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Design and Simulation of a U-Shaped Microstrip Patch Antenna for WiMAX Application

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Abstract: *The design of a microstrip patch antenna based on U-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 2.5GHz frequency this is suitable for WiMAX application. The parameters are calculated for outer dimensions of the U-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_0) 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_0) and effective dielectric constant (ε_{eff}) with W/h ratio are presented. This research work also presents how to choose the dimensions of the patch for design a microstrip patch antenna at specific frequency band by a certain dielectric material.*

Keywords: Microstrip Antenna, U-Shaped patch, WiMAX, W/h ratio, XFDTD.

1. Introduction

The demand for wireless mobile communication services are growing at an explosive rate, with the anticipation that communication to a mobile device Any where 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

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(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 2.5 GHz with substrate element as glass epoxy having dielectric constant $\varepsilon_r = 4.8$ 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 2.5GHz [3]. However, depending upon the allocation authorities of the realm, 2.5GHz 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].

2. Antenna Design

For design of the substrate for the U-shaped microstrip patch antenna we have used duroid material of dielectric constant $\varepsilon_r = 4.8$ [10]. The frequency of operation or resonant frequency (f_r) is considered as 2 GHz. The proposed antenna geometry parameters like height (h) of the substrate, wave length (λ), effective dielectric constant (ε_{eff}), characteristic line impedance (Z_0), 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.

2.1. Calculation of Width (W):

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

With the substituting values of c =$3X10^{10}$ cm/s, f_r= 2.5 GHz and ε_r = 4.8. W = 3.52cm by using equation 1 [3]. 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 = 1.76cm, 1.1 cm, 0.88cm, 0.704cm, 0.58cm, 0.502cm, 0.44cm, 0.39cm and also the corresponding values of ε_{eff} are calculated (using equation 2 [7]). By using different values of ε_{eff} and the values of λ are 7.89cm, 7.746cm, 7.644 cm, 7.58cm, 7.51cm, 7.45cm, 7.41cm, 7.37cm the corresponding values of L_{eff} are calculated respectively.

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

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

For above mentioned values of W/h, h and ε_{eff} , the corresponding values of ΔL= 1.1 cm, 0.47cm, 5.95cm, 0.733cm, 0.255cm, 0.5371cm, 0.1948cm, 0.3644cm. By using above mentioned values of L_{eff} and ΔL we have calculated the corresponding values of L= 1.154 cm, 2.1cm, 8.85cm, 1.6cm, 2.4cm, 1.91cm, 2.5cm, 2.17cm respectively. Where Z_f=376.8 Ω is the wave impedance in free space.

2.3. Calculation of characteristic line impedance (Z_0):

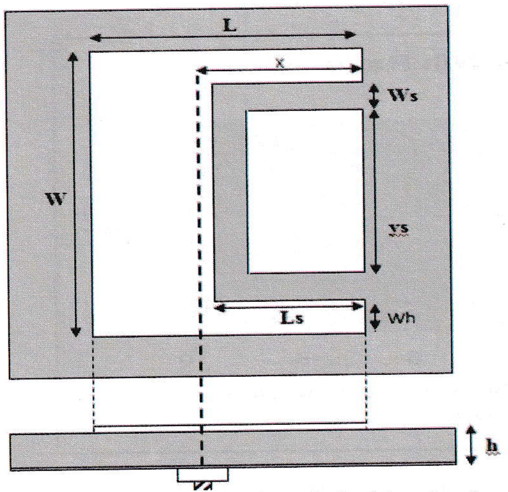
$$Z_0 = \frac{Z_f}{\sqrt{\varepsilon_{eff}}\left[1.393 + \frac{W}{h} + \frac{2}{3}\ln\left(\frac{W}{h} + 1.444\right)\right]}$$ -------------------- (3)

For different values of W/h, and ε_{eff}, the corresponding values of Z_0 = 46.983Ω, 36.12 Ω, 29.452Ω, 24.955Ω, 21.591Ω, 19.073Ω, 17.089Ω and 15.525Ω respectively by using equation 3 [8].

Table 1: Dimensions in cm of the patch for different W/h ratio and resonant frequency in GHz.

W/h	W(cm)	h(cm)	ε_{eff}	λ(cm)	L_{eff}(cm)	ΔL(cm)	L(cm)	$Z_o(\Omega)$
2	3.52	1.76	3.618	6.3	3.15	1.1	1.154	46.983
3	3.52	1.1	3.749	6.19	3.09	0.47	2.1	36.12
4	3.52	0.88	3.85	6.1	3.05	5.95	8.85	29.452
5	3.52	0.704	3.930	6.0	3.0	0.733	1.6	24.955
6	3.52	0.58	3.996	6.0	3.0	0.255	2.4	21.591
7	3.52	0.502	4.0593	5.96	2.98	0.5371	1.91	19.073
8	3.52	0.44	4.101	5.92	2.96	0.1948	2.5	17.089
9	3.52	0.39	4.144	5.8	2.9	0.3644	2.17	15.525

The Structure of the designed U-shaped Patch Antenna as shown in figure 1.



