S-Parameter Comparison of Common Source and Common Gate Low Noise Amplifier

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ABSTRACT
Scattering Parameters or S-parameters are complex numbers which tells us about how voltage waves are propagating in the radio-frequency (RF) environment. In this paper common source and other will be the cascoded common gate topologies have been analyzed. Scattering parameter analysis shows that gain and impedance matching is better for CG LNA. S-parameter is an important tool for LNA design, following information can be obtained a) The frequency b) characteristic impedance (often 50 Ω) c) The allocation of port numbers d)Operating environment such as temperature, control voltage and bias current.

Keywords
LNA, Radio Frequency, Gain, Scattering parameters.

1. INTRODUCTION
An LNA is a key component used in communication system. LNA is placed right to antenna (detection device) in the receiver side. LNA amplifies very weak signals captured by an antenna. Role of LNA is to amplify the signal shown in fig 1. Quality of signal degrades due to availability of noise in environment and electronic component.
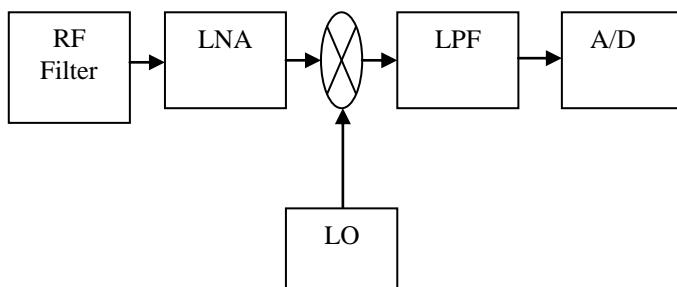

Fig.1. RF Receiver

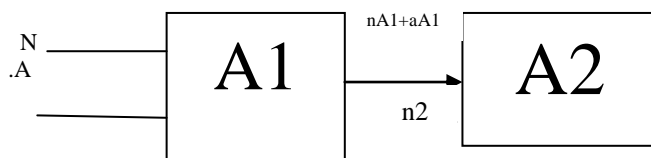Fig 2 shows a normal amplifier has gain A1 amplifies the signal as well as input noise present.

Fig2. Amplifiers in series

S/N at the input is given as a/n. Noise is amplified by factor A1, another noise component n2 get added due to subsequent

stage. SNR at input of 2nd stage = aA1/(nA1+n2) if gain of 1st stage is very large.

$$SNR = a/n \qquad (1)$$

It shows if gain if 1st stage is large than noise of 1st stage is important, subsequent stage noise is irrelevant because subsequent stage adds small quantity of noise while 1st stage already has amplified noise, So subsequent system noise can be ignored. A low noise amplifier does not add much noise but amplify. An LNA add very low noise by own but amplify everything as shown in fig3.
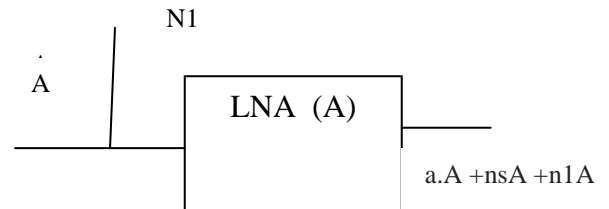

Fig3. Low noise amplifier Noise Analysis

$$SNR = a.A / (n1.A+ns.A) \qquad (2)$$

n1= input referred noise
ns =noise source
a= signal
The four most important parameters in LNA design are:

1. Gain Should Be High
2. Noise Figure NF Should Be Low
3. Non-Linearity
4. Impedance Matching: Input And Output Impedance Should Be Matched

Impedance Matching:- Input impedance of LNA should be match with impedance of antenna. Impedance matching is required for better reception (shape) of signal. If impedance is not matched signal get distorted. Also, maximum power transfer theorem says maximum power will be transfers if source impedance is conjugate of input impedance. Similarly output impedance of LNA should be matched with subsequent stage to conserve shape of signal .
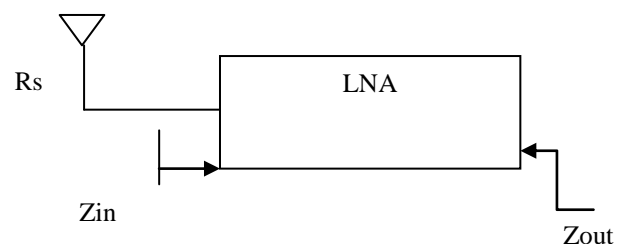

Fig. 4. Impedance Matching

As in this Fig 4 Zin and Zout are two Impedances on input and output respectively and there values should be matched accordingly. As Rs should be equal to Zin and Zout value should be equal to next stage impedance.

