Dielectric-Loaded Compact WLAN/WCDMA Antenna With Shorted Loop and Monopole Elements

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***Abstract*—A compact, planar, dielectric-loaded, and multiple-band antenna for 2.45/5-GHz WLAN and 2.1-GHz wideband code-division multiple access (WCDMA) applications is presented in this letter. The antenna has a planar loop element with a shorting pin and a planar monopole element that are printed on the same substrate and driven by a microstrip line. The loop and monopole elements are covered by a thin FR4 layer on top to achieve good impedance matching at both bands. Analysis of the antenna has been realized using extensive 3-D full-wave electromagnetic simulations. Antenna measurements have also been presented, and it is shown that measurements and simulations are in good agreement.**

***Index Terms*—Electromagnetic analysis, multiple-band antennas, wireless LAN.**

I. INTRODUCTION

A DIELECTRIC-LOADED, compact, planar, and multiple-band antenna for 2.45/5-GHz WLAN and 2.1-GHz wideband code-division multiple access (WCDMA) applications is presented in this letter. The antenna includes a loop element with a shorting pin and a monopole element; both are printed on FR4-type low-cost and easily available dielectric substrate. The antenna is driven by a 50-Ω microstrip line. Loop-type antennas are well known in the literature. These include a vertically mounted planar antenna of loop form on a mobile phone printed circuit board (PCB) that operates from about 2.7 to 5.9 GHz [1], a loop antenna for 2.45-GHz WLAN band [2], and a folded monopole/loop antenna for DCS 1.8-GHz band [3]. These antennas have a single loop element to generate the desired band(s). A multiband capacitively loaded loop antenna for mobile handsets has been reported in [4]. However, the radiating element was placed on another substrate above the PCB, and an overlap region was used to realize a capacitive short between the radiating element and the RF ground. This antenna can operate at 2.1-GHz WCDMA and 2.45/5-GHz WLAN bands with 6-dB return-loss specification. The presented antenna has 10-dB return-loss specification, and therefore it has a better impedance-matching property.

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Multielement antennas including loop- and monopole-type elements have been reported for WWAN [5] and WLAN [6] functionality of laptops. The antenna presented in this letter has also been formed by a planar loop and a planar monopole, however 2.1-GHz WCDMA functionality has been added over the 2.45/5-GHz WLAN band. The presented antenna has also been loaded by a thin FR4 layer on top to achieve good impedance matching at both bands. Dielectric loading technique is not new [7], however the integration of loop and monopole elements with a dielectric layer on top of them is a novel technique. Analysis of the antenna was carried out using 3-D full-wave electromagnetic simulations by Ansoft HFSS [8] and CST Microwave Studio [9].

II. ANTENNA DESIGN: S_{11} SIMULATIONS AND MEASUREMENTS

The antenna was built on a 1-mm-thick FR4 substrate whose permittivity and loss tangent are 4.4 and 0.02, respectively. The substrate dimensions are 58×62 mm^2, and the geometry of the antenna is shown in Fig. 1. A photograph of the fabricated antenna is shown in Fig. 2. The antenna radiating element consists of a planar loop and a planar monopole. The loop element is shorted to RF ground through a 1.2-mm-diameter shorting pin. During the simulations, this shorting pin has been implemented as a 1.2-mm-diameter copper cylinder. For the fabricated antenna, an about 1-mm-diameter hole was drilled after the fabrication and filled with a conductive fluid, which became solid after a while. The width of the feeding microstrip line is chosen to be 2 mm on 1-mm-high FR4 substrate to realize the 50-Ω characteristic impedance. The width of the loop and the monopole elements is also 2 mm. The antenna is loaded by a thin FR4 layer on top whose dimensions are $20 \times 22 \times h$ mm^3. Here, h is the thickness of the top FR4 layer. Top- and bottom-layer copper metallization has a thickness of 0.035 mm for the simulation model.

