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High Gain And Low Noise Single Stage Cascoded Lna Amplifier With Optimized Inductive Drain Feedback For Direct Conversion Wimax Rf Front End Receiver

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Abstract: This paper presents a high gain and low noise cascoded LNA amplifier for direct conversion RF front end receiver architecture for WiMAX application, which operates at 5.8 GHz. A single cascoded LNA design was built to meet the standard of IEEE 802.16. The LNA used inductive feedback, which produced high gain. A low noise figure is obtained by using T - matching consisting of lump reactive elements used at the input and output of the LNA circuit. The cascoded LNA developed, produced a high gain of 26.26 dB with low noise figure (NF) of 0.82 dB. The bandwidth (BW) measured is 1.56 GHz while the S- parameters for the S11, S22 and S12 are of -11.05 dB, -10.5 dB and -30.92 dB respectively. The input sensitivity is -82.6 dBm which is compliant with WiMAX standard. The LNA used Pseudomorphic High Electron Mobility Transistor FHX76LP superHEMT low noise FET and simulated using Ansoft Designer SV.

Key words: RF front-end; Direct Conversion; WiMAX; Receiver Sensitivity; IEEE 802.16; Cascoded LNA; inductive feedback.

INTRODUCTION

The new developed IEEE 802.16 standard or known as WiMAX can be interpreted as Worldwide Interoperability for Microwave Access. It is a new revolution in wireless broadband access. This technology allows us to achieve broadband wireless access instead of using cable and DSL (Digital Subscriber Line) (IEEE 2004). The increasing number of personal wireless communication systems demand for Radio Frequency (RF) front-end capable to handle difference standard specification, i.e. WiMAX, WLAN, WiFi. According to the standard IEEE 802.16 (WiMAX) it can transmit data rates exceeding speeds of 70 Mbps and a service area of about 50km for fixed stations and 5-15 km for mobile stations Roger Marks (2004).

RF front-end receiver for a WiMAX at 5.8 GHz would have to be designed for desired frequency, gain, bandwidths, noise figure, return loss, impedance and efficiency. Multiple parameters such as gain and noise in the RF component for the front – end receiver would have to be compensated. These trade-offs are the challenges that RF designers have to consider in designing a high performance communication system.

In Fig. 1, the RF input signal that goes through the system is very weak. Since the RF front end requires amplifiers to amplify the signal and at the same time lowering the noise that passes through it, this can only be done by using an LNA. To design a low noise amplifier (LNA) RF front-end receiver, we will face many drawbacks. Moreover, the circuit must meet certain specifications as well as to provide good input impedance match, sufficient gain power and low noise figure (NF) within the required band (Ruey-Lue Wang, *et al*., 2008).

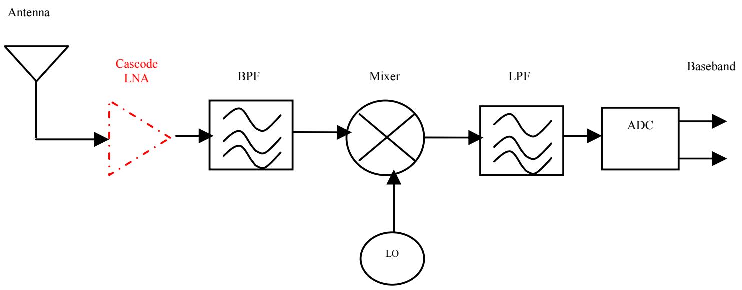

Fig. 1: Direct conversion RF front end receiver configuration for Wimax point to point communication at 5.8 GHz band

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The cascoded topology is a technique that can introduce higher gain, due to the increase in the output impedance, as well as better isolation between the input and output ports (Kalantari, Fatemeh, Masoumi *et al* 2006). To solve the problems of obtaining high gain and low noise encountered in RF receiver, we propose a single cascoded LNA amplifier using inductive feedback from gate to drain of an PHEMT for use as a sub component in the RF front end architecture.

Various methods and steps are used to design the amplifier and such design step must be in an accordance the IEEE 802.16 standard. The specification for the design of single cascoded LNA amplifier as shown in Table 1.

Table 1: Design specifications single cascoded LNA for direct conversion RF front end WiMAX receiver.

