Journal of Electromagnetic Waves and Applications

ISSN: 0920-5071 (Print) 1569-3937 (Online) Journal homepage: https://www.tandfonline.com/loi/tewa20

Compact dual-band hybrid dielectric resonator antenna loaded with magnetic-LC resonator

Abhishek Sharma, Anirban Sarkar, Animesh Biswas & M. Jaleel Akhtar

JOURNAL OF ELECTROMAGNETIC WAVES AND APPLICATIONS, 2018
VOL. 32, NO. 10, 1298–1305
https://doi.org/10.1080/09205071.2018.1433557

Taylor & Francis
Taylor & Francis Group

Compact dual-band hybrid dielectric resonator antenna loaded with magnetic-LC resonator

Abhishek Sharma, Anirban Sarkar, Animesh Biswas and M. Jaleel Akhtar

Department of Electrical Engineering, Indian Institute of Technology Kanpur, Kanpur, India

ABSTRACT

This article presents a compact dual-band hybrid dielectric resonator antenna for wireless communication systems. The proposed design uses a square dielectric resonator loaded with magnetic-LC resonator (complementary of electric-LC resonator) to achieve miniaturization and dual-band operation. Based on the parametric analysis, it is reveled that the two operational bands could be designed independently. The proposed antenna operates at 3.6 and 5.25 GHz with impedance bandwidths of 3.9% (3.53–3.67 GHz) and 3.24% (5.17–5.34 GHz), respectively. The antenna radiates with similar radiation pattern at both the operating frequencies with the cross polarized fields better than −20 dB. The peak gain of the antenna is 6.27 and 6.35 dBi at lower and upper operating frequency, respectively. The proposed antenna is suitable for worldwide interoperability for microwave access and wireless local area network band applications.

ARTICLE HISTORY
Received 20 June 2017
Accepted 22 January 2018

KEYWORDS
Compact antenna; dual-band; dielectric resonator antenna; magnetic-LC resonator

1. Introduction

Dielectric resonator antennas (DRAs) have gained widespread attention in wireless communication systems because of their alluring features such as small size, low loss, high radiation efficiency (due to lack of surface wave and conductor losses), relatively wide bandwidth, ease of excitation, etc. [1]. Being a volumetric radiator, it gives more design flexibility and versatility than the conventional microstrip antennas and the desired radiation characteristics can be obtained using different shapes and various modes of the dielectric resonator (DR).

To meet the stringent demands of modern wireless communication systems, compact and multi-band antennas are becoming indispensable. Several designs have been reported in the past for dual-band operation which includes multi-element/stacking [2–4] and multimode DRA [5–8]. However, using the multimode technique, different bands cannot be controlled independently as the modes are sensitive to dimensions of DR. This limitation has been mitigated by adopting hybridization, where the DRA is combined with another resonator which acts as a radiator as well as feed to the DR at the same time. Several dual-band hybrid DRAs have been reported in the past. For example, in [9], a conical DR is excited by a pair of eccentric ring slots, where the one slot is directly fed and other

CONTACT Abhishek Sharma sharma@iitk.ac.in

one is acting as a radiator along with DRA, thereby generating dual-frequency. In [10], a compact hybrid resonator antenna composed of DRA and T-shaped microstrip line has been designed to achieve dual-band with multifunctional beams. The authors in [11] have proposed a miniature dual-band hybrid DRA fed by a coplanar waveguide inductive slot. A compact dual-band DRA using a parasitic slot has been reported in [12]. In [13], a dual-band hybrid antenna comprises of DRA and split ring resonator as the radiating elements has been presented. In [14], the authors have reported a multi-band hybrid antenna consisting of Z-shaped cylindrical DRA and dual-C-shaped microstrip line (which acts as a feed to DR as well as the radiator).

The concept of using the feed as a radiator makes the overall design compact howbeit, the DR itself is not compact in the above reported designs. Techniques like use of high permittivity/permeability materials [1], edge grounding [15,16], metalized DR [17,18] have been reported in the past to realized compact DRA. Nowadays, split-ring and complementary split-ring resonators, electric-LC (ELC) resonators and magnetic-LC (MLC) resonators (complementary of ELC resonator) are being utilized for antenna design [19–24].

