TR400 - INDUSTRIAL TRAINING

INDUSTRIAL TRAINING REPORT

T.D.B. WANDURAGALA

E/18/379

COMPUTER ENGINEERING

FACULTY OF ENGINEERING

UNIVERSITY OF PERADENIYA

SRI LANKA

INDUSTRIAL TRAINING REPORT I

TRAINING ORGANIZATION: **SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN**

PERIOD OF TRAINING: **FROM 31/07/2023 TO 15/12/2023**

FIELD OF SPECIALIZATION: **COMPUTER ENGINEERING**

T.D.B. WANDURAGALA

E/18/379

ACKNOWLEDGMENTS

I have been waiting for an opportunity to apply my theoretical knowledge gained throughout my academic life to a meaningful, real life situation that impacted other people. I am thankful for all that contributed to making that a reality.

I am thankful for my parents for giving me the education needed to grab onto an opportunity as such.

I am especially thankful for the course coordinators of TR400 Industrial Training Unit including Dr. Dimuth Navaratne, Senior Lecturer, Dr Ajith Vidanapathirana, Senior Lecturer and Dr. M.M.G.V. Shymalee, Senior Lecturer for supporting my internship and also the supporting various requests made. Thanks go out to Prof. Yuen Chau who was my internship supervisor and who gave me this internship position. I hope I lived up to his expectations. Also I'm thankful Dr. Zhao Yufei and Mr. Afkar Ismail who worked together with me during my internship period. I am also grateful for the Head of the Computer Engineering Department Prof. Roshan Ragel for his support.

Finally I am thankful for my fellow batch mates who embarked on the foreign internship together with me. Their presence and support made my internship much more memorable and fulfilling.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVATIONS

SUTD	Singapore University of Technology and Design
NTU	Nanyang Technological University
RIS	Reconfigurable Intelligent Surface
IRS	Intelligent Reflective Surface
MCU	Micro Control Unit
NUS	National University of Singapore
PCB	Printed Circuit Board
GPIO	General Purpose Input Output
GUI	Graphical User Interface

Chapter 1

INTRODUCTION

This chapter covers the internship establishment in brief and the work I was involved in during my internship period.

1.1 TRAINING SESSION

I did my training session at the Singapore University of Technology and Design (SUTD), Singapore, starting from the 31st of July, 2023, until the 15th of December, 2023, covering 20 weeks. The position I filled was a visiting research assistant. Since it was an onsite position, I travelled to Singapore from Sri Lanka and stayed there for the duration of my training. During my training period, I reported daily to the worksite, except for weekends and public holidays. I was employed under the Training Employment Pass given by the Singapore government for 5 months, starting on July 31st. In this training session, I gained a lot of new knowledge and went through different experiences, and it has been the most impactful experience in my personal life so far.

1.2 INTRODUCTION TO ORGANIZATION

The Singapore University of Technology and Design is one of the leading technology-based universities in Singapore. It was established in 2009 and is a public, autonomous university. It is situated in Upper Changi, Singapore, and a landscape view of the university from the east side of the campus can be seen in Figure 1, while the university logo is shown in Figure 2. The address of the SJTD is 8 Somapah Rd., Singapore 487372.

The university offers undergraduate programmes, graduate programmes, and research related to technology and design. 587 undergraduates graduated from the university in 2023, while the university consists of 1014 employees working in administrative positions, faculty positions, and research positions. Apart from the tuition fees for undergraduates, 66% of the university's funding comes from Singapore government institutions, while the rest comes from private corporations, foundations, and individuals. Also, 32 percent of all funds received are intended for research.

Figure 1.1 Buildings 3, 1, 2, 5 of SUTD

SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN

Figure 1.2 SUTD Logo

Out of the funding received, a considerable amount is devoted to research; hence, a lot of research activities have been done at the university in the five pillars of the university.

The five pillars are,

- Computer Science and Design.
- Engineering Product Development.
- Engineering Systems and Design.
- Architecture and Sustainable Design.
- Design and Artificial Intelligence.

1.2.1 Vision and Mission

Vision: “Trailblazing a better world by design.”

Mission: “We redefine design, education and research, and draw on multiple disciplines to make a positive impact on the society. We nurture technically-grounded leaders who embrace risks to continuously innovate for a better tomorrow.”

1.2.2 Organizational Structure

The chairman of the university is Mr. Lee Tzu Yang, while the president is Professor Chong Tow Chong. A detailed organizational structure can be seen in figure 3.

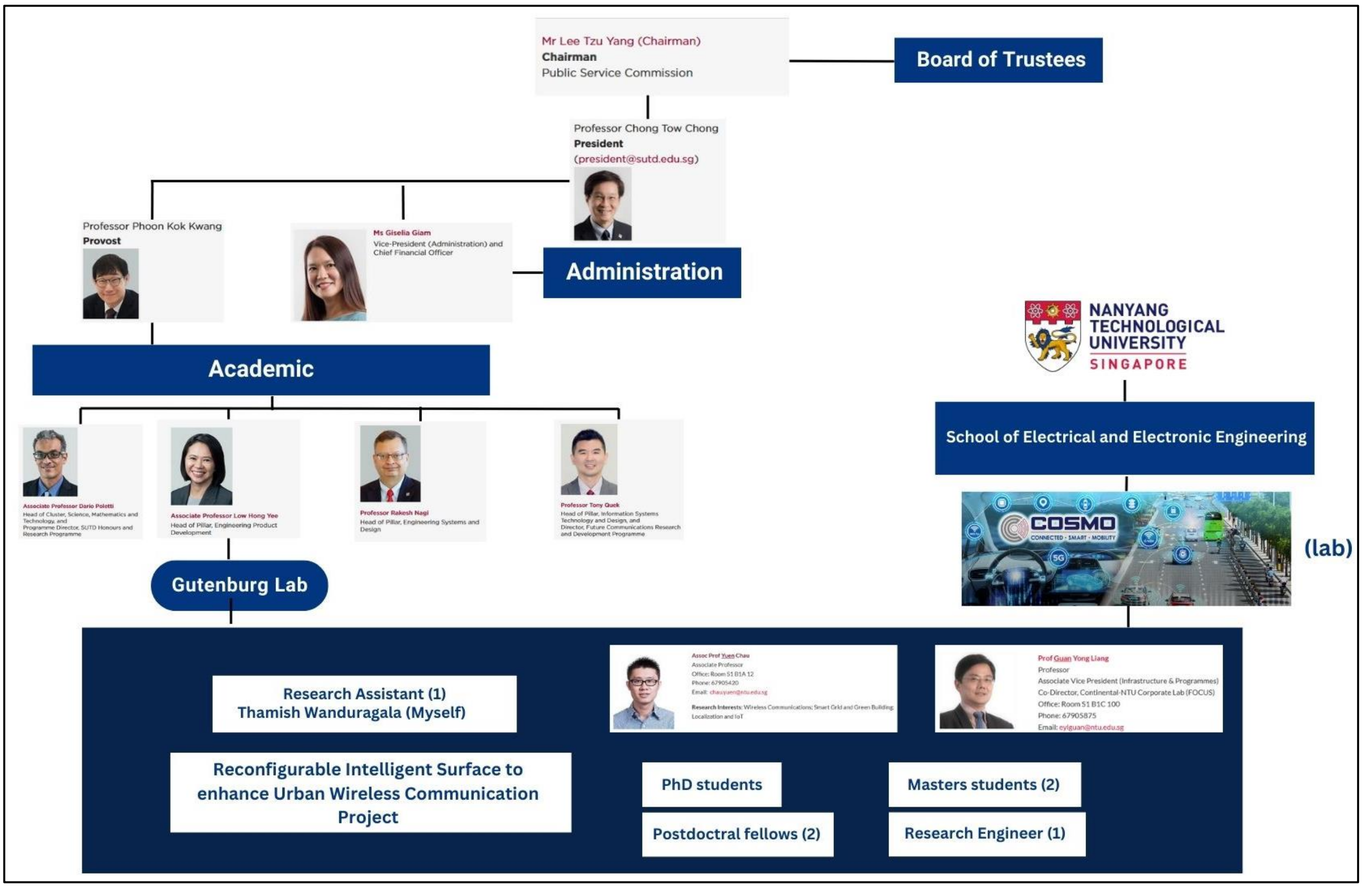

Figure 1.3 SUTD structure

1.2.3 SUTD Research Centers

SUTD consists of several centers devoted for research in various domains. Some major areas of research include artificial intelligence, robotics, communication, digital manufacturing, transportation, and cyber security.

Some key research centers are,

- AI mega center.
- Aviation Studies Institute.
- Centre for smart systems.
- Digital manufacturing and design center.
- Future communications research and development program.
- Game lab.
- Lee Kuan Yew center for Innovative Cities.
- SUTD-LTA transport research center
- Temasak Laboratories.

The research centers have professors, research professionals, research students, and undergraduates working together with other institutes and also companies that fund research activities directly.

1.3 SUMMARY OF THE WORK ENGAGED IN TRAINING

In the training period, I worked on a research and development project that was a joint project with SUTD and Nangyang Technological University (NTU). Therefore, I had to report to SUTD and also to NTU, depending on the requirements of my supervisors. Also, I had to report to a certain experiment lab, which was situated at the National University of Singapore (NUS), on certain days in order to do experiments related to the project. This was my first exposure to the research world and also the industry, as the output of the project was a product, which was expected from the funding partner, DSO National Laboratories Company, which is the national defence research and development organisation in Singapore.

Primarily, I worked on building a controller for a reconfigurable intelligent surface (RIS), which is an upcoming area of use in 6G wireless communications.

The following chapters contain information about my work on the project, tools used, techniques used, experiments done, safety precautions, and the use of engineering knowledge gained.

Chapter 2

THE PROJECT

2.1 INTRODUCTION

The project in which I was involved is a wireless communication project. In this chapter, the project I was working on is discussed in depth, and a background study on the knowledge relevant to the project is mentioned. Also, the people involved in the project are mentioned. Throughout the internship, I had weekly meetings about project-related work with my main supervisor to keep track of my work.

2.2 PROJECT OVERVIEW

2.2.1 Project Description

The project in which I was involved was named “Reconfigurable Intelligent Surface to Enhance Urban Wireless Communication." It is an up-and-coming research field in wireless communications and is expected to contribute to 6G wireless communication applications. The project members consisted of academics, researchers, and students. The main project supervisors were Prof. Yong Liang and Prof. Yuen Chau. Apart from that, I was under the direct supervision of Dr. Zhao Yufei, who is a postgraduate research fellow. Along with them, a research engineer and two master's students were also involved.

The main objective was to build a controller to control a Reconfigurable Intelligent Surface (RIS), which was then used for different types of experiments. Therefore, I contributed to the making of the controllers and also to the experiments related to them.

2.2.2 Day-to-day work

In the first meeting with my supervisor, Prof. Yuen Chau, on August 1st, 2023, at SUTD, I was given the opportunity to choose one project to work on out of four. These projects covered areas of robotics, artificial intelligence, and communication. This particular project was chosen since, personally, in my view, it added more value to my portfolio compared to other projects as there were hardware technologies involved, which aligned with my personal preference. Also, the project has been a 6G research project, and a NTU collaboration project surely added to its merit.

I met NTU officials related to the project at the COSMO lab, School of Electrical and Electronic Engineering, NTU (as shown in figure 2.1), on August 2nd, 2023. There, my responsibilities were stated, and the first task was given. Also, details about the project were revealed.

I was supposed to report to the COSMO lab at NTU once per week for the weekly meeting and also on days with experiments. On other days, I reported to SUTD and continued the relevant work at the Gutenberg Lab.

