Wasit Journal of Engineering Sciences
Journal homepage: https://ejuow.uowasit.edu.iq
Vol. 13 No. 1 March 2025, pp.22-38
https://doi.org/10.31185/ejuow.Vol13.Iss1.604

ISSN 2305-6932
Original Research

Impact of Substrate Dielectric Constant on Performance of 2.4 GHz Microstrip Patch Antenna Array

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ABSTRACT

In recent years, arrays have been widely used in many applications, especially those that need high guidance, whether in military, medical, or other applications. Arrays are highly oriental, unlike single antennas. In this work, we analyze the effect of the insulating substrate insulation constant on the 2X2 microstrip patch antenna array at a frequency of 2.4 GHz, which is suitable for WLAN applications. CST Microwave Studio Version 2019 was used to design, simulate, and analyze the proposed model. The bar line feeding technique was used to feed the array. A set of mathematical relationships was used to calculate the array's dimensions. We simulated and analyzed the array on three dielectric pillars: (FR-4) with a dielectric constant of 4.3, (Polycarbonate) with an isolation constant of 2.9, and (Porcelain) with an isolation constant of 6. The 2X2 array was manufactured and printed on the insulating substrate (FR-4) and the practical results were compared with the simulation results. There was a good agreement between the practical and theoretical results

Keywords: Microstrip Patch Antenna (MPA); Slot-loaded; Bar Line Feeding; 2x2 Antenna Array; Polycarbonate.

1. Introduction

The wireless system has now become an important part of our lives as most electrical and electronic devices use wireless systems. The antenna is an important element in wireless systems and the design of antennas capable of working in a wide range is receiving increasing attention due to the need to use them in high data [1] Microstrip patch antennas are suitable for these devices because of their attractive characteristics such as small size, lightweight, and the possibility of installing them on flat and uneven surfaces, and the low manufacturing cost, distinctive mechanical properties, and the possibility of integrating them with microwave circuits, and other features that make us sure that they will continue to spread widely and find applications New [2] Despite all the advantages that have been mentioned, the single microstrip patch antennas have some disadvantages, the most important of which are that they have a narrow beam width and a decrease in gain [3]. The role of the antenna array is vital in the fields of communications, as it is used as a key element in modern radar and sonar systems and enhances the performance of the fifth generation of cellular communications thanks to its more precise orientation [4]. An antenna array is a set of regularly connected antennas, improving or rejecting the signal according to their spatial orientation, enhancing the performance of advanced communication systems [5], array technology is often used in microchip antennas to improve efficiency, directivity, and profit in radiated systems. This is because the radiation from a single antenna element is very wide in the radiation pattern. This is not good for point-to-point communication which requires more directional antennas. The antennas of the array consist mainly of the meeting of several geometrically arranged radiation elements to generate the desired radiation pattern. Each antenna in the array is called the element [6]. Matrices can be classified into two main types: a linear array where its elements are arranged on a single equidistant line and are known as a "linear array". A planar array [7] is characterized by the distribution of its elements over a plane and is called "planar array". A planar array can be thought of as a composition of linear matrices connected, forming a complex structure that can be conceived as a set of linear matrices [8]. Array antennas are used to direct energy towards a specific angular sector. The radiation pattern is based on factors such as the number of elements in the array, the arrangement of the elements, and the page values and signal length. The Array factor is calculated by summing the radiation diagrams of the individual elements multiplied by a coefficient known as the array coefficient [9]. Antenna arrays come in different shapes such as disks, wires, patches, parabolas, or spiral designs [10]. Microstrip patch antenna arrays have been widely used in recent years thanks to their robust design, there are three advantages of microchip arrays, the first of which is that the process of printing hundreds or even thousands of tape element components within a single production process leads to low economic cost. Secondly, microchip arrays have high reliability as the entire array is a continuous piece of copper. Other types of antennas fail performance at the contact points between the antennas and their input connectors. Thirdly, since the printed circuit boards are very small, the array is designed very efficiently without having an impact on the metal surface of the incubator [11]. You find a variety of uses in areas such as personal communication systems, medical applications, mobile satellite communications, and military systems. As well as its role in WLAN and radio communication systems [12]. In this research, the microstrip patch antenna array was designed with three different insulating materials the first design was designed at (FR-4) with a dielectric constant of 4.3 and a total size of mm (1.6 x 120 x 130). The second design was done using (Polycarbonate) material with an insulation constant of 2.9 and a total size of (1.6 x 120 x 130) mm, while the third design was done using (Porcelain) material with a dielectric constant of 6 and a total size of (1.6 x 110 x 115) mm, where all designs operate at the frequency 2.4 GHz suitable for WLAN application: (2.4-2.65) GHz. The effect of the insulating constant of the insulating substrate on its performance was studied. CST software was used for simulation and design, epoxy (FR-4 epoxy) was used in the manufacture of this model, and copper was used as a conductor for the manufacture of radioactive patches (Patch) and ground plane for array elements. After that, the return loss was examined and measured using the Vector Network Analyzer device, and the practical result was compared with the simulation result. This research hypothesis is that the dielectric constant of the substrate material determines the performance characteristics (gain, radiation pattern, return loss, bandwidth) of a 2.4GHz microstrip patch antenna array. This impact will be investigated using three different substrate materials and simulated and measured results will be compared.

2. Proposed Antenna

conventional microstrip antenna consists of a pair of parallel conducting layers separating a dielectric medium, referred to as the substrate. Physically, the patch is a thin conductor that is an appreciable fraction of a wavelength in extent, parallel to a ground plane and a small fraction of a wavelength above the ground plane. The patch will radiate effectively if the length of the patch is typically about a half guide wavelength in size. In most practical applications, patch antennas are rectangular or circular; however, in general, any geometry is possible.

2.1. Unit Cell Design

When designing a single rectangular antenna, keep in mind that the microstrip patch antenna consists of the ground level, the insulating substrate (FR-4) with an insulation constant of 4.3 = εr, and the radiated patch. The dimensions of the rectangular radiant area were calculated using the following mathematical relationships:

The width of the single patch element was calculated according to the relationship in equation (1) [13, 14].

$$W_P = \frac{C_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

W_P : Width of the Patch.
C_0: The speed of light in a vacuum.
f_r : resonating frequency.
ε_r : Dielectric constant of substrate.
The effective dielectric constant was calculated in equation (2) [15].

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_{r-1}}{2\sqrt{1+\frac{12h}{w}}} \tag{2}$$

ε_{reff} : The effective relative insulation constant of the substrate.
h: Insulating material height.
W: Antenna patch width.
As stated in [16], the effective length was determined by equation (3)

$$L_{eff} = \frac{C}{2f\sqrt{\varepsilon_{reff}}} \quad (3)$$

L_{eff} : Influential area length.
f : Resonant frequency.
C: The speed of light in a vacuum is (3x108 m/s).

