Design and Development of a Portable Radio Telescope

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering (Hons) XXXX Engineering

Faculty of Engineering and Green Technology
Universiti Tunku Abdul Rahman

April 2018

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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I certify that this project report entitled **"TITLE TO BE THE SAME AS FRONT COVER, CAPITAL LETTER, BOLD"** was prepared by **LIM WEI GIE** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons) Electronic Engineering at Universiti Tunku Abdul Rahman.

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Date : ____________________________

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Specially dedicated to

my beloved father, mother and sister for their eternal love, support and caring

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Once again, my sincerely thanks to all of you. Good luck and all the best to be the best.

Design and Development of a Portable Radio Telescope

ABSTRACT

Building a simple radio telescope is relatively easy with a combination of persistence and the proper help. Once radio telescope has been developed, which can be easy build in schools and tertiary institutions make students to further interest in science and technology. Surplus satellite television equipment can be modified to permit radio observe the Sun and the Moon, it can be able to allow the user to learn the fundamentals of radio astronomy. Radio telescope is an astronomical instrument consisting of a radio receiver and an antenna system that is used to detect radio-frequency radiation emitted by the Sun. As radio-wave wavelengths are much longer than those of visible light, radio telescopes have to be very large physically in order to attain the resolution of optical telescopes. A solar flare is a tremendous explosion on the Sun that happens when energy stored in the Sun's "twisted" magnetic field is suddenly released. With a radio telescope we can detect solar flare activities. The most important conclusion is that the site is, in terms of its engineering properties, certainly suitable for conducting radio astronomy

TABLE OF CONTENTS

DECLARATION			**ii**
APPROVAL FOR SUBMISSION			**iii**
ACKNOWLEDGEMENTS			**vi**
ABSTRACT			**vii**
TABLE OF CONTENTS			**viii**
LIST OF TABLES			**x**
LIST OF FIGURES			**xi**
LIST OF SYMBOLS / ABBREVIATIONS			**xiii**
LIST OF APPENDICES			**xiv**
CHAPTER			
1	**INTRODUCTION**		**1**
	1.1	Background	1
	1.2	Problem Statements	2
	1.3	Aims and Objectives	2
2	**LITERATURE REVIEW**		**3**
	2.1	Design of the Ku-band Radio Telescope	3
	2.2	Problems of Radio Frequency Interference on Radio Telescope	4
3	**METHODOLOGY**		**6**
	3.1	Design procedure	6

3.1.1 Type of Dish Antenna 8
3.1.2 RF detector schematic 9
3.1.3 Calibrating the RF detector 10
3.1.4 Calculating Calibration Equation used in Octave 11
3.2 Steps of using Radio Telescope 12
3.2.1 Aligning the ASTRO dish antenna to the sun 12
3.2.2 Setup Arduino kit, PC and Octave 14

4 RESULTS AND DISCUSSION 16
4.1 Measuring the beamwidth of the dish antenna using the Sun 16
4.2 Determine System temperature 20
4.3 Measuring rainfall suing the radio telescope 22

5 CONCLUSION AND RECOMMENDATIONS 24
5.1 Conclusion 24
5.2 Recommendation 25

REFERENCES 26

APPENDICES 28

LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1	RFI sources in Malaysia	5

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Component of Ku-band radio telescope	3
3.1	Radio telescope desgn flow	6
3.2	Astro Dish	8
3.3	RF detector schematic	9
3.4	Measurement setup for calibrating RF detector	10
3.5	Power versus DC voltage at 1550MHz	11
3.6	Tripod mount with ASTRO dish	12
3.7	Aligning RF main-lobe of ASTRO antenna to the Sun	13
3.8	Reflection of the sun off the shinny coin onto the antenna feed	14
3.9	RF connector with Arduino kit	14
4.1	Sun “drift” across the RF main-lobe of stationary dish	16
4.2	Size of sun	17
4.3	Sun-beam drift across the stationary antenna feed	17
4.4	Graph of Power vs Time	18
4.5	Setup for measuring rainfall using the radio telescope	22

4.6 Measured signals from ASTRO satellite Sky Background before and during moderate rain 23

LIST OF SYMBOLS / ABBREVIATIONS

m	gradient
P	power, *dBm*
V	voltage, *V*
M	*dB*
δ	angular diameter of the Sun, degree
φ	RF beamwidth if ASTRO dish antenna
P	peak-power level, *dBm*
P_{3dB}	half-power level, *dBm*
N	noise level, *dBm*
D	distance of the Sun, km
d	distance between Sun and Earth, km
r	radius of the Sun, km
T_{sys}	system temperature, Kelvin (*K)*
T_{sky}	sky temperature, Kelvin (*K)*
T_{GND}	ground temperature, Kelvin (*K)*
T_{An}	Antenna temperature, Kelvin (*K)*
T_R	Receiver noise temperature, Kelvin (*K)*
P_{sky}	Sky power, *dBm*
P_{GND}	Ground power, *dBm*

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	RF detector calibration	28
B	Arduino coding	29
C	Octave coding (***KuRT_online_1V2***)	40
D	Octave coding (***KuRT_offline_1V2***)	44

CHAPTER 1

INTRODUCTION

1.1 Background

Radio astronomy is the study of celestial objects that give off radio waves. In school we study about astronomical phenomena that are often invisible or hidden in other portions of the electromagnetic spectrum. Radio astronomy is an interesting and modern science, which is complement the more common optical astronomy that school commonly perform (Furse and Bhatia, 2006).

Once we know that there was more than our eyes can see, such as microwaves, radio waves, ultraviolet, infrared, x-rays, and gamma rays, we started to look for ways to view the night sky. The full range of electromagnetic wave is called electromagnetic spectrum. Radio telescopes were one of the first successes in that area (Wood, 2015).

Actually a radio telescope is about the same to the radio in our car, but not convenient as the size of radio telescope much bigger and it is able to create a real time visual picture of the signals when it receives. Radio telescopes create a picture of the sky, not in visible light, but in radio waves. This is very useful, because can see the invisible and hidden activities across the Universe and tools can solve some of the greatest mysteries of our Cosmos.

1.2 Problem Statements

To construct radio telescope presents exceptional difficulties. This is mainly due to specificity if this discipline and the limited availability of dedicated instrumentation. The main difficult faced by amateur astronomers in building radio telescope is signal radiated from cosmic sources. Most of these signals are usually very weak and their magnitude may be comparable with thermal noise.

In order to enhance the sensitivity and resolution, the size of a radio telescope is usually large in size, i.e. the diameter of a parabolic dish is larger than 10m. Hence, building a radio telescope is extremely costly. This is the reason why causes related to radio astronomy are seldom taught in secondary and, not to mention, tertiary education. To introduce radio astronomy as a common course, it may be necessary to simplify the process of building a radio telescope so much so that, it can be easily built in schools and tertiary institutions. It is the purpose of this project to explain on effective approach to design and develop an affordable and relatively simple radio telescope. The signal from the cosmic source for detection, since it has the highest intensity and can be easily detected.

1.3 Aims and Objectives

The objectives of the thesis are shown as following:

i) Construct a radio telescope using components from the shelf.

ii) Demonstrate the operability of the telescope by drift-scanning the sun.

iii) Interpret and analyze the obtained data.

CHAPTER 2

LITERATURE REVIEW

2.1 Ku-band Radio Telescope

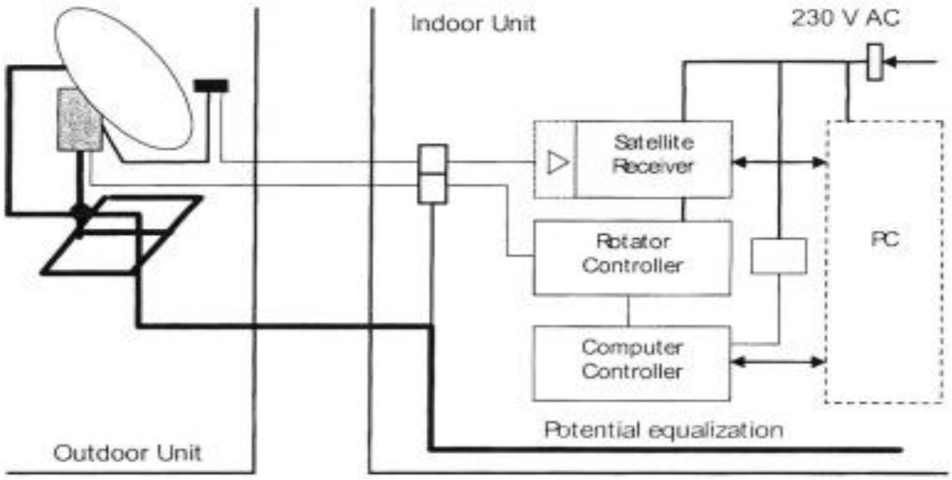

Figure 2.1 Component of the Ku-band radio telescope. (Furse and Bhatia, 2006)

The Ku-band radio telescope can separate in two units which is outdoor and indoor unit. Then the indoor unit included a standard PC and surge protection. The satellite dish focuses incoming electromagnetic waves in the reflection towards the LNB and provides signal amplification. Satellite dishes for the frequency range from 10.7 GHz to 12.75 GHz were focused on when selecting the dish for this system. The LNB consists of mixer and amplifier units, and transforms frequencies from the Ku band to the SAT intermediate frequency (Furse and Bhatia, 2006).

The indoor unit consists of satellite receiver, rotator controller and computer controller. The most important and difficult task was select the most suitable and useful receiver device. A radio telescope has several main parts were that is have a PC interface, with access to measure the results and receiver control. Next also need a power supply (12 V) to activate the low-noise block. It should provide signal-level measurement of L-band (950 - 2150 MHz) signals and adjustable measurement frequency also needed. It should have high input sensitivity (-60 dBm) and signal level indication and transfer via an USB cable in real time. Finally, need computer software in order to display for observing frequency and signal-level indication in dBm, with 0.1 dB resolution.

