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Research Article

Narrowband Optimization of Hybrid RDRA and Microstrip Patch Antennas Design to improve the gain at 28GHz

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Abstract:

Numerous applications necessitate the utilization of antennas. One type of antenna commonly employed in the field of communication is known as the dielectric resonator antenna (DRA). This research aims to improve the gain and efficiency of antenna by hybrid (multiple design) which means collecting rectangular dielectric resonator RDRA antenna with microstrip patch antenna together as (hybrid design) in one design and stacked them. Then change the geometry and thickness of antenna as well as changing the materials of microstrip patch antenna and RDRA antenna. This occurs by creating different shapes of slots placed on different positions on patch of the microstrip antenna and design DRA antenna with same dimensions to enhance gain and efficiency. The efficiency of the DRA antenna increases in this new design, too. However, the bandwidth reduced in the hybrid design to enhance gain and to be suitable for this special design. This hybrid design (RDRA ,Microstrip patch) antennas together can provide ease of integration with circuits and surface wave excitation, while the dielectric resonator enhances radiation efficiency and supports different modes for better performance. Other hybrid antenna designs might combine dielectric resonators with slot antennas, monopoles, or horn antennas to achieve specific performance improvements suited for applications like satellite communication, wireless networks, and radar systems. The comparison based on key performance metrics, including S-parameters, gain, directivity, bandwidth, and voltage standing wave ratio (VSWR). The software CST (Computer Simulation Technology) is employed for testing and to assess the characteristics of the designed microstrip and DRA antennas.

1. Introduction

1.1 Dielectric Resonator Antenna (DRA)

The dielectric resonator antenna (DRA) is a type of antenna utilized in radio communication, featuring various geometric configurations such as rectangular or cylindrical geometries. The antenna incorporates a ceramic material for its construction, which also serves as a dielectric resonator positioned on the antenna's surface. Microwave frequencies employed in this antenna configuration to augment the outcomes and provide the necessary energy for long-range propagation [1]. The metallic components of a dielectric resonator antenna (DRA) experience a loss phenomenon at high frequencies. This instance examines the benefits of utilizing this particular antenna due to its ability to mitigate energy reduction in high frequencies. Hence, the aforementioned benefit renders the DRA antenna superior than dielectric waveguide antennas due to its minimal loss and high efficiency [1] at the required higher microwave frequencies. In 1939, Robert Richtmyer proposed the concept of the initial dielectric waveguide antenna for utilization in wireless devices and radar systems. However, the first development of the proposed DRA antenna occurred only in 1982 [2]. The initial antenna subjected to testing by Long et al. The designer's primary focus lies on the dielectric surface, while also considering the waveguide leakage [3]. Thus arose the HEM11d model, which later developed into the recently introduced HEM12d model [4] in the year 2012. Additionally, the novel design incorporates the utilization of cylindrical ceramic blocks to emit a wider radiation pattern. This was discovered by Guha in the year 2012. Therefore, there exist similarities between the two types of antennas. An illustrative instance would be the Marconi antenna. The present study examines the operational similarities between the Marconi antenna and the dielectric antenna. Nevertheless, the sole distinction lies in the substitution of the inductive component with a dielectric substance [5]. One of the most significant concerns in DRA (Dielectric Resonator Antenna) design pertains to the relative permittivity. The utilization of this technique proves to be advantageous in the design of the aforementioned antenna. Furthermore, the dielectric constant of the antenna commonly accepted to have a value of 9.8. Hence, the CST program's simulation of this antenna is depending on this constant. Nevertheless, certain issues arise in relation to the characteristics of this antenna. For instance, the selection of an appropriate size during the design phase of this antenna. Furthermore, bandwidth (BW) plays a crucial role in many forms in this design. However, variations in attributes result in diverse outcomes. The cylindrical dielectric resonator antenna (DRA) exhibits distinct differences in shape, properties, and outcomes when compared to the rectangular DRA antenna. This antenna exhibits variations in design and radiation pattern because of the varied parameters utilized as the feed. Therefore, the reduction of radiation pattern is one of several challenges encountered in the simulation of dielectric resonator antennas. The manifestation of this phenomenon displayed in the deterioration of ohmic characteristics. This pertains to a variety of DRA types [6]. The complexity of antenna design heightened by this factor.

However, it is imperative for the designer to select the appropriate value of the dielectric constant. This phenomenon is attributed to the inverse correlation between the efficiency ratio (ε_r) and the dimensions of the distributed radio antenna. Consequently, the radiation pattern ascends from the ground and depends on the dielectric constant. Furthermore, it is worth noting that each design incorporates a dielectric constant that is tailored to its specific requirements. The numerical values of these constants are distinct from one another. Hence, the designer would carefully select the appropriate dielectric constant value while designing a good DRA [7]. However, the design of DRA antennas at millimetre frequencies does not seem to encounter any significant issues. The lack of clarity in the manifestation of losses in the design of the dielectric resonator antenna is evident. Furthermore, the choice of ground plane (GP) material might also have an impact. The utilization of the generalized GP in the context of physical materials exhibits distinctions when compared to the application of the boundary GP. Consequently, the values will decrease due to resistive losses incurred while employing physical ground planes. The utilization of a circular slot as a technological approach to extend the bandwidth (BW) of a rectangular dielectric resonator antenna regarded as a significant method for improving the efficiency of the DRA antenna. This technology demonstrates efficacy in attaining optimal outcomes and enhancing the desirable characteristics of DRAs. The software utilized for simulation is referred to as the CST program. Hence, the utilization of circular slot technology within the frequency range of 0.92 to 1.33 GHz will result in a bandwidth capacity of 36.44%. The rectangular slot exhibits a bandwidth value of 6.39% across various ranges. The observed frequencies fell within the range of 1.6 to 1.13 GHz. This implies that the utilization of a circular slot normally results in a five-fold increase in bandwidth, compared to the utilization of a rectangular slot.

In this study, we employed novel technological advancements to improve the gain and bandwidth of a dielectric resonator antenna (DRA) operating at a frequency of 28 GHz. specifically; we incorporated three-square slots of varying forms to achieve this enhancement. The slots positioned in various locations along the top direction of the patch of DRA antenna. Therefore, the geometry of the patch of the DRA underwent a noticeable alteration. The size of the patch of DRA antenna was larger in comparison to the previous version from [8]. Therefore, because of these new design modifications, the shape of the antenna was altered and the gain exhibited a noticeable increase. Nevertheless, several research groups have directed their attention towards the DRA antenna due to multiple factors. One of the factors contributing to the effectiveness of radiation is its efficiency. Additionally, there are other advantages associated with the presence of distinct types of radiation in different positions. This implies that the antenna exhibits utility across several spatial locations [3].

