Bandwidth Enhancement of Hexagonal Patch Microstrip Antenna with Several Approaches

Mahmoud M. Aubais

Kufa Univ.\ Faculty of science

Physics department
mahmood.alhilo@uokufa.edu.iq

Nabeel Abbas Areebi

Qadisiya Univ.\Faculty of Education

Physics department
nabeelabbasph@yahoo.com

Abstract

In this work we calculated the bandwidth of hexagonal patch shape microstrip antenna operate at $2.4\ GHz$ frequency. We found that the bandwidth is narrow if dielectric constant is small. In order to widen the bandwidth we suggest made a slot in the ground plane of the microstrip antenna. The bandwidth became 148.8% when we use the foam after making two wide slots in the ground plane of microstrip antenna. The procedure was applied to different substrate with different dielectric constant, the results show an increase in the bandwidth in both case. The simulation is done by using finite difference method time domain FDTD programing by MATLAB tools.

Keywords:- bandwidth, hexagonal microstrip antenna, FDTD method

Introduction

Since the establishment of the microstrip at the beginning of 1970s [I.J. Bahl, and P. Baharteia (1980)], it has been used in many industrial applications [Sujeet Kumar and et. al. (2014)], according to the their advantage of low cost, ease of manufacturing, low profile together with other advantages[H. F. Pues and A. R. Van de Capelle (1989)]. However, it also has certain disadvantages, such that the narrow bandwidth [I.J. Bahl, and P. Baharteia (1980)]. Therefore many researches are achieved, in order to improve the bandwidth of all microstrip antennas types (e.g. circular, rectangular and triangular…etc) [J.W. Wu and J.H. Lu (2003), J. Y. Sze and K. L. Wong (2000), Avisankar Roy and et. al. (2013)]. According the literature, many approaches have been used to address this issue. These include drilling or changing the shape of the patch and change the feed characteristics and others [H. F. Pues and A. R. Van de Capelle (1989), J. A. Ansari and R. B. Ram (2008)]. This work is aimed to improve the bandwidth of the hexagonal patch microstrip antenna. The adopted method includes making two wide slots in the ground plane of the microstrip antenna. Also, simulation processes were conducted using FDTD method to build up a model through we can address the issue.

FDTD Method

A numerical method introduced by Kane Yee In 1966 to solve electromagnetic problems [A. Taflove (1995)], this is depending on Maxwell's curl equations; this method is called finite difference time domain (FDTD) method. In this method we must assume that every point is as a cell of $\Delta x \Delta y \Delta z$ volume, and the components of $\boldsymbol{E}$ and $\boldsymbol{H}$ are distributed as shown in fig.1 [A. Taflove (1980)].
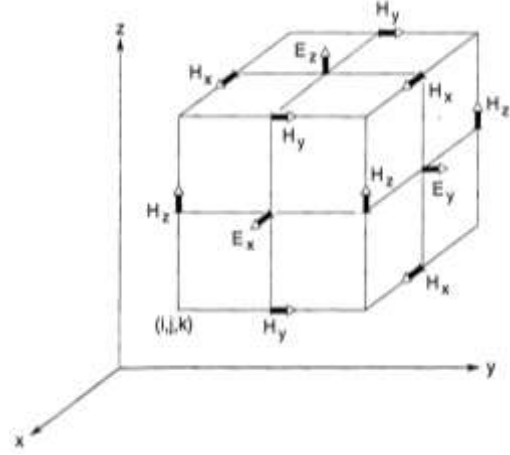

Figure 1: Yee cell in three dimensions, the dimensions of cell are $\Delta x, \Delta y$ and Δz in x, y and z direction respectively.

So the space will become grid of these cells. Since the electric and magnetic fields depend on the space and time, so Δt can be calculated by Courant [J. S. Juntunen and T. D. Tsiboukis (2000)] factor as $\Delta t = \left(c\sqrt{\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2} + \frac{1}{\Delta z^2}}\right)^{-1}$ where c is light velocity. Note that any function u of space and time can be evaluated at a discrete point in the grid of the space and time as follows:

$$u(i\Delta x, j\Delta y, k\Delta z, n\Delta t) = u^n(i, j, k)$$

Where i, j, k and n are integers. The partial derivative in the x- direction evaluated at the fixed time $t_n = n\Delta t$ defined as:

$$\frac{\partial u(i\Delta x, j\Delta y, k\Delta z, n\Delta t)}{\partial x} =$$

$$\frac{u^n((i+1/2),j,k) - u^n((i-1/2),j,k)}{\Delta x}$$
$$+ \mathbf{0}(\Delta x)^2$$

