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TALLINN UNIVERSITY OF TECHNOLOGY

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Department of Electrical Power and Mechatronics

COIL PRODUCTION FLOW, IMPLEMENTATION OF RFID TECHNOLOGY FOR PRODUCTION PROCESS

Mähiste tootmisvoog - raadiosagedus-identifitseerimistehnoloogia kasutuselevõtmine toomises

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Tallinn, 2021

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THESIS TASK

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Study programme, MAHM02/18 - Mechatronics

main speciality: Mechatronics

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Thesis topic:

(in English) : Coil Production Flow, Implementation of RFID Technology for Production Process

(in Estonian) : Mähiste tootmisvoog - raadiosagedus-identifitseerimistehnoloogia kasutuselevõtmine toomises

Thesis main objectives:

1. To reduce the chances of human error while winding the coils of AC machines.
2. To make the production process more reliable, efficient and productive manner.
3. Improve the tracking and identification of coils in AC machines.

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Study of Collected data and Design Research	12/2020
2.	Design development and final calculations	02/2021
3.	Testing and developing of the system	03/2021
4.	Proposing a solution	04/2021
5.	Thesis defense	05/2021

Language: ………… **Deadline for submission of thesis:** "......."........20….a

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CONTENTS

PREFACE

In this thesis, we proposed a solution for identification of coils in production process and tried to emphasize the whole idea to use it in coils to identify the serial manufacturing problem scale. The RFID tag's high performance and increased storage capacity have resulted in the economic acceptance of this technology in many industries. Choosing a right tag for the right application might be difficult task with the too many commercially available tags today. It is very important to test the tags and analyse the findings to obtain insight into the impacts of products being tagged and the environment. Hence, there is a potential need to understand the communication range of tags in industrial conditions.

I would like to express my gratitude to my thesis supervisor Prof. Anton rassolkin from Tallinn University of Technology, who guided and assisted me on the path of graduation and Erko Leppa from ABB, Estonia for his assistance from company. I would also like to thank Prof. Alar kuusik from Institute of electronics for his constant support, help and advice.

Keywords: Passive UHF RFID tags, Chipless RFID tags, Coil production tracking

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List of abbreviations and symbols

RFID – Radio Frequency Identification System

HF – High Frequency

LF – Low Frequency

UHF – Ultra-high Frequency

Auto-ID – Automatic Identification

PIFA - Planar inverted-F antenna

CMOS IC – Complementary metal oxide semiconductor Integrated circuits

EPC tag – Electronic product code tag

Hexagonal SRR – Hexagonal Split ring resonator

RCS – Radar cross-section

RF – Radio frequency

ε_r - Dielectric constant

VPI - Vacuum pressure impregnation

1. INTRODUCTION

The automatic identification (Auto-ID) procedures are becoming very popular in recent years. It is widely using in many industries such as Logistics, Manufacturing companies, Textiles industry, bank cards, Shopping malls and supermarkets etc. The primary use of these identification techniques is to provide information about people, animals, products and goods in transit.

The era of this automatic identification technology starts with barcode technology in a long time ago. It's become well-received by industries suddenly, Because of its low cost and cheap. The main disadvantage of barcode technology is its low storage capacity, and it cannot reprogram. The maximum storage capacity of a barcode available these days is about 2000 characters. Even though due to the emerging demand for data and real-time tracking, the modern world has to rely on new inventions and technologies. The Identification technologies available in these times are.

- Barcode systems
- Optical character systems
- Biometric Procedures
- Smart cards
- RFID Systems

This research aims to design and implement a system for tracking stator winding coils in ABB Motors and generators factory. ABB is one of the large producers of Electrical machines in the world. The ABB in Estonia is manufacturing various motors and generators. The stator winding is an essential part of those machines. The motor and generators get failure due to mechanical related issues even though sometimes stator winding related problems can be the reason for failure. It's a very costly and challenging process to implement the automation in the coil production process. So, the windings related works mostly done by human power. There is a chance to have errors or mistakes while doing the winding related works. It can be why machines failure in the future when the machine gets failure is exceptionally troublesome to track the worker's information such as details of the worker, time of making, and which batch machine was that. So, in this research-based to provide the technologically assisted solution for this problem.

The existing solution is already used in the factory. They are recording those subtle elements on paper but not much proficient enough to urge back the information for a long time. This method cannot retrieve the data in a long time and efficient manner, including workers comfortable working zone and the possibilities for occurring errors that affect the quality of the winding, quality of the entire electrical machine.

For problem-solving, the author trying to impose an RFID/Barcode assisted identification system for tracking the stator winding, and these special RFID tags will be capable of operating in tough conditions like 160℃ of the operating temperature of electrical machines, High current and magnetic flux densities, capable to withstand High electric field and mechanical vibrations produced by the machine.

The RFID / Barcode-based identification system's development would solve the tracking problem in the production process, including errors due to human intervention. The motivation driving is, finding a specialized technical solution for this subject from Engineering principles. ABB M & G factory production workers and higher authorities are the receipt part of this development. The development of this research topic could solve the issue in the production of the stator winding, increase worker proficiency, and increase the overall production quality.

The goal of this work is to implement an RFID/ Barcode based identification of stator windings. The proposed identification method can withstand a higher temperature of operation, high current and magnetic flux densities, Electric field, and Mechanical vibrations.

In the introduction chapter, the main idea is introduced, the current problem in the factory, task description and motivation are clarified, a small introduction of coil production process in the factory described the selection of technology for coil identification process is specified and the main goal is mentioned as well. The main objectives of the thesis is mentioned in this section.

The second chapter contains the literature survey and previous research in chip less RFID tags and conclusion of the research.

The third chapter includes an overview of chipped and chipless RFID and it’s categories and working principles. A detailed description of chipped RFID technology and components described in this section.

The fourth chapter contains the test setup and testing methodology based on industrial needs that includes reliability of RFID tags in High temperature and water medium.

Unfortunately, we couldn’t conduct the experiment to check the reliability of RFID tags in electro-magnetic field at ABB factory because of Covid-19 situations.

The fifth chapter includes the test results and simulation results of chipless RFID tags.

1.1 Objectives of the Thesis

The main objectives of the research work are given below,

- Implement a particular RFID tag that can withstand adverse operating conditions like High temperature, Magnetic flux density, Electric field.
- Analysis of RFID Tags in high electric and temperature of operation.
- In case of failure of the coils or windings, the proposed RFID system could help to identify production history of every individual coil. If every coil has ID and Production manager can track every ID after failure of coil. For example, what person performed what operation, what time, date and description of machine. Then the failures could be analyse with Six sigma methods and those will huge step forward in quality process to identify the root causes.
- To make the production process more reliable, efficient and productive manner.
- Improve the tracking and identification of coils in various types of AC machines.
- Implement the system is cost-effectively and efficiently.
- Modify the workstation based on the new detection devices.
- To find the possibility to tracking stator windings by using RFID / Barcode Technology.
- Design and simulation of Chipless RFID tag by using CST simulation studio.

1.2 Introduction to Coil Production Process

A stator coil is a mechanical device consisting of a stationary part of a motor or generator in or around which the motor revolves. In an electric motor, the stator generates a rotating magnetic field that powers the rotating armature. In the generator, the stator converts the rotating magnetic field to an electric current [1].

Figure 1.1 Stator with stator coil [2]

The production process of stator winding is divided into 5 different stages;

1. Looping
2. Coil spreading
3. Machine insulation / Coil insulation
4. Hand insulation
5. Coil testing

1.2.1 Looping

Looping is the first process of coil manufacturing process, which determines the number of turns that are present in core winding. Once it reaches the correct number of turns, the operator will add scotch tape to ensure that the coil keeps its form after being removed from the looping machine [3].The copper strands used in coil winding has it's own insulation, and the reason for that to avoid the in contact of copper to copper while looping. Because when the current starts flowing through that, then there will be a skin effect that will produce extra losses of the winding [4].

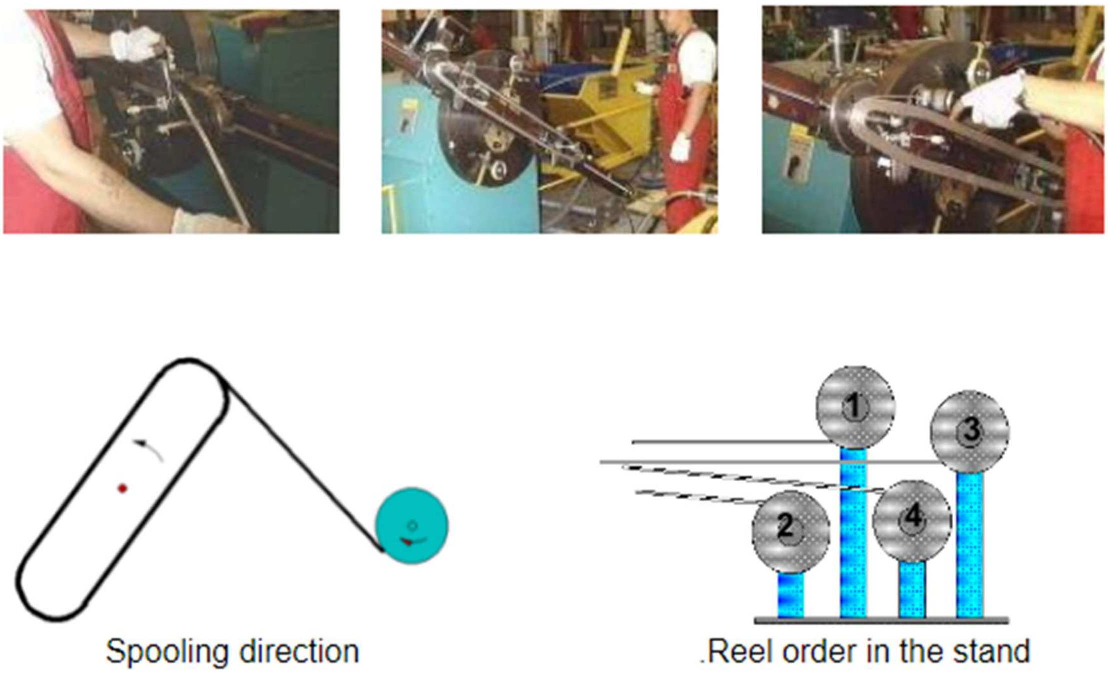

Figure 1.2 Looping process [5]

Figure 1.3 Coil structure after looping process [3]

1.2.2 Coil spreading

During the process of spreading the loop coil structure (Figure 2.2) is changed it's shape or structure to fit properly inside the stator core and this process done by using coil spreading machine. The coil spreading machine is a hydraulic machine which spreads the loop into diamond shaped coils quickly and efficiently. The rotation of the arm on a hydraulic coil spreader is similar to the rotation of the stator axis. The coil's measurements are directly transferred to the spreading machine. The operator will use hammer to make some additional adjustments [3].

The plan to attach the chip after looping at the coil knuckle at the no connection side of the coil. The kapton tape will keep the chip until the insulation will cover it.The chip insertion place is shown in figure 2.4 below (blue circle).

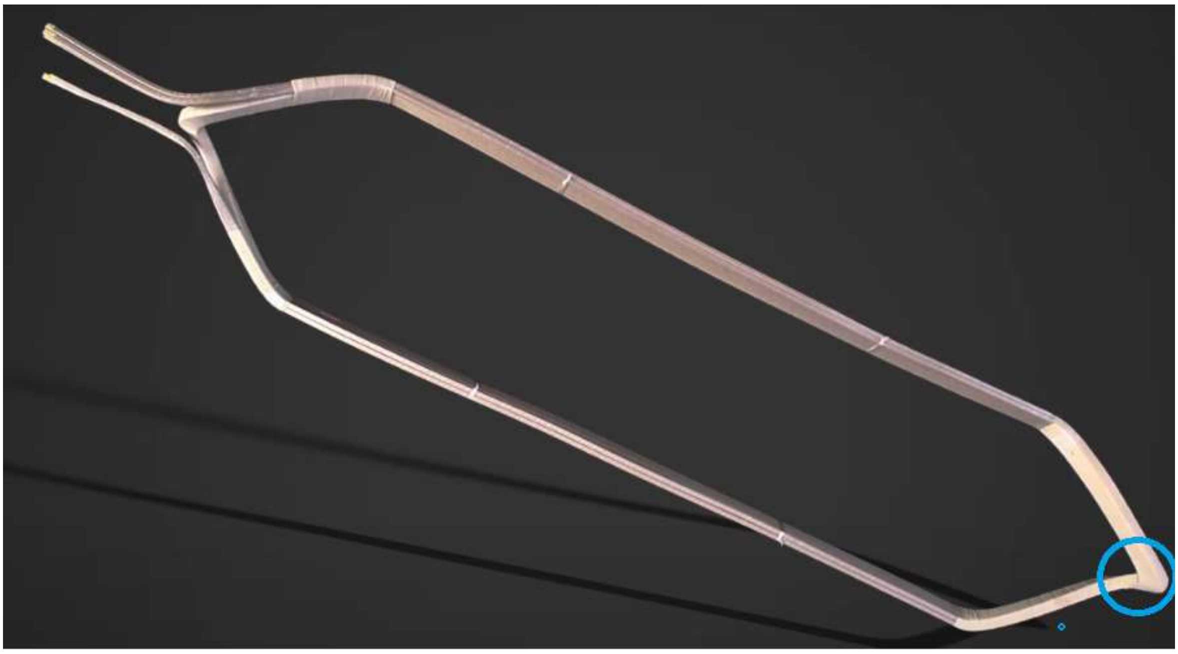

Figure 1.4 Coil structure after spreading process [6].

1.2.3 Machine insulation / Coil insulation

In this process, the straight part of the coil is insulated by using automatic taper machine. After completing the machine insulation, the coil removed from the automatic taping machine. The process of machine insulation is shown in figure 2.5.

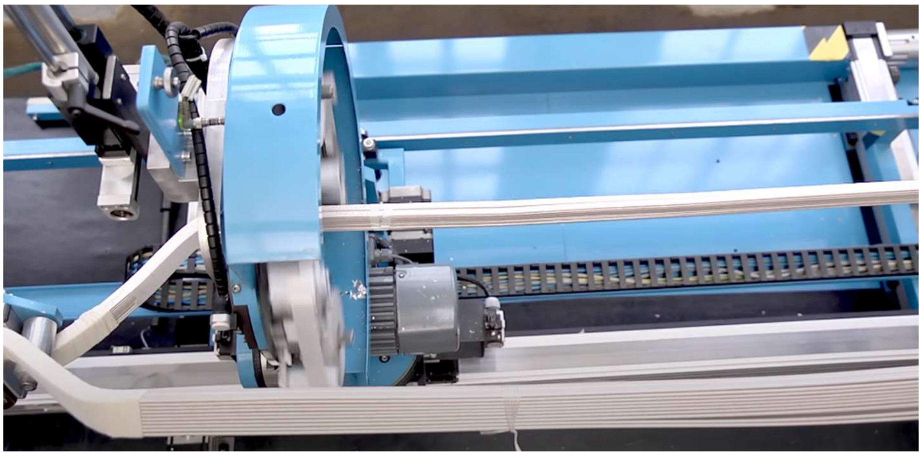

Figure 1.5 Machine insulation process [6]

1.2.4 Hand insulation

In this process, the operator insulates the coil knuckle manually with ground wall insulation and added more tape with the overall coil structure by using hand tape. We also protect our chip during this time. That is, the chip will be covered by insulation.

