LC Matching Circuit Technique For 2.4 Ghz LNA Using AVAGO ATF-54143

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ABSTRACT
This paper presents the design, design and simulates a single stage LNA circuit with high gain and low noise using NPN Epitaxial for frequency range of 2.4GHz. The design simulation process is using Advance Design Simulation (ADS) and performance of each microwave receiver there is Low Noise Amplifier (LNA) circuit. This amplifier exhibits a quality factor of the receiver. When this amplifier is biased for low noise figure, requires the trade-off many importance characteristics such as gain, Noise Figure (NF), stability, power consumption and complexity. Besides its excellent noise performance, this is the highest frequency amplifier ever reported using three terminal devices.

Keywords - Low Noise Amplifier, Lumped Elements Matching, Power gain, Noise Figure, Unilateral

I. INTRODUCTION

The function of low noise amplifier (LNA) is to amplify low-level signals with maintain a very low noise. Additionally, for large signal levels, the low noise amplifier will amplified the received signal without introducing any noise, hence eliminating channel interference. A low noise amplifier function plays an undisputed importance in the receiver.

Low Noise Amplifier (LNA) plays a crucial role in the receiver designs. LNA is located at the first stage of microwave receiver and it has dominant effect on the noise performance of the overall system. It amplifies extremely low signals without adding noise, thus the Signal-to-Noise Ratio (SNR) of the system is preserved. In LNA design, it is necessary to compromise its simultaneous requirements for high gain, low noise figure, stability, good input and output matching . The LNA design in this report is carried out with a systematic procedure and simulated by Advanced Design System (ADS2008).Microwave Amplifier Design.

In this project, ATF 54143 transistor is chosen in designing low pass amplifier. It is because AT-54143 is a high dynamic range, low noise transistor. It can amplify small signal at operating frequency around 2 GHz. Thus, it meets our requirement to design a LNA at 2.4 GHz. Besides that, ATF 54143 can perform with low voltage supplied.

Before start designing, the design requirement is set in order to ensure our LNA designed can achieve the target.

i. Operating range = 2.0 to 3.0 Ghz
ii. Gain > 12 dB
iii. Noise Figure < 2.5 dB
iv. Return loss for source > 10 dB
v. Return loss for load > 10 dB
vi. Power supply = 5V

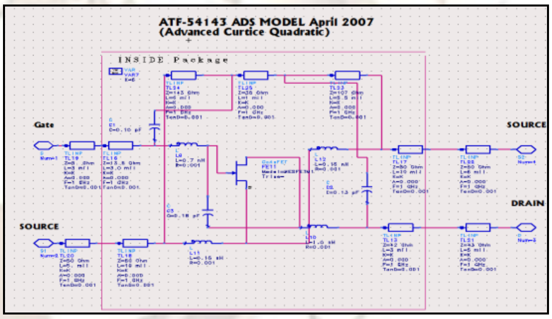


Figure 1: Equivalent circuit of ATF 54143 from AVAGO

II. LNA DESIGN

Transistor must be biased at appropriate operating point before used. So that, transistor can work under values required and achieve less power consumption. In this project, passive biasing method is adopted. The component readings are determined with reference from datasheet.

By referring datasheet, data of Vds = 3V and Ids = 60mA had be chosen because it is believed can give optimum values in gain and noise figure