W/h	2
W	3.52 cm
L	1.154 cm
h	1.76 cm
Ys	2.56 cm
Ls	0.6 cm
W_h	0.48 cm

Figure 1: Proposed E-shaped dual-band microstrip Patch Antenna based on

W/h=2 with dimensions.

2.4. Variation of Z_0 and ε_{eff} with W/h ratio for 2.5 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_0) have been calculated which are shown in the table-1. The characteristic line impedance (Z_0) plotted as a function of line width to substrate thickness (W/h) ratio as shown in figure-2 [12]. This plot represents the variation of Z_0 with W/h for a fixed value of ε_r. The values of Z_0 gradually decreasing with the increase of W/h ratio.

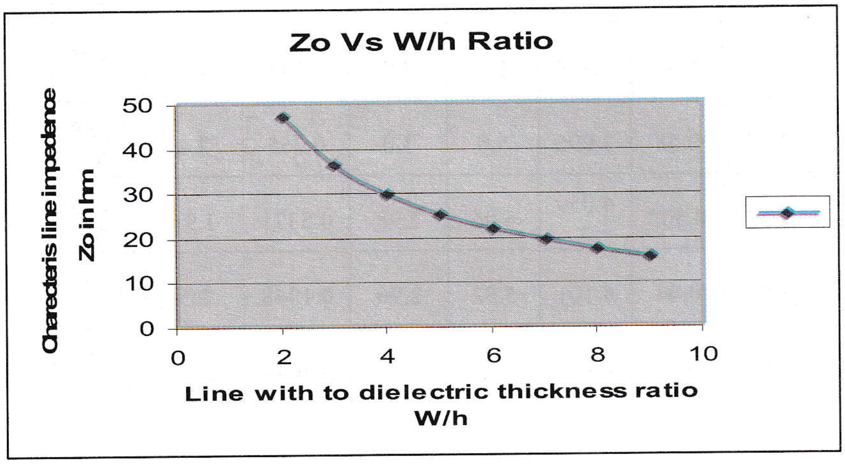


Figure 2: Characteristic line impedance as a function of W/h.

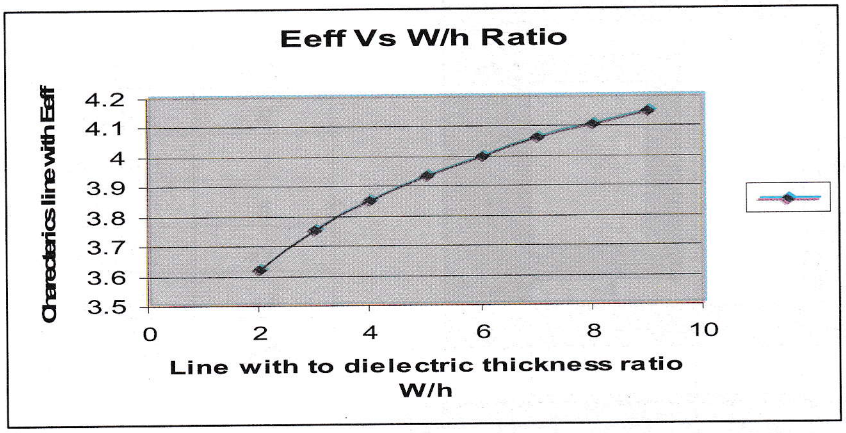


Figure 3: Effective dielectric constant as a function of W/h.

The effective dielectric constant (ε_{eff}) plotted as a function of line width to substrate thickness (W/h) ratio as shown in figure 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_0) plotted as a function of effective dielectric constant (ε_{eff}) as shown in figure 4. This plot represents the variation of ε_{eff} with Z_0 for a fixed value of ε_r. The values of ε_{eff} gradually increasing with the increase of Z_0.

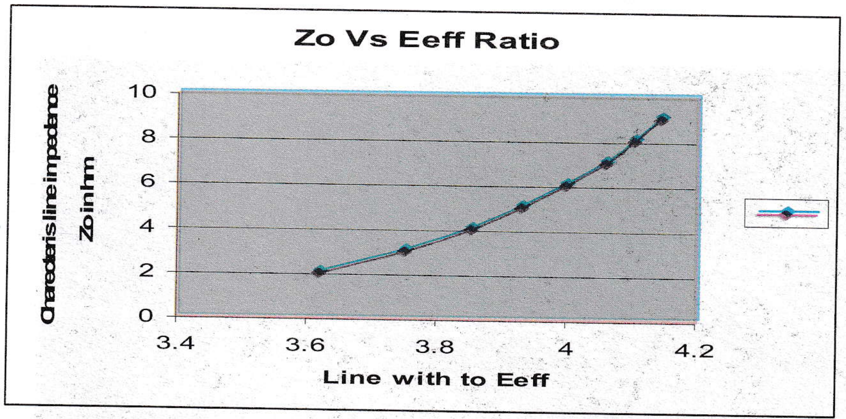


Figure 4: Characteristics line impedance versus effective dielectric constant curve.

