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MINIATURIZATION OF BALANCED LOW NOISE AMPLIFIER FOR WiMAX APPLICATION

By

Nitesh Ram Sharma A/L Nekeram

Thesis submitted in fulfillment of the requirement for the degree of Master of Science

MAY 2010

DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

15 May 2010 NITESH RAM SHARMA A/L NEKERAM

S-LM0326

ACKNOWLEDGEMENT

First I would like to thank GOD for giving me strength, inspiration, motivation and patient to pursue this research studies

The work presented here is not only the result of many working hours, but also the result of a very inspiring and competent working environment. Therefore, perhaps this part of the thesis is the most important one where I get the chance to thank all the people who I have had the pleasure to meet and work with during these years.

I would like to express my gratitude and appreciation to my advisor and supervisor Dr.Mandeep Singh for giving me this opportunity to perform this research and also for his guidance, encouragement and very inspirational way of doing research.

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ADS	Advance Design System
B	Bandwidth
BPSK	Binary Phase Shift Key
C	Capacitor
CAD	Computer Aided Design
dB	Decibel
DC	Direct Current
DSL	Digital Subscriber Line
DUT	Device Under Test
E-PHEMT	Enhancement Pseudormorphic High Electron Mobility Transistor
ESG	Enhanced Signal Generator
F	Noise Figure
FET	Field Effect Transistor
$F_{\min}$	Minimum Noise Figure
f_T	Cutoff Frequency
G	Gain
GaAs	Gallium Arsenide
G_A	Available power gain
$G_{T,MAX}$	Maximum Transducer power gain
g_m	Transconductance

G_{TU}	Unilateral transducer power gain
G_T	Transducer power gain
G_P	Operating power gain
GHz	Giga Hertz
HEMT	High Electron Mobility Transistor
IC	Integrated Circuit
IEEE	Institute of Electrical and Electronic Engineering
k	Boltzmann constant
K	Rollett Stability Factor
L	Inductor
LNA	Low Noise Amplifier
mA	MilliAmpere
MAN	Metropolitan Area Network
Mbps	Megabit per second
MESFET	Metal Effect Semiconductor Field Effect Transistor
MHz	Megahertz
MIC	Microwave Integrated Circuit
mm	Millimeter
MMIC	Monolithic Microwave Integrated Circuit
NFA	Noise Figure Analyzer
NLOS	Non-Line of sight
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access

OIP3	Output Third Order Intercept
pF	Pico Farad
PAE	Power Added Efficiency
PCB	Printed Circuit Board
PDA	Personal Digital Assistant
P1dB	Power at 1dB Compression
PSAT	Saturated Power
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Key
R	Resistor
RF	Radio Frequency
R_n	Minimum Noise Figure
SMD	Surface Mount Devices
SNR	Signal Noise Ratio
S-Parameter	Scattering Parameter
um	Micron
VGA	Variable Gain Amplifier
VHF	Very High Frequency
VSWR	Voltage Standing Wave Ratio
WiMAX	Wireless Metropolitan Area Network
Z	Impedance
Z_{IN}	Input Impedance

Z_{OUT}	Output Impedance
Z_{oe}	Even-mode Impedance
Z_{oo}	Odd-mode Impedance
Z_{opt}	Gamma Optimum
Z_{o}	Characteristic Impedance
Γ_{S}	Source Reflection Coefficient
Γ_{L}	Load Reflection Coefficient
Γ_{IN}	Input Reflection Coefficient
λ	Wavelength
ε_{r}	Dielectric Constant
λ_{o}	Free space wavelength
π	Pi

LIST OF PUBLICATIONS

1. Mandeep Singh and NItesh Ram. (2009). Compact Balanced Low Noise Amplifier for WiMAX Basestation Application. Submitted for review to Microwave Journal, 23 December 2009.

2. Mandeep Singh and NItesh Ram. (2009). Broad Band Balanced Low Noise Amplifier for WiMAX basestation Application. Submitted for review to Microwave Journal, 23 December 2009.

MEMINIMUMKAN REKABENTUK PENGUAT HINGAR RENDAH TERIMBANG UNTUK APLIKASI WiMAX

ABSTRAK

Perkembangan pesat di dalam bidang perhubungan tanpa wayar jalur lebar dengan perkenalan teknologi baru seperti WiMAX mengalakkan pembuat komponen jalur frekuensi untuk merakacipta komponen yang lebih kecil dan berfungsi dalam jalur lebar. Justeru itu, tesis ini melaporkan rekabentuk dua penguat hingar rendah yang sesuai untuk aplikasi stesyen pemancar WiMAX. Penguat hingar rendah serasi yang digunakan untuk aplikasi stesyen pemancar WiMAX besaiz besar disebabkan frekuensi operasi yang rendah iaitu dari 2.3GHz hingga 2.7GHz. Tujuan utama kajian ini adalah untuk menghasilkan penguat hingar rendah serasi yang kompak agar kos stesyen pemancar WiMAX dapat dikurangkan. Penguat hingar rendah yang pertama ialah penguat hingar rendah jalur lebar serasi yang direkabentuk dengan gabungan penguat hingar rendah dan dua peringkat pencabang berdasarkan teknik yang canggih. Penguat hangar rendah direkabentuk dengan menggunakan *transistor ATF-5413* dari *Avago Technologies*. Rangkaian masukan dan keluaran serta litar arus yang sesuai direkabentuk berdasarkan teknik jalur mikro untuk membolehkan penguat hingar rendah beroperasi dalam jalur tinggi dari 2.3GHz kepada 2.7GHz. Kedua-dua litar dihasilkan dengan menggunakan Rogers 4003C. Kesemua ukuran termasuk ukuran isyarat rendah, kuasa, angka hingar dan keserasian di ambil dalam kesemua jalur frekuensi. Penguat hingar rendah serasi pertama yang menggunakan dua peringkat pencabang menghasilkan peningkatan isyarat kecil iaitu 14.10dB pada 2.3GHz kepada 12.50dB pada 2.7GHz. Kuasa keluaran sebanyak 20.18dBm pada titik kompres satu dan OIP3 sebanyak

