THE DEVELOPMENT OF ON-BOARD COMMUNICATION SYSTEM FOR A CUBESAT

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2019

ENDORSEMENT

I, Sharfa Eliya Bt Mohd Fadzil hereby declare that I have checked and revised the whole draft of dissertation as required by my supervisor.

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Date:

DECLARATION

This thesis is a result of my own investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

Signature of Student

Date:

ACKNOWLEDGEMENT

First, all praises to Allah SWT for allowing me to finish this project completely. Without His guidance, I will not be able to finish this report and thankfully, He gives me a lot of patient during my hard times.

Besides, the most important person involves in this project is my supervisor, Dr ‘Aiffah Mohd Ali. I would like to express my gratitude and appreciation for her guidance during the entire project. It is an honor to be under her supervision because she does care about the progress of her students. Truly, I did learned a lot from her both in studies and in real life as well.

My appreciation also goes to my co-supervisor, Encik Azwan for his extraordinary effort on guiding me technically, which is the hardware parts. He did helps me a lot for this project since he has electric and electronic engineering background. Frankly, I did encounter problems especially for me to learn the electronic field since I am from Aerospace Engineering student. It is difficult to push myself to learn something that I did not learn in class but at the end, I found that it is not that hard as long as we keep learning. Moreover, having solid basic in electronic field is like a must due to the overwhelming technologies nowadays. Nevertheless, I know that if we willing to learn no matter how hard it is, God will ease our path.

Finally, and surely not to be forgiven, I am absolutely felt grateful to my beloved family. It such a bless to have them for always supporting me by giving motivation most of the time. I truly appreciate it and with hope that I could effort to repay their sacrifices soon.

THE DEVELOPMENT OF ON-BOARD COMMUNICATION SYSTEM FOR A CUBESAT

ABSTRACT

People sent satellite to the outer space with their own unique missions which gives benefits in return. Now a IU CubeSat has been chosen widely due to its size, compatibility, and very low in cost compared to other traditional satellites. There are many subsystems that contribute to the development of a CubeSat which are power system, payload, thermal, computer system, structure, on board data handling and communication. On board communication system is very crucial in making sure that the CubeSat can operates well. In order for the satellite to achieve its mission, the communication system is important for sending the command from ground station to the satellite and sending the data to the ground station. Since the mission of MYSat is to measure the electron-density in ionosphere E-layer, the data need to be collected to the ground station for further analysis. No communication system means no transmission data will happened and the mission will be unachievable. Command and data handling system also work together with the communication system, as the data will be transmitted to the ground station. The developing process of this CubeSat called MYSat includes in determining the design parameters, conduct experiments involving basic of Morse code for CubeSat, and test and propose RF Transmitter and Receiver 433MHz for on-board communication system for CubeSat. From the findings, the RF Transmitter and Receiver 433MHZ can be used for CubeSat since it operates at real frequency for amateur radio.

PEMBANGUNAN SISTEM PAPAN KOMUNIKASI UNTUK CUBESAT

ABSTRAK

Orang ramai menghantar satelit ke angkasa lepas dengan misi unik mereka sendiri yang memberikan faedah sebagai balasan. Kini IU CubeSat telah dipilih secara meluas kerana saiznya, keserasian, dan kos yang sangat rendah berbanding dengan satelit tradisional yang lain. Terdapat banyak subsistem yang menyumbang kepada pembangunan CubeSat yang merupakan sistem kuasa, muatan, termal, sistem komputer, struktur, pengendalian dan komunikasi data papan. Sistem komunikasi papan adalah sangat penting dalam memastikan CubeSat dapat beroperasi dengan baik. Agar satelit mencapai misinya, sistem komunikasi adalah penting untuk menghantar arahan dari stesen tanah ke satelit dan menghantar data ke stesen tanah. Sistem arahan dan pengendalian data juga berfungsi bersama sistem komunikasi, kerana data akan dihantar ke stesen tanah. Proses pembangunan CubeSat ini dipanggil MYSat termasuk dalam menentukan parameter reka bentuk, menjalankan eksperimen yang melibatkan asas kod Morse untuk CubeSat, dan menguji dan mencadangkan Pemancar dan Penerima RF 433MHz untuk sistem komunikasi di atas papan untuk CubeSat. Daripada penemuan ini, Pemancar RF dan 433MHZ Penerima boleh digunakan untuk CubeSat kerana ia beroperasi pada frekuensi sebenar untuk radio amatur.

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LIST OF ABBREVIATIONS

MYSat	Malaysia Youth Satellite
TT&C	Tracking, Telemetry and Command
UHF	Ultra High Frequency
VHF	Very High Frequency
ATC	Air Traffic Control
UI	Unnumbered Information
RF	Radio Frequency
IOT	Internet of Things
EIRP	The Effective Isotropic Radiated Power
IRL	Isotropic Signal Level
SDR	Software-defined radio

LIST OF SYMBOLS

σ	Boltzmann Constant
λ	Wavelength
δ	Minimum communication elevation
h	Satellite's altitude
l	Turn spacing
n	Number of turns of the helical structure
$\frac{G}{T}$	Figure-of-Merit
G_R	Receiver Gain
G_T	Transmitted Gain
L	Helical circumference
L_a	Atmospheric loss
L_l	Ionospheric loss
L_P	Path loss
L_R	Rain loss
P_T	Transmitted power
R_E	Earth radius
S	Path length or slant range
$\frac{\mathrm{S}}{\mathrm{N}_0}$	Signal-to-Noise ratio
T_S	System noise temperature

CHAPTER 1

INTRODUCTION

1.1 Research background

CubeSat is a class of satellite called nanosatellite that defined by its size, weight and shape. CubeSat development contributes many advantages such as cost reduction, making the deployment system less difficult, require of no thermal blanket and shorter development timing, which eventually suitable for educational purpose. These benefits encourage universities to have their own educational CubeSat development programs.

MYSat, stand for Malaysia Youth Satellite is a CubeSat project under development by a group of students and lecturers from School of Aerospace Engineering, Universiti Sains Malaysia (USM). The mission of MYSat is to measure the electron-density in ionosphere E-layer. The observation on the electron-density is mainly to detect the earthquake, which is unpredictable. MYSat is expected to launch in couple of years which will be carried out by astronauts from the Kibo module owned by JAXA (Japan Aerospace Exploration Agency) at the International Space Station (ISS).