2. SCATTERING PARAMETERS

Scattering Parameters or S-parameters are complex numbers which tells how voltage waves are propagating in the radio-frequency (RF) environment. They characterize the complete RF behavior of a network in Matrix form. S-parameter used to represent 2-port electrical equivalent circuit of RF/microwave. For a two-port device there are four S parameters S11, S21, S12, and S22. S11 and S22 are simply the forward and reverse reflection coefficients, with the opposite port terminated in Z0 (usually 50 ohms.) S21 and S12are forward and reverse gain.

The properties of the individual components and those of the physical structure of the circuit are effectively derived from the equation and circuit analysis is greatly simplified. The characteristics of the 2-port is represented by a set of four S-parameters[1,2]:

S11: Input Reflection Coefficient

S12: Reverse Gain Coefficient

S21: Forward Gain Coefficient

S22: Output Reflection Coefficient

S-parameters are measured under matched and mismatched conditions. This is why S-parameters are favored in microwave applications. S-parameters are both frequency- and system impedance dependent so although manufacturers typically supply S-parameter data with their devices it is not always applicable. Under such circumstances, it becomes necessary to measure the parameters.

We can characterize the behavior of Two port network with various methods. In case when frequency is low we can use parameters like Y, Z, H, T and ABCD. These parameters works under open and short circuit conditions to give information about a linear electric network. But these parameters are tough to realize in case of high frequency models. In radio frequency range, scattering parameters (S-Parameters) is normally employed. It uses matched load termination and the measurements are based on incident and reflected waves [3].

Fig5 shows a two-port network, where a_1 and a_2 are incident waves; b_1 and b_2 are reflected waves. Their relation is expressed as[2]:

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} = [S] \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \qquad (3)$$

The [S] matrix is called scattering matrix.

$S_{11} = \frac{b_1}{a_1} | a_2 = 0$ With matched output port

$S_{12} = \frac{b_1}{a_2} | a_1 = 0$ With matched input port

$S_{21} = \frac{b_2}{a_1} | a_2 = 0$ With matched output Port

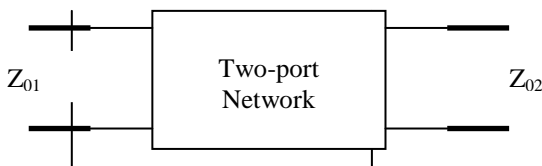$S_{22} = \frac{b_2}{a_2} | a_1 = 0$ With matched input port

Fig 5. Two Port Network

Conclusively, the S-parameters relate the four waves in the following fashion[1,2]:

$$b_1 = S_{11}a_1 + S_{12}a_2 \qquad (4)$$
$$b_2 = S_{21}a_1 + S_{22}a_2 \qquad (5)$$

3. S-PARAMETER ANALYSIS

The S-Parameter analysis is used to compute scattering and noise parameters for 2-port circuits that exhibit frequency translation. S-Parameter analysis is used for small-signal and linear noise analyses, where the circuits are linearized around the DC operating point. Such circuits include LNAs, mixers, samplers and other similar circuits. Cadene spectre used to do SP analysis and noise parameters in frequency-converting circuits. SP computes noise figure, input referred noise, equivalent noise parameters, and noise correlation matrices. For the SP analysis, it is required to specify the input and output ports and the range of sweep frequencies. SP analysis for the LNA provides gain and matching parameters measurements [4].

1. S11, input reflection coefficient
2. S21, forward gain
3. S12, reverse gain
4. S22, output reflection coefficient
5. GT, transducer power gain
6. GP, operating power gain
7. GA, available power gain

By setting the input and output noise port, I can plot NF and NF_{min} with respect to frequency. The Stern stability factor K_f and Δ can be plotted with respect to frequency.