1.2.5 Coil testing: Voltage test with high voltage

The geometry test of the coil structure tested and verified by using the wooden model. In electrical tesing to verify the coil and the integrity of the insulation system. In coil voltage testing, first connect the leads of first coil to testing equipment and adjust the voltage to the appropriate level and verify the waveform with the reference waveform. In next step the process will continue with the second coil and the waveform should match [3]. The chip is placed at the non-connection side of the coil shown in figure 2.5(marked in red arrows). The coil will be fixed into the stator coil after coil testing process. The fully wounded stator goes to VPI (Vacuum pressure impregnation) and then its ready for motor or generator assembly [5].

Figure 1.6 Preferred location of chip to identify the production process(marked in red arrow) [5]

1.3 Selection of Technology for Coil Identification Process

Identification or tracking is essential in every industry or every field of operation to track their goods and products. This chapter discusses the different automatic identification systems and which identification is more suitable for our coil identification process.

The technologies used to detect and monitor the objects are barcode Technology, quick response code. These technologies have a low reading range(0-50cm [7]) [8] and the reader also needs to operate in a clear line of sight technology. But RFID technology doesn't have these limitations. It is more prevalent in the areas of Supply chain management system, Automatic attendance system, Warehouse management. The RFID is the technology working on radio frequency or radio waves. The RFID technology has two parts, the reader and the tag. The RFID tag is used to attach with the objects which we want to track or identify. The RFID reader is continuously sending the radio waves. So, whenever the object is in the reader's range, then the RF id tag is used to transmit its feedback signal to the reader. [8] [9]

1.3.1 Barcode systems

The barcode is a binary code that consists of a field of bars and gaps that are arranged in parallel pattern. They represent data elements that corresponds to an associated symbol and are organised in a predetermined pattern. The sequence made up of large and narrow bars and gaps, can be interpreted both numerically and alpha numerically. The barcodes can be read by using optical laser scanner, which involves a laser beam bouncing back with different reflection of black and white gaps [7].

The barcode technology is very cheap to implement, and it is cost effective. But it needs line of sight to read the barcode and it can use only for identification purpose (it can't use as sensor/only single function). Our production stages consist of looping, Coil spreading, machine insulation, hand insulation and High voltage testing described in previous chapter. We are planning to track the production process from the second stage of production process. The barcode can't read data when it's covered by insulation tape in the second stage of production. So we have use different barcodes in each stage of production. It will make the system more complicate to track.

1.3.2 Optical character recognition

The OCR (Optical character recognition) is the electronic or mechanical translation of images of typed, handwritten, or printed text into machine-encoded text. The OCR was first used in the 1960s. Unique fonts were created for this application, and that stylized characters could be read both manually by people and automatically by machines. The most significant benefit of OCR systems can carry a high density of data and the ability to read data visually in any emergency or for checking purposes.

The OCR is used in production, service and banks for the verification of cheques. However, OCR systems not using much in this time, because of their higher price and complicated readers that they compared to other identification procedures [7].

1.3.3 Biometric procedures

Biometric is the science of counting and measuring procedures, including living beings. Biomtery is the general term for all procedures that classify individual by comparing unmistakable and individual physical characteristics in the sense of identification systems. The biometric system classified as finger print identication, voice recognition and retina or iris identification [7].

This identification not suitable for our identification purpose,Because it doesn't involve any living being.

1.3.4 Smart cards

A smart card is an electronic data storage system, probably with additional processing power (microprocessor systems) encased in a plastic card size of a credit card. The first smart card were introduced in 1984. The smartcards were released in the form of prepaid mobile smart cards. Smart cards are inserted into a reader, which uses contact springs to create a galvanic link with the smart card's contact surfaces. The reader provides energy and clock pulse to the smart card through the contact surfaces. It uses a bidirectional serial interface to transfer data between the reader and the card [7].

The smart cards is not suitable for our identification purpose. Because it needs in contact with the reader and card. It can't operate in wear, corrosion and dirt environment. The smart cards is divided into Microprocessor cards and memory cards.

1.3.5 RFID systems

The RFID systems are closely related to smart cards . It stored data on a electronic data carrying device calle transponder.However, unlike the smart cards it uses magnetic or electromagnetic fields to communicate or trandfer the data between reader and tag. The technology consists of an antenna that is connected to the desired objects and readers that read the stored informations from the tags. The energy from the reader is used to send data from the reader to the tag and back to the reader [7].

The RFID systems divided into three types based on tag energy source which are active and passive. Based on the frequency it divided into 4 types: low frequency (LF, 125 KHz-134KHz), high frequency (HF, 13.56MHz), ultra-high frequency (UHF, 860MHz – 960MHz) and microwave frequency (2.4 GHz). The detailed description of RFID systems described in chapter 3.

It is challenging to select a right operating frequency for RFID because EM waves behave differently at different frequencies. For example, LF system are suitable for tracking high-water-content items like drinks, fruits. However, the reading range is limited to centimetres or inches.

The HF tags have a maximum read range of about 1 meter and work efficiently on metals and products with high water content. HF RFID systems are primarily used in ticketing and tracking of library books.

In comparison to LF and HF, UHF RFID tags provide a much better choice for reading range detection and monitoring data can be transferred much faster. However, because of shorter wavelength, the signals can be attenuated or weakened easily and they are unable to move through thin metal and water medium even though modern UHF RFID tags can provide improved performance when it's placed on metal or water. The UHF tags widely used in parking access control and toll fare collection.

Therefore, in this research, a passive UHF system is preferred over HF and LF RFID systems because their long-read range allows them to detect desired components without having to approach or touch RFID readers. We are planning to attach our RFID tag on coil edges, so the size of the tag is limited. Even though it can give a better read range in that small size. The draw backs of UHF RFID is its higher cost compared to barcode systems. So, we design and simulate a new tag (chipless RFID tags) by combined the advantages of the barcode (low cost) and advantages of UHF RFID (better read range, no line of sight needed) in the upcoming chapters.

Table 1.1 Comparing of different Identification systems [7]

System parameters	**Barcode**	**OCR**	**Biometry**	**Smart card**	**RFID systems**
Data quantity(bytes)	1-100	1-100	-	16-64K	16-64K
Data density	Low	Low	High	Very high	Very high
Machine readability	Good	Good	Expensive	Good	Good
Readability by people	Limited	Simple	Difficult	Impossible	Impossible
Influence of dirt/damp	Very high	Very high	-	Possible	No influence
Influence of optical(covering)	Total failure	Total failure	Possible	-	No influence
Influence of direction and position	Low	Low	-	Unidirectional	No influence
Degradation/wear	Limited	Limited	-	Contacts	No influence
Purchase cost/ reading electronics	Very low	Medium	Very high	Low	Medium
Operational costs(eg. printer)	Low	Low	None	Medium	None
Unauthorised copying/modification	Slight	Slight	Impossible	Impossible	Impossible
Reading speed(including handling of data carrier)	Low ~4s	Low ~3s	Very low > 5-10s	Low ~4s	Very fast ~0.5s
Maximum distance between data carrier and reader	0-50cm	<1cm Scanner	Direct contact	Direct contact	0-5m, microwave

2. LITERATURE REVIEW AND BACKGROUND

2.1 Previous Works on the RFID system

The RFID tag classified into the active RFID tag, Passive RFID tag and Semi-passive RFID tag. The active tag needs an external power supply to operate. However, passive tags use energy from radio waves that are coming from the RF reader. [8] [7]

The author in [9] described the analysis of various RFID Technology tags, and it's applications in modern industries. The tag is available in different size and shapes. This was significant because it represented the various frequency range of RFID systems, wireless sensor networks (WSNs) and wireless information & communication networks. The frequency ranges of an RFID system is divided into three types, Low frequency, High frequency, Amateur radio band frequency and Ultra high frequency. Their study is crucial because it suggested clear evidence of real-time traceability, interaction, connection and position of goods based on RFID identification. Even though the study was limited to real-time traceability concepts, but wasn't analysing different working conditions of RFID. RFID mainly consists of three components. RF signal generator generates radio waves and transmits radio waves through antenna, Microcontroller which is used to process information coming from the tag or RFID reader directly connected to PC and Receiver or signal detector which is used to receives the information is coming from the tag. [8] [9]

K. Finkenzeller [7] has led to renewed interest in various identification or tracking technology. In recent years, researchers have become increasingly interested in RFID tag design capable of various working conditions, high temperature, and interference issues of multiple RFID tags. The RFID tags are three types, Active tag, passive tag, and semi-passive tag. The passive RFID tags are the most commonly used because that's doesn't require any external power supply to operate. But, other tags require an external power supply to operate [7] [9]. The Passive RFID tags are cheaper and relatively compact compared to other RFID Tags. The RFID tags main components of RFID tags are transponder which receives RF waves coming from the reader and send the feedback signal to the reader, Rectifier circuit. As we know, the tags don't have a power source, so they rely on the RF waves which are coming from the RF reader. So, they used to get energy from the RF waves. Using this rectifier circuit, the energy coming from the reader is stored across the capacitor; this energy is used as a supply for the controller and memory elements inside the RF tag. [7]

The previous research [8] [7] [9] shows that the various applications of RFID tags and how they could be merged with real-time tracking. For instance, the following studies [10] were conducted on RFID antenna designs for high "global" bandwidth operations and rugged environmental conditions. A noval RFID prototype is proposed with an embedded power source and other energy harvesting mechanism on a low-cost paper-based substrate. The RFID antenna designed for high global bandwidth (RFID ISO 18000-6C) operation and rugged environments are discussed. In 2007, The "Paper-based Ultra-low-cost integrated RFID tags for sensing and tracking applications" suggested an idea about the simultaneous reading of multiple RFID tags and information modification or erase in RFID tags, such as the WRITE or KILL command. The authors Fredy J. Valentine and Alfredo de Sao carlos employed a modern methodology in 2017, which prescribes RFID in the IoT domain [11]. The existing RFID solution architecture is based on the reference EPC global/GSI framework modified to The IoT can allow new capacities to the "things" such as remote sensing and remote actuation to interconnected devices through intelligent sensors and wireless network.

The RFID tag can record a set of information such as date of manufacture, details of the machine, batch number, and worker's information. The RFID systems intend to classify objects with neither tactile nor visual interaction in open environments. They consist of transponders inserted into the object or coils, readers a, and typically a database containing pieces of information about the objects [10]. The wrong identification performance due to adjacent metallic items is one of the technical difficulties of RFID-based coil identification. The authors, M.Kim and K.Kim from the Sogang Institute of Technology, propose a two-way mechanism called the effective tag attachment method to resolve this problem. The reader antenna is improved by using a metallic case. The first mechanism deals with choosing the appropriate form of a tag by considering the job process and environmental conditions. Second, an antenna case was designed to improve reading efficiency by minimizing the effect from the attached surface and concentrating the RF signal on the target tag [12]. Her study was limited to its application. She chose to focus on large size items identifying the size of the tag is quite long. The identification by using the tag attachment method can considerably increase the size of the RFID tag and not efficient to attach on small size windings.

Environmental effects can easily distort the RF signal, RF signal attenuates in metallic surface, and it makes challenges for RFID based identification. The modern development of the RFID metal mount tags allows applying the RFID infested with metal objects. However, most of the RFID tags use dielectric material or high impedance substrate. To avoid these RF signal attenuation issues, the flag-flag technique developed by UPM has been implemented in the proposed system. So, The Rf communication can be done only if there is enough space between the antenna and metal [7] [12] [11].

According to [11] Fredy J. Valente and Alfredo C. Neto research paper mainly discussed the RFID based identifying, moving and positioning of steel beam products. It is not easy to operate UHF RFID in metal beams. The metal also reflects the RF Signal and prevents RFID reading if the RFID tag is placed on a metal surface. [11].It is possible to eliminate the problem by inserting a ferrite absorber sheet with 0.1mm in between the metal and RFID tag. In this research, the different strategies to avoid this problem, Innovative product positioning system and an innovative RFID tag filtering based on the Doppler effect combined position sensor. [11].

The AC machines produce high temperature in normal working conditions. So, the RFID based identification was sometimes challenging to operate efficiently in this temperature. The standard RFID tag gets damage at this high temperature. According to the research papers [13] [14] [15] [16] mainly describes the solution to the problems mentioned above, an ultra-high temperature 2.4GHz chipless RFID tag capable of operating over 500°C. Conventional RFID tags (ISO18000-6C or EPC Generation 2 tags) are based on silicon CMOS integrated circuits. CMOS ICs have some physical limitations to operate in extreme environmental conditions such as Aerospace and down-hole oil exploration markets [14] [16]. According to the research paper [7], the particular type of ceramic UHF RFID can operate beyond 110°C. This UHF RFID system's main application is to identify and track small metal components in Airbus and Boeing aircraft. The most common layout of UHF RFID antenna's is the inverted-F antenna, Planar inverted-F antenna (PIFA) and patch-like structures [13] [17]. The research paper [14] suggests an idea about the development of RFID tag for ultra-high-temperature applications. But, the study limited to its application for single object detection. It can't detect multiple tags simultaneously, and the tag design is purely mechanical basis with rotating components in it. The metal parts of the design influence the electric field generated by the machines in working conditions.

In the research study [15] [18] [19] , the authors had found that a chipless tag used in RFID technology helps to reduce the cost of the tag considerably. Several bits stored in the tag cost the higher price of the tag and tag dimension. The cost of the tag can be reduced by using a chipless tag. A resonator-based chipless tag is discussing in this paper using the spiral resonating structure for the ultra-high frequency of 2.6GHz. [8]. The pieces of information stored in the tag decide the number of bits needed for the RFID tag. The bits are realized by using resonators. The number of bits can be increased by increasing the number of resonators in the tag and each resonator designed with different frequencies. [8]. The main goal of the work is to achieve a low-cost chipless tag with an increased read range. It can be achieved by using a single bit tag using spiral structural analysis. The passive RFID tag can be designed in different structures like E-shaped resonator, Triangular loop resonator [18], and Hexagonal Split ring resonator (SRR) [19]

In [20], the author described personal detection through a passive radio frequency identification system. The entire system includes hardware implementation, data collection, model training and identification and client implementation. It could provide high precision and real-time efficiency. The various fields of anonymity could be used to detect individuals. The passive RFID tags were mounted on walls with a distance and returned the signal intensity indicator obtained(RSSI). The RFID antenna obtained the signals, and the data were interpreted in advance by the RFID reader. With the help of gathered data, the machine learning algorithm learned and then used to detect the presence of humans in a secure and consistent approach. In the research paper [21], The authors used the particle filter principle to track the target—the presented prototype method for RFID tag tracking by a human carrying a handheld reader. The approach uses the principle of particle filters and sequences of phase measurement obtained during the procedure.