1.2 Problem statement

In any development of a satellite, the communication subsystem is an essential part to allow communication link between the ground station and the satellite. This is the same for a CubeSat as it carries scientific experiments, which repeatedly collects experiment data when the CubeSat orbits the Earth. When all the data has to be transmitted to the ground station before the user can analyze and collect the data received from the satellite. Hence, communication between the satellite and ground station is the effective way in making sure that the data will be able to collected in making the mission achievable.

1.3 Objectives

The first objectives of this thesis is to determine the design parameters for the MYSat's communication system. Theoretically link budget is important to estimate the signal efficiency by considering all the signal gains and losses between satellite and ground station (THAHER, 2017). Secondly, to conduct experiments involving basic of Morse code for on-board communication system of CubeSat. Lastly, the objectives of this thesis is to test and propose RF Transmitter and Receiver 433MHz for on-board communication system for CubeSat.

1.4 Thesis outline

This thesis is divided into five chapters, which includes introduction, literature review, methodology, result and discussion, and conclusion.

Chapter 1 gives a brief overview on CubeSat, specifically called MYSat for this thesis. This chapter introduce the problem statements, which is why this thesis is done. This chapter also review the objectives of the thesis.

Chapter 2, which is contains the literature review, is the studies on the on-board communication system. It elaborates on the mission of MYSat, background of communication subsystem, the frequency band used for the amateur radio, the background of Morse code, and the details on the AX.25 protocol.

Chapter 3 reveals the method and technique implemented in this research. Several experiments have been conducted that involves the Morse code for communication. The experiment used component such as 40M CW Shortwave Transceiver QRP Pixie Kit and 433Mhz RF Transmitter and Receiver Kit.

Chapter 4 highlights the results of all experiments conducted which are in form of tables, figures and texts.

Chapter 5 summarizes the research by reviewing the objective set, the limitations and suggestion for recommendation is included for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Background of CubeSat Development

CubeSat is a type of satellite specially launch at low earth orbit with altitude below 2000 km from Earth's surface that has 10 cm × 10 cm × 10 cm of size measurement. CubeSat usually launched from International Space Station (ISS) or as a secondary payload in any launch vehicle. About 876 CubeSats have been launched based on CubeSat database. The small in size and weight with not more than 1.33kg makes it easier, cheaper and suitable for educational purposes(Chen, 2018).

The first Malaysian CubeSat launched into space was developed by Universiti Teknologi MARA (UiTM), and is known as UiTMSAT-1. It was built as part of the multi-nation Birds-2 project and has six missions in total. This CubeSat missions are to demonstrate UiTM's first commercial off-the-shelf global positioning system technology, collect geomagnetic mapping data for Southeast Asia, measure magnetic fields in space, obtain the measurement of the Single Event Latch-up Detection, demonstrate an Automatic Packet Reporting System Digipeater and capture the images of the Earth. This project was a collaboration with two other countries, Bhutan and Philippines under a project called Joint Global Multi-Nation BIRDS-2.

MYSat is a project solely developed by a group of students and lecturers from Universiti Sains Malaysia (THAHER, 2017) with the mission to measure the electron-density in ionosphere.

2.2 Communication

There are many subsystems that contribute to the development of a CubeSat, which are power, thermal, computer, structure, on-board data handling and communication systems. The on-board communication system is very crucial in making sure that the CubeSat can operates well. In order for the satellite to achieve its mission, the communication system is important for sending the command from ground station to the satellite and sending the data to the ground station. Command and data handling system also work together with the communication system, as the data transmitted to the ground station. Communication for any satellite need to be designed to meet all requirements since it works in space environment.

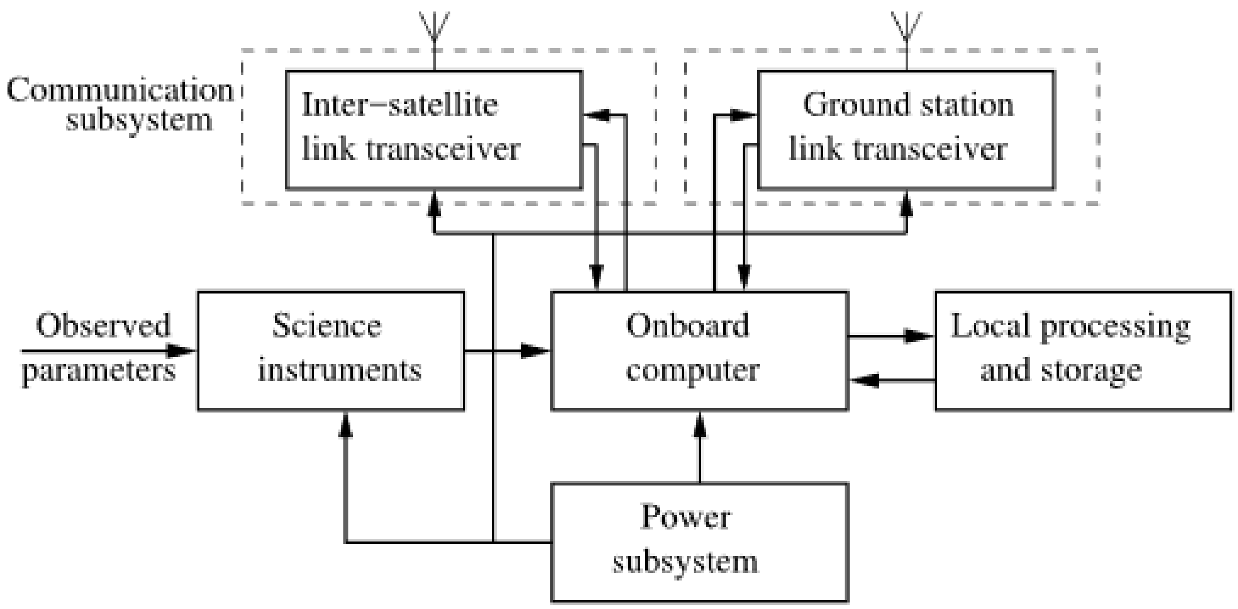


Figure 2.1 Block diagram of subsystems of a CubeSat

Communication is defined by which information is transmitted between a sender and a receiver. It does happened almost every single day including telephones, television, internet, and even us as a human. Communication channel refers on how the communication is delivered, it can be wired or wireless. For example, in the FR radio signals, the medium is the air. While for optical fiber communication, the medium is an optical (glass-like) fiber.

Communication system of CubeSat consists of three main functions, which are to transmit a tracking signal, sending the telemetry to ground station and receive commands from ground station. In general, it refers to TT&C (Tracking, Telemetry and Command) system.

