Bandwidth Improvement for Hexagonal Microstrip Antenna by Adding a Small Slice on One Side of the Hexagonal Shape

Mahmoud M. Aubais[1*], Ali A. Rasheed[2]

Abstract

In this paper, we theoretically designed a hexagonal micostrip antenna with a resonant frequency of (2.4 GHz) using the (finite difference in time-domain) method (FDTD).The main go a was to increase the bandwidth and this was done by changing the shape of the patch by adding a small slice on one of the sides of the hexagonal shape. The letter step was repeated three with three different types of insulators for three types of insulator. The issue of increasing the bandwidth was solved theoretically using the method of finite difference in time domain (FDTD), in which we used the program (CST Studio Suite 2018) to design the antenna and calculated the results.
Will be used we obtained positive and good results to improve the bandwidth, which reached approximately 5%.

Key Words: Bandwidth Improvement, Hexagonal Microstrip Antenna, FDTD Method.

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Introduction

Due to ongoing increase in the use of means of communication and information transmission, the need to improve the techniques of systems for sending and receiving electromagnetic signals and addressing them has become an urgent issue. In this regards, one of the important part of any communication system is the antenna [1]. Antenna is defined as a device that converts electrical signals in communication devices into electromagnetic waves and transmits them intoouter space, but in the case of reception, their work is opposite [2]. There are many types of antennas, but in the recent period, the interest in microstrip antennas has increased because of their advantages, including the cheapness of manufacturing costs, lightness of weight [3], ease of manufacture, and having a flat shape, and they can be easily installed on the surfaces of objects and other positive characteristics. However, this type of antenna has disadvantage of having a narrow range onbandwidth [4], and this is one of the problems or defects in this type of antenna. The bandwidth (BW) ranges between (1-2)% [5]. Many researches have been carried out to improve the beam width, and one of these attempts is to increase the thickness of the substratematerial[6] and reduce the dielectric constant [7] or to make additional radioactive elements orby creating cracks in the patch either in the form of a U-shaped [8]or an E [9].

In this research, we used another method, in which is to add a small strip at one of the edges of the hexagonal patch.

Finite Difference in Time Domain

In 1966, Kane Yee presented a numerical method for solving problems with electromagnetic waves and antennas related to Maxwell's curl equations [10].Yee suppose that thespace is anetwork of cells, each cell has dimensions ($\Delta x \Delta y \Delta z$). The components of the electric field $\boldsymbol{E}$ and the magnetic field $\boldsymbol{H}$ are distributed over the (Yee) cell as shown in Figure (1) [11].

Corresponding author: Mahmoud M. Aubais
Address: [1*]Faculty of Science, Physics Department, Kufa University, Iraq; [2]Faculty of Science, Physics Department, Kufa University, Iraq.

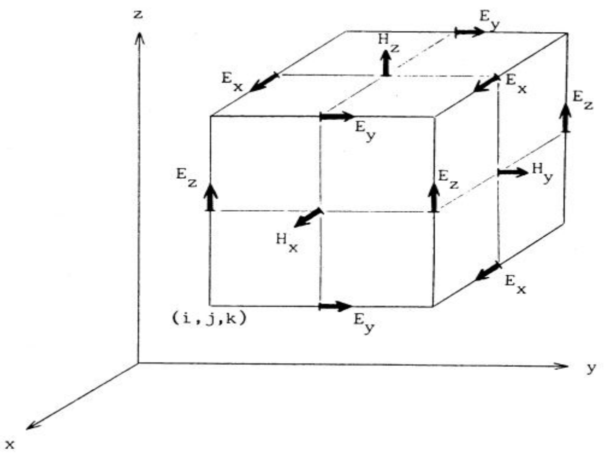

Figure 1. Yee cell in three dimensions Yee cell in three dimensions

Since electromagnetic fields depend on time beside its dependence on the location, one can determine the value of Δt bycourant-factor [12].

$$\Delta t \leq \frac{1}{c\sqrt{\frac{1}{(\Delta x)^2}+\frac{1}{(\Delta y)^2}+\frac{1}{(\Delta z)^2}}} \quad (1)$$

Where$c$is the velocity of light.