2.2 Problems of Radio Frequency Interference on Radio Telescope

Radio frequency interference is a major concern for radio astronomy. Identifying unintentional radio frequency interference signals (for example, from equipment operating in the neighborhood of radio telescope) is a challenging topic due to the highly non-ergodic nature of signals (Czech, Mishra and Inggs, 2016).

Developments in communication and telecommunication fields are the major contributors of man-made RFI in Malaysia and pose a threat to the future of Radio Astronomy. In bands below 2 GHz, interferences mainly come from broadcasting services, communication data, satellite communication, aeronautical satellites, meteorological satellite and radio navigation satellite. Stop band filters of some communication systems and others RFI sources are not always adequate (Goris, 1998).

Meanwhile radio telescopes are easy affect to nearby bands because the received signals of interest are very weak. Interference might through its antennas and analog subsystems enter radio telescope, such as the front end and intermediate frequency (IF) subsystems. Because of the high gain of radio-telescope antennas and the fact that celestial signals are generally a quantity in comparison, the primary path for interference is through the antennas (Ambrosini, Beresford, Boonstra, Ellingson, and Tapping, 2003). Table 2.1 shows those radio frequency interference sources that can disturb the radio astronomical observation in Malaysia.

No	Signal Sources	Frequency (MHz)
1	Radio Broadcasting- Traxx FM	80 - 108
2	Aeronautical Mobile	125 - 150
3	Broadcasting Mobile (Tv-Channel 5)	175 - 217
4	Deuterium (DI), Fixed and Mobile	327
5	Mobile Satellite (intermittent)	150
6	Broadcasting (Tv-channel 38)	574 - 700
7	Mobile Phone(Celcom, Maxis, Digi)	890 - 933
8	Mobile Phone (GSM) (Celcom, Maxis, Digi)	1735 - 1880
9	Telekom Malaysia	1962

Table 2.1 RFI sources in Malaysia (MCMC manual of Spectrum Plan, Malaysian Communication and Multimedia Commission, Resources Assignment Management Department, 2006) and (Abidin Z.Z., Ibrahim Z.A., Adnan S.B.R.S., and Anuar N.K., 2008)

CHAPTER 3

METHODOLOGY

3.1 Design procedure

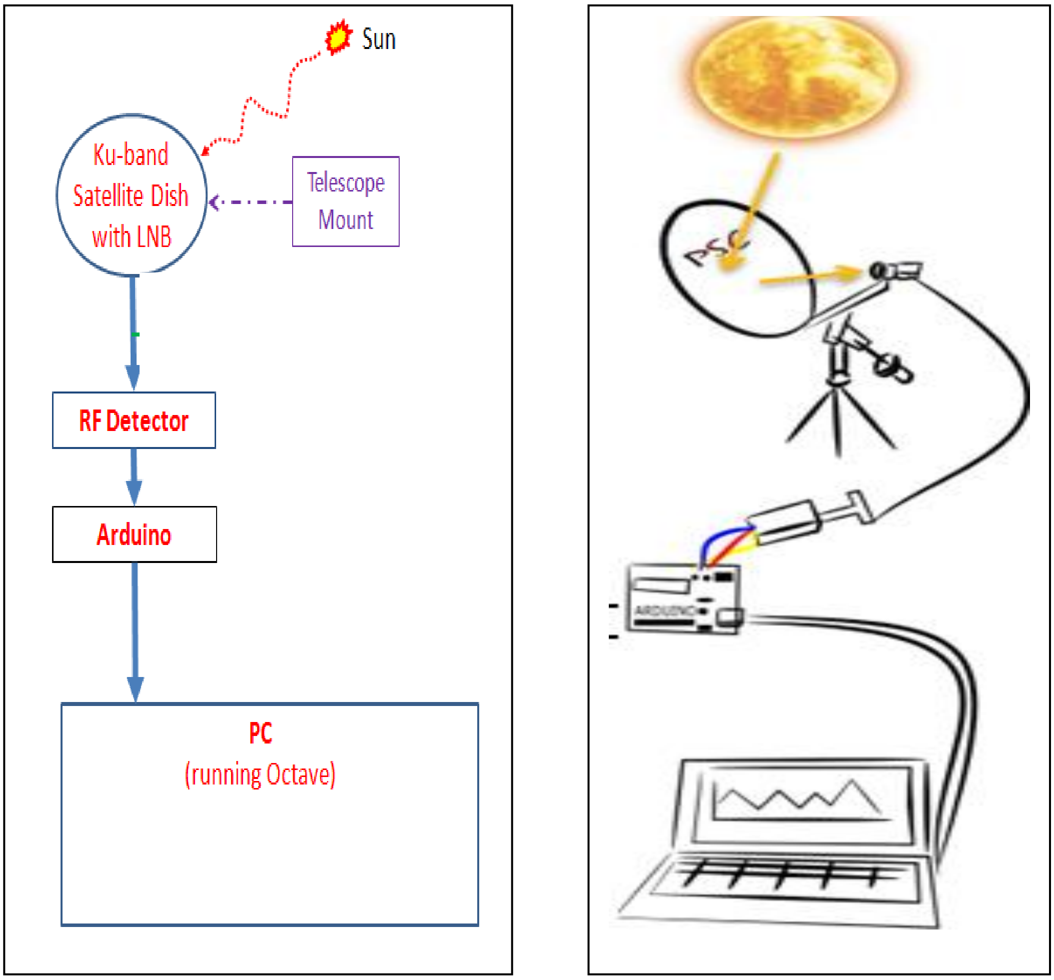

Figure 3.1 Radio telescope design flow

A radio telescope consists of five main parts: a dish and antenna, RF detector, Arduino and PC (running Octave). The dish collects the radio signals from space and focuses them on the antenna. A **low-noise block (LNB)** is the receiving device mounted onto the satellite dish. The LNB down converts the radio waves collected by the dish from 10.7 - 12.75 GHz to 950 – 2150 MHz. This down conversion of the radio signals in order allow to transmitted with less attenuation and through cheaper medium, such as RG – 6 cable. (Kirkman-Bey and Xie, 2014)

A **telescope mount** is a mechanical structure which supports a telescope. Telescope mounts are designed to allow for accurate pointing of the instrument. So majority of effort being put into systems that can track the motion of the stars as the Earth rotates. Equatorial mount is often preferred to Azimuth-Elevation mount.

An **RF detector** monitors the output of the LNB and develops a dc output voltage proportional to the received power.

Arduino is a microcontroller-based board for building digital interactive project. For this project, the Arduino is use as an Analog-To-Digital converter.

GNU Octave is a high-level programming language, primarily intended for numerical computations. It can also be interfaced to Com Ports for real-time data capturing. We used it to capture the data from Arduino and to plot graphs in real-time. It also logs the data to files (data logging)

3.1.1 Type of Dish Antenna

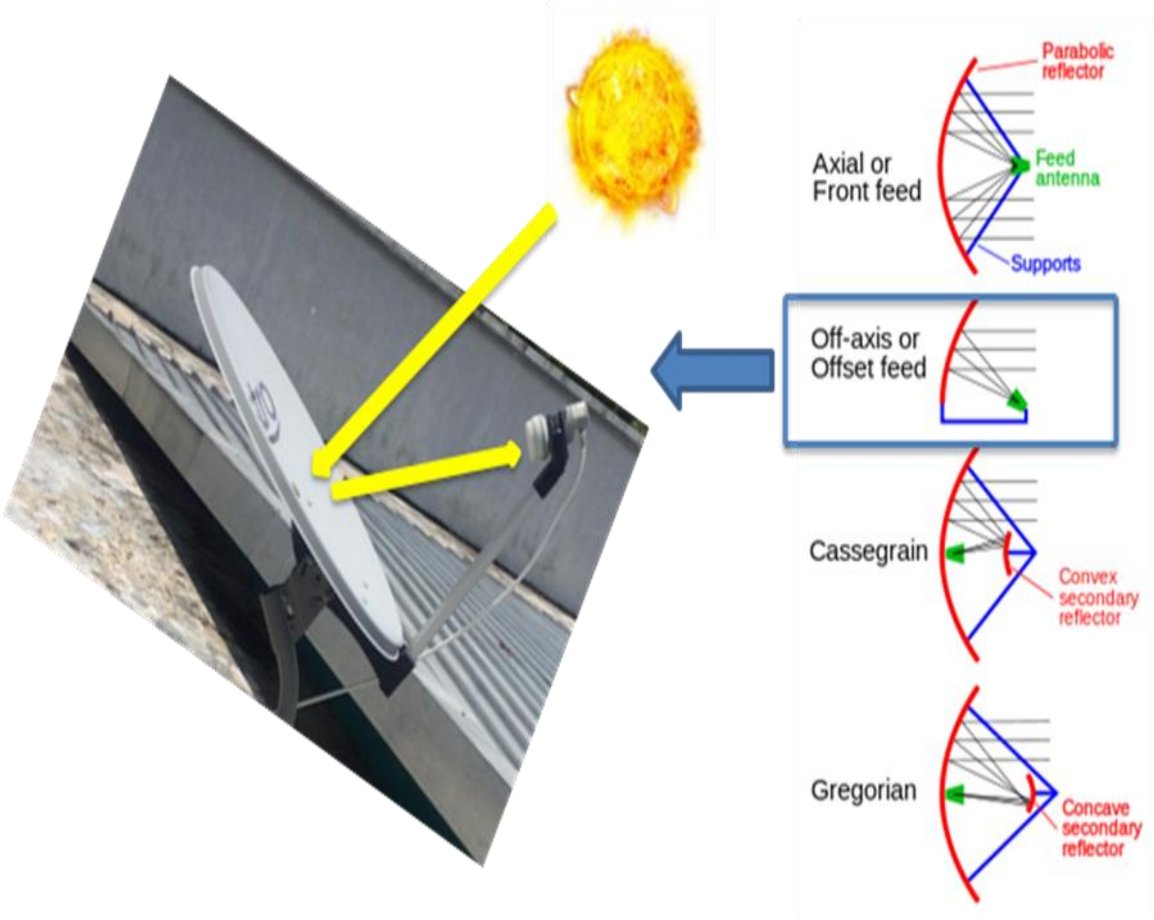

Figure 3.2 Astro Dish

As can be seen in figure 3.2, various parabolic dish antenna configurations are commonly used for radio astronomy they are the front feed, off-axis, cassegrain, and gregorian structures. The off-axis is antenna structure has been implemented in this project. It is selected since this type of antenna can be easily salvaged a television broadcast unit (Tech, 2017).

