Printed Monopole with a Distributed Inductor for Penta-Band WWAN Internal Mobile Phone Antenna

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1. Introduction

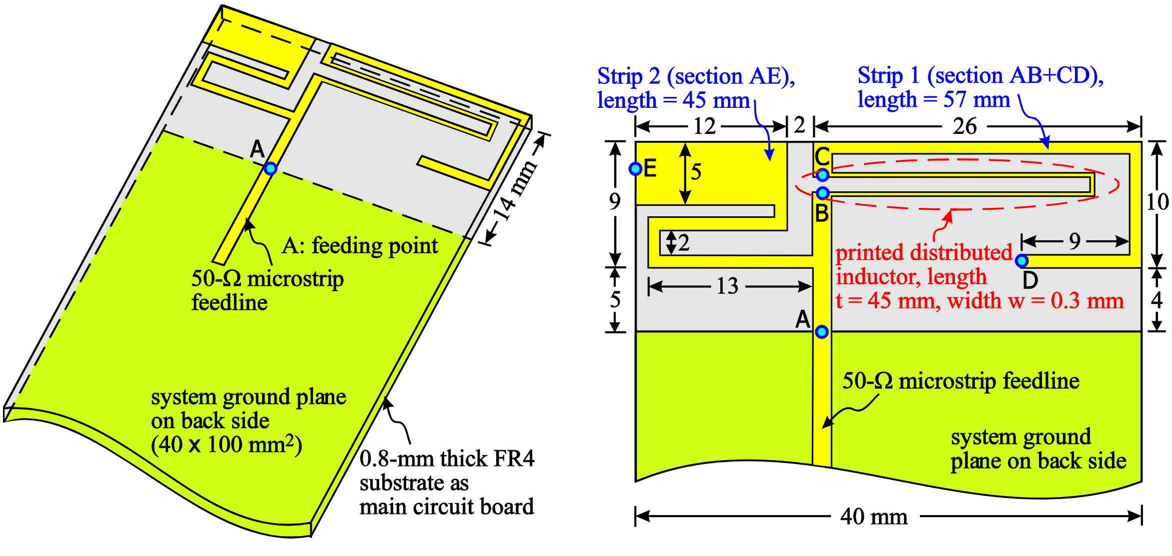
The chip-inductor-embedded small-size printed monopole for WWAN (wireless wide area network) operation in the mobile phone has recently been demonstrated [1]. The printed monopole occupies a small area of 15 x 34 mm^2 on the no-ground portion of the main circuit board of the mobile phone and generally shows no thickness above the circuit board, which is very attractive for thin-profile mobile phone or laptop computer applications. The much reduced size of the chip-inductor-embedded monopole is mainly owing to the additional inductance contributed by the chip inductor to compensate for the increased capacitance resulting from the decreased resonant length of the monopole [2, 3]. However, with the lumped chip inductor, additional process in the fabrication of the antenna is required, which increases the fabrication cost.

In this paper, we present a printed monopole embedded with a printed narrow strip as a distributed inductor for application in the mobile phone to achieve GSM850/900/1800/1900/UMTS penta-band WWAN operation. The printed distributed inductor replaces the lumped chip inductor, leading to an all-printed structure for the proposed small-size monopole applied as an internal WWAN mobile phone antenna. The proposed printed monopole hence can be implemented at low cost. In addition, it has a similar small size as that in [1] for the case of using a lumped chip inductor and can be printed on a no-ground portion of 14 x 40 mm^2 on the main circuit board of the mobile phone (see Fig. 1). Further, the use of a distributed inductor can decrease the possible losses associated with the use of a lumped chip inductor (such as the conductive loss associated with the bending and winding of the strips in the chip inductor and the dielectric loss in the chip element). Detailed effects of the printed distributed inductor on the proposed small-size monopole are studied in this paper. Details of the results are presented and discussed.

2. Design Considerations of Proposed Antenna

Fig. 1(a) shows the geometry of the proposed printed monopole with a printed distributed inductor for penta-band WWAN operation in the mobile phone. The proposed monopole is printed on the no-ground portion of size 14 x 40 mm^2 on the main circuit board of the mobile phone. A 0.8-mm thick FR4 substrate is used as the main circuit board in the study, and the system ground plane of size 100 x 40 mm^2 is printed on the back side of the circuit board. The proposed printed monopole is a two-strip monopole whose dimensions are given in Fig. 1(b). Strip 1 is the longer strip and has a length of 57 mm (section AB and CD in the figure). In-between point B and C, a narrow strip (width 0.3 mm) of length 45 mm is printed, which functions as a distributed inductor with an equivalent inductance of about 15 nH (see the results presented in Fig. 4 and will be discussed in the next section).

