Broadband Annular-Ring Dielectric Resonator Antenna

Mohammad J. Almalkawi

***Abstract*—**A broadband wire monopole antenna loaded by inhomogeneous stack of annular dielectric ring resonators (DRRs) is proposed. The proposed antenna exhibits a broad impedance bandwidth from 3 to 30 GHz. This is achieved by adding an external step matching network at the antenna feed point. The matching network is comprised of three annular DRRs possessing different permittivity values and sharing the same axial over a finite ground plane. The antenna performance is characterized using full-wave EM simulation. Compared to previous-reported wire antennas with improved bandwidth achieved by DRRs, the proposed topology provides relatively compact realization and superior broadband performance.

***Keywords*—**Broadband, dielectric ring resonator, wire monopole antenna.

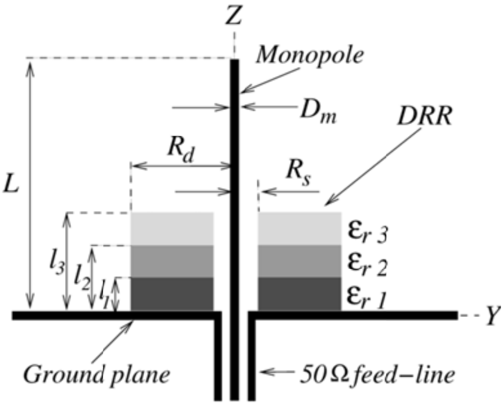
I. Introduction

TYPICALLY, all resonant antennas provide narrow bandwidth due to their limited input impedance matching. In order to meet the demand of emerging broadband wireless services, few techniques have been successfully employed [1]-[3] to increase the operational bandwidth, especially on wire monopole antennas, which have inherently narrow bandwidth. External matching networks were utilized to broaden an antenna impedance bandwidth [4], [5]. To list a few, attempts have been made for designing quarter-wave wire monopole antennas loaded by different cylindrical shapes of dielectric ring resonators (DRRs) exhibiting ultra-wideband (UWB) performance. Dielectric resonator antennas possess high power handling capabilities and stable dielectric parameter with temperature; reasons make such antennas suitable for many active and tunable circuits.

In general, single cylindrical or rectangular dielectric resonator with an air gap over a ground plane is employed as in [6]. Such approach leads to lowering the Q-factor and thus an increase in the bandwidth as described in (1).

$$BW\% = \frac{s-1}{Q\sqrt{s}}100\% \tag{1}$$

where s is the desired VSWR at the input port of the antenna. However, this is usually accompanied by a shift in the antenna resonant frequency or an increase in the dielectric resonator volume. Another way to increase the bandwidth of a cylindrical dielectric resonator antenna (DRA) is by removing a section of the central portion of the dielectric resonator to form an annulus or a DRR antenna with a stepped-radius [5]. This provides low effective dielectric constant and low Q-factor of the DRR, thus an increase in the antenna bandwidth.



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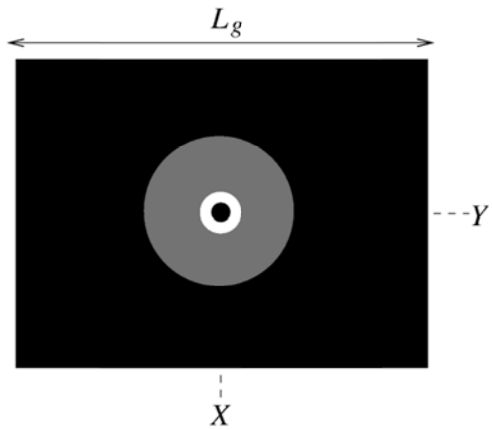

(b)

Fig. 1 (a) Cross-sectional view of the proposed antenna structure; and (b) its top view

In this paper, a broadband wire monopole antenna (Fig. 1) with an external matching network comprised of three annular DRRs possessing different permittivity values, sharing the same axial reference with uniform ring diameters and mounted on a finite ground plane is discussed. With each DRR implemented at a different frequency, the resonators can be combined to provide wideband or multi-band operation. Such approach allows each resonator to be tuned independently, and consequently leads to flexible implementation.

