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New LNA Architecture Topology Using Inductive Drain Feedback Technique for Wireless Applications

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Abstract

This paper presents a design of a single LNA cascaded with double stage cascoded LNA amplifiers using an inductive drain feedback technique. The amplifier is implemented using superHEMT FHX76LP transistor devices. The designed circuit is simulated with Ansoft Designer SV. The LNA is designed by using an inductive drain feedback, inductive generation to the source, and the T-network as a matching technique which is which is used at the input and output terminals. The low noise amplifier (LNA) provides a gain (S_{21}) of 68.94 dB and the noise figure (NF) of 0.64 dB. The return loss (S_{12}) output reflection (S_{22}) and input reflection (S_{11}) are -88.39,-17.37 and –15.77 dB respectively. The measurement shows a 3-dB bandwidth of 1.72 GHz and stability are 4.54 more than 1 has been achieved. The input sensitivity is -92 dBm exceeded the standards required by IEEE 802.16.

Keywords: *RF front-end, IEEE 802.16, cascaded and cascoded LNA, inductive drain feedback, topology*

1. Introduction

3G technologies that are available recently have a significantly higher bit rate than 2G technology, but the bit rate is not adequate to sustain the high demand from consumers for wireless broadband, multi-megabit throughput and lower latency (delay between requesting data and getting a response). To accommodate the high consumer demand, the introduction of WiMAX technology for connectivity to the new generation consumer devices to the latest applications available in the market such as (GSM, WiFi, Bluetooth, ZigBee, UWB HiperLAN etc...) for 3G and 4G networks [1]. WiMAX is a trademark for a family of wireless communication protocol that provides both fixed and mobile internet access. WiMAX is the internet Protocol (IP) based, broadband wireless access technology that provides performance similar to 802.11/WiFi network with coverage and quality of service (QoS) of cellular networks [1]. Figure 1 shows the latest standards for mobile and data communications.

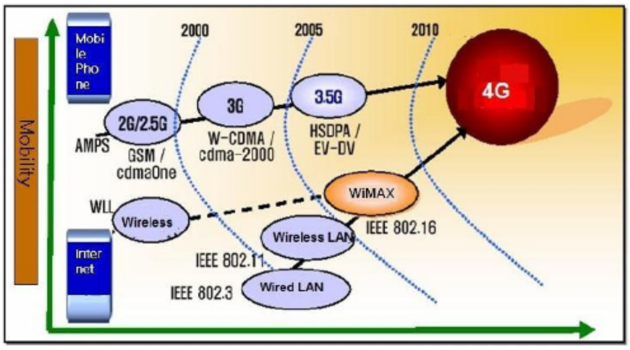

Figure 1. The latest standards for mobile and data communications [1]

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WiMAX is a new trademark and standard for group technologies of telecommunications protocols that provide fixed and mobile Internet access. As WiMAX has high transfer data rates (70 Mbps) and longer reach (50km), it can provide high bandwidth voice and data for residential and enterprise [2]. WiMAX is a replacement technology for cellular phone technologies such as UMTS and GSM and, or can be used to increase capacity of the customer [3]. To support a new trademark at Telecommunication protocol and allow it to operate multiple applications on a single device, RF front end receiver is essential and inevitable in demand.

The design of the RF front-end receiver that complies with the new standards WiMAX meet several challenges and complicated. Thus, the best design on the front-end receivershave been developed to obtain a high overall gain, low noise figure, and sufficient bandwidth to accommodate the needs of new trademark and wireless standard (WiMAX). A proposed new architecture for the receiver front-end should be introduced to ensure high performance signal reception according to the IEEE 802.16 standard. The overall gain for the front-end receiver should introduce more than 65 dB compared to 32 until 50 dB reported from previous researcher by taking consideration to cover the extension of communication distance for the system up to 50km [4]. In the WiMAX standard, the system is designed to accommodate up to 200 channel subscribers while the bandwidth of the system designed is between 1600 to 1700 MHz, which is triple than the standard 20 MHz for 200 sub-carriers. In addition, the noise figure proposed by the IEEE 802.16 (WiMAX) for the RF receiver front-end architecture must be less than 3 dB. The input sensitivity of the system should cover the minimum sensitivity of -80 dBm [4].

