Design Challenges and Performance Parameters of Low Noise Amplifier

S. S. Gore
Department of Electronics & Tele-communication, SITRC Nashik, (India)

G. M. Phade
Department of Electronics & Tele-communication, SITRC Nashik, (India)

Abstract- Wireless communication system is an integral part of day today communication. For effective wireless communication, faithful transreceipition of the signal is required. It can be achieved by careful design of the receiver circuit. Hence there is wide scope of improvement in different blocks of the receiver. LNA is the first block of any receiver in communication system. At the receiver side in communication link weak signal should be amplified for further processing at minimum noise level. Amplification of weak signal and attenuation in noise level is a key role of LNA.
LNA design meets different challenges because of its simultaneous requirements like good transistor selection, suitable DC biasing network, high gain, low noise figure, good input-output matching circuits, high linearity and good stability. All these design parameters are equally important and always independent on each others. To simplify the design and analysis of analog circuits, it is useful to abstract circuit blocks into two-port networks. System analysis for two port network can be achieve using Impedance (z), Admittance (y), Hybrid (h) or Scattering parameters (s). Scattering parameters (s) are more applicable at RF due to its ability to express in terms of powers, are suitable for high frequencies and possibility of complete transmission.
This paper highlights the design challenges, performance parameters or all the necessary steps for LNA design.

IndexTerms-ADS(Advanced Design System), Conditional Stability, Impedance Matching, LNA(Low Noise Amplifier), Smith Chart, S-parameters.

I. INTRODUCTION

Nowaday's effective wireless communication plays an important role in different communication systems like cellular phones, pagers, WLAN(Wireless local area networks), GPS, handhelds and short-range data communication devices employing bluetooth [1].
LNA is the first active building block and special type of electronic amplifier used in communication systems to amplify very weak signals captured by an antenna at receiver. The received signal is typically filtered by BPF and then amplified by an LNA shown in fig.1.

II. BLOCK DIAGRAM

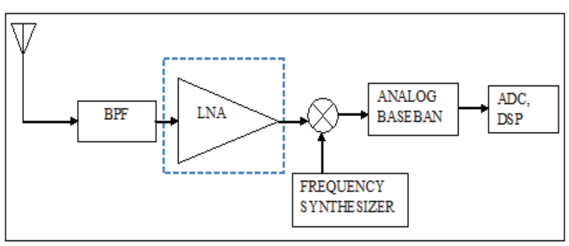


Fig.1 Typical super heterodyne receiver [7]

LNA should be stable i.e. should not be generate unwanted signals and the performance should remain constant with respective to time this is one of the requirement of the LNA. A further requirement of LNA is that, amplifier should provide good reverse isolation and input and output match are also important [6].
Output of the LNA is given to the analog base-band block by mixing with a LO (Local Oscillator).The main function of the this block is demodulate the signal. After being demodulated then these signal is applied to an ADC (Analog to Digital Converter) which digitizes the analog signal. In last stage digital signal is then processed in a

DSP (Digital Signal Processing) [2]. LNA can be use as a two port network. Performance measures of the two-port network should provide transistor selection, DC biasing network, gain, noise figure, input and output match, linearity, and stability that are important in the design of LNA [1].

III. DESIGN PARAMETERS

It is impossible to design a LNA without trade-offs.
Design procedure or steps are different according to designer or receiver but commonly or generally used steps are as follows:

A. Selection of device

Transistor selection is the first and most important step in a LNA design. Examination of a datasheet is a good starting point in a transistor evaluation for LNA
design. The transistor should exhibits or satisfies all the design parameters at the lowest possible current and lower power consumption while working with higher frequency. The transistor selection for the LNA also depends upon the desired frequency range. The BJT is used up to certain frequency due to their structure and manufacturing process but FET (CMOS or HEMT) can be used for higher frequencies. GaAS FET are mostly used for frequency ranges up to several GHz [3]. MESFET and HEMT find applications up to 60 to 70 GHz and HEMT even up to 200 GHz [4].

