Jurnal
Teknologi

Full Paper

A MICROWAVE LOW NOISE AMPLIFIER BASED ON LADDER MATCHING NETWORK FOR WIRELESS APPLICATIONS

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Article history
Received
1 February 2015
Received in revised form
24 March 2015
Accepted
1 August 2015

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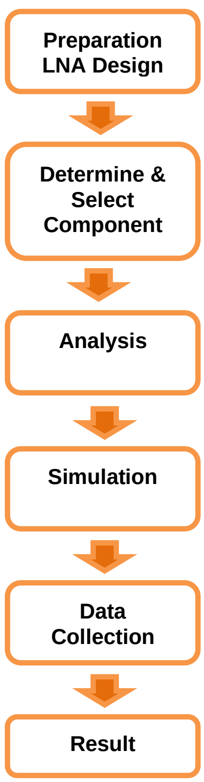
Graphical abstract



Abstract

This paper present a microwave low noise amplifier based on ladder matching networks for Wireless applications. The designed circuit is simulated with Advanced Design System (ADS) software. Specifically, Low Noise Amplifier which is located at the first block of receiver system, makes it one of the important element in improving signal transmition. From the statement above, this study was aimed to design a microwave low noise amplifier for wireless application that will work at 5.8 GHz using high-performance low noise superHEMT transistor FHX76LP manufactured by Eudyna Technologies. The low noise amplifier (LNA) produced gain of 17.2 dB and noise figure (NF) of 0.914 dB. The input reflection (S_{11}) and output return loss (S_{22}) are -17.8 dB and -19.6 dB respectively. The bandwidth of the amplifier recorded is 1.5 GHz. The input sensitivity is compliant with the IEEE 802.16d standards.

Keyword: LNA, Radio Frequency, Ladder -Matching Network

Abstrak

Kertas kerja ini melaporkan sebuah penguat hingar rendah gelombang micro menggunakan rangkaian tetangga untuk kegunaan komunikasi tanpa wayar. Proses rekabentuk menggunakan perisian *advanced design system (ADS)*. Secara umumnya, penguat hingar rendah ini terletak pada blok pertama pada sistem penerima, ianya merupakan element terpenting didalam penghantaran isyarat. Daripada petikan di atas, kajian ini bertujuan untuk merekebentuk penguat hingar rendah gelombang micro untuk kegunaan komunikasi tanpa wayar dan beroperasi pada frekuensi 5.8 GHz dengan menggunakan transistor berkeupayaan tinggi iaitu transistor FHX76LP yang dikeluarkan oleh Teknologi Eudyna. Penguat hingar rendah ini menghasilkan gandaan S_{21} 17.2 dB dan angka hingar adalah 0.914 dB. Refleksi masukan S_{11} dan Kehilangan balikan S_{22} masing-masing ialah -17.8 dB dan -19.6 dB. Bidang ruang yang dicatatkan ialah 1.5 GHz. Kepekaan masukan memenuhi kedendak piawaian IEEE.802.16d.

Kata kunci: *LNA, Radio Frequency, Ladder -Matching Network*

1.0 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 (RF) amplifier and filters for the transmitter and receiver can make or break an entire wireless system [1,5]. Therefore, for the RF receiver design stage, the 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 RF communication system designed which has higher capability in providing higher gains, better input sensitivity, minimize noise level and provides multi-band capabilities. 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 receiver will allow access to different system providing various services. These are the cause of the investigation to increase the bandwidth of the systems for multi-band multi-mode operation.

In WiMAX system, RF transceiver system are breaking the bonds of wired connections in separated buildings to be connected in the area that the wired bridge is impossible to be deployed and installed. WiMAX wireless technology can be more economical and efficient than installing wired networks. With the current technology of Orthogonal Frequency Division Multiplexing (OFDM) adopted in IEEE 802.16 WiMAX standard, the system can provide high data rate up to 70 Mbps [2,9]. The RF receiver in WiMAX system plays a paramount role for converting baseband signal from the RF signal so that the system can be communicating wirelessly. Therefore, the performance of the WiMAX system also relies on the RF front end receiver system where it must be well designed to minimize the noise level (or distortions) in the system [3, 16, 17].

