

INDOOR LOCATION SENSING USING RADIO FREQUENCY NETWORK

By

DOUGLAS TAN

FINAL PROJECT REPORT

**Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)**

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Electrical & Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
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June 2007

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 been undertaken or done by unspecified sources or persons.



DOUGLAS TAN

ABSTRACT

This report discusses the activities in this project. An indoor location sensing system using radio frequency network will be produced by using the triangulation method, where signal strengths received will be used to determine the coordinates of objects tracked. The benefit of this project is that it provides a foundation in the basic of locating objects in a closed area. The flowchart for the main program and hence, the programming of the calculations algorithm has been done and tested using user simulated digital control input. The transmitter and receiver circuits have been constructed and tested. However, no solid results could be obtained as no signals are detected by the DAQ system using LabVIEW. There are several problems when interfacing the circuits with the DAQ board but it is rectified soon after. Thus the possible problems could be due to the use of unsuitable wire and antennas. Nevertheless, this project will be continued until concrete results are obtained to meet the objectives of this project, to be presented during the final presentation.

ACKNOWLEDGEMENTS

I would like to express my gratitude to all those who gave me the possibility to complete this thesis. I have furthermore to thank Ms. Suhaili and Ms. Siti Hawa for their cooperation in providing me with the needed assistance for this project. I am deeply indebted to my supervisor Ms. Norashikin Yahya whose help, stimulating suggestions and encouragement helped me in all the time of research for and writing of this thesis. Especially, I would like to give my special thanks to my parents whose patient love and support enabled me to complete this work.

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LIST OF ABBREVIATIONS

MAX	Measurement and Automation Explorer
GUI	Graphical User Interface
PC	Personal Computer
RFID	Radio Frequency Identification
RF	Radio Frequency
DAQ	Data Acquisition
RSSI	Received Signal Strength Indicator
FYP	Final Year Project
RTSI	Real-Time System Integration
DC	Direct Current
a.k.a.	Also Known As
MATLAB	Matrix Laboratory
VI	Virtual Instrument

CHAPTER 1

INTRODUCTION

1.1 Background Study

In today's industries, goods are mass-produced and shipped to large storage warehouses where they will be kept before transported to customers. To keep track of the number of goods in the warehouse, a tracking and locating system has to be implemented. In recent years, technologies have been developed to accommodate this need. Among the established ones is the Active Badge system using IR (infrared) and the indoor location sensing using RFID (radio frequency identification).

According to [1], the Active Badge system, the person will wear a badge that will transmit IR signal unique to himself for every 10 seconds, in which this signal will be read by sensors located at strategic locations in a building. Among the disadvantages of using infrared [1] are; (a) poor scaling due to limited range of IR, (b) significant installation and maintenance costs, and (c) performs poorly in the presence of direct sunlight, which would be problematic in rooms with windows. Hence, for this project, the RFID technique would be studied and employed in building an indoor location sensing system.

The RFID based system will be manipulating the signal strength that is gathered from the user's transmitter which is being tracked. There are other techniques which can be used such as the random sampling [2], and simulation using signal propagation model [3], but for this project, the triangulation method would be employed. The signal strength from multiple RF receivers will be used to triangulate [1] the user's coordinate.

The remainder of this report will be structured as follows. In Section 2, the literature review and theory on past works and the algorithms used on existing indoor location systems using radio frequency network will be discussed. Section 3 contains the methodology employed throughout this project and the tools required for this system. The results and discussion thus far will be presented in Section 4, while Section 5 covers the conclusion

1.2 Problem Statement

The deliverables for this project is a RF based system which can locate the physical position of an object being tracked. The hardware will consist of a transmitter which sends out RF signal all the time and this signal will be received by the reader and triangulation will be performed by the main unit based on the signal strength to determine the coordinates of the object being tracked. The environment to be used would be a room filled with electrical equipments and furniture, thus a lot of interference is expected.

The significance of this project is that it provides a foundation for another alternative in keeping track of the location and whereabouts of equipments, such as those in laboratories and libraries. For example, books in libraries would not get lost in the library unless it's been borrowed by students.

1.3 Objectives and Scope of Study

The objective of this project is to identify and interpret the theory on indoor location sensing using radio frequency network, and to produce a working system, comprising both hardware and software, that can locate the physical position of an object being tracked. The location sensing must also be accurate to a certain degree of precision because the testing bed will be in an environment with a lot of obstacles and interference.

The project consists of an object mounted with a transmitter which will emit

RF signals all the time, and the receivers located inside the building will receive the signal where a main unit manipulates the signal strength, thus establishing the object's coordinates on the physical plane. Given the scope of the project and the timeframe of 2 semesters, this project is a feasible one.

CHAPTER 2

LITERATURE REVIEW AND THEORY

Among the related projects done based on location sensing system using radio frequency network are the Children Tracker [4], RADAR [1], random sampling algorithm [2], and field simulation for RFID-based indoor location sensing algorithm [3].

The Children Tracker [4] system is built to enable a main unit in determining locations of children in supermarkets and transmit that data to the corresponding parents. The algorithm used in this system is the triangulation method. The children unit emits RF signal which will be received by the parents and main unit. **Figure 1** shows the relationship between the received signal strength and the distance between the transmitter and receiver circuit. By knowing this relationship between the received signal strength and the distance, triangulation can be done to determine the children's and the parents' coordinates.

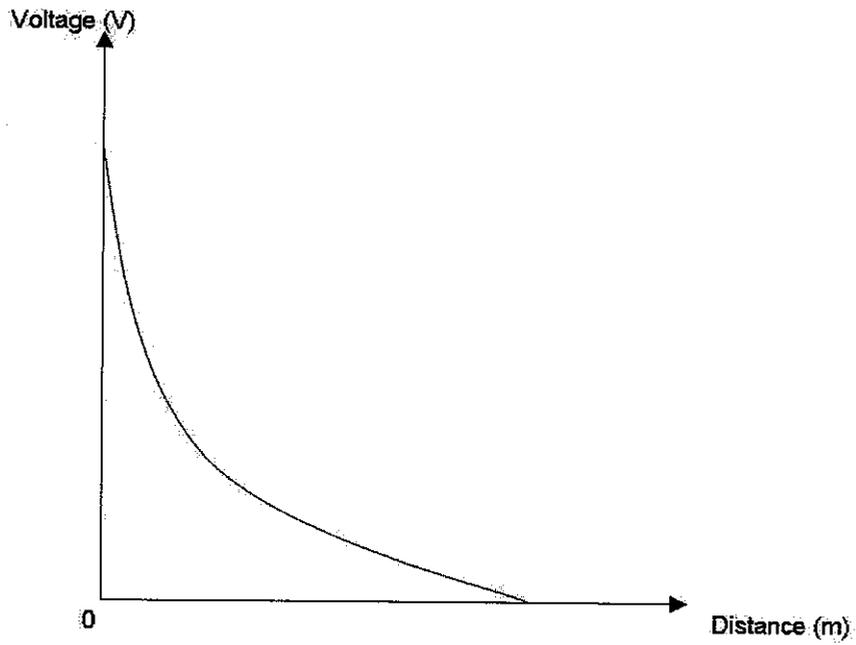


Figure 1 : Relationship between received signal strength and distance

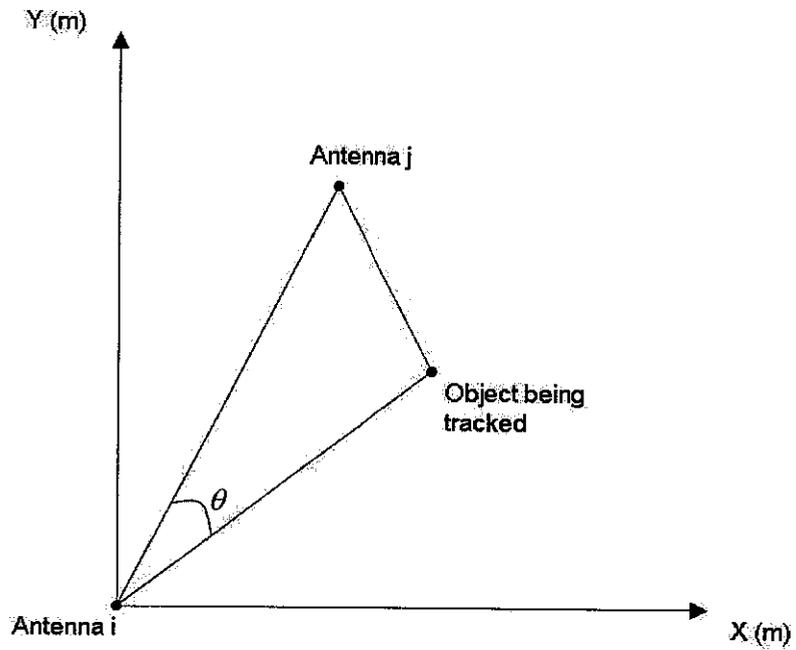


Figure 2 : Triangulation method

Figure 2 shows how the object being tracked is located. The receiver and transmitter is calibrated based on signal strength received by the receiver circuit from

the transmitter when it is measured from certain distances. This relationship is shown in **Figure 1**. It is observed that generally as the distance of the transmitter from the receiver increases, the received signal strength by the receiver circuit decreases exponentially. This generic relationship can be used to determine the distance of a radio frequency transmitting object to a particular radio frequency receiver.