3.1.2 RF detector schematic

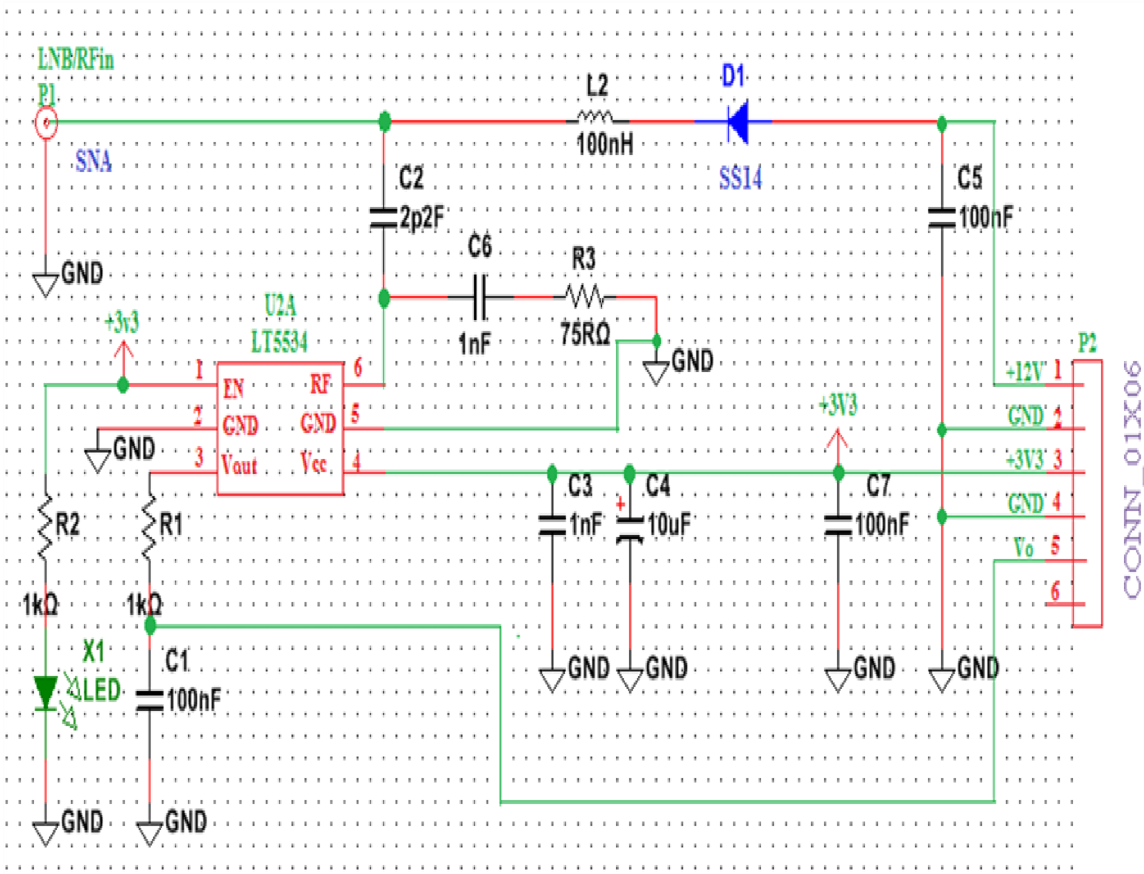

Figure 3.3 RF detector schematic

LT5534: Log detector, 50 MHz-3 Hz, 60 dB (-65 dBm to -5 dBm), 35 mV/db, 2.7 – 5.25 V 7 mA, Vout offset 150 mV, sink 10 mA, source 200 uA, Rout = 32 ohm

On connector P2, an external 3.3 V supplies power to LT5534. The 3.3 V voltage come from hardware which is Arduino connected to a computer by using USB cable. Also on P2, an external DC 12 V supplies power to the LNB of the Ku-band satellite dish. The detector RF level is a low frequency signal (<10 kHz) output at pin-5 of P2. This output pin-5 connected to Arduino input A0-pin for analog-to-digital (A/D converter). The converter has 10 bits resolution, return integers from 0 – 1023.

3.1.3 Calibrating the RF detector

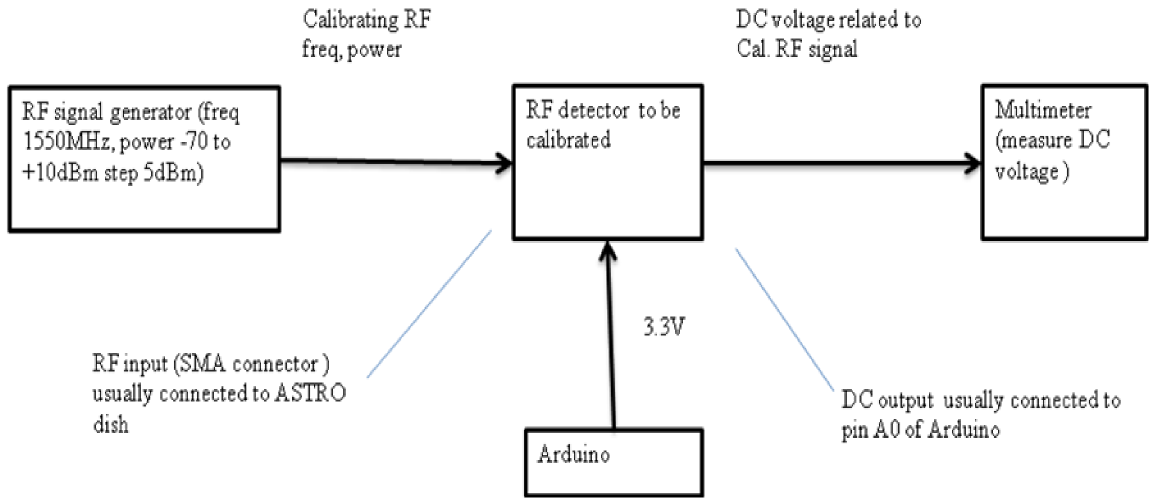

Figure 3.4 Measurement setup for calibrating RF detector

Figure 3.4 shows the measurement setup for calibrating RF detector, which is to be calibrated one at a time. RF signal generator for generating an RF signal at different frequencies and power. Then use multimeter for measuring DC voltage. Refer to APPENDIX A. Calibration is needed because each RF detector convert Power of the signal at the RF input of detector to an equivalent output DC voltage. The calibration process is to determine the relationship between input Power and output DC voltage so that it can be entered into the Octave program.

3.1.4 Calculating Calibration Equation used in Octave

The RF detector detects broadband from 950 – 2150 MHz. Calibration is done around the centre of this band, at 1550 MHz as shown in figure 3.5.

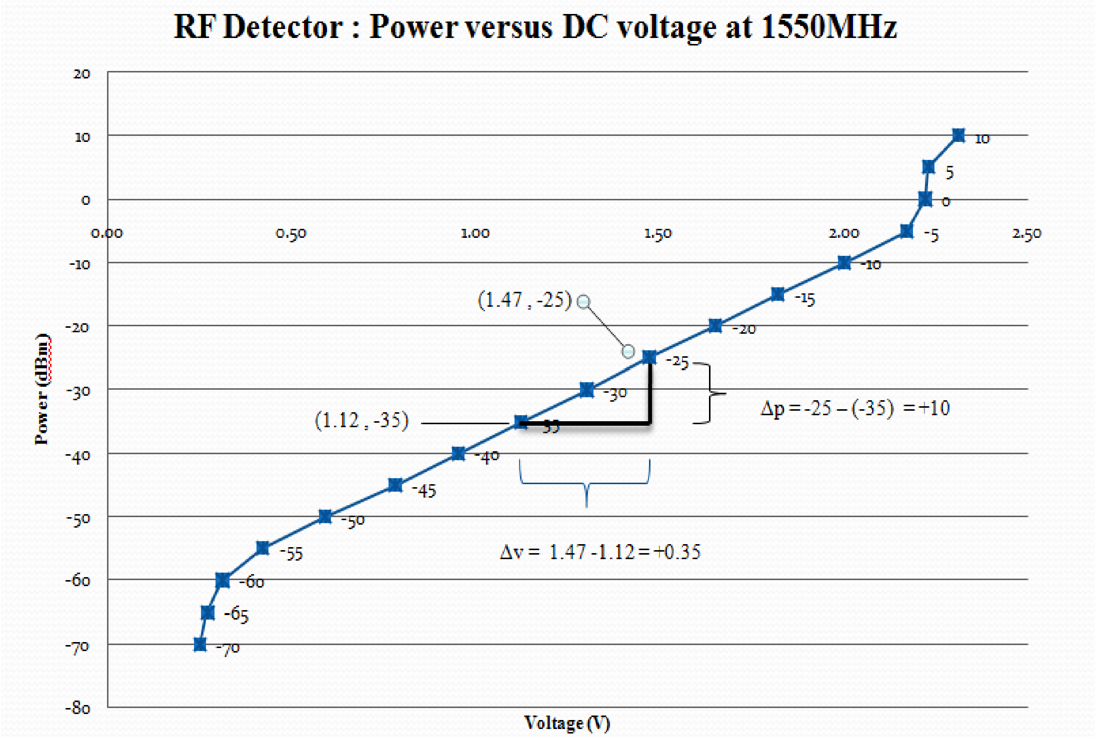

Figure 3.5 Power versus DC voltage at 1550MHz

<u>The relationship between Voltage V and Power P can be assumed to be a straight line:</u>

Power, $p = mv + c$

Gradient, $m = \Delta p / \Delta v = [-25 - (-35)] / [1.47 - 1.12]$

$= 10 / 0.35$

$= 28.57$

p-intercept, $c = p - mc$

point (v,p), $= (1.47, -25)$

$c = -25 - (28.57)(1.47)$

$= -66.99$

$\boldsymbol{p = 28.57\,v - 66.99}$ (where p = Power in dBm , v = voltage in V)

This is the calibration equation used in the Octave program to plot graphs of RF signal power received by ASTRO dish.

