Design and Performance Analysis of a Novel Elliptical Microstrip Patch Antenna Targeting Applications in ISM Band

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Abstract. The growth of portable wireless communication devices has pushed researchers pay great attention to design miniature compact antennas. The most prized among miniature antenna choices is the microstrip patch antenna. These antennas have significant advantages such as conformability to host surface, light weight, low profile and easy installation. In this paper a novel design of a compact elliptical microstrip patch antenna is proposed for Industrial, Scientific and Medical (ISM) band (2.45GHz) applications e.g., Radio Frequency Identification (RFID) Applications. The proposed antenna consists of elliptical patch on FR-4 (PCB) substrate followed by partial ground at the back of the substrate. The overall size of the proposed antenna is 45×38 mm^2. It also compares the performance of the designed antenna for four different dielectric materials such as Dacron fabric ($\varepsilon_r = 3$), Dupont 951($\varepsilon_r = 7.8$), Teflon ($\varepsilon_r = 2.1$) and Taconic RF-35P ($\varepsilon_r = 3.5$) material to investigate their characteristics and performance. After analysis on the different materials, Dacron showed the best performance among all.

Keywords: ISM Band, Elliptical Patch Antenna, Substrate, Low Profile, Narrow band, Return Loss.

1 INTRODUCTION

RFID stands for Radio Frequency Identification and is a term that describes a system of identification (Bohn 2008).It is based on storing and remotely retrieving information or data as it consists of RFID tag, RFID reader and back-end Database (Schwieren *et al.* 2009). It is given to the wireless, radio wave technology that allows for a small RFID chip to be embedded in any physical object and uniquely identified by an RFID reader. RFID systems span a wide spectrum of application areas which has become high demand in the recent years in many fields specially in smart dust, defense, clothes, navigation systems for the visually impaired, edible RFID tags, retail, travel, agriculture, etc. RFID is continuing to become popular because it increases efficiency and provides better service to stakeholders (Bohn 2008).The range of the RFID tags depends on their frequency. This frequency determines the resistance to interference and other performance attributes (Zeisel *et al.* 2006). The use/selection of RFID tag depends on the application; different frequencies are used on different RFID tags (Chen *et al.* 2011). Generally, there are four common bands for RFID systems. They are the Low-frequency (LF) band of 125 kHz to 134 kHz, high-frequency (HF) band for 13.56 MHz, Ultra-high frequency (UHF) for 860MHz to 960 MHz and microwave (MW) band for 2.45 GHz or 5.8 GHz (Mokhtar *et al.* 2013). The microwave bands are popular than other RFID bands in many areas because of its high readable range, fast reading speed, large information storage capability and low cost.

There is no perfect antenna for all the applications of RFID. It is the application that defines the antenna specifications(Tiang *et al*.2011), (Naji *et al.* 2013), (Lu *et al.* 2009). However, the demand for low cost and low profile antenna for RFID applications can be met by microstrip patch antennas. Elliptical microstrip patch antennas are the ones under consideration as their geometry presents greater potentials for a variety of electrically small low-profile antenna applications. The elliptical shape has several advantages like providing larger flexibility in the design, more degrees of freedom compared to the circular geometry (Agrawal *et al.* 2011).

In this paper an Elliptical microstrip patch antenna is proposed at 2.45 GHz (i.e., ISM band) on FR-4 (PCB) substrate. The outline of the paper is structured as the following. Section 2 describes the antenna geometry. Substrate materials selected are mentioned in section 3. Designed antennas with different permittivity are shown in section 4. The antenna performances are evaluated and compared in section 5 & 6. A conclusion is given in section 7. The antenna structures are designed and analyzed using CST Microwave Studio package.

2 ELLIPTICAL MICROSTRIP PATCH ANTENNA

Elliptical patch antenna is shown in Fig. 1, where *a* is the semi major axis, *b* is the semi minoraxis and a_{eff} is the effective semi-major axis.

