IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 9, Issue 3, Ver. VI (May - Jun. 2014), PP 01-07
www.iosrjournals.org

Stacked Equilateral Triangular Dielectric Resonator Antenna Excited With Coaxial Feeding

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Abstract: *This paper examines a stack of triangular dielectric resonator antenna which is equilateral in shape. The impedance bandwidth is 16.43% (S_{11}<-10 dB) with wideband monopole-like radiation pattern over the entire band has been examined with 4.987dBi peak gain. The efficient radiation pattern is achieved when the geometry of two equilateral triangular dielectric volume is placed over a ground plane, and using coaxial probe for the excitation. CST (Computer Simulation Technology) Microwave Studio Suite 10 is used for the simulation of the designed antenna.*

Keywords: *Triangular dielectric resonator antenna (TDRA), Dielectric resonator (DR), Impedance Bandwidth (IBW), S_{11} (S-Parameter), Fractional Bandwidth (FBW), Perfect conductor (PEC).*

I. Introduction

Dielectric resonator has been used at microwave frequencies and higher. From past many years it is used for energy storage. Presently, DR is used as a radiator in microwave circuits.The dielectric resonator antenna (DRA) has some attractive features like small size, low cost, low loss, and relatively wide bandwidth (~10% for εr~10), 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 [1]. 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 [4]. DRs is used for antenna application of relatively low dielectric constant for this reason [4]. 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 [5]. This paper presents the simulation of a stacked equilateral Triangular dielectric resonator antenna excited by a coaxial probe.

II. Theory

The triangular dielectric resonator antenna is used in antenna array designing as large range of spacing between the elements is allowed. 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 [4]. The first subscript l_m 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[4]. The resonance frequency of the TM_{lmn} mode in an equilateral triangular DRA on ground plane is approximately given:

$$f_{mnl} = \frac{1}{2\sqrt{\varepsilon\mu}}\left[\left\{\frac{4}{3a}\right\}^2 \{m^2 + mn + n^2\} + \left\{\frac{1}{2h}\right\}^2\right]$$

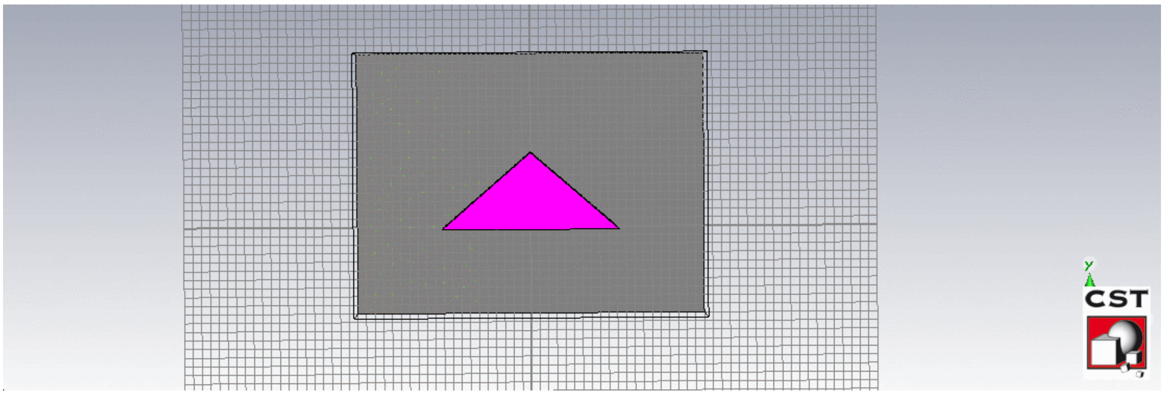
After simplification of the result, it is given as:

