Four-Element Triangular Wideband Dielectric Resonator Antenna excited by a Coaxial Probe

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Abstract-This paper numerically examines an array of four dielectric resonant antenna of equilateral triangle shape. The Structure provides wideband low profile monopole-like antenna. As much as 30.90 % matching bandwidth (S_{11}<-10 dB) with monopole-like radiation pattern over the entire band has been achieved with 6.357 dBi peak gain. The geometry is a four equilateral triangular dielectric volume over a ground plane, and is centrally excited by a coaxial probe to provide a broadside radiation pattern. An approximate expression is used to compute the resonance frequency. Results are simulated using CST (Computer Simulation Technology) Microwave Studio Suite 10.

Keywords-Dielectric resonator (DR), triangular dielectric resonator antenna (TDRA), S_{11} (S-Parameter), perfect conductor (PEC), Impedance Bandwidth (IBW).

I.   Introduction

Dielectric resonator has been used for energy storage for many years. Presently, DR has found its new application as a radiator in microwave circuits. Open dielectric resonators (DRs) offer attractive features as antenna elements [1]. Some features are small size, mechanical simplicity, high radiation efficiency (due to no inherent conductor loss), relatively large bandwidth, and simple coupling schemes to nearly all commonly used transmission lines. In addition it has the advantage of obtaining different radiation characteristics using different modes of the resonator [1-3]. The radiation Q factor of a DR antenna depends on its excitation modes as well as the dielectric constant of the ceramic material. The Q-factor increases and hence the bandwidth decreases with increasing dielectric constant and vice-versa. For this reason, DRs of relatively low dielectric constant are always used in antenna applications [4]. It was found that some geometry might have a wider bandwidth or better linear polarization characteristics than others. The advantage of the triangular DRA is that it offers a smaller area than either a cylindrical or rectangular DRA for a given height and resonant frequency. This paper presents the simulation of a four element Triangular wideband dielectric resonator antenna excited by a coaxial probe. The paper is organized as follows; Section II provides the basic theory of DRA. Details of the proposed antenna structure are provided in Section III. The simulation results of the proposed antenna structure have been presented and discussed in Section IV and finally, Section V provides Conclusions.

II.   Theory

The triangular-shaped DRA, shown in Figure 1, has been introduced as a candidate for low-profile applications. As an example, a high-permittivity, low-profile triangular DRA was designed with $\varepsilon_r = 82$, h=1.1 mm and a=20mm [5]. This DRA was found to have a 5% IBW. To achieve the same resonant frequency, a cylindrical DRA of the same height and permittivity would require a radius of a=7.55 mm, while a rectangular DRA would require dimensions of w=d=19 mm. Thus the size of the triangular DRA would be about 92% that of the cylindrical DRA and about 48% that of the rectangular DRA. The resonant frequency of the TM_{lmn} modes of an equilateral triangular DRA (where $l+m+n=0$) can be estimated using the transcendental equations derived from a waveguide model [5]. The first subscript l_{in} the notation TM_{lmn} states the order of the Bessel functions of the first and second kind which must be used to calculate the resonant frequency of that mode, the second subscript m in the designation of the mode denotes the order of magnitude of the root which is used to calculate the resonant frequency, the third subscript n is merely a coefficient in the argument of a trigonometric function which enters into the expressions for the electric and magnetic fields inside the cavity. The resonance frequency is predicted using a simple waveguide mode of a magnetic wall. Tangential field continuity to the surface of the dielectric interface at z=±h will result in the transcendental equation [3].

$$k_z \tan(k_z h - \frac{\pi}{2}) = k_z^0 \text{ And } k_z^0 = \sqrt{\varepsilon_r - 1 - k_z} \dots (1) \text{ where : } k_z = \frac{p\pi}{2h}, p = 1,2,3\dots.$$

Where k_z and k_z^0 are the wave numbers in the z-direction in the dielectric and free space, respectively. The dielectric resonator height h can be obtained from (1) as [3]

$$h = \frac{1}{k_z}(\tan^{-1}(\frac{k_z^0}{k_z}) + \frac{\pi}{2}) \dots (2)$$

The resonance frequency can be obtained in terms of k_z, using the following expression:

$$f_{mn} = \frac{c}{2\pi\sqrt{\varepsilon_r}}[(\frac{4\pi}{3L_d})^2 (m^2 + mn + n^2) + k_z^2]^{1/2} \dots (3)$$

