# Investigation of Printed Helical Antenna Using Varied Materials for Ultra-wide band Frequency

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***Abstract*— This paper investigates the design of a strip helical antenna for ultra-wideband communication with circular polarization at different frequencies and materials. Unlike the conventional axial-mode helical antenna which is designed using a traditional metallic wire that makes the antenna size large, the strip helical antenna is designed using the metallic strip. As a result, the circular polarization without an impedance matching is achieved. The newly designed strip is printed on a substrate then rolled into a helix shape to achieve circular polarization without an impedance matching and that the proposed antenna can be used for potential applications in wideband and ultra-wideband wireless communication. The antenna design parameters and the simulated results are achieved using the commercial software CST. The helical antenna is designed at different operating frequencies which are 10 GHz, 5.8 GHz, and 5.6 GHz for different materials. The gain achieved is between 7 dB to 14 dB for using Teflon, and fast-film materials at different operating frequencies. While the maximum achieved bandwidth is 2.5 GHz by using fast-film material at 10 GHz operating frequency which makes it suitable for usage in many wideband applications.**

***Index Terms*—Helical Antenna; Wireless applications; Gain; Bandwidth.**

## I. INTRODUCTION

The helical antenna or helix is a combination of dipole and loop antennas radiating elements. The characteristics of radiation of the helix antenna vary according to the design structure and as a result the designed antennas can be different in terms of polarizations either linear or circular and directional or omnidirectional pattern [1]–[6]. A helical antenna or helix consists of a conductor wound into a helical shape and connected to a ground plane. The antenna can support many modes including the normal mode (broadside radiation) and the axial mode (end-fire radiation) [7]. A helical antenna or helix consists of a conductor wound into a helical shape and connected to a ground plane. The helical antenna provides wide bandwidth and circular polarization as indicated in [8]–[14].

The early helical antennas have been used primarily to introduce circular polarization. From that moment, different kinds of helical antennas have been designed with the different physical structure of the helices that affect the helical antennas properties such as radiation pattern and impedance [5]. One of the differences of the helical antenna is the antenna with many turns of the helix in which the radiated beam is circularly polarized. Even though the size of the helical antenna with a single element is large because of the length of the element; the antenna beam-width is narrow which makes the antenna directive [9],[15].

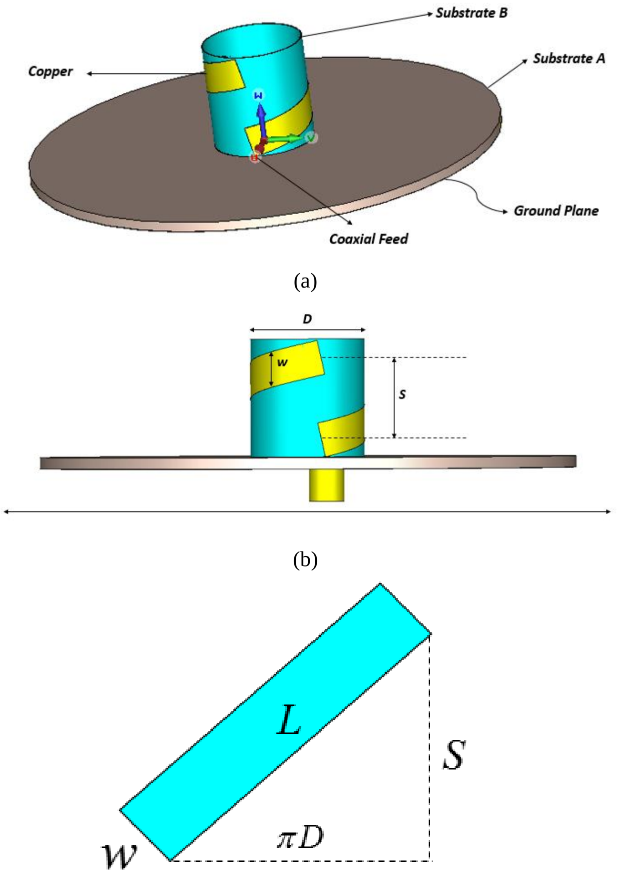
The conventional axial-mode helical antenna is considered as one of best choice design in wireless communications to achieve circular polarizations because of the high gain obtained and the wider Axial Raito (AR) bandwidth but the produced profile is large [2]. A good replacement to obtain low profile is to produce a series of cylindrical helical antennas with a low profile. Even though cylindrical helical antennas give a low profile, the axial ratio AR bandwidth produced is narrow and their characteristic impedances are relatively high which makes it hard to match impedance with 50-coaxial feed and require an extra impedance transformer to transfer the high impedance [2], [10].