3.2 Steps of using Radio Telescope

3.2.1 Aligning the ASTRO dish antenna to the sun

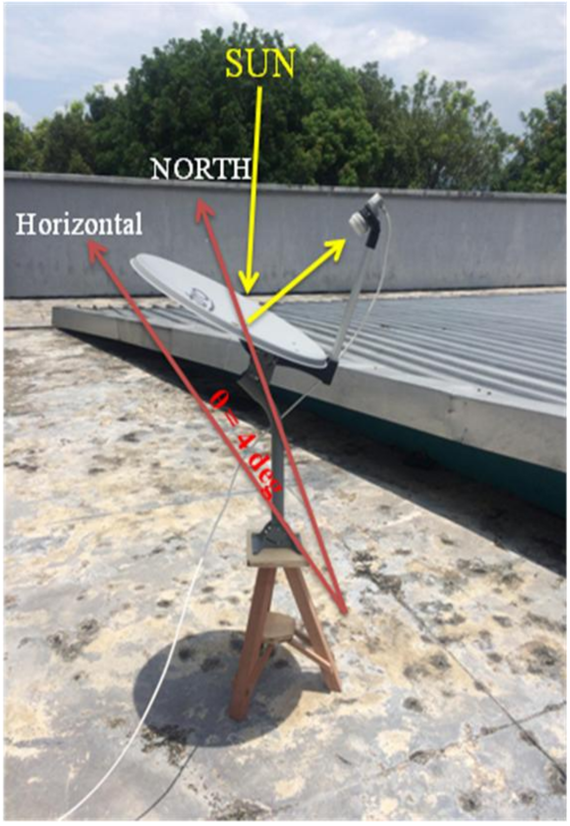

Figure 3.6 Tripod mount with ASTRO dish

First, fully extend the tripod mount and place it at a suitable location for subsequent measurement of the Sun. Use the magnetic compass to measure and align the direction of the mount polar-axis scope towards earth’s magnetic north pole, which is close to earth’s north celestial pole (NCP). Note that the compass direction can be affected by nearby metal object or surface. Check for this possibility. If you are in Kampar, Malaysia, set this angle θ = 4 degrees, approx equal to the Latitude of Kampar which is **4° 18’ 0”N** (Kampar, Malaysia latitude longitude, 2015).

Note that the ASTRO dish is an off-axis antenna as illustrated in Figure 3.2. This makes directing or aligning the RF main-lobe difficult as the main-lobe is not perpendicular (90 degrees angle) to the dish. The antenna dish, besides reflecting radio waves towards the antenna feed, will also reflect optical (visible) light if a shinny coin stuck flat onto the dish. Use shiny coin to a small flat magnet, then the magnet can stick onto the dish can move around freely.

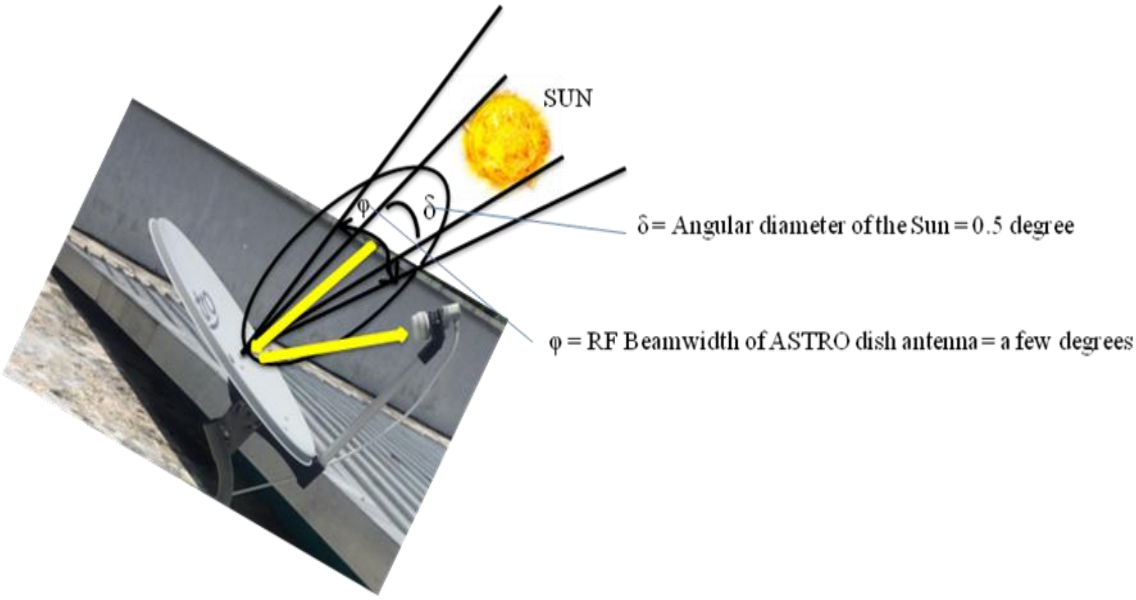

Figure 3.7 Aligning RF main-lobe of ASTRO antenna to the Sun

Align the radio-frequency (RF) main-lobe of the off-axis ASTRO antenna so that it points to the Sun, as shown in Figure 3.7. ASTRO antenna has RF beamwidth φ = a few degrees, while Sun has an angular diameter δ = 0.5 degrees. To align the ASTRO dish, the dish must be exposed to a bright Sun, i.e. the sun should not be covered by cloud. Then look for the reflection of the sun off the shinny coin onto the antenna feed, which is appears as a bright spot as shown in Figure 3.8.

Figure 3.8 Reflection of the sun off the shinny coin onto the antenna feed.

3.2.2 Setup Arduino kit, PC and Octave

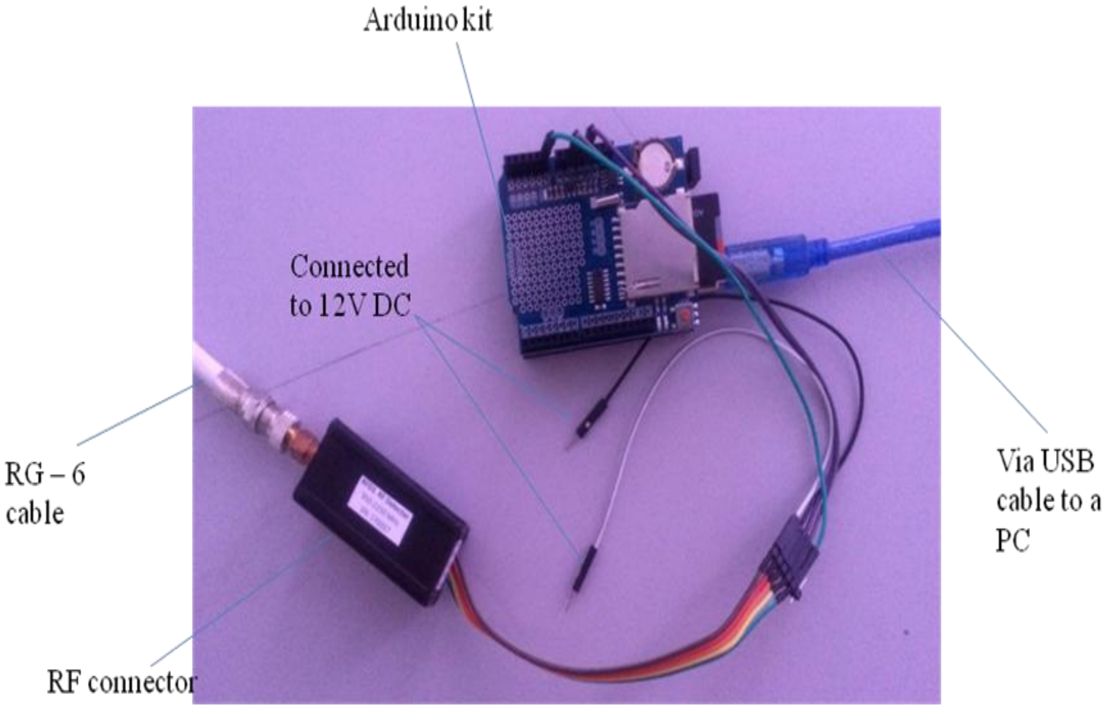

Figure 3.9 RF connector with Arduino kit

Arduino kit assembled ready for operation and connected to 12V DC and via USB cable to a PC with Octave software installed. Note the datalogging and interface shields are stacked on Arduino as shown in figure 3.9. ASTRO dish antenna mounted on tripod mount and connected to RF detector via RG – 6 cable.

Connect up the ASTRO dish with RF detector, the Arduino kit and OC with Octave program, powered up ready for operation, Check that the 12V DC plug from mains is appropriately connected up and powered on. Run the online version of the Octave program KURT_online_1V1 (refer APPENDIX C) and wait for the Received Power vs Time plots to appear.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Measuring the beamwidth of the dish antenna using the Sun

To measure the RF beamwidth φ of the ASTRO dish antenna, which is around a few degrees angle. The beamwidth is determined by the half-power point of the RF main-lobe as shown in Figure 4.1.

