A Quasi-Planar Miniature Broadband Antenna

RongLin Li, Joy Laskar, and Manos M. Tentzeris

Georgia Electronic Design Center
School of Electrical and Computer Engineering
Georgia Institute of Technology, Atlanta, GA 30332-0250
E-mail: rlli@ece.gatech.edu

INTRODUCTION

The antenna size is one of the main concerns in the design of mobile terminals for wireless applications, such as cellular phones, Bluetooth devices, and WLAN (wireless local area network) handsets (e.g., palm handhelds, pocket PCs, laptop computers, and PDAs) [1]. Numerous low-profile miniature antennas have been developed since last decades [2]-[6]. On the other hand, the demand for broadband antennas is becoming strong as nowadays wireless handhelds are required to possess a function of multi-mode/multi-band operations. The first generation cellular mobile communication systems around the world operate near the 1 GHz band with a bandwidth of more than 20% (i.e., AMPS 824-894 MHz in North America, GSP 880-960 MHz in Europe, and PDC 810-915 MHz in Japan). The second generation and future mobile communication systems, such as the emerging third generation systems or beyond [7], are allocated the frequency bands around 2 GHz (i.e., PCS 1850-1990 MHz, DCS 1710-1880 MHz, PHS 1895-1918 MHz, and UMTS 1920-2170 MHz). In addition to cellular mobile communications, the Bluetooth and WLAN systems may operate in the 2.4 GHz ISM band (2.400-2.485 GHz) [8]. This results in a total bandwidth requirement of near 40% around the 2 GHz band. In this paper, we develop a simple antenna structure whose bandwidth is more than 40% while its maximum size is only $0.12\lambda_0$. Also, this miniature antenna has quite high radiation efficiency. In addition, this antenna has a quasi planar structure; hence it is easy to integrate on a printed circuit board (PCB).

ANTENNA CONFIGURATION

The Configuration of the proposed miniature antenna is illustrated in Fig. 1. This antenna has been designed at 1 GHz band based on an RT/Duroid 5880 substrate which has a dielectric constant of ε_r=2.2 and a thickness of 20 mils (0.508 mm). The antenna consists of two perpendicular planar boards (see Fig. 1a). The vertical part could be part of the PCB substrate of most wireless devices, while the horizontal one could serve as a plug-in chip, maintaining a very low fabrication profile suitable for internal installation of antennas in nowadays wireless handhelds. For cellular phone applications, we choose the width of antenna to be 36 mm (<40 mm) and the height of the horizontal chip as 8 mm (<10 mm). The vertical board with a total length of 50 mm is shared by two components: one is a part of the antenna and the other is the microstrip feed line. The length on the vertical board occupied by the antenna is indicated by L_a which has a critical effect on the broadband performance as will be demonstrated in the next section. The vertical board is two-side patterned. On the backside, there is an open rectangular strip-line loop ABCDEF that is connected at C (the middle of the side BD) to the ground plane G by a short strip line (see Fig. 1b). On the front side of the vertical board, we can see a 50-ohms microstrip feed line HI, which is extended to point J and a folded strip line IKLM (see Fig. 1c). The width of all strip lines on the vertical board is 1.5 mm, which is determined by the width of the 50-ohms microstrip line on this board. The horizontal chip is single-side patterned with a double-T (NOPQR and NOST) feeding structure and a folded strip line UVWX (see Fig. 1d). The width of strip lines on the horizontal part is 1.0 mm except for the part NOP whose width was optimized to be 3.0 mm. The vertical board and the horizontal chip are electrically connected at points F-X and M-N respectively. The feed port is defined at the point H. In a practical installation, the antenna part in the vertical board can be processed as a part of printed RF circuits while the horizontal chip can be inserted onto the PCB with a plug-in slot.

The described antenna can be considered as a folded monopole (formed by GCDEF+XWVU) fed through electromagnetic coupling from a double-T-shaped structure (NOPQR+NOST). The critical parts of the antenna are the folded monopole GCDEF+XWV and the feeding structure IKLM+NOPQR. Note that the strip line GCDEF serves as part of the folded monopole as well as the ground plane for the feeding line IKLM (i.e. a microstrip line). The extension UV further increases the length of the folded monopole (hence lowering the resonant frequency) while the addition (ST) of the feeding structure is to further enhance the electromagnetic coupling between the folded monopole and the feeding structure. Parts IJ, CBA have no significant effect on the antenna performance, but help in slightly increasing the radiation efficiency.

