Low Noise Amplifier Using Inductive Source Degeneration for Wideband Application

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***Abstract*— This paper features a design of cascaded wideband low noise amplifier (LNA) operated from 4 – 7 GHz using inductive source degeneration with multi – section quarter wave transformer matching. This design implementing Super-low noise InGaAs HEMT MGF4937AM transistor which able to sustain until 20 GHz. Introducing inductive source degeneration will degrade the gain while improving the stability and maintaining the noise figure of the overall system. However, this problem can be eliminated by introducing cascaded topology which can increase the overall gain. Multi – section quarter wave transformer provides wideband characteristic and good input and output return loss on the desired frequency band. This LNA was designed based on FR4 microstrip characteristic and simulated using Advanced Design System (ADS) software. The LNA achieves input and output return loss of less than -10 dB, gain more than 15 dB and noise figure less than 0.5 dB respectively.**

***Index Terms*— InGaAs; LNA; Microstrip; Wideband.**

I. Introduction

Being the first block in receiver front-ends, low noise amplifier (LNA) involves a trade-off design among several goals. These include providing good input and output voltage standing wave ratios (VSWR1 and VSWR2), minimizing the noise figure (NF) and supplying gains (e.g. 10 dB) that must be high enough to lower the noise contribution of the following blocks without degrading linearity [1].

Low Noise Amplifier (LNA) is a device that amplifies the received signal from the transmitter through atmospheric medium. The signal received by an antenna is weak due to the interference of other signal and the distance between transmitter and receiver. This makes LNA an important device in the front end of telecommunication system. By applying an appropriate matching network located on input and output may produce a good LNA design. Yet, the design may affect the gain, noise figure, return loss and power consumption of the entire system. Figure 1 shows the basic block diagram of LNA consist of input/output matching and biasing circuits which can be seen in Figure 1.

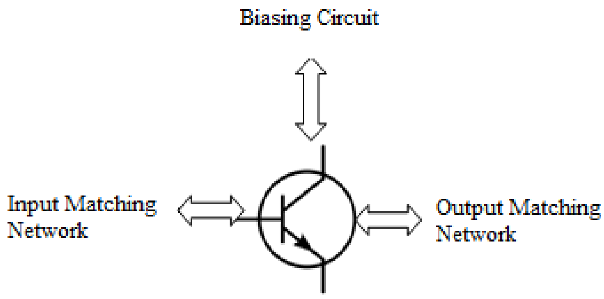

Figure 1: Basic block diagram of LNA.

Several designs LNA have been proposed using 0.18µm CMOS technology. A design of UWB LNA using two-stages shunt-peaked with notch filter managed to cover from 3.1 GHz to 10.6 GHz. However, the return loss (S11) does not meet the specification which is less than -10dB [2]. The Newest UWB LNA design proposed using microstrip technology, which designed using negative feedback technique which covers from 0.5 GHz to 6 GHz frequency band and 2 – 10 GHz respectively [3], [4]. Another design from [5] achieved a wideband low noise amplifier using resistive feedback. Furthermore, A. Serban managed to design UWB LNA cover only for direct sequence spread spectrum (DSSS) or so – called Band Group 1 which operates at 3.1 to 4.8 GHz [6]. The design is based on dual-section input and output matching networks in order to achieve better input return loss. There is also a design that implementing a gate inductor in order to provide good impedance matching and noise figure [7].

Another widely used negative feedback technology is the source inductive degeneration [8], [9], [10], [11] which enhances circuit stability, achieves noise matching, and provides good linearity. However, its small inductance cannot be achieved and controlled easily. What is worse, a little change in the inductance significantly influences the gain, stability, and noise figure. For instance, excessive source inductance can bring about LNA oscillations because of gain peaking at higher frequencies [12]. Therefore, such LNA has to be designed carefully to avoid instability.

II. Design Theory

In designing LNA, there are several steps that need to carry out.

A. Transistor selection

Transistor selection is the first essential step in designing LNA. The researcher need cautiously analyzes the transistor selection maintaining the most important design tradeoffs in mind. The specification needed can be found in transistor datasheet provided by the manufacturer. For this proposed LNA, we identify that the best transistor that could withstand ultra-wideband frequencies from 3.1 to 10.6 GHz is Super-low noise InGaAs HEMT MGF4937AM manufactured by Mitsubishi. According to datasheet provided the transistor capable to operate until 20GHz.

