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Investigations of a Dieleric Resonator Antenna for ISM, WLAN and C-Band Applications

K. SULTAN, G. AHMAD[++], A. SULTAN

Department of Electrical Engineering, UET Peshawar, Pakistan

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Abstract: The paper presents the development and experimental analysis of a triple band dielectric resonator antenna (DRA). The ground plane and feeding line was printed on FR-4 substrate. The antenna has been excited using aperture coupling. The antenna was loaded with an indigenously prepared hexagonal shaped ceramic (Al_2O_3) dielectric material of permittivity 9.6 and loss tangent 0.0003. The proposed antenna was designed and simulated with the help of CST Microwave Studio. It was practically fabricated and the results were verified using Vector Network Analyzer (VNA). A promising match between simulated and measured results was found. The fabricated DRA resonates at three different frequencies in S and C bands with bandwidths of 191 MHz (2.347 GHz2.538GHz), 331 MHz (4.63 GHz-4.961 GHz) and 609 MHz (5.649 GHz-6.258 GHz). The VSWR is under the magnitude of 2 for all the three bands and the Return Loss (RL) at resonance of the bands is -21.18 dB, -36.48 dB and -32.48 dB respectively. A good impedance matching at the resonant frequencies is achieved. The designed DRA is a good candidate for ISM (Industrial, Scientific and Medical) and C-band radar, Wireless LAN (WLAN) and satellite applications.

Keywords: DRA, Hexagonal, Multiband, Aperture, ISM, WLAN, C-Band

1. INTRODUCTION

The microtrip patch antenna is an interesting topic Antenna is a very important part of a wireless communication system. It is most commonly a metal structure which acts like a transducer, converting EM signal into electrical signal and vice versa. Different types of antenna depending upon the physical structure, frequency and application mode are available. Conventional metal antennas become lossy at microwave and millimeter wave frequencies hence their efficiency degrades (Luk and Leung 2002) (Kingsley, *et al.*, 2003). DRA on the other hand have no metal parts to dissipate the energy hence it remain efficient even at high frequencies.

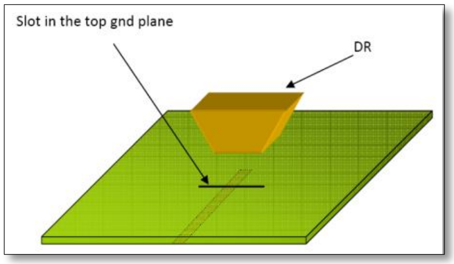
DRA is composed of a dielectric block located on a ground conductor as shown in (**Fig. 1)**. The DR may take any shape but the rectangular and circular cylindrical shapes are commonly employed. Some common prepared shapes of DRs for this and some future designs are depicted in **(Fig. 2)**. The concept of DRA was actually derived from Dielectric Resonators (DRs) which were previously utilized in microwave circuit applications like filters and oscillators and were considered as energy storage devices only. However when properly excited the DRs act as an efficient radiator instead of energy storage device. Incident energy on the DRA is bounced back and forth between walls of the resonator resulting in the formation of standing waves. The walls are transparent to some of the frequencies of incident waves and are directed to the receiver or radiated to air in case of transmitter.

The resonant frequency of DRA is determined by the permittivity and size of DR (Mongia and Bhartia 1994). DRA can be fed by a variety of methods as depicted in Fig 1. These methods include aperture coupling (Petosa, *et al.*, 2003), coplanar wave guide feeding (Kranenberg, *et al.*, 1991), microstrip line feed (Leung, *et al.*, 1997) and coaxial probe feed (Zhou, *et al.*, 1993). Size of the DRA is proportional to $\frac{\lambda 0}{\sqrt{\varepsilon r}}$ (Chen and Hsieh 2005), where $\lambda 0$ is wavelength of resonant frequency and εr is permittivity of the material. As the permittivity increases there is a reduction in the size of DRA for a desired frequency.