Uplink is a communication link from the ground station to the satellite, where transmitter is located at the ground station and receiver at the satellite. Downlink is the communication channel from the satellite to the ground station. The uplink is used to send commands from ground station to the satellite, while downlink is used to transmit telemetry, mission data and housekeeping data. Figure below illustrate the two way of communication channel of data link. Normally, CubeSat build to operate at UHF band (435- 438 MHz) for uplink, whereas operating at VHF band (144-146 MHz) during downlink (Hunyadi *et al.*, 2002).

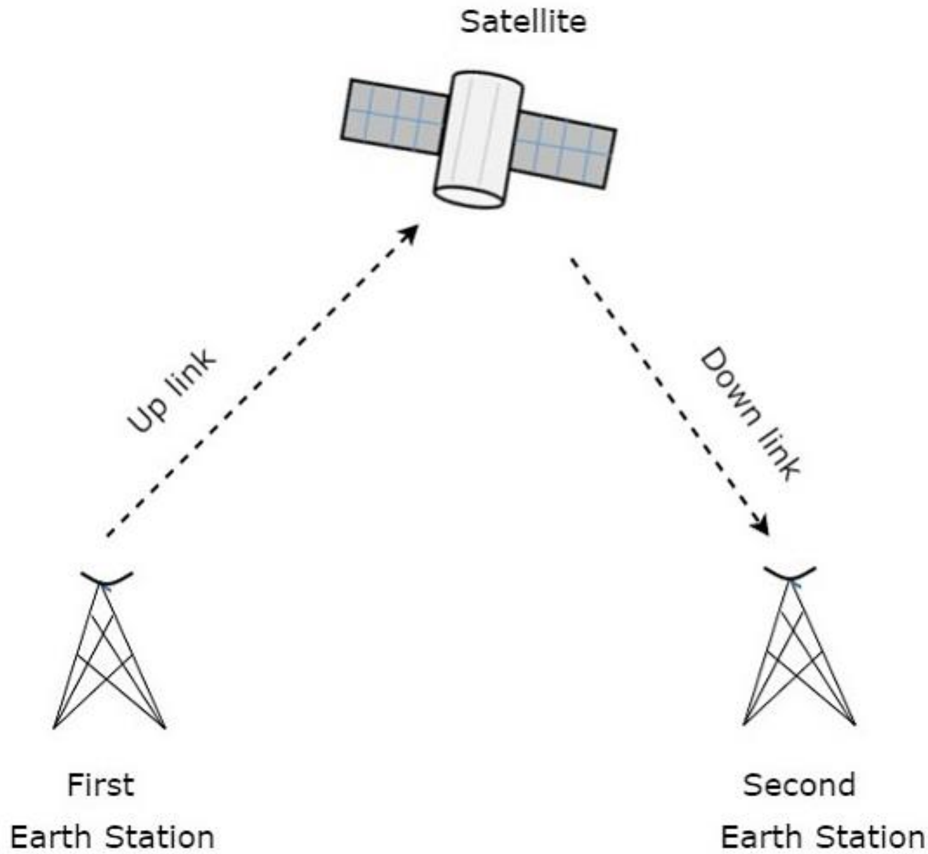


Figure 2.2 Two way of communication channel

2.3 Morse code

One of the historical type of communication is the Morse code. The Morse code was invented by American called Samuel Finley Breese Morse, (1791-1872). The invention begins with the telegraph itself sending messages through cable that connected across long distance with the help of electric pulses (Finley *et al.*, 2006). The first message managed to send is “What hath God wrought”, sent by Morse’s telegraph from Washington to Baltimore between forty miles away in 1844.

Morse code consists of two characters, which are dot (.) and dash (-). Each alphabet or number has its fixed or special combinations of dot and dash (refer Figure 3). The dot has short pulse and the dash has longer pulse, which can be differentiated by listening to the audio tone. The duration of dash is three times longer than the dot. Before radio and satellites replaced the Morse code in the mid-twentieth century, Morse code was used both with wireless telegraph and electromagnetic telegraph.

Morse code has been used as the basic communication in world war especially in sending private messages in the military. In navy, Morse code is used to send messages to other ships. Till this day, Morse code has been used in aviation field. Mainly, they were used to keep communicate between the airplanes and the ATC (Air Traffic Control). Morse code also still used in radio communication, which used in radio amateur.