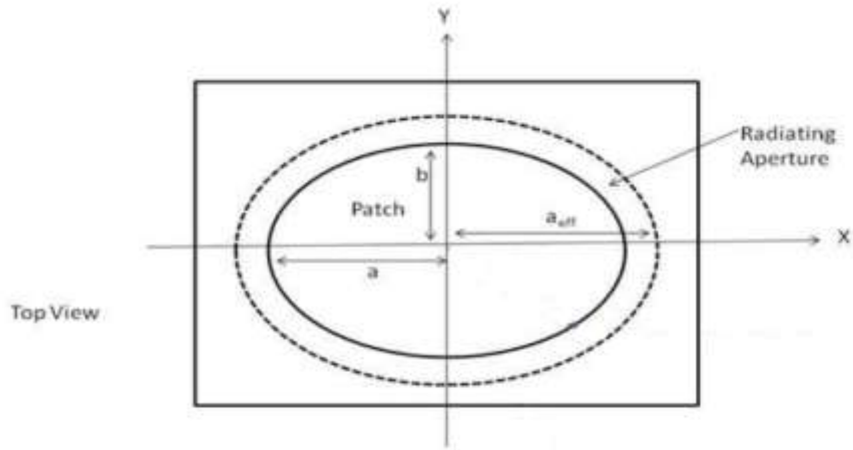


Fig. 1: Top View of Elliptical microstrip patch antenna.

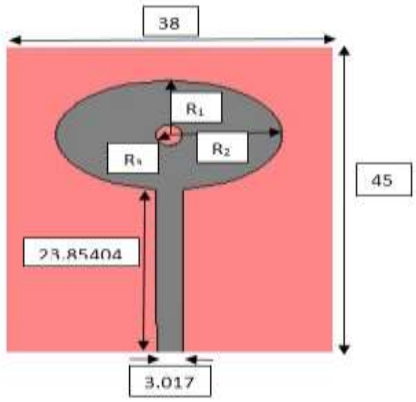
The empirical formulas for calculation of resonant frequency (Mythili *et al.* 1998) are listed below:

$$a=\frac{P}{fr\sqrt{\varepsilon\mu}} \tag{1}$$

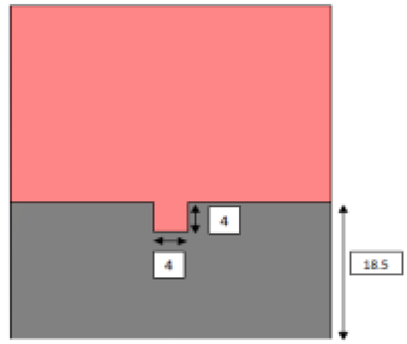
$$a_{eff}= a\left[1+\frac{2h}{\pi\varepsilon_r a}\left\{\ln\frac{a}{2h}+(1.41\varepsilon_r+1.77)+\frac{h}{a}(0.268\varepsilon_r+1.65)\right\}\right]^{1/2} \tag{2}$$

Where, *a* is the semi major axis, *h* is the substrate height, ε_r is the substrate permittivity, a_{eff} is the effective semi major axis and *P* is an empirical constant ranging from 0.27 to 0.29. Normally *P* is taken as 0.275 which agrees very well with the empirical value.

The proposed elliptical microstrip patch antenna operates at 2.45GHz on FR-4 (PCB) substrate. The specifications of the substrate for dielectric permittivity, ε_r is 4.3 and loss tangent is 0.019.Fig. 2 shows the front view and back view of the proposed antenna. In Table I the antenna measurements are shown.



(a) Front view.



(b) Back view.

Fig 2: Elliptical microstrip patch antenna on FR-4 substrate.

Table I
Measurements for Designing the Elliptical Patch Antenna

Parameters(mm)	Dielectric Constant, ε_r= 4.30 (FR-4)
Patch Semi Major Axes, R_1	13
Patch Semi Minor Axes, R_2	8
Slot Radius, R_3	1.5
Substrate Length	45
Substrate Width	38
Substrate Thickness	1.5
Feed Width	3.017
Feed Length	23.85404

The conductive elliptical plane and partial ground plane are made of copper tape. The elliptical patch of the antenna is fed by a 50 ohm microstrip feed line and consists of a circular notch with radius of 1.5 mm. A partial ground plane is placed at the back of the substrate and the dimension is 18×38 mm^2. In addition, the partial ground has a square notch and the dimension of the slot is 4×4 mm^2. Commercial electromagnetic simulation package CST Microwave Studio is applied for designing, implementing and evaluating all the antennas.

