

DESIGN AND FABRICATION OF A 4×1 PATCH ANTENNA ARRAY AT 2.4 GHZ AND STUDY OF THE EFFECT OF SUBSTRATE THICKNESS ON SOME OF ITS RADIATION PROPERTIES

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Abstract:

This paper presents the design and manufacture of a 1×4 microstrip patch antenna array designed for WLAN applications (2.4 GHz) and the effect of substrate thickness on bandwidth and some radiation characteristics is investigated. An FR4 substrate with a dielectric constant of 4.3 is used. Three different values of substrate thickness are considered: 1.2 mm, 1.6 mm, and 2 mm. The design and simulation of the results were performed using the CST 2019 simulation program. The results showed that at a thickness of 1.2 mm, the bandwidth was 0.06881GHz, the return loss was -42.058 dB, the VSWR was 1.0159, the gain was 6.5977 dB, and the directivity was 11.141 dB. At a thickness of 1.6 mm, the bandwidth was 0.09767 GHz, the return loss was -37.293 dB, the VSWR was 1.0277, the gain was 7.2912 dB, and the directivity was 11.13 dB. At a thickness of 2 mm, the bandwidth was 0.1260GHz, the return loss was -25.476 dB, the VSWR was 1.1125, the gain was 7.6222 dB, and the directivity was 11.11 dB. These results show that the substrate thickness is directly proportional to the bandwidth and some other characteristics, i.e., the bandwidth increases as the thickness increases in the proposed model. On the other hand, the thickness is inversely proportional to the directivity, i.e., the directivity decreases as the thickness increases.

Keywords: Microstrip antenna, Arrays, CST, 1 × 4 array, Bandwidth, Thickness, Gain, FR-4.

Introduction

Introduction

A microstrip patch antenna is often described as one of the most exciting developments in the history of antennas and the electromagnetic field, the microstrip patch antenna has grown to become probably the most versatile solution for many systems requiring a radiation element. The thin chip

antenna is an excellent common element in communication and radar applications because it offers a variety of designs that can be fed in many different ways [1]. moreover, a range of these antennas can be easily integrated to form linear or planar arrays and can be designed to operate on a wide range of frequencies and generate different types of polarizations [2]. The reason for the increased use of antennas in a wide range of government and commercial applications is due to their advantages including small size and weight, the ability to adhere to flat and uneven surfaces, low manufacturing cost, and durability [3]. Because microstrip patch antenna have a narrow bandwidth, bandwidth optimization is a prerequisite for practical applications, especially in current mobile communication systems [4], the researchers examined multiple ways to increase the bandwidth of microstrip patch antenna, including modifying the center and type of feeder elements, introducing holes and cracks to the radiation patch and increasing the thickness of the buffer substrate [5]. Some researchers have also made new designs, namely the arrangement of antennas in a geometric way called array or miniature antenna arrays (MSAs) to increase frequency bandwidth and antenna gain [6]. An array antenna is a set of individual antennas arranged in a particular geometric pattern as shown in **Figure 1**. Each antenna in the array is called an array element. Array elements can be of any type of antenna, such as unipolar, bipolar, or thin bracket antennas, the main purpose of designing and manufacturing the array antenna is to improve its technical characteristics. The design of the matrix can increase gain, increase directionality, and improve the distribution of surface currents. These improvements cannot be achieved in a single antenna. Changing the thickness of the dielectric Substrate or its type in a microstrip antenna array changes the performance of the system. Therefore, it is important to know the effect of changing the dielectric Substrate material and the thickness of the substrate on the performance of the microstrip antenna array [7].

In this paper, we will work to change the thickness of the insulating substrate and know its effect on the performance of the microstrip antenna array.

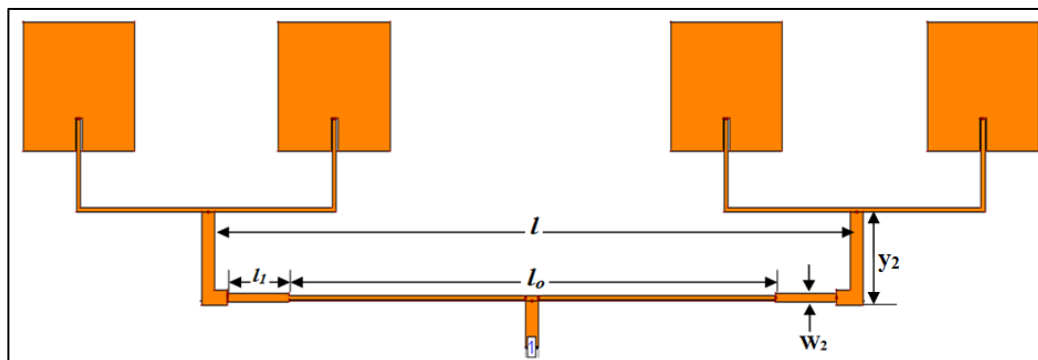


Figure 1. Antenna Array [8].

