Designing a Self Oscillating FET Mixer

(SOM)

Oleh

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ABSTRAK

Di dalam menyelesaikan projek berkaitan dengan rekabentuk litar pencampur ayunan sendiri (SOM) ini, masalah yang paling utama dihadapi ialah mendapatkan frekuensi pertengahan, IF pada frekuensi yang dikehendaki selepas mengimplikasikan litar simulasi ke dalam litar menggunakan papan bercetak. Selain itu, didapati juga gandaan kuasa bagi pencampur ini adalah lebih rendah selepas litar diimplikasikan ke dalam litar papan bercetak berbanding keputusan yang didapati melalui simulasi. Cara-cara project ini dibuat adalah dengan mereka litar pencampur menggunakan perisian simulasi HP-ADS (HP-Advanced Design System). Selepas keputusan yang memuaskan didapati, litar simulasi diimplikasikan ke dalam litar menggunakan papan bercetak FR4 yang bersesuaian. Litar tersebut kemudian dianalisa keuntungan penukaran, sisihan antara masukan dan keluaran, dan isu lineariti nya dengan menggunakan penganalisa spektrum. Keputusan yang didapati ini hendaklah dibandingkan dengan keputusan simulasi menggunakan ADS. Sebagai tambahan, masalah-masalah yang timbul daripada analisa litar juga dikaji dan ketidaktepatan keputusan yang didapati daripada rekabentuk juga akan dibincangkan. Rekabentuk litar akan dibina menggunakan operasi penukaran frekuensi. Litar-litar ini direkabentuk menggunakan perkakasan dan eleman-elemen yang kos efektif dan mengikut kesesuaian penggunaan praktikal. Maka dapat dikatakan bahawa rekabentuk litar pencampur dan analisa litar dibuat tanpa begitu banyak kerumitan. Oleh itu diharapkan rekabentuk pencampur ayunan sendiri (SOM) ini dapat diteruskan dan ditingkatkan dalam pelbagai aplikasi pada masa akan datang.

ABSTRACT

To accomplish the project in designing a Self Oscillating FET Mixer (SOM), the main problem faced is to obtain the exact Intermediate Frequency (IF) at the desired frequency after implement the simulated circuit into printed circuit board (PCB). Besides of that, conversion gain obtains from the circuit after implemented into printed circuit board is less than the value obtains from simulation result. This project is done by design and simulates the circuit using HP-ADS (HP-Advanced Design system). After desired simulation result is obtained, the simulation circuit is implemented into FR4 type of PCB. Then, conversion gain, port-to-port isolation, and linearity issue is analyzed using spectrum analyzer. This result is then compared with the result from simulation using ADS, all problems arise from the design and analyzation will be considered and the inaccurate result from measurement will be discussed. The SOM designed is down conversion system. This circuit is designed using FR4 PCB board and surface mount component that helps in small in size and cost effective that applicable with the practical usage. Therefore, the design of this mixer and the analyzation can be make without any intricacy. Hopefully the design of this self oscillating FET mixer (SOM) can be continued and improved for the usage in variety of application in the future.

ACKNOWLEDGEMENT

First of all, I would like to thanks my parents and my family members for their support to help me morally and financially when I am studying in USM.

To my supervisor, Dr Widad Bt Ismail, I would like to express my gratitude for her guidance, advise, encouragement and assistance on my final year project. Her involvement in this final year project has inspired me with strength to work harder for greater achievements.

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Finally, I hope that this project will give benefit for those people who want to study about Self Oscillating FET mixer (SOM).

TABLE OF CONTENTS

CHAPTER 3: SOFTWARE ANALYSIS USING ADS

CHAPTER 4: FABRICATION

CHAPTER 5: RESULT AND MEASUREMENTS

APPENDIX

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Application of a Self Oscillating FET Mixer (SOM)

In radio communication, transmitter needs to shift the baseband signal to a frequency suitable for electromagnetic propagation to the desired destination. At the destination, receiver reverses the process by shifting the received radio frequency signal back to baseband signal to allow the recovery of information. This frequency shifting is known as mixing. Therefore mixer is very useful in radio communication. Self Oscillating FET Mixer (SOM) is a very attractive design to use in communication because this mixer can produce its own local oscillator (LO) frequency to mix with radio frequency (RF) to produce Intermediate frequency (IF). So, extra circuit to produce the LO signal is eliminated if the transmitter or receiver use SOM instead of typical mixer. For this reason, SOM may reduce the power consumption, reduce the overall circuit size, and also helps in cost reduction. These make SOM a very attractive design especially for use in mobile communication systems which require small in size and low power consuming circuitry.

1.2 Objective

The objective of this project is to design a 5.5 GHz (RF input frequency) Self Oscillating active FET Mixer (SOM) to produce changeable IF frequencies with the following features:

- **Changeable IF frequency** for use in different application.
- **Small in size** due to reduced number of components
- **Low power consuming** due to less active device is used
- **Conversion gain** due to use of active mixer
- **Cost reduction** due to reduced number of components.

1.3 Guide Of The Project

Chapter 1: Introduction

Introduction to the project that involves the application of a SOM and the objectives of the project. This chapter also include guidance of this SOM project.

Chapter 2: Literature Review

Introduction to basic block design of typical mixer and also self oscillating mixer (SOM). This chapter will compare the differences between typical mixer and also self oscillating mixer (SOM). This chapter will also discuss the definition of frequency conversion and mixer characteristics, which include conversion gain, linearity issue and also port-to-port isolation.

Chapter 3: Software Analysis Using ADS

This chapter includes the design of SOM circuit using HP-ADS simulation. Conversion gain, linearity issue and also port-to-port isolation of each circuit is simulated. To produce the best result of conversion gain, the lumped element value that available in the market is used in designing the SOM.

Chapter 4: Fabrication

This chapter consists of implementation of the simulated circuit into hardware in FR4 type of PCB. This involve generate the PCB layout from the schematic in ADS, fabricate the PCB, and mount the lumped element on the PCB board. All of the component used is surface mount device (SMD). Most of the components used in this design are from Hewlett Packard (HP) Company, Agilent and also order from FARNELL industries. This chapter will discuss more about the hardware implementation.

