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E-Shaped Microstrip Patch Antenna for WiMAX Application: Design and Simulation

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Abstract: The design of a microstrip patch antenna based on E-shaped patch for WiMAX application is presented. The proposed antenna is simulated by Electromagnetic simulator, XFDTD (Finite Difference Time Domain Method). The simulation result shows the antenna system resonates at 3.0 GHz frequency this is suitable for WiMAX application. The parameters are calculated for outer dimensions of the E-shaped microstrip patch antenna on the basis of line width to substrate thickness (W/h) ratio by considering loss less dielectric material (FR-4.8 Duroid material). The characteristic line impedance (Z_o) and effective dielectric constant (ε_{eff}) are calculated by considering different values of W/h ratio like 2, 3, 4, 5, 6, 7, 8 and 9. The comparative statement among characteristic line impedance (Z_o) and effective dielectric constant (ε_{eff}) with W/h ratio are presented. Return loss (S11), reflection coefficient and VSWR versus frequency plot are also presented.

Keywords: Microstrip Antenna, E-Shaped patch, WiMAX, W/h ratio, XFDTD, Return loss (S11).

I. INTRODUCTION

The demand for wireless mobile communication services are growing at an explosive rate, with the anticipation that communication to a mobile device anywhere on the globe at all times will be available in the near future. An array of antennas may be used in a variety of ways to improve the performance of communication systems. A very popular type of antenna arrays is the circular array which has several advantages over other schemes such as all-azimuth scan capability and the beam pattern can be kept invariant. Concentric circular array (CCA) that contains many concentric circular rings of different radii and number of elements have several advantages including the flexibility in array pattern synthesis and design both in narrowband and broadband beamforming applications [1–2]. WiMAX (Worldwide Interoperability for Microwave Access) is a telecommunication technology that provides wireless transmission of data using a variety of transmission modes from point to multi point links.

The technology is based on IEEE 802.16 standard. The WiMAX standard specifies 2 to 11 GHz as usable operating frequency range for modulation and channel access etc., WiMAX base station antenna requires a minimum gain of 18dBi with a beam width of 10 degrees [3]. This paper focuses on the concentric and modified concentric microstrip Patch array antennas for WiMAX applications. Microstrip patch antennas are popular, because they have a very low profile, mechanically rugged and can be conformable; they are often mounted on the exterior of aircraft and spacecraft, or are incorporated into mobile radio communications devices. Microstrip Antennas are also relatively inexpensive to manufacture and design because of the simple 2D physical geometry [4-5]. In this work, the microstrip array is simulated at 3.0 GHz with substrate element as glass epoxy having dielectric constant ε_r = 4.8 for all discussed array configurations.

There are several classes of antennas like narrowband antennas, fractal or frequency independent antennas and wideband antennas. Broadband or wideband antennas are termed as those which can cover an octave or two around the designated centre frequency [2]. Present broadband communications involve IEEE 802.11 based Wireless Local Area Networks (WLANs) [3] and IEEE 802.16 based Worldwide Interoperability for Microwave Access (WiMAX) networks [4]. WiMAX serves as a solution for Wireless Metropolitan Area Networks and hence, can accommodate several WLANs for backhaul purposes [5]. The most widely employed spectral band for WLANs is 3.0 GHz [3]. However, depending upon the allocation authorities of the realm, 3.0GHz is also employed for operation of WiMAX networks [6]. Microstrip antennas are low profile antennas which can be easily mounted on surfaces due to their planar geometrical designs [7]. These antennas are manufactured by etching the designed prototype on a dielectric substrate with dielectric constants ranging as $2 \leq \varepsilon_r \leq 12$ [7]. Designs with greater substrate thickness and lesser value of dielectric constants can increase efficiency of the antenna but introduce application constraints as well. Smaller and cheaper designs are required for implementation in practical systems to support wideband communications and offer low reflection losses [8].

