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USE OF ELECTRO-TEXTILES FOR DEVELOPMENT OF WIBRO ANTENNAS

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Abstract—A fully fabric triangular shaped microstrip patch antenna is proposed for Wireless Broadband (WiBro) communication systems operating in the frequency range of 2.3 GHz to 2.4 GHz with 2.34 GHz as centre frequency. Three highly efficient and flexible antennas, built using three different conductive fabrics and an insulating polyester fabric are evaluated and results reported in this paper. To the best of authors' knowledge, this is the first attempt to utilize textile materials for the development of WiBro antennas.

1. INTRODUCTION

In recent years, electro-textiles have emerged as promising materials for the development of antennas, which allows the smart clothes to communicate freely through wireless networks like WLAN, WiMAX and WiBro. The portable Internet service, known as WiBro (also called mobile WiMAX), which meets IEEE 802.16e standards, covers a 100 MHz bandwidth in the 2.3 GHz band [1]. The availability of novel electro-textiles in the market opens up new trends in wireless communications. In [2], the development of helix chip antennas suitable for WiBro and WLAN applications on FR4 materials is discussed. The development of a rectangular–ring microstrip textile antenna for WLAN band is described in [3]. Recently, the authors of this current manuscript have developed Copper based rectangular microstrip antennas for wearable applications [4]. In this paper, an attempt has been made to develop microstrip patch antennas with triangular geometry employing three different conductive fabrics and an insulating polyester fabric. Triangular microstrip patch

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antennas are found to provide radiation characteristics similar to those of rectangular or circular patches, but with a smaller size. In addition, an equilateral triangular patch is capable of sustaining circular polarization. The results obtained for three such electro-textile based WiBro antennas are reported in this paper. The results demonstrate the suitability of fabric materials for the development of patch antennas for WiBro applications.

2. ANTENNA DESIGN AND CONSTRUCTION

The geometry of an equilateral triangular microstrip antenna and the coordinate system used are shown in Figure 1. The equations involved in the design of antennas are given below. The resonant frequency (f_{10}) for TM_{10} mode by considering an effective value of the side length (a_e) of equilateral triangle is given by [5],

$$f_{10} = \frac{2c}{3a_e\sqrt{\varepsilon_r}} \tag{1}$$

The effective side length (a_e) and the actual side length (a) of the triangle are related by

$$\begin{aligned} a_e = a\Bigg[1 + 2.199\frac{h}{a} - 12.853\frac{h}{a\sqrt{\varepsilon_r}} + 16.436\frac{h}{a\sqrt{\varepsilon_r}} \\ +6.182\left(\frac{h}{a}\right)^2 - 9.802\left(\frac{1}{\sqrt{\varepsilon_r}}\right)\left(\frac{h}{a}\right)^2\Bigg] \end{aligned} \tag{2}$$

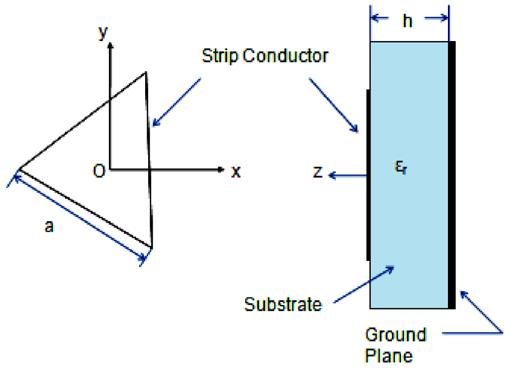


Figure 1. Geometry of a triangular patch antenna.

where h is the thickness of the fabric substrate. The height of the equilateral triangle is

$$H = \left(a\sqrt{3}\right)/2 \tag{3}$$

where a is the side length of the triangle. Its vertices are at

$$\left(-\frac{a}{\sqrt{3}}, 0\right), \left(\frac{a}{2\sqrt{3}}, \frac{a}{2}\right), \text{ and } \left(\frac{a}{2\sqrt{3}}, \frac{-a}{2}\right) \tag{4}$$

Three antennas are designed with centre frequency of 2.34 GHz. All three antennas employ polyester fabric (permittivity value: 1.44) as substrate. The thickness of the polyester fabric substrate is taken as 2.85 mm in order to get the required impedance bandwidth. Flectron and Zelt are the fabric materials used for the conducting parts of

Table 1. Design aspects of electro-textile based triangular patch antennas.