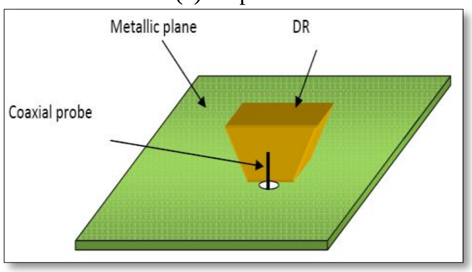
Different modes can be excited within DRA which produces different radiation patterns for various coverage requirements. The Q-factor of some of the excited modes depends upon the aspect ratio of the DRA; hence flexibility in design is achieved. The DRA has high bandwidth as compared to its conventional counterpart microstrip antenna (Mudavath and Behera 2012). The microstrip antenna radiates from two edges while the DRA radiates from all sides except grounded side. Also the desired bandwidth may be varied selecting material of suitable constant and by varying dimensions. DRA can operate in high frequencies. The efficiency of DRA is usually more than 95%. DRA of ceramic can

[++]Correspondence: gulzar@uetpeshawar.edu.pk

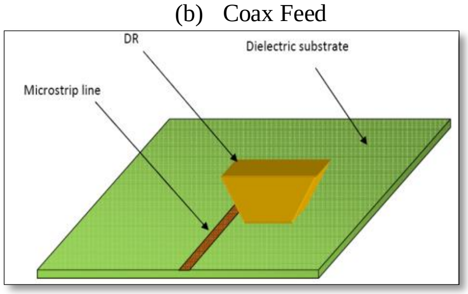
withstand high temperatures which extend the use of DRA in harsh environments.



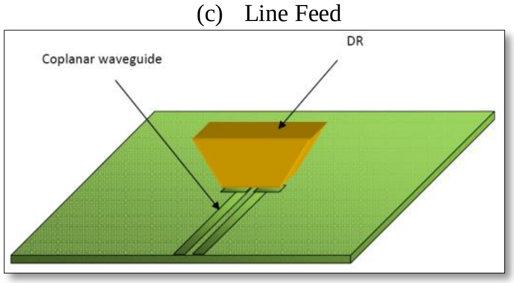
(a) Aperture Feed



(b) Coax Feed



(c) Line Feed



(d) CPW Feed

Fig. 1: DRA and its different Feeding Methods

Fig. 2: Different Shapes of prepared Dielectric Resonators of different materials

DRA can be analyzed using different time domain or frequency domain analysis. Frequency domain contains methods of movement (MOM) and finite element method (FEM) (Petosa 2007) (Luk and Leung 2003). The frequency domain analyses include finite difference time domain (FDTD) method and the transmission line method (TLM). Various bandwidth enhancement techniques are utilized in DRA like through adopting different excitation mode (Buerkle, *et al.*, 2005) (Li and Leung 2005) (Menson, *et al.*, 2004), stacked DRs (Simons and Lee 2003) (Alsharkawy, *et al.*, 2004), embedded DRs (Junker, *et al.*, 1996) (Kishk 2005), shaping DRs (Sangiosvanni, *et al.*, 1997) (Kishk, *et al*, 2001) and hybrid DRs (ittipiboon, *et al.*, 1996) etc. The recent advances in wireless communication demands for multi functions embedded in one single device. Each application in the device may operate at different frequency like WiFi, 3G internet, Bluetooth and GPS in a smart cellular phone. Use of many antennas in today’s smart devices is not feasible. A single antenna which operates at different frequency bands is a solution for it. In this work DRA offering multi bands has been demonstrated. The DRA applications are enormous.

The DRA may be used for frequency from GHz to THz which covers all wireless applications like radars, satellites, ISM band, biomedical imaging applications, military bands and future generation mobile applications (Nallathambi and Perumal 2018).

The invention of DRA has also leaded to the concept of all dielectric non electronic radio front end technology (ADNERF). The continuous trends of today’s modern electronics towards compact size and low voltage in integrated circuit has rendered it susceptible to electromagnetic pulse (EMP) created by different directed energy sources (Radsky, *et al.*, 2004). HPM (high power microwave) weapons and other EMP sources are a great threat to all modern electronic system (Abrams 2003) especially RF receivers. Antenna provides a direct path for electromagnetic pulse to enter the system. The ADNERF receiver provides immunity to such threats by eliminating soft spots for EMP like metal contacts and transistors in front end side of the receiver. The ADNERF consist of all dielectric, DRA is a vital part of this technology.

