Australian Journal of Basic and Applied Sciences, 7(7): 452-460, 2013
ISSN 1991-8178

Double - Stage High Gain and Low Noise Cascoded LNA Amplifiers With Optimized Inductive Drain Feedback for Direct Conversion WiMAX RF Front-end Receiver

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Abstract: This project presents the design of a high gain and low noise cascoded double-stage LNA amplifiers used in the direct conversion RF front-end receiver that operates at 5.8 GHz for WiMAX applications. The double stage cascoded LNA has been designed using the inductive drain feedback, inductive generation to the source and T-network at the input and output terminal as a matching technique. This amplifier uses Pseudomorphic High Electron Mobility Transistor FHX76LP superHEMT low noise FET. The double cascoded LNA was designed to contribute high gain of 54.60 dB and the overall noise figure (NF) of 0.9 dB. Furthermore, the input reflection (S11), output reflection loss (S22) and return loss (S12) measured are -12.72 dB, -17.89 dB and - 62.50 dB respectively. The bandwidth measured is 1.19 GHz. The input sensitivity obtained exceeds the standards set by IEEE 802.16 and the circuit is simulated by using Ansoft 's Designer SV.

Key words: RF front-end; Direct Conversion; IEEE 802.16; Double-Stage Cascoded LNA; inductive drain feedback

INTRODUCTION

WiMAX (Worldwide Interoperability for Microwave Access) technology, is based on the IEEE 802.16 standard, which has attracted the designer to build the communication system have better performance and high speed data rate at larger distances (Yijun *et al*., 2006; Garuda and Mohamed, 2006). It provides connectivity for fixed, normadic, portable and mobile wireless broadband whether it is in line-of-sight (LOS) or non line-of-sight (NLOS) environment (IEEE Computer Society and IEEE Microwave Theory Technique, 2004). Theoretically, the WiMAX can achieve transmission rates up to 70 Mb/s and a service area of around 50 km for fixed stations, and 5 – 15 km for mobile stations (Othman *et al*., 2010). The frequency spectrum for mobile WiMAX technology in NLOS applications is around 2 – 6 GHz, where the 2.3 GHz, 2.5 GHz and 3.5 GHz are dedicated for licensed spectrum while the 3.65 GHz and 5.8 GHz are dedicated for unlicensed spectrum. In this research, we will focus on the unlicensed spectrum at 5.8 GHz frequency (Othman *et al*., 2010).

To achieve the performance specified by IEEE 802.16, the gain, bandwidth, noise figure, frequency, stability, impedance and efficiency need to be considered when designing LNA amplifiers (Ibrahim *et al*., 2012). In RF front–end design, the problem such as noise, reflection and isolation must be determined and reduced. 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 getting a high performance communication system (Ibrahim *et al*., 2012).

In this paper, a double-stage cascoded LNA front-end amplifier for direct conversion receiver for 5.8 GHz (WiMAX) system is presented. This architecture has features such as good image rejection, lower complexity, less component count and low noise figure and high gain (Hoesam *et al*., 2007). Table 1 shows some of the design review and development using a direct conversion RF front-end receiver by previous researchers.

Table 1: Development of direct conversion front-end receiver

Ref	Technique	Freq	Overall gain	Overall noise Figure	BW
(Yijun *et al*., 2006)	DC receiver LNA + mixer + tunable low pass filters	5	21	5.8	20 WiMAX
(Garuda and Mohamed, 2006)	DC Receiver LNA + Balun	5.1-5.9	30	5.9	20 WiMAX
(Huang, 2007)	DC Receiver LNA + Balun + Butterworth filter	5.2-5.8	28	4.6	20 WiMAX
(Atallah, 2007)	DC(RF Receiver) LNA only	5	20	3	20 WiMAX

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(Chen, 2009)	Front-end Receiver LNA + quadrature coupler +Low Pass Chebyshev filter	5.6	17.1	8.7	54 WiMAX
(Park, 2010)	DC receiver LNA only	2-6	23.0	5.6	54 WiMAX
(Othman, 2010)	DC receiver Cascaded LNA + RFA + Power Divider + bandpass Chebyshev Filter	5.8	52.4	3.7	107 MHz WiMAX

With reference to Table 1, most of the RF front-end receiver architecture was developed between 5 to 6 GHz licenses and unlicensed band of frequencies. The maximum gain is 52.4 dB with overall noise figure between 3 to 5.9 dB. The channel bandwidth varies from 20 to 800 MHz depending on the standard requirement and the input sensitivities follows WLAN and WiMAX standard. It can be observed that, for a better fix RF front-end receiver architecture to be developed, the receiver should provide a better overall gain and noise figure with sufficient bandwidth to provide better performance. Thus, it is adapted to the IEEE 802.16 WiMAX standard.

