Miniaturized microstrip cross-coupled bandpass filter using novel stepped impedance resonators with a desirable upper stopband

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wave frequencies, Science DOI: 10.1126/science 1133628, October 2006.
10. M. Gokkavas, K. Guven, I. Bulu, K. Aydin, R.S. Pnciu, M. Kafesaki, C.M. Soukoulis, and E. Ozbay, Experimental demonstration of a left-handed metamaterial operating at 100 GHz, Phys Rev B 73 (2006), 1–4. 193103.
11. D. Wu, N. Fang, C. Sun, X. Zhang, W.J. Padilla, D.N. Basov, D.R. Smith, and S. Schultz, Terahertz plasmonic high pass filter, Appl Phys Lett 83 (2003), 201–203.
12. N. Engheta, A. Salandrino, and A. Alù, Circuit elements at optical frequencies: Nanoinductors, nanocapacitors, and nanoresistors, Phys Rev Lett 95 (2006), 1–4. 095504.
13. J. García-García, F. Martín, J.D. Baena, R. Marqués, and L. Jelinek, On the resonances and polarizabilities of split rings resonators, J Appl Phys 98 (2005), 033103.
14. R. Marques, F. Medina, and R. Rafii-El-Idrisi, Role of bianisotropy in negative permeability and left-handed metamaterials, Phys Rev B 65 (2002).
15. J.D Baena, L. Jelinek, R. Marques, and J. Zehentner, Electrically small isotropic three-dimensional magnetic resonators for metamaterial desing, Appl Phys Lett 88 (2006), 134108–1-3.
16. J. García-García, J. Bonache, I. Gil, F. Martín, M.C. Velazquez-Ahumada, and J. Martel, Miniaturized microstrip and CPW filters using coupled metamaterial resonators, IEEE Trans Microwave Theory Tech 54 (2006), 2628–2635.
17. J.-S. Hong and M.L. Lancaster, Microstrip filters for RF/microwave applications, Wiley, New York, 2001.
18. J.D. Baena, R. Marqués, F. Medina, and J. Martel, Artificial magnetic metamaterial design by using spiral resonators, Phys Rev B 69 (2004), 014402–1-5.
19. F. Falcone, F. Martín, J. Bonache, M.A.G. Laso, J. García-García, J.D. Baena, R. Marqués, and M. Sorolla, Stop band and band pass characteristics in coplanar waveguides coupled to spiral resonators, Microwave Opt Technol Lett 42 (2004), 386–388.
20. F. Aznar, J. García-García, J. Bonache, M. Gil, and F. Martín, Metamaterial transmission lines based on broadside coupled spiral resonators (BC-SRs), Electron Lett 43 (2007), 530–532.
21. K.B. Alici, F. Bilotti, L. Vegni, and E. Ozbay, Miniaturized negative permeability materials, Appl Phys Lett 91 (2007), 071121–1-3.
22. R. Marqués, F. Mesa, J. Martel, and F. Medina, Comparative analysis of edge and broadside coupled split ring resonators for metamaterial design: theory and Experiment, IEEE Trans Antenna Propagat 51 (2003), 2572–2581.
23. F. Martín, F. Falcone, J. Bonache, R. Marqués, and M. Sorolla, Split ring resonator based left handed coplanar waveguide, Appl Phys Lett 83 (2003), 4652–4654.

MINIATURIZED MICROSTRIP CROSS-COUPLED BANDPASS FILTER USING NOVEL STEPPED IMPEDANCE RESONATORS WITH A DESIRABLE UPPER STOPBAND

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ABSTRACT: *A miniaturized microstrip cross-coupling bandpass filter using new stepped impedance resonators (SIRs) with simultaneous suppression of the 2nd harmonic passband response is presented. Four improved and miniaturized SIRs constitute the compact filter, which exhibits a sharp transition band due to two transmission zeros at both sides of the passband. Two quarter-wavelength open-ended stub resonators are applied to provide extra transmission zeros for suppressing the 2nd harmonic passband. A bandpass filter with a center frequency at 2.5 GHz was designed and fabricated, of which experimental results validated the proposed filter design.* © 2008 Wiley Periodicals, Inc.
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Key words: *microstrip bandpass filter; cross-coupling; harmonic suppression; miniaturization; stepped-impedance resonator*

