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Design of Planar Dielectric Resonator Antenna Array at 28 GHz

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Abstract

This article presents a planar array of rectangular Dielectric Resonator Antenna operating for 28 GHz applications. The proposed antenna is formed through two stages of designs which are a single element and planar array. It is made up from a ceramic material with a dielectric constant of 10 and mounted on RT/Duroid 5880 with a relative permittivity of 2.2 and a thickness of 0.254 mm. A prospective study using three different configurations of three by three planar array is done in order to obtain the best performance in terms of bandwidth, gain, and cost reduction. Besides that, this study is also conducted for a beam steering capability of each configuration. Finally, the best configuration is proposed for 5G application.

Keywords: *5G, Millimeter-wave, Dielectric Resonator Antenna, Array Antenna*

1. Introduction

Wireless can be defined as having no wire or in term of networking terminology, it can be used to describe any device network where there is no physical wired connection. Wireless communication technology has brought the biggest contribution to the mankind. It can be used not only in the communication field, yet in medical and robotics' world too. It has been growth from analog to a digital system for human's ease. The first generation known as 1G where analog system is introduced before 2G comes with a better features. The technology growth very rapidly to 3G, 4G and soon to be realized is 5G.

Todays, almost all communication systems used the current cellular spectrum, which is below 3 GHz [1-4]. This lower frequency spectrum becomes overcrowded. Thus, for the future 5G system, millimeter-wave frequency has become a better choice since there are not so many frequencies being utilized [2-3], [5-7]. According to [2, 5], frequency of 28 GHz and 38 GHz is potentially becoming a good frequency candidates for the 5G system as it's negligible to atmospheric absorption.

In terms of designing an antenna at a millimeter - wave frequency, there will be several challenges to be faced. Moving toward much higher frequency, the size of the antenna will be very small and led to high manufacturing precision and capabilities to implement with complicated structure [8]. Conductor loss will also be severe at a millimeter-wave frequency. Therefore, in this study Dielectric Resonator (DR) has been chosen to be designed for 5G system instead of using other conventional antennas such as microstrip antenna. DR has primarily been used in microwave circuits. It is made up from high permittivity ranging from 8 – 100 [9-13]. With several attractive advantages such as exhibit low loss and can produce wide bandwidth, DR will help to maintain the antenna performance and efficiency even at millimeter - wave frequency [14].

According to [5], in order for the signal to be transmitted within 200 meters, the antenna designed for 5G application should have a high gain which is more than 12 dBi and a bandwidth of at least more than 1 GHz. A high gain antenna is needed to compensate the losses problem which will be high at a higher frequency. Due to this, a study for three different configurations of a planar DRA array operating at 28 GHz is proposed. The proposed planar array should be able to obtain high gain, a wide bandwidth and low cost antenna suit for 5G application.

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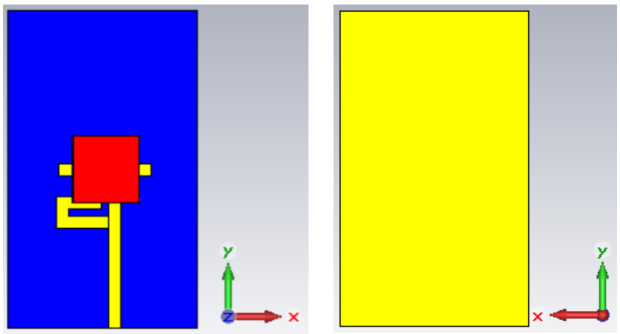
2. Research Method

The proposed antenna design is formed through two stages of design. The first stage started with an investigation on single element DRA with three different excitation for bandwidth improvement. This study has been published in [15]. From the observation, the best antenna performance is obtained when the DRA is hybrid with a 50 Ω modified structure feeding. The second stage involved a continuity proses from the most optimum design of a single element to planar array. The study is limited to three by three (3×3) array simulation analysis only by using CST Microwave Studio Software 2014.