S-Parameter analysis of Common Source Low Noise Amplifier:

The Common Source topology is most basic one in case of LNA topologies. Main reason for choosing this topology was it can give high voltage gain and that's the main requirement in case of LNAs. Apart from high gain it comes with some problems like high output impedance. Though its not as such big issue as compare to its main drawback which is limited high frequency response and it because of presence of C_{gd} i.e. capacitance present between the gate and drain terminal in MOS[5]. we can see this in the small signal circuit model of Fig7. As we are saying its having high gain as we can see in value of S_{21} but its value is negative near to 22dB. Because as basic common source is having phase shift of the 180 and it will completely turn value into opposite phase Thus we will be having negative value of the S_{21}.
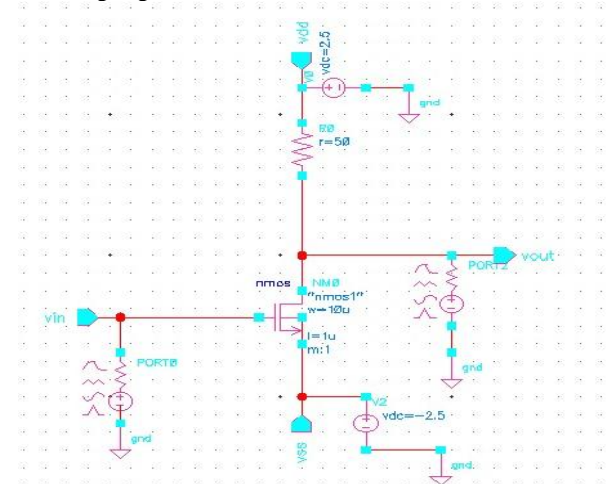

Fig6. Common Source Amplifier

To avoid the problem of capacitance we can use Miller's Theorem, means we will split the capacitance Cgd into two capacitances given by at the $C_{gd}.(1 - A_v)$ value at the input and $C_{gd}.\left(1 - \frac{1}{A_v}\right)$ value at the output, in these expressions A_v is the voltage gain of the amplifier [6].as we said gain will be high and negative then capacitance between gate and source will become very large also and it will result in a low high frequency pole given by
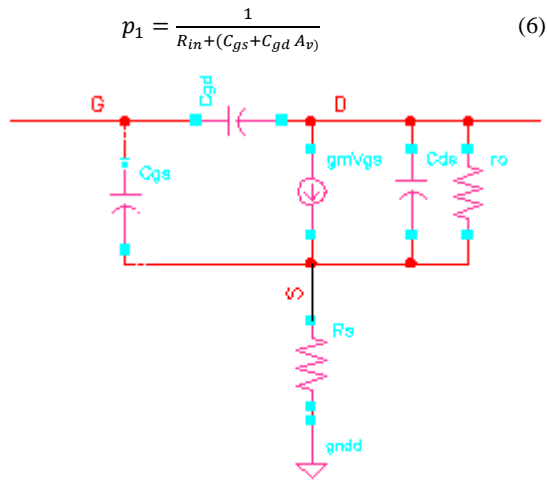
$$p_1 = \frac{1}{R_{in}+(C_{gs}+C_{gd}\,A_v)} \qquad (6)$$

Fig7. Small signal Model of Common Source

Gain is decreasing along with frequency as we told earlier due to high frequencies there is large effect of miller effect and that leads to inefficiency of CS amplifier to work on High Frequency. In order to make this circuit work on high frequency at least near to 900MHz this circuit was modified and in this modified circuit effect of these characteristics on the performance was less. Simulation result of common source s parameter shown in fig 8
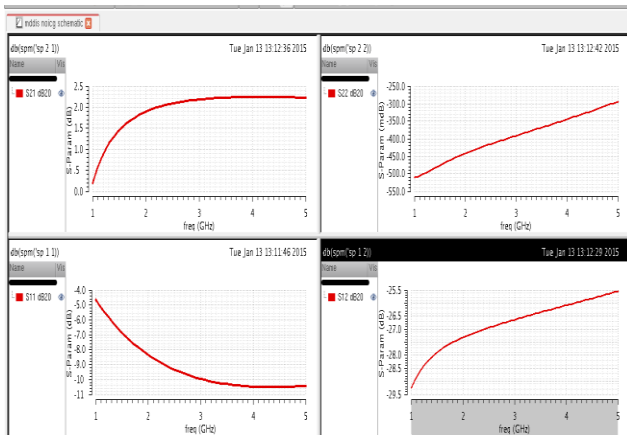