The authors in the research paper [22] proposed a QR-Code-based chipless RFID system for unique identification. The topic's main idea is about an entirely passive printable quick response code embedded in chipless RFID. A series of QR codes were printed in the form of a resonator in a passive RFID tag. The coded information stored in the tag can be retrieved through the frequency domain reflectometry method of identification. The design was demonstrated over a 3-10 GHZ band with several QR-code resonators embedded in a single RFID tag. The tag consists of QR code resonators, crossed polarized transmitting and receiving ultra-wide monopoly band antenna.

The research paper [23]," QoS based RFID system for innovative assembly system", discussed innovative assembly workshop towards the internet of things (IoT). The paper concludes the idea of monitoring, tracking, and controlling the entire objects in an assembly workshop for industrial IoT.The RFID device made of one or more gateways. A web server is integrated into the microprocessor of each gateway to communicate with the user/controller for real-time monitoring and communication. In their design, the author used an ethernet hub to create an intranet for the objects. Both gateways and the user/controller are linked to the intranet for interaction purposes. It also helped them filter out the unnecessary information and local data stored in the database [23].

The introduction of chipless RFID tags has improved the application of tags in various fields. In the research paper [24], the author introduced a real-world modelling technique for chipless RFID tags based on 3D bistatic RCS with the corresponding mathematical framework. The 3D model is successfully applied and simulated in EM studio for various types of frequency coded RCS chipless tags and retransmission ones considering the real-world scenarios of excitation such as the propagation vector of the excitation signals, polarization and relative location of the tag. This technology opens the door for a chipless RFID system to exist in various industrial applications and handle open and complicated issues such as multi-tag scenarios and localization. In [25] [26], the researchers demonstrated the possibility of combining advantages of barcode and RFID technologies on the same smart label. The RFID tag prototypes based on barcodes of varying specifications and sizes were realized and tested using a certified RFID measuring device. In their tag configuration, they avoided soldering the IC to the structure. Based on the coupling of a near-field RFID tag to the barcode, it is also presented. The maximum read range achieved is 12.5m for 12 cm^2 and 7.5 m for 6.3 cm^2 tag configuration [25]. The printing technology concerns both dielectric and conductive components. The realized barcode tag was readable by both an RFID reader and an optical reader. The read rage of about 2 m achieved while the used RFID chip was Impinj Monza 3, which exhibits a sensitivity of -15dbm. [26]

In [27], the author discussed the importance of chipless and chipped RFID tags. This topic has pivotal importance in the future. The chipped RFID tag has more application than the chipless RFID tag. Even though the chipless RFID tag could operate in adverse working conditions such as extremely cold or high temperature, it has fewer environmental effects than a chipped RFID tag.

2.1.1 Chipless RFID Hexagonal SRR

This section reviews the literature related to the analysis of the Hexagonal Split ring resonator. The authors, Neema C.Babu and Sreedevi K.Menon found the effective filter capability of the Split ring resonator at microwave frequencies. The different geometries of SRR can be designed to provide filter characteristics in the frequency spectrum. The research paper [19] introduces a novel SRR that is hexagonal in geometry and is an electromagnetically energised filter response. The detailed analysis of SRR and design approaches described in their research. The authors Considered a hexagonal SRR with dielectric constant ε_r =4.4 and height h=1.6mm for the analysis of Hexagonal SRR. [19]

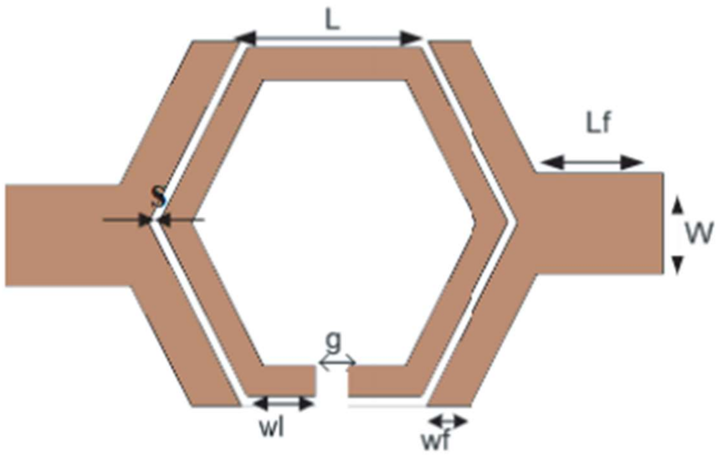

Figure 2.1 Hexagonal SRR [19]

The filtering characteristics of hexagonal SRR depend on geometric characteristics such as Gap of the resonator 'g', Length of resonator 'L', Width of resonator' ωl', the spacing between the feedline and the resonator' s'. [19]. Consider a hexagonal SRR designer for frequency 'f' using the following equations. [19]

$$f = \frac{c}{2L_{eff}\sqrt{\varepsilon_{eff}}} \tag{2.1}$$

$$L_{eff} = 6L - g - 6\omega l = \frac{\lambda g}{2} \tag{2.2}$$

$$\varepsilon_{eff} = \left(\frac{\varepsilon_r + 1}{2}\right) + \left(\frac{\varepsilon_r - 1}{2}\right)\left[\left(1 + \frac{12h}{w_f}\right)^{\frac{-1}{2}}\right] \tag{2.3}$$

L_{eff} = Effective length of SRR, ωl = Width of the hexagonal SRR

W_f = Width of the feed line, h = height of substrate, g = gap in the SRR

S = spacing between SRR, ε_r = Dielectric constant of the substrate

ε_{eff} = Effective dielectric constant of the system

In a 2016 study [19], The authors Sreedevi and Neema found that SRR based filter provides proper miniaturization and reduction in transmission losses. The parameters are optimised for the best performance of transmissions and formulated the design equations.

2.1.2 Triangular loop resonator

In [18], the author described the Triangular based chipless RFID, which was significant because it can operate in high electric and magnetic fields generated by the AC machines. The chipless RFID tags categorized into two types, frequency domain tags and time-domain tags. The chipless RFID tags are essentially finite-sized. They depend upon the relative dimensions of the tag resonator. The specific amount of electromagnetic waves gets absorbed by the structures. In contrast, others are reflected and observed in the tag's radar cross-section(RCS) response. By designing a multi-resonant circuit based on this principle, the number of bits can be stored in the circuit without having an Integrated circuit. The elimination of silicon chips from the tag reduces the tag's price and other advantages like enhanced tag robustness, scalable data storage potential and ease of fabrication. [18]The triangular loop resonator-based antenna is compact. It exhibits good performance in terms of gain, returns loss, compactness, and low mass/volume.lightweight and better radiation efficiency. [15]

2.2 Chapter Summary

This research aimed to track stator windings in AC machines to make the production process efficient and cost-efficient. The problems noticed in the literature survey are outlined below.

- The RF signals attenuate in the metallic surface, and it makes it difficult for RFID based identification in metal-based products. The modern development of the

RFID metal mount tags allows applying the RFID infested with metal objects. However, most of the RFID tags use dielectric material or high impedance substrate. To avoid these RF signal attenuation issues, the flag-flag technique developed by UPM (company name) Reflatac Dogbone type has been implemented in the proposed system. So, RF communication can be done only if there is enough space between the antenna and metal. [7] [12]

- It showed that the maximum temperature capability of a silicon-based chip is about 110°C [16]. But the required RFID tag has to work temperature of about 160°C.
- There was no temperature, electrical field, and magnetic field study of RFID tags in previous research papers. The silicon chip used in RFID tags can be damage in intense magnetic and electrical fields. This problem can be resolved by developing RFID tags using ferrite or electrical field resistance materials.
- The cost of an RFID tag is 10 times higher than the barcode, and it can be overcome by using chipless tags. The chipless tags described in the research paper [15] [19].
- For an RFID tag, you can't read either one at a time like you can with a bar code. The reader checks all the tags he picks in the set at once. These forms of tags are still being created, and another downside to using them is their scripting speed, which takes a lot more time than setting up.

3. CHIPPED AND CHIPLESS RFID SYSTEM

3.1 Overview of Chipped RFID system

The RFID is a simple wireless system used to control, detect and track objects. It is the concept of identification through radiofrequency. It is the way of transferring data wirelessly and without contact using radio waves in magnetic fields. This technology is used to identify things like products and individuals automatically. RFID is an effective system to assist entity recognition, data processing, and product management.

A typical RFID system consists of three major components: The tag, The reader, and the data management system.

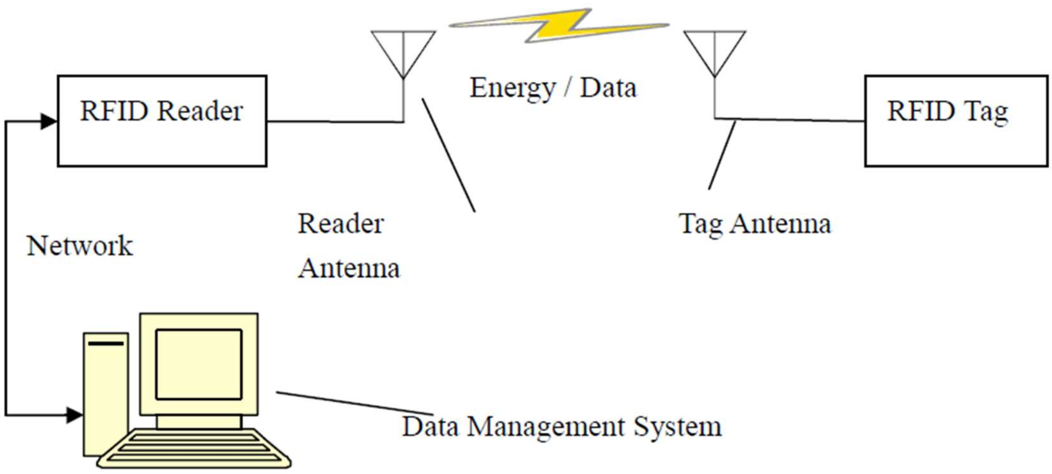

Figure 3.1 The Frame of RFID System [28]

The RFID tag component can also be subdivided into two parts: The antenna and the tag chip. Each tag has a specific identifying code that allows the attached objects to be identified. When the tag receives an RF signal from the reader, it becomes active. It performs the reader's subsequent action before sending the stored target information back to the reader. The tag's storage unit can be read and written more than 10,000 times.

The reader also divided into two parts: The antenna and the reader unit. It sends an RF signal to the tag, will active using the reader antenna and receives target information from the tag. After the initial filtering and signal processing, the reader can extract and analyze the tag information. The valuable data would be transmitted to data processing systems through the network.

The data management system is m used to collect and store the data from the RFID tags to the server or memory of the management system. A data management system can be as basic as local applications or as complex as distributed Enterprise Resource Planning(ERP) management software combined with an RFID management module.

In short, the tag and reader are responsible for identifying and collecting data, while the data processing system in charge of handling and controlling the data transmitted.

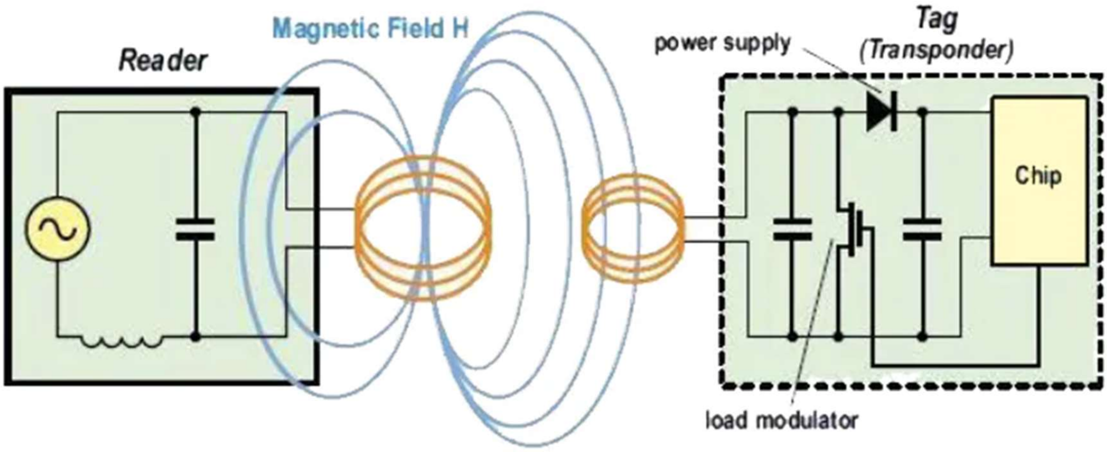

Figure 3.2 A Inductive coupling of RFID System [29]

Data transmission is a crucial part of the RFID function between a tag and a reader. Coupling and backscattering are the two communication strategies in an RFID system.

3.1.1 Communication through coupling

The coupling is transferring energy from one medium to another similar medium, such as metallic wire or optical fiber. There are two common types of coupling: capacitive (electrostatic) coupling and inductive (magnetic) coupling. The transfer of energy from one circuit to another by a common magnetic field caused by mutual inductance between the two circuits, known as inductive coupling. The inductive coupling is used by low-frequency or high-frequency RFID systems. Due to the long wavelengths of the low-frequency waves, the length of the traditional dipole would be too long. As a result, both the tag and reader use a loop-style coil as an antenna.

The power transfer between tag and reader depends on the operating frequency, the angle made with the antennas (for optimum power transfer, the tag antenna and reader antenna should be in the same plane), and the distance between the antenna and size of the antennas.

The following are the key characteristics of an inductive coupling RFID system:

- Big antenna size
- Low cost
- Short read/write range (only works in the near field of the RF signal)
- Low transmission speed

3.1.2 Communication through backscattering

Backscattering is the communication technology used by an RFID system that operates at UHF or Microwave frequencies. It is the process of capturing an RF signal(energy), Processing the signal with the data it contains and reflecting it to the source. A reader sends an electromagnetic wave to a tag at a specific frequency in the RFID system; the tag absorbs the wave, encodes the information into the wave, and scatters it back to the reader. This reflection is made possible by a charging mechanism in the tag, such as a capacitor.