1. INTRODUCTION

In modern wireless communication systems, high-selectivity small-size microstrip bandpass filters with excellent out-of-band rejections are required to enhance the system performance and reduce the fabrication cost. To obtain a sharp transition band, one effective method is to introduce two transmission zeros and locate them at either side of the passband, respectively. Cross-coupled configurations, which exhibit elliptic function-like responses [1], are suitable and commonly applied.

Conventional microstrip bandpass filters are designed with half-wavelength or quarter-wavelength resonators. To reduce filter size, cross-coupled filters using folded half-wavelength hairpin resonators were developed [2]. Stepped impedance resonators have attracted much attention due to their controllable first spurious passband [3, 4]. With modified stepped impedance hairpin resonators, those microstrip filters were more compact and had better stopband extensions [5].

The planar bandpass filters made of resonators inherently have the spurious passbands at multiple of the center frequency, which limit the upper stopbands. Many methods have been proposed to solve the problem, such as providing different electric length for even and odd modes [6], using uniplanar compact electric bandgap (EBG) structure [7] or defected ground structure (DGS) [8], creating transmission zeros by open-ended stub resonators [9], and so on.

In this letter, we propose a novel miniaturized microstrip filter structure that is suitable for realizing the high selectivity and suppressing the 2nd harmonic passband. In the design, four improved folded half-wavelength hairpin SIRs are placed as a two-by-two array to achieve the cross-coupling. Therefore, the cross-coupled capacitance is introduced directly between two adjacent resonators with two transmission zeros introduced. In addition, two quarter-wavelength open-ended stubs are attached at the edges of the resonators in the main-coupling path. One extra transmission zero is introduced at the first harmonic frequency. A compact high-selectivity bandpass filter at 2.5 GHz with harmonic suppression is optimally designed, fabricated, and measured.

2. RESONATOR AND FILTER DESIGN

Figure 1 shows layout of the proposed filter. Four symmetric basic resonators are placed oppositely to each other and form a four-square contour. Tapped-line input/output ports are connected to two resonators, in which the distance between the feed point and the resonator center is L_c. The resonator consists of two triangular patches connected to both ends of a high impedance microstrip line section, which is bent three times to reduce circuit area. The resonator is an improved variation of the SIR with square-shape as well. The main coupling principle is identical to the hairpin SIR's. The SIR section is used in each element, of which the size is adjustable with the relevant impedance ratio [10].

Figure 2 shows the equivalent circuit of the proposed filter. In each resonator, the distributed inductance L_1 and L_2 are formed by

