Low Noise Amplifier at 5.8GHz with Cascode and Cascaded Techniques Using T-Matching Network for Wireless Applications

Ibrahim A.B, Hussain M.N, Othman A.R,Johal.M.S
Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka
abupsp@gmail.com,rani@utem.edu.my

Abstract

This paper present a 5.8 GHz low noise amplifier (LNA) design with cascode and cascaded techniques using T-matching network applicable for IEEE 802.16 standard. The amplifier use FHX76LP Low Noise SuperHEMT FET. The design simulation process is using Advance Design System (ADS) software. The cascode and cascaded low noise amplifier (LNA) produced gain of 36.52dB and noise figure (NF) at 1.2dB. The input reflection (S_{11}) and output return loss (S_{22}) are -21.1dB and -27.7dB respectively. The bandwidth of the amplifier is more than 1GHz. The input sensitivity is complying with the IEEE 802.16 standards.

Keyword: Cascode and Cascade LNA, Radio Frequency, T -Matching Network

1. Introduction

The number of system that use radio links is increasing quickly. At the same time, the number of standards for such systems is increasing very quickly as well. To make this possible the number of frequency band dedicated for wireless communication has also increased [1]. WiMAX, which is short for Worldwide Interoperability for Microwave Access, is a novel wireless communication technology. It is an attractive technology due to the high transmitting speed (up to 70Mbps) and long transmitting distance (up to 30 mile). The system bases on IEEE 802.16 standards and uses several bands (2.3-2.7 GHz, 3.4-3.6 GHz and 5.1-5.8GHz) to transmit data. The design of the front-end low noise amplifier (LNA) is one of the challenges in radio frequency (RF) receivers, which needs to provide good input impedance match, enough power gain and low noise figure (NF) within the required band [2].

Many high gain amplifier topologies have been proposed as a way to satisfy the requirement for low power dissipation as well as good performances. The cascode with cascaded techniques to produces results in a higher bandwidth and gain, due to the increase in the output impedance, as well as better isolation between the input and output ports. [3-7].In this work, LNA with cascode and cascaded techniques is proposed.

2. Theoretical

Basically, for the design of an amplifier, the input and output matching network are designed to achieve the required stability, small signal gain, and bandwidth. Super high frequency amplifier is a typical active circuit used to amplify the amplitude of RF signal. Basic concept and consideration in design of super high frequency amplifier is presented below. For the LNA designed, the formula and equation were referred to [4]. Figure 1, shows a typical single-stage amplifier including input/output matching networks.

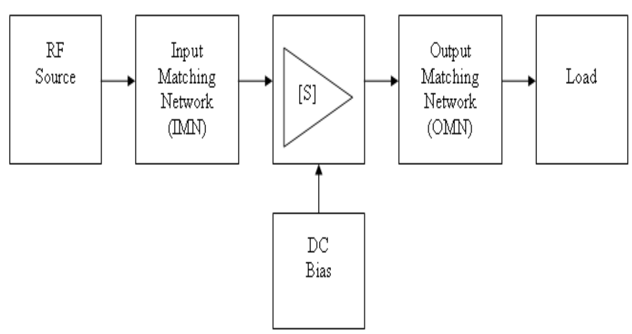

Figure 1: Typical amplifier designed

The basic concept of high frequency amplifier design is to match input/output of a transistor at high frequencies using S-parameters frequency characteristics at a specific DC-bias point with source impedance and load impedance. I/O matching circuit is essential to reduce unwanted reflection of signal and to improve efficiency of transmission from source to load [4-5].

A. Power Gain

Several power gains were defined in order to understand operation of super high frequency amplifier, as shown in Figure 2, power gains of 2 port circuit network with power impedance or load impedance at power amplifier represented with scattering coefficient are classified into Operating Power Gain, Transducer Power Gain and Available Power Gain [4-5].

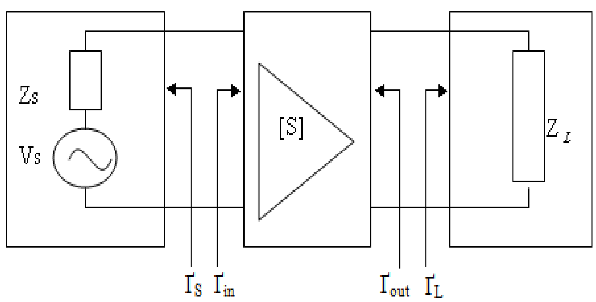

Figure 2: I/O circuit of 2-port network

B. Operating Power Gain

Operating power gain is the ratio of power (P_L) delivered to the load (Z_L) to power (P_{in}) supplied to 2 port network. Power delivered to the load is the difference between the power reflected at the output port and the input power, and power supplied to 2-port network is the difference between the input power at the input port and the reflected power. Therefore, Operating Power Gain is represented by

$$G_P = \frac{Power\ \ delivered\ \ to\ \ the\ \ load}{power\ \ \text{supplied}\ \ to\ \ the\ \ amplifier} = \frac{P_L}{P_{in}} = \frac{1}{1-|\Gamma_{in}|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \quad (1)$$

