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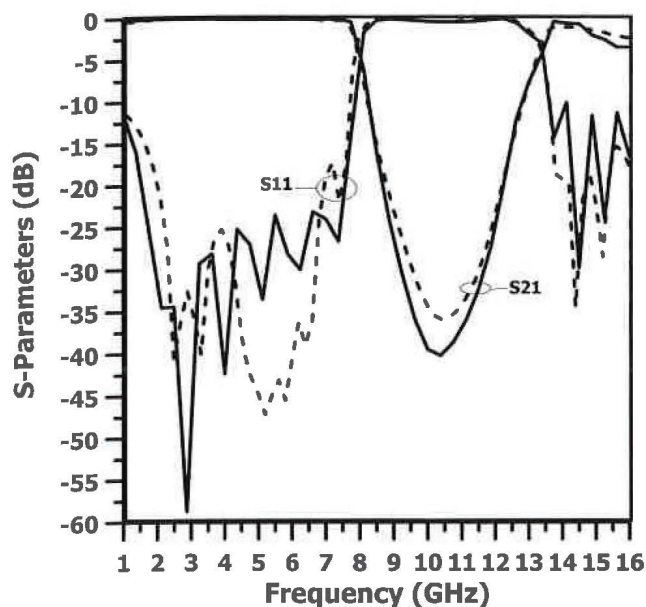


Figure 2 S parameter versus frequency for different radii of the circular PBG lines, Type 1. Solid lines, $r_1 = 56$ mils; dotted lines, $r_1 = 84$ mils, $a = 224$ mils, linewidth 24 mils (50Ω). Dielectric substrate: $\epsilon_r = 10.2$, $h = 25$ mils.

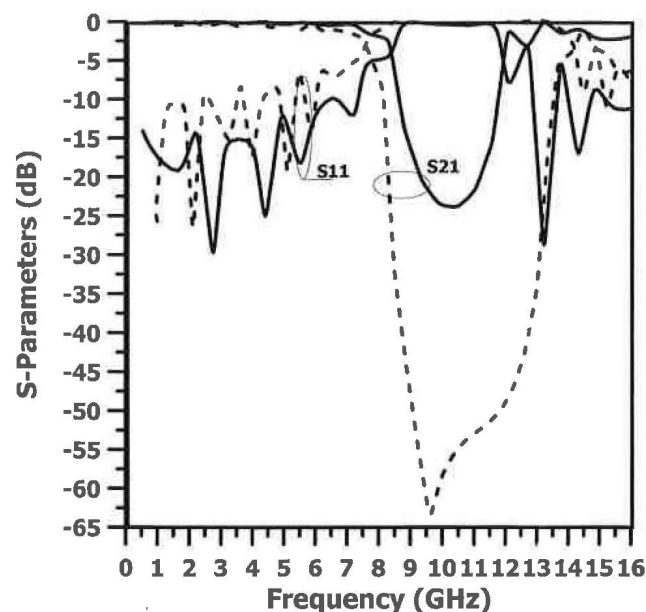


Figure 3 S parameter versus frequency for a 10-element circular-patterned PBG line with Chebyshev distribution with $r_1 = 84$ mils, $a = 224$ mils, and linewidth 24 mils (50Ω). Dielectric substrate: $\epsilon_r = 10.2$, $h = 25$ mils. Solid line, 25 dB; dotted line, 35 dB.

(r), called Type 1; and (b) polynomial coefficient amplitude $\propto$ the area of the PBG circle (πr^2), called Type 2. The investigations are carried out with the two types of PBG configurations with circular patterns, and the respective results are given in Section 4.