The distance of the receivers from the transmitting unit can be determined through calibration discussed from the relationship between the received signal strength and distance of transmitter to the receiver. Since the distance between two RF receivers is known, the angle theta from **Figure 2** can be calculated. This angle is important in determining the distance of the unit for its (x , y) coordinate. Details of this calculation will be discussed in the **Result and Discussion** section.

The RADAR [1] system also uses the basic approach of triangulation. This system investigates how the movements and orientations of users could complement the signal strength information in locating users accurately. These profiles identify with high accuracy the likelihood of users' location, orientation and movements, based on the time of the year and the building layout. The signal strength profiles for various orientations and movements provide high accuracy in locating users in large-scale environments, where the radio frequency signal propagation is affected by other users and equipments radiating electromagnetic frequencies.

The field simulation for RFID-based indoor location sensing algorithm, which is the LANDMARC [3] algorithm, places multiple reference tags in known locations and coordinates. By comparing the signal strengths of the tracking tag and the reference tags, the location of the tracking tag can be computed. The random sampling algorithm [2] uses localization technique where a person with a tag will know his position in real time. The person's state space is represented by maintaining a set of random samples. This algorithm indicated lower positioning errors (under condition where there's no direct Line of Sight) compared to the least square (LS) algorithm. The advantage of the random sampling algorithm is that it does not require a lot of reference tags like the k-nearest neighbor algorithm.

CHAPTER 3

METHODOLOGY AND PROJECT WORK

In this section, the procedure carried out throughout this project and the tools required will be discussed. Firstly, the theory will be identified and the algorithm used for this project will be finalized through literature review. This includes the method discussed earlier which is the triangulation method to determine coordinates of a tracked user. Then, the LabVIEW software will be learned and how the DAQ board can be interfaced with the RF receiver will be clarified. Lastly, is the programming of the algorithm and setup of the hardware in the test bed, which will be in a laboratory.

The tools required for this project are as follows;

1. One LINX RF Transmitter Circuit
2. Three LINX RF Receiver Circuit
3. Main Unit – consists of DAQ board and Personal Computer (PC)
4. Four Antennas from Antenna Factor Technologies
5. RG-174 cable for the antennas
6. LabVIEW software
7. MATLAB software for calibration

3.1 Procedure

From the literature review, the algorithms, simulation results, accuracy, calibrations are among the important issues noted. The algorithms provide a background for the theory employed in this project. Among the techniques employed in determining a person's location is triangulation using lateration and probability density. Also of

equal importance are the factors considered in each system. These factors are important in determining the error distance each system might have, in other words they could be the reasons a particular system fail or succeed. For example, a user's orientation (whether transmitting device on the user has direct line of sight with the reader), the time of the day (most industries operate during the day time, thus more electrical equipments radiating electromagnetic waves will be used during the day time), and the layout of the building, play important roles in each indoor location sensing system. If a user's transmitting device has direct line of sight with a radio frequency reader, then the signal strength is very strong. Also, not only does electromagnetic interference affect the accuracy of the location sensing system by providing inaccurate readings, it will also give the system designer a big headache during implementation of the system.

Last but not least, literature review on the RSSI (received signal strength indicator) is carried out. The articles on RSSI mainly focus on the unit measurement, the calibration using the RSSI, and the threshold range for detection. The number of levels and signal strength associated with each level differs for different products, but all is governed by the 802.11 standard.

Next, the LabVIEW software manuals are referred to, for comprehension of the software, which provides an interface for the DAQ (data acquisition) board and other DAQ devices. This software also comes with many important functions to read inputs from DAQ devices such as a flow transmitter and manipulate the data collected.

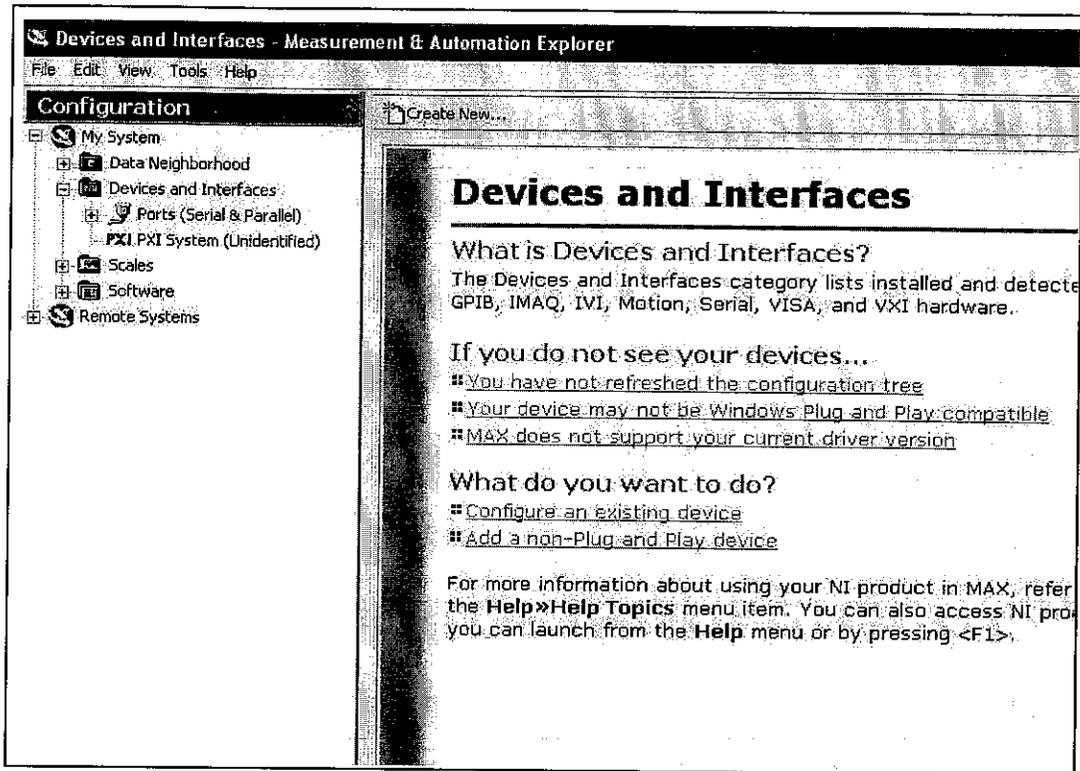


Figure 3 : Measurement and Automation Explorer (MAX) GUI Interface

Programming in LabVIEW does not require coding using text such as those found in Visual Basic or MATLAB. It utilizes the block diagram which has built in functions such as loops, arrays, and input data. To create a DAQ LabVIEW program, the DAQ devices must first be detected and recognized by the MAX (measurement and automation explorer). **Figure 3** shows the configuration options of the DAQ device through the GUI of MAX. The MAX is also used to configure additional analogue/digital input measurement modules installed on the DAQ board. The step-by-step configuration of installed devices/modules can be found from the help files provided, and they are easy to follow.

Then, programming is initiated after the flowchart had been finalized. The flowchart provides a sequence which manipulates incoming signals from DAQ accordingly. In this project, the incoming signals (in digitized form) are calculated mathematically to obtain the location of the object being tracked.