3 SUBSTRATE MATERIAL SELECTIONS

In this paper different substrate materials are used. High frequency circuit materials which have low loss tangent, good chemical resistance, product uniformity, dimension stability, low dissipation factor, efficient in high reliability, defense applications and also have UWB, ISM band applications are chosen as substrates for antenna. In this section the characteristics of four substrates, which were used for the patch are discussed.

3.1 Dacron

Polyethylene terephthalate commonly abbreviated PET, PETE. PET is a hard, stiff, strong, dimensionally stable material that absorbs very little water. It can be highly transparent and colorless but thicker sections are usually opaque and off-white.

3.2 Taconic RF-35P

Taconic RF-35P is an organic-ceramic laminate in the ORCER family of Taconic products based on wovenglassreinforcement, having expertise in both ceramic filltechnology and coated PTFE fiberglass. It is the best choice for low cost, high volume, high frequency applications.

3.3 Teflon

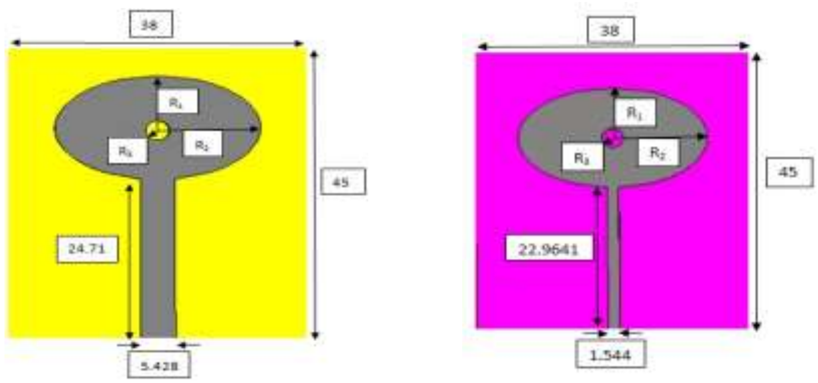
Polytetrafluoroethylene (PTFE), mostly known as Teflon. It is a tough, waxy, nonflammable, colorless, a fluoroplastic with many properties which give an increasingly wide range of uses.

3.4 Dupont 951

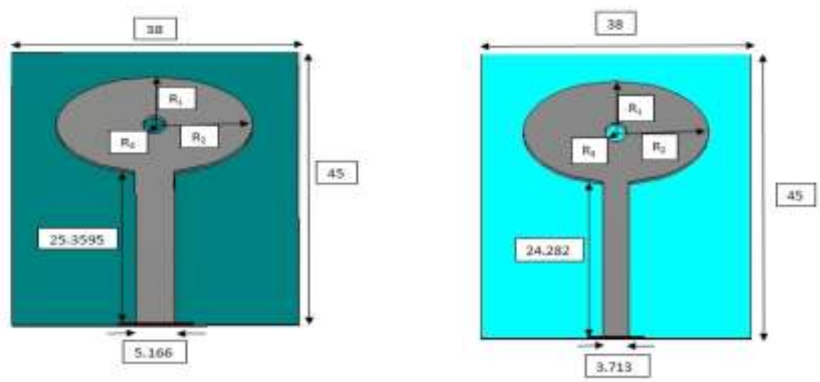
Dupont 951 is a low-temperature cofired ceramic tape. Under proper circumstances 951offers the benefits like cavities, high density interconnections, cofire processing and refire stability, component integration–buried resistors, capacitors, and inductors.