The center frequency of the stopband is calculated approximately with the following expression:

$$\beta a = \pi, \quad (4)$$

where a is the period of the PBG pattern and β is the wave number in the dielectric slab. β is defined by expression (5):

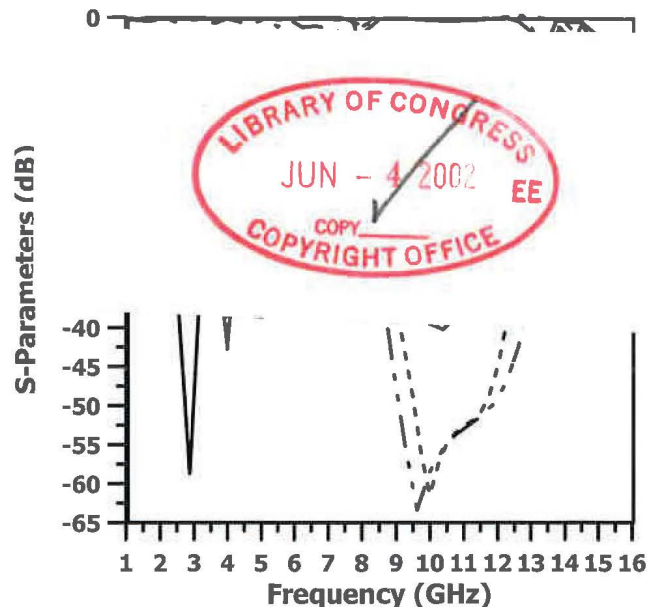


Figure 4 S parameters versus frequency for a 10-element circular-patterned PBG line with 25-dB side-lobe level Chebyshev distribution with $r_1 = 84$ mils, $a = 224$ mils, and linewidth 24 mils (50Ω). Dielectric substrate: $\epsilon_r = 10.2$, $h = 25$ mils. Solid line, Chebyshev (Type 1); dotted line, Chebyshev (Type 2), dot-dashed line, uniform distribution.

$$\beta = \frac{2\pi f_0}{c} \sqrt{\epsilon_e}, \quad (5)$$

where f_0 is the center frequency of the stopband, ϵ_e is the effective relative permittivity of the dielectric slab, and c is the speed of light in free space.

With the use of expressions (4) and (5), the period for any stopband frequency can be determined. For N -element PBG patterns, the n th element's location from the center of the PBG period can be derived from the following equation:

$$d_n = \begin{cases} \frac{2n-1}{2} a, & \text{for even } N, \\ (n-1)a, & \text{for odd } N. \end{cases} \quad (6)$$

Figure 1(b) shows such distribution for even N .

4. RESULTS

The present work uses RT/Duroid 3010 with $\epsilon_r = 10.2$ and thickness $h = 25$ mils. The center frequency is selected at 10 GHz and the period $a = 224$ mils. Based on the design parameters, the Chebyshev distributions of PBG patterns have been designed and analyzed. The PBG structures are simulated with the method-of-moments-based software tool Zeland IE3D. The following subsections present the results of the dispersion characteristics in terms of S parameters versus frequency for (i) uniform, and (ii) Chebyshev distributions.

4.1. Uniform 1-D Microstrip PBG. Figure 2 shows the S parameters versus frequency for two different filling factors $r/a = 0.25$ ($r = 56$ mils) and $r/a = 0.375$ ($r = 84$ mils) for the uniform distribution of circular patterns with a period of 224 mils. As can be seen in the figure, the filling factor plays important role in determining the rejection bandwidth. For $r = 56$ mils (solid lines), the 20-dB (S_{21}) rejection bandwidth is 1.89 GHz, whereas for $r =$