3. SIMULATION AND RSULTS:

The proposed U-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

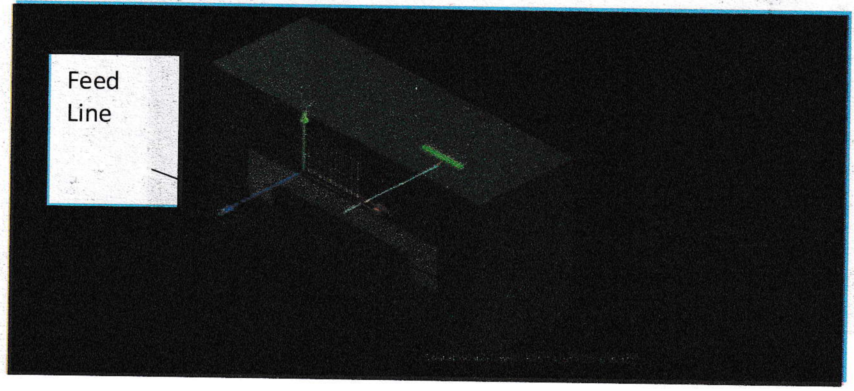


Figure 5: 3D mesh mode geometry with Feed Line

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 [11]. 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 46.983Ω line and the impedance of the antenna is matched to 46.983Ω by the inset feed. Now the stage has come to setup the excitation. The 3D Solid mode geometry with the simple microstrip antenna feed line, 3D vector field display on ZX plane and 3D field display on XY plane are shown in figure 5, 6 and 7.

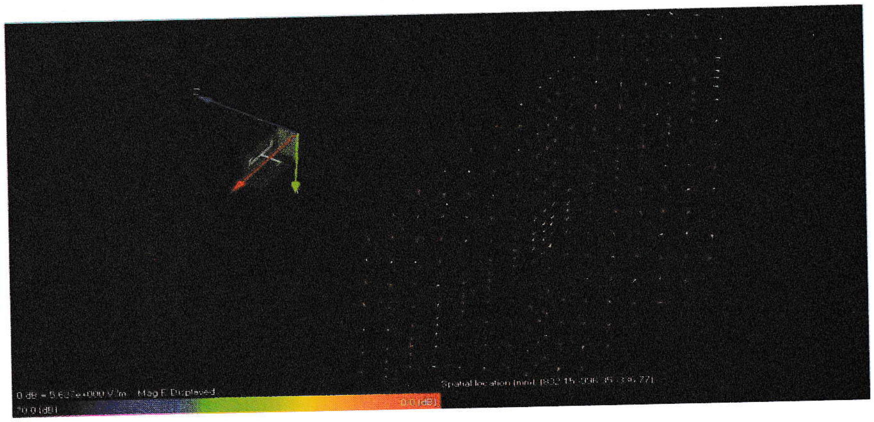


Figure 6: ZX plane 3D vector display

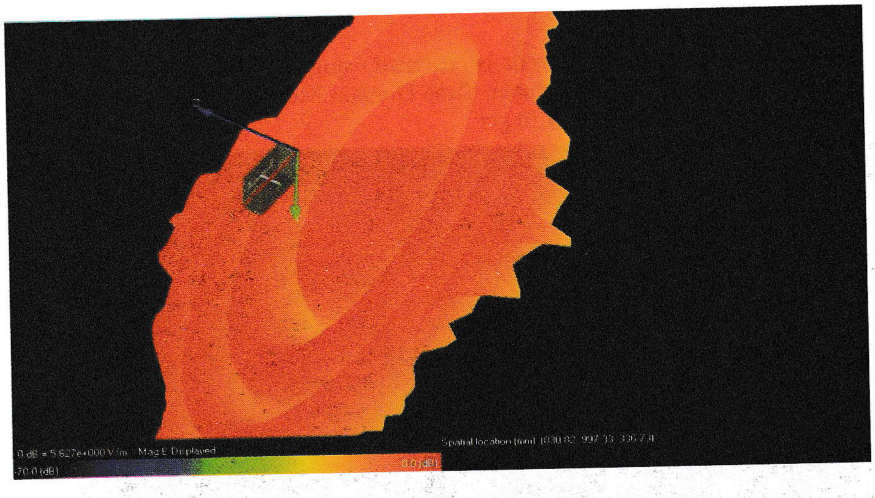


Figure 7: XY plane 3D field display

On the basis of the design, simulation was performed by XFDTD. The voltage versus time plot for Gaussian and Sinusoid input as shown in figure-8 and 9 respectively.