(Monica, *et al.*, 2016) has investigated an aperture coupled DRA of ceramic material using HFFS software. The antenna achieved dual bands for S-band and Wimax applications. The size of the bottom substrate employed in the design is 55×75 mm. Abdul (Abdullah and Majeed 2013) has simulated an aperture coupled dielectric resonator antenna of 55×75 mm size bottom substrate using CST software. The antenna has presented a single wide band (Raggad, *et al.*, 2013)has designed a dual band DRA which is fed by aperture slot and microstrip line. The antenna was simulated both in CST and HFFS. The substrate and ground plan was of 70×70 mm size. (Gharsallah, *et al.*, 2016) designed a cylindrical shaped DRA in CST and HFFS on 60×60 mm substrate. This antenna resonated at a single frequency in C-band.

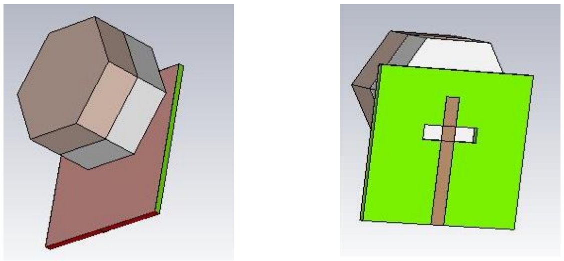
Different other shapes of DRA have also been studied and investigated by researchers like triangular (Ittipiboon, *et al.*, 1993), spherical cap (Leung *et al.*, 1994), cylindrical ring (Mongia, *et al.*, 1993), conical (Kishk *et al.*, 2002) and tetrahedron (Kishk *et al.*, 2003). The drive of the proposed design was to improve the antennas performance already available in literature. The determination was to achieve compact physical size and to attain multiple bands. Hexagonal ceramic dielectric resonator as presented in **Fig. 9(a)** was proposed for design. High dielectric constant resonators help to reduce size of antenna for the design frequency. Two such blocks were used to achieve multi-bands while maintaining a good impedance match. The antenna showed better performance than regarding size and multi-banding.

2. DESIGN AND SIMULATION

Prior to the design and fabrication some critical parameters for anticipated DRA are selected. These include desired frequency and dielectric constant of DR (Luk and Leung 2002).The basic dimensions of DRA of different shapes for a desired design frequency are calculated using formulas as explained in (Kingsley, *et al.*, 2003). The simulations were done in CST Microwave Studio, strong electromagnetic user friendly field simulation software. It is a full package for electromagnetic analysis and design in microwave frequency range. The designed CST model is shown in **(Fig. 3)**.The detailed optimized design parameters of the bottom substrate and the Dielectric Resonator of the proposed antenna after simulation is listed in Table 1. Lg and Wg are length and width of bottom substrate, FR-4 with 1.5mm thickness. Same are the dimensions of ground plane, copper of 0.035mm thickness. An aperture slot is cut in the bottom substrate and ground plane of size 14.5×4 mm. The microstrip feed line is located on backside of FR-4 and is 3mm wide, 35.5mm long and 0.035mm thick. The DR is having each side of 17.5mm and thickness is 10mm.

Table 1: Geometrical Dimensions of Proposed DRA

Dimension	Value	Dimension	Value
Lg	41.5mm	DR Side	17.5mm
Wg	41.5mm	DR Height	10mm
Feed Line Length	35.5mm	FR-4 Height	1.50mm
Feed Line Width	3mm	Copper Thickness	0.035mm
Aperture Slot Width	14.5mm	DR Length (Side to Side)	35 mm
Aperture Slot Length	4mm		



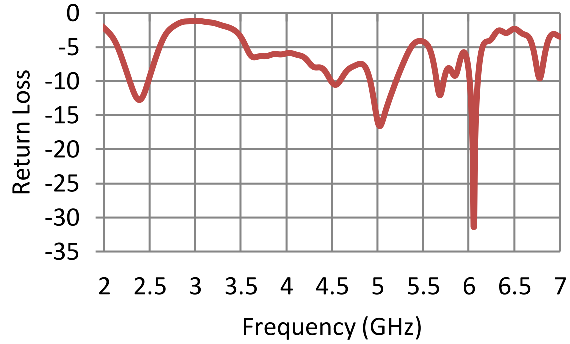
(a) (b)