In this article, a square DR top loaded with MLC resonator is proposed and investigated for compact and dual-band operation. Most importantly, the two bands of the proposed antenna could be designed independently. The design has the advantage of simple structure and compact size which makes it suitable for wireless communication systems such as worldwide interoperability for microwave access (WiMAX) and wireless local area network (WLAN). All the simulations are done using CST Microwave studio and a prototype is built and tested successfully.

2. Antenna design and analysis

2.1. DRA Modes

Before going into the details of the proposed dual-band antenna, the modes of rectangular DR are briefly discussed. The rectangular DRA can support transverse electric modes i.e. TE^x, TE^y, or TE^z, which would radiate like a short magnetic dipoles oriented in the *x*-, *y*, and *z*-directions [1]. The theoretical resonant frequency of fundamental $TE^x_{\delta 11}$ mode of the DR can be calculated from dielectric waveguide model using the following equations [1]

$$k_x \tan\left(\frac{k_x A}{2}\right) = \sqrt{(\epsilon_{rd} - 1)k_0^2 - k_x^2} \tag{1}$$

and

$$k_y = \frac{m\pi}{A} \quad \text{and} \quad k_z = \frac{n\pi}{A} \quad \text{where} \quad m = n = 1 \tag{2}$$

where, k_x, k_y and k_z are the wavenumbers along the x-, y-, and z-directions and are related as

$$k_x^2 + k_y^2 + k_z^2 = \epsilon_{rd} k_0^2 \tag{3}$$

where, k_0 denotes the free space wavenumber. In case of square DRA, the resonant frequency of $TE^x_{\delta 11}$ and $TE^y_{1\delta 1}$ mode is same.

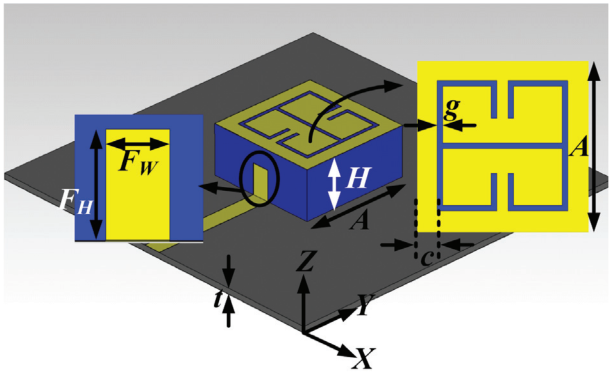


Figure 1. Geometry of the proposed antenna. Geometrical parameters: $A = 15.5, H = 6.35, t = 0.787, F_W = 2.4, F_H = 3.6, c = 1.8, g = 0.5$ (all dimensions are in mm).

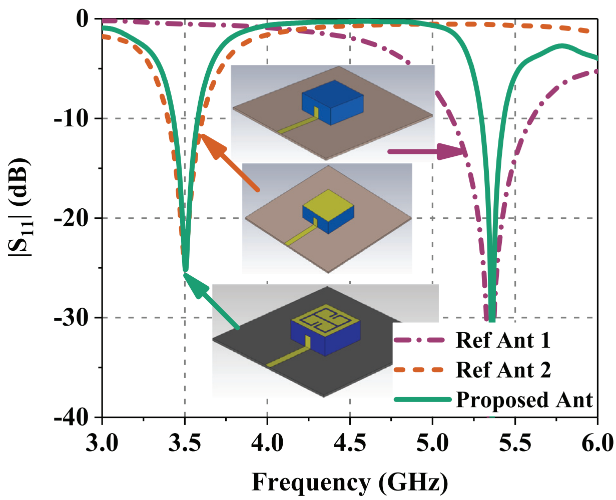


Figure 2. Simulated response of the reference and proposed antennas.

2.2. Dual-band antenna design

The geometry of the proposed dual-band DRA is shown in Figure 1. The antenna resides on a low permittivity substrate ($\epsilon_r = 2.2$ and $\tan\delta = 0.0009$) of dimensions $50 \times 50 \times 0.787 mm^3$. The DR is made from Rogers RT/Duroid 6010 of relative permittivity 10.2 and loss tangent 0.0023.