Where, Γ_{in} indicates reflection coefficient of load at the input port of 2-port network and Γ_s is reflection coefficient of power supplied to the input port.

C. Transducer Power Gain

Transducer Power Gain is the ratio of P_{avs}, maximum power available from source to P_L, power delivered to the load. As maximum power is obtained when input impedance of circuit network is equal to conjugate complex number of power impedance, if $\Gamma_{in} = \Gamma_s$, transducer power gain is represented by

$$G_T = \frac{Power\ \ delivered\ \ to\ the\ \ load}{Power\ Available\ from\ the\ source} = \frac{P_L}{P_{avs}} = \frac{|S_{21}|^2(1-|\Gamma_S|^2)(1-|\Gamma_L|^2)}{|(1-S_{11}\Gamma_S)(1-S_{22}\Gamma_L)-(S_{12}S_{21}\Gamma_S\Gamma_L)|^2} \quad (2)$$

Where, Γ_L indicates load reflection coefficient.

D. Available Power Gain

Available Power Gain, G_A is the ratio of P_{avs}, power available from the source, to P_{avn}, power available from 2-port network, that is, $G_A = \frac{P_{avn}}{P_{avs}}$.

Power gain is P_{avn} when $\Gamma_{in} = \Gamma*_s$. Therefore Available Power Gain is given by:

$$G_A = \frac{Power\ \ available\ \ from\ \ the\ \ amplifier}{Power\ \ available\ \ from\ \ the\ source} = \frac{P_{avn}}{P_{avs}} = \frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2}|S_{21}|^2\frac{1}{|1-S_{22}\Gamma_L|^2} \quad (3)$$

That is, the above formula indicates power gain when input and output are matched [5].

E. Noise Figure

Signals and noises applied to the input port of amplifier were amplified by the gain of the amplifier and noise of amplifier itself is added to the output. Therefore, SNR (Signal to Noise Ratio) of the output port is smaller than that of the input port. The ratio of SNR of input port to that of output port is referred to as noise figure and is larger than 1 dB. Typically, noise figure of 2-port transistor has a minimum value at the specified admittance given by formula:

$$F = F_{\min} + \frac{R_N}{G_S} | Y_s - Y_{opt} |^2 \tag{4}$$

For low noise transistors, manufactures usually provide $F_{\min}, R_N, Y_{opt}$ by frequencies. N defined by formula for desired noise figure:

$$N = \frac{| \Gamma_s - \Gamma_{opt} |^2}{1 - | \Gamma_S |^2} = \frac{F - F_{\min}}{4R_N / Z_0} | 1 + \Gamma_{opt} |^2 \tag{5}$$

F. Condition for Matching

The scattering coefficients of transistor were determined. The only flexibility permitted to the designer is the input/output matching circuit. The input circuit should match to the source and the output circuit should match to the load in order to deliver maximum power to the load. After stability of active device is determined, input/output matching circuits should be designed so that reflection coefficient of each port can be correlated with conjugate complex number as given below [6]:

$$\Gamma_{IN} = \Gamma_S^* = S_{11} + \frac{S_{12} S_{21} \Gamma_L}{1 - S_{22} \Gamma_L} \tag{6}$$

$$\Gamma_{OUT} = \Gamma_L^* = S_{22} + \frac{S_{12} S_{21} \Gamma_S}{1 - S_{11} \Gamma_S} \tag{7}$$

The noise figure of the first stage of the receiver overrules noise figure of the whole system. To get minimum noise figure using transistor, power reflection coefficient should match with Γ_{opt} and load reflection coefficient should match with Γ_{out}^*

$$\Gamma_s = \Gamma_{opt} \tag{8}$$

$$\Gamma_L = \Gamma_{out}^* = \left(S_{22} + \frac{S_{12} S_{21} \Gamma_s}{1 - S_{11} \Gamma_s} \right) \tag{9}$$

3. Design of LNA

Low noise amplifier was design based on the s-parameters were obtained from calculation and simulation using ADS. The S-parameter for each LNA shows in Table 1 and Table 2.