On the other hand, it is worth noting that the bandwidth of the patch microstrip antenna is larger compared to other antennas, and it does not experience any metal losses [9]. Nevertheless, the utilization of high permittivity (ε_r) materials employed as means to mitigate some issues associated with the gain in the system. In the context of frequencies of approximately1 GHz, it is observed that the bandwidth of the dielectric resonator antennas are relatively large. Hence, the DRA antenna is widely employed in various orientations for applications in the UHF band: it is plausible that a solitary DRA antenna could serve as a substitute for multiple narrowband antennas, thereby mitigating the expenses associated with applications operating at lower frequencies. Broadly speaking, there exist three distinct categories of DRA antennas. For instance, the types of antennas that considered are rectangular, cylindrical, and hemispherical in shape. The rectangular dielectric resonator antenna (RDRA) finds extensive utilization in numerous applications. This phenomenon attributed to the increased flexibility in design or simulation processes [10]. Furthermore, numerous experiments aimed to achieve a substantial increase in the bandwidth of this particular antenna. One approach involves utilizing metals with low resistance values in order to achieve a wide bandwidth [11]. However, alternative approaches to achieve high bandwidth involve modifying the geometry of the DRA and adjusting certain characteristics or parameters [12]. Furthermore, the utilization of multiple distributed receiver antennas (DRAs) for stacking in order to improve bandwidth has been explored [13]. One other method for enhancing the bandwidth of the DRA antenna is by the application of a slot feed, which allows a broader variety of frequencies to be accommodated [14]. Every technological innovation possesses both benefits and drawbacks. One of the challenges associated with these technologies pertains to the diverse range of sizes exhibited by DRA antennas, hence the substantial bandwidth achieved by employing slot-DRA technology to feed the antenna, while maintaining its size without any enlargement. This technology employed at low frequencies. The aperture for feeding the antenna exhibits a rectangular configuration, however, this technology may also utilize additional slots in various shapes, for instance, the inclusion of ring slots and circular slots observed. In the previous years, designers employed many types of slots, including circular and square configurations. The utilization of these slots has numerous advantages, including its ability to serve as a coupler that enhances and expands the bandwidth of the antenna [15].

In the following considerations, Section 2 presents a comprehensive description of the methodologies used to improve the characteristics of dielectric resonator antennas. The primary emphasis of this study centers on the adjustment of geometrical factors with the objective of enhancing antenna qualities such as size, bandwidth, gain, efficiency and directivity. In the following, sections, in Section 3 and 4, the theory and properties of surface plasmons (SP) are discussed. Subsequently, techniques for expediting the process of speeding signal processing are discussed. Section 5 of this report pertains to the presentation of the outcomes derived from the conducted tests. The analysis of the findings presented in Section 6, while our future work and conclusion of this comparative study explained in Sections 7 and 8.

1.2 Microstrip Patch Antenna

A microstrip antenna is a radio frequency (RF) antenna that is constructed utilizing microstrip technology, wherein conductive traces formed on a dielectric substrate. The antenna under consideration classified as a planar antenna, indicating its design intended to align with the substrate on the same plane. Microstrip antennas extensively employed in diverse wireless communication systems owing to their compact dimensions, reduced height, and convenient integration capabilities with other circuit board components.

Antennas of this nature possess use in certain applications. The mobile phone market holds significant importance due to its inherent qualities that render it well suited for communication purposes. For instance, this technology exhibits affordability, a discreet physical appearance, and ease of manufacturing. Nevertheless, one drawback of this particular type of antenna is its limited bandwidth. This phenomenon pertains to the resonance of high frequency (HF) signals, which occurs due to the very diminutive size of the antenna. Additionally, the magnitude of its gain may vary depending on the appropriate frequency range of values for utilization. For instance, the level of gain obtained from a single patch antenna is lower compared to the level of gain obtained from a patch array. Certain applications require a high level of gain, for instance, in aircraft and similar entities. These applications necessitate a low-profile design coupled with especially high gain. This type of antenna possesses additional benefits, including variation in polarization. Therefore, the rectangular design path has the potential to serve as a widely used microstrip antenna; this is the reason why it is possible to witness their widespread dissemination in the market. Moreover, the dielectric constant of the recently developed materials clearly extended, consequently, the length of the antenna reduced.

The antenna possesses parameters that hold significant importance and exert influence over several features. For instance, Equation (1) provides the correlation between resonance frequency f_c and length.

$$f_c = \frac{C}{2L\sqrt{\varepsilon_r \varepsilon_0 \mu_0}}. \qquad (1)$$

In the formula above the capacitance (C) is divided by twice the inductance (L) multiplied by the square root of the product of the relative permittivity (ε_r) and the permittivity and permeability of the vacuum ($\varepsilon_0\mu_0$). Hence, the magnitude of L is accountable for the resonance frequency. The length l, height h, and also the width w, are accountable for the impedance L: there exists an inverse proportionality between the three entities. This implies that a decrease in impedance is a result of an increase in width.

In the case of the bandwidth BW, it is also dependent on the L, moreover, the behavior of fields depend also on the permittivity. Consequently, the radiation pattern would exhibit enhancement when the value of ε_r is reduced. Hence, BW is

$$BW \propto \frac{\varepsilon_r - 1}{\varepsilon_r 2 \frac{wh}{l}} \qquad (2)$$

Often, the height of the antenna augmented in order to get an improvement in signal strength. However, as previously demonstrated, this type of antenna exhibited low efficiency and gain. The gain might potentially be -6 dB. Additionally, the system exhibits a high Q-factor with a limited bandwidth. In addition, the device encompasses a variety of antenna types, including dipole patch and printed slot, among others. These categories possess distinct qualities that set them apart. An illustration of this concept is the utilization of a microstrip patch, which consists of a slender square region of pitch located on one side. It often represented as a distinct category [16]. Hence, this particular type employed in a rectangular design, the opposite side hasGP. However, certain shapes, like as circles, associated with this type of antenna, too. Additionally, there are emissions of unwanted direction of this antenna because of electromagnetic fields separation. Hence, the performance of an antenna is influenced by several features or attributes, including its thickness. Nevertheless, certain outcomes of this antenna may exhibit random variations. This implies a limited improvement in outcomes [17]. The outcomes of this study are contingent upon various elements, such as the dimensions of the antenna. Moreover, the efficiency could potentially be reduced by modifying certain dielectric constants. Nevertheless, it is important to note that every antenna possesses both benefits and drawbacks. An illustrative instance characterized by a diminished amplification and reduced energy use. This analysis examines the drawbacks associated with microstrip antennas. Additionally, the efficiency diminished through the implementation of a limited bandwidth. Hence, the aforementioned limitations of the antenna. Nevertheless, there is room for enhancement in both weight and manufacturing.

Another study examines several advantages associated with the utilization of the microstrip and DRA antennas. First, the reducing of the size, then the possibility to enhance the radiation pattern by modifying certain geometric and material parameters [18]. Furthermore, certain structures extensively utilized due to their inherent advantages, such as the ability to facilitate broadening of BW. These structures commonly referred to as the electromagnetic band gap

2. Methods Employed to Enhance the Characteristics of (DRA) and microstrip path antenna

2.1 Adding other slots on patch of microstrip antenna

Alternative slot configurations, such as radiators, employed to enhance the bandwidth. The aforementioned slot exhibits a radiation pattern with a wide bandwidth and improves the properties of the microstrip patch antennas as well as the DRA antennas [19,20]. This pertains to the utilization of wideband (WB) and ultra wideband (UWB) technologies within the frequency range of 3.1 to 10.6 GHz. Therefore, in order to optimize bandwidth and develop a microstrip patch antenna, it recommended for substituting the circular slot with a rectangular one. This phenomenon can occur over several dimensions, such as 0.257 $k\Omega^3$, 0.257 $k\Omega^3$, and 0.051 $k\Omega^3$.

