# TEXTILE ANTENNA FOR 50 OHM APPLICATIONS

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***Abstract.*** *The new generation of textile materials have the capability to conduct electricity and at the same time be wearable. There are much more applications involved if an antenna is made from parts that are totally wearable. This new property of conductivity in textile materials is used to implement the wireless functions to clothing. In general, the antennas are made of highly conductive metal with is a solid structure, which results in stable output. The challenge with textile antenna is output stability which is given by pure textile material of the radiating element, dielectric material and also ground, which can be can be folded and twisted. The paper presents the design and fabricated output results of the textile antenna which is used for the 50 ohm system (as GPS or WLAN) at 2,45 GHz.*

## Keywords

***Antenna design, patch antenna, textile antenna.***

## 1. Introduction

Textile fabric material has become one of the most important things in life. As the technology increases, it is influencing every sector. With the increase in wireless technology the electromagnetic radiation also increases. This increased radiation may affect the human body and thus the conductive property of smart textiles is used as a filter and does not allow the harmful frequency signal to penetrate into the human body [1].

The general use of electronic device is increasing day by day. Portable devices like mobile phone at the present time provides various functions as internet access, personal digital assistance, GPS functions and multimedia. Also in the future with the invent of more advanced technology a person may have to carry lots of sensors with him as for example the one that continuously monitors the human body and at the same time communicate with the outside world. One of the efficient ways is to integrate these sensors in the textile making them a part of it [2].

Going one step further ahead, textile materials are nowadays explored as antennas. The paper [3] describes top signal layer and the bottom ground plane of the antennas made up of copper sheets having thicknesses of 0,1 mm and 0,5 mm. The paper [4] presents conducting ground plane and the antenna fabricated from thin, flexible and lightweight copper plated nylon fabric.

This paper describes two 50 ohm antenna samples which radiating element, dielectric substrate and ground are formed from pure textile material. The first one is made up of non-woven fabric which is metal coated by Cu-Ni. The second one is fabricated from woven fabric which is formed by conductive fibers. Design, simulation and fabrication with measurement results are presented.

The rest of the paper, which comes out from thesis [5], is organized as follows: section 2 describes the design of patch antenna, section 3 presents conductive materials, section 4 denotes simulation of microstrip antenna, section 5 describes antenna fabrication and measurement results. Conclusion is presented in section 6.

## 2. Design of Rectangular Patch Antenna

A microstrip patch antenna consists of a radiating element, a ground and the dielectric substrate sandwiched between them. The radiating patch consists of finite edges and hence fringing occurs. Fringing is mainly dependent on dimension of substrate, height of dielectric substrate and dielectric constant. The electric field lies in both air and dielectric material. Thus, when $W/h >> 1$ and $\varepsilon_r >> 1$ mostly the field will be accumulated in the substrate. This makes the microstrip line looks electrically longer. The effective dielectric constant is almost same for low frequency, but as the frequency increase, the dielectric constant also increases. Thus, at UHF frequency effective dielectric constant has a finite effect. The effective dielectric constant is given as [6]:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 - 12\frac{h}{W}\right)^{-\frac{1}{2}}, \qquad (1)$$

where $W$ represents the width of microstrip patch, $h$ is the height of the dielectric substrate, $\varepsilon_r$ denotes dielectric constant and $\varepsilon_{reff}$ effective dielectric constant.

The width of the microstrip patch is computed as:

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

Due to fringing, the length of the patch increases electrically. Thus, the increase in length is given by [6]:

$$\Delta L = 0{,}412h \frac{\left(\varepsilon_{reff} + 0{,}3\right)\left(\frac{W}{h} + 0{,}264\right)}{\left(\varepsilon_{reff} - 0{,}258\right)\left(\frac{W}{h} + 0{,}8\right)}, \qquad (3)$$

where $\Delta L$ represents an increase in length. The length is increased on both side of the microstrip patch. Thus, the effective length is given as [6]:

$$L_{eff} = L + 2\Delta L, \qquad (4)$$

$$L = \frac{\lambda_{eff}}{2} - 2\Delta L = \frac{1}{2 f_r \sqrt{\varepsilon_{reff}}\sqrt{\mu_0 \varepsilon_0}} - 2\Delta L. \qquad (5)$$

