CORROSION MONITORING USING RADIO FREQUENCY IDENTIFICATION (RFID)

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By

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CERTIFICATION OF APPROVAL

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TRONOH, PERAK

July 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements and that the original work contained herein have not undertaken or done by unspecified sources or persons.

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(NUR MELATEE BINTI MOHD FAUZI)

ABSTRACT

Corrosion monitoring techniques currently available in the market are not suitable for inaccessible places and it is difficult to identify the exact time the corrosion occurred. So, RFID is proposed to monitor the corrosion at inaccessible location by establishing the relationship between the signal strength of RFID transmission with the corrosion rate. For the purpose of this project, the RFID tag had been wrapped with aluminium foil and immersed in 0.5% Sodium Hydroxide solution to create corrosive condition to the aluminium. The signal strength readings and weight loss of corroded metal were recorded for every 15 minutes until the aluminium foil was totally dissolved. From the weight loss, the corrosion rate was calculated and the thickness of metal corrodes was compared with the signal strength obtained from the RFID software. This is to validate that the signal strength of RFID transmission as a technique to monitor corrosion activities. In the end of this project, it is found that RFID can be applied to sense the corrosion activity based on the findings of this project.

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In the name of Allah, The most Gracious, The most Merciful,

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LIST OF ABBREVIATIONS

BAP	Battery Assist Passive
CUI	Corrosion under Insulation
ER	Electrical Resistances
LPR	Linear Polarization Resistance
NaOH	Sodium Hydroxide
RF	Radio Frequency
RFID	Radio Frequency Identification
UHF	Ultra High Frequency

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Corrosion is currently one of the major problems for oil and gas industry. This is because corrosion is unpredictable problem and it can impact the life span of assets such as tank, vehicles, and pipelines. Later on, it can lead to more serious problems such as failure in plant infrastructure, accident and increment of cost. In the end, it can affect the production and bring to the profit loss.

Therefore, manual monitoring was practiced to monitor the corrosion and integrity of complex system. The method is using the man powers that do the regular inspection on the equipment or process. However, the manual monitoring has a few disadvantages such as limits the opportunities for detecting the exact time the corrosion occurred. The event only can be detected when it occurs without the accurate time and also costly in terms of both labour and time.

Since the manual inspection has a lot of disadvantages, the engineers and chemists tried to invent corrosion monitoring techniques. These techniques were invented to replace the use of man power in corrosion monitoring. The research started in early 1950's [1] and today corrosion engineering has become one of the important clusters in mechanical engineering fields.

Currently, there are many techniques available for the corrosion monitoring using different approach and concept such as Linear Polarization Resistance (LPR), corrosion coupons, electrical resistance and many more. All this types of corrosion monitoring are applied depends on its suitability to the places where it will be installed.

1.2 Problem statement

Although there are many corrosion monitoring techniques have been introduced, most of the techniques are not suitable at inaccessible location for high structure such as process columns and flare. For example, the corrosion activity at a 45 meter process column as shown in Figure 1. The corrosion coupons technique is not suitable to be applied at that location. This is because the coupons need to be removed after certain time for the analysis and it requires the operator to climb up the column to take it.

So, Radio Frequency Identification (RFID) technology is proposed to monitor corrosion activity since it is capable to communicate up to 100 m without the need to access the location. It also can save the cost in term of the man power and time.

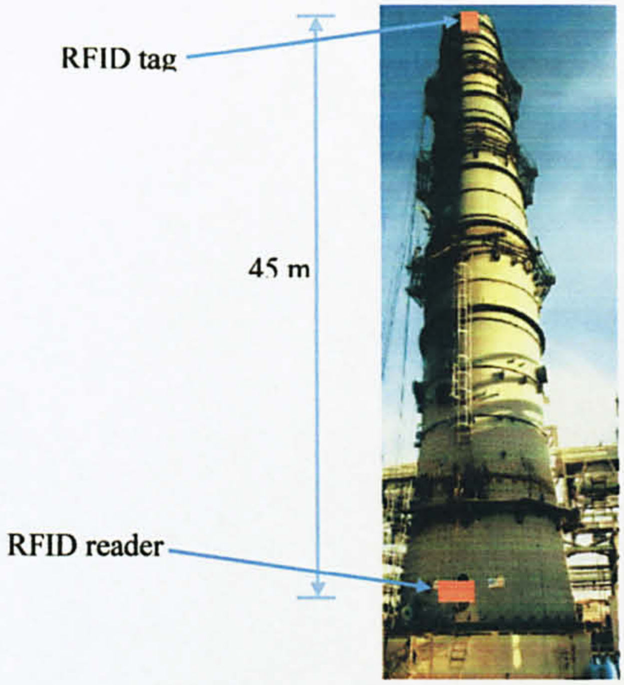


Figure 1: Example of Process Column

1.3 Objectives

The objectives of this project as the followings:

1. To study RFID technologies and review RFID projects done by the previous students.
2. To review currently available corrosion monitoring techniques.
3. To develop a technique for corrosion monitoring using RFID.

1.4 Scope of Study

The scope of study for this project is mainly focused on three main activities namely establishing communication between RFID tag & reader, identifying suitable thickness of metal coatings and then coating the tags with metal layer and lastly, measuring the signal coming out from the tags when the metal layer is corroded. In the first semester, this project is more focused on literature review and gathering the information. In the second semester, the project was focused on calculating the skin depth for metal thickness coated on the tag and relating the signal strength of RFID communication with the corrosion rate.

CHAPTER 2
LITERATURE REVIEW

2.1 Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) is the use of an object applied to or incorporated into a product, animal, or person for the purpose of identification and tracking using radio frequency [2]. Radio Frequency Identification (RFID) consists of three elements which are tags (transponder), a reader (transceiver) and antenna for receiving and transmitting the signal. The invention of RFID started during the World War II for military purpose and now the application had expanded in many aspects of life. Currently, the application of RFID was mostly in code tracking and sensing things.

In RFID system, the tag and the reader communicate between one another via radio waves. The antenna of the reader emits the radio signals and when the tag enters the radio signals field, it detects the activation signal from the reader antenna. This will 'wake up' the RFID tag. Then, the reader will signals to the tag to transmit its stored data. In the tags, there are information about the objects they are attached to, including the serial number and details about the objects.

The advantages of RFID are the tag did not require line in sight and it can be read through plastic and wood. Besides that, it has larger area of coverage and also can easily track the moving object and send the information to the reader immediately. Meanwhile in term of cost, RFID is more expensive compared to the other tracking system like barcode. However it provides better efficiency and it help in long term investment.

Although RFID has a lot of advantages, it also has disadvantages. The main disadvantage of RFID is collision or interference problem. The reader fails to differentiate the tag when the collision problem occurred especially when there are a lot of RFID tags in a location. The other disadvantage is in term of security issue. Any reader using the appropriate RF signal can easily detect the tag and get the contents in the tag [31]. Additionally, the system did not limited line-a-sight, so the high intensity directional could be used to scan sensitive tag.

2.1.1 RFID Reader

RFID reader is an electronic device that emits and receives signals through the antennas and coupled to them. The other functions of RFID reader are:

1. To keep RFID tag powered up for the passive tag.
2. To demodulate incoming signals from the tag down
3. To decode the incoming signals into the words people can interpret

Besides that, the RFID reader can be classified into three types which are fixed reader, hand-held reader and mobile reader. The fixed reader is the original reader introduced during the establishment of RFID. Practically, it can't be removed from its original location once it communicates with the tags. The fixed reader can be used for the application that did not have any constraints in terms of space and detect static tags.

Meanwhile, the hand-held reader allows the user to take the reader to location of tag and small in size compared to fixed reader. Besides that, it is more practical to bring the reader to the tagged object rather than moving object passed though the reader. It is ideal for asset tracking and field services application.

For the mobile reader, it function did not has much difference with the hand held reader. However, the size is smaller than hand held reader and normally come with PDA application. Below are the examples of RFID reader currently available on the market:

(a) (b) (c)

Figure 2: Types of RFID reader (a) Hand-held reader (b) Fixed reader and (c) Mobile reader

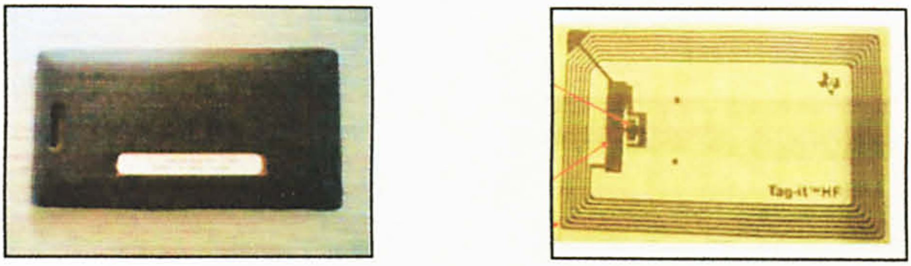
2.1.2 RFID Tags

For RFID tags, it contains at least two parts. The first part is an integrated circuit for storing and processing information, modulating and demodulating a radio-frequency (RF) signal, and other specialized functions. The second is an antenna for receiving and transmitting the signal.

Generally, there are three types of RFID tags which are:

1. Active RFID tags, which contain a battery and can transmit signals autonomously
2. Passive RFID tags, which have no battery and require an external source to provoke signal transmission
3. Battery assisted passive (BAP) which require an external source to wake up but have significant higher forward link capability providing great read range.