Front-End Receiver

Fig. 1 shows the configuration of direct conversion RF front-end receiver architecture using a double stage LNA amplifier for point-to-point communication WiMAX at 5.8 GHz. The overall RF front-end receiver architecture should introduce higher gain at 50 dB compare to 32 dB reported from the literature review. The need to obtain additional gains is to enable communication transmission distance for up to 50 km (Othman *et al*., 2010). In addition, the noise figure proposed by the IEEE 802.16 (WiMAX) for the RF receiver front-end architecture must be less than 10 dB. As well as the noise figure must be less than 3 dB (Othman *et al*., 2010). The input sensitivity of the system should cover the minimum sensitivity of -80 dBm.

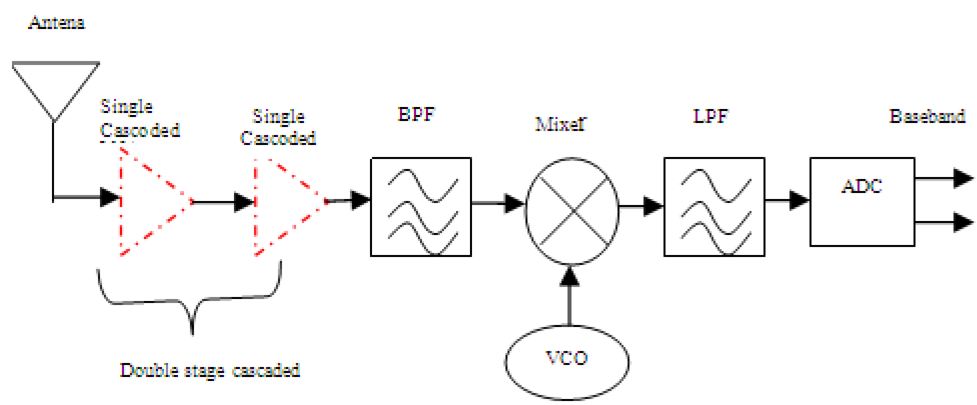

Fig. 1: Direct conversion RF front-end receiver using double stage cascoded LNA configuration

In this paper, we will focus on the design a combination of LNA amplifiers for the RF front-end receiver. As shown in Fig. 1, the LNA amplifiers is a double-stage cascoded LNA using inductive drain feedback. The operation begins when the RF front-end antenna receiver receives RF signals from the transmitter; the signal is then fed to the double-stage LNA amplifier so that it can enhance the gain and at the same time reduce the noise figure. The design of a double stage LNA amplifier at the RF front-end receiver architecture will have face many drawbacks such as image signal, DC offset and reciprocal mixing (Hoesam *et al*., 2007). Moreover, the circuit provide good input impedance match, enough gain power and low noise figure (NF) within the required band (Ruey-Lue *et al*., 2008).

To obtain high gain and low noise at the RF front-end receiver, we present a double-stage cascoded LNA amplifier using inductive feedback from gate to drain of an PHEMT as a sub- component in the RF front- end architecture.

Theoretical Description:

Several aspects were considered before designing a low noise amplifier (LNA). The input and output matching network, would have to be optimized so that the amplifiers can achieve the small signal gain, bandwidth, required stability (Ruey-Lue *et al*., 2008). According to Pozar (2001), the topology for low noise amplifier (LNA) consists of three stages; the input matching network (IMN), the amplifier itself and the output matching network (OMN). The formula and mathematical statements used to design LNA amplifiers are obtained from Pozar (2001). Fig. 2 shows a typical single-stage LNA amplifier including input and output matching networks.