2.2 SP technology and putting arrays of DRA over micro strip

Another scientist, Marcatili, attempted to address the issue of resonance [21]. However, certain methodologies deemed significant for the examination and assessment of qualities or attributes pertaining to DRA antennas. For instance, an assessment of efficiency and the Q-factor, can be estimated by the Wheeler cap method that combines the distant field and the field within the so-called radian sphere. Consequently, previous investigations have predicted and examined the field of nano-plasmonics: if gold served as the primary feed material plasma oscillation quasiparticles called Plasmon appear in the surface of the antenna, or the interface between the dielectric resonator and the metallic layers. In contrast, it is more common to have silver employed as the material to induce surface Plasmon (SP) events, rather than utilizing gold. Silver considered a favorable material for the reduction of chemical reactors [22]. Hence, the utilization of silver material may yield comparable outcomes. Nevertheless, the primary objective of these studies is to achieve a high relative permittivity (ε_r) while simultaneously reducing the complexity in the design of the dielectric resonator antenna (DRA). Several studies have documented an observed increase in the Q-factor due to the surface plasmons. The observed outcomes are directly proportional to the increase in the value of ε_r. Moreover, the dimensions of the DRA experienced a decrease in accordance with these advancements [23], therefore, the surface to volume ratio is increased by adjusting the geometry appropriately. Several specialists utilize water as a dielectric in DRA systems. The utilization of deictic in antenna found to be beneficial in enhancing the ratio, as demonstrated in [24] by O'Keefe and Kingsley. The consideration of radiation efficiency emerges as a crucial aspect in the design of Dielectric Resonator Antennas (DRAs). The Wheeler cap approach deemed appropriate for this objective in order to optimize efficiency. Hence, the assessment and analysis of effectiveness deemed appropriate by this approach.

Variations in specific traits were also observed. For instance, Lai et al. conducted a study that examined the distinguishing properties of DRA and microstrip. The observed variations are not substantial, but they do manifest in certain aspects [25]. The radiation mode of a microstrip antenna is comparatively lower than that of a dielectric resonator antenna (DRA). However, the disparities in radiation arise from the implementation of arrays of dielectric resonator antennas across microstrip configurations. This phenomenon results in an escalation of radiation levels and subsequently gives rise to the observed disparities.

2.3 The proposed technology

We used hybrid design of both microstrip patch antenna and rectangular dielectric antenna (RDRA). We designed both antennas with the same measurements of surface and ground as explained in Section 5. The idea was changing the geometry of the microstrip patch antenna and thickness of DRA antenna, and then compare the results with the new design of RDRA antenna to enhance the gain with reducing bandwidth. We have three slots and special patch slots to enhance the gain and reduce the bandwidth of microstrip .The thickness of DRA became 1.5mm instead of 1 mm as listed in table 2 and table 3 and RDRA integration antenna with changing the materials to alumina (99.5%) Lossy as shown in table 3. In addition, the new design and comparison of the results according to this new technology explained in the next pages by using Computer Simulation Technology (CST) program. Therefore, in the final design E the bandwidth reduced to 0.6 GHz instead of 1.6 GHz in design D as listed in table 4. That means in our new design E as showed in figure 5 we reduced the bandwidth as listed in table 4 by collecting two kinds of antennas such as, RDRA and microstrip patch antenna in one design (hybrid design) to get new geometry and to improve the gain to **9.167 dBi** instead of previous design which the gain was 8.208 dBi as listed in table 4 and reduce bandwidth to 0.53505 GHz which was suitable for this new design. For example, in a rectangular dielectric resonator antenna (RDRA) with a microstrip patch, the microstrip patch can provide ease of integration with circuits and surface wave excitation, while the dielectric resonator enhances radiation efficiency and supports different modes for better performance. Other hybrid antenna designs might combine dielectric resonators with slot antennas, monopoles, or horn antennas to achieve specific performance improvements suited for applications like satellite communication, wireless networks, and radar systems.

3. Theoretical Framework of Surface Plasmon

The observed phenomenon is of significant importance, as it involves the expansion of the field, resulting in an increase in the effective size at the surface. Hence, this phenomenon pertains to surface waves, specifically those associated with electromagnetic radiation. Subsequently, the radiated electromagnetic field will see a gradual decline for decreasing frequencies.

3.1 Two properties and characteristics of SP

There exists a correlation between distance and material properties. Consequently, alterations in materials result in a decrease in distance with a minimal magnitude. Additionally, the propagation of the field will undergo modification. However, at a specific frequency, the wave vector exceeds that of a light wave within this frequency range.

Moreover, the construction of an antenna is a complex task, leading to instances where the stimulation may turn out to be ineffective. However, there exist several methods to expedite the process of an accelerating SP, which are outlined as Waveguide structures – Structures of various ion gating mechanisms – Excitation in the near field – Coupling methods.

3.2 Coupling methods to DRA

The allocation of energy across several atomic orbitals plays a crucial role in the application and utility of Density Functional Theory (DFT)-based Reduced Analysis in many contexts. The port is accountable for ascertaining the magnitude of energy or specifying the active mode. Finding these quantities might be challenging, hence numerical methods aid in their simplification. In order to obtain strong coupling, it is necessary to identify specific regions inside the Distributed Resonant Amplifier (DRA) where a robust current source would be appropriate. Hence, the advantages encompass alterations in the Q-factor and the redistribution of energy.

3.3 Slot aperture

The activation of the magnetic field achieved by the use of an aperture. There exist two distinct types of slots, namely the down ground plane slot and the up ground plane slot. In order to achieve a reasonable radiation impedance matching to a dielectric resonator antenna, the placement of the DRA towards the slot facilitated by employing a microstrip stub. This coupling mechanism is effective for frequencies that are appropriate for the coupling and are above the L-B band. Conversely, for frequencies below the L-B band, a larger slot size is required.

3.4 Coaxial Probe

The utilization of a probe for coupling regarded as an alternative approach. The positioning of the probe varies among different components. Consequently, the positioning of the DRA and the elevation of the probe was modified in order to optimize the connection. The excitation of the magnetic field occurs when the probe is in close proximity to the dielectric resonator antenna, while the mode radius affected vertically when the probe is positioned in the center of the DRA. Another advantage of using probes is the ability to establish direct connections between antenna couples without the need for network matching. Nevertheless, the feasibility of linking may become impracticable as the slot size increases The microstrip line, also known as the microstrip transmission line, is a type of transmission line used in microwave engineering. It consists of a conducting strip placed on a dielectric substrate, with a ground plane located on the opposite side. The microstrip line is widely used in various applications. In the field of microwave circuits, there exists a well-established technique for achieving coupling with microstrip configurations. Furthermore, there exists a direct correlation between coupling and permittivity. The approach exhibits a polarization wherein the microstrip employed as the feed. The topic of discussion pertains to the concept of co-planar feeds, specifically in the context of a given system. This strategy additionally facilitates the establishment of coupling. The co-planar structure exhibits coupling behavior that is analogous to that of a coaxial probe. Hence, the feeding of dielectric resonator antenna with the utilization of a co-planar slot has been shown in prior research [14, 25].

4. Experimental Results

In this article, we designed hybrid antenna by collecting both RDRA and microstrip antennas in one design to enhance the gain as shown in figure 5 and physically in figure 11. This new design used multiple slots and special patch with Slots in microstrip patch antenna and DRA integration to enhance the gain and efficiency of microstrip antenna and RDRA antenna. Therefore, hybrid antenna was necessary to improve the performance of antenna as shown new design in Section 5.C. In addition, the size of the patch of antenna is changed as explained in tables 1 and 2. The positions of multiple slots were useful to enhance the radiation pattern and simultaneously improving the gain of antenna. We designed and simulated hybrid antenna (both the rectangular dielectric resonator antenna (RDRA) and the microstrip patch antenna) in different geometries in one design, and compared them to the design from our previous article [8] (mentioned in figure 1). The purpose was to enhance the gain of DRA antenna in design E and sequentially the efficiency of antenna arrived to 92.9% in case of both microstrip antenna and RDRA antenna at frequency of 28 GHz. In addition, the bandwidth reduced to 0.53505 GHz as shown in table 4 and other parameters such as S-parameters improved clearly. The bandwidth reduced from 1.6 GHz to 0.53505 GHz as showed in the final design E. All these changes in geometry of RDRA antenna are simulated in computer Stimulation Technology (CST) software at the frequency f=28 GHz. These changes in shape of the microstrip and RDRA antennas will be explained in the following points.