$$f_{mnl} = \frac{1}{4h\sqrt{\varepsilon\mu}}$$

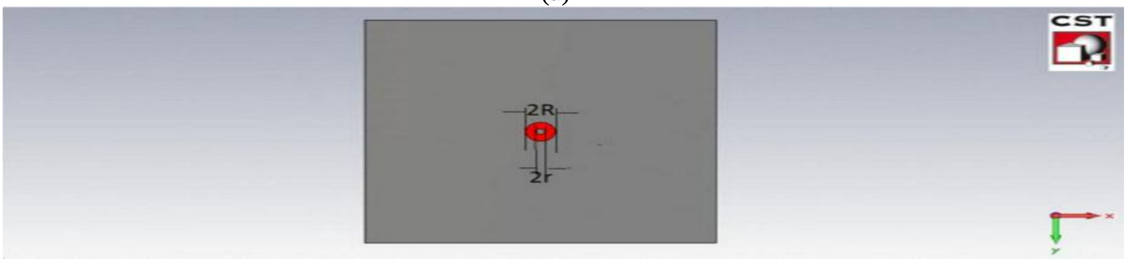
Where 'a' is the length of the equal side of the equilateral triangular antenna and εr is the dielectric constant. Combination of these parameterssay the height of the antenna (h), dielectric constant of the DRA (εr), and the side of the antenna (a) can have better radiation efficiency and bandwidth. So, 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. We have considered an equilateral triangle stacked over each other of side 10mm each. Different materials and different heights are used for the two TDRAs. Materials used are i.e.ROGERS R03210 (lossless) with dielectric constant εr_1=10.2, μ_r=1, thermal conductivity is 0.66W/k/m and Taconic CER-10 (lossless) with dielectric constant εr_2=10, μ_r=1, thermal conductivity is 0.63W/k/m respectively. The two TDRAs are loaded with a coaxial probe whose feeding is given from the center for excitation. The ground plane is a rectangular plane of a perfect conductor of dimension l*b= 40*30 and thickness t=3 mm.



(a)



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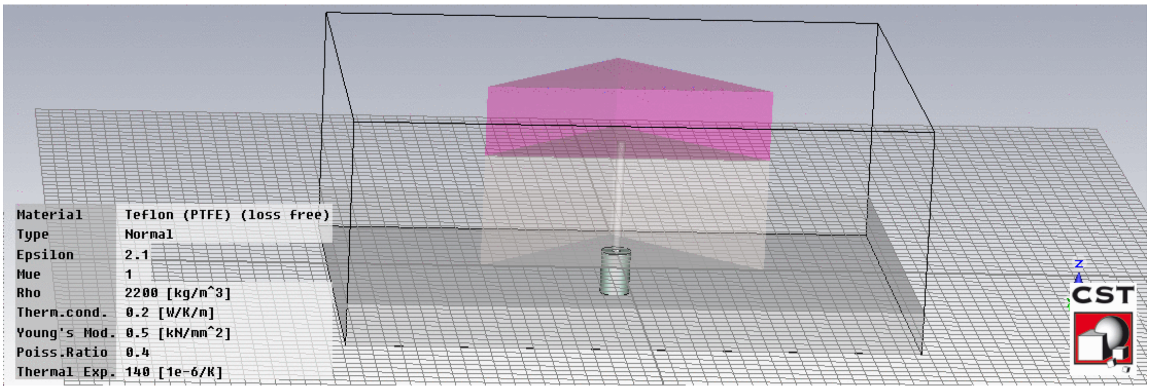


(c)

Fig. 1. Geometry of the Four Triangular DRA with Ground Plane (a) Top View (b) Bottom view (c) Side View [h_1=8, h_2=5, h_3=8, a=10, εr_1=10.2, εr_2=10, r=0.314, R=1.05] All dimensions are in mm

The ground plane is perfectly conductor. The two triangular DRAs of different heights are stacked over each other above the ground plane as shown in Fig. 1(a) and Fig. 1(b). Now center coaxial probe feeding is done whose radius is r=0.314 mm and is insulated by Teflon (material density is 2200 kg/m^3, μ_r=1, εr=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=1.05mm as shown in Fig. 1(c). This Fig. 1(c) helps us to understand the 3-D structure of the TDRA loaded with coaxially feeding. Teflon is used to insulate the probe 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, the graph shows that port1 has resonant frequency at f=10.596GHz with a bandwidth of 1.71GHz ranging from 9.55 to 11.26GHz (where S_{11}<-10 dB). The return loss is maximum up to -26.31154dB at the resonant frequency. The radiation-factor can be used to estimate the impedance bandwidth of a DRA [4]

$$Bandwidth(BW) = \frac{VSWR-1}{Q\sqrt{VSWR}} = \frac{fH - fL}{fc}$$

Here fH 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 at -26.31dB.

