Internship Report on RF Characterization of GaN HEMT/MMIC at The Solid-State Physics Lab DRDO-New Delhi

Submitted by:-

Rahul Kotru

BE ETC(Second year),Don Bosco College Of Engineering , Goa

Submitted to:-

Mr. Sudhir Kumar

Scientist 'D'

MMIC Division, SSPL, DRDO

Duration

21st June 2019 to 19th July 2019

(4 weeks)

Acknowledgement

I would like to take this opportunity to thank Mr. Sudhir Kumar from the MMIC division at SSPL,DRDO .Without his guidance and patience I wouldn't have been able to absorb even a drop from this ocean of knowledge. He inspired me to learn more and addressed any query I had related to the subject.

I would also like to thank the Director of SSPL. Without him, I wouldn't have been able to realize an opportunity of this magnitude and pursue such a challenging endeavor.

Preface

The Solid State Physics Lab is a sub-division of the Defence Research and Development Organization, and aims to cater to the needs of the armed forces of the country and for space exploration projects undertaken by ISRO. It is a premier lab with State-of-the-Art equipment, dedicated at developing and fabricating electronic components like MESFETs and HEMTs. The whole process of acquiring materials to a finished IC takes place in this lab.

Of the many labs within SSPL, I interned at the MMIC (Monolithic Microwave Integrated Circuits) lab. This lab in particular focuses on the various parameters related to microwave technology and testing of the same.

Narrative of Internship

The internship commenced on the 21st of June 2019.After filling up forms and submission of the documents from the college to the HR,I was instructed to go to the MMIC lab and interact with Mr. Sudhir Kumar.

I was briefed about the lab and the work conducted within the lab.

The lab primarily focuses on development of Electronic components and its parameters/response to signals. The devices in discussion are MMICs and the basic electronic device, the transistor lays the foundation for it.

BJT

The Bi-Polar Junction Transistor was developed in 1947 by William Shockley at Bell Labs. It is a 3 layer semiconductor device three layer semiconductor sandwich with an emitter and collector at the ends, and a base in between and operates on application of current. BJTs are current sensitive devices and thus cannot handle large current applications. Also, due to the interelectrode capacitances present between the Emitter-Base/Collector-Base terminal, it doesn't find application in microwave switching.

$X_c=1/(jwC)$....(1)

When f=up till few MHz; $X_c=10^{-4}$ ohms which is already less

But when we reach microwave(300 MHz to 300 GHz); $X_c=0$, or an open circuit.

FET

To overcome the short comings of the BJT, FET or the Field Effect Transistor was developed in 1950.It is a unipolar device and was voltage controlled. It consists of 3 terminals -Gate, Source and Drain. The drawback of FET(JFET and MOSFET) are limited frequency response up to few MHz.

Since military applications require more reliable technologies frequency response is a parameter to focus on.

Also FETs and BJTs don't display high thermal and electrical tolerance required for space application. In the reliability tests, extreme conditions like pressure ,vibration and temperature play a vital role in development of ICs. In space application, there is no scope of repair/replacement. Thus whatever is fabricated has to withstand extreme conditions for a long amount of time.

MESFETS

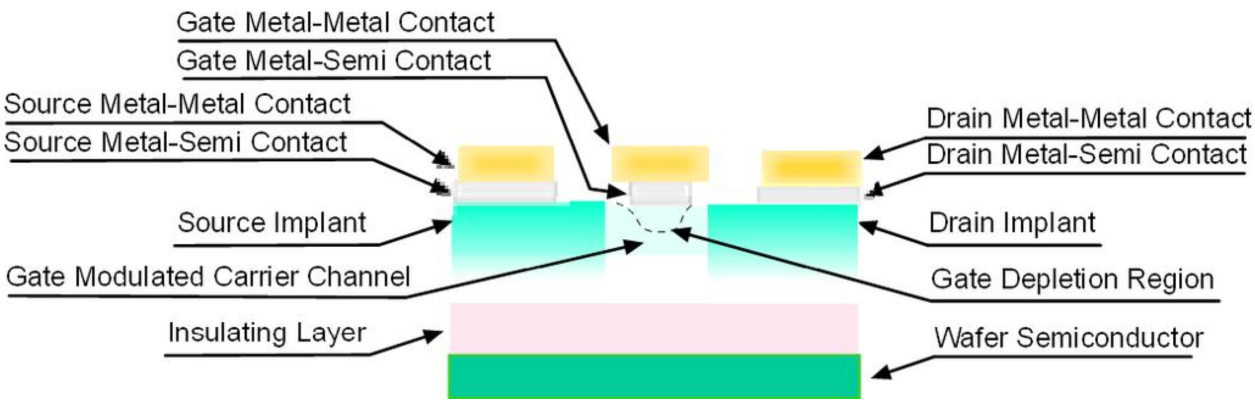
A MESFET (metal–semiconductor field-effect transistor) is a transistor semiconductor device similar to a JFET with a Schottky (metal-semiconductor) junction instead of a p-n junction for a gate. The first MESFETs were developed in 1966, and a year later their extremely high frequency RF microwave performance was demonstrated.

MESFETs are usually constructed in compound semiconductor technologies lacking high quality surface passivation such as gallium Arsenide(GaN), Indium Phosphide(InP), and are faster but more expensive than silicon-based JFETs or MOSFETs. Production MESFETs are operated up to approximately 45 GHz and are commonly used
or microwave frequency communications and radar.

The gate terminal must remain in reverse bias mode and cannot exceed the forward bias mode.

The fabricating material for MESFETs are usually GaAs.

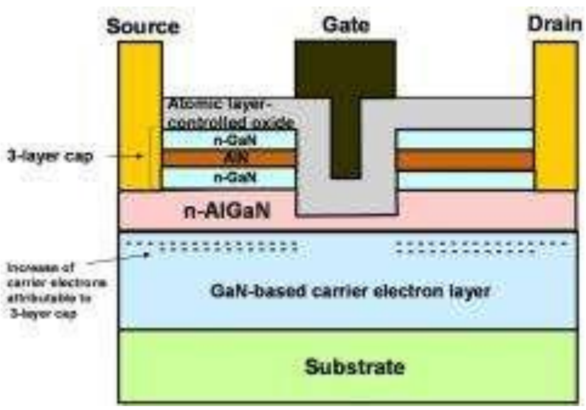
MESFETs are able to amplify small signals to X Band capacity and find their applications primarily in airborne RADAR systems.



HEMT

A High-electron-mobility transistor (HEMT), also Modulation-Doped FET (MODFET), is a field-effect transistor incorporating a junction between two materials with different band gaps (i.e. a heterojunction) as the channel instead of a doped region . The commonly used material combination is Gallium Arsenide (GaAs) with Aluminum Gallium Arsenide(AlGaAs), though there is wide variation, dependent on the application of the device. Devices incorporating more Indium generally show better high-frequency performance. Nowadays, Gallium Nitride(GaN) HEMTs have attracted attention due to their high-power performance. Like other FETs, HEMTs are used in integrated circuits as digital on-off switches. FETs can also be used as amplifiers for large amounts of current using a small voltage as a control signal. Both of these uses are made possible by the FET’s unique current-voltage characteristics. HEMT transistors are able to operate at higher frequencies than ordinary transistors, up to millimeter wave frequencies, and are used in high-frequency products such as satellite television receivers, voltage converters, and radar equipment. They are widely used in satellite receivers, in low power amplifiers in the defense industry.

Advantages of HEMTs are that they have high gain, this makes them useful as amplifiers; high switching speeds, which are achieved because the main charge carriers in MODFETs are majority carriers, and minority carriers are not significantly involved; and extremely low noise values because the current variation in these devices is low compared to other FETs.

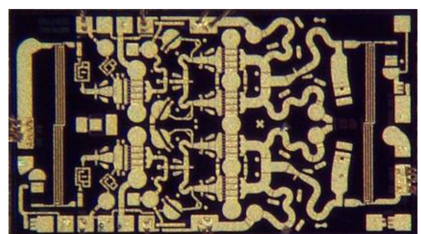


MMIC

A Monolithic Microwave Integrated Circuit, is a type of integrated circuit device that operates at microwave frequencies(300 MHz to 300 GHz). These devices typically perform functions such as microwave mixing, power amplification, low-noise amplification, and high-frequency switching. Inputs and outputs on MMIC devices are frequently matched to a characteristic impedance of 50 ohms. This makes them easier to use, as cascading of MMICs does not then require an external matching network. Additionally, most microwave test equipment is designed to operate in a 50-ohm environment.(Insertion loss is minimum at 75 ohms, Maximum power is transmitted at 35 ohms, thus 50 ohms is the middle ground).

Originally, MMICs used MEtal-Semiconductor Field-Effect Transistors (MESFETs) as the active device. More recently High Electron Mobility Transistors (HEMTs) have found common application for fabrication of MMICs. Technologies, such as indium phosphide (InP), have been shown to offer superior performance to GaAs in terms of gain, higher cutoff frequency, and low noise. However, they also tend to be more expensive due to smaller wafer sizes and increased material fragility.

Silicon Germanium (SiGe) is a Si-based compound semiconductor technology offering higher-speed transistors than conventional Si devices but with similar cost advantages.



MMIC Layout: TriQuint Semiconductor, Inc. Used by permission.

The amount of components that can fit onto an IC keeps on increasing with progress in technology.

Small Scale Integration: Around 100 components

Medium Scale Integration: Around 1000 components

Large Scale Integration : Around 10^5 components

Very Large Scale Integration : Around 1 mil components

Ultra Large Scale Integration: > 1 mil components.

MMICs are at the VLSI scale and are reaching the ULSI scale with further development.

S parameters

Scattering parameters or S-parameters (the elements of a scattering matrix or S-matrix) describe the electrical behavior of linear electrical networks when undergoing various steady state stimuli by electrical signals.

The S-parameter matrix describing an N-port network will be square of dimension N and will therefore contain N^2 elements. At the test frequency each element or S-parameter is represented by a unitless complex number that represents magnitude and angle, i.e. amplitude and phase. The complex number may either be expressed in rectangular form or, more commonly, in polar form. The S-parameter magnitude may be expressed in linear form or logarithmic form. When expressed in logarithmic form, magnitude has the "dimensionless unit" of decibels.

Unlike other 2 port network parameters, S parameters aren't only a ratio of 2 known impedance/admittance values. This is where the real application of s parameters starts evolving.

The complex linear gain is

$G = S_{21}$ .....(1)

Scalar Logarithmic Gain is

$g = 20\log_{10}|S_{21}|$....(2)

Thus insertion loss is given by reciprocal of Scalar Logarithmic Gain

$IL = -20\log_{10}|S_{21}|$

This is just one example as to why s parameters have so much importance in determining the theoretical values for MMIC devices.

With the help of 2 port networks, one can determine

1) Frequency
2) Characteristic Impedance
3) Conditions like Temperature,Control Voltage and Bias Current.

Smith Chart

The Smith Chart is the graphical representation of a complex mathematical equation. It is the circular plot of the characteristics of microwave components. The Smith Chart is the most used tool for microwave engineers to visualize complex-valued quantities and calculate the mapping between them. It consists of two sets of circles for plotting various parameters of mismatched transmission lines. One is the set of complete circles whose centers lie on the straight line and the other one is the set of two arc circles which lie on the either sides of the straight line.

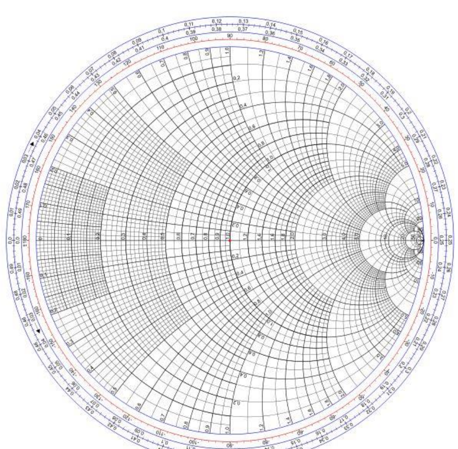


Fig.1 Smith Chart

The topics discussed till now all converge in the applications either found in MMICs or for their development.

After the wafer is successfully fabricated, it undergoes a series of tests that determine its characters. These parameters/ values are recorded on to the data sheet of the device.

VNA

RF network analyzers are vital items of test instrumentation for RF design laboratories as well as many manufacturing and service areas.

Although mainly focused on research and development, RF network analyzers are able to provide vital insights into the operation and performance of RF networks of all types.

The RF network analyzer provides a stimulus for the network and then monitors the response. In this way the operation and performance can be seen and assessed for its suitability.

- RF network analyzers can be used for all RF and microwave frequencies - some network analyzers can operate well into the microwave region.

The VNA network analyzer is a more useful form of RF network analyzer than the SNA as it is able to measure more parameters about the device under test. Not only does the it measure the amplitude response, but it also looks at the phase as well. As a result VNA network analyzer may also be called a gain-phase meter or an Automatic Network Analyzer.

Concept of Vector Network Analyzer

The vector network analyzer utilizes the concept of measuring the transmitted and reflected waves as a signal passes through a device under test.

Measuring the transmitted and reflected signals across the band of interest, and often beyond, enables the characteristics of a device to be determined.

If both transmitted and reflected signals are used to characterize the input and also the output then the device can be fully characterized. This can form a key part of any design or test for an RF circuit.

A VNA is used to measure the amplitude and the phase of the signal.It provides an input signal to the system via attenuators and also knows the output. But the practical values usually differ and thus the VNA gives us the difference or the deviation from the ideal conditions.

Testing of Wafer

Before the final fabrication of IC, the wafer undergoes a string of tests for the determination of its characteristics. These are:-

S-Parameters

The apparatus used were a VNA,CPW Probe station,Signal Generator

DC IV

The apparatus used were CPW Probe Station,DC Supply

Pulse IV

The apparatus used were CPW Probe Station,Funnction Generator

Power Setup

Applications of MMICs

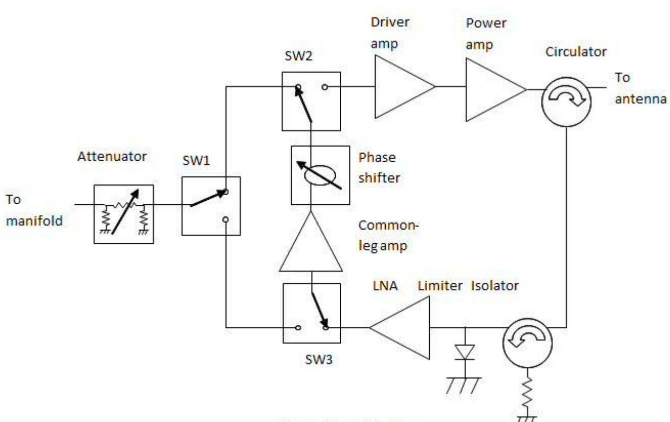
As mentioned earlier, MMICs find huge application in development of equipment in the defence and space exploration projects.

TR Module

Switch

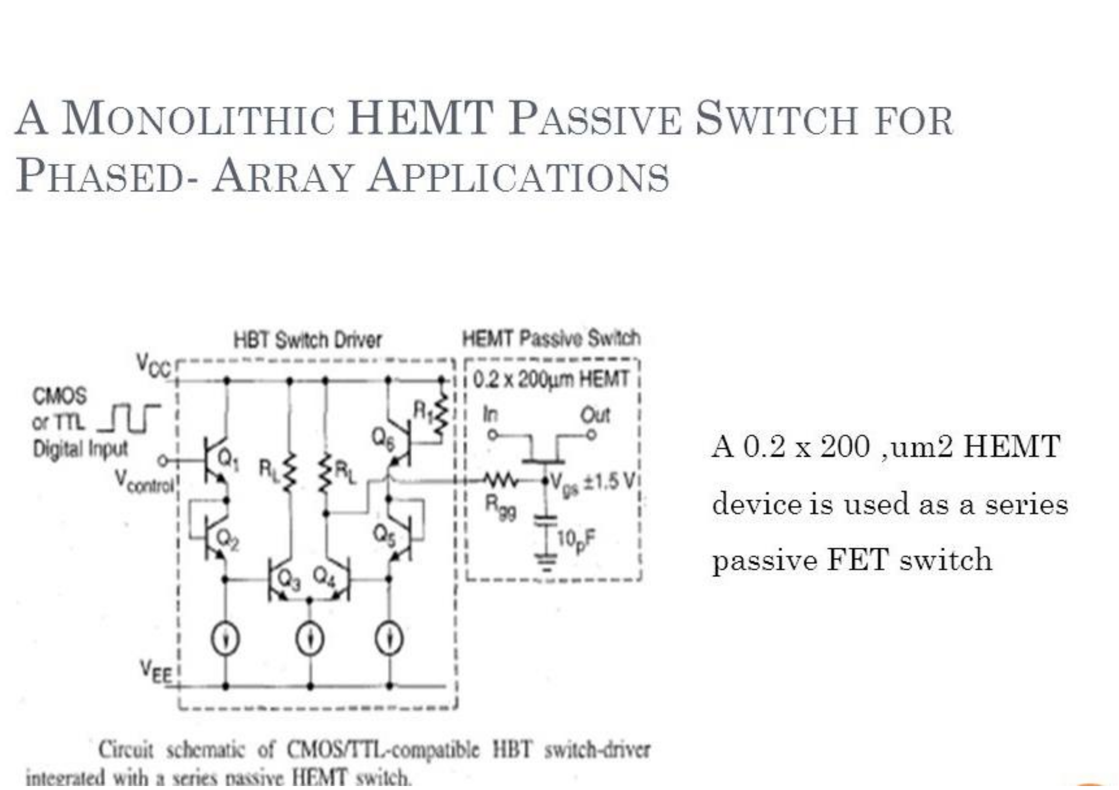
Low Noise Amplifier

TR Module



Receive State

Switch



Low Noise Amplifier