If we denote any component of the electric field or magnetic field with the symbol (f), then its value in cell i of any one Yee cells is written as, $f(i\Delta x, j\Delta y, k\Delta z, n\Delta t)$ or$f^n(i,j,k)$, where i, j, k and n are integers.

The derivativescan be calculated numerically by the central difference method [13].Example the derivative in x-direction has a formula as below:

$$\frac{\partial f^n(i,j,k)}{\partial x} = \frac{f^n((i+1/2),j,k) - f^n((i-1/2),j,k)}{\Delta x} \quad (2)$$

Therefore, the Maxwell's curl equation written in Yee cell in central difference method asfollow [12]:

$$H_x^{n+\frac{1}{2}}\left(i,j+\frac{1}{2},k+\frac{1}{2}\right) = \left(\frac{\mu(i,j,k) - \frac{\rho'(i,j,k)\Delta t}{2}}{\mu(i,j,k) + \frac{\rho'(i,j,k)\Delta t}{2}}\right) H_x^{n-\frac{1}{2}}\left(i,j+\frac{1}{2},k+\frac{1}{2}\right) - \frac{\frac{\Delta t}{\Delta y}}{\mu(i,j,k) + \frac{\rho'(i,j,k)\Delta t}{2}}\left(E_z^n\left(i,j,k+\frac{1}{2}\right) - E_z^n\left(i,j-1,k+\frac{1}{2}\right)\right) + \frac{\frac{\Delta t}{\Delta z}}{\mu(i,j,k) + \frac{\rho'(i,j,k)\Delta t}{2}}\left(E_y^n\left(i,j+\frac{1}{2},k\right) - E_y^n\left(i,j+\frac{1}{2},k-1\right)\right) \quad (3)$$

$$H_y^{n+\frac{1}{2}}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right) = \left(\frac{\mu(i,j,k) - \frac{\rho'(i,j,k)\Delta t}{2}}{\mu(i,j,k) + \frac{\rho'(i,j,k)\Delta t}{2}}\right) H_y^{n-\frac{1}{2}}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right) - \frac{\frac{\Delta t}{\Delta z}}{\mu(i,j,k) + \frac{\rho\prime(i,j,k)\Delta t}{2}}\left(E_x^n\left(i+\frac{1}{2},j,k\right) - E_x^n\left(i+\frac{1}{2},j,k-1\right)\right) + \frac{\frac{\Delta t}{\Delta x}}{\mu(i,j,k) + \frac{\rho\prime(i,j,k)\Delta t}{2}}\left(E_z^n\left(i,j,k+\frac{1}{2}\right) - E_z^n\left(i-1,j,k+\frac{1}{2}\right)\right) \quad (4)$$

$$H_z^{n+\frac{1}{2}}\left(i+\frac{1}{2},j+\frac{1}{2},k\right) = \left(\frac{\mu(i,j,k) - \frac{\rho'(i,j,k)\Delta t}{2}}{\mu(i,j,k) + \frac{\rho'(i,j,k)\Delta t}{2}}\right) H_z^{n-\frac{1}{2}}\left(i+\frac{1}{2},j+\frac{1}{2},k\right) - \frac{\frac{\Delta t}{\Delta x}}{\mu(i,j,k) + \frac{\rho\prime(i,j,k)\Delta t}{2}}\left(E_y^n\left(i,j+\frac{1}{2},k\right) - E_x^n\left(i-1,j+\frac{1}{2},k\right)\right) + \frac{\frac{\Delta t}{\Delta y}}{\mu(i,j,k) + \frac{\rho\prime(i,j,k)\Delta t}{2}}\left(E_x^n\left(i+\frac{1}{2},j,k\right) - E_z^n\left(i+\frac{1}{2},j-1,k\right)\right) \quad (5)$$