Where c is the speed of light, L_d is the length of the equal side of the equilateral triangular antenna and ε_r is the dielectric constant. Here, we used the resonance frequency index mn instead of mnl because the third index l=m+n is dependent on the values of m and n [3]. It has been found that if we vary these parameters say the height of the antenna (h), dielectric constant of the DRA (ε_r) and the side of the antenna (L_d) as shown in equation (1-3) then we can find the combination of these parameters where we can have better radiation efficiency and bandwidth. Then we can calculate the resonant frequency at these specified values.

III.   Antenna Structure
The geometry of the triangular dielectric resonator is shown in Fig. 1. A dielectric resonator with height hand an equitriangular uniform cross section with a side length $L_d$is considered. The material used is Epoxy resin with dielectric constant ε_r=4, material density is 1500 kg/m^3, μ_r=1, thermal conductivity is 0.2 W/k/m, Young's modulus =13 Gpa and Poisson's ratio=0.45. The excitation is a z-directed coaxial probe of length h_P and located at the center. The probe is connected to an SMA connector. The ground plane is a square plane of a perfect conductor of side S and thickness t=3 mm. Center probe feeding is done in this model.

(a)

(b)

(c)
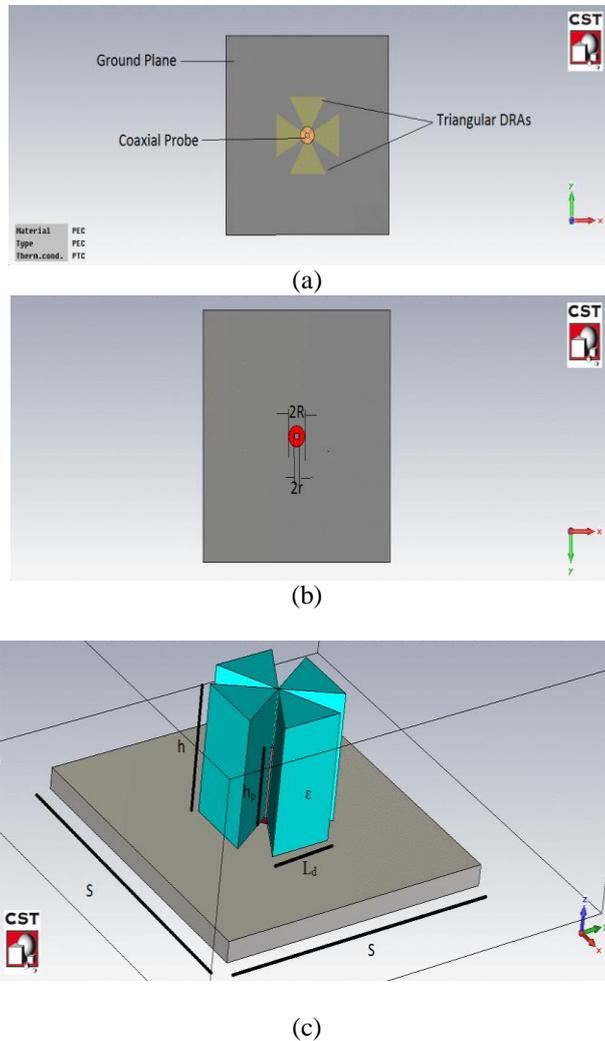
Figure 1. Geometry of the Four Triangular DRA with Ground Plane (a) Top View (b) Bottom view (c) Side View [h=18, hp=10, S=50, L_d=11,ε_r=4, r=0. 635, R=2. 124] All dimensions are in mm

There is a ground plane as shown in Fig. 1(a) which is perfectly conductor. Then four equilateral triangular DRA are placed such that its one edge is touching in the center. Now center coaxial probe feeding is done whose radius is r=0.635 mm and is insulated by Teflon (material density is 2200 kg/m^3, μ_r=1, ε_r=2.1, thermal conductivity is 0.2 W/k/m, Young's modulus=0.5 GPA, Thermal expansion coefficient=1401e-6/K and Poisson's ratio=0.4) up to the ground plane whose outer radius is R=2.124mm as shown in Fig. 1 (b). Fig. 1 (b) shows the bottom view of the antenna where we can see the coaxial probe insulated with Teflon at the center. And the Fig.1 (c) shows the side view of antenna to have a 3-d Visualization of the antenna that helps in understanding the antenna structure. The indicated ring in the Fig. 1 (b) is Teflon which is below the triangular DRA and around the probe to insulate it from the ground plane, so feeding can be done to triangular DRA not to the ground plane.

