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Research Article

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Bandwidth Enhancement for an Equilateral triangular Microstrip Antenna by Slotting in the Base

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Abstract This paper presents the effect of the slotting in the base of microstrip on bandwidth of an equilateral triangular microstrip antenna. The proposed antenna was excited by coaxial feed, at a resonant frequency of 3.5GHz, and the dielectric constant was $\varepsilon_r = 1.07$ for the dielectric substance. Bandwidth enhancement due to the slot of the base of this antenna was noticed to be 34.06% at h=1.59mm. When changing the height of the substrate (1.59 mm to h=3mm), the increasing in the bandwidth becomes 54.94%. The microstrip design was achieved theoretically and solved using FDTD method by MATLAB language.

Keywords Equilateral triangular microstrip, FDTD, Bandwidth, Directivity, Slotting base

Introduction

Microstrip antenna in short (MSA) is one of the most common kinds of printed antenna. MSA can be defined as a device that sends or receives electromagnetic waves, composed of a radiating patch on one facet of dielectric substrate that includes a ground plane on the opposite facet [1]. In comparison to the conventional antenn as the microstrip antenna has several merits like light weight, small volume, low profile planar configuration, low fabrication cost, supports both, linear as well as circular polarization, capable of dual and triple frequency operations, can be easily integrated with microwave integrated circuits (MICs) on the same substrate, and [it] can be made compact for use in personal mobile communication [2,3]. But it has several demerits such low Gain, narrow bandwidth, and low power handling capacity [4,5]. Researchers had already proved that the patch arrays can provide much higher gains than a single patch at little additional cost. Microstrip antennas are becoming very important electronic component in communication devices, particularly with mobile phone and wireless communication systems [6]. Due to compact in size, and light in weight, they can be mounted on the exterior of aircraft and spacecraft. Nowa-days, microstrip patch antennas are preferred in satellite and military applications due to their performance, small size, and light weight [7].

2. The finite-difference time domain (FDTD) method

In 1966 Yee introduced the finite difference time domain (FDTD) method to solve electromagnetic problems depending on Maxwell's curl equations. Yee assumed that every point as a cell of volume ΔxΔyΔz square or rectangle shape known Yee cells and the components of E and H were distributed as shown in figure (1). So the space will become grid of these cells [8].

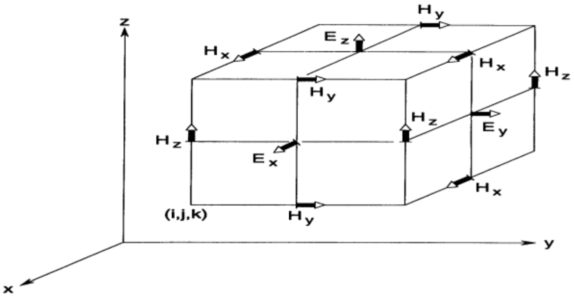

Figure 1: Yee cell in three dimensions, the dimensions of cell are $\Delta x, \Delta y$ *and* Δz *in* x, y *and* z *direction respectively [8].*

The size of cell is determined by highest frequency, therefore, the biggest size of the cell must be smaller than $\frac{\lambda_{min}}{10}$ or $\frac{\lambda_{min}}{20}$ and a time-step limit in three dimensions of the FDTD is [3].

$$\Delta t \leq \frac{1}{v_{max}\sqrt{\frac{1}{\Delta x^2}+\frac{1}{\Delta y^2}+\frac{1}{\Delta z^2}}} \tag{1}$$

Where c is the speed of light.

In FDTD method, equations for electric and magnetic field components can be written as [9,10]:

$$\begin{aligned} E_x^{n+1}(i+0.5,j,k) &= \left[\frac{2\varepsilon_x(i,j,k)-\Delta t\sigma_x^e(i,j,k)}{2\varepsilon_x(i,j,k)+\Delta t\sigma_x^e(i,j,k)}\right]E_x^n(i+0.5,j,k) \\ &+\frac{2\Delta t/\Delta y}{2\varepsilon_x(i,j,k)+\Delta t\sigma_x^e(i,j,k)}\left[H_z^{n+\frac{1}{2}}(i+0.5,j+0.5,k)-H_z^{n+\frac{1}{2}}(i+0.5,j-0.5,k)\right] \\ &-\frac{2\Delta t/\Delta z}{2\varepsilon_x(i,j,k)+\Delta t\sigma_x^e(i,j,k)}\left[H_y^{n+\frac{1}{2}}(i+0.5,j,k+0.5)-H_y^{n+\frac{1}{2}}(i+0.5,j,k-0.5)\right] \\ &-\frac{2\Delta t}{2\varepsilon_x(i,j,k)+\Delta t\sigma_x^e(i,j,k)}J_{i_x}^{n+\frac{1}{2}}(i,j,k) \end{aligned} \tag{2}$$