4.1 Reference design [8] normal microstrip patch antenna

Figure 1 illustrates the fundamental design of the reference Microstrip patch antenna, along by its respective dimensions. The height dimensions along direction Z are imperceptible as a result, of their diminutive scale. In this part, a normal rectangular microstrip patch antenna simulated and designed with Special patch design. The geometrical parameters of the microstrip patch antenna from figure 1 are listed in table 1,2.

4.2 2nd geometry

In the second geometry, we changed the size of the patch of the DRA antenna. We used different shape of patch, larger than the original design especially in the width, as explained in values in table 2 and figure 2. The parameters of this geometry, as explained in CST (Computer Stimulation Technology) software with values at frequency of 28 GHz are listed in table 2, too. The change was useful to enhance the gain of the DRA antenna and other parameters, such as bandwidth, S-parameter, VSWR and directivity D. Then the efficiency of the DRA antenna increased clearly according to the following equation

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$$\eta = \frac{G}{D}\cdot 100\,\% = 11.34/12.20\cdot 100\,\% = 92.9\% \qquad (3)$$

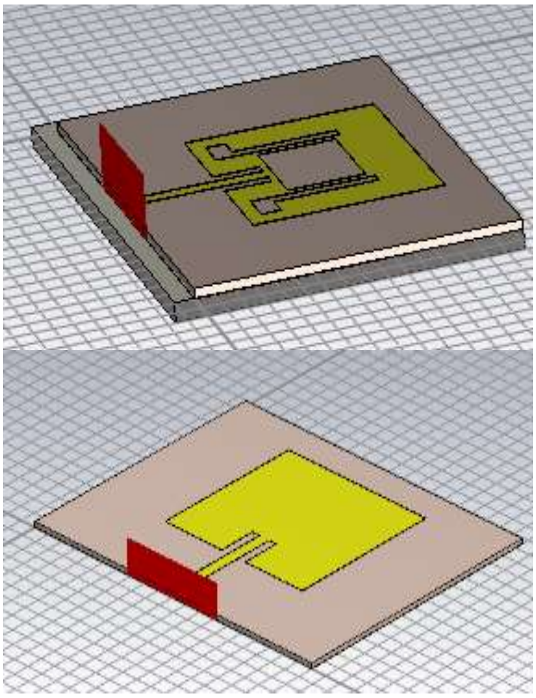

Figure 1. *The fundamental design of the original [8]*

Rectangular antenna exported from CST. The grid shows the millimetre scale

Table 1. *The notations used for the parameters of the antenna, and their meanings*

Notation	Meaning
W_{gr}, L_{gr}, H_{gr}	width, length and height of ground
W_f, H_f	width and height of feed
W_p, L_p, H_p	width, length and height of patch
W_s, L_s, H_s	width, length and height of substrate
W_g, L_g	width and length of gap
X	width dimensions
Y	length dimensions
Z	depth/thickness dimension
X_{min}, X_{max}	minimum and maximum value in x direction
Y_{min}, Y_{max}	minimum and maximum value in y direction
Z_{min}, Z_{max}	minimum and maximum value in z direction
Y_0	inset length
s_i	Shift in direction i
Slot1	Slot to the right position above the patch of DRA antenna
Slot2	Slot to the left position above the patch of DRA antenna
Slot3	Slot to the middle position above the patch of DRA antenna
ε_r	relative permeability

Table 2. *Dimensions of ground plane, substrate, patch, feed, gap and slots of Rectangular DRA with copper, alumina 99.5% Lossy materials*

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	20	0	16.5	0	0.035
Substrate						
Formula	0	W_{st}	0	L_s	H_{gr}	$H_{gr} + H_s$
Dimension (mm)	0	20	0	16.5	0	0.035 + 0.508
Patch						
Formula	$\frac{W_{gr}}{2}-\frac{W_p}{2} - 3$	$\frac{W_{gr}}{2}+\frac{W_p}{2} + 3$	L_f	$L_f + L_p$	$H_{gr} + H_s$	$H_{gr} + H_s + H_p$
Dimension (mm)	$\frac{20}{2}-\frac{9.9}{2} - 3$	$\frac{20}{2}+\frac{9.9}{2} + 3$	4.75	4.75 + 9.7	0.035 + 0.508	0.035 + 0.508 + 0.035
Feed						
Formula	$\frac{W_{gr}}{2}+\frac{W_f}{2}$	$\frac{W_{gr}}{2}-\frac{W_f}{2}$	0	L_f	$H_{gr} + H_s$	$H_{gr} + H_s + H_p$
Dimension (mm)	$\frac{20}{2}-\frac{0.7}{2}$	$\frac{20}{2}+\frac{0.7}{2}$	0	4.75	0.035 + 0.508	0.035 + 0.508 + 0.035
Gap						
Formula	$\frac{W_{gr}}{2}-\frac{W_f}{2} - W_g$	$\frac{W_{gr}}{2}-\frac{W_f}{2}$	L_f	$L_f + L_g$	$H_{gr} + H_s$	$H_{gr} + H_s + H_p$
Dimension (mm)	$\frac{20}{2}-\frac{0.7}{2} - 0.5$	$\frac{20}{2}+\frac{0.7}{2}$	4.75	4.75 + 2.4	0.035 + 0.508	0.035 + 0.508 + 0.035
Slots						
Slot2	$\frac{W_{gr}}{2}-\frac{W_p}{2}+5$	$\frac{W_{gr}}{2}+\frac{W_p}{2}-4$	$L_f + 5$	$L_f + L_p - 2$	$H_{gr} + H_s$	$H_{gr} + H_s + H_p$
Dimension (mm)	$\frac{20}{2}-\frac{9.9}{2}$ +5	$\frac{20}{2}-\frac{9.9}{2}$ -4	4.75+5	4.75+9.7-2	0.035+0.508	0.035 + 0.508 + 0.035
Slot3	$\frac{W_{gr}}{2}+\frac{W_0}{2}$	$\frac{W_{gr}}{2}+\frac{W_0}{2}$	7.5	7.5+l0	H_s	$H_{gr} + H_s + H_p$
Dimension (mm)	$\frac{20}{2}-\frac{4.25}{2}$	$\frac{20}{2}+\frac{4.25}{2}$	7.5	7.5+3.95	0.508	0.508+1
Slot1	$\frac{W_{gr}}{2}-\frac{W_p}{2} + 5 - s_x$	$\frac{W_{gr}}{2}+\frac{W_p}{2} - 4 + s_x$	$L_f + 5$	$L_f + L_p - 2$	$H_{gr} + H_s$	$H_{gr} + H_s + H_p$
Dimension (mm)	$\frac{20}{2}-\frac{9.9}{2} - 5 - 9$	$\frac{20}{2}-\frac{9.9}{2} - 4 + 9$	4.75 + 5	4.75 + 9.7 − 2	0.035 + 0.508	0.035 + 0.508 + 0.035
DRA						
Formula	ws/2-w0/2	ws/2+w0/2	7.5	7.5+l0	hs+hp+hgr	hs+ht+hp+hgr
Dimension (mm)	20/2-4.25/2	20/2+4.25/2	7.5	7.5+3.95	0.508+0.035+0.035	0.508+1.5+ 0.035+0.035

4.3 3rd geometry

We added three kinds of square slots in different shapes and different positions on our new design of patch of DRA antenna to enhance the gain and efficiency of the DRA antenna as shown in figure 3. In addition, the size and shape of patch is the same as in the 2nd geometry, except for the existence of the slots. All values of slots with patch explained above in table 2, in its 2nd part. The right slot, which is located higher within the patch, is the same dimension of the left slot, but it moved to the right to form a symmetric setup; in the direction of axis X with a displacement of $X = 9$ in the positive direction. These changes in geometry of DRA antenna improved the characteristics of this antenna such as, S-parameter, bandwidth and VSWR. The efficiency of DRA antenna enhanced more compared to the previous design.

