Design of Rectangular Patch Textile Antenna at 2.45 GHz ISM Band

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Abstract - **In this paper the design of textile antennas with substrate permittivity, $\varepsilon_r = 1.63$and, $\varepsilon_r = 1.53$ are proposed. The rectangular patch textile antenna is designed at 2.45 GHz Industrial, Science and Medical (ISM) band (2.4 GHz -2.485 GHz) for short range communication system. Fleece and denim fabrics are used as antenna substrates and copper tapes as the conductive part of the antenna patch and ground plane. This paper also presents the effects of antenna bending at four different angles.**

Keywords- microstrip patch antenna, permittivity, ISM Band, antenna bending.

I. INTRODUCTION

The development of textile systems is based on concept of clothing. The advantages of textile antennas are low cost, zero maintenance, no set-up requirements, no damage from obstacles, flexible and lightweight compared to the other conventional antennas [1, 2]. Furthermore, compared with the conventional antenna built on a FR-4 board, textiles antenna has a 'drapable' textile substrate which means something that can be bent in all directions at the same time. There are several types of fabrics used in designing a textile antenna such as aramid, fleece, denim, bakhram, felt and many others.

A microstrip patch antenna is appropriate to be produced out of a textile material mainly because of its compact geometry and planar profile. The radiating elements may be square, rectangular, circular, triangular, and elliptical or some other common shapes [3].There are many advantages of a microstrip patch antenna. The advantages are light weight and low volume, capable of dual and triple frequency operations and low fabrication cost, hence can be manufactured in large quantities [4].

This paper focuses on designing a rectangular patch textile ȁntenna which performs at 2.45 GHz ISM band (2.4 -2.485 GHz) for short range communication system. The comparison between simulated and measured results in terms of return loss, gain, bandwidth and radiation pattern is investigated. The influence of antenna bending at four different angles is the main highlight of this paper.

II. SUBSTRATE MATERIALS SELECTION

Fleece and denim fabrics with permittivity, ε_r = 1.63 and ε_r = 1.53 are used as antenna substrates. Fleece fabric is a material that has excellent characteristics for optimal antenna efficiency. A fleece fabric is chosen because its piled structure yields a permittivity close to 1 and its hydrophobic characteristic results in a low loss-tangent. The low permittivity can allow the design with a high gain and efficiency [5].Hence, the proposed antenna structure is easy to attach to clothing and the structure does not limit the possible antenna placements. The conductive patch and ground plane are made of copper tapes, a thin material with thickness of 0.035 mm which makes it flexible and lightweight.

III.ANTENNA DESIGN AND IMPLEMENTATION

This antenna is designed to operate at 2.45 GHz and fed by 50 Ω impedance as shown in Figure 1 to 3. In designing the patch, a few equations are used as reference before optimising the dimension using CST software. With a specific resonant frequency, the width and the length of patch are expressed as follows:

Patch Width:

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1)$$

Patch Length:

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

$$\frac{\Delta L}{h} = \frac{0.412(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \qquad (3)$$

$$L_{eff} = \frac{C}{2f_r\sqrt{\varepsilon_{eff}}} \qquad (4)$$

$$L - L_{eff} - 2\Delta L \qquad (5)$$

TABLE I

DESIGN SPECIFICATION

Parameters	Fleece(mm)	Denim(mm)
Rectangular Patch length (L)	44	45.9
Rectangular Patch width (W)	42.5	45
Substrate length (L)	80	80
Substrate width (W)	50	50
Substrate thickness (Ts)	2.20	1.72
Microstrip lines and patch thickness (Tm)	0.035	0.035
Feedline (L)	26	25