Before the hardware components are available, the interfacing of hardware to the DAQ board and the LabVIEW software is not possible. Hence, a digital control is used instead to simulate incoming signals from all three transmitters from known locations.

3.1.1 Calibration

Calibration is the process of adjusting an instrument so that its reading can be correlated to the actual value being measured. For this project, calibration is the process of measuring the output of the measuring instrument (analogue input voltage module) with relation to the magnitude of the input that is driving the instrument. The analogue input DC voltage value is measured, and it is related to the received RF signal strength. The stronger the received RF signal strength, the bigger the value of the measured analogue input DC voltage.

Since the received RF signal strength varies according to the distance between the transmitter and receiver, the measured DC voltage can be directly related to the distance between the transmitter and receiver. There are two ways of calibrating the equipments for this project.

The first method is to use a map of the closed environment, where the map is divided into several sections. Each section corresponds to a range of voltage values indicated by the RF receivers. Hence, the range of voltage values for each receiver, for each location, is unique. Thus, after the equipments are calibrated using this method, the location of the object being tracked can be determined, by comparing the DC voltage levels indicated by each RF receiver to the calibrated values.

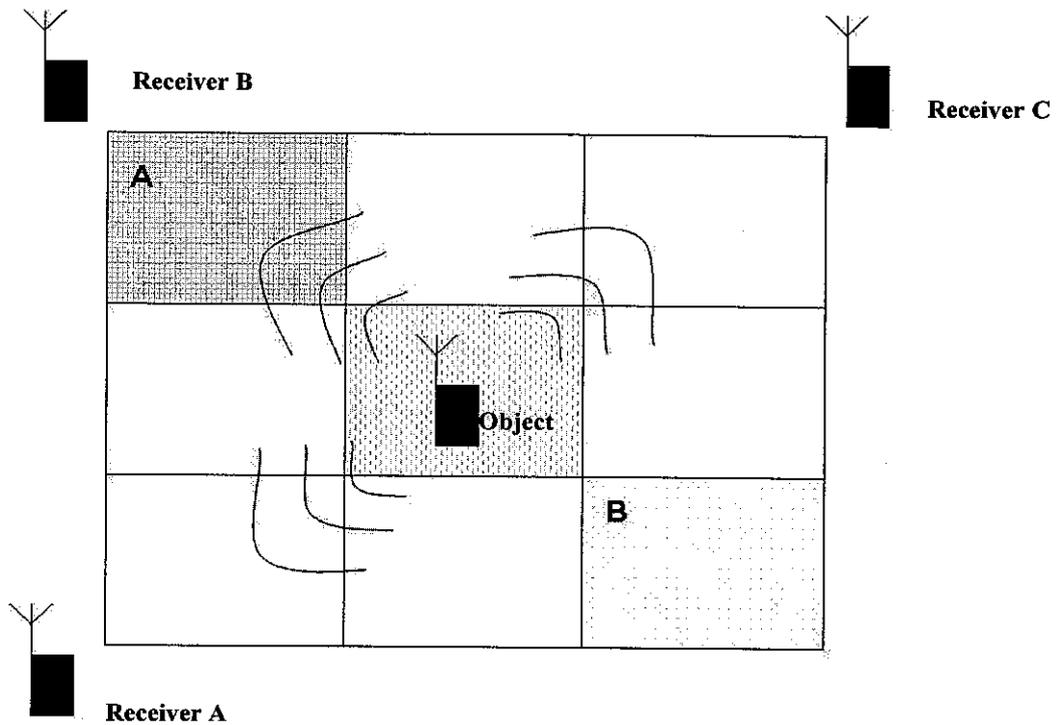


Figure 4 : Map for calibration

To demonstrate how this is done, let's refer to **Figure 4**. **Figure 4** shows how the calibration is performed to obtain the map. Firstly, the object a.k.a. RF transmitter circuit is placed in the middle of the closed environment. Then, the received RF signal strength is measured from each of the three stationary receivers in the closed environment. This received signal strength will be translated into analogue input DC voltage values by the data acquisition modules installed in the PC. Since the object being tracked is located in the middle, there is a high possibility that the magnitude of the signal strength received by the three receivers is almost the same, because the distance between the object and each of the three receivers is the same. However, when the object is moved towards location **B**, the received RF signal strength by Receiver **A** and Receiver **C** would be of greater magnitude compared to the signal strength received by Receiver **B**. This is due to the fact that the distance between the object being tracked and Receivers **A** and **C** is shorter compared to the distance between the object to Receiver **B**. Hence, it can be stated that for each location of the object in the room, the received RF signal strength by each Receiver, is unique. Using

this calibrated map, the location of the object can be determined by comparing the received signal strength at real time, to the calibrated values.

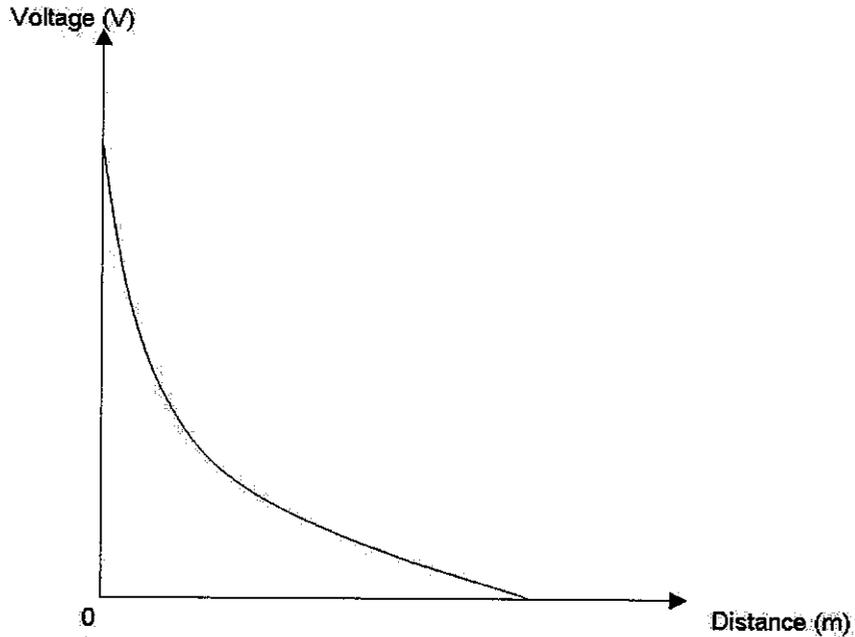


Figure 5 : Relationship between the voltage and distance between the RF Transmitter and RF Receiver

The second method is to calibrate the RF receiver according to the distance between the RF transmitter and RF receiver. **Figure 5** shows the relationship between the analogue input voltage values of the receiver and the distance between the RF transmitter and RF receiver. It is observed that as the distance between the transmitter and receiver circuit becomes greater, the received RF signal strength decreases, exponentially. To perform this calibration, the transmitter and receiver circuit are placed at a known distance. Then, the received signal strength in terms of voltage levels are recorded corresponding to that distance. Next, this step is repeated either by bringing both the transmitter and receiver closer or further. To obtain a precise calibration, the change in distance for each step is kept as small as possible. Then, the graph shown in **Figure 5** is generated using MATLAB, and an equation for the generated graph is acquired. Using this equation, the distance of the object being tracked from each RF receiver can be determined at any time.