Fig. 3 shows the effect of the loop and the monopole elements individually over the antenna S_{11} response. It can be seen that the high band is generated by the monopole, whereas the low band is generated by the coupling of the loop and the monopole. The coupling effect can be explained as follows. In the absence of the monopole, the first loop resonance is around 2 GHz, which is about 1.0-λ resonant mode, with S_{11} more than -9 dB. In the absence of the loop, the monopole has a resonance at around 2.1 GHz with S_{11} of about -10 dB. The resonances due to only-loop and only-monopole cases are weak in the sense that S_{11} does not meet the -10-dB specification with a usable bandwidth. However, when the loop and the monopole elements exist together, a coupling occurs between them through these two weak resonances, and as a result, a stronger resonance

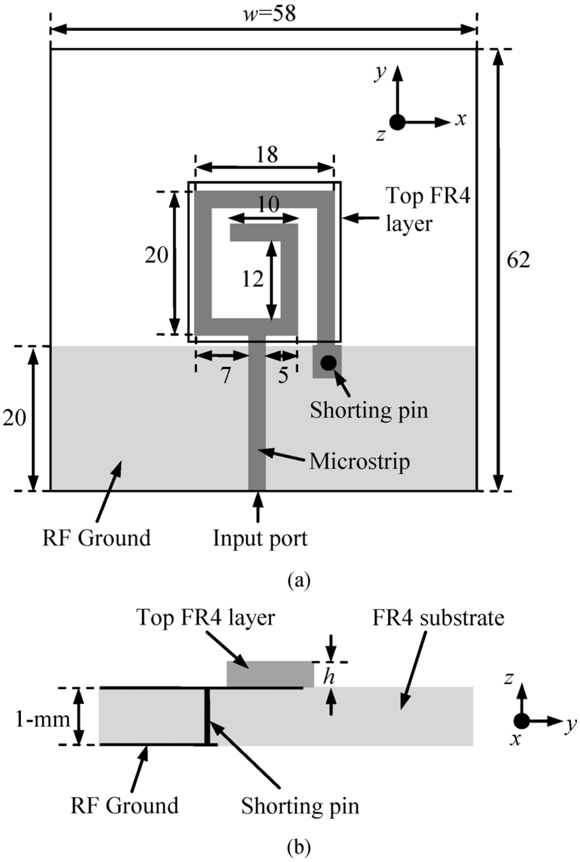

Fig. 1. Geometry of the antenna: (a) top view and (b) side view. All dimensions are in millimeters.

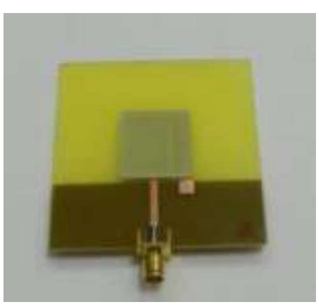

Fig. 2. Photograph of the fabricated antenna.

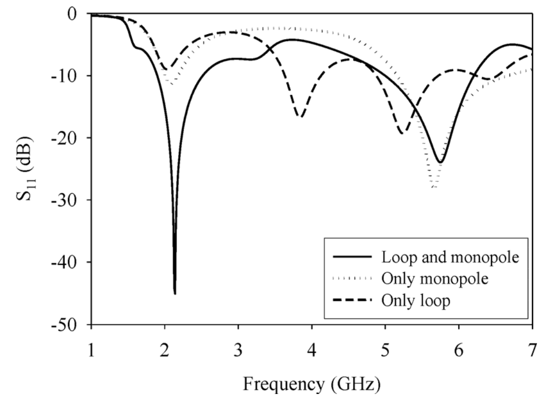

Fig. 3. HFSS simulated S_{11} response of the antenna for only-loop and only-monopole cases.

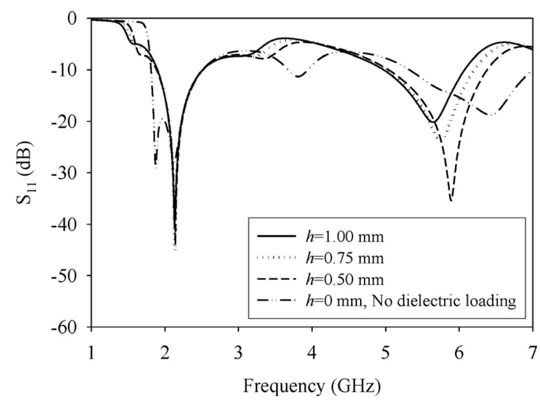

Fig. 4. HFSS simulated S_{11} of the antenna for different thicknesses of the top FR4 layer.