36.155dBm berjaya diperolehi. Penguat hingar rendah serasi yang kedua menggunakan pencabang kecil menghasilkan peningkatan isyarat kecil sebanyak 14.30dB pada 2.3GHz kepada 13.50dB pada 2.7GHz. Kuasa keluaran sebanyak 21.28dBm pada titik kompres satu dan OIP3 sebanyak 37.195 dBm berjaya diperolehi. Prosedure rekabentuk disampaikan dengan terperinci dan keputusan dibincang dan dibandingkan dengan simulasi secara mendalam. Sebagai kesimpulan, kedua-dua penguat hingar rendah serasi yang direkabentuk sesuai digunakan untuk stesyen pemancar WiMAX disamping mengurangkan kos sistem pemancar.

MINIATURIZATION OF BALANCED LOW NOISE AMPLIFIER DESIGN FOR WiMAX APPLICATION

ABSTRACT

Demands for broadband wireless communications has been growing fast recently with the advent of new technologies such as WiMAX. With this growing demand, RF transceiver manufacturers are constantly challenged with the requirements to provide compact and wideband RF components. One such important component especially for WiMAX base-station is the LNA. Current balanced LNAs used in WiMAX base-station is huge in size due to the low frequency of operation which is from 2.3GHz to 2.7GHz. The main objective of this research is to reduce the size of the balanced LNA in an attempt to reduce the cost of the WiMAX base-station. Therefore this thesis presents the design and realization of two LNAs suitable for WiMAX base-station applications. The first LNA is the broadband balanced LNA and a dual stage branch line coupler based on a novel technique. The second amplifier is a balanced LNA design using a novel compact branch line coupler. Small signal and harmonic balance simulations based on ADS have been used extensively in the design process. The LNA design is implemented using ATF-54143 from Avago Technologies. Input and output matching networks and proper biasing circuit have been designed based on microstrip techniques to enable the amplifier to operate at high frequency from 2.3GHz to 2.7GHz. Both the circuits are fabricated using Rogers 4003C material. All measurements which include small signal, power, and noise figure and linearity results were obtained over the whole frequency band. The first balanced LNA design which uses a dual stage branch line coupler exhibits small signal gain of 14.10dB at 2.3GHz to 12.50dB at 2.7GHz.Output power of

20.18dB at 1dB compression point and OIP3 of 36.155dB have been obtained. The second balanced LNA design which uses a compact branch line coupler exhibits small signal gain 14.390dB at 2.3GHz to 13.50dB at 2.7GHz. An output power of 21.28dBm at 1-dB compression point and OIP3 of 37.195dBm have been obtained. The design procedures are given in detail and the results are discussed and compared with simulations and previous work done. Conclusion of this research is the realization of two balanced LNA which are suitable for WiMAX base-station application and at the same time reducing the cost of the base-station.

CHAPTER 1
INTRODUCTION

1.0 Overview

A key building block in any wireless radar or communication system is the radio frequency (RF) front-end. The basic block topology for a heterodyne receiver is shown in Figure 1.1.

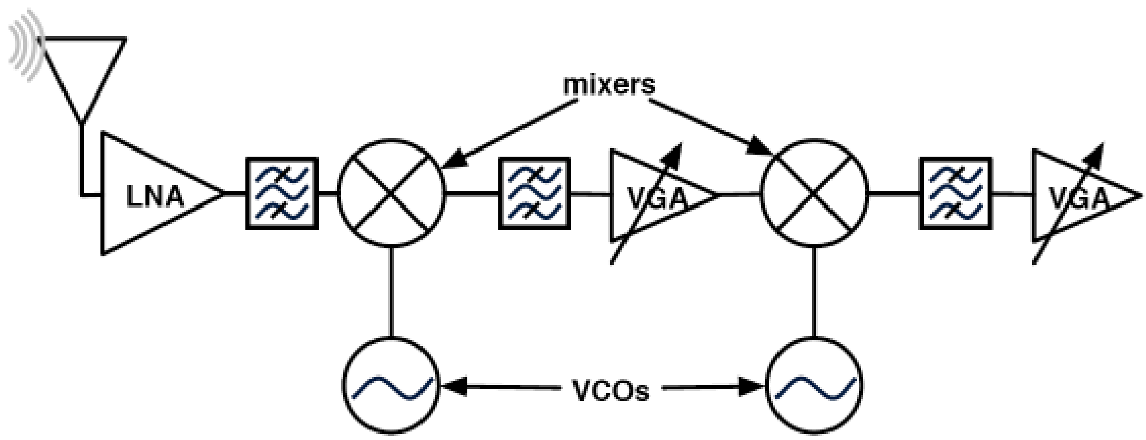

Figure 1.1: RF Front end for heterodyne receiver architecture [1].