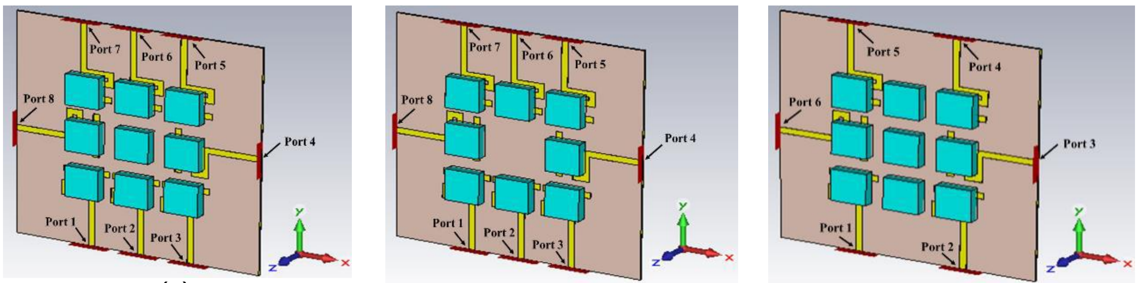
Figure 1 shows the geometry of the proposed single element RDRA with a modified structure feeding for both, front and back views. Study in [15] shows this feeding technique gives a better antenna performance compared with two other excitation methods which are microstrip line feed and aperture coupled feed. Antenna parameters such as reflection coefficient and impedance bandwidth is considered before the modified structure feeding is chosen.



(a) (b)

Figure 1. The proposed RDRD with modified structure feeding (a) Front view (b) Back view

The initial dimension of rectangular shape DRA is obtained from the Dielectric Waveguide Model (DWM). It is characterized by a length (a), width (b), height (d) and permittivity (εr). The optimum dimensions of the proposed DRA is 4.13 mm × 4.13 mm × 1.3 mm.



(a) (b) (c)

Figure 2. Planar array DRA with modified structure feeding (a) Configuration 1 (b) Configuration 2 (c) Configuration 3

Figure 2 shows three different configurations of planar array DRA where nine elements of DRAs are used for 3×3 array structure. In configuration 1, the planar array DRA is fed using eight ports except at the middle element which act like a parasitic. The DRAs in Configuration 2 is almost similar to the first configuration, but the parasitic element at the center is removed. Lastly, the Configuration 3 consists of 3×3 DRA fed in alternate position using only 6 ports. Six radiating elements are fed with the modified structure feeding while the rest three elements become parasitic. In the next section, the result and analysis of the proposed design is discussed.

3. Results and Analysis

In this section, the result of the single element DRA with modified structure feeding and array antenna are discussed. The simulation and measurement result of a single rectangular DRA with modified structure feeding is compared. While for planar array DRA, the simulation analysis between three different 3×3 configuration arrays is analyzed.

3.1. Single Element DRA

As shown in Figure 3(a) is the simulated and measured reflection coefficient of the modified structure feeding. From the graph, it can be seen that the feeding structure able to resonate at 28 GHz frequency with a narrow bandwidth. While Figure 3(b) shows the simulated and measured results of reflection coefficient after combining the RDRA with the modified structure feeding. The coupling between these two elements result in wide bandwidth operation which covers the desired operating frequency of 28 GHz. The proposed antenna is able to cover from 26.9 GHz to 33.4 GHz frequency range.

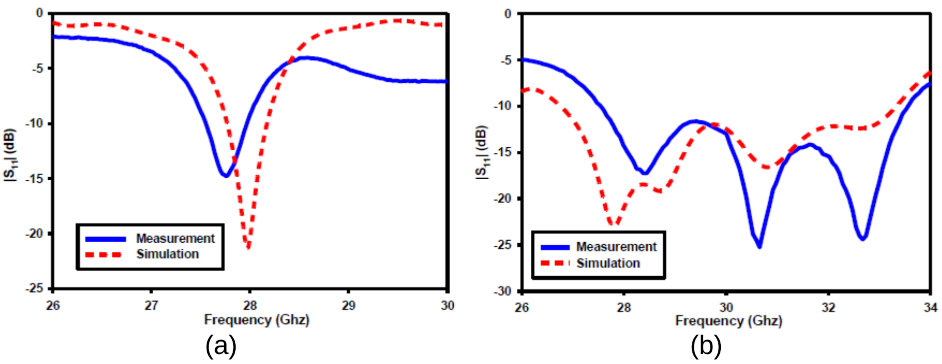


Figure 3. Simulated and measured |S11| of; (a) modified structure feeding (b) DRA with modified structure feeding