In this paper, a new topology for WiMAX front end architecture using an inductive drain feedback is used to achieve a gain more than 65 dB, noise figure less than 3dB and maintain bandwidth more than 1 GHz is proposed for WiMAX application. Figure 2 shows the new architecture for direct conversion RF front-end receiver WiMAX at 5.8 GHz is introduced. The development of combination LNA at the front-end of the receiver will be focused.

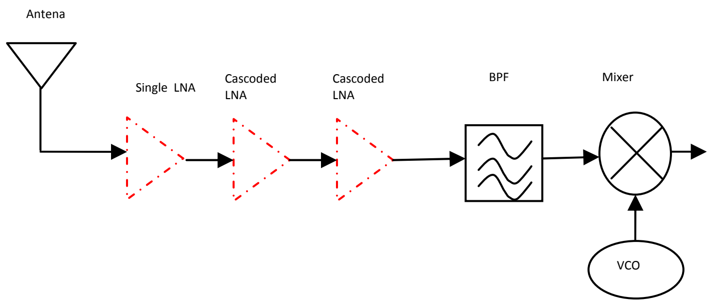

Figure 2. The new architecture for direct conversion RF front-end receiver WiMAX at 5.8 GHz

This configuration consists of double stages cascoded LNA using inductive drain feedback combined with source inductive degeneration, inductive RF choke placed between the two LNA amplifier and the T matching network at the input and output ports. Adding inductive drain feedback at the cascoded topology has improved the gain of the LNA and will suitable at matching output that it also helps in increasing the bandwidth. While the addition of an inductive source generation at cascoded LNA topology enhanced bandwidth, stability and improve input-output matching capabilities. The use of T-matching on a double stage cascoded LNA also has helped reduce the reverse isolation and noise figure.

2. LNA Theory

Low noise amplifiers (LNA) play a significant role in increasing the performance of the RF front-end receiver. LNA at the WiMAX receiver application requires sufficient sensitivity to enable the receiver distinguish signal from the surrounding noise and interference to ensure that it can take an information signal sent by the transmitter. There are five essential characteristics in the design of LNA is under the control of a specialist LNA designer for use in RF front-end receiver that affect directly to the receiver sensitivity is noise figure, gain, bandwidth, linearity, and dynamic range. Even so to control such features requires a deep understanding of the device amplifiers, active and passive components, and fabrication details to ensure the LNA amplifiers built to achieve optimal performance and only a slight tradeoff between the characteristic [5].

Figure 3 shows the usual variables that affect the performance of LNA either on the device and circuit design. However, in this research we only focus on variables such as gain, noise figure, stability, bandwidth, topology, and input and output matching for best performance of LNA amplifiers.

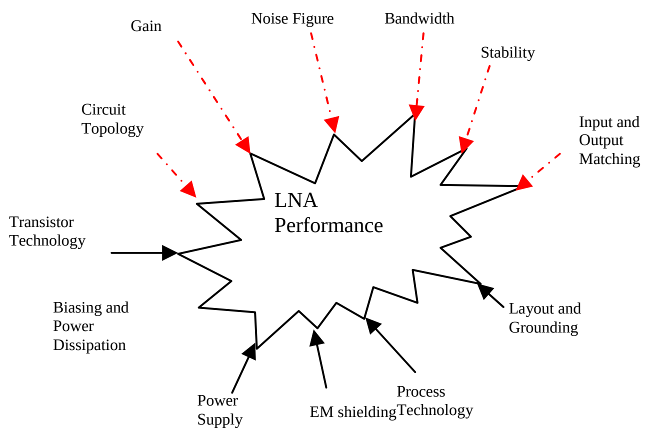

Figure 3. LNA Performance Variable

The targeted S-parameter specification for the single LNA cascaded with double stages cascoded LNA amplifier is shown in Table 1.

