Wide band rectangular wearable microstrip ring antenna with textile substrate and its performance after washing

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Abstract. In this paper introduced a wearable wideband rectangular microstrip patch antenna, fabrication and measurement of different parameters of designed antenna. The textile cotton material was used as substrate in the designed antenna. Here the very thin layered copper material sheet was selected as a ground plate and radiating elements. The conductive copper sheet was mounted on the textile materials by synthetic adhesive. We designed a ring antenna based on ring resonator techniques and measured the dielectric constant of the textile substrate material. The variation result of the proposed antenna with variation of thickness of the textile substrate has been investigated. For performance characteristics, three textile antenna with different substrate as wool, jeans and corduroy material are used.

1. Introduction

The most important needs to protect the cloths and different types of garments from the germs and environmental effects. In this aspect the demand of the most flexible textile microstrip antenna increase rapidly \[1\]. A major part of electronics involves in the field of apparel industry. Cloths are protecting the human body from the effect of environmental germs as well as give us the information of the human who wear the garments \[2\]. The main thing is that to interconnection with environment and control the information of bio signals by the cloths or garments. Actually the garments can give the continuous information of wearer’s state of health. This information are more important for biomedical systems. Not only that it can be used in emergency operations like smoke detections, it can be used as a decision making tools of the smoke detector. However the textile antennas are generally operates in the environment of the wireless communications system. The microstrip antenna may be designed and integrated into garments when textile or garments properties are the major issue arise \[3\]. Hence the antenna designed with textile materials. Textile material is more compatible with environment and easily developed the more numbers of textile antennas. Here we can design, developed and analysis of the microstrip antenna with textile substrate material. Protection of garments is most important factor. Thus increasing the involvement of electronics to textile garments. The characteristics of textile antenna for different substrate materials has been analysed after washing the cloths.
2. Antenna Design Methodology

Before design of the ring microstrip textile antenna, it is most important that to select the proper substrate material and the conducting material of the proposed antenna.

2.1 Selection of the Substrate of the Antenna

It is the most important and primary selection of the antenna design is substrate material. Here, we select the height of the substrate of wearable textile antenna is 1.6 mm, shown in Figure 1.

2.2 Selection of the Patch and Ground material

Another major part of the textile antenna is the selection of the proper conducting material. Hence, we choose very thin conducting copper foil paper due to its low resistivity property and the high value temperature coefficient range. Thus it can be helpful for us to soldering the connector without making any burning hole in the textile electro material, shown in Figure 2.

2.3 Calculate the Dielectric constant with Textile substrate material

To design a wearable textile microstrip antenna using textile substrate material, the value of the dielectric constant of the substrate is always pre-determined. So we can find the value of the dielectric constant of the selected textile substrate material using the value of given dielectric constant of the substrate. For measuring the unknown dielectric constant of the textile material, we used the ring resonator technique [4, 5, and 6]. This method can be given more accurate results because the ring resonator does not provides any errors from the open ended effect as compared with the conventional microstrip line resonator method. The functional design of the textile microstrip ring resonator given as Figure 3.

![Figure 1. Textile Material Substrate (Cotton)](image)

The conducting copper sheet metal foil used to paste on the textile substrate material and fabricated using synthetic resin gum adhesive. To design and fabricate the ring shaped microstrip antenna, upper portion of the copper foil metal has been cut by suitable cutter. Here the height of the textile substrate material and copper foil metal was 1.65 mm and 0.25 mm respectively. The fabricated ring resonator microstrip antenna is shown in Figure 4. For measuring purpose, the two sided ports of the designed ring resonator antenna was connected properly with two SMA connector. The most common network analyser E5071B has been used for measurement of the dielectric constant of the dielectric constant of desired textile ring resonator microstrip antenna. The E5071B network analyser is most applicable for fast and accurate measurements for RF components. Its advanced architecture can minimizes the number of sweeps to complete multiport measurements.
2.4 Dielectric Constant formula

First to calculate the dielectric constant, we used the appropriate desired peak of the resonant frequency. It can be obtained according to [4, 5].

\[ D_{\text{eff}} = \left( \frac{nc}{6.28r_m f_0} \right)^2 \]  

(1)

Where \( n \)th resonance frequency = \( f_0 \) of designed ring resonator. In vacuum, speed of light = \( c \) and mean radius of ring resonator = \( r_m \).

