# High Gain, Low Noise Cascode LNA Using T-Matching Network for Wireless Applications

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***Abstract:*** This paper presents a high gain, low noise Cascoded LNA using T-matching network applicable for wireless applications. The amplifier use 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 cascode low noise amplifier (LNA) produced gain of 18.5 dB and noise figure (NF) of 1.30 dB. The input reflection ($S_{11}$) and output return loss ($S_{22}$) are -11.5 dB and -12.3 dB respectively. The bandwidth of the amplifier recorded is 1.4 GHz. The input sensitivity is compliant with the IEEE 802.16 standards.

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

## I. INTRODUCTION

The request on the technology usage had increased day by day. Nowadays, the technology mostly in communications area has become tremendously expanded with a more sophisticated and even smaller which is easy to carry. The introduction to the wireless communication networks have contributes to the ease of human being where all the data can be obtained only at the tip of the fingers. The field of Radio Frequency (RF) design is a growing one as a result of increased demand for wireless products**.** A microwave amplifier is one of RF system that becomes the most important part and extremely advanced with the involvement of microwave active and passive circuits [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 power dissipation as well as good performances. The cascode 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].

## II. THEORETICAL ASPECTS

Basically, when designing an amplifier, the input and output matching network are consider to achieve the required stability, small signal gain, and 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 designed, the formula and equation were referred to [4]. Figure 1, shows a typical single-stage amplifier including input/output matching networks. 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].

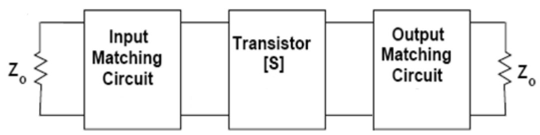


Figure 1: Typical amplifier design

### A. Power Gain

Several power gains were defined in order to understand operation of super high frequency amplifier. Figure 2, show that power gains of 2-port circuit network with power impedance or load impedance at power amplifier. The power amplifiers represented with scattering coefficient are classified into Operating Power Gain, Transducer Power Gain and Available Power Gain [4-5].

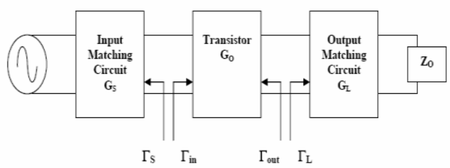


Figure 2: I/O circuit of 2-port network

B. Operating Power Gain

Operating power gain is the ratio of load power ($P_L$) delivered to the load ($Z_L$) to input 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

$$G_P = \frac{Power \ \ delivered \ \ to \ \ the \ \ load}{power \ \ \text{supplied} \ \ to \ \ the \ \ amplifier} = \frac{P_L}{P_{in}} = \frac{1}{1-|\Gamma_{in}|^2}|S_{21}|^2 \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \quad (1)$$

Where, $\Gamma_{in}$ indicates reflection coefficient of load at the input port of 2-port network and $\Gamma_s$ is reflection coefficient of power supplied to the input port.

C. 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

$$G_T = \frac{Power \ \ delivered \ \ to\, the \ \ load}{Power \ \ Available \ \ from\, the\, source} = \frac{P_L}{P_{avs}} = \frac{|S_{21}|^2 (1-|\Gamma_S|^2)(1-|\Gamma_L|^2)}{|(1-S_{11}\Gamma_S)(1-S_{22}\Gamma_L)-(S_{12}S_{21}\Gamma_S\Gamma_L)|^2} \quad (2)$$

Where, $\Gamma_L$ indicates load reflection coefficient.

D. 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:

$$G_A = \frac{Power \ \ available \ \ from \ \ the \ \ amplifier}{Power \ \ available \ \ from \ \ the \ \ source} = \frac{P_{avn}}{P_{avs}} = \frac{1-|\Gamma_S|^2}{|1-S_{11}\Gamma_S|^2}|S_{21}|^2 \frac{1}{|1-S_{22}\Gamma_L|^2} \quad (3)$$

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

E. 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:

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

Where, $R_N$ is the equivalent noise resistance of two ports. $F_{min}$ is the minimum noise factor obtained by adjusting tuners at the input of the amplifier. The normalized presented by the tuners at $F_{min}$ is $Y_{opt}$. With $Y_s=Y_s/Z_o$ being the actual normalized admittance.