The difference between the physical and electrical length of the patch element was addressed by [17, 18] through equation (4).

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff+0.3})(\frac{W}{h}+0.264)}{(\varepsilon_{reff-0.258})(\frac{W}{h}+0.8)} \quad (4)$$

ΔL : represents the difference between the electrical and physical length of the patch.

The length of the patch area (L) was calculated using equation (5), as mentioned in [16]:

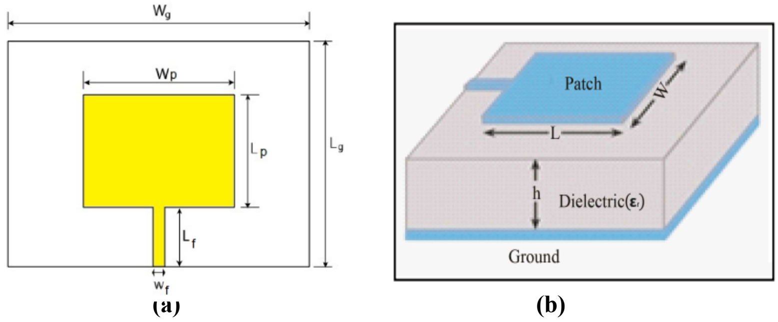
$$\mathrm{L}_P = \mathrm{L_{eff}} - 2\Delta\mathrm{L} \quad (5)$$

L_P **:** Represents the length of the patch**.**

The researchers in [19 - 22] mentioned that the characteristic impedance of the feeding stripe line was considered by equation (6).

$$\mathrm{Z}_0 = \frac{120\pi}{\sqrt{\varepsilon reff}\left(1.393+\frac{W}{h}+\frac{2}{3}\ln(\frac{W}{h}+1.444)\right)} \quad (6)$$

The rectangular thin-slice antenna is designed at 2.4 GHz using strip line feeding technology. The simulation was carried out using CST software. Using FR-4 insulating substrate with an insulation constant of 4.3 and a thickness of 1.6 mm. The design uses a rectangular patch due to its simplicity and ease of improvement. It is also low-cost [23-25]. Fig 2 shows the single antenna.



(a) **(b)**

Figure 1. (a) The front view of the proposed single antenna element, and (b) the structure of the microstrip patch antenna.

Table 1. Shows the design dimensions of the unit cell antenna in (mm).

parameter	**Ls**	**Ws**	**Wp**	**Lp**	**Wf**	**Lf**	**h**	**T**	**Lg**	**Wg**
Value (mm)	50	80	38	29	3	13	1.6	0.035	50	80

a. Antenna Array Constriction

After the single antenna is designed and its dimensions are calculated. The antennas are combined to form a 2x2 microstrip patch antenna array as the 2x2 thin slice antenna array consists of four elements. It is quite traditional to study the effect of the substrate isolation constant on the properties of the array, the array also operates at the frequency 2.4 GHz. He also used the bar line technique to feed the array while keeping the distance between the array elements less than half the wavelength (0.5λ) to avoid the coupling that occurs between the array elements. The design will be at three insulating pillars, namely FR-4 with an insulation constant of 4.3, Polycarbonate with an insulation constant of 2.9, and Porcelain with an insulation constant of 6 Initially, the design will be done using epoxy FR-4 as an insulating substrate with an insulation constant of 4.3 and a thickness of 1.6 mm. Fig 3 shows the design of the 2x2 microstrip patch antenna array when using epoxy FR-4.

Table 2. Shows the dimensions of the array design at the insulating material (FR-4) measured in (mm).

N0	Parameters	Value	No	Parameters	Value
1	Substrate dielectric constant, (ε_r)	4.3	7	Length of insulating substrate, (Ls)	130 mm
2	Width of the patch, (wp)	38.393 mm	8	Width of the insulating substrate, (ws)	120 mm
3	Length of the patch, (Lp)	29.717 mm	9	Length of the actual ground,(Lg)	130 mm
4	Length of the microstrip line, (Lf)	11 mm	10	Width of the actual ground, (Wg)	120 mm
5	Width of the microstrip line, (Wf)	3.14 mm	11	Thickness of insulating substrate,(h)	1.6 mm
6	Thickness of the microstrip patch,(t)				

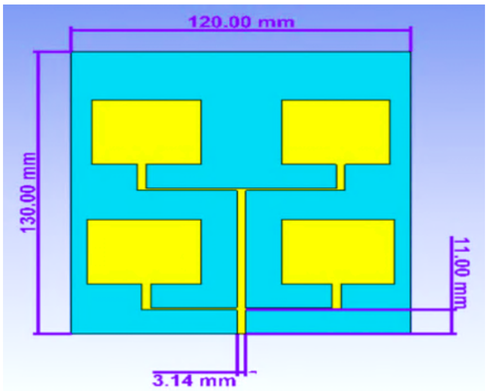


Figure 2. 2x2 array antenna design on FR-4 substrate.

To study the effect of the insulating substrate insulation constant on the properties of the 2x2 array, we change the insulation constant using different insulating materials, that is, by taking a material with a dielectric constant greater than the epoxy constant and a material with a lower insulation constant than epoxy, and by reducing the insulation constant and using the insulating material (Polycarbonate) with an insulation constant of 2.9, which is less than the insulation constant of the insulating substrate material (FR-4), and due to the change in the value of the insulation constant, the dimensions of the radiant patch of the array elements will change according to the change of the insulation constant, By applying the same mathematical relations used previously, the dimensions of the patch are calculated, the length of the patch is equal to Lp = 36.14 mm and the width of the patch is equal to Wp = 44.757mm, and the length of the transmission line was increased to Lf = 15 mm and the width of the transmission line was reduced to Wf = 2.60 mm in order to harmonize between the patch and the transmission line as well as to reduce the return loss and increase the directionally of the array and gain, while the other dimensions remained the same when using (FR-4).

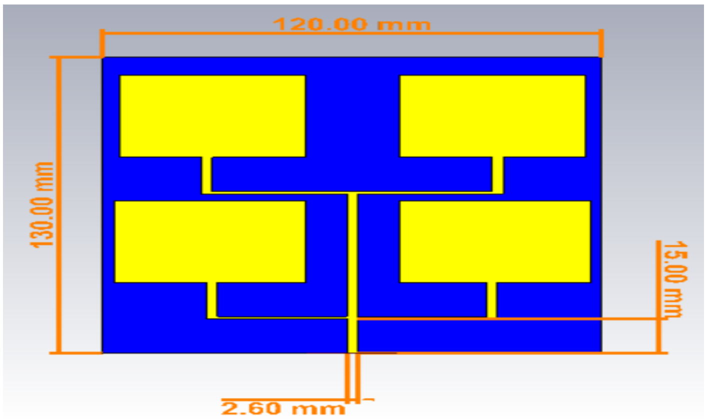


Figure 3. The design of the 2x2 array antenna is illustrated when using polycarbonate

Again when increasing the insulation constant and using (Porcelain) with an insulation constant of 6, which is greater than the epoxy insulation constant (FR-4), and due to the change of the insulation constant, the dimensions of the radioactive patches of the array elements will also change, they are calculated by applying the previously used mathematical relationships, so the width of the radioactive patch Wp =33.40 mm and the length of the radioactive patch Lp =25.24 mm, and some of the radiation properties of the microstrip patch antenna array have been improved to reduce return loss and to harmonize between the patch and the transmission line by reducing The width and length of the transmission line respectively to Wf =0.8 mm and Lf = 8 mm, as well as the width and length of the substrate were reduced to Ws =110 mm and Ls=115 mm in order to obtain a higher orientation of the array and not to fade its radiation, as well as to obtain a small size that can be used in many applications, as for the distance between the elements of the array was less than half the wavelength and fixed between all four elements of the array in order to avoid mutual coupling, and the other dimensions remained the same.