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$$E_x^{n+1}\left(i+\frac{1}{2},j,k\right) = \left(\frac{\varepsilon(i,j,k)-\frac{\sigma(i,j,k)\Delta t}{2}}{\varepsilon(i,j,k)+\frac{\sigma(i,j,k)\Delta t}{2}}\right)E_x^n\left(i+\frac{1}{2},j,k\right) + \frac{\frac{\Delta t}{\Delta y}}{\varepsilon(i,j,k)+\frac{\sigma(i,j,k)\Delta t}{2}}\left(H_z^{n+\frac{1}{2}}\left(i+\frac{1}{2},j+\frac{1}{2},k\right)-H_z^{n+\frac{1}{2}}\left(i+\frac{1}{2},j-\frac{1}{2},k\right)\right) - \frac{\frac{\Delta t}{\Delta z}}{\varepsilon(i,j,k)+\frac{\sigma(i,j,k)\Delta t}{2}}\left(H_y^{n+\frac{1}{2}}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right)-H_y^{n+\frac{1}{2}}\left(i+\frac{1}{2},j,k-\frac{1}{2}\right)\right) \quad (6)$$

$$E_y^{n+1}\left(i,j+\frac{1}{2},k\right) = \left(\frac{\varepsilon(i,j,k)-\frac{\sigma(i,j,k)\Delta t}{2}}{\varepsilon(i,j,k)+\frac{\sigma(i,j,k)\Delta t}{2}}\right)E_y^n\left(i,j+\frac{1}{2},k\right) + \frac{\frac{\Delta t}{\Delta z}}{\varepsilon(i,j,k)+\frac{\sigma(i,j,k)\Delta t}{2}}\left(H_x^{n+\frac{1}{2}}\left(i,j+\frac{1}{2},k+\frac{1}{2}\right)-H_x^{n+\frac{1}{2}}\left(i,j+\frac{1}{2},k-\frac{1}{2}\right)\right) - \frac{\frac{\Delta t}{\Delta x}}{\varepsilon(i,j,k)+\frac{\sigma(i,j,k)\Delta t}{2}}\left(H_z^{n+\frac{1}{2}}\left(i+\frac{1}{2},j+\frac{1}{2},k\right)-H_z^{n+\frac{1}{2}}\left(i-\frac{1}{2},j+\frac{1}{2},k\right)\right) \quad (7)$$

$$E_z^{n+1}\left(i,j,k+\frac{1}{2}\right) = \left(\frac{\varepsilon(i,j,k)-\frac{\sigma(i,j,k)\Delta t}{2}}{\varepsilon(i,j,k)+\frac{\sigma(i,j,k)\Delta t}{2}}\right)E_z^n\left(i,j,k+\frac{1}{2}\right) + \frac{\frac{\Delta t}{\Delta x}}{\varepsilon(i,j,k)+\frac{\sigma(i,j,k)\Delta t}{2}}\left(H_y^{n+\frac{1}{2}}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right)-H_x^{n+\frac{1}{2}}\left(i-\frac{1}{2},j,k+\frac{1}{2}\right)\right) - \frac{\frac{\Delta t}{\Delta y}}{\varepsilon(i,j,k)+\frac{\sigma(i,j,k)\Delta t}{2}}\left(H_x^{n+\frac{1}{2}}\left(i,j+\frac{1}{2},k+\frac{1}{2}\right)-H_x^{n+\frac{1}{2}}\left(i,j-\frac{1}{2},k-\frac{1}{2}\right)\right) \quad (8)$$

where $\mu(i,j,k)$ is the magnetic permeability, $\varepsilon(i,j,k)$ is the electrical permittivity, $\rho'(i,j,k)$ is the magnetic conductivityand $\sigma(i,j,k)$ is the electrical conductivity of the cell material (i,j,k)

Results Discussion

The microstrip antenna which was studied in this work of a hexagonal shape microstrip antenna with a side length (a=25mm) and a thickness of both the patch and the base is (t=0.04mm) of copper material. The thickness of the dielectric of substrateh=1.6 mm, the dielectric constant $\varepsilon_r = 2.33$ and the dimensions of the base are 70×70 mm^2 and the coaxial feed location((7,0)m from the center of the patch as shown in Figure (2).

