DESIGN OF COVID-19 FRACTAL ANTENNA ARRAY FOR 5G WIRELESS APPLICATION

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Abstract

This paper presents a unique microstrip patch antenna with a COVID-19 shape designed for the centimeter wave (sub-6 GHz) frequency for 5G applications. Two types of arrays have been designed, firstly a linear-polarized 2 x 4 antenna array that resonates at 3.16 GHz and has a gain of 9.5 dB is discussed. Secondly, a 4 x 4 triple-band linear-polarized array operating over (2.5, 3.1, 3.4) GHz with a maximum gain of 10.5 dB is shown. The produced patch antenna is simulated and optimized by performing parametric studies of the dimensions using the finite element method (FEM) HFSS software program, where the array elements have a circular shape surrounded by 5 pairs of crowns. The aforementioned microstrip antenna array for the sub-6 GHz is designed on a double-sided copper plate with an FR4-epoxy substrate of 1.6 mm thickness. The prototype and its measured parameters, including S-parameters, polarization, and radiation pattern show a good agreement with 5G wireless applications antenna arrays.

1. Introduction for the Design procedure of COVID-19 antenna array

It is well known that microstrip patch antenna arrays have the positive characteristics of small size, various shapes, low fabrication cost, and lightweight, which makes them widely used in many applications such as WiMAX, Global Position System (GPS), and weather radar devices. Examples of microstrip antennas include the design and realization of radar antenna patch array at 9.4 GHz frequency with coaxial probe feeding [1] and making microstrip patch antenna using inset raising technique feed for weather radar applications at S-band frequencies [2]. In the studies above there are several drawbacks such as complex feeding techniques, and low gain considering the number of antenna elements.

To overcome these obstacles an antenna array is used, where the gain and the beam width of the radiation pattern are increased dramatically. Much research has been done in this area, for instance, to overcome the low gain, an application for weather radar systems with a rectangular microstrip patch antenna was designed [3] it is a 2x4 array that has a microstrip line rationing technique, that works at frequencies from 2.7 GHz to 2.9 GHz uses FR-4 substrate material. Another antenna array design suitable for GPS application is described in [4] which is designed to function in the C-band used to receive signals from the telemetry link of an Unmanned Air Vehicle.

Building a dual-band, and high-efficiency circular patch has become very popular and feasible to be utilized in microstrip antenna array. They are simple and inexpensive to manufacture and are suitable for planar and non-planar configurations [5]. The design and characteristics of the double sided microstrip circular antenna array is presented in [6], for dual bands at 6.05 – 7 GHz and 9 –10 GHz to support weather radar applications and directional radiation pattern with gain of 3.12 dB 3.8 dB at 6.5GHz and 9.5 GHz respectively. In [7], high gain 2×4 circular patch antenna array is designed on an FR4 substrate of standard thickness 1.5 mm. The proposed antenna arrays use probe feeding technique, and are designed for 2.4 GHz resonant frequency suitable for WLAN applications.

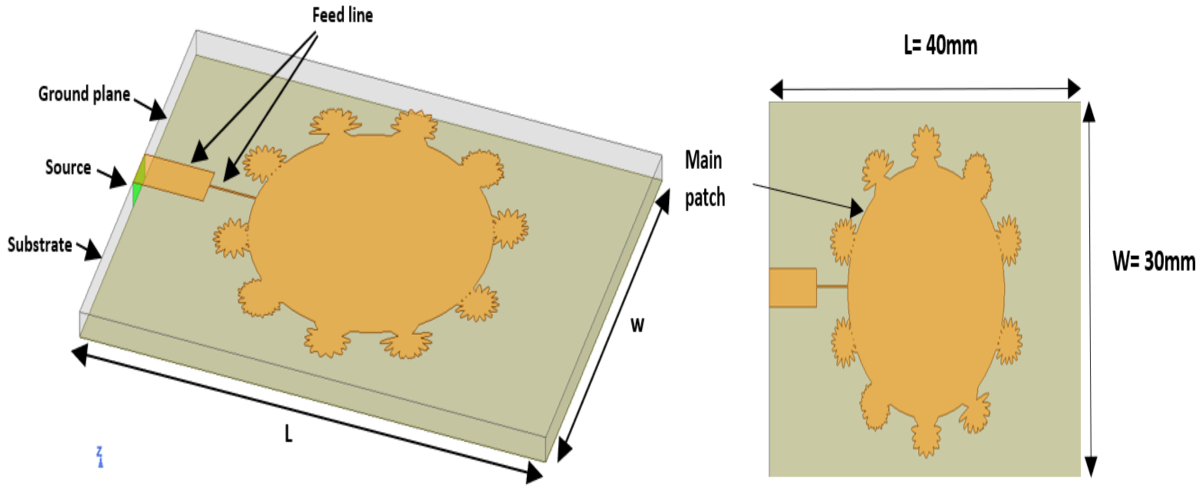
Although the above antenna array solved the issue of low gain and poor radiation efficiency, they are still suffering from its relatively large size and narrow bandwidth, especially for thin substrates. Many techniques have been introduced to improve the characteristics of the patch antenna, one of these techniques is using fractal geometry. Fractal geometry is an efficient technique for fabricating multi-band, low-profile antennas [8, 9]. The scaling and self-similarity in fractal shape antennas facilitate multi-band and broadband properties along with the reduced dimensions of the antennas. Koch, Sierpinski, Minkowski, Hilbert, and Cantor arrays are recent examples of multi-band antenna configurations based on fractal geometries.

