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Design of Dual-Oriented Rectangular Dielectric Resonator Antennas DRAs for Enhanced Bandwidth and Efficiency at Frequency 13 GHz

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Abstract: - The article discusses the design of dual-oriented rectangular dielectric resonator antennas (DRAs) to enhance gain and efficiency at 13 GHz. The study focuses on improving antenna performance by configuring two rectangular DRAs oriented both vertically and horizontally within a single structure. This dual orientation leverages the advantages of each configuration to achieve higher gain and improved efficiency, specifically at the frequency of 13 GHz. The research addresses the technical challenge of optimizing antenna parameters to enhance performance, targeting a gain increase to 7.033 dBi and an efficiency improvement to 94.4%. These advancements are crucial for applications requiring reliable, high-performance signal transmission at this frequency. Additionally, the study focuses on reducing the size of the ground plane and substrate while modifying the geometry of the feed to enhance the radiation pattern compared to previous designs. The design improvements are evaluated using the Computer Simulation Technology (CST) program.

Keywords: geometry of two RDRA (horizontally, vertically) antennas, polarization, gain, feed, efficiency, bandwidth, frequency 13 GHz

1. INTRODUCTION

Dielectric Resonator Antennas (DRAs) offer several benefits that make them an excellent choice for high-frequency communication systems. One of their key features is their high radiation efficiency, achieved through the use of low-loss materials in their design. These materials minimize conductive and dielectric losses, making DRAs highly efficient at microwave and millimeter-wave frequencies. Another advantage is their compact size, made possible by the high dielectric constant of the materials. A higher dielectric constant allows for a smaller antenna size while maintaining the same resonant frequency, making DRAs ideal for space-limited applications such as mobile and wireless devices.

DRAs have wide bandwidth capabilities due to their ability to be fine-tuned to cover a broad range of frequencies by adjusting their shape and dielectric constant. This is crucial for technologies like 5G, Wi-Fi, and satellite communications. Additionally, DRAs offer design flexibility and can be shaped in various forms, such as cylindrical, hemispherical, or rectangular, to optimize performance factors like bandwidth, gain, and radiation pattern for specific uses. In addition to their technical performance, DRAs are mechanically robust, made from durable, temperature-resistant materials, allowing them to withstand harsh environmental conditions like moisture and extreme weather, making them suitable for outdoor applications. Their low profile, especially when integrated into a surface, is another advantage for applications like conformal antennas, where space is limited, or antennas need to blend into surfaces, such as on vehicles or buildings. Unlike traditional antennas that rely on metal conductors, DRAs do not experience conductor losses, which is especially beneficial at higher frequencies where such losses can become significant.

DRA antennas are capable of delivering high gain, making them useful for focused applications such as point-to-point communications or radar systems. They are also cost-effective to produce, as they can be mass-produced using standard ceramic processing techniques, which helps keep production costs down. Another key benefit is their minimal surface wave losses. Unlike microstrip antennas, they do not rely on a substrate, which results in fewer surface waves, reducing interference and enhancing performance. Due to these advantages, DRAs are

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widely used in applications ranging from wireless communications (Wi-Fi, 5G) and satellite systems to radar, medical devices, and automotive sensors. Designing single radiating elements to support different applications is essential for various wireless technologies such as WLAN, WiMAX, and 5G. Therefore, 5G wireless communication is more appealing than the 4G system because of its lower latency and high data rate to handle expanding wireless data traffic [1].

DRAs, or Dielectric Resonator Antennas, offer an efficient, flexible, and compact solution for modern communication and sensing needs. Researchers have explored various methods to design multiband DRAs, including stacked DRAs [2], multiple DRAs [3], and hybrid DRAs [4, 5]. Other approaches involve adjusting the feeding structure to add additional bands [6] and generating higher-order modes [7, 8]. However, most of these DRAs only support dual-band operation [2, 9] or have a high-frequency ratio [5]. Some designs, such as those in [7, 8], achieve multiband operation with a lower frequency ratio but often result in relatively large antennas, especially at their lowest operating frequency.

1.1 Vertical DRA antenna

The vertical design of DRA offers several practical and performance advantages, making it an excellent choice for modern communication systems. One key benefit is its compact size, which is particularly useful for devices with limited space, such as mobile phones or compact wireless systems. Additionally, DRAs provide better bandwidth than traditional metal antennas due to the use of dielectric materials, and the vertical configuration further enhances signal interaction with the surrounding environment, leading to even greater bandwidth performance. DRAs are highly efficient due to low material and energy losses, and the vertical orientation optimizes this efficiency by aligning the radiating modes more effectively. Moreover, vertical DRAs allow for easy control over the polarization of the signal—whether linear, circular, or elliptical—making them suitable for applications like satellite communications and radar systems. They also reduce the creation of surface waves, resulting in less interference and improved performance, especially in crowded electromagnetic environments. Furthermore, these antennas can be designed for multiband or wideband operation, which is crucial for modern communication systems such as 5G, Wi-Fi, and IoT devices that need to operate across multiple frequency bands or handle wide frequency ranges.

