Design and performance analysis of purely textile antenna for wireless applications

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Preface

This thesis is the outcome of the master’s work on textile antenna design, which was done at Czech Technical University in Prague (CVUT), Czech Republic. The thesis work is mainly focused on designing the textile antenna for wireless applications (RFID and 50 Ohm antenna) and the study of the properties of conductive textile materials for their use in designing antenna. The report is presented at the Faculty of Engineering and Sustainable Development, Department of Electronics, Mathematics and Natural Sciences, University of Gävle, Sweden.

We are the students of University of Gävle, Sweden in MSC Electronics/ Telecommunication. The master’s thesis is performed in CVUT and is examined at University of Gävle, Sweden. The thesis is performed under the Erasmus exchange program.

Our supervisor in this thesis is Ing.Bc. Lukáš Vojtěch, Ph.D (CVUT, Czech Republic) and the examiner is Dr. José Chilo (University of Gävle, Sweden).

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Abstract

The new generation of textile has the capability to conduct electricity and at the same time is wearable. There are much more applications involved if an antenna is made that are totally wearable. This thesis uses this new property of conductivity in textile material to implement the wireless functions to clothing. In general, the antennas are made of metal which are highly conductive and also is solid structured which is fixed and hence give the stable output. The challenge with textile antenna is that, because the antenna is purely textile with the radiating element as well as dielectric material and ground being textile, which can be folded and twisted, output stability is the major factor that should be taken into consideration. The thesis work here 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 and also antenna for complex impedance IC chip(128-j577 ohm) at the frequency 869 MHz for RFID application. The design of Micro strip Patch antenna and H-slot antenna has been discussed .The manual calculation for the design of antenna and the simulation result has also been presented. Also the impedance matching technique for 50 ohm and complex conjugate matching for complex impedance has been shown.

As the textile material has higher resistivity, the conductive textile has comparatively lower surface resistivity than that of a pure textile material. However this conductive textile still has comparatively more surface resistivity and hence lower conductivity than the metal. This affects the radiation efficiency. Also the height of dielectric constant plats a greater role in determining the radiating efficiency. Thus a detailed study has been made to find out the relation between them which will be very helpful to choose the appropriate conductive textile material for desired radiation efficiency.
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1 Introduction

In this chapter, the introduction of the thesis, propose and goal of the thesis work is discussed. Also the process used for designing the antenna is mentioned. The simulation software used and its method for solving the electromagnetic equation is presented.

1.1 Basic Introduction

There are various types of antenna which are presently used for many applications. These antennas are generally printed antennas which are rigid and hard. The antenna consists of a copper printed at the top and the bottom of dielectric substrate. The copper print on the upper part of the dielectric substrate represents the radiating part and the print on the lower part of the substrate represents the ground plane of an antenna. This master’s thesis work presents antenna which is different from above mentioned antenna. In place of copper as a radiating and ground element, a conductive textile material is used and in place of solid dielectric substrate, a fabric material having the required dielectric constant is used. The antenna proposed in this thesis work is purely made of textile material so the antenna is called purely textile antenna.

There are some applications at present, where the antennas are used to continuously monitor the biometric data of human body. In order to do this, they need to be so close to the human body all the time so that they can continuously monitor the biometric data and send the information to the outside world. If the antenna is hard it is not suitable to always keep them attached with the human body as they can make some harm due to their physical structure. If the antenna is made of textile material they will not make any harm to human body and will be totally wearable. This is the main motivation to do the thesis.

Two categories of textile antennas, RFID antenna and the antenna for 50 ohm are studied, simulated and fabricated. For RFID antenna design two types of antenna is proposed, namely H-Slot antenna and Patch antenna. For 50 ohm antenna, Microstrip Patch antenna is proposed. The simulated and fabricated antennas along with their measurement results are presented. A comparison between different textile material and their effect on gain, radiation efficiency has also been presented.

The simulation software Zeland IE3D is used to simulate the antennas. This software uses Method of Moment technique. It solves the entire electromagnetic phenomenon related with the antenna by using integral method. This approach gives a very accurate simulated result.
1.2 Propose and Goal of Thesis

In general, mostly antennas made out of copper on a dielectric substrate are in common use. The purpose of this thesis is to design and fabricate the antenna that is made from purely textile material. The antenna designed is for WLAN application which is designed for 50 ohm system and the other antenna for RFID application which is designed for complex chip impedance 128-j577 ohms. The design is mainly focused to integrate the antenna on the clothes.

Generally the printed antenna is manufactured with the metal plating on a solid dielectric substrate. This makes it more stable and always the antenna resonates in desired frequency. However textile antenna is different from printed antenna. The textile antenna is more flexible and easily foldable because the radiating material and ground is not purely copper but conductive fabric and the dielectric substrate is fabric as well. When the antenna is bent, the physical property of the antenna varies and hence the resonance frequency of the antenna may change.

Thus to design a purely textile antenna, a lot more regarding textile material parameter, should be understood. This thesis work also gives the information about the conductive textile material and the study is made on how the various textile parameters affect the gain and radiation efficiency.

Considering all these affects, the main purpose of this thesis is to design an antenna (RFID antenna and 50 ohm antenna) that gives the best performance in the desired frequency and average performance in desired frequency band.

1.3 Method Used

The method used to design the antenna is by using simulation software. The antenna is first simulated in the software, optimized and the final result is fabricated. There is various antenna design software that uses the antenna design method based on numerical methods. Some of the commonly used methods are Method of Moment (MoM), Finite Element Method (FEM) and Finite Difference Time Domain (FDTD). For large antenna structure MoM method can be used to calculate the performance of antenna quickly [1]. Zeland inc’s IE3D (trial version) is the tool used for the simulation of various antennas that works on the method of moment. IE3D is advanced electromagnetic design software which is formally introduction in 1993 IEEE International Microwave Symposium (IEEE IMS 1993). IE3D is full wave electromagnetic designing software which is commonly used for designing various 3D and planer microwave circuits like MMIC, RFIC, RFID, antennas, digital circuits and high-speed printed circuit boards. IE3D solves the current distribution using the integral equation and method of

[2]
moment. Most of the electromagnetic phenomenon is represented by Maxwell’s Equations. IE3D solves the Maxwell’s Equation by integral method and not much assumption is involved. IE3D uses the optimization and tuning methods which is used to achieve the excellent performance of an antenna. This method gives very accurate simulation. The version used is IE3D 12.

IE3D is used to design the antenna because it provides a feature which makes it very easy to use. When designing 50 Ω antennas, the perfect matching of antenna is achieved by looking into the reflection. If both the source and load impedance is equal to 50 Ω the matching is perfect. But in RFID, the load is complex and to have a complete match of IC chip with antenna, the antenna impedance should be complex conjugate with that of the impedance of IC chip. In RFID, unlike in 50Ω system, a perfect match cannot be determined just by looking S11. Hence IE3D provides an advanced feature to analyze the perfect match for RFID. This is called conjugate match factor (CMF). The conjugate match factor vs. frequency graph is a very useful graph that shows the matching in between RFID antenna impedance and the IC chip impedance.
2 Theory

In this chapter, the theories related to the antenna design are presented. Two types of antenna Microstrip patch antenna and H-slot antenna for RFID is discussed which includes the working principle and matching of the antenna. Also a brief discussion on conductive textile material is done.

2.1 Basic Definitions

**Radiation Intensity**

Radiation intensity of an antenna in a given direction is defined as the power radiated from an antenna per unit solid angle [2]. Radiation intensity at a given point is obtained by the product of radiation density and the square of distance from the radiating element is given by

\[ U = r^2 \times W_{\text{rad}} \]  

where, \( U \) is radiation intensity (W/ unit solid angle), \( r \) is distance (m) and \( W_{\text{rad}} \) is radiation density (W/m²)

**Radiation Efficiency**

Antenna is a radiating element. It receives a finite amount of power at its input, a portion of it is lost in it and remaining power is transmitted. If most of the power input to the antenna is radiated, then the antenna is said to have high radiation efficiency. If most of the input power to the antenna is absorbed as losses in the antenna and only few of it is transmitted then it is said to have low radiation efficiency. Antenna radiates low power because either the power is reflected back resulting in poor impedance matching or the power is lost as ohmic loss because of high resistivity of radiating element and also the power is lost due to dielectric loss. Mathematically the radiation efficiency is expressed as,

\[ \text{Radiation Efficiency} = \frac{\text{Power radiated by antenna}}{\text{Power input to antenna}}. \]

Improving the impedance mismatch and using materials with low resistivity increases the radiation efficiency. Also choosing appropriate height for substrate can give best radiation efficiency.
**Directivity**

Directivity is defined as the ratio of radiation intensity by an antenna in the given direction to the radiation intensity in overall direction. In other words, the radiation efficiency is defined as the ratio of radiation intensity by a non isotropic antenna to that of isotropic antenna. The average radiation intensity or the radiation intensity of isotropic source is given by the ratio of the power radiated by the antenna, divided by \(4\pi\).

Directivity is given by,

\[
D = \frac{U}{U_0} = \frac{4\pi U}{P} \tag{2}
\]

Where, \(D\) is directivity, \(U\) is radiation in given direction, \(U_0\) is radiation intensity of isotropic source, \(P\) is power radiated and \(\pi\) is constant and is equal to 3.14.

**Gain**

An isotropic antenna radiates equally in all direction. A directional antenna radiates in a fixed direction. Gain of an antenna is the relative measure of power transmitted in the desired direction by the antenna, when compared with an isotropic antenna. Antenna gain is similar to directivity but also takes into consideration the antenna radiation efficiency. Absolute gain is defined as the ratio of radiation intensity in given direction to the radiation intensity by isotropic radiator when the power input is totally radiated without taking losses due to impedance mismatch and polarization mismatch into consideration[2].

The gain of an antenna is related to radiation efficiency as, \(Gain = Radiation\ efficiency \times Directivity\).

