DEVELOPMENT OF ELECTRON TEMPERATURE AND DENSITY PROBE (TeNeP) FOR MYSAT

by

LAM KUEK SHEN

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ENDORSEMENT

I, Lam Kuek Shen hereby declare that all corrections and comments made by the supervisor and examiner have been taken consideration and rectified accordingly.

(Signature of Student)

Date:

(Signature of Supervisor)

Name: DR. SITI HARWANI MD YUSOFF
Date:

(Signature of Supervisor)

Name: DR. 'AIFFAH MOHD ALI
Date:

DECLARATION

This thesis is the 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:

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DEVELOPMENT OF ELECTRON TEMPERATURE AND DENSITY PROBE (TeNeP) FOR MYSAT

ABSTRACT

MYSat or Malaysia Youth Satellite is a CubeSat project initiated by Space System Lab, School of Aerospace Engineering, Universiti Sains Malaysia and is expected to be launched from International Space Station (ISS) to measure electron density in E-layer of ionosphere. Its application is to detect early warning of earthquake by measuring anomalies of electron. Electron Temperature and Density Probe (TeNeP) will be mounted on MYSat for this mission. MYSat is designed to be a single unit CubeSat with dimension of 10cm x 10cm x 10cm, therefore modification is made by replacing traditional frequency oscillator with radio frequency generator circuit. The circuit will be designed and developed based on the research carried out by National Cheng Kung University. Radio frequency generator circuit is categorised into two stages: first stage circuit generates frequency signals in sequence and second stage circuit to obtain electron current shift and upper hybrid resonance from the sensors. The main circuits in TeNeP are pulse generator, summing amplifier, integrator, voltage controlled-oscillator, local oscillator, mixer, low-pass filter, buffer, non-inverting amplifier and multiplexer. Each of these circuits is modelled on breadboard and tested with oscilloscope to obtain the output signal. The results are validated with the expected output signal. As for this research project, it is a continuous from previous section for first stage circuit. The circuits in this research project involving voltage-controlled oscillator circuit, local oscillator circuit, mixer and low-pass filter circuit. The significant of this research project is to develop a functional radio frequency generator circuit for TeNeP.

PEMBANGUNAN LITAR PENJANA KUAR SUHU DAN KETUMPATAN ELEKTRON (TeNeP) UNTUK MYSAT

ABSTRAK

MYSat atau dikenali sebagai Malaysia Youth Satellite merupakan projek CubeSat yang diasaskan oleh Space System Lab, Pusat Pengajian Kejuruteraan Aeroangkasa Universiti Sains Malaysia dan dijangka dilancarkan dari Stesen Angkasa Antarabangsa (ISS) untuk menguji suhu dan ketumpatan elektron dalam lapisan E ionosfera. Satelit tersebut meramal gempa bumi dengan menguji ketidaktentuan elektron. Prob Suhu dan Ketumpatan Elektron (TeNeP) tersebut akan dipasang pada MYSat untuk menyempurnakan misi ini. MYSat direka dengan dimensi 10cm x 10cm x 10cm iaitu satu unit dan modifikasi dibuat dengan mengantikan penjana frekruensi dengan penjana litar radio. Litar teresebut direka dan dibina berdasarkan hasil kajian daripada National Cheng Kung University. Terdapat dua kategori dalam litar radio frekruensi iaitu litar tahap pertama yang menghasilkan isyarat frekruensi dalam urutan dan litar tahap kedua untuk mendapatkan arus beralih elektron dan gabungan gemaan arus daripada elektrod. Litar-litar utama TeNeP termasuklah penjana frekruensi, penjumlahan pengedaran, integrator, pengayun dikawal voltan, osilator tempatan, pengadun, tapis pelewat pindah, penampan, penguat bukan penyongsangan and pemultipleksan. Setiap litar tersebut akan dibina atas papan reka dan diuji dengan osiloskop untuk mendapatkan isyarat keluaran. Projek ini merupakan kajian berterusan untuk litar tahap pertama. Projek ini melibatkan litar pengayun dikawal voltan, osilator tempatan, pengadun dan tapis pelewat pindah. Hasil kajian yang diperoleh akan dibandingkan dengan jangkaan hasil kajian. Kepentingan projek ini adalah untuk membangunkan litar yang berfungsi bagi TeNeP.

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LIST OF ABBREVIATIONS

MYSat	Malaysia Youth Satellite
TeNeP	Electron Temperature and Density Probe
ISS	International Space Station
PCB	Printed Circuit Board
RF	Radio Frequency
VCO	Voltage-controlled Oscillator
LO	Local Oscillator
MUX/MPX	Multiplexer
I-V	Current-Voltage
TEC	Total Electron Content
OML	Orbital Motion Theory
ABR	Allen-Boyd-Reynolds
BRL	Bernstein-Rabinowitz-Laframboise
ETP	Electron Temperature Probe
IP	Impedance Probe
UHR	Upper Hybrid Resonance
Hz	Hertz
DC	Direct Current
LC	Inductor-Capacitor

LIST OF SYMBOLS

V_{pr} : Probe potential [V]

V_{pl} : Plasma potential [V]

I_{pr} : Probe current [A]

e : Electron charge [e]

n_e : Electron density [cm^{-3}]

v_e : Electron mean velocity [m/s]

S_{pr} : Probe surface area [cm^2]

V_s : Spacecraft potential [V]

V_r : Retarding potential [V]

I_e : Electron current [A]

I_{e0} : Random electron current [A]

k : Boltzmann constant, $k = 1.38 \times 10^{-23} J/K$

T_e : Electron temperature [K]

m_e : Electron mass [KG]

I_i : Ion current [A]

I_{es} : Electron current in saturation region [A]

V_f : Floating potential [V]

f_{UHR} : UHR frequency [MHz]

f_{pe} : Electron plasma frequency [MHz]

f_{ce} : Electron gyro frequency [MHz]

A : Probe surface area [cm^2]

B : Magnetic field [Wb/m^2]

CHAPTER 1

INTRODUCTION

1.1 Research Background

Malaysia Youth Satellite (MYSat) is a project initiated by Space System Lab, School of Aerospace Engineering, Universiti Sains Malaysia in 2016. The mission of MYSat is to measure the electron density in E-layer of ionosphere of the Earth (Mohamed Thaheer *et al.*, 2017). For this mission, Electron Temperature and Density Probe (TeNeP) will be mounted on the MYSat. JEM Small Satellite Orbital Deployer (J-SSOD) from NASA is expected to launch MYSat from International Space Station (ISS) to measure electron-density in E-layer of Ionosphere (Ahmad Shaqeer, 2017).

In the pasts, there is a statistical analysis of ionospheric parameters before an earthquake take place few days before occurrence. Ionospheric effects revealed show that not more than 1-5 days before earthquakes with magnitudes M<5.5 and post seismic influences exist about 1-2 days after earthquakes (Silina *et al.*, 2001). From a research study by L. Jianyong, the total electron content (TEC) showed anomalous variations in the earthquake event. Electric field from tectonic plate movement cause seismo-ionospheric coupling can penetrate to ionosphere (Jianyong *et al.*, 2015). Two elements can be studied from E-layer of ionosphere which are the temperature and density of electron to investigate the anomalies due to the earthquake.

The focus of this research project is the radio frequency circuit (RF) generator on TeNeP. In Malaysia, since 1980s, satellite applications include weather prediction, environment monitoring, planning purposes and even for television broadcasting has been implemented (Subari and Hassan, 2016). Therefore, MYSat will be another milestone in space research in Malaysia.