The figure below showed the picture of the active and passive tag:



(a) (b)

Figure 3: Example of a) active tag & b) passive tag

The most popular tags used for the RFID application are active and passive tag. Each type of this RFID tags has its own application because of its advantages and disadvantages as shown in table below [3]:

Table 1: Advantages and Disadvantages of RFID tags

Type of tag	Advantages	Disadvantages
Active tag	1. Can read at long distance 2. Can have another sensor that used electricity	1. Cannot function without batteries supply 2. More expensive and costly in term of maintenance especially replacing the batteries.
Passive tag	1. Can function without batteries and have long lifetime. 2. Typically small in size	1. Only applicable for short distance which is only a few feet 2. Remain readable after a long time even after the tag did not being used anymore.

1.1.3 RFID Working Frequency

As mentioned before, the RFID tag and reader communicates via radio frequency wave. Frequency is referred as the size of radio waves used for the RFID communication. Below is the table of RFID at various working frequency and the characteristics for each frequency range:

Table 2: RFID Working Frequency

Band	**LF Low Frequency (30-300kHz)**	**HF High Frequency (3-30 MHz)**	**UHF Ultra High Frequency (300 MHz -30 GHz)**	**Microwave (2-30 GHz)**
Typical RFID Frequency	125-134 KHz	13.56 MHz	433 MHz or 865-956 MHz	2.45 GHz
Approximate read range	Less than 0.5 meter	Up to 1.5 meters	433 MHz – up to 100 meters 865-956 MHz – 0.5 to 5 meters	Up to 10 meters
Characteristics	Short range, low data transfer rate, penetrate water but not metal	Higher range, reasonable data rate (similar to GSM phone), penetrates water but not metal	Long range, high data transfer rate, concurrent read of < 100 items, cannot penetrates water or metal	Long range, high data transfer rate, cannot penetrates water or metal

2.2 Corrosion

Corrosion can be defined as the disintegration of a material into its constituent atoms due to chemical reactions with its surroundings. In the most common use of the word, this means the electrons loss of the metal reacting with water and oxygen. It is commonly known as rusting. This type of damage typically produces oxide(s) and/or salt(s) of the original metal. Corrosion also can happen to other materials than metals, such as ceramics or polymers. However, it is called as degradation [4].

Three main factors that can lead to the presence of corrosion itself are temperature, pressure and presence of oxygen. These factors are the prerequisite for the corrosion to happen. If either one is not present, the corrosion can't happen. However, there are also some other factors that can affect the corrosion as shown in a table below [5]:

Table 3: Factors Affecting Corrosion

Category	*Factor*
Conductors	a) Nature of the material or alloy b) Surface c) condition/roughness d) Conductor configuration e) Conductor-conductor spacing
Substrate	a) Composition b) Moisture absorptive c) Structure d) Nature of any reinforcement
Environment	a) Temperature b) Humidity c) Corrosive elements (type; concentration)

Corrosion also can be categorized into a few categories which are atmospheric corrosion, galvanic corrosion, pitting corrosion, crevice corrosion, concentration cell corrosion and graphitic corrosion. All of these categories are categorized based on how the corrosion occurs and its effect to the corroded material. Below are the summary of each category of corrosion [32]:

Table 4: The Category of Corrosion

Corrosion	***Description***
Uniform or general Corrosion	• The metal loss is uniform from the surface. • Often combined with high-velocity fluid erosion, with or without abrasives
Galvanic Corrosion	• Occurs when two metals with different electrode potential is connected in a corrosive electrolytic environment. • The anodic metal develops deep pits and groves in the surface.
Pitting Corrosion	• The metal loss is randomly located on the metal surface. • Often combined with stagnant fluid or in areas with low fluid velocity.
Crevice Corrosion	• Occurs at places with gaskets, bolts and lap joints where crevice exists. • Crevice corrosion creates pits similar to pitting corrosion.
Concentration Cell Corrosion	• Occurs where the surface is exposed to an electrolytic environment where the concentration of the corrosive fluid or the dissolved oxygen varies. • Often combined with stagnant fluid or in areas with low fluid velocity.
Graphitic Corrosion	• Cast iron loosing iron in salt water or acids. • Leaves the graphite in place, resulting in a soft weak metal.

2.2.1 Atmospheric corrosion

Atmospheric corrosion is an electrochemical process, requiring the presence of an electrolyte. Thin film "invisible" electrolytes tend to form on metallic surfaces under atmospheric corrosion conditions, when a certain critical humidity level is reached [5].

Metals exposed to uncontrolled normal atmospheres may corrode more rapidly and by different mechanisms than those kept in pure, dry air. This showed that the atmospheric environment influenced the corrosion activity. Atmospheric environment were divided into 4 groups which are urban, rural, maritime and industrial [6]. Each of environments varies depending on the severity from the corrosive point of view.

Currently, there are several preventions have been taken in order to overcome the atmospheric corrosion. Painting and coating with non corroded material are example of prevention action for the corrosion.

2.2.2 Corrosion under Insulation (CUI)

Corrosion under Insulation (CUI) refers to the external corrosion of piping and vessels that occur underneath externally clad/jacketed insulation as a result of the penetration of water [13]. Normally, CUI rarely detected until the insulation being removed from the piping or when there is leakage on the insulation. There are 3 requirements for CUI to occur which are [7]:

1. Availability of oxygen
2. High temperature
3. Concentration of dissolved species

Currently, the most popular approach to prevent CUI is replacing the insulation with special protective coating [8]. However, this technique consumed high budget compared to the common coating used nowadays and the effectiveness of this method also low because it depend on the location where it have been applied. Besides that, anticorrosion and inhibitive coatings are also other alternatives available to prevent CUI. Below is example of CUI problem in petrochemical industry:

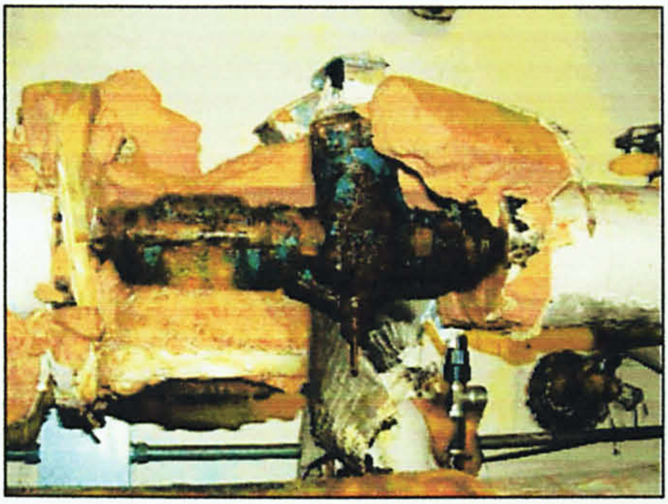


Figure 4: Example of CUI problem

2.3 Corrosion Monitoring

Corrosion monitoring is an activity of measuring or observing activity the corrosion by using some techniques. Nowadays, there are several methods available. All of these techniques are using mechanical, electrical or electrochemical application that can relate to the corrosion. There are 2 types of corrosion monitoring approach used which are:

1. Direct approach – give a direct measure of metal loss or corrosion rate.
2. Indirect approach - provides off-line measurement and used to infer that a corrosive environment may exist.

As mentioned before, the corrosion monitoring techniques is used to sense and detect the corrosion activities. However, it also has other reasons which are [9]:

1. It provided the early warning that the process condition is damaging due to the corrosion activities.
2. It helped in terms of studying the correlation of changes in process parameters and their effect on system corrosivity.
3. It helped the workers to identify the cause of corrosion and the rate controlling parameter such as pressure, temperature, pH, flow rate, etc.
4. It provided the information for the future actions such as maintenance and can forecast for the future condition of the plant.

The most popular corrosion monitoring techniques currently available in the industry are:

1. Corrosion Coupons
2. Electrical Resistances (ER)
3. Linear Polarization Resistance (LPR)

2.3.1 *Corrosion Coupons*

The Corrosion Coupons technique is the best known and simplest of all corrosion monitoring techniques. The method involves exposing a specimen of material (the coupon) to a process environment for a given duration, then removing the specimen for analysis. The corrosion rate can be determined from the weight loss over the period of metal exposure using the formula below [9]:

$$Corrosion\ rate = \frac{Weight\ loss\ (K)}{Density\ \left(\frac{g}{cm^3}\right)\ x\ Exposed\ Area\ (A) x\ Times\ Exposure\ (hr)}$$

The weight loss coupons can be fabricated from any commercially available alloy. The coupon can be made from any size, material and shape as desired [34]. Below is the sample of alloy used for corrosion coupon technique:

Figure 5: Alloy for corrosion coupon technique

Besides that, this technique did not required complex equipment and procedures. It only requires a corrosion coupon and exposes it directly to the process environment without the need of complicated system to monitor it. It also can be implemented in corrosive environments and it applies direct measurement which helped the workers to understand the methodology easily.

However this technique is not applicable to all condition and it has its own limitations and disadvantages. The disadvantages of the coupon technique are the exact time corrosion occurred cannot be identified and it required schedule monitoring by the human to monitor the corrosion activity.

Therefore, coupon monitoring is most useful in environments where corrosion rates do not significantly change over long time periods. However, it can provide a useful correlation with other techniques such as ER and LPR measurements.

2.3.2 Electrical Resistances (ER)

ER probes can be thought of as "electronic" corrosion coupons. It is an improvement technique from the corrosion coupons technique. Like coupons, ER probes provide a basic measurement of metal loss, but unlike coupons, the value of metal loss can be measured at any time, as frequently as required, while the probe is in-situ and permanently exposed to the process stream [5].