Proposed Antenna Array Design

The microstrip antenna array (4×1) **Figure 2**. is designed. Using the CST 2019 simulation program, and because the microstrip patch antenna consists of three basic layers, namely the patch (which is made of conductive material), the insulating material, and the ground level, so epoxy FR-4 was used as an insulating material with an insulation constant of 4.3 and copper was used as a conductive material for the radioactive patch and ground level, it was designed with a working frequency of 2.4 GHz. The elements of the microstrip antenna are connected by a strip feed line so that the distance between its elements is less than half the wavelength to avoid coupling between its elements.

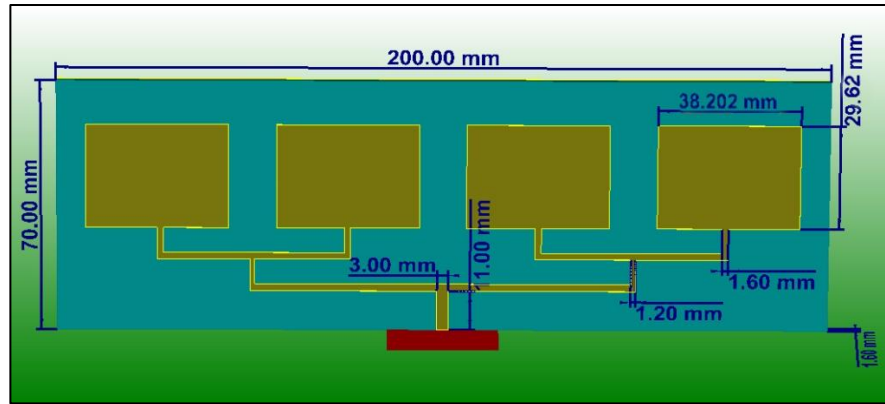


Figure 2. Proposed microstrip antenna array (4×1) .

The parameters of the proposed model are shown in **Table 1**.

Table 1. Proposed antenna array parameters.

Parameter	description	Value
Ws	width of substrate	200 (mm)
Ls	length of substrate	70 (mm)
Wp	width of patch	38.202 (mm)
Lp	length of patch	29.627 (mm)
Wf	width of feedline	3 (mm)
Lf	Length of transmission line	(mm) 11
S	Strip feed line width	2 (mm)
r	Feed line display for the first branch in array antenna	1.5 (mm)
n	Feed line display for array antenna elements	(mm) 1.6
ϵ_r	Dielectric constant	4.3
t	Thickness of the patch	0.035 (mm)
h	Substrate thickness	1.6 (mm)
f	Resonant frequency	2.412 (GHz)

Where the dimensions were calculated according to mathematical equations as follows:

➤ Calculation of the width of the radioactive patch (W_p):

The width of the radioactive patch was calculated at a frequency of 2.4 GHz by applying the mathematical relationship below [9].

$$W_p = \frac{c}{f_r} \sqrt{\frac{2}{\epsilon_{r+1}}} \quad (1)$$

W_p : The width of the patch.

C: The speed of light in the vacuum and equal to (3×10^8 m/s).

f_r : The working frequency of the antenna.

ϵ_r : The dielectric constant of the substrate.

➤ Calculation of the effective dielectric constant of the thin slice antenna array (ϵ_{eff}):

The effective dielectric constant was also calculated by applying the following mathematical relationship [2]:

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12 \frac{h}{Wp}}} \quad (2)$$

ϵ_{eff} : The effective relative insulation constant of the substrate.

h : The thickness of the insulating material.

Wp : width of patch.