Second, calculate the relative dielectric constant by using the value of effective dielectric constant. Here different physical dimension values can be helps for calculation of the relative dielectric constant. The relative dielectric constant express as

\[ \varepsilon_r = \frac{2 + (P - 1)}{P + 1} \]  

(2)

\[ P = \left[ 1 + \frac{12t}{W_{\text{eff}}} \right]^{1/2} \]  

(3)

Where \( t \) is the thickness of the substrate and \( W_{\text{eff}} \) is the effective strip width for \( h \neq 0 \)

\[ W_{\text{eff}} = W + (1.25 \frac{p}{\pi})(1 + \ln(2h/p)) \]  

(4)
Where copper conducting material has thickness $p$, physical width represented by $W$ and calculated substrate thickness is $h$.

Now we have calculated the required dielectric relative constant (by Eqs. (1) and (2)) of the textile substrate material at resonance frequency. After solving the above formula we get the following results, $h = 1.65 \text{ mm}$, $W = 3.65 \text{ mm}$ and $p = 0.25 \text{ mm}$ and $r_m = 39.85$. From figure 5 we get when taking the value of $n = 2$, then $f_0 = 1.662$. Then find the dielectric constant from the Eqs. (1) and (2) is $\varepsilon_r = 2.49$.

### 2.5 Design of Microstrip antenna with copper foil

We developed a rectangular microstrip antenna using copper foil substrate. The copper foil sheet having length 37.85 mm and width is 45.38 mm. Here resin adhesive is used to paste the copper foil sheet to the textile substrate material shown in Figure 6.

Three substrates are wool, jeans and corduroy are separately pasted for three different type of textile antenna design. The feed position, substrate thickness and length are given in Table 1.

| Substrate Type | Thickness ($\text{mm}$) | Length ($\text{mm}$) | Feed position at $X=0$ | Width ($\text{mm}$) |
|----------------|--------------------------|----------------------|------------------------|---------------------|
| Wool           | 2.45                     | 43                   | $Y=-7.8$               | 34                  |
| Jeans          | 2.44                     | 42.5                 | $Y=-7.8$               | 33                  |
| Corduroy       | 2.46                     | 40.5                 | $Y=-8.5$               | 32.5                |

### 3. Antenna results and performance

For the investigation of microstrip antenna we design two different ring resonator textile antenna with same antenna dimension. Here use the same feed point location for this two antennas. Their substrate thickness are different. First antenna has substrate thickness is 1.65 mm and another substrate thickness is 4 mm.

![Front view of Microstrip ring resonator antenna after fabrication on textile material.](image)
Figure 5. $S_{21}$ performance of Microstrip ring resonator antenna

Figure 6. Fabricated textile Microstrip ring resonator antenna with copper foil sheet

Figure 7. $S_{11}$ characterizes of the textile antenna having substrate thickness was 1.65 mm

The most common type network analyser (SNA Type) N5230 has been used to measure the impedance characteristics of the first antenna (1.65 mm substrate) and the performance results are shown in Figure 7.
Now we enhance the substrate thickness from 1.65 mm to 4 mm and continuously observed the performance characteristics. Also measured the variation of the impedance properties of the antenna using the RF vector network analyser N5234B, the performance results shown in Figure 8. From the above observation of the designed textile antennas we conclude that the antenna performance increase when the substrate thickness of the proposed textile ring resonator antenna increases. The performance results of the textile ring generator microstrip antenna shows that the efficiency depends on the thickness of the textile substrate material. Comparison results obtained from the Figure 7 and Figure 8 that the 10dB bandwidth is more when the thickness of the textile substrate more at 4 mm than low substrate thickness at 1.65 mm. The designed textile ring resonator antenna radiation pattern as shown in Figure 9.

![Figure 8. S11 characterizes of the textile antenna having substrate thickness was 4mm](image)

Here the effects of different textile antenna for different substrate materials (Wool, Jeans and Corduroy) has been analysed. The S11 characteristics of three textile antennas are shown in Figure 10 to Figure 12, before and after the washing and dried on the sunlight.

![Figure 9. Radiation pattern of the textile ring resonator Microstrip antenna.](image)
From Figure-11 and Figure-12 shows that the resonance frequencies are increase or decrease but not shifted where as in Figure-10 indicates that the resonance is shifted after washing the jeans cloths.
Radiation patterns of the three different textile antennas are shown in Figure -13 to Figure-15 and radiation pattern of before and after washing the cloths has been analysed.

Figure 13. E plane radiation pattern of Wool antenna

Figure 14. E plane radiation pattern of Jeans antenna

Figure 15. E plane radiation pattern of Corduroy antenna
4. Conclusion

Selection the proper substrate material and designed the two different rectangular textile ring resonator microstrip antennas with same dimensions and same feed location. Fabricated and tested the designed antennas. Results obtained from the given antennas, concluded that the performance of the antenna depends on the thickness of the textile substrate material. In this research paper common textile antenna with different substrate and its performance analysed before and after washing the textile cloths (wool, jeans & corduroy).

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