The ER technique measures the change in electrical resistance of a corroding metal element exposed to the process stream. As the metal corroded, the resistance change and the changes later will be used to determine corrosion rate. The formula used to calculate the resistance changes as below:

$$\boxed{Electrical\ Resistances, R = \frac{Resistivity\ (\rho) X\ Element\ length\ (L)}{Cross\ sectional\ area\ of\ the\ element\ (A)}}$$

There are 3 styles of metal probe used for this ER technique which are [11]:

1. Solid wire loop for highly corrosive waters
2. Tube loop for medium corrosive
3. Thin ribbon loop for low corrosive cooling water

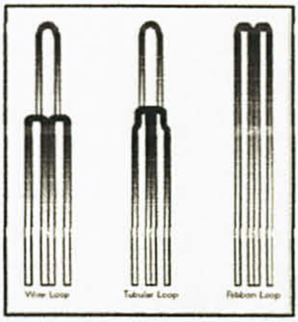


Figure 6: Example of ER Probes

2.3.3 Linear Polarization Resistances (LPR)

The Linear Polarization Resistances (LPR) technique is based on complex electro-chemical theory. For purpose of industrial measurement applications it is simplified to a very basic concept. In fundamental terms, a small voltage (or polarization potential) is applied to an electrode in solution. The current needed to maintain a specific voltage shift (typically 10 mV) is directly related to the corrosion on the surface of the electrode in the solution. Based on the value of voltage and current applied, the resistance polarization is calculated using the formula below:

$$\boxed{\textit{Electrical Resistances}, R = \frac{\textit{Applied voltage } (V)}{\textit{Current between Electrodes}(I)}}$$

By measuring the current, a corrosion rate can be derived. The corrosion rate is inversely proportional to the measured resistances.

The advantage of the LPR technique is that the measurement of corrosion rate can be done instantaneously. This is a more powerful tool than either coupons or ER where the fundamental measurement is metal loss and where some period of exposure is required to determine corrosion rate.

The disadvantage to the LPR technique is that it can only be successfully performed in relatively clean aqueous electrolytic environments. LPR will not work in gases or water/oil emulsions where fouling of the electrodes will prevent measurements being made [5].

Figure 7: Example of Linear Polarization Resistances probes

CHAPTER 3
METHODOLOGY

3.1 Flow Chart

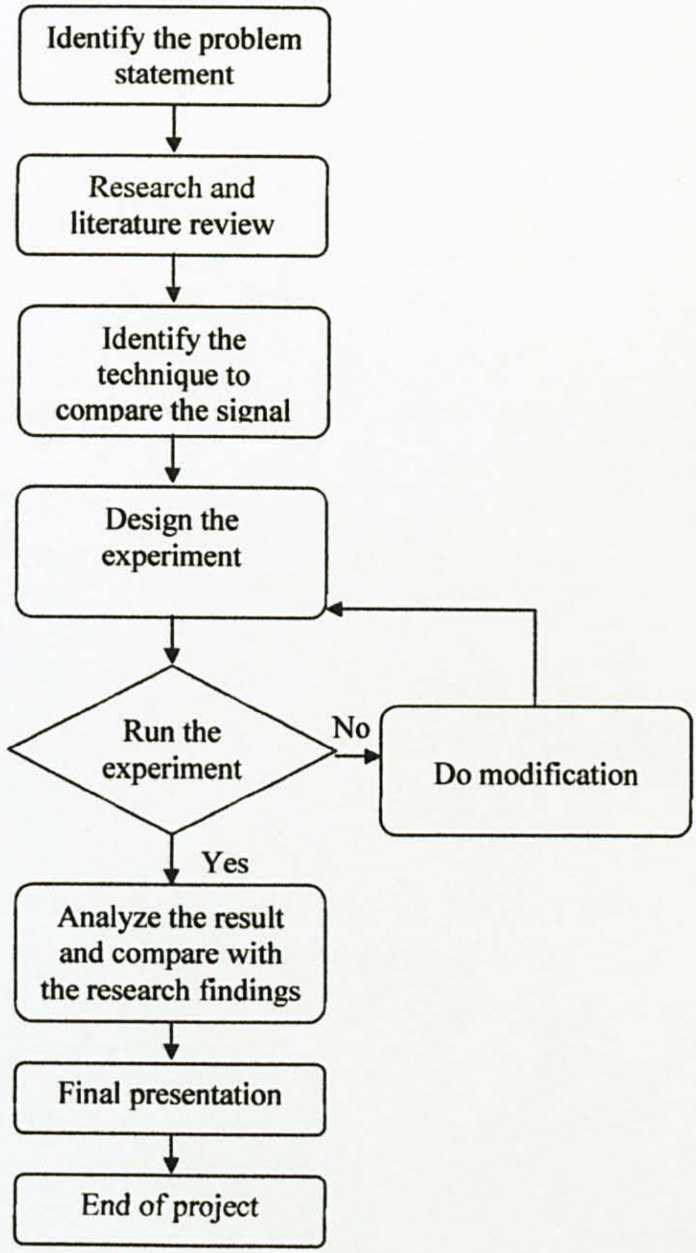


Figure 8: The Project Flowchart

3.2 Project Activities

3.2.1 Establish connection between RFID tag and reader

As stated in the literature review, there are a few factors that affect the signal transmission between the RFID tag and reader. Among the factors are:

1. Types of tag
2. RFID working frequency
3. Distance between the RFID tag and reader.

It is important to identify and test the characteristics of RFID first before moving to next step of the project. The limitation of the RFID can be identified and a solution can be prepared to overcome the limitation. It also can reduce problems when the RFID was applied to monitor the corrosion and a backup can be prepared to face the related problem in the future.

In this activity, the communication between the RFID tag and reader has been tested in 2 factors which are:

1. Types of tag.
2. Different frequency range.

For the first factor, the active tag and passive tag were used. The experiment was done where the signal strength of both tags were measured for different distance and later, the results will be compare to choose the best tag for this project. Besides that, for each distance, the readings were taken 3 times for the accuracy of the result obtained. The signal strength for both tags was measured using the spectrum analyzer. The experiment procedures as showed in the Figure 9 below:

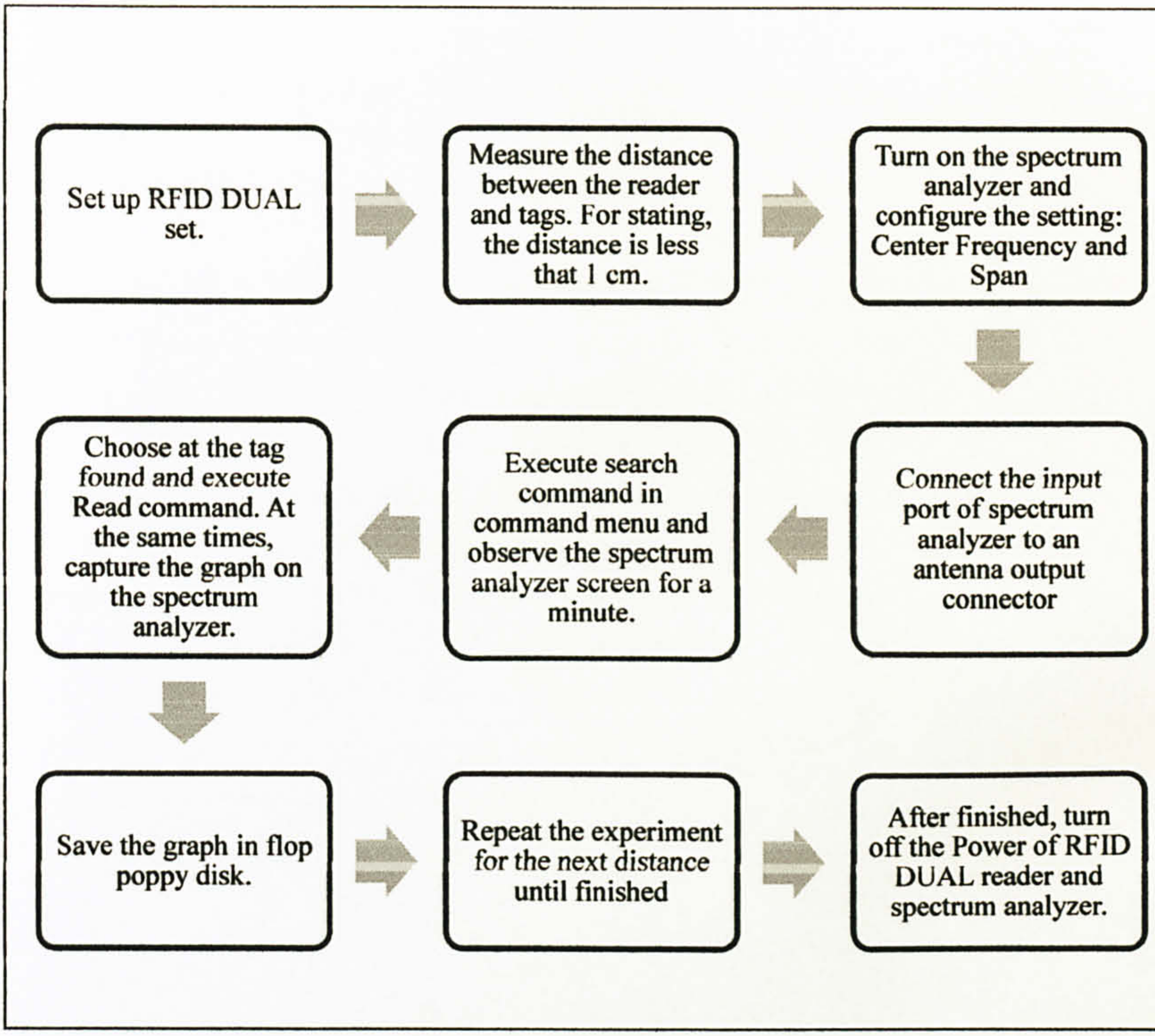


Figure 9: Experiment Procedures

The second factor that can affect the RFID signal strength is working frequency. The working frequency can determine the distance of tag and reader can communicate between each other. As stated in literature review, there are 4 frequencies ranges for the RFID. There are low frequency, high frequency, ultra high frequency and microwave. All of these frequencies had its own read range or distance.