$$\begin{aligned} E_y^{n+1}(i,j+0.5,k) &= \left[\frac{2\varepsilon_y(i,j,k)-\Delta t\sigma_y^e(i,j,k)}{2\varepsilon_y(i,j,k)+\Delta t\sigma_y^e(i,j,k)}\right]E_y^n(i,j+0.5,k) \\ &+\frac{2\Delta t/\Delta z}{2\varepsilon_y(i,j,k)+\Delta t\sigma_y^e(i,j,k)}\left[H_x^{n+\frac{1}{2}}(i,j+0.5,k+0.5)-H_x^{n+\frac{1}{2}}(i,j+0.5,k-0.5)\right] \\ &-\frac{2\Delta t/\Delta x}{2\varepsilon_y(i,j,k)+\Delta t\sigma_y^e(i,j,k)}\left[H_z^{n+\frac{1}{2}}(i+0.5,j+0.5,k)-H_z^{n+\frac{1}{2}}(i-0.5,j+0.5,k)\right] \\ &-\frac{2\Delta t}{2\varepsilon_y(i,j,k)+\Delta t\sigma_y^e(i,j,k)}J_{i_y}^{n+\frac{1}{2}}(i,j,k) \end{aligned} \tag{3}$$

$$\begin{aligned} E_z^{n+1}(i,j,k+0.5) &= \left[\frac{2\varepsilon_z(i,j,k)-\Delta t\sigma_z^e(i,j,k)}{2\varepsilon_z(i,j,k)+\Delta t\sigma_z^e(i,j,k)}\right]E_z^n(i,j,k+0.5) \\ &+\frac{2\Delta t/\Delta x}{2\varepsilon_z(i,j,k)+\Delta t\sigma_z^e(i,j,k)}\left[H_y^{n+\frac{1}{2}}(i+0.5,j,k+0.5)-H_y^{n+\frac{1}{2}}(i-0.5,j,k+0.5)\right] \\ &-\frac{2\Delta t/\Delta y}{2\varepsilon_z(i,j,k)+\Delta t\sigma_z^e(i,j,k)}\left[H_x^{n+\frac{1}{2}}(i,j+0.5,k+0.5)-H_x^{n+\frac{1}{2}}(i,j-0.5,k+0.5)\right] \\ &-\frac{2\Delta t}{2\varepsilon_z(i,j,k)+\Delta t\sigma_z^e(i,j,k)}J_{i_z}^{n+\frac{1}{2}}(i,j,k) \end{aligned} \tag{4}$$

$$H_x^{n+\frac{1}{2}}(i,j+0.5,k+0.5)=\left[\frac{2\mu_x(i,j,k)-\Delta t\sigma_x^m(i,j,k)}{2\mu_x(i,j,k)+\Delta t\sigma_x^m(i,j,k)}\right]H_x^{n-\frac{1}{2}}(i,j+0.5,k+0.5)$$
$$+\frac{2\Delta t/\Delta z}{2\mu_x(i,j,k)+\Delta t\sigma_x^m(i,j,k)}\left[E_y^n(i,j+0.5,k+1)-E_y^n(i,j+0.5,k)\right]$$
$$-\frac{2\Delta t/\Delta y}{2\mu_x(i,j,k)+\Delta t\sigma_x^m(i,j,k)}\left[E_z^n(i,j+1,k+0.5)-E_z^n(i,j,k+0.5)\right]$$
$$-\frac{2\Delta t}{2\mu_x(i,j,k)+\Delta t\sigma_x^m(i,j,k)}M_{ix}^n(i,j,k) \quad (5)$$

$$H_y^{n+\frac{1}{2}}(i+0.5,j,k+0.5)=\left[\frac{2\varepsilon_y(i,j,k)-\Delta t\sigma_y^e(i,j,k)}{2\varepsilon_y(i,j,k)+\Delta t\sigma_y^e(i,j,k)}\right]H_y^{n-\frac{1}{2}}(i+0.5,j,k+0.5)$$
$$+\frac{2\Delta t/\Delta x}{2\varepsilon_y(i,j,k)+\Delta t\sigma_y^e(i,j,k)}\left[E_z^n(i+1,j,k+0.5)-E_z^n(i,j,k+0.5)\right]$$
$$-\frac{2\Delta t/\Delta z}{2\varepsilon_y(i,j,k)+\Delta t\sigma_y^e(i,j,k)}\left[E_x^n(i+0.5,j,k+1)-E_x^n(i+0.5,j,k)\right]$$
$$-\frac{2\Delta t}{2\varepsilon_y(i,j,k)+\Delta t\sigma_y^e(i,j,k)}M_{iy}^n(i,j,k) \quad (6)$$