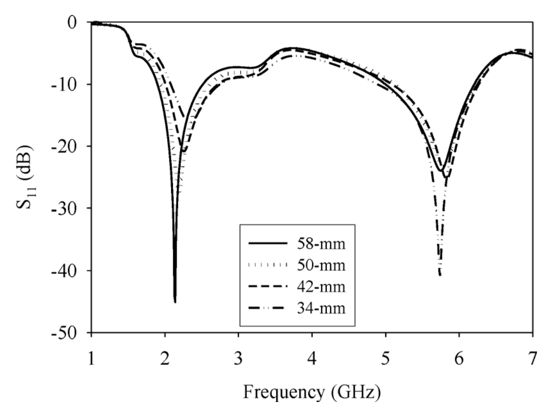

Fig. 5. HFSS simulated S_{11} response for different widths of the RF ground.

with good bandwidth is formed. This is how the low band is generated.

Simulated S_{11} response of the antenna is shown in Fig. 4 for different thickness values (h) of the top FR4 layer. It can be seen that when there is no dielectric loading, the high band exists from about 6 to 7 GHz, which is a detuning of about 1 GHz from the desired 5-GHz WLAN band. In addition, an undesired resonance is generated around 4 GHz. For $h = 1$ mm and $h = 0.75$ mm, the low band seems to be tuned well. The undesired resonance at 4 GHz for $h = 0$ mm has been pushed to 3.3 GHz due to FR4 loading. However, $h = 0.75$ mm was selected for the final design because it provides a slightly better bandwidth at high band.

The RF ground has dimensions of 58×20 mm^2. Its effect over the antenna S_{11} response has been investigated by varying its width (w) from 58 to 50, 42, and 34 mm, as shown in Fig. 5. Width reduction has been realized as trimming the RF ground from board edges in equal amounts. Reducing w detunes the low band, and for $w = 34$ mm, the WCDMA band can no longer be covered, whereas the high band is affected slightly and still covers the entire 5-GHz band. A match improvement may be possible by varying the dimensions and shape of the ground plane without using FR4 loading, however such changes effectively increase the footprint of the antenna and may reduce design flexibility by adding extra layout dependency. On the other hand, dielectric loading technique not only reduces the size and

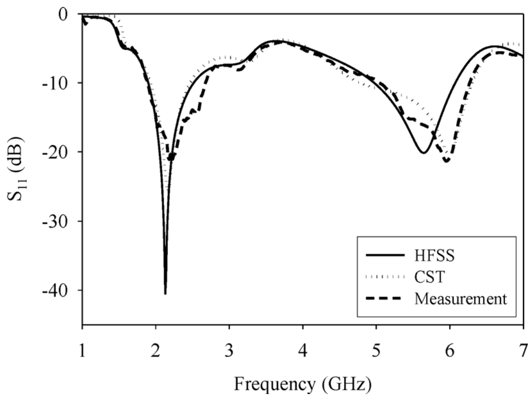

Fig. 6. Measured and simulated S_{11} of the antenna for $h = 0.75$ mm.

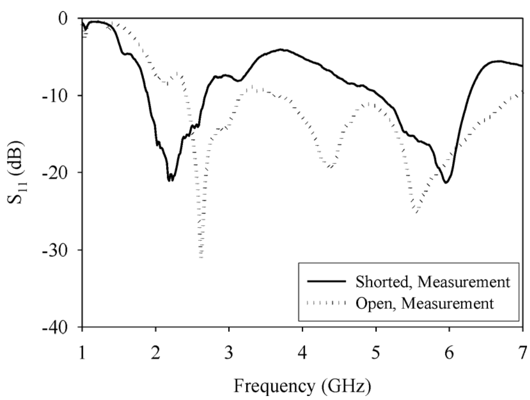

Fig. 7. Measured S_{11} responses of the antenna when the loop element is shorted to RF ground and when the loop element is open-circuited.

footprint of the antenna, but also improves the matching. Even though FR4 is relatively a lossy dielectric, it has been used for this purpose due to its low cost and easy availability.

