Low Noise Figure of Cascaded LNA at 5.8GHz Using T-Matching Network for WiMAX Applications

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Abstract: This project presents the low Noise Figure (NF) cascaded Low Noise Amplifier (LNA) at 5.8GHz using T-matching network applicable for WiMAX application. The amplifier used FHX76LP Low Noise SuperHEMT FET. The LNA designed used T-matching network consisting of lump reactive element at the input and the output terminal. The cascaded LNA produced noise figure of 1.3 dB and forward gain of 36.8 dB. The input reflection (S_{11}) and output return loss (S_{22}) are -12.4 dB and -12.3 dB respectively. The bandwidth of the amplifier is more than 1.24 GHz. The input sensitivity is compliant with the IEEE 802.16 standards.

Keyword*: Cascade LNA, Radio Frequency, T -Matching Network*

I.INTRODUCTION

Today telecommunications industry continues to implement new technologies in an effort to provide high bandwidth, high-speed data transmission capabilities to the consumer. A combination of sophisticated wire line, fiber-optic and wireless technologies will most likely be deployed by this industry to satisfy consumer demand [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, 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 noise figure (NF) as well as good performances. One of the techniques is cascading. Using this technique produces results of higher gain, due to the

increase in the output impedance, as well as better isolation between the input and output ports[3],[4]. Most of the single stage LNA device in the review produced around 2-3 dB noise figure (NF).

II. THEORETICAL

Noise Figure (NF) is a figure of merit quantitatively specifying how noisy a component or system is. The noise figure of a system depends on a number of factors such as losses in the circuit, the solid-state devices, bias applied and amplification. The noise factor of a two-port network is defined as [4]:

$$F = \frac{SNR\ at\ input}{SNR\ at\ output} = \frac{\frac{S_i}{N_i}}{\frac{S_o}{N_o}} \tag{2.1}$$

Where, SNR is signal noise ratio, S_i is input signal, S_o is output signal, N_i is input noise, and N_o is output noise. The noise figure is simply the noise factor converted in decibel notation. Figure 1 shows the two-port network with a gain (or loss) G. we have
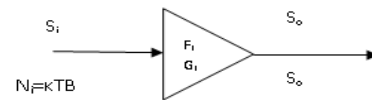
$$S_o = GS_i \tag{2.2}$$

Figure 1: The Two-Port Network

Note that $N_o \neq GN_i$; instead, the output noise $N_o \neq GN+$ noise generated by the network. The noise added by the network

$$N_n = N_0 - GN_i \tag{2.3}$$

Substituting (2.2) into (2.1), we have

$$F = \frac{\frac{S_i}{N_i}}{\frac{N_O}{N_o}} = \frac{N_0}{GN_i} \tag{2.4}$$

Therefore,

$$F = FGN_i \tag{2.5}$$

Equation (2.5) implies that the input noise N_i (in decibels) is raised by the noise figure F (in decibels) and the gain (decibels). The noise component should be independent of the input noise. It is based on a standard input noise source Ni at room temperature in a bandwidth B, where:

$$F = \kappa T_0 B \tag{2.6}$$

Where k is the Boltzmann constant, $T_0 =290K$ (room temperature), and B is the bandwidth (MHz). Then, equation (2.4) becomes

$$F = \frac{N_0}{G\kappa T_0 B} \tag{2.7}$$

For a cascaded circuit with n element as shown Figure 2; the overall noise factor can be found from the noise factor and gains of the individual element [4].
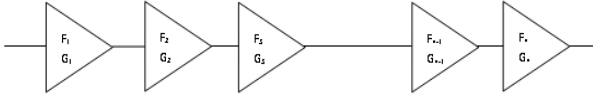

Figure 2: Cascaded Circuit with n Network

The overall noise figure F is:

$$F = F_1 + \frac{F_2-1}{G_1} + \frac{F_3-1}{G_1 G_2} + \cdots + \frac{F_n-1}{G_1 G_2 \ldots G_{n-1}} \tag{2.8}$$

Equation 2.5 allows for the calculation of the noise figure of a general cascaded system. From eq. (2.8), it is clear that the gain and noise figure in the first stage are critical in achieving a low overall noise figure. It is very desirable to have a low noise figure and high gain in the first stage. To use Equation (2.8), all F's and G's are in ratio. For a passive component with loss L in ratio, we will have G = 1/L and F = L.