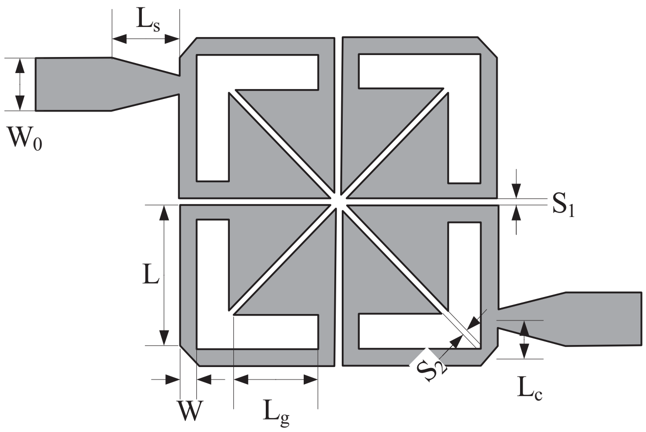

Figure 1 Layout of the novel bandpass filter using proposed resonators

meandered high impedance microstrip line, and one pair of low impedance triangular patches provides distributed capacitance C_3 to ground. Meanwhile, inside each resonator the coupling capacitance C_2, which makes the resonant frequency lower, is formed from the gap S_2 between those two triangular capacitive patches. On the other hand, the coupling capacitance C_1 between resonators is formed by the adjacent pairs of patches belonging to two neighboring resonators with gap S_1. Thus, two transmission zeros closed to the passband are created based on the cross-coupling mechanism. An elliptic function-like frequency response is obtained in the bandpass filter. It must be mentioned that the positions of the input/output tapped lines affect the frequencies of those two transmission zeros. Therefore, the bandwidth of passband can be adjusted to realize the high selectivity by properly choosing the length L_c. On the other hand, the decrease of the gap S_1 between two adjacent resonators enhances coupling capacitance and increases bandwidth.

A bandpass filter has been designed by the proposed method at the fundamental resonant frequency of 2.5 GHz. It is fabricated on a 1-mm thick substrate with a relative dielectric constant of 2.65. The whole filter occupies 18 mm × 18 mm. The width W_0 of feed lines is 2.73 mm to make the characteristic impedance equal to 50 Ω. Other dimensions of the bandpass filter are as following: tapped line length $L_s = 4$ mm; width $W = 0.9$ mm, and length $L = 7.65$ mm for high impedance segments, and $L_g = 4.7$ mm for low

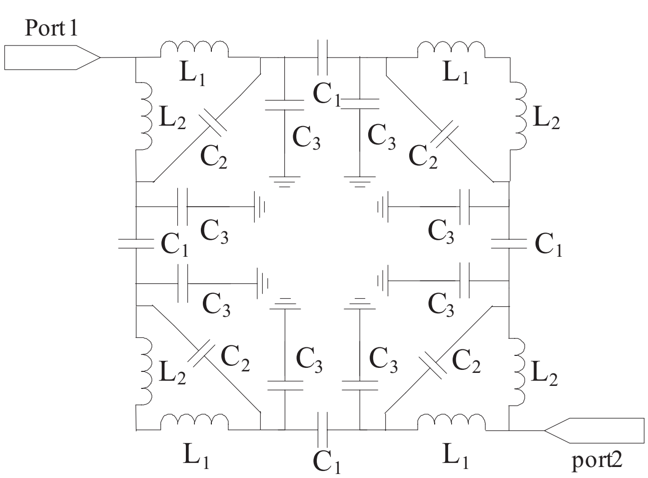

Figure 2 The equivalent circuit of the novel bandpass filter

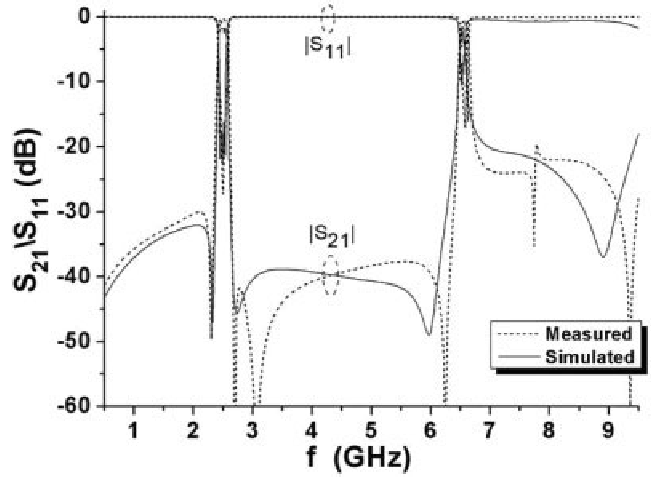

Figure 3 Simulated and measured frequency responses of the bandpass filter

impedance segments; the coupling gaps $S_1 = 0.4$ mm and $S_2 = 0.5$ mm; the feed position offset from the resonator vertex $L_c = 2$ mm.