Figure 2.1 COSMO lab, NTU.

2.3 BACKGROUND STUDY

2.3.1 Reconfigurable Intelligent Surfaces (RIS)

Two or three weeks were spent understanding the background needed for the project. Some of the subjects briefed were RIS, electromagnetic waves, and wireless communication. Also, a reasonable amount of time was devoted to understanding the controller of the already existing design.

RISs are programmable two-dimensional surface structures that can be used to control electromagnetic waves by changing the electric and magnetic properties of the surface. Therefore, by placing the surface between a transmitter and the receiver, the signal can be steered, resulting in better reception and link quality.

A transmitted signal usually encounters a wider range of surfaces in its propagation path, resulting in the reflection of the signal in random directions and changing its strength and distortion. RIS provides a way to control the surfaces found in radio channels by directing them in specific directions, which in turn improves the reliability and energy efficiency of wireless systems. A simple illustration of RIS systems can be seen in figure 2.2. They are also referred to as intelligent reflecting surfaces.

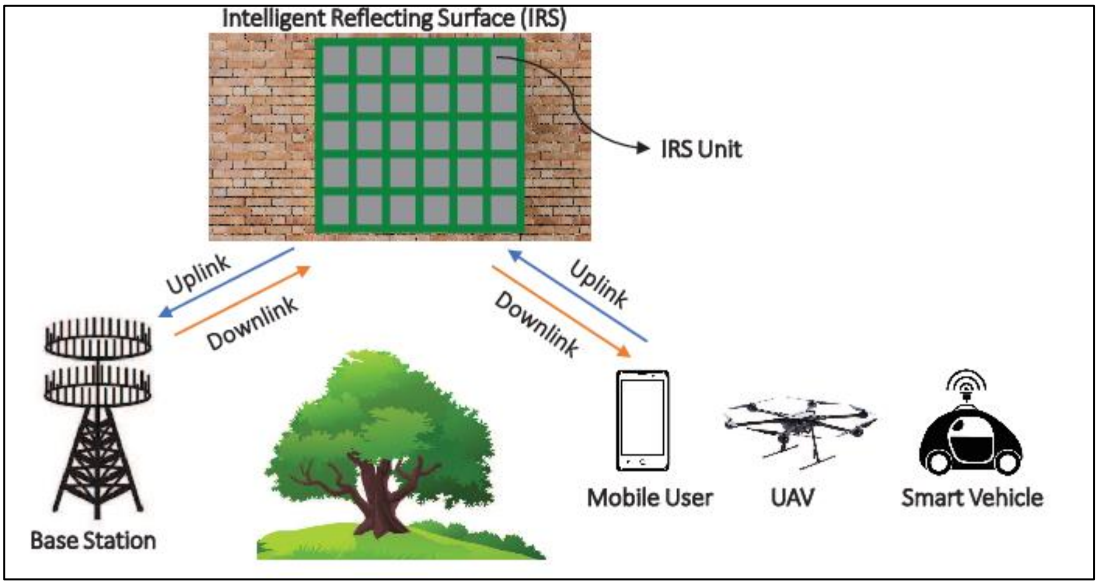

Figure 2.2 Application scenario of RIS

These surfaces can play an important role in 5G and 6G cellular technologies as they go into the mm-wave and THz regions, as these frequency bands cannot propagate very far or penetrate walls like other cellular technologies in the world today.

The individual elements that make up a RIS are referred to as a patch. The number of patches varies according to the size of the total surface. Each patch is a small and discrete element. Patches configured independently contribute to the behavior of the surface as a whole. The surface involved in the project was made out of dielectric material capable of affecting the reflection of the signals by altering the phase and modulation. An image of a patch is shown in figure 2.3.

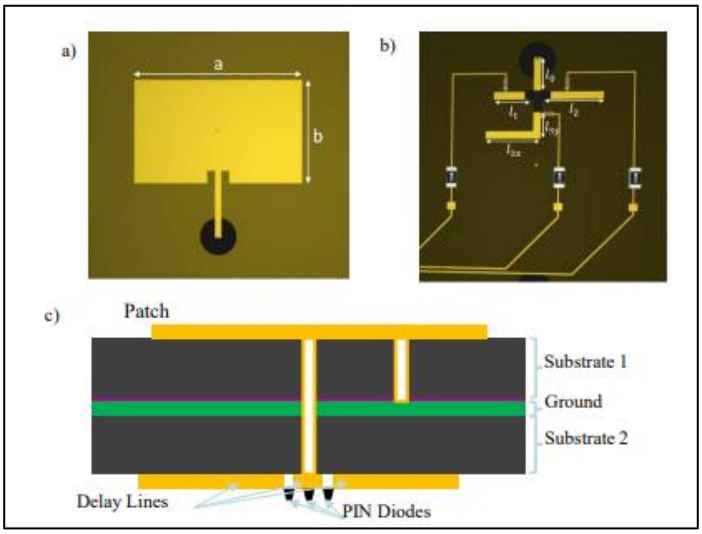

Figure 2.3 One patch of a RIS

By controlling the pin diodes attached to the patches, one is able to control the phase of the waves it is met with. Pin diodes can have a number of states. The RIS prototype worked on in this project had four states to control the phase of the signals.

Once programmed, each patch would introduce a phase shift to the incoming signal, and the incident wave would have alterations. Patches together will be able to reflect signals according to the needed direction.

In this chapter the main project I was involved is introduced and the work that I was involved is briefly introduced as well. In order to get an idea about the type of work an introduction to the topic of Reconfigurable Intelligent Surfaces is given. I was able to gain insights on how research and development projects work in the introduction phase and also gained new knowledge about RIS.

Chapter 3

2-BIT INTELLIGENT REFLECTION SURFACE PROTOTYPE

3.1 INTRODUCTION

This section covers the details about the 2-bit intelligent reflective surface. This was a prototype that was in development at the time of my internship, and I contributed to the controlling aspect of the prototype.

Compared to the 1-bit phase-only shift in the 2-bit phase-only shift, the phase of the waves can be changed by 90 degrees compared to 180-degree shifts in the 1-bit phase-only shift. The unit cell, as shown in figure 2.3, consists of 3 metallic and 3 dielectric layers with the ability to do the phase with less than 0.6 dB amplitude attenuations.

3.2 HARDWARE

3.2.1 IRS board

The prototype consisted of an IRS with 100 2-bit patches capable of shifting the incident waves by multiplications of 90 degrees. As shown in figure 3.1, a 10 x 10 arrangement of patches was customized. It has four different operational states. It operates at a frequency of 10.7 GHz with over 200 MHz of bandwidth.

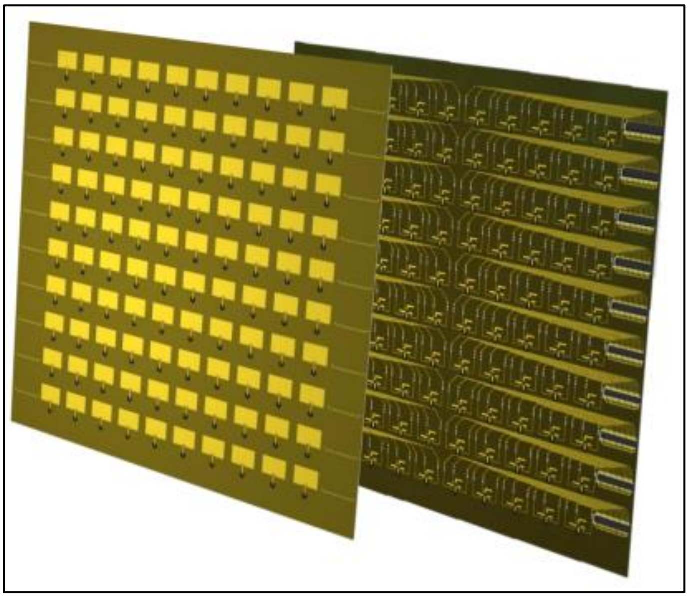

Figure 3.1 Front and back view of the IRS

The front of the IRS board consists of the 100 patches, which are supposed to meet waves and alter their directions, while the back of the board consists of the electronics needed to control the individual patches, compromising pin diodes as well as pins to control the patches. A control system needed to be designed specifically to control this particular IRS board.

3.2.2 Controller

As mentioned above, each individual patch needs to be controlled and designated a state out of the 4 states to make use of the board as a whole. For this purpose, a microcontroller unit was used. This microcontroller was designed using MSP430F5529 Micro Controller Units (MCUs). It consisted of one master MCU and 10 slave MCUs. A patch consisted of 3 inputs corresponding to 3 of the states, and another state was defined by the 3 inputs being all 0. The states and their corresponding phase shifts can be seen in Table 3.1.

Table 3.1 states of the patches with its inputs

Phase Shift (degrees)	Input 1	Input 2	Input 3
0	0	0	0
90	1	0	0
180	0	1	0
270	0	0	1

As three inputs are fed to one patch and there are 100 such patches, 300 inputs are needed to be configurable. The microcontroller compromising the MSP430F5529 MCUs had 502 I/O general-purpose pins built for this particular reason. Out of the 502 pins, only 300 were used, and others were reserved in case there was any change in the size of the IRS board and extra pins were needed. Figure 3.2 shows the microcontroller.

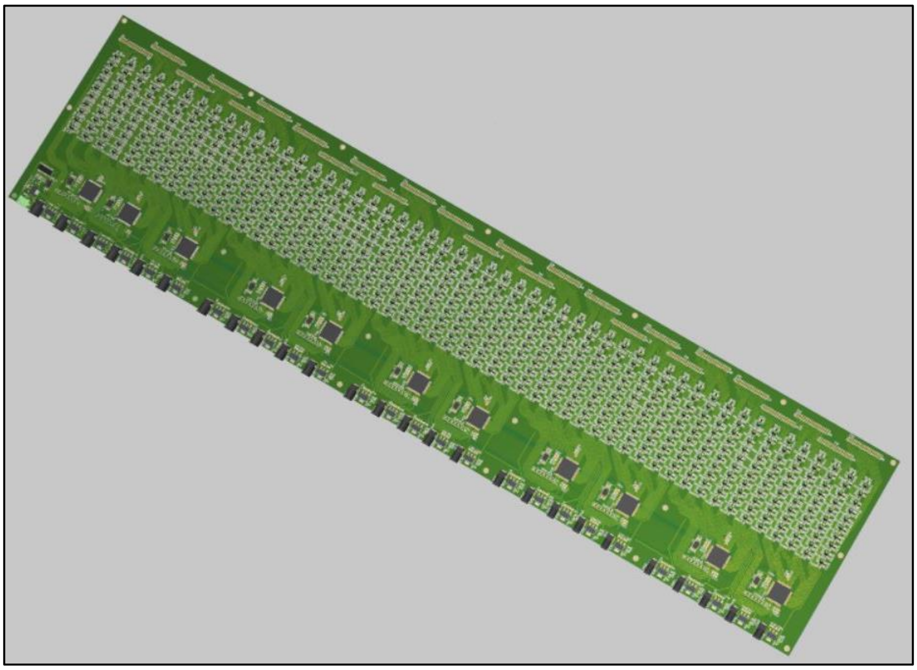

Figure 3.2 Control board consisting the MSP430F5529 MCUs

The microcontroller uses p-channel mosfets to send the data; therefore, negative logic needs to be provided by the MCUs. Figure 3.3 shows the power supply and the cables that were drawn from the microcontroller board to the RIS board to facilitate communication between them. 21 lines of 5V power lines are supplied.