One of the key advantages of vertical dielectric resonator antennas (DRAs) is their stability in challenging conditions. The materials used in DRAs are more resilient to temperature changes and environmental factors compared to traditional metal antennas, making them a reliable choice for harsh environments such as aerospace or industrial settings. Their design also allows for easy integration with other components, such as feed networks or matching circuits, due to their flexible geometry. This makes them ideal for systems that use antenna arrays or beam-forming technologies. In antenna arrays, vertical DRAs help reduce cross coupling between individual elements, which improves overall performance in terms of gain, directionality, and side lobe levels. Furthermore, vertical DRAs offer design flexibility due to their vertical structure, allowing for innovative integrations, such as embedding the antenna into vertical surfaces or using it in conformal antennas. This opens up new possibilities for creative applications and solutions in various industries. The specific 5G operating bands are still being defined. However, as indicated in sources [10, 11], the 5G system is expected to operate in lower bands (below 6 GHz) for better signal coverage and upper millimeter wave bands for higher data speeds. Additionally, several wideband antennas that cover the WLAN, WiMAX, and lower 5G bands have been reported [12].These antennas, however, tend to receive unwanted frequencies, leading to noise issues. A multiband antenna can address this by focusing only on the desired bands.

DRAs offer a highly efficient, versatile, and space-saving solution for high-performance applications, including satellite communications, radar systems, 5G networks, and various wireless technologies. Their compact size, combined with enhanced bandwidth and high efficiency, makes them particularly well-suited for the dynamic requirements of modern communication systems. Additionally, the design flexibility of vertical DRAs enables them to adapt to the ever-evolving demands of the industry, ensuring reliable performance in a variety of applications.

1.2 Horizontal DRA antenna

The horizontal DRA offers several advantages, making it suitable for applications that require specific radiation patterns, low-profile designs, or seamless integration with other systems. One of the primary benefits of a horizontal DRA is its low-profile design. These antennas are naturally compact in height, making them ideal for environments where space is limited, such as in cars, aircraft, or wearable devices. Their slim structure allows them to blend effortlessly into flat surfaces without disrupting the overall design or aesthetics. Another key advantage is their wide bandwidth. Similar to vertical DRAs, horizontal DRAs utilize dielectric materials to provide broad bandwidth capabilities. The horizontal configuration can be fine-tuned to optimize bandwidth for specific applications, ensuring that the antenna meets the rigorous demands of modern communication systems.

The horizontal DRAs have directional radiation patterns, making them suitable for point-to-point communication systems or radar applications where a focused signal in a specific direction is needed. They integrate seamlessly with planar circuits, such as microstrip lines or coplanar waveguides, commonly used in RF and microwave systems. This makes them ideal for compact, integrated setups found in printed circuit boards (PCBs). Horizontal DRAs also leverage the ground plane effectively, enhancing certain radiation modes while minimizing back radiation, leading to improved overall efficiency. Their radiation performance remains stable across different frequencies and environmental conditions due to their proximity to the ground plane, shielding them from external factors, making them ideal for applications like base stations or repeaters where consistent and reliable performance is crucial. Similar to their vertical counterparts, horizontal DRAs also minimize surface wave losses, resulting in improved radiation efficiency and reduced interference with nearby components, which is particularly important in densely packed electronic systems.

Another important feature of horizontal DRAs is their polarization flexibility. By adjusting the feed or design, these antennas can easily switch between linear and circular polarization, which is vital for communication systems where controlling polarization is essential. Additionally, horizontal DRAs can be designed to support multiband operation, making them an excellent choice for systems like 5G or IoT networks that require antennas to handle multiple frequency bands simultaneously. Their thermal stability is another advantage, as the dielectric materials used in their construction provide strong resistance to temperature fluctuations. Moreover, the flat configuration of horizontal DRAs helps dissipate heat across a larger surface area, making them well-suited for environments where heat management is a concern. In antenna arrays, horizontal DRAs exhibit lower mutual coupling between individual elements, which is especially useful in phased array antennas. This reduces interference and enhances performance, allowing for more precise beam steering.From a manufacturing perspective, horizontal DRAs are cost-effective to produce. Their design is easier to integrate with existing planar technologies, making them ideal for mass production in commercial applications, such as consumer electronics or automotive radar systems. Additionally, when embedded in or mounted on a substrate, horizontal DRAs offer greater protection against environmental factors like wind, moisture, and debris, making them durable for outdoor or rugged use.

In certain configurations, horizontal DRAs can also provide higher gain in the horizontal plane, making them ideal for ground-based communication systems where widespread signal coverage is needed. Overall, horizontal DRAs are an excellent option for applications that demand compact designs, broad bandwidth, and easy integration with planar systems. Their directional control, stable performance, and cost-effective manufacturing make them highly suitable for a wide range of applications, including wireless communications, radar systems, and embedded antennas in portable devices or vehicles.

However, the following Table 1 summarizes the comparison between the vertical design and horizontal design of DRA antennas (multiple designs).