IV.   Results

The structure has been simulated and S-Parameter is shown in Fig. 2, we have a resonant frequency at f=5.21GHz with a bandwidth of 1.61 GHz ranging from 4.47 to6.08 GHz (where S_{11}<-10 dB). The return loss is maximum up to-12.89 dB at the resonant frequency. The radiation-factor can be used to estimate the impedance bandwidth of a DRA [4]

$$Bandwidth(BW) = \frac{VSWR-1}{Q_{rad}\sqrt{VSWR}} = (\frac{FH-FL}{FC}) \ldots (4)$$ Where f_H is the higher cut-off frequency and f_L is lower

cut-off frequency. The return loss, S_{11}dB is shown in Fig. 2 where we can clearly see the maximum dip at 5.21GHz.
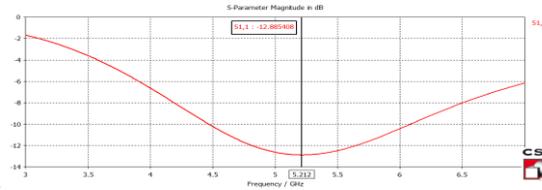
Figure 2. S-parameter representation [h=18, hp=10, S=50, L_d=11, ε_r=4, r=0.635, R=2.124] All dimensions are in mm

The Farfield radiation pattern at f =5.4 GHz can be shown in Fig. 3 which shows a maximum gain of 6.357 dBi. We can have a polar plot of E-plane and H-plane in Fig. 4(a), (b) respectively to understand the variation with change in Theta and Phi. E-Plane is representing Electric Monopole structure created as it is centrally excited and only one mode is excited. Its main lobe direction is 90.0 deg. and its magnitude is 6.4 dB. H-Plane is representing Horizontal Magnetic Dipole whose main lobe direction is 0.0 deg. and its magnitude is -82.8 dB. In Fig. 5 we can see the E - field distribution which is converging at the center. Fig. 6 shows the circularly revolving H- field.
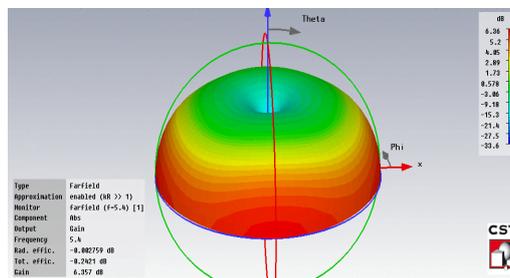
Figure 3.3-D view simulated gain of the triangular dielectric resonator [h=18, hp=10, S=50, L_d=11, ε_r=4, r=0.635, R=2.124] All dimensions are in mm

(a)