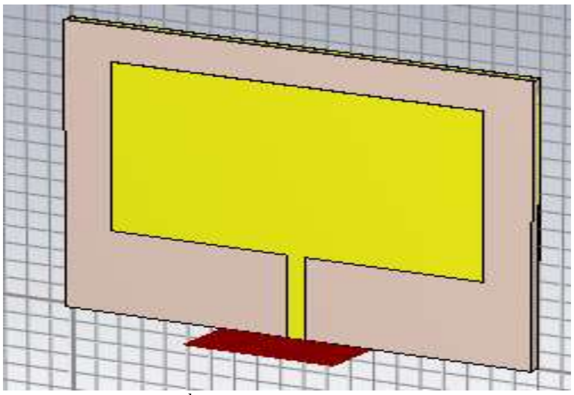

Figure 2. *The 2nd geometry of the antenna, improved with different patch for $f = 28\ GHz$ as Drawn in CST, values are in mm*

4.4 4t[h] geometry: Normal rectangular dielectric resonator (RDRA) antenna

We designed a rectangular RDRA antenna as shown in Figure 4. We used rectangular DRA antenna with the dimensions, suitable type of materials that are used in the design of the antenna as shown in table 3.

4.5 5[th] geometry: Hybrid design (designing and collecting the rectangular dielectric resonator (RDRA) antenna with microstrip patch antenna in one design)

The final design (hybrid design) of RDRA antenna with microstrip patch antenna shown in figure5. The dimensions shown in table 3.We designed and collected two kinds of antenna such as, rectangular DRA and microstrip patch antenna in one design (hybrid design) to enhance the gain and to reduce the bandwidth.

Therefore, the bandwidth reduced to 0.53505 GHz, which was suitable to increase the gain and the signal safety, as well as to decrease the noises and interference of signals. Therefore, the thickness of RDRA changed to 1.5mm instead of 1mm as well as materials have been changed to alumina99.5% Lossy instead of Rogers as listed in table 3.

Table 3. *Geometric parameters for the design of the DRA at f=28 GHz, with electric boundary conditions The type of materials used in the design of the DRA antenna*

Dimension	Size (mm)	Materials
DRA height	3.95	Alumina (99.5%) Lossy
DRA width	4.25	Alumina (99.5%) Lossy
DRA thickness	1.5	Alumina (99.5%) Lossy
Ground plane	Wgr=20, Lgr=16.5	copper
Relative permittivity	ε_r= 9.8	ε_r= 9.8
Strip length	7.5	copper
Strip width	0.7	copper
Strip thickness	0.035	copper
Substrata	Ws=20. ls=16.5	Alumina (99.5%) Lossy

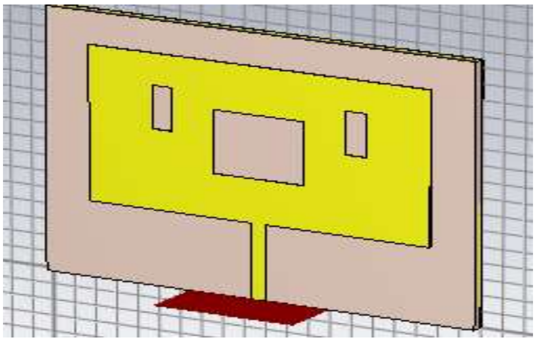

Figure 3. *The 2nd geometry with three different slots on new patch as drawn in CST*

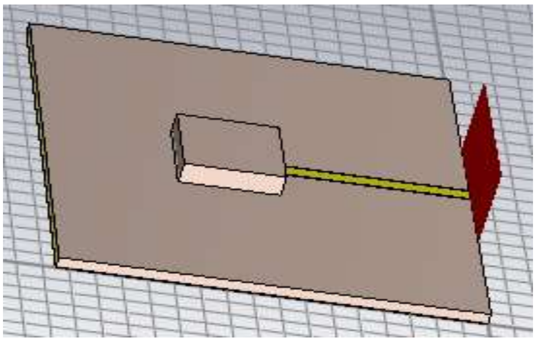

Figure 4. *Design of our rectangular DRA antenna*

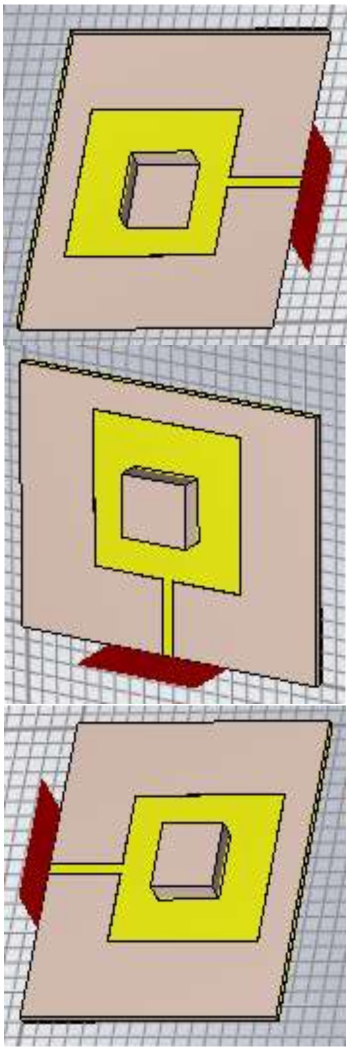

Figure 5. *Design of our hybrid rectangular DRA with microstrip patch antenna*

4.6 Simulation results of hybrid design and normal design

The S-parameters, the voltage standing wave ratios VSWR, bandwidths BW, gains G and directivities D of the designs from points A, C, D and E of designed antennas for the microstrip and RDRA antennas are given in the following figures. Figure 6 corresponds to S_11-parameters, figure 7 to VSWR, figure 8 demonstrates the determination of BW, and figure 9 shows the radiation patterns in 3-dimensional plots. In order to make the results comparable, we grouped the outputs of the simulation according to the parameters, and not according to the designs: the topmost subplots are always the reference, the middle one is the microstrip, (design B) and the lowermost subplots belong to the DRA design in all Figures 6 to 9.