Parameter	Single Cascoded LNA
Gain dB	> 20 dB
Frequency (GHz)	5.8 GHz
NF dB	< 3
Matching Technique	Microstrip and lump reactive element
Bandwidth MHz	>1000 (5.8 GHz Centre)
Input sensitivity	< -80 dBm

With reference to Table. 1, the target gain is 20 dB or above. However, from the literature review for a single stage LNA most amplifiers reported using cascoded topology is less than 20 dB. Most of the LNA amplifier reviewed have a noise figure of less than 3 dB and the bandwidth presented are more than 1GHz. In addition, the input sensitivity is less than -80dBm as compliant with the IEEE 802.16 standard.

Theoritical Description:

The general topology of the LNA amplifier consists of three stages: the input matching network (IMN), the amplifier itself and the output matching network (OMN) (B. Jung Jang, *et al*., 2001; Sungkyung Park and Wonchan Kim, 2001; Yongguang Lu, *et al*., 2010). Essentially, for a LNA amplifier design, we need to ensure that input and output matching network must meet the criteria required for stability, small signal gain and bandwidth (Yongguang Lu, *et al*., 2010). The formula and mathematical statements used to design LNA amplifiers are obtained from Pozar (M. Pozar, David. 2001). Fig. 2 shows a typical single-stage LNA amplifier including input/output matching networks.

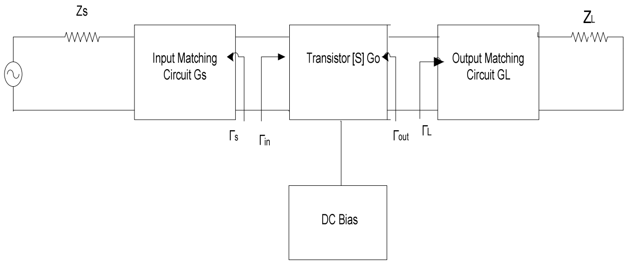

Fig. 2: Typical single-stage LNA amplifier

For a high frequency RF amplifiers, every designer have ensured that input and output matching networks for the amplifiers is the matched to 50 ohms at the input and output terminal D.M. Pozar (2000). I/O matching circuit is necessary to reduce unwanted reflection of signal and to improve the capability of transmission from source to load. The targeted S-parameter specification for a cascoded LNA amplifier is shown in Table 2.

Table 2: Targeted S-Parameters for LNA

S parameter	Single Cascoded LNA
Input reflection S11 dB	< -10 dB
Return Loss S12 dB	< -20 dB
Forward Transfer S21 dB	>+ 20 dB
Output Reflection loss S22 dB	<-10 dB
Noise Figure NF dB	< 3 dB
Stability (K)	K > 1

2.1 Power Gain:

Essentially for the LNA amplifier to operate, the number of power gains derived from the output of the LNA amplifiers need to be considered. With reference to Fig. 3 for a 2 port power gain with power network circuit impedance or load impedance at the LNA amplifier are represented by scattering coefficients classified into Operating Power Gain, Power Transducer and Available Power Gain (M. Pozar, David. 2001).

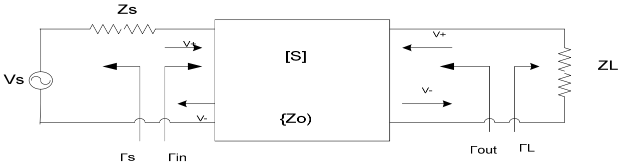

Fig. 3: I/O circuit of 2-port network (Leon, *et al*., 2010)

2.1.1 Operating Power Gain:

Operating power gain is the ratio of the power dissipated in the load Z_L (P_L) to the power delivered to the input (Pin) of the two-port network (M. Pozar, David *et al*., 2001). 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 are the difference between the input power at the input port and the reflected power (IEEE 2004). The Operating Power Gain can be expressed as (Ibrahim A.B., *et al*., 2011) :

$$G_P == \frac{P_L}{P_{in}} = \frac{|S_{21}|^2\left(1-|\Gamma_L|^2\right)}{\left(1-|\Gamma_{in}|^2\right)|1-S_{22}\Gamma_L|^2} \tag{1}$$

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.