This research project is a continuous work from previous research for first stage circuit which is carried out as in Development of Generator Circuit for Electron Temperature and Density Probe (TeNeP) for MYSat (Muhammad Aadam, 2018). From previous research, the three main components had been tested and modelled to produce triangular wave. A pulse generator generates square wave frequency. Next, summing amplifier modulate the amplitude of the square wave from pulse generator. Then, an integrator will convert square wave into triangular wave frequency.

In this research project, there are few other circuits involved which will be integrated into already built circuits in previous section to be tested and optimised. The other parts on RF generator circuit consists of Voltage Controlled Oscillator (VCO), Local Oscillator (LO), Mixer, Filter, Non-inverting Amplifier, Multiplexer (MUX or MPX) and Buffer. These circuits will be built on breadboard and integrated into the three built model circuits to form a complete RF circuit.

1.2 Problem Statement

The purpose of this research project is to build Electron Temperature and Density Probe (TeNeP) for MYSat. Current design of TeNeP built by National Cheng Kung University of Taiwan with dimension of 160mm x 100mm which is approximately equivalent to 3U CubeSat (Y.W.Hsu, C.Z. Cheng, 2014). MYSat is designed at 1U CubeSat with dimension 10cm x 10cm x 10cm which requires engineering modification of TeNeP circuit so that it is able to fit for the size. This project requires engineering knowledge to downscale the circuit yet still able to maintain its function and performance as the original probe.

The critical part in this research project is to test the analogue circuit which is referred based on the design from National Cheng Kung University. The main reason is because TeNeP should fulfil the requirements to obtain accurate reading from the space, and there would be interference of various abrupt conditions to the circuit output. Therefore, the measurement resolution is required to compensate the changes in plasma which would affects the accuracy of TeNeP by building and testing the analogue circuit.

1.3 Objectives

The objectives of this research project are:

1. To design a radio frequency generator circuit diagram for Electron Temperature and Density Probe (TeNeP).
2. To develop functional radio frequency generator circuit for Electron Temperature and Density Probe TeNeP.
3. To optimise radio frequency generator circuit for Electron Temperature and Density Probe TeNeP.

CHAPTER 2

LITERATURE REVIEW

2.1 Electron Temperature Probe (ETP) and Impedance Probe (IP)

TeNeP is based on Electron Temperature Probe (ETP) concept with combination of planar impedance probe (IP). In a measuring probe, TeNeP has advantage of small size, light weight and low power consumption which able to measure electron temperature and electron density. Besides, TeNeP has overcome contamination as its operating frequency exceeded the characteristic frequencies of typical impedance of contamination layer (Oyama and Cheng, 2014). Contamination-free TeNeP is suggested to operate at sweeping frequency of 0.2-10Mhz and sweeping potential below 500mV which is still capable to obtain accurate electron temperature, T_e and electron density, n_e, with surface area ratio below 100. The probe operates at sweeping frequencies higher than 200kHz with amplitudes lower than 500mV is verified by comparing with DC Langmuir probe measurement (Fang *et al.*, 2018). Modification of ETP is not influenced by electrode contamination and can work for small satellite (Abe and Oyama, 2013).

ETP measure the floating potential shift based on high frequency signal applied to the probe (Chen, 2014). In ETP , for the electron to reach the probe, the kinetic energy should overcome the potential difference of probe with respect to plasma $V_{pr} - V_{pl}$. In Maxwellian distribution, the probe current will be:

$$I_{pr} = I_i + I_e = I_i + eAn_e\sqrt{\frac{kT_e}{2\pi m_e}}exp\left(\frac{e\left(V_{pr} - V_{pl}\right)}{kT_e}\right) \qquad (1)$$

Meanwhile, the floating potential is given as:

$$V_f = V_{pr} - V_{pl} = -\frac{kT_e}{e}\ln\left[-eAn_e\sqrt{\frac{kT_e}{2\pi m_e}}/I_i\right] = -\frac{kT_e}{e}\ln\left(-\frac{I_{es}}{I_i}\right) \qquad (2)$$

Next, floating potential can be obtained after filtering the oscillating part of the probe current. The three equations on floating potential shift in a function of electron temperature are shown below.

$$V_f(0) = -\frac{kT_e}{e}\ln\left[-\frac{I_{es}}{I_i}\right] \tag{3}$$

$$V_f(a) = -\frac{kT_e}{e}\ln\left[-\frac{I_{es}}{I_i}I_0\left(\frac{ea}{kT_e}\right)\right] \tag{4}$$

$$V_f(2a) = -\frac{kT_e}{e}\ln\left[-\frac{I_{es}}{I_i}I_0\left(\frac{2ea}{kT_e}\right)\right] \tag{5}$$

Based on the equations above, the floating shift due to applied high frequency signal with amplitude 'a' and '2a' can be derived as follow:

$$\Delta V_f(2a) = V_f(0) - V_f(2a) = \frac{kT_e}{e}\ln\left[I_0\left(\frac{2ea}{kT_e}\right)\right] \tag{6}$$

$$\Delta V_f(a) = V_f(0) - V_f(a) = \frac{kT_e}{e}\ln\left[I_0\left(\frac{ea}{kT_e}\right)\right] \tag{7}$$

$$R = \frac{\Delta V_f(2a)}{\Delta V_f(a)} = \frac{\ln\left[I_0\left(\frac{2ea}{kT_e}\right)\right]}{\ln\left[I_0\left(\frac{ea}{kT_e}\right)\right]} \tag{8}$$

From (6) and (7), T_{e1} and T_{e2} are obtained respectively. Then, T_{e3} can be calculated without knowing the amplifier gain by taking the two floating potential shift ratios as shown in (8). T_{e3} agreed with temperature as obtained from Langmuir probe while T_{e1} and T_{e2} maybe affected by satellite sheath as probe is close to satellite (Jiang *et al.*, 2014). The schematic circuit diagram of ETP is shown in Figure 2.1.

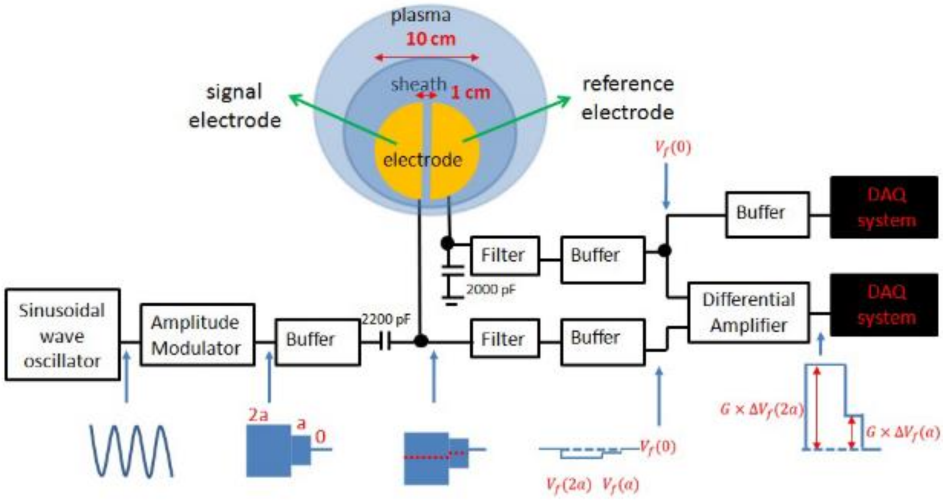

Figure 2.1: Electron Temperature Probe (ETP) schematic diagram (Y.W.Hsu, C.Z. Cheng, 2014).