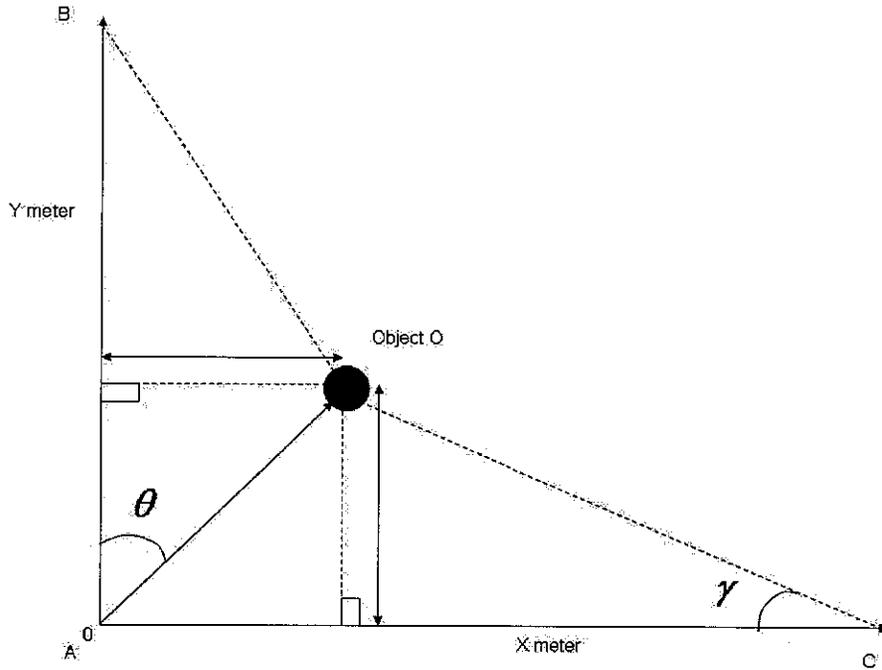


Figure 6 : Triangulation method to determine the location of object being tracked

Upon determining the distance of the object being tracked from each receiver, its location can be established by using triangulation method. **Figure 6** illustrates the parameters that are involved. A, B and C are RF receivers located at known locations. The distance between receivers A and C, as well as between A and B are already known.

$$\theta = \cos^{-1} \left(\frac{(dA)^2 + (R_{AB})^2 - (dB)^2}{2 \times dA \times R_{AB}} \right) \text{-----(1)}$$

Where;

dA = distance of object O to reader A

dB = distance of object O to reader B

R_{AB} = distance between reader A and reader B

$$x = dA \times \sin \theta \text{-----(2)}$$

Equation (1) is used to calculate the angle θ . Thus the x coordinate of the object's location can be determined by taking the *sine* of the angle θ , as shown in **equation (2)**.

$$\gamma = \cos^{-1} \left(\frac{(dC)^2 + (R_{AC})^2 - (dA)^2}{2 \times dC \times R_{AC}} \right) \text{-----(3)}$$

Where;

dC = distance of object O to reader C

dA = distance of object O to reader A

R_{AC} = distance between reader A and reader C

$$y = dC \times \sin \gamma \text{-----(4)}$$

Angle γ can be determined similarly by using **Equation (3)**. Hence, the y coordinate of the object's location can also be determined by taking the *sine* of the angle γ , as shown in **equation (4)**.

3.2 Equipments and Software

3.2.1 Transmitter and Receiver

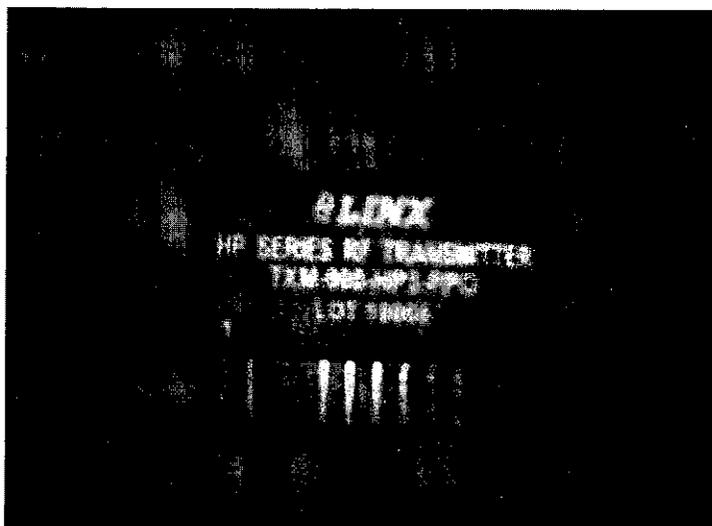


Figure 7 : LINX RF Transmitter Chip

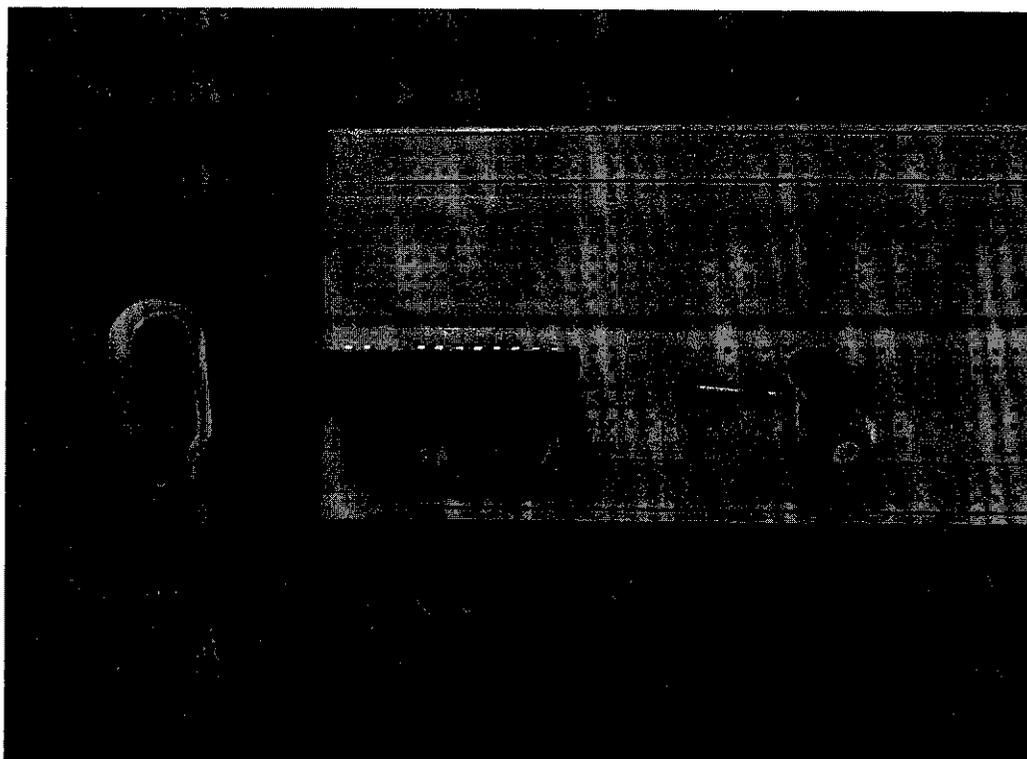


Figure 8 : RF Transmitter Circuit

After acquiring the transmitter and receiver chips, the circuits for transmitting and receiving radio frequency are constructed. **Figure 7** shows the RF transmitter chip from LINX, which is used to build the RF transmitter circuit. **Figure 8** shows this transmitter circuit. The connections in the transmitter chip are connected to allow for parallel channel selection. The connection of each pin on the chip is based on the function of each pin, which is shown in Appendix C. The function of the capacitors used in the circuit is to provide clean power supply for the LINX transmitter chip module. The values of the capacitors may need to be adjusted depending on the noise present on the supply line. This RF transmitter chip module can operate in a range of 2.8 volts to 13 volts DC.

