Design and Simulation Low Noise Amplifier at 5.8GHz for WIMAX Applications

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Abstract. This paper 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 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 53.1dB and noise figure (NF) of 1.17dB. The input reflection (S_{11}) and output return loss (S_{22}) are -19.77dB and -10.07dB respectively .The input sensitivity is compliant with the IEEE 802.16 standards.

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

1. Introduction

The number of systems that use radio frequency links is increasing quickly. At the same time, the numbers of standards for such systems are increasing 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, 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 (3-stage) is proposed.

2. Theoretical Sections

Basically, designing an amplifier, the input and output matching network are consider 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 RF signal. Basic concept and consideration in design of super high frequency amplifier is presented in this paper. The LNA design formula and equation were referred to [4]. Figure 1, shows a typical single-stage amplifier including input/output matching networks.

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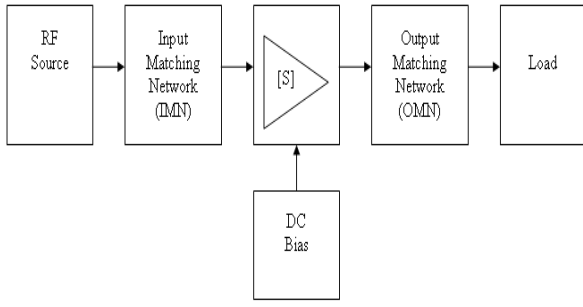
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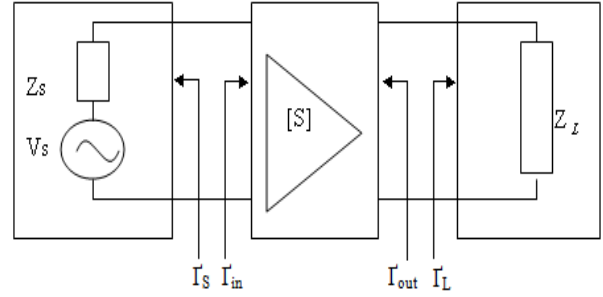
Figure 1: Typical amplifier designed   **Figure 2:** I/O circuit of 2-port network

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].

2.1 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].

2.2 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

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

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

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.

2.3 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

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

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

Where, Γ_L indicates load reflection coefficient.

2.4 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, $G_A = \dfrac{P_{avn}}{P_{avs}}$. Power gain is P_{avn} when $\Gamma_{in} = \Gamma^*_s$. Therefore Available Power Gain is given by:

$$G_A = \frac{Power\ available\ from\ the\ amplifier}{Power\ available\ from\ the\ source} \quad (3)$$

$$= \frac{P_{avn}}{P_{avs}} = \frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2}|S_{21}|^2\frac{1}{|1-S_{22}\Gamma_L|^2}$$

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

2.5 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:

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

2.6 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]:

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

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

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}^*

$$\Gamma_L = \Gamma_{out}^* = \left(S_{22} + \frac{S_{12}S_{21}\Gamma_s}{1 - S_{11}\Gamma_s} \right) \quad (8)$$

3. Design of LNA

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. Figure 3 shows the complete schematic circuit of cascode and cascaded LNA. A T-matching network is used to match the input impedance and suitable matching for output is by a quarter-wave transformer [8]. Using Smith Chart matching techniques, the component values are shown in Table I. To achieve the targeted overall gain of 50dB, it is decided to design cascode and cascaded technique.

Table I: Components of Matching

Components	Values

L_1	1.26 pH
L_2	2.9 nH
C_1	0.32pF
L_3	548.9 pH
L_4	2.92 nH
L_5	3.13 nH
L_6	3.3nH
L_7	1.89nH
L_8	1.97pH
C_2	0.5pF
C_3	0.3pF
C_B	7.50pF
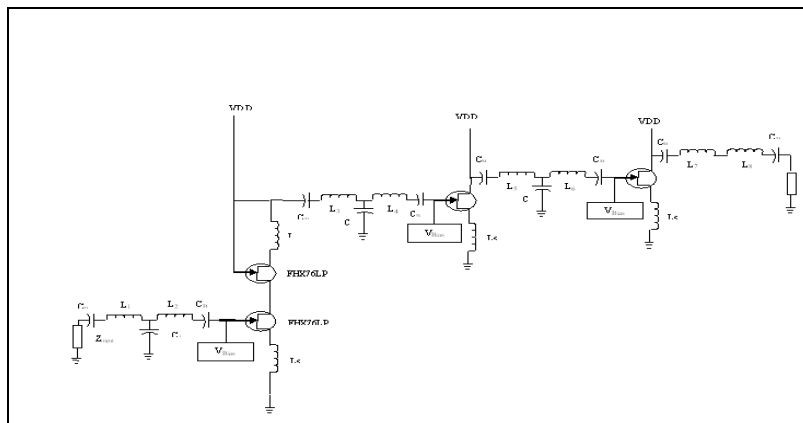
Figure 3: Schematic diagram of proposed LNA

Table II: S-Parameter output

Freq/dB	S_{11}	S_{12}	S_{21}	S_{22}	NF	(K)
5.8GHz	-19.77	-65.72	53.1	-10.07	1.171	2.02

4. Simulation Result

Table II shows the s-parameters output for cascode and cascaded LNA. It is simulated using Advanced Design System (ADS). The simulation recorded that the amplifier gain S_{21} is 53.1dB.The input insertion loss S_{11} is -19.77dB, overall noise figure (NF) is 1.17dB and the output insertion loss S_{22} is -10.07dB.The reflection loss S_{12} is -65.7dB. These values were within the design specification and were accepted. The outputs S-parameter are shown in consistence figure 4a and 4b.

5. Conclusions

A cascode and cascaded LNA 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 53.1dB. The input insertion loss S_{11} is -19.71dB and the output insertion loss S_{22} is -10.07dB. The reflected loss S_{12} is -65.72dB. 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.
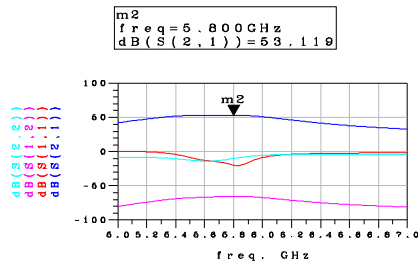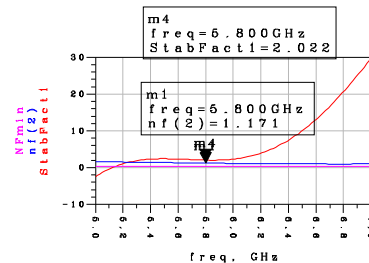

Figure 4a: S-Parameter output   Figure 4b: stability and noise figure

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