B. Biasing Network

Biasing network purposely uses to supply optimum Vds and Id according to the datasheet. In datasheet, the manufacturer provides analysis of gain and noise figure with different value of bias point. By selecting optimum DC bias circuit should demonstrate stable thermal performance. The bias point of VDs = 2V and Id = 10 mA is chosen to give optimum performance to the LNA. The design of the bias network based on voltage divided circuit.

C. Parameter Identification

In a 2 port network connected to a source and load impedance correspondingly, few types of power gain can be distinct in term of S – parameter and reflection coefficient of source and load. In LNA design, the single power transistor is the method to provide amplification at the desired frequency and the desired linearity. The amplifier must be stable because with unstable amplifier, the signal will not advance out but will oscillate. The stability of power amplifier can be identified by using a K test. In the K test, there will also a Rollet's Condition that needs to be fulfilled. If the K-factor is larger than unity, at the frequency and bias level in question, then expressions for matching impedances as input and output can be calculated to give a perfect conjugate match for the device. The set of unconditional stability can be stated in the formula below [12].

Auxiliary Condition

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

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

The above equation refers to Rollet's Criteria for Unconditional Stability which is the important condition. The value of K also can be found using simulation.

The critical part of designing LNA is about noise optimization. The most appropriate technique to find the best optimized noise figure is by using noise circle and gain circle which used to define the input ($\Gamma in = \Gamma opt$) and output reflection coefficient Γout of the circuit. The noise figure of the transistor can be calculated according to several parameters are given by the manufacturer such as F_{min}, R_N and Y_{opt} at the respective frequency by the equation below [13].

$$F = F_{min} + \frac{R_N}{G_S}\left|Y_S - Y_{opt}\right|^2 \tag{3}$$

$$N = \frac{\left|\Gamma_S - \Gamma_{opt}\right|^2}{1 - |\Gamma_S|^2}\frac{F - F_{min}}{4R_N/Z_0}\left|1 + \Gamma_{opt}\right|^2 \tag{4}$$

Power gain, which is the ratio of power dissipated in the load Z_L to the power delivered to the input of the two-port network. This gain is independent of Z_S, although the characteristics of some active devices may be dependent on ZS [13].

$$G = \frac{P_L}{P_{in}} = \frac{|S_{21}|^2(1 - \left|\Gamma_L{}^2\right|)}{(1 - \left|\Gamma_{in}{}^2\right|)|1 - S_{22}\Gamma_L|^2} \tag{5}$$

Available power gain is the ratio of the power available from the two-port network to the power available from the source. This assumes conjugate matching of both the source and the load, and depends on Z_S, but not Z_L [13]

$$G_A = \frac{P_{avn}}{P_{avs}} = \frac{|S_{21}|^2(1 - \left|\Gamma_S{}^2\right|)}{|1 - S_{11}\Gamma_S|^2(1 - |\Gamma_{out}|^2)} \tag{6}$$

Transducer power gain is the ratio of the power delivered to the load to the power available from the source. This depends on both Z_S and Z_L [13].

$$G_T = \frac{P_L}{P_{avs}} = \frac{|S_{21}|^2\left(1 - \left|\Gamma_S{}^2\right|\right)\left(1 - \left|\Gamma_L{}^2\right|\right)}{|1 - \Gamma_S\Gamma_{in}|^2|1 - S_{22}\Gamma_L|^2} \tag{7}$$

III. CIRCUIT DESIGN

According to the previous design, it can be concluded the design specification that needs to be achieved in order to design wideband LNA. Table 1 below shows the design specification for wideband LNA

Table 1
Design specification

Specification	Value
Input Return Loss S_{11} (dB)	<-10 dB
Output Return Loss S_{22} (dB)	<-10 dB
Gain S_{21} (dB)	> 10 dB
Noise Figure (dB)	< 4 dB
Stability (K)	>1

In the proposed design, two types of techniques are used in order to achieve the design specification occur for wideband LNA which is an inductive source degeneration for design architecture and multi - section quarter wave transformer matching network for input and output matching.

i. Inductive Source Degeneration

It introduces negative series feedback and reduces the gain of the amplifier. However, it provides one more degree of freedom with which one can affect the input impedance of the amplifier, the minimum noise figure and the optimal source impedance which results in minimum noise figure. Inductive degeneration is of particular interest because it does not introduce noise [14].