Twenty years later, the spherical and hemispherical helical antennas are both introduced by Cardoso and Hui so that the AR bandwidth has been improved up to 15% when compared with the conventional cylindrical helical antennas for circular polarization [1]. However, the AR bandwidth is still low and cannot be used for high data rate transmission. Therefore, there was a need to design antennas to satisfy the high data rate transmission which is obtained by the wideband hemispherical helical antenna. By replacing the wire with a tapered metallic strip, the AR bandwidth of the hemispherical helical antenna is enhanced to 24% with an antenna height of 0.28 $\lambda_0$ but it requires an impedance matching section which complicates its structure and makes it hard to fabricate. When the number of helical elements increases, the helical antenna can radiate in circular polarization because the helical elements are fed with a certain phase difference and their length is less than one wavelength. As a result, these helical antennas which are called the multifilar helix antenna play an essential role in mobile satellite communication and global positioning systems [11].

In this paper, a detailed analysis of the strip-helical antenna is carried out at different frequencies and materials. The newly designed strip is printed on a substrate then rolled into a helix shape to achieve circular polarization without an impedance matching and that the proposed antenna can be used for potential applications in wideband and ultra-wideband wireless communication. The antenna design parameters and the simulated results are achieved using the commercial software CST. The helical antenna is designed at different operating frequencies which are 10 GHz, 5.8 GHz, and 5.6 GHz for different material such as Teflon, and fast-film materials.

## II. DESIGN IOF HELICAL ANTENNA AND SPECIFICATIONS

The geometry of the strip helical antenna design is depicted in Figure 1. Which is comprises of a cylindrical helix and circular ground plane. The metallic strip which contains the cylindrical helix is printed on substrate A with a uniform width (*w*). Furthermore, rolling the substrate A in to hollow cylinder in order to form the strip helix and the D is the diameter of the helix, S is the spacing between turns (center-to-center), L is the length of one turn, and n is the number of turns. To obtain the axial-mode operation, substrate B is used as a circular ground plane below the helix.




(a)

(b)

(c)

Figure 1: The structure of the proposed antenna: (a) 3D view, (b) Side view, and (c) unrolled strip helix of one turn.

These empirical formulas used to calculate the helical antenna parameters

$$D_o = \frac{15NSC^2}{\lambda_o^{\,3}}(\,dimensionless\,) \tag{1}$$

Where $D_0$ is the directivity, N is the number of turns, S is the spacing between the turns, c is the speed of light, C is the helix circumference, and λ is the wavelength.

$$HPBW = \frac{52}{C}\sqrt{\frac{\lambda^2}{NS}}(degrees) \tag{2}$$

$$FNBW = \frac{115}{C}\sqrt{\frac{\lambda^a}{NS}}(\,degrees\,) \tag{3}$$

$$A_{eff} = \frac{C\lambda^2}{4\pi} meters^2 \tag{4}$$

$$Impedance\ at\ terminal \ = \frac{140C}{\lambda}\Omega \tag{5}$$

$$AR = \frac{2N+1}{2N} \tag{6}$$

Where the HPBW is the half-power band width, FNBW is the First Nulls Beam Width, $A_{eff}$ is the effective aperture, and AR is the Axial ratio.

The ratio of the wave velocity travelled along the helix to that in free space:

$$p = \frac{\frac{L_o}{\lambda_o}}{\frac{s}{\lambda_o}+1} \tag{7}$$

This is for ordinary end-fire radiation. However, for the Hansen-woodyard end-fire radiation, the following expression can be used:

$$p = \frac{\frac{L_o}{\lambda_o}}{\frac{s}{\lambda_o}+\left(\frac{2N+1}{2N}\right)} \tag{8}$$