With V_{gs} = 0.52, I_{BB}=2m, Vds = 3V and Ids = 60mA,

$$R_3 = \frac{Vgs}{IBB} = 260\Omega$$

$$R_4 = \frac{Vdd - Vds}{Ids + IBB} = 32.26m\Omega$$

$$R_1 = \frac{(Vds - Vgs)R_2}{Vgs} = 1.24k\Omega$$

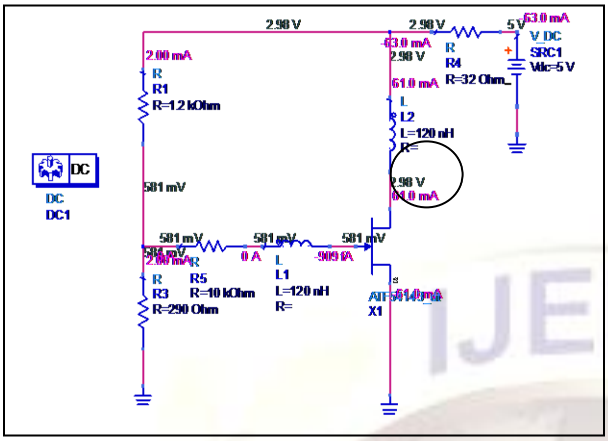


Figure 2: DC biasing Circuit

The R_1, R_4 and R_3 in circuit are slightly adjusted from calculation readings in order to obtain better V_{ds} and I_{ds} reading in the simulation.

Given $Z_L = Z_S = Z_0 = 50\Omega$

From the data sheet, S parameter at 2.5 GHz is:

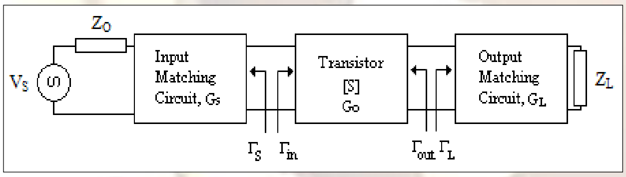
$S_{11} = 0.60 \angle 176.2$

$S_{21} = 6.01 \angle 61.8$

$S_{12} = 0.07 \angle 30.1$

$S_{22} = 0.13 \angle -129.7$

The reflection coefficient to source, Γ_S and reflection coefficient to load, Γ_L. The equation is shown in (1) and (2).



$$\Gamma_S = \frac{Z_S - Z_0}{Z_S + Z_0} \quad (1)$$

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (2)$$

Since given $Z_L = Z_S = Z_o = 50\Omega$, the Γ_L and Γ_S calculated as zero. Reflection coefficient at the input and output:

$$\Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \quad (3)$$

$$= S_{11} = 0.60 \angle 176.2$$

$$\Gamma_{out} = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_S} \quad (4)$$

$$= S_{22} = 0.13 \angle -129.7$$

Power gain, G

$$G = \frac{|S_{21}|^2(1-|\Gamma_L|^2)}{(1-|\Gamma_{in}|^2)|1-S_{22}\Gamma_L|}$$

$= 56.43 = 17.52$ dB

$$G_A = \frac{|S_{21}|^2(1-|\Gamma_S|^2)}{|1-S_{11}\Gamma_S|^2(1-|\Gamma_{out}|^2)} \quad (5)$$

$$= 36.74 = 15.65\text{dB}$$

Transducer gain, GT

$$G_T = \frac{|S_{21}|^2(1-|\Gamma_S|^2)(1-|\Gamma_L|^2)}{|1-\Gamma_S\Gamma_{in}|^2|1-S_{22}\Gamma_L|^2} \quad (6)$$

$=36.12 = 15.58$dB

Stability Consideration

The stability of an amplifier or its resistance to oscillate is an important consideration in a design. It can be determined from the *S* parameters. Oscillation occurs when $|\Gamma_{in}| > 1$ or $|\Gamma_{out}| > 1$. This is due to the dependence of Γ_{in} and Γ_{out} on the source and load matching networks. An amplifier is said to be unconditionally stable if the auxiliary condition along with *Rollet's condition*, defined as in equations below, are simultaneously satisfied.