The simulation was accomplished with an electromagnetic simulator based on the finite element method. Measurements were carried out on an Agilent E8362B vector network analyzer. As shown in Figure 3, the measured results are consistent with the simulated results. At the center frequency 2.5 GHz, the fabricated filter has a narrow passband and exhibits a sharp transition band. Two transmission zeros closed to the passband have been realized at 2.28 and 2.66 GHz, respectively. The 3-dB bandwidth is about 5%. However, there is an unwanted harmonic passband at 6.6 GHz.

3. HARMONIC SUPPRESION

The 2nd harmonic passband at 6.6 GHz of the fabricated filter can be suppressed to obtain a desirable upper stopband attenuation characteristic. Quarter-wavelength open-ended stub resonators, which create transmission zeros at relevant resonant frequencies [11], are applied to suppress the harmonic. In this letter, two transmission zeros are tuned around the 2nd harmonic frequency

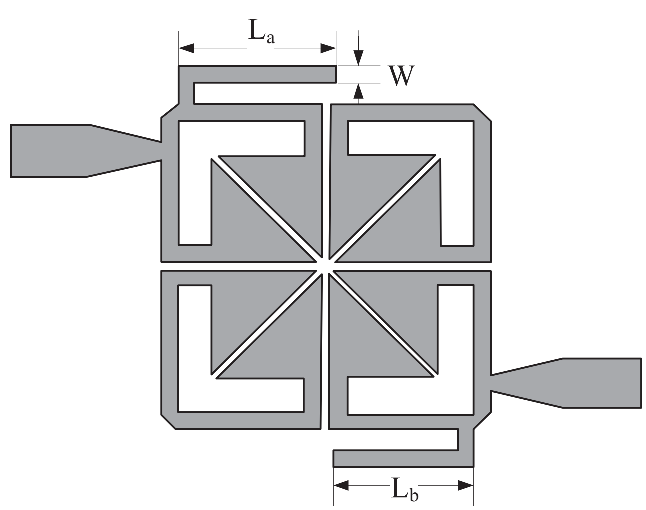

Figure 4 Layout of the novel filter with suppression of harmonic passband

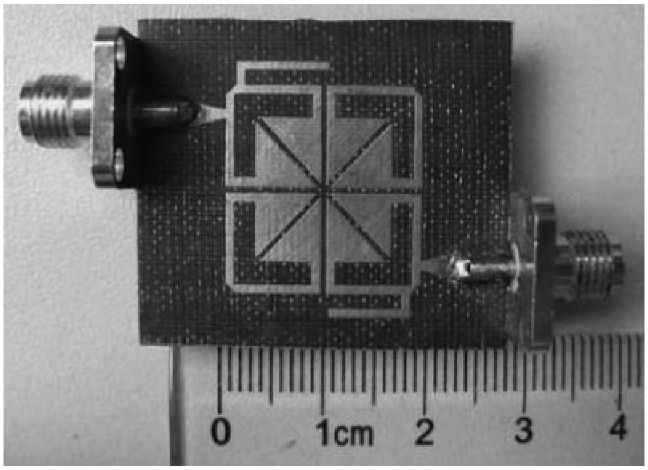

Figure 5 Photograph of the fabricated microstrip bandpass filter

by adjusting the stub lengths. Figure 4 shows the layout of the improved bandpass filter. Two microstrip stubs are placed at the vertexes of resonators connecting the feed lines and are bent to obtain a more compact structure. There is no additional complexity in fabrication for the improved bandpass filter.

With the above design dimensions and substrate material in Section 2, a new filter is fabricated with two open-end stubs connected to input/output resonators, as shown in Figure 5. An open-ended stub, which is about quarter wavelength length at the harmonic frequency 6.6 GHz, is attached to the top-left resonator; another one, which is about quarter wavelength at 7.2 GHz, is attached to the bottom-right resonator. The length of the stubs are $L_a = 8.4$ mm, $L_b = 7.4$ mm, respectively, and the width is $W = 0.9$ mm. As a result, the whole filter occupies 18 mm $\times$ 22 mm, which is only slightly larger than previous bandpass filter.