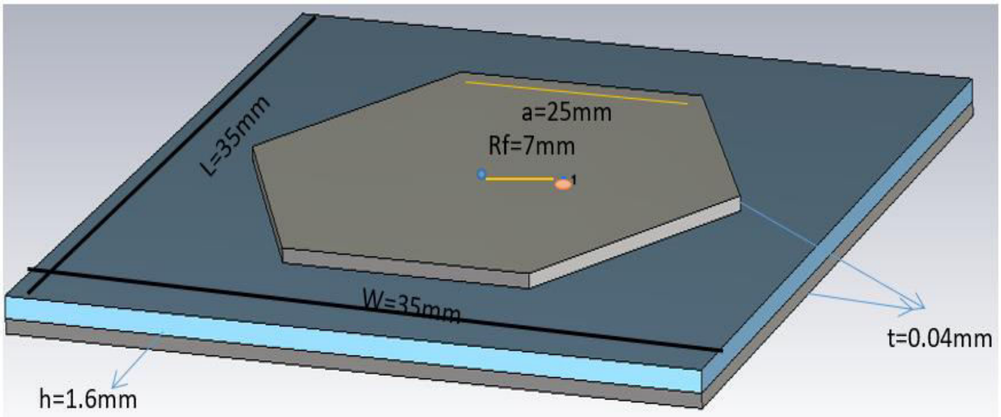

Figure 2. Hexagonal microstrip antenna

Figure (3) Shows the change of impedance ($Z_0 = R + iX$) against frequency, where the resistance and reactance changed with respect to the frequency (the resonant frequency was calculated when the reactance is equal to zero).

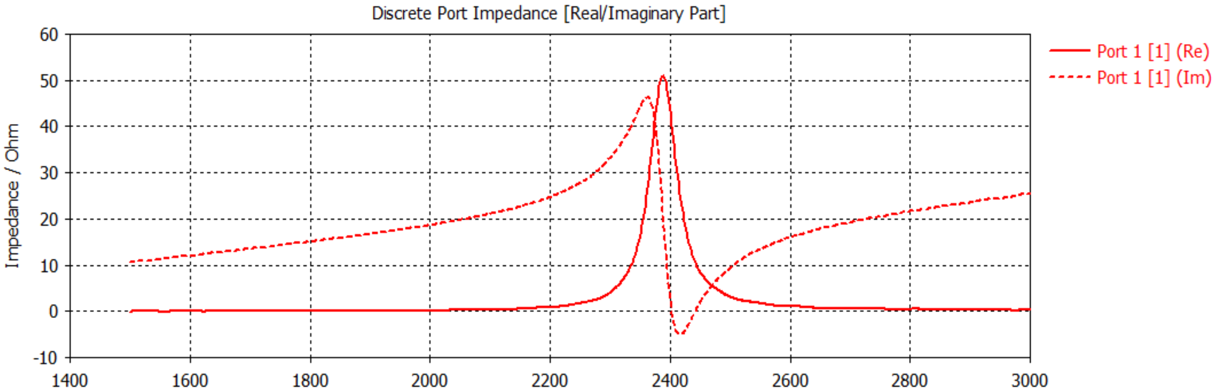

Figure 3. Impedance against frequency (in MHz) calculated by finite difference in time domain

The bandwidth can be determined from the diagram between the return loss factor S_{11} against the frequency, and the values of the frequency chosen when the return loss factor $S_{11}$is less than or equal to (-10db). Figure (4) shown the change of the return loss factor against the frequency. The bandwidth wascalculated using equation below [14].