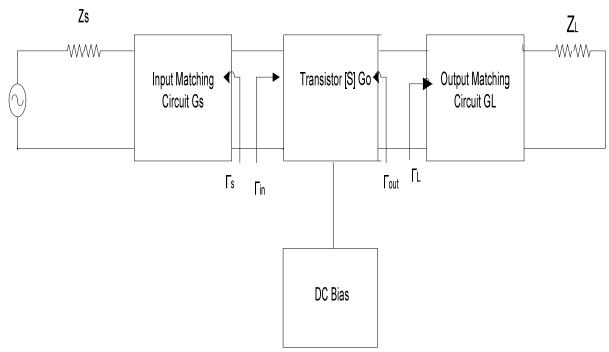

Fig. 2: Typical LNA amplifier

In general, basic concept of high frequency amplifier design is to match the input and output impedance of a transistor for high frequencies. Using S-parameters frequency characteristics at a DC-bias point are set based on the source impedance and load impedance (Pozar, 2000). The main purpose of obtaining input and output matching condition is to avoid reflection and improve the efficiency of signal transmission from the source to the load. The targeted S-parameter specification for the double-stage cascoded LNA amplifier is shown in Table 2.

Table 2: Targeted S-Parameters for a double- stage cascoded LNA amplifier

S parameter	Double-stage Cascoded LNA
Input reflection S_{11} (dB)	< -10 dB
Return Loss S_{12} (dB)	< -20 dB
Forward Transfer S_{21} (dB)	>+ 50 dB
Output Reflection loss S_{22} (dB)	<-10 dB
Noise Figure (dB)	< 3 dB
Stability (K)	K > 1
Bandwidth (MHz)	>1000

3.1 Power Gain:

Several explanations about power gain have been discussed in depth by previous researchers, therefore, an understanding of the power gain to operate operating at high frequency is needed (Ibrahim *et al*., 2012). Amplifier operations can be explained in more detail through the input / output circuit for two port networks. As shown in the Fig. 3, power gains of 2 port networks with circuit impedance or load impedance of the power amplifier are represented with scattering coefficient classified into Operating Power Gain, Power Transducer and Available Power Gain (Ruey-Lue *et al*., 2008; Leon *et al*., 2010).

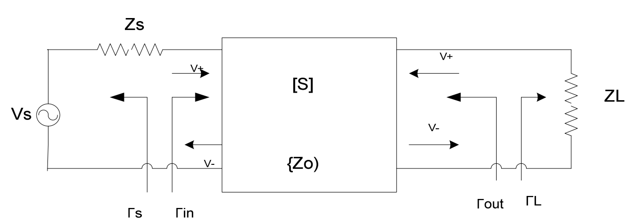

Fig. 3: I/O circuit of 2-port network [5]

3.1.1 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 (P_{in}) of the two-port network (Pozar, 2001). The power dissipated in the load is the difference between the power reflected at the output port and the input power and power delivered to the input is the difference between the input power at the input port and the reflected power (Pozar, 2001). The Operating Power Gain can be expressed as (Ibrahim *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 cans 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 *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.

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, $G_A = \frac{P_{avn}}{P_{avs}}$. The power gain is P_{avn} when $\Gamma_{in} = \Gamma^*_s$.

Therefore Available Power Gain is given by (Othman *et al*., 2010):

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

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

Noise Figure:

Most of the transistor's manufacturers have already set the drain-source voltage and drain-source current for the transistor to operate at minimum noise figure. Consequently the minimum noise figure will be a significant factor in the design of amplifiers that must be met by every designer in obtaining optimal conditions for particular transistor. However, it is impossible to get an LNA amplifier with low noise figure and maximum gain at the same time; therefore, there should be a compromise between these two parameters. It can only be done by using a 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 the formula (Ibrahim *et al*., 2012) :

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

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

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

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:

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

And

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

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

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

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

Design Of Double-Stage Cascoded Lna:

Double - stage cascoded low noise amplifier (LNA) design is based on the specifications stipulated in Table 1. Pseudomorphic High Electron Mobility Transistor FHX76LP is used to design a double-stage cascoded LNA. S-parameters for PHEMT is shown in Table 1, where the parameters are obtained at V_{DD} = 2V and I_{DS} = 10mA of bias 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
Angle	-86.54	33.88	178.66	-10.46

Overall performance of low noise amplifier can be determined by calculating or simulating on the transducer gain (2), noise figure (6) and also on the input and output standing wave ratios, $VSWR_{IN}$ and VSWRout. The optimum, Γ_{opt} and Γ_L were obtained as Γ_{opt}= 21 + +j 48.02 and Γ_L = 79.90- j7.299 for cascoded LNA.