Table1. Summarize the results of comparison between multiple design (vertical and horizontal) of DRA antenna

Feature	Vertical DRA	Horizontal DRA
Profile	Taller with a compact footprint	Low profile, covering a larger area
Radiation Pattern	Omnidirectional or close to omnidirectional	More directional
Bandwidth	Wideband, particularly effective in multiband configurations	Wideband, though more reliant on the ground plane
Polarization	Flexible, supports both linear and circular polarization	Mainly linear; circular is achievable but more difficult
Integration	More challenging to integrate with planar designs	Simpler to integrate with planar circuits
Radiation Efficiency	High efficiency, dependent on vertical mode coupling	High efficiency, but affected by surface wave losses
Array Performance	Greater mutual coupling between elements	Reduced mutual coupling among elements
Directional Gain	Lower gain directionally; favors omnidirectional patterns	Higher gain in specific directions
Design Complexity	More complicated due to its three-dimensional structure	Easier to design and manufacture
Applications	Ideal for mobile stations, IoT, and satellite systems	Well-suited for automotive applications, radar, and embedded systems

It's important to consider the unique advantages of both vertical and horizontal DRAs when making a choice between them. This decision is largely influenced by specific performance goals, physical constraints, and the intended application. With the advancement of wireless communication over the past decades, there has been an increased need for multiband antennas [13]. As a result, multiband planar and multiple DRAs have gained significant attention in wireless applications. DRAs offer several advantages over planar structures, including small size, low cost, and high efficiency due to the absence of surface wave and ohmic loss [14,15].

1. Experimental results

2.1 Basic design with coaxial dielectric [16]

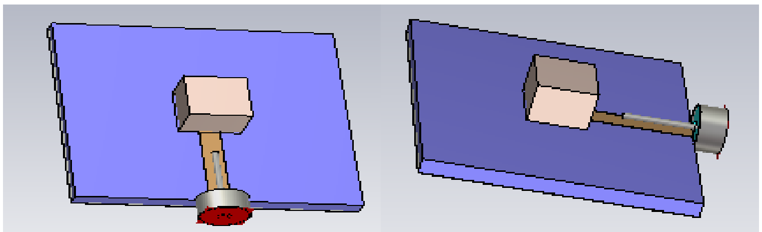

Fig 1. Shown the fundamental design of the initial RDRA rectangular antenna with coaxial dielectric with measurements of the grid indicating in millimeters by CST software

In this new antenna design, we modified the geometry of the previous DRA antenna and utilized different materials. These changes, implemented using the CST program, resulted in an increase in gain from 7.062 dBi to 7.035 dBi at a frequency of 13 GHz. The efficiency of the new design, referred to as Design B, improved to 94.4%, compared to 91% in the previous design A. Additionally, the bandwidth of Design B was enhanced, meeting the required limits and changing from 1.3894 to 0.61178. Consequently, the overall characteristics of the rectangular dielectric resonator antenna (RDRA) were also improved. We reduced also the size of the ground plane and substrate to 20 mm from the original 50 mm. Furthermore, the size of the feed was halved, now measuring 4.75 mm instead of 11.75 mm, as shown in Figure 1, Table 2, and Table 5. The changes in efficiency and bandwidth values from Design A to Design B (multiple designs) are detailed in Table 5 and Equation 4. Overall, the efficiency increased to 94.4% in Design B, reflecting significant improvements over the previous design.

In our study, we removed the coaxial cable's dielectric, including the dielectric material, inner conductor, and outer conductor, to improve the performance of the DRA antenna. This modification resulted in significant enhancements in both gain and efficiency compared to the previous Design A. The values for the inner and outer conductors can be calculated using the equations provided in Table 5.

Additionally, the new Design B has further improved DRA performance by incorporating multiple antennas oriented both vertically and horizontally within a single configuration. This dual orientation strategy allows us to leverage the benefits of both designs, enhancing overall antenna performance.

For the Coax: dielectric

Let X is refer to outer radius, Y is refer to outer diameter, therefore

$$X = \frac{y}{2} \qquad (1)$$

For inner conductor

We suppose inner diameter denotes by Z, which is half of the value of the previous design

$$X = \frac{z}{4} \qquad (2)$$

For outer conductor

Let suppose C refers to outer conductor thickness, therefore

$$X = \frac{y}{2} + \frac{c}{2} \qquad (3)$$

Careful consideration of materials is integral to the design process of a dielectric resonator antenna (DRA). The choice of dielectric material significantly influences the antenna's resonance frequency, bandwidth, and radiation efficiency. By selecting materials with specific permittivity values, engineers can tailor the antenna's performance to meet desired specifications.

Furthermore, the materials used for the inner and outer conductors of the coaxial cable play vital roles in ensuring efficient energy transfer and providing shielding against interference. Therefore, the judicious selection of materials is essential for optimizing the performance, reliability, and functionality of DRAs, aligning them with the requirements of modern wireless communication systems.

Additionally, the changes made to the design were calculated and simulated using the CST program at a frequency of 13 GHz, as detailed in Tables 3 and 5.

Table 2. Geometric the parameters of the DRA, design A coaxial dielectric, inner conductor and outer conductor, with different materials.

Dimension	Size (mm)	Parameters	Materials
DRA height	5.5	DRA	Alumina (99.5%)Lossy
DRA width	5.5		
DRA thickness	4.1	Feed/strip	PEC
Ground plane	25		
Substrate	25	substrate	FR- 4 (Lossy)

Feed length	11.75		
Feed width	1.85		
Feed thickness	0.035	Ground plane	PEC

Table 3. Dimensions of the various components of a rectangular dielectric resonator antenna (DRA) with coaxial dielectric, including the inner conductor, outer conductor, and multiple DRAs (vertical and horizontal) made of different materials, including the ground plane (PEC) material, substrate, and feed.