4 IMPLEMENTATION OF ANTENNA WITH DIFFERENT SUBSTRATE MATERIALS

The design of the proposed antenna is presented in Figure 3 with different substrate materials and the measurements are given in Table II. The antennas operate at 2.45 GHz. The permittivity of a material is usually given relative to that of free space which is known as relative permittivity or dielectric constant; ε_r. Different substrates having different dielectric constants affect the antenna performance in various ways. Here, Dacron fabric with ε_r= 3,



Dupont 951 with ε_r= 7.8, Teflon with ε_r= 2.1 and Taconic RF- 35P with ε_r= 3.5 are used as antenna substrates.



(a) Dacron (b) Dupont 951

(c) Teflon (d) Taconic RF-35P

Fig. 3: Elliptical microstrip patch antenna for substrate permittivity, ε_r= 3 (a),ε_r= 7.8 (b), ε_r= 2.1 (c), ε_r= 3.5 (d).

Table II
Measurements for Designing the Elliptical Patch Antenna

Parameters (mm)	**Dielectric Constant, ε_r= 3 (Dacron)**	**Dielectric Constant, ε_r= 7.8 (Dupont 951)**	**Dielectric Constant, ε_r= 2.1 (Teflon)**	**Dielectric Constant, ε_r= 3.5 (Taconic RF-35P)**
Patch Semi Major Axes, R_1	13	13	13	13
Patch Semi Minor Axes, R_2	8	8	8	8
Slot Radius, R_3	1.5	1.5	1.5	1.5
Substrate Length	45	45	45	45
Substrate Width	38	38	38	38
Substrate Thickness	1.5	1.5	1.5	1.5
Feed Width	5.428	1.544	5.166	3.713
Feed Length	24.71	22.9641	25.3595	24.282

5 SIMULATION RESULTS

5.1 Performance analysis of elliptical microstrip patch antenna with FR-4 substrate

From Fig. 4, it can be seen that the minimum return loss value of the proposed antenna is about -27.281581 dB at 2.45 GHz. It has a bandwidth of 850 MHz (ranging from 2.15 GHz – 3.04 GHz) at 2.45 GHz resonant frequency which reveals that the designed antenna is suitable for the RFID application in a wide range of frequencies.

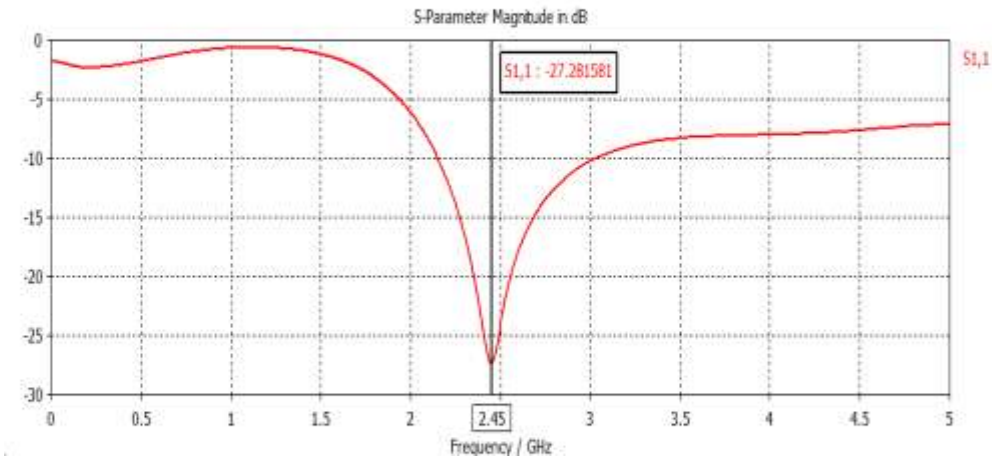


Fig 4: Simulated return loss of the antenna.

From Fig. 5, it is seen that the VSWR value of the proposed antenna is about 1.09.