A crucial component of these architectures is the LNA. The purpose of the LNA is to amplify the very low signal received at the antenna with adding only a minimum amount of noise. The LNA has a direct impact on the receiver signal-to-noise ratio (SNR) and thus can restrict the maximum data rate, receiver sensitivity, and other receiver specifications. Low noise, good linearity and excellent input and output return loss are among the very important characteristics of a base-station low noise amplifier used in WiMAX applications.

GaAs E-PHEMT have an enormous potential for realizing low noise amplifiers at microwave frequencies due to their low noise features, high electron velocity and positive gate Bias voltage requirements.

1.1 Problem Statement

Increasing demand in WiMAX systems drive integrated circuit design to operate at broadband width and higher frequencies. Amplifier designers are challenged to meet stringent requirements of low noise, low voltage and good input and output matching across a wide frequency band. So far, the concept of balanced circuits has offered attractive solutions to some challenging problems in WiMAX communication systems [1].Various techniques could be used to increase the bandwidth of Low noise amplifiers such as Series and Shunt Feedback, Resistive or reactive matching, matching using active device, distributed and balanced approach [2]. The balanced topology is preferred because it has many benefits such as [3]:

1. Good input and output external match, since the reflected power is absorbed by the 50 ohm load in the decoupled coupler port.

2. 3 dB higher intercept point than a single stage.

3. Good isolation between the two halves of the device which improves stability.

4. Redundancy which minimizes a hard failure.

5. Cancellation of harmonics covering 2.3GHz to 2.7GHz.

A typical block diagram of a balanced amplifier [1] and [2] consists of 2 amplifiers in parallel and two 3dB hybrid couplers. However, the splitter or combiner network plays an important role in designing a low loss, physically small, good phase and amplitude tracking. Furthermore, the bandwidth should be high enough to include the frequency range for WiMAX applications which covers from 2.3 GHz to 2.7GHz. In an attempt to reduce the cost of WiMAX base-station or transceiver, research involving circuits techniques to reduce the size of balanced LNA has to be carried out in order to make WiMAX technology appealing to third world and developing countries.

1.2 Objective

In order to tackle the limitations of balanced LNA for WiMAX base-station applications as stated in 1.2, the following objectives were set to address these limitations:

1. Design, Simulate, Fabricate and Measure Balanced Low Noise Amplifier for WiMAX base-station applications to cover a broadband width of 2.3GHz to 2.7GHz Band.

2. Study and investigation of methods to reduce the size of the balanced amplifier in particular the size of the coupler will be considered.

3. Investigations and research to improve the bandwidth of the LNA by researching on the broadband coupler design methods.

4. Understanding and design of specific couplers to realize the required Balanced LNA.

1.3 Research Scope

In order to achieve the objectives specified, the research work involves the circuit level design of a single stage LNA at the center frequency of 2.5GHz to cover the required bandwidth which is 2.3GHz to 2.7GHz. The next step involved is to design the appropriate coupler to be integrated together with the single stage amplifier. Various coupler types and methods will be investigated and appropriate designs will be selected for the balanced amplifier. Once both the LNA and couplers are designed, the balanced amplifier will be simulated and layout of the circuit will be carried out and fabricated. The fabricated LNA will then be measured using a complete test setup to measure all the required parameters such as Gain, Noise Figure, power at 1dB compression point, Output OIP3 and S parameters. Analysis, comparison and discussions of the balanced amplifiers design will be carried out and recommendation will be made.

1.4 Original Contributions

To summarize, the following original research contributions have been reported in this dissertation:

1. Development of a single stage LNA at 2.5GHz using GaAs E-PHEMT FET.

2. First design and demonstration of balanced LNA using compact branch line coupler for WiMAX base-station applications.

3. First design and demonstration balanced LNA using dual stage broadband branch line coupler for WiMAX base-station applications.

1.5 Thesis Organization

In this thesis, the design process of a balanced LNA is documented. Chapter 2 presents the background information in LNA and coupler circuit design. In Chapter 3, more background information is shown with emphasis solely on realizing the Balanced LNA circuit by designing the LNA and various couplers and integration of the both components to develop a balanced LNA. Various simulation techniques in ADS software was used to do the design and simulate of the circuits. Chapter 4 presents the simulation and measured results of the balanced LNA circuits. This chapter also covers the discussion and analysis of the simulation and measured results. Finally, chapter 5 concludes the research work and provides suggestions for future research and developments.

CHAPTER 2
LITERATURE REVIEW

2.0 Previous Work

Infrastructure base-station applications for WiMAX requires LNA with low noise figures, high linearity, compact size and excellent input and output return loss [2]. Balanced amplifier topology is often the preferred choice in LNA applications for base-station transceiver front-ends because it presents several advantages over single-ended amplifiers such as [3].

These requirements present several design challenges that involve technology and design trade-offs of couplers to achieve an optimal solution in terms of size and performance. GaAs E-PHEMT have an enormous potential for realizing low noise amplifiers at microwave frequencies due to their low noise features, high electron velocity and positive gate bias voltage requirements [4],[5]. Branch line coupler is one of the most popular hybrids for the design and implementation of balanced LNA [6]. However, branch line coupler requires a large circuit area due to the quarter wavelength transmission lines [7].