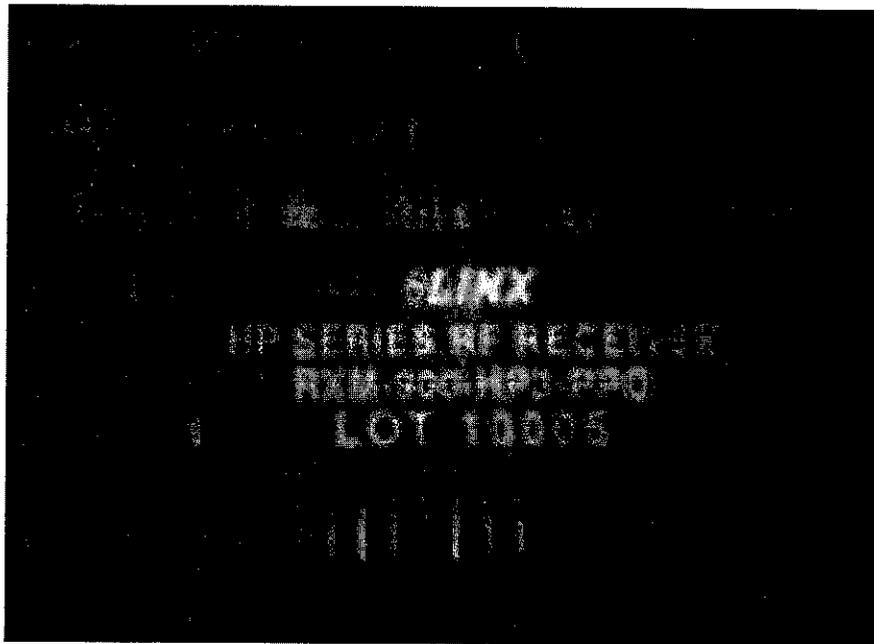


Figure 9 : LINX RF Receiver Chip

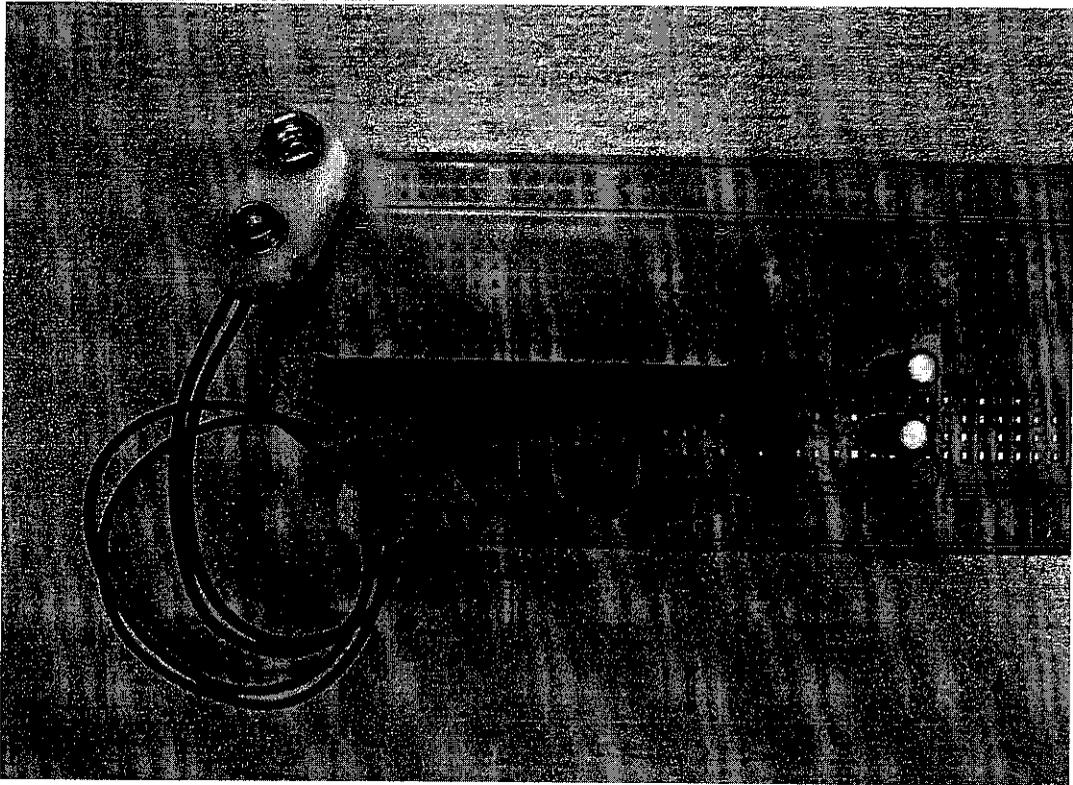


Figure 10 : RF Receiver Circuit

Figure 9 shows the LINX RF receiver chip module that is used to build the RF receiver circuit. **Figure 10** shows the RF Receiver Circuit. The connections in the receiver chip are connected to allow parallel channel selection. The connection of each pin on the chip is based on the function of each pin, which is shown in Appendix D. The function of the capacitors used in the circuit is to provide clean power supply for the LINX receiver chip module. The values of the capacitors may need to be adjusted depending on the noise present on the supply line. This RF receiver chip module can operate in a range of 2.8 volts to 13 volts DC.

3.2.2 Data Acquisition Modules

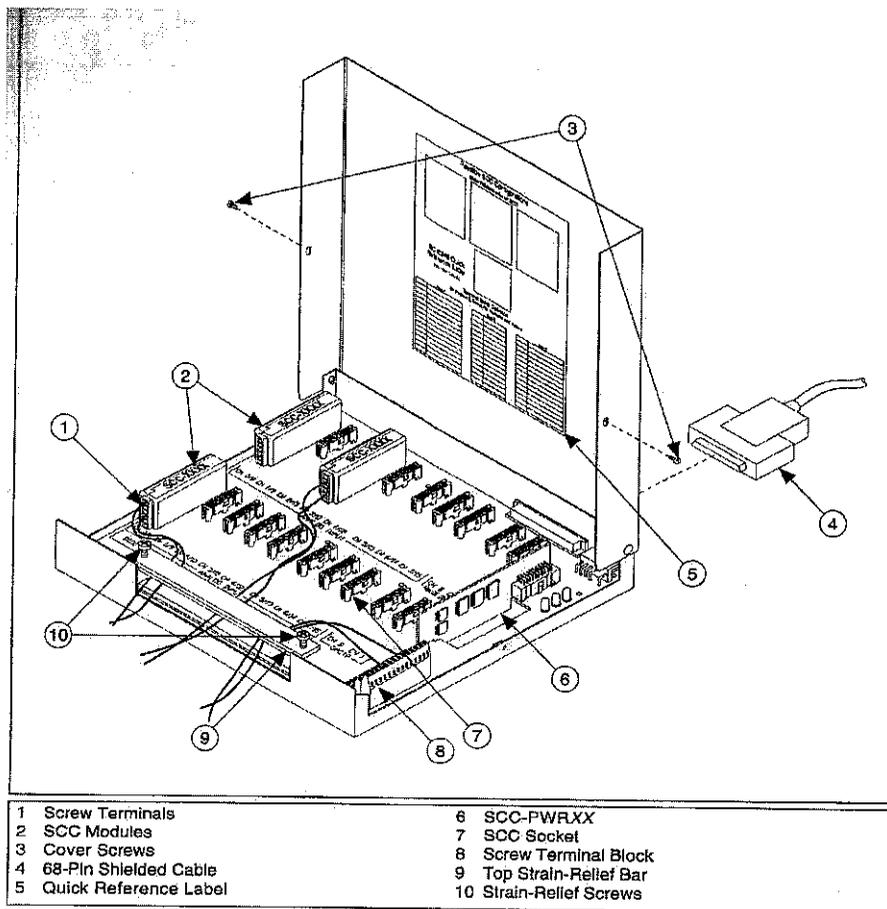


Figure 11 : The DAQ board, SC-2345

Figure 11 shows the SC-2345 DAQ board, which carries signals to and from the 68-pin E Series data acquisition devices. The SC-2345 provides easy-to-use, rugged, low-noise signal conditioning on a per-channel basis, when used with SCC Series modules and a shielded 68-pin cable.