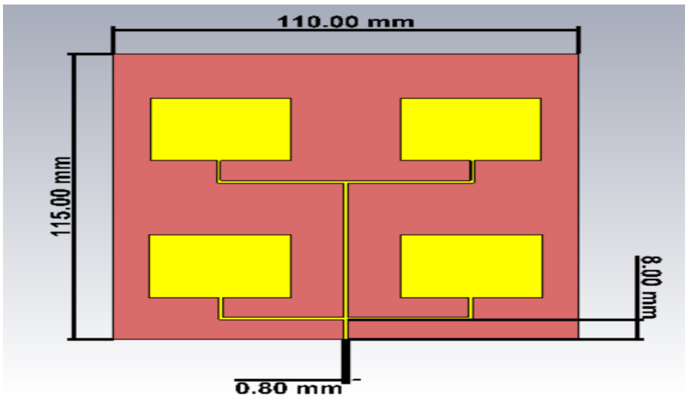


Figure 4. The Design of the 2x2 Array Antenna is Illustrated When Porcelain Is Used.

3. Simulated Results

3.1. Return Loss Results

3.1.1. Return loss with using (FR-4)

After increasing the number of array elements for the second model, forming a 2x2 microstrip patch antenna array, using the FR-4 insulating substrate with an isolation constant of 4.3, and simulating the results using the CST program, the return loss was calculated, and it was found that it has a value equal to -44.208 at the operating frequency 2.4 GHz as shown in the figure below.

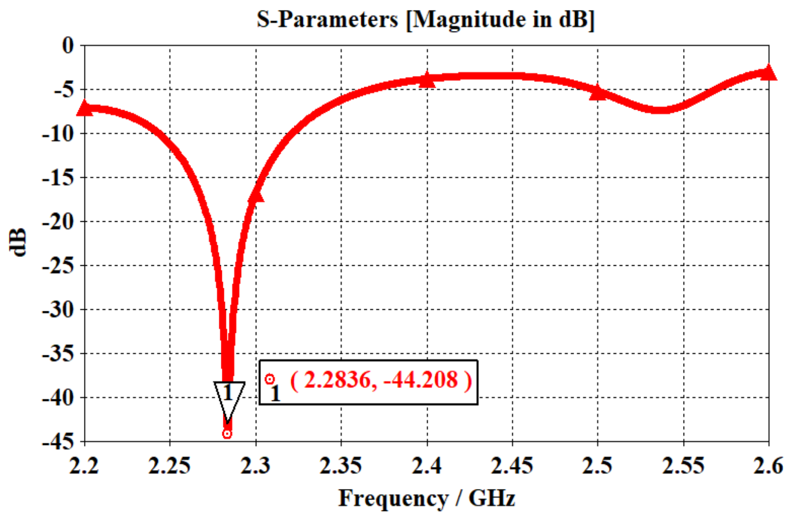


Figure 6. It shows the return loss as a function of the frequency of the 2x2 array when using FR-4.

3.1.2. Return Loss with polycarbonate

As we mentioned earlier, when reducing the insulation constant and taking an insulating material with insulation constant less than the value of the epoxy insulation constant, and by taking the polycarbonate insulation material with an insulation constant of 2.9, which is less than the insulation constant of FR-4, and from Fig 7. It appears to us that the return loss value of this material is equal to -54.044 dB54.044 at the operating frequency GHz2.4, and the return loss value of this insulating material is less than the return loss value when using (FR-4), meaning that the return loss decreased when using insulating material with a low insulation constant value, unlike epoxy material, which was considered as a reference in the results of this research.

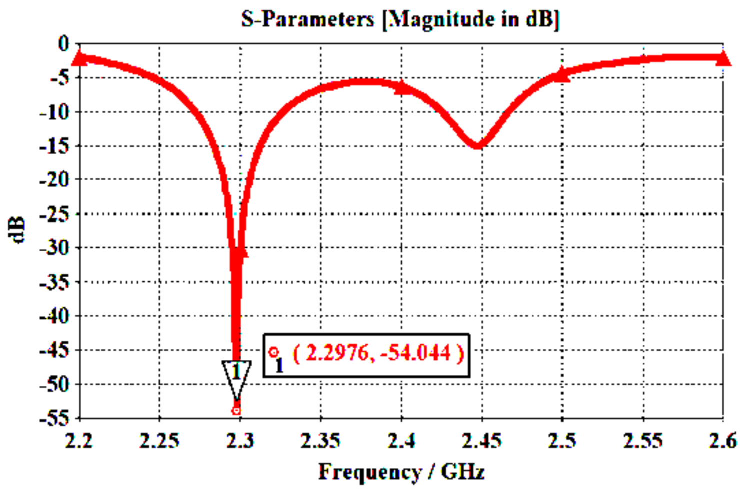


Figure 7. It shows the return loss as a function of the frequency of a 2x2 array when polycarbonate is used.

3.1.3. Return loss with Porcelain

By increasing the value of the insulation constant (i.e. by taking a value greater than the value of the epoxy insulation constant) and taking the insulating material Porcelain with the value of the insulation constant 6, we notice that the return loss increases to -40.553 dB40.553 at the frequency 2.289 GHz2.289 within the application frequency range (WLAN) and this value is greater than the return loss value when using both (FR-4) and (Polycarbonate), and Fig 8. Shows the return loss as a function of the frequency at the above material.