This chapter deals with two types of arrays simulated in HFSS software using fractal geometry and microstrip antenna technology. Arrays allow smaller area higher gain/efficiency, multi-band/broadband characteristics, and larger directivity while fractal geometry increase electrical length and hence reduces the frequency of the patch. Fractal geometry is applied by adding discs around one larger disc to mimic COVID-19 shape. The first array is suitable for WiMAX, GPS, and weather radar applications, centimeter sub-6GHz frequency. The second array is for mm-wave 5G wireless systems. Fabrication and measurement was done in the American University of Beirut labs. The design steps of the first array shall be explained thoroughly in next section

2. Single Element Design

Regarding the one element design, an FR4-epoxy substrate with permittivity of 4.4 is used to construct the COVID-19 patch antenna, and this material is utilized due to its low cost and effectiveness in reproducing the simulated designs. The 2D and 3D simulated models with dimensions are shown in Figure (1). The overall dimensions of the substrate (L, W, h) are (4 x 3 x 0.16) cm^3. The main patch antenna is circular with a radius of

10 mm. The patch antenna is fed using the microstrip line method. It forms the unique shape of the coronavirus for the patch and constitutes the basic element for building the antenna array.



(a) **(b)**

Figure (1): (a) Three-dimensional patch antenna. (b) Two-dimensional structure of the simulated patch antenna.

Before fulfilling the design of the patch antenna, the following equations are used to find the dimensions of the circular patch antenna [26].

$$F = (8.791\times10^{9}) / (f_r \sqrt{\varepsilon_r}) \quad (1)$$

Where F is the fringing factor, f_r is the resonance frequency, c is the free space velocity of light and ε_r is the dielectric constant of the substrate. The main radius of the patch (R) is calculated as follows:

$$R = F \times \{1+ (2h/\pi\, \varepsilon_r F) [(\ln (\pi F/2h) +1.7726] \}^{-1/2} \quad (2)$$

The resonance frequency corresponds to any TM_{mn0} mode is given as

$$f_{rmn0} = (c/2\sqrt{\varepsilon_r}) [X_{mn} /R] \quad (3)$$

Here, n and m are modes concerning R, and X_{mn} is the derivative of the Bessel function.

Initially, when f_r = 4 GHz, h = 1.6 mm, and ε_r = 4.4, the radius of the main patch is calculated to be 3 mm according to equations (1) and (2).

The design steps are similar to those used in the previous chapter, however, the resonance frequency and consequently the patch dimensions are different according to Balanis [10] equations for designing the radius of the circular patch, by setting the frequency to 3.2 GHz. On the other hand, the crowns in this design contribute to improving the reflection coefficient and reducing the resonance frequency. Figure (2) shows a comparison for single element circular patch with and without crowns to show the positive effects of adding the crowns.