Fig. 3 CST Model View of DRA (a) Top (b) Back showing Ground, DRs, FR-4, Aperture and Feeding Line

3 SIMULATION RESULTS

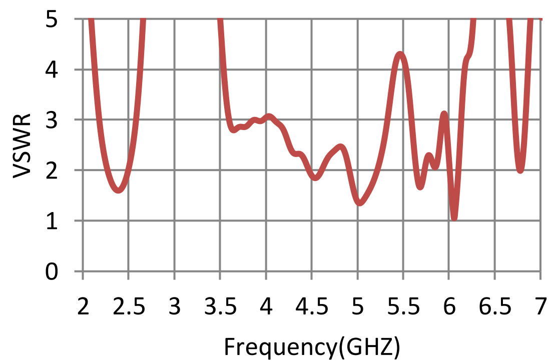
3.1 Return Loss and VSWR

The simulated Return Loss and Voltage standing wave ratio is shown in **Fig. 4** (a) and (b) while **Fig. 5** displays its total efficiency respectively. The antenna shows resonance at three different frequencies namely 2.4 GHz, 5.01 GHz and 6.06 GHz at a return loss of -12.6 dB, -16.5 dB and -31.3 dB respectively.



(a) Return Loss

The VSWR at the three all the three bands are well below the value of 2 which is considered adequate for proper operation of the antenna. The VSWR at resonance are 1.6, 1.3 and 1.07 respectively. This shows a good impedance matching of the antenna with the feed line of 50 Ω impedance.



(b)VSWR

Fig. 4 Simulated Results (a) Return Loss (b) VSWR

The antenna shows resonance at three different frequencies namely 2.4GHz, 5.01GHz and 6.06GHz and the total efficiency at the mentioned resonant frequency are 0.85, 0.91 and 0.83 respectively.

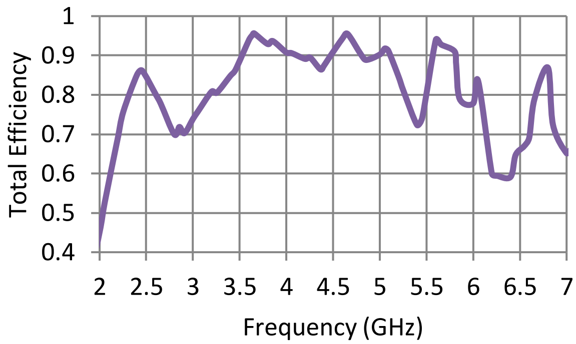


Fig. 5. Efficiency

3.2 Far-field Radiation Pattern and Gain

The simulated far field radiation pattern in polar form at three frequencies, 2.4 GHz, 5 GHz and 6.05 GHz are presented in (**Fig. 6** to **8)** respectively. The antenna offers a gain of 4.17 dB at 2.4 GHz (Fig. 6), 5.87 dB at 5 GHz (Fig. 7) and 5.4 at 6.05 GHz (Fig. 8). The 3 dB angular widths at the three selected frequencies are 100.4 deg., 87.5 deg. and 63 deg. respectively. This shows that the antenna becomes more directive with the increase in frequency.