$$BW = \frac{2(f_u - f_l)}{f_u + f_l} \quad (9)$$

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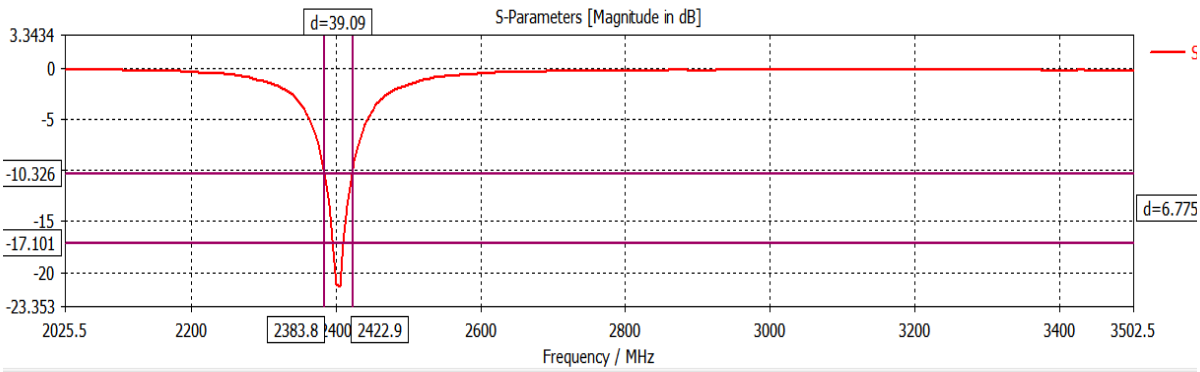
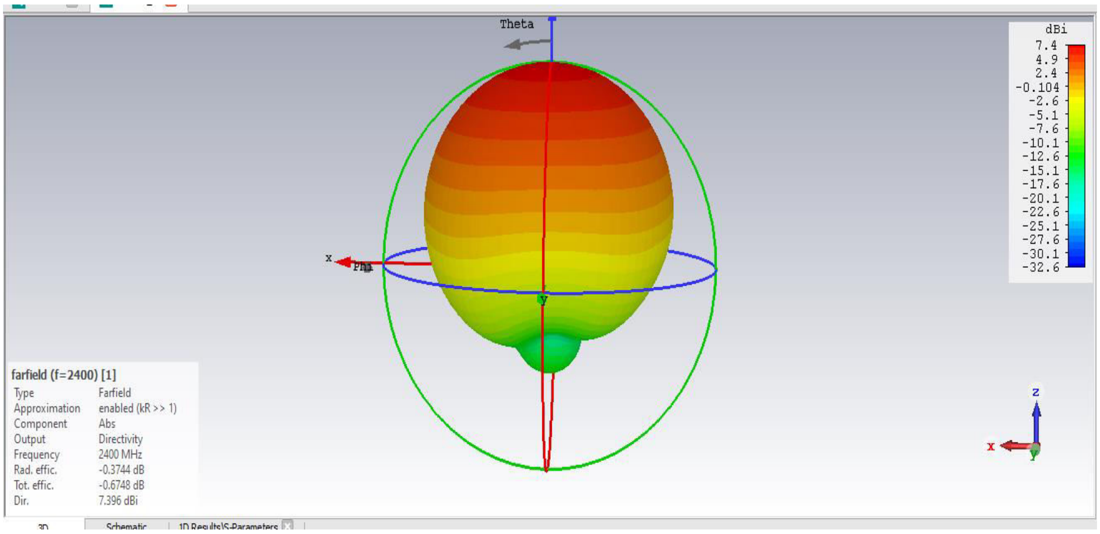


Figure 4. Return loss S_{11}against frequency for hexagonal micostrip antenna "$a = 25\ mm, h = 1.6\ mm, \varepsilon_r = 2.33, r_f = 5\ mm$".



Radiation pattern for hexagonal micostrip antenna "$a = 25\ mm, h = 1.6\ mm, \varepsilon_r = 2.33, r_f = 5\ mm$".