Note that, $F=F_1$ due to the high gain in the first stage. The first-stage amplifier noise figure dominates the overall noise figure. One would like to select the first RF amplifier with a low noise figure and a high gain to ensure the low noise figure for the overall system.

The equivalent noise temperature is defined as

$$T_e = (F - 1)T_0 \tag{2.9}$$

Where T_0=290K (room temperature) and F in ratio; therefore

$$T_e = 1 + \frac{T_e}{T_0} \tag{2.10}$$

For a cascaded circuit shown as Figure 3, equation (2.8) can be rewritten as

$$T_e = T_{e1} + \frac{T_{e2}}{G_1} + \frac{T_{e3}}{G_1 G_2} + \cdots + \frac{T_{en}}{G_1 G_2 \ldots G_{n-1}} \tag{2.11}$$

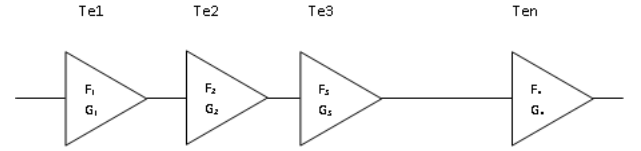Where, T_e is the overall equivalent noise temperature in Kelvin.

Figure 3: Noise Temperature for a Cascaded Circuit

The noise temperature is useful for noise factor calculations involving an antenna for example, if an antenna noise temperature is T_A, the overall system noise including the antenna is

$$T_s = T_A + T_e \tag{2.12}$$

Where, T_e is overall cascaded circuit noise temperature.

As pointed out earlier the antenna noise temperature is approximately equal to 290K for an antenna pointing to earth. The antenna noise temperature could be very low (a few Kelvin) for an antenna pointing to the sky [4].

The design specifications for the cascaded LNA were shown in Table I:

Table I: Design Specification for LNA

	Cascaded LNA
Gain dB	> 35
Frequency	5.8 GHz
NF dB	< 3
Matching Technique	Π Network & Microstrip + Lump reactive element
VSWR	1.5
Bandwidth MHz	>1000(5.8 GHz Centre)
Input sensitivity	- 80 dBm

III. LNA CIRCUIT DESIGN

The Cascaded LNA was design with advanced Design System (ADS 2008) with 2 Volts (V_{DS}) and 10mA of bias current was supply. 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 +j 50.131 and Γ_L = 79.913- j7.304.

The calculated gain for the LNA was 17 dB, which correspond to a noise figure of 0.301 dB. The input matching load Γ_{opt} is required to provide high-loaded Q factor for better sensitivity. A T-network was used to match the input impedance. The elements of T-network can be realized in the form of lump reactive elements and microstrip line impedance. For the output impedance Z_L, since the impedance is real, suitable matching for the load is by using a quarter-wave transformer [6], [8].The quarter-wave transformers convert the complex impedance into real impedance.

Using Smith Chart matching technique, the component values are shown in Table II. The DC block capacitor was selected for the circuit and the value is recommended at least 10 times from the C_1. For this reason 7.5 pF capacitors are selected as bypass capacitors. With these components, the schematic circuit for single stage LNA is shown in Figure 4. From equation (2.1) to (2.12), the related noise figure and gain of the amplifier were calculated. By using ADS 2008, the noise figure circle was obtained in the unit circle and the VSWR recorded was 2.179.
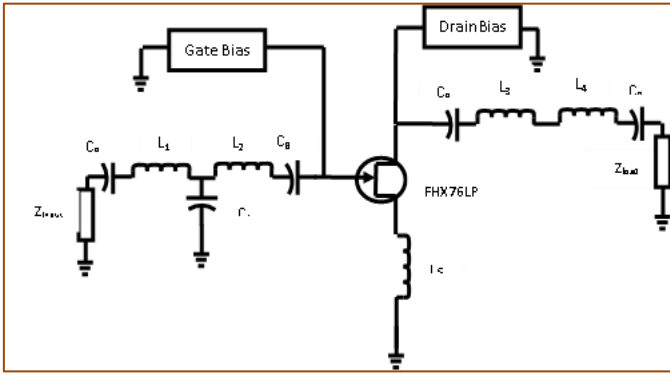

