Frequency Reconfigurable DRA array using wideband Wilkinson's approach

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Abstract— **A quad section wideband Wilkinson power divider based aperture coupled frequency reconfigurable dielectric resonator antenna array is proposed. Frequency agility is achieved by variation of stub lengths due to the various switching states of two PIN diodes used in the feed line. The design methodology is based upon use of two square DRAs having resonant frequencies at 3GHz and 5GHz, fed by a Wilkinson power divider possessing wide bandwidth of about 1GHz to 6GHz. The antenna shows some wideband and multiband frequency agility property within 2GHz to 6GHz. The specialty of the antenna is its capability of being simultaneously used for most of the important wireless applications like Wi-Max, Wi-fi, WLAN, Bluetooth, C-band downlink communication within the intended frequency range.**

Keywords—Wilkinson power divider, Dielectric resonator antenna (DRA), Wi-Max, Wi-fi, Bluetooth.

I. INTRODUCTION

THE importance of reconfigurable planar antennas are growing now a days due to the extensive demand of multi-functional handheld devices. Several authors have already focused on design of these types of antennas including both microstrip and ceramic material based for various applications [1]-[5]. In recent trend dielectric resonator antennas are considered to be more suitable candidate as compared to microstrip because of their inherent features like high radiation efficiency, less conductor loss and wider bandwidth etc [6]. Other advantages include, all types of conventional feeding methods like probe feeding, microstrip line feeding, aperture, coplanar waveguide feed used for microstrip antennas can also be employed to dielectric resonator antenna without any hesitation [6].

Recently considerable effort have been given by researchers to achieve frequency tuning in DR antennas using different methods [7]-[10]. These methods include variation of lengths and positions of parasitic slot and strip which suffers from the problem of dynamic frequency tuning [8]. Another method of frequency agility is the use of adjustable shorting tabs on DRA walls [10]. Though the method has benefit of wide range of frequency tuning, but it suffers from low impedance band width at resonance frequency. Further the shorting tabs were replaced by PIN diodes and varactor diodes for electronic switching purpose [10].

In this article a frequency reconfigurable DRA array is designed using two different DRAs having resonant frequencies nearly at 3 GHz and 5 GHz to achieve wide range frequency tuning from 2 GHz to 6 GHz. A suitable feed network comprising of four stages Wilkinson power divider having a bandwidth of 1GHz to 6 GHz is used to accommodate this frequency range. Two DRAs are excited by apertures on the ground plane. Frequency agility is achieved by variation of the stub lengths by use of suitable PIN diodes. The proposed antenna is designed using a commercial electromagnetic software CST microwave studio suite™ 12 and some wideband along with multi-band frequency tuning characteristics are observed.

II. DESIGN METHODOLOGY OF THE ANTENNA

A. *Design of the wide band Wilkinson power divider*

The proposed antenna is intended to provide frequency re-configurability in the range of about 2GHz to 6 GHz with some wideband and multiband performance. Therefore a wideband Wilkinson power is designed to attune this frequency range.

Wilkinson power divider is a three port hybrid device having capability of providing equal amplitude, zero phase difference and high isolation between the two output ports. The conventional single sectioned Wilkinson power divider has usable bandwidth of $f_2/f_1 = 1.44{:}1$ for VSWR <1.22 and isolation >20dB [11]. But the bandwidth of this hybrid can be improved by use of additional sections [12]. Fig.1 shows layout of the designed quad section wideband power divider.

