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L- shaped square DRA for 5G mm-wave application with enhanced gain

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***Abstract*— In this paper, a L-shaped SDRA (Square dielectric resonator antenna) for 5G mm-wave application is proposed. The antenna is a square L-shaped structure with an increased realized gain and that supports the 24-34 GHz frequency ranges with broadband with fractional bandwidth of 13.8% from 26.3Hz to 30.2 Hz and two narrow bands, constructing a quad-band antenna. The observed gain is approximately 8dB. Simulations and design using commercial software CST Studio Suite that have been performed to confirm the viability of the suggested SDRA for the next fifth-generation (5G) wireless networks.**

Keywords*— Dielectric Resonator Antenna, mm-wave applications, quad band square antenna, millimeter-wave DRA

I. Introduction

The goal of fifth-generation (5G) wireless technology is to deliver rapid data transfer, minimal latency, and extensive connectivity. The deployment of 5G networks has become a global phenomenon as countries around the world race to take advantage of the benefits it offers. The adoption of advanced antenna systems (AAS) is one of the fundamental components that enables 5G to provide the performance enhancements it has promised. AAS uses multiple antenna techniques like beamforming and MIMO (multiple-input, multiple-output), as well as AAS radio and a set of AAS features. Carriers had to use a technology called Dynamic Spectrum Sharing (DSS) to enable 5G and 4G to peacefully coexist on the same frequencies. It was able to give up airwaves to older 4G traffic thanks to its new 5G capability [1]. While the network is being developed, antenna systems are needed to handle all 5G bands. This includes the sub-6GHz bands, which are utilized for greater coverage and better obstacle penetration, as well as the mm-wave bands, which are used for high-speed, low-latency communications.

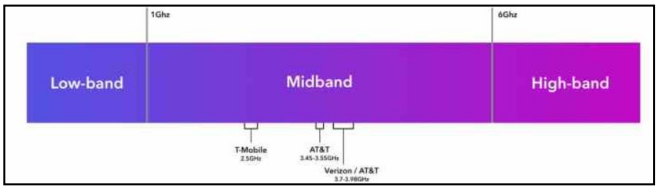


Fig. 1. Mm-Wave spectrum [1]

By offering previously unheard-of levels of connectivity, speed, and dependability, this cutting-edge technology is poised to alter entire sectors of the economy as well as businesses and people's daily lives. Innovative antenna designs that can function at millimetre-wave frequencies are needed to allow these characteristics. One such design that has gained popularity is the dielectric resonator antenna (DRA), which has a high gain and beam-steering ability [3].

A DRA (dielectric resonator antenna) is a type of radio antenna used mostly at microwave frequencies and beyond. It is generally composed of a ceramic of varying forms called the dielectric resonator that is set on a metal ground plane. When radio waves from the transmitter circuit enter the inside of the resonator material and reflect back and forth between its walls, standing waves are produced. The resonator's walls are partially radio wave permeable, allowing the radio power to radiate into space. The class of DRAs (Dielectric Resonator Antennas) is a feasible alternative to more standard and normative antennas, particularly at millimetre wave frequencies and above.

The SDRA(Square Dielectric Resonator Antenna) is fed with a coaxial probe in the proposed design which provides a wide bandwidth, which is essential for 5G mm-wave applications that require high data rates.

TABLE 1 5G NR Frequency Band

5G NR Frequency Bands	**Range**
n257	26.5-29.50
n258	24.25-27.50
n261	27.5-28.35

The antenna's ability to operate across a broad frequency range, which is required for a variety of 5G applications, including wireless communication, sensing, and radar, is made possible by its quad-band operation [4]. Coaxial feeders are typically used to excite the Dielectric Resonator Antennas (DRA), where the coupling level is established by maximizing the overall length and placement of the feeding probe with respect to the DRA. The DRA input impedance may be perfectly adjusted using this method in order to match the antenna. The probe site can either be optimized to be near the DRA or it can be drilled inside the DRA.

