5.8 GHz Radio Frequency Amplifier with 3 dB Π Network Attenuator

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Abstract

This paper presents a design of radio frequency amplifier (RFA), which operates at 5.8 GHz frequency for WiMAX application. The RFA designed used T matching network consist of lump reactive elements, 3 dB attenuator and microstrip line at the input and output impedance. The RFA developed in this project contributes a gain of 15.6 dB with overall noise figure of 2.4 dB. The overall measured bandwidth measures is 1.240 GHz with S parameters S_{11}, S_{12} and S_{22} measured are -12.4 dB, -25.5 dB and -12.3 dB respectively. The RFA used FET transistor EPA018A from Excelics Semiconductor Inc.

1 Introduction

Wireless technology has existed for many years, proving it to be a reliable communication medium in terms of cost and ease of deployment. The selection of RF circuit components including low noise amplifier (LNA), Radio Frequency (RFA) amplifier and filters for the transmitter and receiver can make or break an entire wireless system [1]. The RF receiver system would have to be well designed, so that a high performance of communication link can be achieved.

The progress of wireless communication services has increased the need for designing RF communication systems which have multi-band capability with high gain, better input sensitivity and a minimum noise level. It is desirable to combine two or more standards in one mobile unit for overall capacity enlargement, higher flexibility and roaming capability as well as backward compatibility. Moreover multi standard RF receivers would allow access to different systems provided by various providers. The device chosen for the RF amplifier will be selected based on the input sensitivity which is now at -55 dBm. Once the device is chosen the device parameter will have to be matched for maximum power transfer. At the same time added isolation can be provided by incorporating a matched 50 ohm Π network into the system. This also acts as a buffer for the next stage design. The FET transistor EPA018A from Excelics Semiconductor Inc was selected since it operates at required input sensitivity and bandwidth.

With WiMAX, RF transceiver system are breaking the bonds of wired connections in between separated buildings especially in area where wired bridge is impossible to be deployed. WiMAX wireless technology is more economical and efficient than installing wired networks. With the current technology of Orthogonal Frequency Division Multiplexing (OFDM) adopted in IEEE 802.16 WiMAX, the system can provide a high data rate of up to 70 Mbps [2]. The RFA in WiMAX plays an important role in converting baseband signal from the transmitted RF signal so that the system can communicate wirelessly. Therefore, the performance of the WiMAX system relies on the RF front-end receiver system that should be well designed to minimize the noise level (or distortions) in the system [5].

The approach taken in designing the amplifiers involves a series of chronological steps. No design is complete without some desired goals. The design specifications for the radio frequency amplifier were shown in Table 1.1:

	RFA
Gain dB	> 15
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	- 55 dBm

Table 1.1: Design specifications for RFA

With refer to Table 1.1　the gain targeted for the RFA is more than 15 dB. This gain is necessary to amplify week signals and separated from the noise. The amplifier will maintain noise figure less than 3 dB and provide bandwidth of 1000 MHz. The input sensitivity for the RFA is set at -55dBm compliant with the standard WiMAX application.

2　Theoretical Description

Basically, for a design of amplifier, the input and output matching network are designed to achieve the required stability, small signal gain, and bandwidth [5]. 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 below. For the LNA design the formulae and equation were refer to [2]. Figure 2.1 shows a typical single-stage amplifier including input/output matching networks.
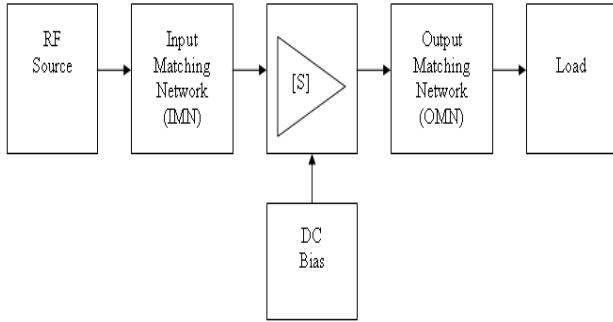

Figure 2.1**:** Typical amplifier designed

In short, basic concept of high frequency amplifier design is to match input/output of a transistor for high frequencies having S parameters [S] frequency characteristics at a specific DC-bias point with source impedance and load impedance. I/O matching circuit is essential to reduce unwanted reflection of signal and to improve efficiency of transmission from source to load. The targeted specification amplifier is shown in Table 1.1.