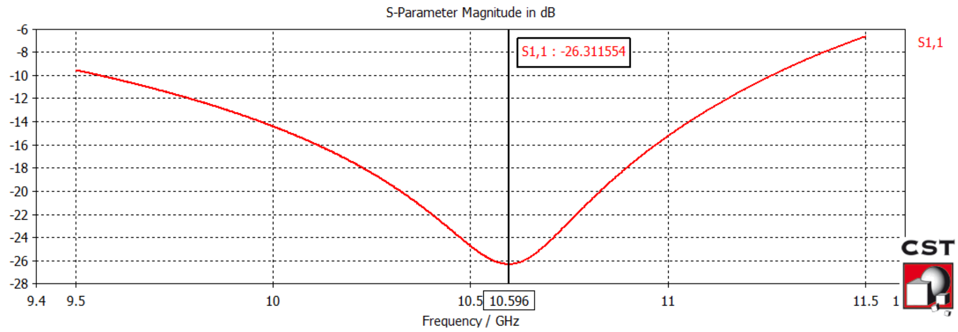


Fig. 2. S-parameter representation [h_1=8, h_2=5, h_3=8, a=10, εr_1=10.2, εr_2=10, r=0.314, R=1.05] All dimensions are in mm

The Far-field radiation pattern at f =10.596 GHz can be shown in Fig. 3 which shows a maximum gain of 4.987dB. We have chosen the far-field at this frequency as the radiation efficiency of the antenna is about 96% whereas the total antenna efficiency is about 96% approximately which was much better from pattern at some other frequency.

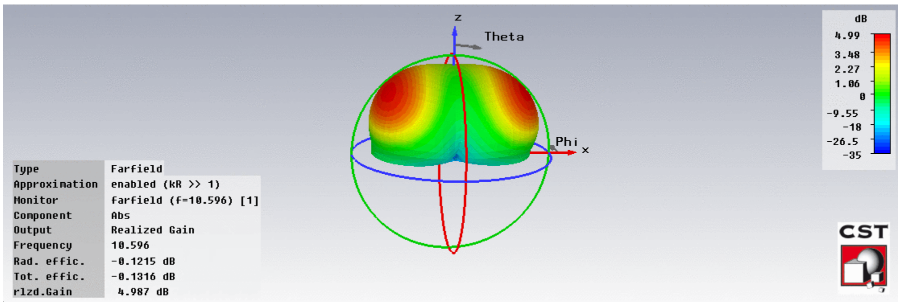
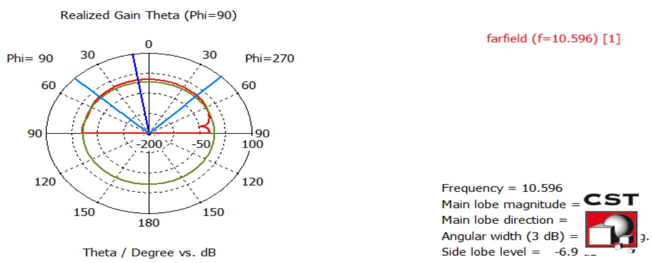
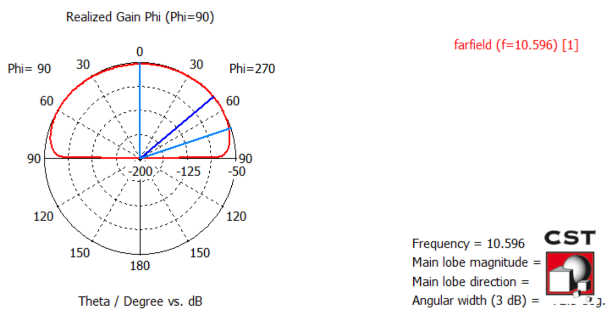


Fig. 3. 3-D view simulated gain of the stacked triangular dielectric resonator [h_1=8, h_2=5, h_3=8, a=10, εr_1=10.2, εr_2=10, r=0.314, R=1.05] All dimensions are in mm.



(a)



(b)

Fig. 4. (a) E-Plane (Electric Monopole), (b) H-Plane (Horizontal Magnetic Dipole [h_1=8, h_2=5, h_3=8, a=10, εr_1=10.2, εr_2=10, r=0.314, R=1.05] All dimensions are in mm.

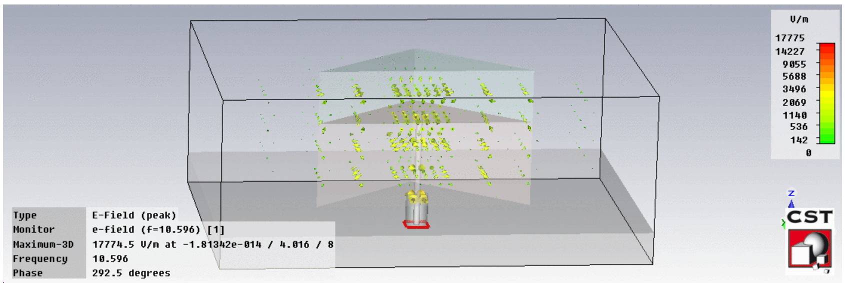


Fig. 5. E-Field distribution at 10.596 GHz [h_1=8, h_2=5, h_3=8, a=10, εr_1=10.2, εr_2=10, r=0.314, R=1.05] All dimensions are in mm.