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

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

F. 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 demand, input/output matching circuits should be designed so that reflection coefficient of each port is correlated with conjugate complex number as given below [6]:

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

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

The noise figure of the first stage of the receiver overrules noise figure of the whole system. To get a minimum noise figure using a transistor, power reflection coefficient should match with $\Gamma_{opt}$ and load reflection coefficient should match with $\Gamma^*_{out}$

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

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

## III. DESIGN OF LNA

Low noise amplifier has been designed based on the s-parameters were obtained from calculation and simulation using ADS. The s-parameter for Cascode LNA shows in Table I.

Table I : S-Parameters of Cascode LNA

| Freq/dB | $S_{11}$ | $S_{12}$ | $S_{21}$ | $S_{22}$ |
|---|---|---|---|---|
| 5.8GHz | 0.712 | 0.065 | 8.994 | 0.237 |
| Angle | -86.54 | 33.878 | 178.66 | -10.456 |

The overall performance of a 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, $\Gamma_{opt}$ and $\Gamma_L$ were obtained as $\Gamma_{opt} = 17.949 + j48.881$ and $\Gamma_L = 79.913\text{-}j7.304$ for Cascode Low noise amplifier.

Figure 3 shows, the complete schematic circuit of 5.8 GHz a cascode Low noise amplifier. It is called inductive source degeneration. The passive elements in the input matching network are $L_1$, $L_2$ and $C_1$.While the passive elements in the output matching network are $L_3$, $L_4$ and $C_2$.This is show in Table II. The load transistor consist of an inductor $L_D$, it call peaking structure to enhance gain and bandwidth [9]. This transistor also improves the reverse isolation and lowers miller effect [10-13].

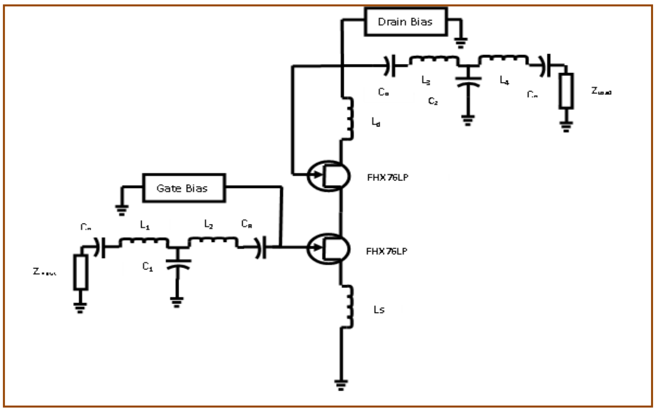


Figure 3: The Schematic Circuit for Cascode LNA

Table II: LNA parameters

| Items | Matching Component |
|---|---|
| $L_1$ | 6.14 nH |
| $L_2$ | 2.4 nH |
| $L_3$ | 1.55 nH |
| $L_4$ | 1.62 nH |
| $C_1$ | 0.315 pF |
| $C_2$ | 429.9fF |

## IV. SIMULATION RESULT

Table III shows the s-parameters output of Cascoded LNA. It is simulated using Advanced Design System (ADS). The simulation recorded that the amplifier gain $S_{21}$ is 19.5 dB. The input return loss $S_{11}$ is -18.9 dB, overall noise figure (NF) of 1.2 dB and the output return loss $S_{22}$ is -20 dB. The reflection loss $S_{12}$ is -22.1 dB. These values were within the design specification and were accepted. The outputs S-parameter are shows in Figure 4a, 4b and 4c. Figure 4a shows the input and output return loss. Figure 4b show the noise figure while, Figure 4c shows the power gain and reverse isolation.