Various efforts and researches to reduce the size of the branch line coupler have been reported [8], [9], [10], [11], [12], and [13]. Lange coupler [14] on the other hand is relatively impractical for fabrication on PCB as the lines are very narrow, close together and is more practical for MMIC designs. Broadband lumped element 3-dB quadrature coupler using lumped element proposed by [15] and [16] are more suitable for MMIC applications. In order to design a reduced size branch line coupler on a PCB for low cost application, design technique proposed by [17] is more promising and hence chosen for this research.

2.1 Microwave Transistor Characteristics

Several solid state transistors are being used to develop wireless circuits which include Silicon Bipolar Junction Transistors (BJT), silicon metal oxide semiconductor field effect transistor (MOSFET), Laterally Diffused Metal Oxide Semiconductor (LDMOS) transistor, GaAs Metal Semiconductor Field Effect Transistors (MESFET) or simply FET, both GaAs and InP (Indium Phosphide) based high electron mobility transistors (HEMT) and both Silicon Germanium (SiGE) and GaAs based hetero-junction bipolar transistors (HBT). Each device technology has its own merits and optimum technology choice for wireless applications depends on not only technical issues but also on economic issues such as cost, power supply requirements, time to develop a product, time to market a product, existing or new markets and so on.

Different RF/Microwave circuits require different transistor parameters. For example, power amplifiers use transistors with higher power densities, low noise amplifiers employ transistors with low noise characteristics and switches use transistors having low "on-resistance" and small "off-capacitance" feature. Various figure of merit terms are used to evaluate and compare transistor characteristics including maximum available gain, cutoff frequency (f_T), maximum frequency of oscillations (f_{MAX}), minimum noise figure (F_{MIN}), output power density (P1dB) and power added efficiency (PAE). GaAs FET and HEMT have the highest frequency of operation, lowest noise figure, excellent switch characteristics and have high power and PAE capability at lower operating voltages [18]. Table A1.0 in Appendix A compares various active device technologies [19].

2.2 Power Gain

The main consideration of designing amplifiers is the power gain, rather than voltage gain and current gain [3]. Generally, power again can be defined as

$$G = 10\log\frac{P_{OUT}}{P_{IN}}(dB) \tag{2.1}$$

Several power gain equations are used in the design of microwave amplifiers, such as transducer power gain G_T, available power gain G_A, and operating power gain G_P. The transducer power gain, G_T is defined as the ratio of the power delivered to the load to the power available from the source and is given by

$$G_T = \frac{1-|\Gamma_S|^2}{|1-\Gamma_{IN}\Gamma_S|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \tag{2.2}$$

The available power gain G_A is defined as the ratio of the power available from the network to the power available from the source. The following equation describes the ratio in terms of the reflection coefficients as

$$G_A = \frac{1 - |\Gamma_S|^2}{|1 - S_{11}\Gamma_S|^2} |S_{21}|^2 \frac{1}{|1 - \Gamma_{OUT}|^2} \quad (2.3)$$

The power gain G_P is defined as the ratio of the power delivered to the load to the input power to the network and can be given by

$$G_p = \frac{1}{|1 - \Gamma_{IN}|^2} |S_{21}|^2 \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2} \quad (2.4)$$

When input and output are both conjugate matched to the two port, then the gain is maximized and $G_T = G_p = G_A$. It is required to design an amplifier with small signal gain with gain ripple of ± 1 dB.

2.3 Noise

2.3.1 Sources of Noise

The dynamic range of a communication transmitter or receiver circuit is usually limited at the high-power point by nonlinearities and at the low-power point by noise. Noise is the random fluctuation of electrical power that interferes with the desired signal. The dominant sources of noise are described as [20]:

1. Shot noise.

2. Flicker noise.

3. Thermal noise.

2.3.1.1 Shot (Schottky) Noise

Shot noise is a white noise current associated with the particulate nature of electrons. In semiconductors, it is related to charge crossing a potential barrier. It is the dominant mechanism in transistors and operational amplifiers at medium and high frequencies [4]. The mean-squared value of shot noise is given by:

$$\bar{i}_{SH}^{2} = 2qI_{DC}\Delta f \tag{2.5}$$

where,

$\bar{i}_{SH}^{2}$ = Shot noise current spectral noise density.

q = Electron charge, 1.6×10^{-9} Coulombs.

I_{DC} = DC operating current.

Δf = Noise bandwidth.

2.3.1.2 Flicker (1/f) Noise

Flicker noise is associated with combination-recombination of carriers in the emitter base area of a transistor that are caused by contamination and defects in the silicon lattice structure. This noise type is also called 1/f noise because the amplitude of the noise increases as the frequency decreases [21]. Other components, such as resistors that are made from semi-conducting materials can also exhibit flicker noise. Most commonly the expression is given as

$$\bar{i_f^2} = 2qI_{DC}^{\gamma} f_C \Delta f \qquad (2.6)$$

where,

$\bar{i_f^2}$ = Flicker noise current spectral density.

q = Electron charge, 1.6×10^{-9} Coulombs.

I_{DC} = DC current.

Δf = Frequency of interest.

f_C = Corner frequency.