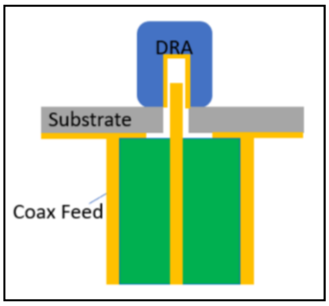


Fig. 2. Coaxial probe fed SDRA [2]

The dielectric resonator antenna has multiple advantages, including ease of excitation, low cost, compact size, light weight, and high radiation efficiency. In the 5th Generation

(5G) of communication, millimeter-wave wireless communication is gaining a lot of attention given to its advantages of faster data transfer rates, greater resolution, and lower latency [5]. Metal components, which become lossy at high frequencies and lose energy, are absent from these kinds of antennas. Overall, the proposed L-shaped square DRA with a coaxial feed is a promising design for fifth-generation (5G) mm-wave applications.

In this study, we propose a coaxial feed and an L-shaped square construction for DRA at 5G mm-wave frequencies. The proposed antenna design differs from the current designs in several of ways, including improved gain, wide bandwidth, and quad-band operation. By extending the antenna's length without greatly expanding it, the L-shaped square structure enables us to increase gain.

A. Dielectric Resonator Antenna

Radiating resonators, which can convert guided waves into unguided waves (RF signals), are the basis of DRAs. These can have a wide impedance bandwidth if the resonator's size and the material's dielectric constant are correctly chosen [6]. Dielectric resonators operate on a fundamentally equivalent concept to cavity resonators, which have been extensively addressed in the literature [7]. The rectangular and cylindrical radiating dielectric resonators are the two most common types. In comparison to the cylindrical DRA, the rectangular DRA has more design flexibility because it is distinguished by three independent geometrical dimensions. The Hemisphere and the cross-shaped DRAs are also widely used. Circularly polarised antenna design is primarily advised to design via the cross-shaped dielectric resonator. By adjusting the length of the arms and rotating the cross DRA by 45° with regard to the slot, it is possible to get a wide-band circular polarisation bandwidth.

DRAs are highly versatile and can be made to function in a variety of frequency ranges, including the millimeter-wave frequency range, which is becoming more and more crucial for next-generation wireless communication systems like 5G [9]. DRAs are extremely adaptable and versatile. DRAs are appropriate for uses like wireless backhaul and satellite communication because they can offer high gain and directivity at millimeter-wave frequencies.

One of the key benefits of DRA is its high radiation efficiency due to their low-loss dielectric materials, which reduce energy loss and increase the amount of power radiated. DRAs are thus appropriate for uses that call for high gain and directivity. DRAs can be constructed to have a relatively low profile and can be integrated easily into the device's structure with their compact size.

B. Literature Survey

DRA is a workable substitute due to the lack of ohmic losses and appealing radiation properties which may be obtained via properly combining the relative permittivity and resonator size, along with a well selected feeding strategy. As a result, various studies on mm-wave single DRAs and arrays have been published over the past few years, [7].

Different designs that were suggested by various researchers [10-15] for the 5G mm-Wave frequency range have low gains and low efficiencies. In [16], the author described a cross-slot-fed embedded substrate-integrated DRA with a potential CP bandwidth of roughly 26.3% at 26 GHz was proposed in. For instance, in [17], a The given trapezoidal shaped DRA, with dual band generation, has attained a greater impedance bandwidth of 26.3% and 7.69%. The suggested antenna has a gain value of 3.98 dBi and is circularly polarised.

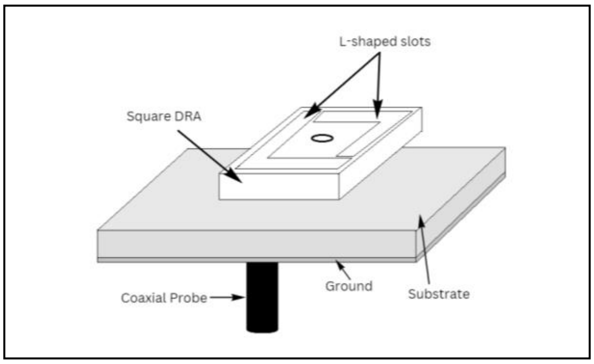
Therefore, the suggested design incorporates a dielectric resonator with two L-shaped slots that are cut through the DRA that creates an antenna of the quad-band capability with enhanced gain. The proposed antenna operates in the 24–34.4 GHz range of the 5G mm-wave frequency band.