For this experiment, the procedures are same as the experiment for the first factor. The only different is that the tags used is only active tags but with different working frequency and types of manufacturer of the RFID set. The working frequency used is 900 MHz and 433 MHz. Both of the frequency is ultra high frequency. Besides that, the signal strength for both frequency is captured using the spectrum analyzer but for the frequency 433 MHz, there are additional source for the signal strength. The signal strength can be captured from the software Reader AnalyzerNetwork.

In the end, based on both experiments, the best tags and frequency range have been chosen to monitor the corrosion activities for inaccessible location. The results and findings from the experiment will be discussed in the next section.

3.2.2 Calculation of skin depth

The next activity for this project was calculating the skin depth. Skin depth is defined as the depth beneath the surface of a conductor, which is carrying current at a given frequency due to electromagnetic waves incident on its surface, at which the current density drops to one neper below the current density at the surface [20]. In this project, the skin depth concept is used to determine the thickness of metal to be layered on the RFID tag in order to allow the RF signal to transmit through it.

In this project, the value of skin depth is important for the corrosion measurement. It is because the skin depth value will determine the thickness of metal layer on the tag. If the thickness is more than the skin depth value, the Radio Frequency (RF) signal can't be transmitted through the metal. As the corrosion occurred, the signal strength can't be detected until the thickness is equal or less than skin depth value. So, during that situation, the corrosion rate can't be determined from the signal strength of RFID tag and reader communication.

The thickness of the metal layered is calculated using the skin depth formula as shown below:

$$\boxed{\delta = \frac{1}{\sqrt{\pi\mu_0}}\sqrt{\frac{\rho}{\mu_r f}}}$$

Where

δ = the skin depth in m

$\mu_0 = 4\pi\times10^{-7}$ H/m

μ_r = the relative permeability of the metal

ρ = the resistivity of the metal in Ωm

f = the frequency of the wave in Hz

From the formula above, it shows that most of the parameters are constant except for the value of frequency. So, the skin depth was affected or depended with the frequency. Because of that, the skin depth has been calculated for different frequencies and the suitable thickness of the metal layer on the RFID tag was chosen from the skin depth value based on the frequency of RFID used for this project.

In this project, for the skin depth calculation, two types of metal were considered for the calculation. The metals were iron and aluminium. For this project, the iron was chosen as the metal layer on the tag that will corrode. It is because iron is a type of metal that easily corroded when all the factors for the corrosion are existed. However, since iron was not available on the market with the thickness required for this project, the aluminium foil used to replace it and the skin depth for the aluminium is also calculated for various frequencies.

3.2.3 *Measuring the signal strength when the metal corroded*

After finished with the 2 previous activities, the next step for this project is to relate the RFID signal strength with the metal corrosion. Based on the findings and literature reviews, an experiment had been designed. The experiment was designed to measure the signal strength when the corrosion occurred at various distances.

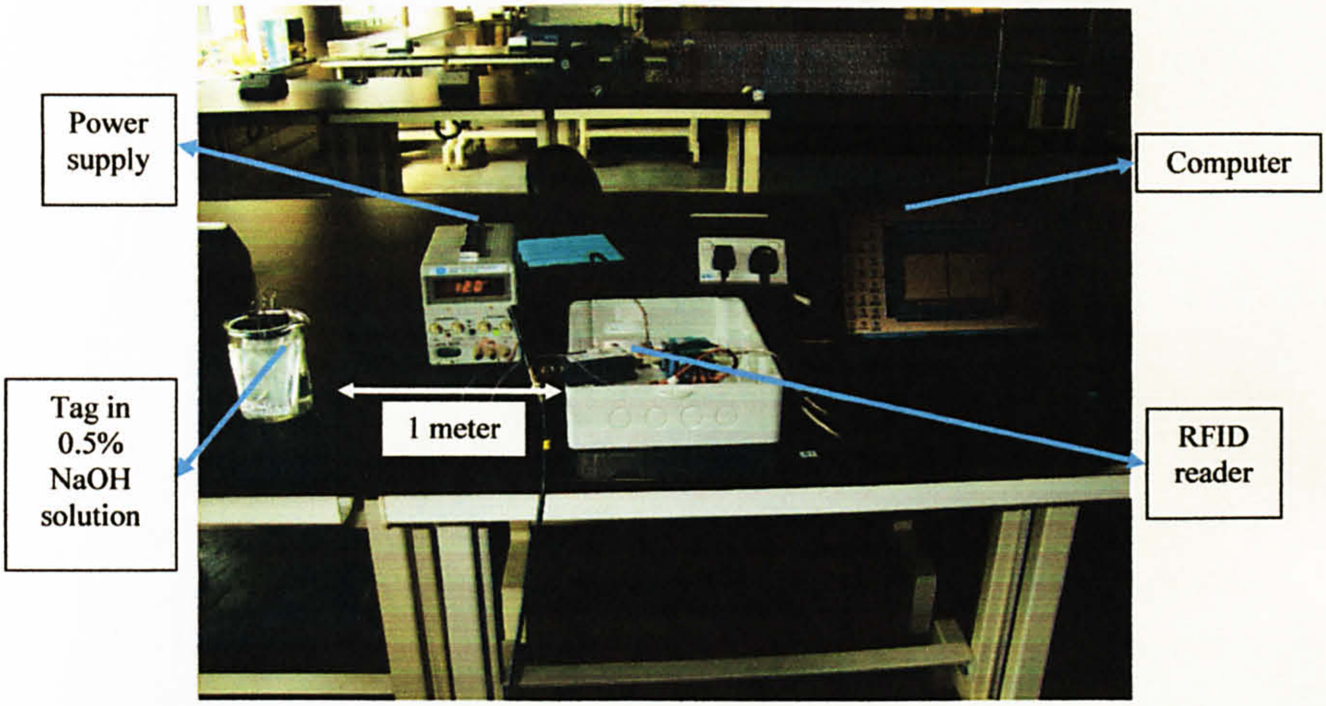


Figure 10: The experiment setup

The experiment procedures are almost the same with the experiment to establish the connection between the RFID tag and reader but the tag had been modified in order to relate it with the corrosion. The tag had been wrapped with aluminium foil as shown below:

(a) (b)

Figure 11: a) RFID tag before wrapped with aluminium foil b) After coated with aluminium foil

In order to make the aluminium corrodes; the tag coated with aluminium foil had been immersed in 0.5% Sodium Hydroxide. This is because aluminium only corrodes in a strong base solution. The time taken by the aluminium to totally corrode depended on the concentration of Sodium Hydroxide and for the concentration 0.5% Sodium Hydroxide; it took about 3-4 hours for the aluminium to totally corrode in Sodium Hydroxide solution. The picture below shown a wrapped tag immersed in NaOH solution:

Figure 12: The wrapped tag immersed in 0.5% NaOH solution

Besides that, the distance between the RFID tag and reader was fixed to 1 meter because at this distance the RFID signal strength is high compared to longer distance. Since the project only to see the relation of RFID application in the corrosion, the distance is not the main priority. However, it also can be considered later in order to apply it at the industry since the RFID will be installed at the inaccessible location where the high is more than 30 meter.

3.3 Tools and Equipment

The tool and equipment used in this project have been divided into 2 groups which are hardware and software.

3.3.1 Hardware

The hardware used in this were included all the tools and equipment used together with the solution used to create the corrosive condition to the tag in order to measure the corrosion rate.

- **RFID tag and reader.**

  For this project, 2 types of RFID set have been used which are RFID-DUAL and Wavetrend. The reason why 2 set of RFID is used because both RFID set had its own specification where the other set of RFID did not has. The specification for both RFID set is important in order to conduct the experiment for this project. Below is the table show the difference between both set of RFID.

Table 5: The difference between 2 RFID set

	RFID DUAL	Wavetrend
Types of tags	- Active tag model (900) - Passive tag model (13.56)	- Active tag only (L-TG 501)
Working frequency	- For active tag, the frequency is 900 MHz - For passive tag, the frequency is 13.56 MHz	- The working frequency is 433 MHz
Power Supply	- For active tags, it used 3 AA batteries. - For the passive tag, it gets the supply from the reader.	- Lithium battery.
Software	- RFID –DUAL	- ReaderNetwork Analyzer

However, for the corrosion monitoring, only Wavetrend RFID set is used for the testing because the tag can be wrapped with the aluminium compared to the RFID –DUAL set.

- **Computer**

  This device used as a medium to install the software and execute the command to communicate between the RFID tags and the reader.