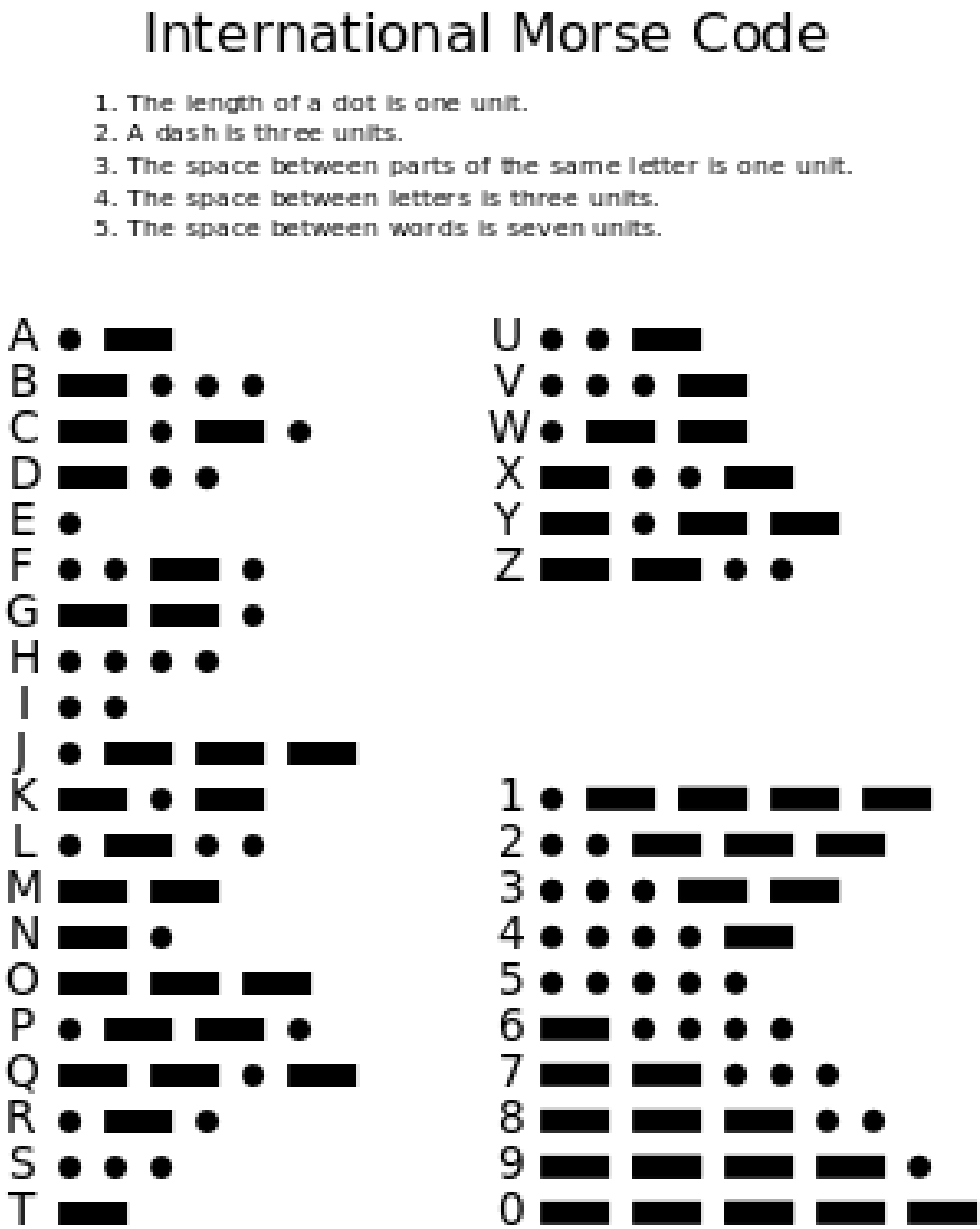


Figure 2.3: International Morse Code

2.4 AX.25 Protocol

Originally derived as layer two of X.25 protocol, this data link layer protocol is widely used in amateur packet radio networks(Cubesat, 2002). Digipeater is included in allowing other station to automatically repeat the packets in order to extend the transmitters range. Data link layer radio are sent in small blocks called frames, which of it consists of several group called fields. Each field has its functions and consists of 8-bit binary number. AX.25 can be categorized in three frames, (1) Information frame, (2) Supervisory frame and (3) Unnumbered frame.

Flag	Address	Control	Info	FCS	Flag
01111110	112/224 Bits	8/16 Bits	N*8 Bits	16 Bits	01111110

Figure 2.4: U and S frame construction

Flag	Address	Control	PID	Info	FCS	Flag
01111110	112/224 Bits	8/16 Bits	8 Bits	N*8 Bits	16 Bits	01111110

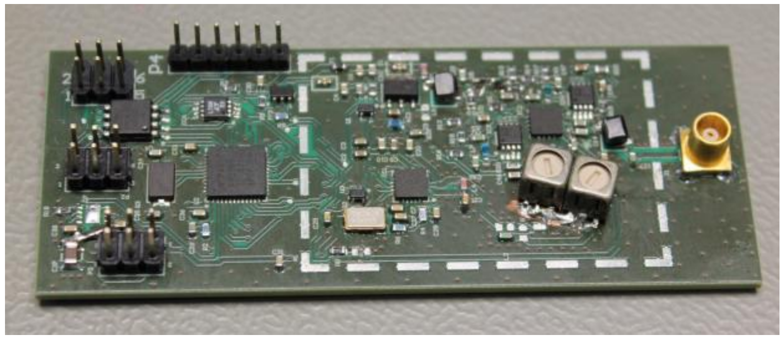
Figure 2.5: Information frame construction

There are several advantages of AX.25 protocol, which it always be the choice for packet data for satellite. It does work well for direct connections between two amateur radio stations and between a station and a multi controller. It allows for self-connections and creation of more than one link-layer connection for device depends on its capability. Every packet sent consists of the sender's and receiver's amateur radio callsign, which provides identification of station with every transmission.

2.5 Reviews on other's work

There are numbers of on-board communication architecture for CubeSat. Studies should to be completed before considering on what components they are using for the on-board communication especially the transmitter and receiver. Table below shows the different component used for different CubeSat.

<table>
<tr><th>Satellite</th><th>Component</th></tr>
<tr><td>Scott E. Palo
Department of Aerospace Engineering Sciences
University of Colorado, Boulder, CO 80309, USA</td><td>
Figure 2.6: High rate (l2.5Mbps) X-band CubeSat transmitter
Frequency used for downlink was 8380 MHz of X-band.
The top of the board (left), a large Actel FPGA can be seen at the microstrip channel. This FPGA was used to take the data stream from LVDS ouput which generaly for testing purposes.
The data stream was encoded for error detection and correction and converted to two bit.
The output was filtered and amplified to generate the transmission</td></tr>
</table>

<table>
<tr>
<td>ESTCube-1</td>
<td>
Figure 2.7 Integrated prototype of the communication system
The objective of this project is to design and prototype a communication system for CubeSat
For downlink, frequency used was 430 MHz UHF band with 9600 baud while for uplink; 143 MHz VHF band was used with 1200 baud. Both uplink and downlink have fixed baud and use 2FSK modulation.
It use separate ADF7021 transceivers for transmitter and receiver circuits.
Silicon Labs Si570 programmable crystal oscillator was used for Morse beacon.</td>
</tr>
</table>

CHAPTER 3

METHODOLOGY

3.1 Link budget

Link budget is important in any radio frequency network deployment. It refers on how many power available for communication link and signal-to-noise ratio needed for transmission with the required quality**.** Calculating the link budget helps to evaluate the receive power and noise power in a radio link and summarize all the gain and losses affecting the signal along the link path(Addaim *et al.*, 2005).

The link budget is calculates for the uplink and downlink communication. Type of antenna used for MySat is dipoleantenna while helical antenna is used at the ground station. The calculation for helical antenna and beamwidth is using Equation (3.11) and Equation (3.12) .

$$G_{Helical} = 10\log(15L\, ln^2); \tag{3.11}$$

$$BW_{helical} = \frac{52.2}{L\sqrt{nL}} \tag{3.12}$$

Where *l* is the turn spacing, *n* refers to the number of turns of the helical structure and *L* is the helical circumference.

The Effective Isotropic Radiated Power, *EIRP*, are calculated by assuming the line loss, L_l , is 0 dB using Equation (3.13). *EIRP* represents the effective power that leaves the antenna.

$$EIRP = P_T - L_l + G_T , \qquad \text{Eq. (3.13)}$$

where, P_T is the transmitted power in dBW.