**Radiation Pattern**

When an antenna radiates, the field strength of the antenna decrease as the distance increase. The measure of field strength of the radiated signal at a given distance is called the radiation pattern. The radiation pattern determines the direction and strength of electromagnetic radiation for an antenna. The pictorial view of radiation pattern can be obtained as a 2D or 3D image. Radiation pattern can be plotted in either rectangular or polar plot. There are two types of radiation pattern which is commonly used namely absolute radiation pattern and relative radiation pattern. When the radiation pattern is measured in the absolute unit of field power or strength, it is called absolute radiation pattern and
when radiation pattern is measured in relative to another field power or strength, it is called relative field pattern. Generally most radiation pattern is relative which is measured in reference to isotropic antenna. The radiation pattern very close to antenna gives the near field radiation pattern and the radiation pattern at a distance greater than \(2*D^2/\lambda\) gives the far field radiation pattern, where \(D\) is the antenna length and \(\lambda\) is the wavelength.

**Polarization**

An electromagnetic wave consists of E field and H field. When the antenna radiated, the orientation of E-field and H-field may be in different direction with respect to the earth surface. This orientation of E-field with respect to earth surface gives the polarization of an antenna. Polarization does not depend upon the antenna directional properties but on the physical alignment of an antenna. Thus an antenna when mounted vertically will have one polarization and when the same antenna is mounted horizontally, it will exhibit the different polarization. When a signal with a certain polarization is reflected, the polarization may not be the same again. Thus polarization is affected by reflection. Generally two types of polarization are used when designing an antenna namely linear polarization and circular polarization. In linear polarization, the electric field of radiated electromagnetic wave by an antenna is forced to orient in the desired direction with respect to earth surface. If an antenna at the transmitter is linearly polarized and have the vertical orientation, the receiver antenna should have the same polarization and same orientation to receive maximum power. In circular polarization the electric field of electromagnetic wave is not fixed but varies in all possible direction with respect to earth surface.

A linearly polarized antenna can be used to radiate circular polarized wave by feeding at two points in the antenna with the same magnitude and 90 degree phase shift between the two feed.

To be able to receive the maximum power transmitted from transmitter antenna, both the antenna should have same spatial orientation and same axial ratio. When the miss alignment of antenna occurs, the power received is greatly reduced. For linearly polarized antenna, loss of power due to polarization mismatch is given as,

\[
\text{Loss (dB)} = 20 \log (\cos \theta) \quad (3)
\]

Where \(\theta\) is the misalignment angle difference between transmit and receive antenna.
Quality Factor

The quality factor of an antenna is defined as the ratio of total energy stored in the reactive field to the energy radiated [4]. The quality factor is given by

\[ Q = \frac{2\omega_{\text{max}} (W_M W_E)}{P} \]  \hspace{1cm} (4)

Where, \( W_M \) is stored magnetic energy \( W_E \) is stored energy and \( P \) is radiated power.

Quality factor is used to determine the losses of an antenna. Generally there are four kinds of losses in an antenna which are radiation loss, ohmic loss, dielectric loss and surface wave losses. The conductive losses are directly proportional to the height of the substrate and radiation losses are inversely proportional to height of substrate. When the dielectric height of the substrate increases, the bandwidth of the antenna also increases and at the same time the conductive losses also increases and when the height of the substrate decrease the radiation loss becomes significant.

Bandwidth

Bandwidth is inversely proportional to quality factor. If the total quality factor increase, the fractional bandwidth decrease. If the conductor surface wave losses and dielectric losses are ignored, the bandwidth is directly proportional to the height of the conductor. Thus on decreasing the height of substrate, the quality factor increases and the radiation efficiency decreases. Bandwidth is also affected by surface permittivity and if the substrate permittivity decrease, the bandwidth increase. However this will increase the dimension of antenna. Thus an optimum value of surface permittivity and substrate height is required .The fractional bandwidth is given by

\[ \frac{\Delta f}{f_o} = \frac{\text{VSWR} - 1}{Q \sqrt{\text{VSWR}}} \]  \hspace{1cm} (5)
2.2 Antenna

The term antenna is a transducer which is used to convert the electrical power flowing into the transmission line to electromagnetic radiation and vice versa. The function of antenna is to receive the electromagnetic waves and radiate the electromagnetic waves to free space. The antenna can be represented by Thevenin equivalent circuit, where the generator is the voltage source, transmission line is represented by the characteristics impedance $Z_c$ and antenna is represented as a load having the impedance $Z_a= (R_a+R_r) +jX_a$. Here $R_a$ is the antenna resistance, $R_r$ is the radiation resistance and $X_a$ is the antenna impedance. $R_a$ is responsible for the combined dielectric and ohmic losses.

If an antenna radiates in all direction and does not consider the losses, the antenna is called isotropic antenna. These are ideal antenna and cannot be physically realizable. If an antenna radiates mostly in one direction and also receives from the same direction then this type of antenna is called directional antenna. If an antenna radiates only either in azimuth plane or in elevation plane then this type of antenna is called omnidirectional antenna. Omnidirectional antenna can radiate spherically only in azimuth or in elevation plane in the same pattern at an angle of 360 degree around antenna.

The field region of an antenna is the space surrounded by an antenna. These are broadly classified into three categories namely reactive near field, radiating near field and far field.

The space surrounding the antenna and close to it is called reactive nearfield. The radial distance that contribute nearfield is $R_1=0.62\sqrt{D/\lambda}$. The region greater than $R_1$ but less than a distance $R_2=2*D^2/\lambda$ is called radiating nearfield and the space surrounding the antenna with the radial distance greater than $R_2$ is called farfield, where $D$ is the length of antenna and $\lambda$ is the wavelength.

2.2.1 Resonance of an antenna

Antenna consists of resistance, inductance and capacitance properties. A resonant patch of a microstrip antenna can be modeled as a parallel RLC circuit. The resonance is a phenomenon in which ,when the supply is given, the capacitor is charged and stores the energy in the form of electric field and the inductor stores the energy in the form of magnetic field when current flows through it. This stored energy may be transferred. When the capacitor discharge, the current flows through the inductor and the electric field in capacitor is now stored as magnetic field in inductor and vice versa. This action makes the interchanging of electric and magnetic field to be oscillatory and hence resonance occurs.

[8]
The admittance of parallel RLC circuit is given by

\[ Y = G + j(\omega C - \frac{1}{\omega L}) \]  

Where admittance \( Y = 1/Z \), conductance \( G = 1/R \), capacitive reactance \( X_C = 1/j\omega C \) and inductive reactance \( X_L = j\omega L \). The resonance occurs in the circuit when the inductive reactance is equal to the capacitive reactance and the total impedance seen will only be the resistance. This can be further more explained from the frequency response characteristics of parallel RLC circuit as shown.

The figure above gives the frequency response characteristics of parallel RLC circuit. It can be observed from the figure that for parallel RLC circuit and for lower frequency \( 1/\omega L \) dominates the \( \omega C \) curve and \( Y \) decreases as the frequency increase. At higher frequency \( \omega C \) dominates \( 1/\omega L \) curve and \( Y \) increases as the frequency increase. Thus a certain frequency \( \omega_0 \) is reached where \( \omega C = 1/\omega L \) and they cancel out the effect of each other. At this point the admittance is minimum having \( Y = G \). At this frequency the impedance is purely resistive and the resonance in the circuit occurs.
2.2.2 Antenna Impedance Matching

Antenna is used to transmit the electrical power received at its input, in the form of electromagnetic radiation. It is a transducer used to convert electrical power to electromagnetic radiation. The maximum efficiency of an antenna is obtained when all the input power to it is radiated. However this is not possible because the performance of antenna over the frequency range not only depends upon its frequency response characteristics but also the frequency response characteristics of the transmission line. Generally the transmission line has real characteristics impedance and the characteristics impedance of antenna is complex. Hence when a transmission line having different characteristics impedance with that of antenna is attached to it, impedance mismatch occurs. Due to this impedance mismatch the input power to the antenna reflects back. Thus only a portion of input power to the antenna is radiated. This has a very severe effect on antenna performance because the gain and radiation efficiency is decreased. Some of the advantage of impedance matching is,

1. If there is perfect impedance match between the transmission line and the antenna, maximum power is delivered from source to antenna (if the generator or source is also matched with the transmission line).

2. The signal to noise ratio of the system is improved if the receiver components such as LNA, MGA and antenna are properly impedance matched.

3. In power distribution network, proper impedance matching results in reduction of amplitude and phase error.

Impedance matching is performed to reduce reflection i.e. to make the reflection coefficient zero. This can be mathematically illustrated as.

$$\Gamma_o = \frac{Z_L - Z_o}{Z_L + Z_o}$$  \hspace{1cm} (7)

Where, $\Gamma_o$ is reflection coefficient $Z_L$ is load impedance and $Z_o$ is characteristic impedance.

From the above mathematical relation, it can be seen that when the load impedance is equal to the characteristics impedance, theoretically there is no reflection and the reflection coefficient is zero, and if $Z_L$ and $Z_o$ are not equal to each other then the finite value of reflection coefficient exist which represents the mismatch.
2.3 Microstrip Patch Antenna

Microstrip patch antenna is formed by overlaying a conducting plane over the ground plane and a dielectric material sandwiched between them. Microstrip antenna is used where size, cost, weight, ease of installation is of prime concern. These antennas are low profile antenna which can be built in any shape and are also very simple to manufacture and at the same time are cheaper in cost. Microstrip antenna gives a very stable output and they are mechanically robust when manufactured in a printed circuit board. It is very easy to form a large array of antenna and is light weight. These antennas are very flexible in terms of resonant frequency, pattern, impedance and polarization and if a load is added between the ground plane and the patch, a radiating element with variable resonance frequency, pattern, impedance and polarization can be designed. Microstrip antenna is generally designed to have a broadside radiation pattern, having maximum radiation along the direction normal to the patch. For a microstrip patch to resonate at a certain resonance frequency, the length of the patch $L$ generally lies in the range $\frac{\lambda_0}{3} < L < \frac{\lambda_0}{2}$ [5], where $\lambda_0$ is the wavelength. Various dielectric substrates can be used when designing a microstrip patch having the dielectric constant in the range of $2.2 \leq \varepsilon_r \leq 12$ [5], where $\varepsilon_r$ is the dielectric constant. There are also some limitations of patch antenna as these antennas have low efficiency, low power handling and lower bandwidth. However there are methods to improve the efficiency and bandwidth such as increasing the height of dielectric substrate but this result in increase in surface waves which is generally undesirable because they degrade the antenna polarization property and pattern. Microstrip patch antenna can be designed in various shapes as shown below.