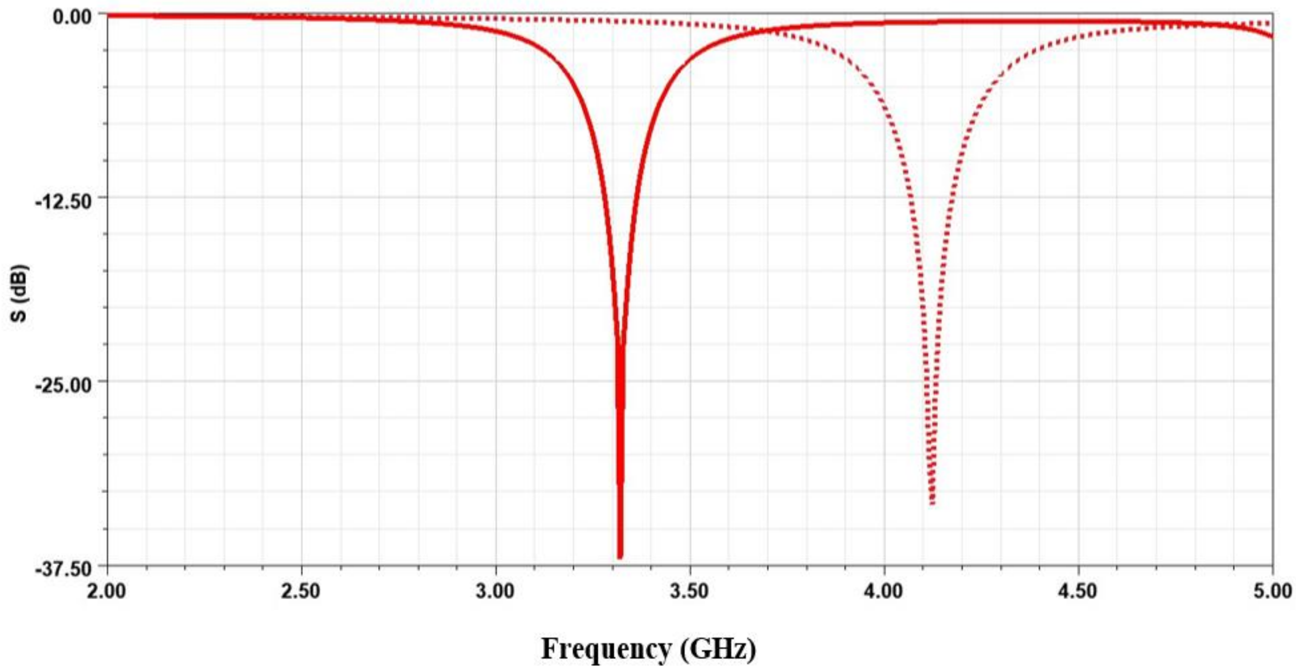


Figure (2) : Comparison between the S-parameters for the single element with crowns (solid line) and without crowns(dotted line).

As shown in Figure (1), the microstrip feeding line is a series of two transmission lines: The first one is matched to 50 Ω, its width is calculated according to equation (4) in [10] to be 3mm and it's length is obtained using the optimization technique in HFSS to be 6 mm. The second 100 Ω transmission line, which is directly connected to the patch (Figure (1)), has a width and length of 5 mm, and 0.15 mm respectively. Note the optimization method here is done using trying and error in changing dimensions to achieve the targeted design. The final results of the single elements are shown in Figure (3), with resonance frequency of 3.4 GHz, and directional radiation pattern, and showing E and H-planes.