After the electromagnetic waves have left the transmitting antenna, it is required to reach the receiver by passing through the free space considering for losses which are called path loss, L_P . This loss can be calculated using Equation (3.14).

$$L_P = 22 + 20\log\left(\frac{S \times 1000}{\lambda}\right) \qquad (3.14)$$

Where, *S* is the path length or slant range, illustrated in Figure 3.1, can be solved using Equation (3.15).

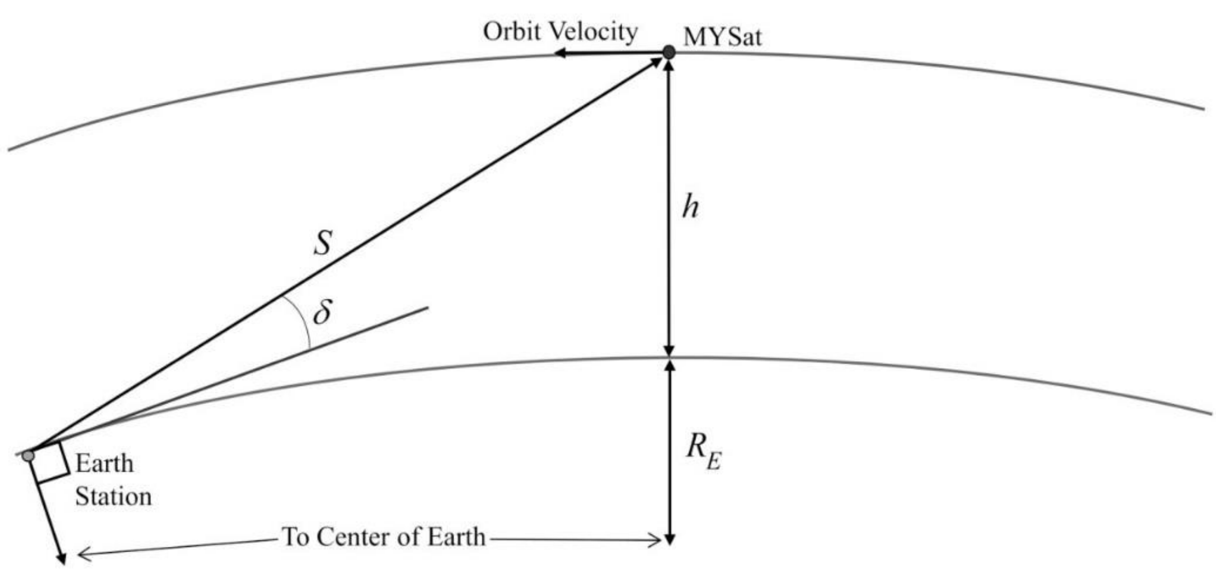


Figure 3.1: Path-length

$$S = \sqrt{(RE\ \sin(\delta))2\ + 2\ RE\ h -\ h^2} - R_E \sin(\delta)\ ; \qquad (3.15)$$

$$ISL = EIRP - (LPointing + LPolarization + LP + La + Li + LR)\ . \qquad (3.16)$$

Isotropic Signal Level, *ISL*, which is the level of signal received in space with an omnidirectional antenna that can be calculated using Equation (3.16). This comes with the assumption listed in Table 3.1.

Table 3.1 Communication losses

Parameters	**Values**	**Units**
Pointing Loss,	0.27	dB
Polarization Loss,	0.06	dB
Line Loss,	0.00	dB
Atmospheric Loss,	2.1	dB
Ionospheric Loss,	Uplink: 0.7 Downlink: 0.4	dB
Rain Loss,	0.00	dB

Figure-of-Merit, $\frac{G}{T}$ that provides details on the receiver performance where T_S is the system noise temperature which is assumed to be 283.2 K is represented in Equation (3.17).

$$\frac{G}{T} = GR - L_l - 10\log T_S\ . \qquad (3.17)$$

The Signal-to-Noise ratio, $\frac{S}{N_0}$, is calculated using Equation (3.18) where, σ refers to Boltzmann Constant (-228.6 dBW/KHz^{-1}) is used to estimate the Ratio of Received Energy-per-bit to Noise-density for command in Equation (3.19).

$$\frac{S}{N_0} = ISL - L_l - \sigma + \frac{G}{T} \qquad (3.18)$$

$$\frac{Eb}{N_{0\,Command}} = 10 \log RAvailable - \frac{S}{N_0} \tag{3.19}$$

Where, $R_{Available}$ is the rate of downlink calculated from the data budget. Assuming, Gaussian Minimum Shift Keying (GMSK) as the demodulation method with a Bit-error Rate of 10^{-5}, the $\frac{Eb}{N_{0\,telemetry}}$ is 9.6 dB, and implementation loss of 1.00 dB, the $\frac{Eb}{N0\,Threshold}$ can be calculated using Equation (3.20). Link margin is then computed using Equation (3.21) with the margin should be no less than 3 dB (Larson *et al.*, 1999).

$$\frac{Eb}{N0\,Threshold} = \frac{Eb}{N0\,Telemetry} - L_{Implementation} \tag{3.20}$$

$$\text{Link Margin} = \frac{Eb}{N_{0\,Command}} - \frac{Eb}{N0\,Threshold} \tag{3.21}$$

3.2 Arduino as Microcontroller

For experiment and testing stage, Arduino Uno will be used mostly for all experiment as the microcontroller since it is easier and suitable for beginner. The main reason of broader usage of Arduino Uno is due to its inexpensive price compared to other microcontroller that cost below than RM100. Unlike Raspberry Pi, it requires some installation before it can be used and run in its own Operating System such as Linux. Meanwhile Arduino Uno does not have its own Operating System and it simply runs in the dedicated program together with the code. Figure 3.2 shows the diagram of Arduino Uno Pinout showing the interfaces on the Arduino.