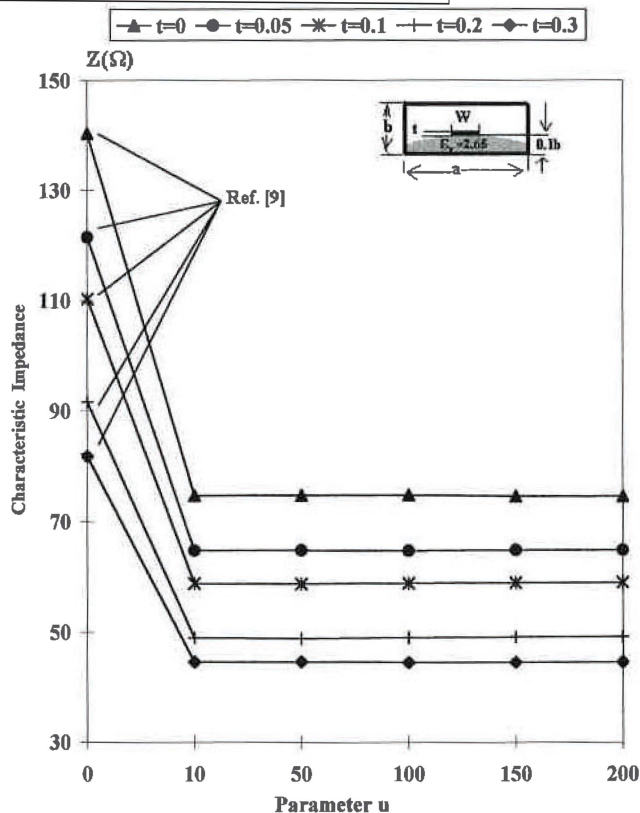


Figure 6 Variation of the static characteristic impedance versus u for different values of (t)

where the parameter u allows control of the shape of the microstrip interface (Figure 3).

Figures 4 and 5 show, respectively, the variation of the characteristic impedance (Z_L), the effective dielectric constant ($\epsilon_{r, \text{eff}, \text{stat}}$), the normalized capacitance (C/ϵ_0) and inductance (L/μ_0) as a function of the shape of the dielectric layer determined by the parameter u [3] considering: $\epsilon_{r1} = 10.185$, $\epsilon_{r2} = 1$, $W = 0.01$ mm, $b = 0.5$ mm, and $t = 0$. Comparison with [7] and [8] also shows good agreement for $u = 0$.

Table 1 shows the characteristic impedance (Z_L) of microstrip lines for $u = 0$ with different combinations of thickness t and width w of the conductor strip. Comparisons were made with Nan-Chang and Tan [9], Ivanov and Djankov [10], and Honma and Fukai [11]. The relative error made in neglecting t in [9] and [10] can reach 1.6%. Good agreement was found for all calculations.

The variation of the characteristic impedance (Z_L) for different values of strip metallization thickness, as a function of u for microstriplines with varying thickness enclosed in a rectangular waveguide, is depicted in Figure 6, with $\epsilon_{r1} = 2.65$, $\epsilon_{r2} = 1$, $W = 0.02$ mm, and $a = b = 1$ mm. It is clearly seen from these curves that Z_L decreases as t increases. Again, these results agree well with those from [9] when $u = 0$.

IV. CONCLUSIONS

In this article the method of lines is extended to the quasi-static analysis of microstrip lines printed on dielectric layers with arbitrarily varying thickness considering zero and finite metallization thickness. Our results show good agreement with data available in the literature.

Furthermore, these results are obtained with substantially smaller computational effort (CPU time and memory) with the use of these equidistant discretization lines. The advantages of the

method of lines are shorter computer time, applicability to many different structures, and high accuracy.

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PLANAR MONOPOLE FOLDED INTO A COMPACT STRUCTURE FOR VERY-LOW-PROFILE MULTIBAND MOBILE-PHONE ANTENNA

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ABSTRACT: A planar monopole consisting of three branch strips and folded into a rectangular-box-like compact structure for very-low-profile GSM/DCS/PCS multiband mobile-phone antennas is presented. The three branch strips are designed to operate as quarter-wavelength structures at 900, 1800, and 1900 MHz, respectively, and the obtained impedance bandwidths cover the required bandwidths of the GSM band (890–960 MHz), the DCS band (1710–1880 MHz), and the PCS band (1850–1990 MHz). The proposed antenna has a compact size of 6.5 mm in height, 6 mm in width, and 25 mm in length, and can be mounted on top of a mobile phone with a small distance of 3 mm to the ground plane, resulting in a very low profile of 9.5 mm (less than 3% of the wavelength at 900 MHz) from ground for the proposed antenna in practical applications. © 2002 Wiley Periodicals, Inc. *Microwave Opt Technol Lett* 33: 22–25, 2002; DOI 10.1002/mop.10219