γ = An exponent between 1 and 2.

2.3.1.3 Thermal Noise

Thermal noise is caused by the random motion of charges due to the thermal energy the charges receive from their surroundings. The noise frequency is random and has amplitude that is proportional to the square root of temperature. The frequency component is due to the random motion of the free charges and the amplitude is directly proportional to the temperature. Thermal noise is unaffected by the presence or absence of direct current. All materials with free charges, such as conductors and semiconductors, exhibit thermal noise. In an ohmic resistance, the mean-square open-circuit thermal noise across the resistance is

$$\bar{e_T^2} = 4kTR\Delta f \qquad (2.7)$$

where,

$\bar{e_T^2}$ = Mean-squared value of Thermal Noise voltage.

k = Boltzmann's constant, $1.38 \times 10^{-23}\, Joules^{o}Kelvin$.

T = Temperature $\left({}^{o}K\right)$.

Δf = Frequency range of interest (e.g., amplifier bandwidth).

2.3.2 Noise Figure

Noise figure is a figure of merit quantitatively specifying how noisy a component or system are [22]. The noise figure of a system depends on a number of factors such as losses in the circuit, the solid state devices, bias applied and amplification [23]. The noise factor of a two port network is defined as

$$F = \frac{\text{SNR at input}}{\text{SNR at output}} = \frac{S_i / N_i}{S_o / N_o} \tag{2.8}$$

The noise figure is simply the noise factor converted in decibel notation. Figure 2.1 shows the two port network with gain or loss (G). We have

$$S_o = GS_i \tag{2.9}$$

Note that $N_o \neq GN_i$; instead the output noise $N_o = GN_i +$ noise generated by the network.

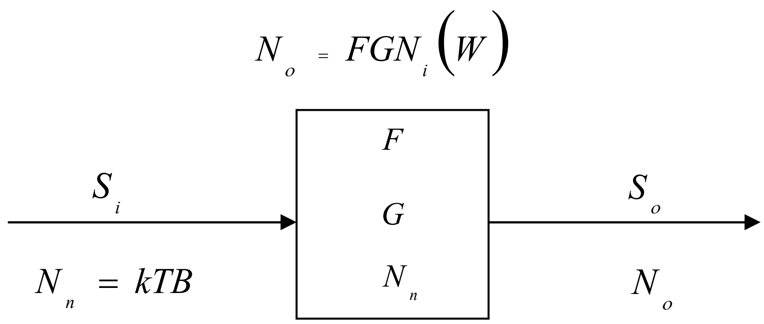

Figure 2.1: Two-port network with gain G and added noise power N_n [22].

For a cascaded circuit with n elements as shown in Figure 2.2, the overall noise factor can be found from the noise factors and gains of the individual elements [22].

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + ... + \frac{F_n - 1}{G_1 G_2 .... G_{n-1}} \tag{2.10}$$

One would like to select the first stage RF amplifier with a low noise and high gain to ensure the low noise figure for the overall system.

The equivalent noise temperature is defined as

$$T_e = (F - 1)T_o \tag{2.11}$$

Where T_o = 290K (room temperature) and F in ratio. Therefore

$$F = 1 + \frac{T_e}{T_o} \tag{2.12}$$

For a cascaded system as shown in Figure 2.2, (2.12) can be rewritten as

$$T_e = T_{e1} + \frac{T_{e2}}{G_1} + \frac{T_{e3}}{G_1 G_2} + \ldots + \frac{T_{en}}{G_1 G_2 \ldots G_{n-1}} \tag{2.13}$$

Where T_e is the overall equivalent noise temperature in Kelvin.

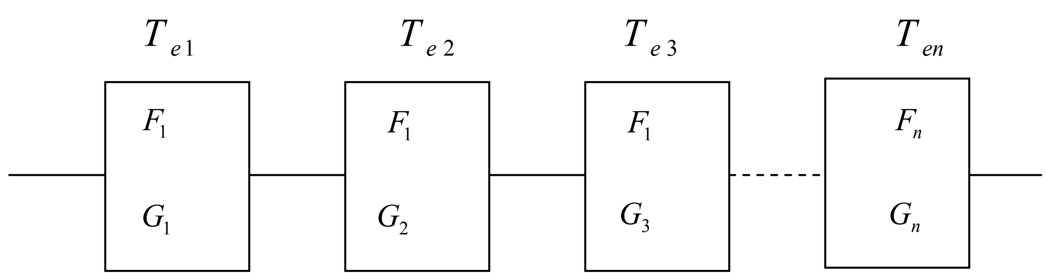

Figure 2.2: Noise temperature for a cascaded circuit [6].

The overall noise factor of an infinity number of identical cascaded amplifiers is

$$F = 1 + M \tag{2.14}$$

with

$$M = \frac{F - 1/G}{1 - 1/G} \tag{2.15}$$

M is called the noise measure. The noise measure is useful for comparing the noise performance of devices or LNA with different power gains.