Parameter	X_{min}	X_{max}	Y_{min}	Y_{max}	Z_{min}	Z_{max}
Ground						
Formula	0	W_{gr}	0	L_{gr}	0	H_{gr}
Dimension (mm)	0	12.5 -10	0	12.5-10	0	0.035
Substrate						
Formula	0	W_{st}	0	L_s	H_{gr}	$H_{gr} + H_s$
Dimension (mm)	0	12.5	0	12.5	0	$0.035 + 1.6$
Feed						
Formula	$\frac{Lf}{4}-$	$\frac{Lf}{4}-$	L_f	$L_f + L$	H_f	$H_{gr} = Hf$
Dimension (mm)	$\frac{-3.7}{4}-$	$\frac{3.7}{4}-$	0	$10.25 + 1.5$	0	0.035
Coax : Dielectric						
Formula	$\frac{OD}{2}$	$\frac{ID}{2}$	$Ucenter$	$Vcenter$	$Wmin$	$Wmax$
Dimension (mm)	$\frac{4.1}{2}$	$\frac{1.2}{2}$	0	0	-2	$\frac{9.9999\, e-0.1}{2}$
Coax : inner conductor						
Formula	$\frac{ID}{4}$	$\frac{IR}{2}$	$Ucenter$	$Vcenter$	$Wmin$	$Wmax$
Dimension (mm)	$\frac{1.2}{4}$	0	0	0	-2	7
Coax : outer conductor						
Slot2	$\frac{OD}{2} + \frac{OD}{2}$	$\frac{OD}{2}$	$Ucenter$	$Vcenter$	$Wmin$	$Wmax$
Dimension (mm)	$\frac{4.1}{2} + \frac{0.41}{2}$	$\frac{4.1}{2}$	0	0	-2	$99 \quad \frac{e-0.1}{2}$
Vertical DRA						
Formula	Xmin/4+5	Xmax/4	Ymin/4	Ymax/4	hgr+hs+hp	hgr+hs+hp+3.2
Dimension (mm)	-5.5/4+5	5.5/4	-5.5/4	5.5/4	0.035+0.508 +0.035	0.035+0.508+0.035+3.2
Horizontal DRA						

Formula	Ws/2-wo/2+4+2	Ws/2+wo/2-1-2	10.5+l0	7.5+l0	hgr+hs	hgr+hs+3.2
Dimension (mm)	20/2-4.25/2+4+2	20/2+4.25/2-1-2	10.5+3.95	7.5+3.95	0.035+0.508	0.035+0.058+3.2

2.2 Design B (Multiple design Vertical and horizontal DRA antenna)

The mathematical geometry of the RDRA antenna is designed to enhance gain and efficiency, beginning with the frequency resonance, as shown in the following equation:

$$f_{resonance} = \frac{c}{2\pi\sqrt{\varepsilon_r}} \sqrt{\left(\frac{\pi}{w}\right)^2 + \left(\frac{\pi}{h}\right)^2 + \left(\frac{\pi}{t}\right)^2}, \qquad (4)$$

The equation of dielectric constant can be defined as,

$$\varepsilon_r = \left(\frac{c}{2\pi f_{resonance}}\right)^2 \left[\left(\frac{\pi}{w}\right)^2 + \left(\frac{\pi}{h}\right)^2 + \left(\frac{\pi}{t}\right)^2\right], \qquad (5)$$

Therefore, from the equation above the equations of height, width and thickness derived as below

$$h = \frac{p.\lambda 0}{2\sqrt{\varepsilon_r}} \qquad (6)$$

$$w = \frac{m.\lambda 0}{2\sqrt{\varepsilon_r}} \qquad (7)$$

$$t = \frac{n.\lambda 0}{2\sqrt{\varepsilon_r}} \qquad (8)$$

where h is the height of the DRA antenna, p is the mode index of height, $\lambda 0 = \frac{c}{f0}$ is the wavelength at the resonant frequency $f0$, c=3x10^8 m/s is the speed of light in a vacuum, ε_r is the dielectric constant of the material., w is the width of DRA antenna, m is the mode index for width ,t is the thickness of the DRA antenna.

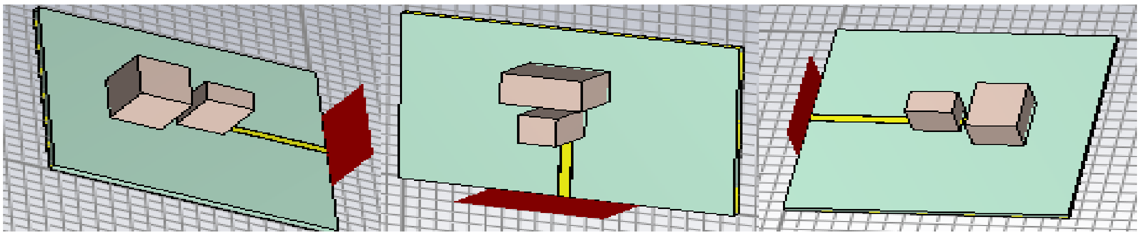

Fig 2. Design of our multiple (vertical, horizontal) DRA antenna

We have designed multiple DRAs (vertically and horizontally) in one configuration, as shown in Figure 2. The aim was to enhance efficiency and improve bandwidth. Moreover, the gain was clearly enhanced. The vertical design of the DRA antenna is a suitable choice for various high-performance applications, including satellite communications, radar, 5G networks, and other wireless communication systems, as explained in Part 1.1. However, horizontal DRAs are an excellent option for applications that demand compact designs, broad bandwidth, and easy integration with planar systems. Their directional control, stable performance, and cost-effective manufacturing make them highly suitable for a wide range of applications, including wireless communications, radar systems, and embedded antennas in portable devices or vehicles, as detailed in Part 1.2. Therefore, the multiple designs of the DRA yielded good results related to efficiency, bandwidth, and gain.