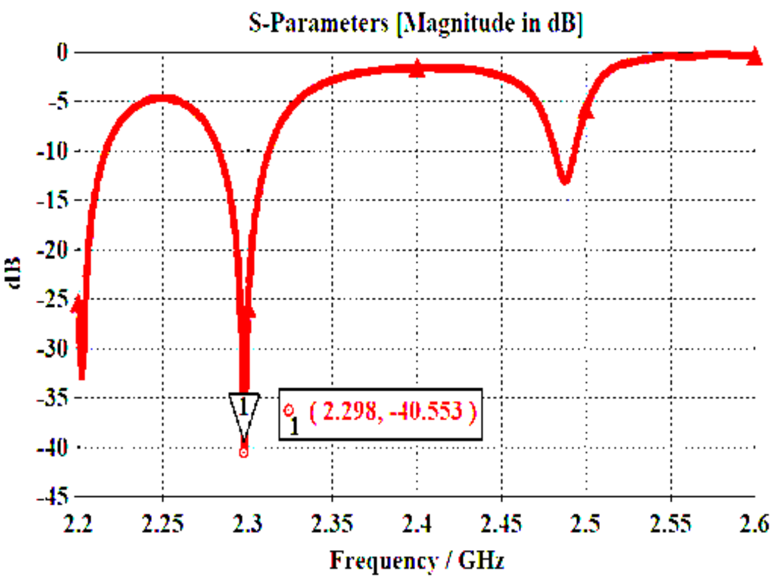


Figure 8. It shows the return loss as a function of the frequency of the 2x2 array when using Porcelain.

From the above, it is clear to us that the effect of the insulating substrate isolation constant on the return loss of the 2x2 array antenna is a direct proportional effect, that is, the lower the insulation constant, the lower the return loss, and the greater the insulation constant, the greater the directionally, and Fig. 9 shows the comparison between the different insulating materials in terms of return loss, and that the best materials used in the 2x2 array in terms of return loss are Polycarbonate, then FR-4, followed by Porcelain.

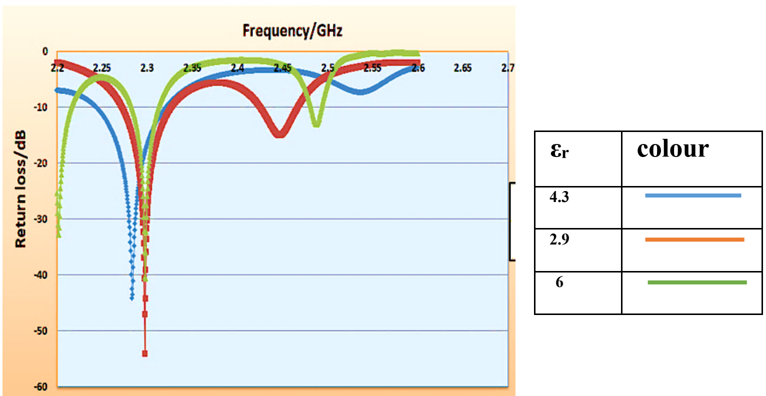


Figure 9. The comparison of return loss as a frequency function of a 2x2 array when different insulating .materials are used

3.2. Bandwidth Results

3.2.1. Frequency bandwidth with FR-4

When using epoxy insulating material with an insulation constant of 4.3 and an insulating loss (tanδ) (const. fit) of 0.025, the beam width was calculated from the return loss curve by applying the relationship of the frequency bandwidth, and it was found that it is equal to BW = 0.078159GHz, which is confined between the lowest frequency 2.2432 GHz and the highest frequency 2.3214 GHz, as well as calculating the width of the fractional beam of its relationship, it was equal to FBW =3.25% This means that the frequency beam of this material is wide because it is FBW>1%, and Fig 10. Shows the bandwidth**.**

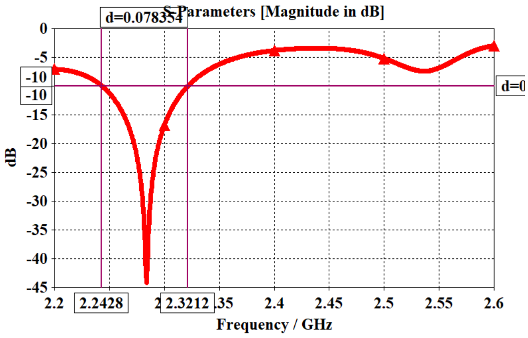


Figure 10. It shows the width of the beam when using FR-4.

3.2.2. Frequency bandwidth with Polycarbonate

By changing the insulating material and by taking the Polycarbonate material with an insulation constant of 2.9 and an insulating loss (tan δ=0.01), which is less than the insulation constant of FR-4, the width of the beam was also calculated by applying the relationship to it by taking the two frequencies facing the value (-10 dB), so it was equal to BW = 0.054596 GHz. Also, the width of the fractional beam was calculated by applying its relationship as well, so it was equal to FBW =2.28% This means that the frequency bandwidth of this material is also wide because it is FBW>1%, but it is less than the frequency bandwidth of (FR-4) and Fig 11. The bandwidth of the above material is shown.

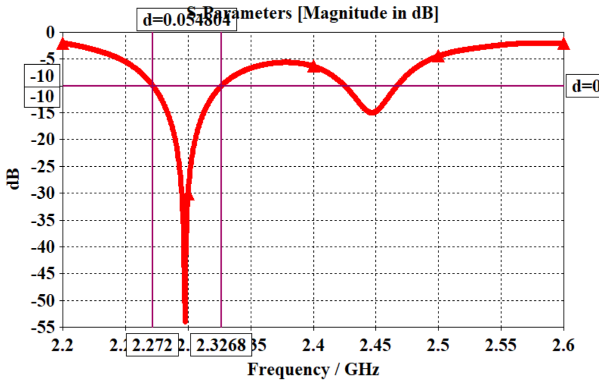


Figure 11. It shows the width of the frequency beam when using (Polycarbonate).

3.2.3. Frequency bandwidth with Porcelain

As we mentioned earlier by changing the insulation constant and taking an insulating material with an insulation constant greater than (FR-4) and taking (Porcelain) with an insulation constant of 6, Fig 12. This shows the beam width of this material above and by applying the equation for the beam width, it is found that the frequency beam width has a value equal to BW = 29.683 MHz. The fractional beam width is equal to 1.23% this means that the frequency bandwidth of this material is also wide because it is FBW>1%, but it is less than the frequency bandwidth of both insulating materials (FR-4) and (Polycarbonate).

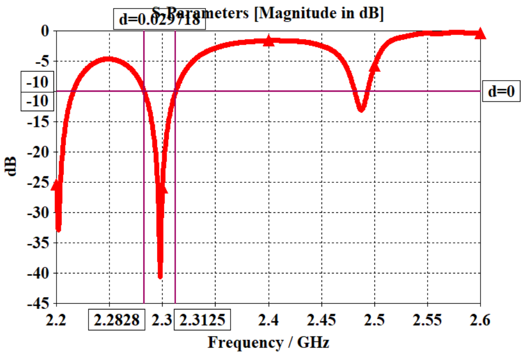


Figure 12. It shows the frequency bandwidth when using Porcelain.