Key words: planar monopole antennas; mobile-phone antennas; folded planar monopole antennas

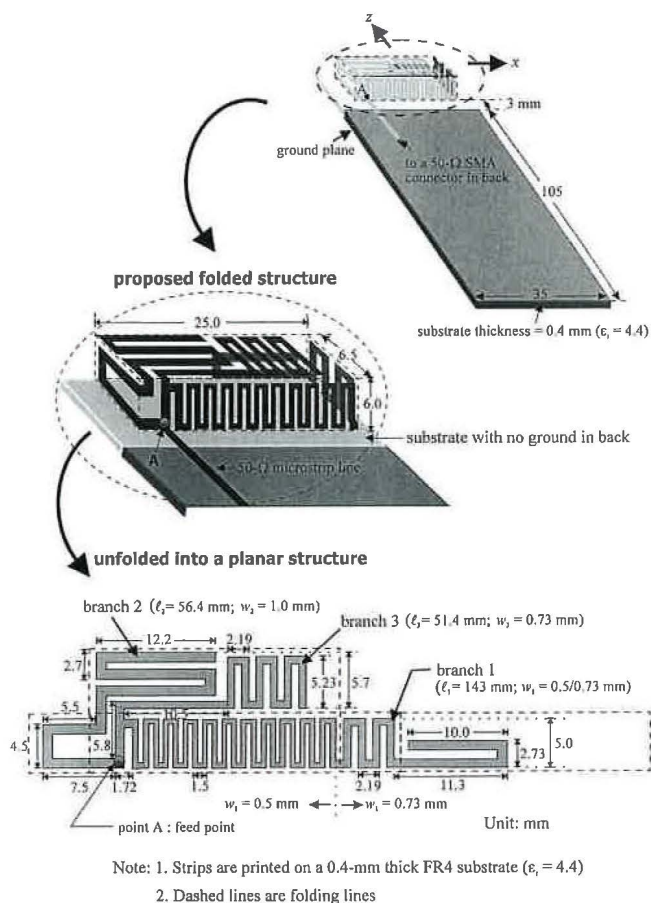


Figure 1 Proposed planar monopole folded into a compact structure for multiband mobile phone antennas

1. INTRODUCTION

Planar monopole antennas with a low profile are very attractive for mobile-phone antenna applications. Recently, a dual-band planar monopole antenna design, capable of operating in the GSM (890–960 MHz) and DCS (1710–1880 MHz) bands has been reported [1]. This design is a two-dimensional structure, and is obtained by modifying the folded loop antenna reported in [2]. Its antenna height, however, is greater than 10% of the free-space wavelength at 900 MHz, which makes it less attractive to be employed in mobile phones that demand protruded monopole antennas with a profile as low as possible.

This Letter presents a novel very-low-profile design of a planar monopole antenna consisting of three branch strips and folded into a rectangular-box-like compact structure for applications in multiband mobile phones for GSM (890–960 MHz), DCS (1710–1880 MHz), and PCS (1850–1990 MHz) operations. The proposed antenna is first printed on a thin FR4 substrate and then folded into a three-dimensional structure like a rectangular box to achieve a much-reduced antenna height (6.5 mm only or about 2% of the wavelength at 900 MHz). Details of the proposed antenna design are described in this Letter, and experimental results of the proposed antenna are presented and discussed.

2. ANTENNA DESIGN

Figure 1 shows the proposed planar monopole folded into a rectangular-box-like compact structure for multiband mobile phone antennas. The design dimensions are given in the unfolded planar structure, whose optimal dimensions are obtained with the aid of the commercially available simulation software Ansoft HFSS