Thus, the resonance frequency for the microstrip antenna with length $L$ and dielectric constant $\varepsilon_r$ is given as [6]:

$$f_r = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0 \varepsilon_0}}. \qquad (6)$$

When the fringing has finite impact, the effective length and effective dielectric constant is considered. In this case, the resonance frequency is computed as:

$$f_{rc} = \frac{1}{2L_{eff}\sqrt{\varepsilon_{reff}}\sqrt{\mu_0 \varepsilon_0}}. \qquad (7)$$

## 2.1. Resonant Input Resistance

The radiating slot in microstrip patch antenna is represented as parallel equivalent circuit with the admittance $Y$ such that $Y = G + jB$.

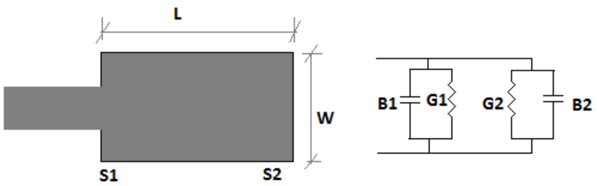


**Fig. 1:** Microstrip patch with equivalent circuit model.

The two radiating slots should be separated by a distance $\lambda/2$ where $\lambda$ is the wavelength. This is not possible because the patch length becomes electrically longer due to fringing. Thus, a length of the patch should be chosen such that $0{,}48\,\lambda < L < 0{,}49\,\lambda$ [7]. The total input admittance is obtained by transforming the admittance at slot 2 to slot 1. The transformed impedance is given by:

$$Y_2' = G_2' + jB_2', \qquad (8)$$

where $B_1 = B_2'$ and $G_1 = -G_2'$. Thus, at resonance the reactive part cancels and the total admittance is given as:

$$Y_{in} = Y_1 + Y_2' = 2G_1; R_{in} = \frac{1}{2G_1}. \qquad (9)$$

When the mutual effects between the slots are considered, the resonance input resistance is obtained as:

$$R_{in} = \frac{1}{2\left(G_1 \pm G_{12}\right)}, \qquad (10)$$

where $G_1$ denotes conductance of single slot of radiating patch antenna and $G_{12}$ represents mutual conductance of the radiating slot.

$R_{in}$ is the value of resonant input resistance at a distance $Y = 0$. This is not a matched input resistance because the characteristics impedance of transmission line is different with that of $R_{in}$. The resonant input resistance can be changed by introducing an inset feed at a distance from the point $Y = 0$. On doing this, the resonance input resistance can be varied and hence a perfect matching of radiating patch with the transmission line can be achieved. Thus, the resonance input resistance at a distance $Y_0$ is obtained as [6]:

$$R_{in}\left(Y = Y_0\right) = \frac{1}{2\left(G_1 + G_{12}\right)}\cos^2\left(\frac{\pi}{L}Y_0\right), \qquad (11)$$

$$R_{in}\left(Y = Y_0\right) = R_{in}\left(Y = 0\right)\cos^2\left(\frac{\pi}{L}Y_0\right). \qquad (12)$$

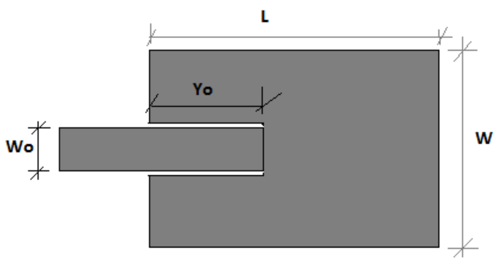


**Fig. 2:** Inset feed microstrip patch resonating at a distance $Y_0$ with the resonant input impedance $R_{in}(Y = Y_0)$.