The updating electric and magnetic fields in space and time given as

$$\frac{\partial H_x}{\partial t} = \frac{1}{\mu}\left(\frac{\partial E_y}{\partial z} - \frac{\partial E_z}{\partial y} - \rho' H_x\right)$$

$$\frac{\partial H_y}{\partial t} = \frac{1}{\mu}\left(\frac{\partial E_z}{\partial x} - \frac{\partial E_x}{\partial z} - \rho' H_y\right)$$

$$\frac{\partial H_z}{\partial t} = \frac{1}{\mu}\left(\frac{\partial E_x}{\partial y} - \frac{\partial E_y}{\partial x} - \rho' H_z\right)$$

$$\frac{\partial E_x}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} - \sigma E_x\right)$$

$$\frac{\partial E_y}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} - \sigma E_y\right)$$

$$\frac{\partial E_z}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} - \sigma E_z\right)$$

The excitation of the system can be done by Gausses pulse [M. Benavides and et. al. (2011)] $p(t) = e^{-\left(\frac{t-t_0}{\tau}\right)^2}$ where τa damping factor is has a value depends on the frequency range of problem, t_0 is the time delay.

The pulse propagated according to the equation above. Since the memory of the computer cannot programing infinity space, we use a model to simulate the infinite space. We used here PML method [M. Benavides and et. al. (2011)] to do that.

When the electric and magnetic fields updating approach to zero at feed point we can calculate the input impedance Z_{in} and S_{11} as follows[Sheen D. M. (1991)]:

$$Z_{in}(\omega) = \left(\frac{\int_{-\infty}^{\infty} V(t)e^{-j\omega t}dt}{\int_{-\infty}^{\infty} I(t)e^{-j\omega t}dt}\right) \text{Where } V(t)$$

Is the voltage in the time domain at the feed point and $I(t)$ is the current in the time domain at feed point.

$$S_{11} = \left(\frac{\int_{-\infty}^{\infty} V(t)e^{-j\omega t}dt}{\int_{-\infty}^{\infty} p(t)e^{-j\omega t}dt}\right) \text{Where } p(t) \text{ is}$$
the Gaussian pulse at feed point. Then we calculated other properties of system.

Results and Discussions

We designed hexagonal patch microstrip antenna as in fig.(2), to operate with resonant frequency $2.4\ GHz$ where dimensions are $a = 29.3\ mm$ is the patch length, $b = 120\ mm$ is the substrate and the ground plane length $h = 1.59\ mm$ is the substrate thick feed point $r_f = 14.56\ mm$, the angle $\alpha = 120^0$and it equals for all inner angels of hexagonal shape, the dielectric constant of foam is $\varepsilon_r = 1.07$.

In order to study the bandwidth of hexagonal patch microstrip antenna, we conduct the following steps: first, calculate the bandwidth without any simulated modification, second, making two slots in the ground plane of the antenna, third, increase the thickness of the substrate with making two slots in the ground plane of the antenna, finally, repeating the above steps to other dielectric substrate of hexagonal patch microstrip antenna.

By applying the first step we found that the resonant frequency is $\approx 2.4\ GHz$ (the resonant frequency calculated when the reactance equal to zero) as shown in figure (3) that illustrates the resistance and reactance opposite the frequency.