Parameter	**Antenna 1 (Flectron)**	**Antenna 2 (Zelt)**	**Antenna 3 (Shieldit)**
Design Specifications			
Resonant frequency (GHz)	2.345	2.345	2.345
Dielectric constant	1.44	1.44	1.44
Substrate Thickness (mm)	2.85	2.85	2.85
Loss tangent	0.01	0.01	0.01
Ground plane material	Flectron	Zelt	Flectron
Patch material	Flectron	Zelt	Shieldit
Designed and Optimized Values			
Designed value of effective side length (mm)	71.07	71.07	71.07
Optimized value of side length of patch (mm)	65.5	66.0	65.5
Optimized location of the coaxial feed* (mm)	8.1	7.6	8.8

* distance from the centriod of the triangular patch towards its apex

Figure 2. Photographs of electro-textile based WiBro antennas developed.

antenna 1 and 2 respectively. Antenna 3 uses Flectron fabric for its ground plane and Shieldit fabric for the radiating patch. The surface resistivity values of Flectron, Zelt and Shieldit fabrics are 0.1 ohms/sq, 0.01 ohms/sq and 0.5 ohm/sq respectively. The nominal thicknesses of these fabrics are 0.01524 mm, 0.0635 mm and 0.17 mm respectively. The modeling of these three WiBro antennas are performed using the Method of Moments (MoM) based IE3D simulator [6] from Zeland Software Inc., USA. An infinite ground plane is assumed in the simulation process. The antennas are excited by means of a 50 Ω coaxial SMA feed. The feed position in each case is optimized to get good matching characteristics (50 Ω) at the centre frequency. By doing so, the performance characteristics of the antenna like return loss, gain, directivity, cross polar discrimination level are expected to be optimized to a level acceptable for practical applications. After the electromagnetic modeling is completed, these antennas are fabricated with a finite ground plane of dimensions 120 mm $\times$ 120 mm and tested. The area of the ground plane is chosen to be at least five times larger than that of the patch in order to avoid back lobes. The fabricated antennas are depicted in Figure 2. Table 1 tabulates the design specifications chosen, designed values of dimensions, optimized values of dimensions and optimized feed locations for all three antennas.

3. RESULTS AND DISCUSSIONS

3.1. Return Loss Characteristics

Simulations and measurements are carried out over the frequency range of 2.0 GHz to 3.0 GHz for all three antennas developed. Figure 3 depicts the experimental set up used for measurement of return

Figure 3. Experimental set up used for return loss measurement.

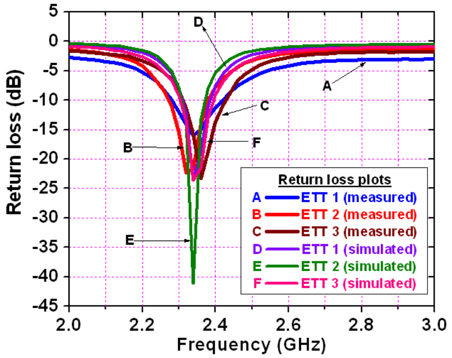


Figure 4. Simulated and measured return loss (S_{11}).

loss characteristics and Figure 4 shows the simulated and measured S_{11} plots of three electro-textile antennas. The simulated resonant frequency in each case of these antennas is 2.34 GHz. The measured resonant frequencies of antennas 1, 2 and 3 are 2.34 GHz, 2.325 GHz and 2.365 GHz respectively. The simulated values of impedance bandwidth of these antennas 1–3 are 76.46 MHz, 64.67 MHz and 91.78 MHz respectively. The corresponding measured values are 140.8 MHz, 107.3 MHz and 91.78 MHz respectively.

3.1.1. Discussions

Considering the simulated and measured values of resonant frequencies, an excellent agreement is found between data obtained with IE3D simulator and measurement. There is a perfect match between simulated and measured resonant frequencies for antenna 1. The deviation between simulated and measured resonant frequencies for antennas 2 and 3 is 0.64% and 1.07% respectively, which are well acceptable for practical considerations. The measured value of return loss bandwidth is greater than the simulated value for all three cases, which may be due to the variations in inductive reactance offered by the coaxial probe. It is observed that each fabricated antenna measures an impedance bandwidth slightly higher than 100 MHz and covers the entire WiBro band.