Antenna S_{11} measurements have been performed at the Scientific and Technological Research Council of Turkey (TÜBİTAK) Center of Research for Advanced Technologies of Informatics and Security (BİLGEM) Antenna Test and Research Center using Agilent E8362C 20-GHz PNA microwave network analyzer. Comparison of measured and simulated S_{11} responses of the dielectric-loaded compact WLAN/WCDMA antenna for $h = 0.75$ mm is shown in Fig. 6. It can be seen that S_{11} measurement and simulations are in very good agreement. For the 10-dB return-loss bandwidth specification, the physical low band of the antenna spans from about 1.9 to 2.52 GHz. The physical high band of the antenna spans from about 5 to 6.2 GHz. Therefore, it can be stated that the presented antenna can operate at 1900–2170-MHz W-CDMA, 2.45-GHz WLAN, and 5-GHz WLAN bands.

The rectangular loop-shaped element is shorted to RF ground through a shorting pin for multiband operation. When the connection to the shorting pin is cut by scratching some copper from the PCB, the loop element is no longer RF-grounded through the shorting pin and, in fact, it behaves like a monopole due to the open end. Measured S_{11} responses of the antenna are shown in Fig. 7 for $h = 0.75$ mm to show this effect. The case "Open"

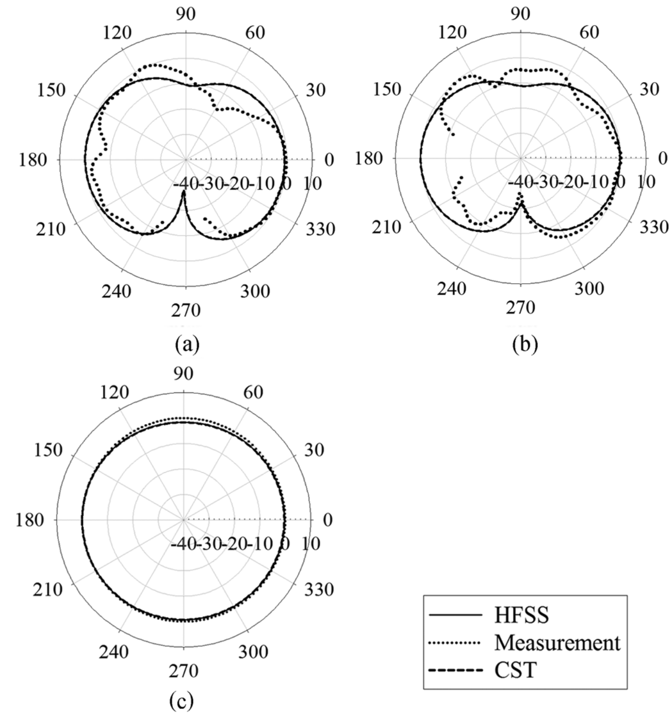

Fig. 8. Radiation patterns at 2.1 GHz in (a) xy-, (b) yz-, and (c) xz planes. Angles are in degrees, and amplitudes are in decibels.

corresponds to the antenna when the connection of the loop element to the RF ground is cut. When the loop element is short-circuited to the RF ground through the shorting pin, the case is "Shorted." For the shorted-loop case, measured S_{11} response clearly shows that there are two distinct resonances around 2.1 and 5.9 GHz. For the open-loop case, the low band is shifted to about 2.7 GHz, and the high band spans from about 3.5 to 7 GHz. It is possible to place an electronic switch such as a p-i-n diode as implemented in [10] to short or open the loop element to achieve wideband operation.