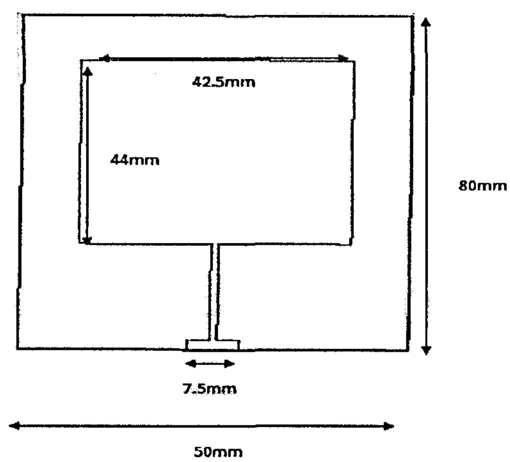


Fig. 1 Microstrip patch antenna (Fleece)

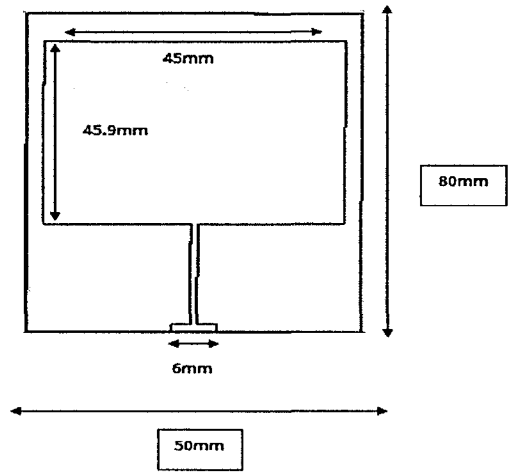


Fig. 2 Microstrip patch antenna (Denim)

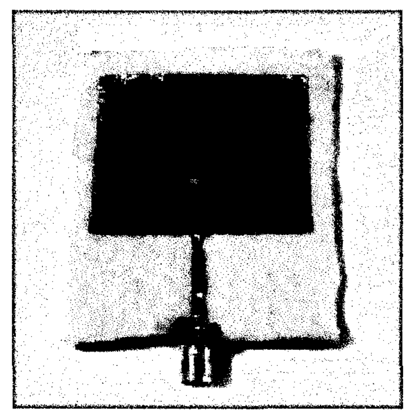


Fig. 3 Fabricated Microstrip patch antenna (Fleece)

IV.BENDING OF MICROSTRIP PATCH ANTENNA

The antenna is bended at four different angles namely 20, 30, 40 and 60 degrees using CST software to find out the effects of bending on the rectangular patch antenna [7] as shown in Figure 4 and Table II. The formula that we used to bend the structure is:

$$S = r\theta$$

Where, S = arc length (width of antenna patch)
r = radius of the circle (cylinder in CST)
θ = measure of central angle in radians

The thickness of patch and microstrip lines is 0.035 mm and the thickness of the substrate is 2.20 mm.

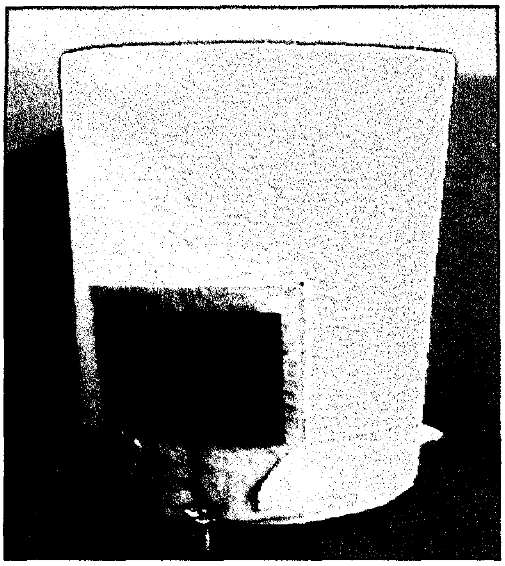
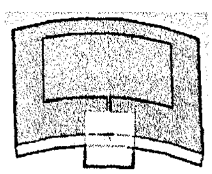
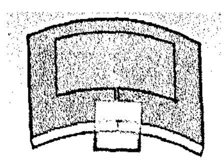
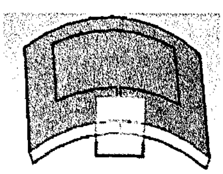
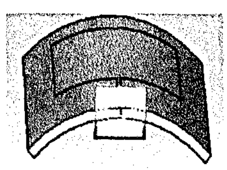