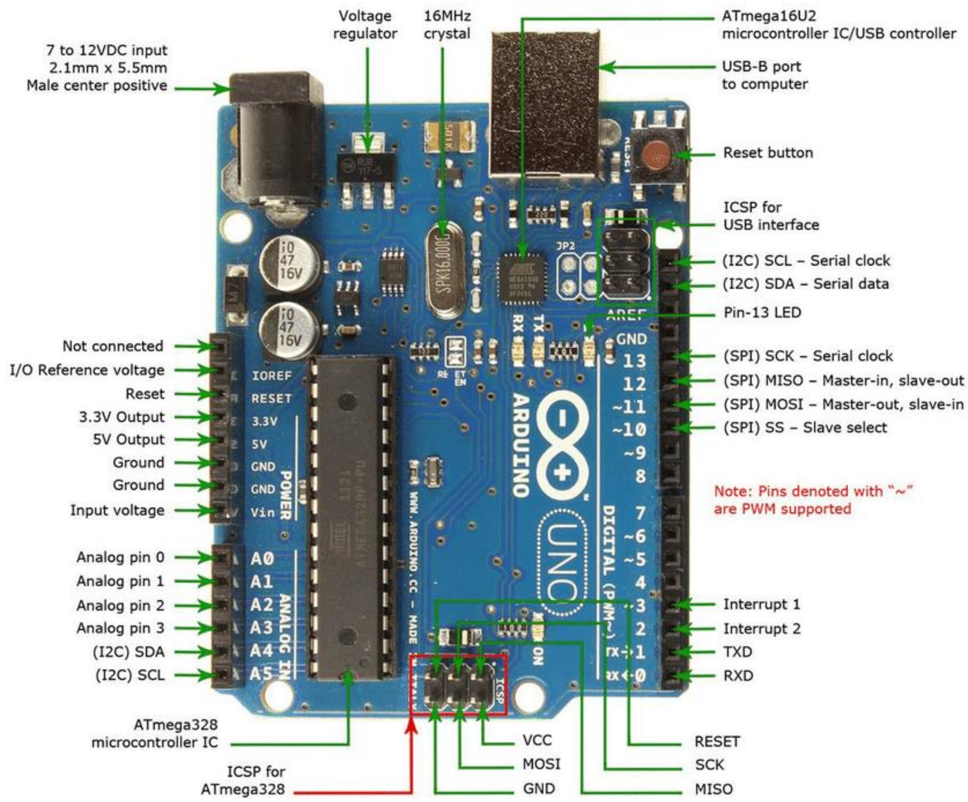


Figure 3.2 Arduino Uno Pinout Diagram

3.3 Morse code encode

The Morse code encode is the experiment mainly to produce a sound as the output by inserting the character as the input.

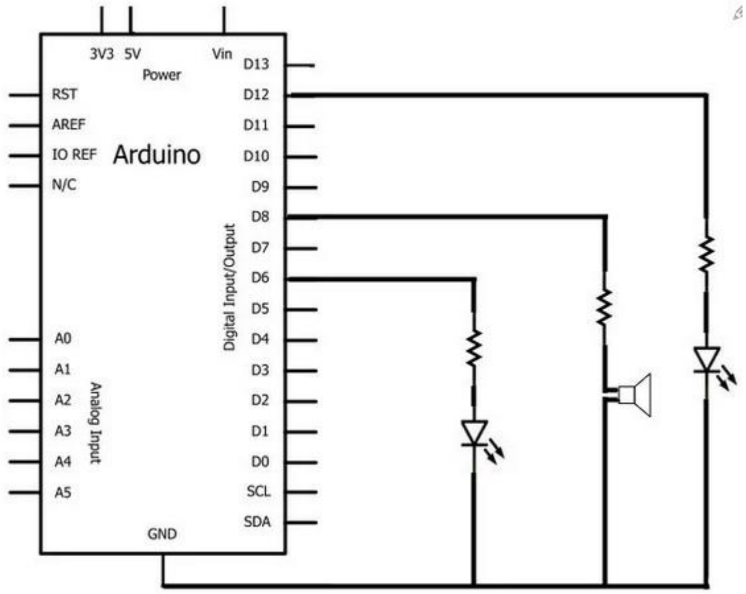


Figure 3.3 schematic diagram of Morse code encoder

In this experiment, two LED, a buzzer, breadboard, Arduino Uno and three resistor (220 Ohms) are used. Firstly, the connection for each of the component were conducted by following the schematic diagram above (Figure 3.3**).** Two jumper wires are connected with the LEDs inline to pin six and pin twelve on Arduino. The buzzer is connected to pin eight by connecting the longer jumper wire. Finally, GND pin on the Arduino is connected to the any ground pin on the breadboard.

Next, Arduino is connected to computer via USB cable. Once the connection is right, the coding is compiled and uploaded into the IDE Arduino software. In the code, pin six and pin twelve is for output as LED lights while pin eight is for audio.

In the next experiment, two types of transmitter and receiver are used to show the basic principle of transmitting and receiving the Morse code. First experiment use 40M CW

Shortwave Transmitter QRP Pixie Kit Receiver 7.023-7.026MHz while the second experiment use 433MHz RF Transmitter and Receiver.

3.4 40M CW Shortwave Transmitter QRP Pixie Kit Receiver 7.023-7.026MHz

This transceiver kit acts as transmitter and receiver that operates at 7.023-7.026MHz frequency. In this experiment, 2 sets of QRP Kit Transceiver and Arduino Uno are used for communication purpose. Figure 3.4 shows the soldered QRP Pixie Kit Transceiver.