Fig. 4 shows the complete schematic double-stage cascoded LNA amplifier. The design of cascoded LNA topology as given in the schematic used T-matching network placed at the input and output impedance. which characteristics of the T - network element used lump reactive element and microstrip line impedance.

For double-stage cascoded LNA amplifier there is an inductive feedback (L16) is inserted to connect to the drain of the M1 in the first stage and the feedback inductive (L26) is connected to the drain of the M3 at double stage, inductive source generation (L10) is connected to a source at the first stage M2 and inductive source generation (L20) is connected to the source M4 in double stage. There is also an inductive L15 placed between the source and drain of M1 to M2. Similarly inductive (L25) is placed between the source M3 and drain M4 in the second stage.

L10 is used inductive generation at the LNA amplifiers to allow more flexibility in matching occurred at the input stage while the L20 will affect the flexibility in the input and output matching to 50 Ohm terminal. Besides, it also can enhance gains, bandwidth and stability of the circuit. The cascode transistor M2 suppresses the Miller capacitance of M1 thereby increasing 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). Inductive L15 and L25 will gives the LNA real input impedance and help in getting the input and output of the optimal matching. When this condition occurs it cans enhance its gain and stability. In addition, it helps the designer set the desired bandwidth and cause noise figure unchanged. When inductive components for the L16 and L26 values raised from the set value, will cause an increase in the gain change dramatically. Additionally inductive L16 will also help the designers to widen the bandwidth while the L26 inductive allows output matching at 50 Ohm impedance terminals. The passive elements in the input matching network are L11, L12, L13 and CA1. While the passive elements in the output matching network are L27, L28, L29 and CB2. Good selection of passive component in the input and output matching cause LNA amplifiers on high gain at the desired frequency. In addition, the changes of capacitor CA1 will affect the value of the noise figure while the capacitor CB2 will effects on the response of the overall bandwidth of the LNA amplifiers. Capacitor CC1 and CC2 are acting as DC block to the cascoded LNA circuit, in which they proposed is worth 10 times the original value of the CB because it acts as a bypass capacitor (Othman *et al*., 2010). To achieve the targeted overall gain of 50dB; it is decided to design double-stage cascoded technique. By using Ansoft Designer SV, Smith Chart matching technique, the components for the double-stage cascoded LNA amplifier is shown in Table 4.

Table 4: Double-Stage Cascoded LNA Amplifier parameters

Double-Stage Cascoded LNA			
Single-Stage		Double-Stage	
Components	Value	Components	Value
L11	0.660nH	L21	0.580nH
L12	1.240nH	L22	1.240nH
L13	0.660nH	L23	0.780nH
L14	0.400nH	L24	0.400nH
L15	1.010nH	L25	0.970nH
L16	7.700nH	L26	7.700nH
L17	1.370nH	L27	1.370nH
L18	0.560nH	L28	0.940nH
L19	1.290nH	L29	1.350nH
L10	0.064nH	L20	0.064nH
CA1	0.350pF	CB1	0.450pF
CA2	0.650pF	CB2	0.650pF
CC1	7.500pF	CC2	7.500pF

From the observation of the designed double-stage cascoded circuit LNA amplifiers, there are some passive component that should be optimized to achieve a targeted specification as required for WiMAX. This passive component values determine the high gain, low noise, good stability and maintain the value of the required bandwidth despite the increasing stage of LNA amplifiers. It is found that the value of the gain, noise figure, stability and bandwidth is greatly influenced by changes in the passive component, in the double stage cascoded LNA amplifiers. Therefore, the designer can identify the specific components of the double-stage cascoded LNA amplifiers that can provide the optimal impact of changes to the gain, noise figure, stability or bandwidth. This facilitates the designer to choose one or all of the four variables as shown in designing cascoded LNA amplifiers. This variable should be determined during the development of the cascoded LNA amplifiers so that the circuit constructed in accordance with the IEEE 802.16 specification (WiMAX).