Fig. 4 Bended microstrip patch antenna (Fleece)

TABLE II

BENDING PURPOSE

20 degree bending	30 degree bending
	
Patch outer radius = 114.635mm Substrate outer radius = 114.6mm	Patch outer radius = 76.435mm Substrate outer radius = 76.4mm
40 degree bending	**60 degree bending**
	
Patch outer radius = 57.335mm Substrate outer radius = 57.3mm	Patch outer radius = 38.235mm Substrate outer radius = 38.2mm

V. PERFORMANCE ANALYSIS OF MICROSTRIP PATCH ANTENNA

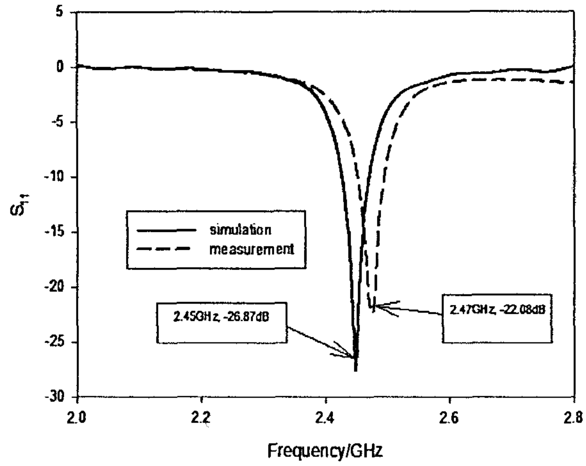


Fig. 5 Simulated and Measured return loss (S_{11}) (Fleece)

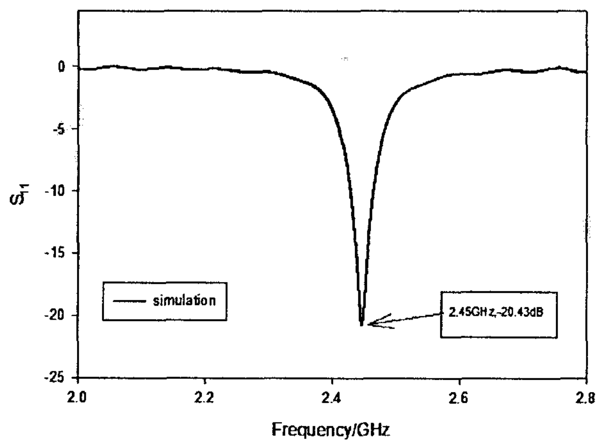


Fig. 6 Simulated return loss (S_{11}) (Denim)

Figure 5 shows the comparison between simulated and measured return loss (S_{11}) results for fleece fabric where good agreement is observed. The simulated and measured S_{11} achieve 26.87 dB and 22.08 dB at resonance frequencies of 2.45 GHz and 2.47 GHz respectively. As expected, a slight shift in the resonance frequency is likely to occur. For the bandwidth, both simulated and measured results are comparable, achieving 44.56 MHz and 40.2 MHz respectively.

Figure 6 shows the simulated return loss (S_{11}) results for denim fabric. The simulated S_{11} achieve 20.43 dB at resonance frequencies of 2.45 GHz which is lower than that of fleece fabric. For the bandwidth, denim fabric achieved 37.113 MHz which is also lower than the bandwidth for fleece fabric. Hence, fleece fabric was chosen to be fabricated and measured due to its superior performance.