$$H_z^{n+\frac{1}{2}}(i+0.5,j+0.5,k)=\left[\frac{2\varepsilon_z(i,j,k)-\Delta t\sigma_z^e(i,j,k)}{2\varepsilon_z(i,j,k)+\Delta t\sigma_z^e(i,j,k)}\right]H_z^{n-\frac{1}{2}}(i+0.5,j+0.5,k)$$
$$+\frac{2\Delta t/\Delta y}{2\varepsilon_z(i,j,k)+\Delta t\sigma_z^e(i,j,k)}\left[E_x^n(i+0.5,j+1,k)-E_y^n(i+0.5,j,k)\right]$$
$$-\frac{2\Delta t/\Delta x}{2\varepsilon_z(i,j,k)+\Delta t\sigma_z^e(i,j,k)}\left[E_y^n(i+1,j+0.5,k)-E_y^n(i,j+0.5,k)\right]$$
$$-\frac{2\Delta t}{2\varepsilon_z(i,j,k)+\Delta t\sigma_z^e(i,j,k)}M_{iz}^n(i,j,k) \quad (7)$$

Where $\varepsilon(i,j,k)$, $\mu(i,j,k)$ are the permittivity and permeability respectively
$\sigma^e(i,j,k)$,$\sigma^m(i,j,k)$are the electric and magnetic conductivity respectively.
$J^{n+1/2}(i,j,k)$,$M^n(i,j,k)$ are the electric and magnetic current density respectively.
The system is excitation by Gaussian pulse [11].

$$g(t)=e^{-\frac{(t-t_0)^2}{\tau^2}} \quad (8)$$

where τ is a damping factor has a value depends on the frequency range of problem, $t_0$is a time delay.
The propagation of the wave in space reduces the values of its compounds and their values are very small compared to the values of the compounds at their highest values.
Thus, after *N*of repeat calculations, Fourier transforms can be used to find the impedance values [12].

$$Z_{in}(\omega)=\left(\frac{\int_{-\infty}^{\infty}V(t)e^{-j\omega t}\,dt}{\int_{-\infty}^{\infty}I(t)e^{-j\omega t}\,dt}\right)=\frac{\sum_{n=0}^{N}V(n\Delta t)e^{-j\omega n\,\Delta t}\Delta t}{\sum_{n=0}^{N-1}I((n+\frac{1}{2})\Delta t)e^{-j\omega\,(n+\frac{1}{2})\Delta t}\Delta t} \quad (9)$$

Where Z_{in} input impedance, ω angular frequency, Δt time step.

The voltage $V(t)$ can be calculated in the time domain at the feed pointfrom Faraday's law.

$$V_{feed}^{n}=-\frac{1}{9}\left(\sum_{i=i_{feed-1}}^{i=i_{feed+1}}\sum_{j=j_{feed-1}}^{j=j_{feed+1}}\sum_{k=u}^{k=d}E_{z}^{n}(i_{feed},i_{feed},k)\ \ \Delta z\right) \quad (10)$$

The current $I(t)$ can be calculated in the time domain at the feed point from Ampere's law.

$$I_{feed}^{n+\frac{1}{2}}=\frac{1}{u-d}\Big(\sum_{k=d}^{k=u}\Big(\sum_{i=i_{feed-1}}^{i=i_{feed+1}}H_{x}^{n+\frac{1}{2}}(i.\mathrm{j}-1,\mathrm{k})\Delta x+\sum_{j=j_{feed-1}}^{j=j_{feed+1}}H_{x}^{n+\frac{1}{2}}(i-1.\mathrm{j},\mathrm{k})\Delta y$$
$$-\sum_{i=i_{feed-1}}^{i=i_{feed+1}}H_{x}^{n+\frac{1}{2}}(i.\mathrm{j}+1,\mathrm{k})\Delta x-\sum_{j=j_{feed-1}}^{j=j_{feed+1}}H_{x}^{n+\frac{1}{2}}(i+1.\mathrm{j},\mathrm{k})\Delta y\Big)\Big) \quad (11)$$

The return loss S_{11} can be calculate as

$$S_{11}(\omega)=\left(\frac{\int_{-\infty}^{\infty}V(t)e^{-j\omega t}\,dt}{\int_{-\infty}^{\infty}p(t)e^{-j\omega t}\,dt}\right)=\frac{\sum_{n=0}^{N}V(n\Delta t)e^{-j\omega n\ \Delta t}\Delta t}{\sum_{n=0}^{N-1}p(n\Delta t)e^{-j\omega n\ \Delta t}\Delta t} \quad (12)$$

Where $p(t)$Gaussian pulse at feed point.

