DESIGN OF 2.4 GHZ NEW WIDEBAND RF FRONT END LNA

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ABSTRACT

Low Noise Amplifier (LNA) in Radio Frequency (RF) circuit is the first stage in which we can suppress the noise, which requires the trade-off many importance characteristics such as gain, Noise Figure (NF), stability, power consumption and complexity. In this paper the aim is to design and simulate a single stage LNA circuit with high gain and low noise using 0.18um TSMC NMOS for frequency 2.4 GHz. A single stage LNA has successfully designed with 18.82 dB forward gain and 1.986 dB noise figures, reverse isolation more than 12 dB at the frequency of 2.4 GHz.

KEYWORDS: Low Noise Amplifier, Noise Figure, Gain,

INTRODUCTION

In first stage of each microwave receiver there is Low Noise Amplifier (LNA), this stage has important rule in quality factor of the receiver. A low noise amplifier (LNA) is utilized in various aspects of wireless communications, including cellular communications, wireless LANs and satellite communications. An LNA provides a steady gain [1] over a specified frequency bandwidth. One common application is the use of a LNA as the input stage of a receiving circuit, such as in a cellular mobile communication device. The LNA must be able to provide enough amplification with minimal noise added to the system in order to improve SNR. It also should be linear enough to tolerate spurious interferers coming from the wireless channel. Inductive source degenerated LNA is used for high linearity and low thermal noise.

The design of an LNA imposes many challenges first of all the signal strength can be tens of millions times lower than the in-band interferers. The pre select filter, which is mandatory between the antenna and the LNA, selects the required band of interest. The presence of the desired weak signal along with strong interferers at the input of the LNA enhances the non-linear effect of the LNA. Due to the non linearity, the gain of the LNA becomes a decreasing function of the “1–dB compression point” where the gain falls by 1 – dB below its ideal value. Also the interferers can be capable of “desensitizing and blocking” the desired signal may experience a vanishingly small gain due to the reduction of the average gain by the strong interferer. One more consequence of the nonlinearity is the “cross modulation” which results the transfer of modulation from one carrier to the other. Another important affect of these blocking signals is the “Inter-modulation”. If the signal is nearer to two strong interferers then their third order Inter-modulation product falls in the frequency band of the desired signal and corrupts the signal of interest. This defines the IIP3 (3rd order inter intercept point)[10]. The RF input signal to the LNA is...
coming from the pre select filter, which is the RF source here [2]. So the LNA must present good “power matching” for maximum power to be transferred from the RF source. In addition to power matching the LNA should have proper “noise matching” to minimize the noise figure. One more constraint in the design of the LNA is the “power dissipation”. In battery operated systems like mobile transceivers the power consumption should be as low as possible to increase the battery time. The “gain” of the LNA should be large enough to decrease the noise contribution of the following stages in the receiver and it should be small enough not to saturate the following stages in the receiver chain.

Figure 1. RF Design Hexagon

1. PROPOSED DESIGN FOR INDUCTIVE LNA

Figure 2: Proposed LNA schematic design with inductors replacing all resistive components for reduction of thermal noise.

LNA CIRCUIT DESIGN

The complete schematic of LNA is shown in figure 1. Lg, Ls and Ld are implemented by using spiral inductors. The method employed here is inductive source degeneration. Cascoding transistor M2 is used to reduce the interaction of the tuned output with the tuned input, and to reduce the effect of the gate-drain capacitance Cgd of M1. The inductors Lg and Ls are chosen to provide the desired input resistance. Ld and the capacitance of the transistors M2 form a tank circuit to tune the LNA to 2.4GHz. M3, L1 and L2 form a bias circuit. Transistor M3 essentially forms a current mirror with M1,
where its width is a small fraction of the width of M1’s in order to minimize the power overhead of the bias circuit. Cin and Cout are DC blocking capacitors.

Due to the limited choice of inductor and capacitor values in the technology we choose, the matching network becomes very challenging. With the comprehensive consideration of the chip size and different performance trade-off, Cin and Cout play important roles in input and output matching respectively. The load L3 is tuned to manage the tradeoff between gain, output matching, and power dissipation of LNA. Both input and output are matched to 50Ω.

LNA DESIGN CONSIDERATIONS

Limitation on the Gain

Friis’ Equation says that the gain of the LNA (1st stage) as high as possible for minimum Noise Figure. The equation shows that if the first stage has infinite gain then the total NF is contributed only by the LNA, which is the first stage. But the gain must be low enough in order to make sure that the down converters are not saturated by the amplified blocking signal. So the largest in band interferer limits maximum gain of the LNA.

\[ \text{F}_{\text{Total}}=F_{1}+F_{2}-1/G_{1}+\ldots+\ldots+F_{N}-1/\prod_{i=1}^{N}G_{i} \]

Non Linearity Effects

The input-output relationship of non linear active devices can be modeled as:

\[ y(t) = a_1 x(t) + a_2 x^2(t) + a_3 x^3(t). \]

In Analog IC design the non linearity is not that much severe as in the case of RF IC design because in RF the strong interferers cause the nonlinear terms (\(x^2\) and \(x^3\) terms) to have significant magnitude. So the effects of non linearity must also be taken into consideration while designing the RF stages. The effect of non linearity includes Harmonic Distortion, Gain Compression, Desensitization and Blocking, Cross Modulation & Intermodulation.