Table 1 : S-Parameters of Cascode LNA

Freq/dB	S_{11}	S_{12}	S_{21}	S_{22}
5.8GHZ	0.637	0.040	2.873	0.536
Angle	-89.645	29.157	86.557	-24.058

Table 2 : S-Parameters of Single LNA

Freq/dB	S_{11}	S_{12}	S_{21}	S_{22}
5.8GHz	0.712	0.065	8.994	0.237
Angle	-86.54	33.878	178.66	-10.456

The overall performance of the low noise amplifier is determined by calculating the transducer gain G_T, noise figure F and the input and output standing wave ratios, $VSWR_{IN}$ and $VSWR_{OUT}$. The optimum, Γ_{opt} and Γ_L were obtained as Γ_{opt} = 17.354 + j50.13 and Γ_L = 79.913-j7.304 for single LNA. While, Γ_{opt} = 21 + j48.881 and Γ_L = 79.913- j7.304 for cascode LNA.

Figure 3 shows, the complete schematic of a single stage LNA and Figure 4 shows the completed schematic of a cascode LNA. A T-matching network was used to match the input impedance. Using Smith Chart matching techniques, the component values are shown in table 3.To achieve the targeted overall gain of 35dB, it was decided to design cascode and cascaded technique. The simulation recorded that the amplifier gain S_{21} was 36.3dB.The input insertion loss S_{11} was -21.1dB, overall noise figure (NF) was 1.2dB and the output insertion loss S_{22} was -27.7dB.The reflection loss S_{12} was -42.5dB. These values were within the design specification and were accepted.

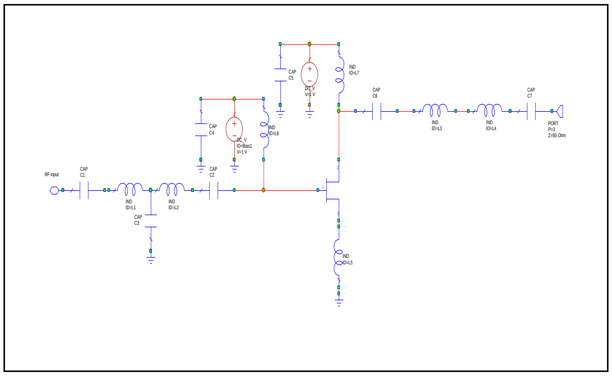

Figure 3: The Schematic Circuit for Single LNA

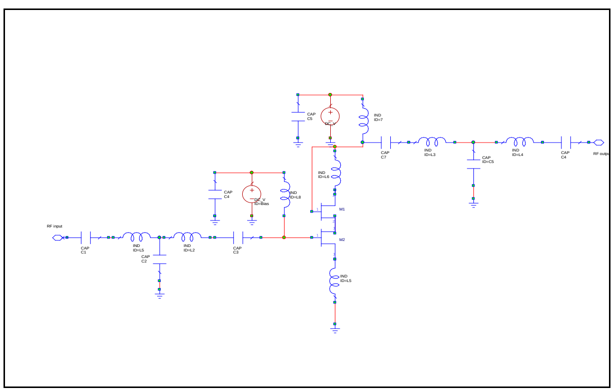

Figure 4: The Schematic Circuit for Cascode LNA

Table 3: LNA parameters

Components	Values	
	Cascode LNA	Single LNA
L_1	1288nH	2.26nH
L_2	2.88nH	3.67nH
L_3	481.2nH	1.93nH
L_4	2.92nH	1.96nH
L_5	0.072nH	0.12nH
L_6	1.18nH	481pH
L_7	1.445nH	2.92nH
L_8	2.74nH	
C_1	2pF	0.615pF
C_2	1.3pF	0.674pF
C_3	0.321pF	0.822pF
C_4	1pF	1pF
C_5	1pF	1pF
C_6	1pF	0.386pF
C_7	0.924pF	0.348pF

4. Simulation Result

Table 4 shows the s-parameters output for comparison of LNA. It is simulated using Advanced Design System (ADS). The output S-parameter (graphs) shown in figure 5a, 5b and 5c.