The input impedance is affected if inductive degeneration, Ls is implemented in the common source amplifier, the input impedance becomes as Eq. (8) and the common source amplifier with source degeneration is shown if Figure 2

$$Z_{in} = R_i + R_c + R_S + \frac{g_m L_s}{C_{gs}} + j\omega L_s + \frac{1 + g_m R_s}{j\omega C_{gs}} \quad (8)$$

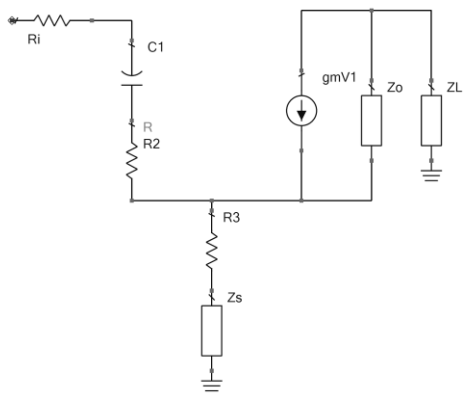

Figure 2: Common source amplifier with source degeneration.

After introducing inductive source degeneration, the input impedance can be found to be as Eq. (9)

$$Z_{in} = R_i + R_c + \frac{1}{j\omega C_{gs}} + \left(1 + \frac{g_m}{j\omega C_{gs}} \cdot \frac{Z_o}{Z_o + Z_L}\right) . ((R_s + Z_S)//(Z_o + Z_L)) \quad (9)$$

Where ZL and ZS are the load and degeneration impedances respectively. It can be concluded that inductive source degeneration affects the input impedance. An electrical simulation was carried out in order to evaluate the behaviour of input return loss, S11 (dB) for various value of inductive source degeneration, Ls. The result is plotted in Figure 3, it is observable from these latter that the bandwidth of the input return loss increase as the value of Ls increase. Furthermore, increasing the value of Ls does not affect the noise figure of the overall amplifier.

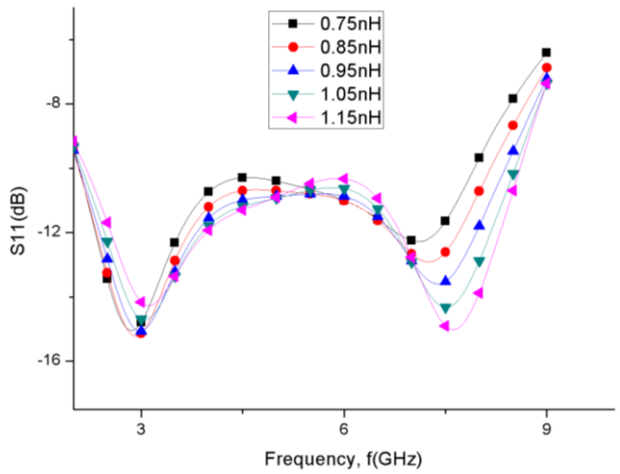

Figure 3: Analysis of input impedance network by varying inductor, Ls

ii. Multi – Section Quarter Wave Transformer

A wideband characteristic of matching network needs to be implemented in the design so that the S11 and S22 would be matched. The most used wideband matching network is multi-section quarter wave transformer. Since the design targeted lowest noise figure, optimum reflection coefficient (ΓOPT) need to be identified in order to design the matching network. Same with the previous design, the matching network is designed at centre of frequency band which is 5.5GHz.

For the matching component, there are several matching network that comply the wideband characteristic. Based on [13], there are resistive matching network and multi-section quarter wave transformer matching network. Resistive matching network will provide good input and output return losses but will degrade gain and noise figure. The multi – section quarter wave transformers normally involve a cascade of constant quarter wave line sections. Discontinuities result from different jumps of impedance, such as a change in the width of the microstrip line. This matching will provide sufficient bandwidth and good input and output return losses to the amplifier.