Figure 6 shows the simulated and measured frequency responses of the filter. The measured results show that the 2nd harmonic passband is suppressed below -27 dB and the stopband with more than 25 dB attenuation is extended to 8.2 GHz. There is no noticeable change in the main passband of the bandpass filter. As shown in Figure 7, the filter has a 3-dB bandwidth of 5.2% approximately. Two transmission zeros closed to the passband have been realized at 2.33 and 2.72 GHz with the attenuations higher than 40 dB. Additionally, the third and fourth transmission

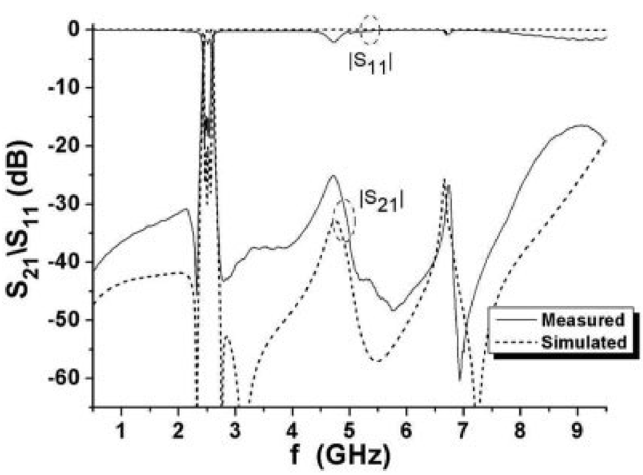

Figure 6 Measured and simulated results of the proposed filter in wide-band frequency responses

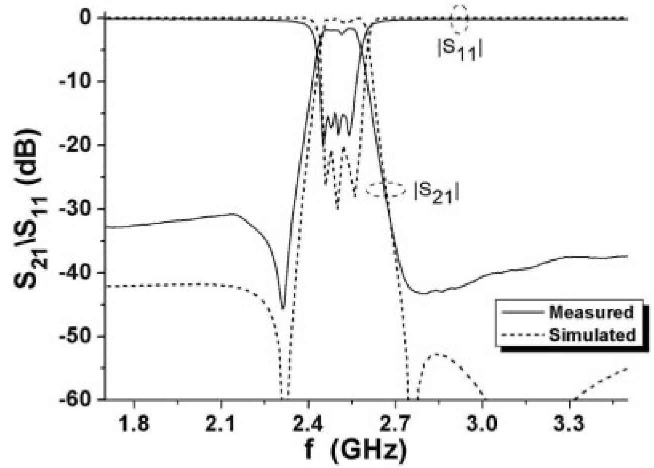

Figure 7 Measured and simulated results of the proposed filter in narrow-band frequency responses

zeros are possibly located at 5.7 and 6.7 GHz, respectively, with attenuations higher than 45 dB. The passband insertion loss is about 1.6 dB from 2.46 to 2.55 GHz. Miniaturization of resonators is usually accompanied with increase of insertion losses [12]. The effects of the conductor loss, the dielectric loss, and the microstrip to coaxial line transition have not been fully modeled in simulations, which lead to higher insertion loss in measurements.

4. CONCLUSION

A miniaturized cross-coupled microstrip bandpass filter using novel stepped impedance resonators with desirable upper stopband characteristic is presented. The proposed resonator is compact and exhibits favorable electrical characteristics. A sharp transition band is achieved from the cross-coupled configuration. Moreover, the harmonic suppression is obtained using two stub resonators. The passband filter is designed at center frequency 2.5 GHz. Good agreements between simulated and measured results are achieved. The proposed method is suitable for realizations of compact high-selectivity microstrip bandpass filters.