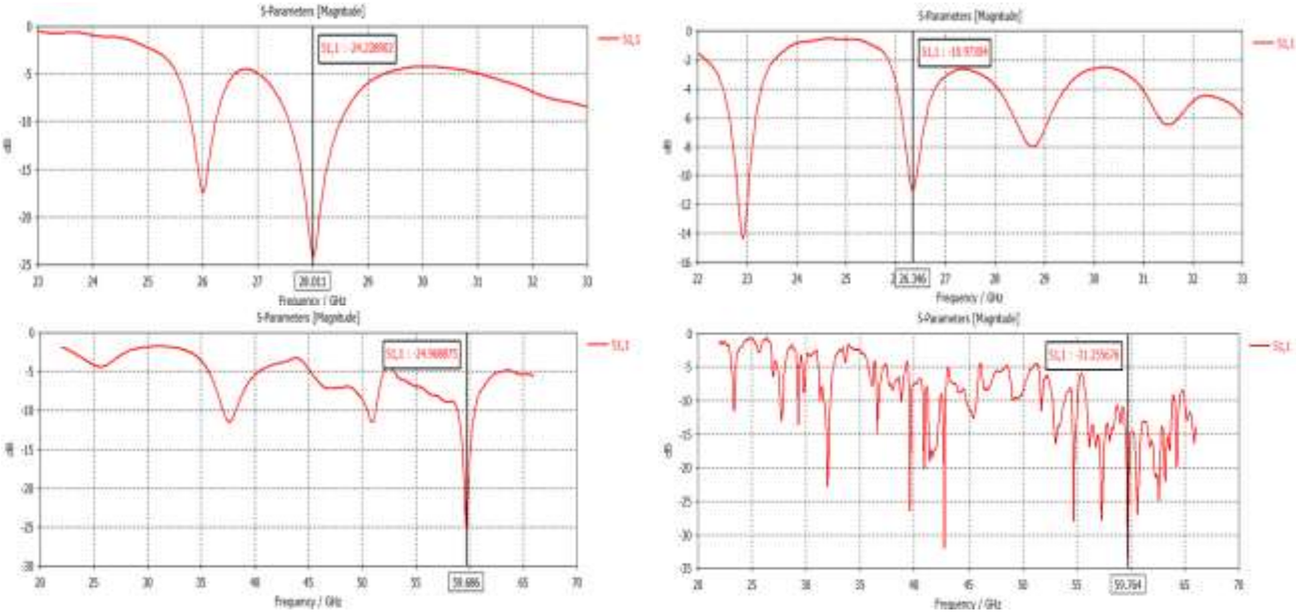

Figure 6. *The value of S_11. Model by CST. The top subplot corresponds to design A. the 2nd subplot to design C, and the 3rd subplot to design D and E*

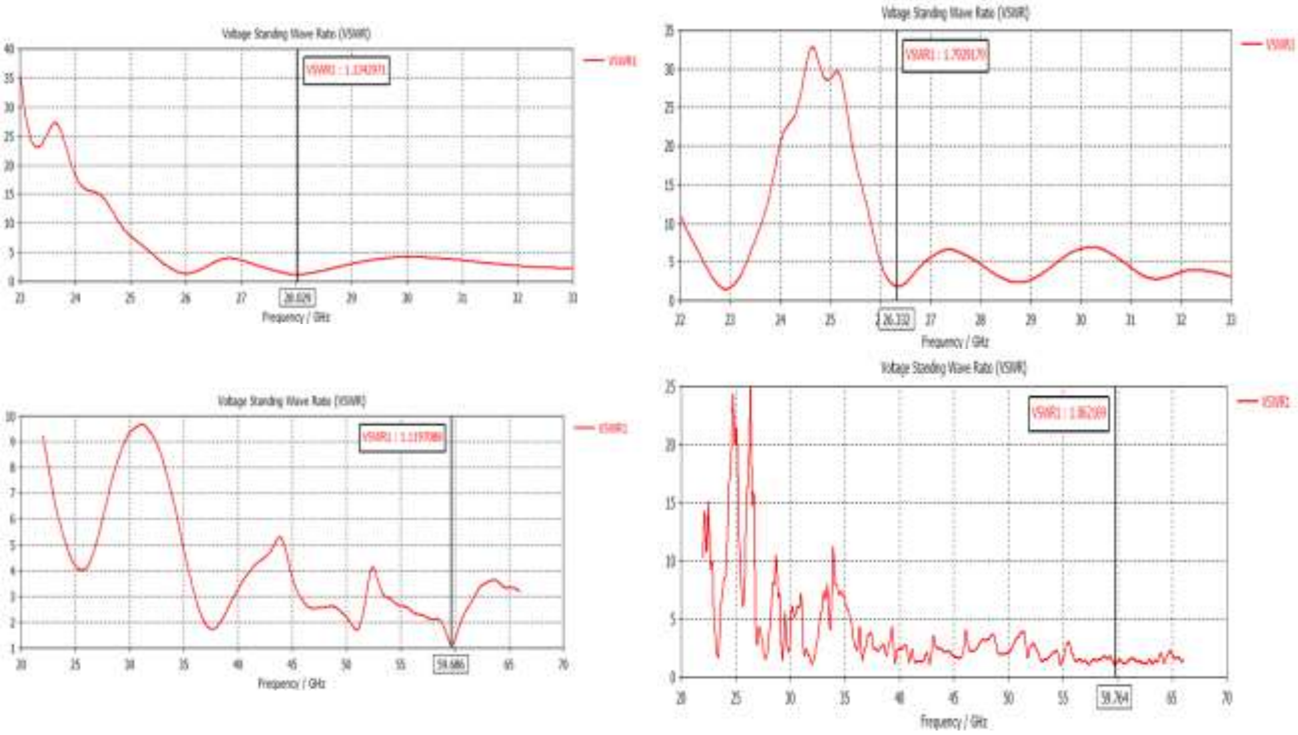

Figure 7. *The voltage standing wave ratio VSWR. Model by CST. The top subplot corresponds to design A. the 2nd subplot to design C, and the 3rd subplot to design D and E*

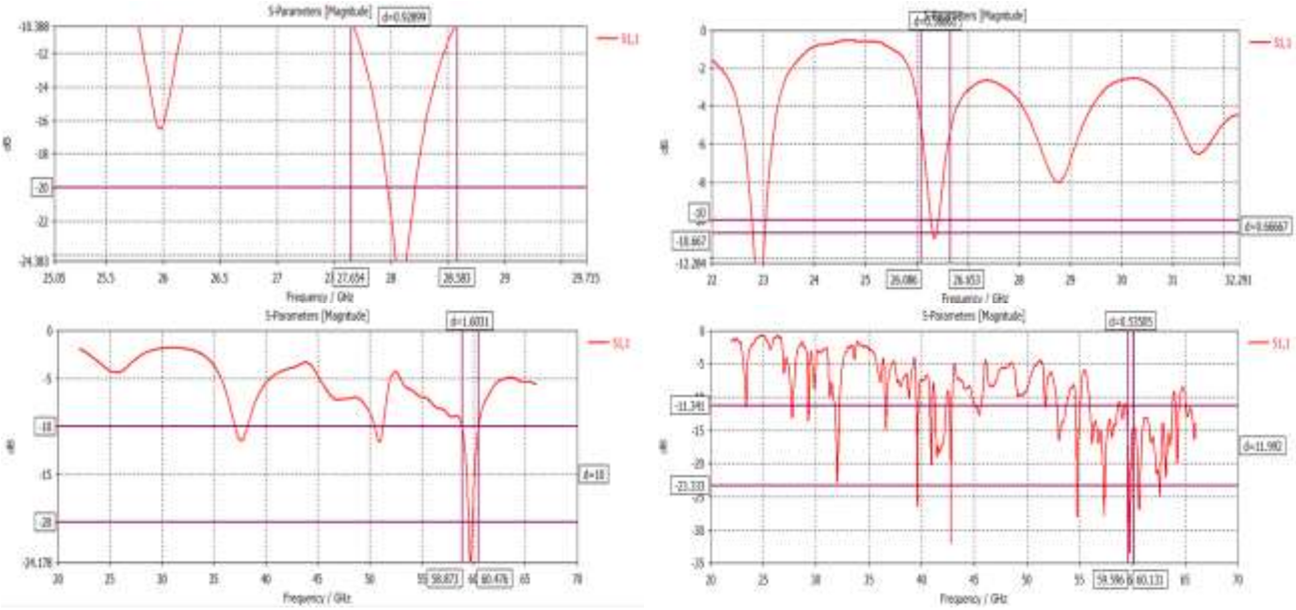

Figure 8. *The calculation of the value of bandwidth form the parameter S_11. Simulation by CST. The top subplot corresponds to design A. the 2nd subplot to design C, and the 3rd subplot to design D and E*