➤ Effective Patch Length Calculation (L_{eff}):

The effective length of the patch is calculated by applying the following mathematical relationship [10]:

$$L_{eff} = \frac{c}{2f_r \sqrt{\epsilon_{eff}}} \quad (3)$$

L_{eff} : The length of the effective Patch.

f_r : Resonant frequency.

➤ calculate the difference between the physical length and the electrical length of a patch (ΔL):

This difference between the physical and electrical lengths was calculated by applying the relationship below [11]:

$$\Delta L = 0.412 h \left[\frac{(\epsilon_{eff} + 0.3) \left(\frac{Wp}{h} + 0.264 \right)}{(\epsilon_{eff} - 0.258) \left(\frac{Wp}{h} + 0.8 \right)} \right] \quad (4)$$

➤ calculate the length of the radioactive patch (L_p):

The length of the radioactive patch is calculated by applying the relationship below [12]:

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

Results And Discussion

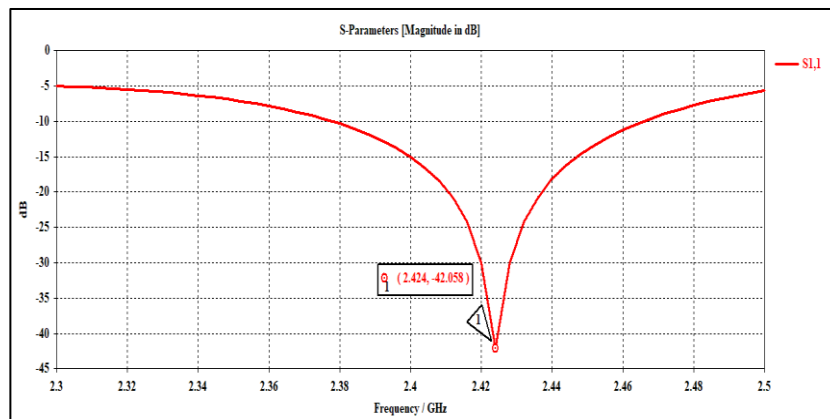
In this part of the paper, we will review the results of the simulation of some radioactive properties of the proposed microstrip antenna array and indicate the effect of the thickness of the insulating material by changing it for several values, as follows:

1. Return Loss

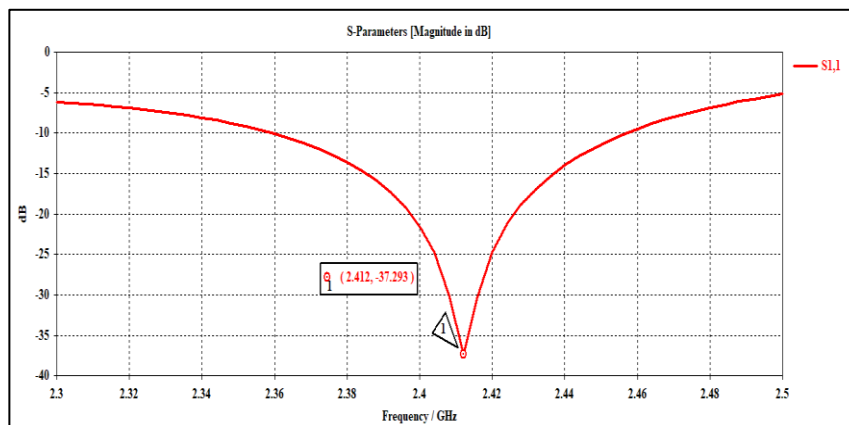
The return loss (RL) or the so-called power reflection coefficient (at the antenna entrance) S_{11} , is the amount of power lost as a result of the incompatibility between the antenna impedance and the transmission line, which is a negative value and is measured in (dB), and to obtain an antenna with the best performance, the return loss value should not exceed (-10 dB) and is expressed according to the following relationship [11] :