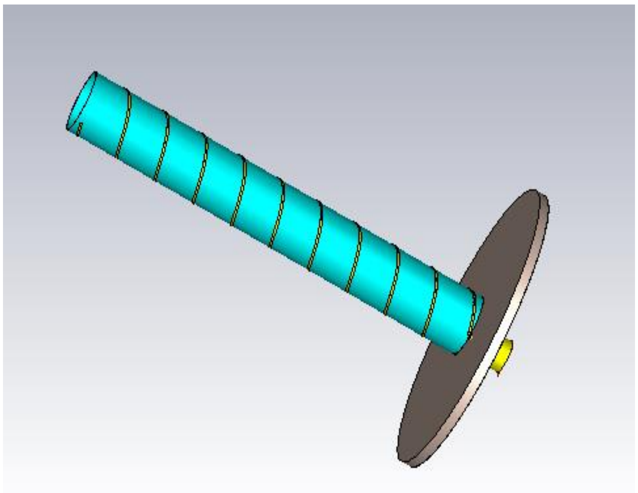
To obtain the axial-mode for the helical antenna, the circumference of the helix (C) should be ranging from ¾ λ < C < 4/3 λ.

### A. *Design strip-helical antenna at 10 GHz*

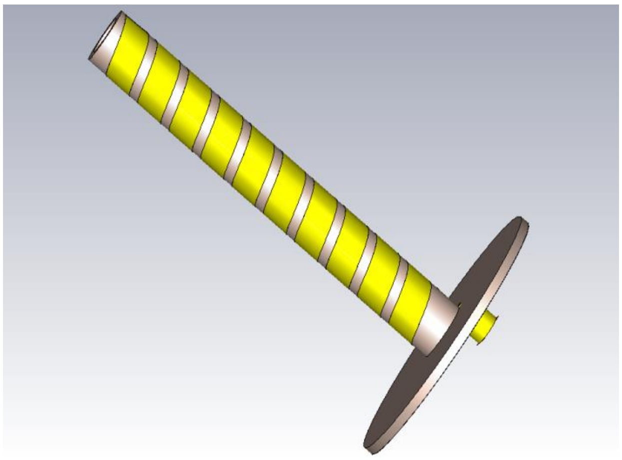
Figure 2 demonstrates the design of helix antenna at 10 GHz operating frequency. This helix antenna has a specification with 10 turns, wavelength of 30 *mm*, length of 310 *mm*, Height of 70 *mm* spacing of 7 *mm*, the diameter of 9.55 *mm*, and calculated strip width of 0.353 *mm* when using the fast-film material. However, by using Teflon material, this helix antenna has the same specifications of using fast-film material except for its width of the strip line is 4.84 mm. Table 1 shows the design specifications for the helical antenna at 10 GHz operating frequency by using Fast-film and Teflon materials.

Table 1
The design specifications of 10 GHz helical antenna using Teflon material

| Parameters | Value | |
|---|---|---|
| | For Fast-film | For Teflon |
| Dielectric constant (εr) | 2.7 | 2.1 |
| Substrate thickness (h) | 0.13 mm | 1.5 mm |
| Pitch angle (∝) | 13° | |
| Wavelength (λ) | 30 mm | |
| Circumference (C) | 30 mm | |
| Number of turns (N) | 10 | |
| Spacing between turns (S) | 7 mm | |
| Cylindrical diameter (d) | 9.55 mm | |
| Length of 1 turn strip (Lo) | 30.8 mm | |
| Total length of helical antenna (L) | 308 mm | |
| Height of helical antenna (H) | 70 mm | |
| Ground Plane (0.75 λ) | 22.5 mm | |



(a)



(b)

Figure 2: Design structure of 10 GHz Helical Antenna: (a) using fast-film material, (b) using Teflon Material

### B. Design strip-helical antenna at 5.8 GHz

The purpose of designing at a different frequency is to be used for applications that are suitable for that frequency. The design of 5.8 GHz helical antenna using both fast-film and Teflon materials are discussed and analyzed. Computer Software Technology (CST) is used to modeled the helical antenna and analyzed the simulated results at 5.8 GHz operating frequency and in range of 4 GHz to 8 GHz. The specifications of 5.8 GHz helical antenna using fast-film and Teflon material is demonstrated in Table 2.