Figure (4) shows the return loss S_{11} against frequency, we find the bandwidth is $(BW \approx 1.3\ \%)$ where it calculated from the relation [Z. N. Chen and Y. W. Michael (2006)].
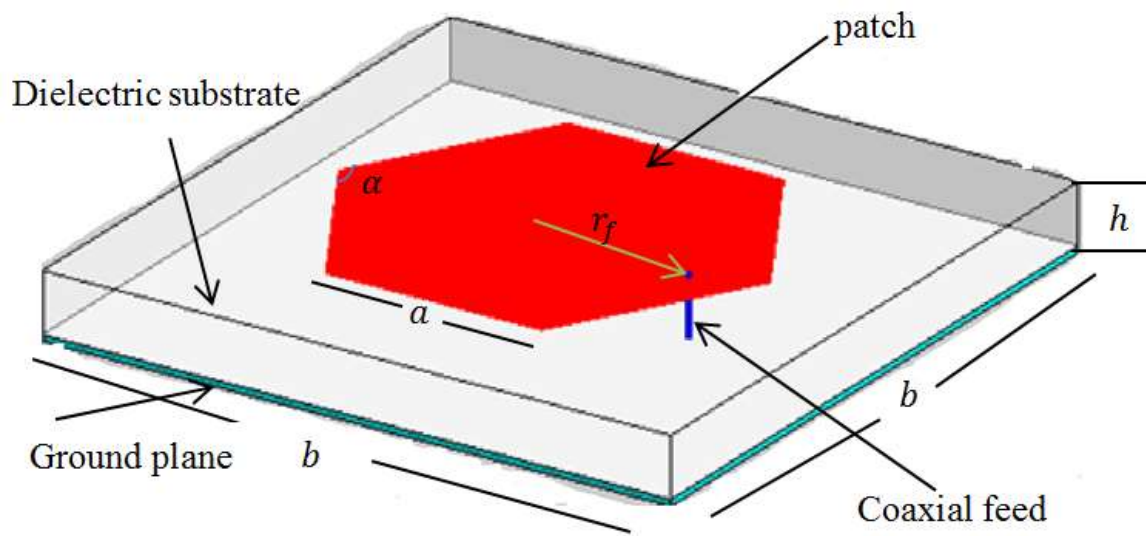
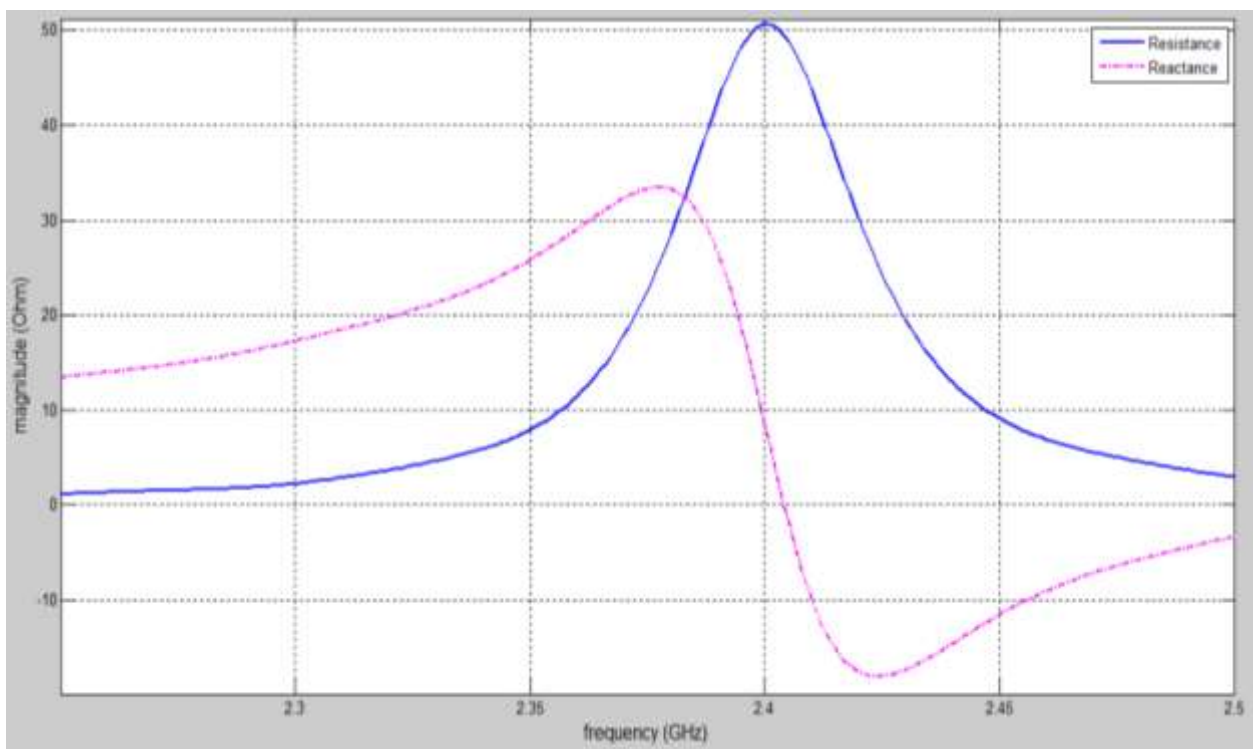*Figure (2): hexagonal patch microstrip antenna*

Figure 3: Input impedance of the hexagonal microstrip antenna calculated by FDTD method

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

Where f_l and f_u are lower and upper frequencies below $S_{11} = -10\ dB$ as shown in figure (4)