III. Antenna Design: Radiation Pattern Simulations and Measurements

Antenna radiation pattern measurements were performed at TÜBİTAK BİLGEM Antenna Test and Research Center. A wideband double-ridged horn antenna was used as the probe antenna. The distance between test and probe antennas was about 2.55 m. The test antenna was placed on a positioner that turns from 0° to $\pm 160^\circ$ with the existing setup. The probe antenna was in vertical polarization. Vertically polarized 3-D patterns were measured, and plane cuts were taken in xy-, yz-, and xz-planes, according to the coordinate system shown in Fig. 1. The radiation patterns of the dielectric-loaded compact WLAN/WCDMA antenna at 2.1 and 5.3 GHz are shown in Figs. 8 and 9, respectively. For the xy-plane radiation pattern, azimuth angle ϕ varies, whereas the elevation angle θ is set to 90°. For the yz-plane radiation pattern, θ varies and $\phi = 90^\circ$. For the xz-plane radiation pattern, θ varies and $\phi = 0^\circ$.

The radiation pattern at 2.1 GHz reveals omnidirectional behavior, and the peak antenna directivity is about 2.2 dBi. The

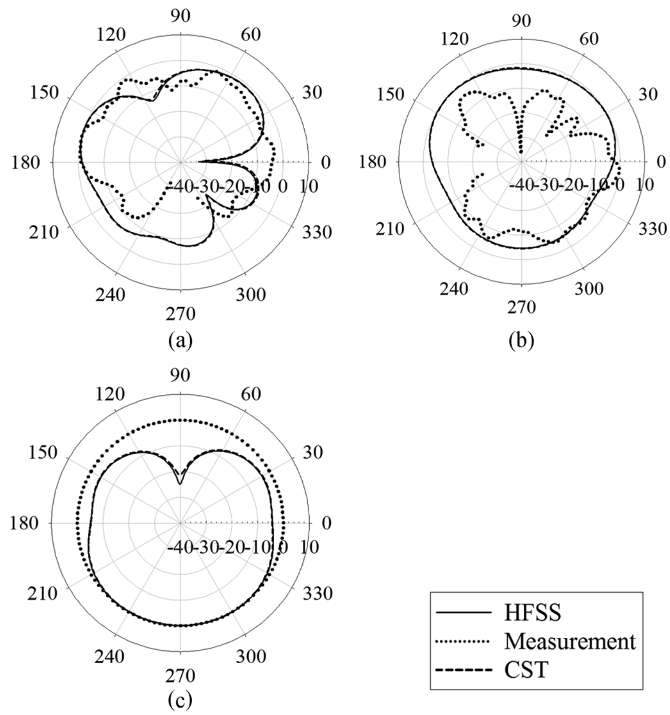

Fig. 9. Radiation patterns at 5.3 GHz in (a) xy-, (b) yz-, and (c) xz-planes. Angles are in degrees, and amplitudes are in decibels.

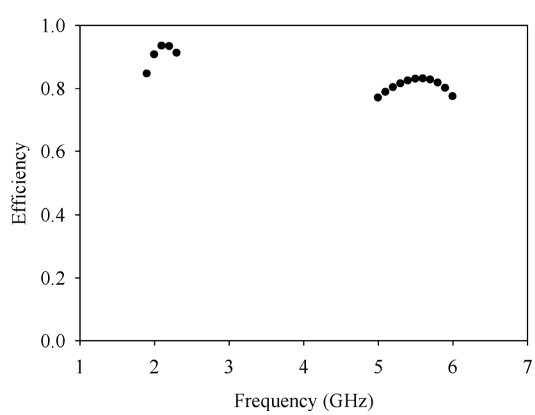

Fig. 10. Simulated antenna efficiency at low band and high band.

peak directivity at 5.3 GHz is about 4.4 dBi, and the pattern exhibits a more complex behavior due to shorter wavelength. All radiation patterns have been normalized to their maximum. The radiation pattern measurements are in good agreement with the simulations. Slight discrepancies can be due to RF currents that are reradiated by the feeding coaxial cable of the antenna and issues related to antenna positioning and alignment. However, CST and HFSS simulations are in excellent agreement. HFSS simulated antenna efficiency, as the ratio of realized gain and directivity, is shown in Fig. 10. Efficiency is about 90% at low band and 80% at high band. Gain measurements are available only at 2.1 and 5.3 GHz due to lack of gain references at other frequencies. Measured gains at 2.1 and 5.3 GHz are about 2 and