II. ANTENNA DESIGN

For design of the substrate for the E-shaped microstrip patch antenna we have used duroid material of dielectric constant ε_r= 4.8 [10]. The frequency of operation or resonant frequency (f_r) is considered as 3.0 GHz. The proposed antenna geometry parameters like height (h) of the substrate, wave length (λ), effective dielectric constant (ε_{eff}), characteristic line impedance (Z_o), width (W), effective length (L_{eff}), length extension (ΔL) and length (L) are calculated on the basis of the line width to dielectric thickness (W/h) ratio [9]. The following three major equations by which we have calculated the parameters for design of the new patch antenna geometry.

A. Calculation of Width (W):

$$Width = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad \text{--------- (1)}$$

With the substituting values of c =3X10^{10} cm/s, f_r= 3.0 GHz and ε_r = 4.8. W = 3.38cm (using equation 1). For W/h = 2, 3, 4, 5, 6, 7, 8 and 9 (W/h ratio will be greater than 1 due to the wide line consideration), the corresponding values of h = 1.94 cm, 1.12 cm, 0.84 cm, 0.70 cm, 0.56 cm, 0.482 cm, 0.44cm, 0.376 cm and also the corresponding values of ε_{eff} are calculated (using equation 2). By using different values of ε_{eff} and the values of λ are 6.3 cm, 6.27 cm, 6.20 cm, 6.16 cm, 6.13 cm, 6.12 cm, 6.10 cm, 6.07 cm the corresponding values of L_{eff} are calculated respectively.

B. Calculation of effective dielectric constant(ε_{eff}):

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + \frac{12h}{w}\right]^{-\frac{1}{2}} \quad \text{---------------------(2)}$$

For above mentioned values of W/h, h and ε_{eff} , the corresponding values of ΔL= 0.87 cm, 0.53 cm, 0.411cm, 0.37 cm, 0.28 cm, 0.2455 cm, 0.2245 cm, 0.19 cm. By using above mentioned values of L_{eff} and ΔL we have calculated the corresponding values of L= 1.43 cm, 2.07cm, 2.28 cm, 2.32 cm, 2.50 cm, 2.57 cm, 2.60 cm, 2.65 cm respectively. Where Z_f= 376.8 Ω is the wave impedance in free space.

C. Calculation of characteristic line impedance (Z_o):

$$Z_0 = \frac{Z_f}{\sqrt{\varepsilon_{eff}}\left[1.393 + \frac{W}{h} + \frac{2}{3}\ln\left(\frac{W}{h} + 1.444\right)\right]} \quad \text{-------------------- (3)}$$

For different values of W/h, and ε_{eff}, the corresponding values of Z_o = 53.23 Ω, 45.55 Ω, 37.46 Ω, 30.55 Ω, 25.94 Ω, 23.22 Ω, 21.08 Ω and 19.19 Ω respectively (using equation 3).

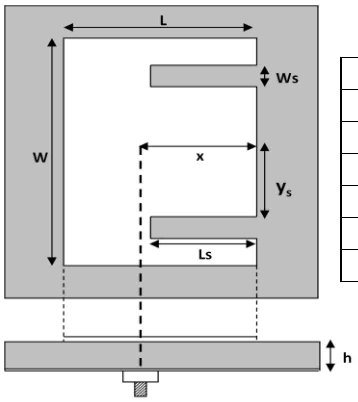
TABLE I (a) Dimensions in cm of the patch for different W/h ratio

W/h	W(cm)	h(cm)	ε_{eff}	λ(cm)
2	3.38	1.94	1.826	6.3
3	3.38	1.12	1.868	6.27
4	3.38	0.84	1.9	6.2
5	3.38	0.70	1.93	6.16
6	3.38	0.56	1.95	6.13
7	3.38	0.48	1.97	6.12
8	3.38	0.44	1.985	6.10
9	3.38	0.37	1.99	6.07

TABLE I (b) Different parameters of the patch for various W/h ratio

W/h	L_{eff}(cm)	ΔL(cm)	L(cm)	Z_o(Ω)
2	3.15	0.87	1.43	53.23
3	3.17	0.53	2.07	45.55
4	3.10	0.41	2.28	37.46
5	3.08	0.37	2.32	30.55
6	3.06	0.28	2.50	25.94
7	3.06	0.24	2.57	23.22
8	3.04	0.22	2.60	21.08
9	3.03	0.19	2.65	19.19

The Structure of the designed E-shaped Patch Antenna as shown in fig. 1



W/h	2
W	2.64 cm
L	1.34 cm
h	1.32 cm
Ys	0.99 cm
Ls	0.65 cm
W_s	0.325 cm

Fig. 1 Proposed E-shaped dual-band microstrip Patch Antenna based on W/h=2 with dimensions.

