Progress In Electromagnetics Research Letters, Vol. 38, 111–118, 2013

MONOPOLE SLOT COUPLING-FED DIELECTRIC RESONATOR ANTENNA FOR MOBILE TERMINALS

Jing-Li Guo, Lin-Ya Zhou*, You-Huo Huang, and Bao-Hua Sun

National Key Laboratory of Antennas and Microwave Technology, Xidian University, Xi'an, Shaanxi 710071, China

Abstract—This paper presents a novel dielectric resonator antenna (DRA) for multiband mobile terminal communication applications. A variation of circular sector dielectric resonator antenna partially coated with metal on its surface is used as the main radiating element. The DRA is fed by a monopole slot-coupled 50-Ω microstrip feed line, which can also provide another radiation mode. By thorough design, the antenna achieves the desired 470–960 MHz band for DVB-H/GSM850/900 operation and 1710–1990 MHz band for DCS/PCS operation. The dimensions of the antenna presented are $\lambda_0/17\times\lambda_0/9\times\lambda_0/35$ at 470 MHz with appropriate dielectric permittivity $\varepsilon_r = 16$.

1. INTRODUCTION

The dielectric resonator (DR) was first used as an efficient radiator in the early 1980s [1]. Some attractive features were discovered such as high radiation efficiency, flexible available feeding mechanisms, various shapes of resonators, lightweight, and a wide range of permittivity values. Many techniques have been developed for its impedance bandwidth expansion such as notched DRAs, stacked DRAs, and so on. The notched DRAs achieved wideband performance by lowering its Q factor [2]. The bandwidth of stacked DRAs can be increased by tuning resonant frequencies of the two DR elements [3]. Furthermore, multi-radiation modes can be utilized to improve bandwidth of the antenna. In [4], a broadband CPW-fed dielectric resonator antenna with metal coating, which was also fed as a monopole, is proposed, and the bandwidth of the antenna was improved by coupling the resonant modes of the metal-coated DR and the monopole.

Received 20 January 2013, Accepted 6 March 2013, Scheduled 10 March 2013
* Corresponding author: Lin-Ya Zhou (jszhoulinyacool@163.com).

For the terminal applications, planar inverted F antennas (PIFAs), monopole antennas, loop antennas and their variations are investigated thoroughly and used widely [5–7]. Besides that, monopole slots were presented and demonstrated to be competitive candidates for terminal antennas [8, 9], which have more compact forms than traditional slots due to the quarter wavelength resonant mode excited efficiently. Recently, the dielectric resonator antennas (DRAs) have been proposed as a potential choice in mobile terminal communication system [10, 11]. In [12], a DRA is designed for DVB-H and GSM900 applications, which is shaped and coated metallically on some faces to get wide bandwidth and relatively low resonant frequency.

In this paper, a multiband dielectric resonator antenna fed by a monopole slot coupling is proposed. The dimensions of the DRA are $\lambda_0/17 \times \lambda_0/9 \times \lambda_0/35$ at 470 MHz, with dielectric permittivity $\varepsilon_r = 16$. The monopole slot is firstly introduced to not only excite the DRA efficiently but also to offer a helpful resonance mode. Then the dielectric resonator is partially coated with metal plates on its two side and top surfaces, and a rectangle portion of dielectric material is removed to fine tune the resonance frequencies. In addition, an air gap is inserted between the DRA and ground plane to expand the frequency band.