2.4 Stability Consideration

Stability is a crucial issue when designing amplifiers because of the combination of capacitive shunt feedback and series feedback, which will include both a resistive and an inductive part that can lead to instability. The amplifier must be stable under all operating frequencies and all possible load terminations [23], [24]. In other words, we have to design the amplifier to reach "unconditional" stability, which means that no matter what the amplifier load is, it does not exhibit spurious oscillations even with drive levels and supply voltages outside their nominal values. Stability considerations can be determined from the S parameters, the matching networks and the terminations of the amplifier. The 2 port network shown in Figure 2.3 is said to be unconditionally stable at a given frequency if the real part of Z_{IN} and Z_{OUT} are greater than zero for all passive load and source impedances.

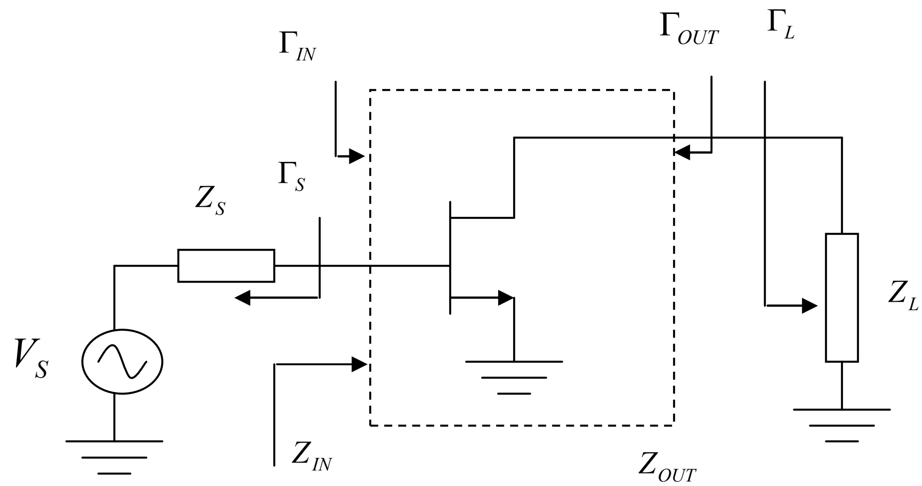

Figure 2.3: Block diagram of a RF amplifier [23].

If the 2 port network is not unconditionally stable, it is potentially unstable which indicates some passive load and source terminations can produce input and output impedances having a negative real part. In terms of reflection coefficients, the conditions for unconditional stability at a given frequency are

$$|\Gamma_S| < 1 \tag{2.16}$$

$$|\Gamma_L| < 1 \tag{2.17}$$

and

$$|\Gamma_{IN}| = \left| S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \right| < 1 \tag{2.18}$$

$$\left|\Gamma_{OUT}\right| = \left| S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_L} \right| < 1 \tag{2.19}$$

All coefficients are normalized to the same characteristic impedance (Z_O).

2.4.1 Test for Unconditional Stability

Simpler tests can be used to determine the unconditional stability. The Rollett's stability factor K test is defined as

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}S_{21}|} > 1 \tag{2.20}$$

Along with the auxiliary condition that are simultaneously satisfied.

$$|\Delta| = |S_{11}S_{22} - S_{12}S_{21}| < 1 \tag{2.21}$$

These 2 conditions are necessary and sufficient for unconditional stability and are easily evaluated and calculated using ADS software.

If the device S-parameters does not satisfy the K and $|\Delta|$ test, the device is not unconditionally stable and stability circles must be used to determine if there are values of $|\Gamma_S|$ and $|\Gamma_L|$ for which the device will be conditionally stable. The K and $|\Delta|$ test cannot be used to compare the relative stability of two or more devices since it involves constraints on two separate parameters. However, a new criterion has been proposed that combines the S parameters in a test involving a single parameter μ defined as

$$\mu = \frac{1 - |S_{11}|^2}{|S_{22} - \Delta S_{11}^*| + |S_{12} S_{21}|} > 1 \tag{2.22}$$

Thus, if $\mu > 1$, the device is unconditionally stable. In addition, larger values of μ imply greater stability [25].

2.4.2 Stability Improvement

Once a stability problem has been identified, it is usually not difficult to correct it. The solutions to instability are [26]:

1. Avoid the instability region when matching.

2. Reduce the stage gain to stay within the maximum stable gain range.

3. Reduce the input and output impedance by resistive damping.

4. Change the bias conditions (only for class A, AB).

5. Choose a different device.

2.5 Matching Network Design

The need for matching networks arises because amplifiers, in order to deliver maximum power to a load or to perform in a certain desired way must be properly terminated at both the input and output ports. Figure 2.4 illustrates typical situation in which a transistor in order to deliver maximum power to the 50 Ohm load must have the terminations Z_S and Z_L. The input matching network is designed to transform the generator impedance (shown as 50 Ohm) to the source impedance Z_S and the matching network transforms the 50 Ohms termination to the load impedance Z_L [27].