Chapter 5: Results and Measurements

This chapter will show the measurement result after the fabricated circuit is tested using spectrum analyzer. The result from the measurements which include the conversion gain, linearity issue and also port-to-port isolation of the SOM will be compared and analyzed. This chapter also consists of the main reason and probability that may occur in obtaining the best result. This measurement results will be compared with the simulation results.

Chapter 6: Conclusion and Suggestion

Summary and conclusion about other opinion on obtaining the accurate result and why the measurement results cannot be as accurate as possible as it should be. It will include what the opinion and suggestion in the design for the future project.

CHAPTER 2

LITERATURE REVIEW

2.1 The Fundamental of a Typical Mixer

Typical mixers are three port (RF, LO, IF) active or passive devices. Additionally, mixers are frequency translation devices that translate signals up or down in frequency without changing them in any other way. They are designed to yield both sum and difference in frequency at a single output port when two input frequencies are inserted into the other two ports. This process is called the frequency conversion or heterodyning. It is used to increase or decrease a signal's frequency.

If the output frequency to be produced is lower than the input signal, it is called as down conversion. In contrast, if the output frequency to be produces is at a higher frequency than the input signal, it is called as up conversion. Mixing is produced by the non-linear behavior of mixing devices such as diodes, transistors, Field Effect Transistor (FET) and bipolar junction transistor (BJT). For this SOM project I used FET instead of diodes. This is because the major advantage of FET mixers than diodes mixers is the ability to provide several decibels of conversion gain, while most diode mixers exhibit at least 5 to 6 dB loss. Besides that, FET mixers have gained more popularity in recent years. The primary reason is because they are generally better suited for MMIC (monolithic microwave integrated circuit) technology than diodes. FETs do not require the nonplanar balun structures commonly required by balanced diode mixers. Another problem for the design of diode mixers is the difficulty of fabricating high-quality diodes. Additionally, FETs often have relatively high series resistance instead of diodes.

A mixer is fundamentally a multiplier. The difference frequency in the IF results from the product of sinusoids. Mixers produce wanted sum and difference frequencies as shown in Figure 2.1.1 along with nonlinear distortion of the signals passing through them.

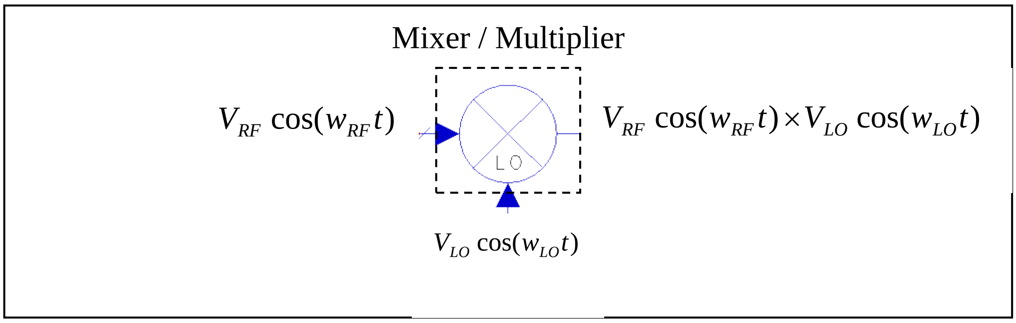

Figure 2.1.1 Typical mixer process

Therefore, the basic mixer design should be capable of injecting the signals to be mixed and producing a strong mixing product that can be extracted by maximizing the efficiency of the conversion. Figure 2.1.1 shows that unwanted spurious product can also produced along the wanted products. The spectrum has a LO frequency below the IF which is known as low-side injection. Thus, in general the mixer produces a range of frequencies given by $mRF \pm nLO$ where m and n are integers. The noise and unwanted signals that are produced at the same IF frequencies as the RF can severely damage the system performance. Normally, filtering or combining / balanced mixers are normally used to help reduce the level of unwanted spurious output in order to enhance performance.

2.2 Introduction to a Self Oscillating FET Mixer (SOM)

Self Oscillating Mixer (SOM) is a mixer which combines both oscillation and mixing functions that generates its own local oscillator (LO) frequency. It is a very attractive frequency converter since a transistor serves both as a local oscillator and as a mixing element. SOM use feedback to produce oscillation for LO signal. This eliminate the use of separate LO signal input thus fulfill the requirement of reducing the size, cost, and power consumption of the overall circuit. Figure 2.2.1 below shows a basic SOM.

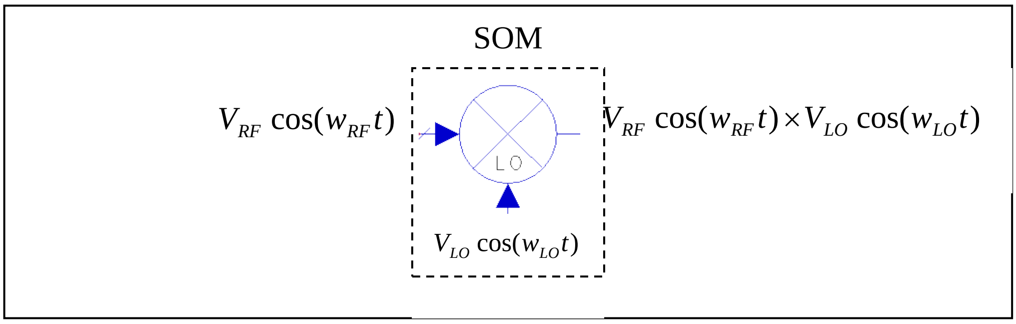

Figure 2.2.1 Basic of a SOM

Self oscillating active FET Mixer (SOM) uses an active FET mixer which requires gate and drain bias. Active SOM is attractive because it produces a conversion gain.

This SOM prefer FET mixer rather than diode mixers because noise figure of well designed FET mixers are consistently lower than those of diode mixers at frequencies well into the millimeter range, and the design techniques necessary for achieving low noise are understood. Other aspects of a FET mixer’s performance such as distortion level, bandwidth, and stability are comparable to those of diode mixers. In addition, FET active mixers provide conversion gain rather than conversion loss.