![Fig. 3. Different structure of microstrip patch antenna](image)

Fig. 3. Different structure of microstrip patch antenna
2.3.1 Rectangular Microstrip Patch Antenna

A rectangular microstrip patch antenna is widely used antenna because they are very suitable for thin substrate and are easy to manufacture. However some parameters should be considered before designing an antenna. The rectangular patch antenna can be modeled as either transmission line model or cavity model. In transmission line model the antenna is assumed to have length L and separated by impedance Zo. In cavity model, the patch antenna is modeled as an array of two radiating surface separated by distance L.

2.3.2 Equivalent model of patch antenna

Transmission line model

In transmission line model, microstrip antenna is assumed to have two radiating slots with a low impedance transmission line between them. This can be viewed as,

![Diagram of transmission line equivalent of an unloaded microstrip rectangular patch](image)

*Fig. 4.* Transmission line equivalent of an unloaded microstrip rectangular patch

When a microstrip line is fed at the input, it generates an electric field. The microstrip patch antenna has finite length and width. Because of this, at the edges of patch, the field undergoes fringing. This fringing depends upon the dimension of the patch, height of the substrate and dielectric constant of the substrate [2]. The fringing field can be reduced if the ratio of length of the patch to the height of dielectric is very high. However this may also affect the resonance length. Due to this fringing, the microstrip line looks wider compared to its real physical dimension. To achieve correct resonant frequency, the effective length and effective width should be considered because due to fringing the dielectric constant changes to effective dielectric constant and this changes the length of the patch.
Cavity Model

Transmission line model is easy to design an antenna but ignores the field variation in the radiating patch. A different approach of analysis concludes the leftover part in transmission line model. This approach is the cavity model. In cavity model the interior of dielectric substrate is considered to be a cavity bounded by electric walls on the top and bottom when the substrate height is very thin ($h \ll \lambda$)[1].

When the microstrip patch is energized, the charge distribution is formed as shown in the figure. The distribution of charge is controlled by two mechanism namely attractive mechanism and repulsive mechanism [7]. The attractive mechanism is between the opposite charges which lie below the microstrip patch and on the ground plane. The repulsive mechanism is in between like charge on the bottom of the patch. This repulsive mechanism tries to push some charge to the edges and further to the top surface of the patch and hence small current flows at the top surface of the patch. This current flow can be minimized to zero if width to height ratio is decreased. This does not create any tangential field on the edges of the patch. Thus this makes the four sides of the substrate to be modeled as perfect magnetic wall that does not disturb any electric and magnetic field below the patch. However in practical consideration, there is always finite width to height ratio and this leads to tangential magnetic field at the top surface of the patch. If the walls of the cavity and materials were lossless, the cavity would not radiate. In order to analyze more practical approach the microstrip should be lossy.
Thus to address loss in cavity model a parameter called loss tangent (\( \tan \delta \)) is introduced. This value is appropriately chosen to consider the losses due to cavity and is inversely proportional to quality factor of an antenna.

### 2.3.3 Design of Rectangular Patch Antenna.

A microstrip patch antenna consists of a radiating element, a ground and a 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. It can be observed from above figure that for the microstrip line, 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 by [2].

\[
\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ 1 + 12 \frac{h}{W} \right]^{-1/2} \quad (8)
\]

Where, \( W \) is width of microstrip patch, \( h \) is height of dielectric substrate, \( \varepsilon_r \) is dielectric constant and \( \varepsilon_{\text{eff}} \) is effective dielectric constant.

The width of the microstrip patch is calculated by [2]

\[
W = \frac{1}{2 f_r \sqrt{\mu \varepsilon_0} \sqrt{\frac{2}{\varepsilon_r + 1}}} \quad (9)
\]

Due to fringing, the length of the patch increases electrically. Thus the increase in length is given by[2]

\[
\Delta L = 0.412 h \left( \frac{\varepsilon_{\text{eff}} + 0.3 (\frac{W}{h} + 0.264)}{\varepsilon_{\text{eff}} - 0.258 (\frac{W}{h} + 0.8)} \right) \quad (10)
\]

Where, \( \Delta L \) is the increase in length.
The length is increased on both side of the microstrip patch. Thus the effective length is given as \[ L_{\text{eff}} = L + 2\Delta L \] (11)

\[ L = \frac{\lambda_{\text{eff}}}{2} - 2\Delta L = \frac{1}{2 f_r \sqrt{\varepsilon_{\text{eff}}} \sqrt{\mu_r \varepsilon_0}} - 2\Delta L \] (12)

Thus the resonance frequency for the microstrip antenna with length \( L \) and dielectric constant \( \varepsilon_r \) is given as

\[ f_r = \frac{1}{2L\sqrt{\varepsilon_r} \sqrt{\mu_r \varepsilon_0}} \] (13)

When the fringing has finite impact, the effective length and effective dielectric constant is to be considered. In this case, the resonance frequency can be computed by

\[ f_{rc} = \frac{1}{2L_{\text{eff}} \sqrt{\varepsilon_{\text{eff}}} \sqrt{\mu_r \varepsilon_0}} \] (14)

**Resonant Input Resistance**

The radiating slot in microstrip patch antenna is represented as parallel equivalent circuit with the admittance \( Y \) such that \( Y= G+jB \) \[2\].

![Fig. 7. Microstrip patch with equivalent circuit model](image)

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 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.
Thus the transformed impedance is given by

\[ Y_2' = G_2' + jB_2' \]  

(15)

Where \( B_1 = B_2 \) and \( G_1 = G_2 \).

Thus at resonance the reactive part cancels and the total admittance is given as,

\[ Y_{in} = Y_1' + Y_2' = 2G_1 \]  

(16)

\[ R_{in} = \frac{1}{2G_1} \]  

(17)

When the mutual effects between the slots is considered, the resonance input resistance is obtained [2] as,

\[ R_{in} = \frac{1}{2(G_1 + G_{12})} \]  

(18)

Where, \( G_1 \) is conductive of single slot of radiating patch antenna and \( G_{12} \) is mutual conductance of radiating slot.

Rin 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 Rin. 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 [2],

\[ R_{in} (Y = Y_0) = \frac{1}{2(G_1 \pm G_{12})} \cos^2 \left( \frac{\pi Y_0}{L} \right) \]  

(19)

From equation (18) and (19) we find,

\[ R_{in} (Y = Y_0) = R_{in} (Y = 0) \cos^2 \left( \frac{\pi Y_0}{L} \right) \]  

(20)
2.4 Radio Frequency Identification (RFID)

RFID stands for Radio Frequency Identification. RFID uses wireless technology to identify the objects. It consists of RFID tag and a reader. The bi-directional communication between the tag and the reader is accomplished by the Radio Frequency (RF) part of the electromagnetic spectrum, to carry information between an RFID tag and reader.

RFID systems are differing for different applications. An RFID system can be a single unit with a single tag and a single reader or it can be complex like an RFID tracking system with thousands of products each tagged with an RFID tag. In complex system, many distributed RFID readers send data to computers to process the information and may share this information with many other companies in different countries.

There are two types of RFID tag. Passive RFID tags are the ones that do not require any external power supply and works by receiving the signal from reader and retransmit the signal back to reader. Active RFID tag consists of external source in them. These are more complex than passive RFID tags and also give long range communication between tag and reader, when compared with passive tag.
2.4.1 Communication structure

In the figure below, the communication between RFID transponder and RFID reader is illustrated by a picture:

![Block diagram of RFID system](image)

*Fig. 9. Block diagram of RFID system*

The basic block diagram describes the bi-directional communication between the tag and the reader. The tag antenna in the block diagram receives the RF signal from the reader. This signal is received by the tag antenna, rectified and supplied to the chip to power it up. After the chip is powered up, it now acts as a source and retransmits the signal back to the reader. The reader after receiving the signal sends further ahead to the computer to process the data. The method used to send the signal back to the reader from the tag is called back scattering.

**RFID Transponder**

RFID Transponder is basically a radio transmitter and receiver. It mainly consists of two parts, antenna and the integrated circuit (IC). The main function of an antenna is to capture the radiated electromagnetic field by the reader at a definite frequency. The received electromagnetic energy is converted to electrical power and supplied to integrated circuit. The IC chip in the transponder has the capability to store the information to be transmitted to the reader, execute the series of command and also sometimes stores new information sent by the reader [1]. The IC chip mainly consists of a rectifier which rectifies the alternating voltage (AC) received by antenna to the continuous voltage (DC) and supplies to the rest of the circuit in the IC chip.