- **Spectrum Analyzer**

  This device used to capture the trend for the RFID signal strength. The graph from the spectrum analyzer then used to obtain the value of signal strength.

- **Weight scale**

  This device used to get the weight of tag during the corrosion process. The device can measure the weight up to 2 decimal points and the unit is grams.

- **Power supply**

  This device used to power up the RFID reader. The supply used to activate the reader is 12 V.

- **Aluminium foil**

  This aluminium used as the metal that corroded. The thickness of aluminium used is 17 μm.

- **Beaker**

  The beaker used to place the tag wrapped with the aluminium foil.

- **0.5 % Sodium Hydroxide (NaOH) solution**

The aluminium only corrodes in strong base solution. So, Sodium Hydroxide used for the purpose to corrode the aluminium foil wrapped on the RFID tag.

3.3.2 Software

- **RFID- DUAL**

For the RFID-DUAL set, this software is used. This software provides a facility to analysis the signal from the RFID reader and trained the user especially at beginner level to get use with RFID.

- **ReaderNetwork Analyzer**

For WaveTrend set, this software is used. This software is used to give command to communicate the RFID tag and reader. Besides that, it also can display the value of signal strength and the user also can limit the signal strength of the tag that they wish to see.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Establish the connection between the RFID reader and tag

In this part, the signal strength between the RFID tag and reader has been tested based on 2 factors. The factors are:

1. Types of tag.
2. Different frequency range.

These 2 factors can affect the performance of RFID. The characteristics obtained of this part also helped in doing the experiment in part 3 in order to relate the corrosion rate with the RFID signal transmission. In the future, the characteristics can be applied in order to install the RFID for the corrosion monitoring technique.

4.1.1 Types of tag.

For this factor, the experiment run by using the RFID-DUAL set. Two types of tag tested in this experiment were active tag and passive tag. The working frequencies for both tags were 900 MHz (Ultra High Frequency) and 13.5 MHz (High Frequency). As stated in the previous section, the signal strength for each of the tags was tested by varying the distance until no signal strength was detected by the spectrum analyzer.

The signal strength was captured using the spectrum analyzer and later, using the *FileView* software, it converted the data save in the spectrum analyzer to the *Excel* file. This is made the analysis become easier. Based on the data obtained, the graph of signal strength at various distances was obtained. The graph below shows the relation between the signal strength with the distance for the active tag.

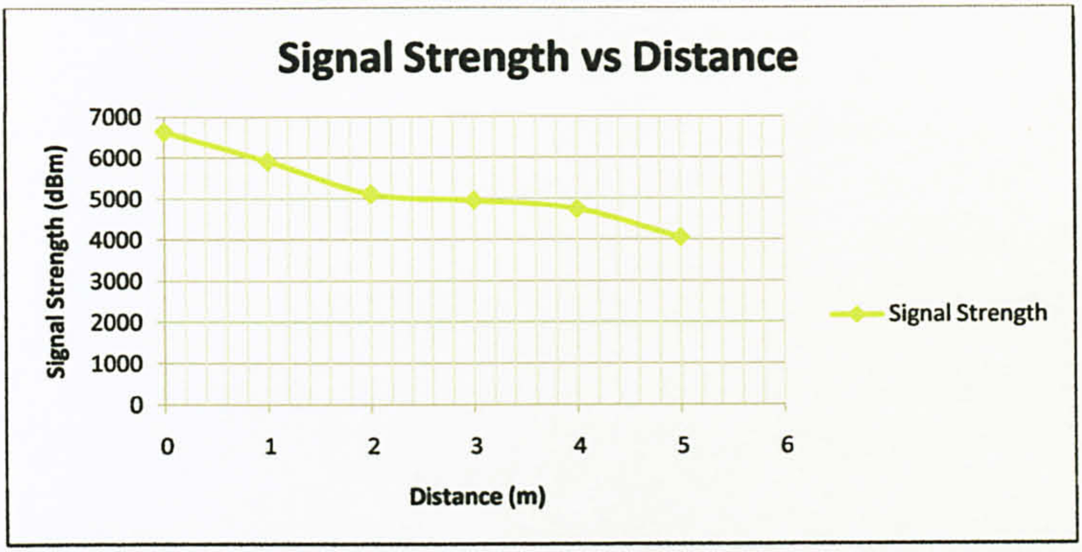


Figure 13: The signal strength of active tag (900 MHz) at various distances

From the graph above, the signal strength is inversely proportional to the distance. As the distance increased, the signal strength decreased. The relationship between signal strength and distance also know as inverse square law. The law stated that doubling the distance between the RFID tag and reader will result the signal strength to decrease one quarter from before.

Besides that, the graph is not smooth because during the transmission of the signal, there was a possibility the signal was interrupt by the noise. As the result, the value of signal strength obtained was not accurate. So, it is important to make sure that there is no external sound or waves that can interrupt the RF waves during the communication of the tag with the reader.

Next, the RFID also have limitation of distance for the tag to communicate with the reader. The maximum distance between the communications of this two was determined by the working frequency used. For this RFID tag, the working frequency is 900 MHz and it can communicate with the reader up to 5 metres only. When the distance is more than 5 meters, the signal strength cannot be detected by the spectrum analyzer. This proved the literature review before where it stated that for UHF, the read range is between 0.5 – 5 metres only.

Meanwhile, the result for the passive tag is different from the active tag. The trend for the passive tag is constant. This is due to the limitation of the distance between the tag and reader which was very short and less than 1 meter. The distance between the tag and reader cannot be increased anymore since for this type of RFID set, the RFID reader only can supply power to the tag with maximum distance up to 60 cm only. The graph below showed the result of signal strength for the passive tag at various distance as discussed before:

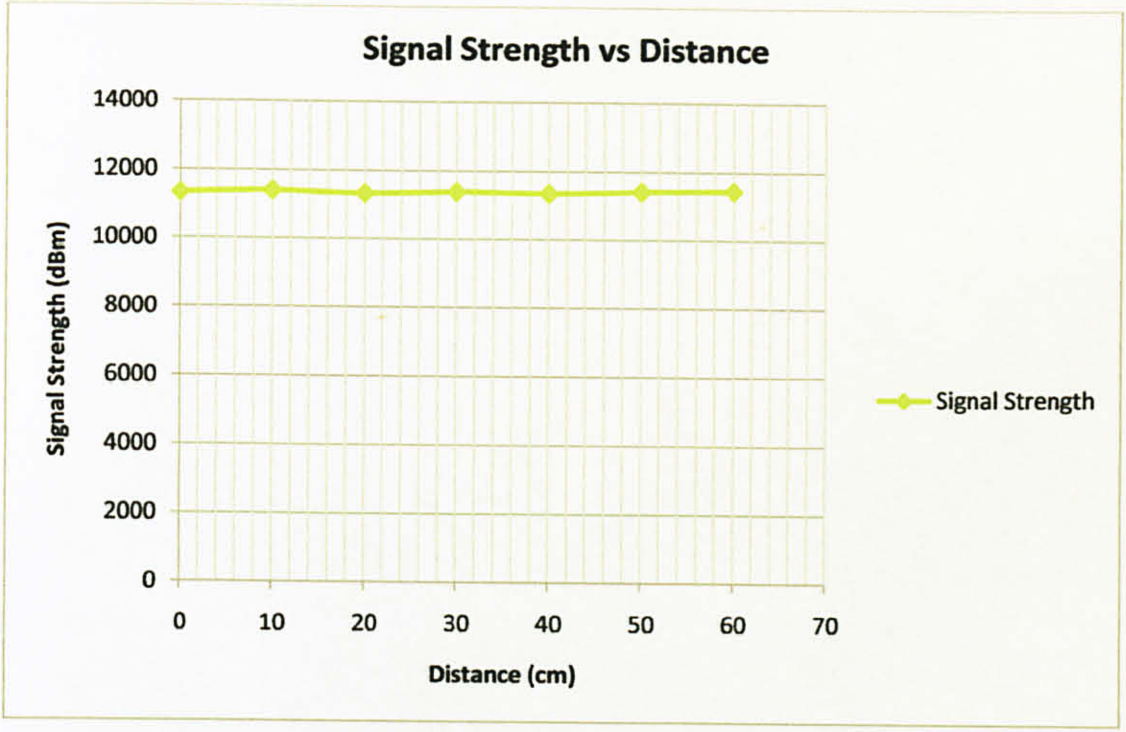


Figure 14: The signal strength of passive tag (13.65 MHz) at various distances

Since the passive tag is not applicable for longer distance, so it can't be applied for this project. This project required long distance for the communication of the RFID tag with the reader. Therefore, the active tag was chosen for this project because it read range is longer than the passive tag and more suitable to this project.

4.1.2 Different Frequency Ranges

The next step is to measure the signal strength for different RFID working frequency and analyze the signal strength effect of different frequency range to the distance. In this activity, the frequencies used were 433 MHz and 900 MHz. Both working frequencies were in category of Ultra High Frequency (UHF). Besides that, the RFID used in this activity were from different manufacturers.