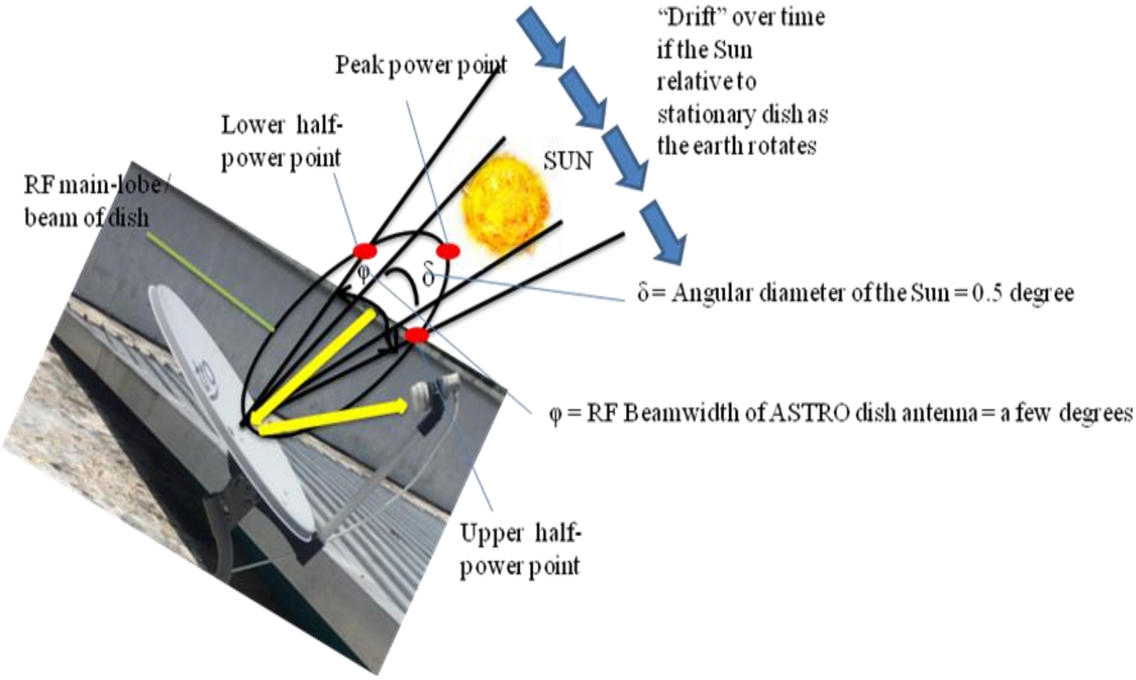

Figure 4.1 Sun "drift" across the RF main-lobe of stationary dish

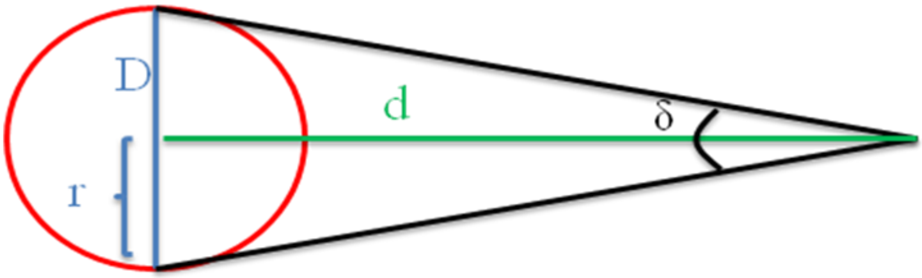

Figure 4.2 Size of the Sun

In the figure 4.2 shows *D* represents diameter of the Sun (1.392 x 10^6 km) and *d* represents the distance between Sun and Earth (149,598,261 km). The *r* represents the radius of the Sun ($r = D / 2$). Delta (δ) is the angular diameter of the Sun from the distance if the Earth and alpha ($\alpha = \delta / 2$). Since d and r form two legs of a right triangle, so trigonometry tell us tangent of the angle $\alpha = r / d$.(Schimmrich, 2012)

$\tan(\alpha) = (r / d)$

when $r = D / 2$ and $\alpha = \delta / 2$

$\tan(\delta / 2) = [(D / 2) / d]$

$\delta = 2 \tan^{-1} [(D / 2) / d]$

$= 2 \tan^{-1} [(1.392 \times 10^6 \text{km} /2) / 149{,}598{,}261 \text{km}]$

$= 0.5°$

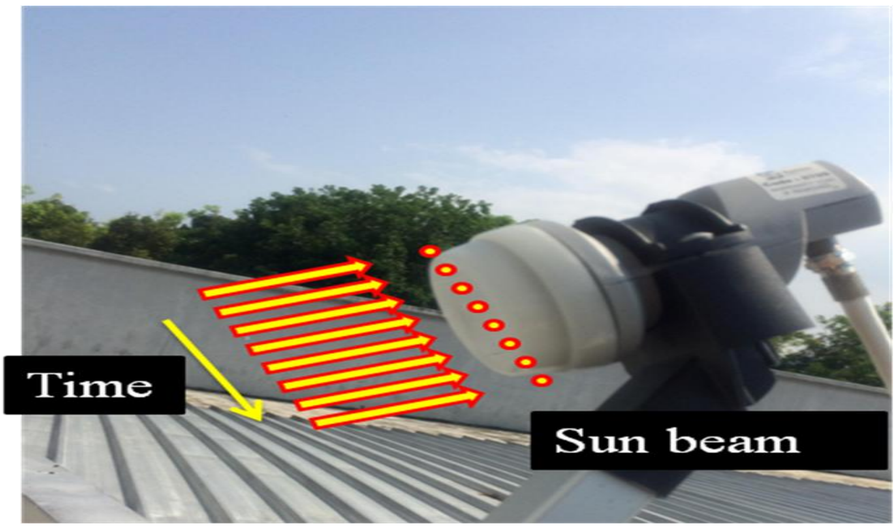

Figure 4.3 Sun-beam drift across the stationary antenna feed

Over time, as the Sun "drift" relative to the stationary dish, the Sun's radiowave reflection off the parabolic dish (let's call this is "Sun-beam") will also drift across the antenna feed as shown in the Figure 4.3.

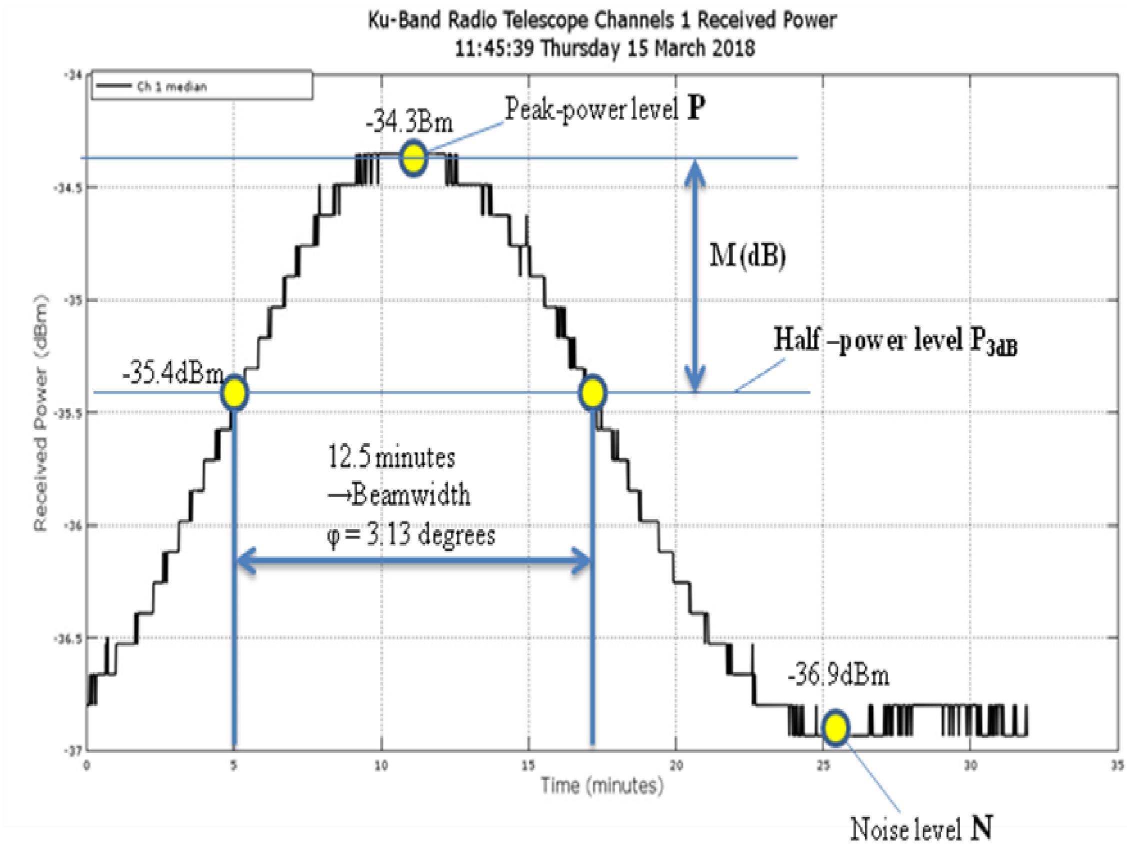

Figure 4.4 Graph of Power vs Time

Use the following equation to calculate the value for *M(dB)* in figure 4.4 which is the dB-offset from the peak-power level at which the signal from the Sun in the presence of noise is at half-power:

P(dBm) = -34.3 *dBm*

P(mW) = 10^(-34.3/10)

= 3.72×10^{-4}

$N(dBm)$ = -36.9 dBm

$N(mW)$ = 10^(-36.9/10)

= 2.04×10^{-4}

P/N = $3.72 \times 10^{-4} / 2.04 \times 10^{-4}$

= 1.82

$$M(dB) = 3.01dB - 10\log_{10}\left[\frac{\left(\frac{P}{N}\right)+1}{(P/N)}\right]$$

$$= 3.01dB - 10\log_{10}\left[\frac{(1.82)+1}{(1.82)}\right]$$

= 1.12 dB

Then calculate P_{3dB}, the half-power level of the signal from the Sun in the presence of noise:

$P_{3dB}(dBm) = P(dBm) - M(dB)$

= -34.3 dBm – 1.12 dB

= -35.4 dBm

To determine the RF beamwidth angle in degrees, convert the time duration of the rotation of the earth to rotation angle:

One day = 24hours = 360 deg

→ 24 x 60 min(time) = 360 deg

→ 1 min(time) = 0.25 deg

From the graph in Figure 4.3, time between P_{3dB} points is 12.5 minutes

→ 12.5 min(time) = 0.25 x 12.5 = 3.13 deg beamwidth

Hence the RF beamwidth of the dish antenna = 3.13 degrees

4.2 Determine System Temperature

System temperature is one of the important parameter of a radio telescope. This quantity measures the overall sensitivity of the receiving system, which are receiver and the antenna (Köppen, 2011).