The IC used for the thesis is EM4222. This is a read only UHF identification device. EM4222 is used as a passive chip for UHF transponder. It does not have any internal power supply source. The RF beam is transmitted by the reader. The antenna in the transponder receives the signal, rectifies it and supply the rectified voltage to the chip.
The table below gives the electrical characteristics of the chip EM4222.

\[\text{Table 1: Electrical characteristics of IC EM4222}\]

VM-VA=2V, TA=25\(^\circ\)C, unless otherwise specified [8]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Test conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oscillator frequency</td>
<td>Fosc</td>
<td>-40(^\circ)C to +85(^\circ)C</td>
<td>400</td>
<td>512</td>
<td>600</td>
<td>KHz</td>
</tr>
<tr>
<td>Wake up voltage</td>
<td>Vwu</td>
<td>VM-VA rising</td>
<td>1.0</td>
<td>1.4</td>
<td>1.8</td>
<td>V</td>
</tr>
<tr>
<td>Static Current Consumption</td>
<td>I STAT</td>
<td>VM=1v</td>
<td>1</td>
<td>5</td>
<td></td>
<td>(\mu)A</td>
</tr>
<tr>
<td>Input Series Impedance</td>
<td>Zin</td>
<td>869 MHz : -10dBm</td>
<td></td>
<td>128-j577</td>
<td></td>
<td>(\Omega)</td>
</tr>
<tr>
<td>Input Series Impedance</td>
<td>Zin</td>
<td>915 MHz : -10dBm</td>
<td></td>
<td>132-j553</td>
<td></td>
<td>(\Omega)</td>
</tr>
<tr>
<td>Input Series Impedance</td>
<td>Zin</td>
<td>2.45 GHz : -10dBm</td>
<td></td>
<td>80-j232</td>
<td></td>
<td>(\Omega)</td>
</tr>
</tbody>
</table>

**RFID Reader:**

An RFID reader also called the interrogator is one of the basic elements for RFID system. It has mainly two functions. The reader generates the RF signal which is used to energize the transponder chip. The reader in this stage acts as a transmitter. The signal to be transmitted by the reader should be modulated with specific code. The RF signal is then amplified and transmitted. The transponder after receiving the signal from reader retransmits the signal with newer information back to the reader. The signal transferred back to reader is called backscattered signal. Thus another function of the reader is to receive the backscattered signal from the transponder. The reader has a receiver which can receive a very low power signal from the transponder. The back scattered signal after being received is filtered, amplified and demodulated. The reader also continuously establish a bidirectional communication with a computer attached to it and sends the demodulated signal to the computer for further processing.
2.4.2 RFID Matching

The tag antenna receives RF energy from the reader. The tag antenna works for a definite resonant frequency. So when the reader transmit RF signal with the desired frequency, the tag receives the signal and supplies to the chip which is attached to it in the transponder. The chip after getting sufficient voltage is able to wake up and hence re transmit the signal at the same frequency to the reader. The purpose of matching an antenna with its load is to insure that maximum power is transferred from antenna to chip. To do this, it is needed to have a perfect match between the antenna and the chip. Perfect antenna matching can be achieved by changing the dimension of an antenna, by adding a reactive component or implementing both of them. A mathematical expression can be overviewed as [9],

\[ P_t = \frac{R_c}{2[(R_{ant} + R_{ic})^2 + (X_{ant} + X_{ic})^2]} V_{ant}^2 \]  

(21)

In the above equation it can be seen that the maximum power can be delivered from the antenna to the IC only if \( R_{ic} = R_{ant} \) and \( X_{ic} = -X_{ant} \). It can be observed that the maximum power can be delivered from antenna to load only if they are conjugate matched. This gives one of the favorable conditions for antenna designer because in general, the antenna impedance is inductive in nature and the impedance of the chip is capacitive. The perfect matching can then be obtained by tuning the antenna impedance.

In this thesis the antenna is designed to work at 869 MHz. At this frequency the input series impedance of the chip is 128-j577 Ω. Thus the requirement is to have antenna impedance of 128+j577 Ω such that it is complex conjugate matched with the load and maximum power is transferred.
**Conjugate Match Factor (CMF)**

Except the radiation efficiency and antenna efficiency, there is another important factor in RFID tag antenna design. The factor is Conjugate Matching Factor (CMF).

CMF can be described as the ratio between antenna input power with given chip impedance $Z_s$ and the antenna impedance $Z_a$ (not matching condition), and the antenna input power with given $Z_s$ and assuming $Z_a$ is complex conjugate of $Z_s$ (perfect matching condition). Thus CMF is used to relate the antenna impedance with that of chip

$$CMF = \frac{\text{Antenna input power (when } Z_a \neq Z_s)}{\text{Antenna input power (when } Z_a = Z_s')}$$

The value of CMF changes between 0 and 1 in linear. If CMF is less than 0.5 then the matching between antenna and chip is not good enough. If CMF is 1 then the antenna impedance is perfectly matched to the chip impedance.

To receive maximum power from the reader and retransmit the maximum power to the reader, the antenna impedance should be complex conjugate match with that of chip. CMF is the factor which tells how good matching is done between the chip impedance and the antenna impedance.

### 2.4.3 Read Range

In a passive RFID system, the transponder is energized by the radio waves emitted by the reader. Thus the wave received by the transponder has to travel in the free space. When the transponder energies, it resends the signal through backscatter to the reader and the radio wave again suffer the free space loss. The reader is always fixed and can transmit with significant power, but the backscattered power by the transponder is comparatively less. Thus maximum read range in the RFID is determined by the maximum distance between transponder and reader such that the backscattered power received by the reader should not be below the reader’s receiver threshold. When the power transmitted by the reader is fixed, the read range is mainly determined by the transponder antenna gain and operating frequency.

Theoretically, a perfect match can be achieved but when an antenna is fabricated practically, due to various imperfections and manual error during fabrication, a mismatch occur which results in different impedance between load and antenna. Due to this mismatch the power delivered to the load is comparatively less and hence the radiated power will also be less. This will also affect the sensitivity and the read range of the transponder.

[21]
Read range by free space equation

The reader antenna has a transmit power and gain as, $P_{\text{reader transmitted}}$ and $G_{\text{reader}}$. The power density at a distance $R$ from the reader where the tag is placed is given by [10]

$$S_1 = \frac{G_{\text{reader}} P_{\text{reader transmitted}}}{4\pi R^2} \quad (22)$$

The received power at the tag is given by,

$$P_{\text{tag received}} = S_1 A_{\text{tag}} \quad (23)$$

Where, $A_{\text{tag}}$ is the area of tag antenna

$$A_{\text{tag}} = \frac{G_{\text{tag}} \lambda^2}{4\pi} \quad (24)$$

Where, $G_{\text{tag}}$ is the gain of tag antenna

So, the power received by the tag antenna when the reader is transmitting, is given by

$$P_{\text{tag received}} = S_1 A_{\text{tag}} = \left(\frac{\lambda}{4\pi R}\right)^2 G_{\text{reader}} G_{\text{tag}} P_{\text{transmitted}} \quad (25)$$

Where, $G_{\text{reader}}$ is gain of reader antenna.

Now, the tag (transponder) receives the power from reader and retransmits the power to the reader. This is called backscatter. At this time the transponder becomes a transmitter and the reader becomes the receiver. The power density at a distance $R$ from transponder (where the reader is located) is,

$$S_2 = \frac{G_{\text{tag}} P_{\text{tag received}}}{4\pi R^2} \quad (26)$$

The backscattered power received by the reader at the distance $R$ from the transponder is,

$$P_{\text{back reader}} = S_2 A_{\text{reader}} = S_2 G_{\text{reader}} \frac{\lambda^2}{4\pi} \quad (27)$$

Where, $A_{\text{reader}}$ is the equivalent aperture of reader antenna. The equivalent transmitted power is,

$$P_{\text{ERP}} = G_{\text{reader}} P_{\text{transmitted}} \quad (28)$$
By combining above equations, we get,

\[ P_{\text{back}}^{\text{reader}} = \left( \frac{\lambda}{4\pi R} \right)^4 G_{\text{read}}^2 G_{\text{tag}}^2 P_{\text{transmitted}} \]  

(29)

This is the power received by reader antenna when the gain of transponder antenna, gain of reader antenna and power transmitted by reader antenna is given. If the receiver threshold of the reader antenna is \( P_{\text{sensitivity}}^{\text{reader}} \), then the maximum read range for the transponder to work effectively with the reader is given by

\[ R = \frac{\lambda}{4\pi} \sqrt{\frac{P_{\text{transmitted}}^{\text{reader}} G_{\text{read}}^2 G_{\text{tag}}^2}{P_{\text{sensitivity}}^{\text{reader}}}} \]  

(30)

**Read range by power transmission coefficient**

The maximum reading distance can be found also from the below equation;

\[ d_{\text{max}} = \frac{c}{4\pi f} \sqrt{\frac{EIRP_{\text{chip}}}{P_{\text{chip}}} G_{\text{tag}}^2} \]  

(31)

\[ \tau = \frac{4R_{\text{chip}}Ra}{|Z_{\text{chip}} + Za|^2} \leq 1 \]  

(32)

Where \( \tau \) is the power transmission coefficient, \( R_{\text{chip}} \) is real part of chip impedance (\( Z_{\text{chip}} \)) and \( R_{\text{a}} \) is real part of antenna impedance (\( Z_{\text{a}} \))

The matching between the antenna and the chip is poor if \( \tau \) is less than 0.5. For each case the power transmission coefficient \( \tau \) is greater than 0.5.

### 2.4.4 H-slot antenna

The designed antenna layout is an H-shape slot place onto a patch for RFID application. In fig.21 shows the layout of the H-slot patch antenna.

The patch with H-slot is placed on a substrate and grounded by a conductive material to decouple from the human body.

[23]
Fig. 1. Layout of the H-slot patch antenna [11]

H-slot is a tuning slot for the required conjugate impedance matching between the microchip and the tag’s antenna. The maximum size of the antenna is 150mm x 180 mm and the gain is rather poor around -7 dB due to the bidirectional radiation of the slot. But the maximum gain can be increased by increasing width of the tag antenna. The impedance matching is done by tuning the internal slot size.

Dielectric material of this patch antenna has a thickness of ‘h’ and it has a longer face of it in the lower part which is placed on the human body through the conductive ground plane. It is an advantage to have longer ground plane because it will avoid the effect of human body radiation.

The radiation is produced by the patch open edge and by the edges at the slot [11]. To achieve better radiation performance, width of the antenna can be increased. The dimension of the central gap is kept fixed, but for tuning, the other dimensions of the slot are optimized. The perfect conjugate matching should be done between antenna and microchip to obtain the maximum reading distance.

2.5 Conductive Textile

The fabric that can conduct electricity is called conductive fabric. The conductivity of the fabric depends on how it is manufactured. Conductive fabric can be made in various ways. They can either be produced by metal inter woven fabric during manufacturing or by metal coated fabric [12] also called electro thread. These conductive textiles has wider application in various fields as they are used for shielding human body and some special equipment from external electromagnetic radiation, are used as pressure sensor and flexible heaters are made out of conductive textile which is easily wearable.

