DESIGN OF LNA AT 5.8GHZ WITH CASCODE AND CASCADED TECHNIQUES USING T-MATCHING NETWORK FOR WIMAX APPLICATIONS

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Abstract

This project presents 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 uses the FHX76LP Low Noise SuperHEMT FET. The design simulation process is done by using the Advance Design System (ADS) software. The cascode and cascaded low noise amplifier (LNA) produces a gain of 53.4dB and noise figure (NF) of 1.2dB. The input reflection (S_{11}) and output return loss (S_{22}) are -24.3dB and -23.9dB respectively. The input sensitivity is complying with the IEEE 802.16 standards.

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

I. INTRODUCTION

The number of systems that use radio frequencies links is increasing rapidly. 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 is based on the 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 produced, 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]. The overall low noise amplifier should introduce a higher gain of 50 dB compared to reported [9]. It is by taking into consideration the extension of communication distance up to 50 km [10]. In this work, low noise amplifier with cascode and cascaded techniques (3-stage) is proposed a shown in Figure 1.
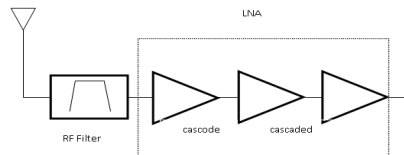

Figure 1: Proposed for Cascode and Cascaded LNA

II. THEORETICAL SECTIONS

Basically, when designing an amplifier, the input and output matching network are considered to achieve the required stability, small signal gain, and a bandwidth. Super high frequency amplifier is a typical active circuit used to amplify the amplitude of radio frequency signal. Basic concept and consideration in

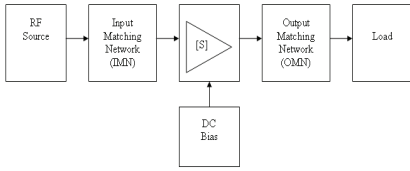design of super high frequency amplifier is presented in this paper.

Figure 2: Typical amplifier designed

The LNA design formula and equation were referred to [4]. Figure 2, shows a typical single-stage amplifier including input/output matching networks. 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. Input/ output matching circuit is essential to reduce the unwanted reflection of signal and to improve efficiency of the 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].
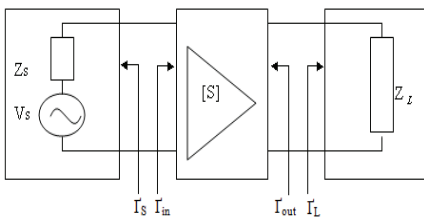

Figure 3: I/O circuit of 2-port network

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

$$G_P = \frac{Power\ delivered\ to\ the\ load}{power\ supplied\ to\ the\ amplifier} \quad (1)$$

$$= \frac{P_L}{P_{in}} = \frac{1}{1-|\Gamma_{in}|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2}$$

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

$$G_T = \frac{Power\ delivered\ to\ the\ load}{Power\ Available\ from\ the\ source} \quad (2)$$

$$= \frac{P_L}{P_{avs}} = \frac{|S_{21}|^2(1-|\Gamma_S|^2)(1-|\Gamma_L|^2)}{|(1-S_{11}\Gamma_S)(1-S_{22}\Gamma_L)-(S_{12}S_{21}\Gamma_S\Gamma_L)|^2}$$

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, respect $G_A = \frac{P_{avn}}{P_{avs}}$. 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:

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

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

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

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]:

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

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

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}^*

$$\Gamma_s = \Gamma_{opt} \quad (8)$$

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

III. DESIGN OF LNA

The overall performance of the low noise amplifier is determined by calculating the transducer gain G_T, noise figure NF 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, Γopt = 21 + j48.881 and ΓL = 79.913- j7.304 for cascode LNA. Figure 4 shows, the complete schematic circuit of cascode LNA and Figure 5 shows the completed schematic circuit of a single LNA. A T-matching network is used to match the input impedance. The elements of T-network can be realized in the form of lump reactive elements. The resultant matching component values are given in Table I.
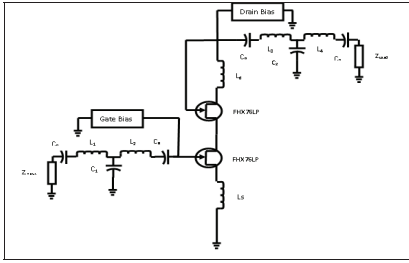
Figure 4: The Schematic Circuit for Cascode LNA

Table I: Components of Matching

Items	Components of Matching	
	Cascode LNA	Single LNA
L_1	6.14 nH	3.661 nH
L_2	2.4 nH	0.8799 nH
L_3	1.55 nH	3.60 nH
L_4	1.62 nH	0.88 nH
C_1	0.315 pF	0.5 pF
C_2	429.9fF	