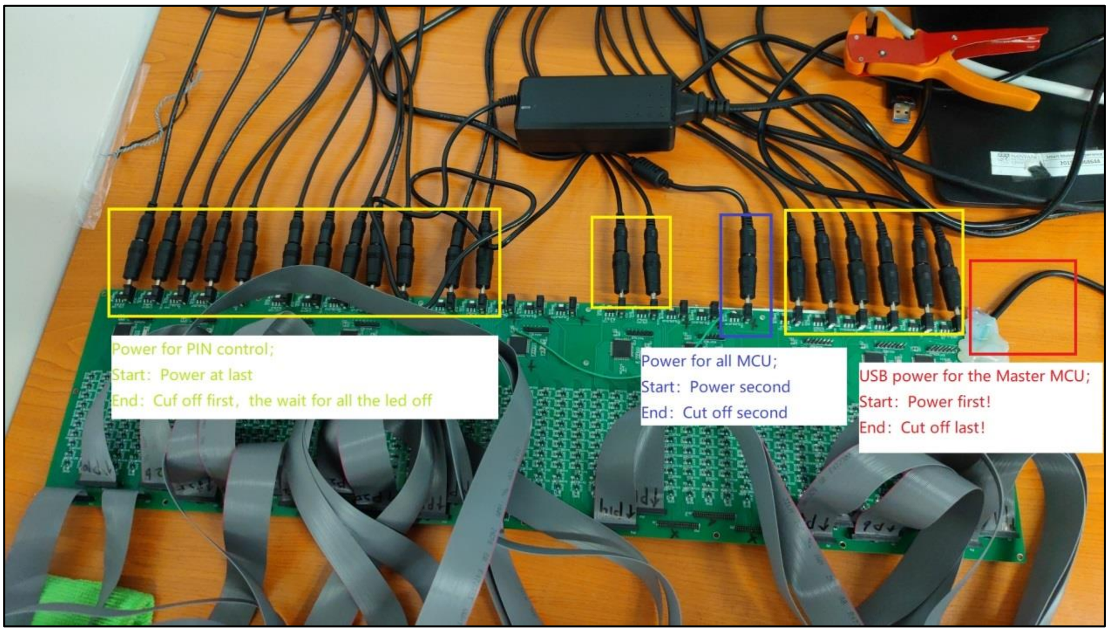

Figure 3.3 Layout of the controller connected to the power supply.

3.3 CONTROL LOGIC

3.3.1 Control logic of microcontroller

One configuration of the board can be referred to as a pattern. A pattern depends on what type of behavior is needed from the RIS. For instance, figure 3.3 shows the states of the hundred patches needed to reflect an incoming signal to the right (as seen from behind the RIS) by 5 degrees in nearfield. This configuration is experimented with and set accordingly.

2	2	2	3	3	3	3	3	3	0
2	2	2	3	3	3	3	3	3	0
2	2	2	3	3	3	3	3	3	0
2	2	2	3	3	3	3	3	3	0
2	2	2	3	3	3	3	3	3	0
2	2	2	3	3	3	3	3	3	0
2	2	2	3	3	3	3	3	3	0
2	2	2	3	3	3	3	3	3	0
2	2	2	3	3	3	3	3	3	0
2	2	2	3	3	3	3	3	3	0

Figure 3.4 States of the 100 patches for a particular pattern

After the configuration is finalized, this pattern needs to be provided to the microcontroller, which in turn sets the actual states of the patches. After experiments, the switching time between two patterns was discovered to be 10 ms. Figure 3.4 shows the detailed diagram of how the MCUs carry out the process of setting the states of 100 patches.

A computer was needed to feed the pattern to the microcontroller through a UART connection, which is facilitated using a USB cable. The pattern will be shared by hexadecimals, and the size is 65 bytes. The first two bytes are a constant '2041', which is the address of the master MCU.

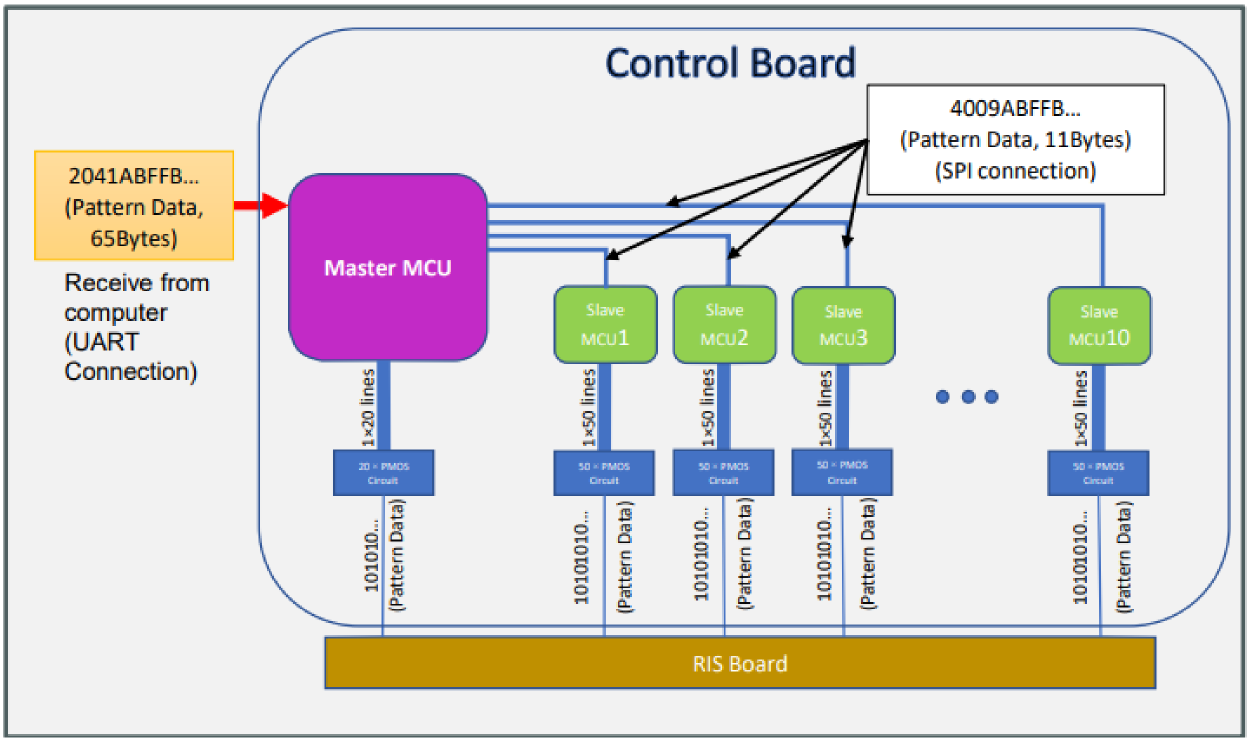

Figure 3.5 Design flow of the control board

The master MCU will receive the pattern and divide it into 11 sections. 10 sections will be fed to the 10 slave MCUs. Then the MCUs will proceed to send the data through to the PMOS circuit, which is connected to the RIS board. 300 bits need to be configured in order to set one pattern on the RIS board. By using 10 slave MCUs, this process can be accelerated. Figures 3.5 and 3.6 show the control flow of both the master MCU and a slave MCU.

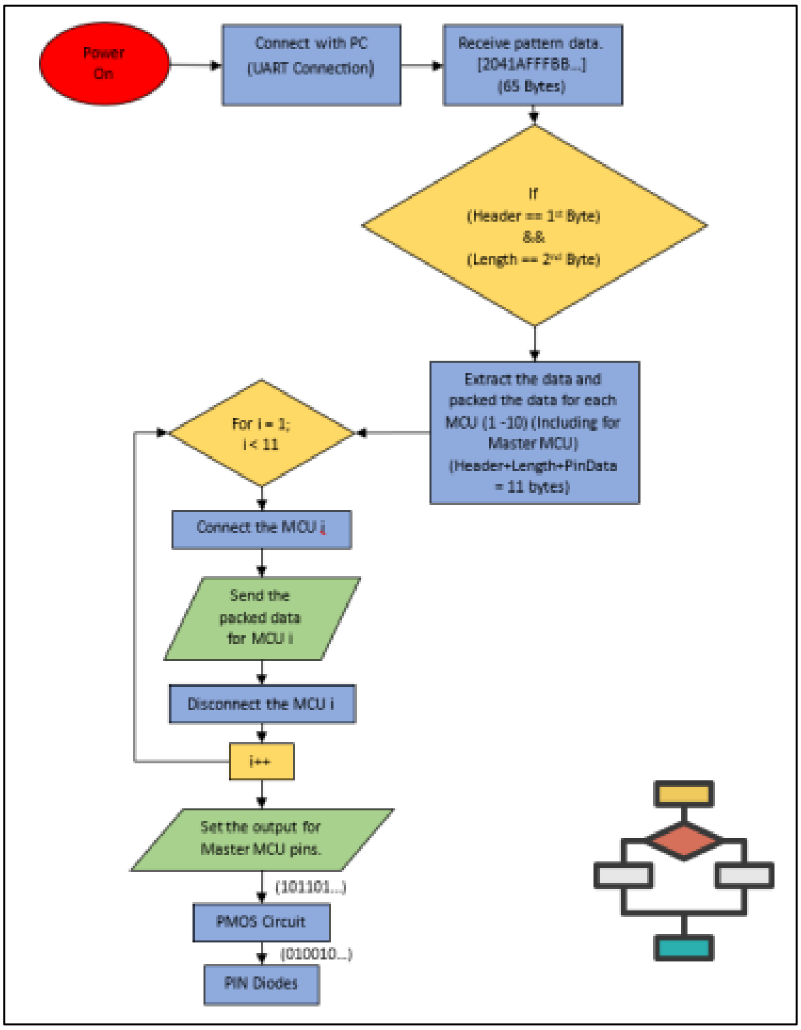

Figure 3.6 Master MCU Data Flow

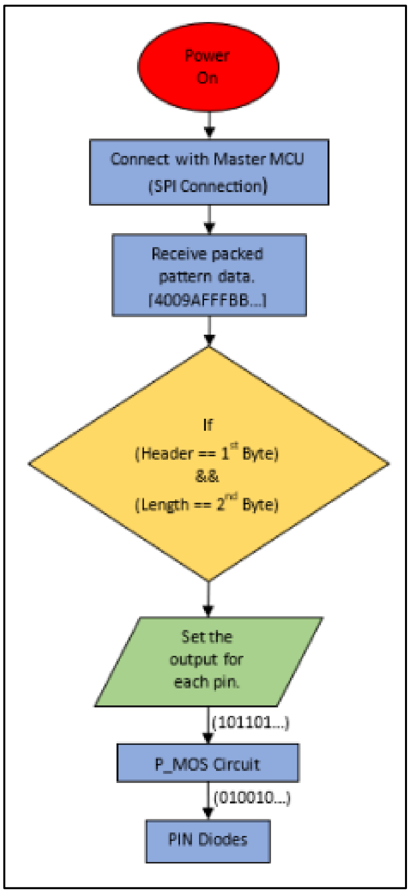

Figure 3.7 Slave MCU data flow

The master MCU receives 65 bytes as hexadecimals from a computer via UART. After that, 11 bytes are sent to each of the slave MCUs. After that, the master MCU proceeds to set 20 pin diodes through the P mosfet circuit, while the slaves set 50 pin diodes.

3.3.2 Pattern generation

As the setting of the bits in the RIS system is automated, the user only needs to provide the bits needed for the desired pattern of the RIS board. This can be done through software that facilitates UART communication. For this purpose, Matlab was used with custom interfaces created through the Matlab app. 300 individual bits needed to be configured, corresponding to the 100 patches, each having 3 configurable bits. Figure 3.7 shows the process of converting the pattern to the hexadecimal input needed by the microcontroller.