The proposed antenna is designed in three steps as shown in Figure 2. First, a square DR of length A and height H is excited in the fundamental $TE^x_{\delta 11}$ mode using a conformal vertical strip of length F_H and width F_W. The theoretical resonant frequency of DRA calculated from the Equations (1)–(3) is 5.25 GHz and the corresponding simulated value is 5.35 GHz (refer Figure 2). Next, the top surface of DRA is loaded with the metal. The boundary enforced by the top metalization and vertical strip excites a new radiating mode [18] and this mode will resonate at much lower frequency compared to the fundamental mode of the DR having similar size. This loading of DR with metal results in miniaturization. After covering the top

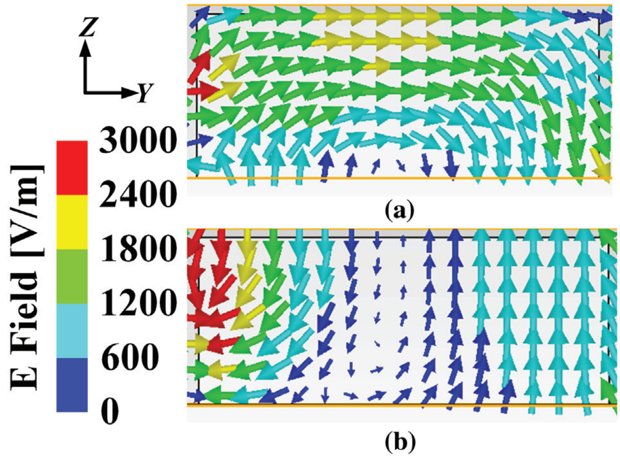


Figure 3. Electric field distribution in (a) square DR (b) top metal loaded square DR.

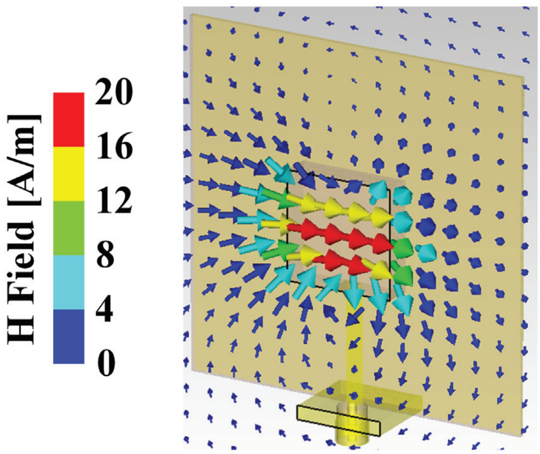
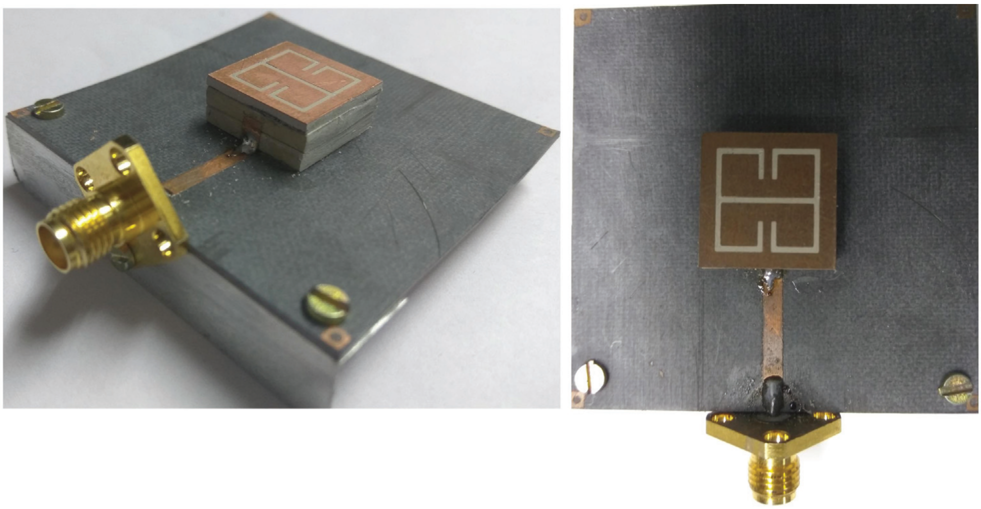