(b)
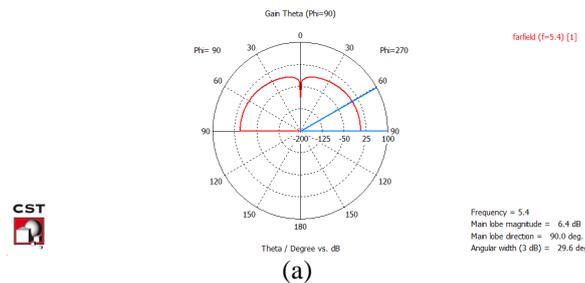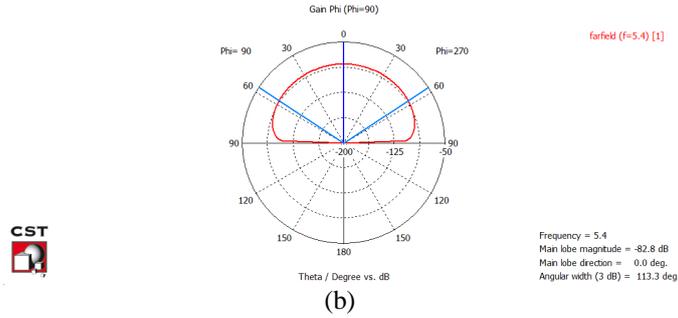
Figure 4. (a)E-Plane (Electric Monopole), (b) H-Plane (Horizontal Magnetic Dipole) [h=18, hp=10, S=50, L_d=11, ε_r=4, r=0.635, R=2.124] All dimensions are in mm
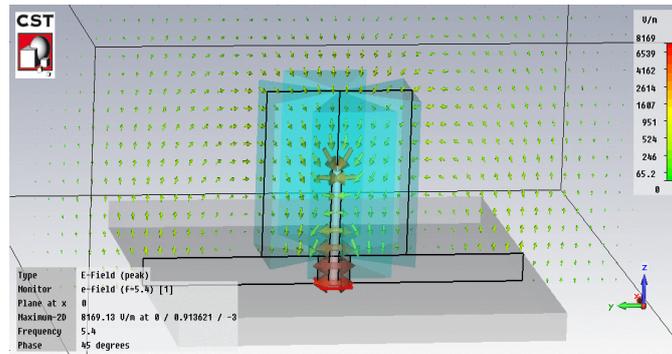
Figure 5.E-Fielddistribution at 5.4 GHz [h=18, hp=10, S=50, L_d=11, ε_r=4, r=0.635, R=2.124] All dimensions are in mm
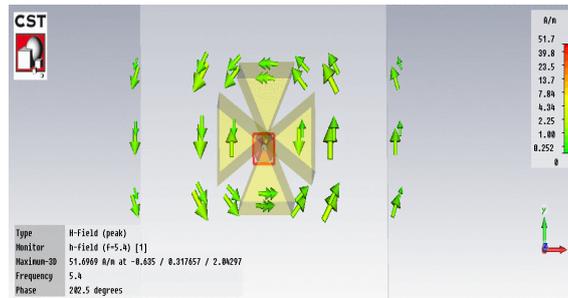
Figure 6. H-Field distribution at 5.4 GHz [h=18, hp=10, S=50, L_d=11, ε_r=4, r=0.635, R=2.124] All dimensions are in mm

Fig. 7 shows the variation in the real (R_{in}) and imaginary part (X_{in}) of simulated input impedance. When there is a proper impedance matching then we get the resonant frequency where the gain is maximized.
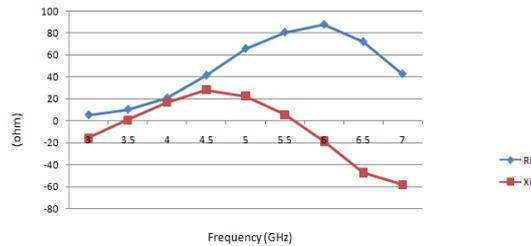
Figure 7. Simulated input impedance [h=18, hp=10, S=50, L_d=11, ε_r=4, r=0.635, R=2.124] All dimensions are in mm

Fig. 8 and Table I shows IBW is maximized (30.90%) for ε_r=4 keeping other parameters constant. As we increase ε_r, IBW will go on decreasing as the Q-factor is directly proportional ε_r and hence inversely proportional to IBW as shown in equation (4). Similarly, in Fig. 9 and Table II represents IBW is maximum for height of antenna h=18 mm by keeping other parameters constant.
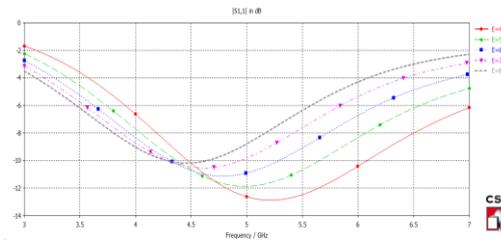
Figure 8. Variation of S-Parameter with variation in ε_r [h=18, hp=10, S=50, L_d=11, r=0.635, R=2.124] All dimensions are in mm

Table I. IMPEDANCE BANDWIDTH FOR DIFFERENT DIELECTRIC CONSTANT [h=18, hp=10, S=50, L_d=11, r=0.635, R=2.124] All Frequency are in GHz