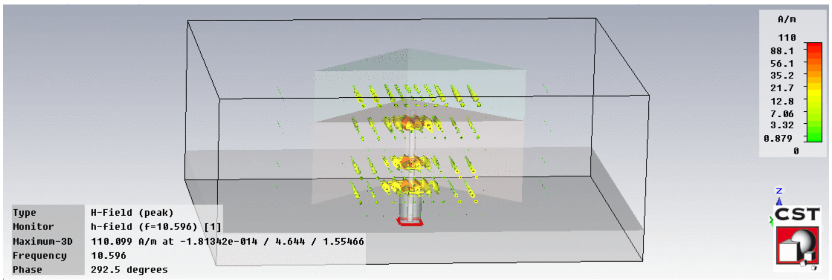


Fig. 6. H-Field distribution at 10.596 GHz [h_1=8, h_2=5, h_3=8, a=10, εr_1=10.2, εr_2=10, r=0.314, R=1.05] All dimensions are in mm.

Fig. 7 shows the magnitude of simulated input impedance. When there is a proper impedance matching then we get the resonant frequency where the gain is maximized. The maximum magnitude at frequency 10.596 GHz is 52.45 at $z_{1,1}$ port.

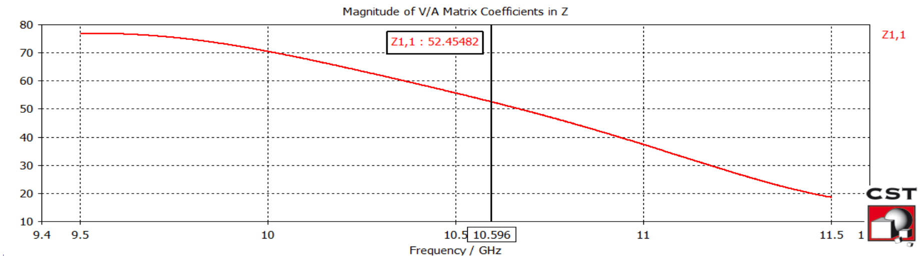


Fig. 7. Magnitude of simulated input impedance [h_1=8, h_2=5, h_3=8, a=10, εr_1=10.2, εr_2=10, r=0.314, R=1.05] All dimensions are in mm.

Fig. 8 shows s-parameter is maximized for εr_1=10.2, εr_2=10 respectively keeping other parameters constant. The Fig. 8 states that the value of epsilon for the two triangles are varied but the result obtained indicates that there is no change in the s-parameter of the antenna. So we have taken εr_1=10.2, εr_2=10 which are ROGERS R03210 (lossless) with dielectric constant εr_1=10.2, μ_r=1, thermal conductivity is 0.66W/k/m and Taconic CER-10 (lossless) with dielectric constant εr_2=10, μ_r=1, thermal conductivity is 0.63W/k/m respectively.

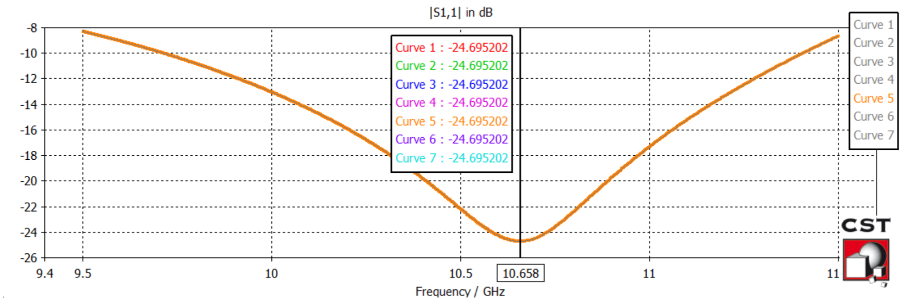


Fig. 8. Variation of S-Parameter with variation in εr [h_1=8, h_2=5, h_3=8, a=10, εr_1=10.2, εr_2=10, r=0.314, R=1.05] All dimensions are in mm.

Similarly, in Fig. 9 and Table I represents s-parameter is maximum for height of antenna h_1=8 mm by keeping other parameters constant.