## 3. Conductive Textile Materials

Textile materials, which contain metal elements, can keep current. The conductivity of the fabric depends on the manufacturing process. It can be produced by metal inter woven fabric during manufacturing or by metal coated fabric [8]. The applications are various. It is used for shielding purposes, flow current, sensors, etc. A good design of a textile antenna has to follow several rules. The most important are small electrical resistance, homogenous surface resistivity and flexible fabric. Two different textile materials were chosen. Fabric called Betex (woven fabric) and Cu-Ni fabric (nonwoven fabric).

**Tab.1:** Textile materials.

| | Betex | Cu-Ni |
|---|---|---|
| **Material** | Shiledex (60 %) Polyster (40 %) | copper + nickel plated non-woven polyamide fabric |
| **Surface Resistivity** | 1,19 Ohm/square | Max average 0,02 Ohm/square |
| **Number of fiber threads per centimeter** | 20 | - |

**Fig. 3:** Copper + nickel plated non-woven polyamide fabric.

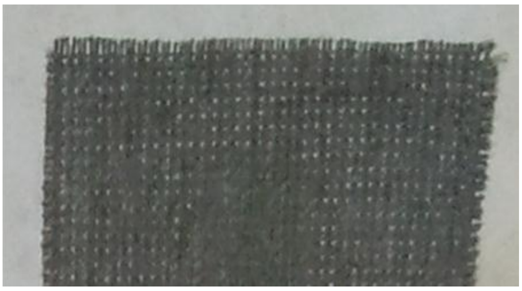

**Fig. 4:** Betex fabric.

## 4. Simulation of Microstrip Patch Antenna

Microstrip patch antenna is widely used for the wireless transmission of information. Bandwidth and efficiency of microstrip patch is dependent on the height of the dielectric substrate and increases as the height of the substrate increases. However with the increase in height, the polarization property and pattern of the antenna radiation degrade. Thus, there is a requirement to choose the optimum height of the dielectric substrate. To know the conductive property of textile material, two different antennas are simulated and fabricated. The radiating and ground plane for one antenna uses Cu-Ni (copper + nickel plated non-woven fabric) and for another radiating and ground plane a woven fabric which is used.

### 4.1. Calculation

**Tab.2:** Antenna parameters used for simulation of two different antennas.

| Sample | Type of fabric | Dielectric Material | Freq. (GHz) | Dielectric constant $\varepsilon_r$ | Height of Dielectric substrate (mm) | Surface resistiv. (Ω/sq) |
|---|---|---|---|---|---|---|
| **Cu-Ni** | Non woven | Fleece fabric | 2,45 | 1,25 | 2 | 0,02 |
| **Betex** | Woven | Fleece fabric | 2,45 | 1,25 | 2 | 1,19 |

Two conductive textile materials are used to designed antenna. One of the conductive textiles has very high conductivity and very low resistivity as that of copper. The other textile material has low conductivity and very high surface resistivity compared to copper. Calculation is performed based on the formulation in chapter 2.3 for the calculation of length width and inset feed distance for the patch as mentioned.

Considering formula (2), dielectric constant $\varepsilon_r$, permittivity of free space $\varepsilon_0$, permeability of free space $\mu_0$, resonant frequency 2,45 GHz, parameters effective dielectric constant of microstrip antenna, width of microstrip patch and increase in length are equaled to:

$$W = 5{,}27\ \text{mm}; \varepsilon_{reff} = 1{,}23; \Delta L = 1{,}09, \tag{13}$$

and the actual length of the patch is calculated as:

$$L = \frac{1}{2 f_r \sqrt{\varepsilon_{reff}} \sqrt{\mu_0 \varepsilon_0}} = -2\Delta L = 59{,}98\ \text{mm}. \tag{14}$$

The patch should be connected with the transmission line having characteristics impedance 50 Ω. Thus, it is required that the patch should also have a resonance input resistance $R_{in}$ = 50 Ω. This can be achieved by feeding the patch at a distance $Y_0$ from the input point. Thus,, from the formula (12), $Y_0$ is equaled to $Y_0$ =18,49 mm.