Epsilon (ε_r)	Range(f_H- f_L)	Resonant Frequency (f_C)	BW	Impedance BW ($\frac{fH-fL}{fC}$)%
4	6.08 – 4.47	5.21	1.61	30.90
5	5.65 – 4.37	4.98	1.28	25.70
6	5.29 – 4.31	4.78	0.98	20.50
7	4.94 – 4.29	4.61	0.65	14.10
8	4.64 – 4.28	4.46	0.36	08.07
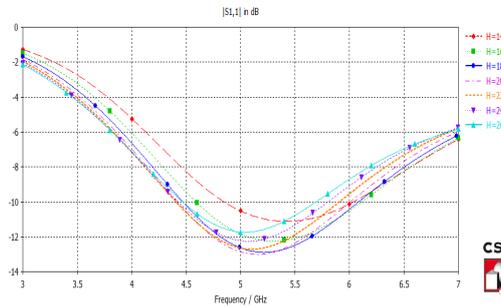
Figure 9. Variation of S-Parameter with variation in h with [hp=10, S=50, L_d=11, ε_r=4, r=0.635, R=2.124] All dimensions are in mm

Table II. IMPEDANCE BANDWIDTHFOR DIFFERENT HEIGHT OF ANTENNA [hp=10, S=50, L_d=11, ε_r=4, r=0.635, R=2.124] All Frequency are in GHz

Height of antenna (h)	Range(f_H- f_L)	Resonant Frequency (f_C)	BW	Impedance BW ($\frac{fH-fL}{fC}$)%
14	6.01 – 4.84	5.42	1.17	21.57
16	6.11 – 4.59	5.30	1.52	28.68
18	6.08 – 4.47	5.21	1.61	30.90
20	6.00 – 4.42	5.15	1.58	30.67
22	5.90 – 4.41	5.10	1.49	29.21
24	5.79 – 4.42	5.07	1.37	27.02
26	5.69 – 4.47	5.04	1.22	24.21

Here, the diameter of the probe is 2r=1.27 mm and its height (h_P) is varied accordingly for proper matching. Fig. 10 and Table III shows IBW is maximum for h_P= 10 mm.
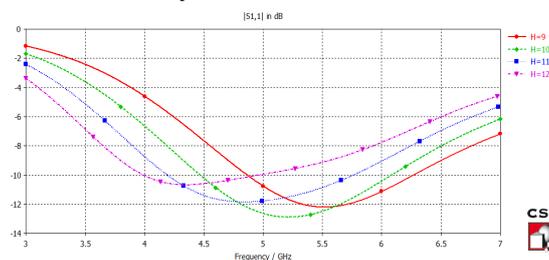
Figure 10. Variation of S-Parameter with variation in hip [h=18, S=50, L_d=11, ε_r=4, r=0.635, R=2.124] All dimensions are in mm.

Table III. IMPEDANCE BANDWIDTH FOR DIFFERENT HEIGHT OF COAXIAL PROBE [h=18, S=50, L_d=11, ε_r=4, r=0.635, R=2.124] All Frequency are in GHz

Height of Coaxial Cable (hp)	Range(f_H- f_L)	Resonant Frequency (f_C)	BW	Impedance BW $(\frac{fH - fL}{fC})$%
9	6.26 – 4.86	5.52	1.40	25.36
10	6.08 – 4.47	5.21	1.61	30.90
11	5.75 – 4.20	4.84	1.55	32.02
12	5.01 – 4.00	4.35	1.01	23.22

It has been observed that we get better results for h=18 mm, h_P= 10 mm, ε_r=4.
The simulated VSWR of Four TDRA is shown in Fig. 11. The matching frequency range is from 4.47 to 6.08 GHz where the VSWR < 2 and return loss (S_{11}) < -10 dB.
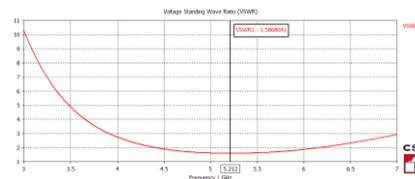
Figure 11.VSWR for Four Triangular DRAs [h=18, hp=10, S=50, L_d=11, ε_r=4, r=0.635, R=2.124] All dimensions are in mm

This can be examined through these formulae
$\Gamma =(Z_1-Z_o)/(Z_1+Z_o)$… (5)
$VSWR = (1+\Gamma) /(1-\Gamma)$ … (6)
Where Γ is the reflection co-efficient. Z_1 is the antenna impedance and Z_o is the feed line impedance.