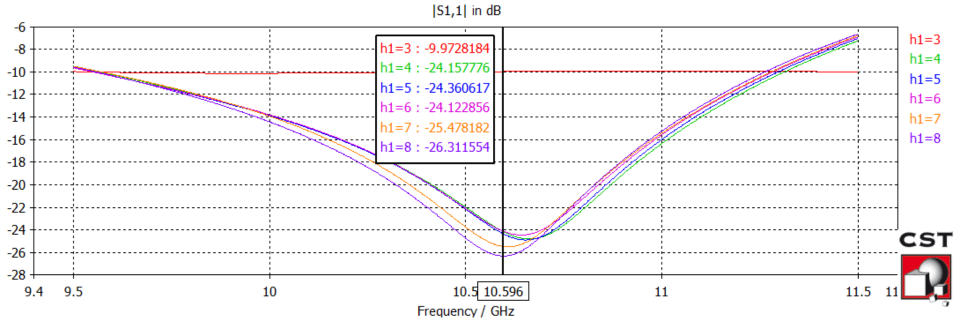


Fig. 9. Variation of S-Parameter with variation in h_1 with [h_1=8, h_2=5, h_3=8, a=10, εr_1=10.2, εr_2=10, r=0.314, R=1.05] All dimensions are in mm.

Table I. IMPEDANCE BANDWIDTH FOR FIRST HEIGHT OF THE TRIANGULAR ANTENNA (h_1) [h_1=8, h_2=5, h_3=8, a=10, εr_1=10.2, εr_2=10, r=0.314, R=1.05] All Frequency are in GHz

Height of the antenna h_1	Range(f_H- f_L)	Resonant Frequency (f_{C1})	s-parameter	Impedance BW ($\frac{f_H - f_L}{f_{C_1}}$)%
4	9.53-11.31	10.42	-24.15	17%
5	9.55-11.30	10.425	-24.36	16.78%
6	9.54-11.28	10.41	-24.12	16.71%
7	9.57-11.27	10.42	-25.47	16.31%
8	**9.55-11.26**	**10.40**	**-26.31**	**16.44%**

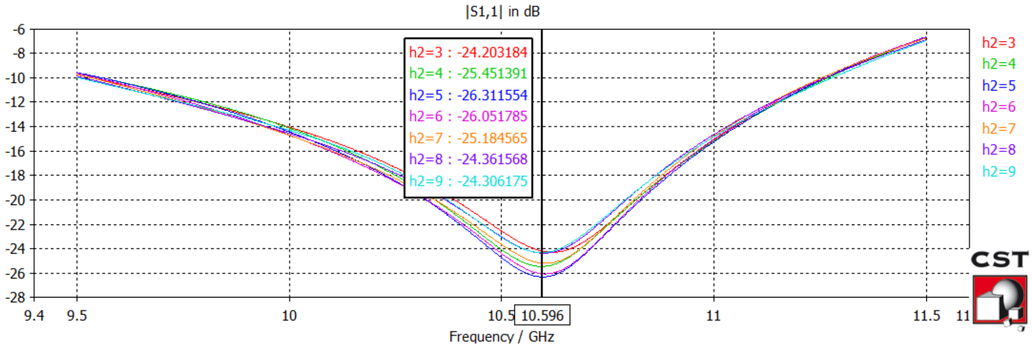


Fig. 10. Variation of S-Parameter with variation in h_2 with [h_1=8, h_2=5, h_3=8, a=10, εr_1=10.2, εr_2=10, r=0.314, R=1.05] All dimensions are in mm.

In Fig. 10 and Table II represents s-parameter is maximum for height of antenna h_1=5 mm by keeping other parameters constant.

Table II. IMPEDANCE BANDWIDTH FOR SECOND HEIGHT OF ANTENNA (h_2) [h_1=8, h_2=5, h_3=8, a=10, εr_1=10.2, εr_2=10, r=0.314, R=1.05] All Frequency are in GHz

Height of antenna (h_2)	Range(f_H- f_L)	s-parameter (s_{11})	BW	Impedance BW ($\frac{f_H - f_L}{f_C}$)%
3	9.53-11.39	-24.20	1.86	12.6%
4	9.55-11.26	-25.45	1.71	16.43%
5	**9.55-11.26**	**-26.31**	**1.71**	**16.43%**
6	9.54-11.25	-26.05	1.71	16.45%
7	9.53-11.25	-25.18	1.73	16.65%
8	9.51-11.26	-24.36	1.75	16.85%
9	9.50-11.27	-24.306	1.77	17.04%

Here, the diameter of the probe is 2r=1.05 mm and its height (h_3) is varied accordingly for proper matching. Fig. 11 and Table III shows s-parameter is maximum for h_3= 8 mm.