1.2.1 Vertical design of DRA antenna

Firstly, we designed a vertical dielectric resonator antenna (DRA) using the CST program with the given measurements: height (h) = 1.375 mm, width = 1.375 mm, and thickness = 11.45 mm, according to the equations (6, 7, 8). Then, we enhanced the results using the CST program.

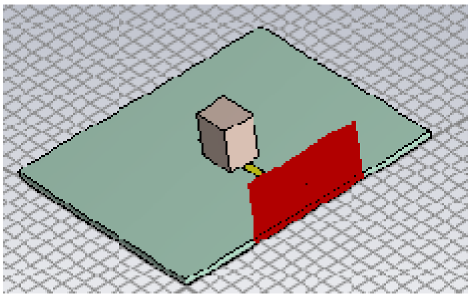

Fig 3.Design vertical DRA antenna

Narrow bandwidth can be quite beneficial for vertical Dielectric Resonator Antennas (DRAs) in specific applications that need to operate within a limited frequency range, as shown in Figure 3. Although DRAs are typically valued for their ability to handle wide bandwidths, there are situations where a narrow bandwidth is actually more suitable. For instance, in fixed-frequency communication systems—like certain transmitters and receivers that don't require a broad range of frequencies—a narrow bandwidth DRA can be more efficient because it focuses its radiation power on a specific frequency range. This focus is especially important in crowded environments, such as urban or industrial areas, where a narrow bandwidth helps reduce interference from competing signals, allowing the vertical DRA to maintain better clarity and performance within its designated frequency band.

By limiting the operating bandwidth, the antenna can also achieve improved signal-to-noise ratios (SNR), leading to enhanced signal quality and more reliable communication. Additionally, in applications like radar systems or specific sensing tasks, a narrow bandwidth DRA provides the precision needed to detect certain objects or frequencies without getting muddled by irrelevant signals from nearby frequencies.

However, for many modern wireless applications, such as 5G or Wi-Fi, a wider bandwidth is often more advantageous. Ultimately, the decision between narrow and wide bandwidth hinges on the specific needs of the system where the DRA will be used. Therefore, the measurements and equations of the parameters of the vertical DRA antenna can be explained in Tables 4 and 5, and Equations 6, 7, and 8.

1.2.2 Horizontal design of DRA antenna

Secondly, we designed a horizontal DRA using the CST program with the following measurements: height (h) = 11.45 mm, width = 4.875 mm, and thickness = 3.743 mm, according to equations 6, 7, and 8. Then, we enhanced the results using the CST program.

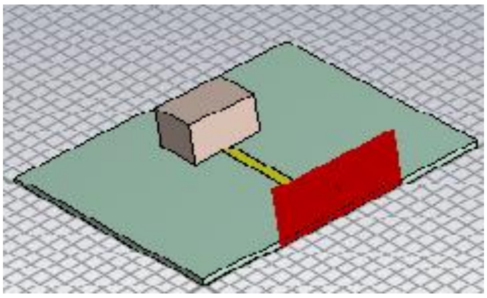

Fig 4-.Design horizontal DRA antenna

Reducing the bandwidth can be quite useful for horizontal Dielectric Resonator Antennas (DRAs) in certain situations, particularly when operating over a limited frequency range is beneficial. For instance, in systems that rely on fixed frequencies, such as certain military communication channels or satellite links, a narrow bandwidth DRA can be fine-tuned for optimal performance within that specific range. These antennas also help reduce interference from nearby frequencies, making them ideal for crowded environments like urban areas or industrial settings.

Furthermore, narrow bandwidth DRAs enhance signal clarity, which is crucial for radar or sensing applications that require precise frequency responses. They can also be more cost-effective and energy-efficient when only a limited frequency range is needed, simplifying the design and manufacturing process. Additionally, by focusing on a narrow bandwidth, these antennas may offer improved gain and more directional radiation patterns, making them perfect for point-to-point communication systems.

However, it is important to note that many modern wireless systems, such as 5G, Wi-Fi, or IoT networks, typically prefer wider bandwidths to support high data rates and multiple frequency bands. Ultimately, whether narrow bandwidth is advantageous really depends on the specific application and the operational requirements of the system.

The measurements of parameters of horizontal DRA antennas can be explained in the following Tables 3 and 4. Then, we combined both designs into a single design, as shown in Figure 2 and Table 4, to achieve better results and to improve the characteristics of the DRA antenna, as explained in the following Table 5. The measurements and equations of parameters of the horizontal DRA antenna can be found in Tables 3, 4, and in equations 6, 7, and 8.

Table 4 .Parameters dimensions geometric of multiple new design (vertical, horizontal) of antenna, with different materials

Dimension	**Size (mm)**	**Parameters**	**Materials**
Vertical DRA height	1.375	DRA	Alumina (99.5%)Lossy
Vertical DRA width	1.375		
Vertical DRA thickness	3.778	Feed/strip	PEC
Horizontal DRA height	11.45		
Horizontal DRA width	4.875		
Horizontal DRA thickness	3.743		
Ground plane	20		
Substrate	20	substrate	FR- 4 (Lossy)
Feed length	4.75		
Feed width	0.7		
Feed thickness	0.035	Ground plane	PEC

2. Simulation results

The data includes S-parameters, voltage standing wave ratios (VSWR), bandwidths (BW), gains (G), and directivities (D) for the designs at points A and B. These designs consist of a previous rectangular dielectric resonator antenna with coaxial dielectric (design A) and a multiple design DRA antenna (vertical and horizontal) (design B).

