THOMSON REUTERS ENDNOTE
[Pargaien*, 5.(1): January, 2016] ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

NOVEL DESIGN PARAMETERS FOR CMOS LOW NOISE AMPLIFIER

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ABSTRACT

This paper presents the study of different important parameters which are considered for LNA design. Input/output matching, noise figure, Stability, Bandwidth, Gain, Power dissipation and Linearity are the key factors of any receiver. First and main part of receiver is LNA whose gain should be greater than 15 dB, Noise figure less than 2dB and power dissipation in mw to achieve the desired specification. A number of topologies are available to achieve proper matching and high gain. Different topologies are used to adjust the tradeoff among design parameters like Bandwidth, Linearity NF, Gain, Power dissipation, Impedance matching.

KEYWORDS— Low Noise Amplifier, High Gain, Low power, Noise figure.

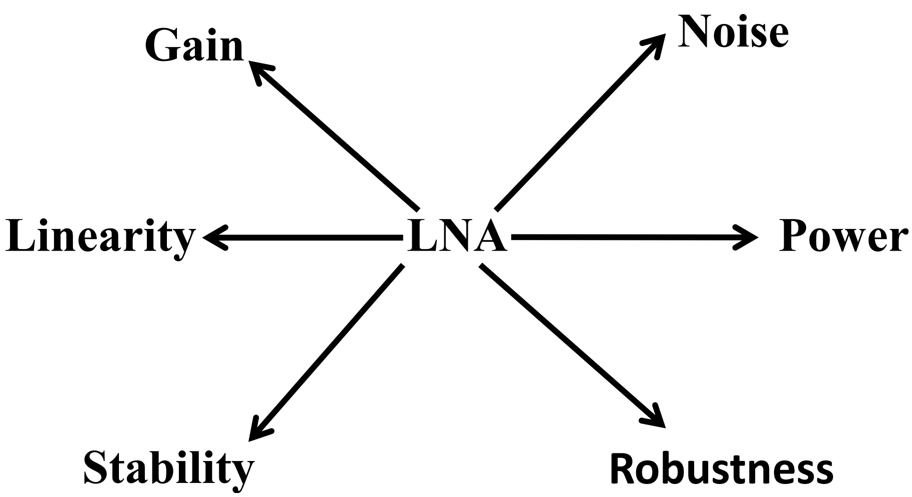
INTRODUCTION (BAYESIAN TECHNIQUE)

The personal communications revolution has triggered a keen interest in the development of low cost and low power RF transceivers for wireless and cellular applications using CMOS technology **[l].** As devices using these technologies like WiFi, Wimax, Bluetooth, Zigbee are continuously shrinking to provide portability and low power consumption to motivate renewable energy.[4]

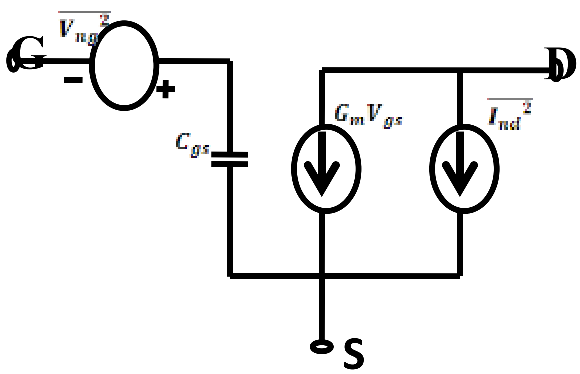
Manufacturers are interested to provide a number of wireless services in a small portable device by using system on chip (SOC) design and by integrating analog and digital blocks. The low noise amplifier (LNA) is one of the most important building blocks in the front end of a wireless communication system. As receiver part is concerned the first and main part is LNA that determines the overall system's noise performance. The other designing parameters of LNA's are input/output matching, noise figure, Stability, Bandwidth, Gain, Power dissipation and Linearity. LNA should provide high amplification to degrade noise figure of upcoming blocks without degrading linearity and by using low power supply.

DESIGN PARAMETERS

Design an LNA is very challenging because of the requirement for high gain, low noise figure, good input and output matching simultaneously. Low power consumption to increase battery life of wireless systems is very necessary. The main design parameters are shown in given figure and discussed in detail.



Noise Figure
The sensitivity of communication system is limited by noise. Analog signals processed by integrated circuits are distorted by different types of noise like internal and external noise.