B.DC Bias Network

The purpose of a good dc bias design is to select the proper Quiescent point (Q-pt.) and hold the constant over variations in transistor parameters with temperature changes. A resistor bias network can be used with good results over moderate temperature changes. However, an active bias network is usually preferred for large temperature changes [5]. Designer will not be satisfied if there is design of poor dc bias network.

C. Selection of the Gain

Fig. 2 illustrates the different powers coming in and out of an amplifier and the different gains. There are three power-gain definitions that are used in RF applications.

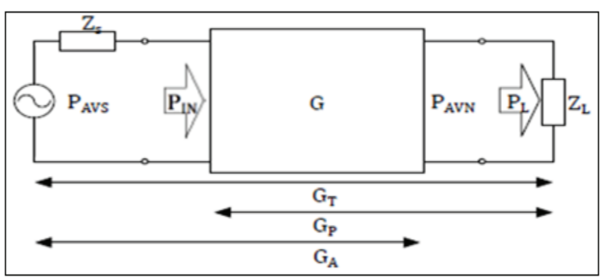


Fig.2 Gain calculation [7]

Power-gain definitions:
P_{AVS} - Power available from source
$P_{AV\,N}$ - Power available from network
P_{IN} - Power delivered to the input
P_L - Power delivered to the load

Power gain = $G_P = P_L/P_{IN}$ 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 some active circuits are strongly dependent on Z_S. [10]

Available gain = $G_A = P_{AVN} / P_{AVS}$ 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. [10]

Transducer power gain = $G_T = P_L / P_{AVS}$ 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. [10]

Conversion gain is another gain definition used in RF-receivers which is the ratio between the intermediate frequency (IF) power at the output of the mixer and the available power at the RF input of the receiver. Theoretical value of the gain should be infinite and practical value should be maximum. When relation between input-output is linear then it is called as linear gain. However all RF& IF circuits are inherently non-linear [3].

D. Noise Figure

NF is a measure of SNR degradation as the signal traverses the receiver front-end. Mathematically, NF is defined as the ratio of the input SNR to the output SNR of the system. NF may be defined for each block as well as the entire receiver.

Generally it is not possible to obtain minimum noise figure and maximum gain for an amplifier, so some sort of compromise must be made. This can be done by using constant gain circles and circles of constant noise figure to select functional trade-off between noise figure and gain. Smith chart plays vital role for this. The constant gain circles and circles of constant noise figure can be drawn on the smith chart and by observing them the input matching network for minimum noise figure can be designed [1]. The input matching network in designed for minimum NF and output matching network in designed for maximum gain. The quality of the termination is defined by the reflection coefficient Γ.

Noise figure parameter, N is given as

$N = [(F-F\ min)/(4Rn/Z_0)]\ x\ |1+\Gamma\ opt|^2$ (1)

Center and Radius of noise figure circle is given as

$C_F = \Gamma\ opt / (N+1)$ (2) $R_F = [N\ (N+1-|\ \Gamma\ opt\ |2)]^{1/2} /(N+1)$ (3)

NF is also a function of the source admittance or impedance driving by the system

$F=Fmin + Rn/Gs\ |Ys-Yopt|^2$ (4)

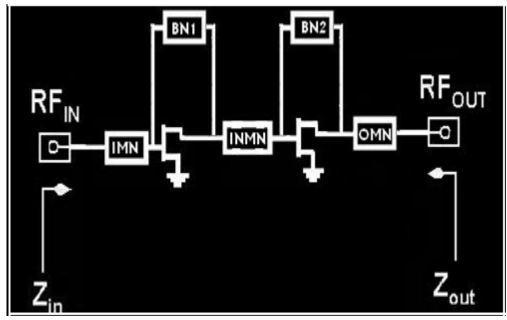
From equation (4) ,Ys = Gs + jBs, represents source admittance presented to the two-port network, Yopt= Gopt + jBopt, is represents source admittance that results in the optimum NF, Fmin represents minimum NF of the network, Rn is the equivalent noise resistance of the two-port network, Gs is the real part of the source admittance and Rn/Gs is represents how dependent the system NF is on departures from optimum conditions.[6]

E. Impedance Matching

Input and output impedance matching network is the main and important in LNA design because often times the system performance can be strongly affected by the quality of the termination. General diagram of impedance match shown in fig 3. and commonly used matching networks are LC and RLC shown in fig.5.