2. ANTENNA DESIGN

Figure 1 shows the geometry of the proposed DRA fed by a monopole slot. The main radiating element is a DR element with partial metal

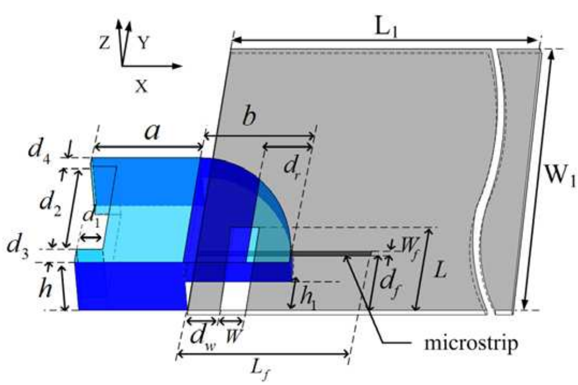

Figure 1. Schematic diagrams of the proposed monopole slot coupling-fed dielectric resonator antenna (metal coating is marked by darkblue).

coating. The DRA is fed through a monopole slot with a microstrip line located on the back side of the system circuit board. The DR element consists of a thin quarter cylindrical sector and a cuboid part which has a rectangle material portion removed. An air gap of height h_1 is introduced between the arc-shaped DRA part and ground plane.

The DR material used in the proposed antenna has dielectric permittivity of $\varepsilon_r = 16$, and loss tangent of $\tan\delta = 1\times10^{-3}$. A 0.8-mm-thick FR4 (dielectric constant $\varepsilon_r = 4.4$, loss tangent $\tan\delta = 0.0245$) substrate of size $230 \times 130\,\text{mm}^2$ (which is chosen to fit in a standard DVB-H handheld receiver) is used as the system circuit board, and one side of the substrate is the ground plane. The dimensions of the coupling monopole slot are $L \times W$, and the 50-Ω feeding line has a length of $L_f \times W_f$. The more detailed dimensions are given in Table 1.

Table 1.

d_1	d_2	d_3	d_w	d_r	b	a	L_f	W_f	W	L	d_4	d_f	h_1	h	W_1	L_1
12	25	6	12	15	37	37	76	0.95	16	51	6	20	12	18	130	230

3. RESULTS

The antenna is simulated firstly using Ansoft simulation software High Frequency Structure Simulator (HFSS). To verify the design, a prototype was fabricated and tested. Figure 2 shows a photograph of the fabricated antenna. With the restrictions of material at hand, the prototype is made of three dielectric layers with 6 mm thickness each. Figure 3 shows the measured and simulated reflection coefficient. It can be observed that the measured result was mainly in agreement with the simulated one. For the measured reflection coefficient, the 3 : 1 VSWR impedance matching bandwidth reaches 537 MHz (468–1005 MHz) in the lower band to cover the operating bands of GSM850/GSM900 and DVB-H operation. In the upper band, the antenna has a bandwidth of 475 MHz (1570–2045 MHz), and it can cover the DCS/PCS operation sufficiently. As can be seen from the results, some resonant frequency shift exists between the measured and simulated results mainly in the lower band. Besides machining errors, the reason for this deviation is mainly the introduction of additional air gap between three dielectric layers during the fabrication, which results in lowering Q value and increasing the resonance frequency.

The effects of varying parameters are discussed by the simulation examples to follow. All parameter dimensions except for one are held constant to the values given in Table 1.

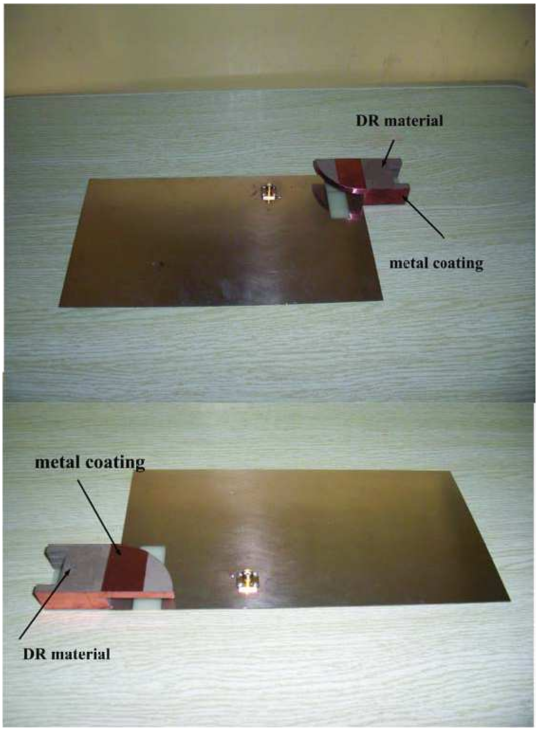

Figure 2. Photograph of the fabricated antenna.