Now, the calculated data are used for simulation in IE3D software. The IE3D allows an optimization tool and using this tool we optimized the design to get the best result. The optimization is chosen for length of patch and position of inset feed. The goal of this optimization is to make the real part of antenna equal to 50 Ω and imaginary part to be zero. This is done because the transmission line has characteristics impedance of 50 Ω.

**Tab.3:** Optimized dimensions for two patch antennas.

| Antenna Type | Length of patch | Width of patch | Inset feed distance | Width of feed line |
|---|---|---|---|---|
| Cu-Ni | 50,37 mm | 52,7 mm | 34,4 mm | 2,2 mm |
| Betex | 54,545 mm | 52,7 mm | 10,61 mm | 11 mm |

The obtained reflection is −45 dB at 2,45 GHz for the antenna with radiating element Cu-Ni and −22,5 dB at 2,45 GHz for the antenna with Betex one, Fig. 6.

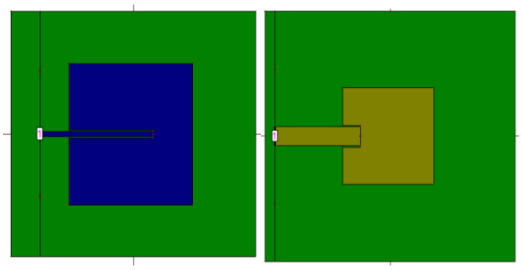

**Fig. 5:** Microstrip patch antenna resonating at 2,45 GHz with surface resistivity of radiating patch 0,02 Ω/sq and 1,19 Ω/sq.

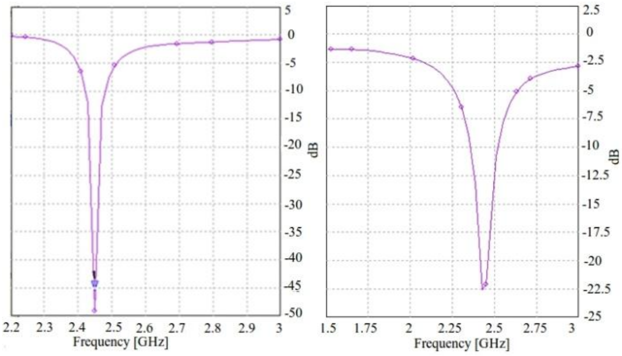


**Fig. 6:** Reflection coefficient ($S_{11}$) measurement for Cu-Ni and Betex respectively.

From the plot of gain vs. frequency it can be noted that the gain for an antenna with surface resistivity 0,02 Ω/sq is 8,1935 dBi (Cu-Ni) and that of antenna using conductive material having surface resistivity 1,19 Ω/sq is 4,5336 dBi (Betex).

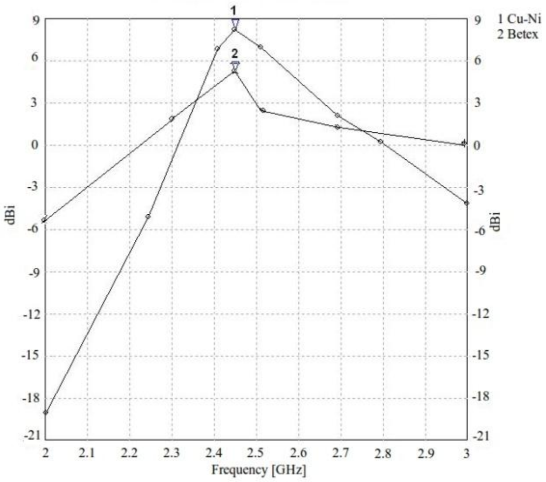


**Fig. 7:** Gain vs. Frequency for both samples.

## 5. Fabrication and Measurements

Two purely rectangular patch antennas are fabricated. The patch radiating elements used are Betex and Cu-Ni. The dimension of ground plane and patch and ground plane are obtained by the manual calculation and after optimization the textile, dielectric substrate and ground plane is cut out using the scissors and knife.