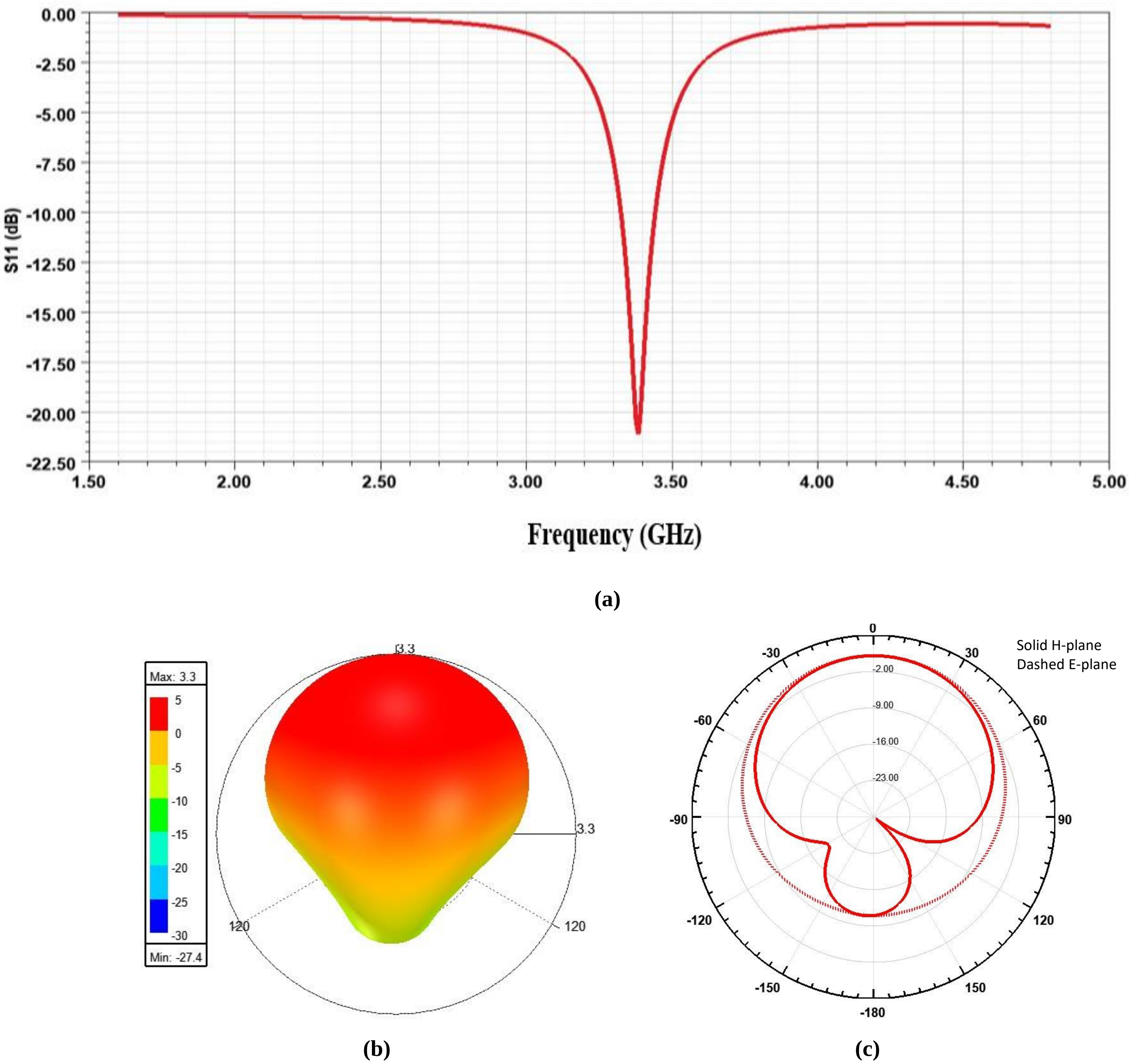


Figure (3): (a) Reflection coefficient curve concerning the frequency, (b) 3D radiation pattern, and (c) 2D radiation pattern.

3. Design of 2x1 Array

The layout of the antenna array structure of 2 x 1 was composed of two identical elements of the basic element patch which was simulated in the previous section. Firstly, two elements were connected in parallel; when the resonance frequency was 3.16 GHz the optimized results were measured when the distance between the two patches is 0.55 λ which is equal to 54 mm. In this case, a parallel network feeding line connection was used to supply a uniform distribution of power to all the elements.

The feeding line consists of 100 Ω transmission line (TL) which is directly connected to the patch with a length of 13 mm and a width of 0.1 mm. The two patches are connected with another 100 Ω line with dimensions of (L, W) (54.2 mm, 0.1 mm) which is connected to the 50 Ω TL . The 50 Ω TL has (5 mm x 3 mm) (length, width) and it is connected directly to the input power entire network. The dimensions of the patch elements, such as width and length, were calculated using equation (4). The 3D radiation pattern, reflection coefficient, and the 2D structure of this array are shown in Figures (4). Note that the antenna has a high gain of 5.32dB for a 6 x 8 cm^2 area and has a directional radiation pattern.

