A Compact Wideband Two-Arm-Antenna for Mobile Phones

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Abstract. *A compact film type antenna capable of generating two wide resonant modes for covering the AMPS/GSM bands and the DCS/PCS/UMTS bands for mobile phones is proposed. The antenna consists of two superimposed radiation arms which can support two resonant modes by themselves. The frequency range of a resonant mode generated by one of the arm is arranged to differ a little with the corresponding mode of the other, at the fundamental and higher-order modes. As a result, the bandwidths at both of the resonant modes are significantly enhanced. The antenna has a compact dimension of 5 x 15 x 40 mm*^{3} *and covers five bands of AMPS/GSM/DCS/ PCS/UMTS for a VSWR less than 2.5:1. It shows fairly good omnidirectional radiation patterns and high gains over 0 dBi in the azimuthal plane, at all the operating bands.*

Keywords

Multi-band antenna, compact antenna, mobile phone.

1. Introduction

Recently, mobile phones are widely spread in the world and many systems are used in different areas and countries. A mobile phone for worldwide use should cover frequency bands from AMPS (824 - 894 MHz), GSM (890 - 960 MHz), DCS (1710 - 1880 MHz), PCS (1850 to 1990 MHz) to UMTS (1920 - 2170 MHz). Many types of internal antennas have been developed for such purpose. For examples, a miniaturized planar inverted-F antenna (PIFA) by using magnetic materials [1], a capacitively-loaded loop antenna [2], a PCB embedded antenna composed of loop and PIFA [3], a monopole slot antenna [4], an antenna composed of a helical and a monopole element [5] and a film antenna with a folded arm [6] have been investigated. For smaller and slimmer body of mobile phones, however, designing an internal antenna which fully covers five bands of AMPS/GSM/DCS/PCS/UMTS is still a very challenging task.

Film antennas have attractive features of compact size, easy installation and low cost. We have presented a film antenna that consists of a folded arm and generates two resonant modes for covering the GSM/DCS/PCS/ UMTS bands [6]. However, the bandwidth of the fundamental mode was not enough to extend the coverage to the AMPS band by only using one radiation arm.

In this paper, we propose a film antenna with two radiation arms to cover all the AMPS/GSM/DCS/PCS/ UMTS bands. Two similar folded arms are used and carefully superimposed so that the frequency range of a resonant mode generated by one of the arm differs a little with the corresponding mode of the other, at the fundamental and higher-order modes. As a result, the bandwidths at both of the resonant modes are significantly enhanced simultaneously. The proposed antenna has a dimension of 5 x 15 x 40 mm^3 and fully covers the cellular and 3G bands. The antenna shows fairly good omni-directional radiation patterns and high gains at all the operating frequencies. Design considerations of the antenna are described in detail and results for a fabricated prototype antenna are discussed in the paper.

2. Antenna Design

The configuration of the proposed antenna is shown in Fig. 1, where a ground plane of 40 x 70 mm^2 is assumed. The antenna consists of two folded radiation arms and a common short-pin, as shown in Fig. 2. This antenna can be easily fabricated from a planar structure. The two arms are made of metal films and are placed parallel to each other with a separation *S* of 5 mm. The total clearance of the antenna including the 3-mm gap from the ground plane is 15 mm. Meandering structure is applied to the two arms with different location for compactness and frequency control.

Both of the arms can support a fundamental resonant mode at around the AMPS/GSM bands and a higher-order mode at the DCS/PCS/UMTS bands when they are used separately. An enlarged short-pin is commonly used by the two arms for broadening the bandwidth of the higher-order mode [6]. Frequency spacing control between the fundamental and higher-order modes of each arm is realized by changing the meandering location on the arm. Fig. 3 shows four types of arms with different meandering location and Fig. 4 shows their input characteristics. It is seen that while the frequency of the fundamental mode is invariant as the overall length is kept constant, the frequency spacing varies as the location changes: the more the meanders are located on the upper part, the larger the spacing becomes.