Table 2
The design specifications of 5.8 GHz helical antenna using Fast-film and Teflon materials

| Parameters | Value | |
|---|---|---|
| | For Fast-film | For Teflon |
| Dielectric constant (εr) | 2.7 | 2.1 |
| Substrate thickness (h) | 0.13 mm | 1.5 mm |
| Pitch angle (∝) | 13° | |
| Wavelength (λ) | 51.72 mm | |
| Circumference (C) | 51.72 mm | |
| Number of turns (N) | 10 | |
| Spacing between turns (S) | 12 mm | |
| Cylindrical diameter (d) | 16.46 mm | |
| Length of 1 turn strip (Lo) | 53 mm | |
| Total length of helical antenna (L) | 530 mm | |
| Height of helical antenna (H) | 120 mm | |
| Ground Plane (0.75 λ) | 38.80 mm | |

### C. Design strip-helical antenna at 5.6 GHz

Helical antenna designs using both fast-film and Teflon material at 5.6 GHz operating frequency are designed and discussed in this paper. It includes the simulation results of the modeled helical antenna designs by using CST simulator. It also includes the analysis of the designed antenna such as return loss, gain, directivity, VSWR, and maximum electric field. The designed helical antenna is simulated in a frequency range of 4 GHz to 8 GHz at 5.6 GHz operating frequency. Table 3 illustrates the design specifications of 5.6 GHz helical antenna using Fast-film and Teflon materials.

Table 3
The design specifications of 5.6 GHz helical antenna using Fast-film and Teflon materials

| Parameters | Value | |
|---|---|---|
| | For Fast-film | For Teflon |
| Dielectric constant (εr) | 2.7 | 2.1 |
| Substrate thickness (h) | 0.13 mm | 1.5 mm |
| Pitch angle (∝) | 13° | |
| Wavelength (λ) | 53.57 mm | |
| Circumference (C) | 53.57 mm | |
| Number of turns (N) | 10 | |
| Spacing between turns (S) | 12.36 mm | |
| Cylindrical diameter (d) | 17.05 mm | |
| Length of 1 turn strip (Lo) | 55 mm | |
| Total length of helical antenna (L) | 550 mm | |
| Height of helical antenna (H) | 123.6 mm | |
| Ground Plane (0.75 λ) | 40.18 mm | |

## III. RESULTS AND DISCUSSIONS

### A. Result of Designed 10 GHz Helical Antenna Using Fast-film and Teflon Material

Figure 3 demonstrates the simulation results for the designed helical antenna at 10 GHz operating frequency with using fast-film and Teflon materials. It is clearly can be seen that the helical antenna using fast-film has a sharper dip and narrower bandwidth compared when using Teflon material. The magnitude of the S11 parameter was recorded at operating frequency of 10 GHz as illustrated in Figure 3. It illustrates the return loss in a range of 8 GHz to 12 GHz and achieved less than -10 dB at 10 GHz operating frequency. It can also be observed that the design has a good matching impedance which nearly equal to 50 Ω and for this reason the obtained results of bandwidth are less than -10 dB (S11 < -10 dB). The S11 demonstrates the power loss which has been reflected and doesn't reach the load and this is known as return loss. It also explained the good matching between the transmitted information and received information. Thus, this antenna has good results of return loss at the operating frequency of 10 GHz which achieved less than -10 dB. However, it can be seen that using Teflon has a wider bandwidth which can be used for many applications but the problem in its directivity and gain.

The effect of changing the fast-film thickness can be seen in Figure 4(a). It can be demonstrated by the thickness of the fast-film substrate is varied in the range of 0.13 mm to 1 mm. The results show that when increasing the thickness of the fast-film substrate, the frequency shifts gradually to lower frequencies while decreasing the thickness of fast-film substrate leads to shifting to higher frequencies. It also illustrates that when increasing the thickness of the fast-film substrate, the return loss decreases and this means more power will be lost. However, the effect of changing the Teflon thickness can be seen in Figure 4(b). It can be demonstrated the thickness of Teflon substrate is varied in the range of 0.5 mm to 1.5 mm. The results show that when increasing the thickness of Teflon substrate, the frequency shifts gradually to higher frequencies while decreasing the thickness of Teflon substrate leads to shifting to low frequencies. It also illustrates that when increasing the thickness of Teflon substrate, the return loss decreases at the 10 GHz operating frequency and this means more power will be lost.

