Internal WWAN Handset Antenna Formed by a Monopole Strip Radiator and a Clearance Region Thereof as Monopole Slot Radiator

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1. Introduction

Printed monopole strips are one of the promising types for the internal handset antennas to cover at least 824~960 and 1710~2170 MHz bands for penta-band WWAN operation [1], [2]. In such cases, the monopole strips are printed on the clearance or no-ground region at the top or bottom edge of the main circuit board. The clearance region is required for the printed monopole strips as efficient radiators in both the desired lower and upper bands of the WWAN operation. In this paper, we demonstrate a design concept of reclaiming the clearance region as an efficient monopole slot or open-slot radiator [3] to contribute its quarter-wavelength resonant mode for the desired antenna’s lower band. The printed monopole strip serves as a radiator to contribute its quarter-wavelength resonant mode for the desired antenna’s upper band and also as an exciter for the monopole slot radiator.

In the proposed design, since the printed monopole strip contributes only the resonant modes at frequencies higher than about 1.7 GHz, the required length of the monopole strip can be limited to be less than about 40 mm, which makes it occupy less board space on the main circuit board of the handset. In order to form an open-slot region for the monopole slot radiator, a C-shaped strip of low profile (4 mm in this study) is added at the long open edge of the clearance region on the main circuit board of the handset. This C-shaped strip has a low profile and can be embedded inside the casing of modern slim handsets. With the C-shaped strip, the clearance region can serve as an open-slot region and a quarter-wavelength slot mode at about 900 MHz for the antenna’s lower band can be generated. By further applying the bandwidth-enhancement technique of using a band-stop matching circuit, an additional resonant mode can be generated to combine with the quarter-wavelength slot mode to achieve a wide lower band for the antenna. In the proposed design, the antenna provides wide operating bands to respectively cover the GSM850/900 operation in the 824~960 MHz band and the GSM1800/1900/UMTS operation in the 1710~2170 MHz band.

2. PROPOSED DESIGN

Figure 1(a) shows the geometry of the proposed handset antenna formed by a printed monopole strip and its clearance region serving as a monopole slot radiator. Detailed dimensions of the proposed antenna are given in Figure 1(b). A 0.8-mm thick FR4 substrate of size 60 × 109 mm² is used as the main circuit board of the handset. On the circuit board, a ground plane is printed, with a clearance region of size 9 × 45 mm² disposed at one corner of the bottom edge of the circuit board. In the clearance region, a two-branch monopole strip is printed. The strip1 (section AE) and strip2 (section AF) contribute respectively a resonant mode in the desired upper band such that a wide operating band is achieved to cover the GSM1800/1900/UMTS operation.

The clearance region is reclaimed as a monopole slot radiator to contribute a resonant mode for the antenna’s desired lower band. For this purpose, a C-shaped strip of height 4 mm and length 46 mm is added at the long open edge of the clearance region, with one end of the C-shaped strip connected to the system ground plane and the other end connected to a metal pad disposed at the short open edge of the clearance region. The metal pad has a size of 4 × 8 mm² and is spaced to the...
system ground plane with a gap of 1 mm, which serves as the open end of the open-slot. A quarter-wavelength slot mode contributed by the monopole slot radiator can occur at about 850 MHz. With an aid of the band-stop matching circuit, which comprises a 3.3-nH chip inductor and a 3.3-pF chip capacitor connected in parallel, a parallel resonance can occur at the high-frequency side of the quarter-wavelength slot mode. This can cause the generation of an efficient resonant mode nearby.

Figure 1: (a) Geometry of the proposed handset antenna formed by a printed monopole strip and its clearance region as monopole slot radiator. (b) Detailed dimensions of the proposed antenna.