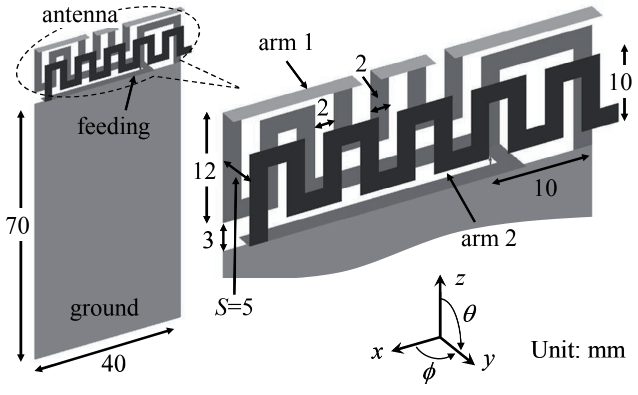

Fig. 1. Configuration of proposed antenna.

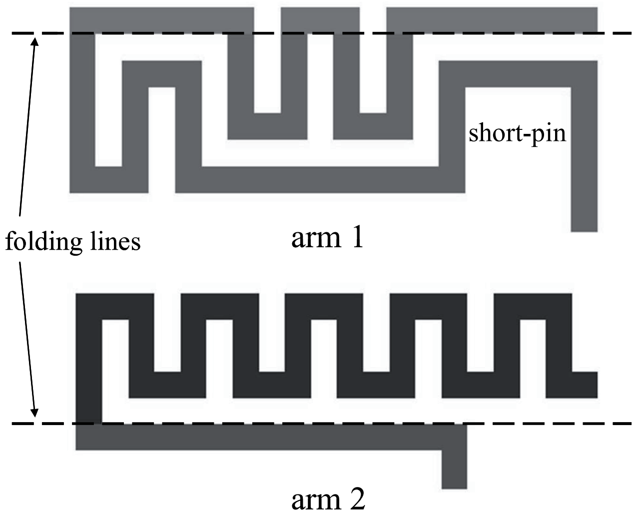

Fig. 2. Unfolded radiation arms.

On the other hand, it turns out that the bandwidth of the antenna with a single arm is not enough to cover the five bands, especially the AMPS and GSM bands. In order to fully cover the five bands, we use two radiation arms and superimpose them in accordance of the following steps:

- First, choosing the length of arm 1 to be longer than that of arm 2 so as the resonant frequency of the fundamental mode of the arm 1 is lower than that of the arm 2.
- Then letting the structure of the arm 1 differs with that of the arm 2 so as the resonant frequency of the higher-order mode of the arm 1 is lower than that of the arm 2.

Specifically, the dimension of the arm 1 is slightly increased and that of the arm 2 is slightly diminished from the original, respectively, and the type 2 structure in Fig. 3 is applied to the arm 1 and the type 1 for the arm 2. In this manner, the frequency of a resonant mode generated by one of the arm shifts a little from the corresponding one of the other, for both of the fundamental and higher-order modes and the bandwidths of both modes can be significantly broadened.

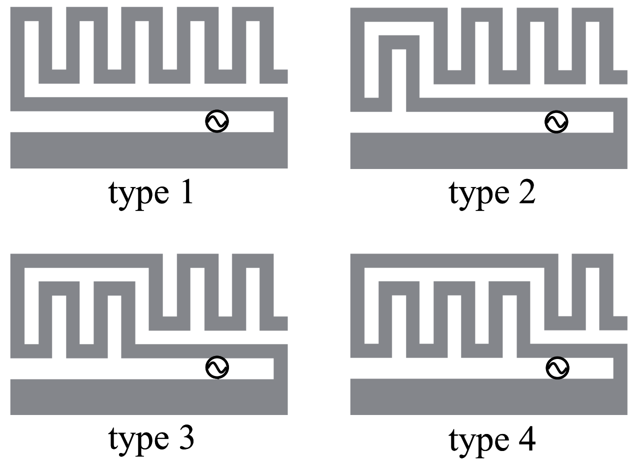

Fig. 3. Antennas with different meanderings.