For a good design of a textile antenna, the conductive fabric should satisfy some of the conditions as given below.
1. The electrical resistance of the conductive textile fabric should be small in order to reduce the ohmic losses in the fabric.

2. The surface resistivity should be homogeneous over the entire conductive textile fabric i.e. the variation of resistance should be minimum.

3. The fabric should be flexible enough to be able to use as a wearable antenna.

The antenna performs better if the conductive textile fulfills the above given characteristics.

**Non woven fabric**

By the name it can be concluded that non woven fabric is prepared by neither knitting process, nor are woven fabric. Thus the non woven fabric does not go through the initial stage of yarn spinning and also a definite web pattern as that of a woven fabric is not obtained. Non woven fabric manufacturing process is similar to that of paper manufacturing process.

![Fig. 12. Copper + nickel plated non-woven polyamide fabric](image)

These kind of fabric are generally manufactured in three ways namely, dry laid system, wet laid system and polymer based system. After the fabric is manufactured, it is then strengthened. There are various ways for strengthening fiber web as by using chemical means by spraying, coating. This can also be achieved by thermal means by blowing air or by ultrasonic impact which partially fuses (connects) the fiber thread. Thus finally the metal layer is coated.

**Woven Fabric**

Woven fabric is a textile fabric made by weaving. These are generally constructed in a big loom and are made of many threads woven together. Conductive nano particles are attached to the thread which makes them conductive and are later on woven to give a fabric shape.
3 Process and Results

In this chapter three different antennas are simulated and fabricated for the conductive textile material. The three designed antennas are microstrip patch antenna with inset feed for 50 Ω, H-slot antenna for RFID having an IC chip EM4222 at 869 Mhz with the impedance 128-j577, microstrip patch antenna for RFID having T-match. Manual calculations and simulation results for all the three antennas is presented below. Each antenna is simulated with two different conductive textile material having surface resistivity 0.02Ω/sq and 1.19Ω/sq. The specification of material used is also explained and the performance of two antennas having different radiating material is compared.

The antenna made from conductive textile material is not the same as the printed antenna made with copper. A conductive textile material is known by its surface resistivity. This surface resistivity affects the antenna performance. An extra work is done in this thesis (simulating 20 different patch antenna) to find the relation between the gain, radiation efficiency and surface resistivity.

3.1 Materials Used

The conductive textile material is used in this thesis to make wearable antennas for various applications. This material is used as a radiating plane and the ground plane of the antenna. The material used is a conductive textile having the finite conductivity. Two types of conductive textile materials are used as explained above. The first material is Cur-Cu-Nip with the thickness measured in the lab is 0.14mm. This is a non woven conductive textile material. The technical specification is given as [2].

Description: copper + nickel plated non-woven polyamide fabric
Roll widths: 102 cm ± 2 cm
Surface resistivity: Max average 0,02 Ohm/square
Shielding effectiveness: 70-90 dB from 50 MHz to 1 GHz
Purpose: Conductive fabric for general use
Temperature range: -30 to 90 (degree centigrade)

Another conductive textile material used is Betex. This is the woven conductive textile material which is specifically manufactured for the laboratory and research purpose at Czech Technical University in Prague (CVUT). The woven fabric consists of silver nano particles attached to the thread of fiber when being constructed and then woven to form a conductive textile. The thickness
of the conductive textile material measured in lab is 0.35mm. The technical specification is given as,

**Name:** Betex  
**Materials Used:** Shieldex (60%) (silver coated)  
Polyester (40 %)  
**Number of fiber threads per centimeter:** 20  
**Surface Resistivity:** 1.19 ohm/sq

The dielectric material used is Fleece fabric. The material is used as a dielectric substrate and has a dielectric constant of 1.25.

### 3.2 Simulations, fabrication and measurement

#### 3.2.1 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 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. There is a tradeoff in between choosing bandwidth and substrate height. Thus there is a requirement to choose the optimum height of dielectric substrate.

To know the conductive property of textile material, two different antennas is simulated and fabricated. The radiating and ground plane used for first antenna is Cur-Cu-Nip (copper + nickel plated non woven fabric) and for second antenna is Betex. Betex is a woven fabric which is manufactured for lab purpose in Czech Technical University in Prague. The specification of the materials used is given in chapter 3.1.

**Manual Calculation**

*Table 2: Antenna parameters used for simulation of two different antenna*  

<table>
<thead>
<tr>
<th>Radiating and ground Patch</th>
<th>Type of fabric</th>
<th>Dielectric Material</th>
<th>Frequency (GHz)</th>
<th>Dielectric constant</th>
<th>Height of Dielectric substrate (mm)</th>
<th>Surface resistivity (Ω/sq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cur-Cu-Nip</td>
<td>Non woven</td>
<td>Fleece fabric</td>
<td>2.45</td>
<td>1.25</td>
<td>2</td>
<td>0.02</td>
</tr>
<tr>
<td>Betex</td>
<td>Woven</td>
<td>Fleece fabric</td>
<td>2.45</td>
<td>1.25</td>
<td>2</td>
<td>1.19</td>
</tr>
</tbody>
</table>
Two conductive textile materials are used to design antenna. The conductive materials are used as a ground plane and the radiating patch for an 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. The two materials used are Betex and Curex with the properties as described in Table 2.

Manual calculation is performed based on the formulation in chapter 2.3.3 for the calculation of length width and inset feed distance for the patch as mentioned in equation (9). The calculated value for width or the rectangular patch is $W = 52.7\text{mm}$. Where the values of $\varepsilon_0$ (the permittivity of free space) is $8.854\times10^{-12} \text{F/m}$, $\mu_0$ (permeability of free space) is equal to $4\pi\times10^{-7} \text{H/m}$ and the effective dielectric constant of microstrip antenna $\varepsilon_{\text{reff}}$ is equal to 1.23. Hence the actual length of the patch $L$ is given by the equation (12) as $L = 59.98\text{mm}$.

The above length and width obtained from the manual calculation is for the patch which radiates at a resonant frequency $f_r=2.45 \text{GHz}$. Both the antennas are designed to operate at 2.45 GHz. Thus the dimension for length and width for both are same because, the dielectric constant and height of dielectric substrate is also the same for both the design. After the optimization the input feed distance and dimensions are changed. The resonance input resistance for the patch is obtained as $R_{\text{in}}(Y = 0) = 155.63\Omega$.

The patch should be connected with the transmission line having characteristics impedance $50\Omega$. In order to have a perfect match between the antenna and the transmission line, it is required that the patch should also have a resonance input resistance of $50\Omega$. This can be achieved by feeding the patch at a distance $Y_0$ from the input point (changing the distance of inset feed point). Thus the distance of the inset feed where the impedance of antenna is $50\Omega$ is given by

$$R_{\text{in}}(Y = Y_0) = R_{\text{in}}(Y = 0)\cos^2\left(\frac{\pi}{L}Y_0\right)$$  (20)

Then, we get $Y_0 = 18.49\text{mm}$.

We calculate the length and width of the microstrip patch antenna. Next we designed a microstrip patch with an inset feed from the data obtained above. At first the ground plane is positioned. For simulation a finite ground plane is choosen. The designed patch is shown in the figure. 13.
A complete design of microstrip patch is first made on IE3D. The next step used in designing the antenna is feeding. Vertical localized port is used to feed the patch antenna (The antenna made with Betex and Curex). After simulating, we get the result. This obtained result is not the good one. IE3D allows an optimization tool and using this tool we optimized our design to get the best results. 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 50Ω and it is desired that the antenna impedance is equal to that of characteristics impedance. The simulated figure of patch antenna with surface resistivity 1.19 Ω/sq is given in figure 41 A[2]. The optimized result for both the antennas obtained is shown in the table as,

<table>
<thead>
<tr>
<th>Antenna Type</th>
<th>Length of patch</th>
<th>Width of patch</th>
<th>Inset feed distance</th>
<th>Width of feed line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cur-Cu-Nip</td>
<td>50.37mm</td>
<td>52.7mm</td>
<td>34.4 mm</td>
<td>2.2mm</td>
</tr>
<tr>
<td>Betex</td>
<td>54.545mm</td>
<td>52.7mm</td>
<td>10.61mm</td>
<td>11mm</td>
</tr>
</tbody>
</table>

When the power from the transmission line is fed to antenna, some of the power is delivered to the antenna and some of it is reflected back. From maximum power transfer theorem, we know that maximum power is transferred from source to load only if the load and source impedance is same. The transmission line has a characteristics impedance of 50Ω. The antenna impedance consists of both resistive and reactive part. Thus maximum power is delivered to antenna only if the reactive part

[29]
of antenna is zero and the resistive part is 50Ω. At this point there will be no reflection and almost all the power is transmitted. In the simulated result we can observe that for the antenna resonating at 2.45 GHz with radiating element Cur-Cu-Nip (surface resistivity=0.02 Ω/sq), the reflection is -45 dB and the reflection for the antenna that uses the radiating element Betex (surface resistivity=1.19 Ω/sq) is -22.5 dB. This is observed in figure 43 A[3].

The smith chart for two simulated antenna, after optimization, gives the perfect match at 50 ohm. The figure obtained after the optimization is presented in figure 42 A[2]. It can be observed that at 2.45 GHz, the impedance of the antenna is perfectly matched and is equal to 50 ohm.

![Gain Vs Frequency plot for the radiating patch having surface resistivity 0.02 Ω/sq](image1.png)

*Fig. 14. Gain Vs Frequency plot for the radiating patch having surface resistivity 0.02 Ω/sq*

It can be observed from figure 14 that the gain for an antenna with surface resistivity 0.02 Ω/sq is 8.1935 dBi.

![Gain Vs Frequency plot for the radiating patch having surface resistivity 1.19 Ω/sq](image2.png)

*Fig. 15. Gain Vs Frequency plot for the radiating patch having surface resistivity 1.19 Ω/sq*
The gain of an antenna using conductive material having surface resistivity $1.19 \ \Omega/sq$ is 4.5336 dBi. The simulation result shows that the gain of an antenna having surface resistivity $1.19 \ \Omega/sq$ is less than half the gain of antenna having surface resistivity $0.02 \ \Omega/sq$, even if the other parameters are kept constant. This proves that surface resistivity of the conductive textile material, when used as radiating element of an antenna, plays an important role in determining the gain of an antenna.