D. Variation of Z_o and ε_{eff} with W/h ratio for 3.0 GHz:
Since for a wide line, W/h > 1, then the values of W/h = 2, 3, 4, 5, 6, 7, 8 and 9 are considered here for a specific relative permittivity (ε_r) of duroid material is 4.8. By using equation no. (2) and (3) the values of effective dielectric constant (ε_{eff}) and characteristic line impedance (Z_o) have been calculated which are shown in the table 1(a) and (b). The characteristic line impedance (Z_o) plotted as a function of line width to substrate thickness (W/h) ratio as shown in fig. 2. This plot represents the variation of Z_o with W/h for a fixed value of ε_r. The values of Z_o gradually decreasing with the increase of W/h ratio.

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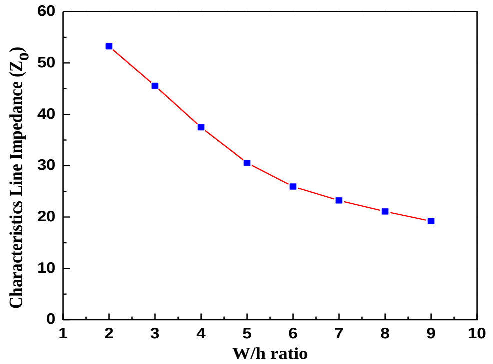

Fig.2 Characteristic line impedance as a function of W/h.

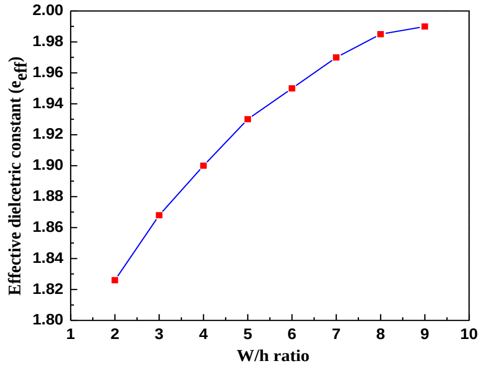

Fig.3 Effective dielectric constant as a function of W/h.

The effective dielectric constant (ε_{eff}) plotted as a function of line width to substrate thickness (W/h) ratio as shown in fig. 3. This plot represents the variation of ε_{eff} with W/h for a fixed value of ε_r. The values of ε_{eff} gradually increasing with the increase of W/h ratio. The characteristic line impedance (Z_o) plotted as a function of effective dielectric constant (ε_{eff}) as shown in fig. 4. This plot represents the variation of ε_{eff} with Z_o for a fixed value of ε_r. The values of ε_{eff} gradually increasing with the decrease of Z_o.

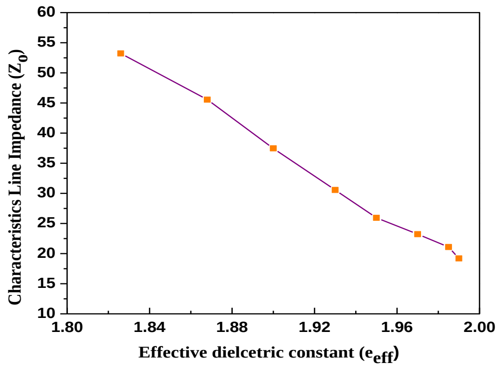

Fig.4 Characteristics line impedance versus effective dielectric constant curve.