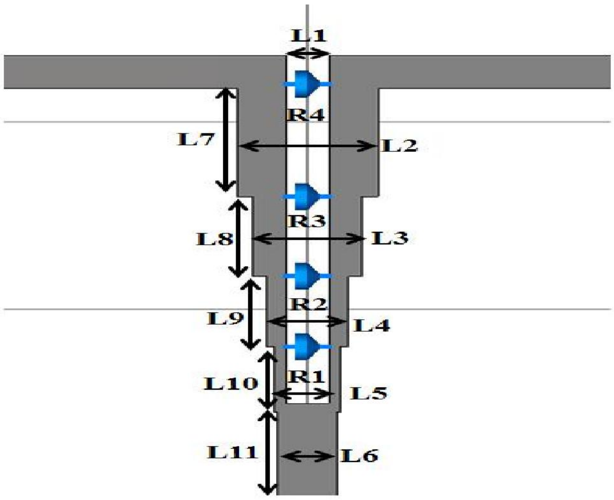


Fig.1. Layout of the quad section wideband Wilkinson power divider.

It consists of four sections of coupled lines having different impedances and four isolation resistances to provide better matching performance throughout the band. The approximate coupled line impedance and the resistor values are calculated as per the design table for $f_2/f_1 = 4:1$ with isolation of 20dB [12]. The antenna is designed using Roggers RO4003 substrate having dimensions 150mm×80mm×1.6mm, $\varepsilon_r = 3.5$ with loss tangent $\tan\delta = 0.002$. The optimized design parameters of the designed power divider are listed in Table I. Four chip resistors having values R1=104Ω, R2=172Ω, R3=292Ω, R4=482Ω are used between the coupled lines to achieve better isolation.

TABLE I.

DIMENSIONS OF QUAD SECTION WIDE BAND WILKINSON POWER DIVIDER

L1	L2	L3	L4	L5	L6
2.6mm	8.54mm	6.56mm	4.9mm	4mm	3.57mm
L7	**L8**	**L9**	**L10**	**L11**	
11.5mm	8.5mm	7.5mm	6mm	10mm	

The simulated scattering parameters for the design are shown in Fig.2. It can be noticed that the S-parameters at output ports S_{11}, S_{22}, and S_{33} are lower than -15dB over the whole frequency range. Also a sound isolation S_{32} (better than -15 dB) is observed for the entire frequency. Power is divided equally between the two output ports S_{21}=S_{31}=-3dB.

B. *Design of the DRA*

The proposed antenna consists of two radiators designed with different resonant frequencies are fed by two output branches of the Wilkinson power divider shown in Fig.3. Ceramic material RT TMM10 having dielectric constant 9.2 is used as DR material. Standard design formulae and transcendal equation (1) are used for designing two square DRAs such that each individual radiator can operate in $TE^{z}_{11\delta}$ mode at their resonant frequencies [6].

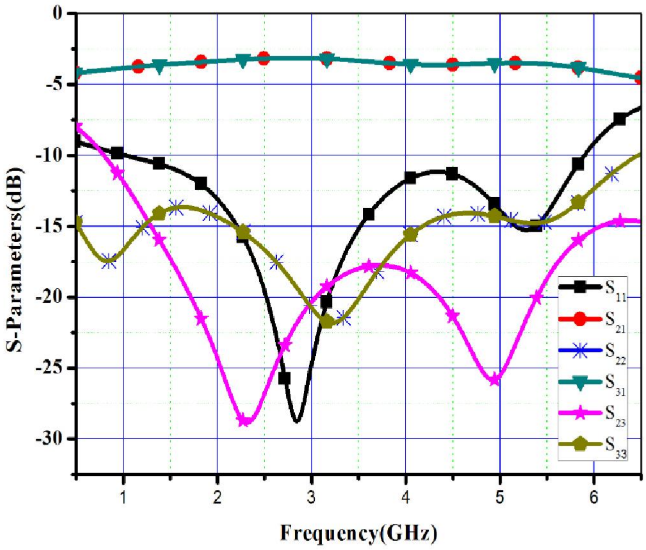


Fig.2. Simulation results of quad section Wilkinson power divider

$$k_x \tan(k_x d/2) = \sqrt{(\varepsilon_r - 1)k_0^2 - k_x^2} \qquad (1)$$

Where $k_0 = \frac{2\pi}{\lambda_0} = \frac{2\pi f_0}{c}$, $k_y = \frac{\pi}{w}$, $k_z = \frac{\pi}{b}$, $k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2$.