2.1 Power Gain

Several power gains are defined to understand operation of super high frequency amplifier, as shown in Figure 2.2, 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.[1],[5]
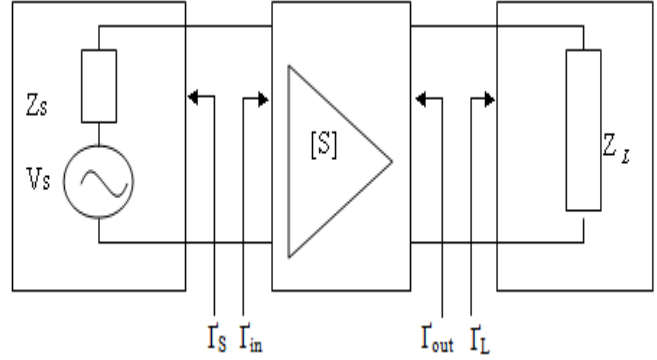

Figure 2.2: I/O circuit of 2-port network

2.2 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

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

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

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.

2.3 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

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

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

Where, Γ_L indicates load reflection coefficient.

2.4 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:

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

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

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

2.5 Noise Figure

Signals and noises applied to the input port of amplifier are 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:

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

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

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

2.6 Design RFA

From equation (1) to (5) and using transistor S parameter, the related power gain and noise figure for the RFA are calculated. By using ADS 2005A, the noise figure circle is outside the unit circle and the VSWR recorded is 2.179. From simulation, it was recorded that the amplifier gain S_{21} is 15.31 dB. The input insertion loss S_{11} is -8.03 dB and the output insertion loss S_{22} is -7.85 dB. The reflected loss S_{12} is -21.45 dB and the noise figure is 2.47 dB. These values were within the design specification and were accepted.

The overall performance of the RF amplifier is determined by calculating gain, noise figure, input and output matching components. The stability factor as is 0.989. This showed a clear tendency for oscillation which confirmed the calculated stability factor. The calculated transducer power gain for matched condition was 16.28 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. For the input matching Γ_{opt}, it is required to provide high loaded Q factor for better sensitivity. A T-network was used to match the impedance. For the output impedance Γ_L, since the impedance is real, suitable matching impedance for the load is by using quarter-wave transformer. 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 a 3 dB insertion loss each for the network. Using Smith Chart matching technique, the component values are shown in Table 2.1. The DC block capacitor is 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 RFA is shown in Figure 2.3.

Components	Values
L_1	7.21 nH
L_2	2.65 nH
C_1	0.30pF
L_3	0.67 nH
L_4	0.75 nH
R_1	8.17 Ω
R_2	8.17 Ω
R_3	616.27 Ω
R_4	8.17 Ω
R_5	616.27 Ω
R_6	616.27 Ω
C_B	7.50pF

Table 2.1: RFA Amplifier parameters
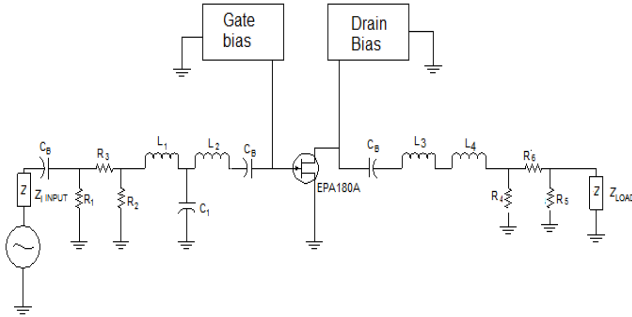
Figure 2.3: The schematic circuit for RF amplifier