Figure 4. Magnetic field distribution in top metal loaded square DR.

surface of DR with the metal, the resonant frequency shifts from 5.35 to 3.5 GHz (refer Figure 2). The electric field distribution of the fundamental $TE^{x}_{\delta 11}$ mode in the square DR and the new radiating mode in the metalized square DR are portrayed in Figure 3(a) and (b), respectively. Finally, a MLC resonator is etched on the metalized surface of the DR. As illustrated in Figure 4, the magnetic field inside the metalized DR is uniform and oriented horizontally along the *x*-direction. This in-plane magnetic field facilitates the excitation of MLC resonator [20,25], which generates the second resonance at 5.36 GHz. Thus, the combination of DR and MLC resonator results in a compact dual-band antenna.

2.3. Experimental results

The prototype of the proposed antenna is shown in Figure 5. Figure 6 depicts the simulated and measured response of the proposed compact dual-band antenna. The simulated



(a) (b)

Figure 5. Prototype of the proposed antenna (a) Isometric view (b) Top view.

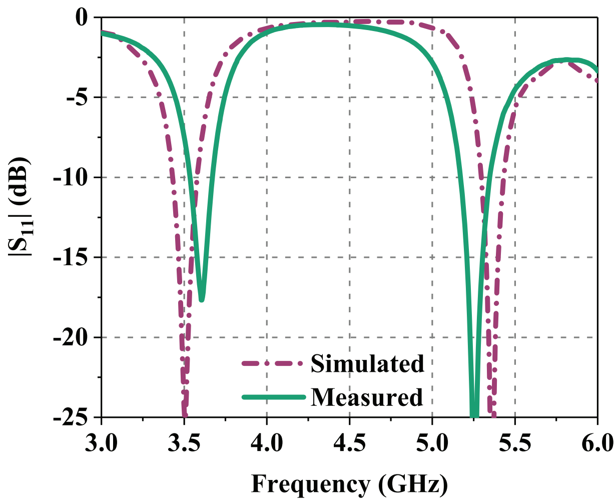


Figure 6. Simulated and measured response of the proposed antenna.

impedance bandwidth is 4.28% (3.43–3.58 GHz) for lower band and 2.62% (5.29–5.43 GHz) for upper band and the corresponding measured values are 3.9% (3.53–3.67 GHz) and 3.24% (5.17–5.34 GHz). A slight disagreement is due to fabrication tolerances, misalignment and inexorable air gap between DR and ground plane. The simulated and measured normalized radiation pattern at both the operating frequencies are shown in Figure 7. The antenna radiates along the broadside direction and the difference between the co-polarized and the cross-polarized fields is 20 dB in both *xz*- and *yz*-planes. The simulated and measured peak gain of antenna is 6.55 and 6.27 dBi, respectively, at lower operating frequency and the corresponding values at higher operating frequency are 6.11and 6.35 dBi, respectively.