Fig. 16. Radiation efficiency Vs Frequency plot for the patch having surface resistivity $0.02 \ \Omega/sq$

From figure 16, it is observed that the radiation efficiency for an antenna with radiating element having surface resistivity $0.02 \ \Omega/sq$ is 83.3889%.

Fig. 17. Radiation efficiency Vs Frequency plot for the patch having surface resistivity $0.02 \ \Omega/sq$

From figure 17 it can be seen that the radiation efficiency for an antenna having surface resistivity $1.19 \ \Omega/sq$ is 30.5796%. This is one of the very important factors when choosing conductive textile material. Radiation efficiency gives the measure of the power being radiated by an antenna. Thus in order to have higher radiation efficiency when using conductive textile as a radiating element, a material with low surface resistivity should be preferred.
3.2.2 Fabrication and measurement of rectangular patch antenna

In this chapter the fabricated and measured result for microstrip patch antenna is shown. The rectangular patch antenna is fabricated with two different materials (Betex and Curex) for radiating element and ground plane. Far field radiation measurement and S11 measurement for both the antenna is performed and the result is presented. The dimensions of the ground plane and patch are firstly obtained by manual calculation and after optimization the textile antenna on IE3D, final dimensions are obtained. Then the dielectric substrate, radiating plane and ground plane is cut out using the scissors and knife to give the shape of antenna.

![Fabricated Microstrip patch using Betex(a), and Microstrip patch using Curex(b).](image)

Fig. 18. Fabricated Microstrip patch using Betex(a), and Microstrip patch using Curex(b).

During the fabrication process, the dielectric substrate (Fleece fabric) is attached to ground plane and radiating patch using gluing technique. Water soluble glue is used to attach the radiating element, substrate and ground. The material Cure-Cu-Nip mainly uses copper and nickel. It is very easy to use soldering on this material, so the 50 Ω cable is directly connected to it by using soldering technique. However the material Betex is not so good with soldering and cable could not be attached to it directly because the material is mainly made with fiber and the silver nano particles is attached in it to make the material conductive. Hence a copper tape with the resistance 0.005 Ω is attached to the input of the microstrip patch as shown in the figure 18(a). This copper tape helps to connect the antenna with the cable. The soldering is then performed as shown in the figure 19.
Measurement

The far field measurement is performed for both the antenna in anechoic chamber and reflection (S11) is measured using VNA. Anechoic chamber is a shielded chamber which is made from the material that is used to absorb or scatter the incident waves. It is a shielding chamber which shields the electromagnetic interference and hence can simulate the space as free space for the measurement of antenna parameters.
The measurement was performed with a reference antenna. The measurement is performed to calculate the gain and far field radiation pattern of the designed antenna. The reference antenna used is DRH 20 has a gain of 8.04dBi. The power received by reference antenna is -43.8dBi.

**Gain measurement**

The normalized gain of test antenna can be measured from the measured data obtained from anechoic chamber. The equation for normalized gain is,

\[ G_a - G_{ref} = P_{RX} - P_{RX_{ref}} \]  

Where, \( G_a \) is gain of test antenna, \( G_{ref} \) is gain of reference antenna, \( P_{RX} \) is received power by test antenna and \( P_{RX_{ref}} \) is received power by reference antenna.

**Gain measurement for antenna with radiating element Cur-Cu-Nip.**

![Far-field amplitude of Patch1.mni](image)

**Fig. 21. Non normalized far field radiation pattern for Cur-Cu-Nip.**

Figure 21 gives the radiation pattern of the fabricated antenna with the radiating element Curex. The maximum power received by the antenna is at azimuth angle (0 deg). At this polarization, the maximum power received by an antenna is -46.1 dBi. The power received by the reference antenna is 43.8 dBi and the gain of reference antenna is \( G_r = 8.04 \) dbi. The maximum (normalized) gain of test antenna from equation (33) is obtained as, \( G_a = 5.74 \) dbi

[34]
Gain measurement for antenna with radiating element Betex.

Fig. 22. Non normalized far field radiation pattern for Betex.

From figure 22, it can be obtained that at 0 degree azimuth angle; the amplitude of the received power at the test antenna is -58.48 dBi. Using the same reference antenna as the previous case, the gain of test antenna can be calculated from equation (33) as \( G_a = -6.64 \) dBi. The difference in gain of antenna in simulated result and measured result is mainly due to fabrication error.

**Reflection measurement**

The reflection of the test antenna is measured using vector network analyzer. One port calibration is used and Open, Short and Match calibration is done in VNA to measure the S11 of test antenna. The figure showing measurement set up for S11 is shown in figure 50 A[6]. The S11 Plot is shown as,

Fig. 23. S11 plot for the purely textile antenna with radiating element Cur-Cu-Nip
As expected, the result obtained is a shift in frequency. It can be seen that 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.

![Return Loss Chart]

The result obtained is different from that of simulated value because of fabrication error and change in dielectric material due to gluing.

The shift in frequency and the increased S11 value from the simulation result seen in plot is due to various reasons which are mentioned in the conclusion.

### 3.2.3 Simulation of H- Slot RFID Tag Antenna

The wearable tag for H-Slot is designed on IE3D, fabricated and tested in real conditions. The overall size of the H-slot antennas is 180mmx200mm. This big dimension of the antenna can be smaller by using a substrate which has a high dielectric constant, because the antenna size depends on the dielectric constant $\varepsilon_r$ of the substrate and also the design frequency. In this design a fleece fabric is used as a substrate which has a dielectric constant of 1.25. This fabric is chosen because of its better radiation performance. When a substrate has low dielectric constant and small thickness then the designed antenna has good radiation performance. But if a small tag is required, then a substrate with high dielectric constant can be used.

[36]
For this H-slot antenna, the fleece fabric is used as a dielectric substrate. The material is chosen because of its low dielectric constant. The design with the Fleece fabric as a substrate is presented below for two antennas. The radiating element of the first antenna is curex (surface resistivity 0.02) and the second antenna is Betex (surface resistivity 1.19). The antenna with radiating element curex is hereafter denoted as TAG1 and that with radiating element Betex is denoted as TAG2.

Table 4: Specification for the radiating element.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cur-Cu-Nip</th>
<th>BETEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>869 GHz</td>
<td>869 GHz</td>
</tr>
<tr>
<td>Surface resistivity</td>
<td>0.02 Ω/sq</td>
<td>1.19 Ω/sq</td>
</tr>
<tr>
<td>Thickness</td>
<td>0.14 mm</td>
<td>0.35 mm</td>
</tr>
<tr>
<td>Conductivity</td>
<td>357143 S/m</td>
<td>2381 S/m</td>
</tr>
</tbody>
</table>

Table 5: Specification for simulating antenna (TAG1 and TAG2)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TAG1</th>
<th>TAG2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductive Material</td>
<td>Cur-Cu-Nip, conductivity of 357143 S/m</td>
<td>BETEX, conductivity of 2381 S/m</td>
</tr>
<tr>
<td>Substrate Material</td>
<td>Fleece Fabric</td>
<td>Fleece Fabric</td>
</tr>
<tr>
<td>Thickness of the substrate</td>
<td>4mm</td>
<td>4mm</td>
</tr>
</tbody>
</table>

**Antenna Layout and Design**

Cur-Cu-Nip conductive textile has high conductivity and the designing with this conductivity gives better radiation performance than Betex textile which have low conductivity. The simulation of two antennas with two different materials having same dielectric substrate and the same dielectric constant is presented below.
Figure 25 represents H-Slot design for an antenna using radiating element Curex. Another design with radiating element Betex is shown in figure 48 [5]. As expected, the tag with high conductive material is giving better radiation performance in simulated results. When a comparison is made between these two tags, a high reading distance and high radiation efficiency are achieved from TAG1 because this tag is designed with high conductive textile material.

![Efficiency Vs Frequency plot for TAG 1](image)

Fig. 26. Radiation efficiency Vs Frequency plot for TAG 1

It can be seen that radiation efficiency obtained for TAG1 is 57.1% . The radiation efficiency obtained for TAG 2 is 3.05% and be observed in figure 51[A6]. As it is concluded before that the radiation efficiency is directly proportional to the surface resistivity of the radiating patch. Therefore, higher radiation efficiency is obtained for the tag having lower surface resistivity. If the antenna were designed from copper material the simulated efficiency would be very high because copper has high conductivity then these conductive textiles. Therefore, this value of 57% radiation efficiency is quite
good simulation result for this conductive textile. The 3D radiation pattern of two antennas TAG1 and TAG2 is presented in figure 45 and figure 46 A[4].

The value of CMF is used to find how good the matching is in between the antenna impedance and chip impedance. The plot obtained for TAG 1 and TAG 2 is given as,

![Conjugate Match Factor Vs. Frequency](image)

**Fig. 27. Conjugate match factor plot for TAG 1**

From the figure 27 it can be observed that the CMF for TAG 1 is 0.975 .The CMF of TAG 2 is obtained to be 0.874 from figure 52[A7]. It can be considered that both of the tag antennas has good matching with the chip, however TAG 1 shows better match among the two.