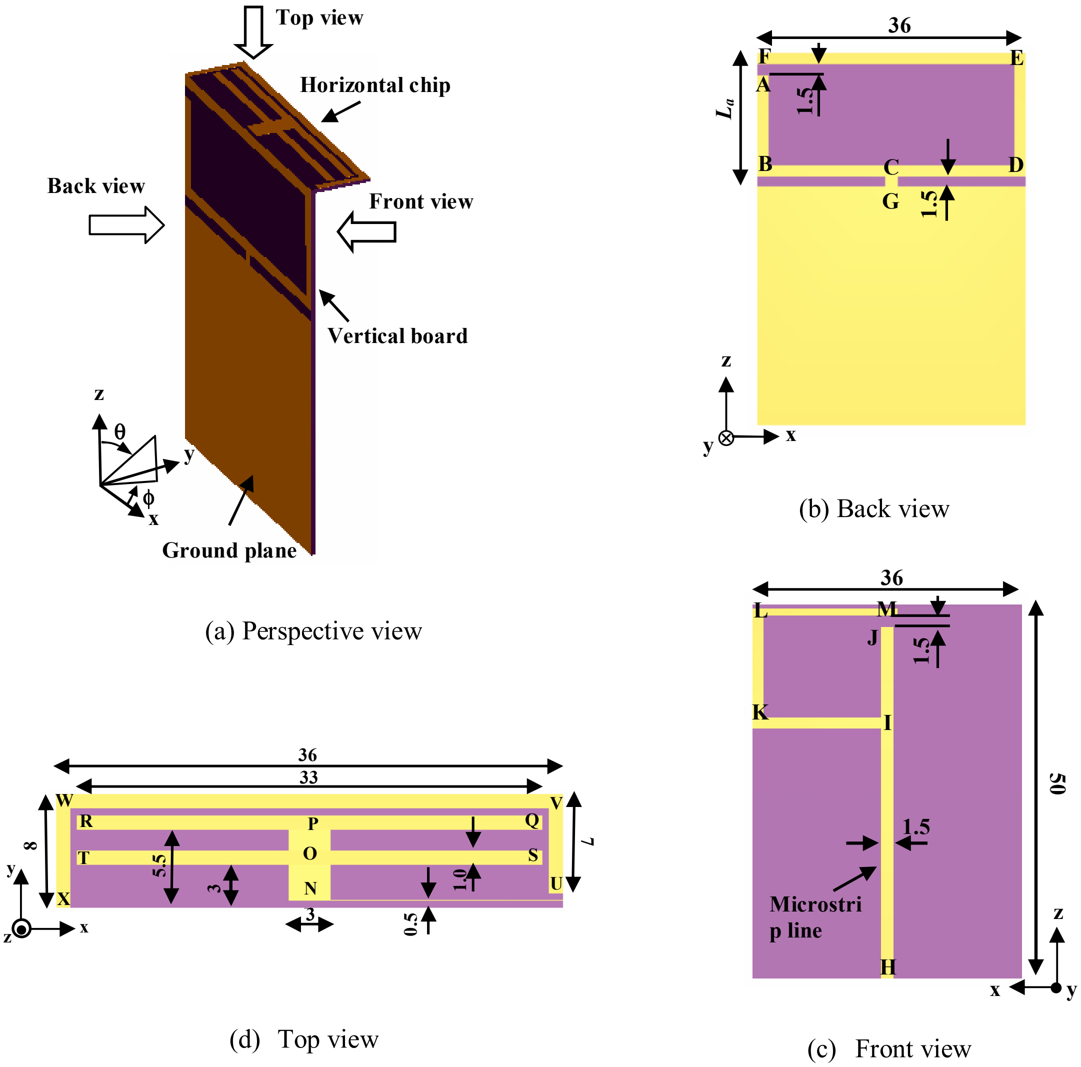


Fig. 1 Configuration of a miniature broadband antenna (unit: mm)

RESULTS

The antenna structure was designed by using the TLM (transmission line matrix) based software–*Microstripes 6.0*. As mentioned before, we have found by simulation that the antenna length L_a on the vertical board plays a critical role in the achievement of broadband performance. Fig. 2 shows the simulation results for VSWR (voltage standing wave ratio) when L_a varies from 14 mm to 20 mm. We can see that as L_a increases, the level of VSWR in the design frequency band decreases. When L_a=18 mm, VSWR reaches 1.6 with a bandwidth of 40% for VSWR<2. As L_a continues increase, the VSWR level does not show further significant decrease but the bandwidth reduces rapidly. Therefore we choose L_a=18 mm as the optimized value. The reason for the L_a dependence of broadband performance is because the antenna part on the vertical board is the major contributor to the radiation fields. As will be shown later, the vertical component (E_θ) of the far-field pattern is dominant. Despite the importance of the vertical part, the horizontal chip of the antenna is also absolutely necessary. The horizontal chip plays the role in two aspects. First it helps in lowering the resonant frequency with the folded strip line XWVU. Secondly it contains a coupling feeding structure (i.e. the double-T feed). Since the strip lines on the horizontal chip radiate far fields with only a horizontal component (E_ϕ) in the horizontal principal plane (i.e. the xy plane), the far-field coupling between the vertical board and the horizontal chip is weak. This is helpful in the increase of radiation power, thus improving the bandwidth performance. It was demonstrated by numerical simulation that there is no way to achieve a broadband performance if printing all strip lines on a fully planar board.