The length, width and height of the DRA are denoted by *w, d* and *b/2* respectively. In the present case both length and width are considered equal to form two square DRAs. By using the curves found from (1) the final dimensions of the two DRAs are found to be 19mm×19mm×4.75mm and 33.2mm×33.2mm×8.3mm operating at 3GHz and 5GHz respectively. The two DRAs are excited by aperture coupling method to make the feed line isolated from the ground plane. The length and width of the slots are chosen to be 8mm ×1.6mm and 17mm×2.7mm for the big and small DRAs respectively. 50 ohm microstrip line having width of 3.57mm is used as feed line for both the DRAs. Frequency reconfigurability is achieved by varying the stub lengths of the two DRAs. Two RF PIN diodes are used to vary the stub lengths for discrete tuning purpose. The PIN diode BAR-64 from Infeneon is used for switching as it has high operating range up to 6GHz. Lumped equivalent RLC values of the diode in both forward and reverse biased condition is used to model the diode for simulation. The diodes are placed at two ends of power divider in such a manner that during the OFF state the stub lengths will be 2 mm and 4mm for the single DRA having higher and lower resonant frequency respectively. When two diodes are in ON state, due to the establishment of a short path the stub lengths become 8mm and 13.7mm. The individual resonant frequency of each DRA is 3GHz or 5GHz. When the DRAs are excited simultaneously the antenna is found to be working in a wide range of frequency of about 2 GHz to 6GHz, much before and after the resonant frequency of single DRAs.

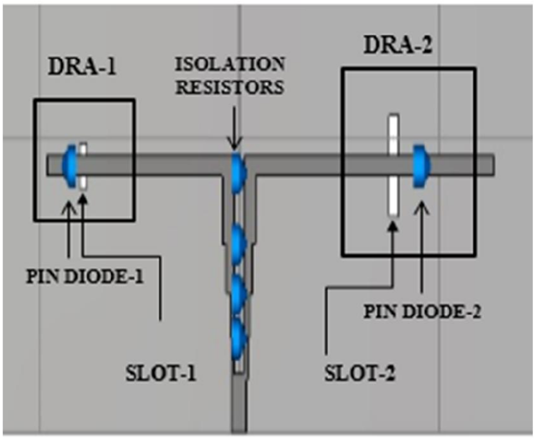


Fig.3. Final configuration of the DRA array

III. RESULTS AND DISCUSSION

A. Analysis of Reflection Coefficients

As two PIN diodes are used in the antenna for switching purpose to provide frequency tuning, there are total four no of states OFF-OFF, OFF-ON, ON-OFF and ON-ON. For each switching states different resonant frequencies of the antenna are observed, providing some wide band as well as multiband characteristics. The Reflection co-efficients of the antenna for different switching states are shown in Fig.4. From the figure it is clear that the antenna has resonant frequencies at 2.389GHz, 3.6498GHz and 5.32GHz having impedance bandwidth of 8.3%, 10% and 16.8% respectively when two diodes are in OFF state. Similarly resonant frequencies at 1.19GHz, 1.79GHz, 3.83GHz, 5.234GHz and 2.57GHz having corresponding impedance bandwidth of 13.9%, 26.99%, 7.5%, 15.05% and 34.72% are achieved when one of the two diodes is in ON state. When both diodes are in ON state, minimum reflection co-efficient value is achieved at