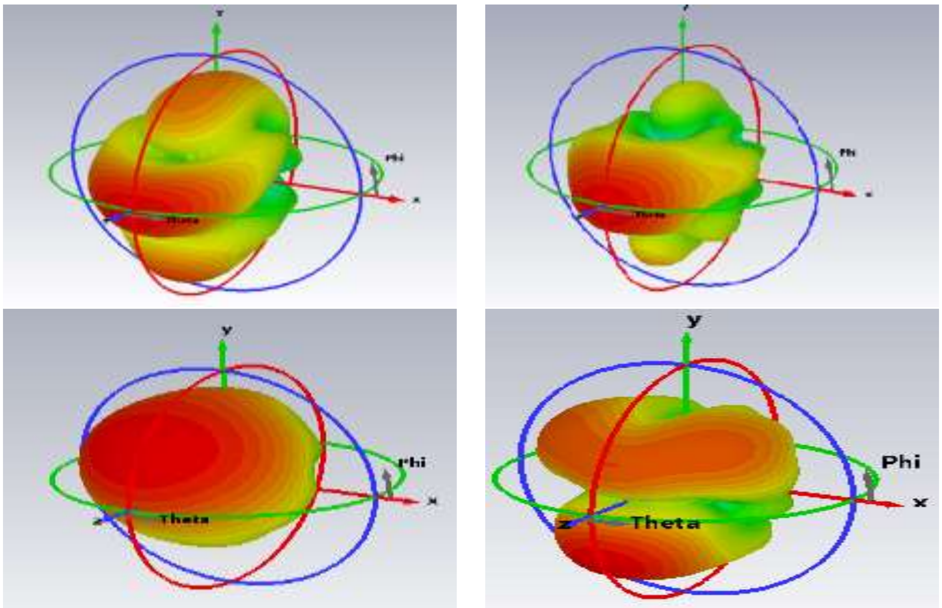

Figure 9. *The radiation pattern of hybrid design E explains the gain G=9.167dBi with directivity D=9.876dBi. Model by CST. The top subplot corresponds to design A. the 2nd subplot to design C, and the 3rd subplot to design D and E*

In order to make the far field gain G and directivity D also visible, Figure 9 contains these values for designs C, D and E.

The following table 4 summarizes the results of the comparison of designs of microstrip and DRA antennas. Design ensures consistent radiation characteristics, making the antenna more stable and reliable for specific applications.

However, the choice between these designs depends on the specific application requirements. If broadband coverage and efficiency are more critical, design D would be the better option. However, if the focus is on achieving higher gain and improved impedance matching, design E would be the preferred choice despite its narrower bandwidth. Where the gain enhanced to 9.167dBi instead of 8.208 dBi, as well as the efficiency arrived 92.8% as shown in table 4and equation 4.

$$\eta = \frac{G}{D} \cdot 100\,\% = 9.167/9.876 \cdot 100\,\% = 92.8\%. \qquad (4)$$

4.7 Physical results of hybrid design

Two antennas were designed in the laboratory, one rectangular RDRA and the other was microstrip patch antenna, in stacking directions, and pressed together into one design and we used several diffrent frequencies as shown in figure 11.Then we summarized the design in the laboratory to know the characteristics of the antenna. It turned out that there were some differences, because of using different materials such as FR-4 Lossy instead of alumina 99.5% (Lossy) as listed in able 3.The results are small due to environmental conditions, diffrent frequencies,different materials and wires if we compare the results with simulation results using the CST program. Figure 11 shows the physical design for RDRA and microstrip pach antennas, as well as other parameters such as S11, VSWR and BW that showed in figure 12, 13 and figure 14, as recorded in laboratory.

Table 4.*The final results of comparison of hybrid design E of(microstrip and DRA) antenna and Previous design*

Parameter	G (dBi)	D (dBi)	BW (GHz)	$VSWR$	S_{11} (dB)	Efficiency η
Reference design (A)	11.02	11.85	0.92899	1.1342971	−24.228902	92.9%
New design (C)	11.34	12.20	0.5661	1.7929179	−10.97304	92.9%
DRA design (D)	8.208	8.581	1.6031	1.1197088	−24.968875	95.6%
The final design (E) Hybrid design	**9.167**	9.876	0.53505	1.062169	-31.255676	92.8%

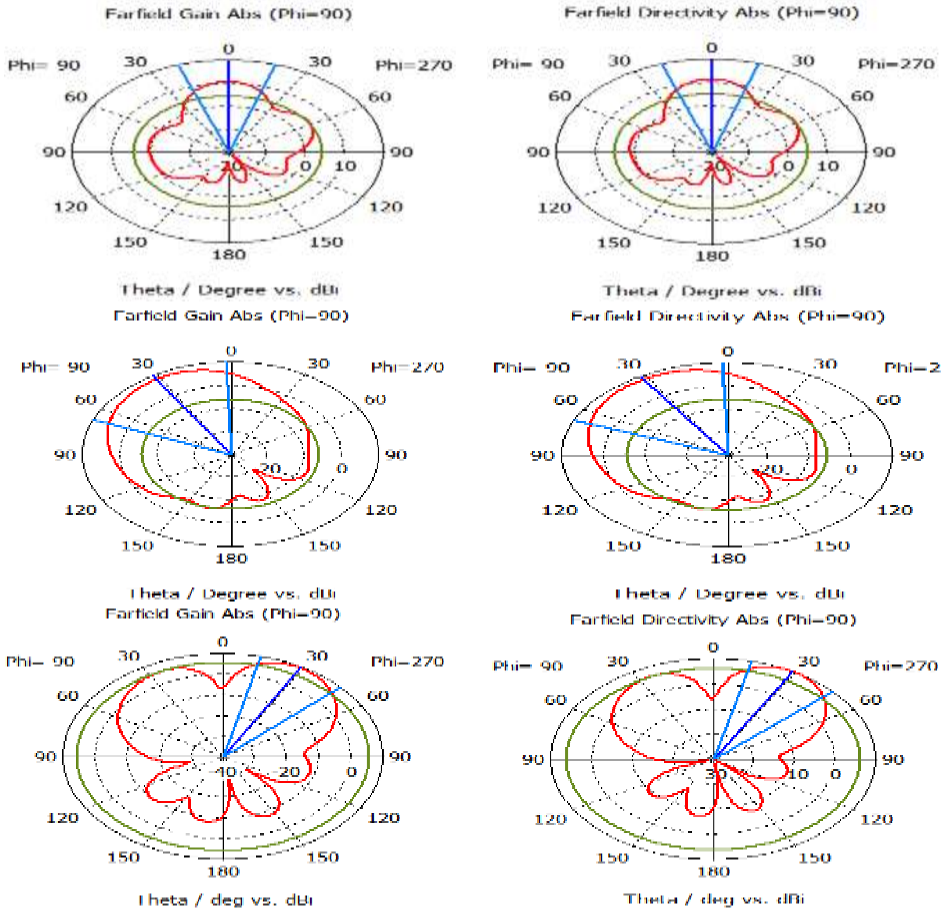

Figure 10. *The far field gain (left) and directivity (right) at f=28 GHz by CST. Top row: design C, bottom row: design D and E.*

Figure 11. *The physical (RDRA, microstrip pach) antennas design as recorded in laboratory*

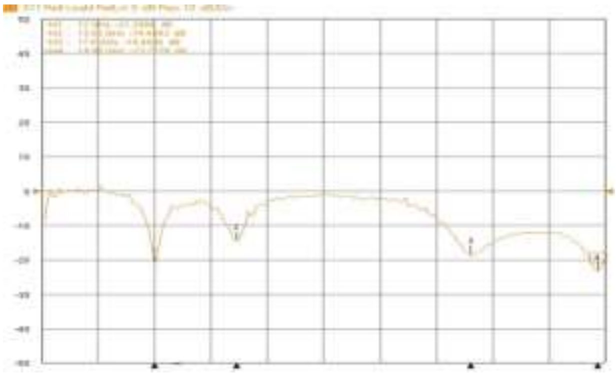

Figure 12. *The value of the reflection coefficient S_11. Designed by CST .This belongs to design, as recorded in lab.*