Antenna and BPF are presents before the LNA. Frequency responses of these will deviate to LNA, from its normal operation. Undesirable reflections from the LNA back to the antenna and BPF must be avoided. Hence quality of termination should be good to avoid the undesirable reflections. The quality of the termination is defined by the reflection coefficient Γ. An impedance match is when the reflection coefficient is equal to zero and occurs when ZS = ZL.

There are two types of impedance matching. The first type of impedance matching concerns with minimizing signal reflection from the load back to the source. The second type of matching concerns with maximum power transfer from the source to the load [11]. Hence it is often referred to as power matching. Power matching occurs when the load impedance is the complex conjugate of the source impedance. Conditions for impedance matching and power matching matching are equal shown in fig 4.



IMN- Input Matching Network
INMN- Inter stage Matching Network
OMN- Output Matching Network
BN- Bias Network

Fig. 3. General diagram of impedance match [2]

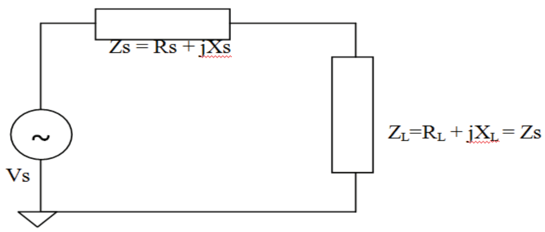


Fig. 4 Condition for impedance and power match

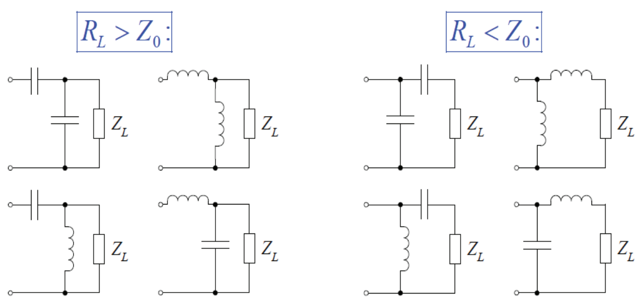


Fig. 5 Matching networks [9]

F. Linearity

Linearity is a key requirement in the design of an LNA because the LNA must be able to maintain the linear operation in the presence of a large interfering signal.There are many ways to evaluate the linearity of the LNA but to measure the third-order intercept point (IP3) is the most commonly used method. The IIP3 is obtained either graphically or using usual method. IIP3 is obtained graphically by plotting the output power versus the input power which is shown by logarithmic scale in fig. 6. Two curves are drawn, one for the linearly amplified signal at an input tone frequency, other for a nonlinear product. Both curves are extended with straight lines of slope 1 and 3. The point where the curves intersect is the third-order intercept point.

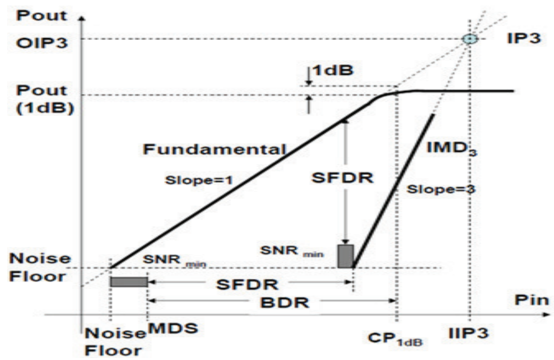


Fig. 6 Measurement of IIP3 [7]

Linearity is the criterion that defines the upper limit of detectable RF input power and sets the dynamic range of the receiver. The linearity of an amplifier is described in terms of 1-dBcompression point (P1dB) and IIP3.The saturation effect begins once the main component of the output signal stops following the input signal with ideal ratio. This is known as 1-dBcompression point and is defined as the level at which the gain drops by 1dB. For IIP3,the inter modulation products will increase in amplitude by 3dB when the input signal is raised by 1-dB.