Basically, Self Oscillating Active FET Mixer (SOM) is a combination of an active FET mixer and an oscillator. LO signal is produced by transistor (FET) oscillator. Figure 2.2.2 below show a conventional SOM configuration.

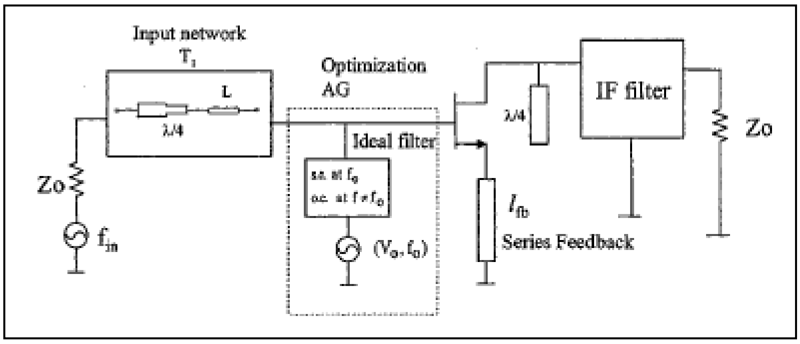

Figure 2.2.2 Conventional SOM configuration

The application of this SOM nowadays is used in wireless communication especially in transmitter and receiver, radar and EW application. Among other interesting functions are forced oscillations for phase and frequency locking, such as ILPLL, where SOM operates as both VCO and phase detector (PD) with a high gain open loop operation. In this approach, a full ILPLL could be achieved without separate amplifiers and PD.

2.3 Down Conversion Theory

Type of SOM designed in this project is a down converter. For down conversion, the signal at Radio Frequency (RF) is converted to a lower Intermediate Frequency (IF). For up conversion, RF is converted to a higher IF. The down conversion allows improved selectivity (filtering) and easier implementation of low noise and high gain amplification. Down conversion theory states that the frequency for RF port and LO port are larger than the frequency at IF port where RF / LO > IF.

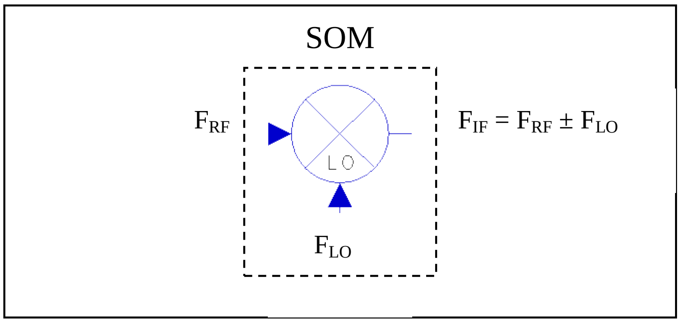

Figure 2.3.1 Down conversion system

The analysis from down conversion is realized from the equation below.

LO signal: $V_{LO}(t) = \cos w_{LO}\, t$

RF signal: $V_{RF}(t) = \cos w_{RF}\, t$

The output of the idealized mixer is the product of the LO and RF as follow:

$$V_{IF}(t) = K\, V_{RF}(t)\, V_{LO}(t)$$

$$= K (\cos w_{RF}\, t)(\cos w_{LO}\, t)$$

$$= K/2\, [\cos 2\pi (F_{RF} - F_{LO})t + \cos 2\pi (F_{RF} + F_{LO})t\,]$$

K is a constant of voltage conversion loss. The output consists of sum and differences of the input signal frequencies and the desired IF output can be selected by using the low pass filter.

$$F_{IF} = F_{RF} - F_{LO}$$

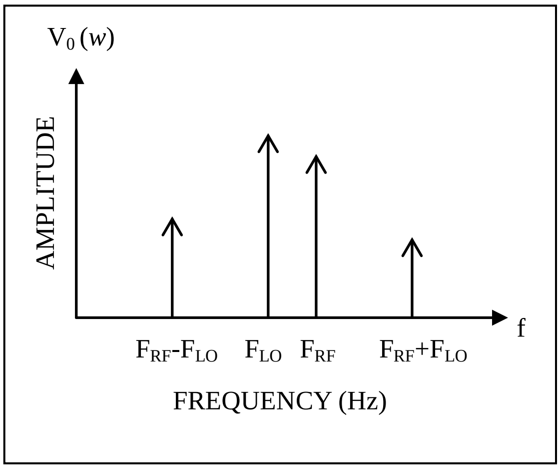

Figure 2.3.2 The spectrum of input and output signal for down conversion

2.4 Mixer Characteristic

Conversion Loss

The ratio of the IF output power to RF input power of one sideband (at either F_{LO} + F_{RF} expressed in dB). It shows the measure of how efficient a mixer is in producing the frequency translation. Mixer design requires impedance matching at three ports (SOM requires impedance matching at two port), complicated by the fact that several frequencies and their harmonics are involved. Ideally, each mixer port would be matched at its particular frequency either RF, LO, or IF and undesired frequency products would be absorbed with resistive loads, or blocked with reactive termination. Resistive loads increase mixer loss; however, reactive loads can be very frequency sensitive. In addition, there are inherent losses in the frequency conversion process because of the generation of undesired harmonics and other frequency products. Conversion loss accounts for resistive losses in a mixer as well as loss in the frequency conversion process from RF to IF port. Conversion loss applies to both up-conversion and down-conversion.

Since the RF stages of receivers operate at much lower power levels than do transmitter, minimum conversion loss is more critical for receivers because of the importance of minimizing losses in the RF stages of receiver noise figure.

Practical passive mixers typically have conversion losses between 4 to 7dB in the 1 – 10GHz range. Active mixer has lower conversion loss, and may even have conversion gain. Since this project is designing SOM using active mixer, conversion gain is expected during simulation and also measurement. Conversion loss, L_c is defined as the ratio of available RF input power to the available IF output power. The value is in dB.

L_c = 10 log (available RF input power / available IF output power) $\geq$0dB

Conversion Gain (dB) = P_{out} (dBm) – P_{in} (dBm)

Note: If the conversion gain is negative, it gives the conversion loss value.