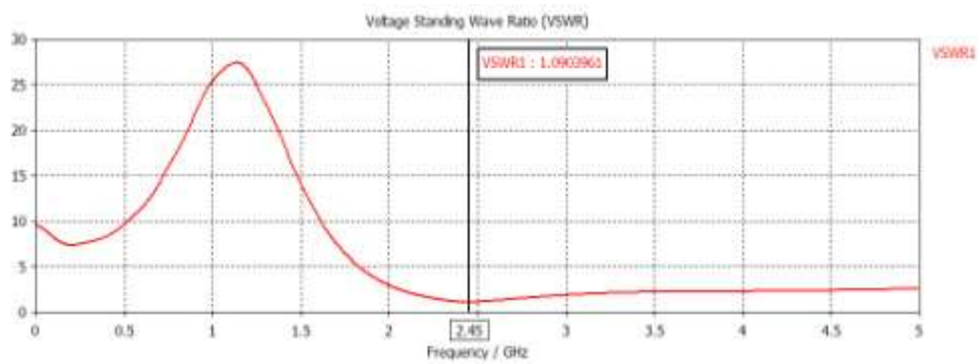


Fig 5: VSWR of the antenna.

Fig. 6 shows the far-field radiation pattern of the antenna. From this figure it can be seen that the directivity and gain of the antenna is about 2.755 dBi and 3.086 dB respectively. The total antenna efficiency can be calculated as 1.077.

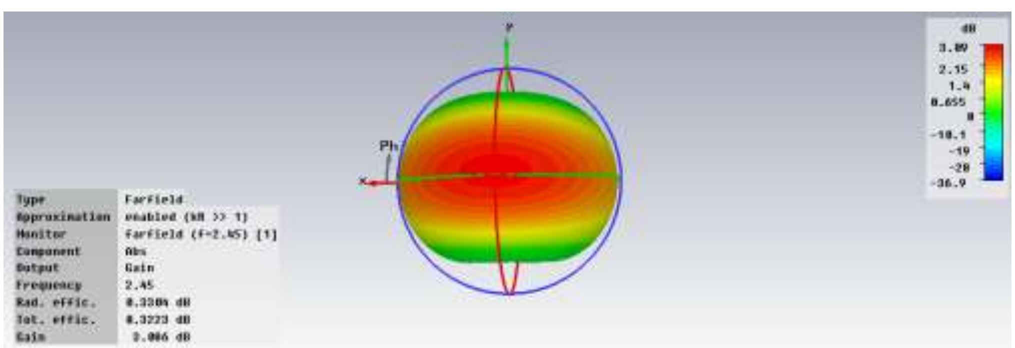


Fig 6: Far Field radiation pattern (3D) of the antenna.

Fig. 7 shows the far-field gain of the proposed antenna. The main lobe magnitude is 3.1 dB, main lobe direction is 178 deg., 3 dB angular beamwidth (i.e., HPBW) is 86.1 deg.