Impedance probe (IP) in the other hand is based on impedance on electrode. To obtain electron density, the impedance value is determined. From the potential shift, upper hybrid resonance (UHR) frequency can be used to determine electron density once the electrode frequency matches the upper hybrid frequency.

$$f_{UHR} = \sqrt{f_{pe}^2 + f_{ce}^2} \qquad (9)$$

Where,

$$f_{pe} = \frac{1}{2\pi}\sqrt{\frac{4\pi n_e e^2}{m_e}} \qquad (10)$$

$$f_{ce} = \frac{eB}{2\pi m_e c} \qquad (11)$$

Therefore, by deriving the equation, electron density can be obtained. Electron density, $n_e = 1.24 \times 10^4(f_{UHR}^2 - f_{ce}^2)$. As a general view, the schematic circuit diagram of IP is represented as in Figure 2.2.

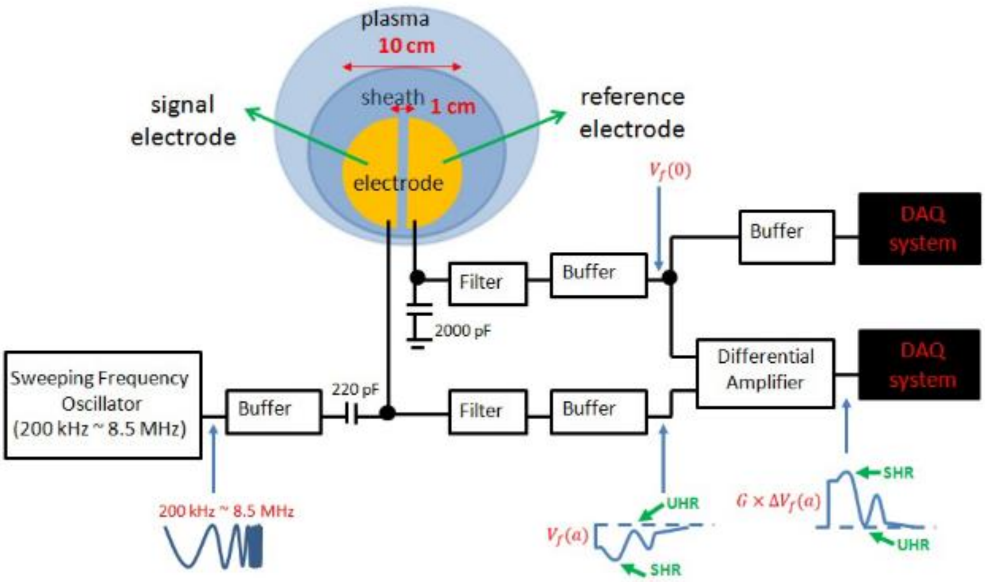

Figure 2.2: Impedance Probe (IP) schematic diagram (Y.W.Hsu, C.Z. Cheng, 2014).

2.2 Electron Temperature and Density Probe (TeNeP)

The designed probe to be built is known as Electron Temperature and Density Probe (TeNeP) . The double probe technique measures current from one to the other as a function of voltage difference between them (Chen, 2003). As comparison, TeNeP has been tested and able to obtain similar result as Langmuir probe (Jiang *et al.*, 2014). The modification made for TeNeP is the replacement of fixed frequency oscillator with radio frequency (RF) circuit that produces the fixed frequency signal and the sweeping frequency signal in sequence.

For simplification, the TeNeP circuit is divided into two stage, which is the first stage circuit and second stage circuit. The schematic diagram for overall circuit is shown in Figure 2.3.

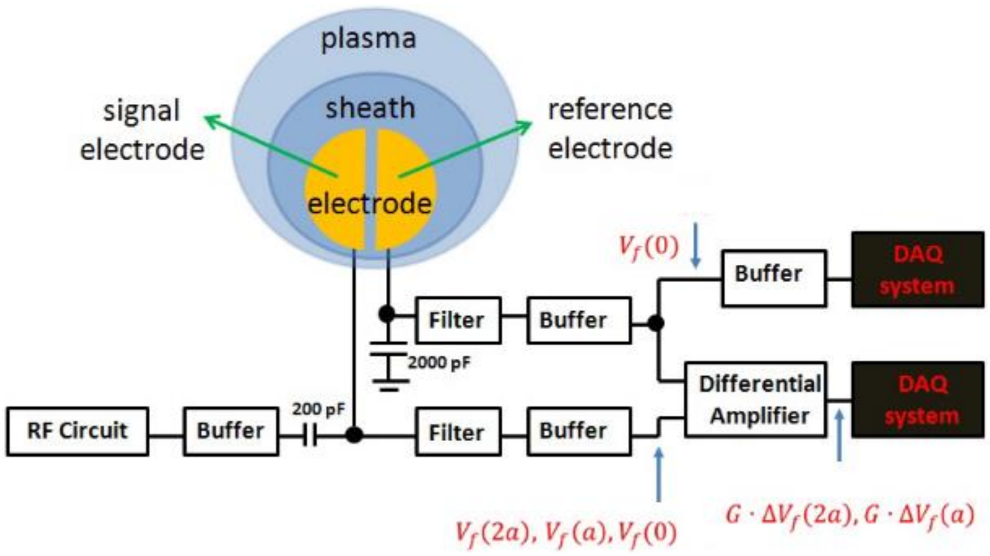

Figure 2.3: TeNeP schematic diagram (Y.W.Hsu, C.Z. Cheng, 2014).

The first stage circuit primary function is to generate frequency signal to sensor (electrode). The suggested sensor is a circular disk which is connected to two electrodes (Y.W.Hsu, C.Z. Cheng, 2014). Langmuir probe is the simplest device with a sticking wire into plasma and measuring the current at various applied voltages. The wire (electrode) must be design carefully to not interfere with plasma sheath (Chen, 2003). The first stage circuit focusing on RF circuit that generates frequency signals.

RF circuit composed of pulse generator CD4060 that produce square wave. Then, it is modulated with summing amplifier. From square wave, integrator transform it into triangular wave. It is known that triangular/square wave generators are widely used in application for instrumentation and measurement system (Abuelma, Alabsi and Triangular, 2004).

Next, 2-to-4 multiplexer CD4052 pick up half of triangular wave with pulse generator circularly generates square wave signals 00, 01, 10, 11 to pick up input signals from channel 1, 2, 3 and 4 separately. Then voltage-controlled oscillator (VCO) produce sinusoidal wave signals of frequencies. Direct current voltage generates about 200kHz while the half of triangular wave produces sweeping frequency from 20.2MHz to 28.5MHz.

A local oscillator with frequency 20MHz and mixer MDL510 are both connected to VCO to get two range of frequencies: 200kHz to 8.5MHz and 40.2MHz to 48.5MHz. Since low frequency is required, low-pass filter will filter out high frequency signal. From there, fixed frequency of 200kHz and sweeping frequency of 200kHz to 8.5MHz are obtained in sequence. Buffer will be used to reduce the loading effect. Another multiplexer CD4052 will modulate 200kHz sinusoidal wave into three amplitudes: 2a, a and 0. In more details, input Channels 0 and 1 have amplitude 2a, Channel 2 with amplitude a and Channel 3 is connected to ground and amplitude at 0. Another buffer amplifier will be used to avoid loading effect after multiplexer modulate the signals. A feeding capacitor to remove DC signal before the first stage circuit is connected to sensor. The first stage circuit is shown in Figure 2.4 (Y.W.Hsu, C.Z. Cheng, 2014).