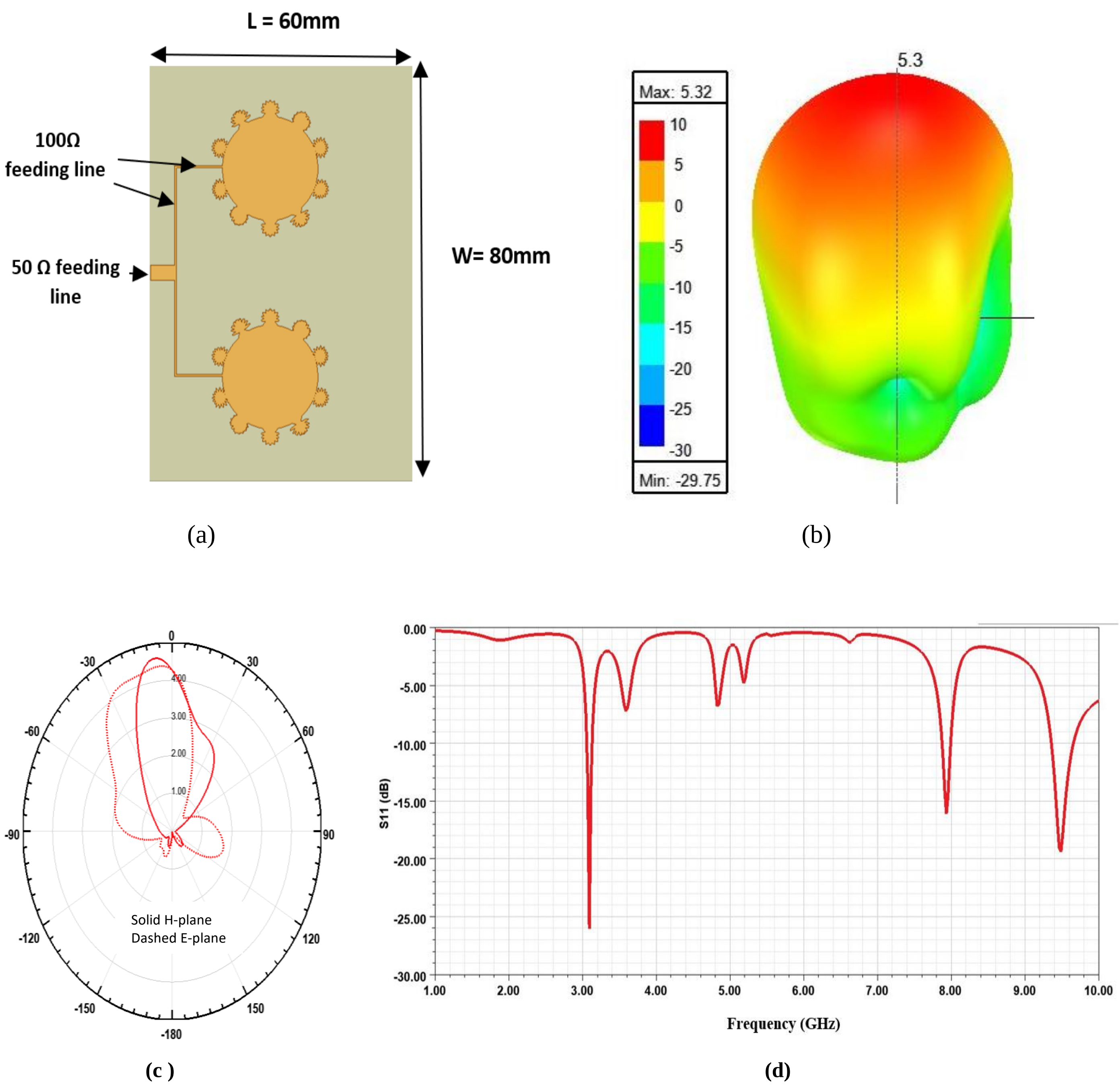


Figure (4): Results for the 2x1 antenna array when the resonance frequency is 3.1 GHz. (a) 2D structure and (b) 3D radiation pattern, (c) E-plane and H-plane radiation pattern, (d) S-parameter curve.

4. Design of 2x2 Array

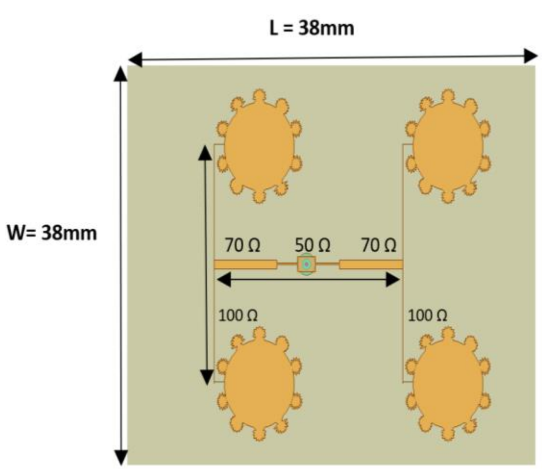
The proposed design procedure continues and a 2 x 2 antenna array is proposed in a square shape to reduce the feeding TL dimensions used and to occupy a small size of 38 mm x 38 mm. The patch is printed at the top layer of the substrate and the bottom layer of the substrate consist of a full ground plane. The configuration follows the same procedure of the 2x1 array. A coaxial prob feeding in the center of the array is connected to provide equalized electrical power for every patch in the network. In this design, the distance between the patch is changed to find the best radiation efficiency, and the results for this design are shown in Figure (5). The simulated antenna array is designed to resonate at 3.26 GHz, and the feeding lines were calculated according to the equation (4). The width W of the feed of an impedance Z_0 of 50 Ω, the following equations [27] was used:

$$W = \frac{2*h}{\pi}\left\{B - 1 - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} * \left[\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right\} = 31\ mm \tag{4}$$

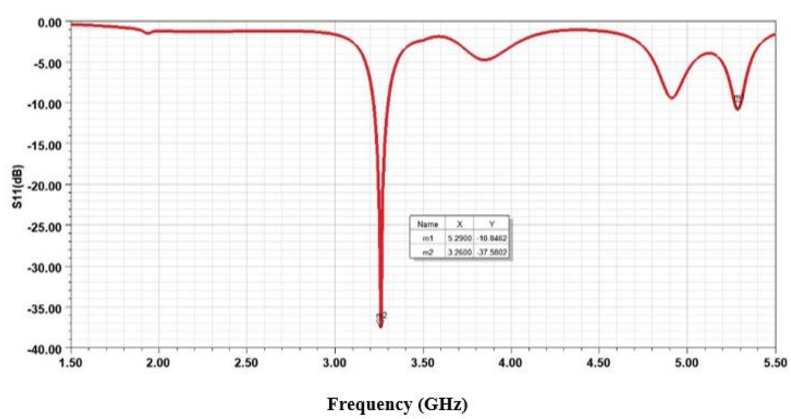
In the above equation, $B = \frac{377\cdot\pi}{2\cdot Z_0\cdot\sqrt{\varepsilon_r}}$

where Z_0 is the feeding line impedance.

The 70 Ω TL has a width and length 2mm and 18 mm respectively, and the 50 Ω TL width, length has 3 mm, 5 mm respectively. Clearly, according to Figure (5), the operating frequency is reduced from 3.4 to 3.26 GHz, the area dropped from 6 x 8 cm^2 , to less than 4 x 4 cm^2 , the radiation pattern has a more regular directive shape, and the gain increased from 5.32 dB to 7.8 dB, compared to the older 2 x 1 array.