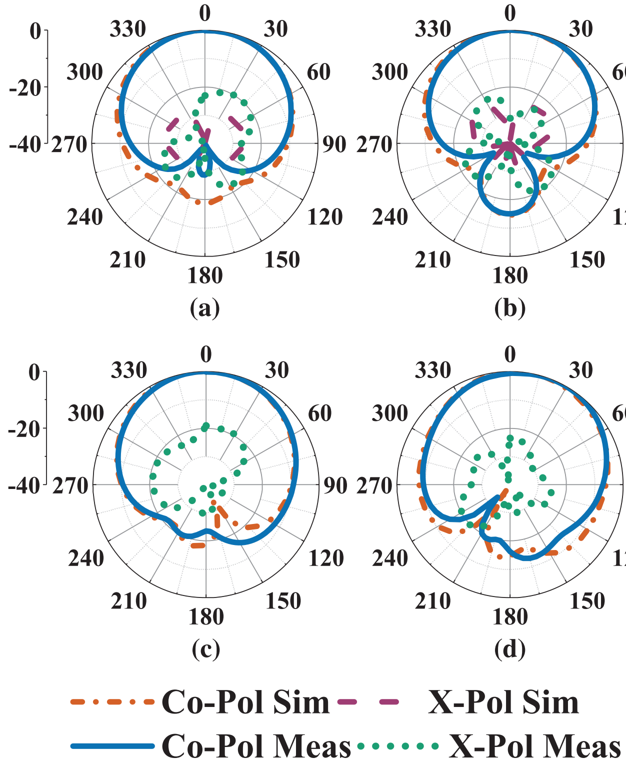


Figure 7. Normalized radiation pattern at (a) f_L, *xz*-plane (b) f_U, *xz*-plane (c) f_L, *yz*-plane (d) f_U, *yz*-plane (f_L: Lower operating frequency and f_U: Upper operating frequency).

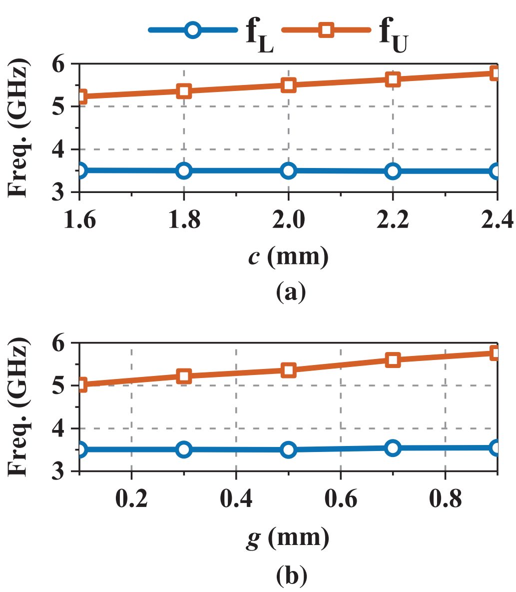


Figure 8. Resonant frequency variation with different geometrical parameters (a) *c* (b) *g*.

3. Parametric analysis

Figure 8(a) and (b) show the variation in resonant frequency with different geometrical parameters of MLC resonator i.e. *c* and *g*, respectively. It is found that on changing the values of these parameters, the lower resonant frequency is not affected much but the effect on higher resonant frequency is discernible. This shows that the DR resonance is responsible for lower band, whereas the upper band is due to the MLC resonator.

3.1. Independent band control

The parametric analysis reveled the possibility of independently controlling the two operating bands of the proposed antenna. The idea is that the lower operating frequency f_L will be fixed while the upper operating frequency f_U will be independently swept across the various WLAN sub-bands. Only the geometrical parameters related to MLC resonator need to be modified for each design, leaving the DR unaltered.

4. Conclusion

A compact dual-band DRA loaded with MLC resonator has been proposed where the two operating band could be designed independently. The proposed antenna operates at 3.6 and 5.25 GHz with impedance bandwidth of 3.9 and 3.24%, respectively. At both the operating frequencies, the radiation is along the zenith with the cross-polarized level better than −20 dB. The peak gain of 6.27 and 6.35 dBi has been obtained at the two operating frequencies. The proposed antenna finds the potential application in WiMAX and WLAN bands, and can also be utilized for multiple-input multiple-output applications.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Abhishek Sharma http://orcid.org/0000-0001-8026-9752

References

[1] Petosa A. Dielctric resonator antenna handbook. Boston: Artech House; 2007.
[2] Fan Z, Antar YMM. Slot-coupled DR antenna for dual-frequency operation. IEEE Trans Antennas Propag. 1997;45:306–308.
[3] Chaudhary RK, Srivastava KV, Biswas A. Multi-band cylindrical dielectric resonator antenna using permittivity variation in azimuthal direction. Progr Electromagn Res C. 2015;59:11–20.
[4] Khan R, Jamaluddin MH, Khan JUR, et al. Multiband-dielectric resonator antenna for LTE application. IET Microw Antennas Propag. 2016;10:595–598.
[5] Fang XS, Leung KW. Design of single-, dual-, wide-band rectangular dielctric resonator antenna. IEEE Trans Antennas Propag. 2011;59:2409–2414.
[6] Guha D, Gupta P, Kumar C. Dual-band cylindrical dielectric resonator antenna employing $HEM_{11\delta}$ and $HEM_{12\delta}$ modes excited by new composite aperture. IEEE Trans Antennas Propag. 2015;63:433–438.