III.SIMULATIONS

The proposed E-shaped patch antenna is designed using an EM simulator which works on principle of Finite Difference Time Domain Method. A feed line is to be installed to the antenna in order to get the RF power to the patch and the feed line and a port number is assigned in order to have a reference while calculating the S-parameters.

The antenna is fed at point 1 [(Xf, Yf, Zf) = (2.5, 2.0, 0)] and at point 2 [(Xf, Yf, Zf) = (2.5, 2.0, 1.76)]. The feeding microstrip line is a 46.98 Ω line and the impedance of the antenna is matched to 46.98 Ω by the inset feed. Now the stage has come to setup the excitation. The 3D Solid mesh mode geometry with the simple microstrip antenna feed line, radiation pattern in mash view, 3D vector field display on XY plane and 3D radiation pattern on XY plane are shown in fig. 5, 6 and 7 and 8.

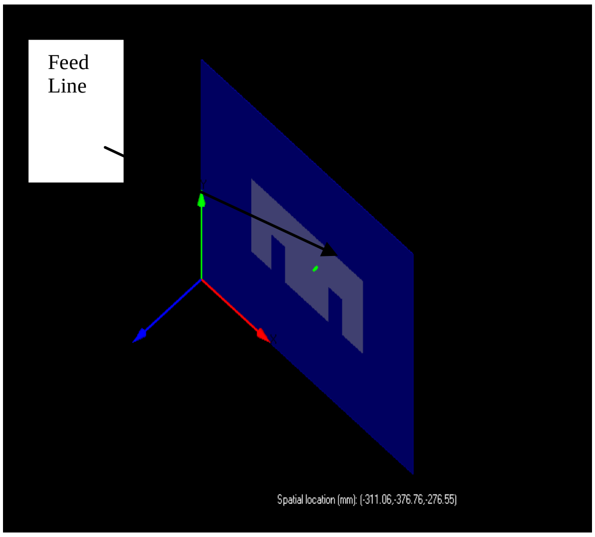

Fig. 5 3D mesh mode geometry with Feed Line

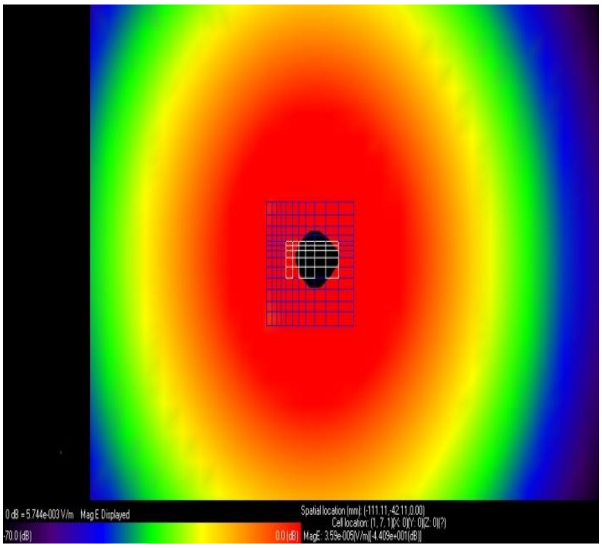

Fig.6 Radiation pattern in mesh view

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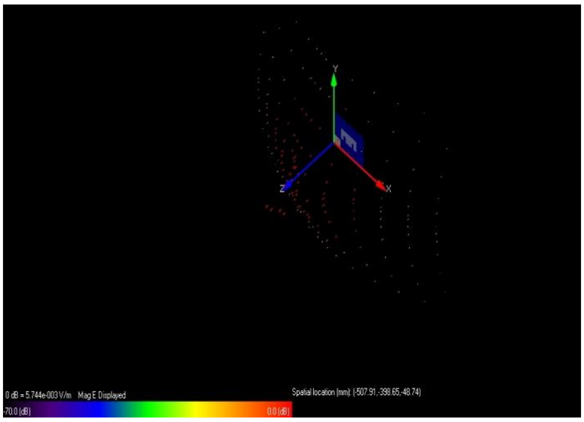