Table III: output Cascode LNA

| S-Parameters (dB) | $S_{11}$ | $S_{12}$ | $S_{21}$ | $S_{22}$ | NF |
|---|---|---|---|---|---|
| Cascode LNA | -18.9 | -22.1 | 19.5 | -20.0 | 1.2 |

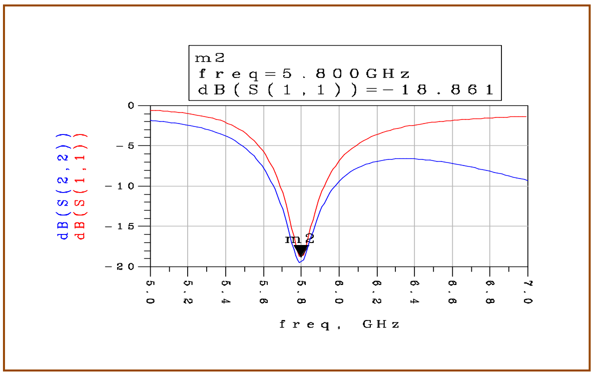


Figure 4a: $S_{22}$ and $S_{11}$

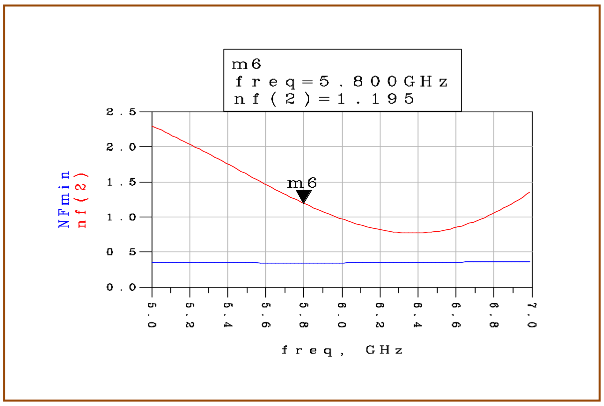


Figure4b: Noise Figure

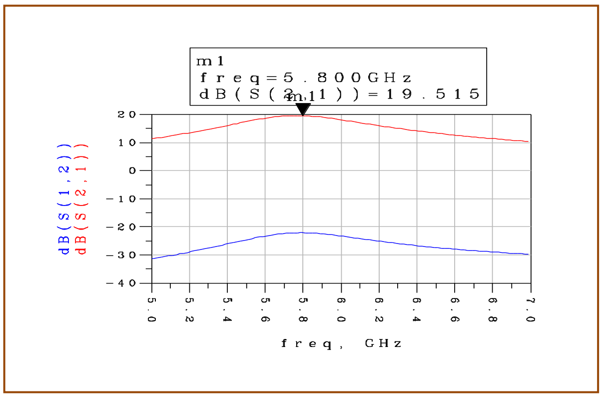


Figure 4c: $S_{12}$ and $S_{21}$

## V. MEASUREMENT

Referring to the measurement setup shown in Figure 5, the S parameter of the amplifier; $S_{11}$, $S_{12}$, $S_{21}$ and $S_{22}$ are measured using the network analyzer. The gain of the amplifier is measured using the setup in Figure 6. The noise figure values and the 3dB bandwidth were obtained from the setup in Figure 7. Before recording all measurement, a standard procedure of calibration is conducted to ensure that the measurement tools were calibrated.