3.2. Radiation Characteristics

To study the radiation characteristics, all three antennas (1–3) are considered. The total far-field radiation patterns of these modeled antennas, in both principal planes of $\Phi = 0^\circ$ (x-z plane) and $\Phi = 90^\circ$ (y-z plane), are obtained at the simulated resonant frequency of 2.34 GHz and the patterns of antennas 1, 2 and 3 are provided in Figures 5, 6 and 7 respectively. The fabricated antennas are subjected to far-field radiation pattern measurements at the corresponding measured resonant frequencies in a rectangular shielded anechoic chamber. Figures 8–10 show the measured patterns of all the three antennas in azimuth and elevation planes. Figure 11 shows the simulated and measured gain values of all three antennas under investigation. The variations of simulated directivity over frequency for all three antennas are shown in Figure 12. Measured value of directivity of antennas 1–3 are obtained from the corresponding measured radiation patterns by using the following standard formula:

$$Directivity = \frac{40000}{(\theta_E)(\theta_H)} \tag{5}$$

where θ_E and θ_H are 3 dB beam-widths in degrees in E and H planes respectively. Measured value of efficiency of antennas 1–3 are computed using the corresponding measured values of gain and directivity.

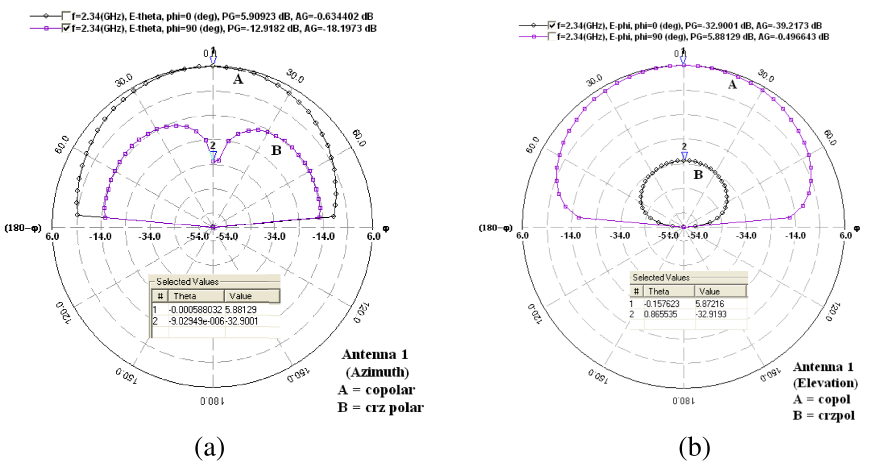
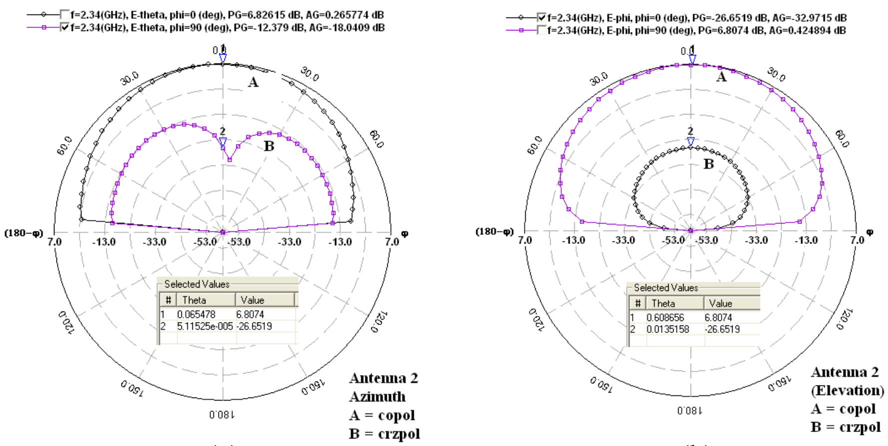
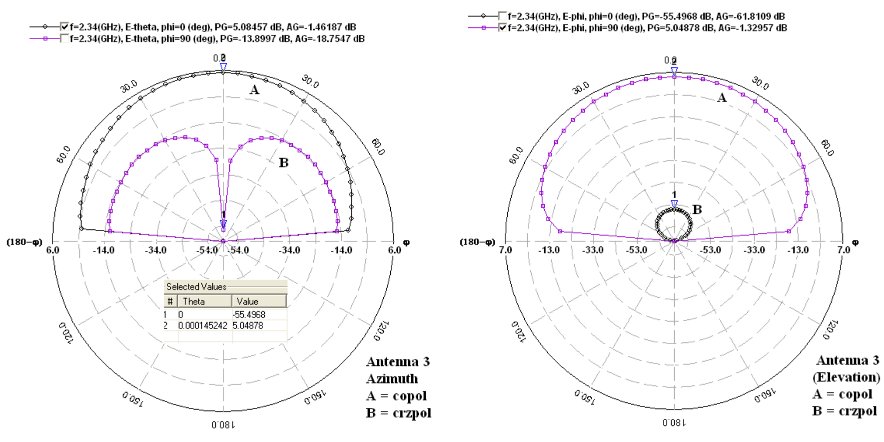


Figure 5. Simulated far-field patterns of Electron antenna (# 1). (a) Azimuth. (b) Elevation.