$$RL \text{ (dB)} = 10 \log \frac{P_{ref}}{P_{in}} \quad (6)$$

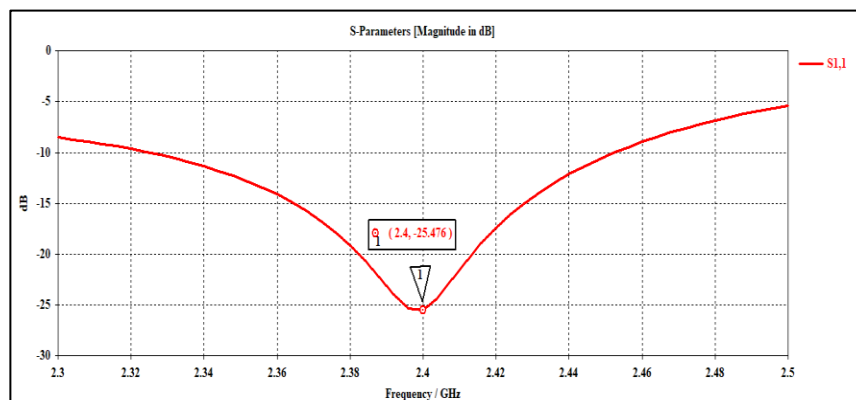
The return loss at the thickness of 1.6mm and the frequency of 2.412 GHz is equal to (-37.293 dB), and when the thickness of the insulator is reduced to 1.2mm and at the frequency of 2.424GHz, the return loss decreases to (-42.058 dB), while when the thickness of the insulator is increased to 2mm at the frequency of 2.4GHz, the return loss increases to (-25.476 dB), **Figure 3. a, b, c.**



(a)



(b)



(c)

Figure 3. Return loss as a function of frequency **(a)** at thickness 1.2mm **(b)** at thickness 1.6mm **(c)** at thickness 2mm.

This shows that the return loss is directly proportional to the thickness of the insulator, i.e. the greater the thickness, the greater the return loss, and vice versa. **Figure 4.** Comparison of return loss in the three stages.

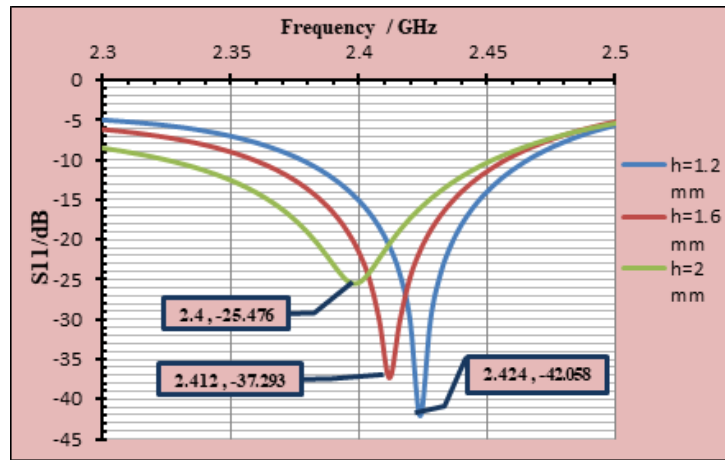


Figure 4. Return loss as frequency function at three different values to thicken the insulating substrate.

2. Bandwidth

Bandwidth (BW) is the frequency range in which the antenna characteristics (gain, direction, efficiency... etc) are within an acceptable range, and the higher the value the better the performance of the antenna [13]. The simulation results showed the width of the beam at the thickness of 1.6mm and the frequency of 2.412 GHz is equal to (0.09767GHz) and when reducing the thickness of the insulator to 1.2mm and at the frequency of 2.424GHz, the width of the beam became a value of (0.068816 GHz) and when the thickness of the insulator increased to 2 mm at the frequency of 2.4GHz it is a value of (0.126 GHz), and from these results it is clear to us that the thickness is directly proportional to the bandwidth, that is, the greater the thickness, the greater the bandwidth and vice versa in the proposed microstrip antenna array, **Figure 5.** Shows the bandwidth of the three thickness values.