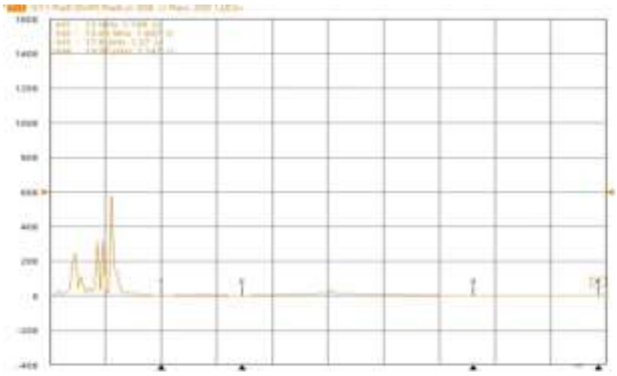

Figure 13. *The voltage standing wave ratio (VSWR). Designed by CST. This relates to design B, as recorded in Lab.*

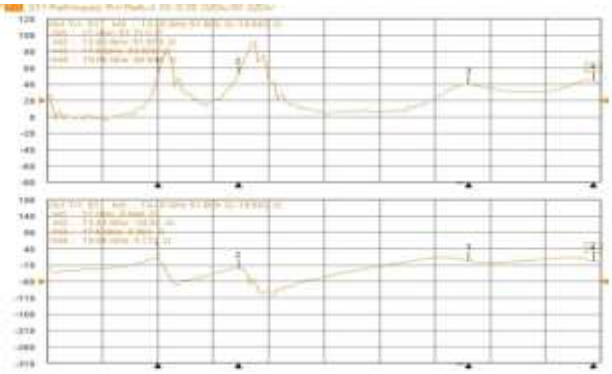

Figure 14. *Calculating the value of bandwidth (BW) based on the value of S_11 parameter Simulation conducted using CST software. This refers to design B, as recorded in Lab.*

Figure 15. *Power supply and signal of our design in Lab*

5. Discussion

We noticed that hybrid design refers to the change in geometry of both microstrip patch antenna and DRA antenna, which were necessary to improve the gain and other parameters as explained in table 4. The three slots were useful to enhance radiation pattern, then enhance the efficiency of microstrip antenna as described in equation (3). Moreover, increasing the size of the patch of microstrip antenna played a good role to improve the radiation pattern compared to the previous, reference design. The efficiency of the DRA antenna improved to 95.6% in case of design D as shown in table 4. Therefore, this antenna considers useful for many communication fields and radio telecommunication. The efficiency of hybrid design for both microstrip patch antenna and DRA antenna were acceptable and rather high, therefore, both antennas were useful in using of communication fields and wireless communication system. The gain of hybrid antenna improved to 9.167 dBi instead of 8.208dBi as shown in table 4 and the efficiency of antenna reduced slowly to achieve 92.8% as shown in design E in table 4 and equation 4, when the geometry was modified into a DRA antenna, as well as when the geometry of microstrip patch antenna was changed, i.e., three different square slots were placed into the patch of the microstrip antenna (one to the centre, and another two symmetrically to both sides) as showed in design D. However, the bandwidth reduced more in the final design E to become 0.53505 GHz instead of 1.6 GHz. However, some differences arose between our hybrid DRA and normal DRA antennas that are listed in Table 5.

Therefore, when designing a rectangular dielectric resonator antenna (RDRA) combined with a microstrip patch antenna (hybrid design), a narrow bandwidth can offer several benefits. First, it enhances the antenna's selectivity, making it ideal for applications requiring precise frequency operation, such as satellite communication and radar systems. A narrow bandwidth also helps reduce interference from nearby frequencies,

Table 5. *Differences between the hybrid DRA antenna and normal DRA antenna*

Feature	**Hybrid Dielectric Resonator Antenna (0.5 GHz Bandwidth)**	**Normal Dielectric Resonator Antenna (1.6 GHz Bandwidth)**
Bandwidth	Means Limited frequency range, less versatile	Supports more frequency channels and applications.
Gain	Generally higher due to hybrid design	Moderate – Gain is usually lower
Radiation Pattern	More flexible – Can be designed for specific patterns	Fixed – Depends on resonator shape and dielectric constant.
Efficiency	Higher	Moderate – Efficiency may reduce at frequency edges.
Polarization	Supports dual or circular polarization if designed accordingly	Linear polarization – Requires modifications for dual/circular polarization.
Operating Frequency Range	Narrower range	Broader range
Design Complexity	More complex	Simpler, easier to design.
Size	Larger – Hybrid structure increases physical dimensions	Smaller – More compact for the same operating frequency.
Tuning Capability	Limited – Reduced bandwidth means less frequency tuning ability	Better tuning – More flexibility across the 1.6 GHz span
Cost	Higher – More materials and complex manufacturing.	Lower – Simpler structure means reduced manufacturing costs.
Applications	Suitable for high-gain but narrowband uses (e.g., radar, satellite, point-to-point communication	Suitable for broadband applications (e.g., 5G, UWB systems, Wi-Fi, wideband radar).

improving signal integrity and overall performance. Additionally, it simplifies impedance matching between the RDRA and the microstrip patch, leading to better gain ,efficiency and reduced reflection losses.
The better antenna depends on your specific needs. The normal DRA (1.6 GHz bandwidth) is ideal if you prioritize wider frequency coverage, simpler design, and lower cost, making it suitable for broadband applications like 5G and UWB systems. In contrast, the hybrid DRA (0.5 GHz bandwidth) is better if you need higher gain, custom radiation patterns, or polarization diversity, making it ideal for satellite communication, radar, and point-to-point systems. If bandwidth and simplicity are crucial, the normal DRA is the better choice; if performance and flexibility are more important, the hybrid DRA is superior.

6. Future work

In design of hybrid antenna, reducing the size of the slots and change thickness of DRA antenna, as well as suitable materials might be good to improve the characteristics of microstrip and DRA antenna in future. In addition, in the future work we think about circular slots or combined multiple slots to enhance the efficiency of microstrip antenna (multiple design). Our other future direction of design is hybrid design of cylindrical DRA antenna to get better results with suitable characteristics. Then we plan to develop the antenna in order to work in multiple fields in communication

7. Conclusions

Dielectric resonator antennas (DRA) possess favourable characteristics for communication applications, including compact dimensions, minimal height, and cost-effectiveness. The study involved the examination of rectangular dielectric resonator antennas (DRAs) as well as microstrip patch antenna with CST modelling and optimization. The microstrip antenna investigation focused on three distinct geometries within the 28 GHz frequency band. These geometries included a geometry of rectangular DRA and basic microstrip antenna, one with multiple square slots, and another with multiple square slots and a unique patch. The design that yielded the highest performance was the one with numerous slots and a special patch. In this configuration, the gain significantly increased to 11.34 dBi in the case of normal microstrip antenna at a frequency of 28 GHz, compared to a gain of 11.02 dBi without the addition of layers. The gain of the hybrid design E of DRA antenna increased to9.167 dBi instead of 8.208 dBi in normal design D as listed in table 4, although the frequency range had to be modified. However, the final hybrid design included the combination between rectangular DRA antennas with microstrip patch antenna in one design to enhance the gain and suitable efficiency with reducing bandwidth. The simulations indicate that the examined antenna have the necessary characteristics to be appropriate for communication purposes because it has efficiency, which was 92.8%Therfore, in the final design E the bandwidth reduced to 0.5 GHz instead of 1.6031 GHz in the case of design D.This gave us high gain about9.167 dBi in case of hybrid design as listed in table 4.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.

- **Author contributions:** The authors declare that they have equal right on this paper.

- **Funding information:** The authors declare that there is no funding to be acknowledged.

- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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