3. Geometry of an Equilateral Triangular Microstrip Antenna (ETMSA)

Equilateral triangular patch is one of the basic microstrip geometries ever investigated and implemented for different application. The geometry is versatile for being conformable over a curved surface and also being physically smaller compared with other common patch shapes [13]. The triangular patch is more compact than its rectangular and circular counterparts at a given frequency. In comparison to shorting post loaded circular and rectangular microstrip antenna configurations, the equilateral triangular patch yields a much larger reduction in resonant frequency and hence yields the most compact configuration [14]. Based on the magnetic wall cavity model analysis by Helszajn, the resonant frequencies of the equilateral microstrip patch (ETMP) antenna are given by formula [15,16].

$$f_{m,n}=\frac{2c}{3a_{eff}\sqrt{\varepsilon_{r,eff}}}\sqrt{m^2+mn+n^2} \quad (13)$$

Where c is the velocity of light in free space.

a_{eff} is the effective side length of ETMP.

$\varepsilon_{r,eff}$ is the effective relative permittivity of the medium below the patch.

The effective side length a_{eff} is given by

$$a_{eff}=a+\frac{h}{\sqrt{\varepsilon_{r,eff}}} \quad (14)$$

And the effective relative permittivity of the medium $\varepsilon_{r,eff}$ is

$$\epsilon_{r,eff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{4}\left(1+\frac{12h}{a}\right)^{-\frac{1}{2}} \quad (15)$$

h is the dielectric substrate thickness, a is side length of ETMP.

The figure (2) shows how to arrange an ETMSA geometry. In order to show the performance of the new antenna, we will first briefly present some results for the ETMSA, with dielectric constant $\varepsilon_r=1.07$, Length of the side $a=48.24\ mm$, dielectric substrate thickness $h=1.59\ mm$, feed point $d=20.89\ mm$ from head of triangle.

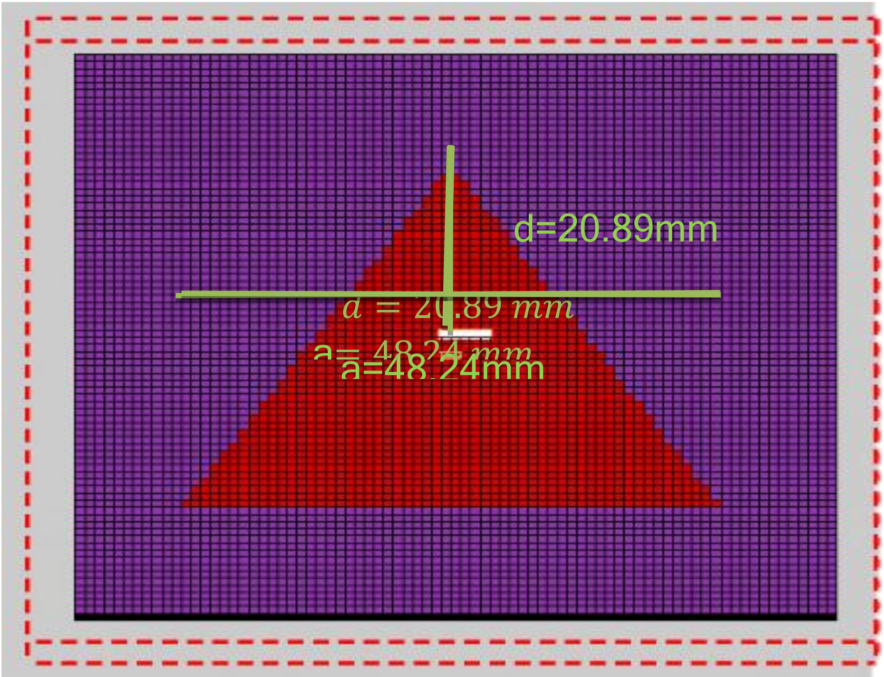

Figure 2: ETMSA $a = 48.24, h = 1.59mm, \varepsilon_r = 1.07, f_0 = 3.5GHz$

4. Results and Discussion

In order to operate the antenna efficiently, the input impedance must be matching at 50Ω as shown in figure (3). To calculate the bandwidth, we need to know the return loss relationship S_{11} versus the frequency shown in figure (4) of the antenna which shown it dimensions above.