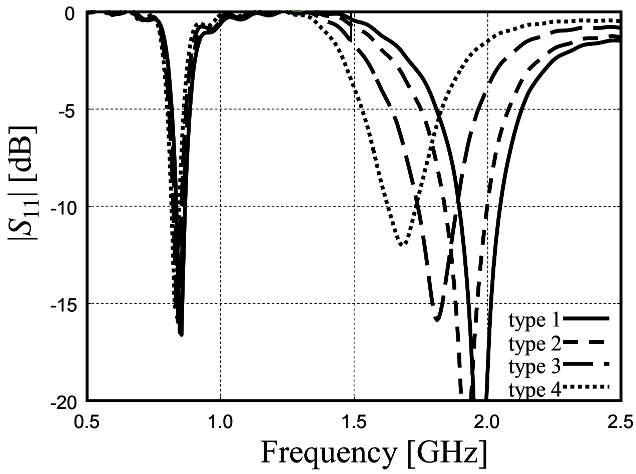

Fig. 4. Input characteristics for different meanderings.

When the two arms are superimposed as in Fig. 1, the input characteristics can be approximated by a parallel circuit shown in Fig. 5, where Z_1 and Z_2 denote the radiation impedance of the arm 1 and 2, respectively, by ignoring the coupling between the arms.

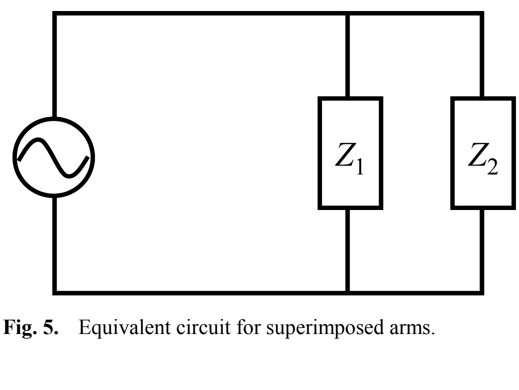

Fig. 5. Equivalent circuit for superimposed arms.

Fig. 6 shows the calculated input characteristics for the individual arm 1, arm 2 and superimposed arms, based on a FDTD simulation, along with a result obtained by the equivalent circuit. Although the result obtained by the circuit differs with the FDTD calculation at the fundamental mode due to a strong coupling, it agrees well at the higher-order mode. It is shown that the resonant frequencies of the arm 1 differ a little with those of the arm 2 and the bandwidth of the superimposed arms is significantly enhanced at the two resonant modes. The feasibility of our design concept is confirmed.

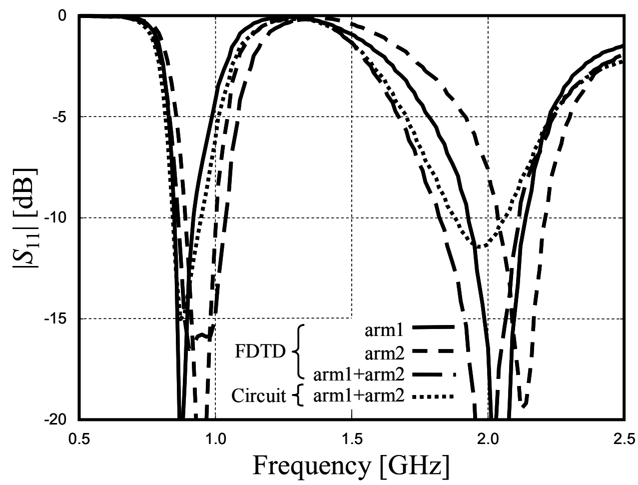

Fig. 6. Calculated input characteristics for different arms.