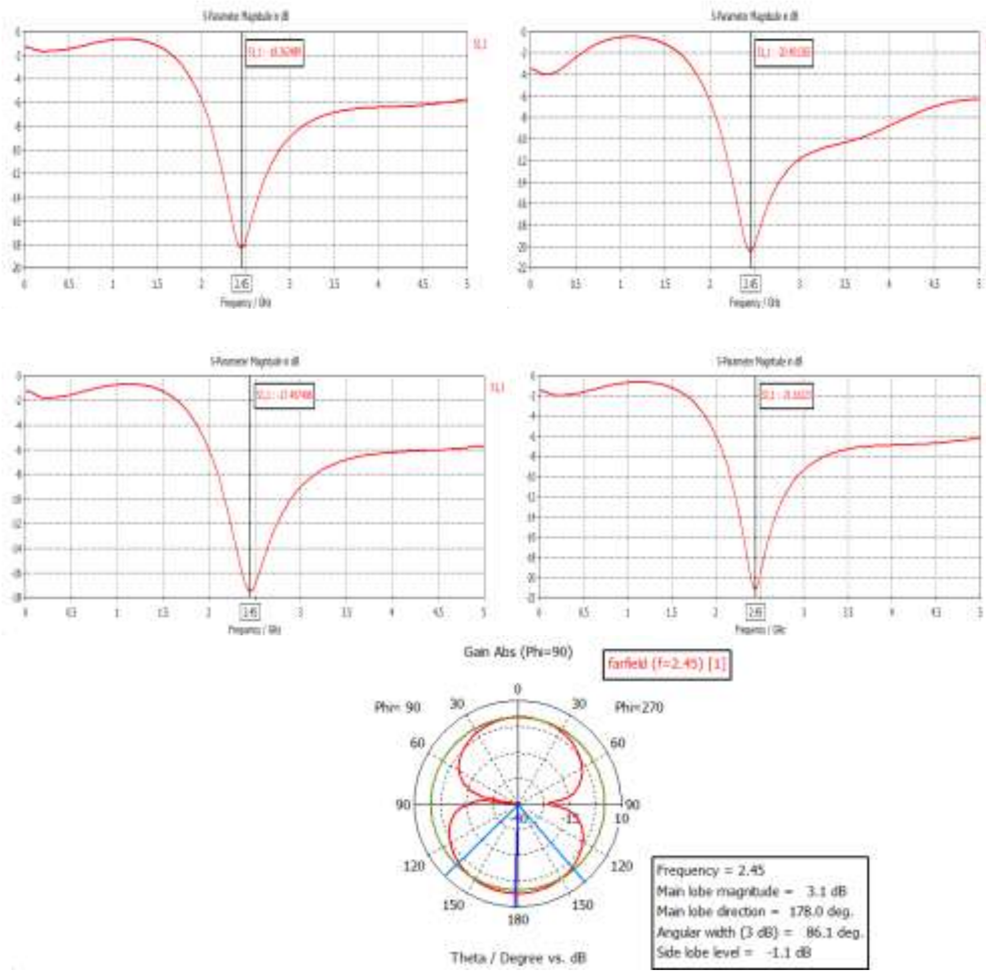


Fig 7: Far Field radiation pattern (polar view) of the antenna.

The return loss, VSWR, far-field radiation pattern, antenna gain, directivity and antenna efficiency of the proposed antenna show reasonable characteristics. This antenna can be used as the RFID reader at ISM band. This antenna can also be used as Wireless LAN, Bluetooth and Wi-Fi antennas at ISM band.

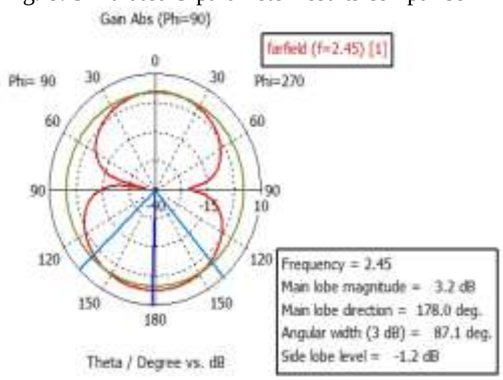
5.2 Performance analysis of proposed elliptical microstrip patch antenna for different substrate materials

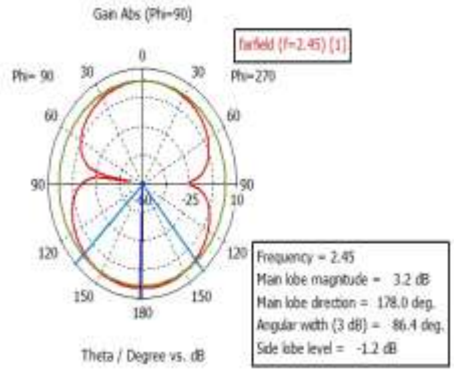
5.2.1 S-parameter analysis of elliptical microstrip patch antenna with different substrate permittivity

(a) Dacron (b) Dupont 951

(c) Teflon (d)Taconic RF-35P

Fig. 8: Simulated S-parameter results comparison





for elliptical microstrip patch antenna.

The S-parameter of different substrate is simulated at 2.45 GHz. For *Dacron*, resonance frequency is 2.45 GHz with a return loss of -18.26 dB. In case of *Teflon* substrate the impedance matching is quite poor with a return loss of -17.497 dB. *Dupont 951* substrate resonates at 2.45 GHz with a return loss of -20.401 dB. *The Taconic RF-35P*substrate exhibits a good impedance matching with a return loss of -21.16 dB at resonance frequency 2.45 GHz which is the best among all five substrates.