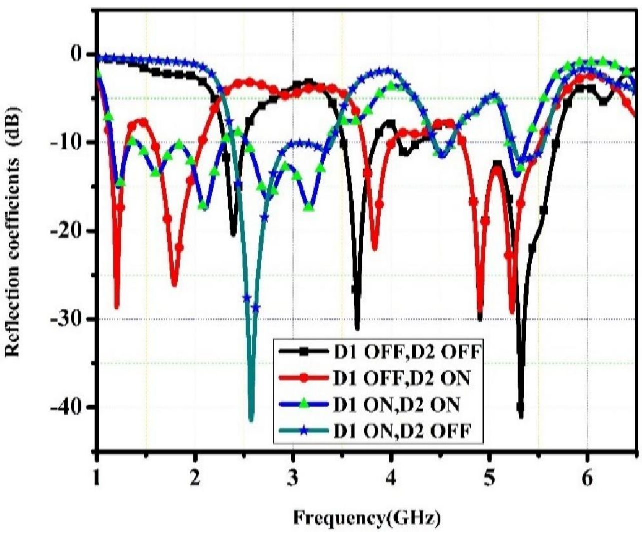


Fig.4. Reflection coefficients of the antenna during different states of the PIN diodes

1.21GHz, 2.10GHz, 3.15GHz, 4.49GHz and 5.27GHz also reflecting both multi band and wideband property of the antenna. Table II summarizes the whole band width properties of the antenna for all four switching states.

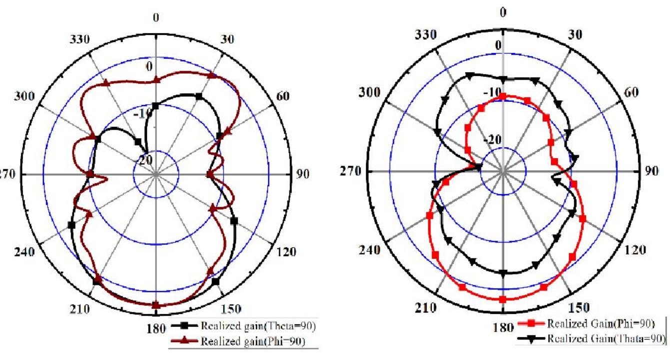
TABLE II.

SUMMARY OF RESONANT FREQUENCIES AND BANDWIDTH DURING FOUR SWITCHING STATES

States		Resonant Frequencies(GHz)	-10 dB Bandwidth	Percentage BW (%)
D1	*D2*			
OFF	OFF	2.389, 3.6498, 5.32	2.3-2.5 3.519-3.89 4.73-5.6	8.3 10 16.8
OFF	ON	1.198, 1.79, 3.83 5.234	1.13-1.3 1.57-2.06 3.71-4.0 4.73-5.5	13.9 26.99 7.5 15.05
ON	OFF	2.57	2.38-3.38	34.72
ON	ON	1.21, 2.10, 3.15 4.49, 5.27	1.15-1.34 1.41-2.29 2.53-3.35 4.43-4.61 5.18-5.39	15.26 47.56 27.89 3.9 3.97

B. Radiation patterns

The radiation patterns of the antenna for different switching states at resonant frequencies are shown in Fig.5. From the plots it is clear that radiation patterns remains nearly same though frequency gets changed. Maximum realized gain of 3dB, 5.7dB and 2.8dB are achieved at frequencies 5.32GHz, 5.234GHz and 5.27GHz respectively for different on-off states of the diodes. For resonant frequencies less than 2GHz, the realized gain of the antenna reduces due to excessive conductor and dielectric loss. Overall gain of the antenna for both E and H plane is fine at different resonant frequencies within 2GHz to 6GHz, which is the intended band of operation.