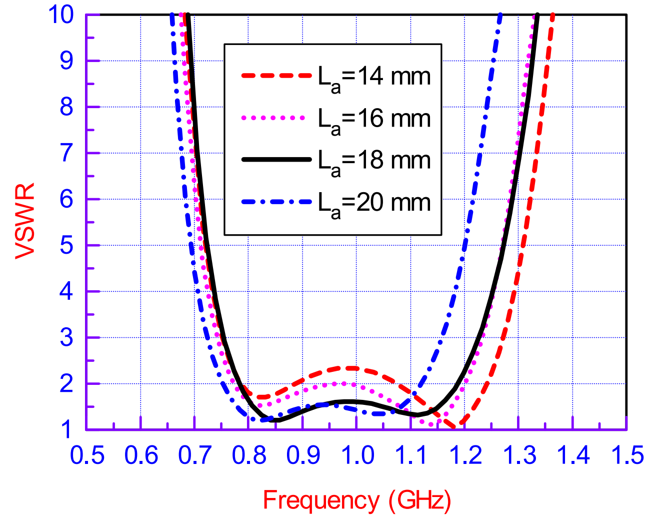


Fig. 2 Dependence of the broadband performance on the antenna length (L_a) on the vertical board

A prototype of the optimized antenna was fabricated. The comparison between the simulated and measured results for the VSWR is shown in Fig. 3 and good agreement is observed. The measured bandwidth is slightly higher than the simulated result. The difference is probably due to two factors: (a) the simulation model and (b) the measurement setup. In the numerical simulation for VSWR, all metal structures (including all strip lines and ground plane) were assumed to be a perfect conductor. In reality, the ohmic loss from these metal structures contributes to the bandwidth increase. During the experiment, on the other hand, we observed that the coaxial cable connecting the antenna for measurement considerably affects the impedance and radiation pattern results due to an induced current flowing in outer conductor of the cable. To alleviate the effect, we employed a quarter-wavelength sleeve choke following the SMA connector for suppressing the current on the feed cable. The quarter-wavelength sleeve choke is bandwidth limited. It may not work well as the frequency shifts away from the center frequency, thus causing the difference between the simulation and measurement results. In the experiment, we also found that the experimental results became more stable when orientating the cable perpendicular to the backside of the vertical board by using a right-angle connector. This is reasonable because such an orientation can reduce the direct coupling between the microstrip feed line and the cable, hence reducing the induced current on the cable. The horizontally orientated connecting cable also avoids the effect of its spurious radiation on the vertically-polarized radiation pattern since a horizontal conductor cannot radiate far fields with vertical polarization.

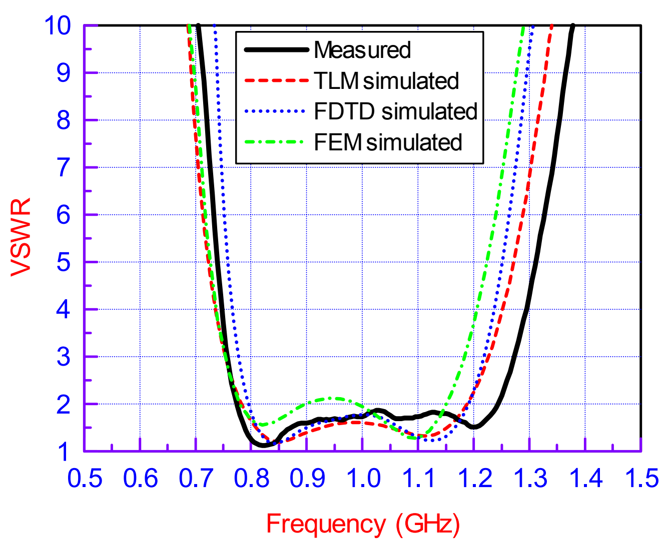
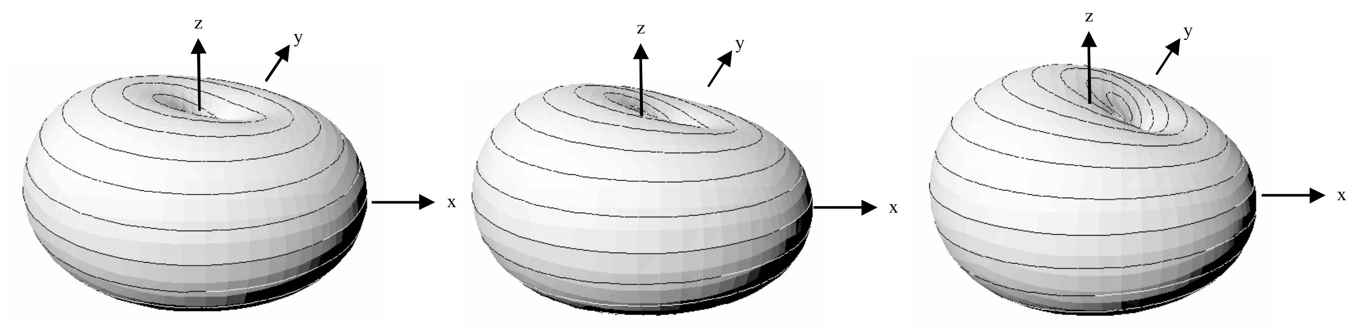