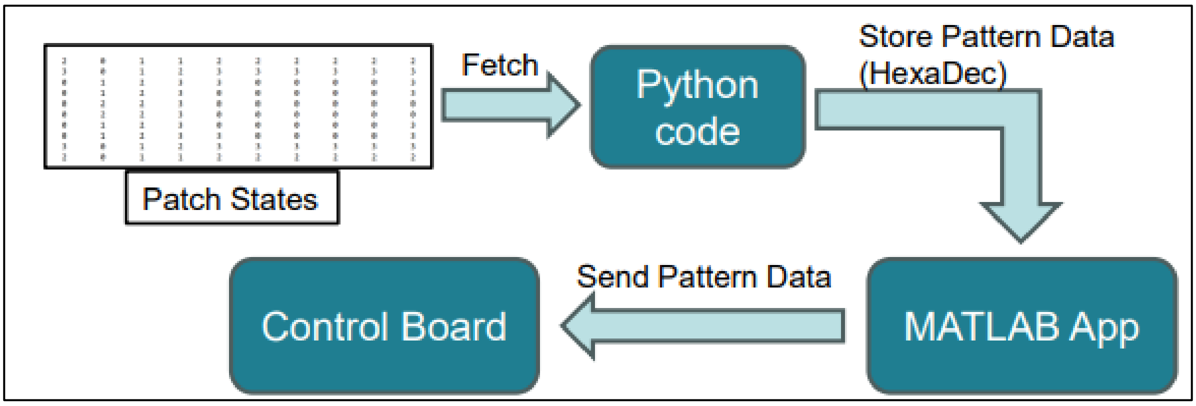

Figure 3.8 Process from setting the pattern on the control board

As shown in figure 3.7, after the patch states are defined, they are converted to a 65-byte hexadecimal and registered in the Matlab app. This way, a user may open the Matlab app and choose a desired pattern, which will then be sent to the control board. Figure 3.9 shows how the patches of the RIS were addressed. As it shows on the back of the RIS board, the bottom leftmost patch is actually the top leftmost patch and is referred to as Patch 11.

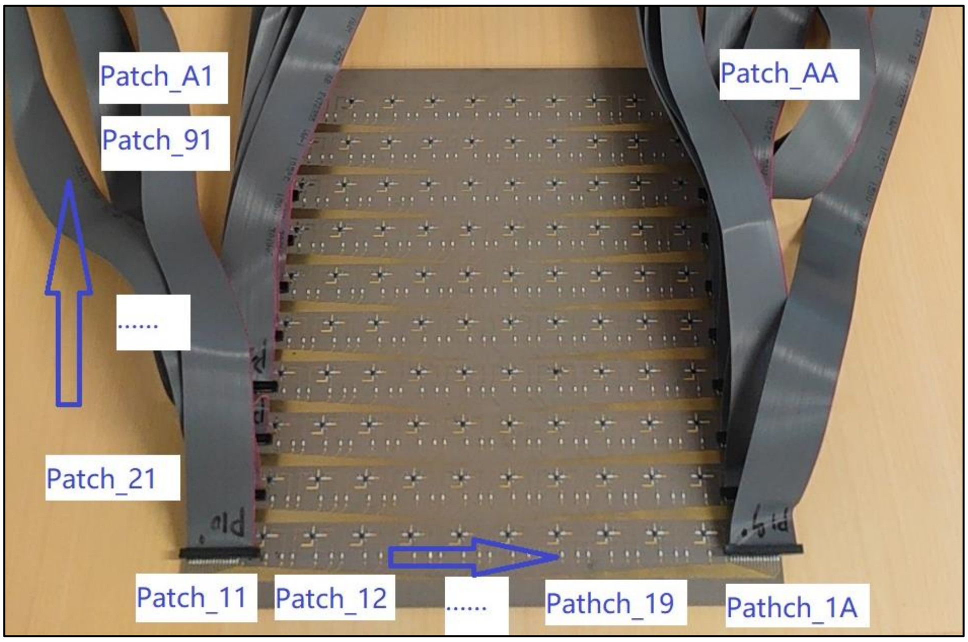

Figure 3.9 The patches of the RIS labeled

Table 3.2 consist how each patch needed to configured according to some given pattern.

Table 3.2 Translation of patch states

Patch Number	Patch Inputs2,3,1	Encode	Encoded Byte	Hexadecimal
Patch_11	2	0		
	3	1		
	1	1		
Patch_12	2	1		
	3	0		
	1	1		
Pacth_13	2	1		
	3	0		
	1	0	011101100	76

This continued for 100 patches, and the code used for the translation of the pattern is given in Annexure 1. All 502 bits of the microcontroller needed to be programmed, and the unwanted bits were padded with 1.

3.4 MATLAB GUI

To add to the usability of the RIS controller a Matlab GUI was made. The interface can be seen in figure 3.10.

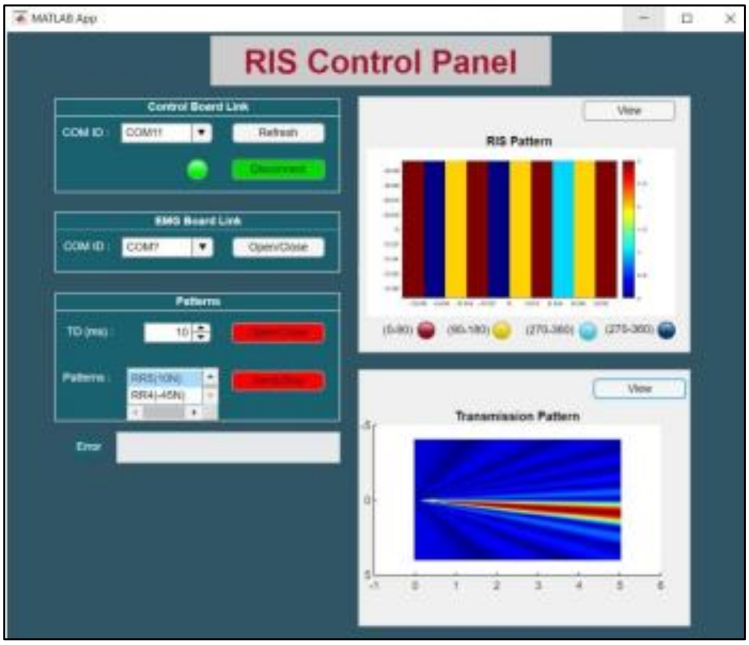

Figure 3.10 Matlab GUI

It has a communication panel to choose the communication port once the RIS controller is plugged in, and a list of patterns that have been converted and are ready to be fed to the RIS. Also included is a graphical representation of the states of the patches and a representation of the resulting wave.

Also, in order to test out multiple patterns in quick succession, a timer can be set. If 1s is chosen with the needed patterns, the software will send the selected patterns in a loop with a 1s gap in between. As mentioned previously, the minimum time gap is 10 ms.

In this chapter, the 2-bit Intelligent Reflective Surface prototype was introduced, and its hardware and software design were discussed. Also, the mechanism involved in practically implementing the reflection of a signal was discussed, starting from the needed direction and setting the pattern in the actual device.

I had already learned Python and Matlab coding; therefore, they were used in building the software solution mentioned in this project. Also, to maintain code between the computer at the office and my personal laptop, the version-control software Github was used.

In the context of this chapter, I started to hold responsibilities for an actual project, and it was a new experience. Also, the controller used in the prototype was something I hadn't come across before; therefore, it was interesting to learn about that.

Chapter 4

EXPERIMENTS

4.1 INTRODUCTION

This chapter contains experiments carried out using the IRS prototype mentioned in the previous chapter. The experiments took place in the COSMO lab at NTU and also in the Antenna and Scattering Processing laboratory at the National University of Singapore (NUS).

4.2 COMPARATIVE EXPERIMENTS

4.2.1 Control Flow

The full system to control the RIS board consists of a computer with Matlab, data cables supporting UART, power lines, a control board, control cables, IRS, and the power supply for these components. Figure 4.1 shows these components put together and ready for experiments.

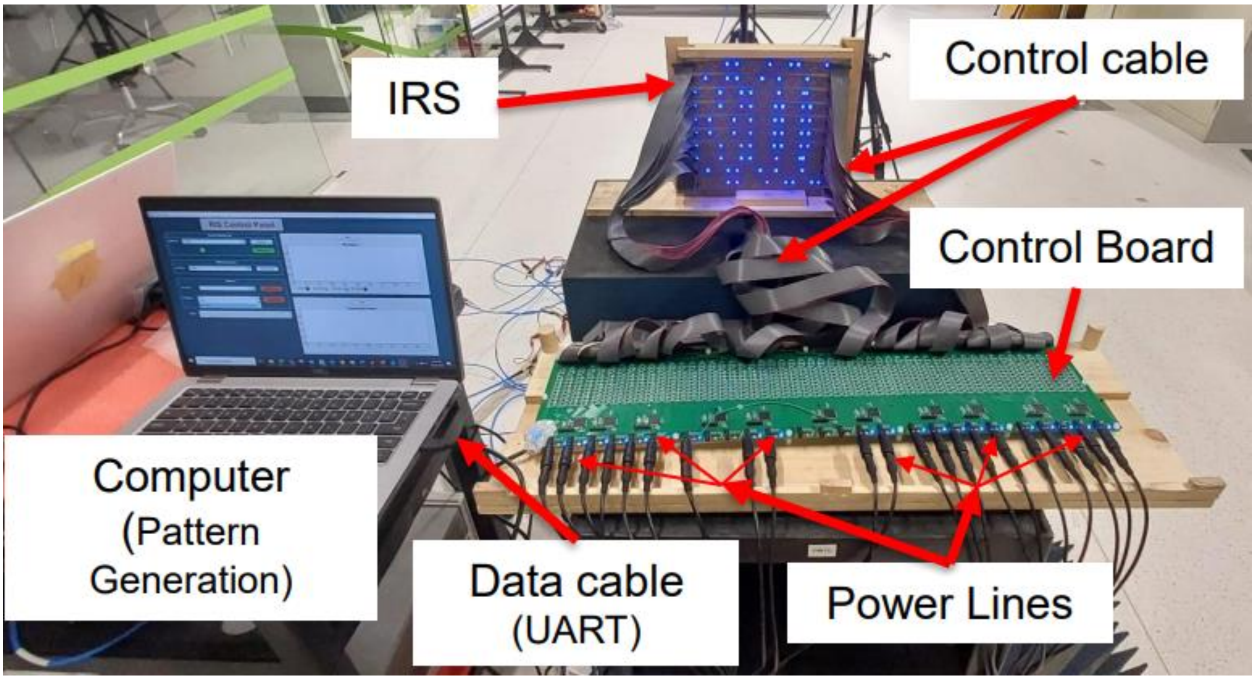

Figure 4.1 Experiment setup of the RIS and its controller

First, the needed patterns needed to be encoded and written in the Matlab application, as mentioned in the previous chapter 3.3. After powering up the components and connecting the data cable, the user can choose any of the patterns installed in the software. The control flow is shown in Figure 4.2, including the transmitters and receivers.