Isolation

Isolation measures the mixer circuit balance. When the leakage or feed thru between mixer ports is very small, isolation will be high. It shows how much an input signal is attenuated when measured at another mixer port. In a typical mixer, there are three type of isolation to be considered: LO to RF isolation, LO to IF isolation and RF to IF isolation. Those isolations will be briefly discussed below:

LO to RF isolation

The amount by which the LO drive level is attenuated when measured at the RF port while the RF port is terminated by 50Ω.

LO to IF isolation

The amount by which the LO drive level is attenuated when measured at the IF port while the IF port is terminated by 50Ω.

RF to IF isolation

The amount by which the RF drive level is attenuated when measured at the IF port while the IF port is terminated by 50Ω.

Linearity Issue

Linearity of a mixer is one important characteristic to determine whether it is a passive mixer or an active mixer. The linearity issue can be proven by plotting the graph of output power P_{IF} versus input power P_{RF}. For a passive or active FET mixer, the I-V curve characteristic from the FET transistor that will be used can affect the linearity of the mixer.

Normally it is best to unbiased the drain at V_{ds} = 0V for the passive FET mixer so that it can provide linearity of the mixer. At this point it indicates that it is at the ohmic region and linear region, so that it will improve the linearity of a passive mixer. This is contrast than the active FET mixer, where the point is located in the saturated region where it is a nonlinear region so that the active FET mixer will provide the nonlinearity of the mixer.

2.5 <u>FET Mixer</u>

In this SOM design, the mixer device that will be used is the FET (Field Effect Transistor) mixer and nowadays it become more attractive because its advantage compared to diode mixers is their ability to provide conversion gain while diode mixers normally produce loss at least 5 to 6dB. It is also operate well at higher microwave frequency.

FET mixers have gained considerable popularity in recent year. The primary reason for their increase in use seems to be the related progress in GaAs monolithic microwave integrated circuit (MMIC) technology. The active FET mixer has an advantage for nowadays technology because it can provide several decibels of conversion gain. So, active mixer is used in this SOM design project.

CHAPTER 3

SOFTWARE ANALYSIS USING ADS

3.1 <u>Designing a 5.5 – 0.5 GHz Down Converter SOM</u>

First of all, to design a 5.5 – 0.5GHz down converter SOM, transistor ATF 36077 is used. To get an IF frequency of 500MHz at the output port, oscillation frequency of the transistor is fixed exactly to 5GHz. The feedback element (L5, L8, C3 and C6) at the MESFET source provides negative resistance at the gate port. Negative resistance is needed to provide the condition for oscillation. Input network or oscillator load (L1) at the gate port also provides oscillation condition. By using S-parameter simulator, oscillation frequency can be finding as shown below:

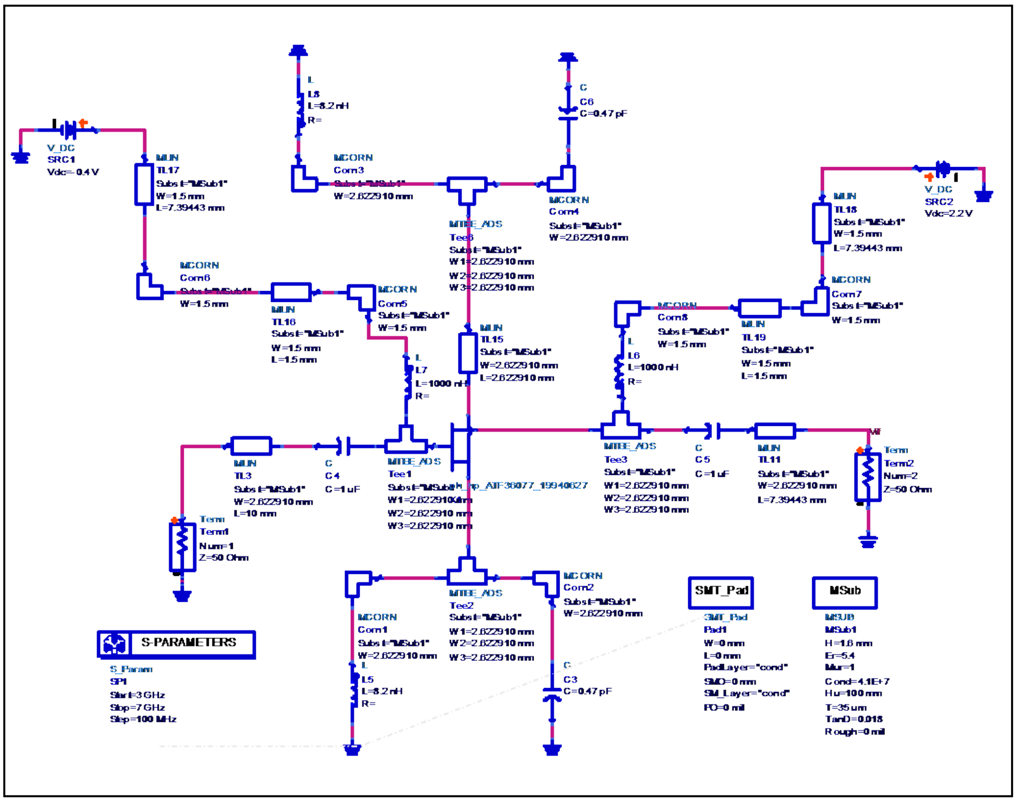

Figure 3.1.1 Circuit to find 5GHz oscillation frequency of the transistor

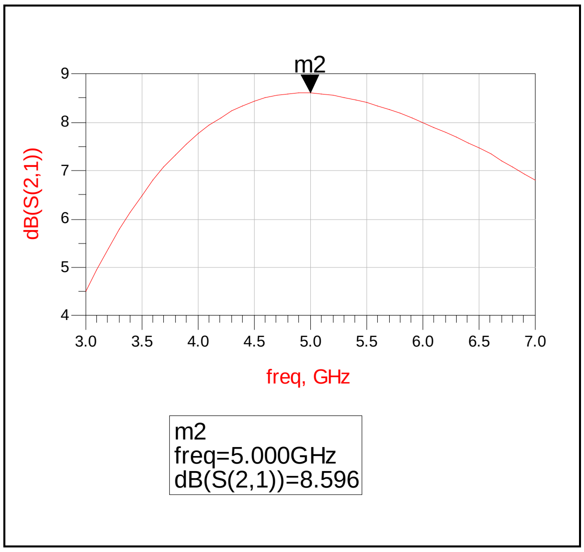

Figure 3.1.2 Simulation result on oscillation frequency at 5GHz

As graph simulation shown above, the transistor is oscillating at frequency 5GHz and the SOM are expected to provide the highest values of conversion gain.