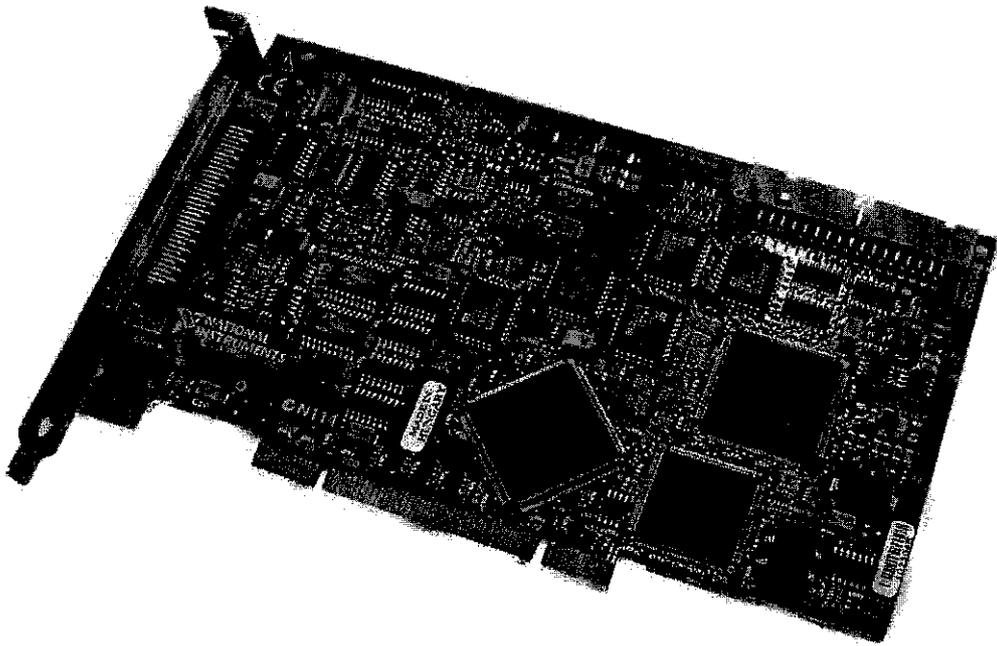


Figure 12 : The PCI-6024E interface card

Figure 12 shows the PCI-6024E Series board, which features 16 channels of analogue input, two channels of analogue output, a 68-pin connector and eight lines of digital I/O. This board provides the Real-Time System Integration (RTSI) function to properly synchronize several measurement functions to a common trigger or timing event.

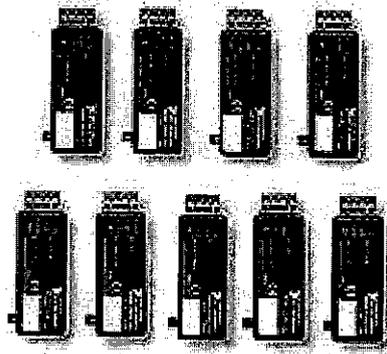


Figure 13 : The SCC-AI03 analogue input voltage measurement modules

Figure 13 shows a type of SCC Series module that is used together with the SC-2345 DAQ device described earlier, the SCC-AI03. This is an isolated analogue input module that can extract a relatively low-amplitude input signal from a high-common-mode voltage so the E Series DAQ device (described in **Figure 12**) can measure the input signal. The input and output range of this module is from -10Volts to +10Volts. This module can produce higher measurement resolution and accuracy by means of amplification and filtering within the module.

The SC-2345 signal conditioning board, PCI 6024E interface card, SCC-CI20 current input modules and the SCC-AI03 analogue input modules are then installed with a PC in the lab.

The RSSI signal from the receiver pin can be connected directly to the analogue input on the SC-2345 board. This is because the RSSI signal is measured in voltage level. Other SCC-XXXX series module can also be used, but it does not take in voltage level as input and this is not so suitable. The SCC-AI03, which is an analogue input module, is mainly used to measure low-amplitude voltage signal from a high-common-mode voltage so the DAQ board can measure the input signal. The signal can also be amplified and filtered.

The software to be used together with the data acquisition equipments, such as the Measurement & Automation Explorer (MAX) and LabVIEW are installed. The

MAX is used to detect and identify the DAQ boards and the corresponding accessories or modules connected to the desktop PC.

The connection from the receiver circuit RSSI output pin to the SC-AI03 analogue input module is reconfigured, but it will only be tested when the antenna has been soldered to be connected to the breadboard. The virtual instruments in LabVIEW are built to obtain the averaged DC voltage values from the RSSI pin out. The front panel graphical user interface (GUI) is also designed directly from the virtual instruments.

3.2.3 Antennas

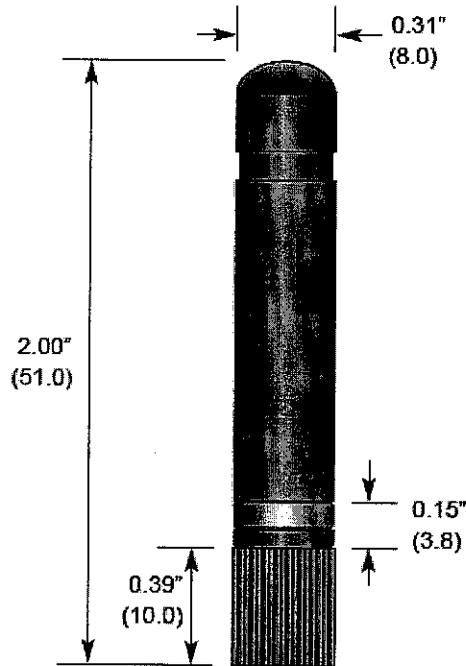


Figure 14 : Antenna from Antenna Factor Technologies

Figure 14 displays the antennas used for both the RF transmitter and receiver circuits. This is the RH series which utilizes a helical element to greatly reduce the physical length of the antenna housing.

This Antenna has the following features:

- Reduced-height helical whip
- Excellent performance
- Omni-directional pattern
- Low VSWR
- Fully Weatherized
- Rugged and damage-resistant
- Part 15 compliant RP-SMA connector

3.2.4 LabVIEW

LabVIEW offers a feature called the Virtual Instrument (VI) to manipulate the analogue input signal to its modules. The VI can be thought of as an electronic or virtual equipment of any function. The VI's in LabVIEW can perform many useful tasks, such as filtering, sampling, and amplification of any analogue signals.

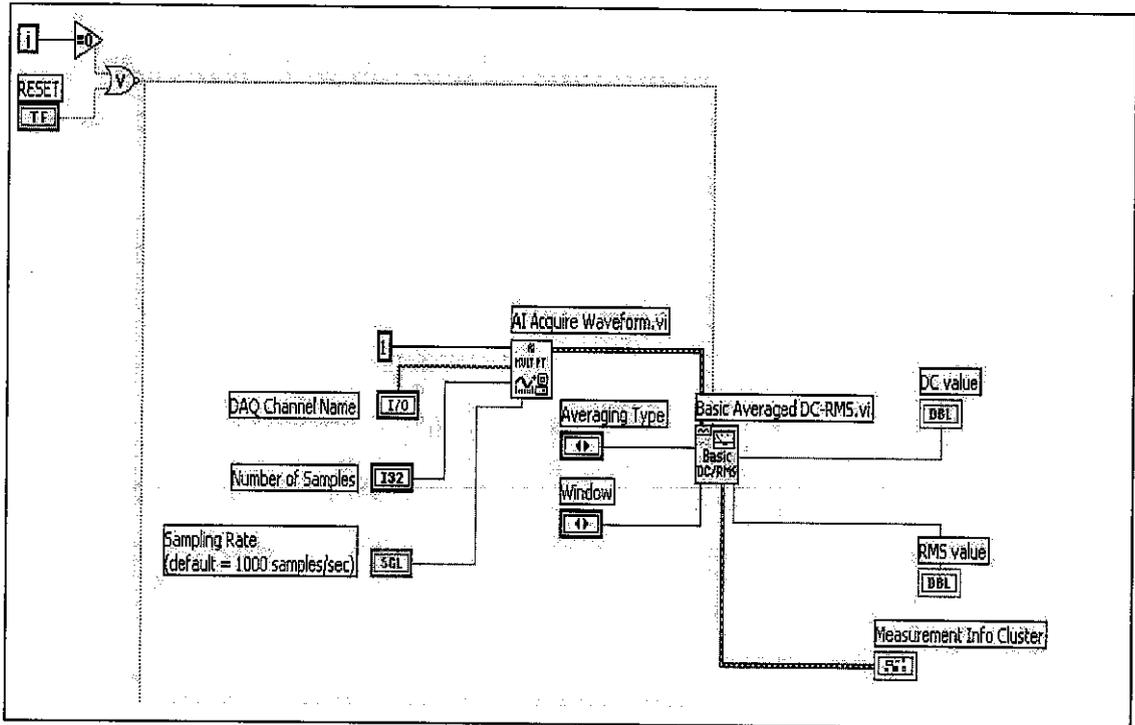


Figure 15 : Block diagram of the virtual instruments in LabVIEW

Figure 15 depicts the two VIs (virtual instruments) used to obtain the DC voltage value from the RSSI pin of the receiver chip. The **AI Acquire Waveform.vi** acquires samples from an analogue input channel according to sampling rates specified by the user. The number of samples to be acquired is also denoted by the user. Basically, this **AI Acquire Waveform.vi** performs timed measurements of a waveform from an input channel, specified by the device number (a constant) and DAQ Channel Name. The user can only specify certain inputs for the DAQ Channel Name parameter, according to the preset Virtual Channel performed in the Measurement and Automation Explorer. A virtual channel is simply an identifier the

software uses to specify an input signal. The virtual channel can be modified (i.e. renamed) to enable the user to easily identify different input channels.