Mosfet noise model

Noise Figure (NF) is a measure of how much a device (such an amplifier) degrades the Signal to Noise ratio (SNR).

$$\text{SNR\_input[linear]} = \frac{\text{Input\_Signal[Watt]}}{\text{Input\_Noise[Watt]}}$$

$$\text{SNR\_input[dB]} = \text{Input\_Signal[dB]} - \text{Input\_Noise[dB]}$$

$$\text{SNR\_output[linear]} = \frac{\text{Output\_Signal[Watt]}}{\text{Output\_Noise[Watt]}}$$

$$\text{SNR\_output[dB]} = \text{Output\_Signal[dB]} - \text{Output\_Noise[dB]}$$

The **noise factor** F of a system is defined as:

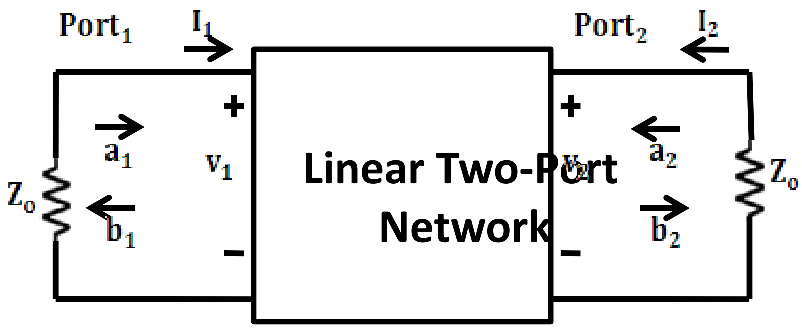
$$F = \frac{SNR_{in}}{SNR_{out}}$$

where, SNR_{in} and SNR_{out} are the input and output signal-to-noise ratios, respectively.

ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785

$$\text{Noise Figure} = 10\log(F)$$

INPUT/OUTPUT MATCHING



Matching at the input and output terminal is required to minimize the return loss or to provide isolation. Input return loss means how much part of input is return back at the input itself. It can be defined as S_{11}.

$$S_{11} = (b_1/a_1) \qquad \text{where } a_2 = 0$$

Output return loss means how much part of output is return back at the output itself. It can be defined as S_{22}.

$$S_{22} = (b_2/a_2) \qquad \text{where } a_1 = 0$$

The value of these two S-parameters should be low. A very less amount of input is reflected back in addition with less amount of noise is introduced. The role of output matching is to suppress the part of output return back. The LNA plays an important role of suppressing noise to improve signal strength.

Gain

The gain of a device is its ability to amplify the amplitude or the power of the input signal. It is defined as the ratio of the output Power to the input power.

$$\text{Power Gain(dB)} = 10\log\left(\frac{\frac{Vout^2}{R_{out}}}{\frac{Vin^2}{R_{in}}}\right)$$

In terms of voltage

$$\text{Voltage gain (dB)} = 20\log\left(\frac{V_{out}}{V_{in}}\right)$$

There are two criteria that affect the gain performance of any RF amplifier: the RF amplifier itself and the input output matching network. Power gain is generally defined as the ratio of power actually delivered to the load to the power actually delivered by the source.

However, as simple as that may seen, this definition is not entirely relevant and is difficult to quantify since the source impedance in turn is difficult to specify. Thus instead we take the ratio of average power delivered to the load to maximum available average power from the source-Transducer Gain, and the ratio of maximum available average power at the load to maximum available average power from the source-Available Power Gain.

Stability

Stability may be the most important property of any system. If the system is not stable, then it may be prone to uncontrollable oscillations which can internally damage the system.

ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785

A brief period of oscillation could permanently damage a circuit because of large voltages and power levels that might be generated, and depending on the system application, it could be hazardous to system operators. In the case of an LNA however, instability can cause internal circuitry damage and ensure that the amplifier will not work.
Oscillation is possible in this circuit if a signal incident on the input or output port of the transistor is reflected with a gain >1. That is, if

$|\Gamma_{in}|>1$ or $|\Gamma_{out}|>1$

the circuit may become unstable and oscillate. The Rollett stability factor, denoted by k, is given by the following expression,

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

where, $|\Delta| = |S_{11}S_{22} - S_{12}S_{21}|$

An amplifier is unconditionally stable if $K > 1 \; and \; |\Delta| < 1.$

Linearity

A system is said to be linear if output of a system follow its input linearly. Linearity is a key parameter of the LNA because it specifies how much, any LNA can maintain linear operation even in the presence of large input signals. The equation below expresses the non-linear power series of two-port network.

$$S_0 = a_1 S_1 + a_2 {S_1}^2 + a_3 {S_1}^3$$

Where a_1,a_2,a_3 are constants. The measurement of linearity is usually done by using two parameters IIP3 and P1dB. The following sub-section briefly introduces these parameters.

