LOW NOISE AMPLIFIER DESIGN FOR RADIO TELESCOPE SYSTEM

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Dedicated to my beloved family and country, Iran.

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ABSTRACT

The purpose of this project is to design a low noise amplifier (LNA) for a radio telescope. The LNA is an electronic amplifier used in communication systems to amplify extremely weak signals captured by antennae. This thesis describes the procedure of designing an LNA for 7 GHz frequency. Noise matching is an important technique which was considered in the design process. The designed LNA achieved a gain of 30 dB with 1 GHz bandwidth. The noise figure achieved was less than 2.9 dB. Return-losses were improved by 6 dB with a new proposed optimization method.

ABSTRAK

Objektif projek ini adalah untuk mencipta sebuah penguat suara rendah (LNA) untuk teleskop radio. The LNA adalah penguat elektronik yang digunakan dalam sistem komunikasi untuk menguatkan isyarat yang sangat lemah untuk ditangkap oleh antena. Tesis ini menjelaskan seluruh prosedur dalam penciptaan sebuah LNA selama 7 GHz frekuensi. Kebisingan yang berpadanan adalah teknik penting yang dipertimbangkan dalam proses penciptaan. LNA yang dicipta dapat mencapai gain 30 dB dengan 1 GHz bandwidth. Angka hingar yang diperolehi adalah kurang daripada 2,9 dB. Kehilangan dapat diperbaiki sebanyak 6 dB dengan kaedah yang dicadangkan.

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LIST OF ABBREVIATIONS

LNA	-	Low Noise Amplifier
ADS	-	Advance Design System
NF	-	Noise Figure

LIST OF SYMBOLSLS / NOTAITIONS

T	-	Total Noise Temperature
Gn	-	Available Power Gain of Nth Amplifier
K	-	Boltzmann’s Constant (J/K)
Δ_f	-	Operating Bandwidth (Hz)
F_{min}	-	The Minimum Noise of Transistor
Z_s	-	Impedance of Source
Z_l	-	Impedance of Load
V_{gs}	-	Voltage of gate-source
Γ	-	Reflection Coefficient
I_{gss}	-	Gate Leakage Current
Mu_load	-	Stability Coefficient

CHAPTER 1

INTRODUCTION

1.1 Radio Telescope

A radio telescope is a form of directional radio antenna which is used in radio astronomy. Radio waves reaching the ground can show objects or phenomena that are difficult or impossible to detect in other wavelength ranges. Radio telescope system involves the reflector, sub reflector, tertiary reflector, feed, cryogenics subsystem, LNA, noise calibration system, frequency converters, digital spectrometers, continuum signal processing, and monitor and control system. In this thesis, the focus of the work would be on Low Noise Amplifier (LNA) design for radio telescope system. [2]

1.2 LNA's Usage in Radio Telescope

The LNA is a particular type of electronic amplifier which can be used in communication systems and radio telescopes to amplify very weak signals which is captured by an antenna. In order to reduce the losses in the feed line, the LNA should be located near to the antenna [1]. The ability of the receiver to detect a weak input signal is fundamentally limited by the electrical noise which is present at its input. Therefore proper design techniques should be considered to achieve the lowest possible noise. LNAs are used in many systems where low-level signals must be sensed and amplified [22]. Generally, the LNA is capable of decreasing most of the incoming noise and amplifying a desired signal in a certain frequency range to increase the signal to noise ratio (SNR) of the communication system and improve the quality of received signal as well.

LNA’s are used in conjunction with many radio frequency functions. The signals which are coming from cosmic sources are originally unprocessed information and should be analyzed in a proper manner. One of the most critical building blocks in a radio telescope is LNA. This is because the incident signals from cosmic sources are very weak in amplitude. Therefore, in order to analyze them they should be amplified more than other signals [12].