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II. Antenna Analysis

It is well-known that DRAs are normally excited using a probe or referred to as a monopole which is less than a quarter wavelength of the frequency of operation. Here, the probe does not act as a radiating element and when a monopole antenna extends beyond the DRRs at an upper end, a good radiation pattern is maintained. The monopole antenna in Fig. 1 mounts above the ground plane in a vertical position and has a physical length *L* of one quarter wavelength at the lowest resonance frequency (i.e., f_o=3.6 GHz) while the DRRs are designed to have a resonance near the upper end of the required spectrum [1]. The monopole located at the center of the DRRs, will excite the $TM_{01\delta}$ mode which radiates like a short vertical electric monopole. Considering uniform DRRs radius and the given dielectric constants, their corresponding resonant frequencies (*f*) are 9.53, 13.1, and 21.8 GHz, calculated using equations:

$$f = \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{\left(\frac{\pi}{2l}\right)^2 + \left(\frac{x_o}{R_d}\right)^2}\,, \quad (2)$$

and

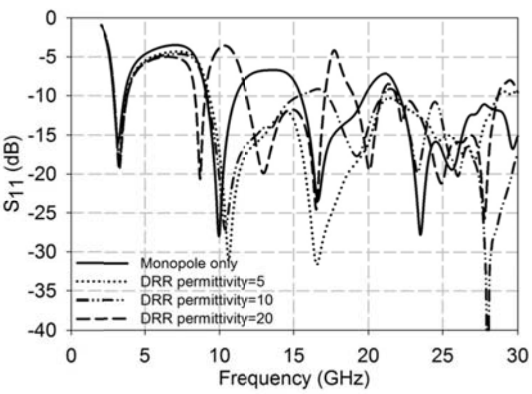
$$\frac{J_1(x_o)}{Y_1(x_o)} = \frac{J_1\left(\frac{R_s}{R_d}x_o\right)}{Y_1\left(\frac{R_s}{R_d}x_o\right)}\,. \quad (3)$$

where *c* is the speed of light, ε_r is the material permittivity, *l* is the DRR height, R_d is the DRR radius, R_s is the air-gap radius, and x_o is the solution to the Bessel's function in (3).

It is worth pointing out that the early studies on DRAs stated that the most critical parameter in achieving the proper broadband response was found to be the DRA's aspect ratio (R_d/l).

III. Results and Discussion

Fig. 2 shows detailed parametric study of the proposed antenna using a single DRR. Each parameter is a function of frequency representing different values of DRR's ε_r including vacuum (i.e., stand-alone monopole antenna), inner and outer DRR radius, and DRR height. In each case study, one parameter is varied at a time.



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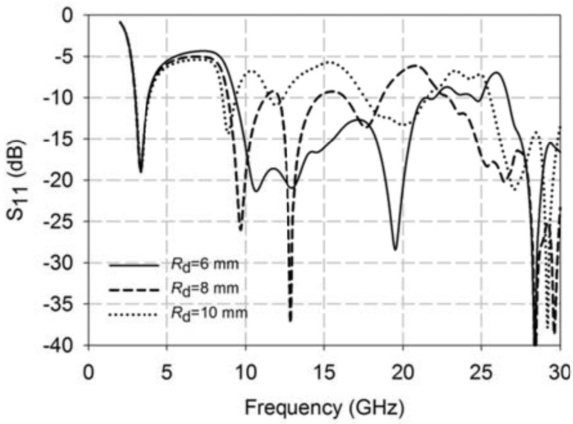

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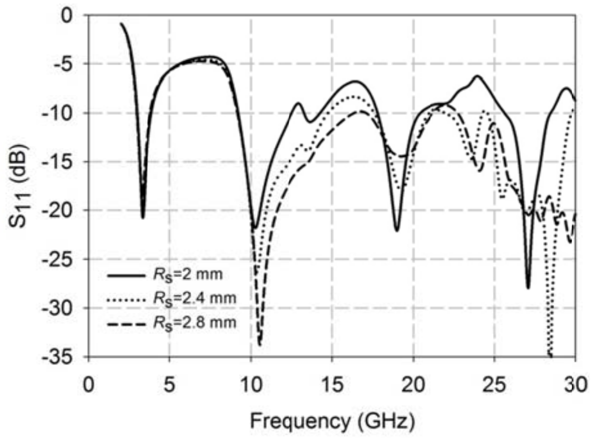

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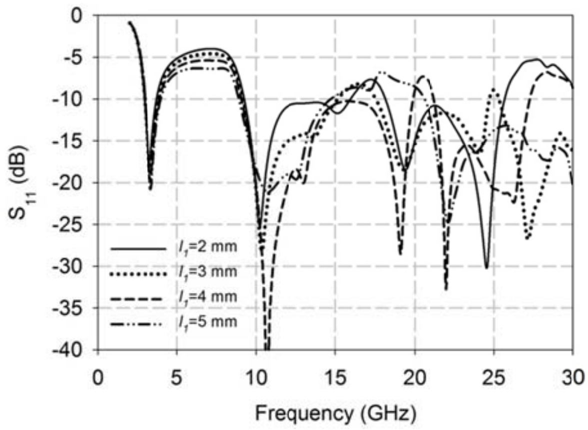


(d)

Fig. 2 Return losses versus frequency of the proposed antenna with: (a) varying ε_r; (b) varying R_d, varying R_s, and varying l_1

It can be seen from Fig. 2 (a) that a DRR with different ε_r values contributes to the high frequency end of the antenna return loss. Hence, the resonate frequency of the monopole antenna (at 3.2 GHz) remains fixed at different ε_r values.