**Fig. 8:** Fabricated Microstrip patch using Betex (left), and Microstrip patch using Cu-Ni (right).

During the fabrication process, the dielectric substrate (Fleece fabric) is attached to the ground plane and radiating patch using gluing technique. Water soluble glue is used to attach the radiating element, substrate and ground. The material Cu-Ni mainly uses copper and nickel so the 50 Ω cable is directly attached to it. However the material Betex is not so good with soldering and cable could not be attached to it directly. Hence a copper tape with the resistance 0,005 Ω is attached to the input of the microstrip patch of Betex.

The far field measurement is performed for both the antennas in a full anechoic chamber and reflection coefficient ($S_{11}$) is measured using VNA, Fig. 9.

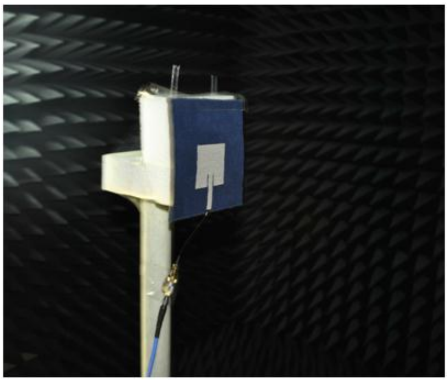

**Fig. 9:** Radiation pattern measurement of textile patch antenna in full anechoic chamber.

The measurement for gain calculation was performed with a reference antenna. The reference antenna was used DRH 20 (gain is 8,04 dBi). The power received by reference antenna is −43,8 dBm. The normalized gain of test antenna can be measured from the radiation pattern data obtained in the full anechoic chamber:

$$G_a = G_{ref} = P_{RX} - P_{RXref}\,, \tag{15}$$

where $G_a$ represents a gain of test antenna, $G_{ref}$ denotes gain of reference antenna (DRH 20), $P_{RX}$ is received power by our tested antenna and $P_{RXref}$ represents received power by reference antenna.

The maximum power received by the antenna is at azimuth angle (0 deg), Fig. 10. At this polarization, the maximum power received by an antenna is −46,1 dBm. The power received by the reference antenna is

 

−43,8 dBm and the gain of reference antenna is $G_r$ = 8,04 dBi. Thus, the maximum gain of test antenna from the measured result is $G_a$ = −46,1 + 43,8 + 8,04 = = 5,74 dBi.

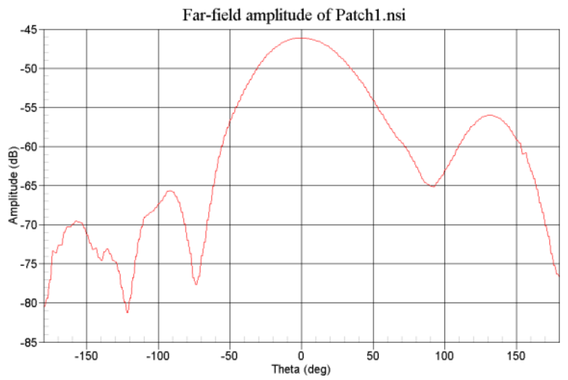


**Fig. 10:** Non normalized far field radiation pattern for Cu-Ni (E-plane).

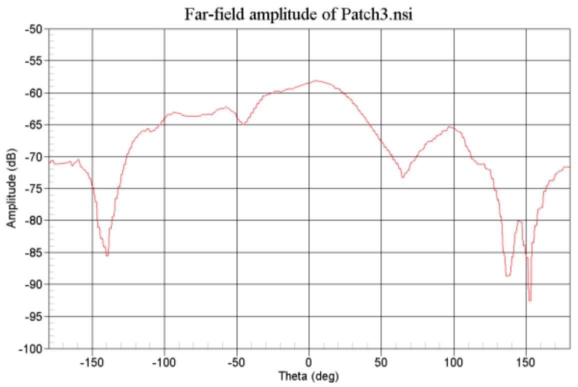


**Fig. 11:** Non normalized far field radiation pattern for Betex (E-plane).

From the Fig. 11, it can be obtained that at 0 degree azimuth angle; the amplitude of the received power at the test antenna is −58,48 dBm. Thus, using the same reference antenna as the previous case, the gain of test antenna can be calculated as $G_a$ = −58,48 + 43,8 + + 8,04 = −6,64 dBi.