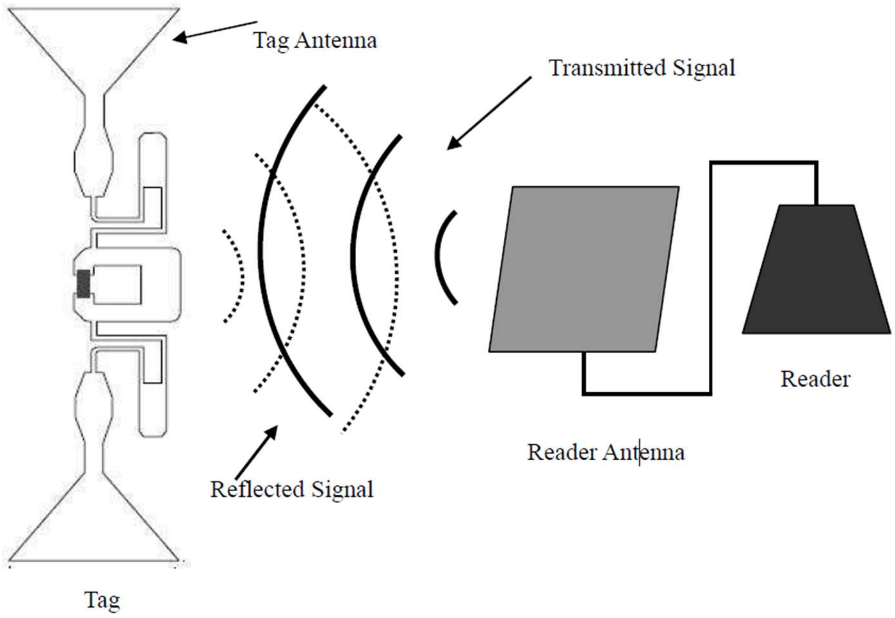

Figure 3.3 The backscatter modulation of RFID system [28]

Table 3.1 The properties of three different tags

Specification	Active tag	Passive Tag	Sem-Active tag
Power supply	Has battery	No battery, Obtains the energy from the the electromagnetic field	Has battery
Operation Life	Depends on the battery, Life is limited	Long operation life	Longer than active tag(because power is only consumed when the tag is activated)
Size	Large thick, heavy	Small, thin, light	Large, thick, heavy
Cost	Expensive	Inexpensive	Intermediate
Tag transmit range	Long (>3m)	Short (<3m)	Short (<3m)
Processing capability	High	Low	High

3.1.3 Technical characteristics of RFID

- Data read and write - RFID reader can read data from RFID tag without having contact, process many tags simultaneously, and write the logistic processing state into the tag for the next step.

- Miniaturized and diverse form - As RFID reads data, it is not constrained by size or shape, so it does not need to use paper with a set size or print quality to match precision. Moreover, due to their small size. RFID tags can be used in various goods. More flexibility controls the production of the products, especially on the production line.

- Anti-pollution – RFID possesses strong anti-pollution nature for water, oil and medicines. RFID can also read data in a low-light or polluted condition.

- Repetitive use – RFID is electric data, which can be written repetitively so that the tag can be used repetitively.

- Penetrability – If RFID is covered by paper, wood, plastics or non-metal or non-transparent materials, it can communicate through these materials except for iron and other metals.

- Big memory capacity of data – The storage size can be expanded with the development of the memory scale.

- System Safety – The system saves the data from the central computer to the workpiece, which significantly improves system security.

- Data safety – The data stored in the RFID tag can be protected by password or permanently locked to ensure data safety.

3.2 RFID Tag

The RFID tag, also known as the transponder, stores the data sent to the reader while the reader interrogates the tag. Today's most common tags contain an antenna and an Integrated circuit (IC) with memory, which is a microprocessor chip. The tag is divided into three types based on their properties and described in table 4.1. The main components of the RFID tag are substrate and conductive material. The substrate is made of PVC, RET or paper or a similar type of material. The antenna is made of conductive materials like copper and silver. The silicon chip is placed on the top of the conductive layer. Finally, it covered with a protective layer.

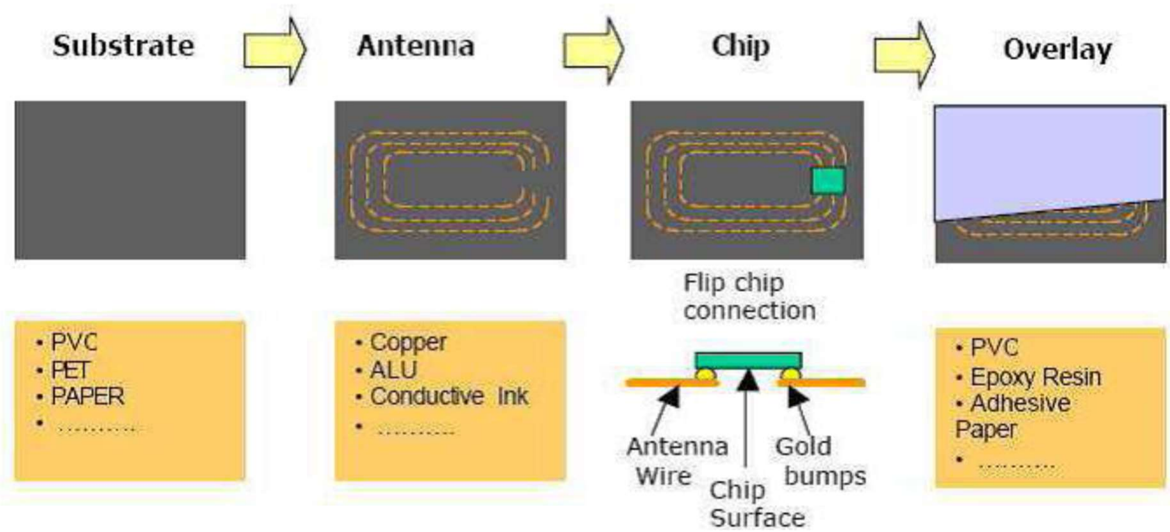

Figure 3.4 Main components of an RFID tag [30]

The RFID tag size and price may vary depending on the type of application, location, and required read range. As a result, the tag has been produced in various types based on their field of usage, the tags classified according to their energy source, frequency of operation, operation and internal memory.

3.2.1 Classification of RFID Tag-Based on Size and shape

RFID tags come in different sizes and shapes. There are tags with a PVC plastic base that generally have a hole in the middle, and they are durable and can be used many times. The tags are similar to credit cards, and they are often referred to as contactless smart cards. Some other tags, such as smart tags, are made like layers of paper on labels. In addition, some tags work well in environments with a possibility of erosion (like water or liquid). Such tags are placed in cylinders. For small tags are embedded in public items such as clothing, watches, and bracelets.

3.2.2 Classification of RFID Tag based on Energy Source

The RFID tags are classified as passive, active and semi-passive or semi-active depending on their energy source. Passive tags obtain the power and energy they need from readers through a set of transmission methods. An internal battery provides the energy required for active tags. It has a CPU, memory, and a sensor to communicate. Semi-passive tags can benefit from transferred energy from readers in addition to their internal battery. In addition to using their batteries, semi-active tags can detect and interact with other forms of tags without the use of a reader.

3.2.3 Classification of RFID Tag-Based on Radiofrequency

Generally, Radio frequencies are divided into four categories:

- Low Frequency (LF,30-300KHz)
- High Frequency (HF, 3-30MHz)
- Ultra-high frequency (UHF, 300MHz-3GHz)
- Microwave (> 3GHz)

However, In RFID systems, the operating frequency spectrum does not interact with other radio equipment. Just a few frequencies are used for this purpose at any frequency band. Different types of RFID tags based on their frequency of operation is described in Table 3.1.

The range of LF frequency used in RFID systems is about 125 to 134 KHz. The reader's reading speed is low in this range, and the read range is short(approximately 3 meters). It is mainly used for livestock monitoring and access control.

In HF, The frequency spectrum is between 13.553 to 13.567 MHz, and the readers read the tag information at an average speed. This frequency range has a limited read range (about 1 meter). It is commonly used for applications such as library management and smart cards.

The UHF frequency spectrum in RFID systems varies depending on the standards of each country (Figure4.5). For example, In the United States, the rea range is approximately 3 meters for 900-950 MHz and 90 meters for 433MHz. These RFID systems used for applications such as tracking pallets and vans.

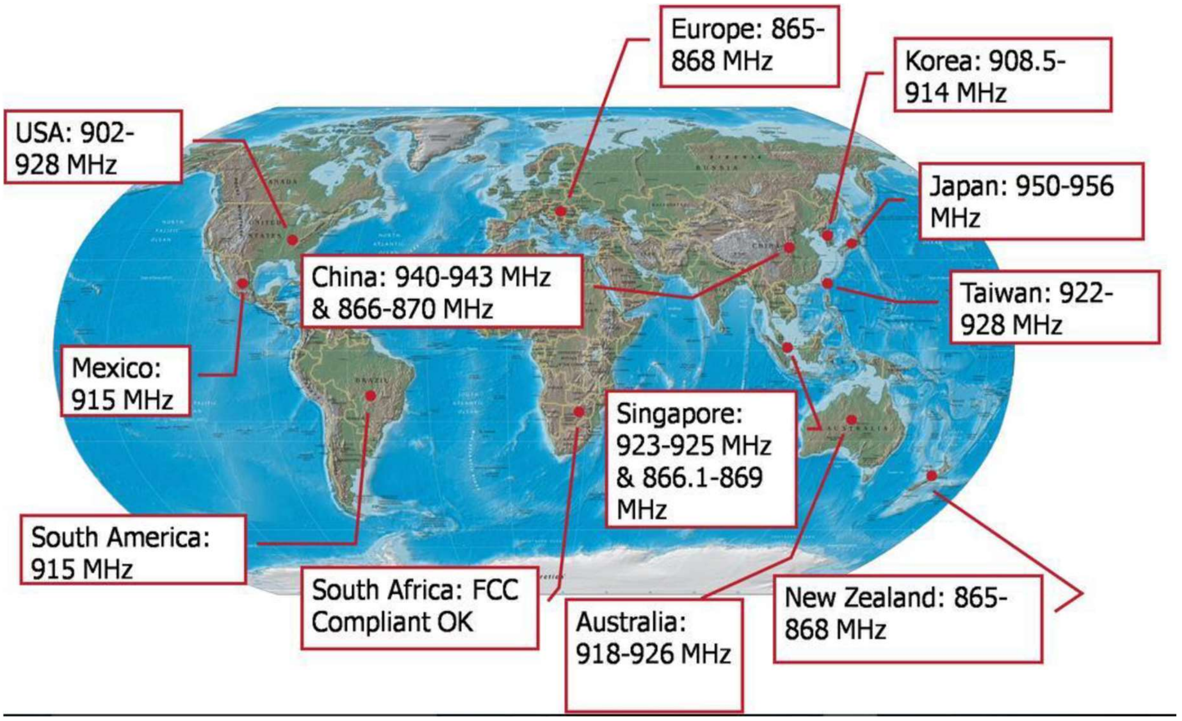

Figure 3.5 UHF frequency bands in different countries [31]

The RFID system operates at microwave frequencies ranging from 2.45 GHz to 5.6 GHz. The reader can scan the information compared to other RFID identification systems. The read range is more than 100 meters. [7]

3.3 RFID Reader

The RFID readers are made up of two parts: an antenna and an electrical module. The antenna is used to communicate wirelessly with RFID tags. The electronic module is typically networked to the host computer through cables. It serves as a relay for messages between the host computer and all tags within the antenna's radius. The electronic module also performs security functions such as encryption/decryption and user authentication and another essential feature known as anti-collision, which allows a reader to connect with several tags simultaneously.

The reader is also referred to as the coupler. The coupler can transfer data in two directions: It can read data from the tag and send it to a PC(read mode), or it can read data from a PC send it to an RFID tag (write mode). The reader supplied the energy required to activate or energise the tag in the electromagnetic field. The range of field depends on the power of the reader and the size of the antenna on both sides. Application requirements typically determine the antenna size. However, the reader's power, which determines the strength and range of electromagnetic field generated, is limited by regulations. Each country has its own set of standards and regulations governing the amount of power produced at different frequencies.

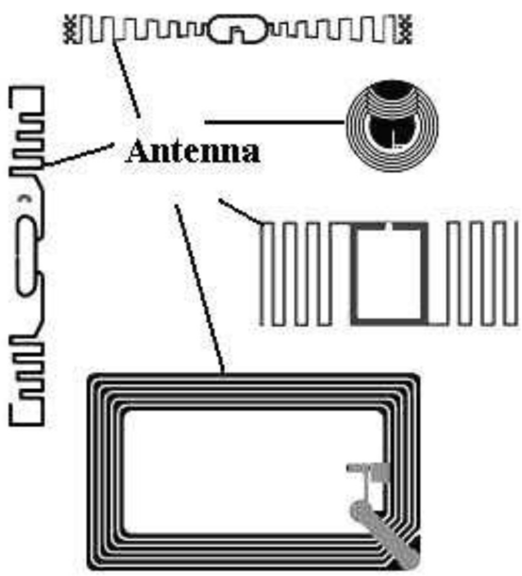

Figure 3.6 The typical Passive RFID tag with antenna [28]

The RFID reader acts as a bridge between the RFID tag and controller, and it has the following tasks. Reading the contents of the RFID tag

- Writing data on the tag (Smart tags)
- Relay or release data for the controller and vice versa
- Supply energy for tag (passive tags)

Table 3.2 Radiofrequency ranges of RFID systems and the corresponding properties

Frequencies	**Low Frequencies** **120-140KHz**	**High Frequencies** **13.56MHz**	**Ultra-high frequencies** **860-950 MHz**	**Microwave frequencies** **2.45 GHz**
Operating range	Upto 1 meter	Up to 1 meter	Upto 3 meters	4-12 meters
Advantages	Simple and robust technology, Lots of shapes and sizes insensitive to disturbance, Good penetration, Works best around metal and liquid	Good anti-collision, Large assortment relatively transponder, Common worldwide standards, Longer read range than LF tags	Good anti-collision, Fast speed, Long read range, Cheap price and good standards	Good anti-collision, High-speed data transfer rates, Very long transmit ranges, Commonly used in active and semi-active modes
Disadvantages	Limited anti-collision, Slow data transfer	Unable to read through liquid, poor performance around metal	Incompatibility issues related to regional regulations, Susceptible to interference	Poor performance around liquid and metal

In addition to the above operations, more complicated RFID readers can cope with a concussion, ensure communication with several tags, accept tags to avoid possible misuse and unauthorized access to the system, and ensure the integrity of data privacy through encryption.

3.3.1 Encryption and Decryption

Data encryption is an authentication process that can be applied to protect the device from external intrusion. Encryption is used to protect the confidentiality of transmitted data and to avoid interception and eavesdropping. The reader is responsible for encryption and decryption.

3.3.2 Reader location and size

It is not mandatory for RFID tags in an RFID system mounted inside the reader device's line of sight (unlike barcode systems). The most important advantage of the above characteristics is that designers can decide where to place the reader according to their needs. Some readers can be permanently connected to walls. In contrast, others can be suspended from the roof. Smaller portable readers allow users to read information while standing a distance apart (for places that is not possible to install the readers permanently). In most cases, this kind of handheld readers can be wirelessly attached to a computer.