Fig. 3 Comparison of measured and simulated results for the VSWR (L_a=18 mm)

To double check the broadband performance of the proposed antenna, we simulated the structure using two additional simulation tools: the FEM (finite-element method) based software–*HFSS 9.0* and an FDTD (finite-difference time-domain) code developed *in house*. The simulation results are also plotted in Fig. 3. It is noticed that the FDTD-simulated result matches well with that obtained from the TLM simulation because both techniques are the time-domain method based on an orthogonal regular Cartesian lattice. The simulation result from the HFSS shows slightly higher VSWR level and a slightly narrower bandwidth, but still maintains a broadband performance (a bandwidth of near 40%).



(a) At 0.8 GHz (b) At 1.0 GHz (c) At 1.2 GHz

Fig. 4 Radiation patterns of the miniature broadband antenna

Fig. 4 shows the radiation patterns simulated at 0.8, 1.0 and 1.2 GHz. It is seen that the radiation pattern, omni-directional on the horizontal plane, looks very similar to the pattern for a dipole antenna. Also, it can be observed that there is only a small variation for the radiation pattern over this frequency band. The simulated radiation efficiency (σ=5.8×10^7 S/m, tanδ=0.0009) keeps around 90% over the frequency range from 0.85 to 1.2 GHz. The measured gain varies from about 0.5 to1.5 dBi in this frequency range.

CONCLUSION

A new configuration of a miniature broadband antenna has been developed for wireless/mobile applications. The bandwidth of this antenna is more than 40% (VSWR<2) while its size is less than $0.12\lambda_0$. The gain achieved is more than 1 dBi while the radiation efficiency is about 90%. The antenna has an omni-directional radiation pattern on the horizontal plane, suitable for the scenario of mobile communication. Another advantage of the antenna is its quasi-planar structure, which make it easy to fabricate with possible integration with RF front-end circuits. This miniature antenna can be extended to 1.7-2.5 GHz for 2G/3G cellular phones and WLAN devices.

REFERENCES

[1] A. K. Skrivervik, J.-F. Zurcher, O. Staub, and J. R. Mosig, “PCS antenna design: the challenge of miniaturization,” *IEEE Antenna and Propagation Magazine*, vol. 43, no. 4, pp. 12-27, August 2001.
[2] T. K. Lo, C.-O. Ho, Y. Hwang, E.K. W. Lam, and B. Lee, “Miniature aperture-coupled microstrip antenna of very high permittivity,” *Electrons. Lett.*, vol. 33, pp. 9-10, Jan. 1997.
[3] R. B. Waterhouse, S. D. Targonski, and D. M. Kokotoff, “Design and performance of small printed antennas,” *IEEE Trans. Antennas Propagat.*, vol. 46, no. 11, pp. 1629-1633, Nov. 1998.
[4] H. K. Kan and R. B. Waterhouse, “Size reduction technique for shorted patches,” *Electrons. Lett.,* vol. 35, pp. 948-949, June 1999.
[5] K. Noguchi, M. Mizusawa, and S. Betsudan, “Broadbanding of a plate antenna with slits,” *IEEE AP-S International Symposium*, vol. 3, pp. 1662-1665, July 2000.
[6] M.-C. Huynh and W. L. Stutzman, “A low-profile compact multi-resonant antenna for wideband and multi-band personal wireless applications,” *IEEE AP-S International Symposium*, vol. 2, pp. 1879-1882, July 2004.
[7] H. Honkasalo, K. Pehkonen, M. T. Niemi, and A. T. Leino, “WCDMA and WLAN for 3G and beyond,” *IEEE Wireless Communications*, vol. 9, no. 2, pp. 14-18, 2002.
[8] A. Doufexi, S. Armour, M. Butler, A. Nix, D.Bull, J. McGeehan, and P. Karlsson, “A comparison of the HIPERLAN/2 and IEEE 802.11a wireless LAN standards,” *IEEE Communication Magazine*, vol. 40, no. 5, pp. 172 –180, 2002.