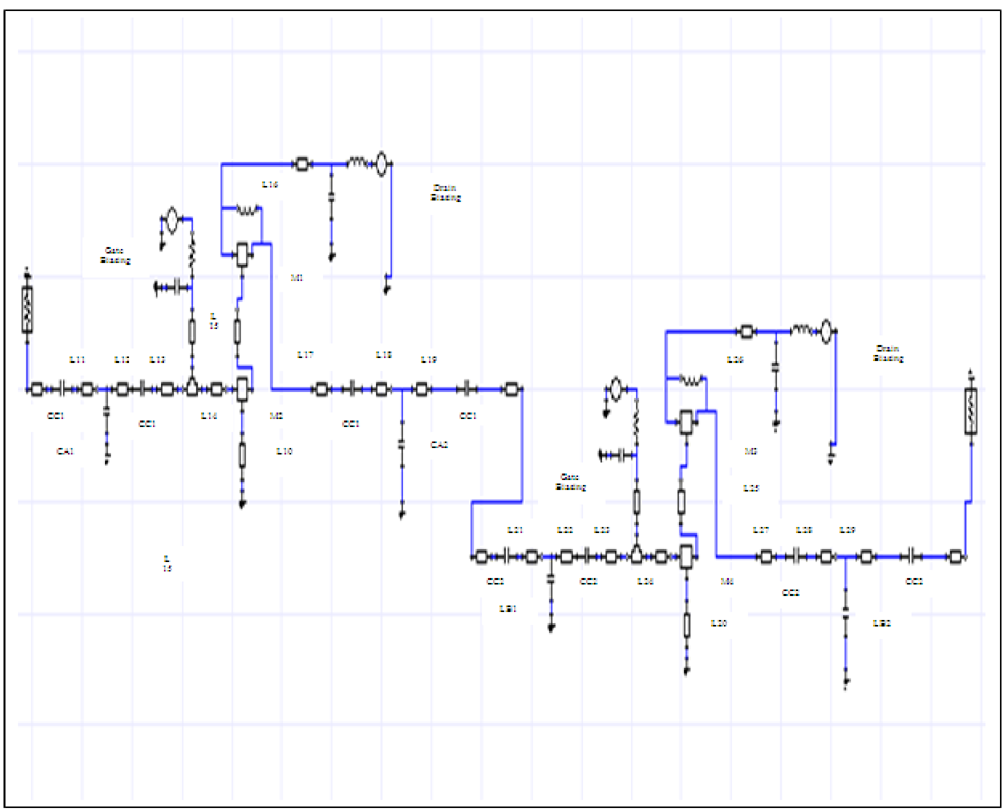

Fig. 4: Complete schematic double- stage Cascoded LNA

Simulation Results:

The simulation result for the double stage cascoded LNA amplifier is presented in Table 5.

S- parameter	Targeted	Simulated	Comment
Input Reflection S_{11} dB	<-10	-12.72	Achieved
Output Reflection S_{22} dB	<-10	-17.89	Achieved
Forward transfer S_{21} dB	>50	54.60	Achieved
Return Loss S_{12} dB	<-20	-62.50	Achieved
NF dB	<3	0.90	Achieved
BW MHz	1000	1190	Achieved
Stability (K)	>1	1.31	Achieved

From the tabulated values, the input reflection S_{11} is -12.72 dB while the output reflection loss S_{22} is -17.89 dB. The value obtained is better than the targeted and acceptable. Figure 5 (a) shows the output from the S_{11} and S_{22} parameters at 5.8 GHz.

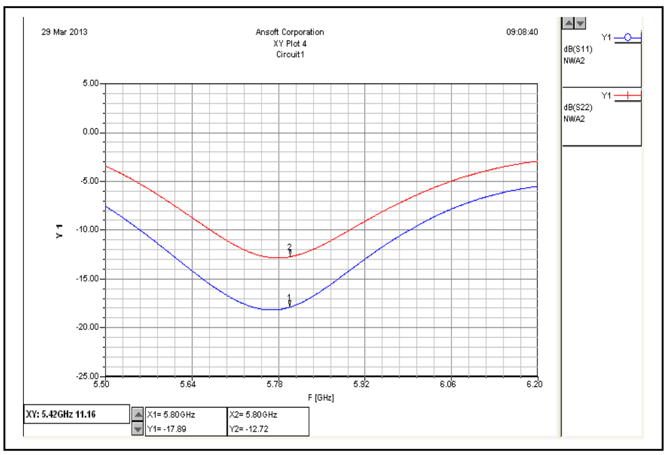

Fig. 5(a): Input Reflection Loss (S_{11}) and Output Reflection Loss (S_{22})

While the output gain S_{21} in double stage cascoded LNA amplifier is 54.6 dB, and return loss S_{12} is -62.50 dB have been obtained. The output gains earned more than 4.6 dB from the targeted value and return loss is -42.5 dB better than the targeted and thus the result is acceptable. Figure 5 (b) shows the S_{21} and S_{22} parameters at 5.8 GHz.