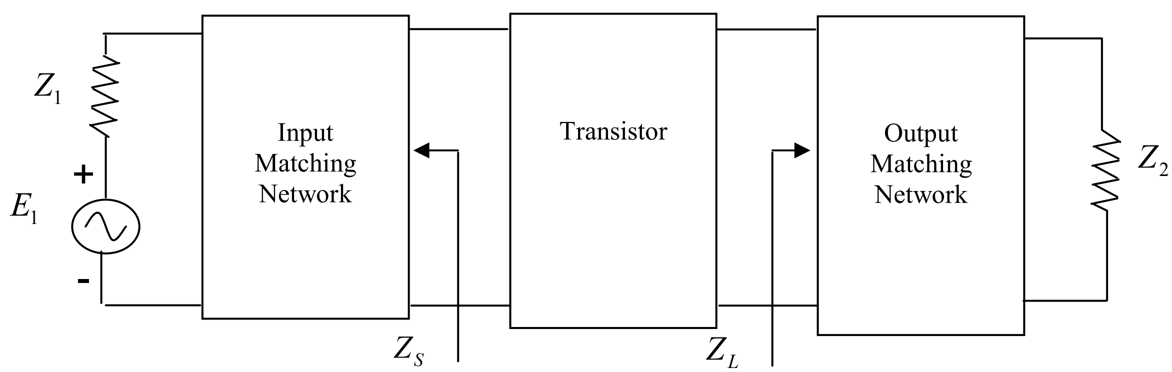

Figure 2.4: Block diagram of a microwave amplifier [27].

2.5.1 Impedance Matching Network

Several methods can be used for impedance matching [28], [29]:

1. Matching Stubs (shunt or series, single or multiple).

2. Quarter wavelength transformers (single or multiple).

3. Lumped elements

4. Combinations of the above.

The multiple section transformers and the tapered lines are generally used for broadband impedance matching [30], [31]. Computer aided design using commercial available software can be utilized to facilitate the design process.

2.6 Broadband Amplifier

Signals carrying information generally possess a finite bandwidth and therefore the electronics employed to process such signals need to have characteristics constant over that bandwidth [32].

2.6.1 Wideband LNA Topologies

The major challenges of a wideband LNA design can be summarized in terms of S parameters and Noise Figure as follows [33]:

1. Forward gain degradation (decreases in S_{21}) which necessitates some techniques to compensate the gain roll-off.

2. Frequency variations of S_{11} and S_{22}.

3. Increase in $|S_{12}|$ which will reduce the forward gain and increase the possibility of oscillation and instability.

4. Noise Figure degradation at high frequencies.

To address these challenges in the design of a wideband LNA, several topologies and circuit techniques have been proposed [34]. In this section, we will introduce briefly some of the popular wideband architectures and briefly discuss their advantages and disadvantages. Designing a broadband amplifier, that is, one which has nearly constant gain over a prescribed frequency range is a matter of surrounding a transistor with external elements in order to compensate for the variation of forward gain $|S_{12}|$ with frequency.

2.6.2 Negative Feedback

The classical approach to satisfy the required impedance matching at the input of a wideband LNA is to employ negative feedback [35], [36]. This technique will provide a flat gain and a very small VSWR at the input and output ports, and also it reduces the sensitivity of the circuit to the active device parameters [37]. However, the feedback circuitry may increase the minimum NF and reduce the maximum achievable gain. Feedback technique has the advantages of increasing bandwidth, stabilizing gain, establishing and controlling input/output impedances, reducing parametric sensitivities and reducing distortion. There are four basic feedback configurations: shunt-shunt, shunt-series, series-shunt and series-series [38], [39].

The resistive matching networks are independent of frequency and hence can be used to design broadband amplifiers. The upper limit will be determined from the frequencies when the resistances cease to work due to associated parasitic elements. Further, the noise figure of such amplifiers may be unacceptable.

2.6.3 Distributed Amplifier

Distributed Amplifier (also known as Traveling Wave amplifier) use discrete transistors in a distributed manner as illustrated in Figure 2.5. In this technique, lumped inductors form artificial transmission lines in conjunction with input and output capacitance of the transistors [40].The input signal travels through the gate line that is terminated by impedance Z_G at the end. An amplified signal is signal is available via the drain line that is terminated by impedance Z_D at its other end. This arrangement provides the possibility of increasing the gain –bandwidth product of the amplifier.

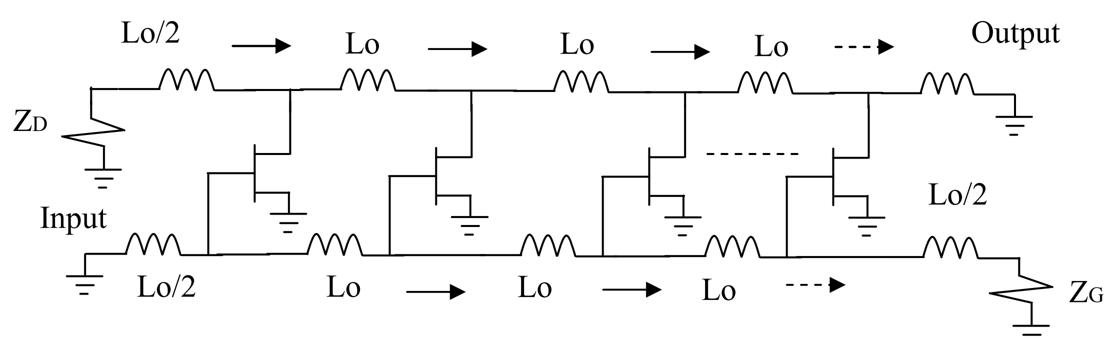

Figure 2.5: Schematic of a traveling wave amplifier circuit [40].

The gate of each FET taps off the input signal traveling along the gate line and transfers it to the drain line through its transconductance. The remaining input signal is dissipated in terminating impedance Z_G. The drain line parameters are selected in such a way that the amplified signals available from each transistor are added in a forward traveling wave and an amplified signal is available at the output. This happens when the phase velocities and the drain and gate lines are same. Any signal propagating on the drain line in the opposite direction is dissipated in Z_D.