(a)



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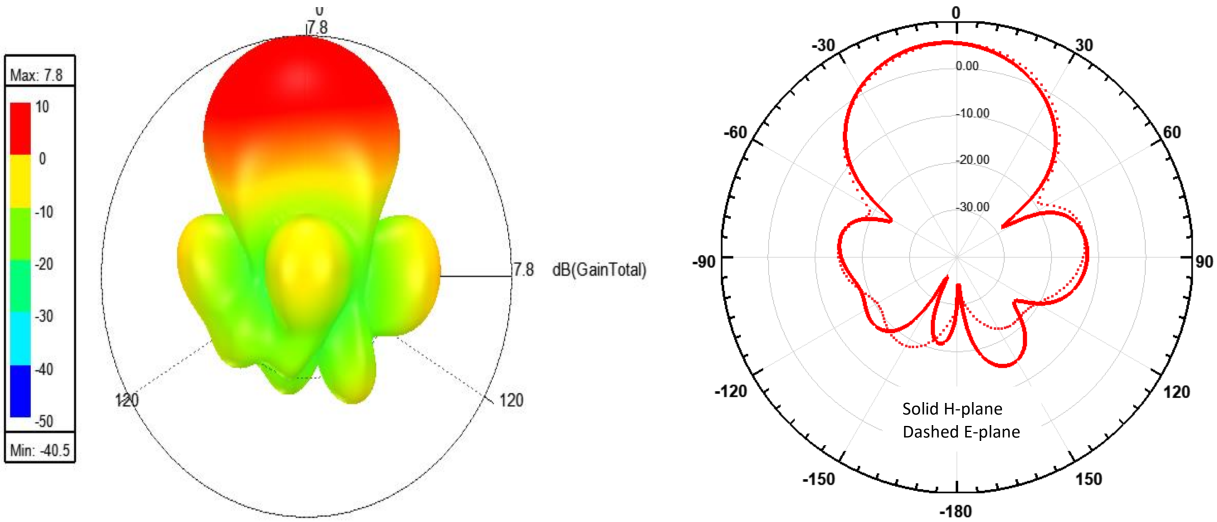


(c) (d)

Figure (5): Results for the 2x2 antenna array, where (a) structure of the array, (b) radiation coefficient curve, (c) 3D gain plot at 3.26 GHz, (d) 2D radiation pattern at the resonance frequency.

5. Design of 2x4 Array

When the 2 x 2 array is finalized a 2 x 4 array is set to study with different feeding line models. This type of array is also simulated on a rectangular substrate with dimensions of (L, W, h) to be (20 x 13 x 0.16) cm^3 as shown in Figure (6) . The patch antenna is fed using the coaxial probe feed method which is connected at the center of the antenna array to provide similar feeding for every element in the array.

After using the optimization technique of the HFSS program the best dimensions of the substrate was found, where the vertical distance between two elements is 53mm and horizontal distance is 55 mm and the TLs have width and length of (3.5,10) mm^2, (1.2 ,67) mm^2 and (0.3, 161.5) mm^2 for the 50 Ω, 70 Ω, and 100 Ω lines respectively. It is remarkable to notice the current distribution density on the 2x4 antenna array surface.

The design shows that the current distribution reached the far edge of the crowns at every patch in the array, hence explaining the obtained increased gain and the reduced frequency compared to the previous 2 x 2 array, where the gain jumped to 9.5 dB and the lowest operating frequency dropped to 2.08 GHz compared to 7.8 dB and 3.26 GHz for the previous 2 x 2 array.