3.4 Chipless RFID Tag

The chipless RFID technology has received much attention in recent years because of its low cost and applicability in a broad market spectrum. The chipless RFID tag doesn't require a silicon microstrip for its functionality. Instead of silicon-based microstrips, some chipless tags use plastic or conductive polymers. The development efforts in chipless RFID tags are more concentrated on item-level tagging, sensing and security purposes. Despite the high level of activity in this field, chipless RFID technology is far from commercialization. Further research is needed to bridge the gap between development and the market. [32]. The chipless RFID tags divided into 3 types based on their encoding principles [32].

1. Time-domain chipless RFID tags
2. Frequency domain chipless RFID tags
3. Hybrid chipless RFID tags

3.4.1 Time-domain chipless RFID tags

They receive some pulsated signal from the antenna, and there are some reflectors in the chipless tag. The reflectors produced some echos, and the presence or absence of echos, we can obtain ID. The clipless tags that have been successfully commercialized are acoustic wave (SAW) tags. [33].The figure 3.7 and 3.8 represents the basic block diagram of time-based chipless RFID system and the interrogation signal. But, the cost of such tags is almost the same as silicon chip-based RFID because that tag uses piezo-electric material and submicron lithography production techniques.

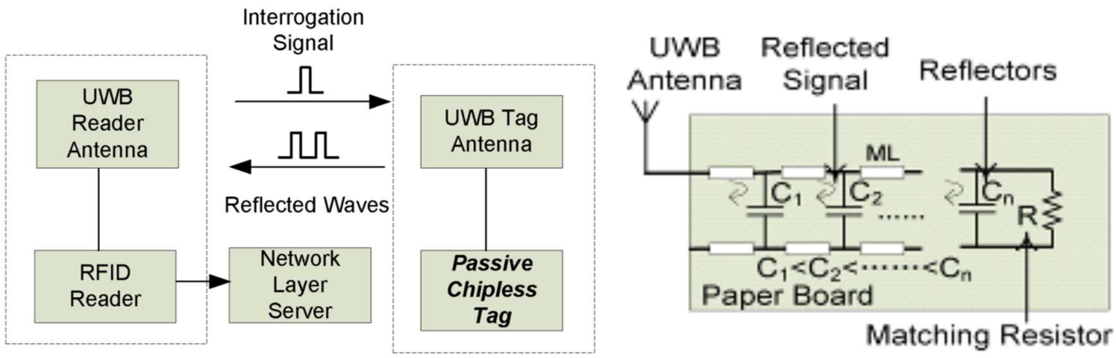

Figure 3.7 Block diagram of UWB RFID system with chipless RFID tag and Schematic diagram of the RFID tag based on time-domain reflections. [33]

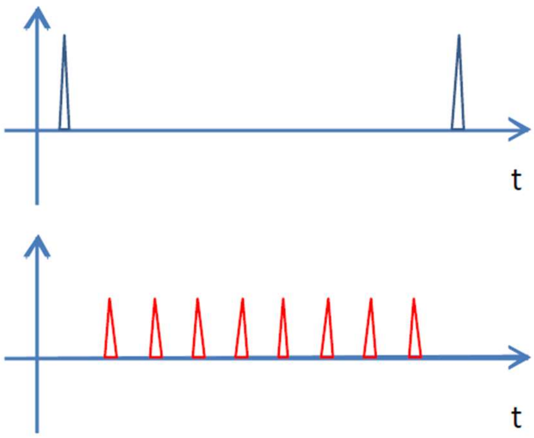

Figure 3.8 Interrogation signal (upper) and the train of reflected signals(below) in sequence [33]

3.4.2 Frequency domain chipless RFID tags

In this section, circular-shaped frequency domain based chipless RFID tags by using inductor-capacitor resonators (L-C). The proposed chipless tag can store 5 bits. It can vary by changing the number of resonators in the design. The resonator consists of a square inductor and a plate capacitor. [17].

A through-hole or via is needed to connect the two-layer metals on opposite sides of the used substrate. The inductor has been purposefully left disconnected. Suppose the LC device is to be used in the future. In that case, the disconnecting point can be filled using a printing process or other material depositing techniques, allowing for a versatile encoding feature. Filling the encoding point, for example, represents the code of the digit "1," while leaving it blank encodes the digit "0." As a result, the tag can be recycled and reused several times, lowering the tag's cost per time used. [17]

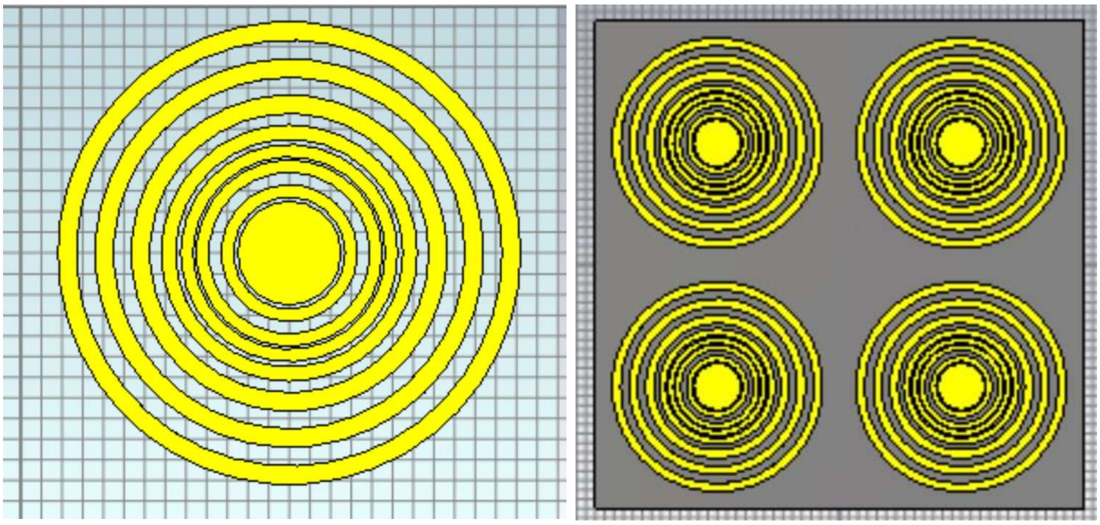

Figure 3.9 Proposed LC resonator-based circular chipless RFID structure

The proposed circular tags designed to work within the range of Ultra-wideband (UWB) frequencies, specifically from 3.1 – 10GHz.The proposed tag has 8 concentric circular rings with a radius of 11.2mm,9.4mm,7.65mm,6.2mm,5.25mm,4.5mm,3.3mm & 3mm, respectively. Up to 5 bits can be encoded within the bandwidth and by using the geometry and backscattering properties of the tag. The base of this circular shape is to assure the compatibility to attach and independence of polarization. [32].

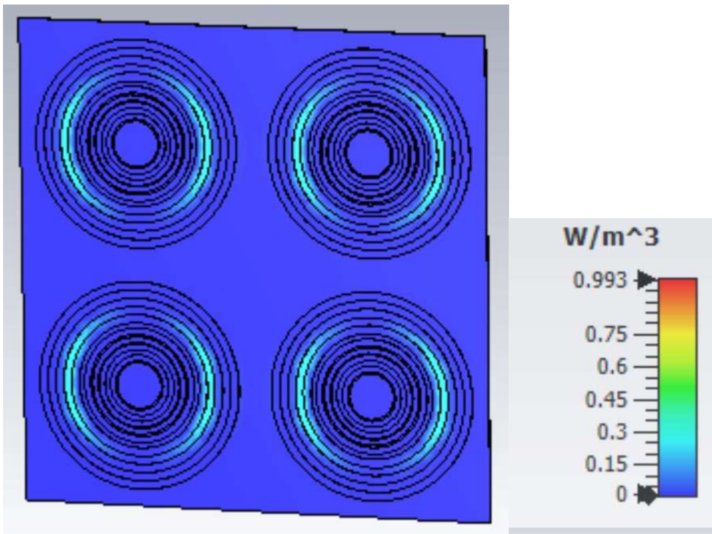

Figure 3.10 Power loss in the proposed circular chipless RFID tag

- **WORKING PRINCIPLE AND CODING**

The tag is illuminated by an incident field (Ei, Hi) from a transmitting antenna to study the scattering mechanism in the circular chipless RFID tag, as shown in Fig 5.11. A surface current is caused when an incident field (Ei) impinges on the structure generated by only one ring [4], [24]-[25]. The equivalent current source is the surface current (J), which generates a radiated field dispersed from the tag (Es). The maximum E-field observed in far fields is proportional to the diameter of the octagonal ring, so the ring with a diameter of 18.8mm has the highest maximum E-field at 5.5 GHz, shown in figure 3.11. [32]

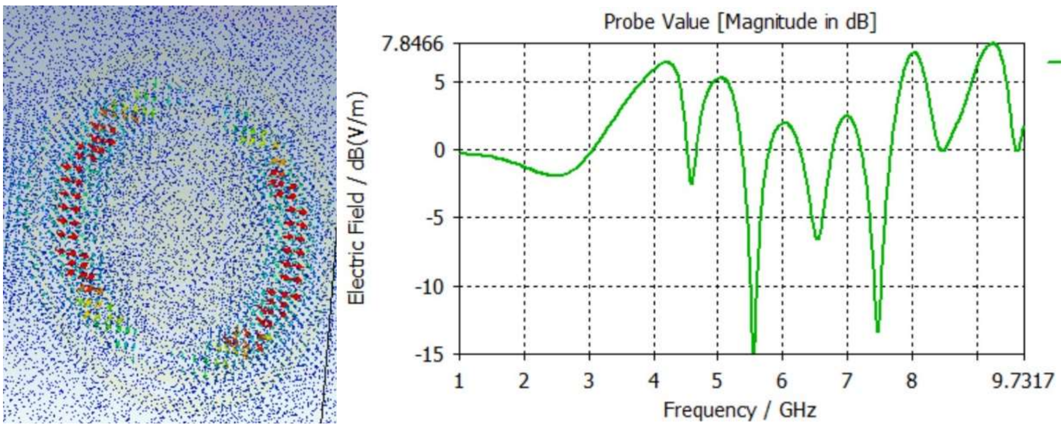

Figure 3.11 circular-shaped chipless RFID tag illuminated by a plane wave at 5.5 GHz and the maximum electric field measurement at 5.5 GHz. (simulation result)

The distribution of currents can now be changed by inserting a collection of short-circuits between adjacent rings, and the far-field response at 5.5 GHz changes. These short circuits (when applied symmetrically at four points of the structure) cause standing waves to have the same phase. Thus, the radiated E-field formed by these identical current sources is constructively interfered in free space, suppressing the resonance [32].

The following technique is used to add an ID code to the name. A reference tag is created in the first stage. The reference tag usually has no short-circuited and displays all of the tag's possible notches in the frequency signature. When no short-circuits exist, a notch in the frequency signature is associated with a gap between adjacent rings. This characteristic is digitalized by assigning a logic 1. A different code is generated in a second phase by printing a series of short circuits on the structure to eliminate the resonance created by two adjacent rings. If there are short-circuits, the frequency signature changes, causing the notch to disappear; this transition is digitalized by assigning a logic 0. Encoding of an octagonal chipless RFID tag with code 110111 is shown in Figure 5.6. The most important aspect has to do with the outer rings.

- **Fabrication of RFID tag**

We are using our tag for high-temperature application. So, the tag materials must be capable enough to withstand this temperature level. The electrical and thermal properties of substrate is discussed in this section. We are using Scott FOTURAN ceramic 810℃ as substrate and annealed copper used as solid metal.

Table 3.3 Electrical and thermal properties of substrate [34]

Electrical Properties – Glass state and ceramic state			
	Frequency (GHz)	Ceramized at 810 ℃	Glass state annealed at 40 ℃ /hr
Dielectric constant (Permittivity) ε_r	1.1 1.9 5 24 77	5.4 5.5 5.4 5.41 5.27	6.4 6.4 6.4 - -
Dissipation factor Tanδ(*10^{-4})	1.1 1.9 5	39 44 55	84 80 109

	24 77	105 135	- -
Thermal properties – Glass state			
Transformation temperature Tg in ℃ Coefficient of mean linear thermal expansion $\propto$ (20℃; 300℃) in $10^{-4}K^{-1}$ (static measurement) Thermal conductivity λ in W/(m*K) ($\theta = 90$ ℃)			455 8.49 1.28

Table 3.4 specifications for copper(annealed)

Specification	Range
Material	Copper (annealed)
Type	Lossy material
Mu	1
Electrical conductivity	5.8e+07 (S/m)
Rho	8930 (kg/m^3)
Thermal conductivity	401 (W/K/m)
Heat capacity	0.39 (kJ/K/kg)
Diffusivity	0.000115141(m^2 /s)
Young's modulus	120 (kN/mm^2)
Thermal expansion	17 (1e-6 /K)

4. TESTING METHODOLOGY

This chapter tests the reliability of the selected UHF RFID tags based on our industrial working conditions (ABB M&G). The purpose of this test was to evaluate whether the given RFID system performs with temperature and the effects of reading range with temperature. The tags selected for testing based on ISO/IEC 18000-6C [35], EPC Class 1 Gen 2 protocol [36] and technical parameters of the selected tags given in table 4.1 [5].

The maximum operating temperature of large AC machines is between 120℃ to 175℃ [5]. There are several commercial tags available with a gazillion inlay and various antenna styles. Unfortunately, not all tags are suitable for all applications, and each RFID application needs its customization. The main reason behind testing and analyzing RFID tags is to choose the appropriate tags for the correct application. Testing and performance analysis indicates the impact of the environment and objects fixed on the tags themselves. Thus it is essential to understand and analyzes the performance of different tags in various environments [37].

The key parameters in the efficient implementation of the RFID system are the correct choice of readers, tags, tags location, antennas, reader configuration, analysis of objects to be tagged, and characterization of environment., Several parameters such as tag sensitivity, backscatter signal strength, communication range, tag reflection range, the sensitivity of reader, IC design and antenna design affect the performance of tags in various environments and on various objects to be tagged. It is essential to evaluate the performance of tags on the items that must be tagged and identify the natural environment. It is mainly to ensure higher read speeds, higher precision, and overall device performance. In this segment, the author introduces a systematic approach to testing passive UHF RFID tags and analyzing the test results to understand better specific vital parameters that influence tag efficiency.

4.1 Test Setup

There are several methods for testing and comparing the results of different tags. Antennas and cables can be checked by taking measurements [37]. Traditional RF testing has been done using a network analyzer to calculate the properties of RFID IC's. In this part, the author explains how to set up the test equipment to check passive UHF RFID tags. RFID tag testing can be accomplished with either the conventional network analyzer or the most modern tag analyser. Another approach to test tags is to use a commercial UHF RFID reader.

All experiments were performed using a SkyeTek M9 RFID reader. We need to install the skydemo m9 version 3.0.3.437 software and skyware4 software to test and valuation the RFID tags. The majority of the measures covered in the following paragraphs to set up the test equipment is generic with any signal source that connected to a computer assume that the Gen2 protocol for passive UHF RFID reader is implemented [35] [36].