REFERENCES

1. S.H. Jang and J.C. Lee, Design of novel cross-coupling elliptic function filters with the miniaturized edge-coupled split ring resonators, Microwave Opt Technol Lett 45 (2005), 495–499.
2. S.Y. Lee and C.-M. Tsai, New cross-coupled filter design using improved hairpin resonators, IEEE Trans Microwave Theory Tech 48 (2000), 2482–2490.
3. M. Sagawa, M. Makimoto, and S. Yamashita, Geometrical structures and fundamental characteristics of microwave stepped-impedance resonators, IEEE Trans Microwave Theory Tech 45 (1997), 1078–1085.
4. M.L. Her, M.W. Hsu, Y.D. Wu, W. Ko, and C.J. Hsu, A wide rejection bandwidth bandpass filter with stepped impedance hairpin resonator and interlaced coupled-line, Microwave Opt Technol Lett 49 (2007), 542–545.
5. Y.W. Chen and M.H. Ho, Stepped impedance hairpin design of a tunable bandpass filter with harmonic suppression, Microwave Opt Technol Lett 48 (2006), 697–701.
6. J.T. Kuo, W.H. Hsu, and W.T. Huang, Parallel coupled microstrip filters with suppression of harmonic response, IEEE Microwave Wireless Compon Lett 12 (2002), 383–385.
7. F.R. Yang, K.P. Ma, Y. Qian, and T. Itoh, A uniplanar compact photonic-bandgap (UC-PBG) structure and its applications for microwave circuits, IEEE Trans Microwave Theory Tech 47 (1999), 1509–1514.
8. J.H. Cho and J.C. Lee, Microstrip stepped-impedance hairpin resona-

tor low-pass filter with defected ground structure, Microwave Opt Technol Lett 48 (2006), 405–408.
9. X.Y. Zhang, Q. Xue, and B.J. Hu, Novel bandpass filter with size reduction and harmonic suppression, Microwave Opt Technol Lett 49 (2007), 914–916.
10. F.H. Guan, J.Z. Gu, and X.W. Sun, A bandpass filter with harmonic suppression using SIR and zigzag coupling, Microwave Opt Technol Lett 49 (2007), 2071–2074.
11. J.R. Lee, J.H. Cho, and S.-W Yun, New compact bandpass filter using microstrip λ/4 resonators with open stub inverter, IEEE Microwave Guided Wave Lett 10 (2000), 526–527.
12. J.T. Kuo, and C.Y. Tsai, Periodic stepped-impedance ring resonator (PSIRR) bandpass filter with a miniaturized area and desirable upper stopband characteristics, IEEE Trans Microwave Theory Tech 54 (2006), 117–1112.

INTERNAL MULTIBAND SURFACE-MOUNT MONOPOLE SLOT CHIP ANTENNA FOR MOBILE PHONE APPLICATION

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ABSTRACT: *A multiband monopole slot chip antenna surface-mountable on the system circuit board of the mobile phone is presented. The antenna comprises two monopole slots of different lengths, which are folded and attached onto a foam base in the study. With a compact volume of 30 × 10 × 8 mm^3 (2.4 cm^3), the antenna can generate a lower band at about 900 MHz to cover GSM operation and a very wide upper band (bandwidth >1 GHz) to cover DCS/PCS/UMTS operation and 2.4 GHz WLAN operation. It is also promising to use a ceramic base of relative permittivity 7.8 to replace the foam base of the antenna. In this case, the antenna volume can be reduced to be 24 × 10 × 8 mm^3 (1.92 cm^3) only, yet still capable of covering GSM/DCS/PCS/UMTS quad-band operation. The proposed antenna is studied, and obtained results are presented and discussed.* © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 50: 1273–1279, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.23342

Key words: *surface-mount chip antennas; internal mobile phone antennas; monopole; slot antennas; quarter-wavelength slot antennas; multiband antennas*