Wireless communication is a type of telecommunication that available for transmitting the large amounts of data, voice and video over long distance using a different frequency. This is also considered with several technologies with transmission rates above the fastest speed available over a telephone line. In most high-frequency communication system, Gallium-Arsenide (GaAs) metal-semiconductor-field-effect transistor (MESFET) and heterojunction bipolar transistor (HBT) show their strong presence in RF product because they give high performance on output power.[4,18]

Usually the first active signal processing block after the antenna is Low noise amplifier (LNA). The amplitude of the received signal at the input LNA may vary from few nV that is less than -130 dBm for GPS signals to tens mV. The LNA should be capable of amplifying all these signals without causing any significant distortion. This requires that very little noise from the LNA be introduced to the entire receiver[5,13,19].

Figure 1 is the basic to the structure of the RF receiver. As the first block is active after the antenna, LNA has the advantage of high and should be able to reduce noise in the system. The signal received from the antenna will be screened and will be amplified by the LNA and will be sent to the bandpass with a local oscillator. After the demodulated, modulated signal will be used for analog-to-digital (ADC) that converts analog signals to digital signals. Digital signal processing (DSP) will process the digital signal produces by an analog-to-digital (ADC). Therefore, a lot can affect the LNA parameter sensitivity and performance of the overall receiver noise.

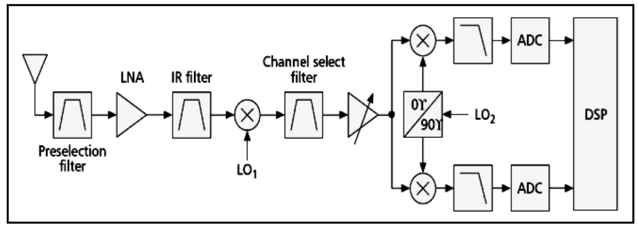


Figure 1 Structure of the RF receiver

The LNA is one of the most important components of in communication receiver. The LNA requires amplifying the received signal with sufficient gain and if possible having a little additional noise. Noise Figure has a major impact on deciding the system's overall in LNA. An LNA can be designed with different circuit topologies; each method proposes to accommodate a wide bandwidth through input and output impedance matching. Such as, shunt-series feedback topology is having broadband behavior as well as good input and output matching characteristics. A capacitor is used in series with feedback to avoid the effect of the output voltage at the optimum basing point in IV curve.

Therefore the higher gain is achieved when the power consumption is low. An inductive load which improves the output noise performance as well as overcomes the gain degradation at higher frequencies is employed. Another inductor is added in series with feedback to give an additional gain at higher frequencies. The inductive degenerated topology had a superior performance as compared to its common gate. Also this topology provides simultaneous input matching and minimum Noise Figure[1,2,20].

2.0 THEORETICAL ASPECTS

Initially, 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 2, 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].

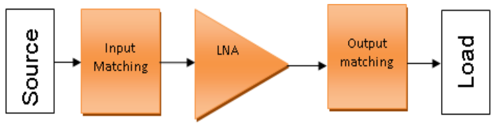


Figure 2 Typical amplifier design

A. Power Gain

Several power gains were defined in order to understand operation of super high frequency amplifier. Figure 3, show that power gains of 2-port circuit network with power impedance or load impedance at power amplifier. The power amplifiers represented with scattering coefficients are classified into Operating Power Gain, Transducer Power Gain and Available Power Gain [4, 5].

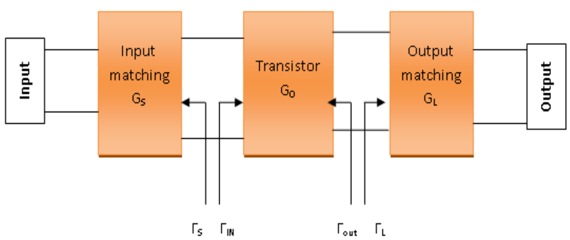


Figure 3 I/O circuit of 2-port network

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

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

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

Where, Γ_L indicates load reflection coefficient.

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

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:

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

That is, the above formula indicates power gain when input and output are matched [5,15].

