High Gain, Low Noise Cascode LNA with RF Amplifier at 5.8GHz Using T-Matching Networks

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Abstract: This paper presents the high gain, low noise Cascode LNA with RF amplifier at 5.8GHz using T-matching network applicable for WIMAX application. The Cascode LNA uses FHX76LP Low Noise SuperHEMT FET and RF amplifier use EPA018A. The LNA designed used T-matching network consisting of lump element reactive element at the input and the output terminal. The Cascode LNA with RF amplifier produced gain of 35.5 dB and noise figure (NF) at 1.4 dB. The input reflection (S_{11}) and output return loss (S_{22}) are -12.4dB and -12.3 dB respectively. The bandwidth of the amplifier is more than 1.2 GHz. The input sensitivity is compliant with the IEEE 802.16 standards.

Keyword*: Cascode LNA, RFA, T -Matching Network*

I.INTRODUCTION

THE increasing number of personal wireless communication systems demand for Radio Frequency (RF) front-end capable to handle difference standard specification, i.e. WiMAX [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 with RF amplifier 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]. Most of the single stage LNA device in the review could only around 20 dB gain. It was proposed that the low noise amplifier should have a gain of at least 30 dB [8]. By taking consideration the extension of communication distance of up to 50 km [8]. A budgeted high gain of LNA will ensure a good signal to noise separation for further amplification.

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For this gain of 30 dB, a Cascode LNA with RF amplifier is introduced. It is shows in Fig.1.

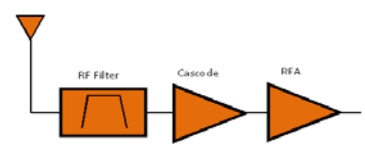

Fig. 1 Cascode LNA and RFA

II. THEORETICAL ASPECTS

Basically, 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 2, shows a typical single-stage amplifier including input/output matching networks.

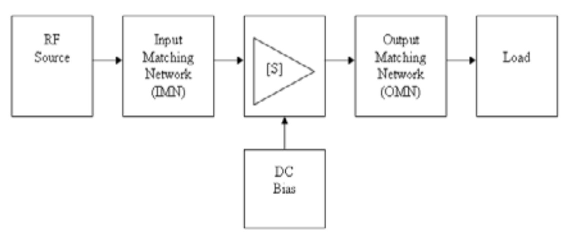

Fig. 2 Typical amplifier design

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].

A. Power Gain

Several power gains were defined in order to understand operation of super high frequency amplifier, as shown in Fig.

3, power gains of 2-port circuit network with power impedance or load impedance at power amplifier represented with scattering coefficient are classified into Operating Power Gain, Transducer Power Gain and Available Power Gain [4],[5].

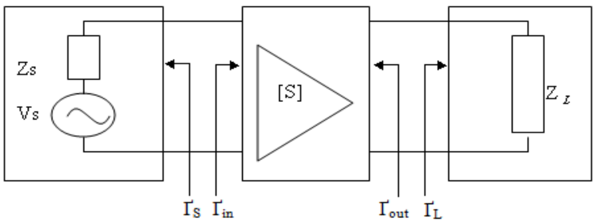

Fig. 3**:** I/O circuit of 2-port network

B. Operating Power Gain

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

$$G_P = \frac{Power \;\; delivered \;\; to \;\; the \;\; load}{power \;\; \text{supplied} \;\; to \;\; the \;\; amplifier}$$

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

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.

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

$$G_T = \frac{Power \;\; delivered \;\; to \; the \;\; load}{Power \; Available \; from \; the \; source} \qquad (2)$$

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

Where, Γ_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:

$$G_A = \frac{Power \;\; available \;\; from \;\; the \;\; amplifier}{Power \;\; available \;\; from \;\; the \; source} \qquad (3)$$

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

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:

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

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

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

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]:

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

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

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

$$\Gamma_s = \Gamma_{opt} \tag{8}$$

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

III. Cascode LNA and RFA Design

Cascode LNA is designed based on the S-parameters were obtained from calculation and simulation using ADS 2008. The S-parameter for Cascode LNA is shows in Table I.

TABLE I: S-PARAMETERS OF CASCODE LNA

Frequency/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 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} = 17.949 + j48.881 and Γ_L = 79.913-j7.304 for single LNA.

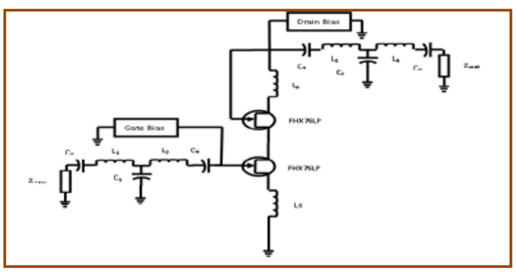

Fig. 4: The Schematic Circuit for Cascode LNA

Fig. 4 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. 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].