$T_{sys} = T_{sky} + T_{An} + T_R$

T_{sys} = Total system temperature measured due to sum of all the contributors

T_{sky} = Temperature due to cosmic microwave, dry atmosphere, water vapour and radiation from side lobes (O'Neil, 2001).

T_{An} = Antenna temperature of the target we want to measure (in this case it is Sun)

T_R = Receiver noise temperature due to dish, LNB and RG-6 cable.

$T_{sys} = T_{sky} + T_{An} + T_R = kP$

Dish pointed at the sky ($T_{An} = 0$) $T_{sky} + T_R = kP_{sky}$

Dish pointed at the ground ($T_{sky} + T_{An} = T_{GND}$) $T_{GND} + T_R = kP_{GND}$

$T_{sky} \approx 15\ K$ $T_{GND} \approx 300\ K$

P_{sky} = 10^(-37.7/10)

= 1.7×10^{-4} mW

P_{GND} = 10^(-33.4/10)

= 4.57×10^{-4} mW

P_{sun} = 10^(-34.3/10)

= 3.72×10^{-4} mW

$15 + T_R = k\ (1.7 \times 10^{-4})$

$300 + T_R = k\ (4.57 \times 10^{-4})$

$k = (15 + T_R) / (1.7 \times 10^{-4})$

$300 + T_R = [(15 + T_R) / (1.7 \times 10^{-4})] \times (4.57 \times 10^{-4})$

$300 + T_R = 40.5 + 2.7T_R$

$T_R \approx 153\ K$ $k = (15 + T_R) / (1.7 \times 10^{-4}) \approx 9.88 \times 10^5$

$T_{sky} + T_{An} + T_R = kP$

$15 + T_{An} + 153 = (9.88 \text{ x } 10^5) \text{ x } (3.72 \text{ x } 10^{-4})$

$T_{An} = 199\ K$

$T_{sys} = T_{sky} + T_{An} + T_R$

$= 15 + 199 + 153$

$= 367\ K$

4.3 Measuring rainfall using the radio telescope

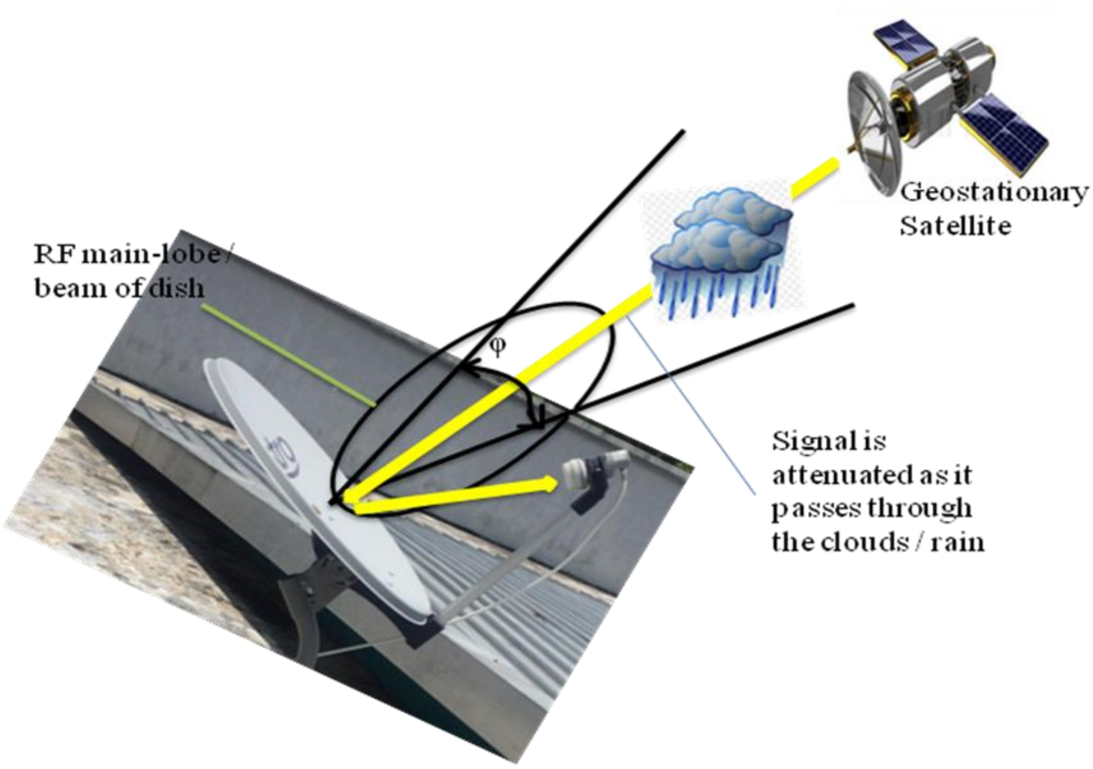

Figure 4.5 Setup for measuring rainfall using the radio telescope

The goal of this experiment is to measure the sun-beam during a rainy day. This is possible because the clouds and rain contain water droplets which absorb and scatter Ku – band radiowaves, as shown in Figure 4.5. The heavier the rain, the greater the absorption and scattering, hence it is possible to relate the amount of rainfall with the drop or attenuation in received signal level.

The best signal to use for this experiment would be a TV satellite such as the ASTRO's Measat satellite, because it would have a strong signal compared with other TV satellite and also be at a fixed location in the sky relative to earth. This type of satellite is called geostationary and rotates together with the earth so that it appears stationary when viewed from the earth.

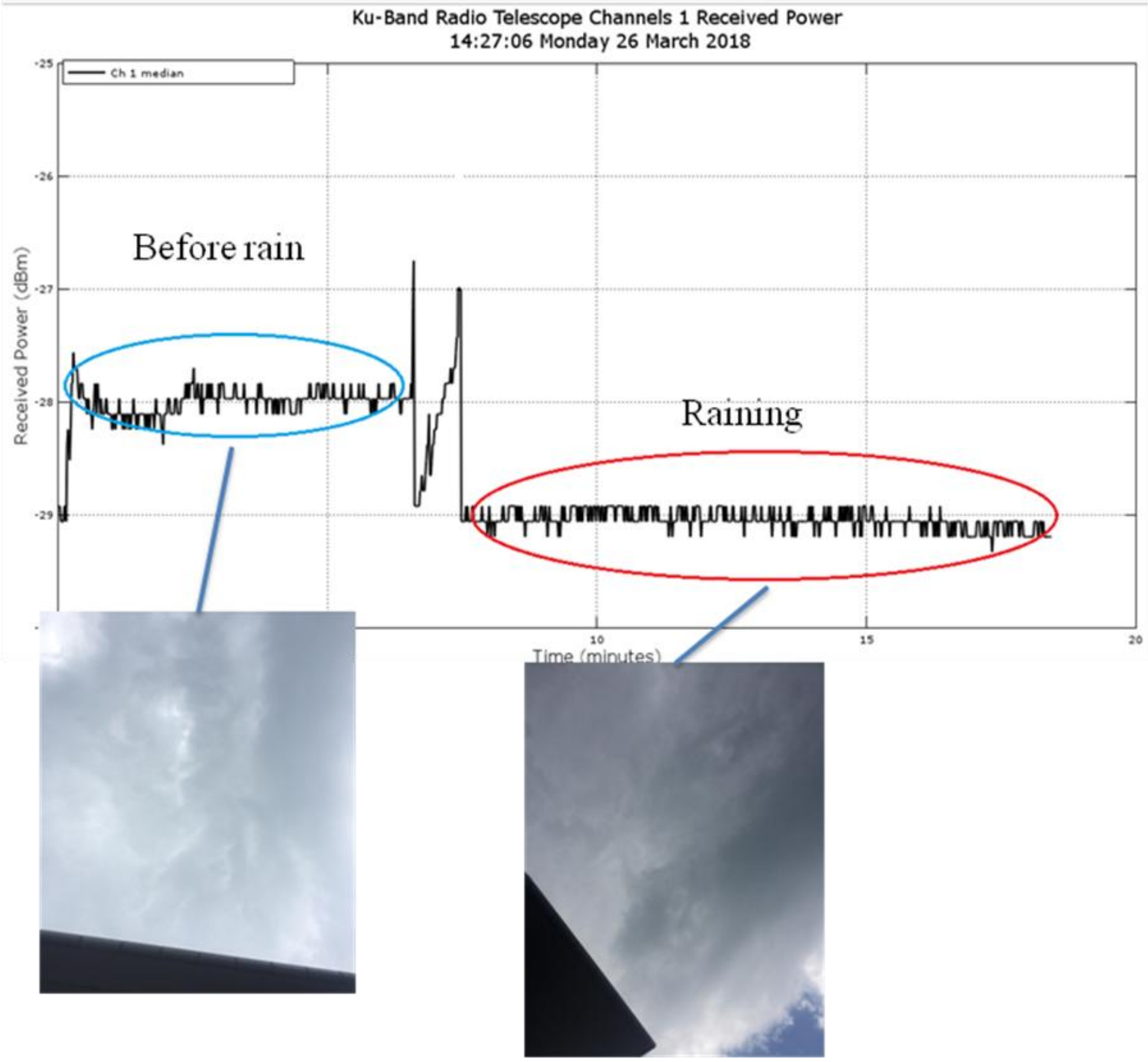

Figure 4.6 Measured signals from ASTRO satellite Sky Background before and during moderate rain

Observe the received power as the clouds start to gather and turn dark and as the rain begins to fall. The power level should drop or attenuate as shown in Figure 4.6. Once frequencies higher than 10 GHz are transmitted and received in a heavy rain fall area will occurs noticeable degradation, due to some of problems caused by and proportional to the amount of rain fall. This Astro dish (Ku band) is not only used for television transmission, which some sources imply, but also very much for digital data transmission via satellites, and for voice or audio transmissions. (Ameen, 2015)

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

An Arduino-based engineering prototype of the Ku-band radio telescope has been successfully designed, built and tested at the UTAR. It is capable of measuring electromagnetic signals from 10.7-12.75 GHz. It can also log and display measured data at 1 second intervals for up to several days. Its capability has been used to carry out a number of scientific experiments including measuring the beamwidth of the dish antenna, solar flare monitoring, observation of the effect of rain on satellite signals and sky background emissions.