Figure 5. Shows the radiation pattern where we found the directivity is (7.4 dB)

When we put a small slice with dimensions of($2 \times 16\ mm^2$) on oneside of the hexagonal shape, a small change occurred in the shape of the patch as shown in Figure 6, this change led to a new shape of the resonant region of the hexagonal microstrip antenna, so we obtained the best results when we put the coaxial feed at the point ((13,0) mm) from the center of patch as shown in Figure 7. Figure8 showsthe radiation pattern for the new design.

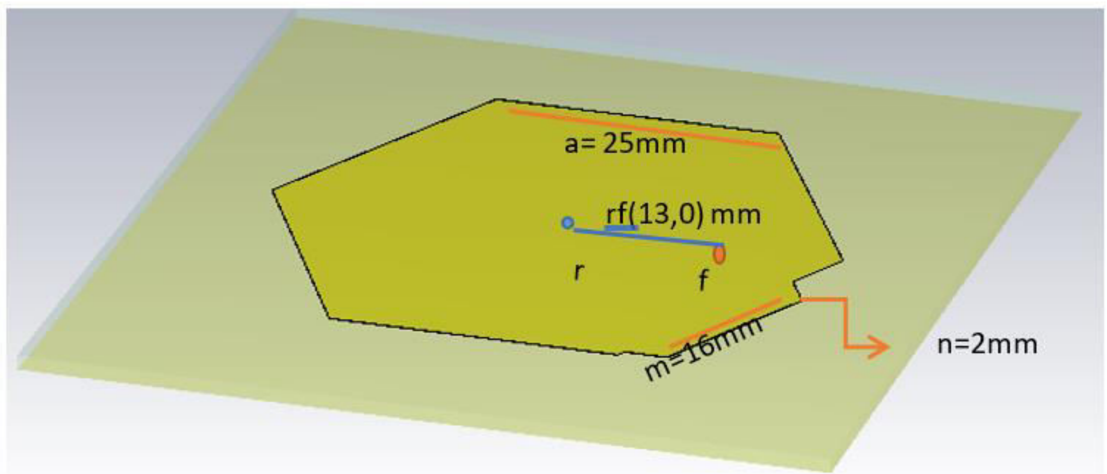


Figure 6. The modified patch of hexagonal micostrip antenna

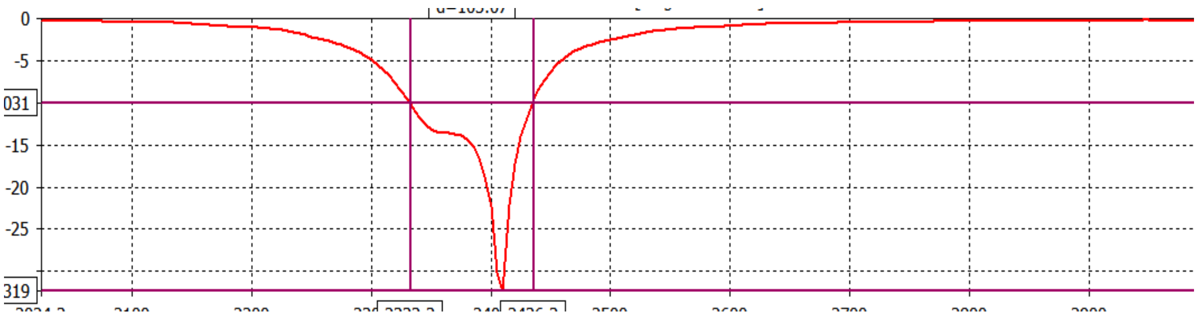


Figure 7. Return loss againstS_{11} frequency for the modified hexagonal micostrip antenna$a = 25\ mm, h = 1.6\ mm, \varepsilon_r = 2.33, r_f = 13mm$"