With this distributed inductor, strip 1 can resonate at about 900 MHz, although it has a length of 57 mm only or about 0.17λ at 900 MHz (excluding the length of the distributed inductor), resulting in a wide lower band for the antenna to cover GSM850 (824~894 MHz) and GSM900 (880~960 MHz) operation. In addition, owing to the presence of the printed distributed inductor, a higher-order mode at about 2000 MHz contributed by strip 1 can also be generated. This higher-order mode incorporates the resonant mode excited at about 1800 MHz contributed by strip 2 of length 45 mm or about 0.27λ at 1800 MHz (the shorter strip, section AE in the figure) to form a



(a) (b)

Figure 1: (a) Geometry of the proposed printed monopole with a printed distributed inductor for penta-band operation in the mobile phone. (b) Dimensions of the proposed antenna.

wide upper band for the antenna to cover GSM1800 (1710~1880 MHz), GSM1900 (1850~1990 MHz) and UMTS (1920~2170 MHz) operation. Hence, with the distributed-inductor-loaded strip 1 and the simple strip 2 for the proposed antenna, two wide operating bands for covering GSM850/900/1800/1900/UMTS penta-band WWAN operation are obtained. For testing the proposed antenna in the experiment, a 50-Ω microstrip feedline printed on the front side of the circuit board is connected to point A (the antenna's feeding point), and effects of the distributed inductor on the antenna performances are analyzed.

3. Results and Discussions

The proposed antenna was fabricated and studied. Fig. 2(a) presents the measured and simulated return loss. Agreement between the measured data and the simulated results obtained using Ansoft HFSS [4] is seen. Two wide operating bands at about 900 and 1900 MHz are obtained. With the definition of 3:1 VSWR (6-dB return loss) generally used for the internal mobile phone antenna design, the lower band covers GSM850/900 operation, while the upper band formed by two resonant modes covers GSM1800/1900/UMTS operation.

To analyze the effects of strip 1 and strip 2 on the antenna performance, Fig. 3 shows the simulated return loss for the proposed antenna, the case with strip 1 only, and the case with strip 2 only. Results clearly show that strip 2 contributes a resonant mode at about 1800 MHz, while strip 1 generates two resonant modes, with one at about 900 MHz and the second one at about 2000 MHz.

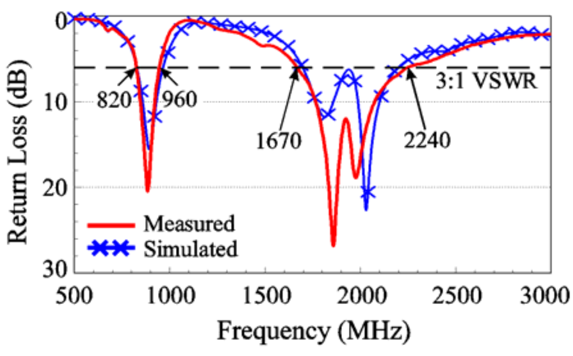


Figure 2: Measured and simulated return loss for the fabricated antenna.

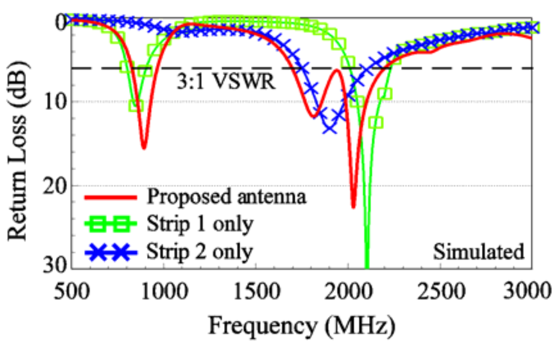


Figure 3: Simulated return loss for the proposed antenna, the case with strip 1 only, and the case with strip 2 only.