Fig. 7 XY plane 3D vector field display

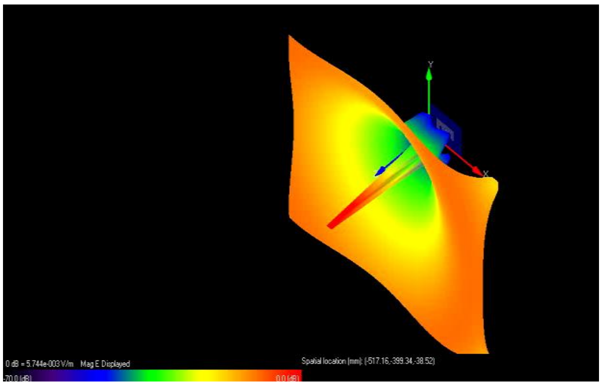

Fig.8 XY plane 3D radiation pattern

IV.RESULTS

On the basis of the design, simulation was performed by XFDTD. The impedance versus frequency plot for sinusoid input as shown in fig. 9. It is seen that, the maximum current distributed at 3.0 GHz frequency band. Return loss (S11) parameter versus frequency plot for sinusoid input is presented as shown in fig. 10. It is seen that return loss is minimum (-0.128 dB) at the specific frequency 3.0 GHz which our expected result because at this frequency the antenna resonated. Power & normalized power versus frequency plot is presented where maximum power is transmitted continuously by the antenna at the frequency 3.0 GHz which is shown in fig. 11.

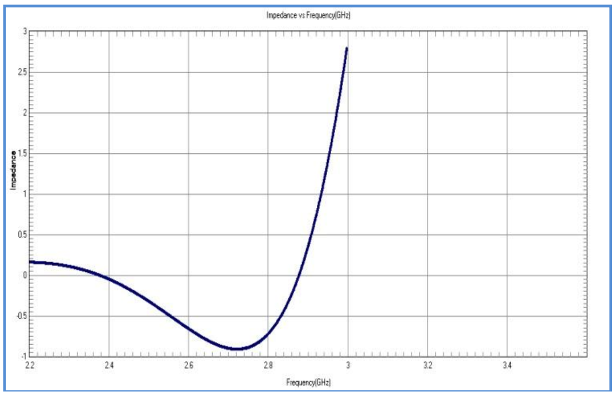

Fig. 9 Frequency domain results for sine wave

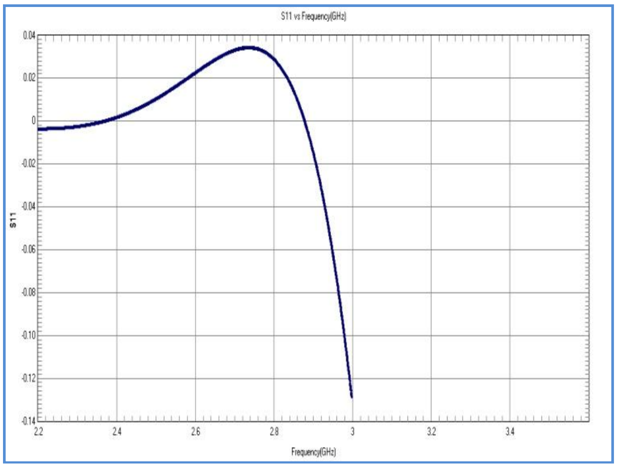

Fig.10 S11 vs Frequency (GHz)

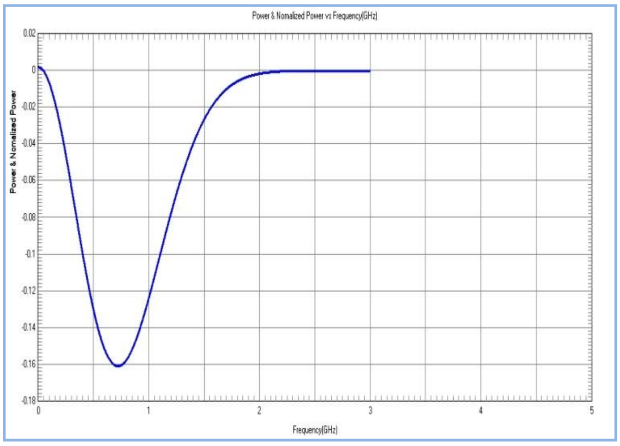

Fig.11 Power& Normalized Power vs Frequency (GHz)