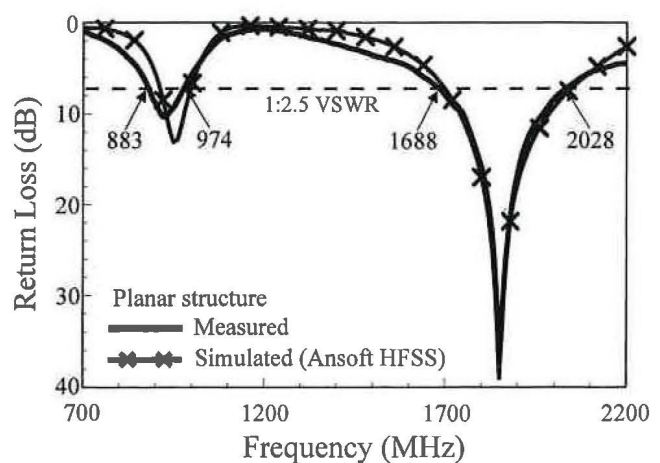


Figure 2 Measured and simulated return loss versus frequency for the proposed monopole antenna unfolded into a planar structure

(high-frequency structure simulator). The proposed monopole consists of three branch strips: Branches 1–3 shown in Figure 1. The three branches are all printed on a thin (0.4 mm) FR4 substrate, and then, by following the dashed lines shown in the figure, folded into a compact structure like a rectangular box. Branch 1 is mainly for generating a resonant mode at about 900 MHz for GSM operation. Notice that, starting from Point A (the feed point), the strip length (ℓ_1) of Branch 1 is 143 mm (about 0.43 wavelength at 900 MHz), which is meandered in the proposed design to achieve a compact structure, and owing to the coupling effect between two adjacent or nearby meandered sections, the effective electrical length will be less than the physical length. This is the reason that the strip length of Branch 1 is larger than the required 0.25 wavelength. Also notice that, at the portion close to the end of Branch 1, the strip width (0.73 mm) is designed to be larger than the other portion (0.5 mm), which is helpful in achieving a wider impedance bandwidth (> 70 MHz) for the 900-MHz band.

Branch 2 is designed for operating at about 1800 MHz for DCS band, and its strip length (ℓ_2) is 56.4 mm (about 0.34 wavelength at 1800 MHz). Branch 3 is for operating at about 1900 MHz for PCS band, and has a strip length (ℓ_3) of 51.4 mm (about 0.32 wavelength at 1900 MHz). Notice that the strip lengths of Branches 2 and 3 are closer to 0.25 wavelength than that of Branch 1, which is largely because less-meandered sections are in

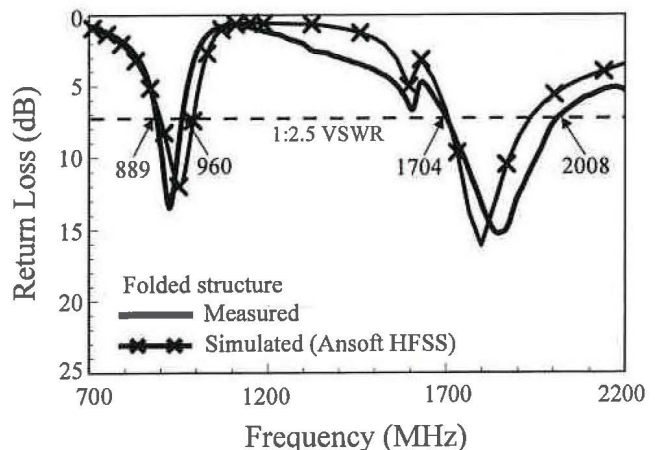


Figure 3 Measured and simulated return loss versus frequency for the proposed monopole antenna in a folded compact structure