The loading effects of the printed distributed inductor are further analyzed in Fig. 4, in which results for the simulated return loss for the proposed antenna, the case with a chip inductor of 15 nH replacing the printed distributed inductor (Ref 1), and the case without the printed distributed inductor or chip inductor (Ref 2) are shown. For both the proposed antenna and Ref 1, a resonant mode at about 900 MHz is generated, while the lowest resonant mode for Ref 2 is centered at about 1200 MHz only. This suggests that the printed distributed inductor used in the proposed antenna has an equivalent inductance of 15 nH, and the additional inductance can indeed result in the decrease of the antenna's lowest resonant mode. Furthermore, from the comparison of the proposed antenna and Ref 1, there is an additional resonant mode generated at about 2000 MHz, which is owing to the use of the printed distributed inductor instead of the chip inductor.

Fig. 5 shows the simulated return loss for the proposed antenna as a function of the position *d* of the printed distributed inductor. Results for *d* varied from 6.7 to 10.7 mm are shown. Strong effects of the position *d* on the antenna's lower and upper bands are seen. Results indicate that the printed distributed inductor should be not too close to the connecting point of strip 1 and strip 2. For the case of *d* = 10.7 mm used in the proposed antenna (distributed inductor away from the connecting point of the two strips), good excitation of both strip 1 and strip 2 to achieve wide operating bandwidths can be obtained.

The radiation characteristics are also studied. Fig. 6 shows the measured three-dimensional (3-D) radiation patterns for the proposed antenna. Dipole-like radiation patterns at 859 and 925 MHz are seen, while more variations in the radiation patterns are observed at 1795, 1920 and 2045 MHz. The measured radiation patterns show no special distinctions as compared to those of the chip-inductor-embedded printed monopole for WWAN operation studied in [1] and many other internal WWAN mobile phone antennas that have been reported [5]. Fig. 7 shows the measured radiation efficiency and antenna gain for the proposed antenna. For the frequencies over the GSM850/900 bands shown in Fig. 7(a), the radiation efficiency is about 57~87%, and the antenna gain is about 0~1.7 dBi. Over the GSM1800/1900/UMTS bands in Fig. 7(b), the radiation efficiency ranges from 50 to 89%, and the antenna gain varies from 1.6 to 4.8 dBi. The obtained radiation characteristics are acceptable for practical mobile phone applications.

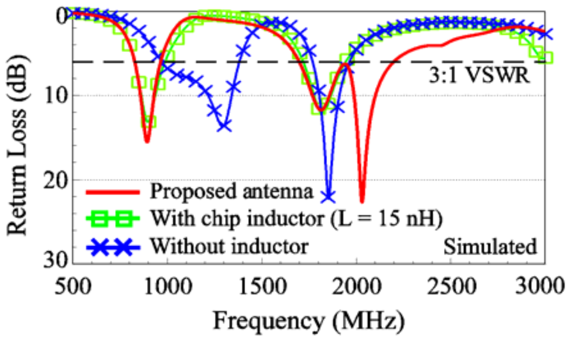


Figure 4: Simulated return loss for the proposed antenna, the case with a chip inductor of 15 nH replacing the printed distributed inductor, and the case without the printed distributed inductor or chip inductor.

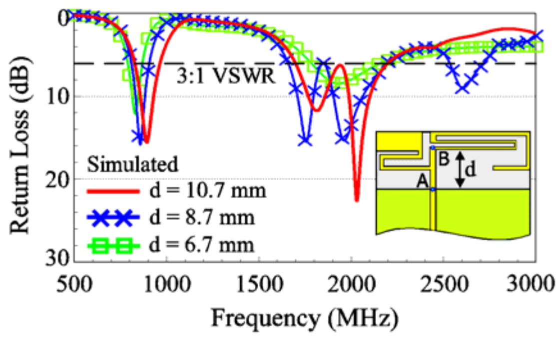


Figure 5: Simulated return loss for the proposed antenna as a function of the position *d* of the printed distributed inductor. Other dimensions are the same as given in Fig. 1.

4. Conclusion

A small-size printed monopole consisting of a distributed-inductor-loaded longer strip and a simple shorter strip for achieving penta-band WWAN operation in the mobile phone has been proposed. The proposed antenna shows an all-printed uniplanar structure occupying a size of 14 x 40 mm^2 only, making it easy to fabricate at low cost for practical applications. The printed distributed inductor in the longer strip of the antenna shows an equivalent inductance of 15 nH, providing additional inductance to compensate for the increased capacitance resulting from the decreased resonant length of the longer strip for the 900 MHz band covering GSM850/900 operation. In addition, the distributed inductor studied here provides an additional higher-order mode to effectively widen the antenna's upper band to cover GSM1800/1900/UMTS operation, which is an advantage over the case of using a lumped chip inductor.