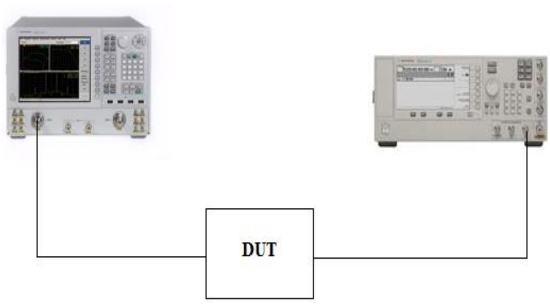


**Figure 5:** Setup for device under test S Measurement using Network Analyzer

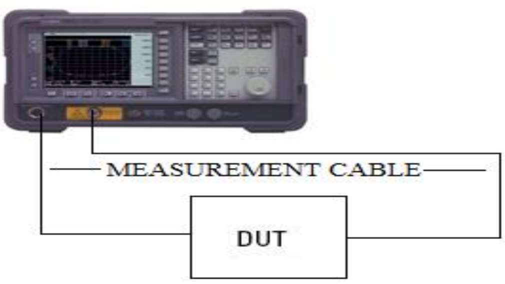


**Figure 6:** Frequency response measurement setup for device under test.

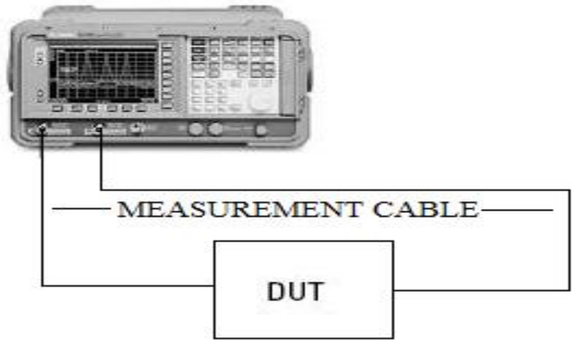


**Figure 7:** Measurement setup for device under test for Noise Figure

## VI. RESULT

The result for Cascode LNA RF front-end is presented in Table IV. From the tabulated values, the $S_{11}$ parameter measured is -11.5 dB. This is -1.5 dB less than targeted value which is better and acceptable. $S_{22}$ measured is -12.3 dB which is less than targeted and acceptable. The return loss required $S_{12}$ obtained is less than -27.3 dB. The related measured gain $S_{21}$ for the LNA amplifier is 18.5 dB measured using the setup in Figure 6.

Table IV: Measurement Results

| S Parameters | Targeted | Measured |
|---|---|---|
| Input Reflection $S_{11}$ dB | <-10 dB | -11.5 |
| Return Loss $S_{12}$ dB | <-10 dB | -27.3 |
| Forward transfer $S_{21}$ dB | >50 dB | 18.5 |
| Output Reflection$S_{22}$ dB | <-10 dB | -12.3 |
| NF dB | <3 dB | 1.30 |
| BW MHz | >1000 | 1400 |

The noise figure values obtained from setup in Figure 7 is 1.30 dB which complied with the targeted value of less 3 dB. The use of T lump reactive element and microstrip line matching technique at the input of the LNA contributes the best performance for the amplifier [9]. This matching technique was used to provide high-loaded Q factor for better sensitivity and thus minimized the noise figure.

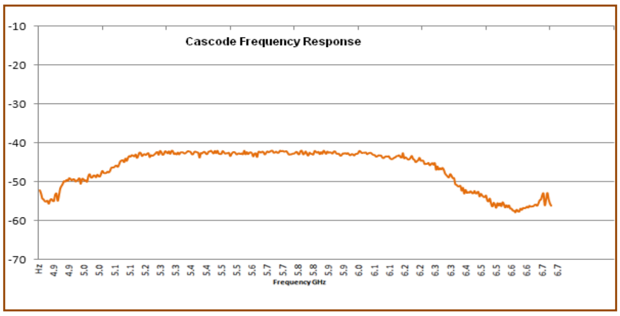


Figure 8: Frequency Response

The elements of T-network were realized in the form of lump reactive elements and microstrip line impedance. The 3 dB bandwidth for the amplifier is measured using setup Figure 5. It is shown in Figure 8. The 3dB bandwidth obtained is 1.4 GHz compliant with targeted result of more than 1 GHz. It is observed that the 3 dB gain is 18.5 dB.The measured parameters for the LNA were also compliant with the equation (1) to (9) using MathCAD analysis.

## 7. CONCLUSION

A Cascoded low noise amplifier has been simulated and developed successfully with IEEE standard 802.16 WiMAX. It is observed that the simulated and experimental results giving almost the same figure as required. It observed that the gain of the simulated analysis is 19.5 dB and the experimental value is 18.5 dB. 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 [11]. Higher gain would expand the coverage or communication distance.

## ACKNOWLEGMENT

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