The S – Parameter simulation with the biasing circuit provides optimum impedance (Zopt), Source impedance (Zsource) and Load impedance (Zload). Tradeoff impedance ZS = 135+j45.7Ω and ZL = 191+j91.6Ω is between optimum impedance and source impedance to achieve a balanced gain and noise figure. The achieve impedance is normalized and plotted it Smith Chart. The Eq. (10),(11) and (12) used to calculate the input and output impedance for each of the quarter wave transmission line.

$$Z_1 = \sqrt[8]{Z_L Z_0^7} \quad (10)$$

$$Z_2 = \sqrt{Z_0 Z_L} \quad (11)$$

$$Z_3 = \sqrt[8]{Z_0 Z_L^7} \quad (12)$$

From the input and output impedance achieved from the Eq. 10, the combination of cascaded topology, inductive source degeneration and multi-section quarter wave transformer is shown in Figure 5.

The proposed wideband LNA which shown in Figure 5 is simulated and several parameters are identified. Figure 6 shows the stability of proposed LNA while Figure 7 shows simulated input and output return achieved. Figure 8 shows the gain and noise figure achieved.

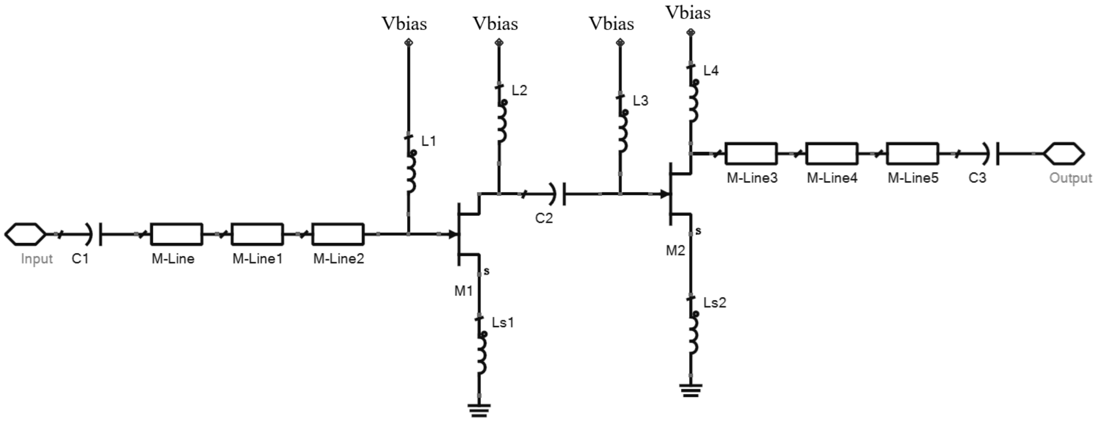

Figure 5: The schematic diagram of low noise amplifier with multi-section quarter wave transformer