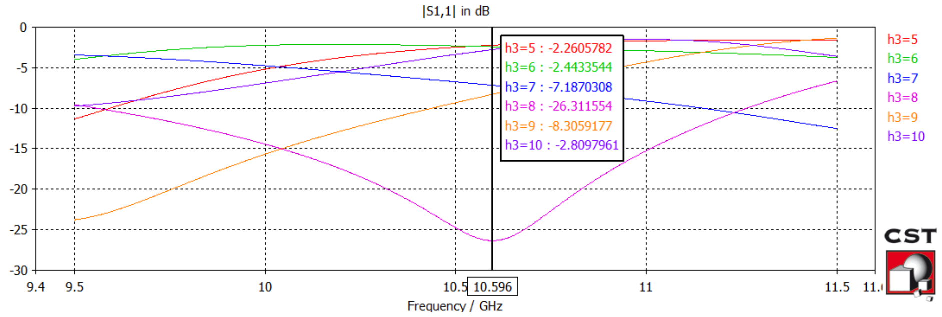


Fig. 11. Variation of S-Parameter with variation in h3 [h_1=8, h_2=5, h3=8, a=10, εr_1=10.2, εr_2=10, r=0.314, R=1.05] All dimensions are in mm.

Table III. IMPEDANCE BANDWIDTH FOR DIFFERENT HEIGHT OF COAXIAL PROBE (h_3) [h_1=8, h_2=5, h_3=8, a=10, εr_1=10.2, εr_2=10, r=0.314, R=1.05] All Frequency are in GHz

Height of Coaxial Cable (h3)	Range(f_H- f_L)	s-parameter	BW	Impedance BW($\frac{f_H - f_L}{f_C}$)
6	5.5-6.5	-2.44	1	16.6%
7	11.5-12.18	-7.18	0.67	5.65%
8	**9.55-11.26**	**-26.31**	**1.71**	**16.42%**
9	8.4 -10.49	-8.30	2.09	29%
10	9.5-11.5	-2.80	2	19.04%

Thus it was observed that we get a better result when the height of the coaxial probe is 8mm

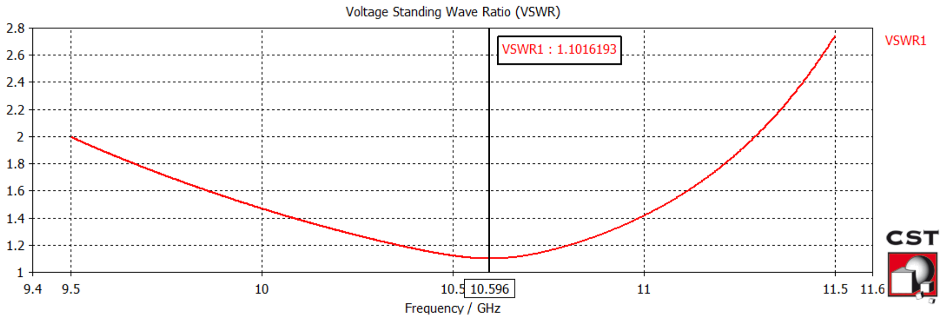


Fig. 12. VSWR for Stacked triangular DRAs [h_1=8, h_2=5, h_3=8, a=10, εr_1=10.2, εr_2=10, r=0.314, R=1.05] All dimensions are in mm.

The VSWR and reflection coefficient can be examined through the equations:

$\Gamma = (Z_1 - Z_o) / (Z_1 + Z_o)$

$VSWR = (1+\Gamma) / (1-\Gamma)$

Where Γ is the reflection co-efficient. Z_1 is the antenna impedance and Z_o is the feed line impedance. The VSWR should be less than 2 and the reflection coefficient should be less than1 for proper matching

V. Conclusions

This paper examined the performance of the TDRA excited by a coaxial probe. Approximate expression are used to compute the resonance frequencies. TDRA has IBW 16.43% (> 20 %) where S_{11} < -10 dB from 9.55 to 11.26 GHz. It has a monopole like radiation pattern which is stable in the pass band with gain 4.987dBi at 10.596 GHz. So, it is used in satellite communications and biomedical radiators.

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