Figure 4: Single Stage LNA

Table II: LNA Parameters

Components	Values
L_1	3.60 nH
L_2	0.88 nH
L_3	0.67 nH
L_4	0.75 nH
C_1	0.5 pF
C_B	7.5 pF

Figure 5 shows the cascaded amplifier, this is realized from two single stages amplifiers. To achieve the targeted overall gain of 35 dB, it was decided to design a cascaded amplifier using similar stages to double the LNA gain. The components of matching are similar with single LNA but the L_4=0.67nH, L_5=0.88nH and C_2=0.5pF was inserted. It is call inter-stage matching network.
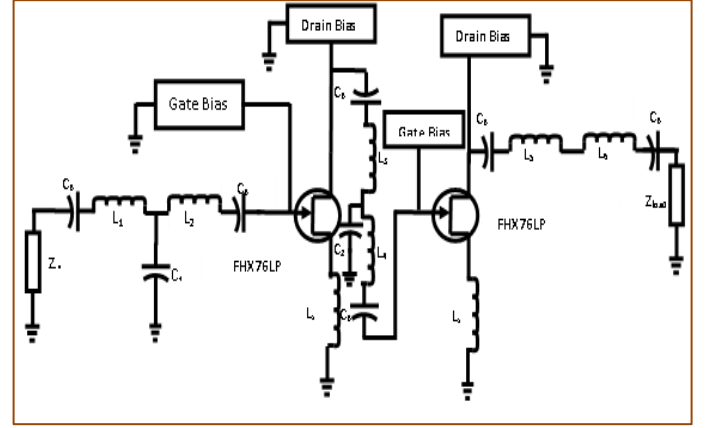

Figure 5: Cascaded LNA

IV. SIMULATION RESULT

The simulated cascaded amplifiers results are shown in Table III. These values were within the design specification and were accepted. The graph outputs S-parameter are shown in Figure 6a, 6b, 6c and 6d.

Table III: S-Parameter Results for LNA

LNA/dB	S_{11}	S_{12}	S_{21}	S_{22}	NF	(K)
Single	-12.8	-20.2	18.2	-27.9	0.747	1.023
Cascaded	-22.5	-40.4	36.1	-37.6	1.171	1.492
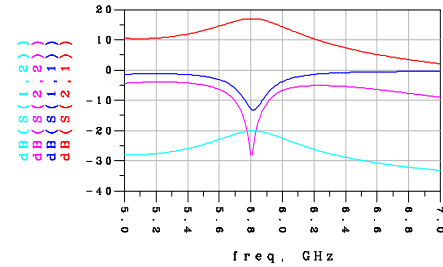
Figure 6a: S-Parameter for Single LNA
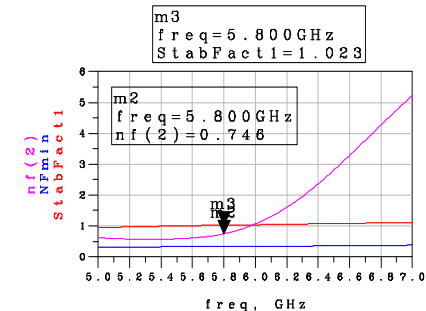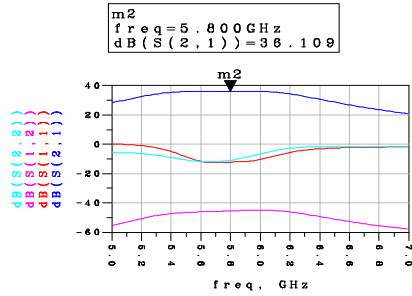