IF frequency (500MHz) is selected through a filter at the drain port. The 500MHz filter is designed and simulated using S-Parameter as shown below.

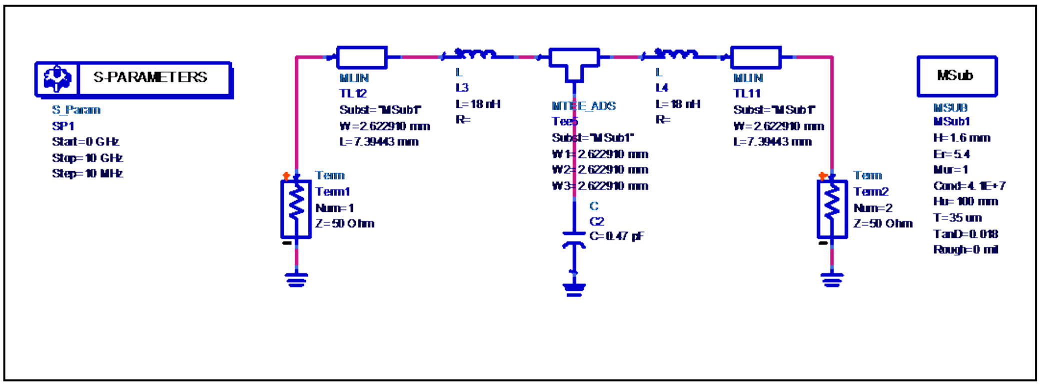

Figure 3.1.3 500MHz IF filter

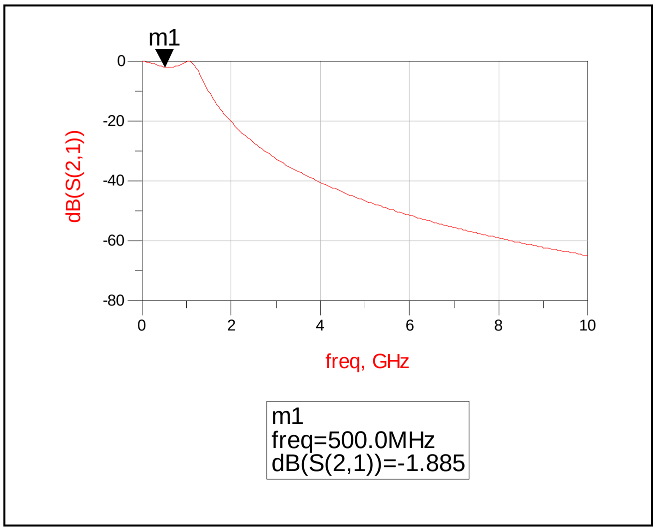

Figure 3.1.4 Simulation result of 500MHz filter

An open-circuited λ/4 (15mm) parallel line is employed at drain port to attenuate the oscillation frequency (f_0 = 5GHz). Full circuit of the designed 5.5 – 0.5GHz down converter SOM is as shown below:

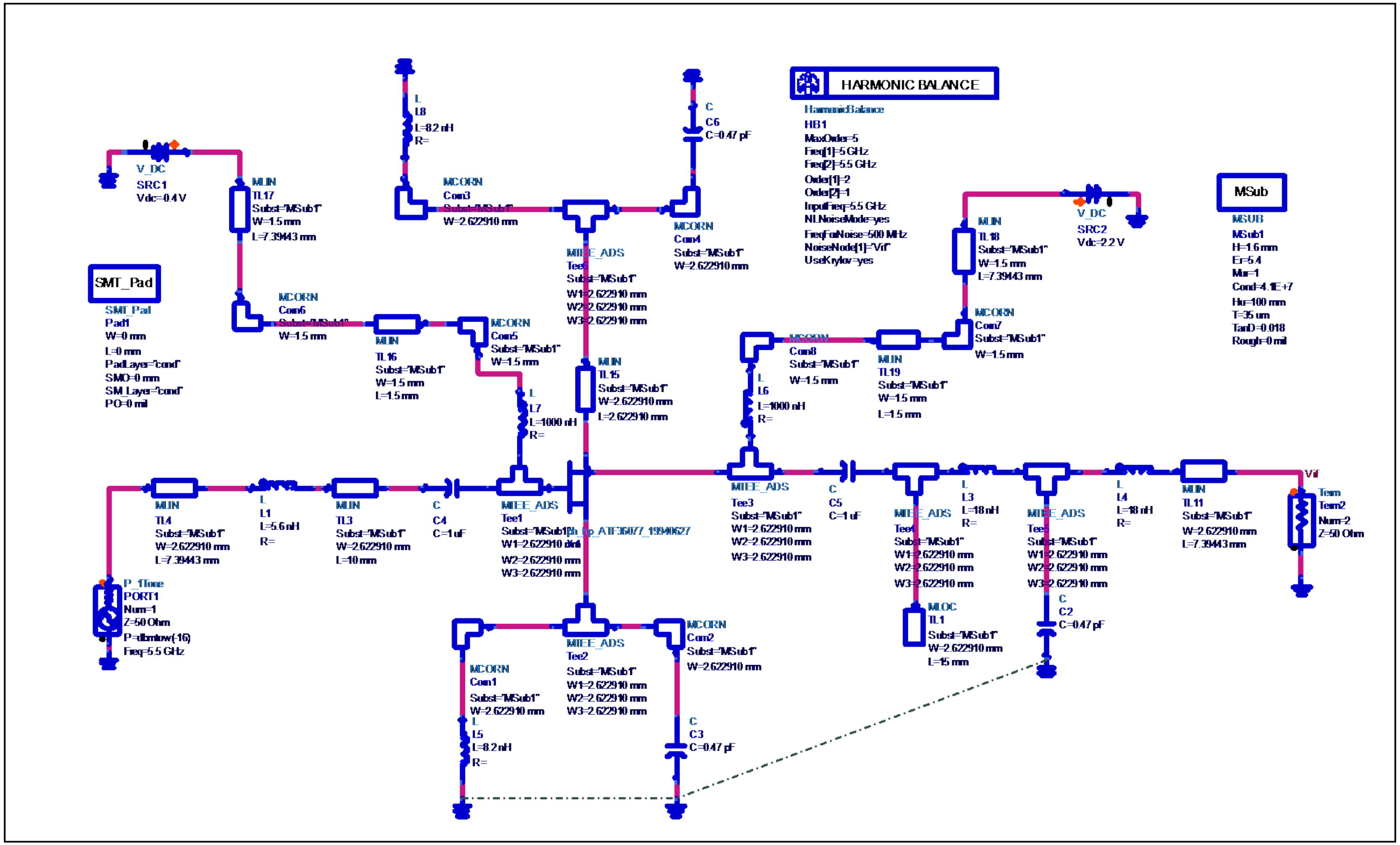

Figure 3.1.5 5.5 – 0.5GHz down converter SOM full circuit

After the circuit is simulated using Harmonic Balance simulator in ADS with an input RF power of -16dBm at frequency 5.5 GHz, the following result is obtained:

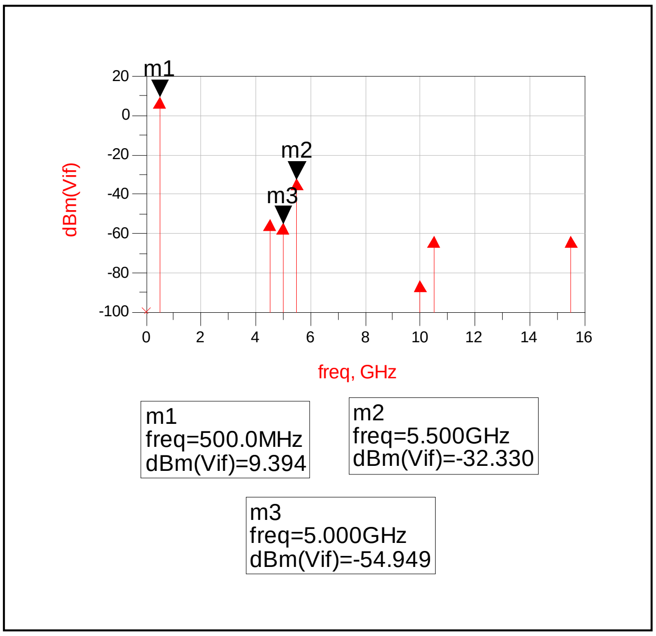

Figure 3.1.6 5.5 – 0.5GHz down converter SOM output spectrum

From Figure 3.1.6 above, we can see that maximum power output spectrum for this SOM is at IF = 500MHz. We can also seen that the LO to IF isolation and RF to IF isolation is quite good.

Conversion Gain

From Figure 3.1.6 above,

Conversion gain = Output power (IF) – Input power (RF)

$= P_{IF}$ (dBm) – P_{RF} (dBm)

= 9.394 – (-16)

= 25.394 dB

This SOM is producing conversion gain instead of conversion loss since this SOM gives a positive conversion gain,

Port-to-port Isolation

From Figure 3.1.6 above,

RF to IF isolation = Output IF Power– Output RF Power

$= P_{500MHz}$ (dBm) – $P_{5.5GHz}$ (dBm)

= 9.394 – (-32.330)

= 41.724 dB

LO to IF isolation = Output IF Power– Output LO Power

$= P_{500MHz}$ (dBm) – P_{5GHz} (dBm)

= 9.394 – (-54.949)

= 64.343 dB

From the calculation above, this SOM has a high RF to IF and LO to IF isolation. This shows that there is not much leakage has occurred between RF to IF and also LO to IF. Better isolation gives better result for conversion.

Linearity Issue

Linearity of a mixer can be seen from the graph of output power at intermediate frequency (IF) port versus the input power at radio frequency (RF) port. Table Appendix 3 shows the simulated output IF power at different RF input power. Conversion gain is also calculated for each level of input RF power level. To show the linearity issue of this SOM, graph of output IF power versus input RF power is plotted. Graph of conversion gain versus input RF power is also plotted as well.