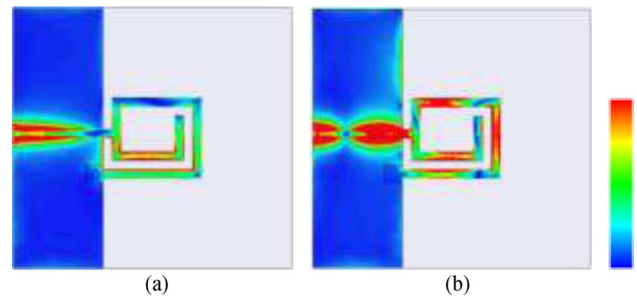

Fig. 11. Surface current distributions at (a) 2.1 and (b) 5.3 GHz. Color scale is from 0 (darkest blue) to 2 A/m (reddish red).

2.7 dBi, respectively. Antenna surface current density plots as obtained from HFSS simulations are shown in Fig. 11.

IV. Conclusion

A compact, planar, dielectric-loaded, and multiple-band antenna for 2.45/5-GHz WLAN and 1900–2170-MHz W-CDMA applications has been presented. The antenna has been designed on low-cost and easily available FR4-type substrate, and the dielectric loading material has also been selected as FR4. The dielectric-loaded compact WLAN/WCDMA antenna has good impedance matching and gain properties as observed from measurements and simulations, has a compact size of 20×22 mm^2, and can be integrated with the RF circuitry on the same circuit board easily. For future work, an electronic switch will be placed to short or open the loop element to achieve WCDMA/WLAN and wideband antenna functionalities.

References

[1] M. N. Kawakatsu and V. A. Dmitriev, "A compact and simple loop-type planar antenna for broadband applications," in *Proc. IEEE MTT-S Int. Microw. Optoelectron. Conf.*, 2009, pp. 159–162.

[2] A.-C. Chen, C.-L. Tang, and Z.-H. Lu, "A loop antenna for WLAN application," in *Proc. Asia–Pacific Microw. Conf.*, 2005, vol. 2.

[3] E. Lee, P. S. Hall, and P. Gardner, "Dual band folded monopole/loop antenna for terrestrial communications system," *Electron. Lett.*, vol. 36, pp. 1990–1991, Nov. 23, 2000.

[4] Y.-L. Shih, B.-H. Wang, Y.-J. Lu, J.-C. Cheng, S.-Y. Chen, and P. Hsu, "Capacitively-loaded loop antenna for multi-band mobile handsets," in *Proc. Int. Workshop Antenna Technol.*, 2008, pp. 239–242.

[5] Y.-W. Chi, T.-W. Chiu, and F.-R. Hsiao, "Printed penta-band laptop computer antenna for WVAN operation," in *Proc. Asia–Pacific Microw. Conf.*, 2009, pp. 1987–1989.

[6] T. Kim, S.-J. Kim, J. Byun, F. J. Harackiewicz, M.-J. Park, Y.-S. Chung, and B. Lee, "Internal dual-band WLAN antenna for laptop applications," in *Proc. IEEE APS-URSI Int. Symp.*, 2010, pp. 1–4.

[7] B. Yildirim, "Multiband and compact WCDMA/WLAN antenna for mobile equipment," *IEEE Antennas Wireless Propag. Lett.*, vol. 10, pp. 14–16, 2011.

[8] 3D EM-Field Simulation for High Performance Electronic Design. Ansoft HFSS. ver. 11, Ansoft Corporation, Pittsburgh, PA, USA, 2010.

[9] 3D EM Simulation of High Frequency Components. CST Microwave Studio. CST AG, Darmstadt, Germany, 2011.

[10] H. Altun, E. Korkmaz, and B. Türetken, "Simulation of a conformal reconfigurable fractal tree antenna with adaptive multi beam and frequency characteristics," in *Prog. Electromagn. Res. Symp. Proc.*, Suzhou, China, 2011, pp. 619–623.