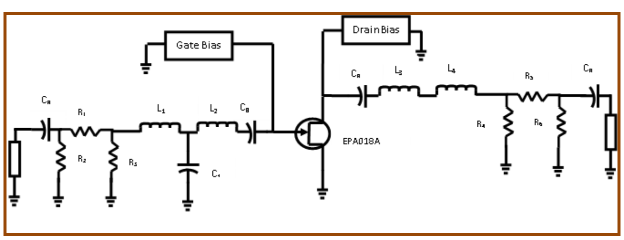

Fig. 5: The Schematic Circuit for RFA

Fig. 5 shows the completed schematic circuit of a RF amplifier with associated component and the 3 dB attenuator resistors. The RF amplifier was design based on [6] and [7]. Using theoretical design equation for the RFA, the equations are computed using Mathcad. The FET chosen for the design is EPA018A.The S-parameter given for the FET is shown in Table II. These parameter were measured at V_{DD} =2V and I_{DS}= 10mA which sets the biasing for FET. This transistor biasing circuit is similar with the LNA amplifier.

TABLE II : S-PARAMETERS OF RF AMPLIFIER

Frequency/dB	S_{11}	S_{12}	S_{21}	S_{22}
5.8 GHz	0.728	0.049	6.327	0.237
Angle	-103.02	25.88	89.98	10.456

Gain, noise figure, input and output matching component were calculated and simulated using MathCAD and ADS 2008. Both calculated and simulated results were almost similar shows in Table IV. The calculated transducer power gain for matched condition was 17.3 dB. The input matching for optimum Γ_{opt} and Γ_L were obtained as Γ_{opt} = 12.662 +j 38.168 and Γ_L = 79.97- j7.286. The noise figure calculated is 2.475 dB**.** The RF amplifier can also act as an isolator for the overall front-end system and a suitable Π-network with 50 Ω load impedance was inserted at the input and output of the amplifier to provide 3 dB attenuation each for the network. The purpose of 3 dB attenuation is to isolate the system from the reflected load power and to improve the return loss of overall systems. The Cascode LNA and RF amplifier Matching component are shown in Table III.

TABLE III: CASCODE LNA AND RFA MATCHING PARAMETERS

Components	LNA(Values)	RFA(Values)
L_1	6.14 nH	7.21nH
L_2	2.4 nH	2.65nH
L_3	1.55 nH	0.67nH
L_4	1.62 nH	0.75nH
C_1	0.315 pF	0.3pF
C_2	429.9fF	

IV. Simulation Result

Table IV is shows the S-parameters output for Cascode LNA, RF amplifier and Cascode LNA with RFA. It is simulated using Advanced Design System (ADS). The simulation recorded that the Cascode with RF amplifier gain S_{21} is 36.1 dB. The input insertion loss S_{11} is -12.14 dB, overall noise figure (NF) is 1.3 dB and the output insertion loss S_{22} is -10.87 dB. The reflection loss S_{12} is -45.47 dB. These values were within the design specification and were accepted. The outputs S-parameter are shown in Fig. 6a, 6b and 6c.

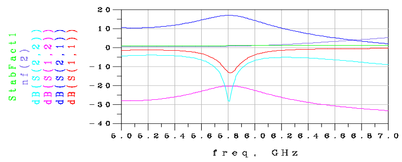

Fig. 6a: S-parameters for Cascode

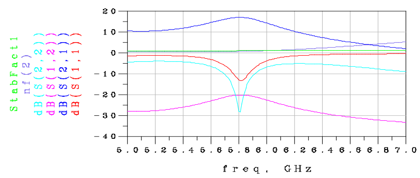

Fig. 6b: S-parameters for RFA

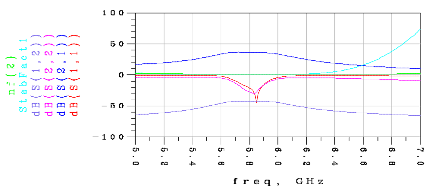

Fig. 6c: S-parameters for Cascode + RFA

TABLE IV: COMPARISON OF OUTPUT 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
RF Amplifier	-12.5	-21.5	17.3	-12.6	2.40
Cascode and RFA	-24.3	-62.6	36.1	-23.86	1.30

V. MEASUREMENT AND ANALYSIS

The result for Cascode LNA RF front-end was presented in Table V.

TABLE V: S PARAMETER RESULT FOR CASCODE LNA

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	>17 dB	18.5
Output ReflectionS_{22} dB	<-10 dB	-12.3
NF dB *	<3 dB	1.3
BW MHz	>1000	1400

From the tabulated values, the S_{11} parameter measured is 11.5 dB. This is -1.5 dB less than targeted 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 was less than -27.3 dB. The related measured gain S_{21} for the LNA amplifier was 18.5 dB. The noise figure values obtained was 1.3 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. This matching technique was used to provide high-loaded Q factor for better sensitivity and thus minimized the noise figure. 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 and the frequency response of LNA is shown in Fig. 7. The 3dB bandwidth obtained was 1.4 GHz compliant with targeted result of more than 1 GHz

The RF amplifier measurement setup was similar to the measurement set up for LNA. The results were shown in Table VI.