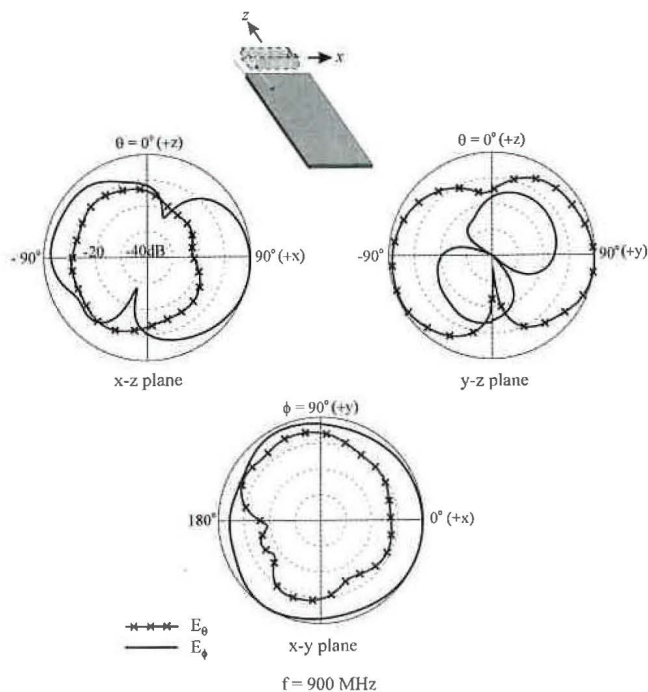


Figure 4 Measured radiation patterns for the proposed antenna at 900 MHz

Branches 2 and 3; thus the coupling effect in reducing the effective electrical length is relatively smaller. Through the combined excitation of Branches 1 and 2, an upper band centered at about 1850 MHz with a wide bandwidth of about 300 MHz covering the DCS and PCS bands can be obtained.

For experimental studies, the proposed antenna is mounted on the top portion of an FR4 substrate (thickness 0.4 mm and relative permittivity 4.4), which can be considered as the circuit board of a practical mobile handset. Notice that the top portion has no