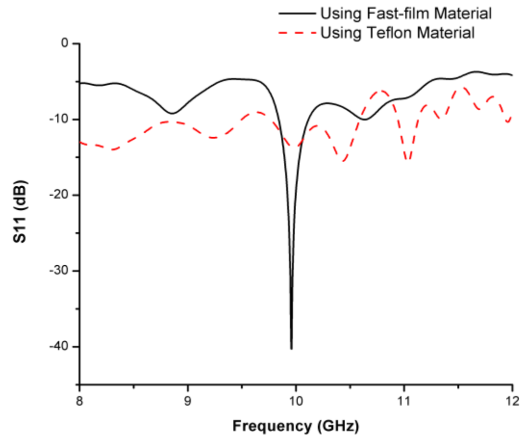
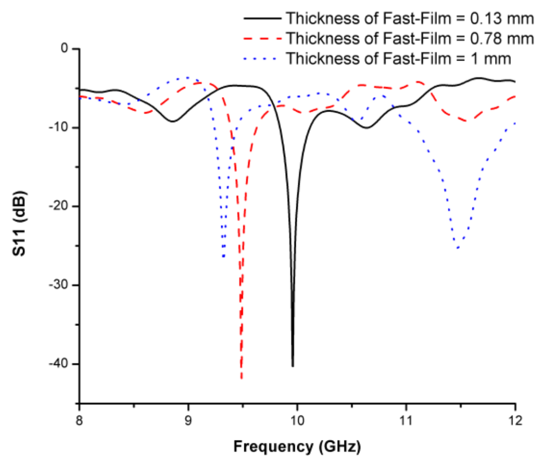
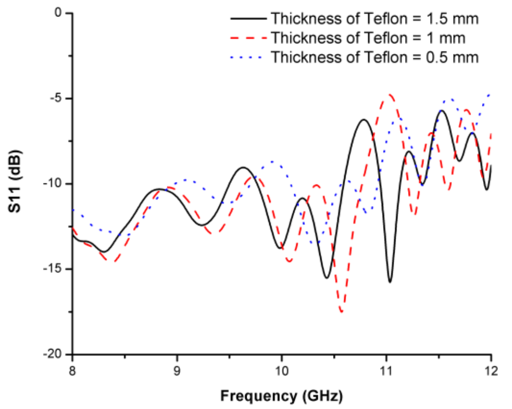



Figure 3: Comparison of 10 GHz helical antenna using fast-film and Teflon material



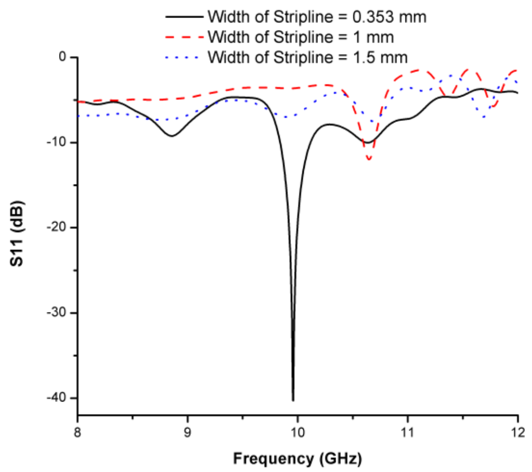

(a)



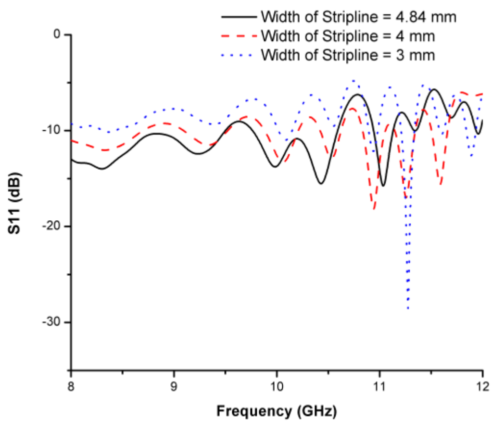

(b)

Figure 4: Effect of changing the substrate thickness of: (a) fast-film material, (b) Teflon material

Furthermore, the effects of varying the width of stripline are shown in Figure 5(a) for using fast-film material at 10 GHz. it can be clearly seen that the width of stripline is varied in the range of 0.353 mm to 1.5 mm and it can be seen that when increasing the width of stripline, the operating frequency shifts to a higher frequency while decreasing the width of stripline shifts operating frequency to lower. Not only this, but also it can be demonstrated that the frequency is not operating at 10 GHz when the width of stripline is at 1 mm and 1.5 mm. The return loss at these two points is not exceeding less than -10 dB and for this reason it is not operating. However, in case of using the calculated value at 0.353 mm width of stripline, the helical antenna achieved the condition which is less than -10 dB and this makes the helical antenna operates at this point. Moreover, the effects of varying the width of stripline are shown in Figure 5(b) for using Teflon material. it can be clearly seen that the width of stripline is varied in the range of 3 mm to 4.84 mm and it can be seen that when increasing the width of stripline, the operating frequency shifts to a higher frequency while decreasing the width of stripline shifts operating frequency to low frequencies. In addition, it can be demonstrated that the return loss is less than -10 dB when used the calculated stripline width of 4.84 mm while at stripline width of 3 mm and 4 mm doesn't achieve below than – 10 dB.