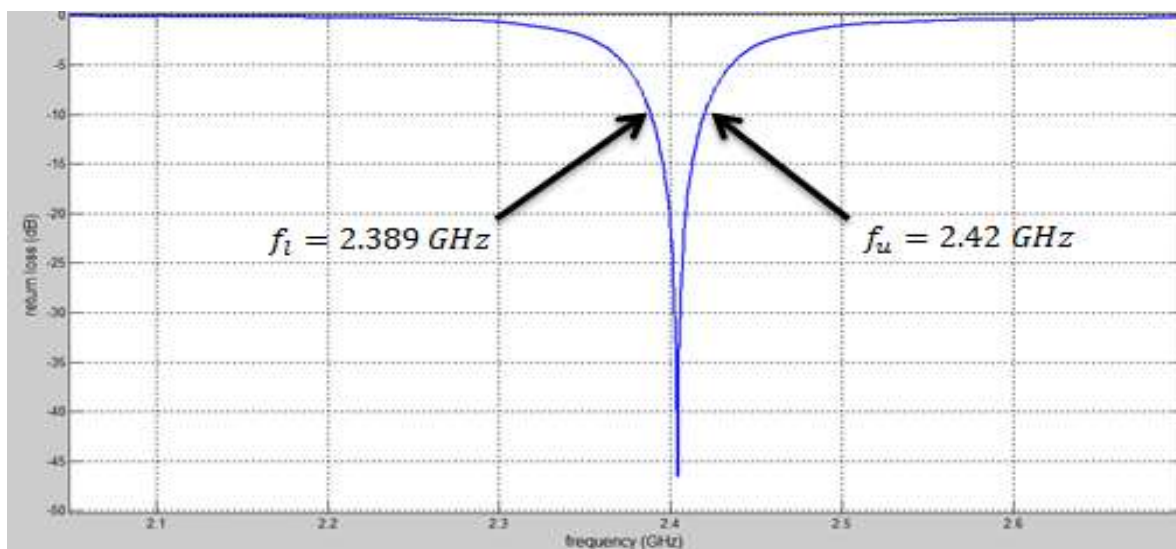*Figure 4: Return loss S_{11} of the hexagonal microstrip antenna using FDTD method $\varepsilon_r = 1.07$*

$$h = 1.59\ mm.$$

By conducting step two the BW was enhanced through making two wide slots in the ground plane of the microstrip antenna as shown in figure (5), the slot dimensions are $L_x = 101\ mm\ \ and\ L_y = 49.2\ mm$. The BW Increased up to $\approx 77\%$ as shown in figure(6). In this context, the two slots are situated midpoint at of the ground plane.
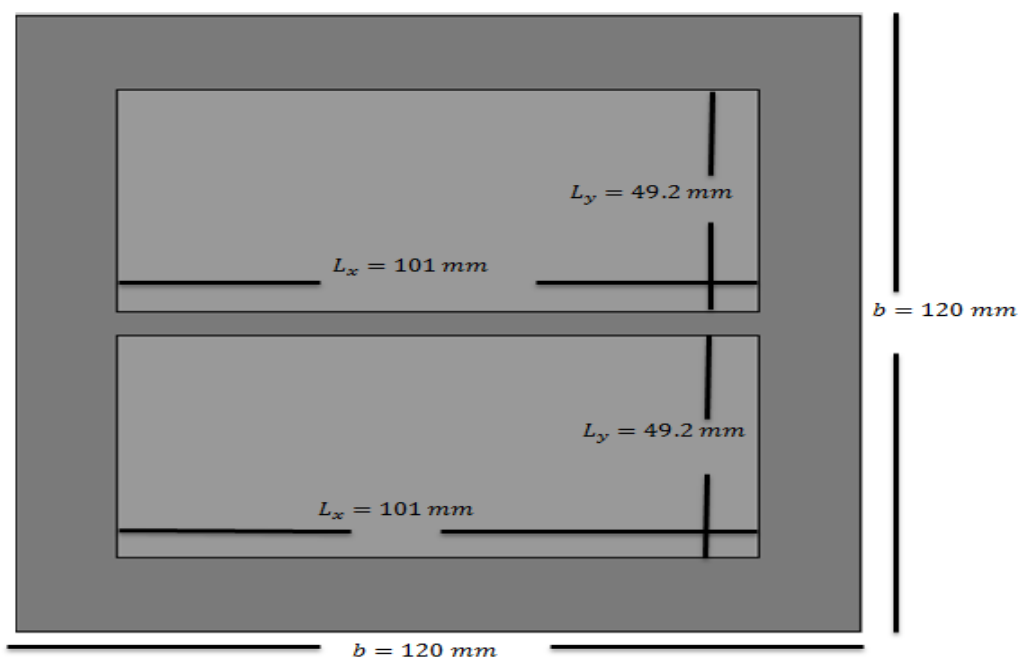