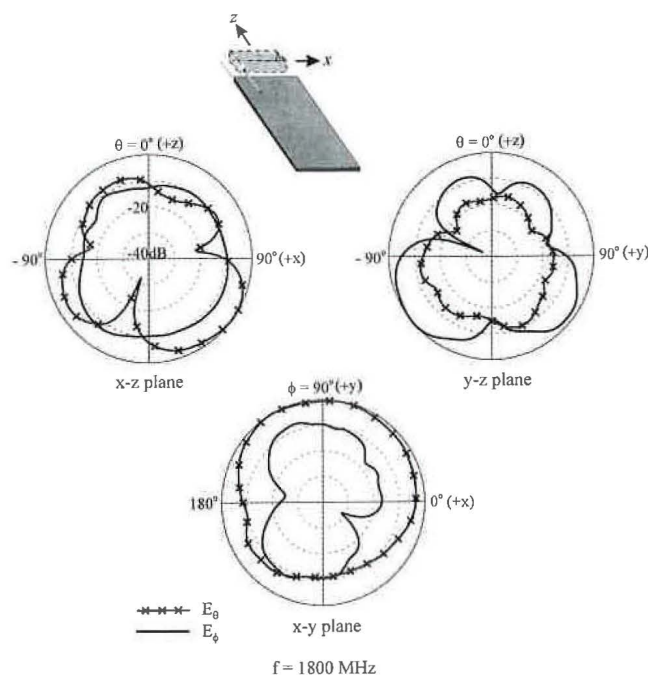


Figure 5 Measured radiation patterns for the proposed antenna at 1800 MHz

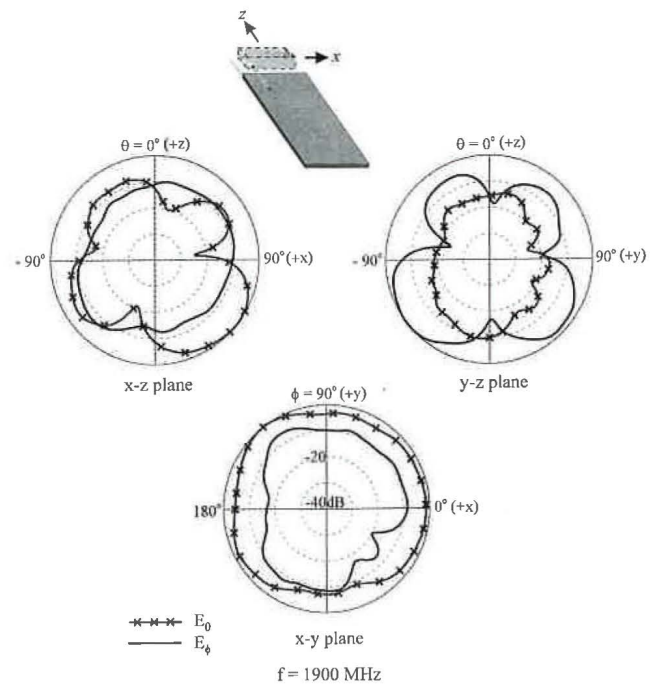


Figure 6 Measured radiation patterns for the proposed antenna at 1900 MHz

ground plane in back, and the proposed antenna should be placed at a minimum distance of 3 mm away from the other portion with a ground plane in back (see the figure), which has dimensions of $35 \times 105 \text{ mm}^2$. The proposed antenna can then be easily fed at Point A with the use of a 50- Ω microstripline printed on the FR4 substrate. In the experiment, the microstripline was further connected to a 50- Ω SMA connector placed in the ground-plane side of the FR4 substrate.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed antenna has been successfully constructed. Figure 2 shows the measured and simulated return loss against frequency for the proposed monopole antenna unfolded into a planar structure, and the results for the proposed monopole antenna in a folded compact structure are shown in Figure 3. It is first seen that good agreement between the measurement and the simulation is obtained, and some deviations between the measured data and the simulated results in Figure 3 are largely due to the construction errors. In addition, it is seen that there are slight variations in the obtained impedance bandwidths for the proposed antennas in planar and folded structures. From the obtained results in Figure 3, the lower band has a bandwidth (1:2.5 VSWR) of 889–960 MHz, covering the required GSM band. For the upper band, a bandwidth of 1704–2008 MHz is obtained, which covers the required DCS and PCS bandwidths.

Radiation characteristics have also been studied. Measured radiation patterns for the proposed antenna at 900, 1800, and 1900 MHz are presented in Figures 4–6, respectively. The radiation patterns at 900 MHz are close to those of a simple monopole antenna. On the other hand, no prominent differences between the radiation patterns at 1800 and 1900 MHz are seen. Measurements at other operating frequencies also show similar radiation patterns as shown. This suggests that the radiation patterns are stable in the upper band for DCS and PCS operations; so are the radiation patterns in the lower band for GSM operation. However, in the azimuthal plane (x-y plane), the radiation pattern at 1900 MHz is

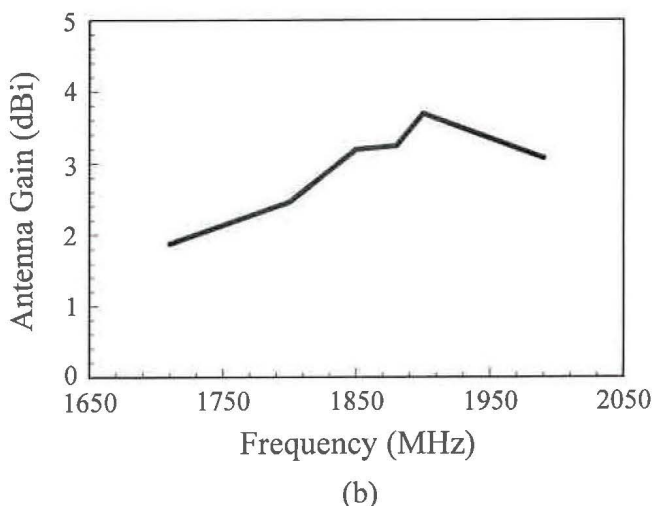
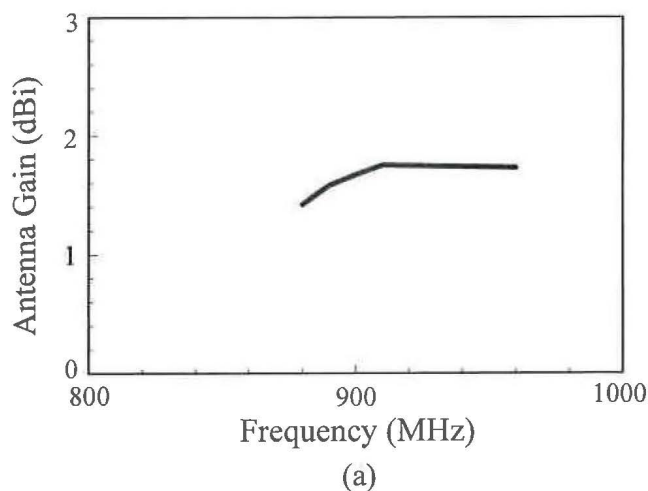