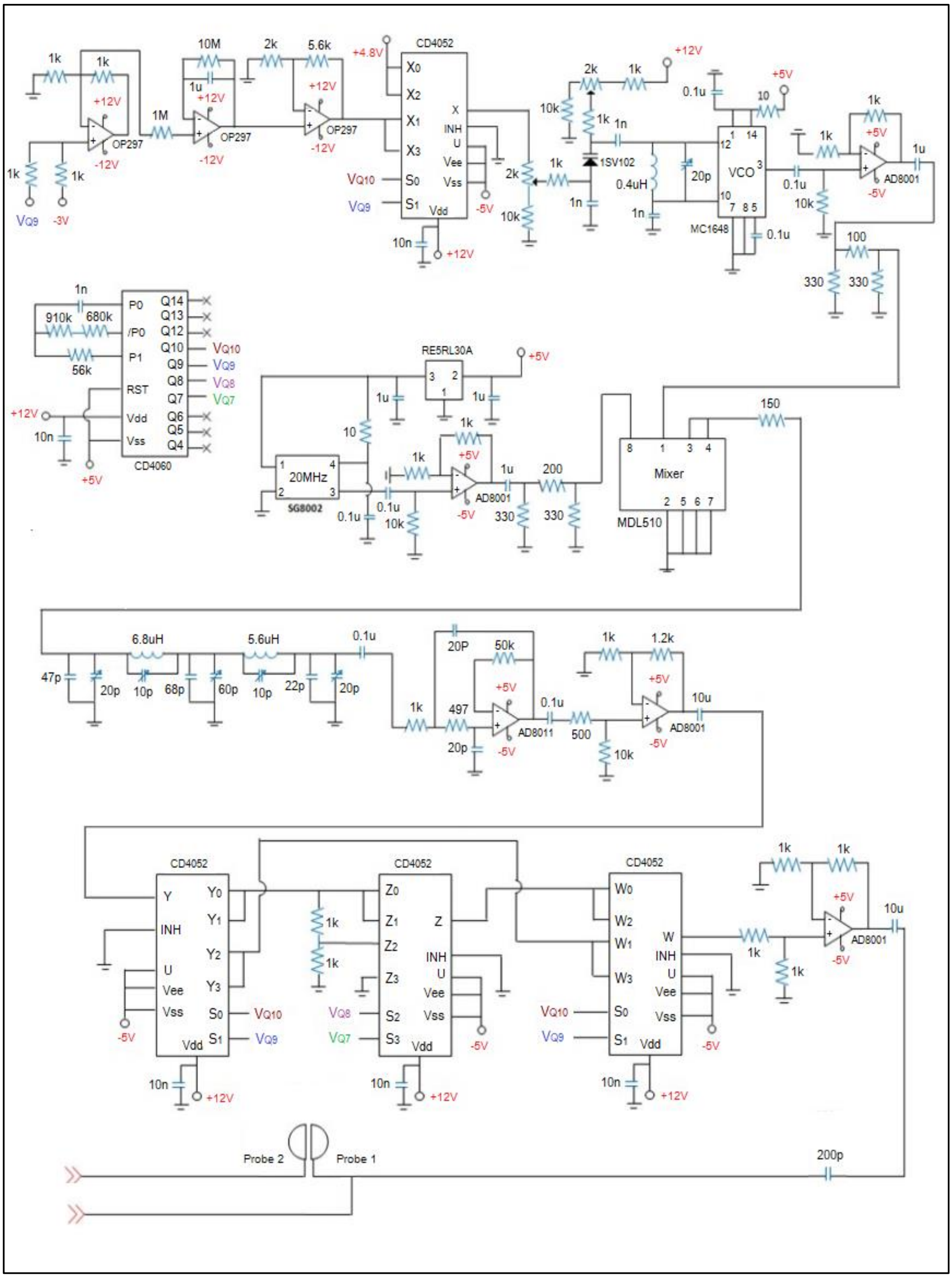

Figure 2.4: Schematic diagram of first stage circuit (Y.W.Hsu, C.Z. Cheng, 2014).

Meanwhile, the second stage circuit is used to obtain electron current shift, sheath resonance and upper hybrid resonance. The main function of the buffer is to avoid loading effect followed by the differential amplifier that is used to obtain the difference of two input signals, which are the two floating potentials. Then, floating potential shift and original floating potential in the plasma can be obtained. The circuit diagram for second stage circuit is shown in Figure 2.5.

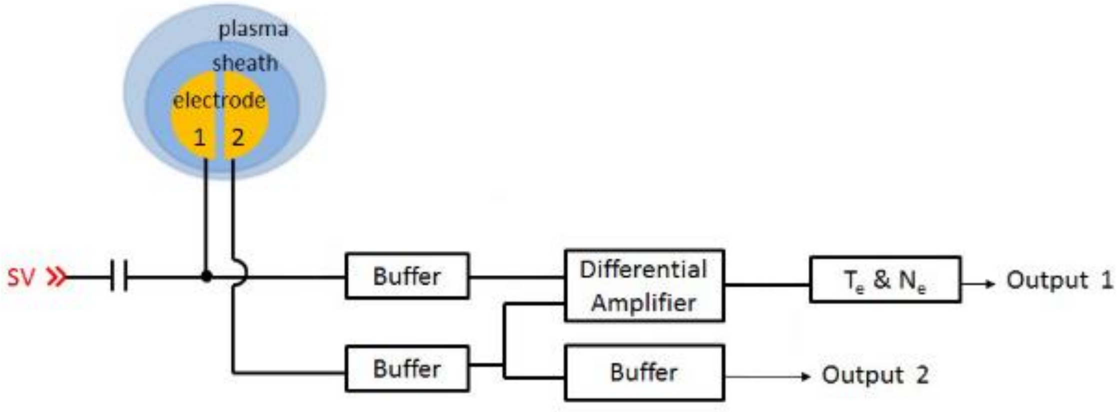

Figure 2.5: Schematic diagram of second stage circuit (Y.W.Hsu, C.Z. Cheng, 2014).

As an overview on this research project, it is the continuous from previous section that is partially of the first stage circuit. However, to achieve the mission of MYSat, both circuits will be built and fabricated once the first stage circuit is completely tested. Plasma chamber is a versatile equipment that simulates Earth ionospheric environment for testing purpose (Fang, Oyama and Cheng, 2015). In final testing for TeNeP circuit, the test should be done in plasma chamber to make sure it achieves its function.

CHAPTER 3

METHODOLOGY

3.1 Radio Frequency (RF) Circuit System Configuration

The focus for this research project is to remodel the RF circuit and obtain the respective frequency signals. To be more specified, the first stage circuit is modelled on breadboard and tested with oscilloscope. The components of RF circuit are shown in Figure 3.1. Previous research project has completed up to output frequency signal (4) that consists of pulse generator, summing amplifier circuit, integrator circuit and multiplexer (Muhammad Aadam, 2018). Meanwhile, the components involved for this research project are voltage-controlled oscillator circuit, local oscillator circuit, mixer and filter circuit which produce the waveform (5), (6), (7) and (8) respectively. For next phase, the project will continue in future for three multiplexers and buffer circuit before continuing for second stage circuit. Each number at the end of respective circuit is the output frequency signal that should be obtained as shown in Figure 3.2.