Fig8. S-parameter Analysis of Common Source

S parameter analysis of Cascoded Common gate with low noise:

The parallel RLC input matching network of the CGLNA limits its noise and gain performance. At resonance, the CGLNA's input impedance is $1/g_m$. We wished to improve the NF of the Common Gate amplifier using shunt inductor. As reported NF of conventional basic Common Gate amplifier is nearly 5dB, with this design we will be getting noise figure of 2.6dB.On-chip inductor L_d acts as output impedance. Capacitors C_b are bypass capacitors. On-chip inductors L_s are used to tune out the total capacitances at the source nodes including pad capacitances[7]. The second stage of the LNA acts as an output buffer. It has 50 Ω output impedance to match with the 50 Ω load of the measuring equipment.
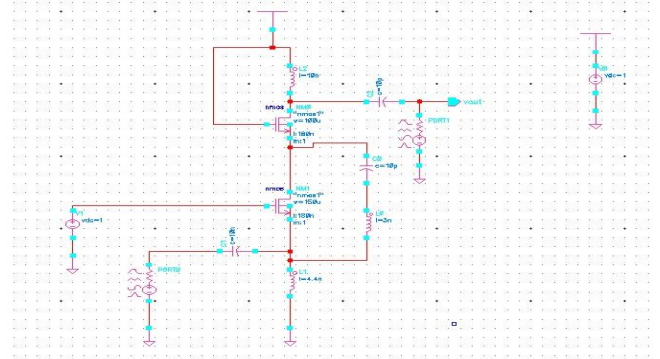

Fig9. Cascoded Common Gate schematic

Circuit given in Figure 9 is proposed for better noise figure performance of the common gate using cascoded circuit as well as C_b and L_a are used to control the noise figure. With the help of small signal analysis we can calculate different values of our capacitors and inductors and then we will simulate that circuit in the Cadence to check the values. Simulation result of common source s parameter shown in fig 10.
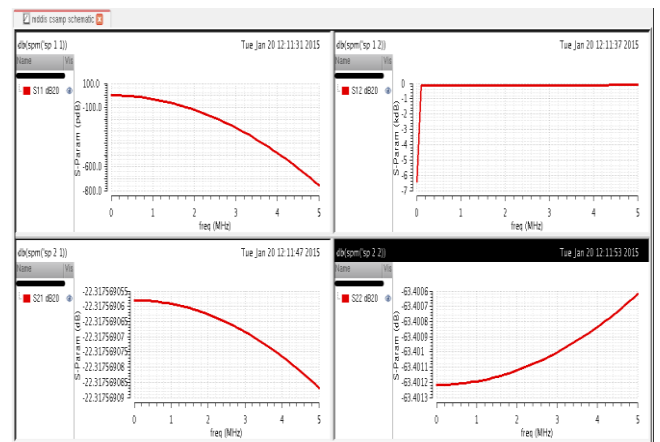

Fig10. S-parameter Analysis of cascoded Common Gate

4. CONCLUSION
The LNA is designed in CMOS 180nm technology. Common source amplifier is having fewer values and moreover values are not optimum due to working of basic common source amplifier, on the other hand results of Cascoded Common gate is very much on the required side as S_{21} is giving reasonable gain as circuit is much dependent on noise reduction. S_{11} and S_{22} are providing good values for input and output matching as compare to the common source amplifier. S_{12} is providing better reverse isolation rather than that of common source amplifier.

TABLE I

S-Parameter	Common Source Topology	Cascoded Common Gate Topology
S_{11}	-150 pdB	-10dB
S_{12}	-1kdB	-27dB
S_{21}	-22 dB	2.5 dB
S_{22}	-63 dB	-.45dB

Result for S11 is -10dB and the frequencies are at 2.4GHz while S21 is observed 2.5dB and these values show that the resistance at the input of LNA is matched. In the end if we want to look at future, these LNA's can be modified according to user's requirements and in communication purposes they have a highly rated future.

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