II. The Proposed Antenna

A microwave antenna known as a dielectric resonator antenna (DRA) radiates waves that abruptly transition from a medium with a higher dielectric constant to air. Due of its high Q potential, ceramic is frequently used to make it. To regulate the frequency of the radio waves produced, dielectric resonators are primarily used in millimetre-wave electronic oscillators (also known as DROs) [4]. In addition to being employed as antennas, they are bandpass filters. Here, the SDRA is energized by a coaxial probe supplied through the substrate, which is perhaps the most common for discreet DRAs. Both the DRA's input impedance and its resonance frequency can be modified by adjusting the feeding probe’s length and position. Primary advantage of employing a probe feed is that it couples a significant amount of signal into the DRA, which then results in a high radiation efficiency [9].

The antenna that is being described here in Figure 3 is a compact Dielectric Resonator Antenna consisting of two L-shape on a square substrate, with a coaxial feed. The substrate used for the antenna is a Roger RO4350B with permittivity(ε_r) = 3.36, loss tangent 0.0037, thermal conductivity = 0.62, loss-free material of 0.254mm thickness. The square DRA of 0.83mm thickness is made of a folder1/mm wave 20.8 dra material that is placed above the substrate. The antenna has two L-shaped slots of thickness 1mm that are cut through the DRA. These slots are used to create the quad-band capability of the antenna. The slots are designed to resonate at specific frequencies, which allows the antenna to operate over a wider frequency range. The specific dimensions and placement of the slots depends on the desired frequency bands and the overall design of the SDRA.

The Square dielectric resonator antenna is fed using a coaxial feed made of PEC or Perfect Electric Conductor material. The antenna's radiating element receives electromagnetic energy from the transmission line via the



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coaxial feed.

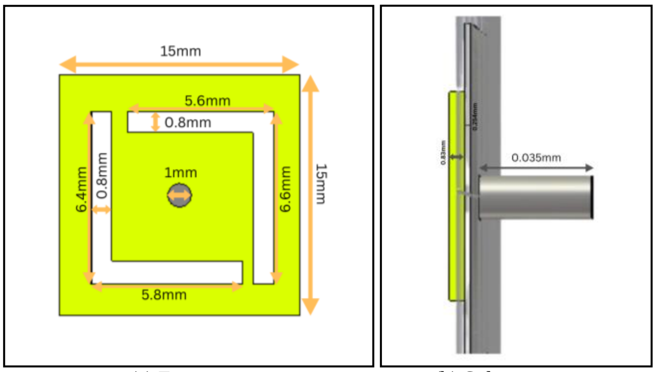
Fig. 3. The projected DRA's structure

The SDRA's structural design assists in minimizing the antenna's overall measurement while maintaining its resonance properties. Additionally, it helps in lowering the mutual coupling between the radiating components, which might enhance the effectiveness of the SDRA. The antenna offers enhanced gain, which is the measure of the increase in the power of the signal as it passes through the square antenna. An antenna's gain is inversely related to its radiation efficiency, which is defined as the ratio of the power radiated to the total power input. With the use of a high-quality substrate material and the design of the square DRA helps to improve the radiation efficiency of the antenna, which in turn leads to higher gain.

The suggested antenna also has wide bandwidth, which means that it can operate over a wide range of frequencies. This is important for 5G mm-wave applications, which require antennas that can operate over a broad frequency range to support different use cases and applications. The wide bandwidth of the antenna is achieved through the use of the L-shaped slots and the overall design of the antenna.

A. *Geometric details of Antenna*

Figure 4 below illustrates the envisioned dielectric resonator antenna's geometry. Finite integration technique (FIT) based on the EM (electromagnetic) simulation software CST microwave studio suite has been used for developing and analyzing. Firstly, the ground plane is present over which the antenna is designed. It is of PEC material which is an idealized material that has zero electrical conductivity and infinite permeability. The substrate is of size of 15×15×0.254mm^3 over which DRA is present of 17.9×17.9×0.83mm^3. Four slots are cut through the DRA of different lengths making two L-shaped structures, consisting of, slot1(6.4mm), slot2(5.8mm), slot3(6.6mm) and slot4(5.6mm) as shown in Figure 4(a). A coaxial probe feeds the square antenna which is also of PEC material and is of thickness 1mm and length of 0.035mm as seen in Figure 4(b).