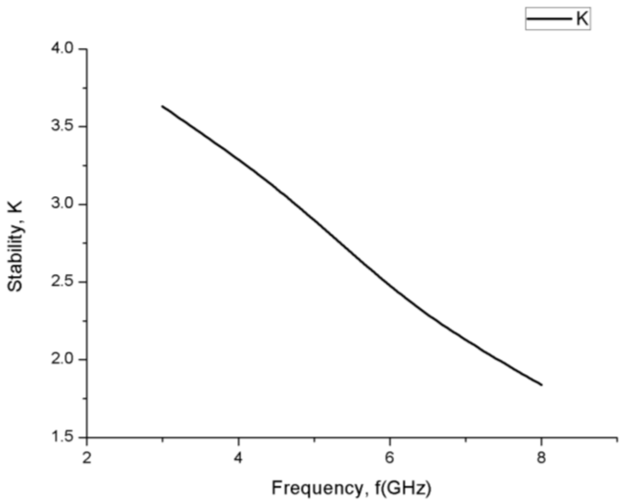

Figure 6: Simulated stability of wideband LNA

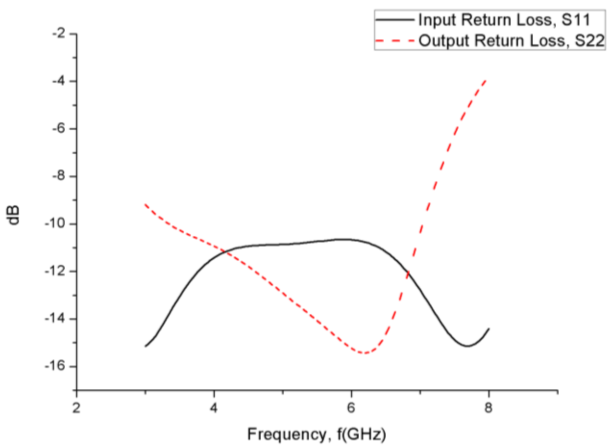

Figure 7: Simulated input and output return loss of wideband LNA

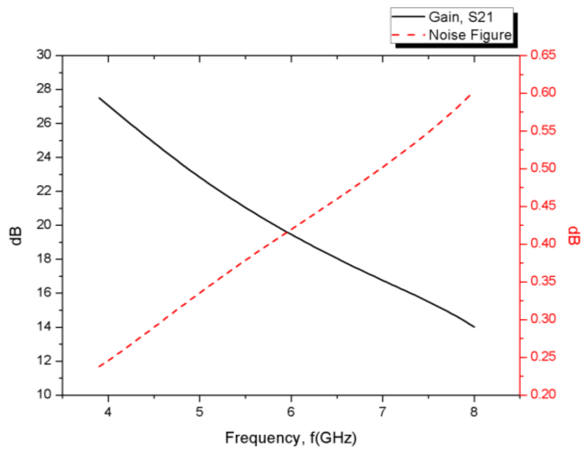

Figure 8: Simulated gain and noise figure of wideband LNA

The simulated stability, input and output return loss, gain and noise figure that describe the amplifier is shown in Figure 6, 7 and 8. From Figure 6, it shows that the amplifier managed to maintain to be stable (K > 1) for the entire frequency band. Furthermore, the input return loss (S11) and output return loss (S22) is shown in Figure 7 achieves lower than -10 dB from 4 GHz – 7 GHz. This defines that the designed amplifier is wideband LNA. Amplifier gain, which can be seen in Figure 8 achieve from 14.34 dB to 23.2 dB from 4GHz to 7 GHz frequency bands while the noise figure produces a very good response which lower than 0.6 dB for the entire frequency band.

Table 2
Comparison between previous achievements of LNA

Parameter	Frequency (GHz)	Max Gain (dB)	S11 & S22 (dB)	Min Noise Figure
[3]	0.5 – 6	22	< -10	2.3
[4]	2 - 10	36	< -10	2.02
[6]	3.1 – 4.8	15.8	< -10	2.27
[7]	2 - 5	13	< -10	6
[11]	1 - 3	35	< -10	3
[15]	3.2 – 9.7	9.3	< -10	4.8
[16]	1 - 5	21	< -10	2.6
[17]	5.4 – 5.9	17.5	< -17.2	1.3
[18]	1 - 3	37	< -10	0.8
This Work	4 - 7	23.2	< -10	0.32

The proposed LNA is compared with other previous researches that design nearly the same operating frequencies in Table 2. Based on the maximum gain, the proposed design achieves highest gain due to the introducing of cascaded topology. For the input and output return, all of the previous researches achieved the same which is less than -10 dB. The best performance achieved from the proposed design is the noise figure which has the lowest minimum noise figure compared with other design.

IV. Conclusion

The design of cascaded 4 – 7 GHz low noise amplifier with inductive source degeneration and multi – section quarter wave transformer to achieved wideband characteristic has been proposed, designed and simulated. The design is biased at Vds = 2V and Ids = 10 mA. The result shows that the return loss achieves less than -10 dB for the entire band and maximum gain is at 23.2 dB. Furthermore, the noise figure is kept lower than 0.6 dB for entire UWB frequencies. The design is compared with previous achievement which designed using microstrip technology.

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