G. Stability

The stability analysis is the last and important step in the LNA design. The stability of an amplifier is a very important consideration in a microwave circuit design. Stability or resistance to oscillation in a microwave circuit can be determined by the S-parameters. Oscillations are possible in a two-port network if either or both the input and the output port have negative resistance. This condition occurs when the magnitude of the input or output reflection coefficients is greater than one, $|\Gamma in|>1$ or $|\Gamma out|>1$.
There are two types of amplifier stability, unconditionally stable and conditionally stable. If the real part of the input and output impedances of the amplifier is greater than zero for all passive load and source impedances then amplifier is said to be conditionally stable or potentially unstable. The stability test should be done for every frequency in the desired range.
Fig.7 shows the source, load, input, and output reflection coefficients for a two-port network.

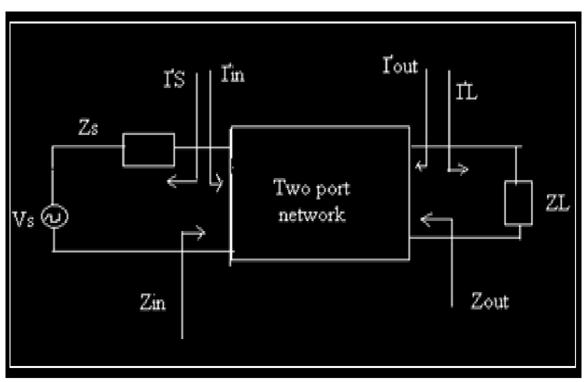


Fig.7 Stability of two-port network [11]

In terms of reflection coefficients, the necessary conditions for unconditional stability at a given frequency are:

$$|\Gamma S| < 1 \quad \text{and} \quad |\Gamma L| < 1 \qquad (5)$$

$$|\Gamma in| = |S_{11}+(S_{12}.S_{21}.\Gamma_L) / (1-S_{22}.\Gamma_L| < 1 \qquad (6)$$

$$|\Gamma out| = |S_{22}+(S_{12}.S_{21}.\Gamma S)/(1-S_{22}.\Gamma S| < 1 \qquad (7)$$

$K = (1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2) / (2|S_{21}| * |S_{12}|) > 1$ (8)

$\Delta = S_{11}*S_{22} - S_{12}*S_{21} < 1$ (9)

S-parameters provided by the manufacturer of the transistor will support in stability analysis of the LNA circuit. Two main methods exist in S-parameter stability analysis numerical and graphical. Numerical analysis consists of calculating a term called Rollett stability factor K and Intermitted quantity called delta (Δ).When the K >1 the circuit will be unconditionally stable for any combination of source and load impedance. When K <1 then circuit is potentially unstable and oscillation may occur with a certain combination of source and/or load impedance presented to the transistor. The K factor represents a quick check for stability at given frequency and given bias condition.[8]

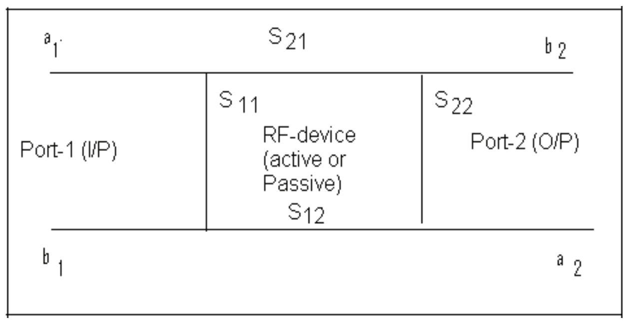


Fig.8 Graphically representation of two-port network

Representation of two-port network in the form of equations are:

$b_1 = S_{11}a_1 + S_{12}a_2$ and (10)

$b_2 = S_{21}a_1 + S_{22}a_2$ (11)

Where as :
Input Return Loss (S_{11}) = b1/a1
Output Return Loss (S_{22}) = b2/a2
Gain (S_{21}) = b2/a1
Isolation (S_{12}) = b1/a2

Each and every transistor having separate S-parameter file designed or given by the designer's. Which includes all the parameters mentioned above in proper sequence including frequency, bias conditions (Vds, Id), ratio of Rn/Z0 , reflection coefficient (Γ) and last updated information.

IV. CONCLUSION

LNA is a crucial part in RF receiver. All design parameters reflect the quality of LNA. LNA is designed for amplify the weak signals , attenuate the noise level and providing an appropriate working condition to the mixer. This paper highlights the design challenges, performance parameters or all the necessary steps for LNA design. Smith chart is a useful tool in impedance matching circuit design. Scattering parameters (s) are more applicable at RF due to its ability to express in terms of powers, are suitable for high frequencies and possibility of complete transmission.

The scope of this paper or project to be simulate the LNA using different tools like Cadence, Spice ,QUCS(Quit Universal Circuit Simulator), Microwind or Agilent-ADS-Simulation tool by applying microwave frequency. ADS-Simulation tool is powerful for the circuit or LNA design at RF frequency. Another scope of this project is to design the LNA for GPS (Global Positioning System) application for frequency 1.52GHz and SiGe-BiCMOS technology can be preferred for high frequency applications or for fabrication of LNA.

REFERENCES

[1] Ratnaparkhi Vivek, S.B.Deosarkar and L. Punitha "An Effective Design of Two Stage Low Noise Amplifier for WiMAX", PP.1-4, May-2008,

[2] M. Challal, A. Azrar and D. Vanhoenacker, "K- Band Two Stages Low Noise Amplifier Design in Microstrip Technology", 8th International Multi-Conference ,Tunisia , PP.22-25, March- 2011. E-mail: mchallal@ieee.org
[3] Varish Diddi , Kumar Vaibhav and Animesh Biswas, "Design of Low Power LNA for GPS Application", International Conference on Circuits, System and Simulation, IACSIT Press, Singapore, vol.7, March-2011.
[4] D. K. Shaeffer and T. H. Lee, "A 1.5-V, 1.5-GHz CMOS Low Noise Amplifier", *IEEE* Journal Solid-State Circuits, vol.32, No.5, PP. 745-759, May2007.
[5] Dan Zhang and Wei Wu,"Circuits, System and Simulation,"International Conference, Singapore- IPCSIT vol.7. 2011.
[6] J.P.Silver, "MOS- Common source LNA-Design Tutorial", www.rfic.uk, Email:john@rfic.co.uk PP. 1-11.
[7] S. S. Gore and G. M. Phade, "Design challenges of Low Noise Amplifier" A conference for Post Graduate Students in Electronics / Electronics and Telecommunication Engg. (ePGCON-2013), PP.1-6, 20-21March-2013.E-mail:- shukra2007@gmail.com
[8] T. H. Lee, "The Design of CMOS Radio Frequency Integrated Circuits", PP.221-225,334- 356 and 364-400. Press-2010.
[9] Reinhold Ludwig and Pavel Bretchko, "RF Circuits Design Theory and Applications", ISBN: 0-13-095323-7,PP. 37-93,101-130 and 201-263. Press-2008.
[10] David M.Pozar,"Microwave Engineering",Third Edition, ISBN: 978-81-265-1049-8, PP. 64-69,542-545 and 570- 572, Press-2010.
[11] J. Rogers and C. Plett, "Radio Frequency Integrated Circuit Design", ISBN: 1-58053-502- x,PP.1 - 93,141-189 and 319-343. Press-2003.