Figure 5 shows the S11 parameters, Figure 6 shows the VSWR, Figure 7 illustrates the calculation of bandwidth, and Figure 8 displays the radiation patterns in two-dimensional graphs. To ensure comparability, we categorized the simulation outputs based on the parameters and designs. The top subplots on the right consistently represent the new multiple DRA antenna (vertical and horizontal) (design B), while the bottom subplots on the left pertain to the DRA (design A) with a coaxial cable in all Figures 5 to 9.

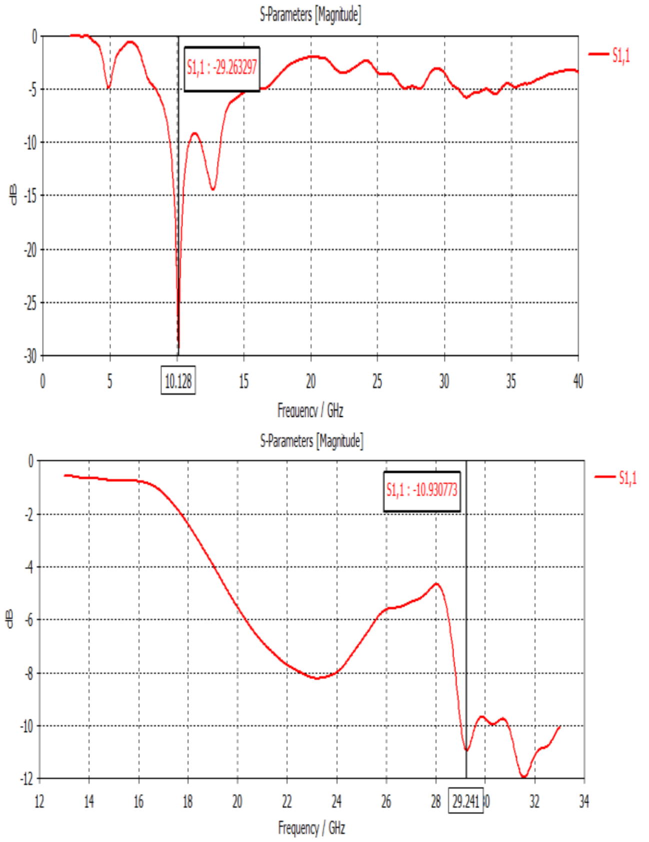

Fig 5. The value of the reflection coefficient S_11. Designed by CST. The first subplot belongs to design A, whereas the second subplot relates to design B

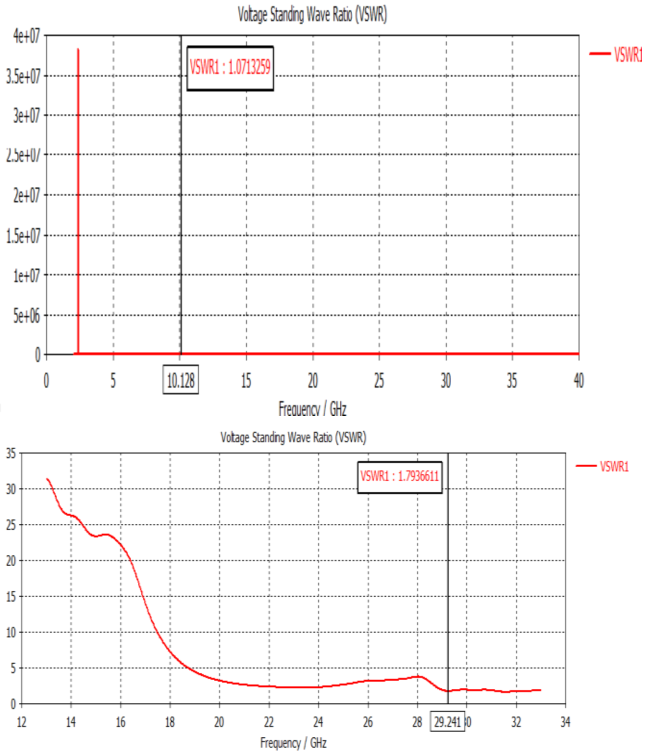

Fig 6 . The voltage standing wave ratio (VSWR). Designed by CST. The first subplot relates to design A, whereas the second subplot belongs to design B