(a)




(b)

Figure 5: Effects of changing the width of stripline in: (a) Fast-film material, (b) Teflon material

Table 4 demonstrates the simulation results of 10 GHz helical antenna using fast-film and Teflon materials in terms of return loss, voltage standing wave ratio (VSWR), gain, directivity and maximum electric field. It can be noted that using fast-film material has a better gain, VSWR, directivity, and return loss compared to Teflon material.

Table 4
Comparison of 10 GHz helical antenna using fast-film and Teflon materials

| Parameters | 10 GHz Helical Antenna | |
|---|---|---|
| | Using Fast-film Material | Using Teflon Material |
| Return loss (S11 dB) | -19.44 | -13.71 |
| Bandwidth | 264 MHz | 815 MHz |
| Voltage standing wave ratio (VSWR) | 1.24 | 1.52 |
| Gain (dB) | 12.4 | 7.88 |
| Directivity (dBi) | 13.6 | 8.63 |
| Electric Field (V/m) | 79.9 | 80.9 |

### *B. Result of Designed 5.8 GHz Helical Antenna Using Fast-film and Teflon Material*

The simulation results of the designed helical antenna at 5.8 GHz operating frequency using both fast-film and Teflon materials is demonstrated in Figure 6. It can be illustrated that the Teflon material has a deeper and higher bandwidth compared when using the fast-film material.

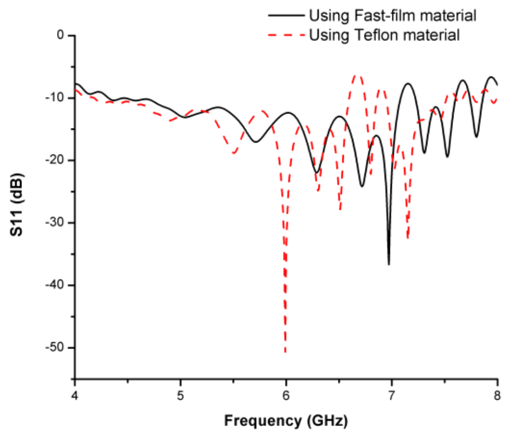



Figure 6: Comparison of 5.8 GHz helical antenna using fast-film and Teflon material

The simulation results of the designed helical antenna using both fast-film and Teflon materials at 5.8 GHz operating frequency are compared as demonstrated in Table 5. The results show that the 5.8 GHz helical antenna using fast-film materials has a better performance such as gain, VSWR, directivity and return loss compared to Teflon material. However, using Teflon material in the designed helical antenna has a better bandwidth which peaked up to 2.41 GHz compared to fast-film materials. For this reason, using Teflon material could be used as Ultra-wide band applications due to its wide range of bandwidth.

Table 5
Comparison of 5.8 GHz helical antenna using fast-film and Teflon materials

| Parameters | 5.8 GHz Helical Antenna | |
|---|---|---|
| | Using Fast-film Material | Using Teflon Material |
| Return loss (S11 dB) | -15.72 | -12.39 |
| Bandwidth (BW) | 2.37 GHz | 2.41 GHz |
| Voltage standing wave ratio (VSWR) | 1.39 | 1.63 |
| Gain (dB) | 13.3 | 12.1 |
| Directivity (dBi) | 13.8 | 12.9 |
| Electric Field (V/m) | 79.6 | 77.3 |

### *C. Result of Designed 5.8 GHz Helical Antenna Using Fast-film and Teflon Material*

The simulation results of the designed helical antenna at 5.6 GHz operating frequency using both fast-film and Teflon materials is demonstrated in Figure 7. It can be illustrated that the Teflon material has a deeper and narrower bandwidth with less return loss of about -32 dB while using fast-film, it has a wider bandwidth of about 2.5 GHz compared to Teflon which has only 825 MHz bandwidth.