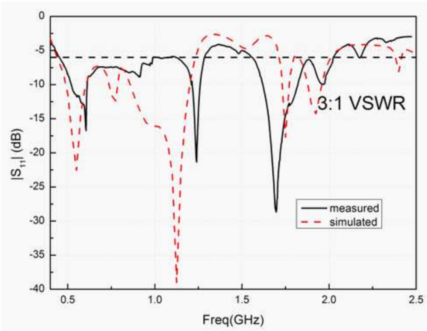

Figure 3. Measured and simulated reflection coefficient of the antenna.

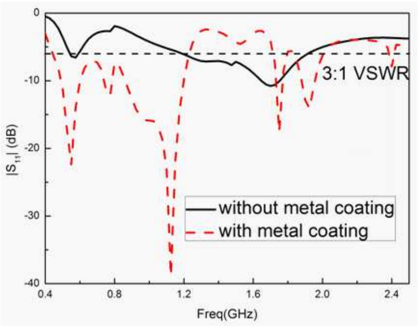

Figure 4. Effects of the metal coating on the resonant frequency, with other parameters fixed.

The comparison of the simulated reflection coefficient between the DRA with and without metal coating is shown in Figure 4. By adding the metal coating, some new resonant modes are inspired, which is due to the variation of the boundary condition of the DR cavity. With metal coating, a lowering of the resonant frequency is achieved and the low resonance is enhanced, the low band is broaden significantly to cover the desired DVB-H/GSM850/900 operation. To lower the resonant frequency, other approaches can be used, such as increasing the DRA dimensions, improving the permittivity values of the DR material, and so on. But adding metal coating may be a more competitive technique, because it can not only achieve a compact configuration but also expand the impedance bandwidth. For the antenna presented, the operation frequency tuning can be achieved by using metal plates on its side and top surface.

In the antenna design, a part of the dielectric material is removed between the DR and the ground plane which can be seen as an air-gap. Figure 5 depicts the effect of varying the height of the air-gap (h_1) on the simulated reflection coefficient of the antenna. It can be seen that the introduction of air-gap has a significant impact on two lower resonant modes. As h_1 increases, the first resonance frequency of the antenna become a little higher but the reflection coefficient in the whole low frequency band become better. It is also observed that the height of the air-gap affects the higher frequency resonance more significantly. By changing the height of air-gap, appropriate resonances can be obtained. In order to achieve better desired impedance bandwidth, including lower and upper bands, the height h_1 is selected to be 12 mm in this paper.

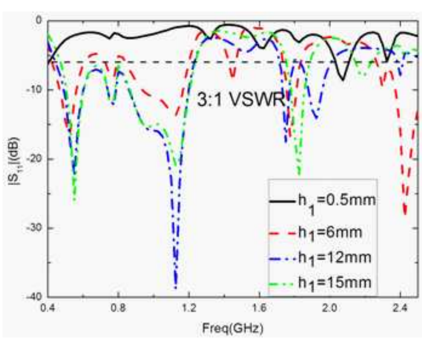

Figure 5. Simulated reflection coefficient as a function of the air-gap height h_1, with other parameters fixed.

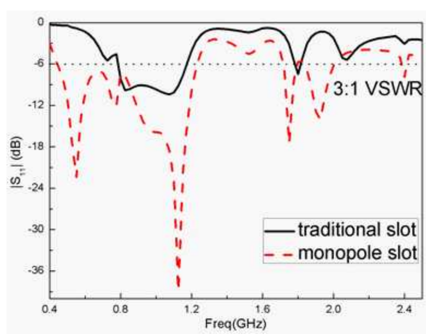

Figure 6. Simulated reflection coefficient of the proposed antenna with monopole slot and traditional slot, respectively.