Table 1. Targeted S-Parameters for a a single LNA cascaded with double stages cascoded LNA amplifier

S- parameter	Single LNA cascaded with double stages cascoded LNA
Input reflection S11 (dB)	< -10 dB
Return Loss S12 (dB)	< -10 dB
Forward Transfer S21 (dB)	>+ 65 dB
Output Reflection loss S22 (dB)	<-10 dB
Noise Figure (dB)	< 3 dB
Stability (K)	K > 1
Bandwidth (MHz)	>1000

2.1. Stability, Noise Figure and Power Gain

Stability is one of the important characteristics in designing LNA amplifiers. Determination of stability is essential to avoid oscillation occurs at the operating frequency. The oscillation is possible if either of input or output port impedance has produce a negative real part. This would imply that Γ_{in} (input reflection coefficient) >1 or Γ_{out} (output reflection coefficient) >1. This because Γ_{in} and Γ_{out} depend on the source and the load matching network. However, the stability of the amplifier depends on Γ_s (the reflection coefficient of the source) and Γ_L (the reflection coefficient of the load) as presented as matching network. If low noise amplifiers is not stable, it would become useless since major properties including bandwidth, gain, noise, linearity, DC power consumption and impedance matching can be significantly degraded. For this design, a good stability can be achieved (unconditionally stable) by employing the signal flow theory and S-parameter [6]. Alternatively, the amplifier will be in good stability , when the stability factor (K) and delta factor (Δ) following necessary and sufficient conditions are met:

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

And,

$$|\Delta| = |S_{11}S_{22} - \ S_{12}S_{21}| < 1 \qquad (2)$$

(K > 1) and (| Δ | < 1) is condition requirement for unconditional stability (good stability).

Noise optimization is the most critical step in the LNA design procedure. The best way to make the balance optimization of noise figure and gain using constant gain circles and circles of constant noise figure. 2-port transistor has a minimum value of the noise figure at the specified admittance given by the Equation (3), [7] :

$$F = F_{\min} + \frac{R_N}{G_S} | Y_s - Y_{opt} |^2 \qquad (3)$$

For low noise transistors, manufacturers usually provide F_{min}, R_N and Y_{opt} by frequencies. N defined by the formula for desired noise figure, shown in Equation (4):

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

The Power gain of 2-port networks with circuit impedance or load impedance of the power amplifier are represented with scattering coefficient classified into Available Power Gain, Power Transducer Gain and Operating Power Gain [8].

Operating power gain (G_P), is the ratio between the power delivered to the load (P_L) and the power input (P_{in}) to the network. The Operating Power Gain can be specified as an Equation (5), [7]:

$$G_P == \frac{P_L}{P_{in}} = \frac{|S_{21}|^2 \left(1 - |\Gamma_L|^2\right)}{\left(1 - |\Gamma_{in}|^2\right)|1 - S_{22}\Gamma_L|^2} \qquad (5)$$

Available power gain (G_A) is the ratio between the power available from the network (P_{avn})and the power available from the source (P_{avs}) as shown in Equation (6), [7]:

$$G_A = \frac{P_{avn}}{P_{avs}} = \frac{1 - | \Gamma_S |^2}{| 1 - S_{11}\Gamma_S |^2} | S_{21} |^2 \frac{1}{| 1 - S_{22}\Gamma_L |^2} \qquad (6)$$

Transducer power gain (G_T) is the ratio between the power delivered to the load (P_L) and the power available from the source (P_{in}) as shown in Equation (7), [7] :

$$G_T = \frac{P_L}{P_{in}} = \frac{| S_{21} |^2 \ (1 - | \Gamma_S |^2)(1 - | \Gamma_L |^2)}{| (1 - S_{11}\Gamma_S)(1 - S_{22}\Gamma_L) - (S_{12}S_{21}\Gamma_S\Gamma_L) |^2} \qquad (7)$$

2. Design Of Single LNA Cascaded With Double Stages Cascoded LNA

Figure 4 shows the complete schematic single LNA cascaded with double stage cascoded LNA using inductive feedback. The selection of the transistor is important in the design of LNA. The design of the single LNA with double stages cascoded LNA is based on the specification in Table 1. For reasonable gain and low noise figure at the required frequency requirement, the transistor used for the design of LNA is PHEMT Transistor FHX76LP. The transistor parameter at frequency 5.8 GHz are S_{11}=0.712∟-86.54, S_{12}= 0.065∟33.88, S_{21}=

8.994∟178.66 and S_{22} = 0.237∟-10.46, where the parameters were obtained at V_{DD} = 2V and I_{DS} = 10mA of bias set at PHEMT.

From the S-parameters, determining the overall performance of LNA can be determined by calculating the input and output standing wave ratios, VSWRIN and VSWROUT, the transducer gain (GT) and the noise figure (NF). The optimum, Γopt and ΓL were obtained as Γopt = 21 + j48.02 and ΓL = 79.90-j7.299 for cascoded LNA. While, Γopt = 18.41 + j50.12 and ΓL = 79.913-j7.304 for a single LNA.