(a) (b)

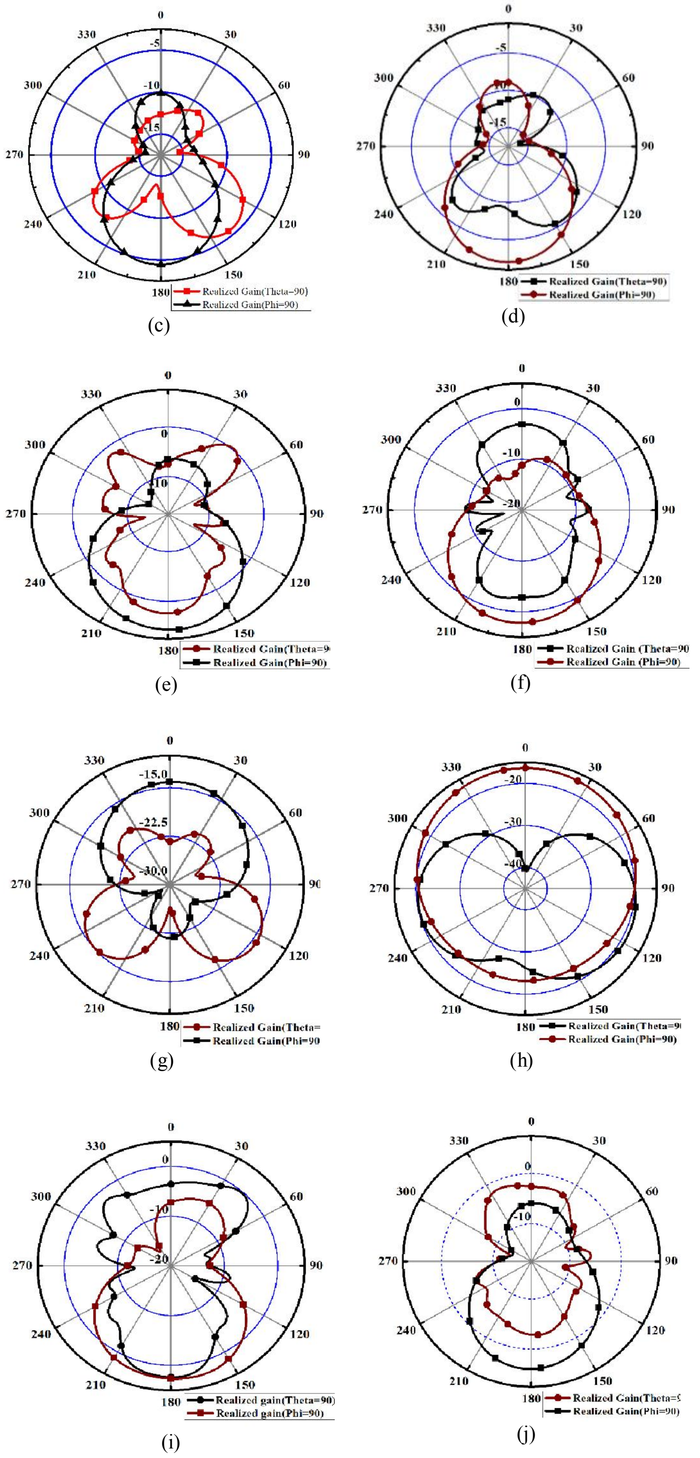


Fig.5. Radiation patterns at different switching states, when (a)-(c) D1 and D2 both off state at 5.32GHz, 3.64GHz, 2.38GHz (d) D1 is on and D2 is off at 2.57GHz (e)-(h) D1 is off and D2 is on at 5.27GHz, 3.83GHz, 1.79GHz, 1.198GHz (i) D1 and D2 both on at 5.27GHz, 4.29GHz.

IV. Conclusion

The antenna is having frequency agility and multiband characteristics in a wide operating range of 5 GHz covering fully S and partially C-band. This antenna can be used for various wireless applications like Wi-Max (2.3GHz-2.4GHz, 2.4GHz-2.6GHz, 3GHz-3.8GHz), Wi-Fi (2.412GHz-2.483GHz, 4.9GHz- 5.9GHz), WLAN (5.15GHz-5.8GHz), Bluetooth (2.402GHz-2.482GHz), C-band downlink communication (3.7GHz-4.2GHz) etc. The size of the antenna can be miniaturized by use of high dielectric constant ceramic material so that it can be directly used in various handheld devices like tablets and laptops.

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