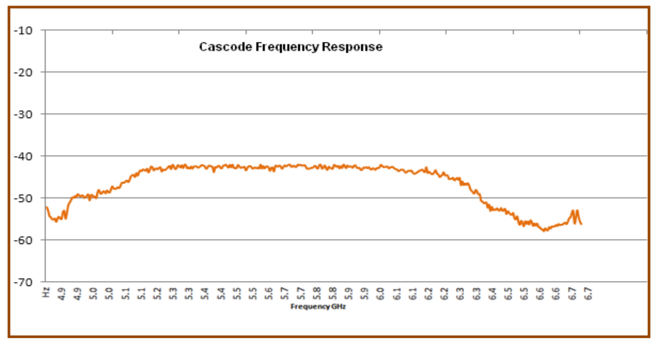

Fig. 7: Power output vs Frequency GHz Cascode LNA

From the tabulated values, the S_{11} parameter measured is -10.6 dB. This is -0.6 dB less than targeted which is better and acceptable. S_{22} measured is -13.3 dB which is less than targeted and acceptable. The return loss required S_{12} obtained is less than -31.8 dB which is also acceptable and better. The use of Π-network with 50 Ω load impedance at the input and output of the RFA shows a better return loss which is lower than -31.8 dB.

The minimum return loss targeted for this amplifier is less than -10dB. The related measured gain S_{21} for the RF amplifier is 16.8 dB measured. The noise figure values obtained is 2.47 dB which complied with the targeted value of 3dB. Again shows that the use of T lump reactive element and microstrip matching network provide best performance for the RF Amplifier since the measure value nearly optimized. The 3dB bandwidth obtained is 1200 MHz which is more than the targeted result of 1GHz.

Both amplifiers were then cascaded and tested with 10dB attenuation set on the spectrum analyzer the output power versus frequency is shown in Fig. 9. It was observed that the power output is -36.5 dBm and is expected if includes the total loss from cable and connector of 2 dB.

The Front-end system designed consisted of a LNA with RFA were developed. The final result for overall amplifier gain is 35.5 dB gains with noise figure of 1.3 dB. The total insertion loss is -25.5 dB. With injecting a -60 dBm signal and that attenuator setup of spectrum is 10 dB.

Table VI: S-Parameters for RF Amplifier

S Parameters	Targeted	Measured
Input Reflection S_{11} dB	<-10	-10.6
Return Loss S_{12} dB	<-10	-31.8
Forward transfer S_{21} dB	>15	16.8
Output ReflectionS_{22} dB	<-10	-13.3
NF dB *	<3	2.47
BW MHz	1000	1200

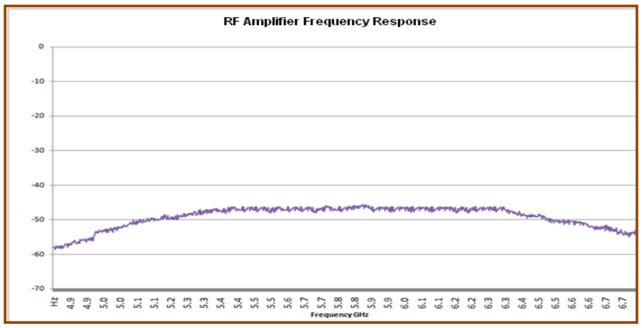

Fig. 8: Power output vs Frequency GHz RFA

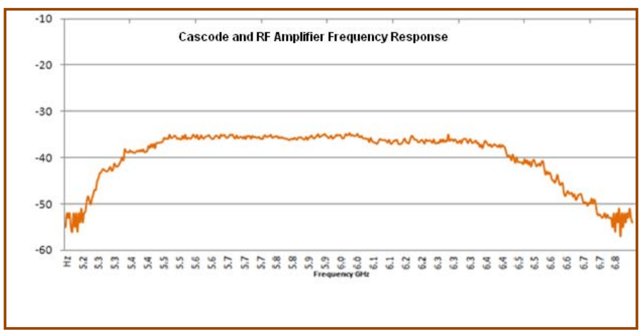

Fig. 9: Power output vs Frequency for Cascode LNA + RF Amp

For a wireless communication system such as WiMAX system, this RF front-end receiver will capable to provide a better pipeline for the receiver with minimum noise figure and provide a high gain. This output is acceptable for further processing of the baseband system for IEEE 802.16 WiMAX standard.

VI. CONCLUSION

The Cascode LNA with RFA 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 observed that the gain of the simulated analysis is 36.1 dB and the experimental value is 35.5 dB while; the noise figure (NF) measured is less than 1.4 dB. It is important to take note when designing the amplifier to match the amplifier circuits. The Cascode LNA with RF Amplifier has been developed successfully and the circuit cab 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.

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