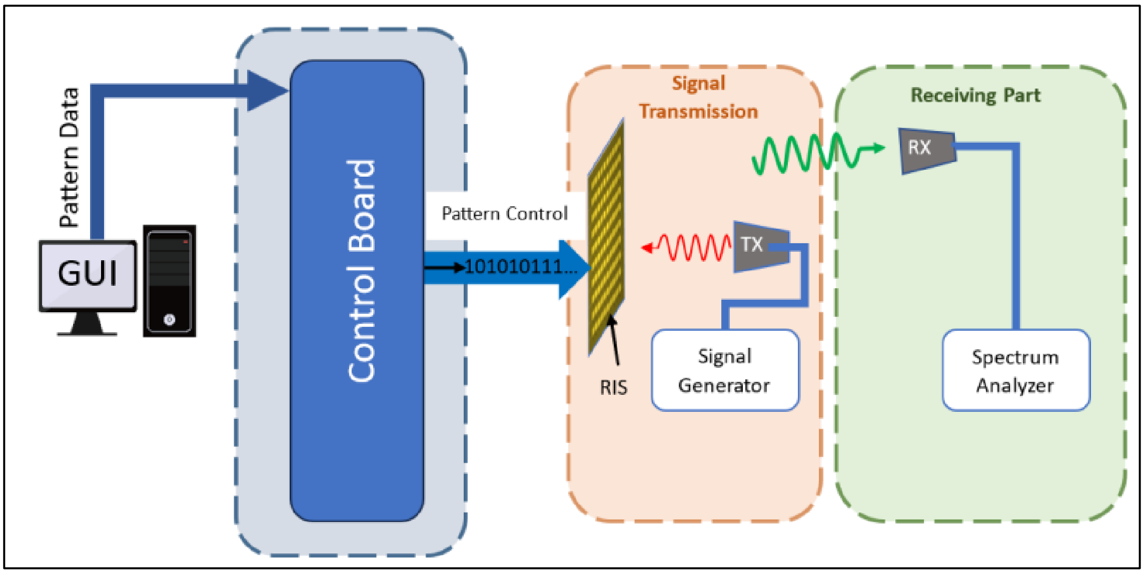

Figure 4.2 Overall experiment setup

A signal generator is used to generate a signal, and a transmitter connected to it will transmit the signal in the direction of the RIS. This experiment needs to be done at 10.7 GHz, as the RIS facilitates waves at that frequency. Receivers may be stationed at needed places in the experiment stage to test the reflected signals of the RIS. For this, a spectrum analyzer can be used at the receiver's end along with the receiver antenna.

4.2.2 Experiment setup

The experiment set up can be seen in Figure 4.3. This was done in the corridor outside the COSMO lab at NTU.

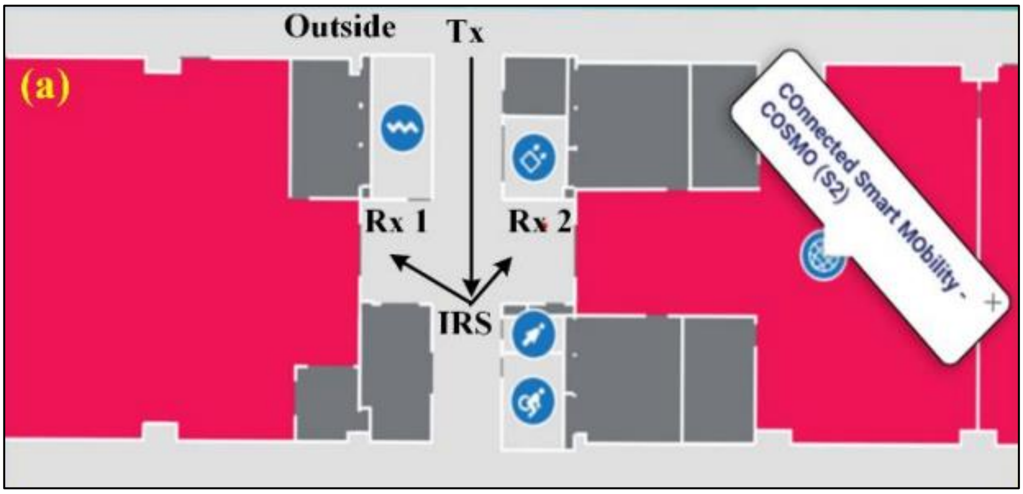

Figure 4.3 Plan view of the experiment setup

TX is the reflective antenna used to generate a single carrier pointed directly at the IRS. RXs are the standard gain-directional antennas connected to the spectrum analyzers.

The TX is set to a frequency of 10.7 GHz and a power of 10 dB. There is a line of sight from the TX to the IRS, and the RXs and the TX are not in any line of sight. Scenario 1 of the experiment is done by having no IRS or any other reflective object along the line of sight of the TX. Figure 4.4 shows this setup.

Figure 4.4 Experiment setup of scenario 1

In scenario 2, a metal plate is positioned on the line of sight of the Tx. The metal plate is made out of copper and is reflective. Once the transmitter is set, the receivers will pick up any signals at 10.7 GHz coming from their pointed area. Figure 4.5 shows scenario 2. These data are recorded.

Figure 4.5 Experiment setup of scenario 2

In this final scenario, the IRS is set in the line of sight of the transmitter. Then the pattern that corresponds to reflecting the signal towards the right is set on the IRS. After that, Rx1 and Rx2 readings are recorded. After that, the pattern that corresponds to reflecting the signal to the left is recorded, and the readings are recorded. The reflection is done according to a specific value in degrees. Figure 4.6 shows the experiment setup for scenario 3.

Figure 4.6 Experiment setup of scenario 3

Finally, the results are observed, and conclusions are drawn. Table 4.1 includes the experiment scenarios and their results.

Table 4.1 Experiment results

Experiment	Position 1 RSSI (dBm)	Position 2 RSSI (dBm)	Middle Position RSSI (dBm)
No RIS	-	- 61.2	- 56.6
Metal plate	-	- 49.6	- 40.6
RIS points to position 1. (30° left)	- 35.8	- 51.7	-
RIS points to position 2. (50° right)	- 41.7	- 40.6	-

It can be seen that the metal plate only provides specular reflection and is not adaptable to dynamic communication environments. The reflection is fixed by physics. On the other hand, the RIS is able to change its beam angle and direction on demand with a small beam-forming gain compared to the metal plate.

Therefore, as a conclusion, it can be said that the IRS prototype demonstrates active beam control and is capable of steering the beam to non-mirror-symmetric angles.

A video of the experiment made by the Filmora video editing software can be viewed at RIS_experiment.

4.3 REBUILDING THE WIRELESS COMMUNICATION NETWORK

Another application of the RIS would be to reconnect a lost communication network by trying out different reflection configurations. If the signal strength is getting bad for a certain user in some particular area, adjusting the RIS and reflecting the signal towards that particular area with a low signal connection can be reestablished.

The experiment can be setup in the same manner as scenario 3 in the comparative experiment with the RIS board. These time modulation techniques are used to further enhance the quality of the experiment compared to normal plane waves. 16 QAM modulations are used in digital communication, which combines both phase modulation and amplitude modulation. The clarity of the received signals can be understood by the constellation diagram, with the points arranged in a square grid.

The 16 QAM carrier signal can exist in 16 different states, and each state represents a combination of amplitude and phase levels. The modulation was done using the LabView software. A set of data was modulated and fed to the signal generator, which would transmit the signal directly to the IRS. Then a receiver would pick up on the signal based on how the IRS is configured. Figure 4.7 shows the experiment setup.

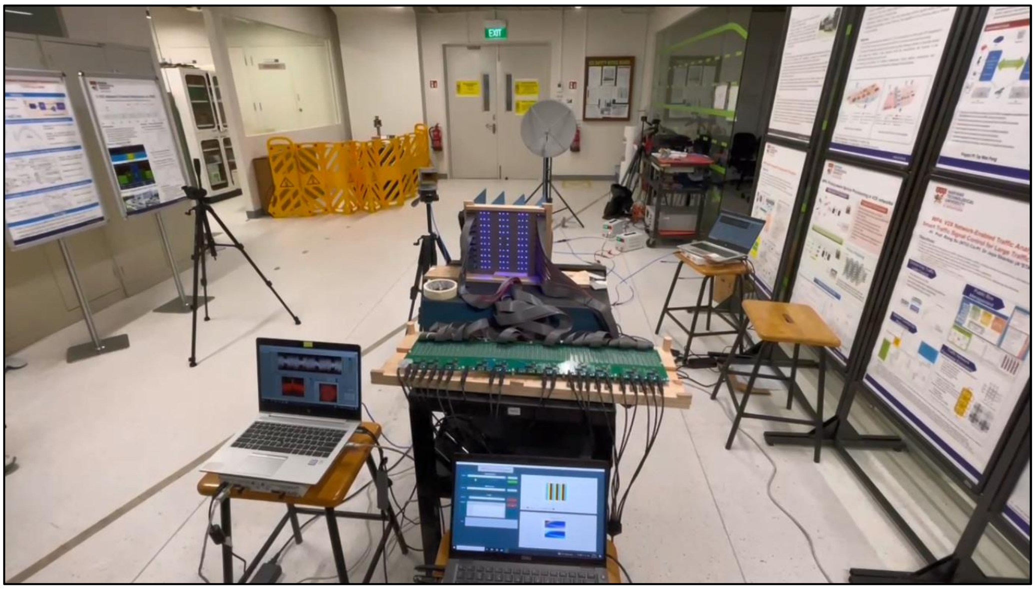

Figure 4.7 Experiment setup for Rebuilding the Wireless Communication Network

The transmitter antenna generates a data stream at 10.7 GHz. The receiver is located on the left, 30 degrees from the perpendicular incident from the transmitter to the RIS board. Initially, the RIS is set to reflect the signal to the left by 30 degrees. Then the data stream can be demodulated, but as soon as the configuration of the RIS is changed to the right side by 20 degrees, the constellation is disturbed. Again, if the configuration is shifted to the left by 30 degrees, the constellation is recovered. This is how the rebuilding of the communication network was tested.

4.4 RIS BEAM TRACKING FOR A MOVING USER

Another application where the RIS can be used is when there is a moving target of interest in the communication system. The moving target may experience numerous barriers in communicating with a base station as the signal can reflect and bounce off various obstacles. In this case, an intermediate RIS system may be able to support such a dynamic connection by automatically changing the configuration based on the position of the target and helping restore the connection.

As in previous experiments, the signal generated is at 10.7 GHz. The moving target is represented as a horn antenna. At first, the connection is stable and established via the RIS board. As shown in figure 4.8, the experiment is done by moving a receiving antenna. A program is fed into the RIS board to start trying out different patterns in order to find the pattern with the most accurate signal demodulation. This is referred to as beam-sweeping.

The target will find the best serving signal and give feedback to the RIS using the TCP protocol, which is related to the programme running in the RIS. After it is found, the programme is stable and communication is reestablished. The pseudocode for the beam sweeping can be found in Annexure 2.