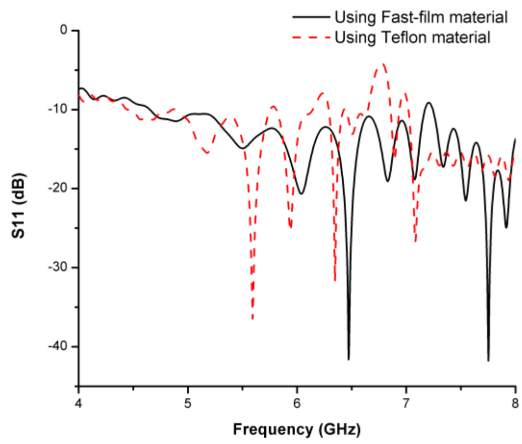



Figure 7: Comparison of 5.6 GHz helical antenna using fast-film and Teflon material

The simulation results of the designed helical antenna using both fast-film and Teflon materials at 5.6 GHz operating frequency are compared as demonstrated in Table 4.9. The results show that the 5.6 GHz helical antenna using fast-film materials has a better performance in terms of gain, directivity and bandwidth. While using Teflon, it has a better performance in terms of return loss and voltage standing wave ratio. In addition, using the fast-film material in the designed helical antenna has a better bandwidth which peaked up to 2.5 GHz compared to Teflon materials. For this reason, using fast-film material could be used as Ultra-wide band applications due to its wide range of bandwidth.

Table 6
Comparison of 5.6 GHz helical antenna using fast-film and Teflon materials

| Parameters | 5.6 GHz Helical Antenna | |
|---|---|---|
| | Using Fast-film Material | Using Teflon Material |
| Return loss (S11 dB) | -13.78 | -32.75 |
| Bandwidth (BW) | 2.5 GHz | 826 MHz |
| Voltage standing wave ratio (VSWR) | 1.52 | 1.05 |
| Gain (dB) | 13.3 | 10 |
| Directivity (dBi) | 14 | 10.2 |
| Electric Field (V/m) | 79.9 | 79.1 |

## IV. COMPARISON BETWEEN ALL DESIGNS

Table 7 demonstrates the comparison of all designed helical antenna at 5.6 GHz, 5.8 GHz, and 10 GHz operating frequencies, respectively. The comparison is between using two different materials for each design and these materials known as fast-film and Teflon materials. The result is compared in term of return loss, bandwidth, VSWR, gain, directivity and maximum electric field distributions.

Table 7
Comparison between all helical antenna designs

| Parameters | 10 GHz | | 5.8 GHz | | 5.6 GHz | |
|---|---|---|---|---|---|---|
| | Fast-film | Teflon | Fast-film | Teflon | Fast-film | Teflon |
| Return loss (S11 dB) | -19.44 | -13.71 | -15.72 | -12.39 | -13.78 | -32.75 |
| Bandwidth (BW) | 2.64 % | 8.15 % | 23.7% | 24.1 % | 25% | 8.26% |
| Voltage standing wave ratio (VSWR) | 1.24 | 1.52 | 1.39 | 1.63 | 1.52 | 1.05 |
| Gain (dB) | 12.4 | 7.88 | 13.3 | 12.1 | 13.3 | 10 |
| Directivity (dBi) | 13.6 | 8.63 | 13.8 | 12.9 | 14 | 10.2 |
| Electric Field (V/m) | 79.9 | 80.9 | 79.6 | 77.3 | 79.9 | 79.1 |

## V. CONCLUSION

The work presented in this paper is mainly focused towards the development of helical antenna for industrial applications. The design of helical antennas at 10 GHz, 5.8 GHz, and 5.6 GHz operating frequencies for both using fast-film and Teflon material have been successfully investigated and analyzed. The designed helical antenna based on a strip-line structure with overall dimensions for different frequencies as specified in Section II (A, B, C) has been realized using fast-film and Teflon materials with a thickness of 0.13 mm and 1.5 mm respectively. And also, the dielectric constant of the two materials fast-film and Teflon 2.1 and 2.7 respectively. The covered frequency is from 4 to 8 GHz range for the operating resonant frequencies of 5.6 GHz and 5.8 GHz while the covered frequency is from 8 GHz to 12 GHz range for 10 GHz operating frequency for the helical antenna. These structures achieve high directivity which peaked up to 14 dB for 5.6 GHz helical antenna using fast-film with a maximum gain of 13.3 dB. Followed by the 10 GHz helical antenna using same materials with high efficiency in term of reflected power. The highest value obtained for directivity is in range of 10.2 to 14 dB which indicates it has very high efficiency. The fabrication process will be carried out in the next stage in order to verify the simulation results with the experimental results measurement.

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