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. The maximum power can be obtained, when the input impedance Γ_{in} of the network is terminated conjugately matched to the source impedance Γ_s ., if $\Gamma_{in} = \Gamma_s$, Transducer Power Gain can be expressed by (Othman A. R, *et al*., 2010):

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

Where, Γ_L indicates load reflection coefficient.

2.1.3 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 [14] :

$$G_A = \frac{P_{avn}}{P_{avs}} = \frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2}|S_{21}|^2 \frac{1}{|1-S_{22}\Gamma_L|^2} \tag{3}$$

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

Stability:

Important factors in the high frequency amplifier are to determine stability. Determination of stability is necessary to avoid oscillation occurs at the operating frequency. In the circuit Fig. 2, oscillation is possible if either input or output port impedance has a negative real part. This would imply that $|\Gamma_{in}| > 1$ or $|\Gamma_{out}| > 1$. This is because Γ_{in} and Γ_{out} are defend on the source and the load matching network. The stability of the LNA amplifier defends on Γ_s and Γ_L as presented as matching network. Alternatively, it can be shown that the amplifier will be unconditionally stable if the stability factor (K) and delta factor (Δ) following necessary and sufficient conditions are met by (Othman A.R, *et al*., 2010):

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}S_{21}|} > 1 \tag{4}$$

And

$$|\Delta| = |S_{11}S_{22} - S_{12}S_{21}| < 1 \tag{5}$$

Noise Figure:

Apart from the stability and gain another design consideration must be taken into account in the design of LNA amplifiers that is noise figure. LNA amplifier is usually placed as the first stage of an RF front end receiver architecture. This provides the dominant effect on the overall system noise performance (M. Pozar, David. 2001). However, it is impossible to get an amplifier with minimal low noise figure and maximum gain; therefore, there should be a compromise between these two parameters. It can be done by using constant gain circles and circles of constant noise figure to select usable trade-off between noise figure and gain. Typically, noise figure of 2-port transistor has a minimum value at the specified admittance given by (Othman A.R, *et al*., 2010):

$$F = F_{\min} + \frac{R_N}{G_S} | Y_s - Y_{opt} |^2 \tag{6}$$

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

$$N = \frac{| \Gamma_s - \Gamma_{opt} |^2}{1 - | \Gamma_S |^2} = \frac{F - F_{\min}}{4R_N / Z_0} | 1 + \Gamma_{opt} |^2 \tag{7}$$

After stability of active device is determined, input and output matching circuits should be designed so that reflection coefficient of each port can be correlated with conjugate complex number as given below:

$$\Gamma_{IN} = \Gamma_s^* = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \tag{8}$$

And

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

To obtain minimum noise figure using 2-port transistor, source reflection coefficient should match with Γ_{opt} and load reflection coefficient should match with Γ^*_{out} with a complex conjugate number as formula below:

$$\Gamma_s = \Gamma_{opt} \tag{10}$$

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

Design Of Cascoded Lna:

Cascoded low noise amplifier design is based on the specifications mentioned in the previous section. Types of transistors used in cascoded LNA are PHEMT FHX76LP. S-parameters for PHEMT is shown in Table 3, where the parameters are obtained at VDD = 2V and IDS = 10mA of biasing set at PHEMT.

Table 3: S-parameter from Transistor PHEMT FHX76LP datasheet

Frequency GHz	S_{11}	S_{12}	S_{21}	S_{22}
5.8 GHz	0.712	0.065	8.994	0.237

In determining the overall performance of the low noise amplifier we need to obtain the value of transducer gain (G_T), noise figure (F) and the input and output standing wave ratios, $VSWR_{IN}$ and $VSWR_{OUT}$ either through calculations or simulations. The optimum, Γ_{opt} and Γ_L were obtained as Γ_{opt}= 17.354 + j 50.131 and Γ_L = 79.913- j7.304 respectively. T-matching network was used in the input and output impedance. Lump reactive elements and microstrip line impedance are used to design the element of the T-network. By using Ansoft Designer SV Smith Chart matching technique, the desired component is shown in Table 4.