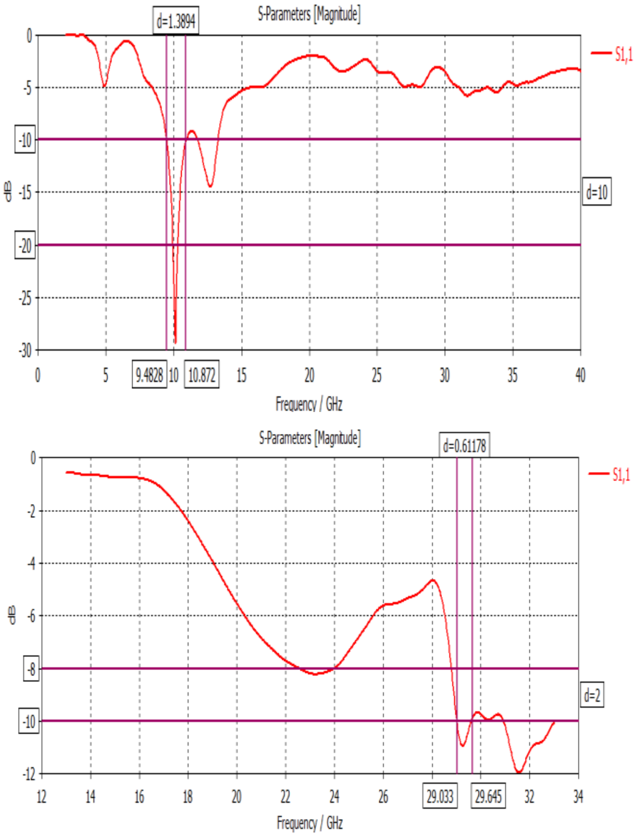

Fig 7.Calculating the value of bandwidth (BW) based on the value of S_11 parameter Simulation conducted using CST software. The first subplot refers to design A, whereas the second subplot belongs to design

B.

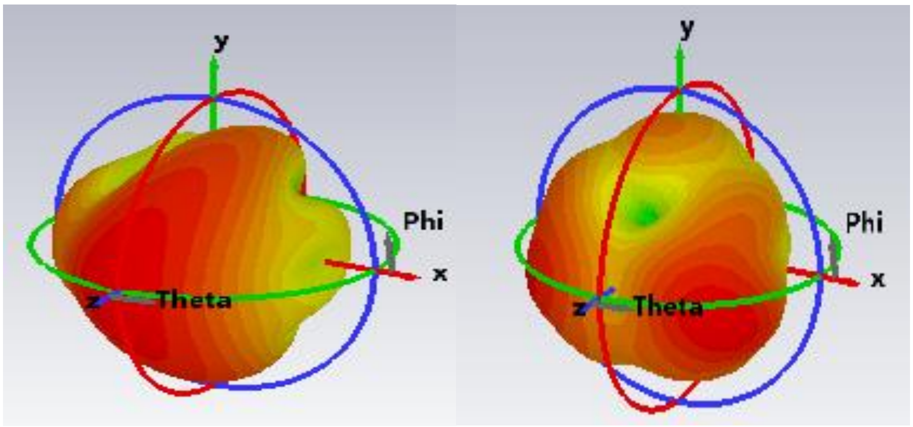

Fig 8. Radiation pattern explains the gain G=7.035dBi with directivity D=7.451 dBi. Model by CST. The top subplot corresponds to design A and the 2nd subplot to design B.

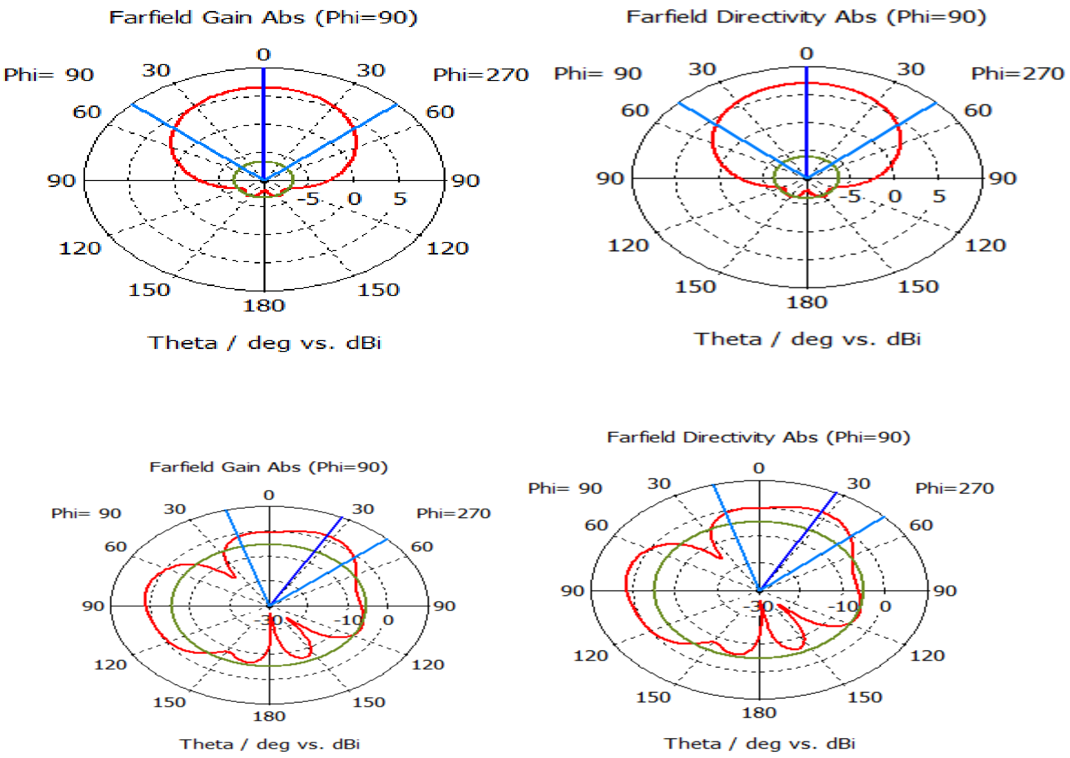

Fig 9. Far field gain (on the left) and directivity (on the right) at frequency 13GHz, as determined by CST. The top row displays design A, while the bottom row showcases design B.

