WIDEBAND 5.8 GHz RADIO FREQUENCY AMPLIFIER WITH 3 DB ∏- NETWORK ATTENUATOR ISOLATION

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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 consisting of lump reactive elements, 3 dB attenuator and microstrip line at the input and output impedance. The RFA developed in this project contribute 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 S11, S12 and S22 measured are -12.4 dB, -25.5 dB and -12.3 dB respectively. The RFA used FET transistor EPA018A from Excelics Semiconductor Inc.

Keywords: *Amplifier, Radio Frequency Amplifier, Microstrip.*

I. 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 was 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 was now at -80 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 before 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:

TABLE 1: Design specifications for RFA

	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

With refer to Table 1 the gain targeted for the RFA was more than 15 dB. This gain was necessary to amplify week signals and separated from the noise. The amplifier will maintain noise figure less than 3 dB and provide bandwidth above 1000 MHz. The input sensitivity for the RFA was set at -80 dBm compliant with the standard WiMAX application.

II. THEORETICAL DISCRIPTION

Basically, for the design of an 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 RFA designed, the formulae and equation were referred to [1]. Figure 1 shows a typical single-stage amplifier including input/output matching networks.

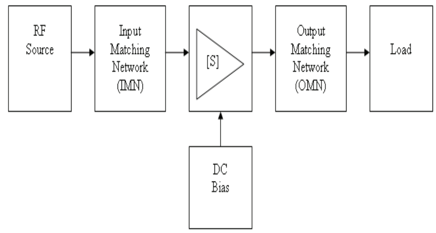

Figure 1: Typical amplifier designed

The basic concept of high frequency amplifier design is to match input/output of a transistor at high frequencies using 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.

Power Gain

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

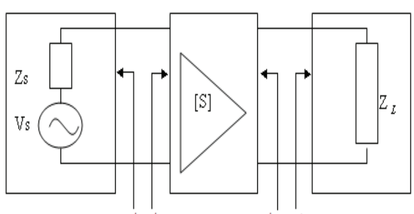

Figure 2: I/O circuit of 2-port network

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.

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

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

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

Where, Γ_L indicates load reflection coefficient.

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:

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

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

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

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:

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

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 determined, input/output matching circuits should be designed so that reflection coefficient of each port can be correlated with conjugate complex number as given below:

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

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

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}

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

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

Design RFA

From equation (1) to (9) and using transisitor S parameter, the related power gain and noise figure for the RFA were calculated. By using ADS 2005A, the noise figure circle was outside the unit circle and the VSWR recorded was 2.179. From simulation, it was recorded that the amplifier gain S_{21} was 15.31 dB. The input insertion loss S_{11} was -8.03 dB and the output insertion loss $S_2$2 was -7.85 dB. The reflected loss S_{12} was -21.45 dB and the noise figure was 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. 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 RFA is shown in Figure 2.

Table 2: RFA Amplifier parameters

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

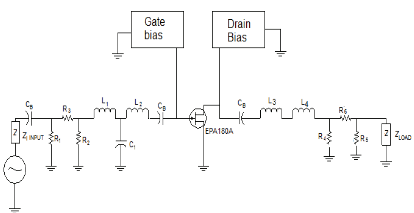

Figure 3: The schematic circuit for RF amplifier

III. SIMULATION

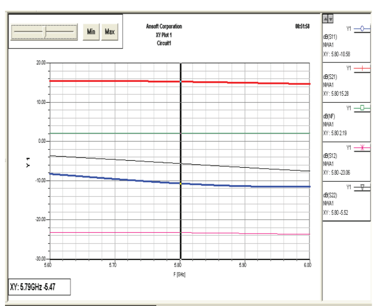

Figure 4: S Parameters output of the RF Amplifier

The related S parameters output of the amplifier was shown in Figure 4. The simulated S parameter results in Figure 4 show that the S21 gain at 5.8 GHz was 15.28 dB. The corresponding input return loss S11, output return loss S22 and reflection loss S12 were -10.58 dB,-5.52dB and -23.06 dB. The noise figure output observed was -2.19 dB. For this amplifier, the consideration is on the maximum gain with noise figure less than 3 dB. This S parameter output was acceptable with the targeted specification required for the system. The stability factor after matching load is shown in Figure 5 and Figure 6. Figure 5 shows the stability circle lies inside Smith Chart diagram while Figure 6 shows the obtained stability factor was 1 and VSWR observed was 1.41. These parameters were compliant with the targeted specifications of the amplifier for unconditional stable condition k was 1 and VSWR was targeted as 1.5. The noise figure output observed was 2.19.