Table 4: Single- Stage Cascoded LNA Amplifier parameters

Components	Value
L1	1.16 nH
L2	1.35nH
L3	0.71nH
L4	0.40nH
L5	0.92NH
L6	6.5nH
L7	1.38nH
L8	0.76nH
L9	1.27nH
L10	0.07NH
CA	0.5pF
CB	7.5pF

The design of cascoded LNA has its own topology, where there is an inductive feedback L6 is connected to the drain of the M1, inductive source generation L10, which is connected to the source M2, while inductive L5 placed between the source and drain of M1 in M2 refer to Fig. 4. The cascoded LNA amplifier circuit designed using inductive feedback to drain is shown in Fig. 4.

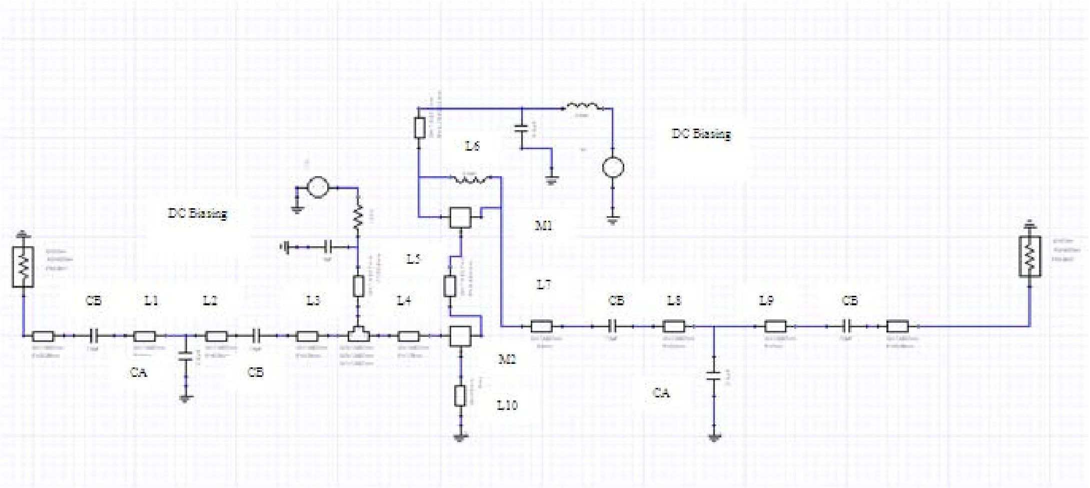

Fig. 4: Complete schematic of the LNA Cascoded amplifier circuit designed using inductive feedback to drain

From Fig. 4, inductive at the circuit has its own characteristics, for example, when performing the optimization in L6 we will obtain a high gain, but whenever the value of L6 exceeds 50% of the stated value it will cause the LNA amplifiers be unstable (potentially unstable) that is going to happen isolation and bandwidth will be reduced significantly. The degenerating inductor L10, which gives the LNA its purely real input impedance (Leon, *et al*., 2010) and help in getting the input and output of the optimal matching, when this condition occurs bandwidth (BW) and noise figure (NF) will not decline further and set at a value. The cascoded transistor M2 suppresses the Miller capacitance of M1 thereby increases the reverse isolation. The suppression of the parasitic capacitances of the input transistor also improves the high frequency operation of the amplifier (Leon, *et al*., 2010). Between M2 and M1 are placed inductive L5 that will help in getting higher input impedance matching. When the L5 altered and elevated the value of K values also increased drastically, and that show cascoded LNA amplifiers are in unconditionally stable and will not isolate. Whenever L5 value increased by 50% from the value specified isolation may be seen that the value of K <1 and the value of gain and noise figure will decreases. Passive elements contained in the input matching network at the LNA circuit is built as follows L1, L2 and CA1. While there are passive elements in the output matching network, they are L7, L8, L9 and CA2. From the observations made at L1, L2, L3, L7, L8 and L9 after optimizing we obtained high input /

output impedance that will affect the input and output matching to 50 Ohm terminal. This causes us to improve the value of S-parameters S11 and S22 according to the required specifications of <-10. Other than that it will also offer higher gain at the desired frequency and to control the bandwidth (BW) in cascoded LNA circuit. Passive component such as CA1 and CA2 seek to control the input and output match. This is because if we reduce the value of the proposed specification in it will result in S22 would have a value of less than-10dB and if the CA1 and CA2 raised from the optimized value they will cause the S11 has a value of <-10dB. Therefore, we need tuned to get the right value. Apart, if we decreased the CA1 or CA2, we can reduce noise figure and cause the circuit bandwidth will increase. While if the CA1 and CA2 are increasing the value, the opposite will happen. Capacitor CB is acting as a DC block to cascoded LNA circuit built, in which they proposed is worth 10 times the original value of the CB because it acts as a bypass capacitor (Othman A.R, *et al*., 2010).