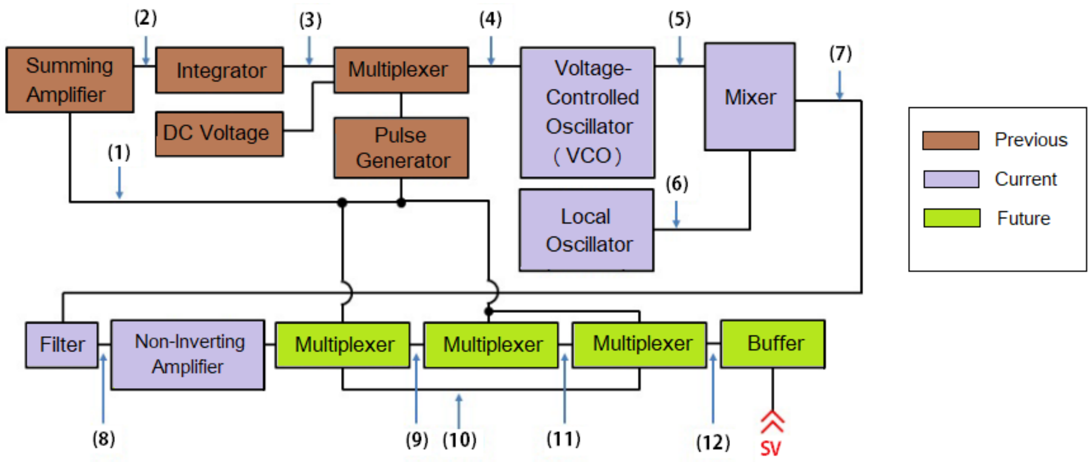

Figure 3.1: Components of RF circuit (Y.W.Hsu, C.Z. Cheng, 2014).

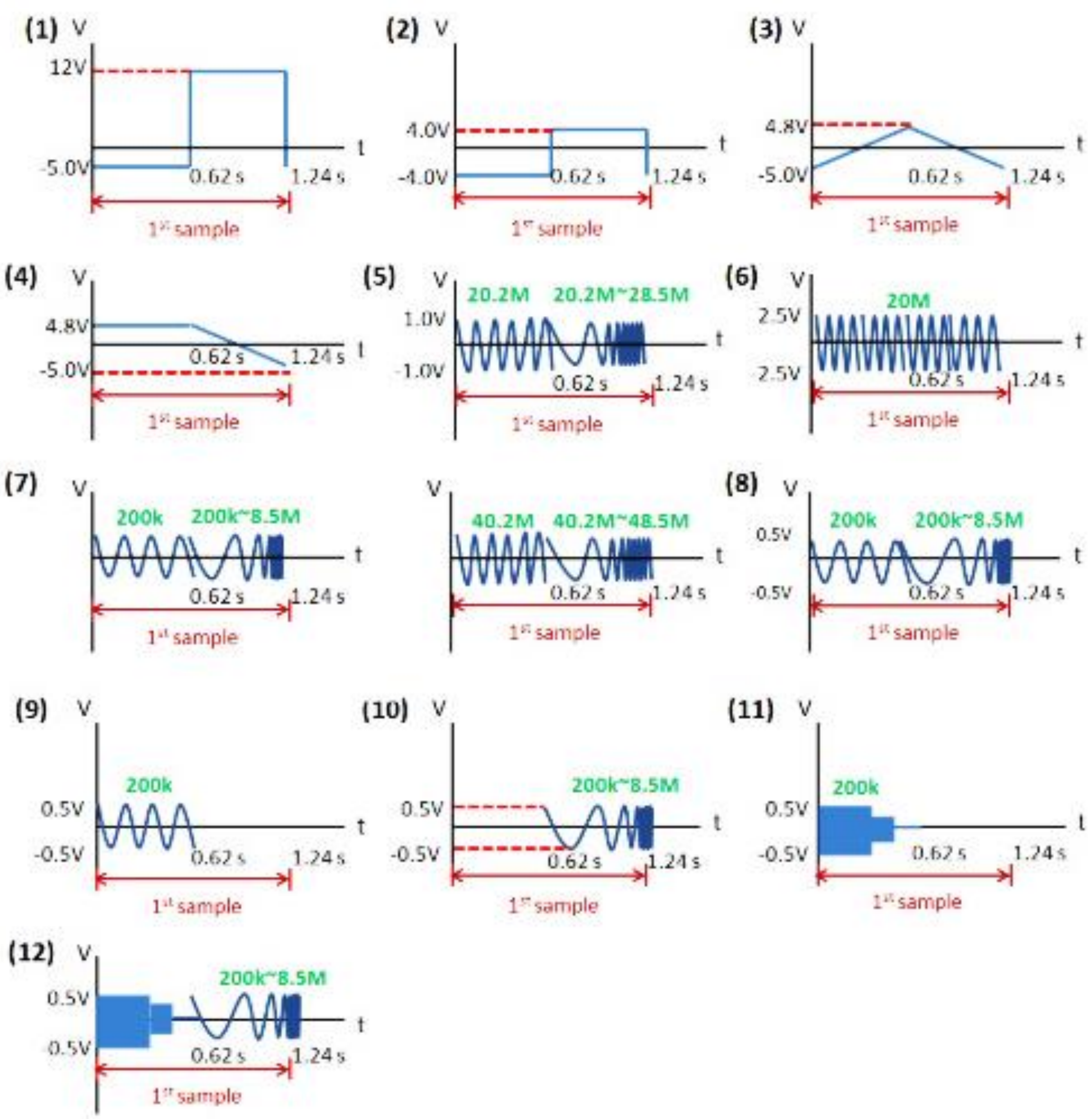

Figure 3.2: Frequency signal on each component of RF circuit (Y.W.Hsu, C.Z. Cheng, 2014).

DSO-X 2002A Digital Storage Oscilloscope that is used for laboratory testing is shown in Figure 3.3.

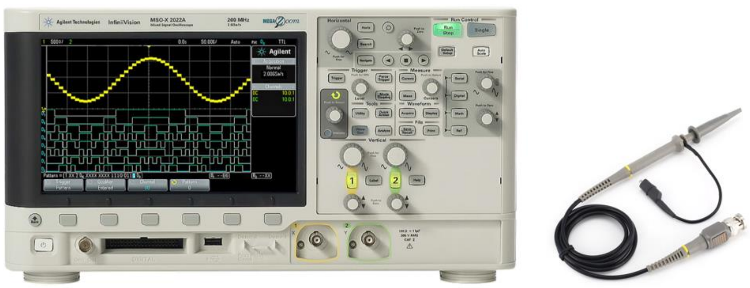

Figure 3.3: DSO-X2002A Digital Storage Oscilloscope in laboratory.

3.2 Previous Built Circuit Model

Figure 3.4 shows the components for first stage circuit which have been completed for summing amplifier, integrator and multiplexer (Muhammad Aadam, 2018).

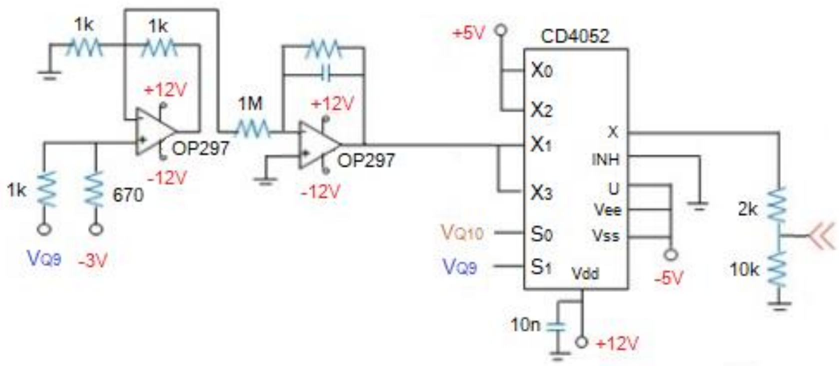

Figure 3.4: Circuit connection for summing amplifier, integrator and multiplexer (Muhammad Aadam, 2018).

Another component involved in this section is pulse generator. Figure 3.5 shows the connections on pulse generator CD4060 which are connected to summing amplifier and multiplexer for V_{Q9} and V_{Q10} (Muhammad Aadam, 2018).