**Table 6: The combined results obtained from the simulation of two tag antenna**

<table>
<thead>
<tr>
<th>@869Mhz</th>
<th>TAG1</th>
<th>TAG2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation Efficiency</td>
<td>57.1%</td>
<td>3.05%</td>
</tr>
<tr>
<td>Conjugate Match Efficiency</td>
<td>28.5%</td>
<td>1.52%</td>
</tr>
<tr>
<td>CMF</td>
<td>0.975</td>
<td>0.874</td>
</tr>
<tr>
<td>Gain</td>
<td>-8.46dBi</td>
<td>-15.25 dBi</td>
</tr>
<tr>
<td>Directivity</td>
<td>7.8939dBi</td>
<td>8.47 dBi</td>
</tr>
<tr>
<td>Size of the Tag Lg x Wg</td>
<td>180x200mm</td>
<td>180x200mm</td>
</tr>
<tr>
<td>Antenna impedance, Za</td>
<td>100+j597</td>
<td>206+j472</td>
</tr>
</tbody>
</table>
Reading Range Calculation:

From the above mentioned equation (31), (32) in chapter 2.4.3, the read range is obtained as,

\[ d_{\text{max}} = \frac{c}{4\pi f} \sqrt{\frac{EIRP_R}{P_{\text{chip}}} \tau G_{\text{tag}}} \]

\[ \tau = \frac{4R_{\text{chip}}R_{\text{a}}}{|Z_{\text{chip}} + Z_{\text{a}}|^2} \leq 1 \]

Where, \( d_{\text{max}} \) is the maximum read range obtained for an RFID antenna when transmission coefficient, gain of tag antenna, receiver threshold of tag antenna and the maximum radiated power by the reader is given.

Here, chip sensitivity is -10dBm and the maximum radiated power by the reader is 3.2 W EIRP. Hence from the formula the power transmission coefficient ’\( \tau \)’ for TAG1 is equal to 0.97 and for TAG2 is equal to 0.87.

Then the maximum range is obtained as \( d_{\text{max}} = 2 \text{ m} \) for TAG1 and \( d_{\text{max}} = 1.2 \text{ m} \) for TAG2.

3.2.4 Simulation of Microstrip Patch RFID tag antenna

In this chapter, another technique of designing RFID tag antenna is proposed. A rectangular patch antenna is used as a tag antenna for RFID. The rectangular microstrip patch antenna for RFID is designed to resonate at 869 MHz. The manual calculation of microstrip patch is calculated in the similar ways as for the rectangular microstrip patch in chapter 2.3.3. Firstly the actual length and width of the rectangular patch is calculated considering the fringing effect so that the patch resonates at desired frequency. In this design, the feeding to the patch is different from the one discussed in chapter 2.3.3. A T-match is used to match the impedance of the antenna to the chip. The calculated length of the patch is 150 mm and the width is 190mm.

The dielectric material used is the simulation of Fleece fabric with dielectric constant 1.25 and dielectric height of the substrate 2mm. The radiating element and the ground is simulation of conductive textile material having surface resistivity 0.02Ω/sq.

The simulated antenna is presented below,
After obtaining the manual calculation an antenna is designed. The designed antenna is then optimized to obtain the dimensions as shown in figure 28.

The simulated graph is presented below.

From figure 29 it can be observed that the radiation efficiency obtained at the frequency 869 MHz is 41.82%.
From the figure the CMF obtained is 0.956. A perfect match is obtained when the value of CMF at desired frequency is `1´ in linear scale. The obtained value of CMF in figure 30 shows a very good match of designed antenna impedance with that of IC chip impedance.

The 3D radiation pattern for TAG3 is shown in A[4].

The overall simulated result obtained is shown as,

<table>
<thead>
<tr>
<th>Table 7: Simulated output results for TAG 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency (869 MHz)</strong></td>
</tr>
<tr>
<td>TAG3</td>
</tr>
<tr>
<td>Radiation Efficiency</td>
</tr>
<tr>
<td>Conjugate Match Efficiency</td>
</tr>
<tr>
<td>CMF</td>
</tr>
<tr>
<td>Gain</td>
</tr>
<tr>
<td>Directivity</td>
</tr>
<tr>
<td>Size LxW</td>
</tr>
<tr>
<td>Imput Impedance , Za</td>
</tr>
<tr>
<td>Reading distance</td>
</tr>
</tbody>
</table>
3.2.5 Fabrication and measurement of H-Slot and RFID patch antenna

In this chapter, two H-slot antenna is fabricated by using two different materials Betex and Curex. The fabricated antenna by curex material is TAG1 and the fabricated antenna with Betex textile material is TAG2.

One microstrip patch antenna for RFID is fabricated using textile material Curex. The antenna is TAG3. The range measurement of the fabricated antenna is done and the comparison of read range between fabricated antenna and commercially available antenna is made.

For fabrication of these two tag antennas, as mentioned above, the fleece fabric is used as a dielectric material. The available fleece fabric had a thickness of 2 mm, but the height of dielectric substrate used is 4mm. In order to have this thickness, thickness two layers of fleece is overlapped by using gluing technique. The conductive textile material is also attached to the substrate by using the same technique.

Fig. 31. Fabricated antenna (a), chip connection to slot arm (b) for TAG 1.
It can be seen from figure 54[A7] that TAG 2 is constructed from radiating element Betex which has the higher surface resistivity (1.19 Ω/sq). It is very difficult to connect the chip directly to the radiating element by soldering, because the material is not good with solder. An alternative way is used to connect the chip to the antenna. First a copper tape is attached, similar to that as shown in figure 54[A7] and then the chip is soldered on top of it. This will affect the performance of tag antenna, because during simulation the copper tape is not considered, but in fabrication it is used. The result of adding copper tape leads to poor matching. When the result is compared between the simulated and fabricated antenna using Betex as radiating element, the performance is degraded in fabricated antenna because of the copper tape used during the fabrication but not in simulation.

TAG1 is fabricated with the radiating element Curex. This material being a mixture of copper and nickel is good with soldering and a chip can be directly attached to the radiating element (Curex). Thus a copper tape is not used for this case as shown in figure 31(b) and the antenna performance is more accurate.

To Measure the tag performance, an RFID reader is connected to the computer. The reader shown in figure 50A[6] generates the frequency signal which is captured by the tag antenna, and the tag antenna retransmits the signal back to the reader with some new information. This signal is received by the reader and is sent to the computer for further processing of the signal.

The RFI21 RFID Reader Demo application program is used in the computer to read the reader. This application uses Python 2.6 programming language in the computer to accomplish this task.

The computer is connected to the reader. When the reader antenna detects the backscattered signal from RFID tag, the information about the chip in the tag is read and shown on the display of the computer.
Figure 33 shows the RFI21 RFID reader Demo settings to read the RFID tag. The protocol used to detect the signal from the reader is IP-X.

During the measurement, the reading distance of the TAG1, TAG2 and TAG3 is measured. Tags are moved towards the reader’s antenna till the reader detects the signal from the tag. The measurement is performed in the lab environment which is an open space.

Various settings were made on the software for the reader to detect the fabricated tags. The frequency set to 869 MHz and the RF Power level was set to 25 dBm.

As soon as RFID tag is detected by reader’s antenna, the information is displayed on the computer. The chip that is used to fabricate the tags is detected firstly by the reader, and then, the ID is displayed on the computer screen.
EM4222 chip is used in the tag antenna. When the tag is detected by the reader the tag ID is displayed in the computer. This can be seen in the figure which is the ID of the chip in red color.

From the measurement results, the reading distance for TAG1 is measured to be 50cm. This is quite smaller then simulated results because of the fabrication errors, because during fabrication process, a hole was created in the substrate due to soldering iron.

The reading distance for TAG2 is quite close to the simulation results. The simulated reading distance for this tag is 1.2 m and the read range obtained after fabricating the tag antenna is 90 cm. Thus TAG 2 gives the better performance and the read range obtained is very close to simulated values. This is because TAG2 is fabricated with Curex which has a very low surface resistivity compared to Betex. This gives the better radiation efficiency. A copper tape is also not used in TAG2. A better matching condition is achieved which results in lower reflection. Because of this we can obtain the greater range. The read range obtained by all three manufactured tag is given in Table 8 as,
Table 8: Measured read range from the three designed tag

<table>
<thead>
<tr>
<th>Range</th>
<th>TAG1</th>
<th>TAG2</th>
<th>TAG3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading range</td>
<td>50cm</td>
<td>90cm</td>
<td>60cm</td>
</tr>
</tbody>
</table>

A short experiment is done to compare working of the fabricated tag and the tag available in the market. To make a comparison of reading distance, the reading distance between two different UHF RFID tags is measured and is compared with the reading range of fabricated tag. The tags used are UPM Hammer 258-1 and UMP short dipole 211_2. These are the commercially available tag in the market. The tag antenna that is used in commercially available tag is dipole antenna.

![Image](image_url)

Fig. 35. UPM Hammer 258-1 RFID tag (a), UMP short dipole 211_2 RFID tag (b)

Table 9: Comparison of read range of manufactured tag with commercially available tag

<table>
<thead>
<tr>
<th>Parameter</th>
<th>UPM Hammer 258-1 RFID tag</th>
<th>UMP short dipole 211_2 RFID tag</th>
<th>H-slot TAG2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading Distance</td>
<td>98 cm</td>
<td>152cm</td>
<td>90cm</td>
</tr>
<tr>
<td>Chip Protocol</td>
<td>EPS S1 Gento</td>
<td>EPS S1 Gento</td>
<td>IP-X</td>
</tr>
</tbody>
</table>

The measurement was performed in open space in the lab.
3.3 Comparison and performance analysis

While working with textile antenna on the project, it is found that the antenna is not working properly as it should work. This is because the antenna which is generally made of very high conductive material has very good radiation efficiency and gain. This can be seen from the radiation efficiency vs frequency graph in Fig. 33 and Fig. 34. However the antenna made of conductive textile material has high surface resistivity and hence lower conductivity as compared with the copper. Because of this property of textile material it is difficult to choose the appropriate conductive textile material for desired gain. Also the height of dielectric substrate plays a major role in determining the radiation efficiency. In this chapter the study is made to address the above mention problems. This study is done because it is very much important to know these parameters when designing antenna with conductive textile material.

3.3.1 Effect on antenna performance when radiating element having different surface resistivity is used.

When an antenna is made with conductive textile material, surface resistivity is one of the factors that limit the gain of an antenna. To obtain an appropriate gain, we also need to have the knowledge of surface resistivity. Different conductive textile can have different surface resistivity. Because of the problem of different surface resistivity associated with the conductive textile material, a relation between surface resistivity, gain and radiation efficiency is analyzed. In chapter 3.2.1 we can see that two patch antenna is simulated keeping all the other parameters same but only surface resistivity of radiating element is different.