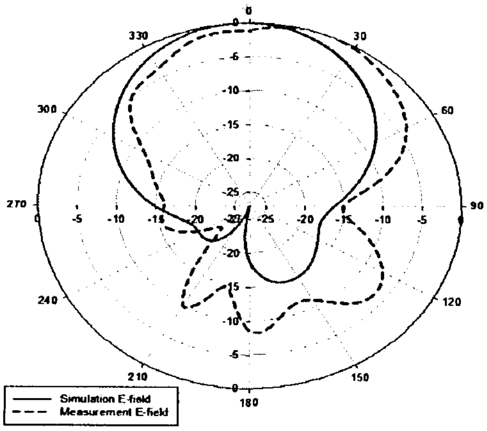


Fig. 7 Simulated and measured normalised radiation patterns at E-plane (phi = 90°)

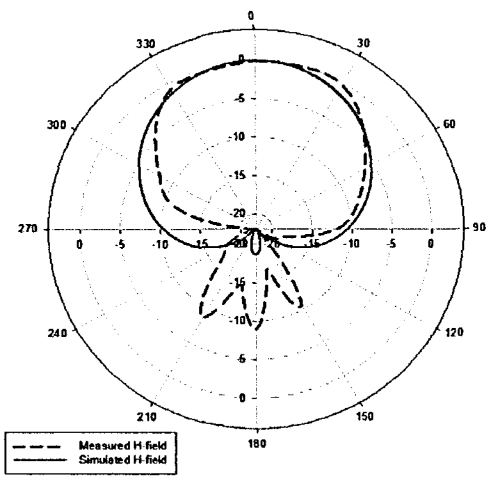


Fig. 8 Simulated and measured normalised radiation patterns at H-plane (phi = 0°)

Figure 7 and 8 show the comparison between the simulated and measured radiation patterns for E- and H-planes at resonance frequency of 2.45 GHz respectively. The radiation patterns are measured in an anechoic chamber. Overall, the power density is mostly radiated in the main lobe for both simulated and measured results. At the side lobe level, the power density is much lower than the main beam. A lower back lobe level is desirable to minimize the interference at the back side and allow for efficient use of the radiated power. From the E- and H-plane radiation patterns, the antenna simulated gain achieves 6.825 dB while the measured gain is around 5.01 dB. The antenna efficiency for simulated is 81.59 % while the measured efficiency decreases to 66.91 %.

VI. INFLUENCE OF ANTENNA BENDING

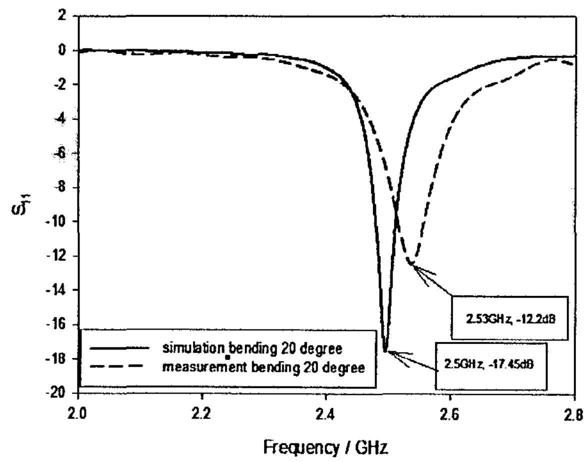


Fig. 9 Simulated and Measured Bending at 20 Degree

At 20 degree bending, the simulated S_{11} is 17.45 dB which is resonating at frequency of 2.5 GHz. However, the measured S_{11} decreases to 12.2 dB and the frequency is slightly shifted to 2.53 GHz.