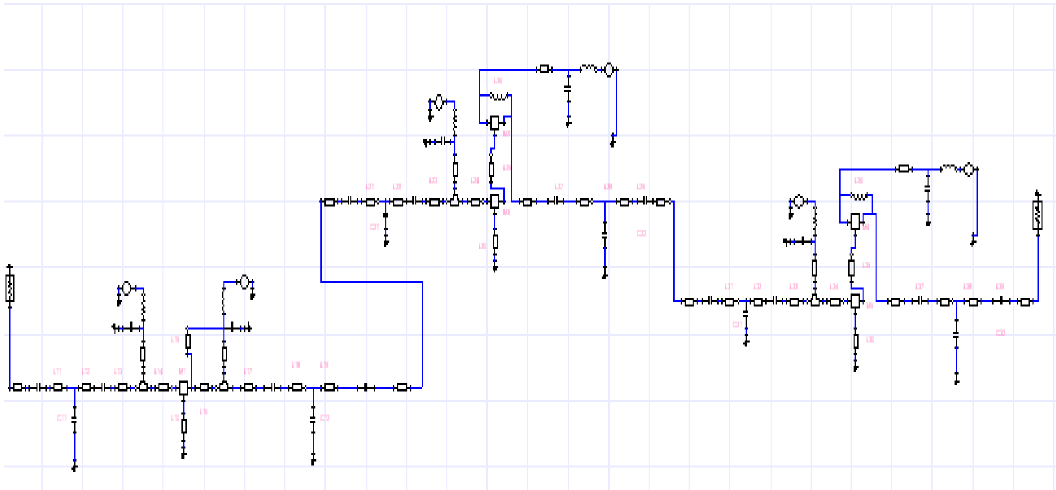

Figure 4. The complete schematic single LNA cascaded with double stage cascoded LNA using inductive feedback

In this configuration, it combines single LNA at the first stage, then use cascoded LNA with inductive feedback at the drain on the second and third stage. The proposed single LNA design is based on a source degenerated topology (L_{10}), inductive shunt peaking at the drain (L_{15}) and T-matching network at the input and output impedance (input impedance matching at L_{11}, L_{12}, C_{11}, and output impedance matching at L_{18}, L_{19}, C_{12}). While the double stages cascoded LNA topology using latest techniques consisting of inductive feedback (L_{26} and L_{36}) are at drain M2 and M4, inductive generation source (L_{20} and L_{30}) connected to the source of the M_3 and M_5. In Addition, there L_{25} and L_{35} inductive RF choke were placed between the source drain on the M_2 and M_3, and the source drain on the M_4 and M_5 respectively. This topology also used the T-matching network at the input and output impedance (input impedance matching component at L_{21},L22, L_{31}, L_{32}, C_{21} and C_{31} and output impedance matching component at L_{28},L_{29},L_{38}, L_{39}, C_{22} and C_{32}). By using Ansoft Designer SV, Smith Chart matching technique, the components for the amplifier are shown in Table 2.

Table 2. Single LNA Cascaded with Double Stages Cascoded LNA Amplifier parameters

	Components											
1st Stage LNA	L_{10}(nH)	L_{11}(nH)	L_{12}(nH)	L_{13}(nH)	L_{14}(nH)	L_{15}(nH)	L_{16}(nH)	L_{17}(nH)	L_{18}(nH)	L_{19}(nH)	C_{11}(pF)	C_{12}(pF)
Value	0.078	1.346	1.371	0.449	0.439	1.271	0.445	1.366	1.195	1.368	0.264	0.010
2nd Stage Cascoded LNA	L_{20}(nH)	L_{21}(nH)	L_{22}(nH)	L_{23}(nH)	L_{24}(nH)	L_{25}(nH)	L_{26}(nH)	L_{27}(nH)	L_{28}(nH)	L_{29}(nH)	C_{21}(pF)	C_{22}(pF)
Value	0.064	1.346	1.016	0.698	0.367	1.159	9.000	1.367	0.658	1.369	0.100	0.600
3rd Cascoded LNA	L_{30}(nH)	L_{31}(nH)	L_{32}(nH)	L_{33}(nH)	L_{34}(nH)	L_{35}(nH)	L_{36}(nH)	L_{37}(nH)	L_{38}(nH)	L_{39}(nH)	C_{31}(pF)	C_{32}(pF)
Value	0.084	1.318	1.278	0.658	0.283	1.139	9.560	1.368	0.658	0.228	0.500	0.750

Observations on projects implemented in these LNA are passive elements at each stage component that was designed to play an important role in influencing the gain, noise figure, stability and bandwidth. Here, we show evidence on passive component elements which at every stage LNA that will affect performance LNA variables as discussed in the previous section.