V.   Conclusions

This paper examined the performance of the TDRA excited by a coaxial probe. The resonance frequencies were computed using an approximate expression. The selected mode was verified using H-field pattern. It is found that the proposed TDRA has a wideband pattern as it has IBW 30.90% (> 20 %) where S_{11} < -10 dB from 4.47 to 6.08 GHz. It has a monopole like radiation pattern which is stable in the pass band with gain 6.357 dBi at 5.4 GHz. This antenna may be suitable for C-band application like IEEE 802.11a Wi-Fi and cordless telephone.

References

[1]   J. K. Plourde and C. Ren, MEMBER, IEEE "Application of Dielectric Resonators in Microwave Components,"*IEEE Transactions on Microwave Theory and Techniques*, vol. MTT-29, NO. 8, pp. 754–770, AUGUST 1981.
[2]   R. K. Mongia and P. Bhartia, "Dielectric resonator antennas—A review and general design relations for resonant frequency and bandwidth,"*International Journal of Microwave and Millimeter-Wave Computer Aided Engineering*, vol. 4, pp. 230–247, July 1994.
[3]   A. A. Kiosk, "A Triangular dielectric resonator Antenna Excited by a coaxial probe,"*Microwave and Optical Technology Letters* / Vol. 30, No. 5, pp. 340-341, September 5 2001.
[4]   R. K. Chaudhary, K. V. Srivastava and A. Biswas, "Four Element Multilayer Cylindrical Dielectric Resonator Antenna Excited by coaxial probe,"*IEEE* 978-1-61284-091-8/11/2011.
[5]   Lo, H.Y. and K. W. Leung, "Excitation of low –Profile Equilateral- Triangle Dielectric Resonator Antenna Using a Conducting Conformal Strip," *Microwave and Optical Technology Letters*, Vol. 29, NO. 5, pp. 317-319, June 2001.
[6]   Yoshihiko Akaiwa, "Operation Modes of a Waveguide Y Circulator*," IEEE Transactions on Microwave Theory & Techniques*, pp. 954-960, November 1974.
[7]   H.Y. Lo, K. W. Leung, K.M. Luk, and E.K.N. Yung, "Low profile triangular dielectric resonator antenna,"*2000 IEEE Antennas and Propagation Society International Symposium*, Vol. 4, pp. 2088-2091, July 2000.
[8]   S. A. Long, M. W. McAllister and L.C. Shen, "The resonant cylindrical dielectric cavity antenna,"*IEEE Transactions on Antennas Propagation*, pp. 406-412, April 1983.
[9]   M. C. McAllister, G.L. Conway and S. A. Long, "Rectangular dielectric-resonator antenna,"*Electron Letter*, pp. 218-219, March 1983.
[10]   A. A. Kishk, G. Zhou, and A. W. Glisson, "Analysis of dielectric resonator antennas with emphasis on hemispherical structures,"*IEEE Antennas and Propagation Magazine,* Vol. *36,* No. 2, pp. 20-31,April 1994.
[11]   R. K. Mongia, A. Ittipiboon, P. Bhartia, and M. Cuhaci, "Electric monopole antenna using a dielectric ring resonator,"*Electron Letter*, 1530-1531, August 1993.
[12]   B. Owen, "The identification of modal resonances in ferrite loaded waveguide Y-junctions and their adjustment for circulation," *Bell System Tech. J.*, Vol. 51, pp. 595–627, March 1972.
[13]   J. Helszajn and F. C. Tan, "Design data for radial-waveguide circulators using partial-height ferrite resonators," *IEEE Trans. Microwave Theory Tech.,*Vol. MTT-23, pp. 288–298, March1975.
[14]   K. K. Chow, "On the solution and field pattern of cylindrical and dielectric resonators," *IEEE Transaction on Microwave Theory and Techniques*, vol. MTT-14, pp. 439, September 1996.
[15]   D. Guha and Y. M. M. Antar, "Four-Element Cylindrical Dielectric Resonator Antenna for Wideband Monopole-Like Radiation,"*IEEE Transaction on Antennas and Propagation*, Vol.54, No.9, pp. 2657-2662, September 2006.