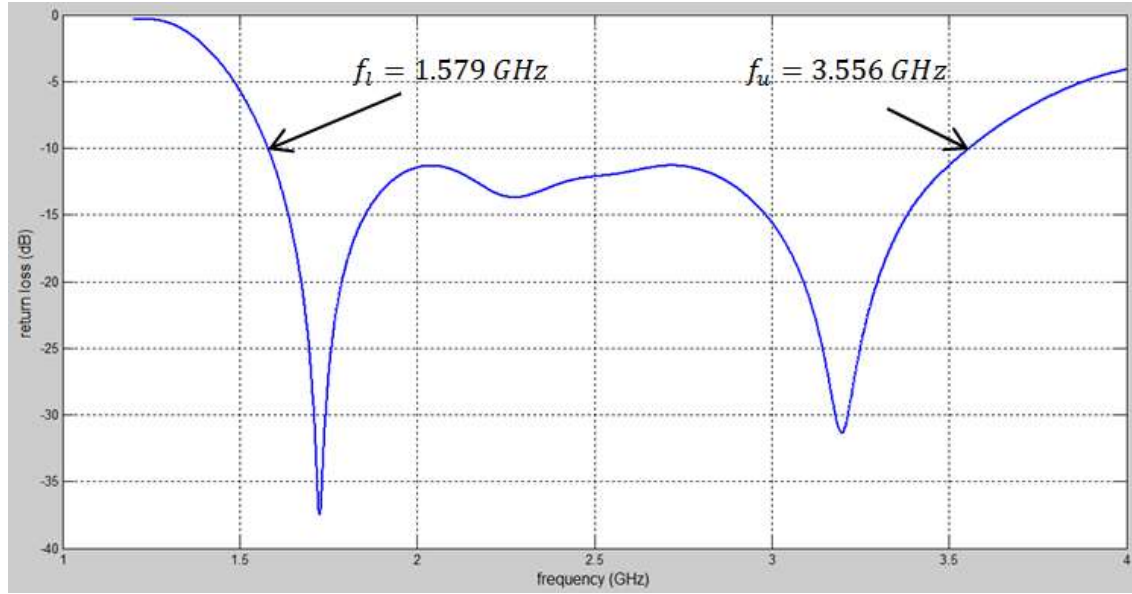*Figure 5: slots dimensions in the base of hexagonal microstrip antenna*

Figure 6: Return loss S_{11} of the hexagonal microstrip antenna with slotted ground plane $\varepsilon_r = 1.07$ $h = 1.59\ mm$.

The third step includes increasing the thickness h to $3mm$, rather than $1.5\ mm$ and the place of the feed location was changed ($i.e\ r_f = 13.32\ mm$) and the two slot dimensions became $L_x = 73.36\ mm\ and\ L_y = 35.35\ mm$. This therefore led to the BW to be enhanced to around $\approx 148.84\%$ as shown in fig.(7)

Finally we repeated the same steps (above) but with different dielectric substrates, one of the latter substrates has a dielectric constant ($\varepsilon_r = 2.25$), the dimensions change to become $a = 20.9\ mm, b = 85\ mm, h = $

$1.59\ mm$, feed point $r_f = 5.5\ mm$, the angle $\alpha = 120^0$ and which have the same meaning as mentioned earlier. From the figure (8) we find that the BW is about 1.16%.

After making the two slots in the ground plane with dimensions of $L_x = 77.4\ mm$ and $L_y = 35.85$,   the BW increased to about $\approx 33.9\%$ as shown in fig (9). We applied these techniques for hexagonal patch

microstrip antenna with dielectric substrate of $\varepsilon_r = 3.38$. The results are depicted in table 1.