(a) (b)

Figure 6. Simulated far-field patterns of Zelt antenna (# 2). (a) Azimuth. (b) Elevation.



(a) (b)

Figure 7. Simulated far-field patterns of Shieldit antenna (# 3). (a) Azimuth. (b) Elevation.

3.2.1. Discussions

A reasonable match is obtained between predicted and measured values of peak gain in all three cases. But in some cases, the average gain over the band shows considerable discrepancies. These deviations

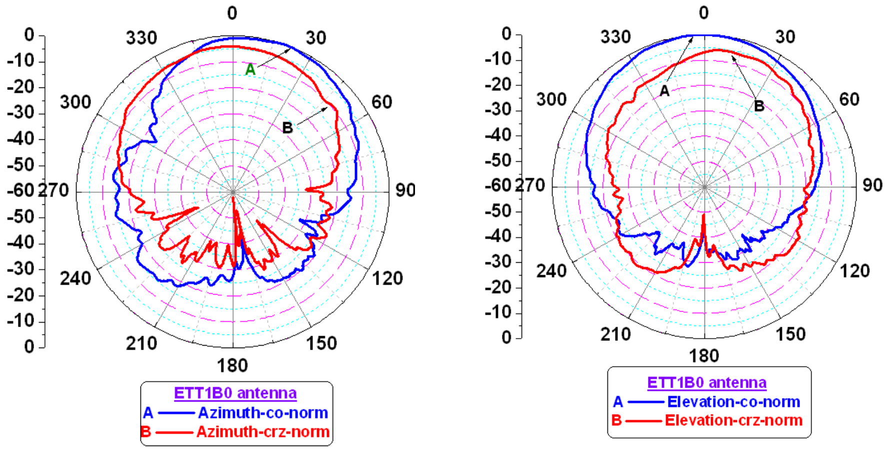


Figure 8. Measured radiation patterns of triangular antenna (# 1) in principal planes.

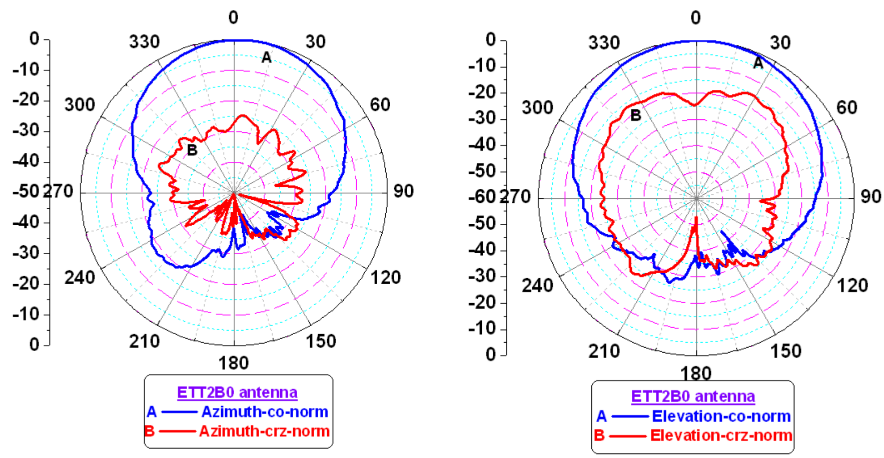


Figure 9. Measured radiation patterns of triangular antenna (# 2) in principal planes.

may be due to infinite ground plane size assumed in the simulation process. The simulation process yields cross polar components of very small magnitude which are not practically achievable. However, in the case of measurements, the discrimination between coplanar and cross polar components and the 3 dB beamwidth values for all three types of antennas are reasonably good for practical considerations.

On comparing the performance characteristics of all three investigated antennas, it is observed that Zelt fabric based antenna yields better performance characteristics (gain of 7.49 dBi at design frequency) as it has got high value of conductivity. The performance characteristics of the antennas under investigation are tabulated in Table 2. In

Table 2. Performance characteristics of electro-textile based WiBro antennas.