3.2. Planar array DRA

The simulation S-parameters result provides similar graph pattern, hence in Figure 4(a), S33 plot is used to represent S11, S22, S44, S55, S66, S77, and S88 for the Configuration. 1 As can be observed from the figure, the DRAs in configuration 1 able to resonate from 27.1 GHz up to 31.3 GHz frequency range. The impedance bandwidth of 4.2 GHz is achieved across -10 dB reflection coefficient. Besides that, Figure 4(b) shows the S77 plot versus frequency for the Configuration 2. The operating range of the second configuration is from 27 GHz to 31.4 GHz across -10 dB impedance. This design could provide a total of 4.4 GHz bandwidth. The reflection coefficient plot versus frequency of Configuration 3 is shown in Figure 4(c). The graph of S55 is used to represent S11, S22, S33, S44, and S66. The third configuration of 3×3 array managed to operate from 26.3 GHz to 31.6 GHz. This makes the impedance bandwidth equal to 5.3 GHz that is much wider compared to the first and second configuration of 3×3 array DRA.

In order to realize a beam steering antenna, the main beam should be radiated at the center. Since in this planar array design, all ports are excited at different direction, so the beam is already been shifted. In order to tune back the main beam at the center, an excitation phase is given to each of the ports. Table 1 shows the value of the excitation phase given for all ports of respective configurations. The value set for this excitation phase is with the reference of radiation angle. It can be seen from Figure 5 the main beam is tuned at 0 degrees after an excitation phase is given accordingly to each port. In a real situation, the phase shifter can be used in order to control the beam of the proposed arrays.

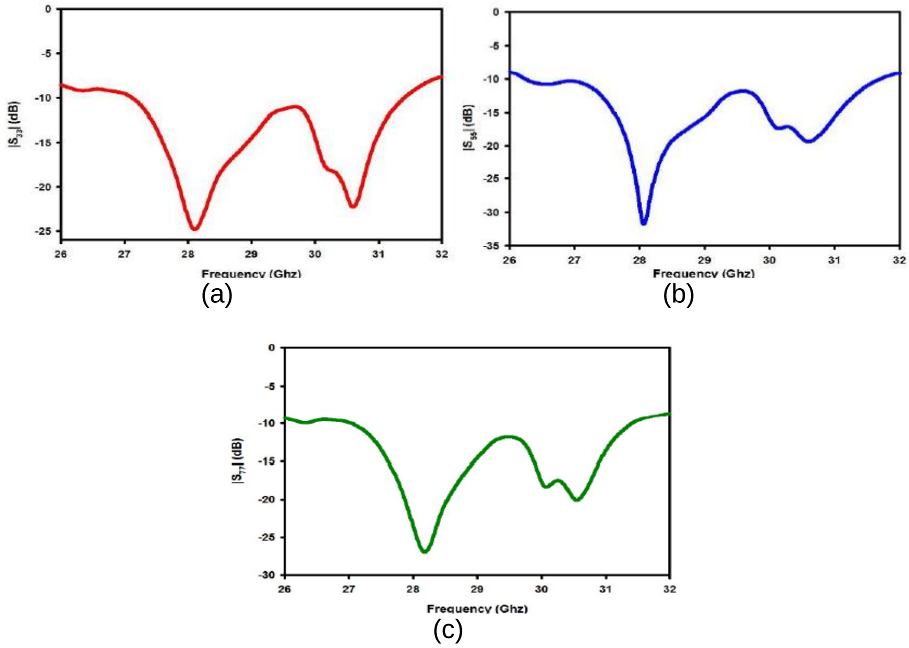


Figure 4. Simulated and measured S-parameters for; (a) Configuration 1 (b) Configuration 2 (c) Configuration 3