Conclusions

Our results suggest that when made two wide slots on the ground plane of hexagonal patch microstrip antenna, this technique may lead to broaden the bandwidth. The bandwidth increases when the dielectric constant decreases and it increases when the dielectric material is thicker. To ensure good results the ground plane's dimensions must be slightly large.
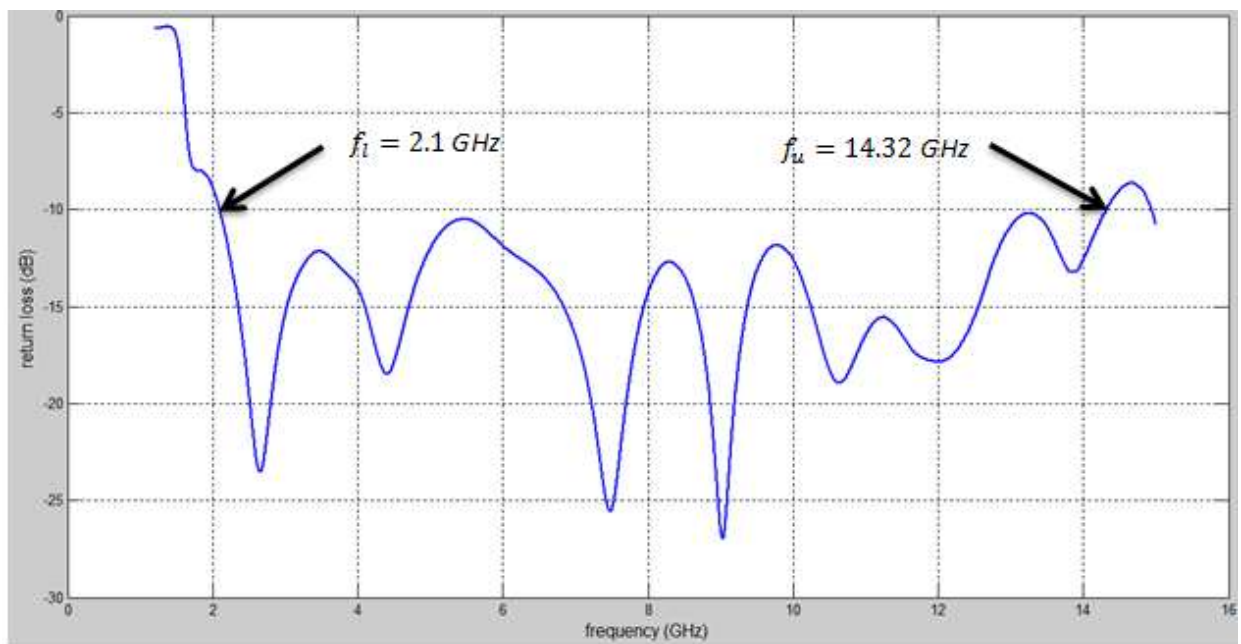
Figure 7: Return loss $S_{11}$of the hexagonal microstrip antenna with base slotted using FDTD method
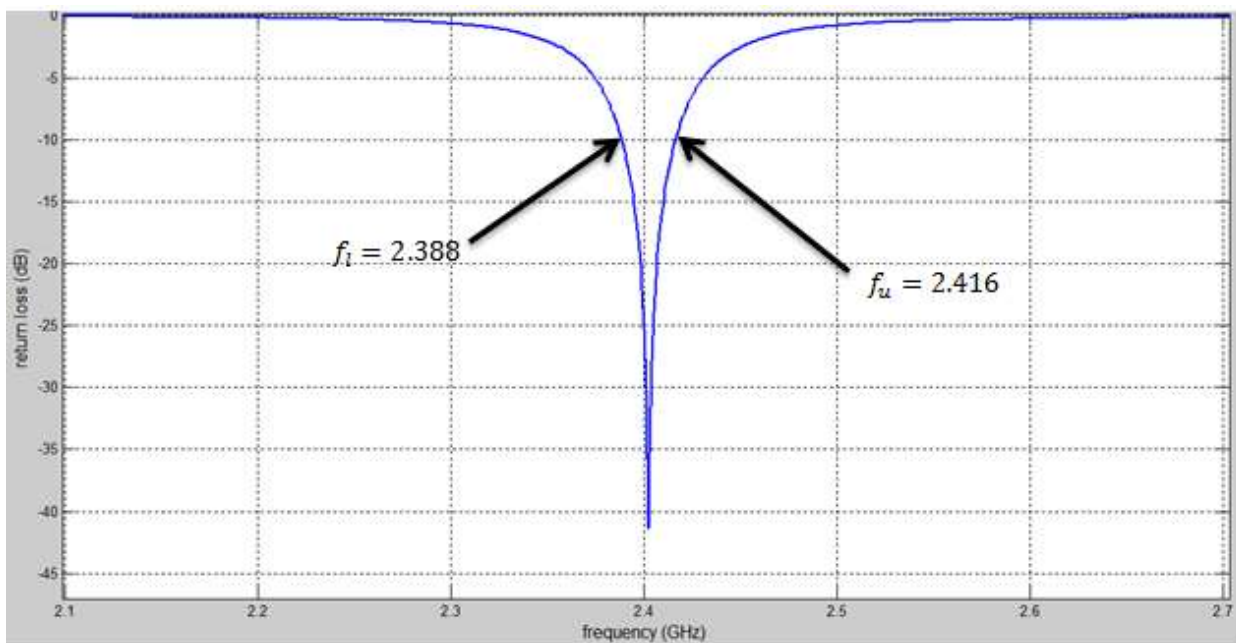$$\varepsilon_r = 1.07 \quad h = 3 \, mm.$$