It is desirable to decrease the separation S between the two arms as far as possible. However, when S is too small, the coupling between the two arms will become too strong and this diminishes the effect of the bandwidth enhancement. As a parameter study, Fig. 7 shows the calculated input characteristics for several different separations. It is shown that the bandwidth of the fundamental mode decreases significantly when S is 2 mm. Minimum separation is 3 mm for covering all the five bands.

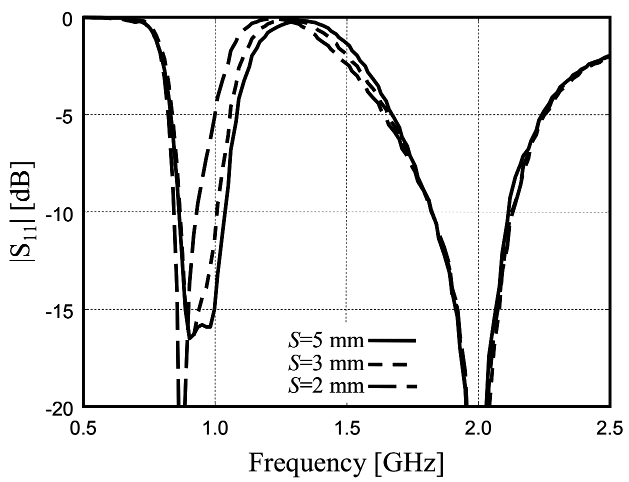

Fig. 7. Calculated input characteristics for different separations.

3. Experimental Results

A prototype antenna is fabricated for measurement, as shown in Fig. 8. A semi-rigid coaxial cable with a length of 100 mm and a diameter of 1.3 mm is used for feeding. Fig. 9 shows the measured input characteristics for different arms and agrees well with the results in Fig. 6.

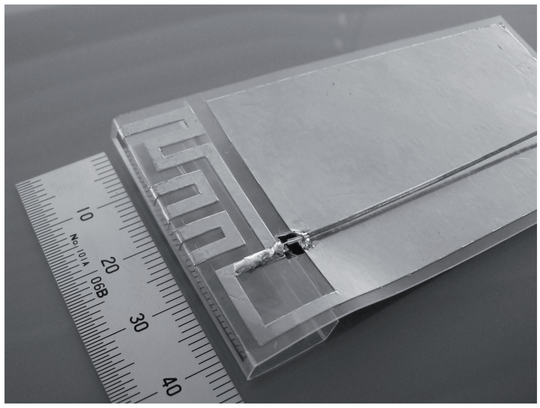

Fig. 8. Fabricated prototype antenna.

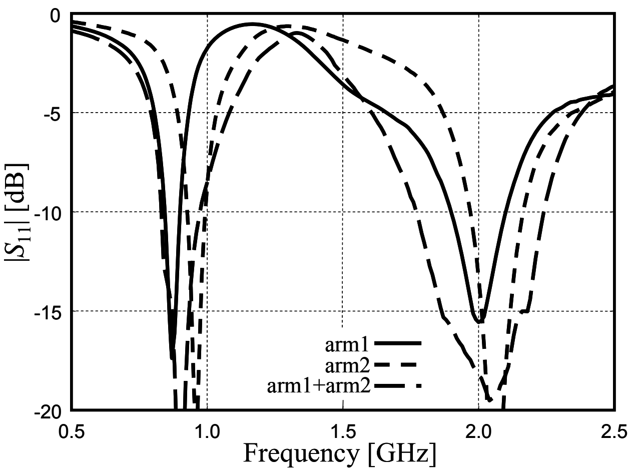

Fig. 9. Measured input characteristics for different arms.