From the above, it is clear to us that the effect of the substrate isolation constant on the frequency beam width of the 2x2 array antenna is according to the loss of the insulation (tanδ) of the insulating material used, as it was found that the insulating material (FR-4) has a frequency beam width equal to 78.15 MHz, which is greater than the width of the beam when using both materials, (Polycarbonate) and (Porcelain) because epoxy FR-4 has a greater dielectric loss than the rest of the insulating materials used, this means that it has a smaller quality factor because the insulator loss is proportional Inversely with the quality factor. Thus we get a wider frequency beam width because the beam width is also inversely proportional to the quality factor (i.e. the larger the insulating material with (tanδ), the bandwidth is wide) and that the best insulating material used in this research from the beam width side for the 2x2 array is (FR-4). This result is consistent with the findings of Ivan et al. in their 2018 research, where they designed a 2x2 array antenna operating at the frequency 28 GHz using five different dielectric substrates with different dielectric loss (tanδ) as well and obtained the best frequency beam width when using the insulating material (FR-4) with an insulation constant of 4.3, which is the largest dielectric loss among the materials used [26-28].

3.3. Voltage Standing Wave Ratio Results

3.3.1. Standing wave voltage ratio when using (FR-4)

From Fig 13. The standing wave voltage ratio (VSWR) of a 2x2 array antenna is shown when using the FR-4 insulating substrate material with an insulation constant of 4.3, which shows that it has a value equal to 1.0124 at the frequency 2.2836 GHz, and this value is close to one and good, this means that the compatibility between the transmission line and the source is good because the bounce wave is small, and this value is very close to the value of the 2x1 array antenna at the same insulating material.

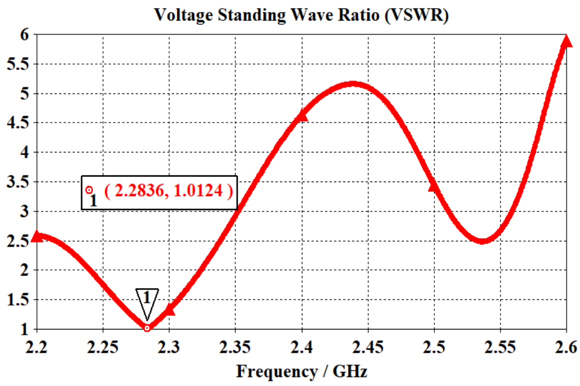


Figure 13. It shows the ratio of standing wave voltage VSWR when using (FR-4).

3.3.2. Standing wave voltage ratio when using polycarbonate

When changing the insulating substrate material and using an insulating material with insulation constant lower than FR-4, and by taking the insulating material Polycarbonate with an insulation constant of 2.9, VSWR is calculated, which shows a value less than the value of epoxy FR-4, as it is equal to 1.004 at the frequency 2.3724GHz, which is very close to the one, which is an excellent value, this means that the alignment between the transmission line and the source is very high, because the wave from the source is very small, unlike epoxy, and Fig 14. Shows the ratio of voltages of the standing wave at the above material.

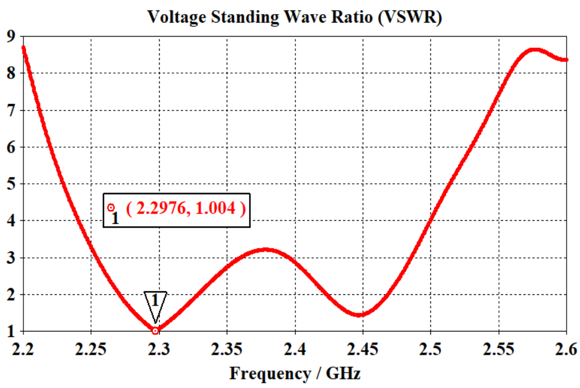


Figure 14. The percentage of standing wave voltage VSWR when using (Polycarbonate)

3.3.3. Standing wave voltage ratio when using (Porcelain)

By increasing the insulation constant and taking the material (Porcelain) with a dielectric constant of 6, which is greater than the insulation constant of epoxy material, which was considered as a reference, we note that the voltage ratio of the standing wave at this material is 1.0189 at the frequency 2.298 GHz, and this value is greater than the value of VSWR when using both (FR-4) and (Polycarbonate), and Figure 15. Shows the percentage of standing wave voltage when using the above material.

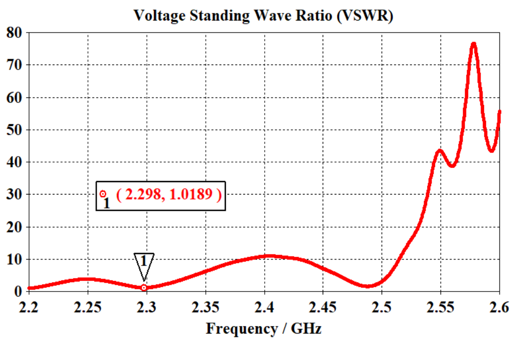


Figure 15. It shows the ratio of standing wave voltage VSWR when using (Porcelain)

From the foregoing, it becomes clear to us that the effect of the insulating substrate insulation constant on the property of the standing wave voltage ratio is a direct proportional effect, that is, the lower the insulation constant, the lower the percentage of voltages of the standing wave, and the greater the insulation constant, the greater the percentage of standing wave voltages, and that the best materials used in this research in terms of the ratio of voltages to the standing wave of the microstrip patch antenna array 2x2 is the insulating material (Polycarbonate) because its value is very close to one, followed by (FR-4) and then (Porcelain), and Figure 16, shows the comparison of the standing wave voltage ratio when different insulating materials are used.

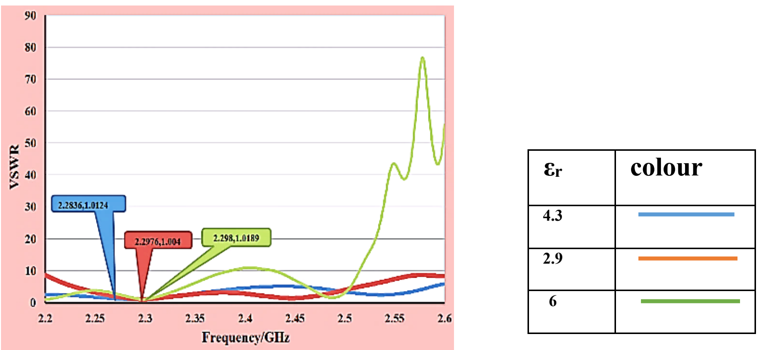


Figure 16. Shows the comparison of VSWR for a 2x2 array when different insulating materials are used.

3.4. Gain Results

3.4.1. Gain when using FR-4

Fig 20. The gain is expressed as a function of the frequency when using (FR-4) as an insulating substrate for the antenna of the 2x2 array with a dielectric constant of 4.3, and the gain value at this material is 5.235 dB5 at the working frequency or the frequency at which 2.4 GHz is designed. Where the gain of the antenna is one of the important properties through which it is possible to know the efficiency of the antenna and to know the application that this antenna can be compatible with. The gain is always less than the directivity and cannot be greater than it, and if the gain is greater than the directivity, this means that there is a defect in the design of this antenna.