There are 3 types of UHF RFID tags considering for this experiment, and the specification details below in table 4.1.

Table 4.1 Specifications of UHF RFID tags

Model	Ultra-micro-PCB UHF RFID tag	Ultra-micro-ceramic UHF RFID tag_A	Ultra-micro ceramic UHF RFID tag_B
Types	Passive, read/write	Passive, read/write	Passive, read/write
Size	Dia 10mm	Dia 10mm	Dia 10mm
Material	PCB	ceramic	ceramic
Frequency	860-960 MHz	860-960 MHz	860-960 MHz
Chip protocol	UHF EPC Gen2 Class-1	UHF EPC Gen2 Class-1	UHF EPC Gen2 Class-1
Chip	Impinj Monza4QT	Alien h3	Impinj Monza4QT
EPC memory	96 bits	96 bits	96 bits
User memory	512 bits	512 bits	512 bits
Materials/Substrate	PCB	Ceramic	Ceramic
Anti-interference	Anti-metal resistance	Anti-metal resistance	Anti-metal resistance
Installation method	Glue sticker	Glue sticker	Glue sticker

The following are some of the measures to get the equipment ready for testing.

1. The hardware connections for the testing system(reader or analyzer) must be made following the manufacturer's instructions. The unit must be configured with the required hardware and software following the manufacturer's instructions.

2. Also, make sure that the transmitter and receiver antennas are at least 25 cm apart. The antenna stands must be made of non-conductive material like wood or plastic.

3. After setting up and configuring the reader, the tag must be fixed to any RF transparent material like foam for free space testing or on the product to be tagged. Again the tag must be mounted on a stand made of non-conducting material. It is better to use a roughly parallel tag (same height as antenna stand) to the antenna.

4. Set the tag at the desired distance from the test equipment. Typically, for range checking, the tag is near the test unit, and then the tag is moved to the highest distance from the test unit until the tag can read.

5. Follow the same steps for various tags and note the maximum distance the tag can read.

Figure 4.1 Different types of RFID Tag PCB, ceramic model-a, ceramic model-b

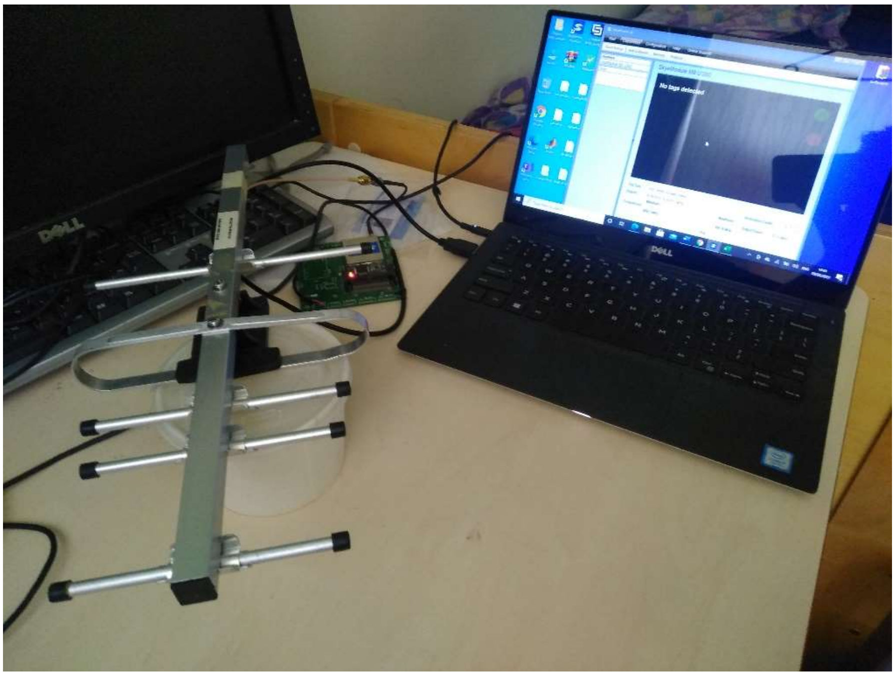

Figure 4.2 Test setup

4.2 Read Range Test

In this section, the read range of UHD RFID tags was measured. The read range is the fact that passive RFID tags are operated solely by incoming RF energy, combined with cost and fabrication requirements, imposes a specific set of parameters on RFID tag antenna design, including frequency bandwidth, directivity, size and shape, sensitivity to various objects the tag is mounted on, durability and finally read range [38]. We need to calculate the read range of RFID tags in normal conditions to compare how they can be effective in high temperature and water medium applications. In the research paper [37], the author used a glass chamber embedded with a heat gun and RFID reader to study the temperature effects of RFID.

Read range is a significant characteristic of RFID tag. It is the maximum distance from which the tag can be detected. The maximum distance from which the tag absorbs only enough power to turn on and scatter back is one restriction of the range. Another constraint is the maximal distance at which the reader can sense this scattered signal. The read range is smaller of the two distances (typically, the first one since RFID reader sensitivity is usually high).

The theoretical read range is determined by the power reflection coefficient and can be calculated using the friis-space formula as,

$$\gamma_{max} = \frac{\lambda}{4\pi}\sqrt{\frac{p_t G_t G_\gamma (1-|s^2|)}{P_{th}}} \tag{4.1}$$

Where λ is the wavelength, P_t is the power transmitted by the RFID reader, G_t is the gain of the transmitting antenna (P_t G_t is EIRP, equivalent isotropic radiated power), G_r is the gain of the receiving antenna, and P_{th} is the minimum threshold power necessary to power up the chip. Typically, P_t, G_t, G_r, and P_{th} are slowly varying, and $|s^2|$ dominant in frequency dependence and primarily determines the tag resonance. [38]

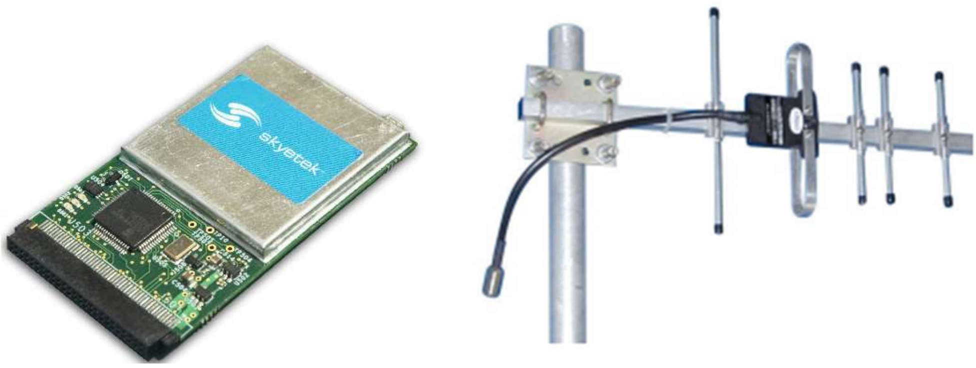

Figure 4.3 Skyetek passive UHF RFID reader and directional antenna G: 9dB [39]

The results and analysis of the read range test discussed in Chapter 5.

4.3 Effect of Temperature on Passive UHF RFID Tag

In recent years, RFID technology has become more and more common in several industries. But, due to the extreme environments tag antennas encounter during various types of uses, the increasing use of RFID technology has expedited the requirements for tag antennas. In this section, the author tries to figure out the effect of temperature versus reading range on passive RFID tags. [37] [40].

Temperature variation is a significant environmental challenge for RFID tags. RFID tag antennas are expected to operate at low and high temperature in various circumstances when used for identification purposes in the production process. For example, suppose it's using for the coil identification purpose of machines. In that case, the temperature becomes low when the machine in an off state and the temperature maximum while the machine in operation mode. It is essential to ensure that the tag antennas function does not break down and with no performance loss at various temperature levels. We are following the experiment similar to the research paper [37].

4.3.1 Experimental Setup for analyzing the temperature effects on RFID tags

In this section, three types of 860-690 MHz UHF passive RFID tags (Ultra micro PCB UHF RFID tag, Ultra micro-ceramic UHF RFID tag_A, Ultra micro-ceramic UHF RFID tag_B) tested in various environmental condition from 12℃ to 179.6 ℃ by using Vötsch VTM 7004 climate chamber (figure 6.5) and the read range measured by using Skyetek M9 RFID reader and directional antenna TDJ-900ACY5(figure 6.4) with gain 9dB, operating at 824-960 MHz.The RFID reader is connected to the computer through a USB interface for data collection and analysis. The antenna connected to the computer is placed outside the climate chamber and shown in figure 4.5.

Figure 4.4 Directional antenna TDJ-900ACY5 [39]

Figure 4.5 Vötsch VTM 7004 climate chamber

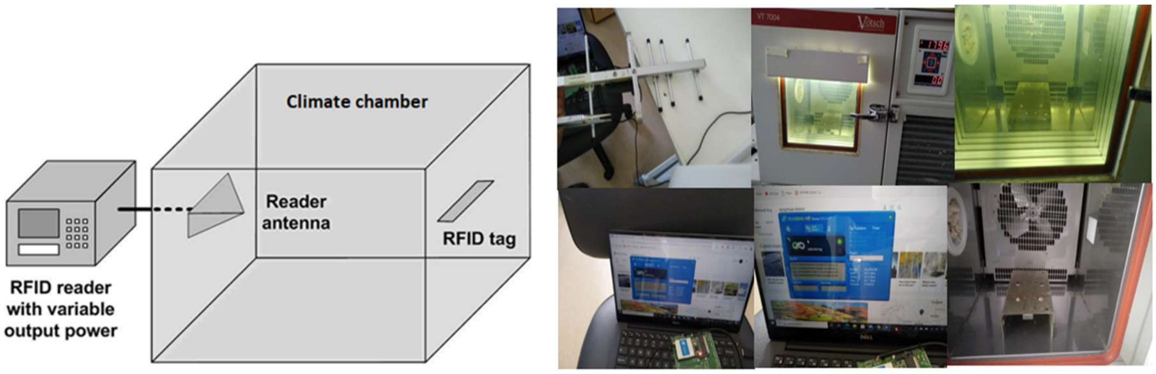

Figure 4.6 Experimental setup for temperature effects on UHF RFID tags

4.3.2 Test Methodology for analysing the temperature effects

The test was performed in industrial environmental conditions like temperature varies from +12℃ to 179.6 ℃. [41] The relative humidity (RH) kept constant 'Zero' in this experiment. The RFID tags were placed on a metallic surface shown in figure 4.6. Three different substrates and IC chip-type passive ISO 18000-6C EPC global Class1 gen2 RFID tags used for this experiment. The effects of temperature on RFID tags were measured in 4 different circumstances – at a temperature of +12℃, +70℃, 120℃ and 179.6℃. The maximum reliable read range (MRRR, Continuous 1 minute identification with over 75% of maximal reads-per-second rate) is measured in these temperature levels. The climate chamber turned off, and data was taken with the climate chamber door open at the conditions mentioned above. The door was kept open for a few seconds at each test point. For example, after taking data at +70℃, the door kept open for signal propagation and data collection for a particular condition for few seconds. The conductive interaction with the RF signal propagation is reduced because of this operation. The description of the chosen tag types:

- Ultra-micro PCB UHF RFID tag | Chip-Impinj Monza4QT | UHF EPC Gen2 Class-1 | anti-metal
- Ultra-micro-ceramic UHF RFID tag_A | Chip-Alien h3 | UHF EPC Gen2 Class-1 | anti-metal
- Ultra-micro ceramic UHF RFID tag_B | Chip-Impinj Monza4QT | UHF EPC Gen2 Class-1 | anti-metal

The tag performance was measured in threshold power in the 860-870 MHz in various circumstances. In the atmosphere, the propagation of radio waves is affected by distance and the various forms of gas molecules and particles. The sum of gas molecules, such as oxygen and water, determines the electrical characteristics of the atmosphere. Their polarization affects signal attenuation resonance and refraction. These effects are not discussed in this experiment. The experiment results will be discussed in chapter 5.

4.4 Performance Analysis of Passive UHF RFID tags in Water Medium

The RFID, like all other radio technologies, cannot work in the environment of water. While water is not a pure conductor, dissolved salts or other ingredients transform it into a partial conductor [42]. The electromagnetic waves cannot travel through electrical conductors, which means RFID technology cannot communicate underwater. But some experiments have shown that the potential to transmit radio signals is primarily determined by two factors: water conductivity and radio wave frequency. We cannot modify or alter the conductivity of water. So, the only possible solution is to increase the performance of radiofrequency [42] [43].

4.4.1 Experimental setup and testing methodology for analyzing effects of RFID tags in water medium

This section performs some experiments in our selected passive UHF RFID tags (ISO 18000 6C /EPC C1 Gen2) to determine their reading effect on the water environment. The description of the chosen tags types:

- Ultra-micro-PCB UHF RFID tag | Chip-Impinj Monza4QT | UHF EPC Gen2 Class-1 | anti-metal
- Ultra-micro-ceramic UHF RFID tag_A | Chip-Alien h3 | UHF EPC Gen2 Class-1 | anti-metal
- Ultra-micro ceramic UHF RFID tag_B | Chip-Impinj Monza4QT | UHF EPC Gen2 Class-1 | anti-metal

The read range of RFID tags measured by using Skyetek M9 RFID reader and directional antenna TDJ-900ACY5(figure 4.4) with a gain of 9dB.The RFID reader is connected to the computer through a USB interface for data collection and analysis using Skydemo and skyeware4 softwares.

The experiment divided into two sections. First, we dipped UHF RFID tags into a transparent glass filled with water and measures the reading range, then measured again after 24 hours of keeping the tag into water. We drop a single tag into the water at a time. Second, measure the reading range of RFID tags water after taking it from the water medium. The experimental setup is shown in figure 4.7 [44].

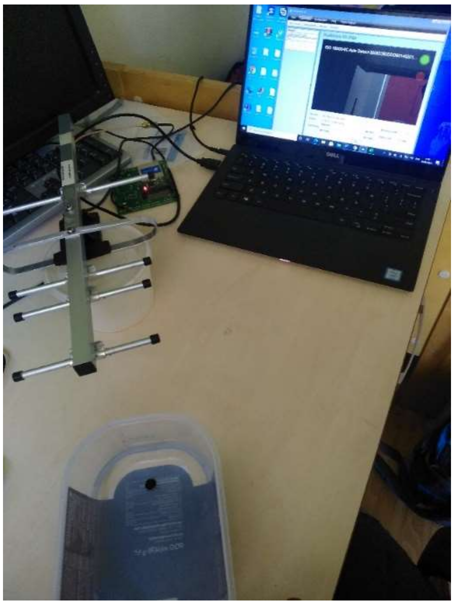

Figure 4.7 Read range measurement of ceramic UHF RFID tags

5. TEST RESULTS

The experimental results in this work consist of two parts,

- Experimental results of selected passive UHF RFID tags
- Simulation-based results on chipless RFID tags

The experimental results of passive UHF RFID tags include: Normal read range test, the performance of passive UHF RFID tags in high temperature and water. All tests were done based on the industrial conditions of ABB. The methodology used for the test based on the requirement from the factory. The result and analysis discussed below.