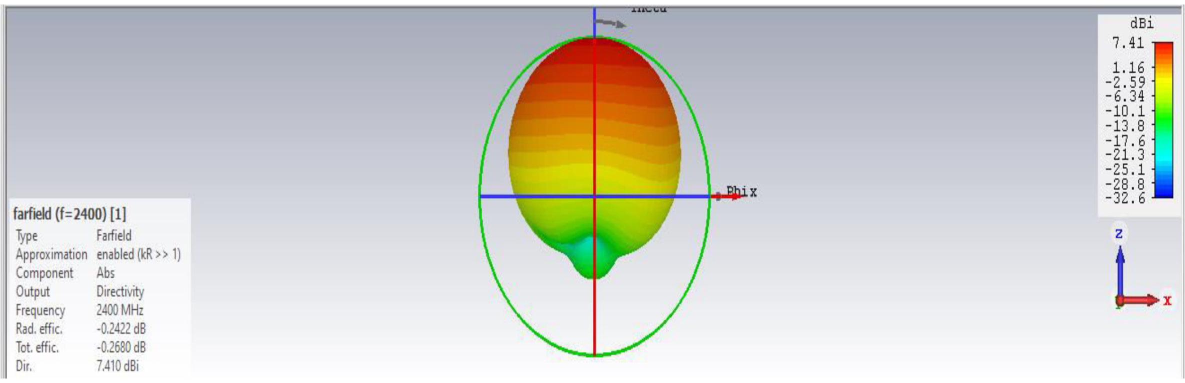


Figure 8. Radiation pattern for the modified hexagonal micostrip antenna $a = 25\ mm, h = 1.6\ mm, \varepsilon_r = 2.33, r_f = 13mm$"

When we increase the thickness of the substrate up to h = 3.2 mm, the bandwidth increases to 5.6% as shown in Figure (9).Figure 10 shows the radiation pattern for the modified hexagonal micostrip antenna.

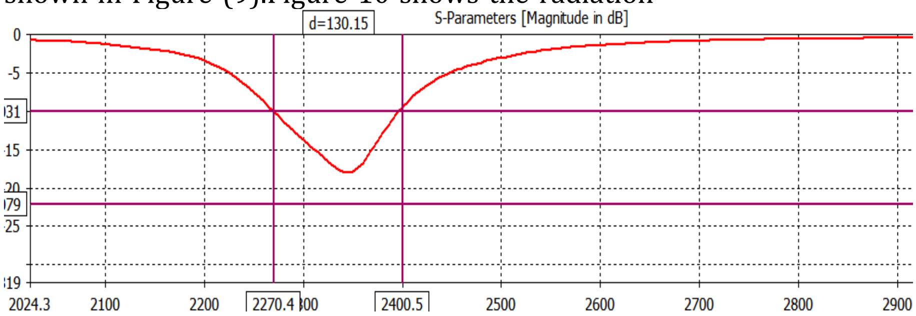


Figure 9. Return loss S_{11} against frequency for the modified hexagonal micostrip antenna $a = 25\ mm, h = 3.2\ mm, \varepsilon_r = 2.33, r_f = 13mm$"