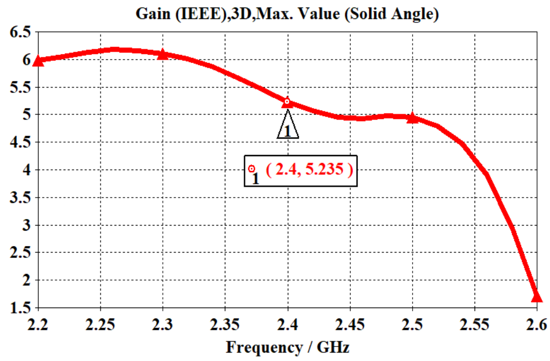


Figure 20. Gain is shown as a function of frequency when using FR-4.

3.4.2. Gain When Using (Polycarbonate)

As mentioned earlier, changing the insulation constant and taking the polycarbonate material with an insulation constant of 2.9, which is less than the value of the epoxy insulation constant, which is considered a reference, and from Fig 21. It shows us that the gain value is equal to 7.2539 dB7.2539 at the working frequency of 2.4 GHz, and the gain value of this material above is greater than the gain of the insulating material FR-4.

3.4.3. Gain When Using (Porcelain)

Again, by taking an insulating material greater than the insulating constant of FR-4 and by taking Porcelain as the dielectric substrate for the 2x2 array antenna with an insulation constant of 4.3, and from Fig 22. We find that the gain has a value equal to 7.4264 dB7.4 at the operating frequency of 2.4 GHz, and this gain value is also greater than the gain value when using FR-4.

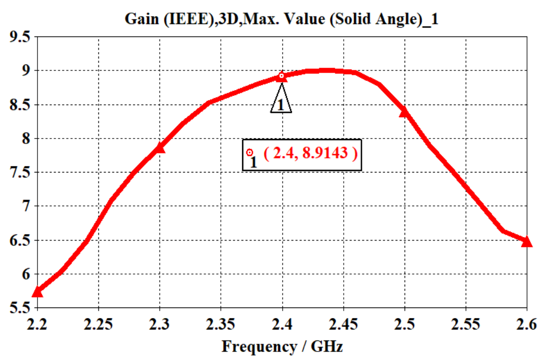


Figure 21. Gain is shown as a function of frequency when using polycarbonate

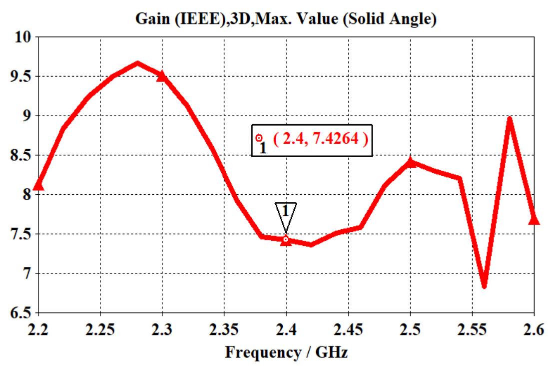
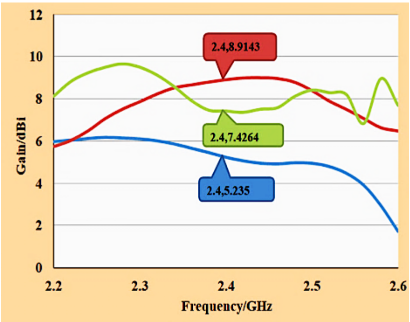


Figure 22. Gain is shown as a function of frequency when using Porcelain

From the above, it becomes clear to us that the best insulating materials used in terms of gain are (Polycarbonate) with an insulation constant of 2.9, which is the lowest insulation constant among the materials used, and the reason is that the low value of the insulating substrate isolation constant means a lower amplitude of the ground level of the array antenna, which leads to an increase in the field of collation in the vicinity of the patch (patch) and thus an increase in the radiant force, which leads to an increase in gain, while a higher value of the insulating substrate isolation constant means a higher capacity of the ground level of the antenna array which leads to the storage of more energy in the ground plane and less energy radiation, which leads to a decrease in gain, we note that this effect on the gain in the 2x2 array is the same as the effect on the gain in the 2x1 array as mentioned earlier, Figure 23. It shows the comparison of the gain of a 2x2 array when using different insulating materials .The above result is consistent with a 2018 study by researchers, including Ivan et al. who designed a 2x2 antenna operating at 28 GHz, used five different insulating substrates, and showed that the use of Astra MT77 insulation material with an insulation constant (3) resulted in the best gain among the materials used, which is the lowest insulation constant among the materials used [24, 25].



ε_r	colour
4.3	
2.9	
6	

Figure 23. The comparison of gain vs frequency for a 2x2 array with different dielectric materials are used.

3.5. Directivity Results

3.5.1. Directivity When Using (FR-4)

Fig 24. Shows the directivity of the 2x2 array antenna when using the insulating material FR-4 with a dielectric constant of 4.3 and its value was equal to 9.5848 dBi at the working frequency 2.4 GHz, and the directivity value of this 2x2 array is greater than the directivity value of the 2x1 array when using the same insulating material above and the reason is due to the increase in the number of elements of the array to four elements, which led to an increase in directivity as well as an increase in gain.

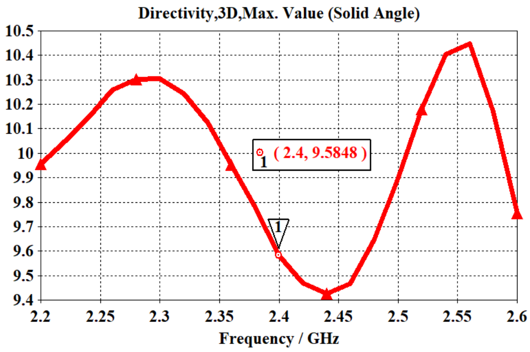


Figure 24. It shows directivity as a function of frequency when using (FR-4).

3.5.2. Directivity When Using (Polycarbonate)

By reducing the insulation constant and using the material Polycarbonate with an insulation constant of 2.9, which is less than the insulation constant of (FR-4) that we considered as a reference, and from Fig 25. It turns out that the value of directivity at this material is dBi 10.713 at the working frequency GHz2.4, and it turns out that the value of directivity at this material for the 2x2 array is higher than the value of directivity for the 2x1 array at the same insulating material, and the reason, as we mentioned earlier, is due to the increase in the number of elements of the array to four elements instead of two elements as in the 2x1 array, and that the value of directivity at this material is greater than its value at epoxy.