For the 900 MHz frequency range, the result obtained was same as before where the trend of signal strength was inversely proportional. Besides that, the signal strength for the working frequency 900 MHz is high which was around 4000 – 7000 and the maximum distance the RFID tag and reader can communicate was up to 5 meters. The graph as shown below:

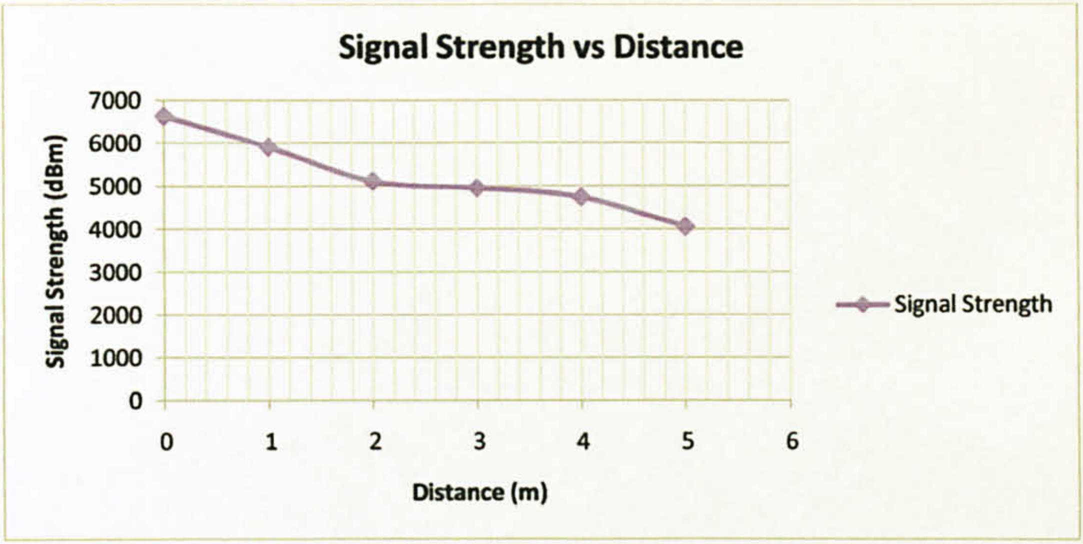


Figure 15: The Signal Strength for 900 MHz working frequency

Next, for the working frequency of 433 MHz, the trend was almost same with the working frequency of 900 MHz. The graph was inversely proportional but the trend was almost constant at the distance more than 1 meter compared to the working frequency of 900 MHz where it almost constant at distance of 2 meter. This shows that the working frequency can affect the signal strength of the RFID. However, the ranges for the signal strength value for both frequencies are almost the same which is between 3000 – 4000 dBm. So, either one of this working frequency can be used for this project since it did not have much difference in the value of signal strength. The graph for the working frequency 433 MHz as shown below:

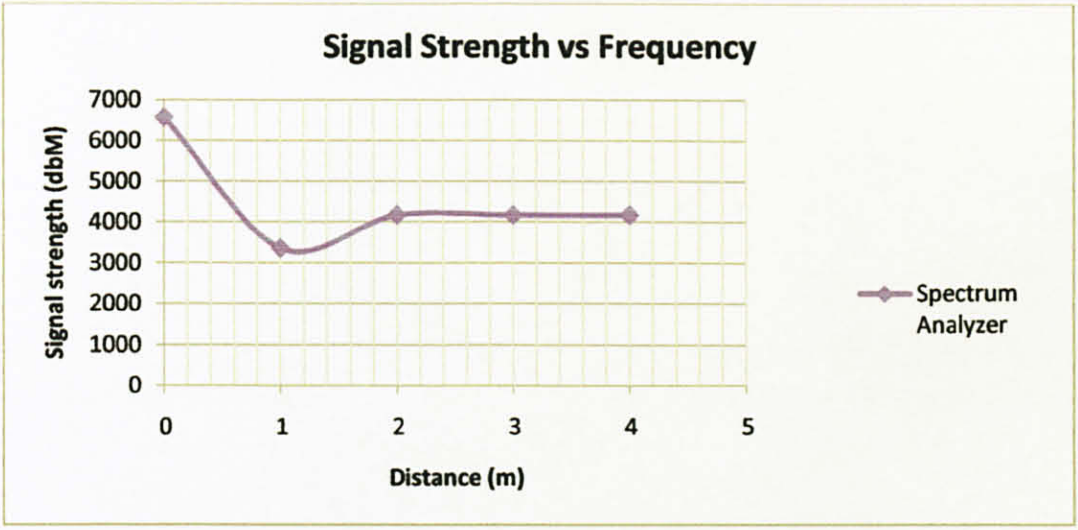


Figure 16: The Signal Strength for 433 MHz working frequency

As discussed before, the 900 MHz working frequency can communicate the RFID tag and reader to maximum distance of 5 meter. However, for the 433 MHz working frequency, the maximum distance it can communicate between the RFID tag and reader was up to 4 meter only which was shorter than the distance for the 900 MHz working frequency.

Although the 433 MHz working frequency have lower performance compared to the 900 MHz working frequency, it has an advantage over the 900 MHz working frequency. The advantage was for the 433 MHz working frequency, the RFID set (WaveTrend) come with software that can gave the signal strength value more accurate than the spectrum analyser. The graph below shown the signal strength result obtained from the RFID set software which was called as ReaderNetwork Analyzer.

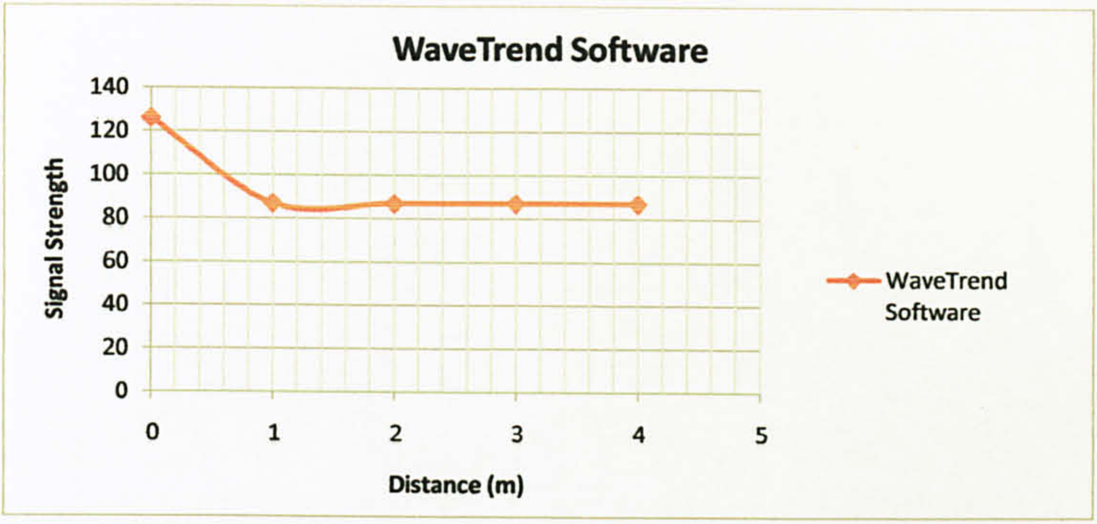


Figure 17: the Signal Strength for 433 MHz working frequency using the ReaderNetwork Analyzer

From the both graphs, it showed that ReaderNetwork Analyzer gave more accurate results compared to the spectrum analyzer. The value of signal strength is more stable compared to the readings gave by the spectrum analyzer. Besides that, the software also can detects the signal strength value from 0 until its maximum but the spectrum analyzer only can detects the signal strength of above 80 only.

So, for the project, the 433 MHz RFID set was chosen as the RFID working frequency for this project. It is because the software can give more accurate result for the signal strength compared to spectrum analyzer and it can detect the smallest value of signal strength between the RFID tag and reader.

The other reason the 433 MHz RFID was chosen for the project was because of the condition of active tags itself. The tag manufactured by the Wavetrend was small and the circuit covered properly. Later, this will help in coating or wrapping the metal on tag which was easier and convenient. Besides that, it also used Lithium battery as the power supply which had longer lifetime compared to the 900 MHz of RFID set where it only used 3 AA batteries that had limited lifetime. Below were the pictures for Wavetrend active tag (433 MHz) and RFID-DUAL kit active tag (900 MHz):

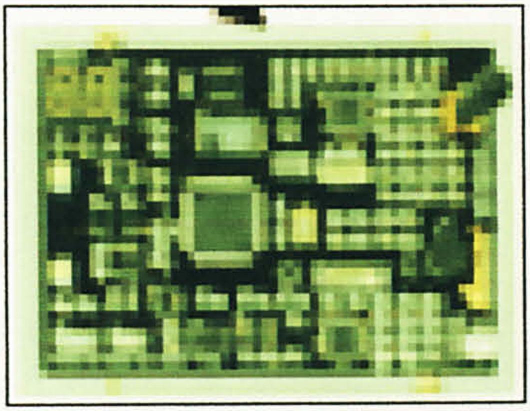


Figure 18: a) Wavetrend active tag **b) RFID-DUAL active tag**

4.2 Skin Depth

Skin depth calculation is important in order to determine the thickness of metal that should be coated on the RFID tag. It tells us when the radio frequency (RF) signals attenuate to about 33% of its unity amplitude. As mentioned in the methodology section, the skin depth calculation involved 2 types of metal which were iron and metal. The example calculation of the skin depth for iron as shown below:

For iron skin depth:

$$\boxed{\delta = \frac{1}{\sqrt{\pi\mu_0}}\sqrt{\frac{\rho}{\mu_r f}}}$$

Where

δ = the skin depth in m

$\mu_0 = 4\pi\times10^{-7}$ H/m

μ_r = the relative permeability of iron = 1

ρ = the resistivity of the iron in Ωm = 1.18×10^{-7} Ωm

f = the working frequency of the wave in Hz = 433 MHz

$$\delta = \frac{1}{\sqrt{\pi(4\pi\ X\ 10^{-7})}}\sqrt{\frac{1.18\ X\ 10^{-7}}{(1)(433\ X\ 10^{6})}}$$

$$\delta = \frac{1}{1.99\ X\ 10^{-03}}\ (1.65\ X\ 10^{-08})$$

$$\delta = 503(1.65\ X\ 10^{-08})$$

$$\delta = 8.30\ \mu\text{m}$$

Since the working frequency is 433 MHz, the thickness of iron metal coated on the RFID tag should be 8.31 μm before the signal will be attenuated. Later, this calculation was continued for other frequencies range to see the trend of skin depth at different frequencies.