The simulation results of VSWR for the frequency range from 0 to 1.5 GHz is shown in fig. 12. The VSWR of the antenna is closely related to the return loss. The value of VSWR can be seen to be within 1 to 3 GHz in the operating range [11]. The reflection coefficient as a function of the frequency as shown in fig. 13. The reflection coefficient has a value of 0.986dB at a resonant frequency of 3.0 GHz [12].

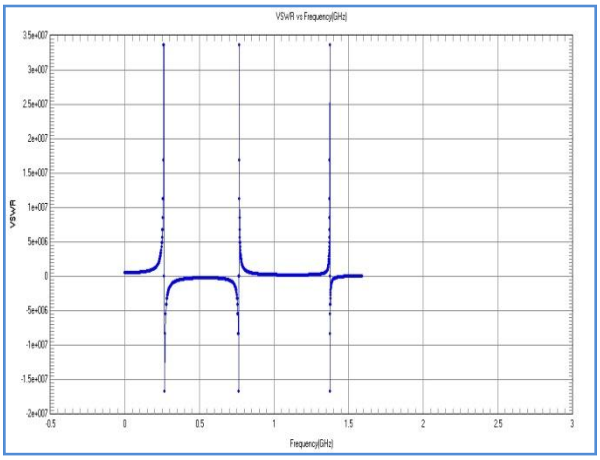

Fig.12 VSWR vs Frequency (GHz)

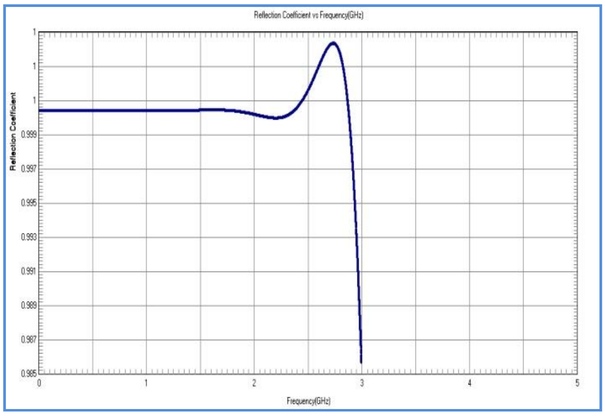

Fig.13 Reflection Coefficient vs Frequency (GHz)

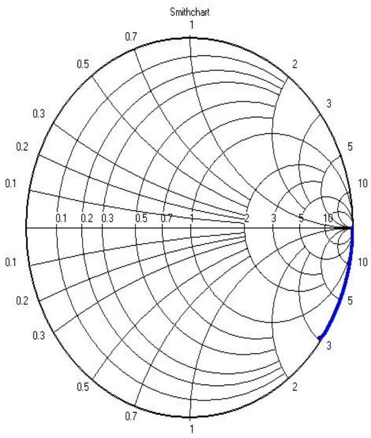

Fig.14 Smith chart representation

The XFDTD also simulates the graph for the input reflection coefficient and the smith chart as shown in fig. 14. The single E-shaped microstrip patch antenna resonates at 300 GHz with minimum impedance at that particular point which is also indicated by the blue shaded region on the Smith chart [13].

V. CONCLUSIONS

In this research work E-shaped microstrip patch antenna for the frequency of 3.0 GHz has been presented. The antenna designed by considering line width to substrate thickness (W/h) ratio at certain relative dielectric constant. The designed antenna is simulated by XFDTD software. After simulation it is seen that, the frequency domain analysis and return loss (S11)vs frequency result shows the proposed E-shaped patch antenna system resonates at 3.0GHz frequency. This frequency is good agreement with the frequency band of WiMAX applications.

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