Simulation Of Result:

Result of simulations performed on the cascoded LNA circuit for output gain and reflection loss is shown in Fig. 5 (a). Simulated S-parameters for the amplifier output shows that, the output gain S21 at 5.8 GHz is 26.26 dB and reflection loss S12 is -30.90 dB. While Fig 5 (b) refers to the input return loss S11 and S22 output return loss, each has value -11.10 dB and -10.50 dB respectively.

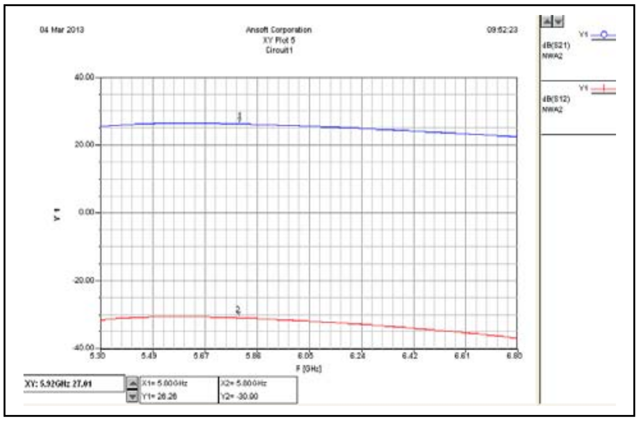

Fig. 5(a): Output Gain (S_{21}) and Reflection Loss (S_{12})

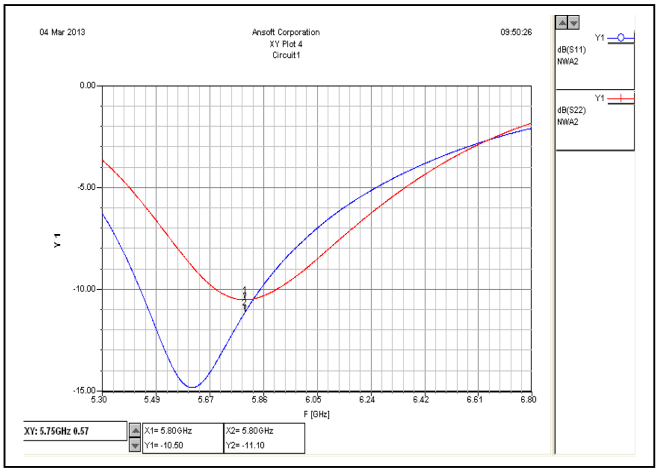

Fig. 5(b): Input Return Loss (S_{11}) and Output Return Loss (S_{22})

The noise figure output observed in Fig 5 (c). is -0.83 dB. For this amplifier, the consideration is on the maximum gain with low noise figure less than 3 dB. This S-parameter output is acceptable with the targeted specification required for the system.

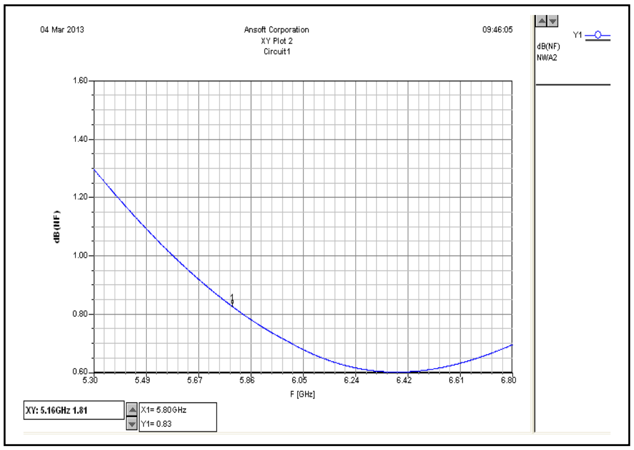

Fig. 5(c): Noise Figure

The stability factor after matching load is shown in Fig 5 (d), and the stability obtained is 1.04. These parameters are compliant with the targeted specifications of the amplifier for unconditional stable condition k > 1 mean that no isolation occur at the amplifier. The noise figure output observed is 1.04. From Fig. 15 (a), we measured that, the 3dB bandwidth obtained is 1.56 GHz compliant with targeted result of more than 1 GHz.