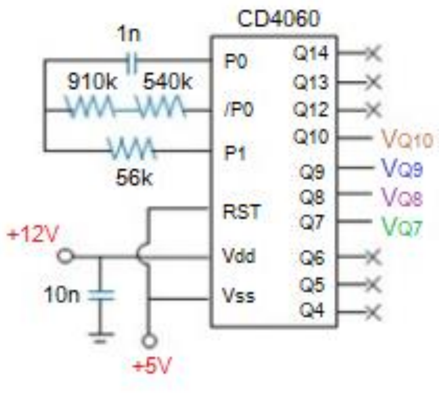

Figure 3.5: Circuit connection for pulse generator, CD4060.

3.3 Circuit Component Laboratory Setup

For the starting of this research project, each circuit will be modeled. Then, the circuits are connected to previous section that generates triangle wave. Once all the circuit is connected, power is supplied for each supply sources which include +12V, +5V, -3V, -5V and -12V. For the power distribution, a power supply module HW-520 is used to step up input voltage of 3V to +12V and -12V. Then, it is distributed to respective voltage with linear voltage regulator and resistor. The main circuit components in this research project are voltage-controlled oscillator (VCO) circuit, local oscillator (LO) circuit, mixer and low-pass filter circuit.

3.3.1 Voltage-Controlled Oscillator (VCO) Circuit

The research project is started with voltage-controlled oscillator (VCO) circuit. The basic of a simple oscillator usually modelled as LC tank circuit that consists of inductor, L and capacitor, C (Qirollari, 2016). The main component used is voltage-controlled oscillator MC1648 (Motorola, 1997). The pin for each channel on VCO MC1648 is shown in Figure 3.6.

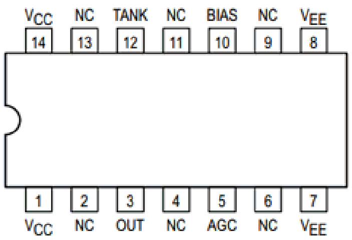

Figure 3.6: Voltage-controlled Oscillator MC1648 pins (Motorola, 1997).

For the changes, the variable capacitor on LC tank circuit is replaced with a fixed known capacitor, 200pF capacitor. The VCO circuit is shown in Figure 3.7.

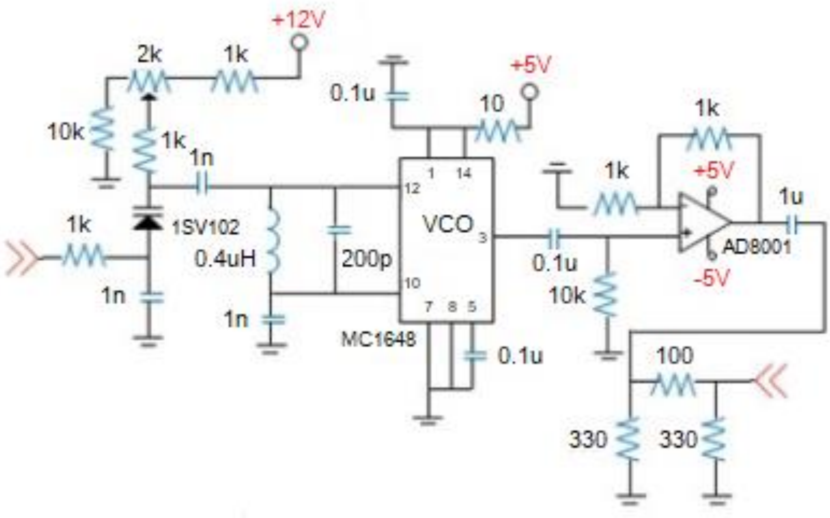

Figure 3.7: Schematic diagram of VCO circuit (Y.W.Hsu, C.Z. Cheng, 2014).

In the laboratory testing, two data are obtained. For the instantaneous oscillation frequency from VCO, DC voltage will be supplied to V_{SV5} at various voltage from +5V to -5V. Then, the measuring testing tip (or probe needle) of oscilloscope will be placed on the output of VCO, f_{SV5}. Figure 3.8 shows the connection for DC voltage input and output frequency.

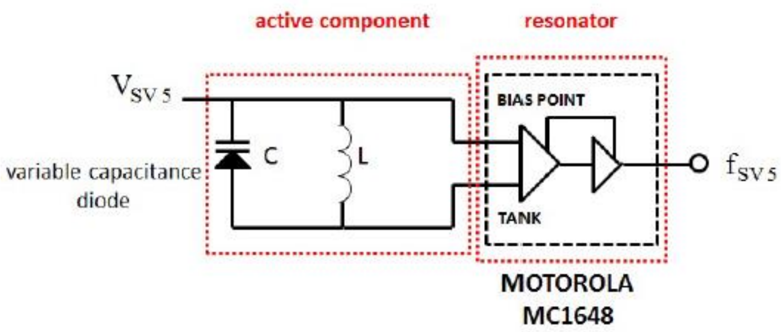

Figure 3.8: Connection on VCO for instantaneous oscillation frequency (Y.W.Hsu, C.Z. Cheng, 2014).

For second result, measuring testing tip (or probe needle) of oscilloscope will be placed on the end of VCO circuit which is connected to previous built circuit to obtain the waveform. The expected result will be a sweeping frequency signal from 20.2MHz to 28.5MHz.

3.3.2 Local Oscillator (LO) Circuit

Next part for this research project is local oscillator circuit. The oscillator used is crystal oscillator SG8002 that produce oscillating frequency of 20MHz. The pin on SG8002 is shown as in Figure 3.9 (Epson, 2018). Each pin terminal is labelled as shown in Table 3.1.

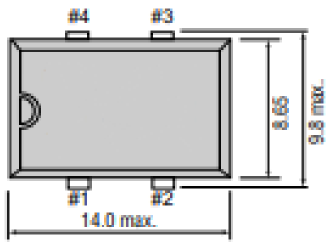

Figure 3.9: Local Oscillator SG8002 (Epson, 2018).

Table 3.1: Pin terminal of Local Oscillator SG8002.

No.	Pin Terminal
1	Ts
2	GND
3	OUT
4	V_{DD}

Figure 3.10 shows the LO circuit diagram. For LO circuit, it can be test as an independence frequency signal as it does not connect with other circuits.

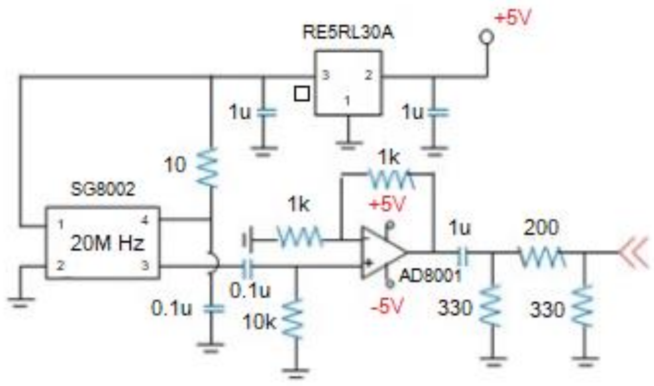

Figure 3.10: Local Oscillator circuit diagram (Y.W.Hsu, C.Z. Cheng, 2014).

Similar as VCO circuit, the measuring testing tip of oscilloscope will be placed at the end of LO circuit which is connected to previous built circuit to obtain its waveform. The expected output signal is the fixed frequency signal of 20MHz.

3.3.3 Mixer Circuit

Mixer MDL510 will mix both frequency signal from VCO and LO to produce sweeping frequency signal in sequences. The pin on mixer for this model is shown in Figure 3.11 (Mini-Circuits, 2007). The terminal connection for each pin is shown in Table 3.2.