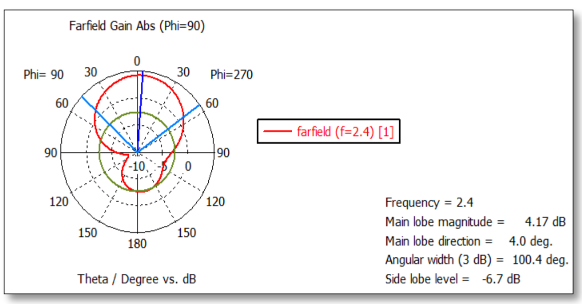


Fig. 6 Farfield Pattern and Gain at 2.4 GHz

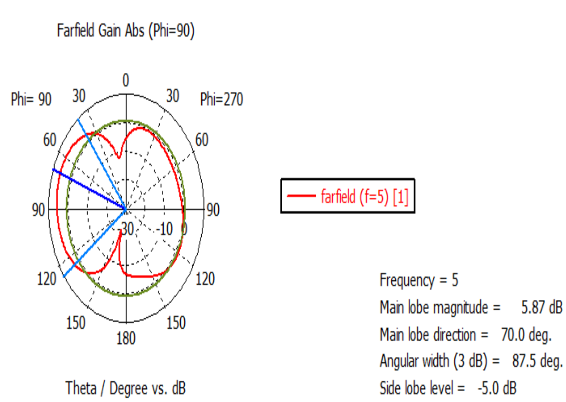


Fig. 7 Farfield Pattern and Gain at 5 GHZ

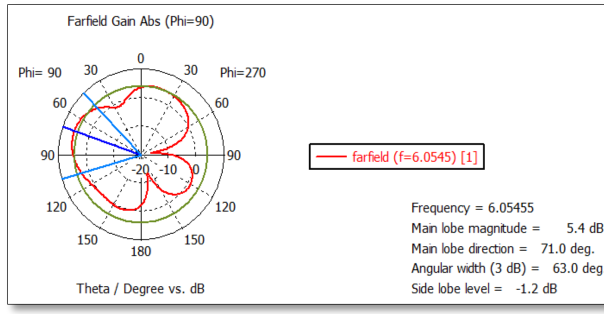


Fig. 8 Far field Pattern at 6.05 GHz

4. FABRICATION OF THE ANTENNA

The pictorial dimensional view of the antenna is shown in **Fig. 10**. The DRA comprises of two substrates, one is dielectric resonator the other substrate supports ground, the DR and microstrip line on the other side. The ground and feed line are copper. The two hexagonal shaped dielectric resonators of 10 mm thickness were prepared from alumina (AL2O3) as shown in **(Fig. 9(a).** Alumina powder was mixed in a ball mill, pressed in an axial press in dye of required shape. The pellets were then sintered in furnace at high temperature of 1600^0C. The prepared pellets were finally shaped according to dimensions using grinding and milling machines. Surface cleaning was also done. The prepared alumina substrate has a dielectric constant of 9.6 and loss tangent of 0.0003. These values were measured using an LCR meter by capacitance method. The other substrate on which ground and feeding line are printed is FR-4 of 1.5 mm thickness. A slot was made to in the bottom substrate to couple EM energy from microstrip line to the loaded DRs. This feeding mechanism is called aperture coupling and have advantages over the other available techniques as discussed. Two DRs (one shown in **(Fig. 9(b))** were placed one above the other **(Fig. 3(c)).**For testing purpose no adhesives were used between DRs itself and DR and the ground plane. A photograph of the fabricated antenna and measurement setup is shown in **(Fig. 9(d).**

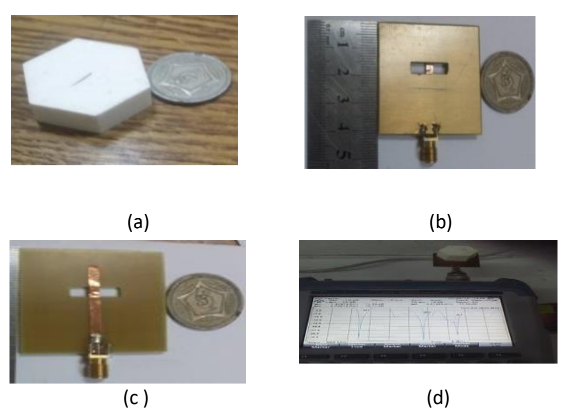
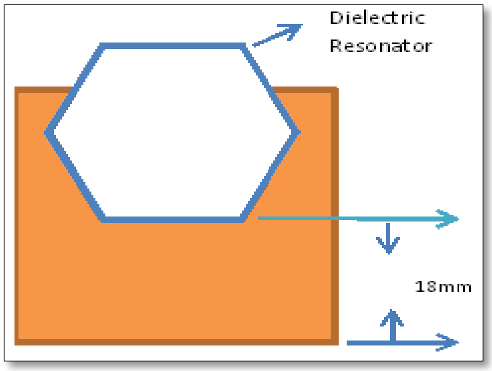
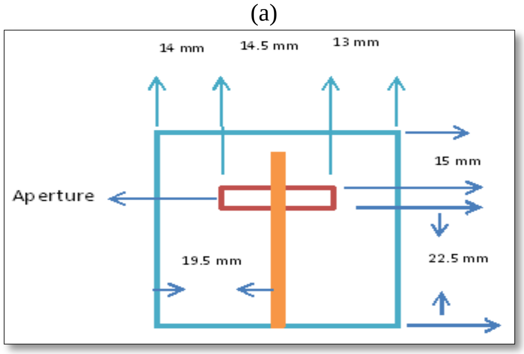