Table 1. The value of excitation phase for the respective ports of all configurations

Configuration	Excitation Phase							
	Port 1	Port 2	Port 3	Port 4	Port 5	Port 6	Port 7	Port 8
1	0°	0°	0°	90°	180°	180°	180°	270°
2	0°	0°	0°	90°	180°	180°	180°	270°
3	0°	0°	90°	180°	180°	270°	-	-

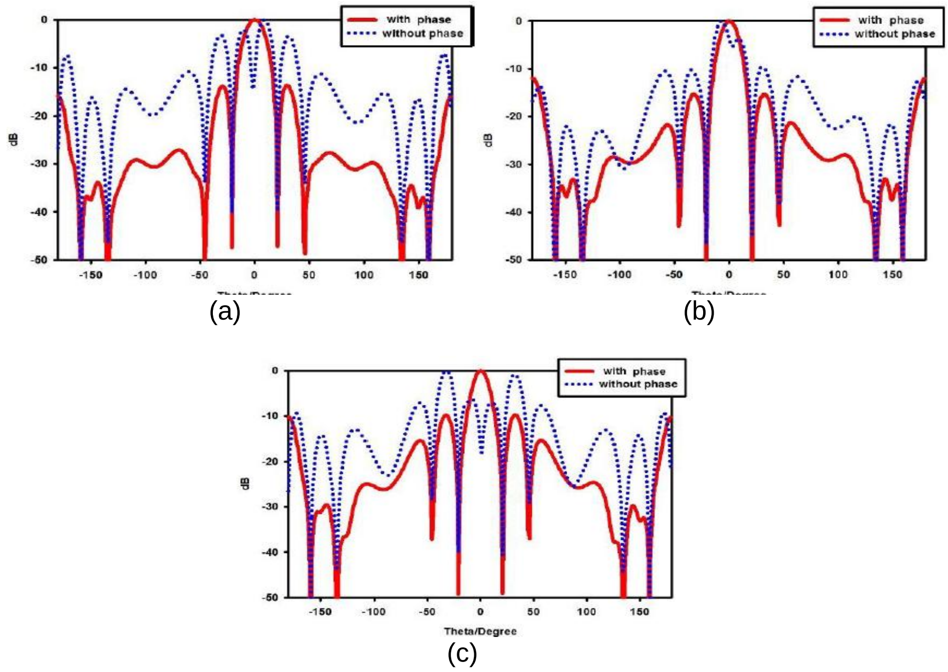


Figure 5. The radiation pattern of each respective configuration; (a) Configuration 1 (b) Configuration 2 (c) Configuration 3

Table 2. The comparison of antenna parameters between 3×3 planar array configurations

Configuration	1	2	3
No. of element	9	8	9
No. of port	8	8	6
Frequency range	27.1 - 31.3 GHz	27 - 31.4 GHZ	26.3 – 31.6 GHz
Bandwidth	4.2 GHz	4.4 GHz	5.3 GHz
Gain	14.5 dB	12.8 dB	13.7 dB

Table 2 shows the summary of comparison between the three configurations of planar array based on certain parameters. From the table, it can be seen that Configuration 1 achieved the highest gain of 14.5 dB by having nine elements and eight ports. It covers a frequency range from 27.1 GHz to 31.3 GHz, which result in 4.2 GHz impedance bandwidth. In Configuration 2, parasitic element is removed to see the effect on antenna performance. It manages to maintain the impedance bandwidth almost the same with the first design. This antenna can resonate from 27 GHz to 31.4 GHz, which result in 4.4 GHz impedance bandwidth. However, the gain drop to 12.8 dB, yet its gain still more than the desired gain value for this research. Next, the third configuration is proposed with the consideration of number of ports. Only 6 ports have been used to make the antenna array function. Configuration 3 able to provide relatively high gain even though the number of ports is reduced. The gain is about 13.7 dB and the operating frequency ranging from 26.3 GHz to 31.6 GHz. The -10 dB impedance bandwidth of 5.3 GHz is also achieved. As a conclusion, all design configurations are able to meet the requirement of wide bandwidth and high gain for 5G system. Yet, Configuration 3 is the solution for a low cost antenna as compared with Configuration 1 and 2. By using less number of ports to excite the antenna, a wide bandwidth and high gain performance could be achieved.