Overall Noise figure is heavily influenced in the first stage LNA, especially in the input matching. Therefore, the selection of the appropriate value required in this part, to get the lowest noise figure for the LNA. While at the output matching of the first stage, will not influence the noise figure of the LNA.

Figure 5 shows the effect of inductive component elements in the input T-matching on the first stage that affect the noise figure. Changing the value of inductive L_{11} from 1mm to 6 mm have caused the noise increased from 0.63 dB to 0.73 dB while the value decreases to 0.53 dB when changing $L_{11}$to the 12mm. While the inductive value L_{12} changes from 1mm to 6mm cause noise figure changing from 0.63 dB to 0.60 dB, will increase to 0.66 dB when inductive L_{12} to 12mm. However, the noise figure can be changed significantly in Figure 6 if changes are made on the capacitive input T-matching. Change the capacitive value C_{11} from 0.1 pF to 1 pF cause noise figure rising from 0.59 dB to 1.22 dB. However, after making optimization in passive component at the input matching, selecting the noise figure of 0.64 dB is best for the whole system.

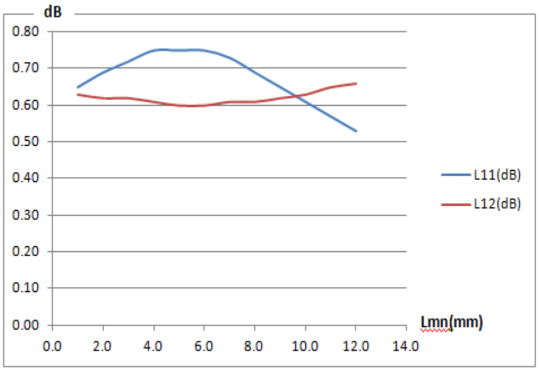

Figure 5. Affect changes value the L11 and L12 to the overall noise figure

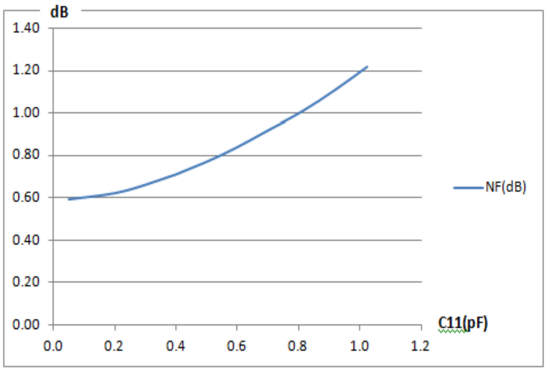

Figure 6. Affect changes value the C11 to the overall noise figure

To control the gain of the whole system, there are a few passive components at each stage that should be considered. The passive component is inductive source degeneration at every stage of L_{10}, L_{20} and L_{30}. Gains for the whole system changed from 63 dB to 69 dB if the width (W) on the L_{10}, L_{20}, L_{30} changed from 2mm to 30 mm. Additionally L_{10} and L_{20} also help in getting the pure impedance input matching, which enable value of the input reflection S_{11} less than 10 dB. While the output matching L_{30} helped to enable the value of the output reflection loss S_{22} less than 10 dB. This can be shown in Figure 7. In addition, there are other components in the amplifier LNA that significantly affect the overall gain, which is the inductive drain feedback (L_{26} and L_{36}) which placed on cascoded LNA topology on second and third stages of LNA. This is shown in Figure 8, which changing the value of inductive L_{26} from 1pF to 10 pF will increase the gain from 60.5 dB to 69.2 dB. While the varying inductive L_{36} from 1 pF to 10pF will be raise gain from 53.74 dB gain to 68.2 dB. When optimization was made on inductive L_{10}, L_{20}, L_{30}, L_{26} and L_{36}, gain values obtained was 68.96 dB.