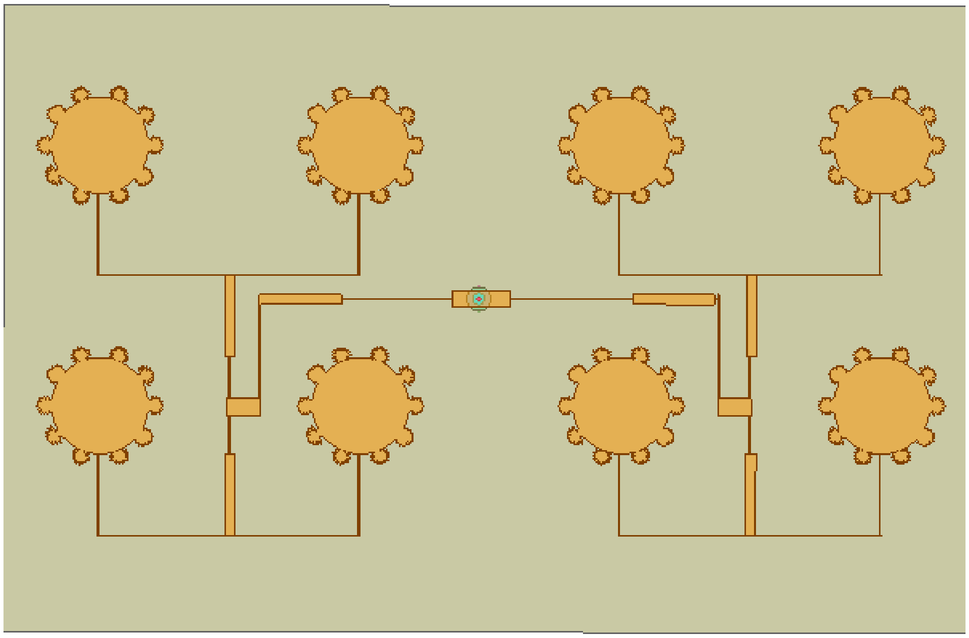
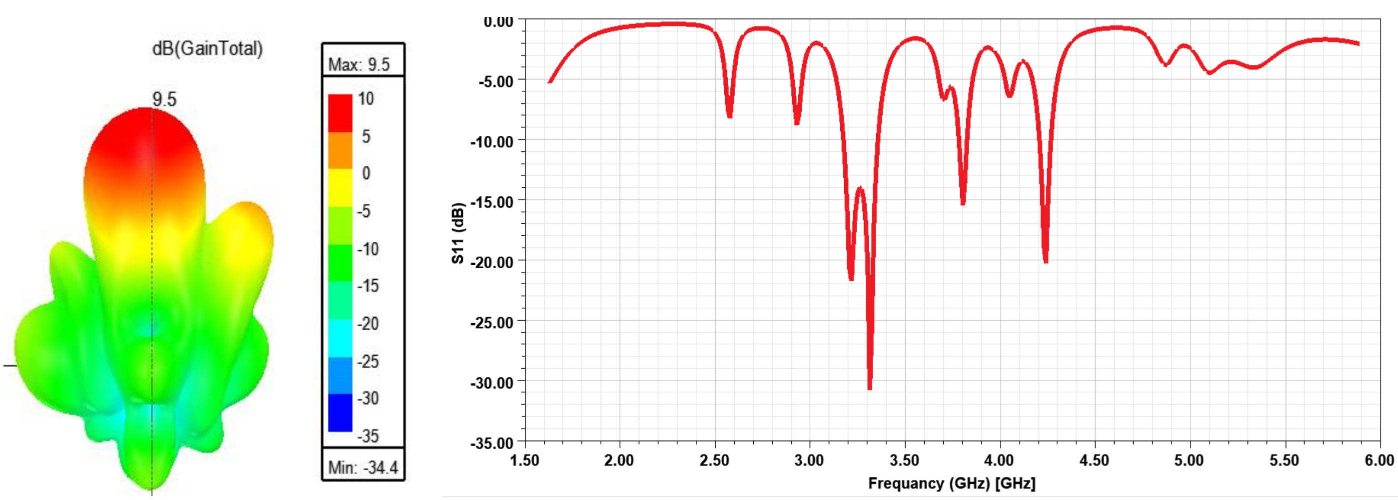


Figure (6): The two-dimensional structure of the simulated 2x4 patch antenna array.

The best dimensions of the substrate were found, where the vertical distance between two elements is 53mm and horizontal distance is 55 mm and the TLs have a width and length of (3.5,10) mm^2, (1.2 ,67) mm^2 and (0.3, 161.5) mm^2 for the 50 Ω, 70 Ω, and 100 Ω lines respectively. The design shows that the current distribution reached the far edge of the crowns at every patch in the array, hence explaining the obtained increased gain and the reduced frequency compared to the previous 2 x 2 array, where the gain jumped to 9.5 dB with respect to 7.8 dB and 3.26 GHz for the previous 2 x 2 array. The results from the reflection coefficient curve and the radiation pattern for this design is shown in Figure (7).



(a) **(b)**

Figure (7): Optimal results for the 2x4 antenna array with different feeding methods. (a) 3D radiation pattern, (b) Resonance frequency curves.

6. Design of 4x4 Array

The design procedure continues and a 4 x 4 antenna array is proposed in a square shape to reduce the feeding TL dimensions used and to occupy a size of 22 cm x 22 cm. The patch is printed at the top layer of the substrate and the bottom layer of the substrate consists of a full ground plane. A coaxial probe feeding is designed to be in the center of the array to provide equalized electrical power for every patch in the network. In this design, the distance between the patches is changed to find the best radiation efficiency, and the results for this design are shown in Figure (8). The final results from the reflection coefficient and the radiation pattern are shown in Figure (9).