Fig. 2 (b) shows the return losses of the proposed antenna for different values of the antenna outer radius (R_d), and ε_r=10. As can be seen, the high resonant frequency modes of the return loss shift down as the outer radius of the DRR increases. This leads to degradation in matching at the antenna high frequency end, while improving the return loss at the lower band (< 10 GHz).

Fig. 2 (c) illustrates that the impedance matching at the antenna high frequency end improves by varying the antenna inner radius (R_i), while the lower band remains relatively the same.

Variations of return loss for different values of the DRR heights, l_1, are also shown in Fig. 2 (d). It is observed that the height of the DRR has a significant effect at the impedance matching across the broad bandwidth.

Although a single DRR can improve the impedance matching at multiple high resonant frequencies (beyond the monopole resonant frequency), a DRR stack with different ε_r values are required to provide a smooth and continuous matching over abroad frequency range. DRR stack variation leads to different and consecutive high frequency modes that lead to an improved impedance bandwidth.

Upon investigating the parametric study results in Fig. 2, the proposed antenna in Fig. 1 has been constructed and significant parameters affecting the impedance matching of the proposed antenna have been identified and optimized.

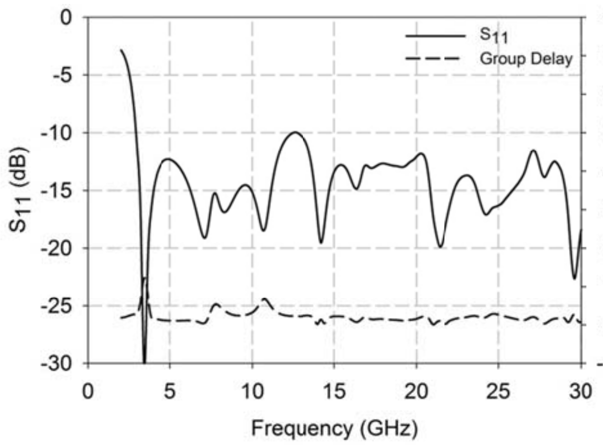


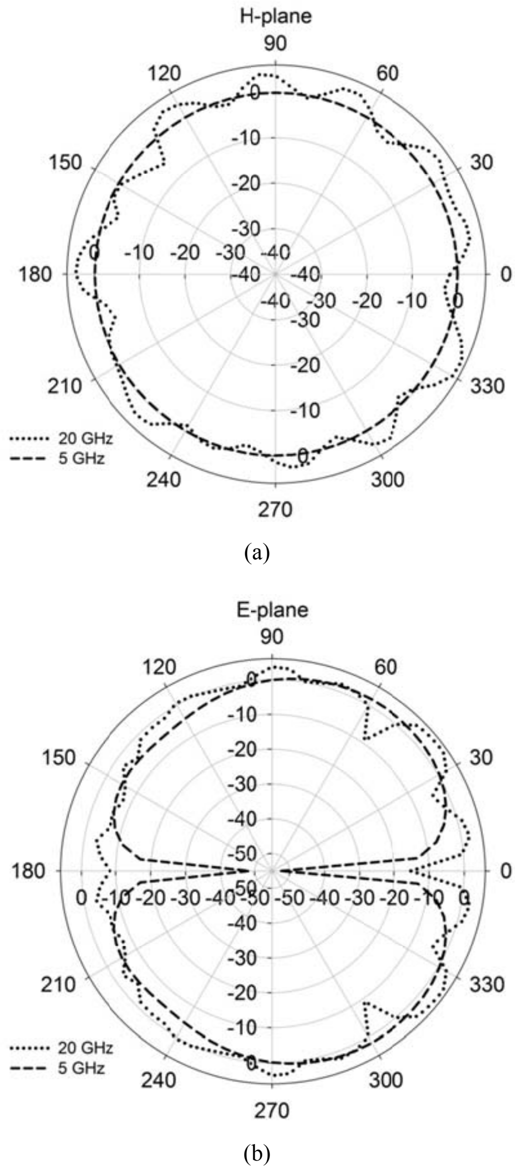
Fig. 3 Simulated return loss and group delay response against frequency of the proposed broadband antenna.