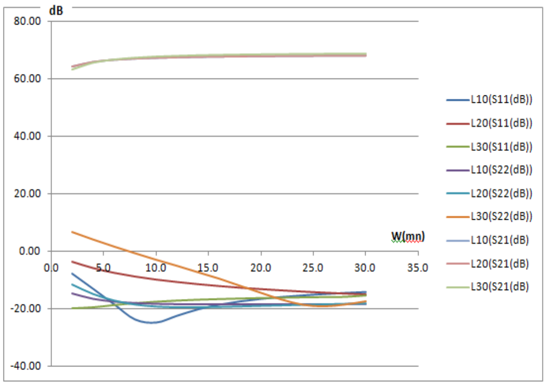

Figure 7. Affect changes value the L_{10}, L_{20} and L_{30} to the overall gain

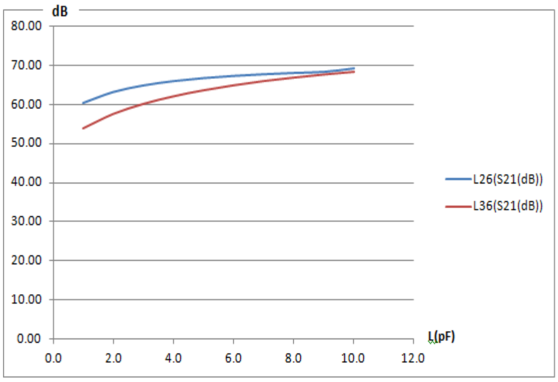

Figure 8. Affect changes value the L_{26}, L_{36} to the overall gain

From here we can see by adding cascoded LNA in the second stage has resulted in increased bandwidth of LNA that is shown in Figure 9. Using the inductive component at the output matching L_{27} and L_{29} in the second stage, the designer can control the desired bandwidth up to a maximum of 1.83 GHz.

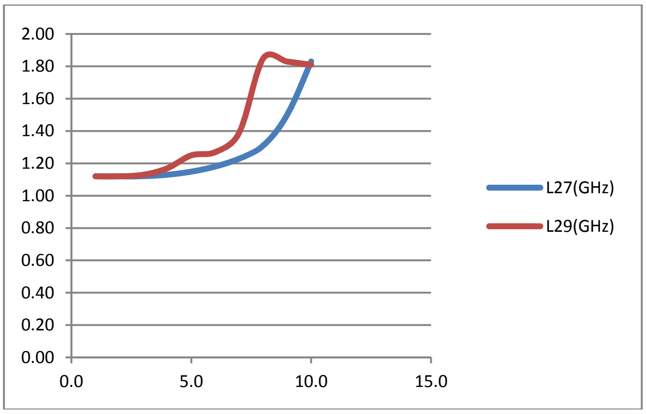

Figure 9. Affect changes value the $L_{27}$and L_{29} to the overall bandwidth

3. Results

The proposed LNA LNA a gain of 68.94 dB, 3-dB bandwidth of 1.72 GHz, and a minimum NF of 0.64 dB over the band is achieved implemented. The measured input reflection S_{11} is – 15.77 dB while the output reflection loss S_{22} is -17.37 dB, and the return loss S_{12} is -88.39 dB. The stability factor obtained after matching load is 4.54 at 5.8 GHz frequency. The value of stability obtained is greater than 1, and the LNA amplifiers are currently in a state of unconditionally stable. Thus, these values achieved the design specification as stated in Table 2. Table 3 shows the s-parameters output for comparison of topology LNA. From this comparison, we find this topology has resulted in improved performance in gain, noise figure, and bandwidth. In a variable gain performance improvements, there has been a 4-fold increase when using the proposed topology and just 2 ½ times when using the second topology if both topologies are compared with the gain result at the first topology. Meanwhile, there was a significant reduction on noise figure of 0.87 dB to 0.64 dB and an increase in on the 3-dB bandwidth of 1.08 GHz to 1.72 GHz when using the proposed topology compared using single LNA topology.