Parameter	**Antenna 1 (Flectron)**	**Antenna 2 (Zelt)**	**Antenna 3 (Shieldit)**
Simulated resonant freq. (GHz)	2.34	2.34	2.34
Measured resonant freq. (GHz)	2.34	2.325	2.365
Simulated bandwidth (MHz)	76.46	64.67	91.78
Measured bandwidth (MHz)	140.8	107.3	117.0
Simulated gain (dBi)	5.91	6.83	5.12
Measured gain (dBi)	5.01	7.49	7.95
Simulated directivity (dBi)	8.38	8.41	8.38
Measured directivity (dBi)	10.98	8.414	8.997
Simulated efficiency (%)	58.0	71.2	47.0
Measured efficiency (%)	45.62	89.02	88.36
Simulated 3 dB beamwidth in azimuth (deg)	73.85	73.41	73.95
Measured 3 dB beamwidth in azimuth (deg)	56.2	64.26	57
Simulated 3 dB beamwidth in elevation (deg)	82.09	81.79	82.15
Measured 3 dB beamwidth in elevation (deg)	64.8	73.98	78
Simulated cross polar discrimination in azimuth (dB)	38.78	33.46	60.55
Measured cross polar discrimination in azimuth (dB)	5.4	25.23	6.24
Simulated cross polar discrimination in elevation (dB)	38.79	33.46	60.55
Measured cross polar discrimination in elevation (dB)	8.1	20.79	16.0

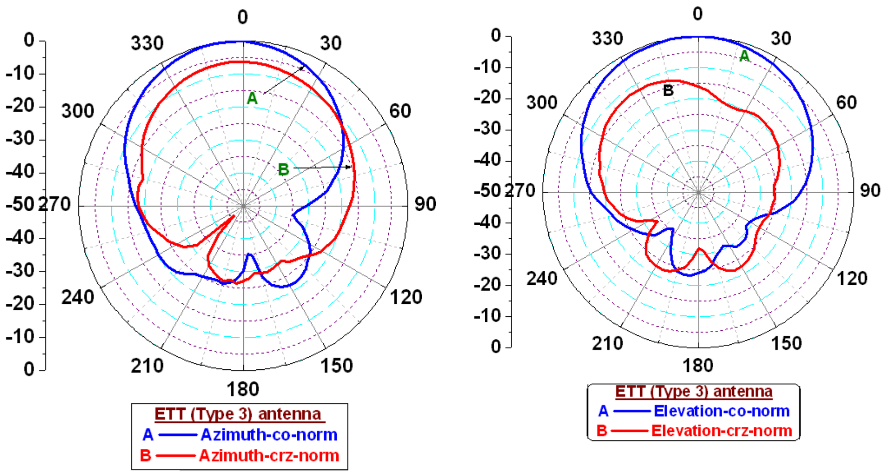


Figure 10. Measured radiation patterns of triangular antenna (# 3) in principal planes.

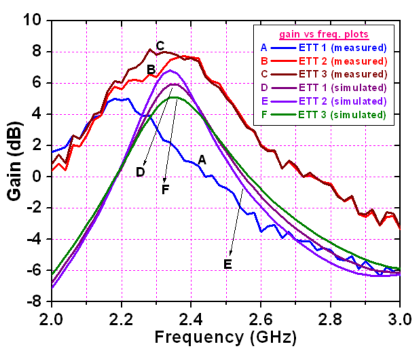


Figure 11. Variations of simulated and measured gain as functions of frequency.

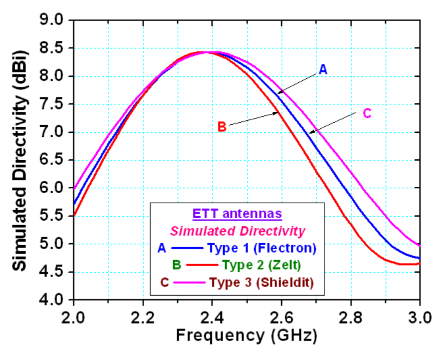


Figure 12. Variations of simulated directivity over frequency.

general, all the tested fabric antennas yield moderate and acceptable gain in this WiBro band and therefore they are good enough for use in corresponding communication link.

4. CONCLUSION

The use of electro-textile and insulating fabric materials for the development of WiBro antennas has been demonstrated for the first time in this research work. These designs result in good impedance and radiation characteristics of antennas. These antenna structures are compatible for wearable applications too as they are constructed using only light weight and flexible textiles.

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