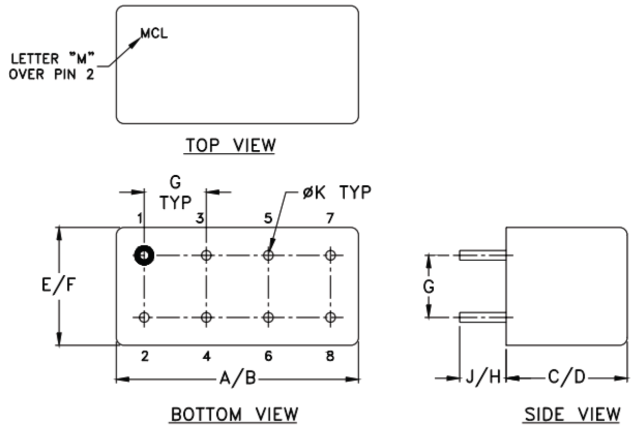

Figure 3.11: Mixer MCL 9124 (Mini-Circuits, 2007).

Table 3.2: Pin terminal of mixer.

No.	Pin Terminal
1	RF
3,4	IF
8	LO
2,5,6,7	GND

In mixer, the input and output frequencies are obtained by supplying a range of DC voltage from +5V to -5V on V_{SV5} as in VCO (refer Figure 3.7). Then, the testing probe measured frequencies on f_{SV5} and f_{SV6}. The output frequencies, f_{SV7} and f_{SV8} are calculated with the formula below.

$$f_{SV7} = f_{SV5} - f_{SV6} \quad (12)$$

$$f_{SV8} = f_{SV5} + f_{SV6} \quad (13)$$

The connection on input and output frequencies of mixer is shown in Figure 3.12.

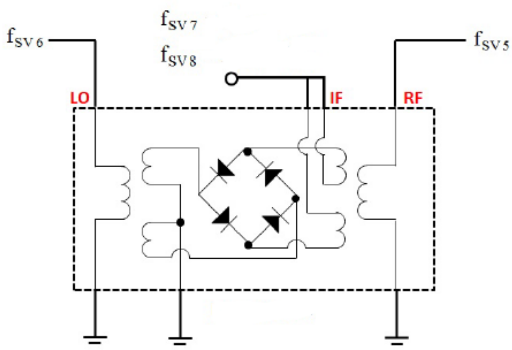

Figure 3.12: Connection of input and output frequencies on mixer (Y.W.Hsu, C.Z. Cheng, 2014).

The mixer circuit diagram that is connecting both VCO and LO is shown in Figure 3.13.

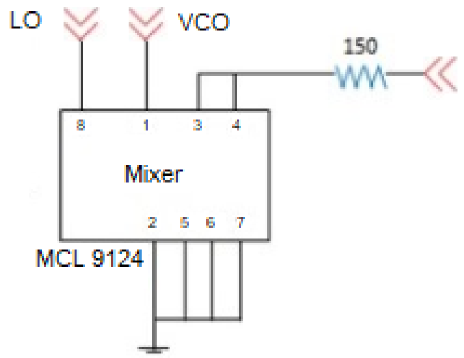

Figure 3.13: Mixer circuit diagram (Y.W.Hsu, C.Z. Cheng, 2014).

Waveform on the output signals are obtained by placing the measuring testing tip of oscilloscope on the output of mixer that is connected to Channel 3 and Channel 4 of mixer.

3.3.4 Low-pass Filter Circuit

In low-pass filter circuit, the main component used is operational amplifier AD8011. The pin on AD8011 is shown in Figure 3.14 (Analog Devices, 2003).

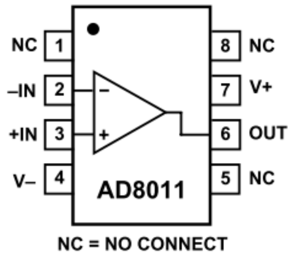

Figure 3.14: Ops-Amp AD8011 pin terminals (Analog Devices, 2003).

In the circuit, the variable capacitors are replaced with fixed capacitor with known value. The output frequency of the low-pass filter will be the same as the lower frequency component obtained from mixer. The frequencies for low-pass filter circuit can be simplified as in Figure 3.15.

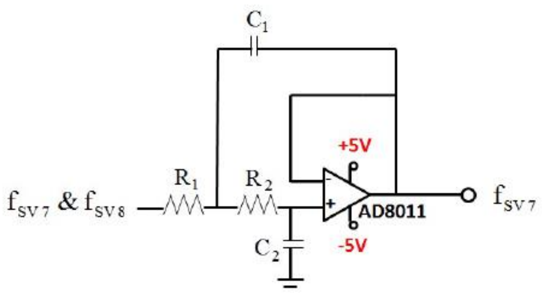

Figure 3.15: Input and output frequencies of low-pass filter circuit (Y.W.Hsu, C.Z. Cheng, 2014).

Figure 3.16 shows the circuit diagram for low-pass filter. The testing probe will be placed at the end of the circuit which is the output channel of the operational amplifier AD8011 to obtain the waveform of the frequency signal (8).

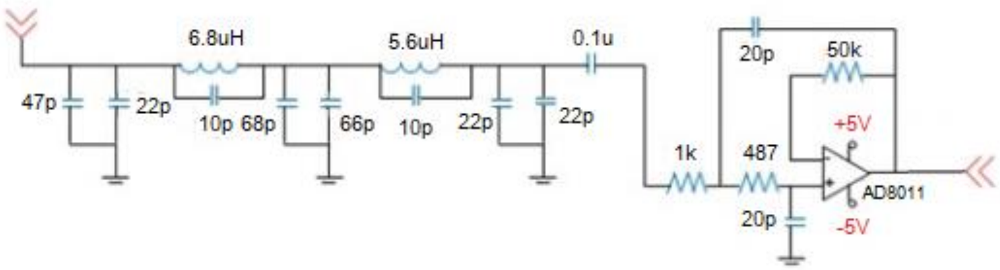

Figure 3.16: Low-pass filter circuit diagram (Y.W.Hsu, C.Z. Cheng, 2014).

The flow chart for this research project is shown in Figure 3.17. The project is started by setting up the circuits for TeNeP which include voltage-controlled oscillator circuit, local oscillator circuit, mixer circuit and low-pass filter circuit. Suitable components are selected as the designed circuits and build on breadboard. Then, the circuit is tested with oscilloscope. If designed components are changed, the steps will loop back to rebuild the circuit model; if not it will proceed for testing. Once satisfactory results are obtained from the testing, the process will end. Else, the process is repeated again by setup the circuit model to achieve satisfactory results.