The bandwidth of an antenna means the range of frequencies that the antenna can operate and can be calculated by equation [17].

$$Bandwidth = \frac{2(f_{\max} - f_{\min})}{(f_{\max} + f_{\min})} 100\% \quad (16)$$

f_{max}, f_{min} are frequencies at $S_{11} = -10\ dB$, where the bandwidth was $\approx 1.68\%$ and the directivity $\approx 10.2257\ dB$

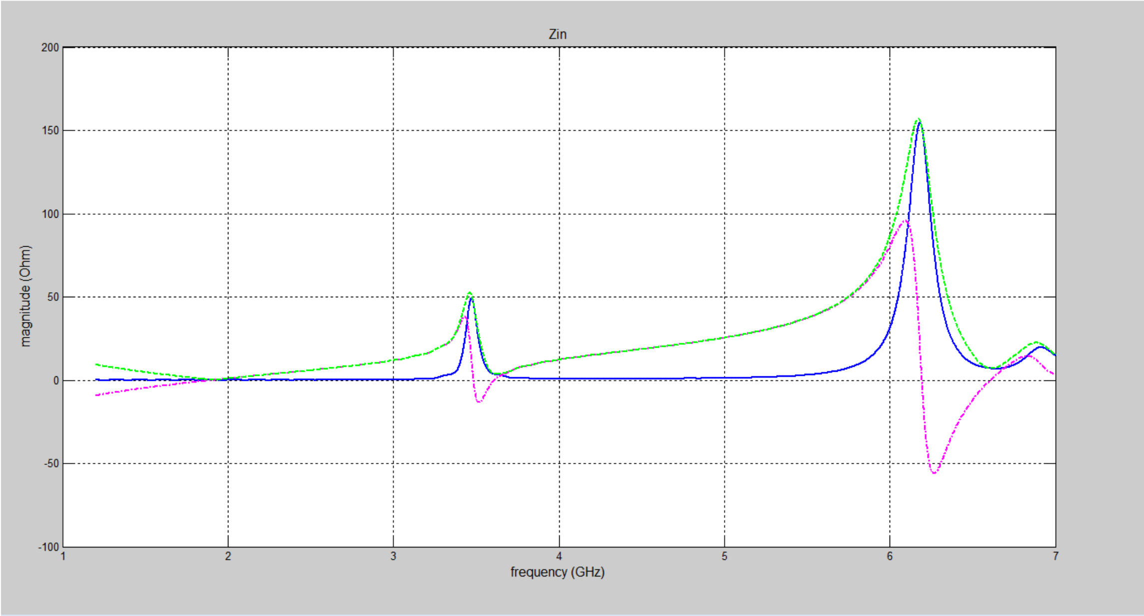

Figure Error! No text of specified style in document.: Input impedance of the ETMSA calculated by FDTD method " a= 48.24 mm, h= 1.59mm, $\varepsilon_r = 1.07$

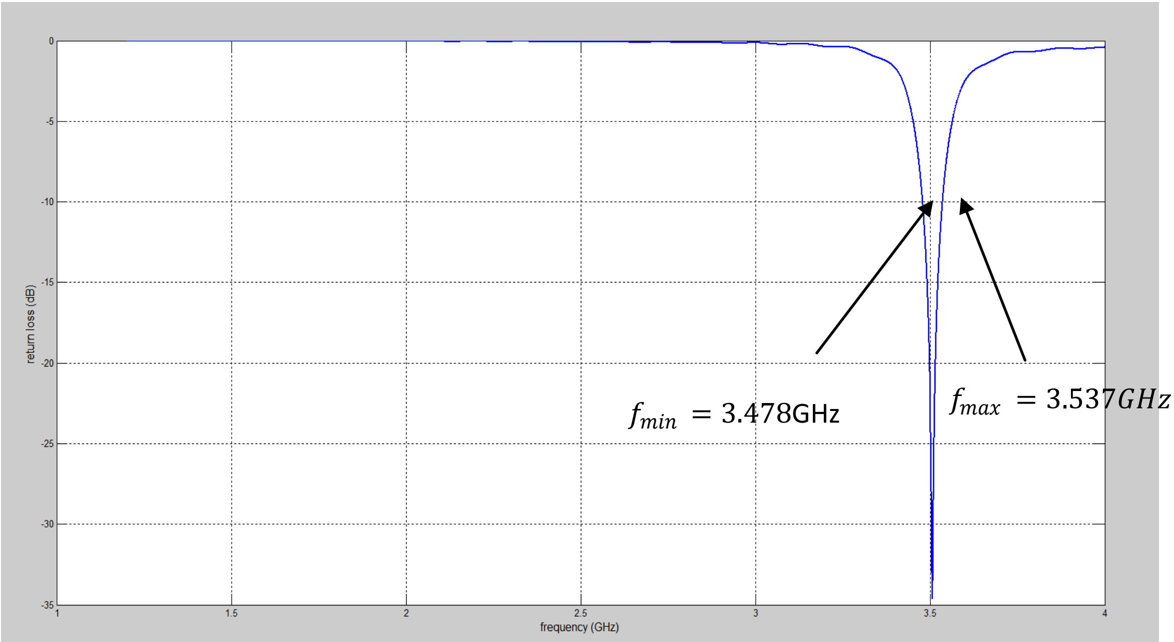

Figure 4: Return loss of the ETMSA calculated by FDTD method " a= 48.24mmh= 1.59mm, $\varepsilon_r = 1.07$

The following figures shown the radiation pattern and directivity.

