COMMERCIAL SiGe AND GaAs LOW NOISE AMPLIFIERS (LNA) PERFORMANCE UNDER ELECTRON RADIATION

BY

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ABSTRACT

In this dissertation, a characterization and comparison between the effects of Electron irradiation on low noise amplifiers (LNAs) implemented in a Silicon-Germanium (SiGe) Heterojunction Bipolar Transistor (HBT) and Gallium-Arsenide (GaAs) HBT technologies, respectively, was carried out. Nowadays, commercial on the shelves (COTS) LNAs have been used in CubeSat communication system lunched in Low and Medium Earth Orbits. It therefore believed that the electron radiation in space may degrade the LNA's performance and lead to it failure. This is shows the importance of such investigation in evaluating and comparing the performance of the GaAs and SiGe LNAs which represent an important module in the front end of the communication receiver system. Two samples of GaAs and SiGe have been selected: the SiGe BFU730F and the ADL 5523 GaAs LNAs which are respectively cover a frequency range of 2.3 to 2.7 GHz and 400MHz to 4 GHz. The SiGe BFU730F achieves a peak gain of 21.5 dB and a peak of 0.8 dB noise figure within the frequency range before radiation. While the ADL 5523 GaAs LNA achieves a peak gain of 21.5 at 900 MHz; and it achieves approximately 15 GHz of gain, with a noise figure (NF) of 0.9 dB in the interested band of 2.3 GHz. Samples were irradiated with 3 MeV Electron doses ranging from 50 kGy to 250 kGy. The results show the increase of the NF and the drop of the gain of both LNAs which indicate that both SiGe and GaAs HBT technologies have been affected by the electron Irradiation. However, the GaAs LNA exhibits to be robust with a minimal degradation compare with the SiGe LNA, where it can still achieve a peak gain of 12 dB and a mean of Noise figure below 3 dB. However, the SiGe degraded with a drop of the gain down up to 7 dB and an increase of the Noise Figure above 3 dB within the frequency range.

خلاصة البحث

في هذه الأطروحة، يتم دراسة عن آثار الإشعاع الالكتروني على مكبرات الصوت منخفضة الضوضاء (LNAs) نفذت في السيليكون الجرمانيوم (SIGE) متغاير الترانزستور ثنائي القطب (HBT) وزرنيخيد الغاليوم (GaAs) التقنيات المتباينة، على التوالي. في الوقت الحاضر تستخدم (COTS) (المهود) LNAs في نظام الاتصالات للأقمار الصناعية المكعبة (CubeSat) المرسل إلى المدار المنخفض لكوكب الأرض. ولذلك يعتقد أن الإشعاع الإلكترون في الفضاء قد يقل أداء LNA ويؤدي إلى ذلك فشله. وهذا ما يدل على أهمية هذا التحقيق في تقييم ومقارنة أداء زرخنيد الغاليوم (GaAs) والسليكون الجرمانيوم (SiGe) LNAs التي تمثل وحدة مهمة في الواجهة الأمامية للنظام استقبال الاتصالات. وقد تم اختيار عينتين من زرخنيد الغاليوم والسليكون الجرمانيوم: SIGE BFU730F و ADL 5523 الغاليوم LNAs التي هي على التوالي تغطي نطاق الترددات 2.3 و 2.7 غيغاهرتز وبسرعة MHz400 إلى 4 غيغاهرتز. وSIGE BFU730F يحقق ذروة كسب 21.5 ديسيبل وذروة 0.8 الضوضاء ديسيبل في نطاق التردد ، قبل الإشعاع. في حين أن ADL 5523 الغاليوم LNA يحقق ذروة كسب 21.5 في 900 ميغاهيرتز. ويحقق ما يقرب من 15 غيغاهرتز من مكاسب، و 0.9 ديسيبل بنسبة للضوضاء على التردد المعني 2.3 غيغاهرتز. كانت المشع عينات مع 3 جرعات إلكترون فولت إلكترون تتراوح بين 50 كيلو جراى إلى 250 كيلو جراى. وتشير النتائج إلى أن كل من التكنولوجيات SIGE والغاليوم HBT وقد تأثرت بتشعيع الإلكترون. ومع ذلك، فإن زرخنيد الغاليوم LNA تكون قوية مع تدهور الحد الأدنى مقارنة مع SIGE LNA، حيث لا يزال تحقيق ذروة كسب 12 ديسيبل ومتوسط الرقم الضوضاء أقل من 3 ديسيبل. و SIGE LNA وصلت انخفاض الكسب إلى 7 ديسيبل وزيادة في الشكل الضوضاء أكثر من 3 ديسيبل في نطاق التردد.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion; it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Communication Engineering)

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except Where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Abdouraouf Said Youssouf

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Firstly, it is my utmost pleasure to dedicate this work to my dear parents and my family, who granted me the gift of their unwavering belief in my ability to accomplish this goal: thank you for your support and patience. I express my gratitude and appreciation to my Supervisor Associate Professor Dr. Nurul Fadzlin Hasbullah; and my Co-supervisor Dr. Hadi Habaebi, from the department of electrical and computer engineering – faculty of engineering and my field supervisor Dr. Yusof Abdullah, from nuclear Malaysia for their continuous support, encouragement and leadership, and for that, I will be forever grateful.

Final, special thanks to those who provided their time, effort and support me through this project; first and foremost my little and wonderful family, family members and friends. I dedicate this work to my parents who raised through the path of seeking knowledge for sake of almighty Allah, may Allah reward them his paradise. I dedicate it as well to my little daughter Fatma and her mother who are inspiring me to become a good father and a role model for our little family. May Allah accept for us, Amine.

Reflection

One of the aspect that the almighty Allah (SWT) bestows to human is the intellectual capability and accountability. This is conformed the vicegerent (Khilafah) of mankind in Earth. In other words, man is trusted to maintain peace and justice, and to protect the right of everyone in the society. In order to achieve this objective, one of the basic tool to achieve that is thorough knowledge in all its branches. As the almighty Allah (SWT) says: “O assembly of Jinns and men! If you have power to pass beyond the zones of the heavens and the earth, then pass (them)! But you will never be able to pass them, except with authority (knowledge) (from Allah)!” Al- Rahman (33). Therefore, I believe that this work reflects on the objectivity of mankind in earth; it contribute scientifically in the advance and development of human life in earth though is a little but Allah says: “and you have not received knowledge except a little” Al-Isra (85).I thank the almighty Allah (SWT) who makes me one his servant to bring an input in the development of humanity, and to contribute positively to the objectives “Makassid” of the “Khilafah”.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

COTS: commercial on the shelves

DC: direct current

DD: displacement damage

DUT: device under test

ESD: electrostatic discharge

GaAs: gallium arsenide

GEO: geosynchronous earth orbit

GNSS: global navigation satellite system

HBT: heterojunction bipolar transistor

LEO: low earth orbit

LET: linear energy transfer

LNA: low noise amplifier

MEO: medium earth orbit

NF: noise figure

NMA: nuclear Malaysia agency

PCB: printed circuit board

RF: Radio Frequency

SEB: single event burnout

SEE: single event effect

SEU: single event upset

SiGe: silicon germanium

SNR: signal to noise ratio

TID: total ionizing dose

LIST OF SYMBOLS

+: Plus
-: Minus
=: equal
β **:** Beta
μn: electron mobility

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The space radiation environment is known to be multifaceted as well as dynamic. Charged particles, electrons and protons are trapped in the Earth's magnetic field. The Earth is surrounded by belts of these particles, which is called as Van Allen Belts. The operating time, duration and orbit of the space missions are affected by the characteristic of the radiation environment. In recent years, there has been a strong effort for the development of high frequency technologies for the cellular, wireless and space communication markets using either gallium arsenide (GaAs) or silicon –based devices. Among the semiconductor –based devices, particularly there is a strong competition of silicon germanium (SiGe) and GaAs devices for the wireless communication systems such as low noise amplifiers (LNA). LNAs are used in a variety of applications such as RF communications systems including wireless computer networks, mobile phones and satellite receivers. It is well established that SiGe LNAs have a tolerance to total ionizing dose (TID) exposure to multi-Mrad levels [1]. Furthermore, previous research have investigated the effect of Gamma irradiation between SiGe and GaAs LNAs, it has proven that both technologies are tolerant to gamma irradiation. It has been shown that the characteristics of the SiGe HBT's are very tolerant to proton, gamma and neutron irradiation without further radiation hardening. GaAs Heterojunction Bipolar Transistor (HBT) are also well known to be robust with radiation. In this work, the effects of the electron radiation in both candidates are investigated.

1.2 Problem statement

Some of the commercial off –the-shelf (COTS) SiGe and GaAs LNA are used in the receiver module of the communication systems in GNSS and CubeSat satellite. It believed that the communication system, operating time, duration of the space mission are affected by the characteristic of the radiation environment which affect some major components of the satellite such as the LNA. Electron radiation has a significance presence medium earth orbit (MEO) as well as low earth orbit (LEO). Therefore, this is shows the very importance of investigating the effect of electron radiation on both SiGe and GaAs HBTs implemented in LNAs.

Research objectives

This research aimed to achieve the following objectives:

1- To characterize the RF parameters of SiGe LNA before and after electron radiations

2- To characterize the RF parameters of GaAs LNA before and after electron radiations

3- To analyse and compare the degradation of the LNAs performance of SiGe and GaAs after Irradiation.

1.3 Research scope

This research investigated two LNAs namely the BFU730F SiGe Silicon Germanium (SiGe) and the ADL5523 Gallium Arsenide (GaAs) on Commercial off-the-shelf *(*COTS)*;*by characterization of the Radio Frequency (RF) parameters more specifically the scattering parameters (S- Parameters): Input Return Loss (S11), Output Return Loss (S22), Gain (S21), and the Isolation (S12) (S- parameters) and the Noise Figure of both LNAs; before and after electron irradiation process in the Alutron Facilities in Malaysian Nuclear Agency (MNA). Finally, a Comprehensive Analysis before and after radiation.

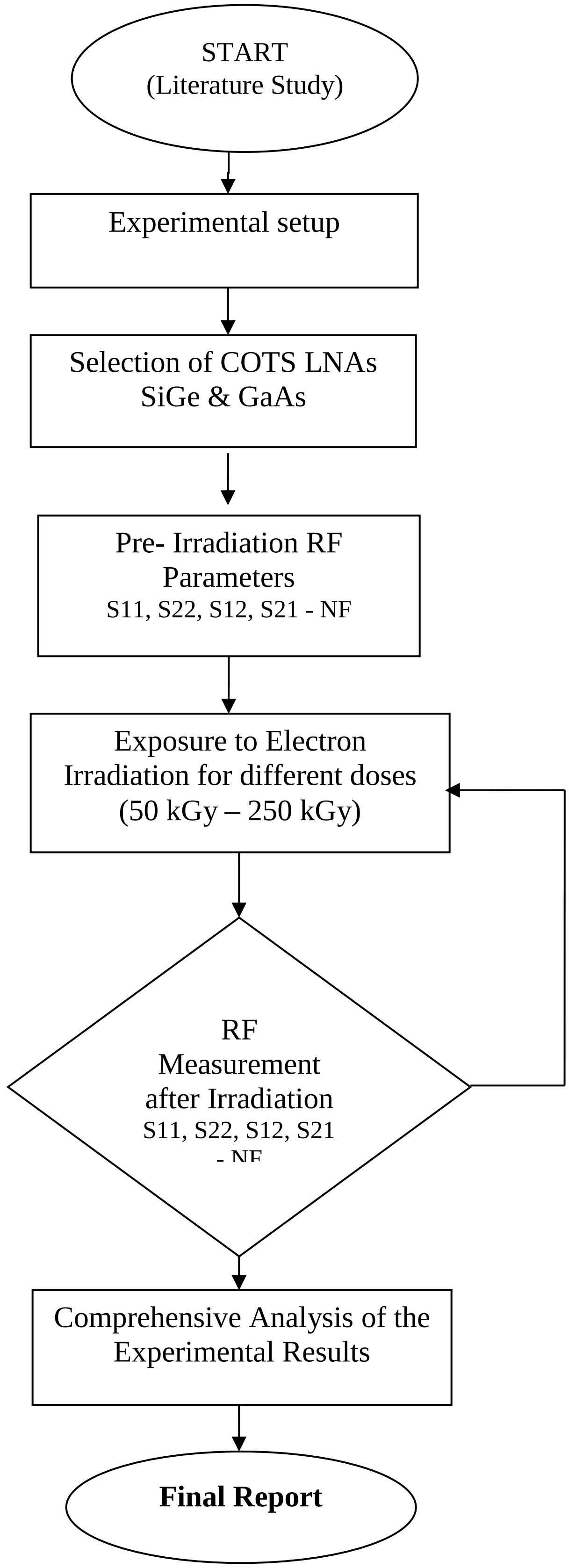
1.4 Research Methodology

In order to achieve the research objectives stated, the research work will be conducted through the following steps:

1. Exploring related previous works on the radiation effect on Low Noise Amplifiers (LNA); and identifying the major parameters that researchers are evaluating the performance of the LNAs. Literature study of the Vector Network Analyser, the main machine to be used in the scattering parameters measurement. Moreover, review of the techniques used in the process of measuring the Noise Figure of the LNA; especially the method of using the signal generator, spectrum analyser and a power supply. Finally, Literature review of the recent updates on the LNAs candidates under investigation namely: Silicon Germanium (SiGe) and Gallium Arsenide (GaAs); in identifying the main RF parameters to be investigated.
2. Selection of commercial SiGe and GaAs LNAs based on required criteria.
3. RF parameters measurement before Irradiation: where the S- parameters, Noise Figure will be measured.
4. Exposure to Electron Irradiation: Irradiation of the LNAs samples will be implemented in Nuclear Malaysia Agency (MNA) at various dose levels.

5. Electrical Measurement after Irradiation: measurement of S- Parameters and Noise Figure will be conducted.
6. Comprehensive Analysis of the Results obtained
7. Report writing and submission of overall research findings.

1.5 Flow chart



1.6 Outline of the thesis

This thesis is organized as follows:

Chapter 1of this dissertation starts with an introduction to the research by presenting a brief background of the research work, followed by the Problem statement, Objectives of this research. Next, boundaries of the study are emphasized in the research scope and a detailed research methodology is presented. Finally, the chapter ends with dissertation organisation by outlining the contained chapters. Chapter 2covers the theoretical background and results findings of related previous works. Chapter 3 presents the simulations and technical details and description of the equipment that used in the study. Moreover, a brief highlights of the nuclear facility where the irradiation process take place during the investigation. Chapter 4 presents the results obtained the investigation process, discussion and analytical comparison. Finally, chapter 5 includes the main conclusion of the overall research findings and limitations encountered. Lastly, recommendations for future works are discussed.

CHAPTER TWO

LITERATURE REVIEW

INTRODUCTION

Modern advancements in SiGe BiCMOS technology have stimulate from radio frequency designers in the domain of satellite communication and science applications. Receiver and transmitter circuits for low earth orbit (LEO) and medium earth orbit (MEO) satellite communication are designed using SiGe BiCMOS technology. The most common use for satellites in this region is for navigation, communication, and space environment sciences. The advance of wireless telecommunication system has made into very firm requirements regarding the performance of the microwave application such as low noise amplifier (LNA).

The circuit should meet the requirement such as low noise figure, high gain and also high linearity due to the excess spectrum. More than that, for wireless use, the power consumption also should be as minimum possible [2]. On the other hand, to moderate the size and cost of the transmitter/receiver modules, multi-function monolithic microwave integrated circuits have been created by using GaAs technologies in space application [2].

2.1 SATELLITE RECEIVER

Satellites in MEO are more for navigation purposes with the name of global navigation satellite systems (GNSS). They provide the essential physical capacities of the outright position, velocity, and time information to customers in a diversity of applications [1]. Up to nowadays, the global positioning system (GPS) developed by the United States is the only fully operating in the global positioning system. The European Union's Galileo positioning system, however, is in the initial positioning phase and is start operating initially in 2013 [3]. We can notice that at the front of the satellite receiver is located the low noise amplifier (LNA).

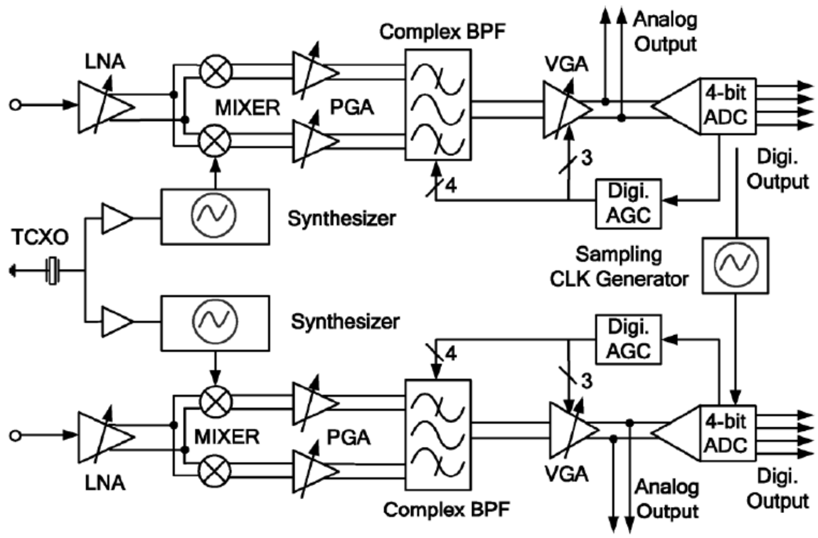


Figure 2.1: Typical schematic of the GNSS receiver. [3]

The design and application of a dual-channel multiband RF receiver for GPS/Galileo systems is shown in figure (2.1).

2.2 LOW NOISE AMPLIFIER (LNA).

A low noise amplifier (LNA) is an electrical device used to amplify and filter out the noise of input signals received at the front ends of communications systems. LNAs are used in a widespread variation of applications such as RF communication systems including wireless