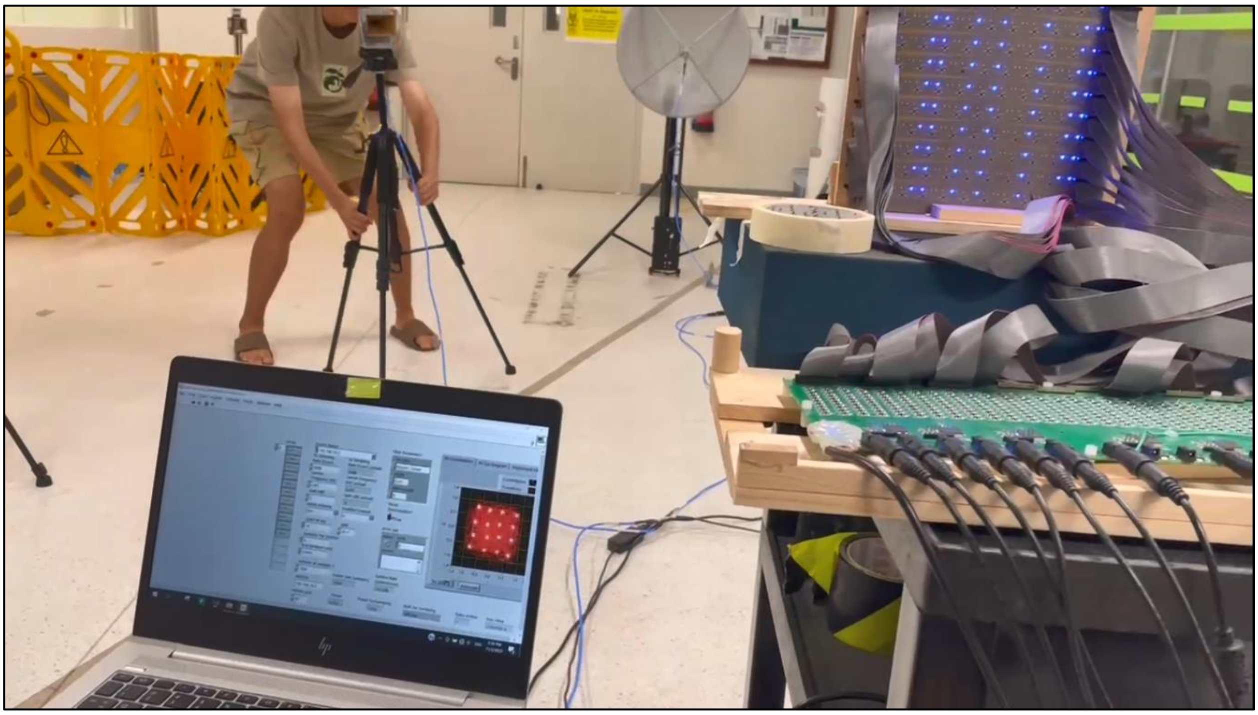

Figure 4.9 Experiment setup for RIS beam tracking for a moving user

A video demonstration for the two experiments Rebuilding the Wireless Communication Network and also RIS beam tracking for a moving user can be found at Experiment 2 and Experiment 3. These video demonstrations were created using Filmora video editor.

4.5 EXPERIMENTS AT THE ANECHOIC CHAMBER

4.5.1 Anechoic chamber

An anechoic chamber is a room designed to minimise the reflection of sounds and electromagnetic waves. These rooms have sound-absorbing material on the walls, ceiling, and floor to create an echo-free environment. Such a lab can be found at the Antennas and Scattering Processing Laboratory, NUS College of Design and Engineering. It can be seen in figure 4.10. It is used for near-field experiments. The lab is a property of the DSO National Laboratories.

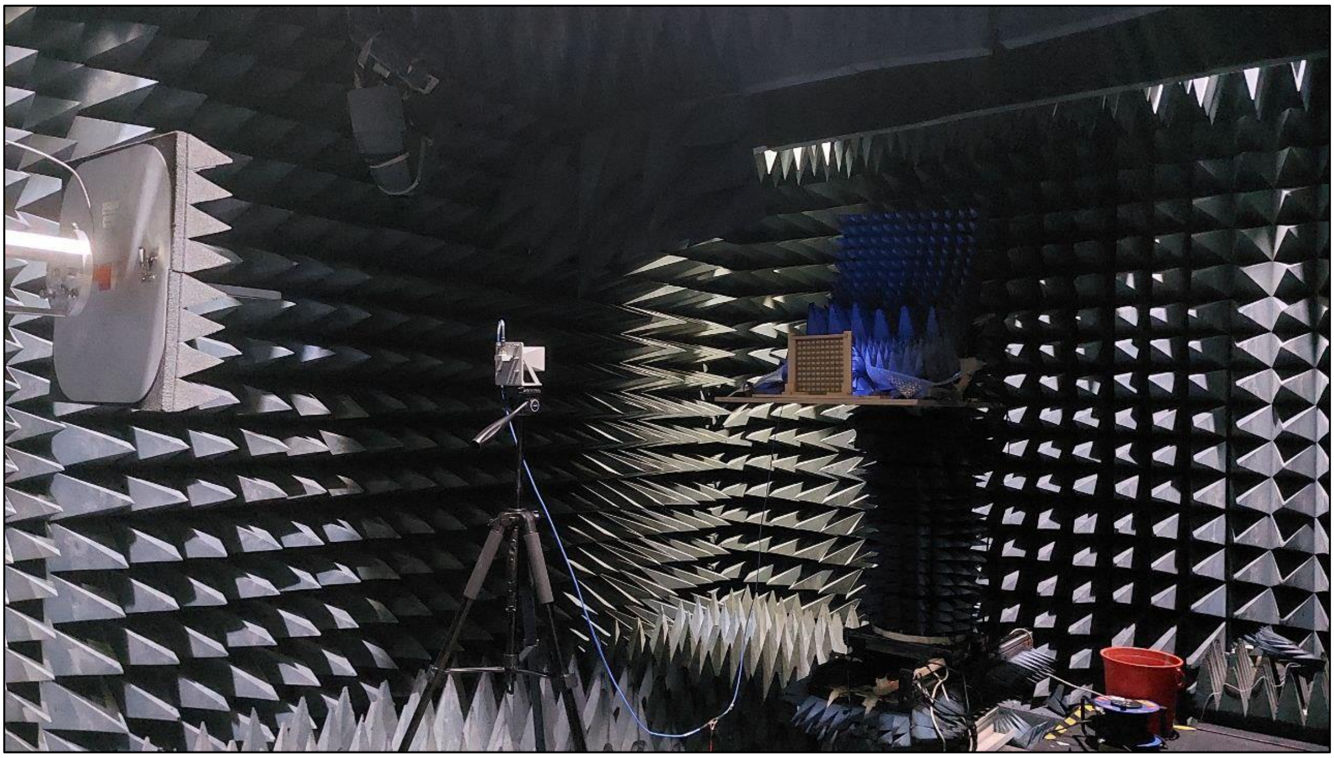

Figure 4.10 Anechoic chamber, NUS

This chamber was used by the research team for a total of two weeks in order to get more precise and accurate results and to avoid various environmental disturbances and obstacles. It is important to verify the proper configuration of the RIS board, as the results obtained are very sensitive to various adjustments, unlike in the real world.

4.5.2 Operation of the anechoic chamber

In order to perform experiments, the RIS is set accordingly with its controller, and power is supplied. Then a transmitter is placed in front of the RIS to transmit plane-wave signals. On the right of figure 4.10, a receiver can be seen catching any signal of a given frequency. When the experiment starts, this receiver moves in a 2D plane on a specified x and y axis and catches and stores data on the amplitude and phase of the waves it is met with at these positions. Figure 4.11 shows the instruments responsible for performing the scan of the receiver.

Figure 4.12 Computer system for the anechoic chamber

Once these instruments are set and activated, they will record the data of the signals they receive. In the 2D plane, the receiver will start from and move along the line of x = 0 and move on from there to different x values on the plane. Usually, one experiment would take around 10 minutes to complete. Therefore, testing one pattern of the RIS board took that amount of time.

4.5.2 Testing OAM patterns.

During my time with the team experimenting in the anechoic chamber, we spent a considerable amount of time experimenting with OAM waves, or orbital angular momentum waves. That is, the RIS was set to turn the plane waves it was receiving and reflect back OAM waves.

OAM refers to the angular momentum associated with the spatial distribution of electromagnetic waves. Instead of traditional modulation techniques such as amplitude and frequency modulation, OAM modifies the phase structure of the wave front. There are different modes when it comes to modulating these waves, and they can be used for high-capacity and long-distance communication.

Figure 4.13 shows the states of the 100 patches for trying out mode +3 on a RIS board.

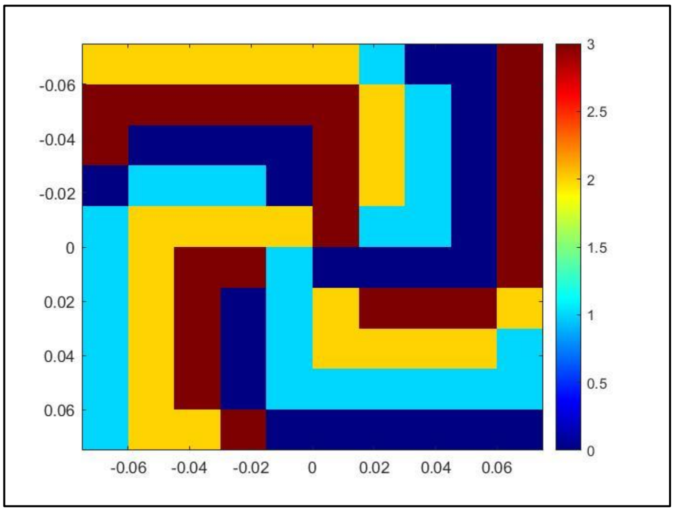

Figure 4.13 States of the 100 patches for OAM mode +3

4.5.3 Results of the experiments at Anechoic Chamber.

The results of the experiments were given in text file and they were translated into a plot using a program developed by Matlab. For instance the raw data given for testing mode +1 of OAM can be seen in figure 4.14.

```
File    Edit    View

Test Title:     PLN test
Date:   31/8/2023
Time:   12:19 PM
Operator Name:  User
Comment:        Freq: 10.7GHz
Source Power: -16dBm
+20dB Amplifier

[Scan Axis] Name:       Y  [mm]
Start:  -500.000000     Stop    500.000000      Increment       10.000000
[Step Axis] Name:       X  [mm]
Start:  -500.000000     Stop    500.000000      Increment       10.000000
[Tert] Name:    None
[Forth] Name:   None
 [ Freq.]  (Single)     GHz.    10.700
 [Switch]       Beam_1
 [Channel]      CH1
 [ Beam]        None


Database:
First Question
2nd
3rd
4th

Frequency       10.700  GHz
Step Axis :X  [mm]      -500.00
Channel CH1
Switch  Beam_1
Scan Axis name  Y  [mm]
Scan Axis       Amplitude       Phase

-500.00 -61.800 47.236
```

Figure 4.15 Example of the data collected at Anechoic chamber

This needed to be read and converted into a plot for a better understanding of the results. It contained both data about the magnitude and the phase. After the programme was done, the results and plot can be seen in figure 4.16.

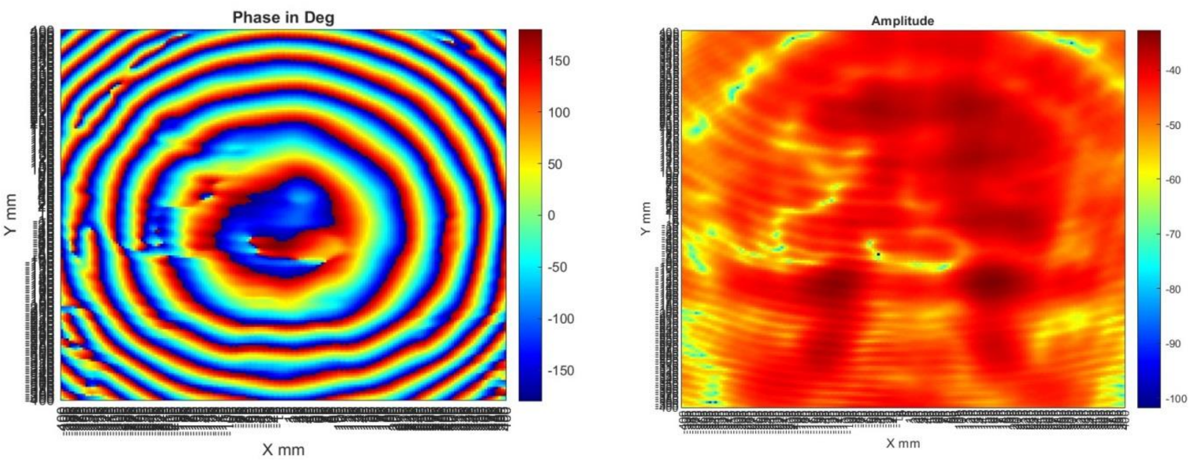

Figure 4.16 Phase and Magnitude plots of the OAM experiments

As shown in this particular experiment the configuration of the RIS is fairly good but can be further accurate. Further adjustments were made by changing such parameters as,

- The pattern.
- Distance from the transmitter to the RIS.
- Distance from the receiver to the RIS.
- Power of the transmitted signal.
- Adjustments to the placement of the absorption material.