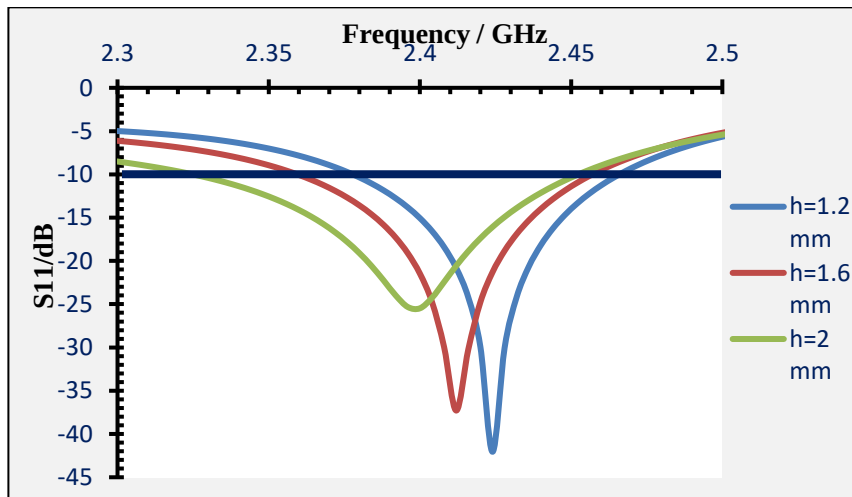
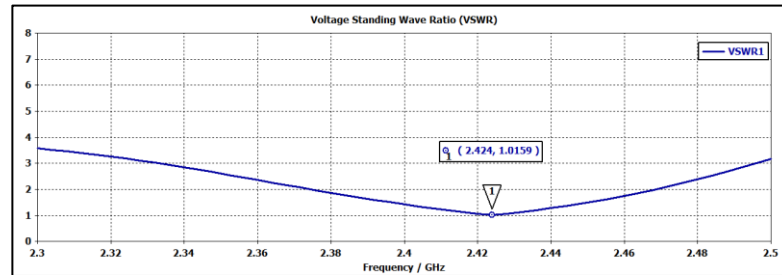


Figure 5. The bandwidth of the three thickness values.

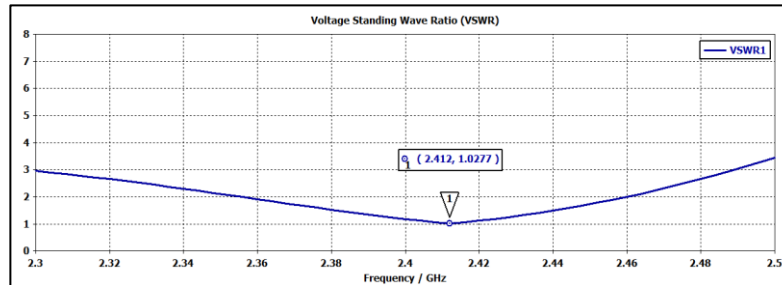
3. Standing Wave Voltage Ratio

It is the ratio of the maximum voltage in the voltage transmission line to the minimum of it, it can be easily measured in many scientific situations, and when the value of (VSWR) is equal to 1, it means that the entire energy is transferred to the antenna, and for the antenna to work well and acceptably, the value of (VSWR) must be ≤ 2 approaching the right one [14]. The results of the simulation of the standing wave voltage ratio at the thickness of the insulator were 1.6mm and the frequency of 2.412 GHz is equal to (1.0277), and when the thickness of the insulator is reduced to 1.2mm, and at the frequency 2.424 GHz, it became (VSWR) with a value of (1.0159), and when the

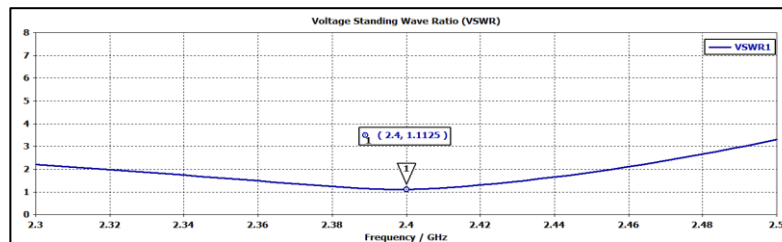
thickness of the insulator is increased to 2mm at the frequency 2.4 GHz, it is (VSWR) with a value of (1.1125), **Figure 6.** Shows VSWR values as a function of frequency.



(a)



(b)

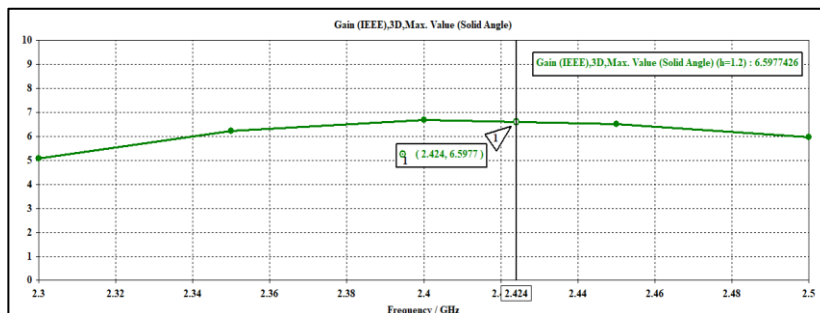


(c)

Figure 6. Voltage standing wave ratio as a function of frequency (a) at a thickness of 1.2mm (b) at a thickness of 1.6mm (c) at a thickness of 2mm.