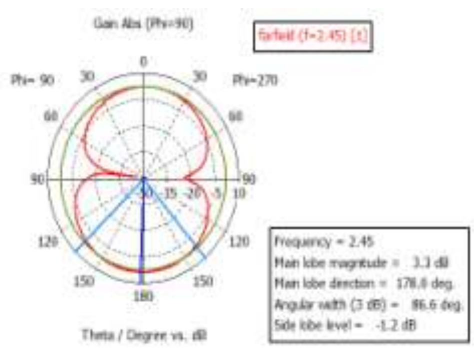
5.2.2 Radiation pattern analysis of elliptical microstrip patch antenna with different substrate permittivity

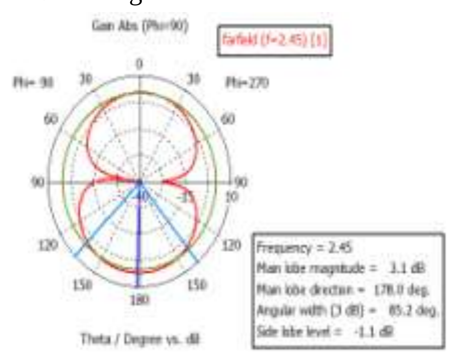
(a) Dacron (b) Dupont 951

(c)Teflon (d) Taconic RF-35P

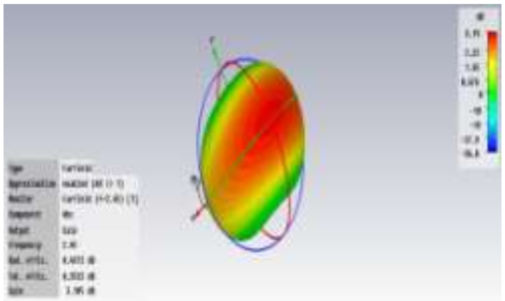
Fig. 9: Comparison of radiation pattern of the antenna with different substrate.

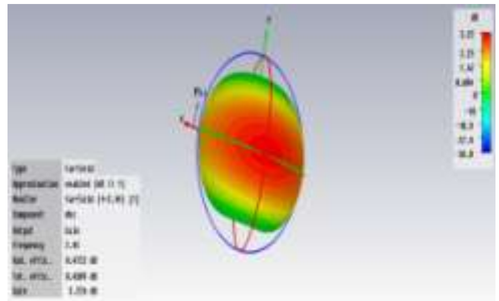
The simulated radiation pattern is depicted in fig. 9. The power is radiated mostly in the upper and lower hemisphere; the power is directed towards 178 degree with a main lobe magnitude of around 3.1dB to 3.3dB for all the cases. At 2.45 GHz frequency, the radiation pattern of the antenna with *Dacron* substrate has a main lobe magnitude of 3.3dB (fig. 9(a)), which is the best among all the patterns. It also exhibits a reduced side lobe level which illustrates its effectiveness over the antenna with other substrates. The angular width of this antenna is 86.6





degree at 3dB (half power) level. The elevation pattern of *Dupont 951* fabric at 2.45 GHz frequency is shown in fig. 9(b); the power





beam is directed toward 178 degree with a magnitude of 3.1 dB where the half power beam width is 85.2 degree. Fig. 9(c) shows the elevation pattern of *Teflon* fabric resonating at 2.45 GHz shows a main lobe direction towards 178 degree and with a main lobe magnitude of 3.2 dB. Fig. 9(d) shows the radiation pattern of *Taconic RF-35P* with a main lobe magnitude of 3.1 dB and is lowest compared to the other materials. At 3 dB the angular width of *Taconic RF-35* is 86.4 degree.