Figure 8: Return loss $S_{11}$of the hexagonal microstrip antenna using FDTD method $\varepsilon_r = 2.25 \quad h =$
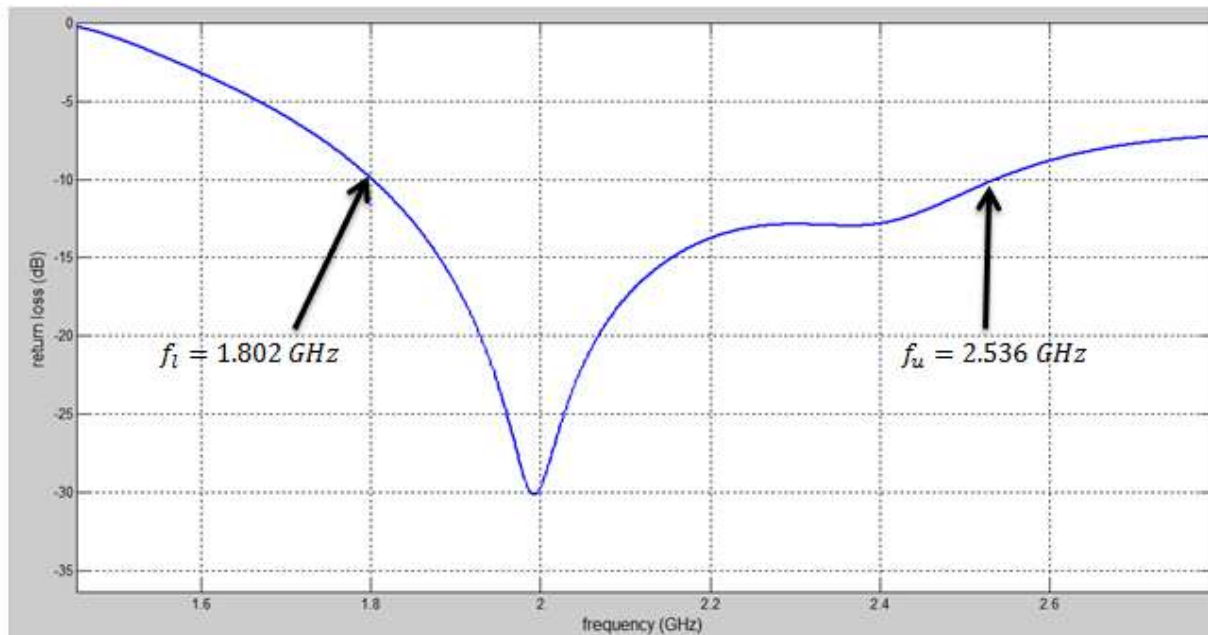$$1.59 \, mm.$$

Figure 9: Return loss S_{11} of the hexagonal microstrip antenna with base slotted using FDTD method $\varepsilon_r = 2.25$ $h = 1.59$ mm.

Table (1): The values of the bandwidth for different dielectric constants

	$h = 1.59\ mm$ $L_x = 0\ mm$ $L_y = 0\ mm$ $r_f = 14.56\ mm$	$h = 1.59\ mm$ $L_x = 101\ mm$ $L_y = 49.2\ mm$ $r_f = 15.98\ mm$	$h = 3\ mm$ $L_x = 73.36\ mm$ $L_y = 35.35\ mm$ $r_f = 13.32\ mm$
$a = 29.3\ mm$ $b = 120\ mm$ $\varepsilon_r = 1.07$	1.3%	77%	148.84%
	$h = 1.59\ mm$ $L_x = 0\ mm$ $L_y = 0\ mm$ $r_f = 5.5\ mm$	$h = 1.59\ mm$ $L_x = 77.4\ mm$ $L_y = 35.85\ mm$ $r_f = 10.45\ mm$	$h = 3\ mm$ $L_x = 66\ mm$ $L_y = 33.95\ mm$ $r_f = 9.5\ mm$
$a = 20.9\ mm$ $b = 85\ mm$ $\varepsilon_r = 2.25$	1.16%	33.9%	83.48%
	$h = 1.59\ mm$ $L_x = 0\ mm$ $L_y = 0\ mm$ $r_f = 4.27\ mm$	$h = 1.59\ mm$ $L_x = 63.79\ mm$ $L_y = 31.12\ mm$ $r_f = 9.31\ mm$	$h = 3\ mm$ $L_x = 57.59\ mm$ $L_y = 28.02mm$ $r_f = 9.31\ mm$
$a = 17.07\ mm$ $b = 70\ mm$ $\varepsilon_r = 3.38$	1.3%	29.5%	93.5%

References

[1] A. Taflove, "**Application of the finite-difference time-domain method to sinusoidal steady-state electromagnetic penetration problems**", IEEE Trans. Electro. Comp. Vol. 22, pp. 191-202, 1980.