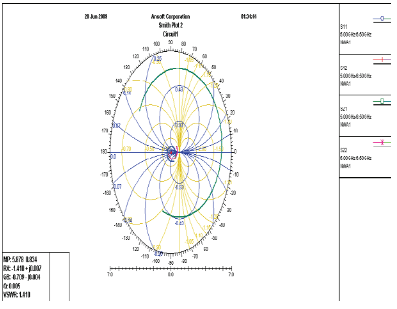

Figure 5: Stability circle refer to Smith Chart

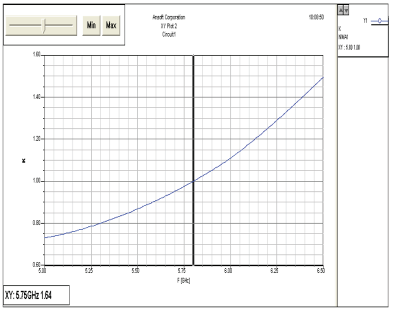

Figure 6: Stability factor with matched load

The simulated S parameters of the amplifier is tabulated in Table 3.

Table 3: S Parameter Output and Targeted Parameters of RFA

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

The designed circuit is sent for fabrication and the LNA layout is shown in Figure 7

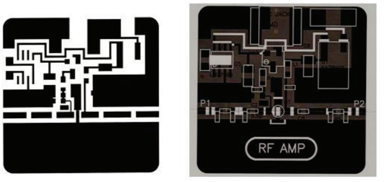

Figure 7: Layout of RF amplifier

IV. MEASUREMENT

Referring to the measurement setup shown in Figure 8, the S parameter of the RF amplifier; whereas S11, S12, S21 and S22 were measured using the network analyzer. The gain of the amplifier was measured using the setup Figure 9. The noise figure values and 3 dB bandwidth were obtained from setup Figure 10. Before all measurement was recorded, a standard procedure of calibration was followed to ensure that the measurement tools were calibrated.

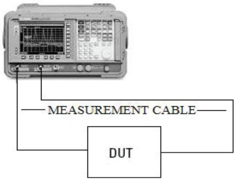

Figure 8: Setup for device under test S Measurement using Network Analyzer

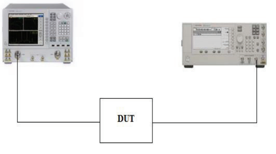

Figure 9: Frequency response measurement setup for device under test.

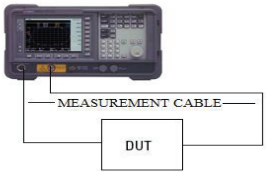

Figure 10: Measurement setup for device under test for Noise Figure

V. RESULT

The result for LNA RF front-end module is presented in Table 4.

Table 4: S Parameter result for LNA

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

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

From the tabulated values, the S11 parameter measured was -12.4 dB. This is -2.4 dB less than targeted which is better and acceptable. S22 measured was -12.3 dB which is less than targeted and acceptable. The return loss required S12 obtained was 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 S21 for the RFA amplifier was 15.6 dB measured using the setup Figure 8 and 9. The noise figure values obtained from setup Figure 10 was 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 9. 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 (9) using MathCAD analysis.

VI. CONCLUSION

A wideband 5.8 GHz radio frequency amplifier with 3 dB ∏-network attenuator isolation was designed and developed. This RF front-end receiver is capable of providing a better pipeline for the receiver with minimum noise figure and provides a high gain. This output is acceptable for further processing of the baseband system for IEEE 802.16 WiMAX standard.

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