The surface resistivities for two different radiating elements were chosen to be 0.02Ω/sq and 1.19 Ω/sq. Fleece fabric is used as dielectric material which has a dielectric constant of 1.25. The antennas are simulated and the result is noted as shown in figure 16 and figure 17.

It is observed from the simulation result that, though all the other antenna parameters are same, the difference in surface resistivity of the two radiating element affect a lot in their radiation efficiency and gain.

To know the relation between these parameters in detail, a simulation is done for 20 different microstrip patch antennas keeping other parameters same and only changing the surface resistivity. The results of 20 different simulated antennas are shown in Table 10 [A1]. The simulation is performed for the antenna having radiating element and ground plane thickness 0.14mm, dielectric constant of the substrate 1.25 and the height of substrate 2mm. The simulated result is then plotted in
matlab. These results obtained after analyzing different antennas provide valuable information when a conductive textile material is to be used to design an antenna.

**Fig. 36. Gain Vs Surface Resistivity Plot**

From figure 36 it can be seen that for very low surface resistivity, the gain is maximum. When the radiating element (antenna) surface resistivity is increased, the gain of the antenna starts to decrease.

**Fig. 37. Radiation Efficiency vs. Conductivity Plot**

Figure 37 illustrates the relation between the conductivity and the radiation efficiency for above mentioned conductive textile material when used as an antenna. It can be seen that conductivity is related to radiation efficiency in logarithmic manner. When the conductivity of radiating element is
lower, the radiation efficiency is also very small, and increases as the conductivity increases. However radiation efficiency does not increase in linear way, and to achieve the radiation efficiency in higher percentage, the conductivity of the radiating material should be very high.

The entire simulated antenna has reflection (S11) less than -35 dB. However as from Table 10 [A1], the entire antenna does not have same S11. This affects the smoothness of the curve obtained in figure 36 and figure 37.

3.3.2 Effect on antenna performance when the thickness of dielectric material is changed to different values.

When the dielectric material thickness is changed, this affects the radiation efficiency. To analyze this effect, three microstrip patch antenna is designed. Technical specification for the antenna is shown as,

Frequency is 2.45 GHz, surface resistivity of radiating element is 0.02 Ω/sq, the thickness of radiating element is 0.14mm. Dielectric material is fleece fabric, dielectric constant is 1.25 and height of dielectric material is 1mm, 2mm and 3mm respectively.

Three rectangular patch antennas are designed for different height of dielectric material. On doing simulation, various parameters like reflection, gain, radiation efficiency and antenna efficiency for different patch antenna were observed.

From S11 plot presented in appendix figure 49 A[5] it can be seen that the reflection is less than -30 dB for all three antennas with dielectric thickness 1mm, 2mm and 3mm.

For the same specification of antennas, the radiation efficiency is measured with different height of dielectric material.
The radiation efficiency of three antennas with different thickness of dielectric substrate is used. Figure 38 gives the measure of radiation efficiency of the antenna with the dielectric substrate having thickness 1 mm. The radiation efficiency at 2.45 GHz is 61.199%. The radiation efficiency with substrate thickness 2mm and 3mm is shown in figure 53 to be 83.3889% and 90.156% respectively. It can be noted that for antenna with higher dielectric thickness, the better radiation efficiency is obtained.

### 3.3.3 Effect on antenna performance when different dielectric materials is used as a substrate.

In this case two different dielectric materials are used. One is the fleece fabric with the dielectric constant 1.25 and the other is silicone slab with dielectric constant 11.9. The silicone slab with high dielectric constant is used to reduce the size of antenna and also is hydrophobic in nature. This is very useful characteristics of silicon slab. The simulated results of the antennas with two different dielectric material is shown as,

The radiation efficiency obtained after simulating two antennas is,
As seen from the figure 39 and figure 40, the antenna which use silicone slab as dielectric substrate and have higher dielectric constant, has less radiation efficiency when compared with the one using fleece fabric. Though the size of antenna was reduced, the efficiency was also decreased drastically. It is due to this reason; fleece fabric is preferred in this project.
4 Conclusions

The thesis work presents the full potential of conductive textile materials to be used as an antenna. The design is made for antennas, using two different conductive textile materials Cur-Cu-Nip and Betex which is used as radiating element for patch antenna and RFID antenna. The design of patch antenna and RFID antenna in the thesis gives the idea to choose the appropriate conductive material for the radiating element of an antenna. A detail study on the effect of surface resistivity on the textile antenna is also presented. A comparison is made between the antennas made from two different radiating materials. A comparison is also made between the antennas using different dielectric substrate and also different dielectric height. The property of antenna under these conditions is analyzed. From the results obtained, it could be concluded that surface resistivity of textile material affects the radiation efficiency. Lower the surface resistivity, better the radiation. If high value of dielectric material is chosen, it decreases the height of antenna but the radiation efficiency also decrease.

The fabricated output result however did not match with the simulated results. This is because of various reasons during the fabrication of the antenna which are,

1. The height of Dielectric Substrate.

   The dielectric substrate height for patch antenna is taken to be 2mm and 4 mm for RFID antenna. With this value, we get the simulation result. However when fabricated, the fleece fabric (dielectric substrate) did not give the constant thickness. Being a fabric material, it has some ups and downs in its surface and hence is not smooth.

2. Dielectric constant.

   When fabricating a microstrip patch antenna with solid substrate, the copper is plated on the substrate and the unwanted material is etched out. When fabricating a textile antenna it is required to attach the radiating patch and ground plane to the dielectric substrate. This is done by putting glue in between the dielectric substrate and radiating patch. When the glue is added in the upper and lower layer of the substrate, the dielectric constant of the substrate is increased. This leads to shift is resonance frequency because the sq root of dielectric constant of the substrate is inversely proportional to the frequency. Thus resonance at lower frequency occurred during measurement which can be seen in S11 plot. This also affects the reading distance performance in RFID tag.
3 Homogeneity.

When the glue is applied to the surface of dielectric, the contact between the dielectric substrate and the radiating patch becomes non homogeneous. This affects the antenna performance.

4. Rough Edges.

During fabrication, when the textile material is cut to give the shape according to the dimensions obtained, a knife and scissor was used. Use of these equipments introduced two types of errors. When cutting, due to parallax error, the sides and edges of the radiating element were not straightly cut. Because of this, antenna matching is poor. Also when cutting the edges of the conductive textile material, some fiber thread comes out. These threads are on the edges from which the antenna radiates. This affects the radiation of antenna and hence the range of RFID decreased when compared with calculated results.

The above mentioned problems can be solved by taking careful attention and the right tools for the fabrication. The fabrication of textile antenna is more complicated than that of printed antenna. Considering these facts, we were supposed to fabricate the antenna in an industry with appropriate tools and materials, but due to lack of time, we had to do it our self. However this gave us an opportunity to learn more about fabrication process and to deal with the problems that arise during fabrication process.
5 Future Work

The textile antenna is mainly worn on the body. When moving or doing some physical work, the antenna may bend. If it is bent, the physical parameter of antenna may change and if the physical parameter changes, the antenna radiation parameter may also change. The antenna designed and manufactured in this thesis is big in size. The smaller the textile antenna the less it bends. There is various miniaturization technique for antenna made from copper. The future work can be to work on the miniaturization of textile antenna. The miniaturized textile antenna leads to less bending and hence more stable output from the antenna can be achieved. Also increasing the radiation efficiency is one of the main challenges for the antenna made from textile material. Due to lack of time detailed study could not be made on this topic. A detail research work on decreasing the size of textile tag antenna for RFID and increasing the range could be done in the future.
Reference


## Appendix

*Table 10. Simulation result for 20 different rectangular patch antenna with h=2mm, $\varepsilon_r=1.25$*

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Conductivity</th>
<th>Gain(dBi)</th>
<th>Surface Resistivity(Ω/sq)</th>
<th>Radiation Efficiency (%)</th>
<th>Directivity (dBi)</th>
<th>Reflection (S11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.45</td>
<td>2381</td>
<td>0.9902</td>
<td>2.9999</td>
<td>15.311</td>
<td>9.14</td>
<td>-50.94</td>
</tr>
<tr>
<td>2.45</td>
<td>2500</td>
<td>1.4</td>
<td>2.8571</td>
<td>16.833</td>
<td>9.14695</td>
<td>-43</td>
</tr>
<tr>
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Fig. 41. Simulated Microstrip patch antenna with radiating element having surface resistivity 1.19 ohm/sq.

Fig. 42. Smith chart representation for patch with surface resistivity 0.02 Ω/sq and 1.19 Ω/sq

The pictorial representation is given by smith chart which shows the matching condition. In the above figure, we can see that for both the design the impedance of both the antenna is 50Ω at 2.45 GHz. The line indicates the impedance of antenna at different frequencies when the frequency sweep between 2 GHz and 3 GHz is used.
Fig. 43. Reflection (S11) measurement for antenna using radiating element Cur-Cu-Nip and Betex.

Fig. 44. S11 measurement for purely textile patch antenna using VNA.

Figure showing measurement setup for measurement of S11 through VNA. A 50Ω connector is connected to VNA. Firstly the VNA is calibrated and then S11 measurement for antenna is done.
The 3D radiation pattern for the RFID antennas (TAG1, TAG2, and TAG3) is shown as below.

Fig. 45. 3D pattern of TAG1

Fig. 46. 3D pattern of TAG2

Fig. 47. 3D radiation pattern for TAG 3

Fig. 48. Simulated H-slot antenna for radiating element having surface resistivity = 0.02 Ω/sq.

Fig. 49. S11 for antenna with dielectric thickness 1mm, 2mm and 3mm correspondingly.
Fig. 50. The RFID tag Reader.

Fig. 51. Radiation efficiency of tag 2 (radiating element Betex)
Fig. 52. Conjugate match factor plot for TAG 1

Fig. 53. The Radiation Efficiency for antenna having thickness 2mm and 3mm respectively.

Fig. 54. Fabricated antenna for TAG 2 and chip connection