(a) Front-view (b) Side-view

Fig. 4. Dimensions of the Antenna

The above antenna's dimensions are determined using the size of the DRA formula:

$$fr = \frac{c}{2\pi a\sqrt{\varepsilon r}}\left[1.71 + 2\left(\frac{a}{2h}\right) + 0.1578\left(\frac{a}{2h}\right)^2\right]$$

where 'a' is the DRA element's radius, 'c' is the speed of light, and 'h' is its height.

The depicted DRA's dimensions in Table 2 have been estimated via mathematical calculations.

TABLE 2 The projected SDRA's dimensions

Name	Value
wg	15
lg	15
hs	0.254
ht	0.035
wd	17.9
ld	17.9
hd	0.83
hs	1.42275

The DRA has many elements, including, square DRA (wd×ld×hd mm^3), ground (wg×lg mm^2) of PEC material, substrate (wg×lg×hs mm^3) and four slots (hs mm) are cut through the DRA making the result more effective and the design more compact.

III. Results And Discussion

A. *S11(Return Loss)*

The modelling of return loss using CST simulation software is shown in Figure 5 as a plot. The obtained impedance bandwidth of the presented DRA is less than -10 dB, and it has been found that with the designed structure including 2 L-shaped slot cut-outs in an DRA, there is significant increase in the bandwidth. The obtained structure results in a broadband between 26.3Gz to 30.2Gz (fractional bandwidth of 13.8%) and two narrow bands between 23.4Gz to 24.1Gz (fractional bandwidth of 2.94%) and between 26.3Gz to 30.2Gz (fractional bandwidth of 13.8%). The proposed DRA resonates at 24Gz, 26.8Gz, 28.8Gz and 34.4Gz frequencies comprising a quad-band. 5G mm-Wave applications use the 28GHz frequency.

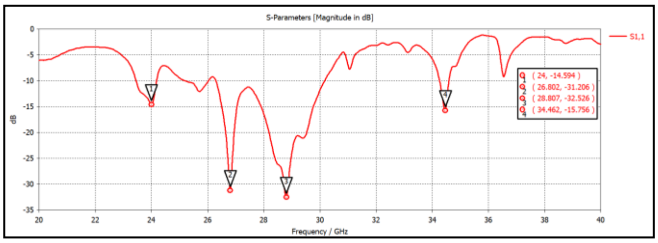


Fig. 5 The projected SDRA's Reflection coefficient s11

B. *VSWR (Voltage Standing Wave Ratio)*

In a same manner, the Voltage Standing Wave Ratio (VSWR) is used to evaluate the power delivered to an antenna. Not all of the energy received by the antenna is necessarily transmitted outside. Thus, VSWR evaluates radiative capability; Figure 6 shows its plot. A return loss of 15 dB, for instance, indicates 3% reflection, 97% power into the antenna, and 1.4 VSWR. When the return loss is greater, the VSWR is at its lowest. The plot of VSWR with respect to frequency is shown in Figure 6.

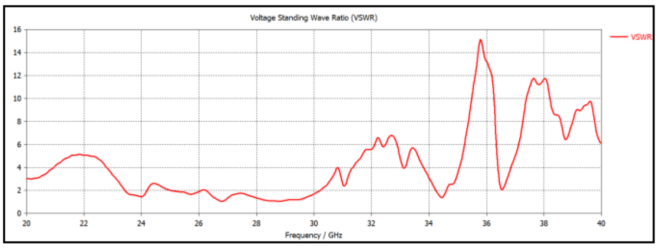


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Fig. 6 The projected SDRA's VSWR Plot

C. Directivity and Antenna Gain

Directivity defines the concentration of radiated power in a specific direction. Gain specifies the concentration of input power in a particular direction. Directivity and electrical efficiency combine to form gain. The change in the value of the simulated peak gain and directivity in dB versus frequency is shown in Figure 7. At 38 GHz, the suggested design achieves 7.8dBi of gain and 8dB of directivity, while at 27.9 GHz, it achieves 6.6dBi of gain and 6.7dB of directivity.