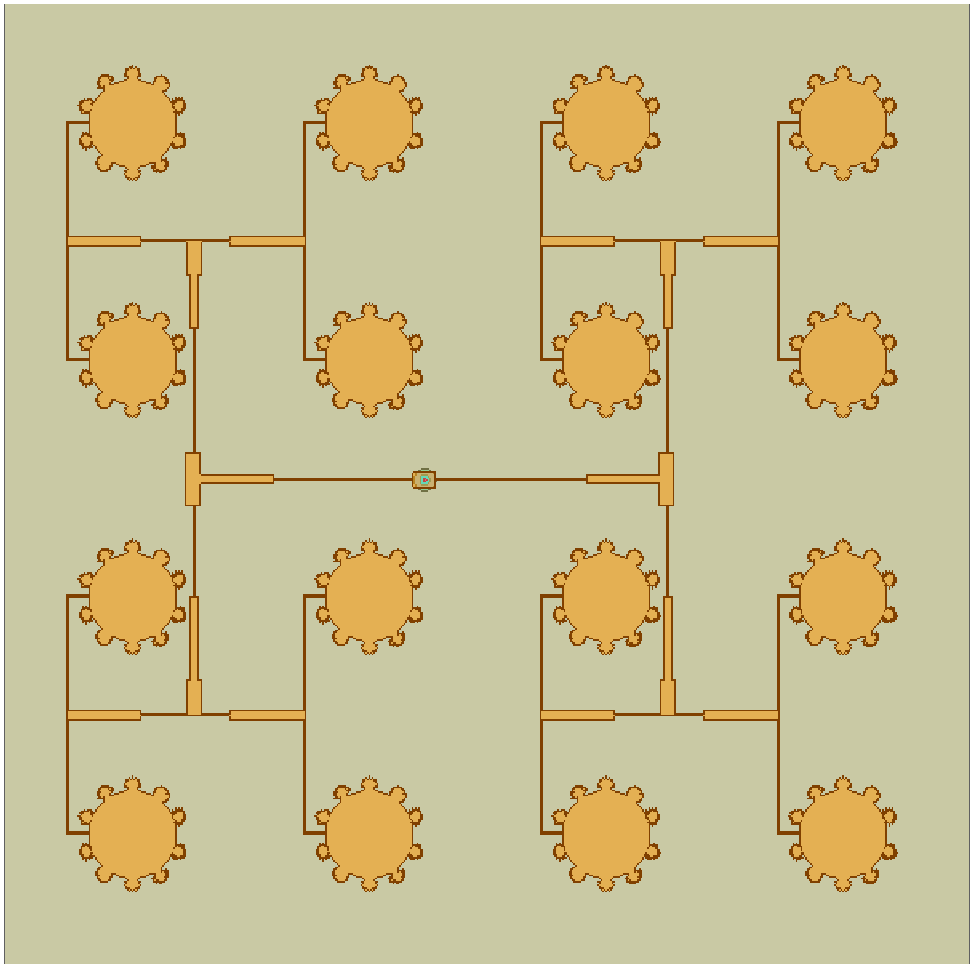
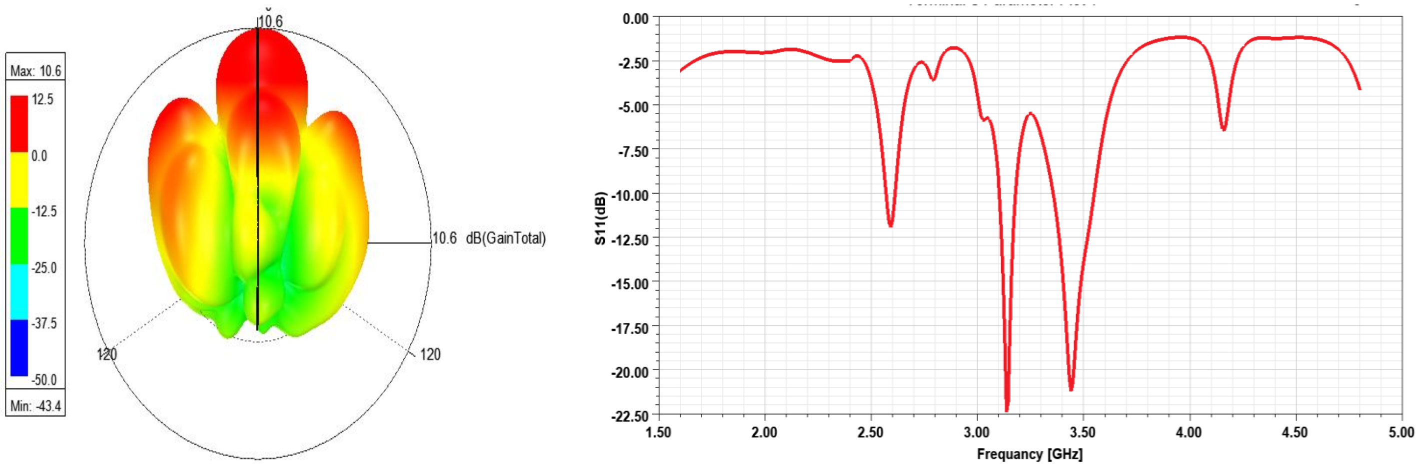


Figure (8): The two-dimensional structure of the simulated 4x4 patch antenna array.



(a) **(b)**

Figure (9): Optimal results for the 4x4 antenna array with different feeding methods. (a) 3D radiation pattern, (b) Resonance frequency and reflection coefficient curves.

7. Conclusion:

A COVID-19 patch antenna is constructed in the centimeter wave band suitable for WiMAX, GPS and radar applications. An array was created from this patch which was printed on an FR4-epoxy material with 0.16 cm height. This array is a 4 x 4 single polarized antenna with 22 cm x 22 cm length and width respectively. At 3.16 GHz operating frequency, the maximum simulated gain is 10.5 dB. These results allow this array to perform in an extremely wide band of applications, especially in the range of the new radio (NR) 5G wireless applications. Even though the design of COVID-19 patch antenna elements and arrays faced many challenges, there are very important potentials harvested from it to support the reality of the 5G cellular networks, and without doubt, this technology will stay the main field for researchers to develop the next generation of the mobile network and cellular services systems and applications.

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