$$K = \frac{1-|s_{11}|^2-|s_{22}|^2+|\Delta|^2}{2|S_{21} - S_{12}|} > 1 \quad (7)$$

$$|\Delta| = |S_{11}S_{22} - S_{12}S_{21}| < 1 \quad (8)$$

$K = 1.11478 > 1$ $\quad \Delta = 0.3427 < 1$

Noise Figure

Besides the stability and gain requirement, noise figure is another important consideration for a microwave amplifier. In receiver applications, it often required preamplifier with as low noise figure as possible as it has dominant effect on the noise performance of the system. From the ATF-54143 datasheet, $F_{min} = 0.52$, $\Gamma_{opt} = 0.26$ and $R_N/Z_o = 0.04$ at 2.4 GHz at 2.4 GHz (There are not reference for 2.5 GHz)

$$F = F_{min} + \frac{4R_N}{Z_o}\frac{|\Gamma_s - \Gamma_{opt}|^2}{(1-|\Gamma_s|^2)|1+\Gamma_{opt}|} \quad (9)$$

$= 0.52$

NF = 2.769 dB

Matching Network

The impedance matching basic idea is presented in Fig. 2, which ensembles that an impedance matching network placed between the load impedance and transmission line.Matching network is made to ideally avoid the unnecessary loss power. There are variety of factors that needed to be considered in the matching network selection e.g. complexity, implementation and adjustability. In this paper, the LNA is designed by using lumped elements matching and quarter-wave transformer matching techniques.

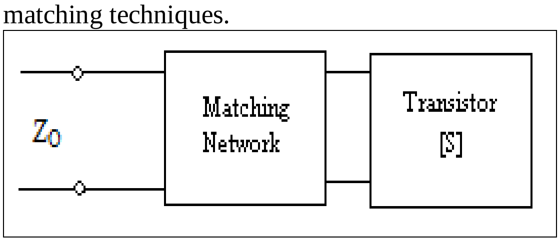


Figure 4: Impedance Matching Network

III. RESULTS AND DISCUSSIONS

A. Before Matching

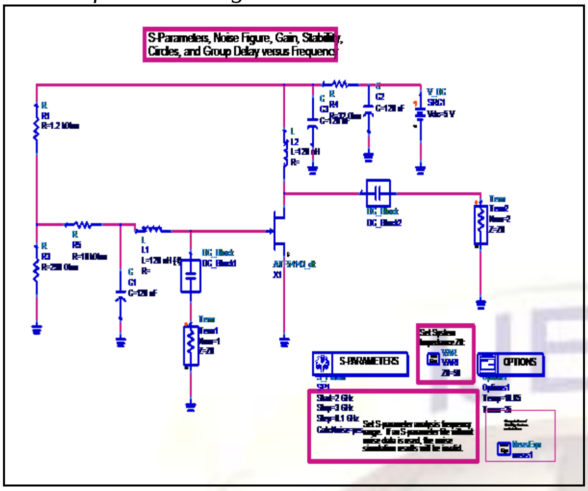


Figure 5: Circuit before matching

The parameters of noise figure, stability factor, return loss and gain values are calculated by using equations (1 to 9). While simulation results before the matching are listed as in Table 1.

Parameters	Calculated	Simulation
$\|\Gamma_S\|$	0	$0.51 \angle -164.1$
$\|\Gamma_L\|$	0	$0.34 \angle 21.3$
$\|\Gamma_{in}\|$	$0.60 \angle 176.2$	$0.702 \angle 169.92$
$\|\Gamma_{out}\|$	$0.13 \angle 129.7$	$0.037 \angle -70.502$
K	1.1478	0.97
G	17.52 dB	17.25 dB
G_A	15.65 dB	15.31 dB
G_T	15.58 dB	15.76 dB
G_{Tmax}	15.58 dB	15.63 dB
NF	2.769 dB	0.375 dB

Table 1: Results differences in calculated and simulation before applying matching network.

B. After Matching

To match both impedance of input and output. Lumped elements matching is added into LNA circuit with assistance of smith chart utility in AdS software. After matching from smitch chart, the Lumped elements circuit will automatical generated.