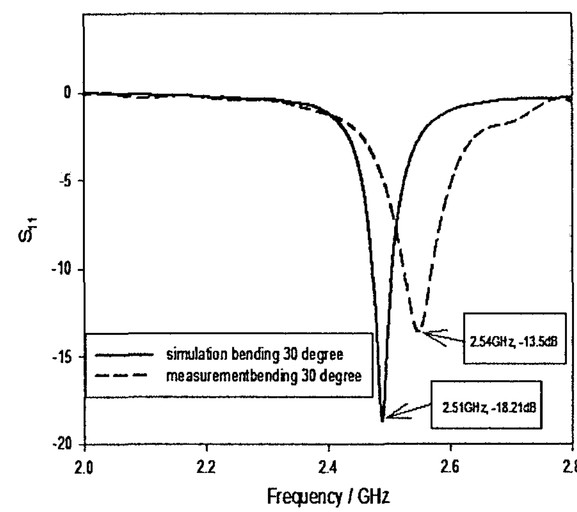


Fig. 10 Simulated and Measured Bending at 30 Degree

By bending the antenna at 30 degree, the simulated S_{11} achieves 18.41 dB at 2.51 GHz .The frequency is then shifted to 2.54 GHz with measured S_{11} of 13.58 dB. It can be observed that the result of bending at 30 degree is better than the result of bending at 20 degree.

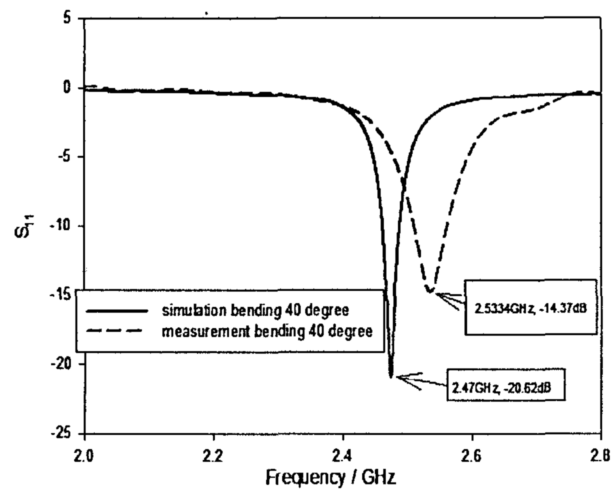


Fig. 11 Simulated and Measured Bending at 40 Degree

If the antenna is bent further at 40 degree, a good impedance matching is attained with S_{11} of 20.62 dB at 2.47 GHz in simulation. For measured S11, it decreases to 14.37 dB at 2.53 GHz.

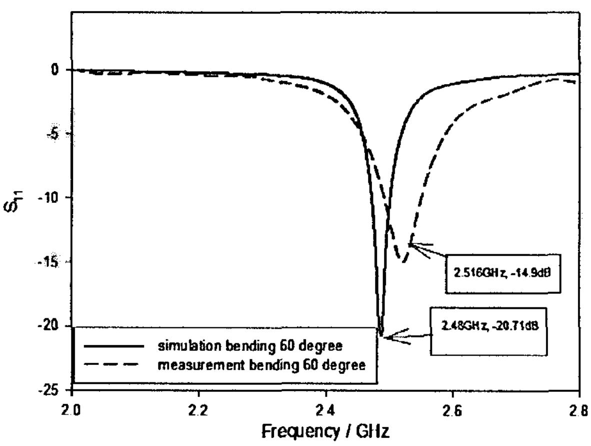


Fig. 12 Simulated and Measured Bending at 60 Degree

Lastly, by bending the antenna at 60 degree, the S_{11} increases the impedance matching considerably with simulated result of 20.71 dB at frequency 2.48 GHz. For measured, the S_{11} achieves 14.98 dB at 2.5 GHz. In this case, we found that the highest return loss is by bending at 60 degree compared to others.

VI. CONCLUSION

The rectangular patch textile antenna is presented in this paper operating at ISM band (2.4 GHz -2.485 GHz). Good agreement is observed between simulated and measured results in term of reflection coefficient, gain, antenna efficiency and radiation pattern. Besides that, the effect of incremental antenna bending shows that the resonance frequency tends to shift but the impedance matching improves considerably.

VII. REFFERENCES

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