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:

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

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:

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

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 [6,14]:

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

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

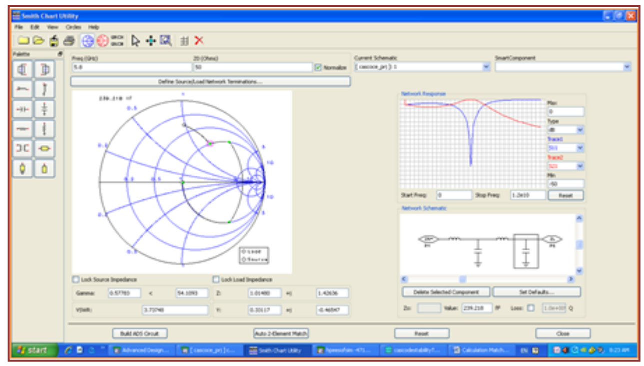
The noise figure of the first stage of the receiver overrules noise figure of the whole system. To get a minimum noise figure using a transistor, power reflection coefficient should match with Γ_{opt} and load reflection coefficient should match with Γ^*_{out}

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

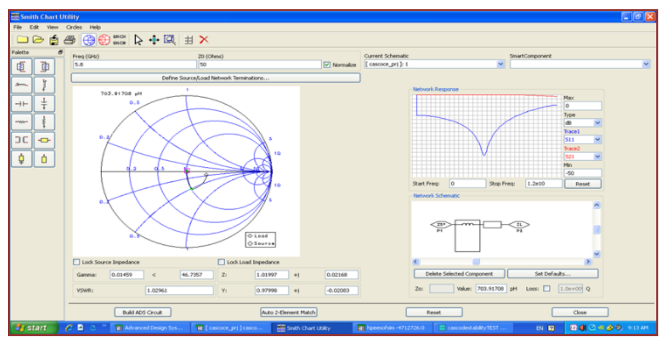
$$\Gamma_L = \Gamma^*_{out} = \left(S_{22} + \frac{S_{12}S_{21}\Gamma_s}{1 - S_{11}\Gamma_s} \right) \tag{9}$$

3.0 DESIGN OF LNA

The Figure 4(a) is the matching network for input matching network port, while the Figure 4(b) is the matching network uses for output port respectively to provider the good performance in term of stability, power gain and S-Parameter. The goals in LNA design are to maximize its gain and minimize its noise figure with sufficient linearity and impedance matching [7, 8, 13, 14]. In order to achieve the key demands for WiMAX receiver characteristics, a LNA is designed should be met are the noise figure less than 3 dB and power gain should be more than 15 dB. Also good input and output impedance matching to achieved the s-parameter values.



(a)



(b)

Figure 4 (a) The Ladder matching network for Input and (b) The matching network for Output

Figure 5(a) shows, the complete schematic circuit of 5.8 GHz a single stage of Low noise amplifier. It was simulated using the same software to fine and further optimized for a better performance.

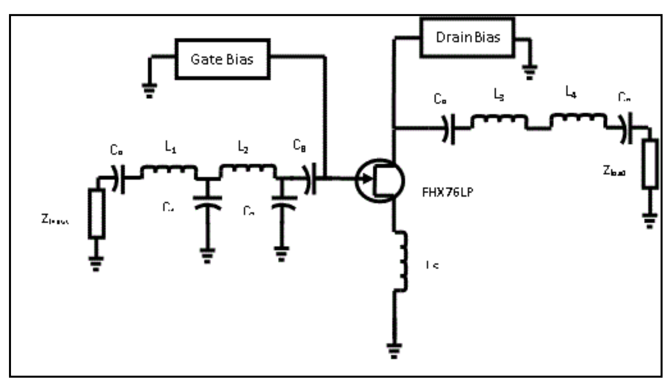


Figure 5 (a) The Schematic Circuit for LNA

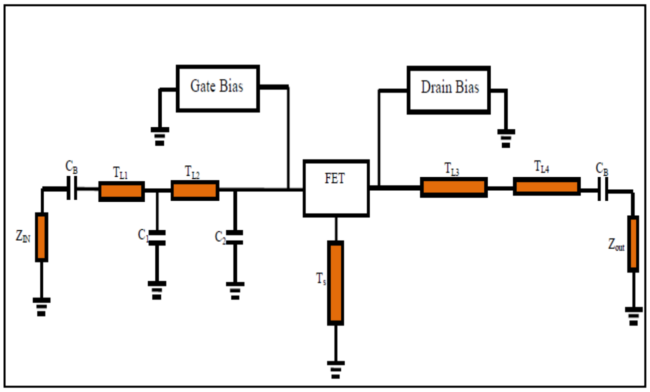


Figure 5 (b) The Schematic Layout for LNA

For purpose of fabrication, the inductances and capacitances need to be converted to microstrip layout. Figure 5(b) shows, the complete schematic layout. The Duriod 5880 TYL-0200 was selected for fabricate. The LNA parameter is shown in a Table 1.