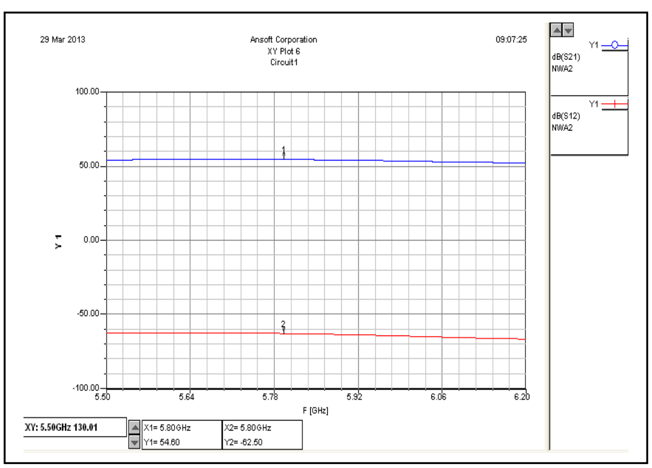

Fig. 5(b): Forward Tranfer (S_{21}) and Return Loss (S_{12})

The noise figure obtained from the double stage cascoded amplifier LNA is 0.9dB. Specified noise figure value conferred by the IEEE 802.16 is 3 dB while the noise figure obtained was lower by 2.1 dB. Figure 5 (c) shows the noise figure at double stage cascoded LNA amplifier at 5.8 GHz.

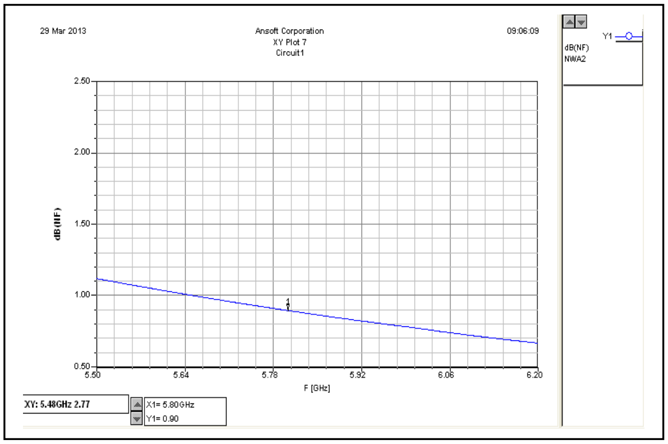

Fig. 5(c): Noise Figure

Stability factor obtained after matching load is 1.31 at 5.8 GHz frequency as shown at figure 5(d). Value acquired for stability factor is greater than 1, the LNA amplifiers currently in a state of unconditionally stable and no isolation. From Fig. 5 (b), we observed that, the 3dB bandwidth a 1.19 GHz bandwidth was obtained and compliant with the targeted result of more than 1 GHz.

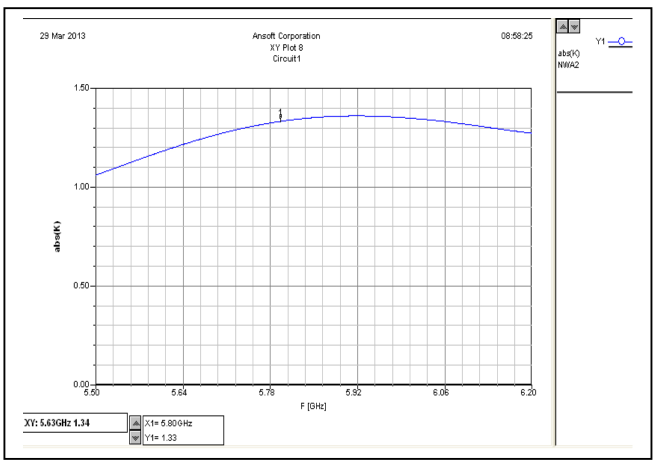

Fig. 5(d): Stability Factor

Conclusions:

The double-stage cascoded LNA amplifier with inductive drain feedback has been simulated and developed successfully with the IEEE standard 802.16 WiMAX. Observations made from the results of S-parameters in the double-stage cascoded LNA amplifier has reached predetermined specifications in Table 2. The double-stage 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. From the tabulated values in Table 6, it has been observed that the gain of the simulated is 54.6dB at frequency 5.8 GHz. While the input reflection loss S11– 12.72 dB and, the output reflection loss S22 was -17.89 dB. The S12 return loss was -62.50dB. The stability (K) and noise figure (NF) were 1.31 and 0.9 dB respectively. In conclusion, we have shown that using a double-stage cascoded LNA amplifier can achieved higher gain, minimal noise figure and maintain the bandwidth.