2.6.4 Balanced Amplifier

A typical block diagram of a balanced amplifier is shown in Figure 2.6.It consists of two amplifiers in parallel and two 3dB Lange or hybrid couplers. The balanced amplifier topology is chosen in this research because it is the most suitable and appropriate approach for wideband LNA for base-station applications due to the lowest noise and excellent VSWR achievable using this method.

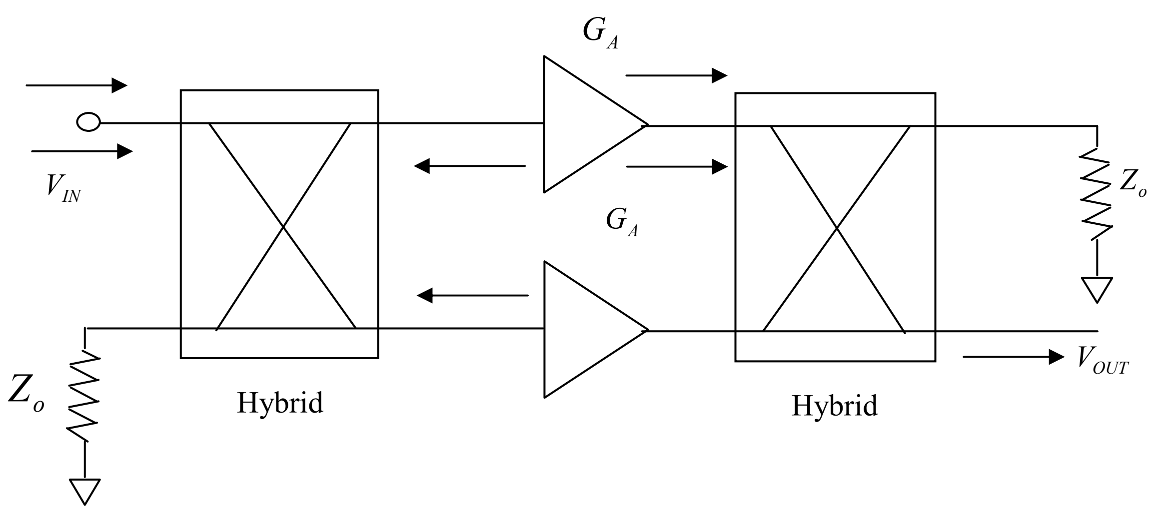

Figure 2.6: Block diagram of balanced amplifier [3].

2.7 Introduction to WiMAX

Worldwide Interoperability Microwave Access, WiMAX, also known as IEEE 802.16, is a wireless digital communication system that is intended for wireless metropolitan-area network technology that provides interoperable broadband wireless connectivity to fixed, portable and nomadic users. It provides up to 50-kilometers of service area for fixed station, 5-15 Km for mobile station, allowing users to get broadband connectivity without the need of direct line-of-sight to the base-station, and provides total data rates up to 70 Mbps enough bandwidth to simultaneously support hundreds of businesses and homes with a single base-station. In fact, the term WiMAX has become synonymous with the IEEE 802.16 Wireless Metropolitan Area Network (MAN) air interface standard [44].

In its original release the 802.16 standard addressed applications in licensed bands in the 10 to 66 GHz frequency range. Subsequent amendments have extended the 802.16 air interface standard to cover non-line of sight (NLOS) applications in licensed and unlicensed bands from 2 to 11 GHz bands, or WiMAX. This is an enormous spectrum range; however the practical market considerations dedicated that the 3.5GHz spectrum will be the first to enjoy WiMAX products, than it will be followed in the future by the 2.5 and 5.8 GHz spectrums. The WiMAX -compliant systems will provide a cost effective broadband access to users at home, in the office, in areas under-served by wire-line DSL and cable services and even to users on the pause or on the move equipped with portable devices like laptop, PDA and smart-phones.

2.7.1 WiMAX Properties

WiMAX is a worldwide certification addressing interoperability across IEEE 802.16 standards based products [37]. The IEEE 802.16 addresses two usage models: Figure 2.7 illustrates the network topology of a typical WiMAX network:

1. Fixed.

2. Portable.

2.7.1.1 Fixed Model

The fixed access model was introduced in the IEEE 802.16-2004 standards [38]. It is a fixed model because it uses a mounted antenna at the user's site. It is a wireless solution for fixed broadband Internet access that provides an interoperable, carrier-class solution for the last mile. This wireless technology presents an efficient replacement to the cable modem, digital subscriber lines (DSL), transmit/exchange (TX/Ex) circuits and optical carrier level (OC-x) circuits.

The modulation technique used in WiMAX systems and optimized for non-line-of-sight transmission is OFDM which will optimize the wireless data services [39]. In the WiMAX air interface, the basic OFDM symbols are based on a 256 point, bandwidths that range from 1.25 MHz to 20 MHz, and carrier frequencies up to 11 GHz. As with other OFDM systems, a portion of these 256 sub carriers are set aside (unused) for guard bands and the centre frequency sub carrier is not used because it is easily susceptible to RF carrier feed through. In WiMAX, only 200 sub carriers are actually