Table 3. The S-parameters output for comparison of topology LNA

S- parameter	Topology (1) Single LNA	(2) Single LNA Cascaded with Cascoded LNA	(3) Single LNA with Double Stages Cascoded LNA
Input Reflection S_{11} dB	-14.77	-10.48	-15.77
Output Reflection S_{22} dB	-14.69	-19.06	-17.37
Forward transfer S_{21} dB	**17.01**	**43.76**	**68.94**
Return Loss S_{12} dB	-20.53	-52.40	-88.39
NF dB	**0.87**	**0.7**	**0.64**
BW MHz	**1.08**	**1.24**	**1.72**
Stability (K)	1	1.37	4.54

The output S-parameter, noise figure and stability for single LNA are shown in Figure 10(a). While, the output S-parameter, noise figure and stability for single LNA cascaded with cascoded LNA is shown Figure 10(b). The S-parameter for single LNA cascaded with double stages cascoded LNA shown by Figure 10(c). While noise figure and stability are shown in Figure 10(d) and 10(e) respectively. Table 4 shows the comparison of recently reported LNA.

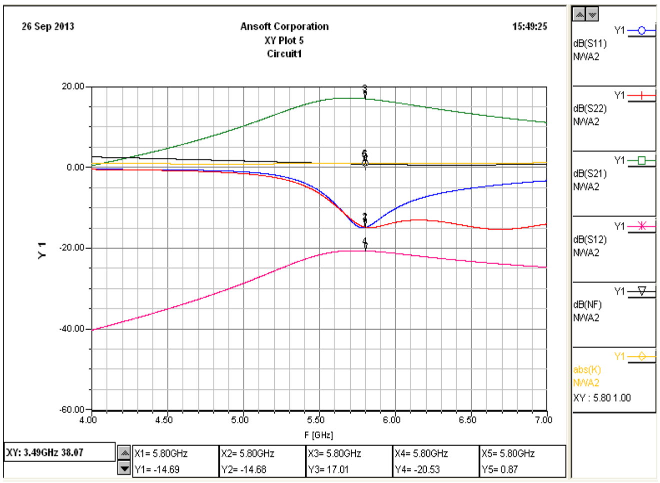

Figure 10(a). S-parameter, Noise Figure and Stability for Single LNA

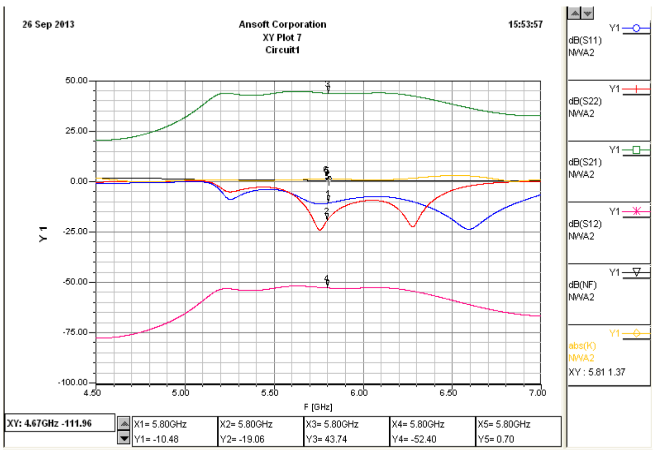

Figure 10(b). S-parameter, Noise Figure and Stability for Single LNA Cascaded with Cascoded LNA

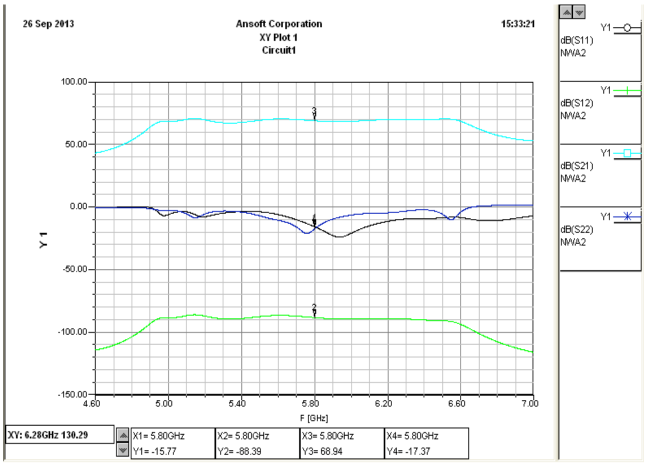

Figure 10(c). S-parameter for Single LNA Cascaded with Double Stages Cascoded LNA