The experiments related to OAM waves were carried out past my internship period as well and I believe improved results were obtained and published.

4.6 SAFETY DURING EXPERIMENTS

Safety was the utmost consideration when doing these experiments. As it can be seen from Figure 4, Four safety cones were placed throughout the corridor as it was a public space and people went through it. The cones were placed near the items of interest for the safety of the public. Also, safety guidelines specific to the anechoic chamber were followed. Figure 4.17 shows some of the instructions mentioned in the laboratory.

Figure 4.17 Safety guidelines at the Anechoic chamber

It was mentioned that the area was a toe-covered shoe area since a large number of electrical object were present in the lab. Also I noticed that there were some instructions for putting a harness for experiments which involved a much bigger antenna which needs a platform with railings which could be elevated.

Also included in the guidelines were the plan of the building with fire exits and fire exit paths noted. As such important emergency protocols were displayed. They included,

- More than 20 seconds of the fire alarm sounding meant there was a live emergency.
- Activities needed to be stopped and if possible electrical items needed to be removed.
- Everyone should evacuate the building and gather at the emergency assembly point which was the car park next to the building.

The experiments done with the prototype device are mentioned in this chapter. Mainly, five experiments were done. It was very exciting to take part in these experiments, as it gave us a chance to test out the prototypes. Through this, several key points were learned by me. Mainly, experiment setups, experiment procedures, safety procedures, and methods to change different factors in the experiment were learned.

Chapter 5

VERSION 2 OF 2-BIT INTELLIGENT REFLECTIVE SURFACE PROTOYPE

5.1 INTRODUCTION

This chapter contains details of work done on building a second version of the existing IRS unit mentioned in the previous chapters. This new design is much larger in size in terms of the area of the IRS but smaller in size when it comes to the controller.

5.2 THE DESIGN PLAN

The existing design of the IRS is small in surface size. There are only 100 patches, and it is only suitable for near-field communication. By designing a much larger IRS prototype, new application areas can be uncovered and investigated. This decision also had backing from the project stakeholders. The plan was to create a control system to support four times the number of RISs compared to now. That would mean controlling 400 patches, meaning controlling 1200 bits and also other control bits. One option is to have more MCU units, as mentioned in Chapter 3, but that would mean having more resources, and the end prototype would be a very large prototype, which could be harder to do experiments with and also would not impress the stakeholders.

Consider figure 5.1 which consists a similar controller designed for a different metasurface.

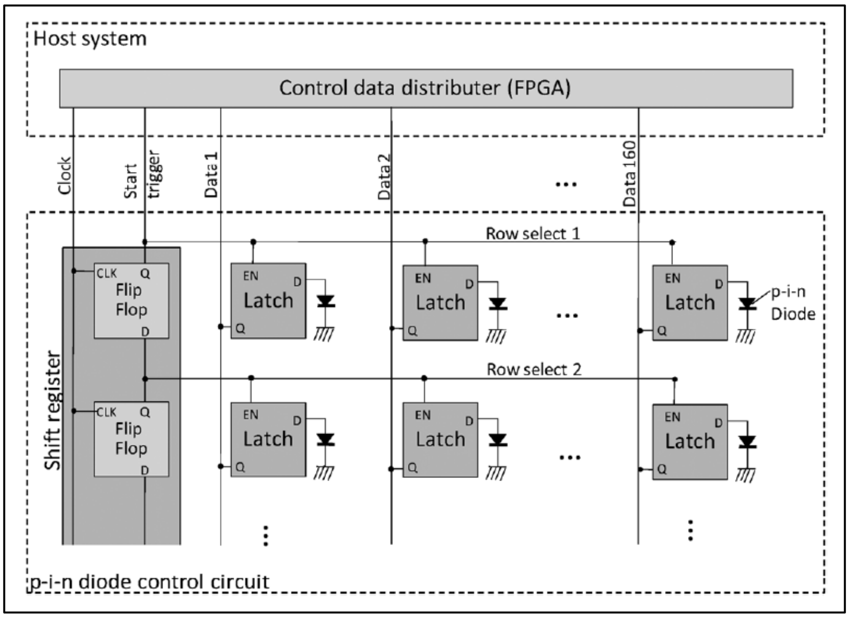

Figure 5.1 Proposed design for the new IRS system

5.2.1 Working principal

In figure 5.1, the developers use a shift register to shift the region of interest from one row of pin diodes to the next. This principal can be successfully implemented on the IRS controller as well.

As stated, the 1200 pins need to be controlled by the new IRS board. If this is divided into 40 data lines, they can all be controlled using a 16-bit shift register, as the number of bits that can be controlled is 1280. It should be noted that they are controlled concurrently but consecutively. After the latches shown in figure 5.1 are matched with the pin diodes of the IRS, the 40 bits that are supposed to be meant for the first row are sent on the data lines, and at the same time, the first row is enabled by the shift register, setting the pin diodes of the first row to the value of the data lines. As such, all 32 rows of latches are set. The value that needs to be inputted into the shift registers is 1, followed by fifteen 0s. This is because, by then, all other rows will be disabled and only one row will be active. This needs to be done for both the shift registers and needs to be controlled by the controller.

5.2.2 Choosing the controller

Mainly, the controller used in this design needed to have around 45 General Purpose Input Output (GPIO) pins, as 40 data lines needed to be controlled with some control lines. For this purpose, specifically, the Launch XL-F28379D microcontroller was used. The microcontroller can be seen in figure 5.2. It is based on the MSP430F5529 MCU.

Figure 5.2 Launch XL – F28379D microcontroller

5.2.3 Other components

Table 5.1 Other components used other than the microcontroller and their purpose.

Component	Objective	Reference
Shift Register 16 Bit	To shift the active row one by one.	https://www.digikey.com/en/products/detail/rochester-electronics-llc/74F673APC/11551966
D Latch	To latch on to the assigned value and pass it on to the pin diode.	https://www.mouser.sg/ProductDetail/Texas-Instruments/SN74LVC1G373DBVR?qs=pajgIaoyDUhGcf%252BSO1j05w%3D%3D
D Sub 50	This D sub is used as an interface for the data lines from the microcontroller to the RIS board.	https://www.mouser.sg/ProductDetail/TE-Connectivity/5787190-5?qs=Lu3apKW7jUjY%2FX2S9sNwow%3D%3D
LDO	In order to regulate the voltage power supply of 5V to the required value of 3.3V.	https://www.mouser.sg/ProductDetail/Diodes-Incorporated/AZ1117IH-3.3TRG1?qs=cpo3%2FpBou2jnS4SxLgAVoA%3D%3D
Header	This is to facilitate the connection between the MCU and the PCB. Once set to the PCB the MCU can be placed on top.	T821120A1S100CEU Amphenol Commercial Products | Mouser Singapore

5.2.4 Design Overview

Figure 5.3 shows the design overview of the expected system. It comprises of the components selected and their connections.

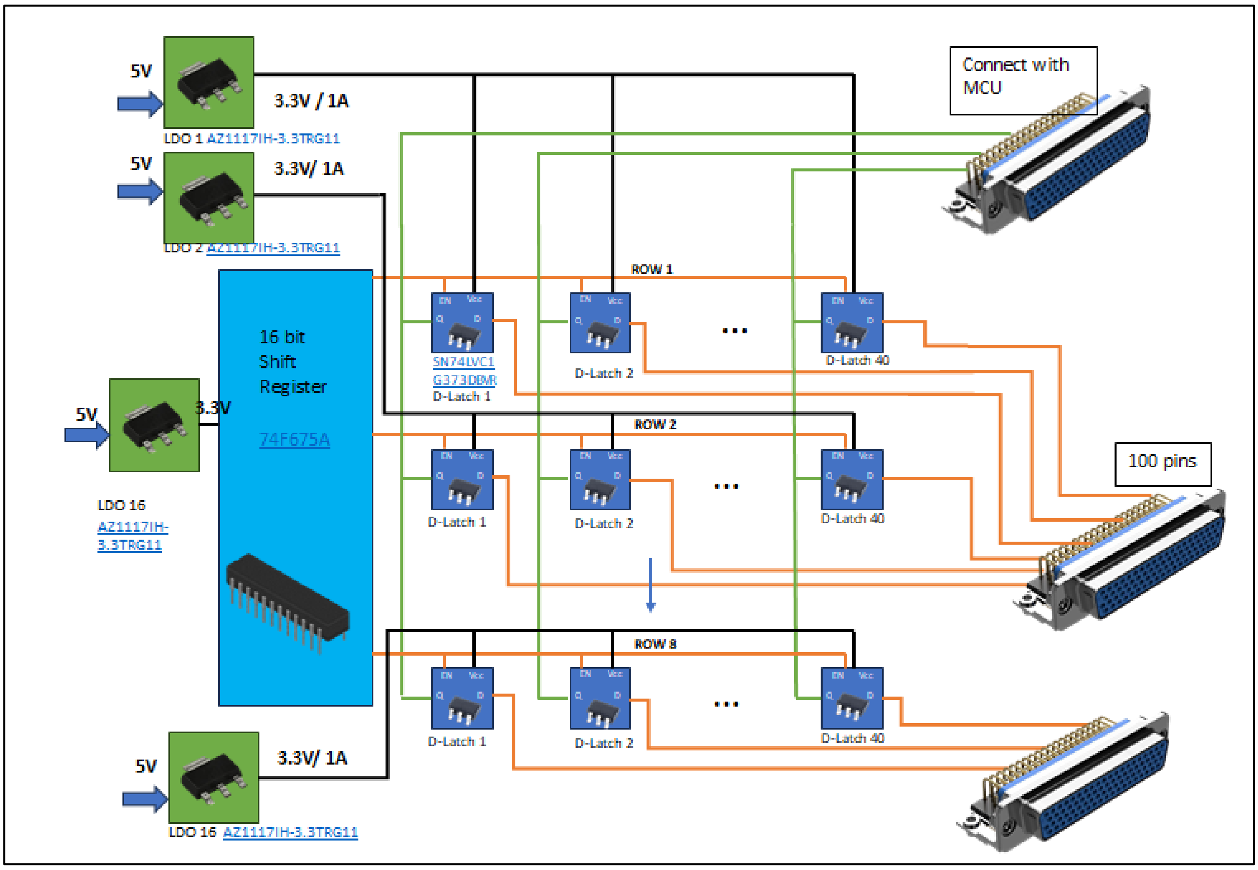

Figure 5.3 Overview of the new IRS system

5.3 PCB DESIGN

A PCB needed to be designed to facilitate the components. I contributed to the part of the PCB where the microcontroller and D sub connecting the microcontroller to the latches were placed. Figure 5.4 shows the PCB design related to that part. It connects the microcontroller, and in turn, the microcontroller is connected to the d sub. The configuration is noted and needs to be referenced when programming the MCU.