The simulated reflection coefficients of the antenna with different types of slots (same length) are shown in Figure 6. The monopole slot is different from a traditional slot on its open end, and it can generate a quarter-wavelength resonant mode. Compared with the traditional slot, the monopole slot can achieve a lower resonant mode. Using the monopole slot, a low resonance at about 0.5 GHz is obtained, thus a good impedance matching (3 : 1 VSWR bandwidths) mainly in the lower band is achieved to cover DVB-H operation, and it also enhance the resonant modes in the upper band.

The effect of altering the monopole slot width (W) is illustrated in Figure 7. It is observed that this parameter contributes to the whole frequency band. As the width W increases, the performance of the proposed antenna in the upper band is getting better; on the contrary, it is getting worse in the lower band. In order to achieve good

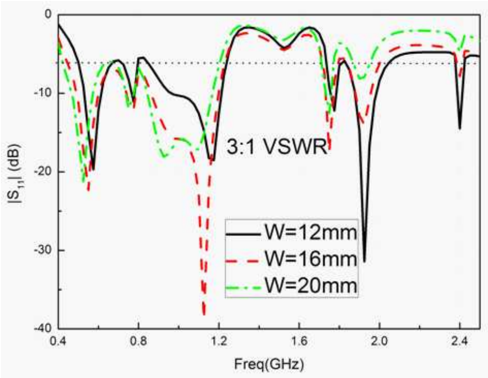

Figure 7. Simulated reflection coefficient as a function of width W of the monopole slot, with other parameters fixed as in Table 1.

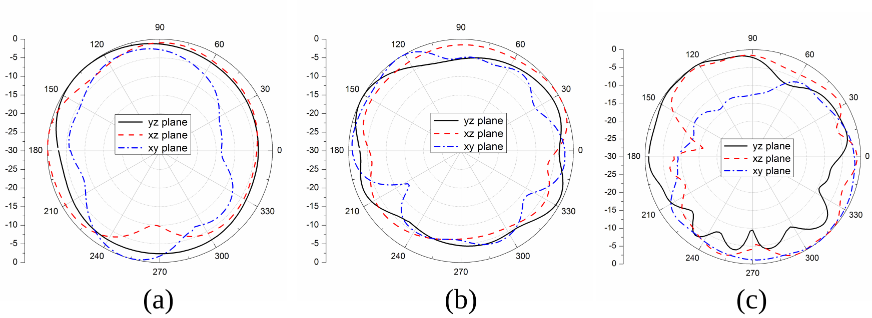

Figure 8. Simulated radiation patterns at (a) 0.5 GHz, (b) 0.9 GHz, (c) 1.9 GHz.

impedance matching in both bands, a tradeoff $W = 16\,\text{mm}$ is chosen.

Figure 8 plots the simulated radiation patterns of the proposed antenna at 0.5 GHz, 0.9 GHz and 1.9 GHz, respectively. It can be seen that the radiation patterns are nearly omnidirectional at most frequencies, which is acceptable for terminal communication applications. Figure 9 shows the measured antenna peak gain from 0.475–2 GHz for the proposed antenna. The measured antenna peak gain is about 0.9–3.5 dBi for the lower band and about 3.5–4.7 dBi for the upper band. The peak gain is high enough to be used in practical DVB-H and mobile terminal applications such as netbook or portable devices.