Matching (Impedance, Power and Noise Matching)

The LNA is the first stage of the receiver so that the input is coming either directly from the antenna or from the output of the band pass filter[3] (the Duplexer). Since the antenna has a characteristic impedance of 50Ω, the BPF also has both input and output impedance of 50Ω for unidirectional power flow and maximum power transfer from the antenna to the BPF and from BPF to the LNA. So the major requirement of the LNA is to provide the matching so that maximum amount of power will be transferred from the source i.e., Power Matching and also allow the flow of power unidirectional i.e., with no reflections which is called as Impedance Matching. Apart from these two being the first stage and the main contributor of the overall noise, the LNA should introduce as minimum noise as possible. The matching designed at the input of the LNA to achieve the minimum NF is called as Noise Matching.
Impedance Matching requires \( Z_{\text{source}} = Z_{\text{termination}} = Z_{\text{in}} \) (LNA)

Power Matching requires, \( Z_{\text{source}} = Z \cdot \text{termination} = Z \cdot \text{in} \) (LNA)

Noise Matching requires source is such that it minimizes the Noise Figure.

### Noise

The two noise sources are related by the correlation admittance. The noise factor, \( F \), is described by Equation:

\[
F = 1 + \frac{R_g}{R_s} + \left( \frac{\omega}{\omega_0} \right)^2 Y_{g00} A B + \frac{4 \text{Re} g_{d03} (1 - \omega^2 L_4 C_{p3})^2}{g_{m1} \alpha_4^2 L_4^2} A ,
\]

Where,

\[
A = \left[ \left( \frac{R_g + \omega L_4}{R_S} \right)^2 + \left( \frac{\alpha L_4 + \omega L_4 - \frac{1}{\omega C_{g3}}} \right) \right] \frac{1}{R_S} .
\]

\[
L_{12} = \frac{L_L}{L_L + L_2} .
\]

\[
B = \left[ 1 + \frac{\omega L_2}{R_s + j \omega (L_s + L_d) + \frac{1}{j \omega C_{g3}}} \right]^2 .
\]

[4]

Resistors \( R_g \) and \( R_{l, g} \) represent the resistances of the transistor M1 gate and the inductor \( L_g \). Since their values are negligible in regards to source resistance \( R_s \), their contribution to the total noise figure is mostly ignored.

### IMPEDANCE MATCHING

In this section, we will see the sensitivity analysis of the proposed LNA design. We mainly focus on the sensitivity analysis of gain and noise figure to the inductors. Suppose we are interested in the sensitivity of the gain to \( L_g, L_s, \) and \( L_d \).

We choose the same variation for \( L_g, L_s, \) and \( L_d \), then we

Calculate \( \Delta L_{\text{in}} \), and \( \Delta \text{gain/gain}[2] \). The gain is in an absolute value, not in dB.

The overall stage transconductance \( G_m \) is

\[
G_m = g_{m1} Q_{in} = g_{m1}/(\omega_0 C_{gs} (R_s + \omega TL_s))
\]

Where \( \omega_0 = 1/[(L_g + L_s C_{gs})^{1/2}] \)

The gain of LNA is \( A_v = G_m Z_L \).
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It shows that the gain is determined by transistor size, \( L_g, L_s, \) and load impedance \( Z_L. \)

**SETTING DC BIAS VOLTAGE**

Before applying the AC signal to the device we have to check the dc bias operating point for amplifier.

![Figure 3: DC Bias operating point](image)

**2. OUTPUT VOLTAGE SWING**

The amplifier swing is one of the important parameters, because application of large signal AC to the gate may cause transistor to change its region i.e. out of saturation.

![Figure 4: LNA output voltage swing](image)

**LNA STABILITY ANALYSIS**

In the presence of feedback paths from the output to the input, the circuit might become unstable for certain combinations of source and load impedances. An LNA design that is normally stable might oscillate at the extremes of the manufacturing or voltage variations, and perhaps at unexpectedly high or low frequencies.
The Stern stability factor characterizes circuit stability as in Equation:

\[ K = \frac{1 + |\Delta| - |S_{11}|^2 - |S_{22}|^2}{2|S_{21}||S_{12}|} \]

\[ |\Delta| = |S_{11}S_{22} - S_{21}S_{12}| < 1 \]

For NMOS in saturation: \( V_{ds} > V_{gs} - V_{th} \), means our amplifier is stable.

**SIMULATION RESULTS**

All the simulations are done using input signal of 1.0 volts for different outputs of 2.4 GHz Low Noise Amplifier for wireless networks using TSMC 0.18um technology.

![Figure 5: Noise figure of the LNA (Minimum Noise Figure is 1.986 dB at 2.4 GHz)](image)

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![Figure 6: Reverse isolation of LNA (More than 12 dB)](image)

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CONCLUSIONS

In this paper a 1.0 volt 2.4 GHz low noise amplifier with inductive design for wireless communication is proposed for low noise and low power consumption for improvement the battery life and improved distance of WLAN applications, using TSMC 0.18um technology. Tanner EDA and Agilent ADS software tools are used to simulate the proposed design.

REFERENCES


[7] Pankaj Sahu, Avinash Gaur “ 2.4 GHz CMOS Low Noise Amplifier’s Gain & Noise Figure Calculation”, National conference ICSSD-12,GGits,Jabalpur,1-2March-2012 page27.
[8] Don T. Lieu, Thomas P. Reduced Current Class AB Radio Receiver Stages Using Novel Superlinear Transistors with Parallel NMOS and PMOS Transistors at One GHz, Weldon University of North Carolina at Charlotte, NC, 28223, USA

[9] Ahmed M. El-Gabaly, Carlos E. Saavedra, A Low-Voltage Fully-Integrated 5GHz Low Noise Amplifier in 0.18µm CMOS, 21 Microwave Integrated Circuits Laboratory, Electrical and Computer Engineering, Queen's University, 19 Union St, Kingston, Ontario K7L 3N6, Canada.