Note that the strip2 is placed to the system ground plane (1-mm in-between) such that large spacing between the strip1 and strip2 is obtained to avoid strong coupling between the two strips to degrade the achievable bandwidth of their respective resonant mode. Owing to the small spacing between the strip2 and the system ground plane, some coupling there-between may occur. The strip2 can also cause the parallel resonance generated by the band-stop matching circuit to slightly shift to lower frequencies. To take into account of this effect, the parallel resonance is designed to occur at about 1.15 GHz. Hence, when the strip2 is added, the parallel resonance is shifted to proper position and makes the new efficient resonant mode occurred at proper frequencies (at 1 GHz in this study) to combine with the quarter-wavelength slot mode to form a wide operating band for the antenna’s lower band.
3. RESULTS OF FABRICATED ANTENNA

The measured and simulated results of the proposed antenna and the photos of the fabricated prototype are presented in Figure 2. The simulated results are obtained using the three-dimensional full-wave electromagnetic field simulator HFSS. The measured data are seen to agree with the simulated results. The obtained bandwidths also respectively cover the desired 824–960 and 1710–2170 MHz bands (the shaded regions in the figure).

![Figure 2: Measured and simulated return loss of the proposed antenna and photos of the fabricated antenna](image)

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![Figure 3: (a) Simulated electric-field distribution at 850 and 1000 MHz in the open slot region of the proposed antenna, and (b) simulated surface-current distribution at 1700 and 1990 MHz on the printed monopole strip (strip1 and strip2) of the proposed antenna.](image)

Figure 3: (a) Simulated electric-field distribution at 850 and 1000 MHz in the open slot region of the proposed antenna, and (b) simulated surface-current distribution at 1700 and 1990 MHz on the printed monopole strip (strip1 and strip2) of the proposed antenna.

Figure 3(a) shows the simulated electric-field distribution at 850 and 1000 MHz in the open slot region of the proposed antenna, and Figure 3(b) shows the simulated surface-current distribution at 1700 and 1990 MHz on the printed monopole strip (strip1 and strip2) of the proposed antenna. At 850 MHz, the electric-field distribution is strong at the open end and generally decreases toward the closed end, which is similar to that of the quart-wavelength slot mode excitation [3]. At 1000 MHz, similar electric-field distribution is also seen, indicating that the open-slot region is also excited to perform as an efficient monopole slot radiator. This behavior is largely because the new resonant mode at about 1000 MHz is occurred at the high-frequency tail of the excited quart-wavelength slot mode at about 850 MHz. Hence, it is reasonable that the new resonant mode will have similar characteristics as the quart-wavelength slot mode at about 850 MHz. Figure 3(b) clearly show that at 1700 MHz, the strip2 is excited, while at 1990 MHz, the strip1 is excited. The antenna’s wide upper band is formed by two resonant modes contributed by both the strip1 and strip2, with the first mode of the upper band generated by the strip2 and the second mode generated by the strip1.
The measured far-field radiation characteristics of the proposed antenna are shown in Figure 5. The measured antenna efficiency which includes the mismatching loss was measured in a far-field anechoic chamber. The antenna efficiency is about 55~62% and 50~88% over the lower and upper bands, respectively. The measured three-dimensional (3-D) total-power radiation patterns are plotted in Figure 5. Results for five representative frequencies are shown. The full 3-D patterns and half 3-D pattern with cross-sectional cut at the $x$-$y$ plane are shown. Note that the antenna is at the bottom edge of the main circuit board as shown in Figure 1. At frequencies of the lower band (859 and 925 MHz), dipole-like radiation patterns with omnidirectional radiation in the $x$-$y$ plane are seen. At frequencies of the upper band (1795, 1920 and 2045 MHz), stronger radiation in the upper half-plane than that in the lower half-plane is seen, and there are also radiation dips in the $x$-$y$ plane. The results indicate that the system ground plane plays a dominant role in the obtained radiation patterns. This behavior is similar to those observed for many traditional internal handset antennas.

![Figure 5: Measured three-dimensional total-power radiation patterns of the proposed antenna.](image)

More results on the operating principle, parametric analysis and SAR test will be shown in the presentation.

4. CONCLUSION

A promising technique of reclaiming the clearance region of the printed monopole strip on the main circuit board of the handset to perform as an efficient monopole slot radiator has been proposed. Results of the fabricated prototype of the proposed design have been presented. The antenna can cover the penta-band WWAN operation with a small reality space on the main circuit board of the handset. Good far-field radiation characteristics of the antenna over the operating bands have been observed. The SAR results of the antenna have been analyzed as well. The obtained results indicate that the proposed antenna is promising for practical handset applications.

References