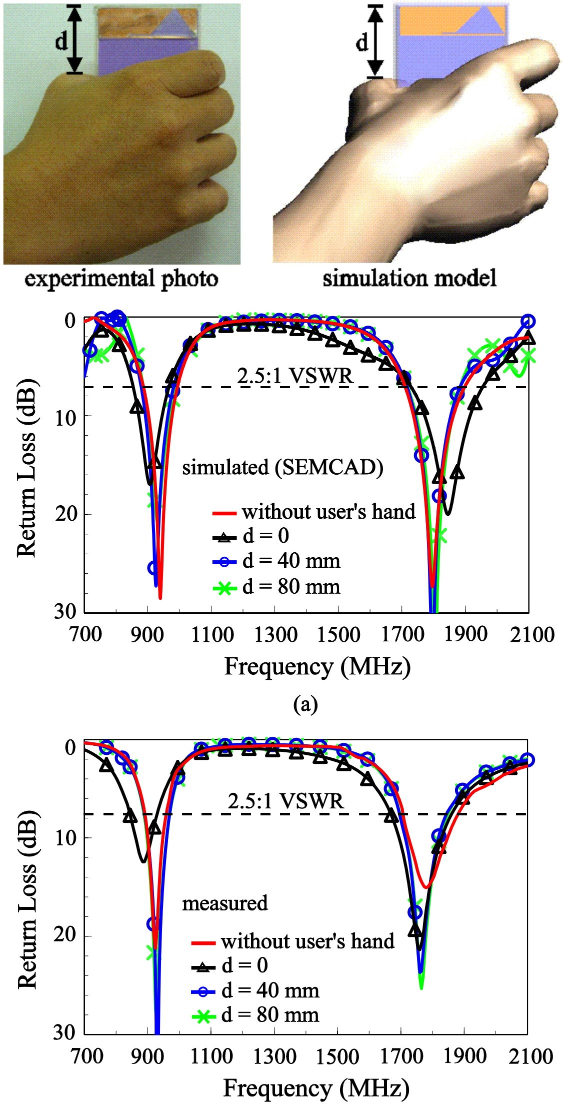


Fig. 5: (a) Simulated (SEMCAD) and (b) measured return loss for *d* = 0, 40 and 80 mm for the proposed antenna with the user's hand.

4. CONCLUSION

A thin internal patch antenna for GSM/DCS operation in a PDA phone has been proposed. With an air-layer substrate thickness of 4 mm only, the proposed antenna can generate two wide bandwidths in the 900/1800 MHz bands for GSM/DCS operation. The enhanced bandwidths of the proposed antenna are obtained by adding a widened end portion to the longer resonant path and a tapered end portion to the shorter resonant path. Detailed effects of the angles controlling the widened end portion and the tapered end portion have been analyzed. Furthermore, effects of the user's hand holding the studied PDA phone with the proposed antenna have been analyzed. Strong effects of the user's hand on the radiation efficiency and radiation pattern of the proposed antenna have been observed. When the user's hand is present, large decrease in the radiation efficiency is seen, which is mainly owing to the radiation power absorption by the user's hand. Large distortion in the antenna's radiation patterns is also seen, especially when the antenna is overlaid by the user's hand.

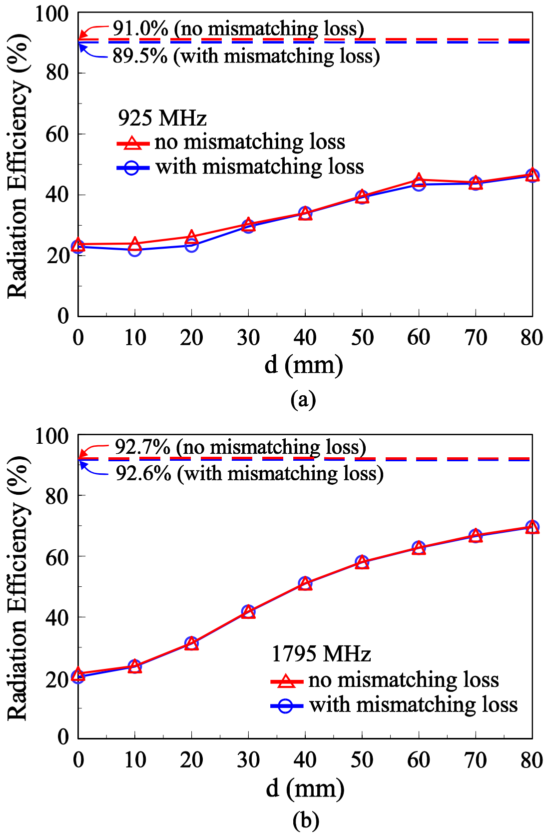


Fig. 6: Simulated (SEMCAD) radiation efficiency as a function of *d* for the antenna studied in Fig. 10. (a) 925 MHz. (b) 1795 MHz.

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