TABLE I
GEOMETRICAL PARAMETERS OF THE PROPOSED DRR ANTENNA IN FIG. 1

Parameter	Value (mm)
Square ground plane length (L_g)	60
L	20.75
l_1	3.1
l_2	3.4
l_3	2.2
R_d	6.8
R_s	2.5
D_m	2.4
ε_{r1}	20
ε_{r2}	10
ε_{r3}	5

The optimal dimensions of the constructed antenna are listed in Table I. Antenna dimensions were obtained with the aid of a full-wave electromagnetic (EM) simulations based on the finite element method (FEM), ANSYS-HFSS [7]. Copper was considered as a conductor for the monopole antenna and the ground plane.

Fig. 3 shows the simulated return loss response of the proposed antenna and the antenna group delay. The frequency performance demonstrates broad impedance bandwidth from 3 to 30 GHz with $|S_{11}|$ < -10 dB and a relatively constant group delay.



(a)

(b)

Fig. 4 Far-field radiation pattern of the proposed antenna: (a) H-plane; and (b) E-plane at 5 GHz and 20 GHz

Fig. 4 depicts the far-field radiation patterns along the antenna E-plane (i.e., YZ-plane) and H-plane (i.e., XY-plane) at 5 and 20 GHz, respectively. The monopole-like patterns are maintained over the broad bandwidth.

Fig. 5 illustrates the estimated antenna radiation efficiency over the broad frequency range. It can be observed from the radiation efficiency response that the proposed antenna can effectively radiate its energy from 3 to 30 GHz.

One of the reasons behind the poor radiation efficiency performance at high frequencies is the effect of the nearby ground conductor and dielectric materials which will constrain and absorb the near-fields of the antenna and cause significant losses. In addition, the ohmic (i.e., conduction and dielectric) losses and skin depth effect cause the effective resistance of the conductor to increase at higher frequencies where the skin depth is smaller.

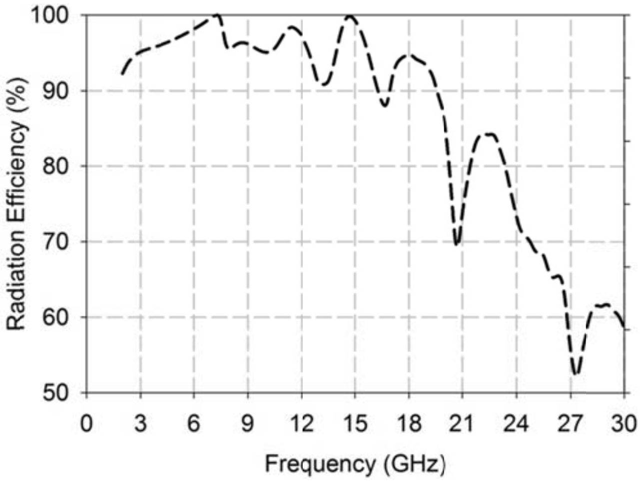


Fig. 5 Estimated radiation efficiency of the proposed antenna

IV. Conclusion

A compact and simple implementation of a hybrid broadband wire monopole antenna has been presented. Bandwidth improvement has been achieved by introducing inhomogeneous stack of three DRRs at the antenna feed point as an external step matching network loading the monopole antenna. Having the DRRs sharing the same vertical axis with uniform inner and outer radius led to straightforward implementation and flexible optimization.

References

[1] M. Lapierre, Y. Antar, A. Ittipiboon, and A. Petosa, “Ultra wideband monopole/dielectric resonator antenna,” IEEE Microwave and Wireless Components Lett., vol. 15, pp. 7–9, Jan. 2005.

[2] S. Ghosh and A. Chakrabarty, “Ultrawideband performance of dielectric loaded T-shaped monopole transmit and receive antenna/EMI sensor,” IEEE Antennas and Wireless Propag. Lett., vol. 7, pp. 358–361, 2008.

[3] M. Jazi and T. Denidni, “Design and implementation of an ultrawideband hybrid skirt monopole dielectric resonator antenna,” IEEE Antennas and Wireless Propag. Lett., vol. 7, pp. 493-496, 2008.

[4] D. Guha, B. Gupta, and Y. Antar, “New pawn-shaped dielectric ring resonator loaded hybrid monopole antenna for improved ultrawide bandwidth,” IEEE Antennas and Wireless Propag. Lett., vol. 8, pp. 1178-1181, 2009.

[5] C. Ozzaim, “Monopole antenna loaded by a stepped-radius dielectric ring resonator for ultrawide bandwidth,” IEEE Antennas and Wireless Propag. Lett., vol. 10, pp. 843-845, 2011.

[6] K. Luk, K. Leung, and J. James, Dielectric Resonator Antennas, Research Studies Press Ltd., Hertfordshire, England, June 2002.

[7] High Frequency Structure Simulator (HFSS). ver. 14, ANSYS.