Figure 6b: Noise Figure and Stability for Single LNA

m2
freq=5.800GHz
dB(S(2,1))=36.109

Figure 6c: S-Parameter for Cascaded LNA

m4
freq=5.800GHz
StabFact1=1.492

m1
freq=5.800GHz
nf(2)=1.171
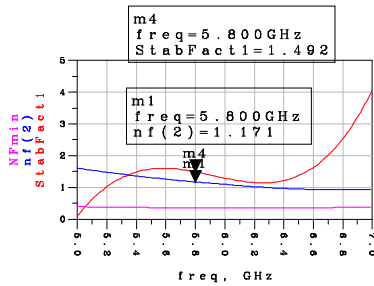
Figure 6d: Noise Figure and Stability for Cascaded LNA

CASCADE LNA (2-STAGE)

Figure 8: Noise Figure (Cascaded)

VI. CONCLUSION

A Cascaded LNA has been simulated and developed successfully with IEEE standard 802.16 WiMAX. It is observed that the simulated and experiment results have not much different. It is important to take note when designing the amplifier to match the amplifier circuits. The 5.8GHz LNA has been developed successfully and the circuit contributed to the front end receiver at the described frequency. For 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. Higher gain would expand the coverage or communication distance.

V. MEASUREMENT

Before recording all measurements, a standard procedure of calibration is followed to ensure that the measurement tools were calibrated. Figure 7 shows the power output versus frequency for Cascaded amplifier. It is also tested for their frequency response. The signal generator output is set to -80 dBm according to IEEE 802.16 standard. The amplifier produced 36.8 dB and the output of the amplifier measured is -43.2 dBm with bandwidth more than 1.24 GHz. Figure 8 shows the noise figure measured for cascaded amplifier. The Noise Figure (NF) is measured using noise figure setup. It observed that the NF of the simulated analysis is 1.17 dB and the experimental value is 1.3 dB.
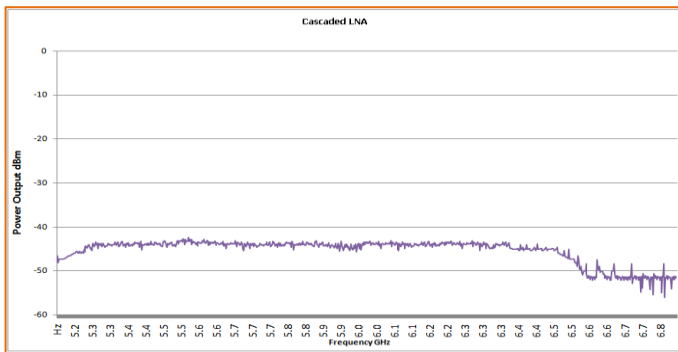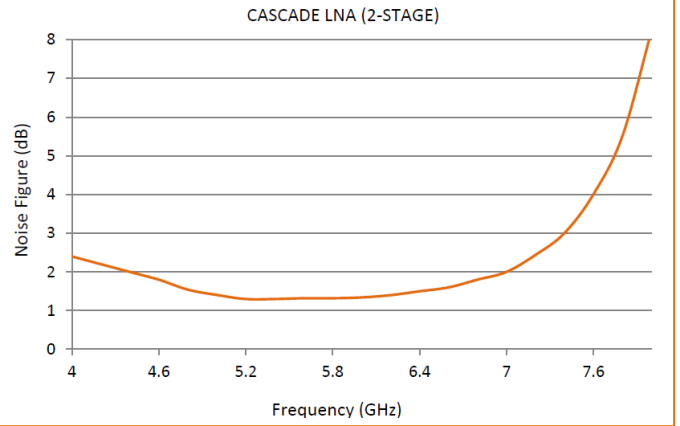

Cascaded LNA

Figure 7: Power output vs Frequency (Cascaded)

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