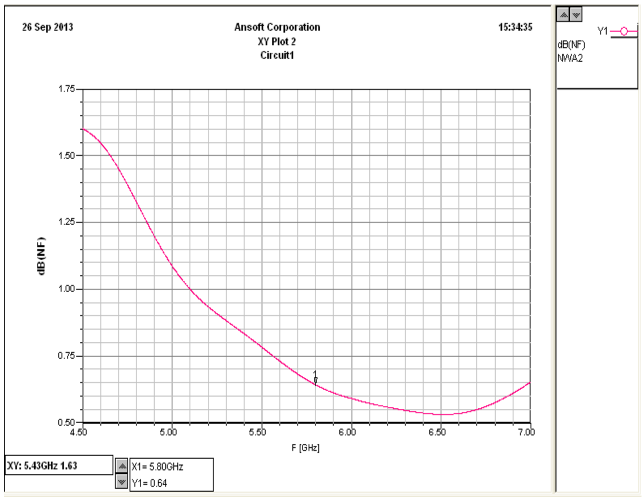

Figure 10(d). Noise Figure for Single LNA Cascaded with Double Stages Cascoded LNA

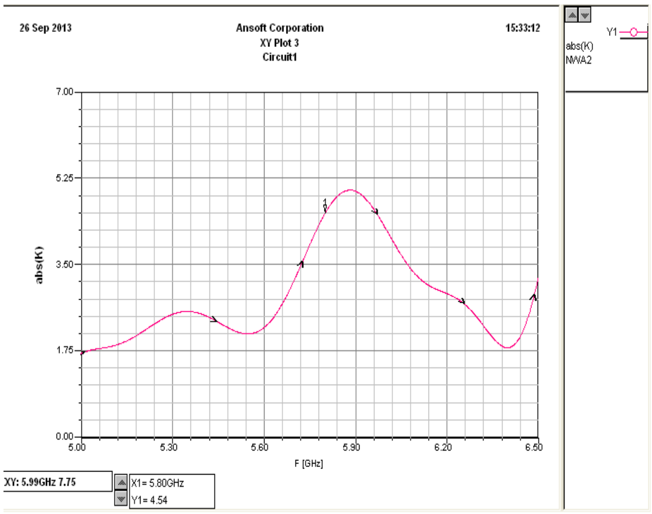

Figure 10(e). Stability for Single LNA Cascaded with Double Stages Cascoded LNA

Table 4. Comparison of recently LNAs

S- parameter	**This work**	[9]	[10]
Topology	Single LNA Cascaded with Double Stages Cascoded LNA	CGLNA with multiple feedback	Differential LNA
Input Reflection S_{11} dB	-15.77	<-10	-15.075
Output Reflection S_{22} dB	-17.37	<-10	-
Forward transfer S_{21} dB	**68.94**	**23**	**25.07**
Return Loss S_{12} dB	-88.39	-	-
NF dB	**0.64**	**2**	**1.07**
BW GHz	**1.72**	1.76	-
Stability (K)	4.54	>1	1.12

Table 4 depicts the comparison of topology double stages cascoded LNA using an inductive drain feedback combined with source inductive degeneration with a recently reported LNA. From this comparison, we find this topology has resulted in improved performance in gain, noise figure, and bandwidth. Meanwhile, there was a significant reduction on noise figure of 0.64 dB and an increase in on the gain to 68.24 dB when using the proposed topology compared using CGLNA with multiple feedbacks or differential LNA topology.

4. Conclusion

The new topology using inductive drain feedback was successfully developed and implemented in SuperHEMT technology compliant with the IEEE 802.16 standard**.** Obtained from the proposed topology allows the designer to control LNA variables performance such as gain, noise figure, bandwidth and stability in the LNA circuit. Recorded result for amplifier obtained the gain (S_{21}) of 68.93 dB and the noise figure (NF) of 0.64 dB. While the 3-dB bandwidth is 1.72 GHz and stability (K) to 4.54. LNA performance can be further enhanced by strengthening input and output impedance matching of the input reflection loss (S_{11}), output reflection loss (S_{22}) and return loss (S_{12}) of the respective value are -15.77 dB, -17.37 dB and -88.39 dB. In conclusion, it has been shown that by using this topology amplifier can improve on the noise figure, gain, bandwidth and stability.

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