[7] Sharma A, Biswas A. Dual-frequency half split cylindrical dielctric resonator antenna. In: IEEE applied electromagnetics conference (AEMC). Guwahati, India; 2015.
[8] Liu H, Liu Y, Wei M, et al. Dual-broadband dielectric resonator antenna based on modified sierpinski fractal geometry. IET Electron Lett. 2015;51:806–807.
[9] Rao Q, Denidni TA, Sebak AR. A new dual-frequency hybrid resonator antenna. IEEE Antennas Wireless Propag Lett. 2005;4:308–311.
[10] Rao Q, Denidni TA, Sebak AR, et al. Compact independent dual-band hybrid resonator antenna with multifunctional beams. IEEE Antennas Wireless Propag Lett. 2006;5:239–242.
[11] Lin YF, Chen HM, Lin CH. Compact dual-band hybrid dielectric resonator antenna with radiating slot. IEEE Antennas Wireless Propag Lett. 2009;8:6–9.
[12] Chen HM, Wang YK, Lin YF, et al. A compact dual-band dielectric resonator antenna using a parasitic slot. IEEE Antennas Wireless Propag Lett. 2009;8:173–176.
[13] Bala BD, Rahim MKA, Murad NA, et al. Dual band dielectric resonator based metamaterial antenna. In: 2014 international symposium on antennas and propagation conference proceedings; Kaohsiung; 2014. p. 79–80.
[14] Sharma A, Gangwar RK. Circularly polarised hybrid z-shaped cylindrical dielectric resonator antenna for multiband applications. IET Microw Antennas Propoag. 2016;10:1259–1267.
[15] Kishk AA, Huang W. Size reduction methods for dielectric resonator antennas. IEEE Antennas Propag Mag. 2011;53:26–38.
[16] Patel P, Mukherjee B, Mukherjee J. A compact wideband rectangular dielectric resonator antenna using perforations and edge grounding. IEEE Antennas Wirless Propag Lett. 2015;14:490–493.
[17] Rashidian A, Shafai L. Super-miniaturized dielectric-metallic resonator antennas. In: 2015 IEEE international symposium on antennas and propagation and USNC/URSI national radio science meeting; Vancouver (BC); 2015. p. 1238–1239.
[18] Rashidian A, Shafai L. Comapct lightwieght polymeric-metallic resonator antennas using a new radiating mode. IEEE Trans Antennas Propag. 2016;64:16–24.
[19] Xiong J, Lin X, Yu Y, et al. Novel flexible dual-frequency broadside radiating rectangular patch antennas based on complementary planar ENZ or MNZ metamaterials. IEEE Trans Antennas Propag. 2012;60:3958–3961.
[20] Odabasi H, Teixeira FL, Guney DO. Electrically small, complementary electric-field-coupled resonator antennas. J Appl Phys. 2013;113:084903.
[21] Yoo M, Lim S. SRR- and CSRR-loaded ultra-wideband (UWB) antenna with tri-band notch capability. J Electromagn Waves Appl. 2013;27:2190–2197.
[22] Bala BD, Rahim MKA, Murad NA. Complementary electric-LC resonator antenna for WLAN applications. Appl Phys A. 2014;117:635–639.
[23] Yeo J, Lee JI. Design of series-fed dipole pair antenna with split-ring resonator directors for dual-band operation. J Electromagn Waves Appl. 2015;29:154–168.
[24] Sarkar D, Saurav K, Srivastava KV. Four-element array of complimentary split-ring resonator loaded printed directive dipoles for triple band applications. IET Electron Lett. 2016;52:785–786.
[25] Hand TH, Gollub J, Sajuyigbe S, et al. Characterization of complementary electric field coupled resonant surfaces. Appl Phys Lett. 2008;93:212504-1–212504-3.