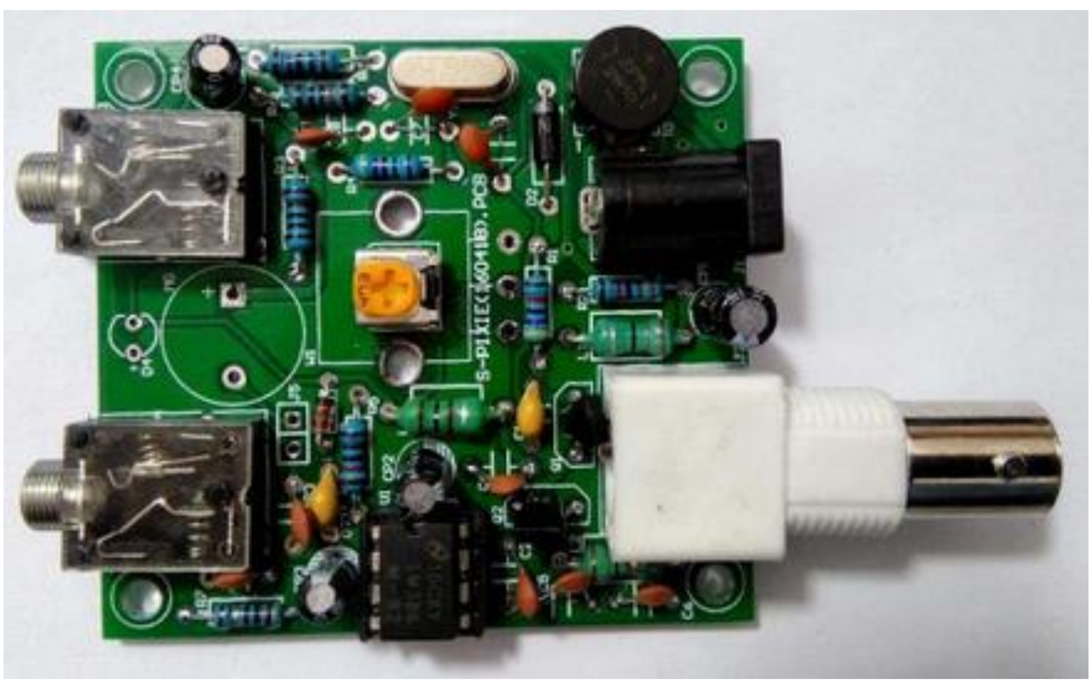


Figure 3.4 QRP Pixie Kit Transceiver

Figure 3.5 shows the block diagram for this experiment. The character inserted in the coding is encoded and audio signal is produced through the buzzer. The receiver antenna detect the signal thus converting it into character, which displayed on the PC through serial monitor in Arduino IDE software.

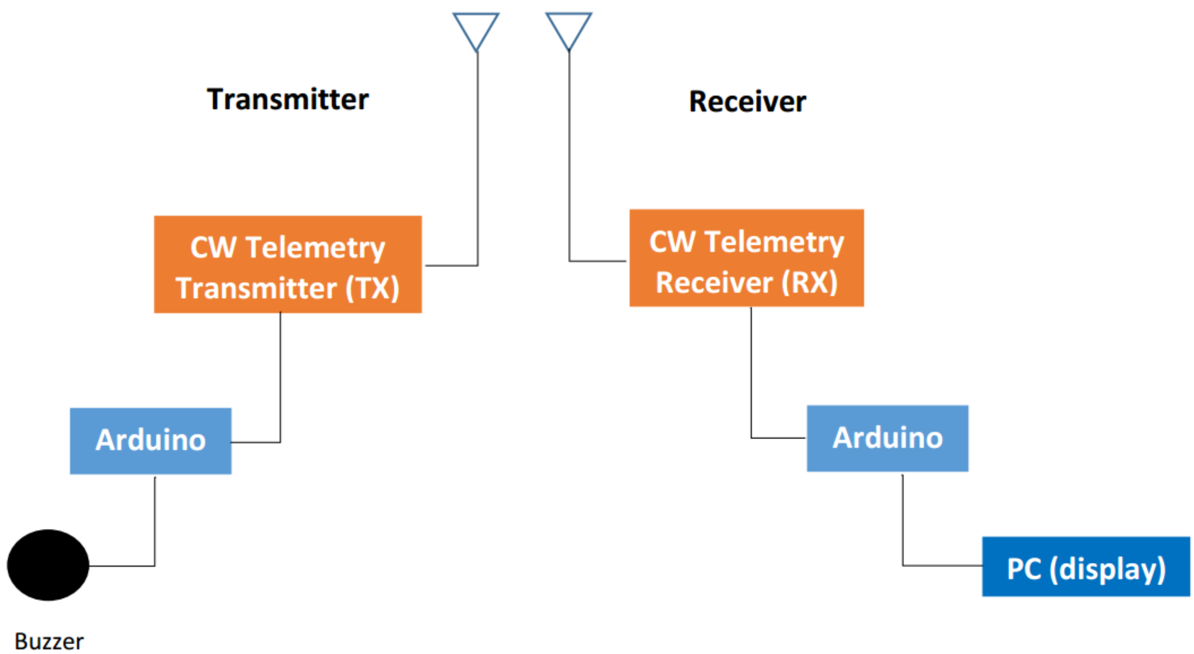


Figure 3.5 Block diagram for QRP Pixie Kit

Since it was received in a Kit, the board need to be self-soldered first before it can be ready to used. The list of components is checked to get familiar with the components and able to identify all of it in order to prevent from soldering the wrong component at the wrong pins. It is recommend to solder from low to high order starting from the resistor, diode, capacitor, triode, crystal oscillator, bridge rectifier, electrolytic capacitor, ICs, inductor, LED and others. The tools required are electric iron, soldering iron, solder wire and a multimeter (refer to Figure 3.8). After complete with soldering, now the board is ready to be tested. Figure 3.6 below shows the schematic diagram for QRP Pixie Kit while Figure 3.7 shows all items received for QRP Pixie Kit.