5.1 Read Range Test

The UHF RFID tags are used in many applications due to no power source requirement on the tag and ease of use. The selected UHF RFID tags provide a better-read range in the normal read range test. The RFID tags give a better reading rate at a frequency of 866.5 MHz. The results and graphs are described in table 5.1 and figure 5.1. we measure the read range of RFID tags for comparing the read range in adverse operating conditions such as high temperature and water medium.

Table 5.1 Read range test results

Frequency	Read range_PCB RFID Tag	Read range_Ceramic model_A	Read Range Ceramic model_B
865.7	12	10	12
865.9	13	14	13
866.1	15	15	14
866.3	25	22	25
866.5	30	31	32
866.7	32	30	26
866.9	31	30	30
867.1	25	28	25
867.3	24	24	25
867.5	23	24	24
867.7	20	19	22
867.9	18	17	19

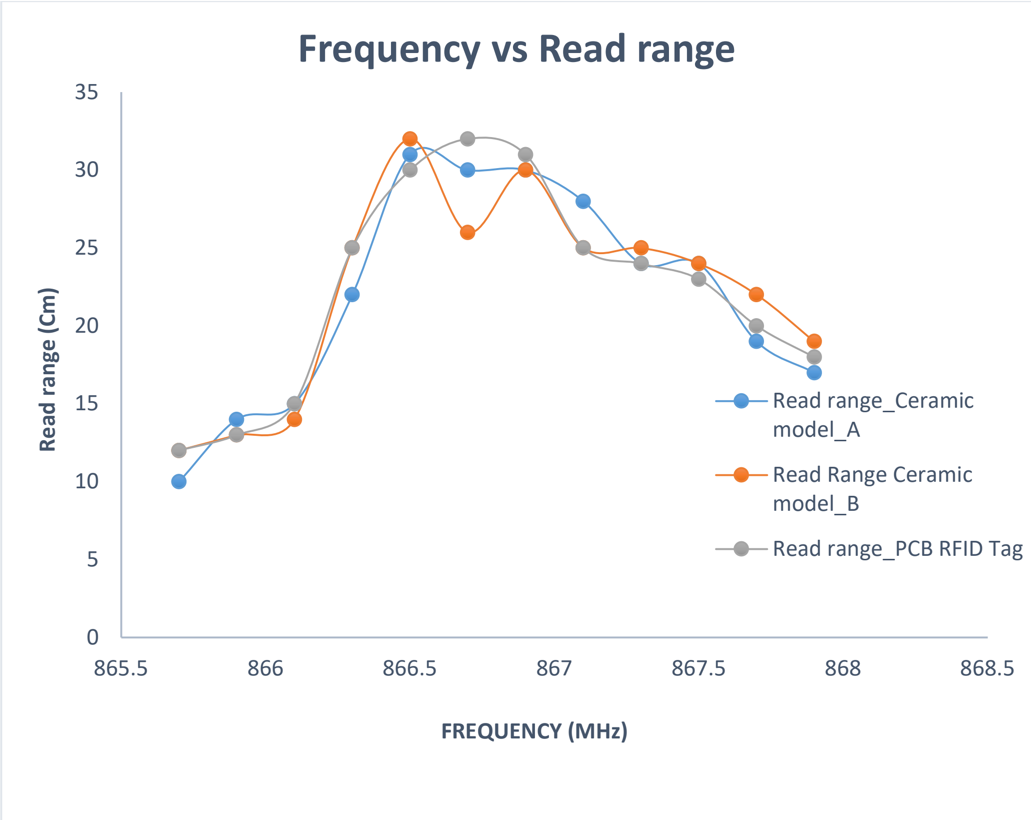

Figure 5.1 Normal read range test

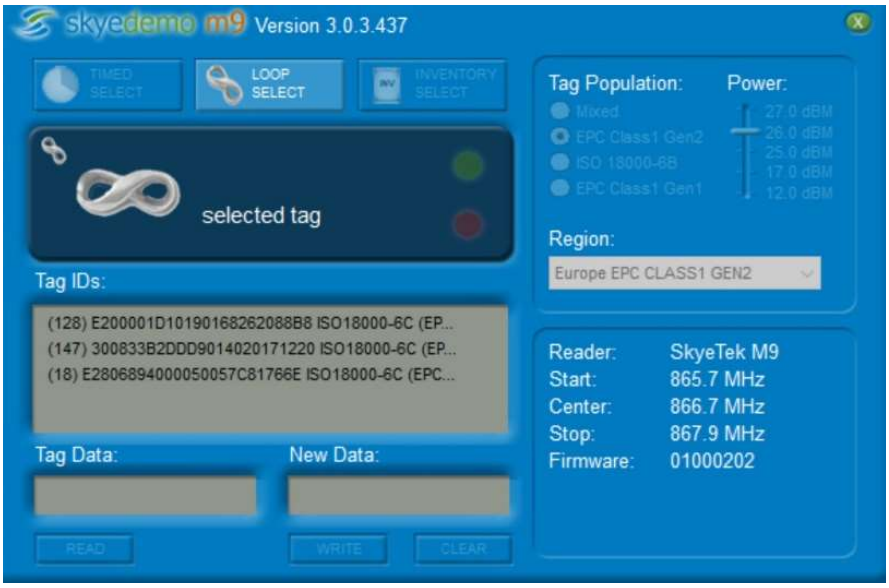

Figure 5.2 Read rate of RFID tags in Skyedemo M9 software.

The ID code of different RFID tags shown in the tag ID column of skyedemo software. The tag population choose as EPC class 1 gen2, and the region set to Europe EPC Class 1 gen2. The informations in the RFID tag can read and write using skyware 4 software shown in figure 5.3.So, we can use this method while producing the coil. We can feed the information of workers and further informations either manually or automatically. Here, i used manual option to feed the informations to RFID tag. We can use rfid reader or any ERP software connected to the RFID system to retrieve the data from RFID tags.

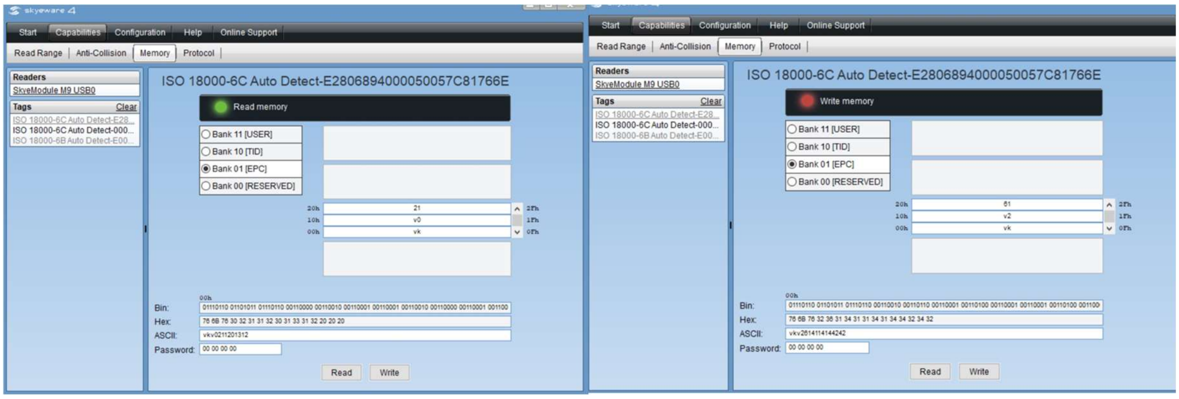

Figure 5.3 Write and read operation of RFID tags by using Skyware 4

The reader and tag informations show the left bar of skyware4 software—the reader Skyetek M9 module connected through a USB interface, and the tags detected by using radiofrequency. The data or informations stored in the tag can be protectetd by using pasword option while feeding inforamtions to the tag.

5.2 Effect of temperature in UHF passive RFID tags

In this section, we present the experimental results of the maximum reliable read range (MRRR- continuous 1-minute reliable read range with overall 75% of maximal reads – per-second rate). The MRRR of different ISO18000-6C EPC Global Class, 1 Gen 2 RFID tags with different substrates and IC chips, is shown in figure 7.3 below.

The temperature affects tag operation due to thermal expansion and electrical characteristics that are thermally dependent. The thermal expansion can cause problems when two materials with different thermal expansion coefficients are coupled together. Due to changes in antenna size, thermal expansion can also alter the surface current of the antenna. In antenna technology, temperature affects the level of thermal noise, which emits from the antenna. The effect is negligible for less than 50℃, but it has considerable effects on the higher operating temperature. [41].

The IC chips used in RFID tags are usually based on CMOS technology. They include semiconductors as well as passive components. The semiconductors have better conductivity in higher temperature, even though the lifetime of semiconductor components considerably decreased if it's regularly exposed in higher temperature.

The thermal noise is the crucial factor in high temperature (> 50℃) of operation. It may impact the reading rate in RFID because our RFID system uses the small range wireless communication to read the transmitted data from the tag. The reading rate, which indicates how quickly the RFID device can detect or read the tag at the reader, was chosen as the parameter to measure the system's output. We use two factors to measure the reading rate in RFID. The first one is the distance from the RFID tag to the antenna and the second one is the temperature. The read range of tags in different temperatures is shown in table 5.2.

Table 5.2 Read range of RFID tags in different temperature, the distance measured in centimetres.

Temerature (℃)	Read range_PCB RFID Tag	Read range_Ceramic model_A	Read Range Ceramic model_B
12	25	20	23
70	18	14	15
120	11	6	4
176.6	7	6	3

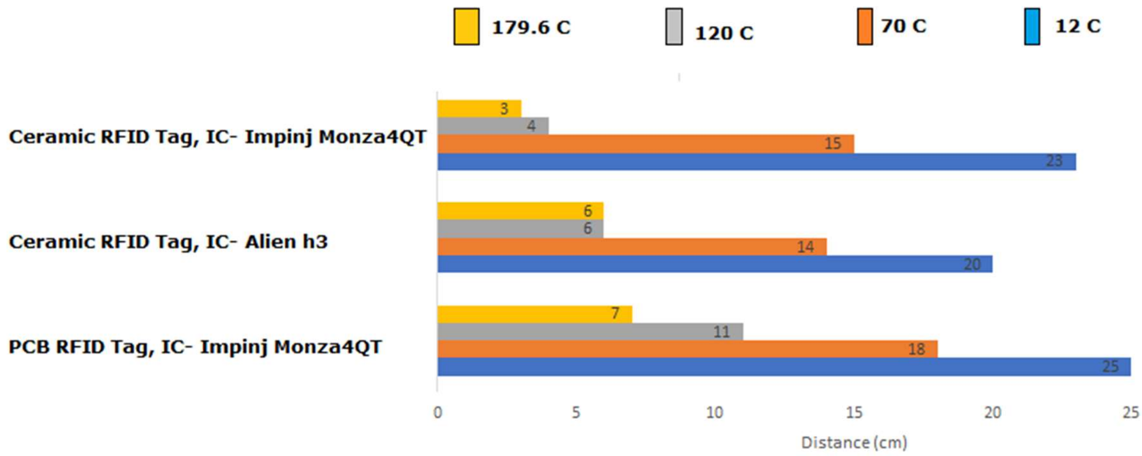

Figure 5.4 MRRR rate of RFID tags in a different range of temperature

Figure 5.4 shows that the PCB substrate with Impinj Monza 4QT IC tags has better MRRR at 179.6 ℃ compared to other RFID tags. All RFID tags have a substantial read range in low-temperature level at 12 ℃. All RFID tags can survive even at 179.6 ℃ temperature and detect a minimum read range of 3-7cm. The measurements were done after few seconds at the desired temperature. The tags can retrieve their standard read range capacity when the temperature becomes in the normal range.

5.3 Effect of RFID in Water Medium

The RFID, like all other radio technologies, is unsuitable to work in the presence of water. But the water, not a natural conductor; the presence of dissolved salts or other materials in the water turn it into a partial conductor. Since electromagnetic waves cannot pass through electrical conductors, radio waves cannot communicate underwater in most situations. Regardless, experiments have shown that the ability to transmit radio signals underwater is primarily determined by two factors: water conductivity and radio wave frequency. Although water conductivity cannot be changed to increase the possibility of using radio waves underwater, the only variable that can be changed to improve efficiency is the radiofrequency [42].

The test results of tag performance in water medium are shown in table 5.3 below. The selected RFID tags can provide a better-read range in water medium. The experiment setup of the water medium experiment is shown in figure.6.7 and 6.8. The ceramic UHF RFID tag_B having tag ID E200001D10190168262088B8 has a better-read range of about 45 cm in all conditions described in table 5.3, and figure 5.4 represents the RFID tag performance in water medium.

Table 5.3 Read range of RFD tags in different conditions in water medium.

Tag Type	Read range in water medium (CM)	Read range in water medium after 24 hours	Read range after taken from water medium
Ceramic UHF RFID Tag_B	45	43	45
Ceramic UHF RFID Tag_A	15	16	15
PCB UHF RFID Tag	21	20	20

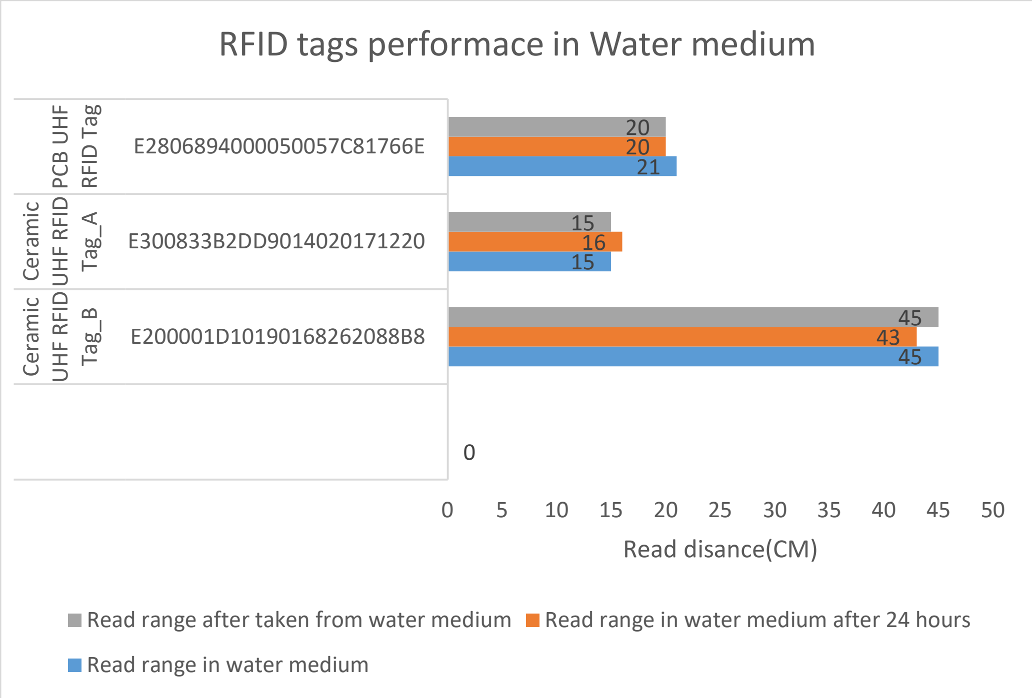

Figure 5.5 RFID tag performance in water medium

All the selected can be able to work in the industrial conditions. But the temperature noise effects the read range of RFID tags. The read range of tag reduced from 35 cm to 5-7 cm in 179℃. Even though, the tags can retrieve their read range when the temperature back to normal temperature range and these tags can also work in a water medium. The ceramic type of UHF tag with chip Impinj Monza 4QT provides better performance compared to other passive UHF RFID tags.