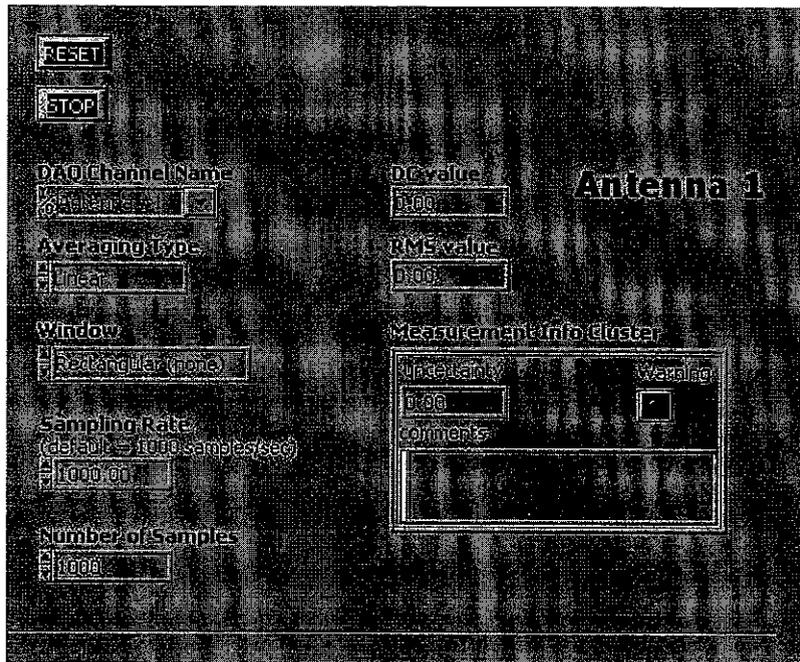


Figure 16 : Front panel for the virtual instruments

The front panel shows exactly the display the user(s) will see. **Figure 16** shows just a fraction of the final front panel. This portion of the front panel displays the DC voltage value from the RSSI output of every RF receiver. The final front panel would enable the user(s) to locate the object being tracked graphically. This is done by using a layout of the closed environment as a map. The front panel shown in **Figure 16** need not necessarily be displayed, since it only shows how the signal from the object being tracked, is sampled and processed into a form (voltage levels) that the users can understand.

However, such block diagrams in LabVIEW is not desirable since it would be tedious to trace the complex wiring when the program is completed. Hence, the LabVIEW's express virtual instruments block diagrams are used instead, where each block diagram takes an input and gives one output. This means that parameters such

as the sampling rate, virtual channel name and averaging type is done 'internally' inside the block diagram.

CHAPTER 4

RESULTS AND DISCUSSION

The programming is done on the calculations algorithm using LabVIEW. This part of the programming is pretty straightforward because I use a digital control as the input voltage, where any kind of input can be inserted. This is used to simulate the digitized signal from the input signal in analogue form (from the transmitter/receiver). As soon as the interfacing of the DAQ system and the DAQ devices (transmitters and receivers) is established, then the analogue received signal strength can be digitized and the calculations can be done to obtain the user location.

After the algorithm is successfully tested in the lab, other parts of the programming such as creating START/STOP button for looping purposes, creating front panel, and designing location map can be carried out.

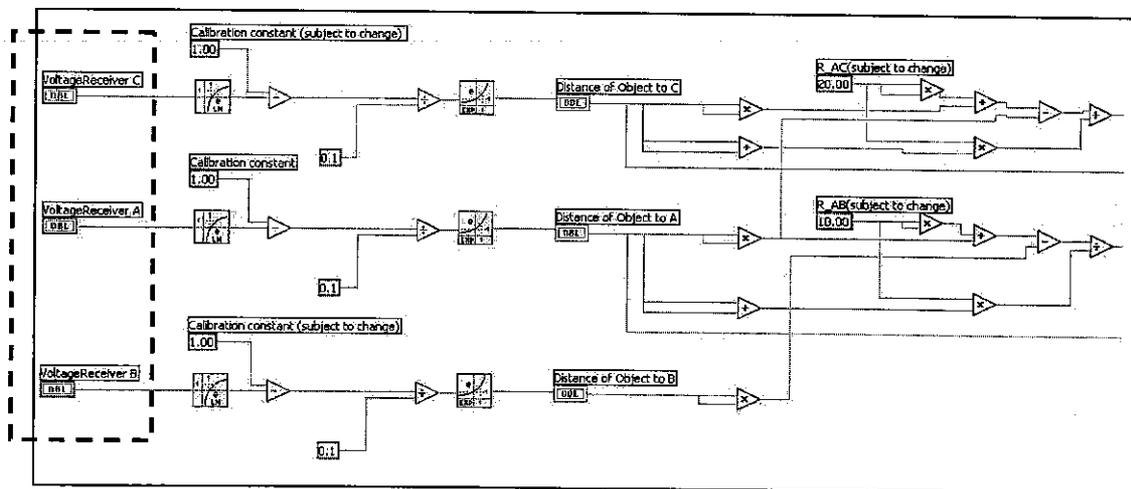


Figure 17 : Calculation algorithm done on LabVIEW

Figure 17 shows the calculation of equation (1) and (3) being performed on the input voltage values. The input voltage values are indicated by the dashed-lined box. The calculation is performed on the three RF receivers by using the mathematical operator blocks available from LabVIEW. However, the acquisition of the analogue input voltage values and the calculations to determine the object's location can be achieved by using the express VI's (virtual instruments) available from LabVIEW.

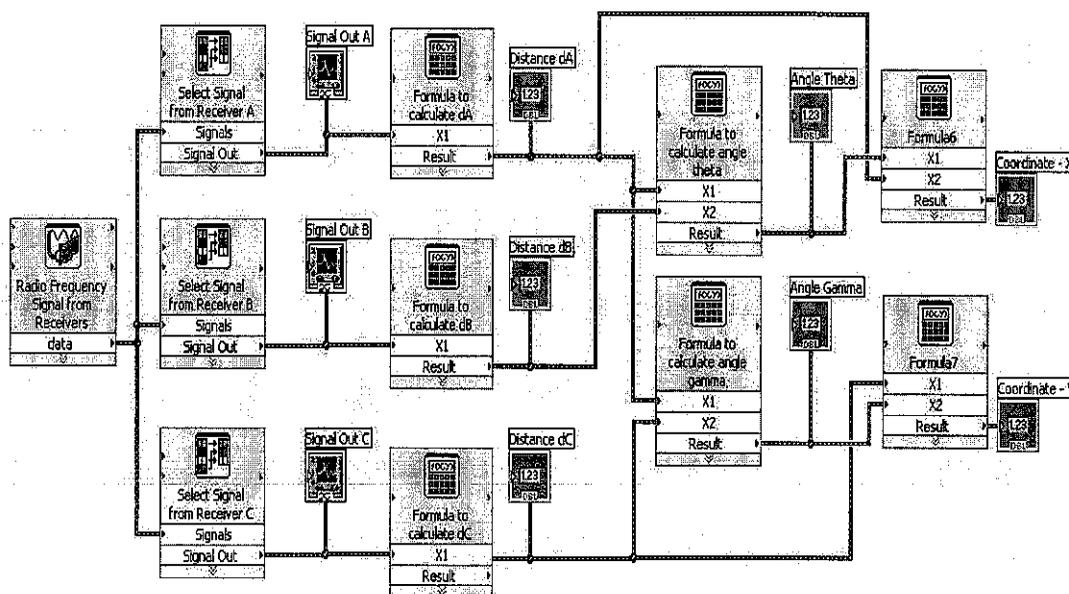


Figure 18 : Express VI's of the virtual instruments using LabVIEW

The block diagram in Figure 18 minimizes the calculations done in Figure 17 and also takes care of the functions to acquire the analogue input voltage signal from the RF receiver circuits. The *Radio Frequency Signal From Receivers* block diagram performs the sampling of the analogue input DC voltage from each of the three stationary RF receivers. Next, the *Select Signal from Receiver A* block diagram will identify the analogue input voltage signal from receiver A. The same function is performed for the *Select Signal from Receiver B* and *Select Signal from Receiver C* block diagram. Then, the *Formula to calculate distance* block diagram will calculate the values for dA , dB and dC , which are the distances of the object being tracked to the RF receivers A, B and C, respectively. The *Formula to calculate angle* block

diagram represents a mathematical function, which is to calculate the angle θ and γ . Equations (1) and (3) are included inside the block diagram. Lastly, the *Formula6* and *Formula7* block diagrams contain equations (2) and (4) respectively to calculate the location of the object being tracked in terms of its coordinate (x , y).