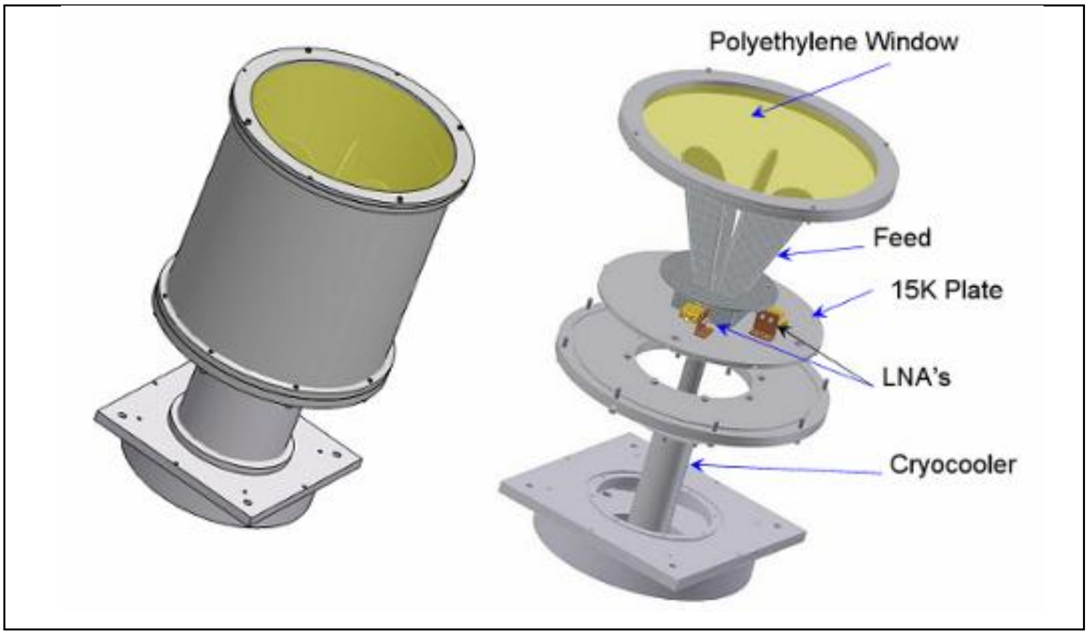

Figure 1.1 LNA's Position in Radio Telescope [2]

1.3 Noise and Temperature

Generally, noise is something indistinguishable and undesirable. In electronics fields however, it is something that always exist and have to be dealt with. When an amplifier doesn't have any input signal, a tiny randomly oscillating output signal can still be detected and is referred to as noise. Noise in electronic components is made by random thermal oscillating of electrons so any device that operates over absolute zero produces noise. [10].

In radio astronomy, noise is defined in terms of noise temperature. The noise temperature of an antenna is the thermal temperature of a resistor whose terminals, over a specific frequency bandwidth, have a mean available noise power due to thermal agitation equivalent to the available power at the antenna's terminals. Using temperature units permits direct comparison with celestial "source temperatures" [12].

Every object will produce electromagnetic waves if its temperature is above absolute zero. The noise temperature of an antenna's radiation resistance will be equal to the temperature of the particular source the antenna is "looking at" if the angular extent of the source "fills" the antenna beam. This statement excludes non-thermal mechanisms that generate electromagnetic waves such as synchrotron radiation. In such cases, the noise temperature of the antenna's radiation resistance is not equal to the thermal temperature of the source but instead would be equivalent to the thermal temperature of an ideal blackbody emitting the same radiation at the observing frequency. An ideal blackbody is defined as a perfect absorber and radiator: it absorbs radiation at all frequencies and its own radiation is a function of only temperature and frequency [12].

1.4 FET Modeling and Noise Parameter

The noise parameters of a FET can be calculated upon obtaining its equivalent circuit noise model. Theoretically, the noise parameters depend on certain parameters of the circuit model. The circuit model of the transistor is obtained by iteratively fitting the model S-parameters to the actual measured S-parameters of the device. There are various methods of doing this. Here, the chosen method is centered on least-squares fitting of the simulated output of a circuit model to measured S-parameters. After convergence, reliable values for various circuit elements such as package capacitances and inductances are obtained. This method had been used for manual calculation to obtain the value of NF and it is obvious that by using sophisticated and strong software there is no worry about complicated calculations [12]. Figure 1.2 shows intrinsic noise equivalent circuit of a FET.

