Design of Microwave Oscillator for IM3 Measurement Training Kit

by

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20081

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Electrical and Electronic)

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Universiti Teknologi PETRONAS

Bandar Seri Iskandar

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CERTIFICATION OF APPROVAL

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Approved by,

____

(Dr. Cheab Sovuthy)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2017

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NUR AQILAH BINTI MOHD SHAHAR

ABSTRACT

Microwave oscillators are the main source in generating electronic signal. The fundamental of oscillators' operation is to carry message through transmission medium all the way to the desired destination. This project focus on designing a microwave oscillator with center frequency at 1.9 GHz and 1.95 GHz. Both of the generated signals will be combined using power combiner. The method used in designing the oscillator in this project is based on negative conductance method. GaAs MESFET is selected to be the transistor in producing the signals. The proof of concept is clarify using a software called Agilent Advanced Design System (ADS). Calculations have been made to identify the parameters needed in designing oscillator.

Power combiner is design using Wilkinson power divider and its circuit is simulated in ADS. The simulation shows a matched response for each port (S11, S22, and S33 are all below 20 dB) and the power slit of -3 dB. The power combiner prototype is fabricated and tested. The measured response shows the return loss of more than 15 dB for each port is achieved. This shows that all the 3 ports are matched as desired. In terms of transmission coefficient, the measured S12 is -3.405 dB. The measured reflection and transmission response are slightly higher than the simulated one but acceptable. This is due to fabrication tolerance and the integration of the connectors and resistor in to the prototype. This report contains total of five chapters which include Introduction, Literature Review, Methodology, Result and Discussion and also Conclusion and Recommendation.

ACKNOWLEDGEMENT

My greatest gratitude goes to my supervisor Dr. Sovuthy Cheab for all the time and effort he had done to help me throughout my final year project, his great supervision, continuous support and understanding. With his guidance, I was able to complete the project successfully.

Special thanks to my Co-supervisor, Assoc. Prof. Dr. Wong Peng Wen and all of the lecturers in Electrical and Electronic Engineering Department that encouraged me on finishing my project.

This final year project would have been impossible without the support from my parent. Thanks to them for their mental support, strength and help.

Thank you.

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CHAPTER 1

INTRODUCTION

1.1 Background

Intermodulation distortion is the generation of the undesired crossedproduct frequency when mixing two or more frequencies in a nonlinear device such as transistor and diode. These undesired signals will increase the conversion loss and also contribute to signal distortion. Harmonic and intermodulation distortions will be present whenever two or more frequencies are amplified in a nonlinear device. The harmonics produced by the system are classified by their order. The first-order harmonic is called fundamental which is the desired response from the system. While the higher-order harmonics is consider to be harmonic distortion. This phenomena can occur in any system that using nonlinear device such as in mixer, detector, amplifier and oscillator.

1.2 Problem statement

The distortion patent itself by diverting the input power into various harmonics. The third order intermodulation (IM3) is the product caused by the third-order nonlinear term to the linearly amplified signal. It is normally appears so closed to the linearly amplified signal which is the fundamental. This type of distortion have become very difficult to filter compare to other distortions.

The existing filter normally cannot filters this IM3 even in narrow-band system. Hence, the solution proposed in this paper will produce a training kit that serve as the tool to show the generation of these signals.

1.3 Objective

The objectives of this project are mainly to design microwave oscillators and power combiner. The oscillators will provide sinusoidal signals with center frequency at 1.9 GHz and 1.95 GHz. These oscillating frequencies are then combined in the power combiner. At the end of the project, a prototype of these devices will be fabricate using microstrip.

1.4 Scope of Study

The study covers the understanding of the operating requirements of an oscillator and power combiner. This include the knowledge of the working principle of transistor in choosing the right one for the desired system.

A software called Agilent Advance Design System (ADS) is used to stimulate the designated circuit and come out with respected output. Only then, the circuit will fabricated on a microstrip.

CHAPTER 2

LITERATURE REVIEW

2.1 Oscillator

Oscillator is comprised of three components which are resonator, active device and output matching. These components are then connected to the matching load. The design of the resonator need to be a frequency selective network. It is require to make the oscillation only apply at one frequency. The active device that is mention above is mainly a transistor. A suitable type of transistor need to be chosen to ensure the oscillator to be unstable which oscillate at certain frequency. The transistor also must able to operate at the desired frequency and able to easily find the output matching

An oscillator is a circuit which delivers a persistent, rehashed, exchanging waveform with no input. Oscillators fundamentally change over unidirectional current flow out of a DC source into a alternating waveform which is of the desired frequency, as chose by its circuit components. The fundamental standard behind the working of oscillators can be comprehended by breaking down the conduct of a LC tank circuit, which employs an inductor L and a completely pre-charged capacitor C as its components.

Here, at first, the capacitor starts to discharge via the inductor, which results in the conversion of its electrical energy into the electromagnetic field, which can be stored in the inductor. Once the capacitor discharges completely, there will be no current flow in the circuit. However, by then, the stored electromagnetic field would have generated a back-emf which results in the flow of current through the circuit in the same direction as that of before.

This current flow through the circuit continues until the electromagnetic field collapses which results in the back-conversion of electromagnetic energy into electrical form, causing the cycle to repeat. However, now the capacitor would have charged with the opposite polarity, due to which one gets an oscillating waveform as the output.

However, the oscillations which arise due to the inter-conversion between the two energy-forms cannot continue forever as they would be subjected to the effect of energy loss due to the resistance of the circuit. As a result, the amplitude of these oscillations decreases steadily to become zero, which makes them damped in nature. This indicates that in order to obtain the oscillations which are continuous and of constant amplitude, one needs to compensate for the energy lost. Nevertheless, it is to be noted that the energy supplied should be precisely controlled and must be equal to that of the energy lost in order to obtain the oscillations with constant amplitude. This is because, if the energy supplied is more than the energy lost, then the amplitude of the oscillations will increase leading to a distorted output; while if the energy supplied is less than the energy lost, then the amplitude of the oscillations will decrease leading to unsustainable oscillations.

Practically, the oscillators are nothing but the amplifier circuits which are provided with a positive or regenerative feedback where in a part of the output signal is fed back to the input. Here the amplifier consists of an active amplifying element which can be a transistor or an Op-Amp and the backfed in-phase signal is held responsible to keep-up (sustain) the oscillations by making-up for the losses in the circuit.

Once the power supply is switched ON, the oscillations will be initiated in the system due to the electronic noise present in it. This noise signal travels around the loop, gets amplified and converges to a single frequency sine wave very quickly.

2.2 Power Combiner

Power combiner is the reverse process of power divider. The development of this system is from T-junction which have been improvise as it suffer from poor isolation between the output ports. An example of the improvise version of this system is Wilkinson power divider. The Wilkinson power divider is a network that have lossless property when the output ports are matched. The fabrication of this power divider and power combiner is made in microstrip or stripline form.

Basically, a 0° splitter is a passive device which accepts an input signal and delivers multiple output signals with specific phase and amplitude characteristics. The output signals theoretically possess the following characteristics:

- equal amplitude
- 0° phase relationship between any two output signals
- high isolation between each output signal
- insertion loss

Since the 0° power splitter is a reciprocal passive device it may be used as a power combiner simply by applying each signal singularly into each of the splitter output ports. The vector sum of the signals will appear as a single output at the splitter input port. The power combiner will exhibit an insertion loss that varies depending upon the phase and amplitude relationship of the signals being combined. For example, in a 2 way 0° power splitter or combiner, if the two input signals are equal in amplitude and are in phase then the insertion loss is zero.

However, if the signals are 180° out-of-phase the insertion loss is infinite. And, if the two signals are at different frequencies, the insertion loss will equal the theoretical insertion loss shown above. The power combiner will also exhibit isolation between the input ports. The amount of isolation will depend upon the impedance termination at the combiner output or sum port. For example, in the 2 way 0° power splitter/combiner if port S is open then the isolation between ports A and B would be 6dB. And, if port S is terminated by a matched impedance (for maximum power transfer) then the isolation between ports A and B would be infinite.

When used as a 0° power splitter, the input is applied to port S and equal outputs appear at ports A and B. When used as a power combiner, both inputs are applied to ports A and B and the sum taken from port S.

The following signal processing functions can be accomplished by power splitter/combiners:

1. Add or subtract signals vectorially.

2. Obtain multi in-phase output signals proportional to the level of a common input signal.

3. Split an input signal into multi-outputs.

4. Combine signals from different sources to obtain a single port output.

5. Provide a capability to obtain RF logic arrangements.

The most basic form of a power splitter is a simple "T" connection, which has one input and two outputs. If the "T" is mechanically symmetrical, a signal applied to the input will be divided into two output signals, equal in amplitude and phase. The arrangement is simple and it works, with limitations.

2.3 Microstrip

The application of microstrip is useful when dealing with high frequency system. It is basically made of a conducting strip and ground plane that is separated by dielectric layer called substrate. An example of the substrate available in the market is named Roger Duroid 5880 and FR4. Roger Duroid is more expensive with less loss. But in this study, the power combiner is fabricated on FR4.

2.4 Critical analysis

Comparing all type of transistors, MOSFET seems to be the most suitable transistor for the oscillator. The criteria in choosing the transistor is so that it can operate at 2 GHz of frequency. The single stage Wilkinson power divider is selected for the power combiner system and to ensure it has good isolation.

CHAPTER 3
METHODOLOGY

3.2 Methodology

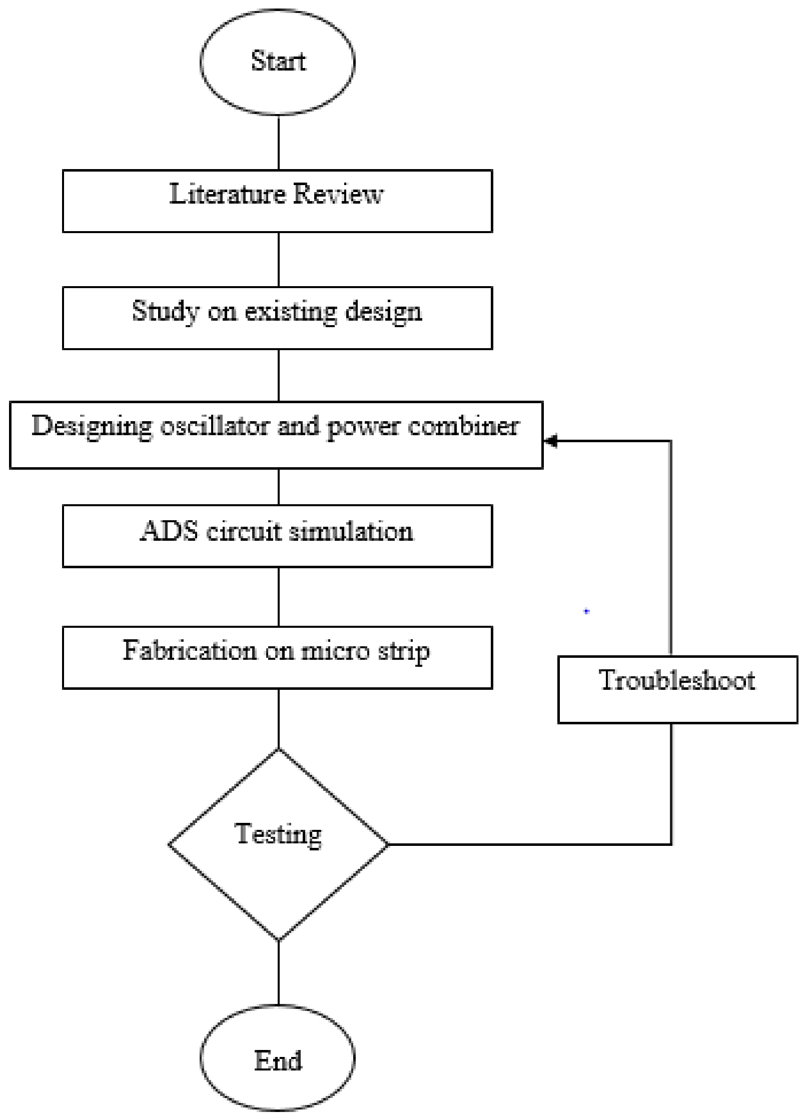

Figure 1: Project Identification

3.2 Gantt chart & Key Milestone

Table 1: Timeline for FYP I

No.	Activities/ Week	FYP I													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Reading Literature Review														
2	Designing Oscillator														
3	Submission of Extended proposal														
4	Oscillator simulation & troubleshoot														
5	Proposal Defense														
6	Oscillator design continue														
7	Interim Draft Report														
	Interim Report														

Key milestone

Process

Table 2: Timeline for FYP II

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<tr><th rowspan="2">No.</th><th rowspan="2" colspan="2">Activities/ Week</th><th colspan="15">FYP II</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th></tr>
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Key milestone (red)

Process (yellow)

CHAPTER 4
RESULT AND DISCUSSION

4.1 Overall design of the training kit.

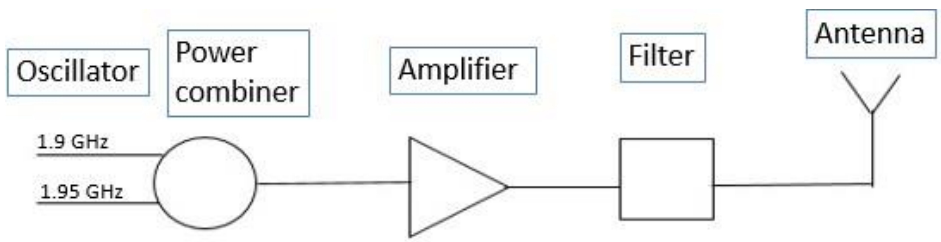

Figure 2: Training kit design

In this project, oscillator and power combiner are designed while amplifier, filter and antenna are designed in separate project.

Oscillator design step

Step 1: Determine the oscillator specification

The center frequencies are 1.9 GHz and 1.95 GHz. Providing the load to be 50 Ω. The transmission medium of this microwave oscillator is microstrip board.

Step 2: Decide the suitable transistor

The transistor used in this project is GaAs MESFET NE76038. FET is chosen as against BJT as it drawing essentially zero input-output current at their control leads, they are easier to manufacture, cheaper to make which require less silicon, and can be made extremely small, making them useful elements in integrated circuits. Table 3 shows the comparison between FET and BJT.

Table 3: Comparison between FET and BJT

BJT	FET
Require a biasing input (or output) current at their control leads.	Require only a voltage—practically no current.
Require both positive (holes) and negative (electrons) carriers to operate.	Only require one charge carrier, because FETs draw little or no current, they have high input impedances (~ 1014 Ω) which means no effect on external components or circuits connected to its gate.

Step 3: Select Quiescent Operating Point (QOP)

Based on the datasheet of the transistor, the nonlinear and linear model is provided. Figure 3 and Figure 4 below show the nonlinear and linear model of the transistor respectively.

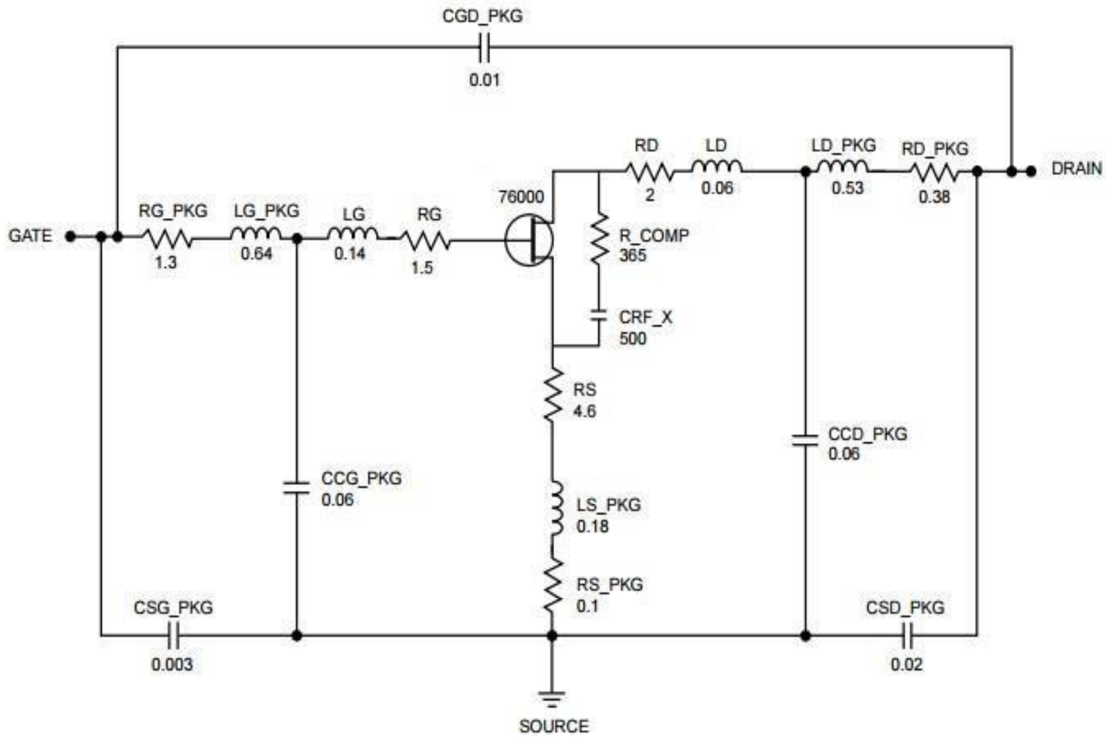

Figure 3: Nonlinear model schematic

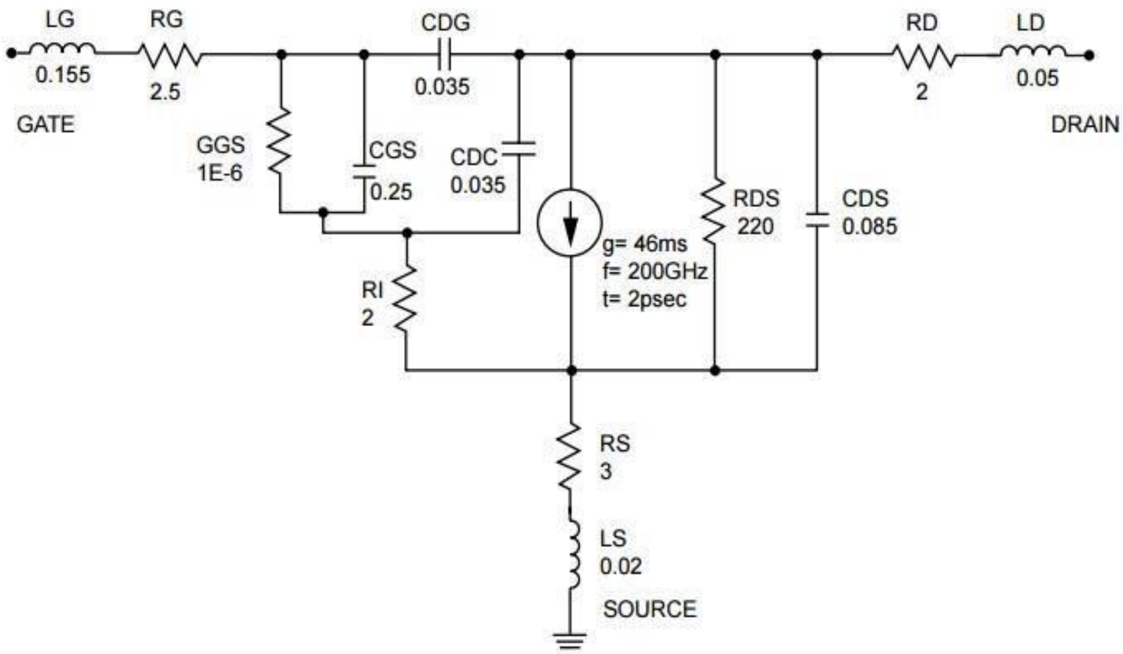

Figure 4: Linear model schematic

Both schematics are used to compare with the simple small signal equivalent circuit to obtain C_{gd}, g_o, c_o *and* g_m parameters. These parameters help in designing the oscillator.

Parameters obtained: Cgd

=0.035 pF go = 1/R = 1/220 Ω

= 0.0045 S

Co = 0.085 pF

Step 4: Determine g_m

Figure 5 is the output characteristic of the transistor.

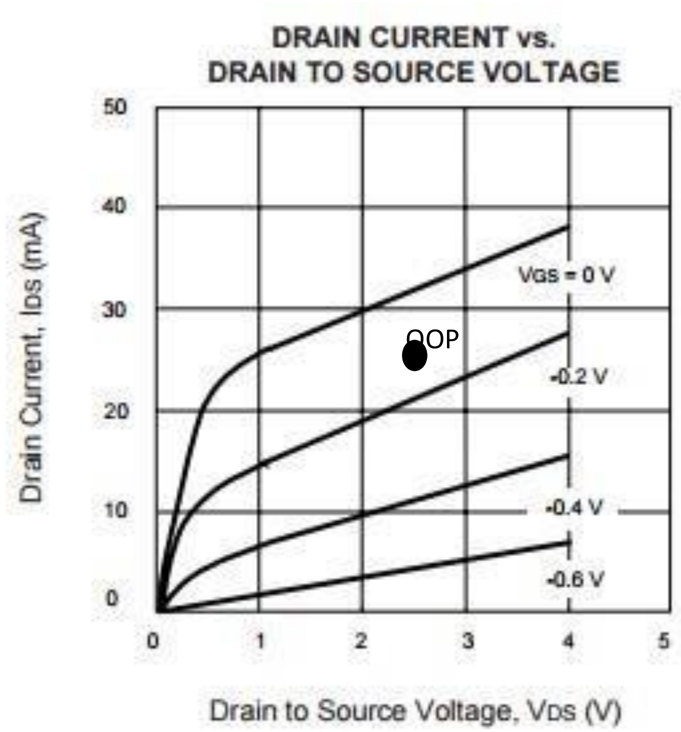

Figure 5: Output characteristic of the transistor

From Figure 4, QOP : I_D = 25 mA

: V_{DS} = 2.5 V

Hence g_m = 250 mS

Step 5: Determine k value of the maximum

negative conductance $k = (2g_o + g_m) / (2(g_o + g_m)) = 0.5088$

Step 6: Determine the synthesized device admittance

Figure 6 shows simple small signal equivalent circuit of FET with feedback elements.

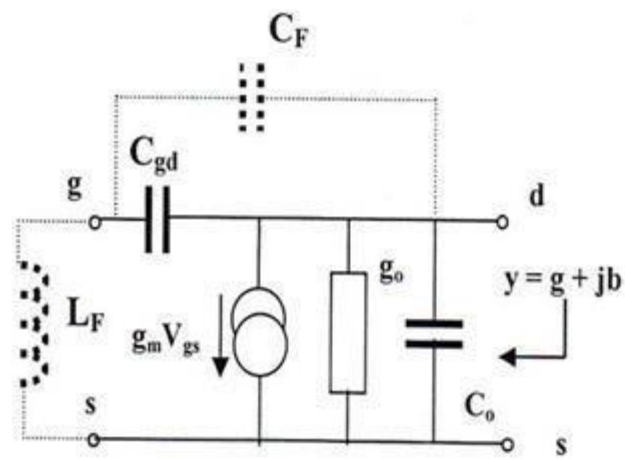

Figure 6: Simple small signal equivalent circuit of FET with feedback elements

From the circuit in figure 6, $g_{opt} = -0.2546$ S

For 1.9 GHz using formula to find jb and LF; jb = j1.865 mS

LF = 1.02 x 10^-7 H

For 1.9 GHz using formula to find jb and LF; jb

= j1.914 mS

LF = 9.68 x 10^-8 H

Step 7: Design the Frequency Determining Network

By inserting the susceptance $-jb_{opt}$ in parallel with the synthesized device admittance, the operation frequency can be create.

For 1.9 GHz using formula to find Ys and Yo;

Ys = 1.865 mS

Yo = 20 mS

For 1.9 GHz using formula to find Ys and Yo;

Ys = 1.914 mS

Yo = 20 mS

Step 8: Design the Matching Network

Figure 5 shows oscillator circuit with frequency determining network and energy storage element and power maximization network.

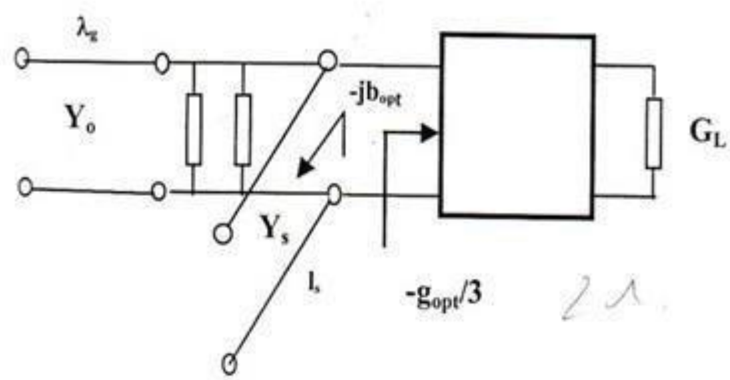

Figure 7: Ocillator circuit with frequency determining network and energy storage element and power maximization network

$Yt^2 / Yo = g_{opt} / 3$

Yt = 41.21 mS

With all the parameters obtained for both the center frequencies, the theoretical design can be verify by constructing the design in ADS.

4.1.1 Oscillator design

Oscillator design consist of three important parts including a load of 50 Ohm. The resonator, active device output match together with 50 Ohm load are connected in parallel.

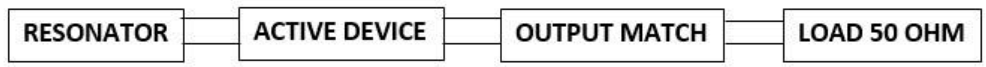

Figure 8 : Oscillator parts

4.1.1.1 Realizatoin of transistor

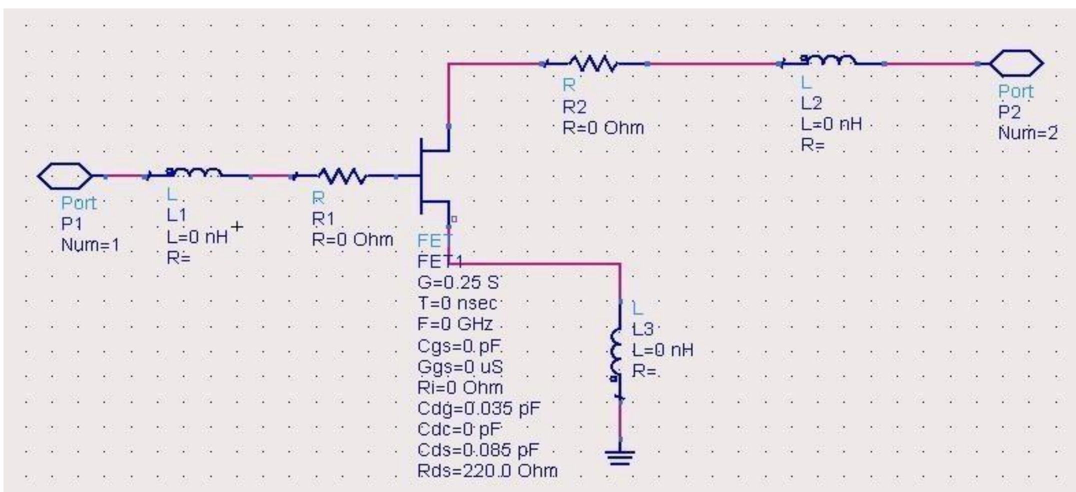

Figure 9 : Realization of transistor

4.1.1.2 Realization of negative conductance oscillator

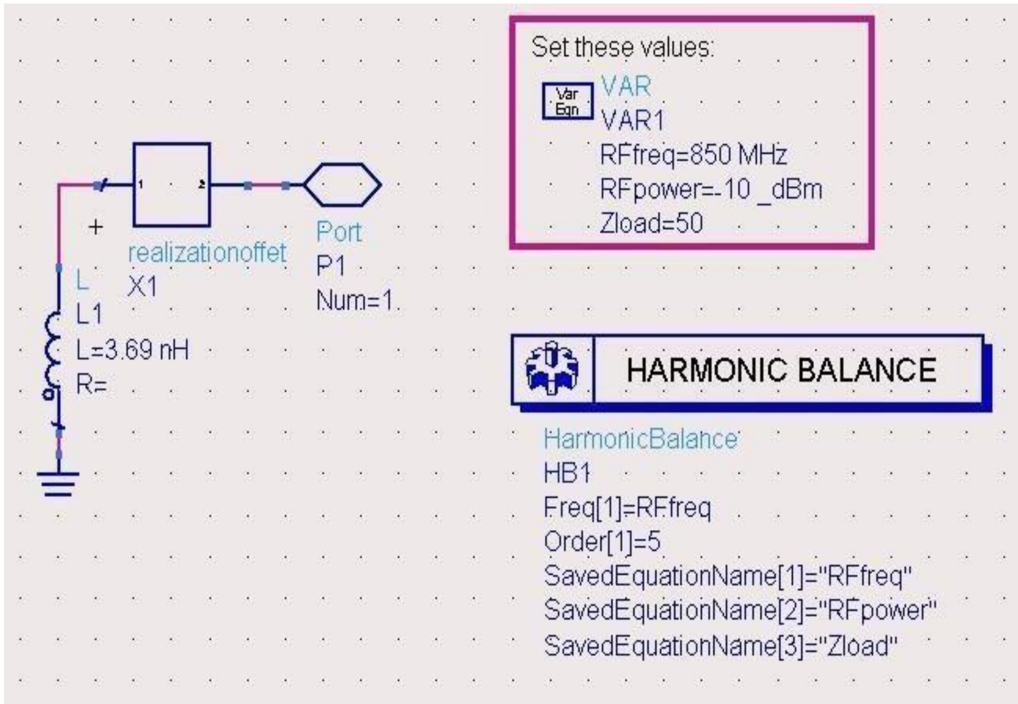

Figure 10 : Realization of negative conductance oscillator

4.1.1.3 Oscillator design

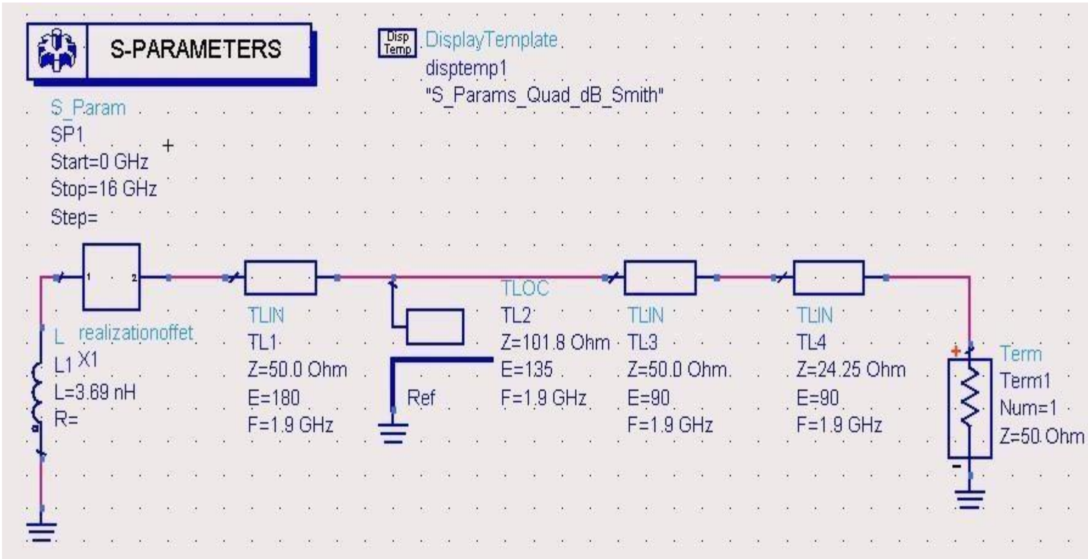

Figure 11: Oscillator design

4.2 Power combiner design

In order to have a good isolation in a power combiner, a design must be made so that all the output ports matched with the isolation between the output ports.

4.2.1 Power combiner without compensation

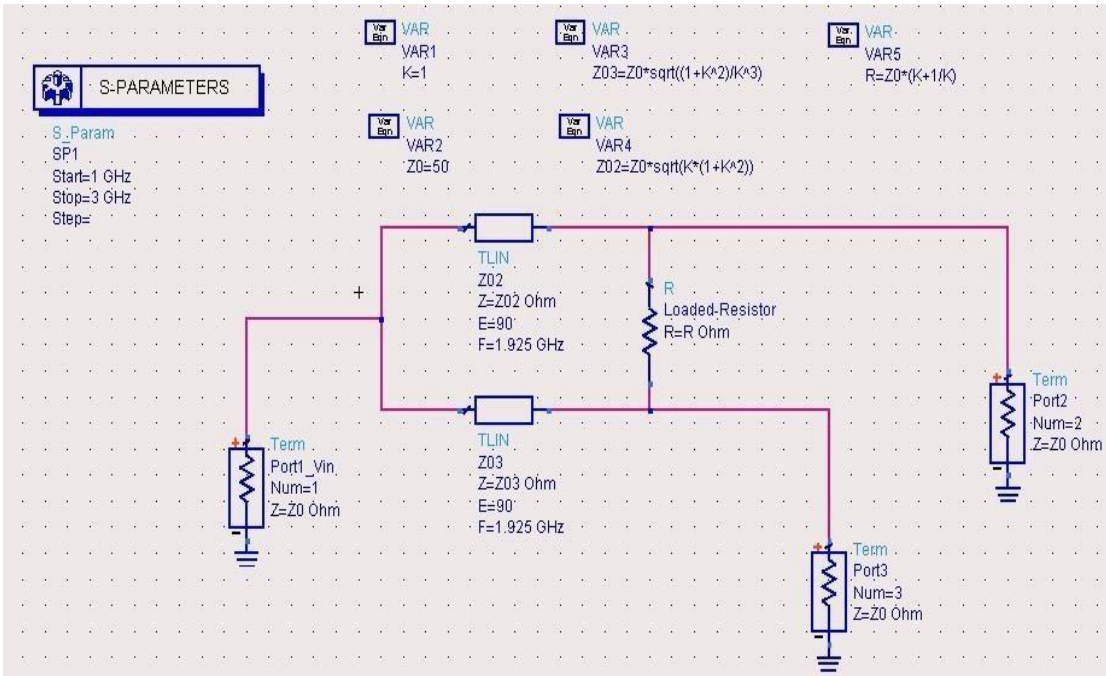

Figure 12 : Power combiner without compensation

The power ratio between ports 2 and 3 is K^2=P3/P2. Therefore, for EQUAL POWER P3 = P2 and K = 1. The impedances are not well matched. 50 Ohm and 70.7 Ohm. So we must include the Impedance Transformer at port 1 for better result. Z0 is normally 50 Ohm.

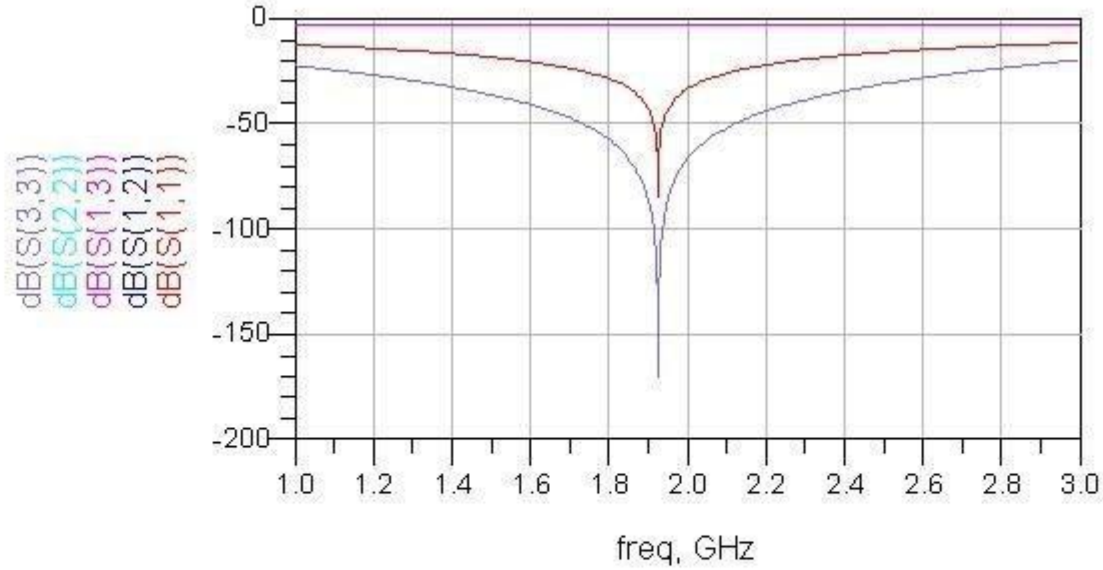

Figure 13 : Power combiner without compensation response

4.2.2 Power combiner design with compensation

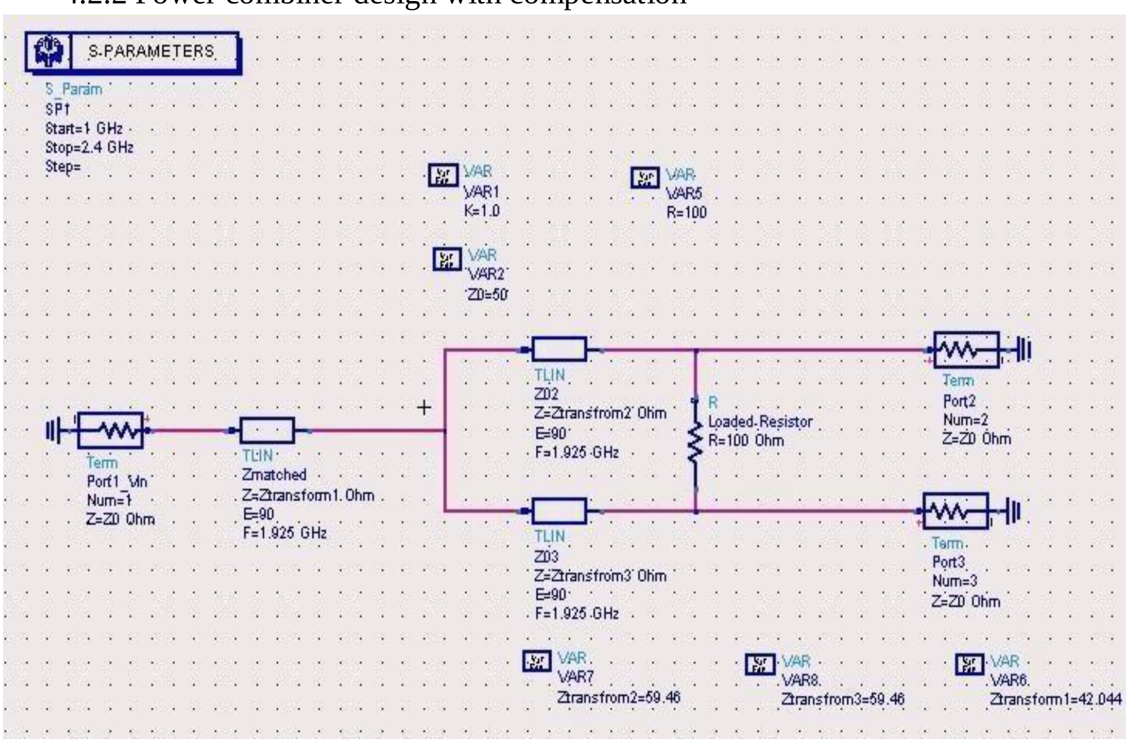

Figure 14 : Power combiner design with compensation

The power ratio between ports 2 and 3 is K^2=P3/P2. Therefore, for EQUAL POWER P3 = P2 and K = 1. Left-end of Z02 Line, impedances is Z (if K=1, Z = 70.7 Ohm) matched with Rightend of Zmatched. Right-end of Z02 Line, impedance is Z (Z=50 Ohm) matched with 50 Ohm. The TLIN for Zmatched is used to have a matched response at each end. And hence give a better performance. Z0 is normally 50 Ohm.

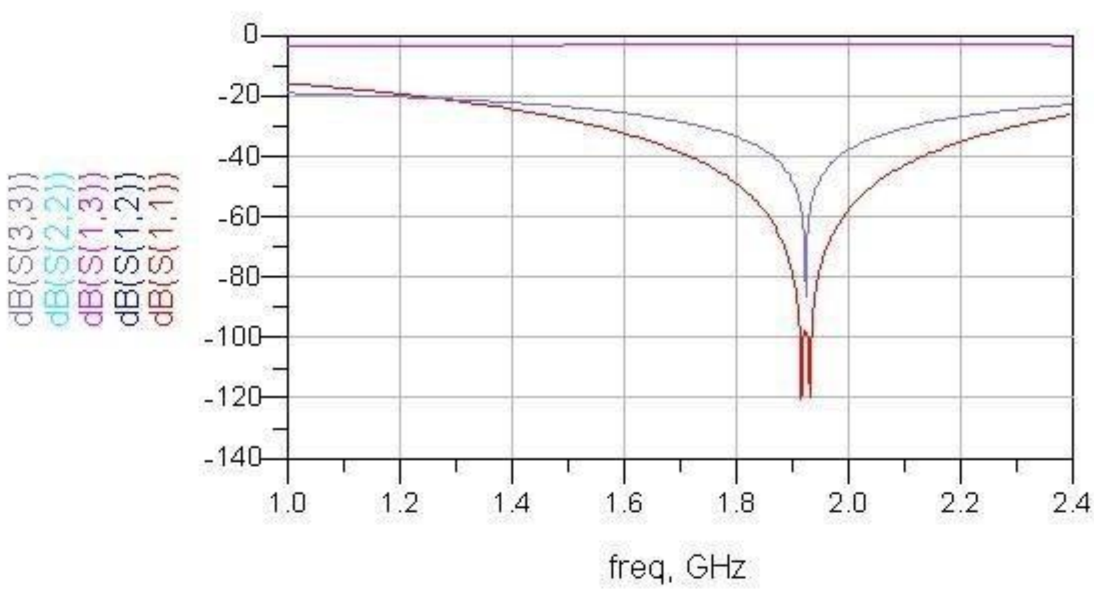

Figure 15 : Power combiner design with compensation response

The design of power combiner with compensation give a good response compare to the design without compensation. The compensation is designed by adding a quaterwave transformer in the circuit.

4.2.3 Power combiner design in FR4

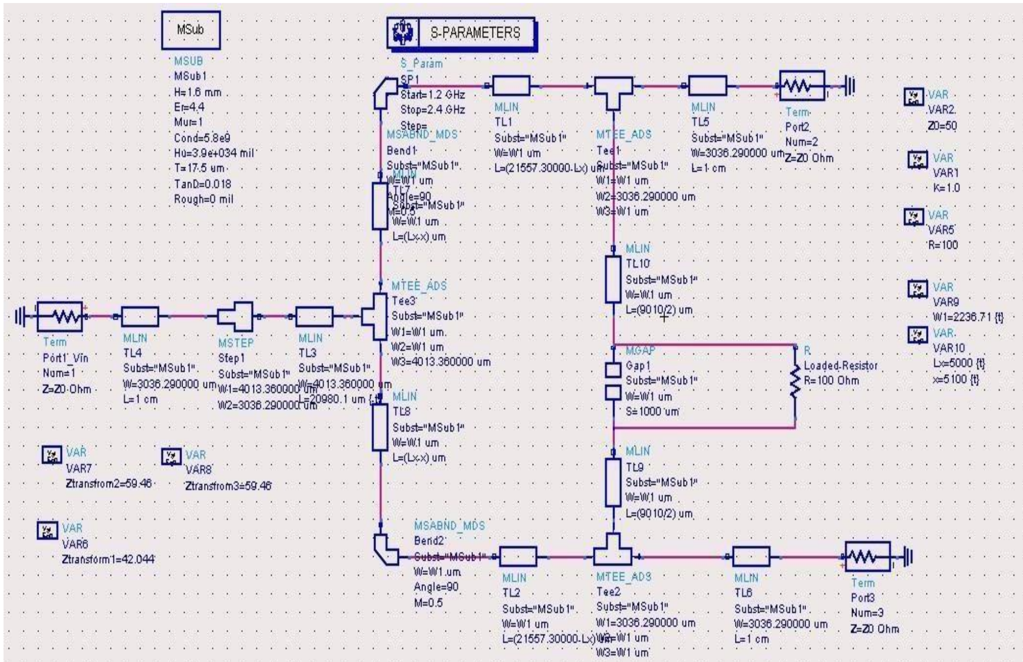

Figure 16 : Power combiner design in FR4

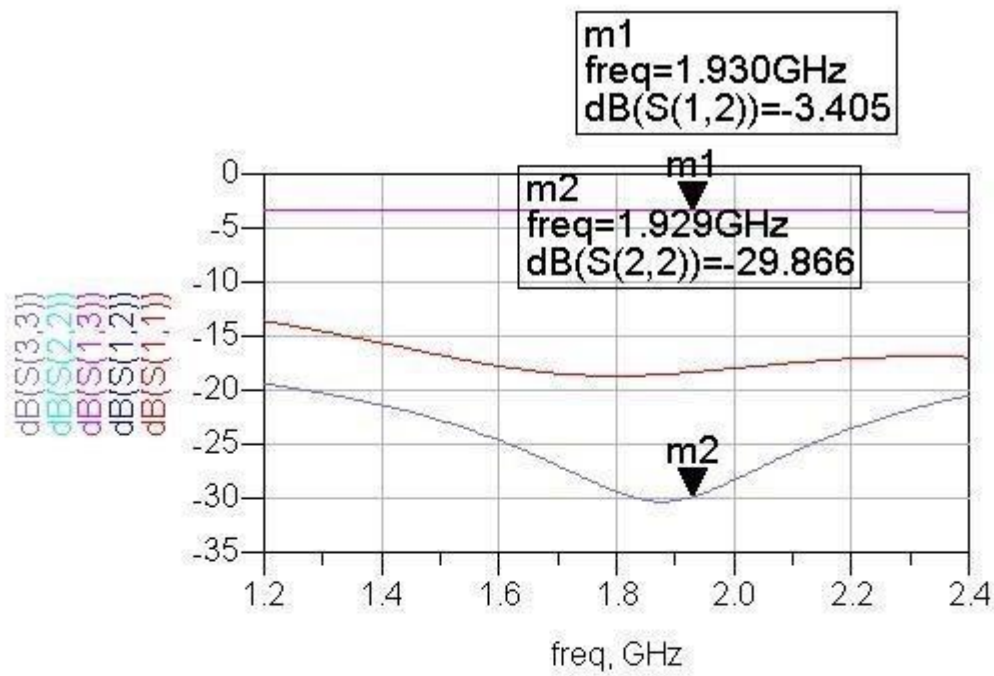

Figure 17 : Power combiner design in FR4 response

4.2.4 Power combiner layout

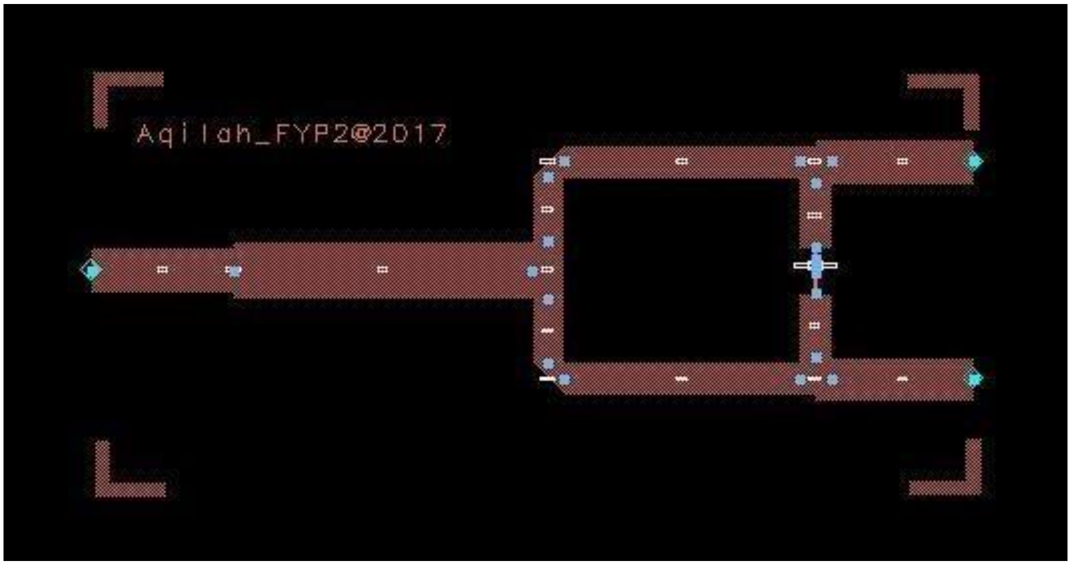

Figure 18 : Layout of power combiner

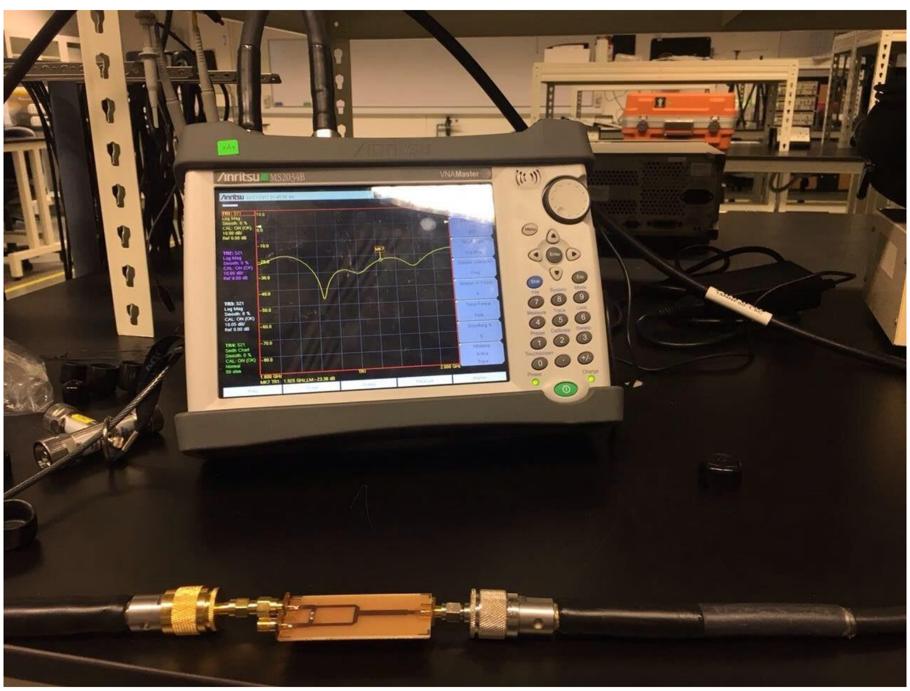

Figure 19 : Measurement of power combiner

The loss become greater when the power combiner is measured by a spectrum analyzer as the connector also contribute to the loss in the signal.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

Two type of devices have been designed in this project which are oscillator and power combiner. Microwave oscillators are the main source in generating electronic signal. This project focus on designing a microwave oscillator with center frequency at 1.9 GHz and 1.95 GHz. Both of the generated signals are combined using power combiner. The method used in designing the oscillator in this project is based on negative conductance method. GaAs MESFET is selected to be the transistor in producing the signals. The proof of concept is done using a software called Agilent Advanced Design System (ADS). Calculations have been made to identify the parameters needed in designing oscillator. However, both oscillators have not been fabricated as planned due to the timing factor.

Power combiner is design using Wilkinson power divider and its circuit is simulated in ADS. The simulation shows a matched response for each port (S11, S22, and S33 are all below 20 dB) and the power slit of -3 dB. The power combiner prototype is fabricated and tested. The measured response shows the return loss of more than 15 dB for each port is achieved. This shows that all the 3 ports are matched as desired. In terms of transmission coefficient, the measured S12 is -3.405 dB. The measured reflection and transmission response are slightly higher than the simulated one but acceptable. This is due to fabrication tolerance and the integration of the connectors and resistor in to the prototype.

Further recommendation would be more exposure to the students on the software used in this project during their Communication course. For example, Agilent Advance Design System software. Last but not least, Electrical and Electronic Engineering Department should consider to offer Major in Communication for coming final year students.

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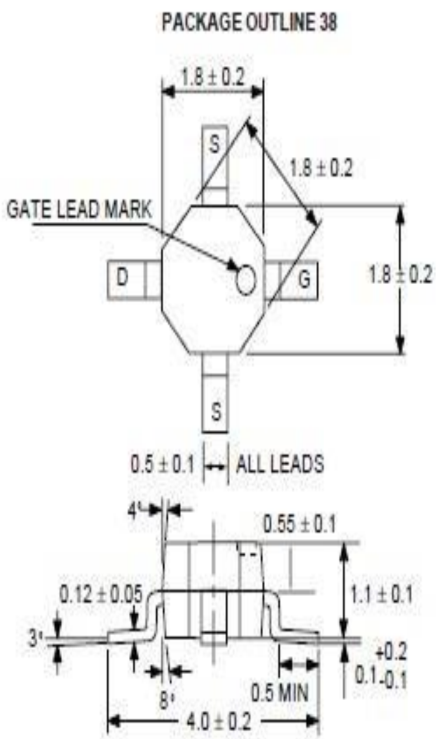
APPENDIX

NE76038

OUTLINE DIMENSIONS (Units in mm)



Properties of FR4

Parameter	Value
Specific gravity/density	1.850 g/cm³ (3,118 lb/cu yd)
Water absorption	−0.125 in < 0.10%
Temperature index	140 °C (284 °F)
Thermal conductivity, through-plane	0.29 W/(m·K), 0.343 W/(m·K)
Thermal conductivity, in-plane	0.81 W/(m·K), 1.059 W/(m·K)
Rockwell hardness	110 M scale
Bond strength	> 1,000 kg (2,200 lb)
Flexural strength (A; 0.125 in) - LW	> 415 MPa (60,200 psi)
Flexural strength (A; 0.125 in) - CW	> 345 MPa (50,000 psi)
Dielectric breakdown (A)	> 50 kV
Dielectric breakdown (D48/50)	> 50 kV
Dielectric strength	20 MV/m

https://en.wikipedia.org/wiki/Relative_permittivity

Relative permittivity (A)	4.4
Relative permittivity (D24/23)	4.4
Dissipation factor (A)	0.017
Dissipation factor (D24/23)	0.018
Dielectric constant permittivity	4.70 max., 4.35 @ 500 MHz, 4.34 @ 1 GHz
Glass transition temperature	Can vary, but is over 120 °C
Young's modulus - LW	3.5×10^{6} psi (24 GPa)
Young's modulus - CW	3.0×10^{6} psi (21 GPa)
Coefficient of thermal expansion - x-axis	1.4×10^{-5} K^{-1}
Coefficient of thermal expansion - y-axis	1.2×10^{-5} K^{-1}
Coefficient of thermal expansion - z-axis	7.0×10^{-5} K^{-1}
Poisson's ratio - LW	0.136
Poisson's ratio - CW	0.118
LW sound speed	3602 m/s
SW sound speed	3369 m/s
LW Acoustic impedance	6.64 MRayl

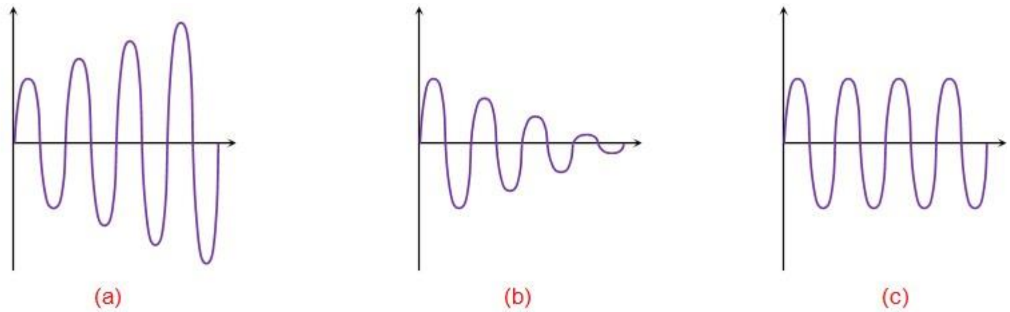
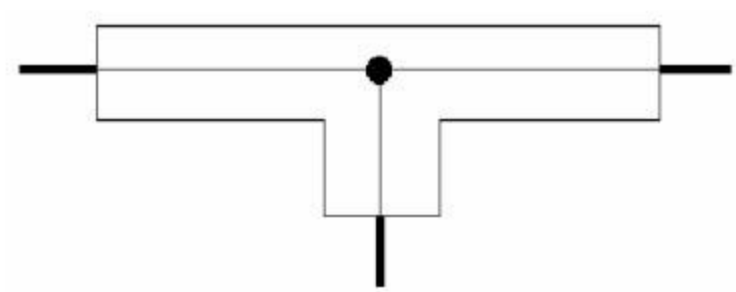


Figure 2 (a) Increasing Oscillations (b) Decaying Oscillations (c) Constant-Amplitude Oscillations



Basic 2 way 0° power splitter, simple "T".