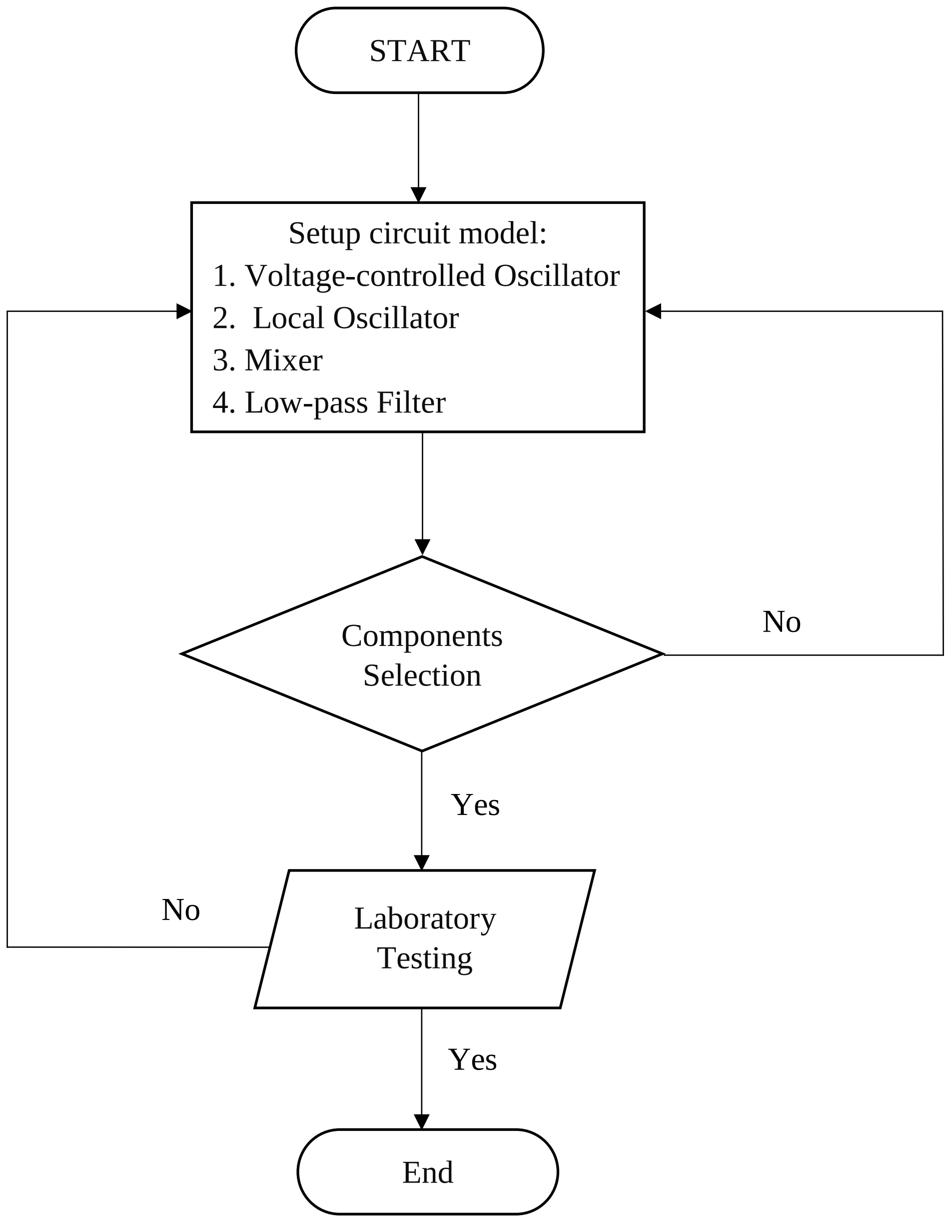

Figure 3.17: Flow chart on TeNeP RF Circuit testing.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Signal Waveform and Instantaneous Frequency

The output frequency for voltage-controlled oscillator circuit, local oscillator circuit, mixer circuit and low-pass filter circuit are recorded with respect to the input voltage, V_{SV5}. The graph of frequency in voltage domain is plotted for comparison with the expected result (Y.W.Hsu, C.Z. Cheng, 2014). Besides, the waveform for each frequency signal is obtained from the oscilloscope. In this section, the waveform for frequency signals are plotted and presented. Comparison between waveform obtained and the expected waveform are made. The differences on the results are discussed. The images captured for each result will be included in appendices for references.

4.1.1 Voltage-Controlled Oscillator (VCO) Circuit

The instantantenous output signal frequency of voltage-controlled oscillator with respect to different input voltage are tabulated in Table 1 (refer Appendices B – Frequency with respect to Input Voltage). The reading on oscilloscope shows fluctuation and affected by the noise.

The value measured is assumed to be the instantaneous frequency as the voltage is varying at a very large range. As for example at input voltage of +5V will give minimum frequency at 19.9MHz and maximum frequency at 27MHz due to the fluctuation. One of the contribution to fluctuation is the inconsistent voltage supply to VCO circuit. This is caused by various reasons including improper components used, damaged components and unstable power supply. The results obtained is plotted in Figure 4.1 and compared with the expected result.

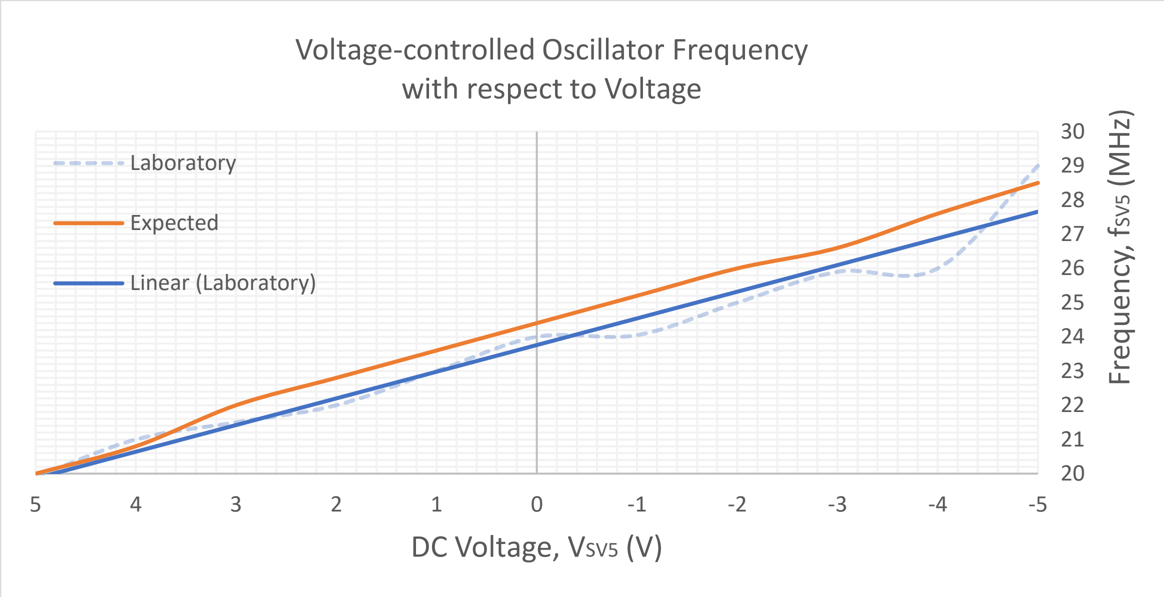

Figure 4.1: Signal frequency of VCO with respect to input voltage.

From Figure 4.1, the laboratory result shows the frequency is shifted slightly lower than the expected result. The result is acceptable as the value taken at each input DC voltage is within the range of frequencies intended which is at 20MHz to 28MHz.

The output signal frequency waveform obtained from oscilloscope (refer Appendices A-1) for time, t = [0 15] ns is plotted in Figure 4.2. The signal frequency oscillates from -0.7V to +0.7V with frequency fluctuates at 19.9MHz to 28MHz (refer Appendices A-1). The waveform is considered as not excellent as it does not show a perfect sinusoidal curve. It can be described that the frequency signal is producing more noise than it should be. Unavoidable noise is observed on the waveform (refer Appendices A-2). The causes for the noise are contributed by the poor or unstable connection of circuit as it is built on breadboard and inconsistent voltage supply. As comparison, the sinusoidal curve as in Figure 4.3 is not observable. The oscillation shows a sudden drop after second peak and third peak. Then, the curve regained back to normal and the drop for second and third peak are repeated. Nevertheless, the frequency for the