This thesis more concentrates on explaining the operation principle of a simple radio telescope, explaining the concepts of angular diameter of the Sun, RF beamwidth of the ASTRO dish antenna and such. Finally, it is important to understand some basic concepts behind the electronics of a radio telescope so that we can construct a radio telescope and use them to obtain the best and accurate results possible.

5.2 Recommendation

This radio telescope can be considered as the starting point of amateur radio astronomy and platform for one to become familiar with the radio astronomy techniques. To improve the functionality of the telescope, additional feature which turn the telescope into a measuring tool that estimates the RF beamwidth of the dish antenna and angular diameter of the Sun can be added.

The best experimental approach for radio astronomy always involves starting with compact, ”handy” instruments that observe the most intense radio sources in the sky, such as the Sun. In this way it is easy to learn the instrumental and observation technique. One learns how to calibrate the instrument, and understands the process of radiometric measuring, with the various issues that make the measurement difficult and uncertain. For future enhancements of the radio telescope include investigate other receivers or develop a special receiver and improve the sensitivity of the low-noise block or an additional position sensor to improve the pointing accuracy.

.

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APPENDICES

APPENDIX A: RF detector calibration

V_{cc} = 3.203, 4.960 f = 1550MHz	Keysight High-Performance Signal Generator
Temperature = 28celcius	Model = E5504A
26/09/2017	SER = US37039015

	Voltage (V)
-70	0.25
-65	0.27
-60	0.31
-55	0.42
-50	0.59
-45	0.78
-40	0.95
-35	1.12
-30	1.30
-25	1.47
-20	1.65
-15	1.82
-10	2.00
-5	2.17
0	2.22
5	2.23
10	2.31

APPENDIX B: Arduino coding

```
//*******************
//*** DEFINITION ***//
//*******************
#include <Wire.h>
#include "RTClib.h"
#include <SD.h>

RTC_DS1307 rtc;
char filename1[] = "00000000.txt";    //maximum array size is 13
char filename2[] = "00000000.txt";    //maximum array size is 13
char daysOfTheWeek[7][12] = {"Sunday", "Monday", "Tuesday", "Wednesday",
"Thursday", "Friday", "Saturday"};
int sortValues1[21];
int sortValues2[21];
int data_log_started=false;
int old_second, current_second; // For 1s synchronization
int a;
String b;
File ch2;
File ch1;

//***********************
//*** INITILIAZATION ***//
//***********************
void setup () {
  Serial.begin(9600);// baudrate for arduino uno to communicate with computer
  pinMode(A4, OUTPUT); //Vcc of RTC
  pinMode(A5, OUTPUT); //GND of RTC
  pinMode(A0,INPUT);//input 1
  pinMode(A1,INPUT); // input 2
  pinMode(10, OUTPUT); // Output to SD reader
  pinMode(3, INPUT_PULLUP); // stop logging button
  pinMode(2, INPUT_PULLUP);//start logging button
```

```
  pinMode(4, OUTPUT); //indication of data-logging(light up = start logging)
  SD.begin(10); // Activate CS pin of SD reader
  if (! rtc.begin()) {
    Serial.println("Couldn't find RTC");
    while (1);
  }
  if (! rtc.isrunning()) {
    Serial.println("RTC is NOT running!");
    // following line sets the RTC to the date & time this sketch was compiled
    rtc.adjust(DateTime(F(__DATE__), F(__TIME__)));
    // This line sets the RTC with an explicit date & time, for example to set
    // January 21, 2014 at 3am you would call:
    // rtc.adjust(DateTime(2014, 1, 21, 3, 0, 0));
  }
}
//**********************
//*** MAIN PROGRAM ***//
//**********************
void loop () {
  int v_in_1, v_max_1=0,v_min_1=1023;
  int v_in_2, v_max_2=0,v_min_2=1023;
  int median_1;
  int median_2;
  sortValues1[0]={0};
  sortValues2[0]={0};
  while(true){
    for(int i=0; i<20; i++){
      if(data_log_started==true){
        if (digitalRead(3) == LOW){   //stop button pressed
           digitalWrite(4, LOW); //turn off led
           data_log_started=false;
           ch2.close();
           ch1.close();
```

```
        break;
      }
     else{
      }
    }
    else{
      if (digitalRead(2) == LOW){   //start button pressed
        digitalWrite(4, HIGH); //turn on led
        data_log_started=true;
        DateTime now = rtc.now();
        a=now.month();
        if(a==1){
          b=String("January");
        }
        if(a==2){
          b=String("February");
        }
        if(a==3){
          b=String("March");
        }
        if(a==4){
          b=String("April");
        }
        if(a==5){
          b=String("May");
        }
        if(a==6){
          b=String("June");
        }
        if(a==7){
          b=String("July");
        }
```

```
        if(a==8){
          b=String("August");
        }
         if(a==9){
          b=String("September");
        }
        if(a==10){
          b=String("October");
        }
        if(a==11){
          b=String("November");
        }
        if(a==12){
          b=String("December");
        }

        getFilename1(filename1);
        getFilename2(filename2);
        ch2=SD.open(filename2, FILE_WRITE);//open file for channel 2
        ch1=SD.open(filename1, FILE_WRITE);//open file for channel 1
        // Codes below are use to save date and time as header for both files
        ch1.print("# ");
        if(now.hour()<10){
          ch1.print("0");
        }
ch1.print(now.hour(), DEC);
        ch1.print(":");
```

```
        if(now.minute()<10){
          ch1.print("0");
        }
        ch1.print(now.minute(), DEC);
        ch1.print(":");
        if(now.second()<10){
          ch1.print("0");
        }
        ch1.print(now.second(), DEC);
        ch1.print(" ");
        ch1.print(daysOfTheWeek[now.dayOfTheWeek()]);
        ch1.print(' ');
        ch1.print(now.day(), DEC);
        ch1.print(' ');
        ch1.print(b);
        ch1.print(' ');
        ch1.println(now.year(), DEC);
ch2.print("# ");
        if(now.hour()<10){
          ch2.print("0");
        }
        ch2.print(now.hour(), DEC);
        ch2.print(":");
        if(now.minute()<10){
          ch2.print("0");
        }
        ch2.print(now.minute(), DEC);
        ch2.print(":");
        if(now.second()<10){
          ch2.print("0");
        }
```

```
        ch2.print(now.second(), DEC);
        ch2.print(" ");
        ch2.print(daysOfTheWeek[now.dayOfTheWeek()]);
        ch2.print(' ');
        ch2.print(now.day(), DEC);
        ch2.print(' ');
        ch2.print(b);
        ch2.print(' ');
        ch2.println(now.year(), DEC);
      }
    }
    delay(40);
    int v_in_1=analogRead(A0);
    int v_in_2=analogRead(A1);
    sortValues1[i+1]=v_in_1;
    sortValues2[i+1]=v_in_2;

if (v_in_1>v_max_1){
      v_max_1=v_in_1;
    }
    if(v_in_1<v_min_1){
      v_min_1=v_in_1;
    }
    if (v_in_2>v_max_2){
      v_max_2=v_in_2;
     }
    if(v_in_2<v_min_2){
      v_min_2=v_in_2;
     }
   }
```

```
DateTime now = rtc.now();
    current_second=now.second();
     if(current_second==old_second);{//for 1s synchronization
       delay(200);
     }
     old_second=now.second();//update the old second

     sortValues1[0]=sortValues1[21];  // Fill first element for next sort
     sortValues2[0]=sortValues2[21]; // Fill first element for next sort
     sort(sortValues1,21);//call the sort function
     sort(sortValues2,21);//call the sort function
     median_1=sortValues1[10];
     median_2=sortValues2[10];

     Serial.println(v_max_1);
     Serial.println(median_1);
     Serial.println(v_min_1);
     Serial.println(v_max_2);
     Serial.println(median_2);
     Serial.println(v_min_2);

     if(data_log_started==true){//when start button is pressed,then data log is start
       ch1.print(v_max_1);
       ch1.print(" ");
       ch1.print(median_1);
       ch1.print(" ");
       ch1.println(v_min_1);

       ch2.print(v_max_2);
       ch2.print(" ");
       ch2.print(median_2);
       ch2.print(" ");
       ch2.println(v_min_2);
```

```
      }
      v_max_1=0,v_min_1=1023;
      v_max_2=0,v_min_2=1023;
   }//while
}//void

//***********************************
//*** FUNCTIONS AND SUB-ROUTINE ***//
//***********************************
//sort function
void sort(int a[], int size) {
  for(int i=0; i<(size-1); i++) {
    for(int o=0; o<(size-(i+1)); o++) {
       if(a[o] > a[o+1]) {
         int t = a[o];
         a[o] = a[o+1];
         a[o+1] = t;
       }
    }
  }
}

//function to save our filename with date and time
void getFilename1(char *filename1) {  //maximum array size is 13
  DateTime now = rtc.now();
  int year = now.year();
  int month = now.month();
  int day = now.day();
  int hour = now.hour();
  int minute = now.minute();
  int second = now.second();
  float dJulianDate,dDecimalHours,dElapsedJulianDays;
```

```
  long int liAux1;
  long int liAux2;
  long int ref=2457389, diff;
  int first, seconds, last;

  //calculation of julian date
  liAux1 =(month-14)/12;
  liAux2=(1461*(year + 4800 + liAux1))/4 + (367*(month
        - 2-12*liAux1))/12- (3*((year + 4900
        + liAux1)/100))/4+day-32075;
  dJulianDate=(float)(liAux2)-0.5+hour/24.0;
  diff=dJulianDate-ref;
  first=diff/100;
  last=diff%10;
  seconds=(diff/10)%10;

//code below is use to create desire filename
  filename1[0] = '1';
  filename1[1]= diff/100 + '0';
  filename1[2] = (diff/10)%10 + '0';
  filename1[3] = diff%10 + '0';
  filename1[4] = hour/10 + '0';
  filename1[5] = hour%10 + '0';
  filename1[6] = minute/10 + '0';
  filename1[7] = minute%10 + '0';
  filename1[8] = '.';
  filename1[9]= 't';
  filename1[10]= 'x';
  filename1[11]= 't';
  return;
}
```

```
void getFilename2(char *filename2) {  //maximum array size is 13 //function to
save our filename with date and time
  DateTime now = rtc.now();
  int year = now.year();
  int month = now.month();
  int day = now.day();
  int hour = now.hour();
  int minute = now.minute();
  int second = now.second();
  float dJulianDate,dDecimalHours,dElapsedJulianDays;
  long int liAux1;
  long int liAux2;
  long int ref=2457389, diff;
  int first, seconds, last;
  //calculation of julian date
  liAux1 =(month-14)/12;
  liAux2=(1461*(year + 4800 + liAux1))/4 + (367*(month
        - 2-12*liAux1))/12- (3*((year + 4900
        + liAux1)/100))/4+day-32075;
  dJulianDate=(float)(liAux2)-0.5+hour/24.0;
  diff=dJulianDate-ref;
  first=diff/100;
  last=diff%10;
  seconds=(diff/10)%10;
  //code below is use to create desire filename
  filename2[0] = '2';
  filename2[1]= diff/100 + '0';
```

```
  filename2[2] = (diff/10)%10 + '0';
  filename2[3] = diff%10 + '0';
  filename2[4] = hour/10 + '0';
  filename2[5] = hour%10 + '0';
  filename2[6] = minute/10 + '0';
  filename2[7] = minute%10 + '0';
  filename2[8] = '.';
  filename2[9]= 't';
  filename2[10]= 'x';
  filename2[11]= 't';
  return;
}
```