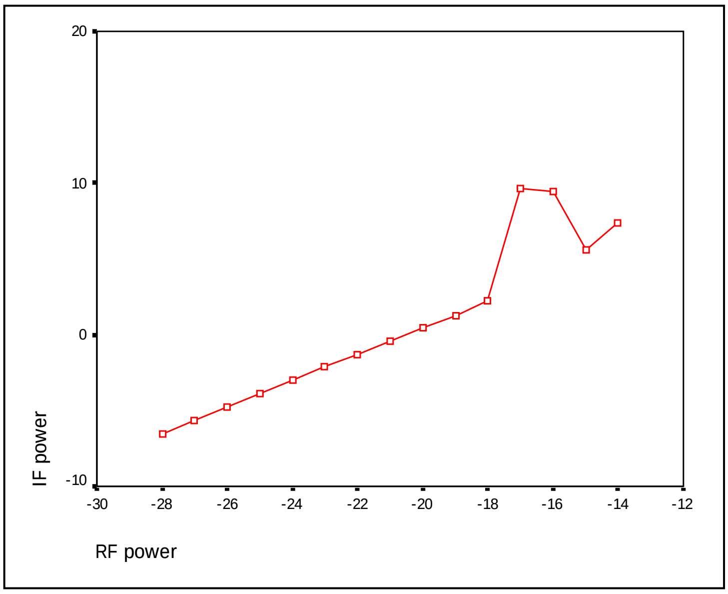

Figure 3.1.7 Output IF power versus input RF power

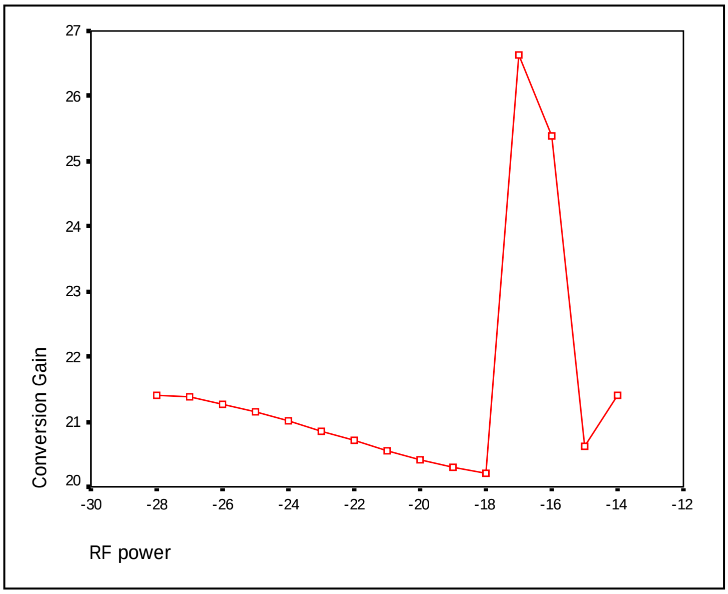

Figure 3.1.8 Conversion gain versus input RF power

Conversion Gain versus FET Biasing Voltage

To select the most suitable gate and drain biasing for the FET, both biasing voltage is varied and conversion gain for each biasing voltage is taken. Table in Appendix 4 shows the reading. Then conversion gain versus both biasing voltage is plotted as follow.

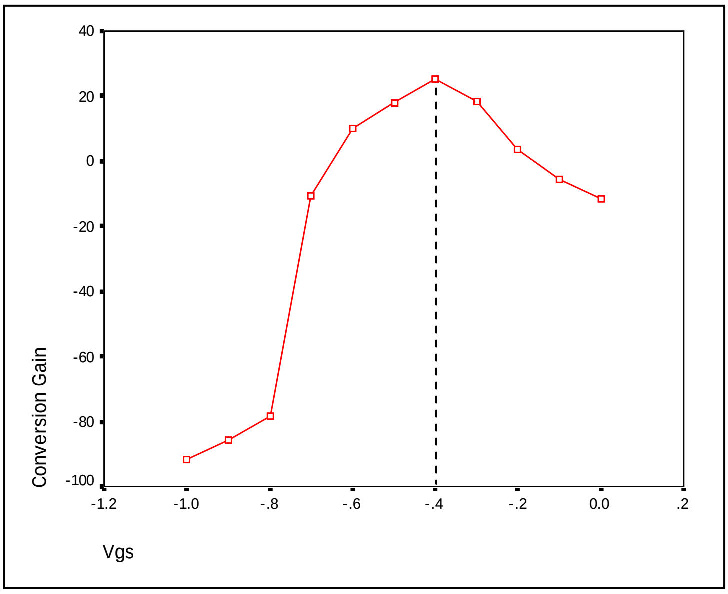

Figure 3.1.9 Conversion gain versus gate voltage V_{GS}

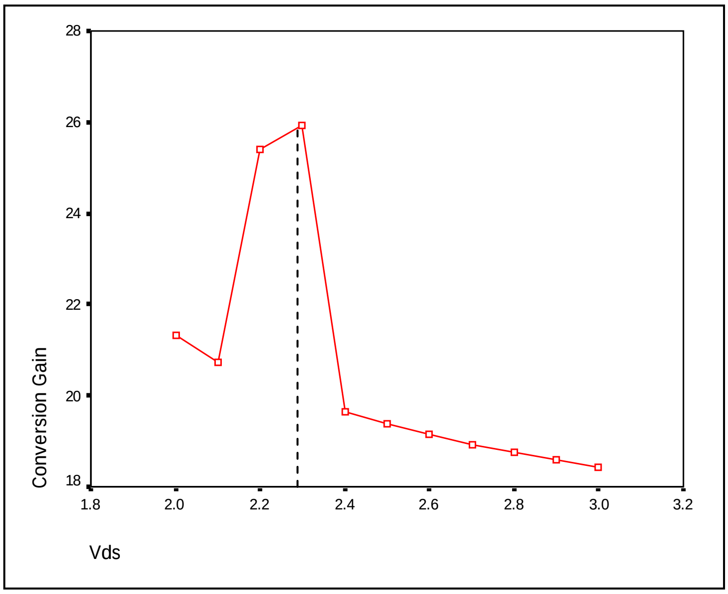

Figure 3.1.10 Conversion gain versus drain voltage V_{DS}

Refer to Figure 3.1.9, it can be seen that gate voltage V_{GS} = -0.4V gives maximum conversion gain to the SOM. Refer to Figure 3.1.10, it can seen that drain voltage V_{DS} = 2.3V gives maximum conversion gain to the SOM. So, this SOM will produce maximum conversion gain at V_{GS} = -0.4V and V_{DS} = 2.3V biasing voltage.

3.2 <u>Designing a 5.5 – 0.1 GHz Down Converter SOM</u>

The question is, can the IF frequency of the SOM change to different frequency other than 500MHz for variety application? The answer is exactly yes. For example, to design a 5.5 – 0.1GHz down converter from the designed SOM, we just need to change the oscillation frequency to 5.4GHz, change the IF filter to 100 MHz and also change the length of the open-circuited parallel line to attenuate oscillation frequency (f_0 = 5.4GHz) at drain port.

To change the oscillation frequency to 5.4 GHz, The feedback element (L5, L8, C3 and C6) at the MESFET source is tuned to get the maximum conversion gain. By using S-parameter simulator, oscillation frequency can be finding as shown below:

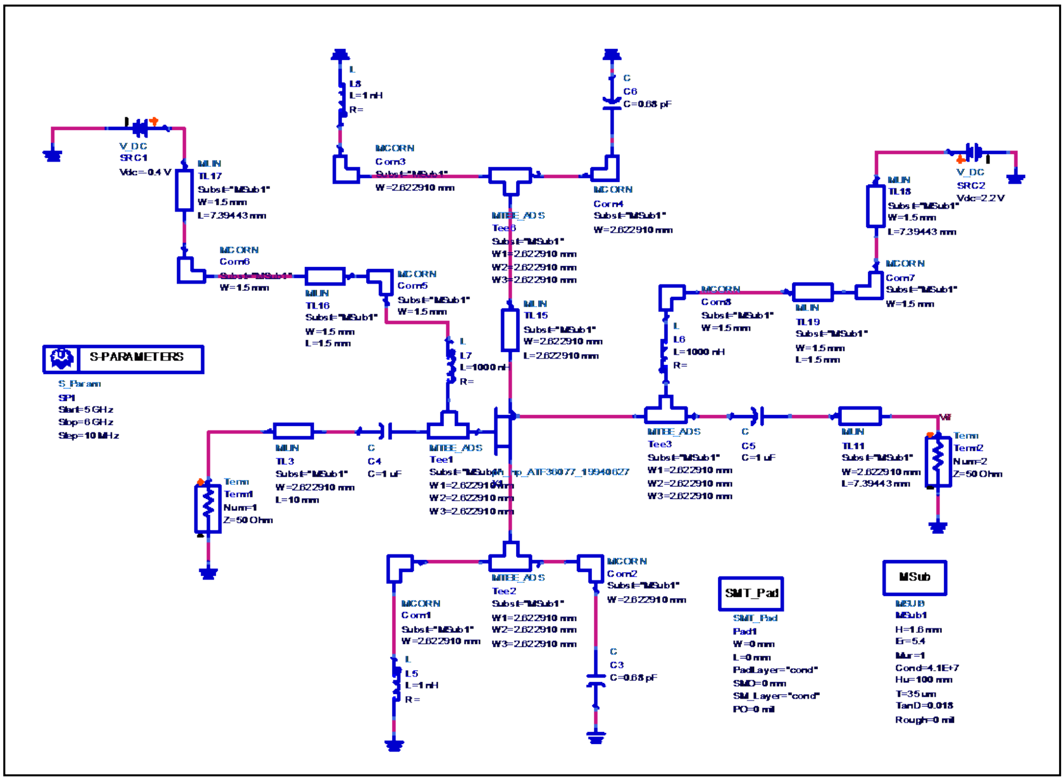

Figure 3.2.1 Circuit to find 5.4 GHz oscillation frequency of the transistor

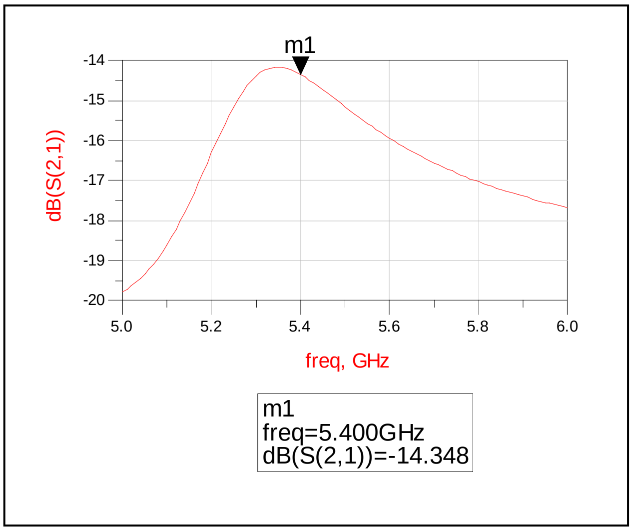

Figure 3.2.2 Simulation result on oscillation frequency at 5.4GHz

As graph simulation shown above, the transistor is oscillating at frequency near to 5.4GHz and the SOM are expected to provide the highest values of conversion gain.

To change the IF filter to 100 MHz, inductor and capacitor of the IF filter changed as below:

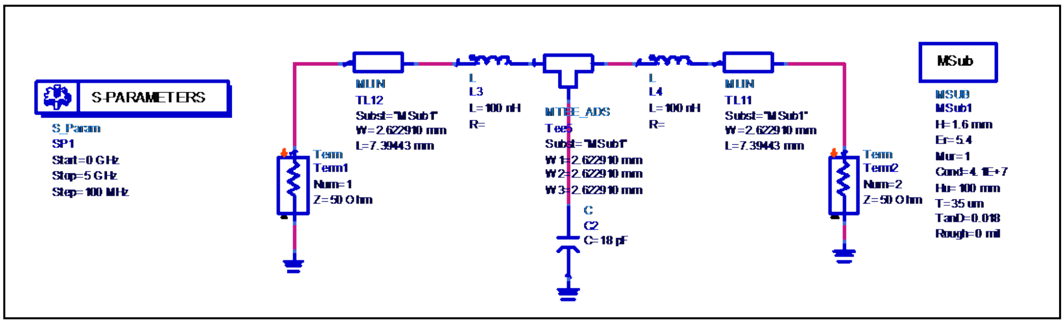

Figure 3.2.3 100MHz IF filter

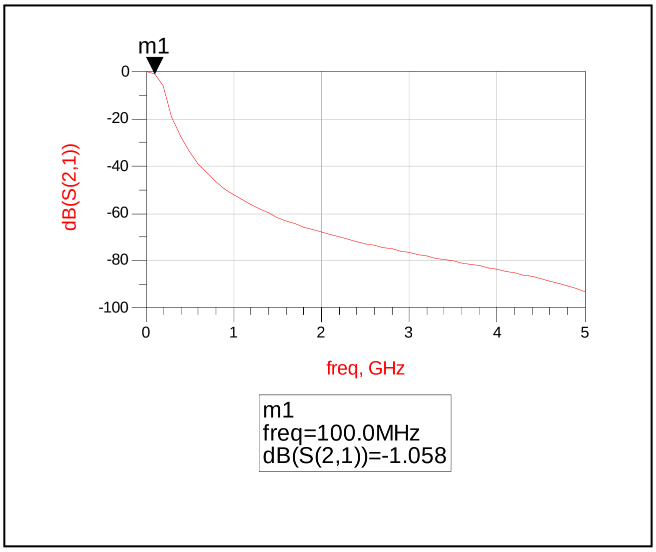

Figure 3.2.4 Simulation result of 100MHz filter

From figure 3.2.4 above, it can be seen that the IF filter only allow frequency equal or lower than 100MHz to pass through it.

An open-circuited $\lambda/4$ parallel line is now change to length of 13.89mm employed at drain port to attenuate the oscillation frequency (f_0 = 5.4GHz). Full circuit of the designed 5.5 – 0.1GHz down converter SOM is as shown below: