DESIGN OF A LOW NOISE AMPLIFIER FOR A SATELLITE RECEIVER AT KA BAND FOR TROPICAL REGION

BY

KAZI SHIHAN MIRZA

A dissertation submitted in fulfilment of the requirement for the degree of Master of Science (Communication Engineering)

Kulliyyah of Engineering
International Islamic University Malaysia

December 2019

ABSTRACT

In satellite communication systems, Ku and C bands have become highly congested and future applications need to move towards Ka band. Satellite downlink communication for Ka band at 20GHz in the tropical region is challenging because of high precipitation rate and susceptible to high rain attenuation. That is why there is a need to study rain fade and BER performance of RF receiver at Ka band for tropical region. Low Noise Amplifier is the most crucial part of a RF receiver as it is located immediately after the antenna in the receiver. An LNA with a quite high gain and low noise figure can mitigate the noise contribution role of next stages of RF receiver and thus enhancing the receiver BER performance. In this project, a six staged cascaded Low Noise Amplifier with a high gain of 35.236 dB and a noise figure of 2.242 dB has been designed. Rain fades using ITU-R model are calculated for 99.9%, 99.99% and 99.999% availabilities for vertical, horizontal and circular polarization. The rain fades at 99.99% availability for vertical, horizontal and circular polarizations are found to be 34.741 dB, 40.843 dB and 37.635 dB respectively. Integrating the designed LNA into a RF satellite earth station receiver, the BER performance of the receiver is estimated for different availability rates for different levels of PSK modulation schemes and different polarizations. The bandwidth of 20 MHz for DBS-TV has been used. The result shows that BER performances are unacceptable at 99.9%, 99.99% and 99.999% availabilities for all three types of polarizations and all levels of PSK modulation schemes. However performances are found acceptable at varying availabilities from 99.1% to 99.7% for BPSK and QPSK modulation with different polarizations. From 8-PSK to higher level of PSK modulation schemes, BER is inappropriate for 99.1% or higher availabilities for all three polarizations. The minimum fade margins for BPSK, QPSK, 8-PSK, 16-PSK, 32-PSK are 2.88 dB, 5.89dB, 11.22 dB, 17.07 dB, 23.08 dB respectively by considering 8.5 dB as threshold for DBS-TV.

خلاصة البحث

في انظمة الاتصالات الفضائية، أصبحت احزمة Ku و C مزدحمة جدا وتحتاج تطبيقات المستقبل الى التوجه لاستخدام حزمة Ka. ان الاتصالات الفضائية الهابطة لحزمة Ka في حدود 20 غيغا هرتزفي المناطق الاستوائية يعتبر تحديا وذلك بسبب معدل الهطول العالي للامطاروبالتالي تتعرض الاشارة للتخفيف بسبب المطر. ولهذا فهناك حاجة لدراسة تلاشي وتخفيف اثر المطر وإداء BER لمتلقي او لمستقبل RF في حزمة Ka في المنطقة الاستوائية. ان مضخم الضوضاء المنخفض هو ألجزء المهم والحاسم في مستقبل RF وهو يقع مباشرة خلف الهوائي في مستقبل RF. ان مضخم الضوضاء المنخفض مع مكسب عالي وضجيج منخفض يستطيع أن يخفف من اثر مساهمة الضجيج لمراحل لاحقة لمستقبل RF وذلك يعزز ويسحن من أداء BER . في هذه الأطروحة، تم تصميم مضخم الضوضاء المنخفض على ست مراحل متتالية بمكسب عالي مساوي ل 35.236 dB ورقم ضوضاء مساوي ل 2.424 dB. تم حساب تخفيف وتلاشي تاثير المطرباستخدام نموذج ITU-R للنسب 99.9%, 99.99%, 99.999% من المتاح للاستقطابات الأفقيية والعمودية والدائرية.ان تلاشي تاثير المطر المتاح في 99.99% للاستقطابات العمودي، الأفقي والدائري كان 34.741 dB، 40.843 dB و37.635 dB على التوالي. تم دمج وتكامل مضخم الضوضاء المنخفض المصمم في مستقبلRF المحطة الفضائية الارضية واداء BER للمستقبل تم تقيرهما لمتاحيات واستقطابات مختلفة لمعدلات مخطط التعديل PSK درجات مختلفة للاستقطاب.تم استخدام عرض نطاق 20 ميغاهيرتز لDBS-TV . ان النتائج دلت على ان اداء BER كان غير مقبول في متاحيات 99.9%, 99.99%, 99.999% لكل الاستقطابات ولكل مستويات مخطط التعديل PSK. ومع ذلك لقد وجد بان اداء BER كان مقبولا مقبولة في متاحيات متفاوتة تتراوح بين 99.1% وبين 99.7% لمخطط التعديل BPSK وQPSK لكل انواع الاستقطابات الثلاثة. من مخطط تعديل 8-PSK الى مخطط تعديل عالي، كان اداء BER غير مقبول لمتاحية لقيمة متاحية 99.1% او اعلى لكل انواع الاستقطابات الثلاثة . الحد الأدنى من هوامش التلاشي لBPSK، QPSK، 8-PSK، 16-PSK و32-PSK هو 2.88 dB، 5.89 dB 11.22 dB، 17.07 dB، 23.08 dB على التوالي باعتبار 8.5 dB عتبة او بداية ل. DBS-TV

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 dissertation for the degree of Master of Science (Communication Engineering).

Md. Rafiqul Islam
Supervisor

Khaizuran Bin Abdullah
Co-Supervisor

I certify that I have 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 dissertation for the degree of Master of Science (Communication Engineering).

Sheroz Khan
Internal Examiner

Ahmad Zamani Bin Jusoh
Internal Examiner

This dissertation was submitted to the Department of Electrical and Computer Engineering and is accepted as a fulfilment of the requirement for the degree of Master of Science (Communication Engineering).

Mohamed Hadi Habaebi
Head, Department of Electrical and Computer Engineering

This dissertation was submitted to the Kulliyyah of Engineering and is accepted as a fulfilment of the requirement for the degree of Master of Science (Communication Engineering).

Ahmed Faris Ismail
Dean, Kulliyyah of Engineering

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.

Kazi Shihan Mirza

Signature .... Date ....

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

DECLARATION OF COPYRIGHT AND AFFIRMATION OF FAIR USE OF UNPUBLISHED RESEARCH

DESIGN OF A LOW NOISE AMPLIFIER FOR A SATELLITE RECEIVER AT KA BAND FOR TROPICAL REGION

I declare that the copyright holders of this dissertation are jointly owned by the student and IIUM.

1. Any material contained in or derived from this unpublished research may be used by others in their writing with due acknowledgement.

2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purposes.

3. The IIUM library will have the right to make, store in a retrieved system and supply copies of this unpublished research if requested by other universities and research libraries.

By signing this form, I acknowledged that I have read and understand theIIUM Intellectual Property Right and Commercialization policy.

Affirmed by Kazi Shihan Mirza

……..…………………….. ………………………..
Signature Date

ACKNOWLEDGEMENTS

All praises and glory be to Allah swt without whose help and mercy it would not be possible for me to finish this research. Peace and blessing be upon His last messenger and prophet Muhammad (pbuh).

I am immensely grateful to my supervisor, Prof. Dr. MD Rafiqul Islam who constantly guided and motivated me throughout this research. He was kind enough to give me consultation whenever I sought. Because of his brilliant apprehension of the aim and goal of this research, he was able to provide me with insights and suggestions which enabled me to finish this research. I am also grateful to my co-supervisor Assoc. Prof. Dr. Khaizuran Bin Abdullah whose comments also contributed to the accomplishment of this research.

Last but not least, I am grateful to my parents whose prayer probably is the thing that kept me going till the last of this research and who had to bear the hardship of my being away from them for so long for the purpose of this research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

LNA	Low Noise Amplifier
RF	Radio Frequency
ADS	Advanced Design System
BER	Bit Error Rate
CNR	Carrier to Noise Ratio
DBS-TV	Direct Broadcast Satellite Television
Ka	Kurz Above
PSK	Phase Shift Keying
BPSK	Binary Phase Shift Keying
QPSK	Quadrature Phase Shift Keying
NF	Noise Figure

LIST OF SYMBOLS

I	Current
V	Voltage
Z	Impedance
G	Gain
NF	Noise Figure
S_{11}	Input Reflection Coefficient
S_{22}	Output Reflection Coefficient
S_{21}	Forward Gain Coefficient
Ω	Ohm
M	Micro
P	Power
T	Noise Temperature
K	Kelvin
CNR	Carrier to Noise Ratio
BER	Bit Error Rate
Θ	Angle in Degree

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The application of satellite communication system is increasing day by day in line with all other wireless communications. In addition to Direct Broadcast Satellite TV (DBS-TV) and telecommunication services, satellites are widely used for navigation, remote sensing, pollution monitoring, disaster management, auto piloting etc. Currently, C and Ku bands are completely congested and future satellite applications are forced to move towards higher frequencies, Ka and V bands. Ka band generally covers from 20 GHz to 30 GHz of frequencies. The 'Ka' is the short form of Kurtz above implying that its bandwidth is just above the Ku. However, these bands are very sensitive to environment and performance may degrade seriously due to tropospheric impairment.

The tropical region, which is also known as tropics, covers the area of the Earth which is around the Equator. It is extended from the tropic of Cancer in the Northern hemisphere at about 23°26′13.6″ N to the tropic of Capcicorn in the south Hemisphere at 23°26′13.6″ S. The most prominent features of this zone are high temperature, heavy rainfall and active vertical uplift or convection of air. That's why it's very common to observe high rate of precipitation with thunderstorm. These features of tropical region actively play a role in distorting and attenuating the signals transmitted by Satellite communication. Signals with frequency more than 10GHz, hence the Ka band signals as well, are highly attenuated by rainfall (Saad et al, 2013). Rain is the main impairment which contributes significant attenuation and noise signals in tropical region (Chuan, Tian and Hon, 2015). The rain rate that exceeds

0.01% of a year in this region according to latest International Telecommunication Union statistic ITU-R P.837-7 is 90 mm/hr. At Ka band, this rate of rain causes serious attenuation reaching more than 30dB. Hence the performance of satellite system is required to be investigated at Ka band in the tropical region.

Satellite receiver contains Low Noise Amplifier, Bandpass Filter, Down Converter, Local Oscillator, Mixer, Image Rejection Filter, Intermediate Frequency Filter, Intermediate Frequency Amplifier and Demodulator. Received signals are attenuated and distorted by noise. Low noise amplifier (LNA) is the first component of any receiver front end circuitry. The performance of the receiver mainly depends on it. It is the first amplifying block which boosts the weak input signal from antenna receiver without making noise dominating it. Optimum design of LNA is the major part in optimizing the receiver performance (Yadav, Pandey and Nath, 2016).

While there have been many LNA designs for Ka Band specification such as that by (Curuk, Bilgic, Yegin and Ozdemir, 2016) with a gain of 22 dB, none of their performance effects have been assessed by integrating them into a satellite receiver. That is why this research undertakes to combine LNA design and investigation of performance of satellite receiver operating at Ka-band in tropical climate based on rain fade occurred and optimum design of LNA. The satellite receiver performance in this research will be compared with that in (Qonita and Muhtadin, 2019) for same Ka band and downlink frequency of 20 GHz.

1.2 PROBLEM STATEMENT AND ITS SIGNIFICANCE

The tropical region is characterized by features such as heavy rainfall, high temperature, high humidity, cloud etc (Lee, Natarajan, Meng, Yeo and Ong, 2014). All of these effects degrade the performance of satellite communication, but the most significant of them is high rainfall. Any satellite communication performed above 10 GHz frequency is susceptible to high rain fade. Since C and Ku bands are already congested, future applications are forced to move to Ka and V bands. In Ka band, which operates at frequency above 20 GHz, rain fade is severe and may reach up to 30 dB in tropical region.

Rain causes not only attenuation, but also contributes in increasing noise. Every droplet of rain acts as noise source. Rain increases system temperature of RF receiver and thus decreases the CNR ratio of the signal received by the receiver, which in turn degrades BER performance of the received signal.

That is why the RF receiver's performance at Ka band in rainy situation needs to be investigated. LNA is one of the most significant parts in a satellite receiver. An LNA of a good configuration can significantly improve noise performance of the whole satellite receiver by minimizing the noise contributed by stages subsequent to it. There have been many LNA designs specified to work at Ka band but none of them has been assessed by integrating them into a RF satellite receiver.

In this research, An LNA is designed and integrated into a RF receiver and the BER performance of the receiver is investigated for different availabilities and for different modulation schemes at different polarizations for tropical region thus enabling a novel and more comprehensive study of the performance of a RF satellite receiver at Ka band. In designing LNA, the designs proposed by (Curuk, Bilgic, Yegin and Ozdemir, 2016) have been considered as benchmarks. The performance of the Satellite receiver in this research will be compared with that of found in (Qonita and Muhtadin, 2019) for Ka band at the same downlink frequency of 20 GHz.

1.3 RESEARCH OBJECTIVES

The study aimed to achieve the following objectives:

1- To design a low noise amplifier with a gain of at least 30 dB and noise figure less than 2.8 dB at the operating at Ka-band with 20 MHz bandwidth.
2- To estimate the rain fades at Ka-band for various outage probabilities of and for vertical, horizontal and circular polarizations in a tropical climate.
3- To evaluate the performance of the satellite receiver using designed LNA at Ka band based on estimated rain fades.

1.4 RESEARCH METHODOLOGY

The main steps of the methodology followed in this research are as follows:

Step 1: To Design an LNA using Advanced Design System (ADS)

- Selecting a proper transistor
- Finding out bias point
- Designing RF choke
- Designing first stage of LNA using transistor and RF choke
- Designing input impedance matching network
- Adding stages until optimum noise and gain are achieved

Step 2: To estimate rain fade for different outages for vertical, horizontal and circular polarizations

- Finding out rain rate that exceeds 0.01% of a year using digital map given in ITU-R P.837-7.
- Calculating rain fade for rain rate that exceeds 0.01% of a year using instructions given in ITU-R P.618-13.
- Finding out other rate of outages from that of 0.01% using formula given in ITU-R P.618-13.

Step 3: To find out BER performance of the receiver for different outage rates and different polarizations

- Finding out received power for clear air and for different rain fades calculated in step 2.
- Finding out noise power for clear air and for different rain fades.
- Finding out Carrier to Noise Ratio (CNR) for clear air and different rain fades.
- Finding out Bit Error Rate (BER) from CNR calculated in the previous step for different levels of PSK demodulation schemes.
- If the BER is unacceptable then find out BER repeating the steps mentioned previously in step 2 and step 3 for lower availability rate.
- Finding out minimum fade margin for different levels of PSK modulation scheme.

The research methodology has been represented by algorithm block diagram in figure 1.1.

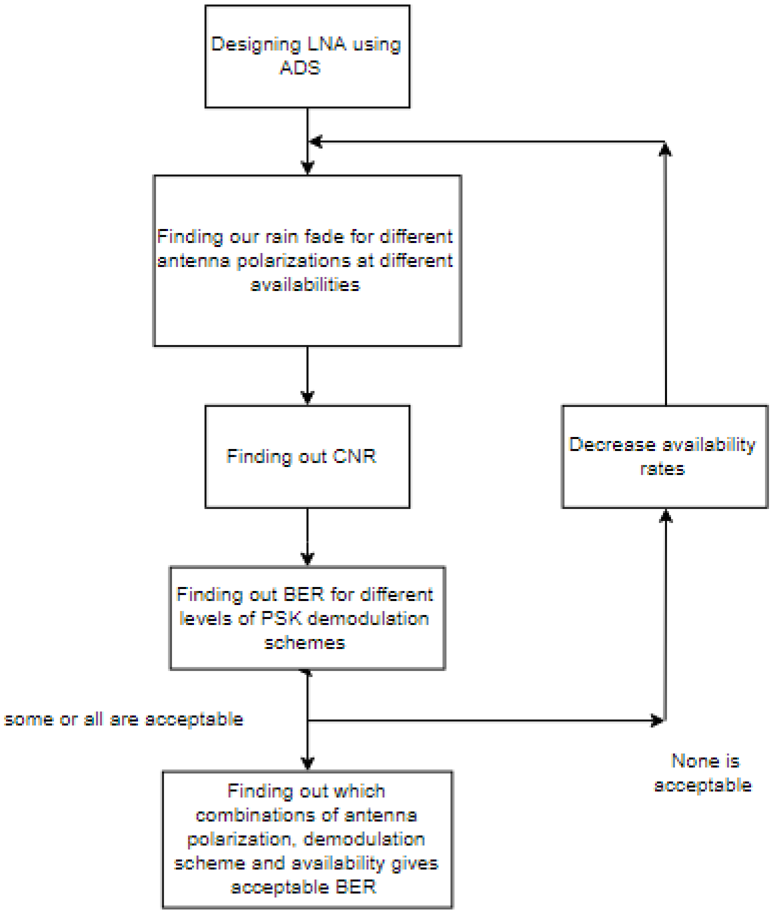

Figure 1.1 Research Methodology Chart

1.5 RESEARCH SCOPE

This work focuses on the down link of Ka-band with centre frequency of 20 GHz and bandwidth of 20 MHz. The LNA in this work has been designed for this specification with an aim of minimum 30 dB of gain and noise figure less than 2.8 dB. The rain fade and BER performance have been estimated considering the climate of Malaysia. BER performance has been estimated for Phase Shift Keying (PSK) modulation schemes (BPSK, QPSK, 8-PSK, 16-PSK and 32-PSK) and for various outage probabilities and for vertical, horizontal and circular polarizations.

1.6 THESIS ORGANIZATIONS

Chapter 1 of this thesis gives an introduction where research background, research problem statement, research objective, methodology and scope have been delineated. Chapter 2 presents literature review in details. Chapter 3 discusses the details of designing of proposed Low Noise Amplifier and its performance. Chapter 4 is on the second and third objective of the research namely, estimating rain fade at different availabilities and evaluating BER performance for different modulation schemes. Chapter 5 is about conclusion and suggesting future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents an overview of a satellite receiver. It includes different approaches to Low Noise Amplifier design. The different factors leading to signal attenuation when signal is transmitted through channel are discussed in brief. This phenomenon is also known as channel transmission impairment. This chapter also describes how to estimate rain fade step by step using the updated model proposed by International Telecommunication Union in details.

2.2 SATELLITE RECEIVER

A RF receiver is an essential component of satellite communication. It receives the transmitted signal and processes it to extract the replica of the original transmitted signal from the received signal, which becomes distorted as the transmitted signal travels through the channel because of attenuation and noise. A simplified block diagram of a satellite receiver is shown in Figure 2.1.

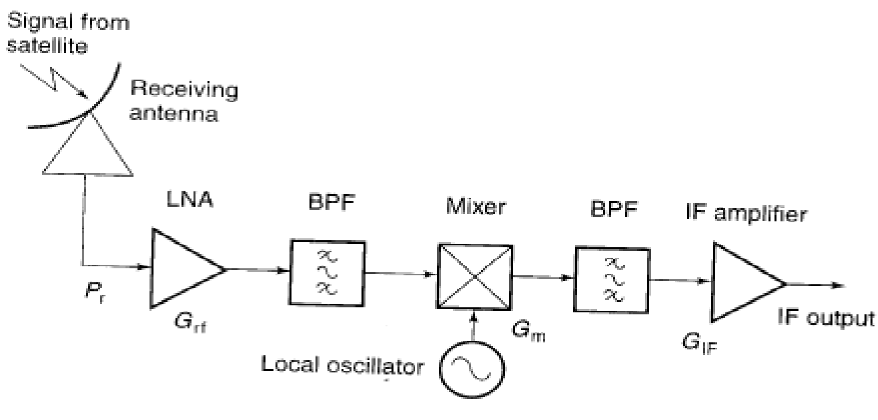

Figure 2.1: A Superheterodyne Receiver Block Diagram (Pratt, 2003)

Most of the satellite systems now-a-days use superheterodyne receiver. A RF receiver generally consists of three parts namely, front end, IF amplifier and a demodulator and baseband section. Front end is composed of LNA, mixer and oscillator. IF amplifier section consists of IF amplifiers and filters. The demodulator and baseband section contains demodulator and other stuffs (Pratt, 2003). Low Noise Amplifier is situated after the receiver antenna. It amplifies the received attenuated signal and amplifies it adding a minimal amount of noise from itself. The bandpass filter filters out signals outside of the desired bandwidth. The downconverter consists of a mixer and local oscillator. The signal amplified by the LNA is mixed with signal of lower frequency produced by local oscillator and converted down to a fixed intermediate frequency that is suitable to process for the receiver circuitry. The signal then can be amplified and filtered more accurately (Pratt, 2003).

2.3 LOW NOISE AMPLIFIER

Low noise amplifier is a very significant component in the front end part of the receiver. It receives the transmitted signal, whose power becomes very low during the transmission because of the attenuation and noise in the channel, and amplifies the received signal and adds noise of a low level from itself. Low Noise Amplifier plays a very important role in decreasing the overall noise of the satellite receiver. If Low Noise Amplifier has a sufficiently large gain, it helps to undermine the noise contributed by the stages situated after the LNA in the receiver to an extent where their contributed noise can be almost ignored. In the following from 2.3.1 to 2.3.9, different approaches to designing Low Noise Amplifier presented by different researchers have been described in brief.

2.3.1 0.18µm pHEMT Based Four Stage Monolithic LNA

Yang, Yang & Liu in 2009 proposed a design fora four-stage self-biased monolithic low noise amplifier for Ka band application, which is shown in Figure 2.2.A commercial 0.18-µm pseudomorphic high electron-mobility transistor(pHEMT) process was used to fabricate this LNA.

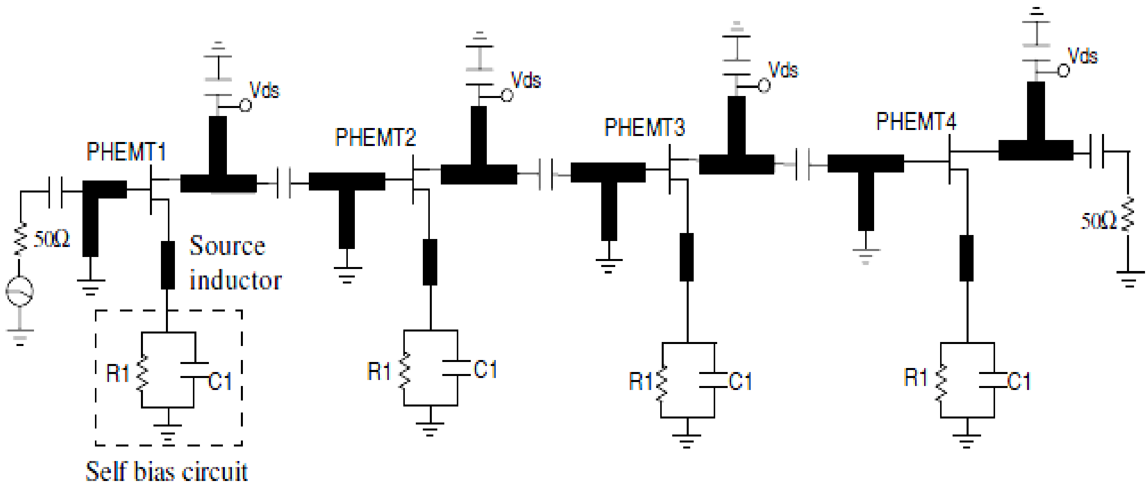

Figure 2.2: Circuit topology of the Ka-band four-stage monolithic LNA (Yang et al., 2009)

The low noise amplifier (LNA)is biased from a single power supply rail to achieve self-bias technique. The LNA has a gain of more than 18 dB, a noise figure of less than 3.8 dB in the RF frequency of 26to 40 GHz as shown in figure 2.3. The chip size is 3×1 mm^2. The stability of the LNA as well as low noise figure can be attained by using series inductive feed-back.A transmission line is inserted via hole ground between source electrode of the pHEMT to form the sourceinductor. Increasing transmission line length can enhance the circuit's stabilitybut with the cost of a serious decrease of the gain at MMW band. An optimal compromise among gain, low noise, andstability is achieved by choosing the length of the transmission linecarefully. In this design, the self bias circuit is used to stabilize the lowerfrequency region.