4. Gain

Antenna gain is expressed as a measure of the antenna's ability to convert the input power into radiation in a certain direction, and the larger it is, the better the antenna will perform [15]. The results of the simulation of the gain at the thickness of the insulator were 1.6mm and the frequency of 2.412 GHz is equal to (7.2912 dB) and when reducing the thickness of the insulator to 1.2mm and at the frequency of 2.424 GHz the gain became a value of (6.5977 dB) and when the thickness of the insulator is increased to 2mm at the frequency 2.4 GHz the gain is worth (7.6222 dB), from these results it turns out that the gain is also directly proportional to the thickness of the insulating material, that is, the greater the thickness, the greater the gain and vice versa, as shown in **Figure7.**



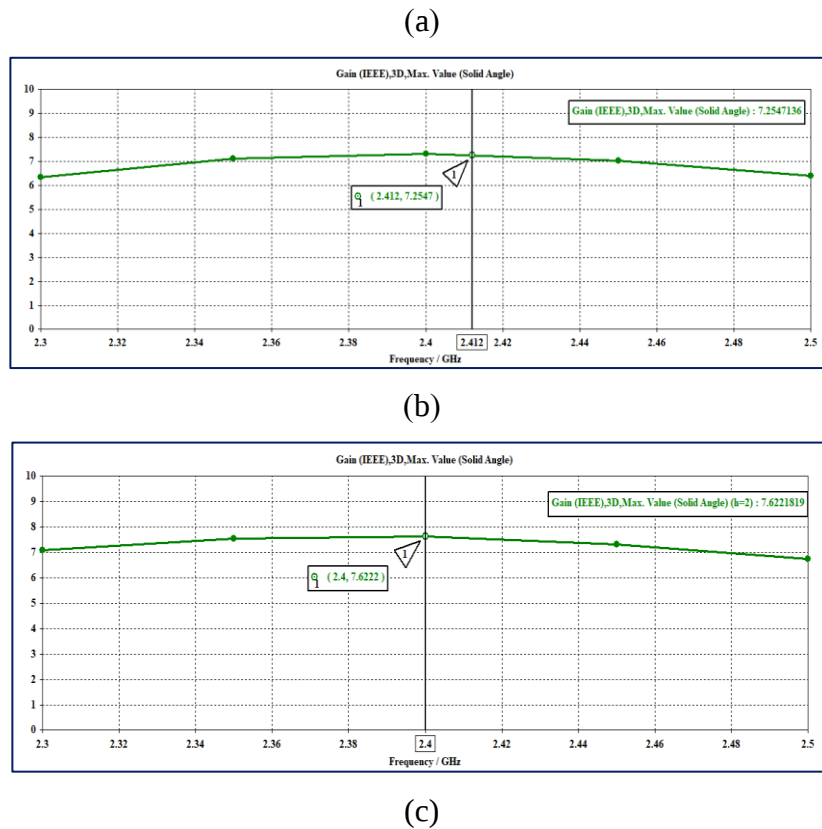
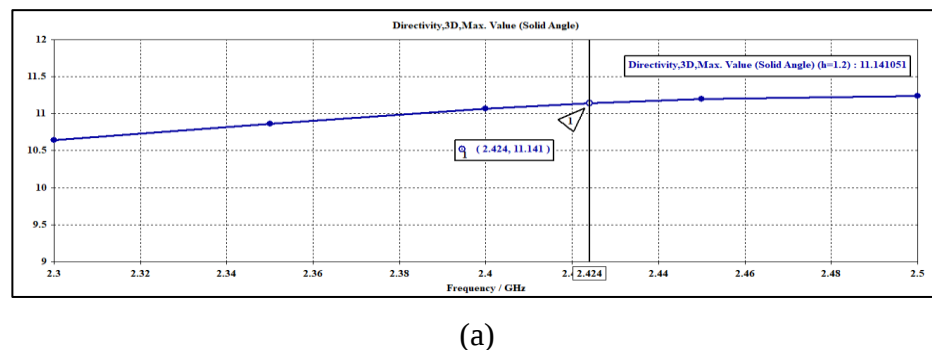
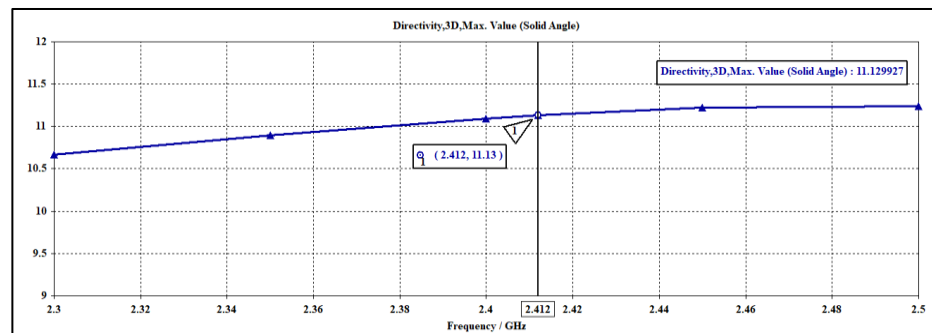