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

Indoor sensing using radio frequency network is going to be an important system in the future for tracking and locating objects in a building, especially in big warehouses where large number of equipments is stored. Here, we present a project to locate objects in one radio frequency indoor network. The algorithm to be used is the triangulation method. This method computes the coordinates of an object by efficiently manipulating the signal strength received by each RF receiver. The deliverables of this project at the end is a working model of the indoor location sensing RF network.

Thus far, the flowchart for the algorithm has been completed and the programming is done. The transmitter and receiver circuits have been constructed and tested, but no signal could be detected through the DAQ interface, using LabVIEW. This could be due to several reasons, including inappropriate design of antenna used and the unsuitable cable used, causing RF transmission loss. Hence, thus far there are no hard results to be presented for this project. However, this project will be carried out until results are obtained to be presented in the final presentation.

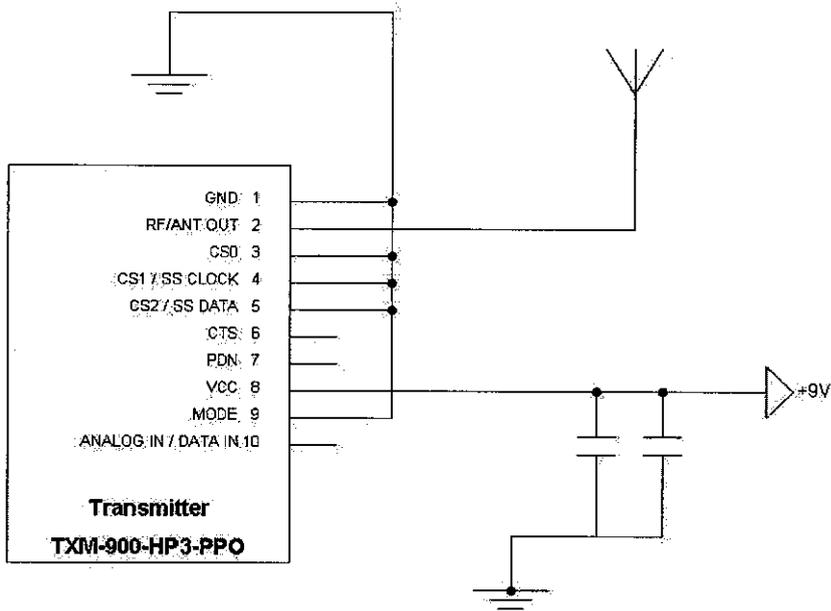
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APPENDICES

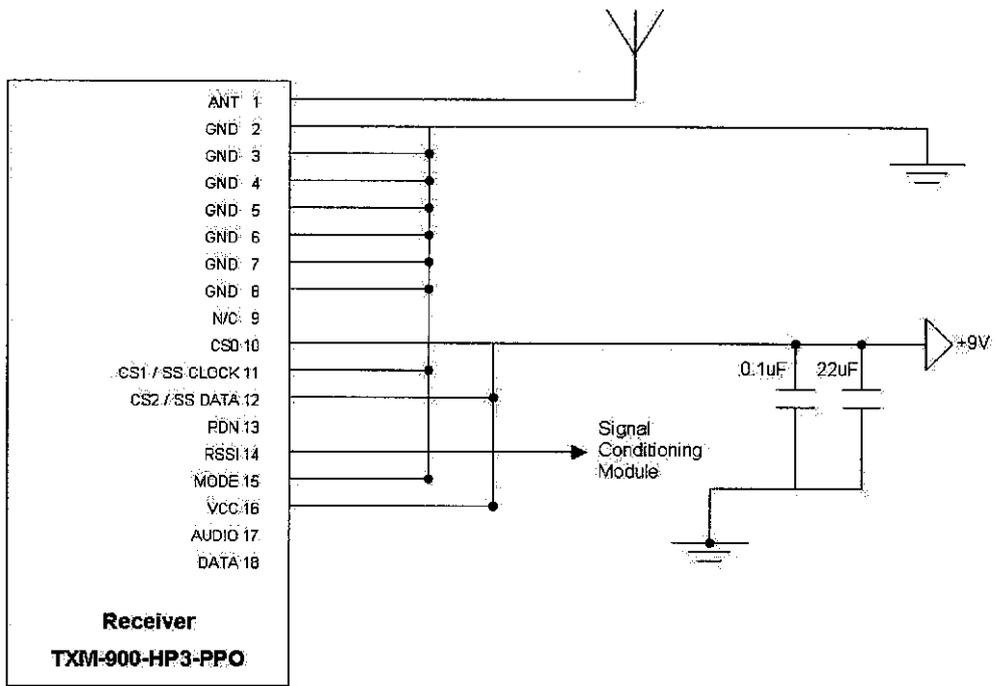
APPENDIX A

TRANSMITTER CIRCUIT



APPENDIX B

RECEIVER CIRCUIT



APPENDIX C
TRANSMITTER PIN DESCRIPTIONS

Pin # (SIP)	Name	Description
1	GND	Analogue Ground
2	ANT	50-ohm RF Output
3	CS0	Channel Select 0
4	CS1 / SS CLOCK	Channel Select 1 / Serial Select Clock. Channel 1 when in parallel channel selection mode, clock input for serial channel selection mode.
5	CS2 / SS DATA	Channel Select 2 / Serial Select Data. Channel 2 when in parallel channel selection mode, data input for serial channel selection mode.
6	CTS	Clear-To-Send. This line will go high when the transmitter is ready to accept data.
7	PDN	Power Down. Pulling this line low will place the receiver into a low-current-state. The module will not be able to receive a signal in this state.
8	V _{CC}	Supply Voltage
9	MODE	Mode Select. GND for parallel channel selection, V _{CC} for serial channel selection
10	DATA	Digital / Analogue Data Input. This line will output the demodulated digital data.

APPENDIX D
RECEIVER PIN DESCRIPTIONS

Pin # (SIP)	Name	Description
1	ANT	50-ohm RF Input
2-8	GND	Analogue Ground
9	NC	No Connection
10	CS0	Channel Select 0
11	CS1 / SS CLOCK	Channel Select 1 / Serial Select Clock. Channel Select 1 when in parallel channel selection mode, clock input for serial channel selection mode.
12	CS2 / SS DATA	Channel Select 2 / Serial Select Data. Channel Select 2 when in parallel channel selection mode, data input for serial channel selection mode.
13	PDN	Power Down. Pulling this line low will place the receiver into a low-current-state. The module will not be able to receive a signal in this state.
14	RSSI	Received Signal Strength Indicator. This line will supply an analogue voltage that is proportional to the strength of the received signal.
15	MODE	Mode Select. GND for parallel channel selection, V _{CC} for serial channel selection
16	V _{CC}	Supply Voltage
17	AUDIO	Recovered Analogue Output
18	DATA	Digital Data Output. This line will output the demodulated digital data.

APPENDIX E
PARALLEL CHANNEL SELECTION TABLE

CS2	CS1	CS0	Channel	Frequency (MHz)
0	0	0	0	903.37
0	0	1	1	906.37
0	1	0	2	907.87
0	1	1	3	909.37
1	0	0	4	912.37
<i>1</i>	<i>0</i>	<i>1</i>	<i>5</i>	<i>915.37</i>
1	1	0	6	919.87
1	1	1	7	921.37