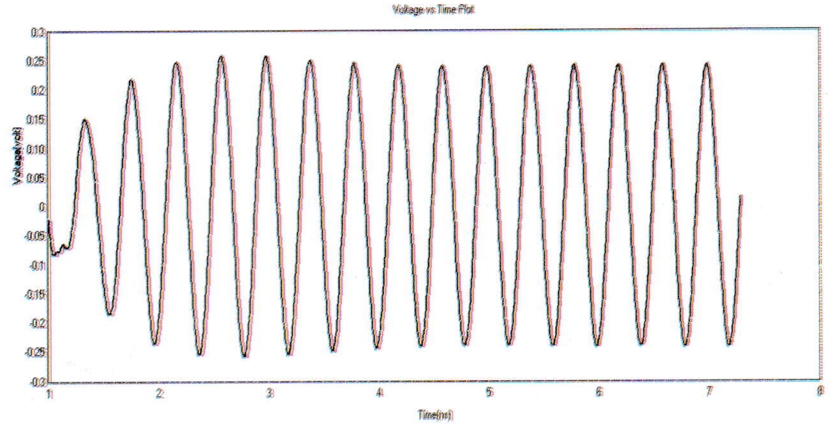


Figure 8: Time domain results for Gaussian wave

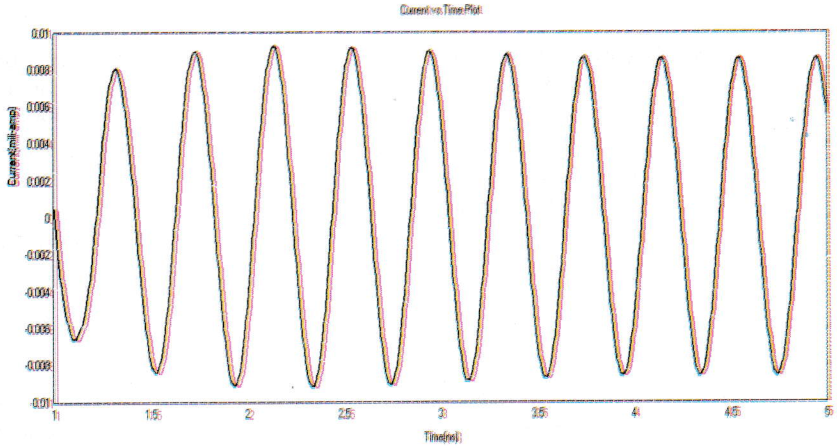


Figure 9: Time domain results for sine wave

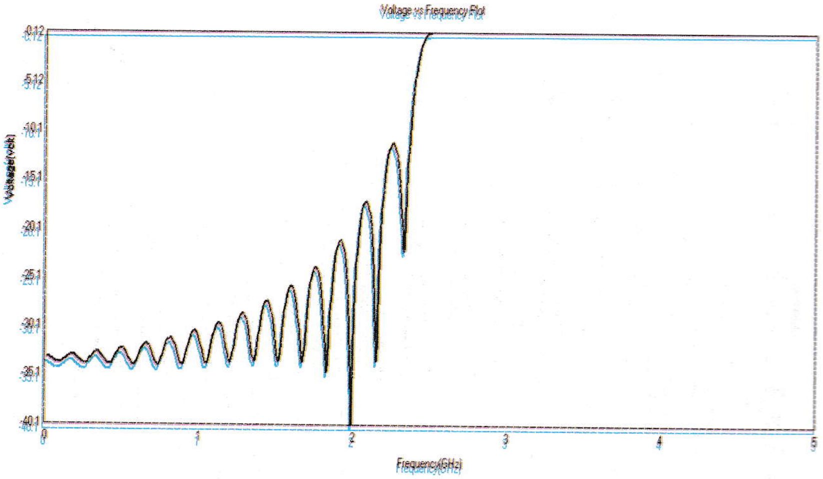


Figure 10: Frequency domain results for sine wave

The surface current distributions of the corresponding frequencies are plotted as shown in figure-10. It is seen that, the maximum current distributed at 2.5 GHz frequency band.

4. Conclusions

In this research work U-shaped microstrip patch antenna for the frequency of 2.5 GHz has been proposed. The antenna designed by considering line width to substrate thickness (W/h) ratio at certain relative dielectric constant. The proposed antenna is simulated by XFDTD software. After simulation it is seen that, the time-domain and frequency domain analysis and voltage vs frequency result shows the proposed U-shaped patch antenna system resonates at 2.5GHz frequency. This frequency is good agreement with the frequency band of WiMAX applications.

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