Figure 7. Gain as a function of frequency **(a)** at thickness 1.2mm **(b)** at thickness 1.6mm **(c)** at thickness 2mm.

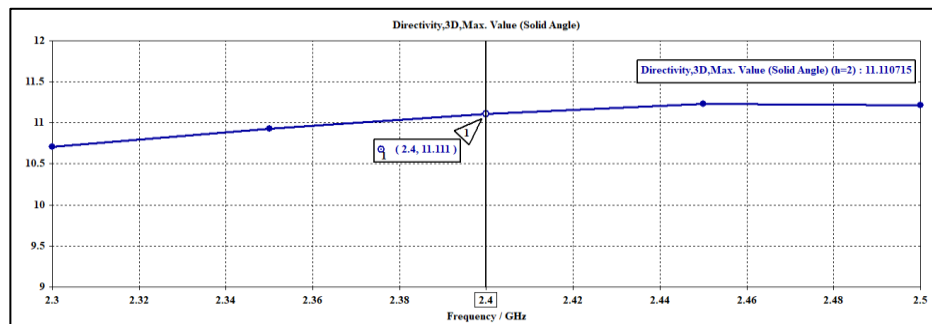
5. Directivity

Antenna orientation is defined as the ratio of radiation intensity in a given direction to the rate of radiation intensity in other directions [16], The results of the simulation of the direction at the thickness of the insulator were 1.6mm and the frequency of 2.412GHz is equal to (11.13 dB) and when reducing the thickness of the insulator to 1.2mm and at the frequency 2.424 GHz, the direction became a value of (11.141 dB) and when the thickness of the insulator is increased to 2mm at the frequency 2.4 GHz the direction is with a value of (11.111 dB), from these results it becomes clear to us that the direction is inversely proportional to the thickness of the insulating material, that is, the greater the thickness, the lower the directional and vice versa, **Figure 8.**





(b)



(c)

Figure 7. Directionality as a function of frequency **(a)** at thickness 1.2mm **(b)** at thickness 1.6mm **(c)** at thickness 2mm.

6. Efficiency

Antenna efficiency is defined as a measure of the antenna's ability to transmit incoming energy, in other words, it can be said as "the ratio between radiated energy to energy received in the antenna"[17], as it can be calculated by applying the relationship below [18].

$$(7)\eta = \frac{G}{D} \times 100\%$$

η :Antenna efficiency.

G :Gain.

D :Directivity.

From the values of gain and direction above, it turns out that the efficiency when the thickness of the insulator is 1.6mm and a frequency of 2.412 GHz is equal to 65.5 %, and when the thickness of the insulator is reduced to 1.2mm, and at the frequency 2.424 GHz, the efficiency becomes 59.21 %, and when the thickness of the insulator is increased to 2mm at the frequency 2.4 GHz, the efficiency is worth 68.6 %, and from this, it is clear to us that the greater the thickness, the better the efficiency of the antenna array.