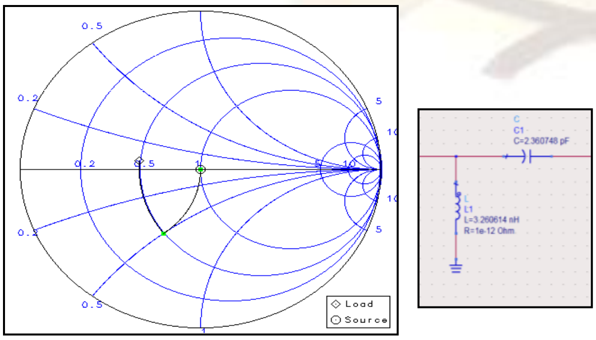


Figure 5: Input source matching

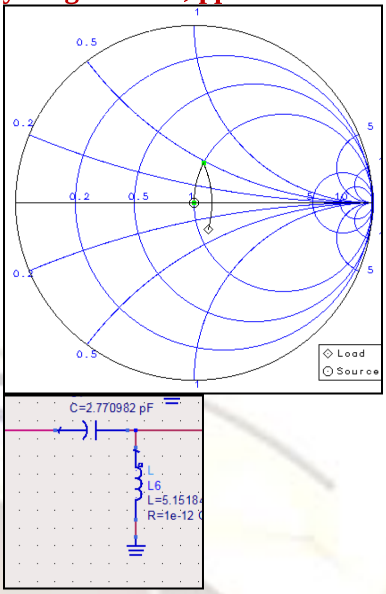


Figure 6: Output load matching

The components reading designed by ADS software are not exist in market. Thus, to fabricate, it must change to actual values.

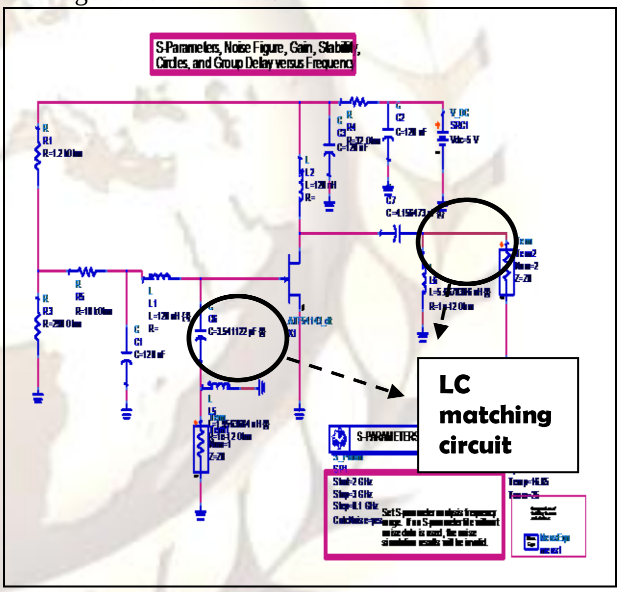


Figure 5: Circuit after matching

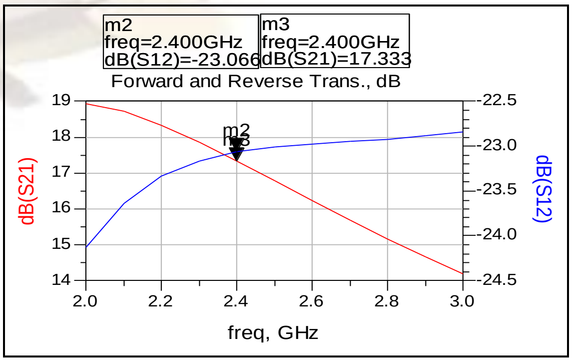


Figure 6: S12 (isolation) and S21 (gain)

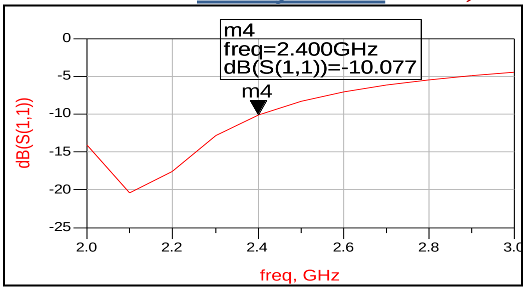


Figure 7: S11 (dB)