1. INTRODUCTION

In recent years, promising monopole chip antennas surface-mountable on the system circuit board for mobile phone applications have been reported [1–7]. These monopole chip antennas mainly comprise a dielectric base and metal strips printed on or embedded within the base. The dielectric bases such as the ceramic, plastic, and foam bases have been applied. For this kind of chip antennas, the metal strips are the main resonant or radiating portion, and it is usually not easy to achieve wide operating bandwidths at about 900 and 1800 MHz to cover multiband operation such as GSM (890 ~ 960 MHz), DCS (1710 ~ 1880 MHz), PCS (1850 ~ 1990 MHz), and UMTS (1920 ~ 2170 MHz) for mobile communications [8]. In this article, we demonstrate a novel promising monopole chip antenna using the monopole slot or quarter-wavelength slot as the main resonant element, which is different from the operating principle of the conventional monopole chip antenna [1–7], to generate two wide operating bands at about 900 and 1800 MHz for multiband operation.

The monopole slot antenna is obtained by cutting the printed slot at the edge of the ground plane [9–16]. With comparison to the general slot antenna that is operated as a half-wavelength resonant structure [17–20], the monopole slot antenna has an attractive feature of compact in size for a fixed operating frequency. The promising designs of the monopole slot antenna printed on the system circuit board of the mobile phone for multiband mobile communications have also been devised recently [14, 16]; they can be printed either at the center portion [14] or the top portion [16] of the system circuit board. When printed at the center portion, the monopole slot antenna is easy to provide sufficient bandwidth and efficiency to cover the multiband operation, because in this case maximum coupling to the low-Q chassis dipole type resonance can be obtained [14]. However, this design will also complicate the circuit floor planning and signal line routing on the system circuit board. When printed at the top portion, the reported monopole slot antenna [16] occupies an area of 15 × 40 mm^2 (6 cm^2) on the system circuit board and can cover the desired multiband operation.

In this study, the proposed surface-mount monopole slot chip antenna is to be placed at the top portion of the system circuit board. The antenna comprises two monopole slots of different lengths, which are folded and attached onto a foam base of area 10 × 30 mm^2 and height 8 mm. The proposed antenna thus occupies a much smaller valuable board space than that of the printed monopole slot antenna in [16] (3 cm^2 vs. 6 cm^2). Moreover, the proposed antenna also provides wide operating bands covering GSM/DCS/PCS/UMTS and 2.4 GHz WLAN (2400 ~ 2484 MHz) operation. Detailed design considerations of the antenna are described in the article, and results for the constructed prototype with a foam base are presented. Effects of various parameters on the antenna performances are analyzed. The promising design of using a ceramic base of relative permittivity 7.8 to replace the foam base of the antenna is also discussed. In this case, the occupied area of the monopole slot chip antenna on the system circuit board can be further reduced.

2. DESIGN CONSIDERATIONS OF PROPOSED ANTENNA

Figure 1(a) shows the geometry of the proposed surface-mount monopole slot chip antenna for the mobile phone. The antenna is to be surface-mounted at the top no-ground region (size 10 × 40 mm^2) of the system circuit board, which can reduce the packaging cost of the mobile phone. In the study, a 0.8-mm thick FR4 substrate of size 90 × 40 mm^2 is used to be considered as the system circuit board. On the front side of the circuit board, there is a printed ground plane of length 80 mm and width 40 mm. These dimensions are reasonable for practical mobile phones. Notice that when the antenna is mounted at the no-ground region, the antenna is grounded to the top edge of the ground plane at point A (the grounding point). The antenna does not occupy the whole no-ground region. It is to be flushed to the left edge of the circuit board, thus leaving an unoccupied area of 10 × 10 mm^2, which can be used to accommodate the associated electronic components such as the speaker, the lens of the embedded digital camera [21, 22], etc.

The antenna with its metal pattern folded and attached on the surfaces of a foam base (size 30 × 10 × 8 mm^3), whose relative permittivity is about that of air, is first studied. From the unfolded metal pattern shown in Figure 1(b), the antenna can be considered