Fig. 9 DR (a), Front (b) and back (c) view of DRA and VNA Measurement setup (d)



(a)



(b)

Fig. 10 Dimensional View of DRA with Dimensions in mm (a) Top Plan View (b) Bottom View

4 EXPERIMENTAL RESULTS

The antenna was tested using Vector Network Analyzer for most important parameters like Return Loss (RL), Bandwidth (BW), Voltage Standing Wave Ratio and Input Impedance of the antenna. As shown in **(Fig. 11)** the DRA resonated at three different frequencies. All the three bands are separately analyzed. The Results are summarized and presented in Table 2. From the results table it is pretty clear that the resonant frequencies of the practically manufactured antenna are almost same as were seen in simulations. However a little shift towards lower frequency is found in 2nd resonance. The results of the practically fabricated antenna are even better than the simulated one with regard to return loss and bandwidths. The measured results are discussed in detail in the following sections. A promising match was observed between simulated and measured results.

Table 2: Summarized Results of DRA

Parameter	Band 1	Band 2	Band 3
Resonance Frequency, f_r	2.43 GHz	4.81 GHz	6.09 GHz
Return Loss at f_r	-21.18 dB	-32.48 dB	-26.48 dB
Bandwidth, BW	191 MHz	331 MHz	609 MHz
VSWR at f_r	1.09	1.03	1.10
Impedance at f_r	45.7+j0.85 Ω	49.7+j1.47 Ω	49.6+j4.93 Ω

4.1 Return Loss and Bandwidth

This parameter measures the degree of mismatch between transmission line and antenna. It is the ratio of reflected power to the source to the power fed to the antenna. Greater the absolute value of the return loss greater is the impedance match.

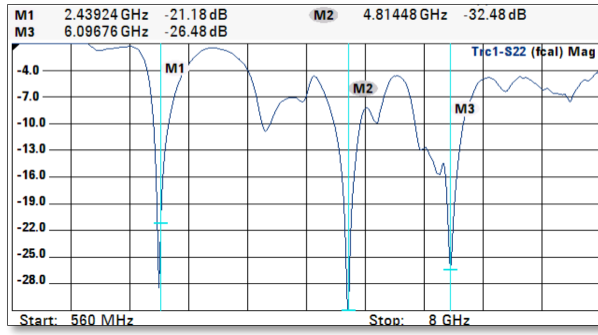
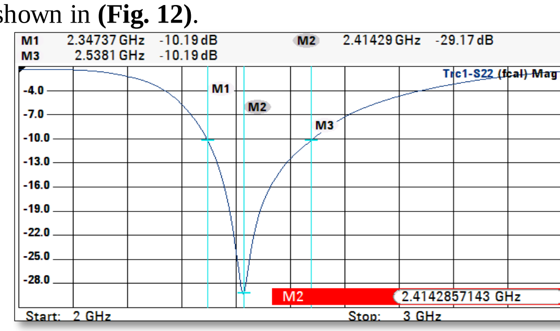


Fig. 11: DRA Resonances

A return loss of -10 dB below is acceptable value for antenna to perform properly. The -10 dB return loss at resonance frequencies are -21.18 dB, -32.48 dB and -26.48 dB with a bandwidth of 191 MHz, 331 MHz and 609 MHz respectively. The measured return losses are shown in **(Fig. 12)**.