The reflection coefficient of the test antenna is measured using vector network analyzer. One port calibration is used and Open, Short and Match calibration is done to measure the $S_{11}$ of the test antenna.

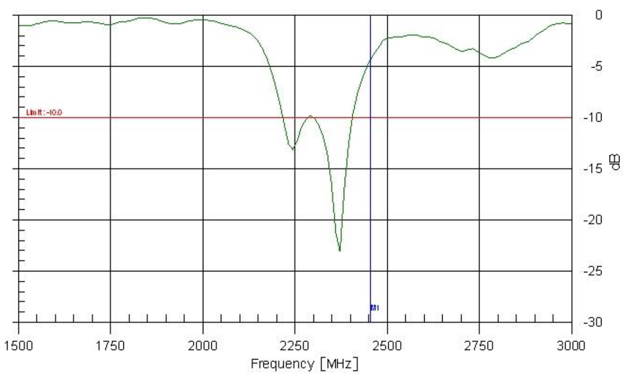


**Fig. 12:** Reflection coefficient $S_{11}$ plot for the purely textile antenna with radiating element Cu-Ni.

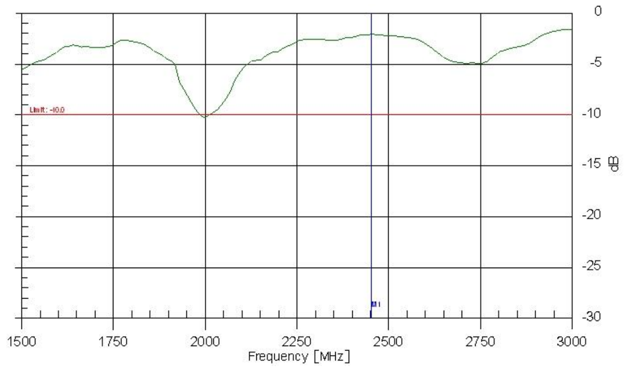


**Fig. 13:** Reflection coefficient $S_{11}$ plot for purely textile antenna with radiating element Betex.

As expected, result of Cu-Ni is shifted in frequency because a glue which is put between the dielectric substrate and radiating patch affects dielectric parameters, Fig. 12. However, the resonance is good enough and the bandwidth is also sufficient for this textile material to be used as an antenna. If the antenna is bent, the resonance frequency may change and if the antenna is wideband, even if the resonance frequency changes, the reflection will still be below −10 dB at the desired frequency and hence sufficient output from the antenna is obtained.

The results obtained for Betex are different from that of simulated value because of change in dielectric material due to the non-precise determination of permittivity and also gluing, Fig. 13.

The shift in frequency and the increased $S_{11}$ value from the simulation result is caused by used glue between layers, which cause inhomogeneity, and by cutting process, which cause rough edges.

## 6. Conclusion

Design and realization of two patch antenna samples, which are based on pure textile material, i.e. radiating element, dielectric substrate and ground, are presented in the paper. The results show high electrical conductivity and relative high antenna gain of both samples, i.e. non-woven and woven fabric. The woven sample consists of electrically conductive yarn which ensures high stability of mechanical and electrical parameters of the textile in time (number of washing cycles).

However, resultant gain of woven fabric is not too high, it is perspective way of future research. Future work includes optimization of the production process of composite antenna, namely lamination of specific layers of composite. Then the antenna can be used in protective overalls during communication of personal terminals with the central system for data gathering of actual physiological condition of workers (heavy duty, rescue operation, etc.).

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