[2] A. Taflove," *Computational Electrodynamics the Finite-Difference Time-Domain Method*", Artech House, Inc., Boston, 1995.

[3] Avisankar Roy, P. P. Sarkar, Sunandan Bhunia," **Compact and Broadband Monopole Triangular Microstrip Patch Antenna with Shorting Pin**" nternational Journal of Soft Computing and Engineering (IJSCE), Volume-2, Issue-6,pp. 381-385, January 2013.

[4] H. F. Pues and A. R. Van de Capelle, "**An impedance-matching technique for increasing the bandwidth of microstrip antenna**", IEEE Transactions on Antennas and Propagation, Vol. 37, No. 11, pp. 1345–1354, 1989.

[5] I.J. Bahl, and P. Baharteia, "**Microstrip Antennas**", Artech House Inc., London, 1980.

[6] J. A. Ansari and R. B. Ram, "**Broadband Staked U-Slot Microstrip Patch Antenna**", Progress In Electromagnetics Research Letters, Vol. 4,pp.17–24, 2008.

[7] J. S. Juntunen and T. D. Tsiboukis," **Reduction of Numerical Dispersion in FDTD Method through Artificial Anisotropy**", IEEE Transactions on microwave theory and techniques, VOL. 48, NO. 4, 2000.

[8] J. Y. Sze and K. L. Wong, "Slotted Rectangular Microstrip Antenna for Bandwidth Enhancement", IEEE Transactions on Antennas and Propagation, Vol. 48, No. 8, pp. 1149-1152, 2000.

[9] J.W. Wu and J.H. Lu," **Slotted Circular Microstrip Antenna for Bandwidth Enhancement**", IEEE antenna and propagation society international symposium, vol. 2, PP. 272-275, 2003.

[10] M. Benavides, M. ´Alvarez, C. Calder ´on, J. Sosa, M. Galaz, M. Rodr´ıguez, M. Enciso and C. M´arquez, " **A novel set of reduced equations to model perfect layer matched (PML) in FDTD**", Revista Mexicana DE Fisica E 57 (1) 25–31, 2011.

[11] Sheen D. M., "**Numerical Modeling of Microstrip**

Circuits and Antennas", Ph. D. Thesis Submitted to the Electrical Engineering and Computer Science Massachusetts Institute of Technology, USA,1991.

[12] Sujeet Kumar Yadav, Kirti Vyas and Sudarshan Kumar, "**A Hexagonal Shape Microstrip Patch Antenna for Wideband and Multiband Applications**", International Journal of Scientific & Engineering Research, Volume 5, Issue 6, pp 1469-1475. June-2014

[13] Z. N. Chen and Y. W. Michael, "Broadband Planar Antennas", John Wiley & Sons, Ltd, England, 2006.

نبيل عباس عريبي

جامعة القادسية / كلية التربية

قسم الفيزياء

محمود مسافر عبيس

جامعة الكوفة/ كلية العلوم

قسم الفيزياء

الخلاصة

قمنا في هذا البحث بحساب عرض الحزمة لهوائي شريطي ذو مشع سداسي الشكل يعمل عند تردد 2.4 GHz. وجد انه كلما كان ثابت العزل صغير كان عرض الحزمة اوسع، ولزيادة عرض الحزمة اقترح عمل شق في قاعدة الهوائي الشريطي ازداد عرض الحزمة الى 148.8% باستخدام مادة foam بعد عمل شقين واسعين في قاعدة الهوائي الشريطي. طبقنا الطريقة على مادتين ذاتا ثابتي عزل مختلفين وكانت النتائج حصول زيادة في عرض الحزمة لجميع المواد العازلة الاخرى. تم محاكاة المسألة بطريقة الفروق المحددة في المجال الزمني واستخدمت لغة الماتلاب (MATLAB) لغرض البرمجة.

الكلمات المفتاحية:– عرض الحزمة، هوائي شريطي سداسي الشكل، طريقة الفروق المحددة في المجال الزمني