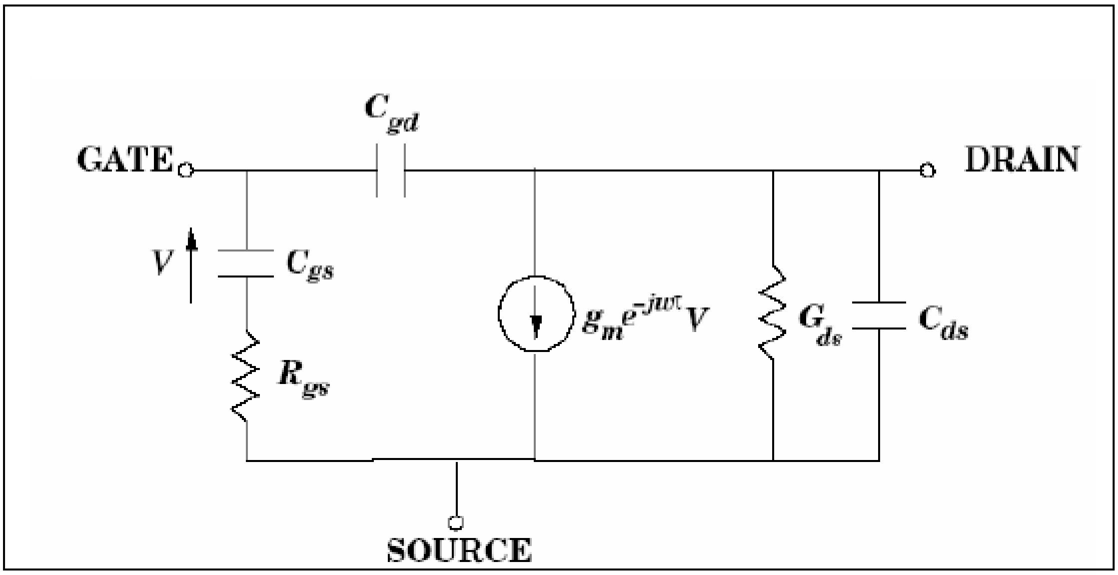

Figure 1.2 Intrinsic Noise Equivalent Circuit of a FET [12]

1.5 Reducing Receiver Front-End Noise

When radio signals reach Earth from thousands of light years away, they have been really flagged and very weak. For detecting these signals, receiver front-ends must have high gain and most importantly, very low noise amplifiers. Noise and gain are important due to a particular property of amplifiers: first stage amplifier has the most noise that typically dominates the noise of the stages after it. For a cascade of amplifiers, the total noise temperature can be obtained by [12]:

$$T = T_1 + [T_2/G_1] + [T_3/(G_1 . G_2)] + [T_4/(G_1 . G_2 . G_3)] + \ldots \quad (1.1)$$

Where-

T = total noise temperature

Tn = noise temperature of nth amplifier

Gn = available power gain of nth amplifier .

The solution to achieve low noise in an amplifier depends on the type of transistor being used in the design. Gallium arsenide field-effect transistors (GaAs FETs) and high electron mobility transistors (HEMTs) are the most familiar types of transistors that have been used in LNAs for high frequencies. Technology has made it probable for high frequency amplifiers to have excellent noise performance without using cryogenic cooling. Although cryogenic cooling of receivers is usually used to obtain low system noise temperatures in radio astronomy but the high cost of procedure and maintenance are two main disadvantages of using cryogenic cooling. Therefore, the application of cryogenic cooling is not considered in this work. There are several limitations in the design of LNAs for high frequency applications. For instance, a design for lowest noise may not lead to attain lowest return losses. Therefore an optimized design is necessary to achieve the lowest noise and return losses [12].

1.6 Problem Statement

Radio astronomy signals are very weak in amplitude. Therefore, in order to analyze these signals an amplification of the signal is essential while the noise is minimized. In order to solve this problem, LNA should be used in radio telescope receivers. There are several limitations in design of LNAs for high frequency application, for instance a design for lowest noise may not lead to attain lowest return losses. Therefore an optimized design is necessary to achieve the lowest noise and return losses [12].

1.7 Project Objectives

The objective of this project is to design a LNA for radio telescope with high gain and stability and low return losses and noise figure.

1.8 Scope of Study

This study is limited to the following scope of work in order to meet the specified objectives:

(a) The LNA has been designed for 7 GHz frequency.
(b) LNA should have a gain more than 20 dB.
(c) NF should be less than 3.5 dB.
(d) The input and output return losses should be less than -10 dB.
(e) LNA should be unconditionally stable therefore the K factor should be more than 1.
(f) The ADS has been used to simulate the circuit and to investigate the stability, noise figure, gain and return losses.