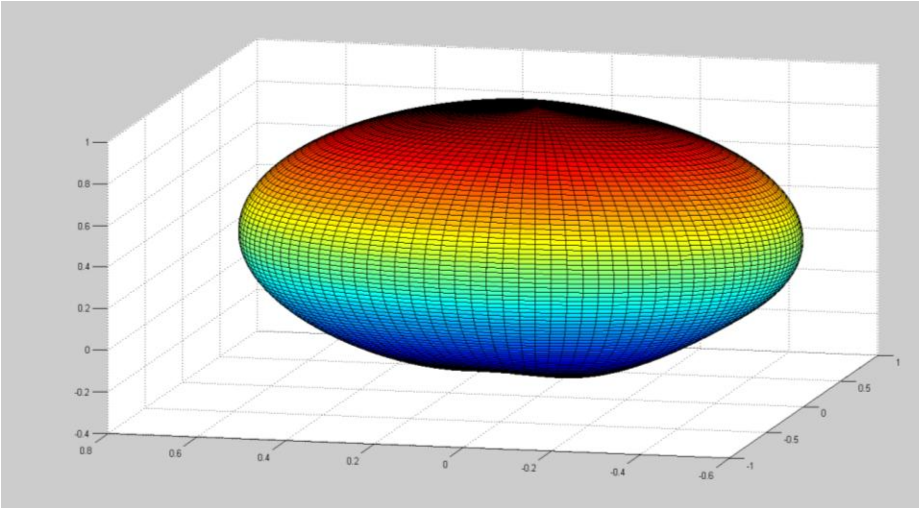

Figure 5: Radiation pattern of the ETMSA calculated by FDTD method "