Figure 3.2: Stability circle refer to Smith Chart

3   Simulation

The related S parameters output of the amplifier is shown in Figure 3.1. The simulated S parameter results in Figure 3.1 show that the S_{21} gain at 5.8 GHz is 15.28 dB. The corresponding input return loss S_{11}, output return loss S_{22} and reflection loss S_{12} are -10.58 dB,-5.52dB and -23.06 dB.
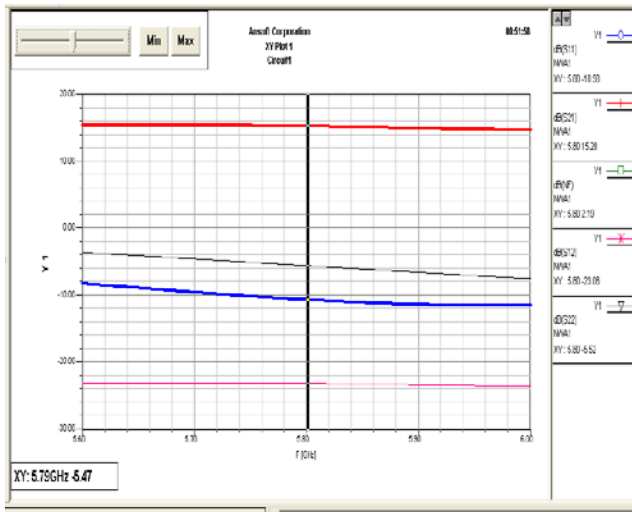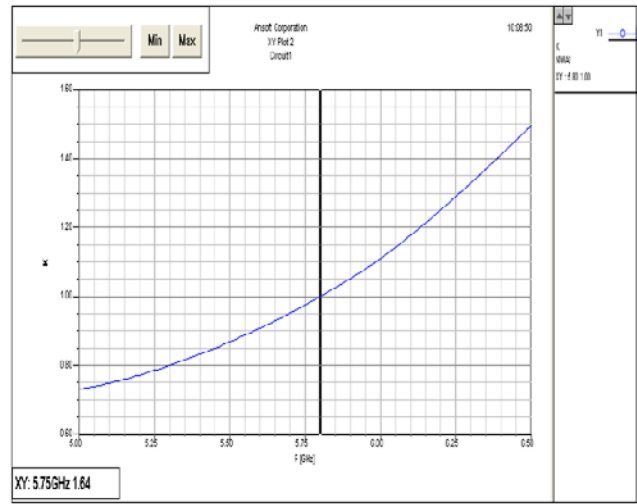

Figure 3.3: Stability factor with matched load

XY: 5.79GHz -5.47

Figure 3.1: S Parameters output of the RF Amplifier

The noise figure output observed is -2.19 dB. For this amplifier, the consideration is on the maximum gain with noise figure less than 3 dB. This S parameter output is acceptable with the targeted specification required for the system. The stability factor after matching load is shown in Figure 3.2 and Figure 3.3. Figure 3.3 shows the stability circle lies inside Smith Chart diagram while Figure 3.4 shows the obtained stability factor is 1 and VSWR observed is 1.41. These parameters are compliant with the targeted specifications of the amplifier for unconditional stable condition k is 1 and VSWR is targeted as 1.5. The noise figure output observed is 2.19 .
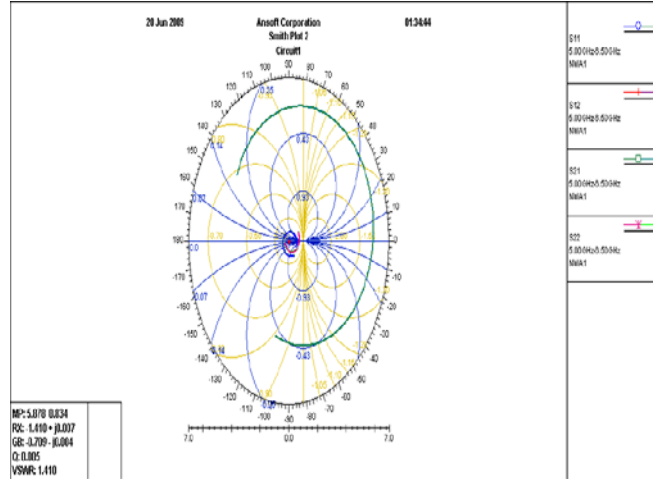
The simulated S parameters of the amplifier is tabulated in Table 3.1.