Table 1 LNA Parameters

Component	Width (mm)	Length (mm)
TL_1=3.24nH	W = 1.554	L=15.25
TL_2=1.23nH	W = 1.554	L=6.07
TL_3=0.40pF	W = 1.554	L=12.44
TL_3=0.24pF	W = 1.554	L=10.44
TL_4=1.55nH	W = 1.554	L=7.64
TL_5=1.62nH	W = 1.554	L=7.98

4.0 SIMULATION RESULT

The simulated results of S-Parameter output of the LNA are shown in Figure 6(a-d). It is simulated using Advanced Design System (ADS). The simulation recorded that the power gains S_{21} is 17.2 dB. The input return loss S_{11} is -18.9 dB, overall noise figure (NF) of 0.914 dB and the output return loss S_{22} is -19.6 dB. The reflection loss S_{12} is -19.9 dB. These values were within the design specification and were accepted. Figure 6(a) shows the forward transfer and output return loss. While, Figure 6(b) shows the input reflection and the output reflection loss. Figure 6(c) and (d) are shows the Noise Figure and Stability Factor respectively.

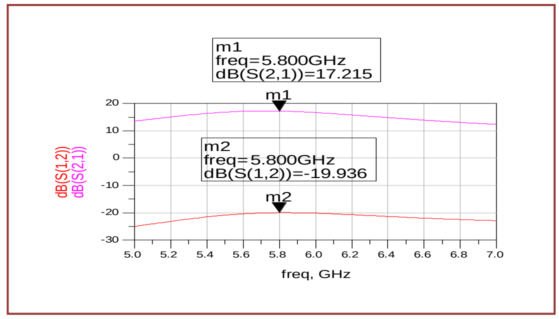


Figure 6(a) S_{21} and S_{12}

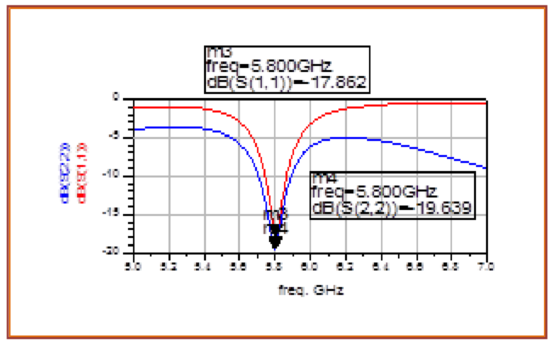


Figure 6(b) S_{11} and S_{22}

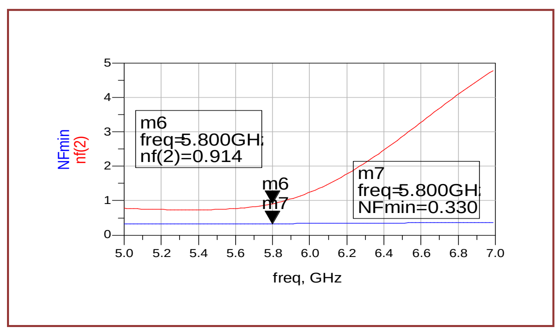


Figure 6(c) Noise Figure

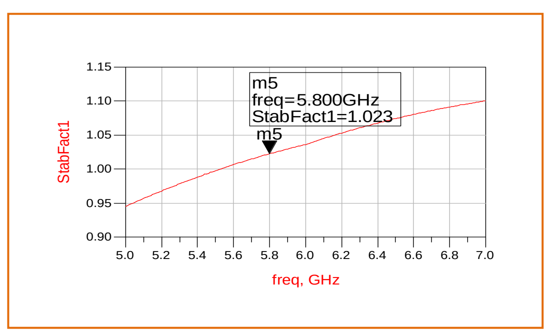


Figure 6(d) Stability Factor

5.0 CONCLUSION

The microwave low noise amplifier with ladder matching network has been simulated and designed. It is observed that, this system is compliant with IEEE standard 802.16 WiMAX applications. It is observed that the simulated and targeted results giving almost the same figure as required. It observed that the gain of the simulated analysis is 17.2 dB. It is important to take note when designing the amplifier to match the amplifier circuits. The 5.8 GHz microwave 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 [9,10]. Higher gain would expand the coverage or communication distance.

ACKNOWLEDGMENTS

I would like to take this opportunity to thank the Research Management & Innovation Centre (RMIC) of Sultan Idris Education University for permitting and supporting in this research (2015-0052-104-01).

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