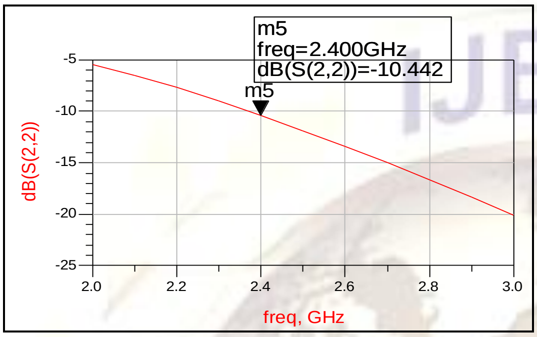


Figure 8: S22 (dB)

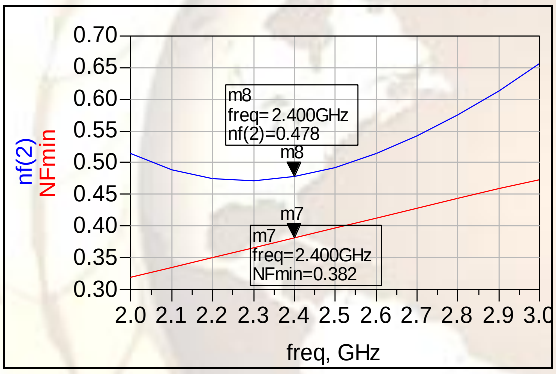


Figure: Minimum Noise Figure (NFmin), Noise Figure (nf2)

Parameters	Before Matching	After Matching
S_{11}	-3.078	-10.077 dB
S_{22}	-28.530	-10.442 dB
S_{12}	-25.438	-23.066dB
S_{21}	14.960	17.333 dB
NF_{min}	0.382	0.382
NF	0.375	0.478
K	1.004	1.004

Table 1: Results differences in calculated and simulation after applying matching network.

The stability of this transistor is unconditionally stable at 2.5 GHz since its K constant is more than 1, which is 1.004 from the simulation. Therefore, no stability circle has to be drawn. Stability and maximum available gain are two of the more important considerations in choosing a two-port network LNA for use in amplifier design. As used here, stability measures the tendency of an LNA to oscillate.

The gain is also an important factor in designing LNA for use in amplifier design. Maximum available gain is a figure of merit for the LNA, which indicates the maximum theoretical power gain when it is conjugate matched to its source and load impedances. The calculated gain is 17.52 dB compared to the simulated gain which is 17.25, the calculated and simulated power gain show almost the same result. The matching network of amplifier design is measured by the tranducer power gain where it can be defined as separate effective gain for input (source) matching network, transistor and the output matching network.

An LNA is a design that minimizes the noise figure of the system by matching the device to its noise matching impedance, or Gamma optimum. Gamma optimum occurs at impedance where the noise of the device is terminated. All devices exhibit noise energy. To minimize the noise as seen from the output port, we need to match the input load to the conjugate noise impedance of the device. Otherwise, the noise will be reflected back from the load to the device and amplified. The noise figure passes the requirements. It can be observed that the calculated noise figure and the simulated noise figure is not the same. This is because the input and output port of the network is not matched.

For the result obtained from the simulation, the power gain is 17.25dB and the noise figure is 0.382dB, while the return loss for source and return loss for load is -10.077dB and -10.442dB respectively. The results obtained from the LNA simulation have achieved the requirements that have been set.

Filter matching can be included into the designed circuit which is used at the output of transistor method. This is used to eliminate gain at high frequencies and increase the band of operation. On the other hand, resistive loading is recommended to have at the input as the stability of circuit can be improved. The matching procedures for input and output have to be carried out simultaneously to ensure prefect matching is achieved.

IV. CONCLUSION

A Low Noise Amplifier with given desired characteristics was able to design. From the comparison of the calculated and simulated result it can be seen that there is a slight difference in values. From the simulation result above, it is difficult to design a low noise amplifier that has both low noise figure and high gain together. So, it is very important to tolerate between the input and output matching in order to get the perfect match.

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