Table 4: Comparison of output LNA

S-Parameters (dB)	**S_{11}**	**S_{12}**	**S_{21}**	**S_{22}**	**NF**	**(k)**
Single LNA	-12.8	-20.2	17.0	-27.9	0.76	1.02
Cascode LNA	-18.9	-22.1	19.5	-20.0	1.2	1.02
Cascode and Cascaded LNA	-21.1	-42.5	36.3	-27.7	1.20	1.26

5. Conclusions

A cascode and cascaded LNA was successful design and simulated. The amplifier uses the T-matching network in input of LNA. At 5.8GHz, gain (S_{21}) of LNA was recorded that the amplifier gain S_{21} was 36.3dB. The input insertion loss S_{11} was -21.1dB and the output insertion loss S_{22} was -27.7dB. The reflected loss S_{12} was -42.5dB. The better performance in gain of the amplifier, it can be achieved by increasing the number of stages to improve the gain and noise figure of the design. For this reason the cascoded and cascaded was proposed.

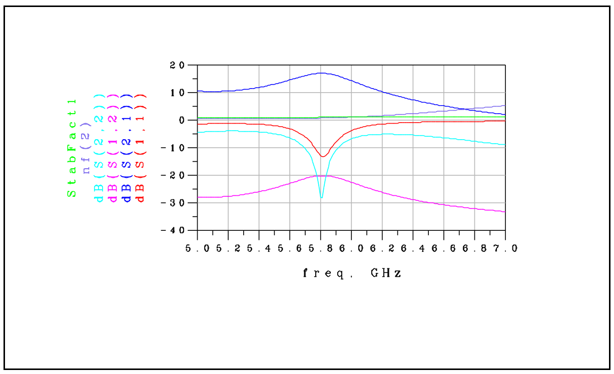

Figure 5a: S-parameters for single LNA

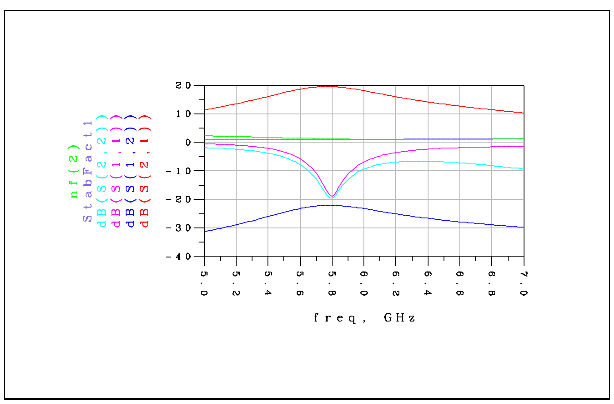

Figure 5b: S-parameters for single cascode

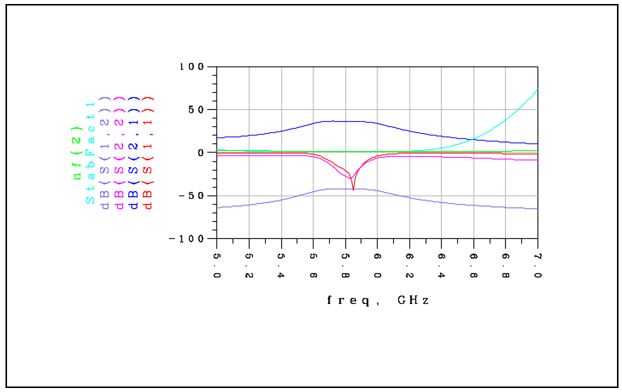

Figure 5c: S-parameters for cascode and cascaded

REFERENCES

[1] M.Ben Amor, M.Loulou, D.Pasquut, "A wideband CMOS LNA design for WiMAX application." IEEE 2008.

[2] Ruey-Lue Wang, Shih-Chih Chen,Cheng-Lin Huang,Chien-Hsuan Lie,Yi-Shu Lin. "2-6GHz Current-reused LNA With Transformer-type Inductors." IEEE 2008.

[3] Leon, Michael Angelo G.Lorenzo and Maria Theresa G.De. "Comparison of LNA Topology for Wimax Application in a Standard 90-nm CMOS Process." *12th International Conference on Computer Modelling and Simulation.* 2010. pp-642-647.

[4] M.Pozar, David. *Microwave and RF Wireless System.* Third Avenue,N.Y.John Wiley & Sons,in, 2001.

[5] Gonzalez, Guillermo. *Microwave Transistor Amplifier.* 1996.

[6] Othman A.R, Hamidon A.H,Ting J.T.H and Mustaffa M.F. "High Gain Cascaded Low Noise Amplifier Using T-Matching Network." 4th ISBC 2010.

[7] Weber, Wuezhan Wang and Robert. "Design of a CMOS Low Noise Amplifier (LNA) at 5.8GHz and its Sensitivity Analysis." 11th NASA Symposium 2003.