a= 48.24mm , h= 1.59mm , $\varepsilon_r = 1.07$

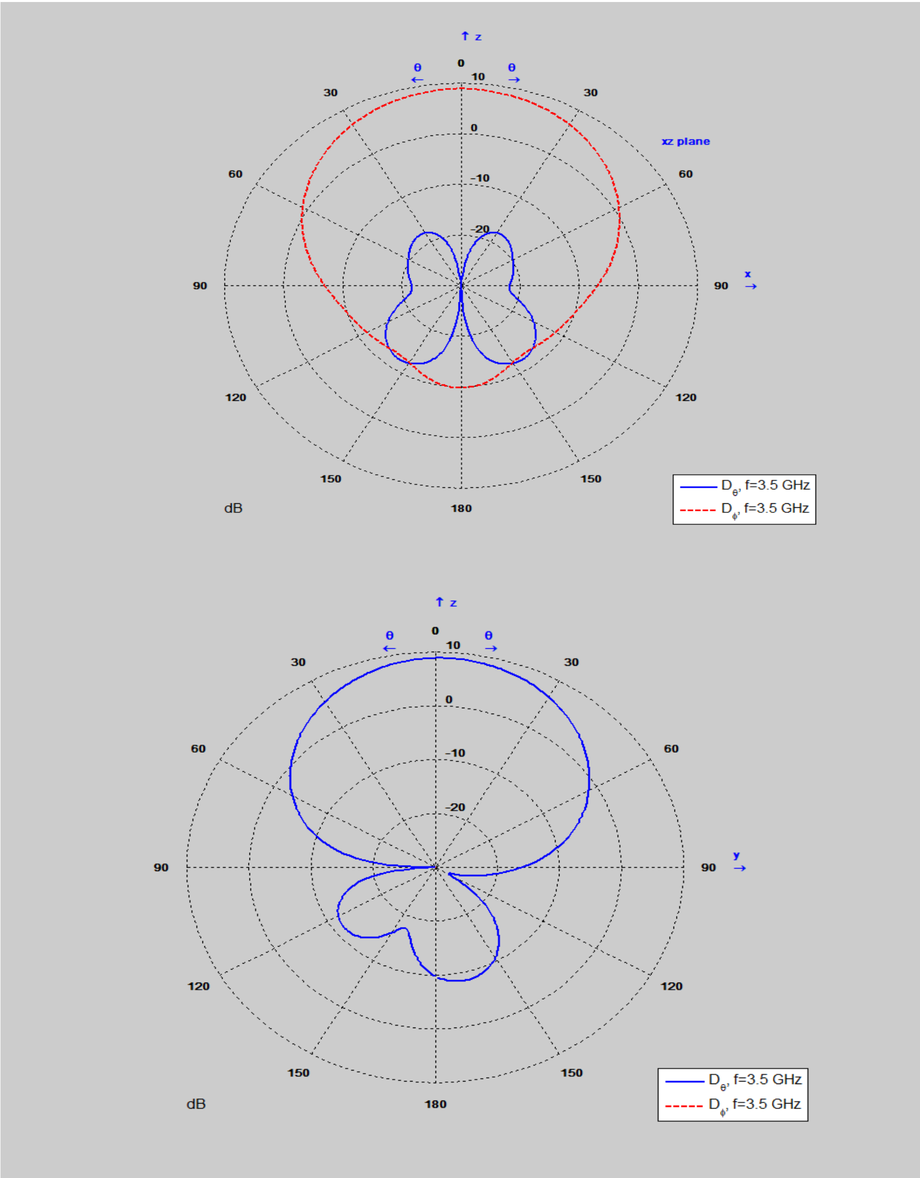

Figure 6 : Directivity of ETMSA $\varepsilon_r = 1.07$

In order to enhance the bandwidth of the proposed antenna, we modified the original ETMSA by slotting the base of microstrip as show in figure (7). This method led to the design of another antenna called the modify equilateral triangular microstrip antenna in brieflyM-ETMSA.

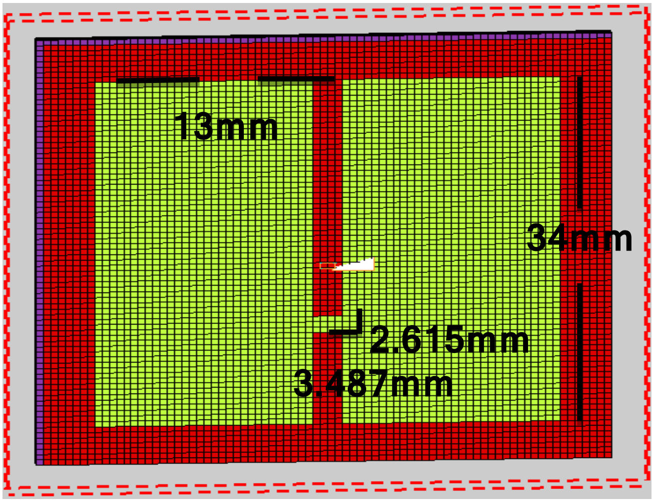

Figure 7: The Modified shape for an equilateral triangular microstrip antenna (M-ETMSA)

and by using a=*48.7 mm* , $\varepsilon_r = 1.07$ and *h=1.59 mm and*f_0= *3.5 GHz* , we obtained increase in bandwidth about 34.06% as shown in figure .

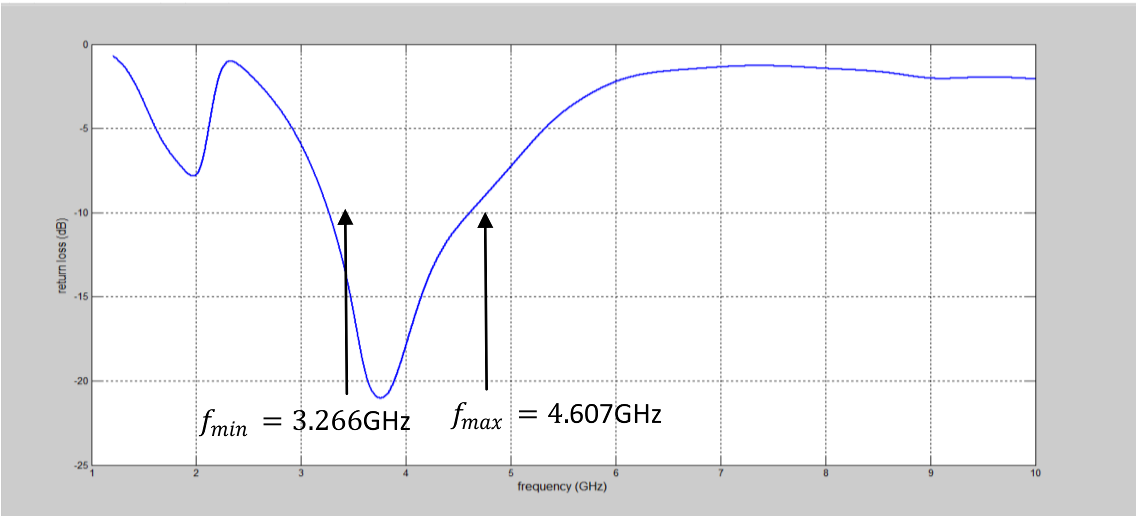

Figure 8: Return loss of the M- ETMSA calculated by FDTD method " a= 48.7mm , h= 1.59mm, $\varepsilon_r = 1.07$