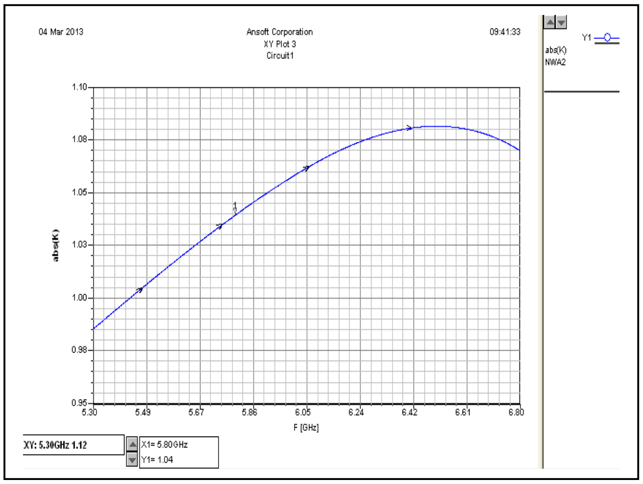

Fig. 15(d): Stability factor after matched load

The simulated of S-parameters of the cascoded LNA amplifier as shown in Table 5.

Table 5: S-Parameter Output Targeted and Simulated Parameters of Single Cascoded LNA at 5.8 GHz

S Parameters	Targeted Single Cascoded LNA	Simulated Single Cascoded LNA
Input reflection S_{11} dB	<-10	-11.10
Return Loss S_{12} dB	<-10	-30.90
Forward Transfer S_{21} dB	>20	26.26
Output Reflection loss S_{22} dB	<-10	-10.50
Noise Figure NF dB *	<3	0.83
Bandwidth GHz	>1 GHz	1.56 GHz
Stability K	>1	1.04

The comparison and lists of performances cascoded LNA is shown in Table 6.

Table 6: Comparison with recently Cascoded LNA

Item/Author	[This Work]	(Ibrahim A.B, *et al*., 2011)	(Ruey-Lue Wang, 2008)	(Leon, *et al*., 2010)	(Arjuna Maruki, 2009)
Technology	Supe r HEMT	Super HEMT	0.18um CMOS	90nm	Gas pHEMT
Freq (GHz)	5.8	5.8	2-6	5.8	5.5
Gain (S21) dB	26.26	19.5	13.5	13.8	11
NF (dB)	0.83	1.2	2.7-4.5	1.7	1.6
S11 (dB)	-11.1	-18.9	<-9	-	-9.2
S22 (dB)	-10.5	-19.49	<-9	-	-8
Bandwidth (GHz)	1.56	> 1	-	-	-
Stability (K)	1.04	1.016	-	-	-

Note **: (-) – not mention

Conclusions:

The cascoded LNA amplifier with inductive drain feedback has been simulated and developed successfully according to IEEE standard 802.16 WiMAX. It is observed that from simulated S-parameter results the amplifier achieved the targeted specification shown in Table 5. The cascoded topology was chosen for this design as it offers an improvement in gain, low noise figure, reverses isolation and reduces the miller effect. The cascoded LNA designed amplifier achieved the lowest noise figure and high gain due to the noise optimization in the implementation of the input matching using inductive degeneration and used inductive drain feedback. At a frequency of 5.8 GHz cascoded LNA amplifiers recorded gain S_{21} of 26.26 dB. While input Insertion loss S_{11} is - 11.1 dB and, the output insertion loss S_{22} is -10.50 dB. The S_{12} reflected loss is -30.90 dB. The stability (K) and noise figure (NF) was 1.04 and 0.83 respectively.

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