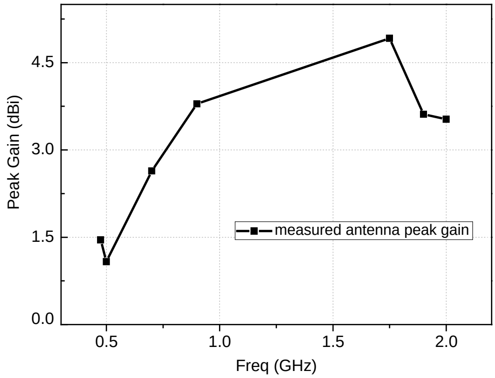

Figure 9. Measured antenna peak gain for the proposed antenna.

4. CONCLUSIONS

A multi-band dielectric resonator antenna fed by monopole slot coupling is proposed. Parametric studies have been shown that by adjusting the dimensions of the feeding monopole slot, adding an air-gap, and coating some faces with metal plates, the resonances are excited at desired frequencies and a wide frequency band is derived with a compact size. Acceptable radiation characteristics have also been achieved over all the bands. The simulated and measured results indicate that the proposed antenna is suited for DVB-H/GSM/DCS/PCS band applications.

ACKNOWLEDGMENT

The work is supported by "the Fundamental Research Funds for the Central Universities" K5051202008.

REFERENCES

1. Long, S. A., M. W. McAllister, and L. C. Shen, "The resonant cylindrical dielectric cavity antenna," *IEEE Trans. Antennas Propagat.*, Vol. 31, No. 3, 406–412, May 1983.
2. Ittipiboon, A., A. Petosa, D. Roscoe, and M. Cuhaci, "An investigation of a novel broadband dielectric resonator antenna," *IEEE AP-S. Digest*, 2038–2041, Jul. 1996.
3. Kishk, A. A., B. Ahn, and D. Kajfez, "Broadband stacked dielectric resonator antennas," *Electron. Lett.*, Vol. 25, No. 18, 1232–1233, Aug. 1989.
4. Chang, T.-H. and J.-F. Kiang, "Broadband dielectric resonator antenna with metal coating," *IEEE Trans. Antennas Propagat.*, Vol. 55, No. 5, 1254–1259, May 2007.
5. Liu, C.-L., Y.-F. Lin, C.-M. Liang, S.-C. Pan, and H.-M. Chen, "Miniature internal penta-band monopole antenna for mobile phones," *IEEE Trans. Antennas Propagat.*, Vol. 58, No. 3, 1008–1011, Mar. 2010.
6. Nepa, P., G. Manara, A. A. Serra, and G. Nenna, "Multiband PIFA for WLAN mobile terminals," *IEEE Trans. Antennas Propagat.*, Vol. 4, 349–350, 2005.
7. Chi, Y.-W. and K.-L. Wong, "Internal compact dual band printed loop antenna for mobile phone application," *IEEE Trans. Antennas Propagat.*, Vol. 55, No. 5, 1457–1462, May 2007.
8. Chu, F.-H. and K.-L. Wong, "Simple folded monopole slot antenna for penta-band clamshell mobile phone application," *IEEE Trans. Antennas Propagat.*, Vol. 57, No. 11, 3680–3684, Nov. 2009.
9. Lin, C.-I. and K.-L. Wong, "Printed monopole slot antenna for penta-band operation in the folder-type moile phone," *Microwave and Opt. Technol. Lett.*, Vol. 50, No. 9, 2239–2242, Sep. 2008.
10. Matthew, T., K. Tam, and R. D. Murch, "Compact circular sector and annular sector dielectric resonator antennas," *IEEE Trans. Antennas Propagat.*, Vol. 47, No. 5, 837–841, May 1999.
11. Moon, J.-I. and S.-O. Park, "Dielectric resonator antenna for dual-band PCS/IMT-2000," *Electron. Lett.*, Vol. 36, No. 12, 1002–1003, Jun. 2000.
12. Huitema, L., M. Koubeissi, C. Decroze, and T. Monediere, "Ultrawideband dielectric resonator antenna for DVB-H and GSM applications," *IEEE Antennas Wireless Propagt. Lett.*, Vol. 8, 1021–1024, 2009.