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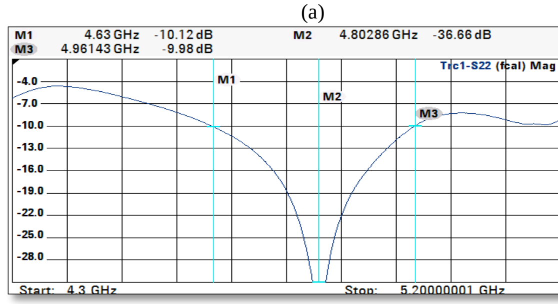

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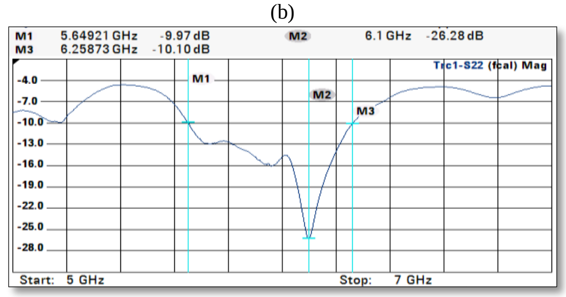
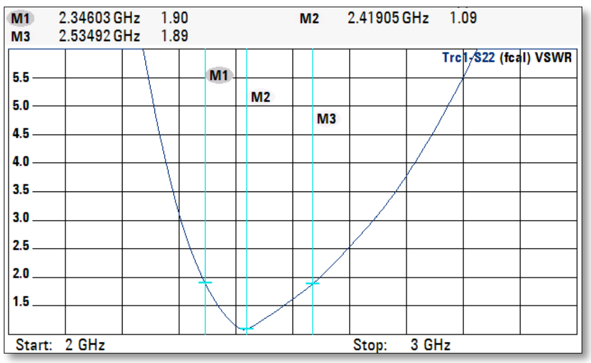


(c)

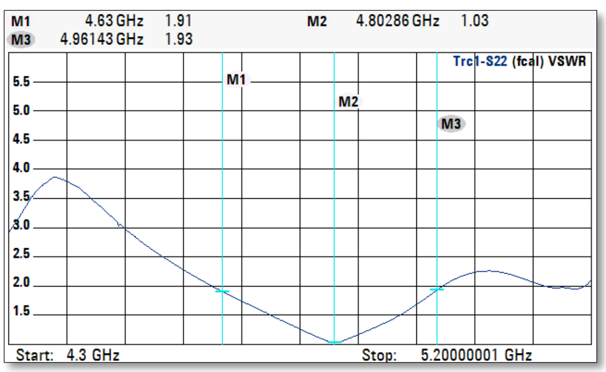
Fig. 12: Return Loss of (a) Band 1 (b) Band 2 (c) Band 3

4.2 Voltage Standing Wave Ratio

The ratio of maximum value of RF signal to the minimum value is identified as VSWR. Some portion of the input signal to the antenna gets reflected back to the source due to impedance mismatch. The reflected wave constructively interferes with the input wave at some points and destructively at some other points resulting in the formation of standing wave. The VSWR value of 2 and below is considered adequate for antenna operation. The resulted VSWR of the DRA is shown in (**Fig. 13**). The values are 1.09, 1.03 and 1.10 at resonance of the three achieved bands respectively. The VSWR remain below 2 for the whole operating range of frequencies in all three bands.



(a)



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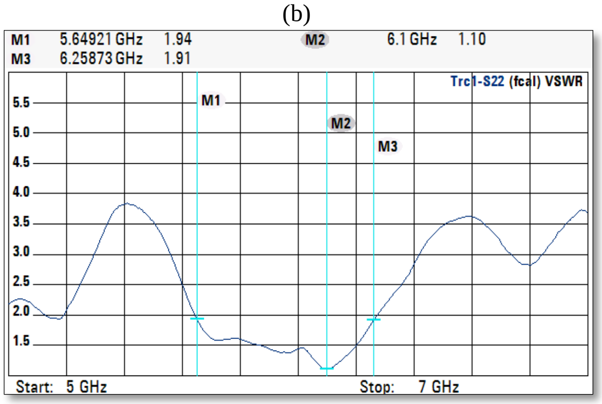
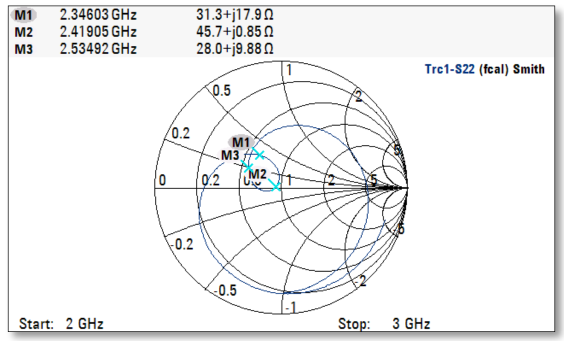