The Practical Part

Figure 9. shows A model manufactured for the proposed microstrip antenna array (4×1), which was manufactured based on measurements used in the simulation program and with a thickness of 1.6mm available in the local market, and the results were measured practically using the Vector Network Analyzer as in **Figure 10**. At a frequency of (1 GHz – 3 GHz), the measurement results showed that there is convergence in the return loss curves when comparing the practical results and the simulation results as shown in **Fig. 11**. The reason for the complete mismatch in these curves is the different practical measurement conditions and the presence of metals in the laboratory that

affect the accuracy of the device results, while the simulation is carried out under ideal conditions in the CST 2019 program.



Figure 9. Front and rear view of the antenna array (4×1).

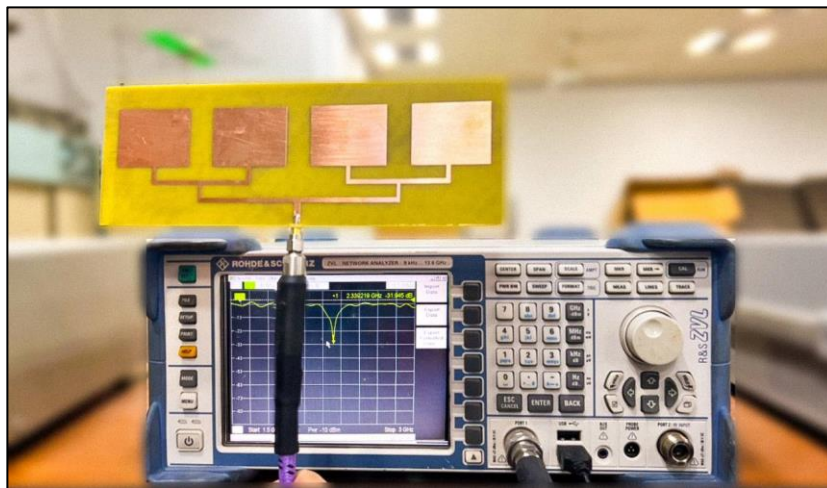


Figure 10. Measure return loss in VNA device.

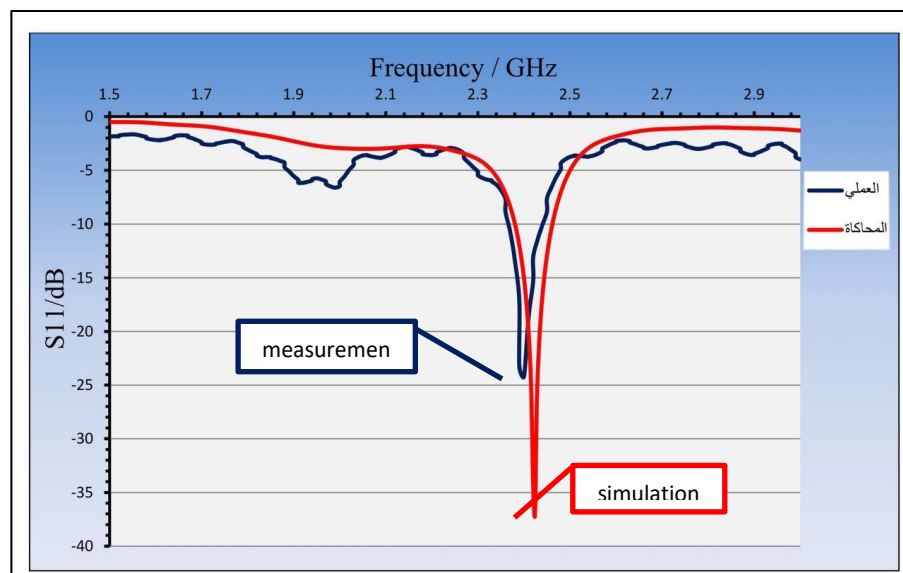


Figure 11. comparing simulation results and measurements at a thickness of 1.6mm.

Conclusion

In this research paper, the effect of insulating material thickness on the performance of the microstrip antenna array was studied, where an antenna array (4×1) was designed using the CST 2019 simulation program, and the dimensions of the antenna matrix were calculated using several mathematical relationships mentioned above, it was designed at a frequency range of 2.4GHz which is suitable for WLAN applications, from the simulation results it was found that the increase in the thickness of the insulating material is directly proportional to the return loss, bandwidth, standing wave voltage ratio, gain and efficiency in While the increase in the thickness of the insulator is inversely proportional to the direction. From these results, it is clear that the increased thickness of the insulator makes the microstrip antenna array perform better in the range of WLAN applications.

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