Figure 7 Measured antenna gain for the proposed antenna. (a) The GSM band (890–960 MHz). (b) The DCS (1710–1880 MHz) and PCS (1850–1990 MHz) bands

more like omnidirectional radiation than that at 1800 MHz. Measured antenna gain for the proposed antenna in the lower band for GSM operation and in the upper band for DCS and PCS operations is shown in Figures 7(a) and 7(b), respectively. The antenna gain is about 1.4–1.7 dBi for the operating frequencies in the GSM band; for the DCS and PCS operations the antenna gain ranges from about 1.9 to 3.6 dBi.

4. CONCLUSIONS

A very-low-profile planar monopole antenna suitable for applications in GSM/DCS/PCS multiband mobile phones has been proposed and implemented. The proposed antenna is folded into a rectangular-box-like structure and has a compact size of dimensions $6.5 \times 6 \times 25 \text{ mm}^3$. With the inclusion of a 3-mm distance from the ground plane in practical applications, the proposed antenna has a very low profile of 9.5 mm only (less than 3% of the wavelength at 900 MHz).

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A MODEL FOR THE NUMBER OF INDEPENDENT SAMPLES IN REVERBERATION CHAMBERS

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ABSTRACT: Antenna efficiency measurements in reverberation chambers are done by averaging a number of sampled power levels, measured while the mode stirrer rotates. The number of independent samples is the number of stirrer positions that give uncorrelated fields in the chamber, and thereby uncorrelated power levels. A larger number of samples gives a better accuracy of the measured value. This report presents a proposed theoretical model for the number of independent samples of a reverberation chamber, thereby giving a better understanding of how to optimize a chamber design. Measured data from chambers with three different types of stirrers are compared with the use of the model. © 2002 Wiley Periodicals, Inc. *Microwave Opt Technol Lett* 33: 25–28, 2002; DOI 10.1002/mop.10220

Key words: reverberation chamber; mode stirred chamber; multimode chamber; mode stirring

1. INTRODUCTION

A reverberation chamber (RC) measurement gives the efficiency of the antenna under test by the average received power over all stirrer positions. The accuracy of the value depends on how many stirrer positions there are that give uncorrelated fields in the chamber. Even if the stirrer is moved continuously, there is still a limited number of stirrer positions that give uncorrelated fields. This number is called the number of independent samples N_{ind} . A high N_{ind} is always desired. Today, RC mode-stirrer design is to some extent based on previous experience, but unfortunately also contains some guesswork. In order to design an optimal RC, specifically the stirrer, it would be good to know what affects N_{ind} and how. In order to determine the accuracy of the RC measurements, N_{ind} is usually calculated after each measurement. This is a more complex analysis than finding the average power. A better understanding of what affects N_{ind} might reveal relations from which N_{ind} can be concluded without extra calculations. This study aims to find a theoretical model that improves the understanding of what lies behind the value of N_{ind} in a specific chamber, with a specific stirrer.

2. THEORETICAL MODEL

A crude model is derived, based on chamber volume V and some equivalent stirrer volume V_s . Chamber volume is easily measured. It is more difficult to define the stirrer volume V_s , but here it is taken as the smallest cylinder within which the stirrer fits. It can of course be defined in other ways as well. Because of the arbitrary definition of stirrer volume, absolute relations are not used to begin with, but rather proportionalities. Later on the constant of propor-