References

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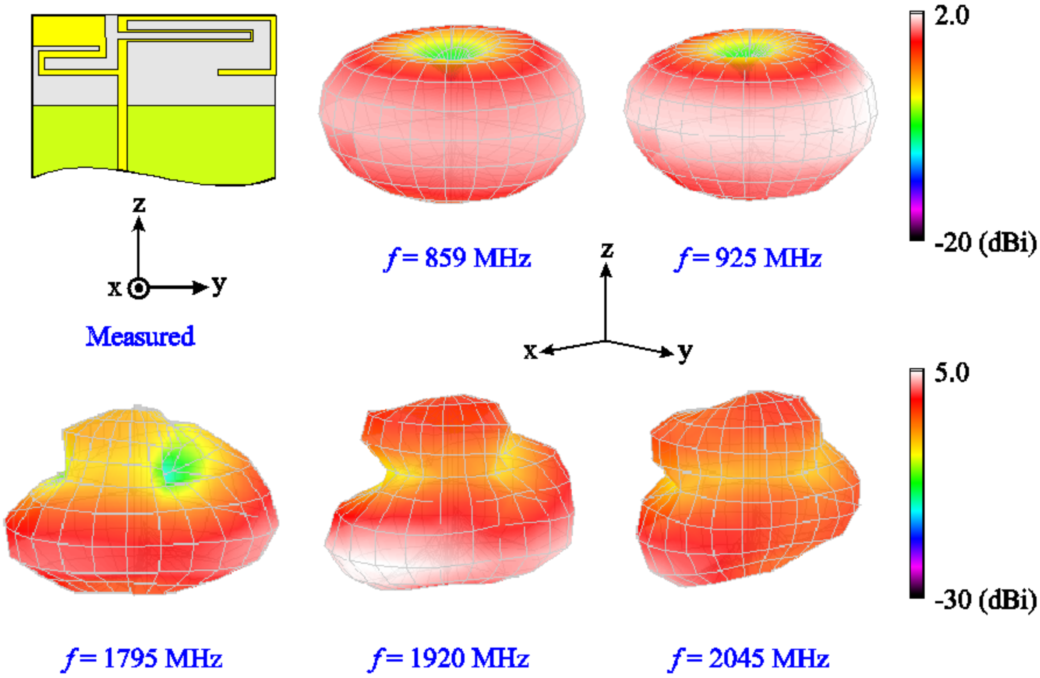

Figure 6: Measured 3-D radiation patterns for the proposed antenna.

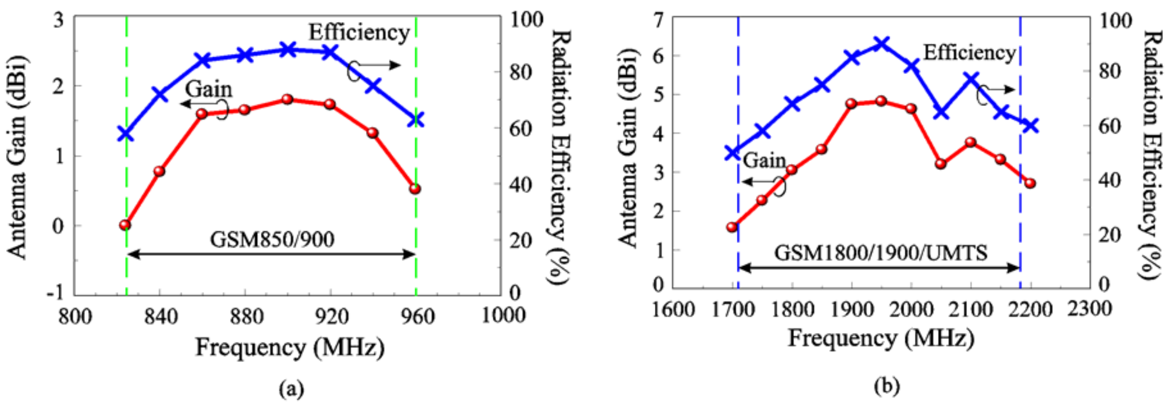

Figure 7: Measured radiation efficiency and antenna gain for the proposed antenna. (a) GSM850/900 bands. (b) GSM1800/1900/UMTS bands.