3.5.3. Directivity When Using (Porcelain)

Fig 26. Directivity appears as a function of frequency when using the insulating material Porcelain with an isolation constant of 6 and this material is greater than the insulation constant of (FR-4), as it was found that this insulating material has a directional value equal to dB7.6855 at the operating frequency GHz2.4 and this value is less than the value of directivity when using both (FR-4) and (Polycarbonate). It is clear from the above that the directivity increases with the decrease of the insulation constant and decreases with its increase, that is, the effect of the isolation constant of the insulating substrate on the directivity for the 2x2 antenna array is an effect with inverse proportionality, and as we mentioned earlier that the reason for this effect and the reason is due to the fact that the low value of the insulating substrate isolation constant means a lower amplitude of the ground level of the array antenna, which leads to an increase in the field of collation in the vicinity of the patch (patch) and thus an increase in the radiant force, which leads to an increase in gain and directivity, while a higher value for the insulating substrate insulation constant means a higher amplitude of the ground plane of the array antenna, which leads to the storage of more energy in the ground level and less energy radiation, which leads to a decrease in gain and directionality, and the best directional value when the insulating materials used in this result is (Polycarbonate) with an insulation constant of 2.9, which is the least insulation constant between the materials used, and Figure 27. The comparison of directivity values is shown with different insulating materials.

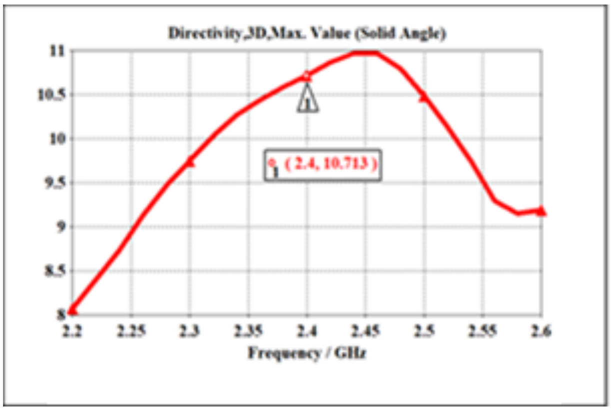


Figure 26. Shows directivity as a function of frequency when using polycarbonate

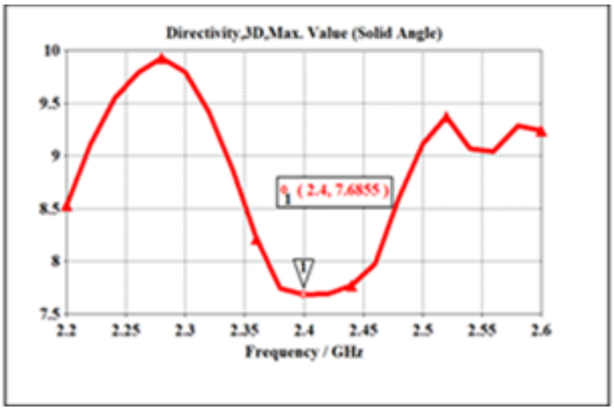


Figure 26. Shows directivity as a function of frequency when using Porcelain

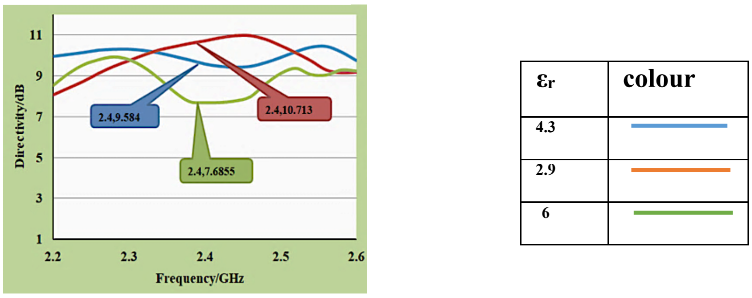


Figure 27. The comparison of directivity vs frequency with different insulating materials are used.

3.6. Radiation pattern results

3.6.1. Radiation Pattern When Using FR-4

Fig 28 shows. The radiation pattern when using FR-4 material with a dielectric constant of 4.3, as the X-Y plane represents a horizontal plane, the electric plane represents E-Plane at the angle Phi = 0^0, the X-Z plane represents a vertical plane and the magnetic plane represents H-Plane at the angle Phi = 90^0, as it was found that the angular width is equal to 72.7 edges at Phi = 90^0 and 49.8 edges at Phi =0^0

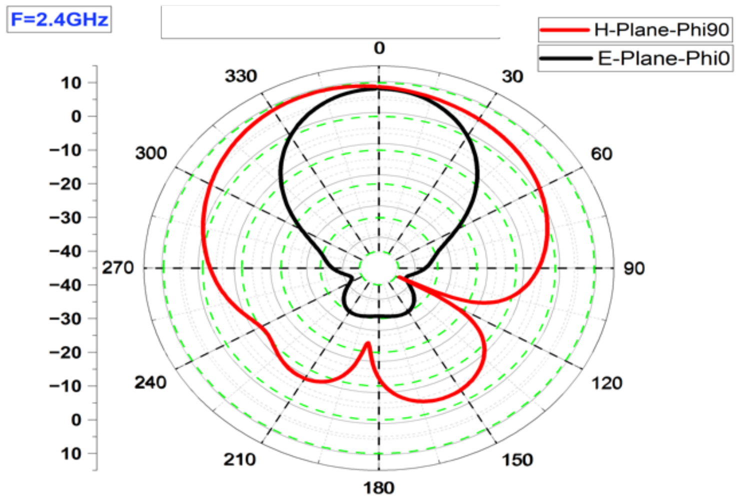


Figure 28. The radiation patterns (E-Plane and H-Plane) utilize the FR-4 substrate.

3.6.2. Radiation Pattern When Using Polycarbonate

By reducing the insulation constant and taking the insulating material Polycarbonate with an insulation constant of 2.9 and from Fig 29. It was found that the angular width has a value equal to 53.8 edges at Phi = 90^0 at the frequency 2.4 GHz, as we note that this value decreased from what is in the insulating material (FR-4), while the value of the angular width at Phi = 0^0 is equal to 47.5 edges at the frequency 2.4 GHz, as it turns out that this value also decreased from what it was previously.

3.6.3. Radiation Pattern When Using Porcelain

When increasing the insulation constant and taking the insulating material Porcelain with an insulation constant of 6 and from Fig 30. It was found that the angular width has a value equal to 120.1 edge at Phi = 90^0 at the frequency 2.4 GHz, as we note that this value increased from what is in the insulating material (FR-4), while the value of the angular width at Phi = 0^0 is equal to 59.2 edge at the frequency 2.4 GHz, as it turns out that this value also increased from what it was previously.

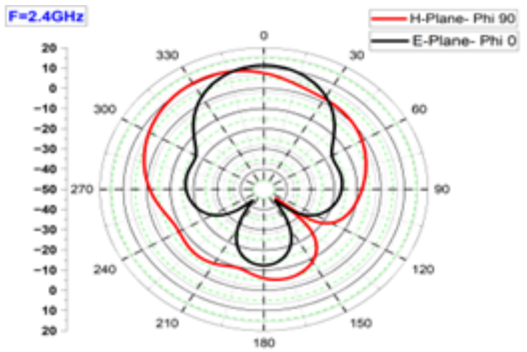


Figure 29. The radiation patterns (E-Plane and H-Plane) using polycarbonate substrate.