4. Conclusion

A planar array of three by three (3×3) array of DRA fed with modified structure feeding has been designed in this paper. Three different configurations have been analyzed to meet the requirement of 5G system. The desired frequency of interest is at 28 GHz with at least 1 GHz of impedance bandwidth and 12 dBi of gain. The proposed designs able to achieve a good antenna performance which are high gain, wide bandwidth and low cost antenna. The radiation pattern results proved that the proposed antenna array has a capability of steering in real situations. Therefore, antenna designs proposed in this article could be one of the antenna's candidates for 5G applications where a beam steering is required.

References

[1] Pi Z, Khan F, Electronics S. An Introduction to Millimeter-Wave Mobile Broadband Systems. *IEEE Communications Magazine*. 2011; 49(6): 101-107.

[2] Rappaport TS, et al. Millimeter-Wave Mobile Communications for 5G cellular: It Will Work!. *IEEE Access*. 2013; 1; 335-349.

[3] Wei L, et al. Key Elements to Enable Millimeter Wave Communications for 5G Wireless Systems. *IEEE Wireless Communications*. 2014; 21(6): 136-143.

[4] Nor NM, Jamaluddin MH. A Dual Band Mimo Dielectric Resonator Antenna for WLAN Application. *Jurnal Teknologi (Sciences & Engineering)*. 2015; 77(10): 1-4.

[5] Sulyman AI, et al. Radio Propagation Path Loss Models for 5G Cellular Networks in the 28 GHz and 38 GHz Millimeter-Wave Bands. *IEEE Communications Magazine*. 2014; 52(9): 78-86.

[6] Roh W, et al. Millimeter-Wave Beamforming as an Enabling Technology for 5G Cellular Communications: Theoritical Feasibility and Prototype Results. *IEEE Communications Magazine*. 2014; 52(2): 106-113.

[7] Niu Y, et al. A Survey of Millimeter Wave (mmWave) Communications for 5G: Opportunities and Challenges. *Wireless Networks*. 2015; 21: 2657-2676.

[8] Liu D, et al. Guest Editorial for the Special Issue on Antennas and Propagation at MM- and Sub MM-Waves. *IEEE Transaction on Antennas Propagation*. 2013; 61(4): 1502-1507.

[9] Petosa A. Dielectric Resonator Antenna Handbook. MA: Artech House. 2007.

[10] Luk KM, Leung KW. Dielectric Resonator Antennas. Hertfordshire, England: Research Studies Press Ltd. 2003.

[11] Abedian M, et al. Novel Design of compact UWB Dielectric Resonator Antenna with Dual Band Rejection Characteristics for WiMAX/WLAN Bands. *IEEE Antennas and Wireless Propagation Letters*. 2015; 14: 245-248.
[12] Nasir J, et al. A reduced Size Dual Port MIMO DRA with high isolation for 4G Applications. *International Journal of RF and Microwave Computer-Aided Engineering*. 2015; 14(6): 495- 501.
[13] Shahadan NH, et al. *Switched Parasitic Dielectric Resonator Antenna Array using Capacitor Loading for 5G Applications*. 2016 10th European Conference on Antennas and Propagation (EuCAP). 2016: 1-5.
[14] Lai, et al. Comparison of Radiation Efficiency for the Dielectric Resonator Antenna and the Microstrip Antenna at Ka Band. *IEEE Transactions on Antennas and Propagations*. 2008; 56(11): 3589-3592.
[15] Nor NM, et al. Rectangular Dielectric Resonator Antenna Array for 28 GHz Applications. *Progress In Electromagnetics Research (PIER) C*. 2016; 63: 53-61.