ACKNOWLEDGMENT

The work described in this paper was fully supported by Centre For Research And Innovation Management (CRIM), Universiti Teknikal Malaysia Melaka (UTeM). Melaka, Malaysia.

REFERENCES

Atallah, J.G., S. Rodriguez, L.R. Zheng & I. Mohamad, 2007. A direct conversion WiMAX RF front end in CMOS Technology. IEEE Proceedings.

Chen, H.C., T. Wang, H.W. Chiu, T.H. Kao, S.S. Lu, 2009. 0.5-V 5.6-GHz CMOS receiver Subsystem, IEEE Transactions on Microwave Theory and Techniques, 57(2): 329-335.

Garuda, C., I. Mohamed, 2006. A Multi Band CMOS RF Front End For 4G WiMAX and WLAN Application, ICAS 2006 IEEE Transactions on Microwave Theory and Techniques, pp: 3049-3052.

Hoesam Jeong, Byoung-Joo Yoo, Cheolkyu Han, Sang-Yoon Lee, Kang- Yoon Lee, Suhwan Kim, Deog-Kyoon Jeong, and Wonchan Kim, 2007, A 0.25um CMOS 1.9-GHz PHS RF transceiver with a 150- kHz Low-IF Architecture,. IEEE Journal of Solid-State Circuits, 42(6): 1318- 1327.

Huang, D.R., W.K. Shiau, H.Y. Yi, 2007. A WiMAX Receiver with variable bandwidth of 2.5-20 MHz and 93 dB Dynamic Gain range in 0.13um CMOS Process. IEEE Radio Frequency Integrated Circuits Symposium, pp: 369-372.

Ibrahim, A.B., A.R. Othman, M.N. Husain, M.S. Johal, 2012. The Cascode and Cascaded Techniques LNA at 5.8GHz Using T-Matching Network for WiMAX Applications. International Journal of Computer Theory and Engineering, 4: 1.

Ibrahim, A.B., M.N. Husain, A.R. Othman, M.S. Johal, 2011. High Gain of Cascoded LNA at 5.8GHz Using T-Matching Network for wireless applications. International conference on Wireless and Optical Communication.

Ibrahim, A.B., M.N. Husain, A.R. Othman, M.S. Johal, J. Sam Hamidon, 2012. The Cascode LNA with RF Amplifier at 5.8GHz Using T-Matching Network for WiMAX Applications. Journal of Telecommunication and Computer Engineering, 4: 1.

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

Kalantari, Fatemeh, N. Masoumi, F.S. Saadati, 2006. A Low Power 90 nm LNA with an Optimized Spiral Inductor Model for WiMax Front End,. MWSCAS '06. 49th IEEE International Midwest Symposium on , vol.1, no., pp: 172-176.

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

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

Pozar, David., M., 2000. “Microwave and RF Wireless System”, United States of America: John Wiley and Sons Inc. 77-97: 205-207.

Othman, A.R., A.H. Hamidon, C. Abdul Wasli, M.F. Mustaffa, J.T.H. Ting, A.B. Ibrahim, 2010. Low Noise, High Gain RF Front-end Receiver at5.8GHz for WiMAX Application. Journal of Telecommunication and Computer Engineering.

Othman, A.R., A.H. Hamidon, C. Abdul Wasli, J.T.H. Ting, 2010. RF Front- end Receiver For WiMAX Application”, Indonesia-Malaysia Microwave – Antenna Conference.

Park, J., S.N. Kim, Y.S. Roh, & C. Yoo, 2010. A Direct Conversion CMOS RF Receiver Reconfigurable From 2 to 6 GHz. IEEE Transactions on Microwave Theory and Techniques, 58: 2326-2333.

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

Yijun, Z., C.P. Yoong, L.S. Weng, Y.J. Khoi, C.Y. Michael, A.C. Moi, Fat, W.T., 2006. A 5 GHz dual Mode WiMAX/WLAN Direct Conversion Receiver. IEEE ISCAS, pp: 3053-3056.