Next, the graph of skin depth versus frequency for iron was shown below. The skin depth is inversely proportional with the frequency. As the frequency increasing, the skin depth decreased and almost constant at frequency of 950 MHz and above. This showed that in order to transmit the RF signal the range of thickness for iron must be at 6-25 μm only.

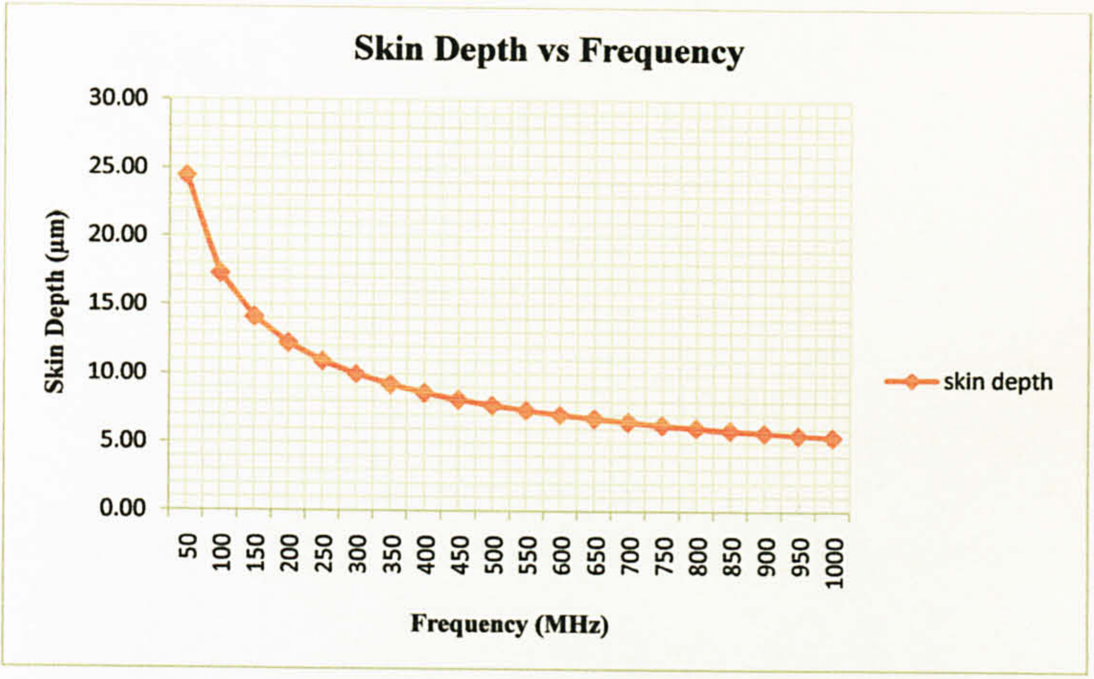


Figure 19: The relationship between skin depth and frequency for metal iron

Next, for the aluminium, the skin depth also gave the same trend as the iron. The skin depth is inversely proportional with the frequency but the skin depth value for the aluminium is almost half of the skin depth for iron at the same frequency. The graph below showed the relation of the skin depth with the various range of frequencies.

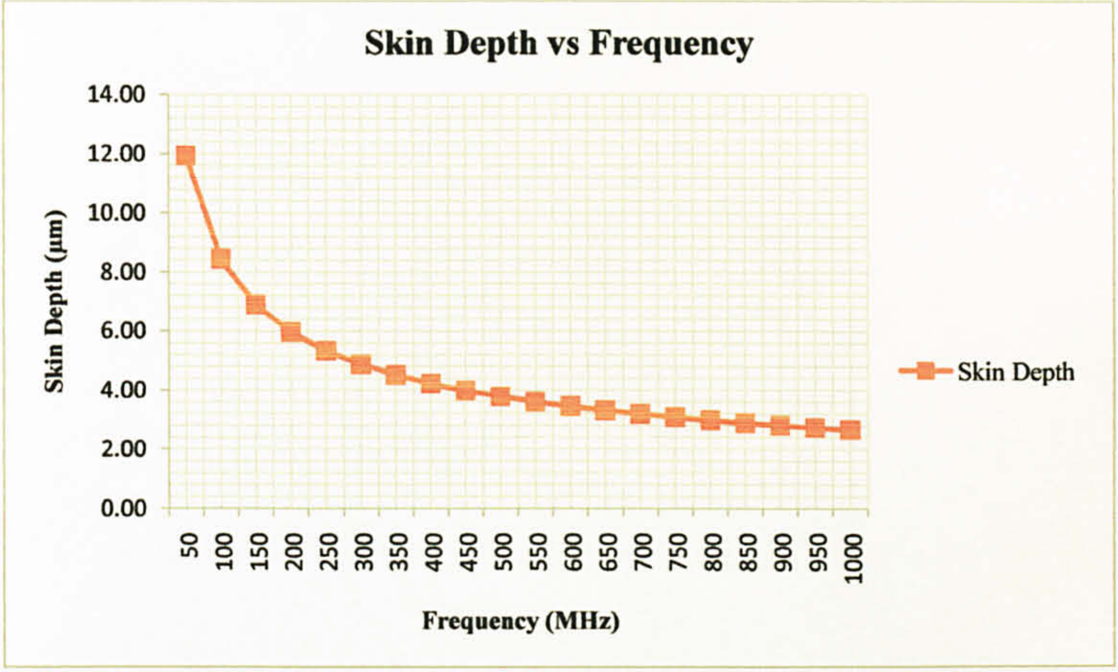


Figure 20: The relationship between skin depth and frequency for metal aluminium

In this project, the working frequency used is 433 MHz. So the skin depth of aluminium at that working frequency is 4 µm. However, this result is only based on the theory and calculation. Next, an experiment will be conducted in order to test the accuracy of the result.

4.3 Measuring the signal strength during the corrosion of metal

The result for this activity had been obtained from the readings of signal strength given by the ReaderNetwork analyzer. Besides that, the weight loss of the aluminium corroded also taken to validate the result from the signal strength. Below was the graph showed the signals strength of the communication between the RFID tag and reader during aluminium corrosion process.

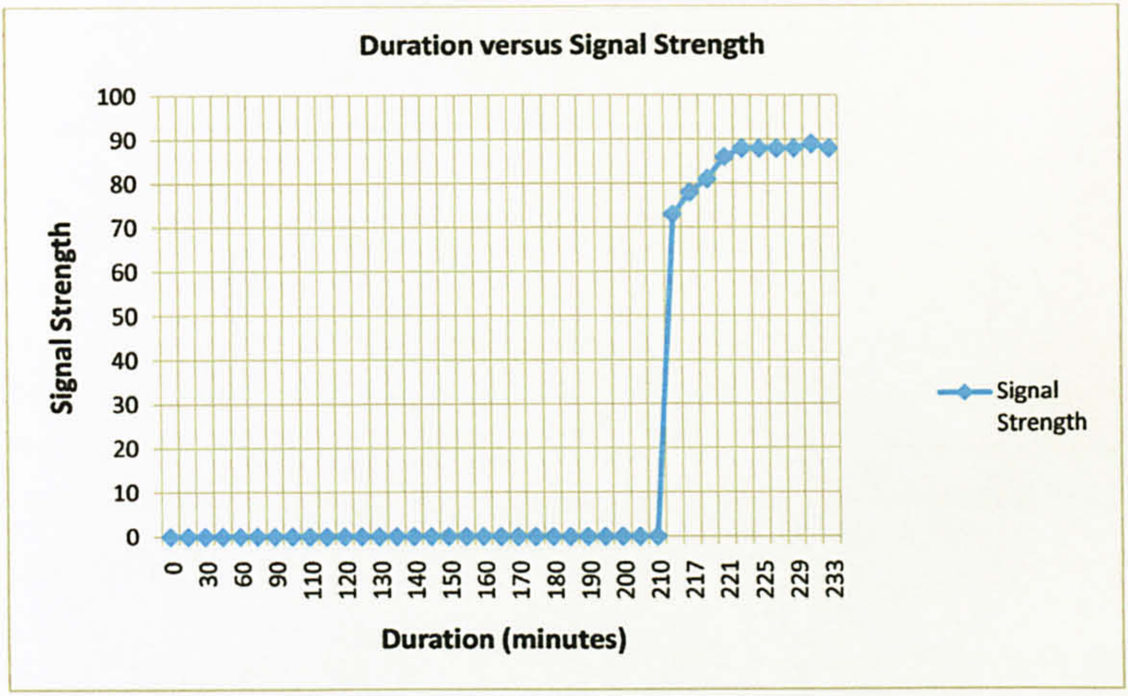


Figure 21: The signal strength of the RFID communication during corrosion

From the graph above, the signal strength cannot be detected at first 210 minutes after the tag immersed in the Sodium Hydroxide solution. This is because the thickness of aluminium foil that wrapped the tag was 17 μm while the skin depth for frequency 433 MHz was 4 μm only. So, the signal strength can't be detected as no the RF signal had been attenuated through the aluminium foil.