After comparing design A with the new design B, the final results show that the gain significantly increased to 7.035 dBi in design B, while it was 7.062 dBi in design A. Furthermore, the efficiency improved to 94.4% in design B compared to 91% in design A. Additionally, the bandwidth met the required specifications for the new design dimensions. This indicates that the new design of the multi-directional antenna was necessary to enhance both gain and efficiency, achieving 94.4% in design B at a frequency of 13 GHz, as shown in Table 5 and Equation 9.

The final comparison between design A and the new design B explains that the gain clearly enhanced to 7.035 dBi in design B, while the gain was 7.062 dBi in design A. Also, the efficiency increased to 94.4% in design B instead of 91% in design A. Moreover, the bandwidth improved to meet the required dimensions of the new design. This means that the new design of the multiple (vertical and horizontal) antenna was necessary to enhance both gain and efficiency, reaching 94.4% in design B instead of 91% in design A at a frequency of 13 GHz, as shown in Table 5 and Equation 9.

Table 5 .The final results of design A and design B

Parameter	G (dBi)	D (dBi)	BW (GHz)	VSWR	S_{11} (dB)	Efficiency
Design A with coax dielectric	7.062	7.794	1.3894	1.0713259	-29.263297	91%
Multiple design of DRA antenna, new design B	7.035	7.451	0.61178	1.7936611	-10.930773	94.4%

The efficiency of design B (multiple design) enhanced to become 94.4%, as explained in the following equation:

η= G/D · 100 % = 7.035 /7.451· պղղ100 % = 94.4% (9)

3. Conclusion and Future Work

As previously detailed in the tables, dielectric resonator antennas (DRAs) come in various shapes and sizes, with rectangular and cylindrical designs being the most common. The resonance frequency, bandwidth, and radiation pattern of these antennas are influenced by their shape. The redesign of the rectangular dielectric resonator antenna (RDRA) was essential to enhance gain and efficiency at a frequency of 13 GHz. This redesign improved the gain to 7.035 dBi in design B, compared to 7.062 dBi in design A. Additionally, the efficiency of the new design B increased to 94.4%, up from 91% in design A, as illustrated in Table 5 and Equation 4, along with an improved bandwidth.

We can further enhance the efficiency of the RDRA by altering its geometry without using coaxial dielectrics, such as reducing its height, width, and thickness, or by incorporating multiple designs of DRAs (both vertical and horizontal) into a single configuration. For instance, when the height is set to 1.25 mm, width to 2.25 mm, and thickness to 4.458 mm, the efficiency reaches 93.7%, although the gain decreases to 6.094 dBi. Conversely, utilizing a combination of vertical and horizontal designs can increase efficiency to 94.4%, with dimensions of 1.375 mm in height, 1.375 mm in width, and 3.778 mm in thickness for the vertical DRA. The measurements for the horizontal DRA then become 11.45 mm in height, 4.875 mm in width, and 3.743 mm in thickness.

Overall, integrating multiple DRA designs optimizes performance parameters, minimizes signal losses and interference, and ensures clearer and more reliable communications. Moreover, the use of various antenna designs enables operation across a broader range of frequencies, which is crucial for modern communication systems that span diverse bands. Incorporating omnidirectional features with multiple designs can enhance the gain of the dielectric resonant antenna (DRA) in several ways. Firstly, it improves compatibility with other components, facilitating more efficient power transfer between the antenna and the transmission line. This increased efficiency directly contributes to the antenna's overall performance. Secondly, the combination of different designs in a multi-design setup allows for a more streamlined and integrated antenna structure without compromising effectiveness, potentially leading to higher gain. Furthermore, employing multiple dielectrics provides improved control over the antenna's signal emissions, enhancing precision in transmission and reception.

However, rectangular DRAs typically have narrower bandwidths since they are optimized for a single resonant mode. Their more directed emission pattern makes them particularly suitable for point-to-point transmission, making them an excellent choice for compact wireless communication devices. Generally, rectangular DRAs are more complex to manufacture than cylindrical DRAs, as achieving optimal performance requires finer construction and calibration. The small size and omnidirectional emission pattern of cylindrical DRAs, on the other hand, make them ideal for portable communication devices such as smartphones and tablets. Rectangular DRAs are widely used in point-to-point communication systems like satellite communication and radar due to their directional emission patterns.

Choosing between these two types of DRAs depends on the specific application requirements and design limitations. DRAs play a crucial role in radio communication systems. In the future, we aim to enhance gain, bandwidth, and other parameters (e.g., x, y, z) by altering the antenna's shape or employing multiple DRA designs with different configurations. This may involve removing or adding elements within the DRA, as well as optimizing the substrate to improve the antenna's gain. Additionally, selecting appropriate feeding ports is essential for the antenna's performance. For example, optimizing the characteristics of the rectangular DRA can involve adding or removing certain components or using multiple layers for stacking.

We can also improve gain by incorporating layers of photonic crystals and modifying the antenna structure, as demonstrated in previous designs simulated using CST (Computer Simulation Technology) software to reduce the size of the DRA. These modifications will enable us to enhance the gain and bandwidth while improving antenna efficiency, as illustrated in the figures above. We will continue to work on enhancing gain, bandwidth, efficiency, and radiation patterns in the future by adjusting the structure and parameters of the DRA using Computer Simulation Technology.

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