5.4 Simulation Results of chipless RFID tags

The experimental results presented in this work include coding and late-stage coding methodology verification of 3bit square shaped chipless RFID tags and 6 bit circular shaped chipless RFID tags.

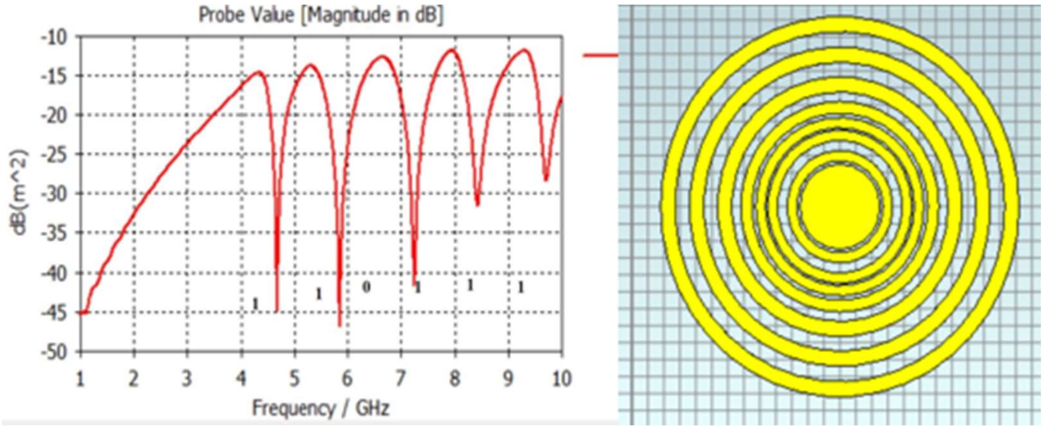

Figure 5.6 Notch based codification of circular chipless RFID tag.coding based on the presence of notches in the frequency signature response of the tags. Simulated response of the tag with code 110111(red lines)

5.4.1 Tag performance and code verification

A collection of tags with 4 different IDs were created to check the efficiency of the square chipless RFID tag and the feasibility of the late-stage coding methodology. The following IDs were used in the measurement campaign: 100,110,111,110. (Figure5.6 and 5.7).

The radar equation can be used to estimate the maximum read range for the chipless RFID tag [32].The conventional method of numerically estimating the RCS of a tag can be used to estimate the read range R based on known parameters for this purpose. The following formula is as follows:

$$R = \sqrt[4]{\frac{G_T G_\gamma \lambda^2 \sigma^{tag} Pt}{4\pi^3 Pmin}} \qquad (7.1)$$

Where Pt is the transmitter power as set as in skydemo software (RFID reader), or VNA used to measure the RCS, λ is the wavelength and G_T, G_γ are the gains of the interrogating antenna. σ^{tag} radar cross section of chipless RFID tag (experimental value). Pmin represents the sensitivity of the receiver, that is the minimum power that the receiver detects.

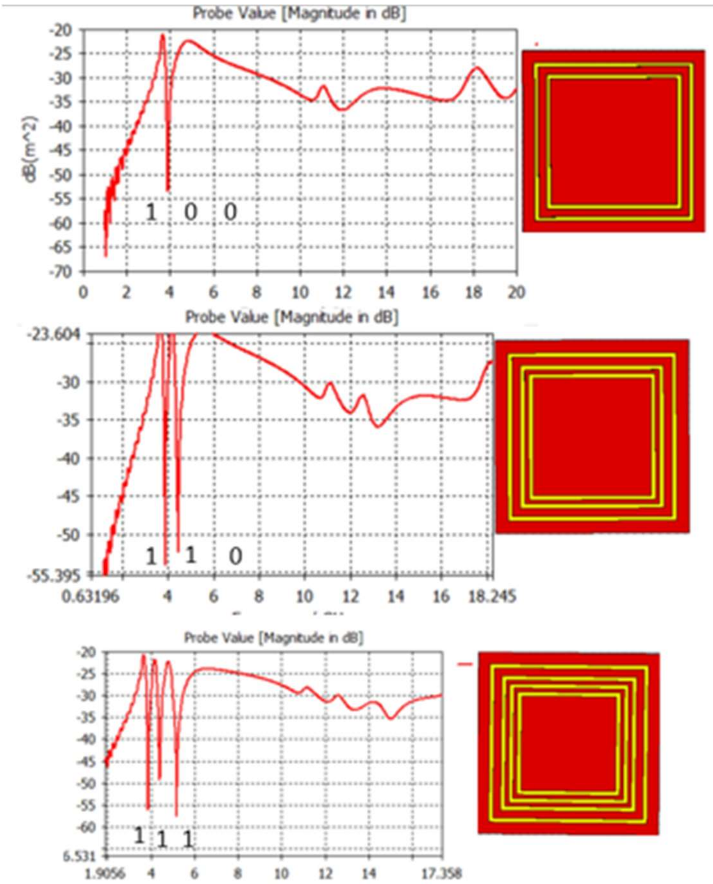

Figure 5.7 |RCS| measurement for the 3 different ID’s square type chipless RFID tags.The corresponding tag mentioned in right side.

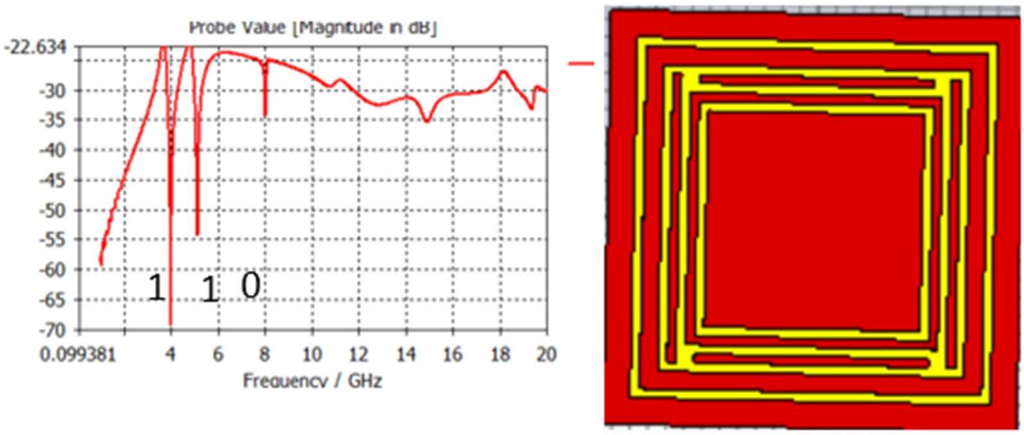

Figure 5.8 Late-stage coding (111 code changed to 111 by short-circuiting the notch)

The chipless tag in figure 5.8 is similar to the last figure mentioned in figure 5.7, but the code of those tags is different. The 2^{nd} notch in figure 5.8 were short-circuited by using same material of notch or conductive ink from Chemitronics. It easy to produce large quantity of tags with code 111 by using screen printing technology and can change their code by changing the notch using conductive ink from chemitronics shown in figure 5.8. These process of changing the code of chipless tag after printing the tag is called Late-stage coding. The memory bits of these RFID tags depends on the number of notches presented in the tag. The memory can be increased by increasing the number of nothces. The main limitation of this chipless RFID is requirement of large bandwidth spectrum to accommodate a significant number of bits. If we need to store huge amount of bit we need to have huge boundary.

SUMMARY

This research introduces the RFID based identification for the coil production process. We have covered the test procedures for the factors affecting the performance of UHF RFID tags in the coil identification process. All tests were performed under lab conditions except for the ones performed in a climate chamber. Test procedures and analysis guidelines to examine the read range of tag in stator coil windings. The selected RFID tags can survive the harsh industrial working conditions. However, the thermal noise affects the read range capacity of RFID tags. The read range of tags becomes in centimetres ranges at 179℃. Even though the tags can retrieve their performance when the temperature down to the normal range. The ceramic RFID tags have better performance than PCB type passive UHF tags. The tags can be attached to the coil at the 2nd stage of the coil production process, called coil spreading. The attached tags can communicate through an RFID reader placed in each workstation and store the product-related information to computer data management software. The experiemental work in this research includes effects of read range in higher temperature and water medium which is described in chapter 4 and 5.

The next stage of the research will be a VPI test of the coil with attached RFID tags and measure the read range of RFID tags after these process.But ,the actual industrial test postponed due to the covid19 situation in Estonia.

The cost of the passive UHF RFID tag can overcome by using a chipless RFID design, and the proposed chipless RFID in this research is based on Frequency selective surfaces. The cost of these RFID tags same as barcodes and gives the advantage of RFID(no line of sight needed). It can be produced by roll to roll printing technology which dramatically reduces the production cost of tags. It can also be used for temperature and vibration detection of stator coils. It can be monitored through the online system. So, the production manager can monitor the production flow without visiting the plant—a 3-bit square type chipless RFID and 6-bit circular-shaped chipless RFID tags designed and simulated in this research. We can increase the memory bits of the tag by increasing the resonator structure in the design. The proposed chipless RFID design and simulation described in chapter 3 and the results section. It can be produced by using mass production techniques such as Roll-to-Roll printing techniques with a reference tag code 111, and later the code can be varied by short-circuiting tag. The chipless tags can short circuit by using a conductive ink pen from Chmetronics. The different codes for each one of the sample were introduced in the result section. The

main drawback of this technology requires a broadband spectrum to accommodate more bits.

The proposed Chipless RFID tags in this research are still much far from commercialization. More research and development needed to bridge the gap between the development and market is necessary. The surface acoustic wave (SAW) is the only tag commercially available chipless tag at the moment. This tag employs the piezoelectric substrate materials and submicron lithography processing techniques, resulting in a higher production cost than the traditional RFID tag. Therefore, chipless RFID tags with low manufacturing costs and satisfactory practical performance are in high demand.

Despite good through the chipless RFID simulations, further research to increment the tag’s capacity is still needed.

KOKKUVÕTE

See uurimus tutvustab spiraalide tootmisprotsessi RFID-põhist identifitseerimist. Oleme uurinud UHF RFID-siltide toimimist mõjutavate tegurite testimisprotseduure mähiste tuvastamise protsessis. Kõik testid viidi läbi laboritingimustes, välja arvatud kliimakambris. Katseprotseduurid ja analüüsijuhised staatori mähise mähiste loetud vahemiku uurimiseks. Valitud RFID-sildid suudavad tööstuslikes töötingimustes üle elada. Kuid termiline müra mõjutab RFID-siltide lugemisulatuse võimet. Siltide loetud vahemik muutub sentimeetrites vahemikku 179 ℃. Isegi kui sildid saavad oma jõudluse kätte, kui temperatuur on normi piires. Keraamilised RFID-märgised on parema jõudlusega kui PCB tüüpi passiivsed UHF-märgised. Sildid saab mähise külge kinnitada mähise tootmise 2. etapis, mida nimetatakse mähise levitamiseks. Manustatud sildid saavad suhelda igas tööjaamas asuva RFID-lugeri kaudu ja salvestada tootega seotud teavet arvuti andmehaldustarkvarasse. Selle uuringu eksperimentaalne töö hõlmab lugemisulatuse mõju kõrgemal temperatuuril ja veekeskkonnas, mida on kirjeldatud peatükkides 4 ja 5.

Uuringu järgmiseks etapiks on kinnitatud RFID-siltidega mähise VPI-test ja RFID-siltide lugemisulatuse mõõtmine pärast seda protsessi. Kuid tegelik tööstuslik test lükati edasi covid19-olukorra tõttu Eestis.

Passiivse UHF RFID-märgendi maksumusest saab üle ilma kiibita RFID-disaini abil ja selles uuringus kavandatav kiibita RFID põhineb sageduse selektiivsetel pindadel. Nende RFID-siltide maksumus võrdub vöötkoodidega ja annab RFID-le eelise (vaatevälja pole vaja). Seda saab toota rull-rulltrükkimise tehnoloogia abil, mis vähendab märgendite tootmiskulusid dramaatiliselt. Seda saab kasutada ka staatori mähiste temperatuuri ja vibratsiooni tuvastamiseks. Seda saab jälgida veebisüsteemi kaudu. Niisiis, tootmisjuht saab jälgida tootmisvoogu ilma tehast külastamata - 3-bitised ruudukujulised kiibita RFID ja 6-bitised ümmarguse kujuga kiibita RFID-märgised, mis on välja töötatud ja simuleeritud selles uuringus. Saame suurendada märgendi mälu bitti, suurendades resonaatori struktuuri kujunduses. Kavandatav kiibivaba RFID-disain ja simulatsioon, mida on kirjeldatud 3. peatükis ja tulemuste osas. Selle saab toota masstootmistehnikate abil, näiteks rull-rull-printimistehnikad koos viitemärgikoodiga 111, ja hiljem saab koodi varieerida lühisliidese abil. Kiibivabad sildid võivad lüheneda, kasutades juhtivat tindipliiatsi ettevõttelt Chmetronics. Tulemuste jaotises tutvustati iga valimi erinevaid koode. Selle tehnoloogia peamine puudus nõuab lairibaspektrit, et mahutada rohkem bitte.

Selles uuringus pakutavad kiibita RFID-märgised on veel kaugel kommertsialiseerimisest. Arengu ja turu vahelise lõhe ületamiseks on vaja rohkem teadus- ja arendustegevust. Pinna akustiline laine (SAW) on praegu ainus kaubanduslikult saadaval olev kiibita silt. See silt kasutab piesoelektrilisi põhimaterjale ja submikronilise litograafia töötlemise tehnikaid, mille tulemuseks on kõrgem tootmiskulu kui traditsioonilisel RFID-märgisel. Seetõttu on madalate tootmiskulude ja rahuldava praktilise toimivusega kiibita RFID-märgised väga nõutavad.

Vaatamata kiibita RFID-simulatsioonide heale tulemusele on silti võimekuse suurendamiseks vaja täiendavaid uuringuid.

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