When the tag was immersed more than 210 minutes, the signal strength increased rapidly and after some time it became constant. This is because of the corrosion process. As the corrosion occurred, the thickness of metal will be lesser. After 210 minutes, the thickness of the aluminium had been decreased to 4 μm which is same as the value of skin depth. Because of that, the RF signal can be attenuate through the aluminium foil and the information about the tag can be send to the reader.

The signal strength become stronger as the metal thickness became lesser. This is shown in the graph where the signal strength increased from 210 minutes until 221 minutes the tag immerged in the solution. So, the thickness of metal affects the signal strength of the RFID tag and reader.

Besides that, as time increased to 221 minutes and above, the value of signal strength become constant because at this moment, the thickness of aluminium is 0 μm. At 221 minutes, the aluminium was totally dissolved in the 0.5% Sodium Hydroxide solution. So, the communication of RFID tag and reader did not have the metal between them and the RF signal can be sent directly between the RFID tag and reader without any barrier. This show that the corrosion took place and the value of the signal strength can be used as an indicator of how severe the corrosion was.

However, the result was not accurate since the corrosion rate cannot be calculated and the value of signal strength just indicated that the metal was corroded. So, in order to validate the results obtained before, there are a few alternatives that can be done. One of methods is using the weight loss of metal corroded. So, the weight loss of the metal during the corrosion process was recorded and the corrosion rate was calculated from the weight loss. Later the calculated weight loss will be compare to the signal strength obtained as shown in Figure 21.

As mentioned before, the alternative used to calculate the corrosion rate was using the weight loss since the thickness of metal corroded cannot be measured and the percentage of corrosion on the metal surface also not accurate. For the corrosion rate calculation, the weight loss of the tag with the Sodium Hydroxide solution taken and the corrosion rate was calculated using the formula below:

$$\boxed{Corrosion\ rate = \frac{W}{DAT}}$$

Where

W = The weight loss of the metal, g

D = Density of the metal, g/cm^3

A = Area of metal exposed, cm^2

T = Duration of exposure, hrs

Besides that, the data also collected from the experiment in order to help to calculate the corrosion rate. The results from the experiment as below:

Table 6: The experiment data

Data	Value
Initial weight	452.00 grams
Final weight	450.51 grams
Total weight loss	452.00 – 450.51 = 1.49 grams
Weight of aluminium	0.43 grams
Density of metal corroded	2.7 g/cm^3
Area of metal exposed	8.5 cm x 5.5 cm x 2 = 93.5 cm^2
Duration of exposure	4 hours
Thickness of aluminium	17 µm

However the total weight loss measured from the experiment is not totally the weight from the metal corrosion. There are a few things need to be considered before the final weight loss of metal corroded was obtained.

In the reaction of Aluminium with the Sodium Hydroxide, it released the hydrogen gas and based on the stoichiometric equation, the weight of hydrogen gas released can be calculated.

The stoichiometric equation:

$$Al_2O_3 + 2\ NaOH + 3\ H_2O \longrightarrow 2\ Na^+ + 2\ [Al(OH)_4]^-$$

$$Al(OH)_3 + NaOH \longrightarrow Na^+ + [Al(OH)_4]^-$$

$$2\ Al + 6\ NaOH \longrightarrow 2\ Na_3Al\ (OH)_3 + 3H_2$$

The mol of aluminium = Weight (g) / Molar mass of aluminium (g / mol)
= 0.4 g / 26.98 g/mol
= 0.016 mol

The weight of hydrogen, H_2 released, g = 3 / 2 x 0.016 mol x 2
= 0.048 grams

So, for this experiment, it is proven that the hydrogen gas was released and it affected the final weight measured in the end of experiment.

Beside the hydrogen was released, the reaction also released heat in the form of vapour because it is exothermic reaction and the weight vapour released also need to be considered. The vapour released need to be considered because the weight of water or vapour was big and its can affect the total weight loss. So, the total vapour released as calculated below:

Initial weight of solution	= 300 g
Final weight after the reaction	= 298.88 g
Weight of vapour, H_2O released	= 300 – 298.98 g
	= 1.02 g

Based on the information and calculation above, the total weight loss of metal corroded can be calculated. The calculation as shown below:

Weight loss of metal corroded, g	= total weight loss – weight of H_2 – weight of H_2O
	= 1.49 – 0.048- 1.02
	= 0.422 g

Now, from all the information above, the corrosion rate can be calculated.

$$\text{Corrosion rate} = \frac{W}{DAT}$$

$$\text{Corrosion rate} = \frac{0.422\ g}{\left(2.7\frac{g}{cm^3}\right)(93.5\ cm^2)(4\ hrs)}$$

$$\text{Corrosion rate} = 4.18\ \mu m\ /\ hrs$$

Since the aluminium totally dissolved in the Sodium Hydroxide solution, the total thickness of metal corrosion should be 17µm. To ensure that the experiment were right, the total thickness of metal corroded can be calculated.

$$\text{Total thickness of metal corrosion} = 4.18\ \mu m / hrs \times 4\ hrs$$
$$= 16.72\ \mu m \approx 17 \mu m$$

This showed that the RFID signal strength can be used in order to monitor the corrosion activity. Although the RFID signal strength was proven can be used to monitor the corrosion activity, the corrosion rate can't be calculated directly from the value of signal strength.

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 Conclusion

The main objective of this project is to apply the Radio Frequency Identification (RFID) system as one of the corrosion monitoring technique. Based on the results, the Radio Frequency Identification (RFID) can be applied to sense the corrosion activity. However, it failed to detect the exact corrosion rate. This is because the corrosion rate can't be determined from the value of signal strength during the communication of the tag with the reader.

Besides that, the value of signal strength only can be detected when the thickness of metal corroded is equal or less than the skin depth of the metal. If the thickness of metal is more than its skin depth, no signal strength can be detected and the corrosion activity also can't be sensed.

Although the RFID can't give the exact value of the corrosion rate, this method still has an advantage over other corrosion monitoring techniques. It can give the fast alarm to the system that the corrosion is happening since the RF wave from the tag send to the reader continuously. So, prevention can be done before the corrosion become severe.

5.2 Recommendation

There are a lot of improvement can be done for this project in the future. One of the improvements is in terms of determining the corrosion rate from the value of signal strength. The metal should be expose to the atmospheric environment in order to let it corrode naturally rather than immerge it in corrosive solution. By doing that, the weight losses of the metal corrode can be determined and the exact corrosion rate can be calculated.

Besides that, the signal strength from the communication of the tag and the reader also become more accurate. It is because the tag can communicate directly to the reader without any barrier other than the metal. Unlike in this project, other than the metal, the Sodium Hydroxide solution and the beaker also become the barrier between the communication of RFID tag and reader and yet, it affects the value of signal strength. In addition, the exact duration for the metal to corrode also known and the prevention can be done before that time.

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APPENDICES

Gann Chart For Final Year Project 1

ACTIVITIES	week															
	1	2	3	4	5	6	7		8	9	10	11	12	13	14	19
Research about RFID and its characteristics								mid semester break								
Research about Corrosion and its factors																
Study about currently available corrosion monitoring techniques																
Design the experiment																
Submit the interim report																
Oral presentation																

APPENDIX B

Gann Chart For Final Year Project 2

ACTIVITIES	week 1	2	3	4	5	6	7		8	9	10	11	12	13	14	19
Study and understand about spectrum analyzer and RFID-DUAL kit								mid semester break								
Understand the skin depth concept and calculate the skin depth for the aluminum																
Measure the RFID signal strength for active and passive tags - using RFID - DUAL kit																
Measure the RFID signal strength for active and passive tags - using AAID kit																
Measure the RFID signal strength by coating the tags with aluminum foils																
Layered the tags with metal and let it to corrode																
Analyse the data get and if necessary do the modification																
Finalize the design																
Submit the final report																
Final presentation																

The data for the experiment to relate the RFID sigmal strength with corrosion

duration	signal strength	weight (grams)	time	weight loss (grams)	time exposure per hour
0	0	452.00	14:00	0.00	0.00
15	0	451.80	14:15	0.20	0.25
30	0	451.79	14:30	0.21	0.50
45	0	451.78	14:45	0.22	0.75
60	0	451.75	15:00	0.25	1.00
75	0	451.70	15:15	0.30	1.25
90	0	451.66	15:30	0.34	1.50
105	0	451.65	15:45	0.35	1.75
120	0	451.61	16:00	0.39	2.00
135	0	451.56	16:15	0.44	2.25
150	0	451.51	16:30	0.49	2.50
165	0	451.44	16:45	0.56	2.75
180	0	451.36	17:00	0.64	3.00
195	0	451.33	17:15	0.67	3.25
210	0	451.29	17:30	0.71	3.50
215	73	451.25	17:35	0.75	3.58
217	78	451.15	17:37	0.85	3.62
219	81	451.03	17:39	0.97	3.65
221	86	450.96	17:41	1.04	3.68
223	88	450.88	17:43	1.12	3.72
225	88	450.83	17:45	1.17	3.75
227	88	450.73	17:47	1.27	3.78
229	88	450.61	17:49	1.39	3.82
231	89	450.58	17:51	1.42	3.85
233	88	450.51	17:53	1.49	3.88