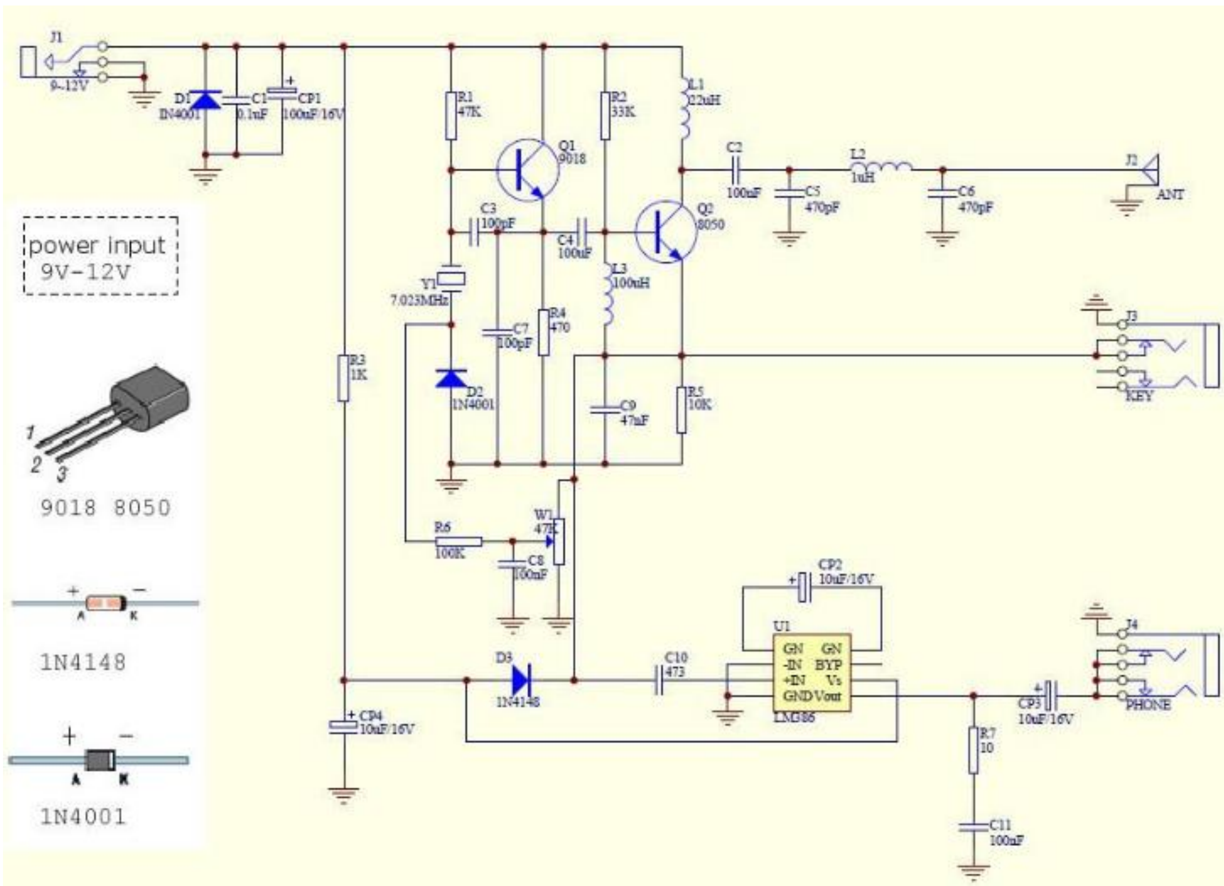


Figure 3.6 schematic diagram of QRP Pixie Kit Transceiver

Figure 3.7 list of items received

In wireless communication, one will partly transmit and the one will received the information. In other words, transmitter and receiver are the important components in communication. Therefore, it requires two set of QRP Pixie Kit Board in order to transmit and receive the RF signal.

Figure 3.8 Set up apparatus for soldering

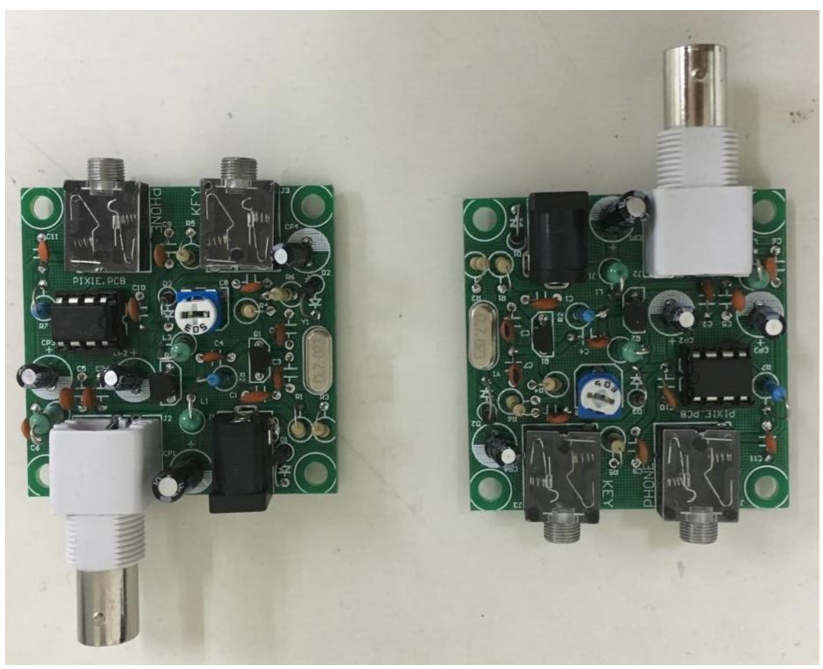


Figure 3.9 Final product after solder

3.4.1 Adjusting the current and voltage

The range of voltage and current is checked by adjusting the power supply probe in order to know at what voltage and current does the board support and work. The range for voltage is 8.5V – 12V and current is 0.013-0.03 A. Figure 3.10 shows the apparatus required to adjust the value of current and voltage.

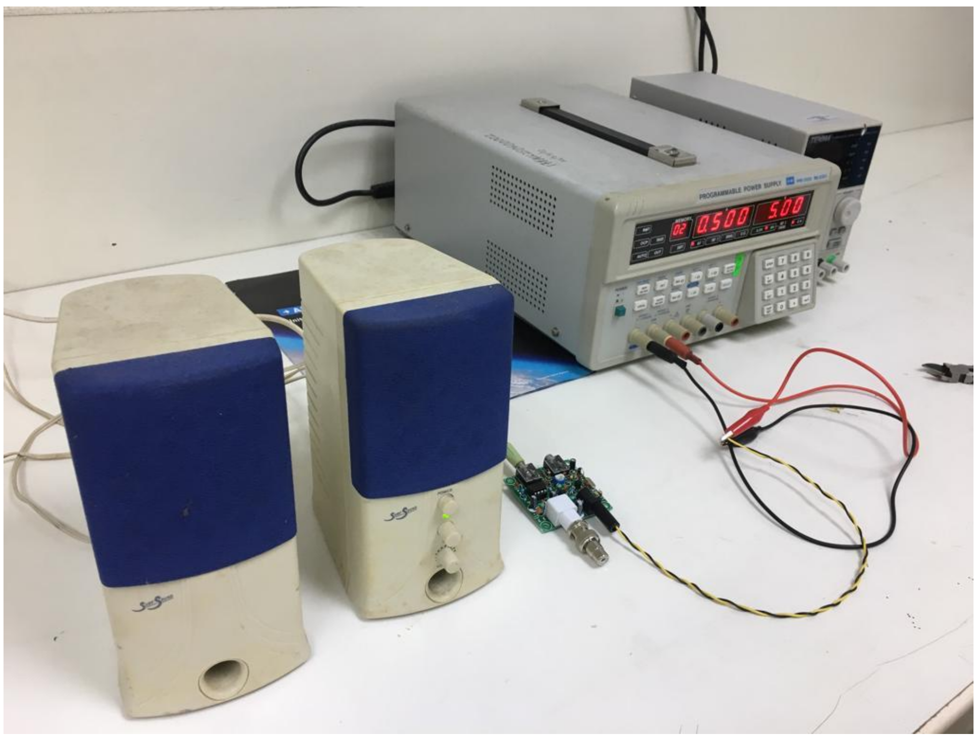


Figure 3.10 Set up apparatus to adjust voltage and current