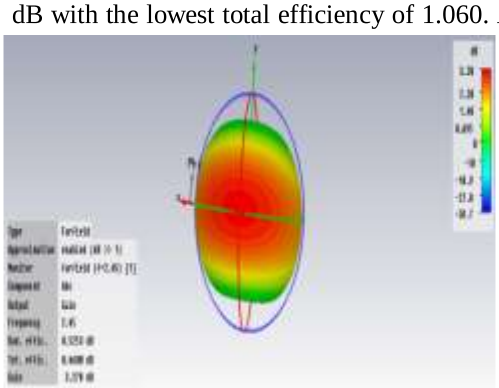
5.2.3 3D radiation pattern analysis of elliptic microstrip patch antenna with different substrate permittivity

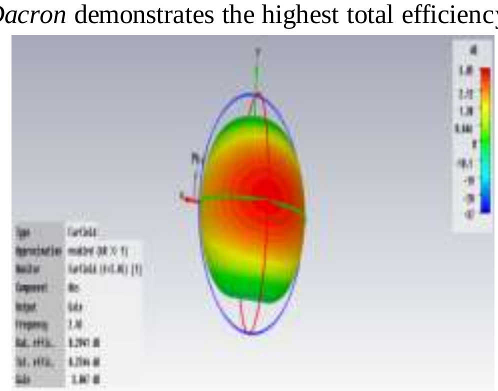
(a) Dacron (b) Dupont 951

(c)Teflon (d) Taconic RF-35P

Fig. 10: Comparison of 3D radiation pattern for elliptical microstrip Patch antenna.

The fig. 10 shows the 3D directional radiation pattern of the narrowband elliptical microstrip patch antenna on different substrates. Gain of *Dacron* fabric and *Taconic* fabric are quite close but *Dacron* demonstrates comparatively the highest gain of 3.278 dB. The antenna with *Teflon* fabric has gains of 3.185dB. *Dupont 951* fabric material has the lowest gain of 3.047 dB with the lowest total efficiency of 1.060. *Dacron* demonstrates the highest total efficiency





with a magnitude of 1.112 on a linear scale.

The directivity of the antennas follows the similar trend of the gain. The S-parameters of the antennas which are discussed in the earlier section are completely compatible with the radiation characteristics.

6 COMPARISON OF ANTENNA PERFORMANCE FOR DIFFERENT SUBSTRATES

The Table III illustrates the parameters of the substrate showing optimum performance. All the antennas are resonating at 2.4 GHz and are at a matched impedance of $Z_0 = 50\Omega$.

Table III
Performance of antenna for different dielectric substrate

Parameters	Substrates				
	FR-4	**Dacron**	**Dupont 951**	**Teflon**	**Taconic RF-35P**
Dielectric Constant	4.3	3	7.8	2.1	3.5
Resonant Frequency (GHz)	2.45	2.45	2.45	2.45	2.45
Return Loss (dB)	-27.286	-18.262	-20.401	-17.497	-21.162
VSWR	1.090	1.278	1.211	1.308	1.191
Main Lobe Magnitude(dB)	3.1	3.3	3.1	3.2	3.2
Gain (dB)	3.086	3.278	3.047	3.185	3.224
Directivity (dBi)	2.755	2.752	2.753	2.754	2.752
Total Efficiency	1.077	1.112	1.060	1.085	1.106

Thorough analysis of the above results indicates that *Dacron* fabric with a dielectric constant (ε_r) 3 show the best performance. We expect the antenna performance to best the others as the gain achieved (3.278 dB) is greater than the other materials. Main lobe magnitude (3.3 dB) and total efficiency (1.112) is also high compared to the other materials. Thus, it is suggested that Dacron can be given preference over other four considered substrates.

7 CONCLUSION

The aim of this paper is to design a compact novel narrow band (2.45 GHz) elliptical microstrip patch antenna and analyzing its performance for the RFID applications. The designed elliptical patch antenna was analyzed for four different materials with different substrate permittivity, feed length and feed width .The key finding of this paper lies in the fact that the textile material Dacron turn out to be better than the other material in terms of performance and radiation characteristics. Among all the materials Dacron has the best performance with the highest gain of main lobe magnitude and efficiency, these properties makes it more attractive than the other materials. Here, it can be noticed that Dacron shows good impedance matching with return loss of -18.262 dB which ensures that a very small amount of power is reflected back to the transmitter. The overall performance of the antenna on Dacron material reveals that this antenna is suitable for RFID applications at ISM band.

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