The input matching load is required to provide high-loaded Q factor for better sensitivity. Several types of matching techniques had been tested for input matching. The criteria that is taken into consideration for choosing the most suitable matching network include low noise figure, high gain and high sensitivity.
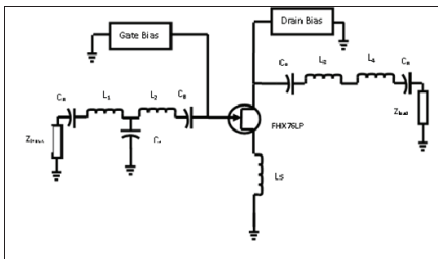

Figure 5: The Schematic Circuit for Single LNA

Regarding the impedance of $\tilde{A}_L$ is real, suitable matching impedance for the load is by using a quarter-wave transformer[8] Theoretically, the other types of matching techniques can be also applied on matching the $\tilde{A}_L$. However, all of the

techniques require the usage of capacitor. From simulation, as we fixed the capacitance to the value witch available on market, it is not possible to match the load. An adjustable capacitor can be used to solve this problem; however, due to the higher cost of adjustable capacitor, it is not in our consideration. Thus, the best matching techniques is the quarter-wave transformer. The quarter-wave transformer converts the complex impedance into real impedance.

IV. SIMULATION RESULTS

Table II shows the s-parameters output for comparison of LNA. It is simulated using Advanced Design System (ADS). The simulation recorded that the amplifier gain S_{21} is 53.4dB.The input insertion loss S_{11} is -24.3dB, overall noise figure (NF) is 1.2dB and the output insertion loss S_{22} is -23.9dB.The reflection loss S_{12} is -62.6dB. These values were within the design specification and were accepted. The output S-parameter (graphs) shows in figure consistence 6a, 6b and 6c.

V. CONCLUSION

A 5.8GHz cascode and cascaded low noise amplifier is successful design and simulated. The amplifier uses the T-matching network in input of LNA. At 5.8GHz, gain (S_{21}) of LNA is recorded that the amplifier gain S_{21} is 53.4dB. The input insertion loss S_{11} is -24.3dB and the output insertion loss S_{22} is -23.9dB. The reflected loss S_{12} is -62.6dB. 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 is proposed.

Table II: Comparison of output LNA

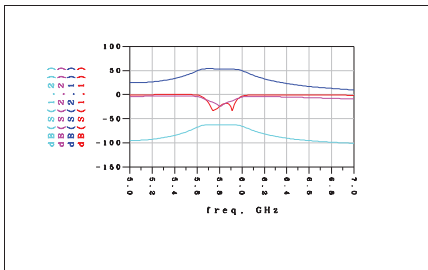| S-Parameters (dB)	S₁₁	S₁₂	S₂₁	S₂₂	NF	(k)
Single LNA	-12.8	-20.2	17.0	-27.9	0.76	1.02
Cascode LNA	-18.9	-22.1	19.5	-20.0	1.2	1.02
Cascaded LNA	-22.5	-40.4	34	-37.6	0.76	1.29
cascode and cascaded	-24.3	-62.6	53.4	-23.86	1.20	1.59

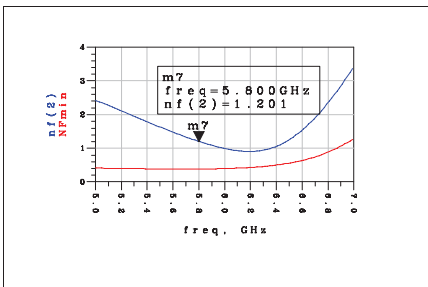Figure 6a: S-parameters Output for LNA
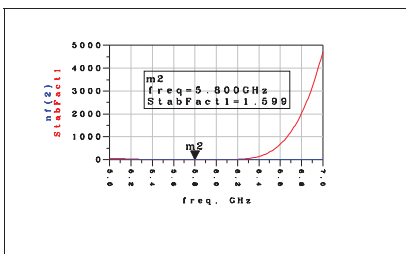

Figure 6b: Noise Figure vs. frequency

Figure 6c: Stability factor vs. frequency

REFERENCES

[1] M. Amor, M. Loulou, and D.Pasquut. A wideband CMOS LNA design for WiMAX Application. IEEE Proceeding 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 Proceeding 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. IEEE Proceeding.

[8] I. Bahl and Prakash Bhartia. Microwave Solid State Circuit Design Second Edition. 2003.

[9] Pengfei, Z., Lawrence, D., Dawei, G., Isaac, S., Taoufik, B., Chris L., Alireza Z., Jess, C., Douglas, G., Baohong, C., Sujatha, G., Siegfried, H., Lam, H., Thai, N., & Behzad, R.A CMOS Direct-Conversion Transceiver for IEEE 802.11a/b/g WLANs, IEEE Journal of Solid State Circuits, Vol. 38, pp 2232-2238, 2004.

[10] IEEE Computer Society and IEEE Microwave Theory Technique and Society. Part 16 Air Interface For Fix Broadband Wireless System, IEEE Standard 802.16,2004