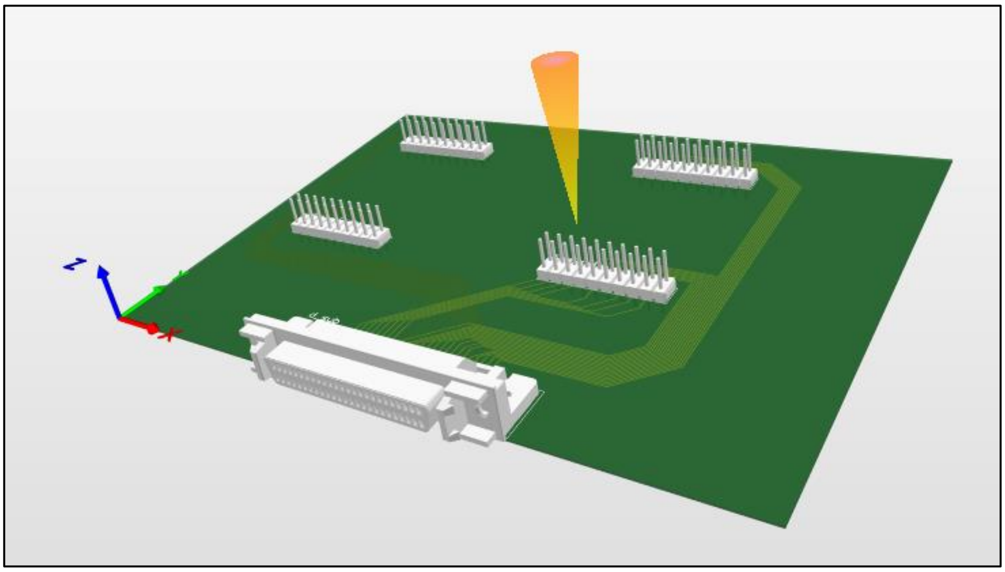

Figure 5.4 3D view of the PCB part with the microcontroller

5.4 QUALITY ASSURANCE

Quality assurance and control of the designed prototypes were focused on a lot during the development stage of the prototypes. One of the main concerns was the hardware design. During the hardware design, the ordering of the components was done based on the recommendations of several members of the team, including professors. This way, the possibility of having components that were not suitable for the prototype was minimized. Also, this ensured that no money was wasted during the ordering of the components.

Decisions taken during the design process were always done through weekly physical meetings. This meant that all members of the team were up to date with major and important decisions that were made. Also, this meant that everyone could put their ideas on the table regarding any matter.

Also, since it is a research and development project, a lot of time was spent on experiments, which ensured that the quality of the product being developed was at its highest. This meant countless hours of doing experiments and changing different parameters in the experiment to get the best possible result. Before the actual experiment dates, each and every step of the experiment was planned. Experiments were done according to a script prepared beforehand that had all possible scenarios that needed to be tested out.

This ensured that we were getting the most out of the limited time given in the experimental environments. To ensure that the patterns generated in the actual IRS were tested before the experiments, The quality assurance procedure had to be done in an integrated manner, meaning both the software and the hardware outputs were tested together. A few random patterns were fed to the software, and the output of that was given to the IRS board. After the output of the IRS board was observed, it was compared with the input pattern in the software. This ensured that the whole system was working as intended. To assure quality control, the tests were done at the start of each experiment day within a couple of minutes.

5.5 HANDING OVER THE PROJECT

As my internship ended before the completion of the new system, I was not able to see the design of the prototype come to an end. My work related to this was handed over to the other individuals in the project. They would move on to the coding of the MCU, fabricate the PCB design, connect all the wiring to patches of the IRS, and carry on further testing of the product.

There were a few ethical concerns about outsourcing information about the internship. The project being a research and development project further attributed to this factor. Therefore, I had the responsibility of asking the supervisor whether I could outsource information in a report or a presentation, and I did get a positive response. Also, throughout the internship, I maintained good ethical relationships with all my coworkers. This is evident as I had numerous invitations to outings for fun activities with the team, including badminton matches, dinner, and tea outings.

This project, once finished, will contribute largely to the improvement of the communication system. This is largely beneficial to the general public, moving forward to a technologically advanced world. Environmental impact was not considered largely during my period of the project, but I believe it will be in the production stages. The material used to develop the product will be a main environmental concern. During my stay, Panasonic Holdings Cooperation showed much interest in the project. If they are going ahead with the prototype, I believe they will do whatever necessary to make the product and its development procedure environmentally friendly, as they have done with previous products.

In this part of my internship, I had the opportunity to contribute to PCB design. Also, I had the opportunity to come up with a new mechanism to scale the prototype already in use.

CONCLUSION

My internship took place at the Singapore University of Technology and Design, and I worked on a project called "Reconfigurable Intelligent Surface to Enhance Urban Wireless Communication," which was done in collaboration with Nanyang Technological University. I reported directly to Dr. Zhao Yufei, and my main supervisor was Prof. Yuen Chau.

In the project, my main objective was to contribute to building a controller for the RIS and also experiment with it. The system had potential applications in the new era of 6G communication systems. Mainly, it was designed to be used for reflecting the signals in a needed direction. It had application scenarios such as enhancing signal coverage, tracking targets, and changing the concentration of signals according to time of day. These applications helped utilise the power efficiently. The main stakeholder in the project was the DSO National Laboratories Company, which is the national defence research and development organisation in Singapore.

I faced many challenges in this internship, such as getting used to a different country, getting used to working with a new team, working on a project invested in by some main stakeholders, and also getting used to all the new responsibilities in a manner I never had when it came to academics.

During my internship, I also made new contacts with people in academia as well as industry.

The foundation I am receiving at the University of Peradeniya was very crucial for me, as it helped me successfully complete various tasks of my internship. All the hard work done back at the university learning new knowledge was put into action in this internship.

As a conclusion, this internship has been the most impactful experience of my life up to date, and I gained a lot from it and enjoyed it as well. I would like to suggest making the internship period 24 weeks, as then more opportunities will be open for oncoming students. This will encourage new internship opportunities locally as well as internationally.

REFERENCES

1. Singapore University of Technology and Design (SUTD) (accessed March 8, 2024)

Annexure 1

```
# Strips the newline character
for line in Lines:
    temp1 = line.split('\t')
    temp2 = []
    for i in temp1:
        temp2.append(int(i))

    arr.append(temp2)
a = np.array(arr)

c = []                #array to store converted patterns of each
patch

for i in range(10):   #for loop to iterate over the read pattern

    d=[]    #array to store each values whether 0,1,2,3

    for j in range(10):        #for loop to iterate over each row
in array start from the right top

        if(a[i][j]==0):     #if pattern value 0 add 111
            d.append(1)
            d.append(1)
            d.append(1)
        elif(a[i][j]==1):   #if pattern value 1 add 110
            d.append(1)
            d.append(1)
            d.append(0)
        elif(a[i][j]==2):   #if pattern value 2 add 011
            d.append(0)
            d.append(1)
            d.append(1)
        else:                 #if pattern value 3 add 101
            d.append(1)
            d.append(0)
            d.append(1)

    c.append(d)            #add to c

c = np.array(c)
c_trans = np.transpose(c)          #get transpose for excel

# df2 = pd.DataFrame(c)
# formatted = name+"/"+name+"_converted.csv"
#df2.to_csv(formatted)       #write to csv

final=[]        #final array to store
```

```
#**********************Convert to
bits*******************************************************

for i in range(9, 3, -1):          #row A to 5

    for j in range(27,12,-3):
        for k in range(3):
            final.append(c[i][j+k])

    for j in range(5):         #set last 5 bits to 1 (not used)
        final.append(1)

for i in range(60):        #set 1 since not used
        final.append(1)

for i in range(3, 1, -1):          #row 4 and 3

    for j in range(27,12,-3):
        for k in range(3):
            final.append(c[i][j+k])

    for j in range(5):         #set last 5 bits to 1 (not used)
        final.append(1)

for i in range(60):        #set 1 since not used
        final.append(1)

for i in range(1, -1, -1):          #row 4 and 3

    for j in range(27,12,-3):
        for k in range(3):
            final.append(c[i][j+k])

    for j in range(5):         #set last 5 bits to 1 (not used)
        final.append(1)

for i in range(9, -1, -1):          #row A to 1

    for j in range(12,-1,-3):
        for k in range(3):
            final.append(c[i][j+k])

    for j in range(5):         #set last 5 bits to 1 (not used)
        final.append(1)

final_trans = np.transpose(final)
```

```
#write converted bits to csv
# df3 = pd.DataFrame(final)
# formatted = name+"/"+name+"_final.csv"
# #df3.to_csv(formatted, index=False)       #write to csv

# df4 = pd.DataFrame(final_trans)
# formatted = name+"/"+name+"_final_trans.csv"
# #df4.to_csv(formatted, index=False)       #write to csv


#**********Genearte Hexa
Code***********************************************************
hex_str = '2041'

for i in range(0,520,8):
    bin_str = ''
    for j in range(8):
        bin_str = bin_str + str(final[i+j])

    dec = int(bin_str, 2)
    hexa = format(dec, 'X')
    hex_str = hex_str + str(hexa)


#****************WRite
hexa***********************************************************
# Append-adds at last
file1 = open(name+"_hex_code.txt", "w")  # write mode
#file1.write(name+"\n")
file1.write(hex_str+"\n")
file1.close()
```

Annexure 2

<u>Algorithm: A strategy to track User Equipment using Beam Sweeping of the RIS board.</u>

<u>For the RIS Board:</u>

```
1.  interval = 1 s;                        #An interval for time between patterns when beam sweeping.
2.  port = serialport(COM#, Bitrate = 115200, DataBits =  8, StopBits = 1, Parity = none);
3.  patterns =scan(“pattern.txt”)      ;       #Read the patterns locally using function
4.  t_server = tcpip(“0.0.0.0”, 80, NetworkRole = server);          #open TCP connection using function
5.  while TRUE do
6.        while TRUE do
7.              if  t_server.BytesAvailable > 0               #Wait till data is detected
8.                    break;
9.        data_recv = scan(t_server, t_server.BytesAvailable);     #Read received data using function
10.       flush (t_server);
11.       num = str2num(data_recv);           #Convert received string to number using function
12.       if num == 0                     # if received is 0 need to beam sweep
13.             for i=1 to 10 do          #iterate over the patterns to get best pattern for User Equipment
14.                   pattern = patterns{i};
15.                   patternHexBytes = hex2dec(patternData);
16.                   write(port, patternHexBytes);              #send to RIS after converting to hexadecimal
17.                   pause(interval);
18.       if num != 0                     #if pattern number is received send pattern
19.             pattern = patterns{num};
20.             patternHexBytes = hex2dec(patternData);
21.             write(port, patternHexBytes);
```

<u>For the User Equipment</u>

```
1.  interval = 1 s;                       #an interval for time between patterns when beam sweeping.
2.  threshold = 20                        #threshold for Signal to Ratio value
3.  t_client = tcpip(“0.0.0.0”, 80, NetworkRole = client);          #open TCP connection using function
4.  while TRUE do
5.        while TRUE do
6.              if SNR of received signal < threshold
7.                       break
8.         t_client.send(0);
9.         pause(0.8);                    #wait a predefined amount of time till RIS starts beam sweeping
10.        max_power = power of first received signal;
11.        max_power_pattern = 1;
12.        for i=2 to 10 do
13.              power = power of received signal;
```

```
        pause(interval);
        if power > max_power
            max_power_pattern = i;
    t_client.send(max_power_pattern);
```

I am responsible for the accuracy of opinions, contents, data, figures, illustrations, photographs and other information included in the report/s. The University of Peradeniya will not bear any liability for the accuracy of technical and other information in the report/s.

....

Date: 08/04/2024 Signature of the Student

Name: T.D.B. WANDURAGALA

Reg. No.: E/18/379