(c)

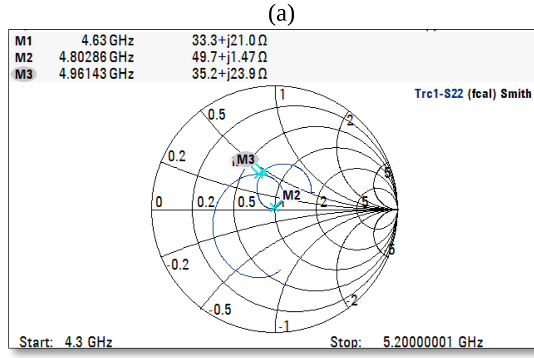
Fig. 13: VSWR of (a) Band 1 (b) Band 2 (c) Band 3

4.3 Smith Chart and Input Impedance

Smith chart is a graphical view of the the input impedance at the terminals of the antenna. It represents the impedance variations with the frequency. If the impedance of antenna is properly matched with the line impedance no reflections occur. Smith chart at all the three bands of the DRA is shown in (**Fig. 14)**. The impedances at resonant frequencies of the three bands are 45.7+j0.85 Ω, 49.7+j1.47 Ω and 49.6+j4.93 Ω respectively. These impedances show a good impedance match of the antenna with the transmission line of 50 Ω.



(a)



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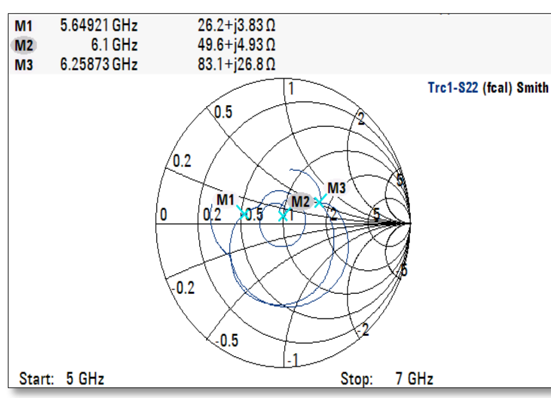

(c)

Fig. 14: Input Impedance of (a) Band 1 (b) Band 2 (c) Band 3

A comparative analysis of proposed DRA with some of recent designs available in literature is summarized in **(Table 3).**

Table 3: Comparative summary of proposed design

Reference	Size (L×W) mm	Bands in GHz	Bandwidths In MHz	Return Loss in dB
Proposed	53×41.5	2.34-2.53 4.63-4.96 5.64-6.25	191 MHz 331 MHz 609 MHz	-21.18 dB -36.48 dB -32.48 dB
Ref [28]	75×55	2.45-3.70	1025 MHz	-45 dB
Ref [29]	75×55	2.24-3.80	1056 MHz	-51.26 dB
Ref [30]	70×70	1.71-1.88 2.40-2.48	170 MHz 80 MHz	-20 dB -18 dB
Ref [31]	60×60	4.50-7.10	2600 MHz	-32 dB

It is clear from the comparison table that the proposed antenna is compact in size. It has presented triple resonance with a return loss that is better than and at respective frequencies.

5 CONCLUSION

A hexagonal shaped aperture coupled DRA was designed, simulated, fabricated and experimentally investigated in this work. DRA's have many advantages over conventional microstrip antennas. DRA has a greater flexibility in excitation schemes. Higher order modes can easily be achieved in DRA to achieve multi and wide bands. The proposed DRA offered wide triple bands. A good agreement between simulated and measured results was found. For the bands obtained the DRA size is compact. Excellent impedance matching is achieved with aperture slot coupling feeding scheme. The antenna parameters are better than the already proposed designs in literature. The ground and the substrate are of the equal size of 41.5mm×41.5mm. The antenna is a better candidate for ISM band, WiFi, WLAN, Radar and Satellite communication.

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