APPENDIX C: Octave coding (***KuRT_online_1V2***)

```
clear; % clear previous figures
pkg load instrument-control
Setup_data = load('KuRT_Octave_setup.txt');

N = num2str(Setup_data (1));
m1 = Setup_data (2);
c1 = Setup_data (3);
m2 = Setup_data (4);
c2 = Setup_data (5);

s=serial(strcat("COM",N),9600);
n=3600;
srl_flush(s); % flush serial com port ;
close all; % reset all figures here ...
date= strftime ("%r %T %A %e %B %Y", localtime (time ()));
A = strftime ("KuRT_Ch1_%y%m%d_%H%M%S.txt", localtime(time()));
B = strftime ("KuRT_Ch2_%y%m%d_%H%M%S.txt", localtime(time()));
fid_1 = fopen(A,"wt");
fprintf(fid_1,"%s","#",date);
fid_2 = fopen(B,"wt");
fprintf(fid_2,"%s","#",date);
printf("KuRT will run for %d seconds ... (press any key to abort)\n",n);

for i = 1:n
  kill = kbhit (1);
  if (kill!=1)
    display("Key pressed, closing ... ");
    fclose(s);
    break;
  end

  max1_serial = str2num(ReadToTermination(s,13));
```

```
v1_max (i) = max1_serial*5/1023;
  p1_max(i) = m1*v1_max(i)+c1;

  median1_serial = str2num(ReadToTermination(s,13));
  v1_median (i) = median1_serial*5/1023;
  p1_median(i) = m1*v1_median(i)+c1;

  min1_serial = str2num(ReadToTermination(s,13));
  v1_min (i) = min1_serial*5/1023;
  p1_min(i) = m1*v1_min(i)+c1;

  max2_serial = str2num(ReadToTermination(s,13));
  v2_max (i) = max2_serial*5/1023;
  p2_max(i) = m2*v2_max(i)+c2;

  median2_serial = str2num(ReadToTermination(s,13));
  v2_median (i) = median2_serial*5/1023;
  p2_median(i) = m2*v2_median(i)+c2;

  min2_serial = str2num(ReadToTermination(s,13));
  v2_min (i) = min2_serial*5/1023;
  p2_min(i) = m2*v2_min(i)+c2;

  fprintf(fid_1,"\n%i",max1_serial);
  fprintf(fid_1," %i",median1_serial);
  fprintf(fid_1," %i",min1_serial);

  fprintf(fid_2,"\n%i",max2_serial);
  fprintf(fid_2," %i",median2_serial);
  fprintf(fid_2," %i",min2_serial);
```

```
x(i)=i;
figure(1);
plot(x/60,p1_max,':r','linewidth',3);
hold on;
plot(x/60,p1_median,'k','linewidth',2);
hold on;
plot(x/60,p1_min,':b','linewidth',3);
hold off;
xlabel('Time (minutes)','fontsize',16);
ylabel('Received Power (dBm)','fontsize',16);
grid on;
legend('max','median','min','Location','NorthWest');
title({'Ku-Band Radio Telescope Channel 1 Received Power';date},'fontsize',18);

figure(2);
plot(x/60,p2_max,':r','linewidth',3);
hold on;
plot(x/60,p2_median,'k','linewidth',2);
hold on;
plot(x/60,p2_min,':b','linewidth',3);
hold off;
xlabel('Time (minutes)','fontsize',16);
ylabel('Received Power (dBm)','fontsize',16);
grid on;
legend('max','median','min', 'Location','NorthWest');
title({'Ku-Band Radio Telescope Channel 2 Received Power';date},'fontsize',18);
```

```
figure(5);
  plot(x/60,p1_median,'k','linewidth',2);
  hold on;
  plot(x/60,p2_median,':r','linewidth',3);
  hold off;
  xlabel('Time (minutes)','fontsize',16);
  ylabel('Received Power (dBm)','fontsize',16);
  grid on;
  legend('Ch 1 median','Ch 2 median','Location','NorthWest');
  title({'Ku-Band Radio Telescope Channels 1 & 2 Received Power';date},'fontsize',18);
endfor
  fclose(fid_1);
  fclose(fid_2);
fclose(s);
```

APPENDIX D: Octave coding (***KuRT_offline_1V2***)

```
pkg load io;

Setup_data = load('KuRT_Octave_setup.txt');
%N = num2str(Setup_data (1));   % not used here
m1 = Setup_data (2);
c1 = Setup_data (3);
m2 = Setup_data (4);
c2 = Setup_data (5);

c = csv2cell('1.txt');
a = c{1,:};
date = a(2:length(a));

file_1 = load('1.txt');
x1=length(file_1);
b=file_1(1:x1,1);
c=file_1(1:x1,2);
d=file_1(1:x1,3);

file_2 = load('2.txt');
e=file_2(1:x1,1);
f=file_2(1:x1,2);
g=file_2(1:x1,3);

  v1_max = b*5/1023;
  p1_max = m1*v1_max+c1;

  v1_median = c*5/1023;
  p1_median = m1*v1_median+c1;

  v1_min = d*5/1023;
  p1_min = m1*v1_min+c1;
```

```
v2_max = e*5/1023;
p2_max = m2*v2_max+c2;

v2_median = f*5/1023;
p2_median = m2*v2_median+c2;

v2_min = g*5/1023;
p2_min = m2*v2_min+c2;

x=(1:x1);
figure(1);
plot(x/60,p1_max,':r','linewidth',3);
hold on;
plot(x/60,p1_median,'k','linewidth',2);
hold on;
plot(x/60,p1_min,':b','linewidth',3);
hold off;
xlabel('Time (minutes)','fontsize',16);
ylabel('Received Power (dBm)','fontsize',16);
grid on;
legend('max','median','min','Location','NorthWest');
title({'Ku-Band Radio Telescope Channel 1 Received Power';date},'fontsize',18);
```

```
figure(2);
plot(x/60,p2_max,':r','linewidth',3);
hold on;
plot(x/60,p2_median,'k','linewidth',2);
hold on;
plot(x/60,p2_min,':b','linewidth',3);
hold off;
xlabel('Time (minutes)','fontsize',16);
ylabel('Received Power (dBm)','fontsize',16);
grid on;
legend('max','median','min', 'Location','NorthWest');
title({'Ku-Band Radio Telescope Channel 2 Received Power';date},'fontsize',18);


figure(5);
plot(x/60,p1_median,'k','linewidth',2);
hold on;
%plot(x/60,p2_median,':r','linewidth',3);
hold off;
xlabel('Time (minutes)','fontsize',16);
ylabel('Received Power (dBm)','fontsize',16);
grid on;
legend('Ch 1 median','Location','NorthWest');
title({'Ku-Band Radio Telescope Channels 1 Received Power';date},'fontsize',18);
```