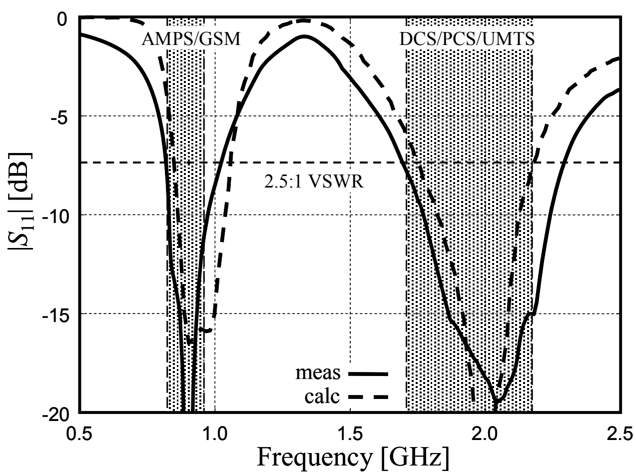

Fig. 10. Input characteristics for prototype antenna.

Fig. 10 compares the measurement with the calculation for the fabricated antenna. The antenna covers five bands of AMPS, GSM, DCS, PCS and UMTS for a 2.5:1 VSWR, which is a higher bandwidth standard for practical mobile phone applications. The bandwidth for the fundamental and higher-order modes is 22% and 29%, respectively. Fig. 11 shows the total radiation efficiency which includes mismatching for the prototype antenna, where the measurement is done by using the Wheeler cap method [7]. The radiation efficiency is larger than 65% in the operating frequencies.

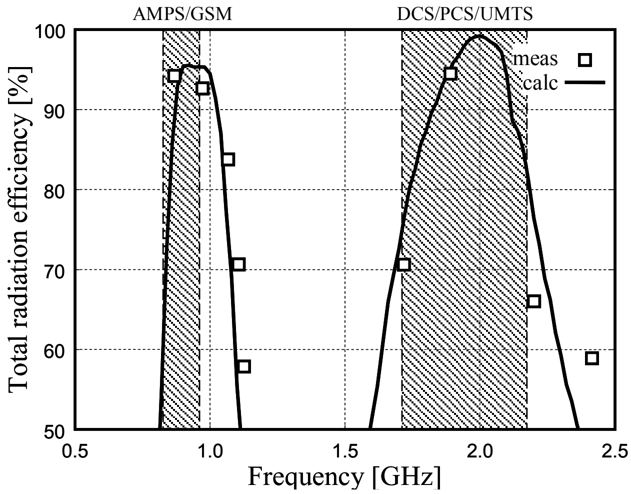

Fig. 11. Radiation efficiency for prototype antenna.

Figs. 12 and 13 show the radiation patterns for the antenna at 0.92 and 1.92 GHz, respectively. Good agreement between the measurement and the calculation is obtained. Fig. 14 shows the measured radiation patterns for total field in the *xy*-plane at the center frequencies of all the bands and fairly good omni-directional patterns are observed at all the frequencies. The average gain in the *xy*-plane is 1.8, 1.8, 1.9, 0.9, 0.8 dBi at 0.86, 0.92, 1.795, 1.92, 2.045 GHz, respectively.

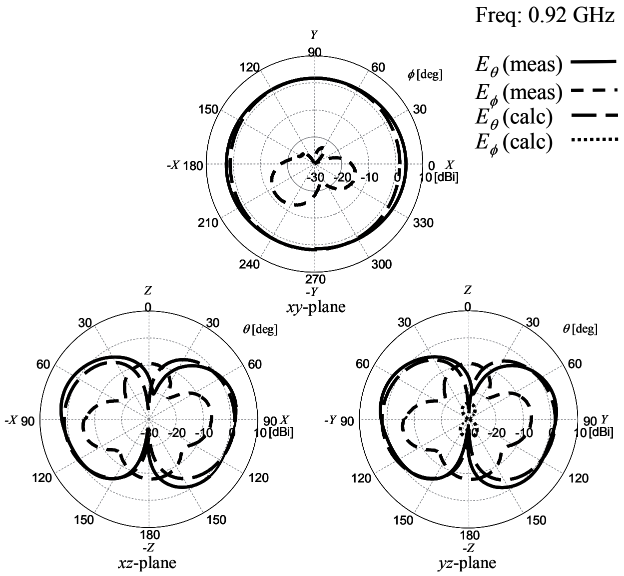

Fig. 12. Radiation patterns at 0.92 GHz.