Since increasing the thickness of the insulating substrate lead to increasing the bandwidth, we will change the height of substrate (*h= 1.59 mm to h=3mm)* in ETMSA and M_ETMSA and the results obtained are shown in the following table

Table 1: The Bandwidth and Directivity for$\varepsilon_r = 1.07, f_0 = 3.5$GHz

Antenna	*ETMSA h=1.59mm*	*M-ETMSA h=1.59mm*	*ETMSA h=3mm*	*M-ETMSA h=3mm*
Bandwidth	*1. 68%*	*34.06%*	*2. 61%*	*54.94%*
Directivity	*10.2257*	*6.5372*	*10.0512*	*4.9079*

5. Conclusion

The main objective of the study is to find a new way to bandwidth enhancement, because increasing the bandwidth causes more information to be transferred. Slotting the base of an equilateral triangular microstrip antenna lead to increasing the bandwidth. Then we notice that when the increases the thickness of the insulating substrate, the bandwidth enhancement in ETMSA and M-ETMSA antenna.

References

[1]. I.J. Bahl, and P. Baharteia, "Microstrip Antennas", Artech House Inc., London, 1980.
[2]. Parul Pathak (Rawat) and P.K. Singhal,"Design and Analysis of Broadband Microstrip Antenna using ltcc for Wireless Applications", Springer Nature Singapore Pte Ltd. 2018
[3]. C. A. Balanis, "Antenna Theory, Analysis and Design," John Wiley & Sons, New York, 1997.
[4]. G. Kumer, and K.P. Ray, "Broadband Microstrip Antennas", Artech House Inc., London, 2003.
[5]. S. Toshniwal, T. Mukherjee, P. Bijawat, S. Rawat and K. Ray, "Design and Analysis of Fabricated Rectangular Microstrip Antenna with Defected Ground Structure for UWB Applications", Springer Nature Singapore Pte Ltd. 2018.
[6]. Rajvir Singh, Randhir Singh, "Design and Modeling of Parallel Rectangular Patch Based Microwave Antenna", International Journal of Engineering and Computer Science ISSN: 2319-7242 Volume 3 Issue 1 January, 2014 Page No.3794-3804.
[7]. R. Arora, A. Kumar, S. Khan and S. Arya, "Finite Element Modelling and Design of Rectangular Patch Antenna with Different Feeding Techniques," Open Journal of Antenna and Propagation, vol. 1, no. 1, pp. 1117, 2013.
[8]. A. Taflove, "Computational Electrodynamics the FiniteDifference Time-Domain Method", Artech House, Inc., Boston, 1995.
[9]. A. Z. Elsherbeni and V. Demir, The Finite-Difference Time-Domain Method for Electromagnetics with MATLAB Simulations. Second edition 2016.
[10]. C .Kalialakis, "Finite Difference Time Domin Analysis of microstrip antenna-circuit Modules", Ph.D. Sc. Thesis Submitt. to Coll. Sci. Birmingham Univ.,1999.
[11]. R. Garg, P. Baharteia, I.J. Bahl, and A. Ittipiboon , "Microstrip Antenna Design Hand Book ", Artech House Inc., London, 2001.
[12]. D. S. Katz, E. T. Thiele, and A. Taflove, "Validation and Extension to Three Dimensions of the Berenger PML Absorbing Boundary Condition for FD-TD Meshes", IEEE Microwave and Guided Wave Letters, Vol. 4, No. 8, 1994.
[13]. M. Biswas D. Guha, "Input impedance and resonance characteristics of superstrate-loaded triangular microstrip patch", IET Microw. Antennas Propag., 2009, Vol. 3, Iss. 1, pp. 92–98.
[14]. B. Singh, N. Sarwade and K. P. Ray," A 50-X microstrip line fed shorted equilateral triangular microstrip antenna", Microw Opt Technol Lett. 2018;60:1215–1219.
[15]. D. Guha and J. Y. Siddiqui," Debatosh Guha and Jawad Y. Siddiqui", IEEE TransactionsonAntennasand Propagation, Vol. 52, No. 8, 2004.
[16]. J. S. Dahele, S. Member, and K. Lee," On the Resonant Frequencies of the Triangular Patch Antenna", IEEE Transactionon Antennas and propagation, Vol. AP-35, No. 1, 1987.
[17]. M. Purohit, S. Khant,"Review of Broadband Techniques for Microstrip Patch Antenna",International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering,Vol. 3, Issue 2, February 2014