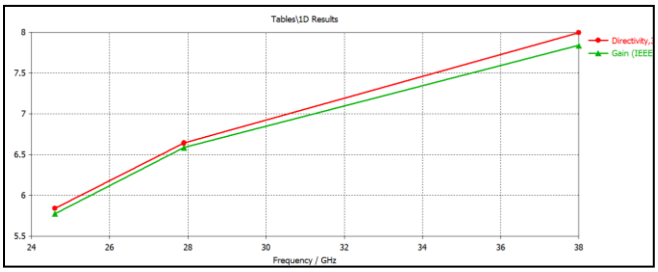

Fig. 7 The projected SDRA's Directivity and Gain plot

D. RE (Radiation Efficiency) and TE(Total Efficiency) radiation patterns (RP)

The ratio of the power emitted by an antenna to the power provided to its excitation port is known as the antenna's RE. The RE of an antenna measures the efficiency with which the radio-frequency power received at its terminals is transformed to radiated power. Total efficiency (TE) is 98% at 27.9 GHz, while RE is 99%. The RE and TE are shown in Figure 7 for the entire frequency range (24–34.46 GHz). RP identifies the antenna's far-field radiations.

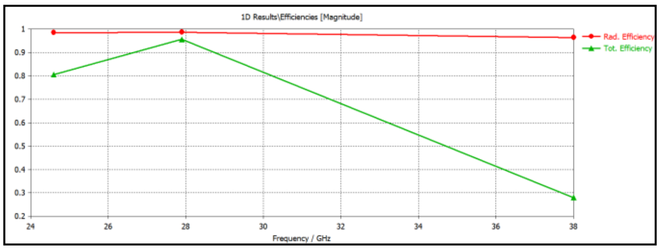

Fig. 7 The projected SDRA's RE and TE plot

E. RP (Radiation Pattern)

The figure below (Figure 8) depicts the proposed DRAs simulated far-field RP at 27.9Ghz frequency for phi = 90 degrees.

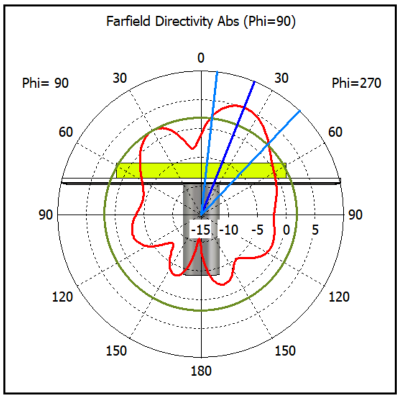

Fig. 8 The projected SDRA's far-field radiation pattern

F. Comparison of proposed work with previous work

The performance of the basic DRA (Dielectric Resonator Antenna) shape has been compared with the proposed one, and the results are presented in the table below. The table describes the previous work's performance compared to the proposed one. The proposed DRA shape has shown better performance in terms of various parameters like return loss, impedance bandwidth, and gain. The suggested DRA shape has performed better in terms of a number of different metrics, including return loss, impedance bandwidth, and gain. Based on experimental findings, the proposed form has noticeable improvements to the standard DRA shape.

TABLE 3 Performance evaluation of proposed work with prior work

S.no.	DRA Geometry	Gain	Ref.
1.	SIF Dielectric Resonator Antenna	6.7 dBi	[8]
2.	Cylindrical-ring Dielectric Resonator Antenna	2 dBi	[9]
3.	Circularly Polarized Dielectric Resonator Antenna	6.5dBi	[10]
4.	Rectangular Dielectric Resonator Antenna	6.38dBi	[11]
5.	L-Shaped Dielectric Resonator Antenna	6.1dBi	[12]
6.	Circularly Polarized Hybrid Dielectric Resonator Antenna	6.74	[13]
7.	**L- shaped square DRA for 5G mm-wave application with enhanced gain**	**7.8**	**Proposed**

CONCLUSION

In conclusion, the compact DRA described is a high-performance antenna designed for use in 5G mm-wave applications. It offers enhanced gain, quad-band, and wide bandwidth capabilities, and is made using high-quality materials that are efficient and loss-free. The proposed DRA is a quad-band antenna at the frequencies 24Gz, 26.8Gz, 28.8Gz and 34.4Gz. The simulated results show that a high gain of 7.9 dBi and directivity of 8dBi has been achieved. Radiation efficiency of 99% is attained. The simulated design shows that there is less loss due to the use of Roger material. The design of the antenna, including the use of L-shaped slots helps to reduce its size while maintaining its performance, making it an ideal choice for space-constrained applications.

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