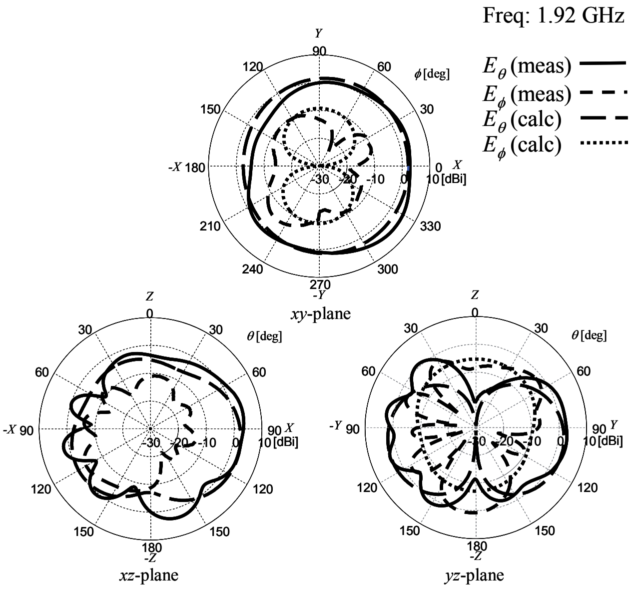

Fig. 13. Radiation patterns at 1.92 GHz.

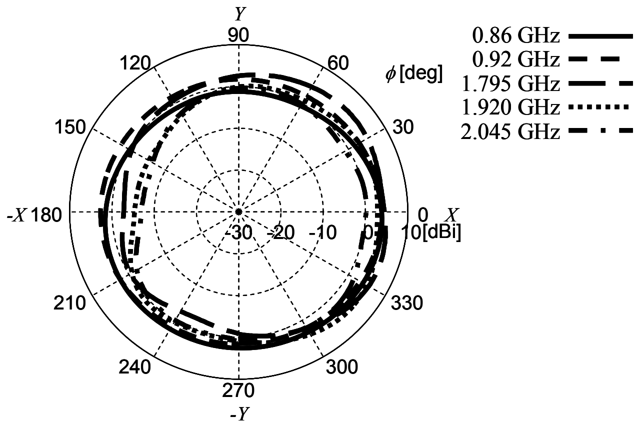

Fig. 14. Measured radiation patterns in *xy*-plane.

4. Conclusion

We have proposed a film antenna that consists of two radiation arms. The bandwidth of the antenna is significantly enhanced by shifting the resonant frequencies of the two arms a little from each other. The antenna has a compact dimension of 5 x 15 x 40 mm^3 and covers the AMPS, GSM, DCS, PCS and UMTS bands. It shows fairly good omni-directional radiation patterns and high average gains at all the bands of interest. The film structure of the antenna is suitable for application in the modern mobile phones.

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Ning GUAN was born in Hunan, China, in 1962. He received the B.E., M.E. and Ph.D. degrees in electrical and electronics engineering from Chiba University, Chiba, Japan, in 1985, 1987, and 1990, respectively. From 1991 to 2000, he was a Research Associate at the Department of Electronics and Mechanical Engineering, Chiba University, studying on magnetostatic wave devices, theory of propagation of electromagnetic waves and applications of wavelet to boundary value problems in electromagnetic theory. Since 2000, he joined the Optics and Electronics Laboratory, Fujikura Ltd. His current research interests include analysis and design of optical fibers and optical devices for telecommunications, microwave devices and antennas for mobile communications. Dr. Guan is a member of the IEEE and the IEICE of Japan.

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