Third - order Intermodulation Intercept Point Referred to the Input (IIP3)

While noise puts a limit on the lower level of the signal which can be received, an upper limit is imposed by the finite power supply voltage used for active circuits and the nonlinear transfer characteristic inherent in the semiconductor devices. As the input signal increases in amplitude, these limitations cause distortion, compression and saturation of the signal being processed by the amplifier. Intermodulation distortion caused by nonlinearities of the active components can result in spurious distortion.
Even-order intermodulation products are normally found at frequencies well above or below the signals which generated them and are usually of little concern. The odd-order distortion produced by an LNA can give rise to distortion products which can mask or interfere with the desired signal. The third-order products are the most significant and can lie very close to the signals which generated them in frequency. Third-order non-linearity is customarily characterized by a specification called the third-order intercept point. Mathematically, IIP3 is obtained as in equation

$$IIP3 = \sqrt{\frac{4}{3}\left|\frac{a_1}{a_3}\right|}$$

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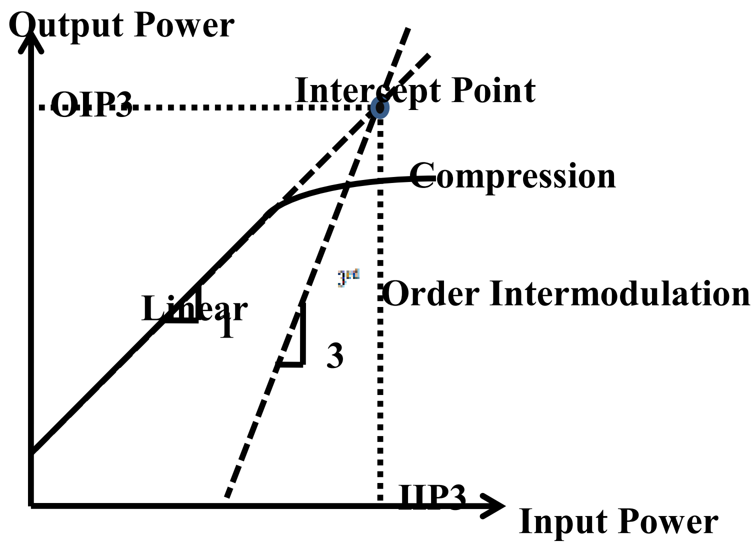

Fig: Amplifier power output versus power input characteristics

The given figure illustrates the relationship between the fundamental and Intermodulation distortion products generated by an amplifier for two equal amplitude input signals at different frequencies. The upper line shows the relationship between the fundamental output and the input signal (i.e., the gain), which is linear (1: l slope) at low input power levels, but rolls-off or compresses at high input power levels.

The third order intermodulation lies well below the fundamental or linear curve at lower input powers, but increases with a 3:1 slope for increasing input power. The fundamental and Intermodulation distortion curves can be extrapolated to a point of intersection, which is called the third order intercept point. The intercept point can be referred to either the input or output power axes; then respective points are known as the third-order intercept point referred to the input (IIP3) or to the output (OIP3).

P1dB

It is known that the third order term in the power series can either cause gain compression or gain expansion depending on its sign. If we assume that the sign between a_1 and a_3 are different, then gain compression will occur and compression point can be measured. P1dB is a measure of the power of the input signal such that it causes the third order non-linearity to decrease the linear gain by 1 dB. Therefore mathematically it is obtained as:

$$20\ \log\left(1+\frac{3a_3}{4a_1}S_1{}^2\right) = -1\ \text{dB}$$

Power Dissipation

The LNA typically exhibits a direct trade-off among noise, linearity and power dissipation
LNA consumes a small fraction of the overall power.

CONCLUSION

All the design parameters used for designing LNA are studied. S-parameters are used to define input/output return loss, gain of LNA. Several designs with their simulated and manufactured results are also studied and it was observed that the key factors of LNA are high gain, low noise figure, large bandwidth and low power dissipation.

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