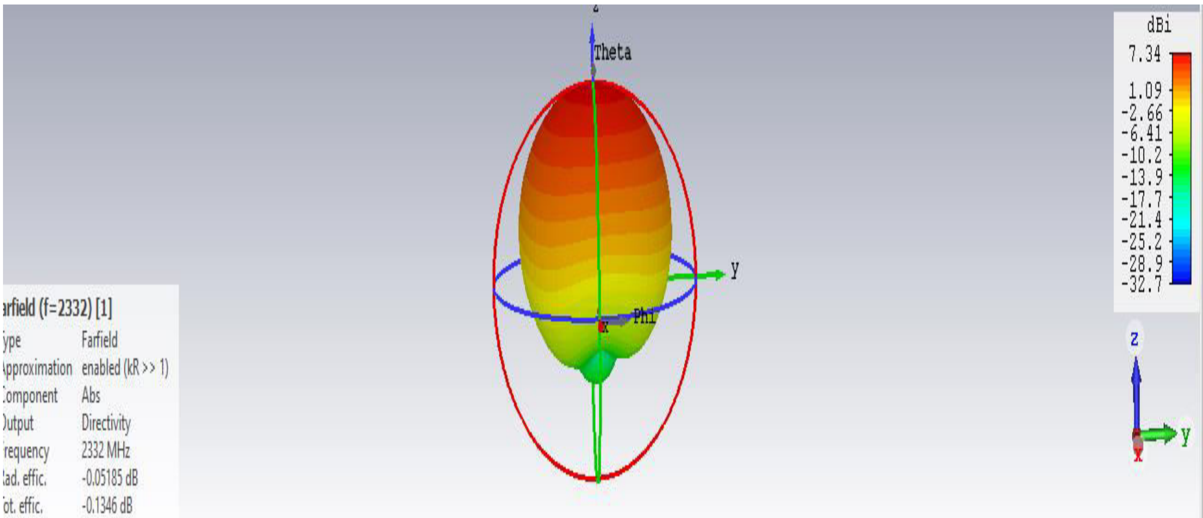


Figure 10. Radiation pattern for the modified hexagonal micostrip antenna $a = 25\ mm, h = 3.2\ mm, \varepsilon_r = 2.33, r_f = 13mm$"

Table 1.summarize the results of the modified hexagonal micostrip antenna

	h *mm*	Δf *MHz*	$f_0 MHz$	*BW*	Dir*dBi*
Hex patch	1.6	39	2400	1.6%	**7.4**
	2	43	2396	1.8%	**7.387**
	3.2	61,5	2388	2.58%	**7.38**
M-Hex-patch	1.6	103	2400	4.3%	**7.41**
	2	121	2400	5.1%	**7.392**
	3.2	130	2332	5.57%	**7. 37**

Table 1 Resonance frequency, bandwidth and directivity for hexagonal and modified hexagonal

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microstrip antennas for substrate has insulator constant 2.33.

It should be noted that the same procedures to hexagonal and modified hexagonal microstrip antennas was appliedwith different substrate insulator constant. Table (2) summarizes the results we obtained.

Table2. Resonance frequency, bandwidth and directivity for hexagonal and modified hexagonal microstrip antennas have substrate insulator constants 2, 2.33, 3.3 and 4.4

Dielectric substrate type		h mm	Δf *MHZ*	f_0 MHZ	BW%	DIR dbi
RT5880LZRogers ε_r=2 $a = 27\ mm$	hex patch	1.6	42	2400	1.75	7.61
		3.2	64	2330	2.75	7.54
	M-Hex-patch	1.6	105	2376	4.56	7.62
		3.2	132	2326	5.67	7.57
Arlon Diclod87 ε_r =2.33 $a = 25\ mm$	hex patch	1.6	39	2400	1.6	7.4
		3.2	61.5	2388	2.58	7.38
	M-Hex-patch	1.6	103	2400	4.3	7.41
		3.2	130	2332	5.57	7.37
Rogers xt8000 ε_r=3.3 $a = 21\ mm$	hex patch	1.6	36	2400	1.5	7.03
		3.2	59	2345	2.5	6.93
	M-Hex-patch	1.6	99	2400	4.13	7.04
		3.2	127	2337	5.43	6.96
Preperml440 ε_r=4.4 $a = 18\ mm$	hex patch	1.6	33	2400	1.37	6.515
		3.2	57	2374	2.4	6.45
	M-Hex-patch	1.6	96	2425	3.95	6.56
		3.2	125	2361	5.3	6.47

Conclusions

The main objective of this paper was to increase the bandwidth of the hexagonal microstrip antenna with Arlon Diclad87insulator,where it was been increased from 1.6% to 4.3% by changing the shape of the patch while keeping the thickness of the dielectric (h = 1.6 mm), while the radiation pattern remaining unchanged, a simple increase in Directivity was occurred when weincreased the thickness of the substrate material increases, the width of the bandwidth was increased and reaches up to 5.6%.

The same procedurewas repeated for alpha and beta insulators and we found good results for the aforementioned insulators.

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