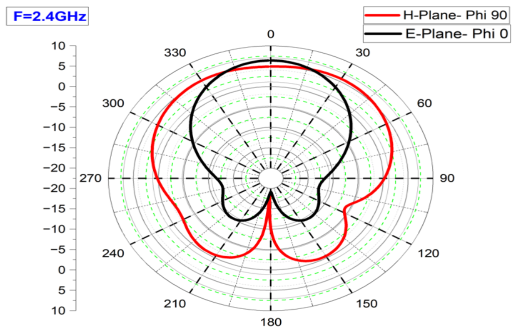


Figure 30. The radiation patterns (E-Plane and H-Plane) using Porcelain substrate

It is clear from the above results that the effect of the dielectric substrate dielectric constant on the radiation pattern of the array is a directly proportional effect, i.e. the lower the dielectric constant, the lower the value of the angular width of the electric and magnetic fields, and this means that we obtain an array with high orientation and high gain. The greater the dielectric constant, the greater the angular width, and the multiradiation array becomes and radiates in all directions. The best radiation pattern was when using the insulating material (Polycarbonate) with a dielectric constant of 2.9, where the value of the angular width of the electric and magnetic fields decreased, which means high directivity of the array and no radiation in all directions and at the same time high gain. This is what we want to obtain, which is high guidance to use in applications that require such guidance, especially as we are in the era of development and technology, as well as fifth-generation applications that need high guidance.

4. Practical Validation Results

The 2X2 array was manufactured on the insulating substrate (FR-4) only and other insulating materials were not manufactured due to the availability of this material in the local market. The return loss was measured in the laboratory of the Faculty of Electronics Engineering, Department of Communications at the University of Nineveh by VNA (Vector Network Analyzer), and found an acceptable agreement between the practical and theoretical results as shown in Fig 33.

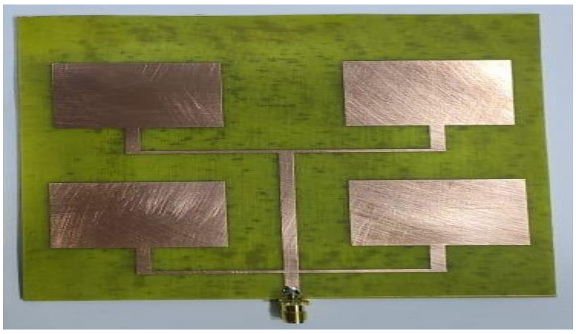


Figure 31. 2x2 printed array antenna.

Figure 32 shows VNA device shows the return loss value of the 2X2 microstrip patch antenna array

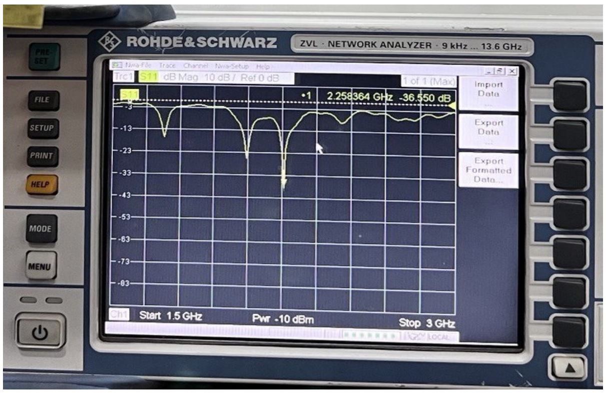


Figure 32. The practical value of the return loss of the array

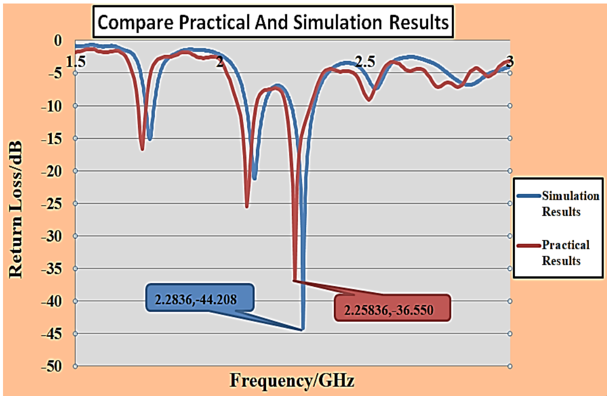


Figure 33. Practical value and simulation value for return loss.

Figure 32 shows VNA device shows the return loss value of the 2X2 microstrip patch antenna array

It is illustrated in Fig 33. There is an acceptable compatibility between the simulation value and the practical value and there is a difference in the two values due to several reasons, the most important of which is that the measurements were not made in an echoless laboratory and that some of these frequencies are present in the laboratory atmosphere due to the presence of different wireless communication networks and therefore these frequencies are subject to constructive and destructive interference. In addition to the simple manufacturing technique, which contains an error rate such as an increase or decrease in the dimensions of the patch, ground level, or insulation.

5. Conclusion

Through the results that have been mentioned above in this research, we have reached many conclusions related to the study of the effect of the substrate isolation constant on the microstrip patch antenna array 2x2, which is the basis of our work, including that the effect of the insulating substrate isolation constant on the return loss for the 2x2 array is directly proportional, while the effect of the insulation constant on the frequency beam width for the 2x2 array is an effect according to the dielectric loss, that is, whenever the insulator loss of the insulating material is large. The lower the quality factor and therefore the greater the package width because the quality factor and the width of the package are an inversely proportional relationship. While the substrate isolation constant affected the current distribution relative to the array with a direct effect. We also concluded that the gain of the array increases by reducing the insulating substrate isolation constant, because the low value of the insulation constant means a lower amplitude of the ground plane of the array antenna, which leads to an increase in the field in the perimeter of the patches of the array and thus increase the gain. The array radiation pattern was also better when we used a low dielectric constant because we obtained high directivity, unlike when we used a high-value dielectric constant. We also found that the lower the dielectric constant, the gain and directivity value increases, and the standing wave voltage ratio approaches the correct one. One of the results shown for the designs is that the 2X2 microchip antenna array is suitable for WLAN applications. In conclusion, the performance of the proposed antenna is dependent on the substrate material. However, return loss worsens as the dielectric constant increases and bandwidth improves. Because of narrow radiation patterns, lowering dielectric constants increases gain and directivity. Polycarbonate is best for high-gain applications (satellite communication). With its wide bandwidth, FR-4 is suitable for broadband and radar systems. For some IoT and sensor applications, Porcelain offers gain, bandwidth, and directivity balance not afforded by traditional ceramic or plastic materials. Material selection is important for RF system performance optimization.

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