S Parameters	Targeted RFA	Simulated RFA
Input reflection S_{11} dB	-10	-10.58
Return Loss S_{12} dB	-10	-23.06
Forward Transfer S_{21} dB	15	15.28
Output Reflection loss S_{22} dB	-10	-5.52
Noise Figure NF dB *	<3	2.19
Bandwidth MHz	>1000	>1000

Table 3.1: S Parameter Output and Targeted Parameters of RFA

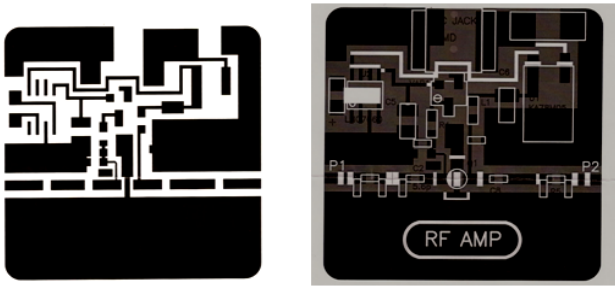The designed circuit is sent for fabrication and the LNA layout is shown in Figure 3.4

Figure 3.4: Layout of RF amplifier

4 Measurement

With refer once to measurement setup shown in Figure 4.1, the S parameter of the RF amplifier; whereas 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 Figure 4.2. The noise figure values and 3 dB bandwidth are obtained from setup Figure 4.3. Before all measurement was recorded, a standard procedure of calibration was followed to ensure that the measurement tools were calibrated.
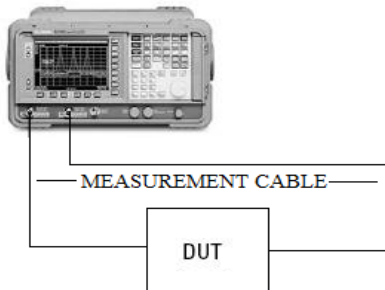

Figure 4.1: Measurement setup for device under test for S
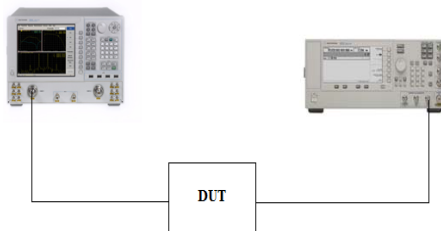
Measurement using Network Analyzer

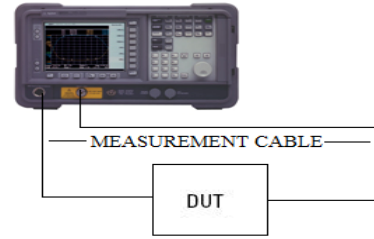Figure 4.2: Measurement setup for device under test for

Frequency Response.

Figure 4.3 Measurement setup for device under test for

Noise Figure

5 Result

The result for LNA RF front-end module is presented in Table 5.1.

S Parameters	Targeted	Measured
Input Reflection S_{11} dB	<-10 dB	-12.4
Return Loss S_{12} dB	<-10 dB	-25.5
Forward transfer S_{21} dB	>15 dB	15.6
Output ReflectionS_{22} dB	<-10 dB	-12.3
NF dB *	<3 dB	2.4
BW MHz	>1000	1125

Table 5.1: S Parameter result for LNA

* Measured using noise figure analyzer in Telecom R&D.

From the tabulated values, the S_{11} parameter measured is -12.4 dB. This is -2.4 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 is less than -25 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 -25 dB. The minimum return loss targeted for this amplifier is less than -10dB. The related measured gain S_{21} for the RFA amplifier is 15.6 dB measured using the setup Figure 5.3a. The noise figure values obtained from setup Figure 4.3b is 2.4 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 RFA since the measure value nearly optimized. The 3dB bandwidth for the amplifier is measured using setup Figure 5.3a. The 3dB bandwidth obtained is 1125 MHz which is more than the targeted result of 1000 MHz. The measured parameters for

the RF were also compliant with the formulae (1) to (5) using MathCAD analysis.

6 Conclusion

With considering the attenuation set at the spectrum analyzer, the actual signal output at the RF front-end receiver is -39.00 dBm. 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.

Acknowledgement

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