Design and Analysis of Broadband Matching Networks for a Low Noise Amplifier

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Abstract: ***Designing Broadband matching networks is an important part of RF amplifier design. Reflection factors and the placement of a LNA in each matching network at a specified frequency place an important role for designing the Broadband matching network. In this paper the author discussed about the procedure for designing a LNA over a specified bandwidth by lumped LC elements and analyse the performance like target gain and noise figure using RFTOOL box . A direct search based approach is used to arrive at the optimum element values in the input and output matching network***

Keywords: LNA, Lumped elements, UWB, RF amplifier

1. Introduction

Ultra Wide Band (UWB) system is capable of transmitting data over a wide spectrum of frequency bands with low power and high data rates. CMOS technology is a promising candidate for UWB systems for providing scaling of the CMOS devices for high frequency operation and also facilitates the processing of large bandwidth analog signals with low power. First stage of a UWB RF receiver is a Low Noise Amplifier (LNA), whose main function is to provide enough gain to overcome the noise of subsequent stages. Main functions of LNA in radiofrequency chain are to increase the signal energy and to limit noise in the receiver as much as possible. Design of LNA demands low NF, sufficient gain with flatness over the wide frequency range, low power consumption and low cost.

1.1 Broadband matching

Synthesis of impedance matching networks for RF amplifiers using Low Noise Amplifier. One the most important design aspect of RF power amplifier is impedance matching network. Any impedance mismatch in the source or load side leads to reduced device gain and large reflected power. As the rating of the power amplifier increases, any loss of power due to impedance mismatch will reduce the efficiency of the power amplifier drastically. The reflected power also affects the reliability of the device in use and complicates its thermal management. Impedance matching network is the key for complete transfer of power to the load. For any RF amplifier, impedance matching network should provide matching over the complete frequency band of interest. The two element impedance matching network and stub matching techniques are not very effective over a wide band of frequencies, since they provide matching over a very narrow band. The other disadvantage of the two element matching network is that the frequency at which the matching takes place is very sensitive to the inductor and capacitor tolerances.

1.2 Problem

Designing of Broadband matching network by LNA is very much needed in all wireless devices. It is critical, since the location of the input and output matching network with reference to the amplifier interfaces is so challenging task.

1.3 Solution

In this paper, we are going to discuss about the design procedure of Broadband matching networks by LNA using RF tool box of MATLAB.

1.4 MATLAB RFtoolbox

RF Toolbox provides functions, objects and apps for designing, modeling, analyzing, and visualizing networks of radio frequency (RF) components, and also using RF Toolbox for wireless communications, radar, etc,. With RF Toolbox we can build networks of RF components such as filters, transmission lines, amplifiers, and mixers. Components can be specified using measurement data, network parameters, or physical properties. And also calculate S-parameters, convert among S, Y, Z, ABCD, h, g, and T network parameters, and visualize RF data using rectangular and polar plots and Smith Charts. RF Toolbox provides functions to manipulate and automate RF measurement data analysis, including de-embedding, enforcing passivity, and computing group delay. MATLAB and Simulink provide the required tools for supporting all the RF system design tasks, from system exploration to algorithm development and lab prototyping. Modelling and simulating RF, Analog and digital systems together enables faster development and easier debugging.

2. Design Aspects

2.1 Design

The Impedance matching of an amplifier is shown in **Fig:1**

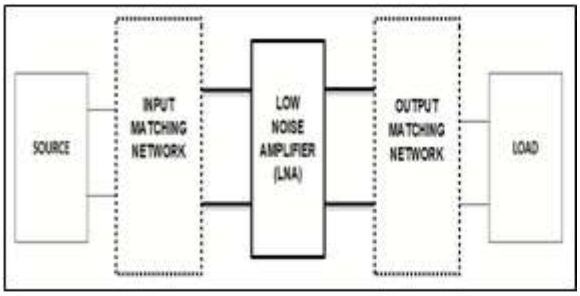

Figure 1: Impedance matching of an amplifier

In this design, Broadband matching networks for a low noise amplifier (LNA). In an RF receiver front end, the LNA is commonly found immediately after the antenna or after the first band pass filter that follows the antenna. Its position in the receiver chain ensures that it deals with weak signals that have significant noise content. As a result the LNA has to not only provide amplification to such signals but also minimize its own noise footprint on the amplified signal.

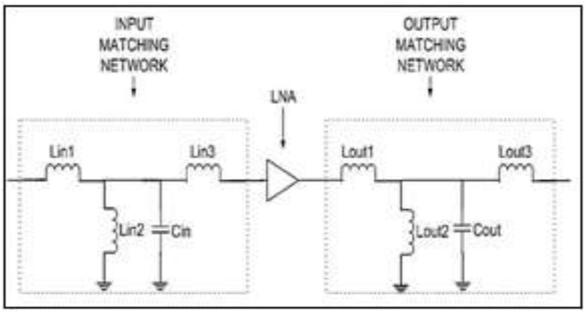

Figure 2: Matching Network Topology

We design a LNA to achieve the target gain and noise figure specifications over a specified bandwidth, using lumped LC elements. A direct search based approach is used to arrive at the optimum element values in the input and output matching network.

2.2 Flow diagram for the proposed design:

The flow diagram of proposed design is shown in Fig: 2

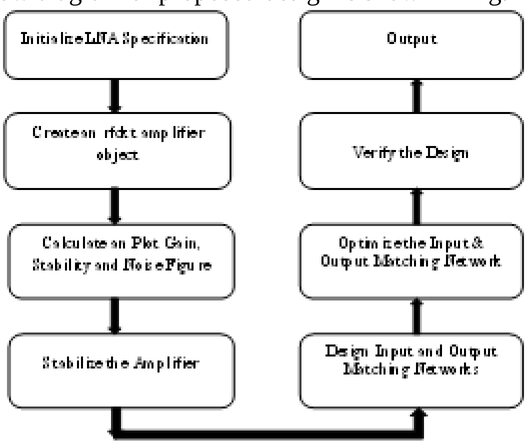

Figure 3: Flow diagram of proposed design

2.3 Design procedure

In this paper we designed matching network having Centre Frequency = 250 MHz, Bandwidth = 100 MHz

Step 1: LNA Design Specifications: The LNA design specifications are as follows:

Source impedance (Z_s), Reference impedance (Z_0), and the Load impedance (Z_1)=50-Ohm, Noise Figure <= 2.0 dB, Transducer Gain ≥ 10 dB.

Create an RF circuit amplifier: RF circuit. Amplifier object to represent the amplifier. Analyse the amplifier in the Source impedance(Z_s), Reference impedance (Z_0), and the Load impedance(Z_1)=50-Ohm. Plot the transducer power gain (G_t), the available power gain (G_a) and the maximum available power gain (G_{mag}).This is Shown in the (**Fig: 4**)

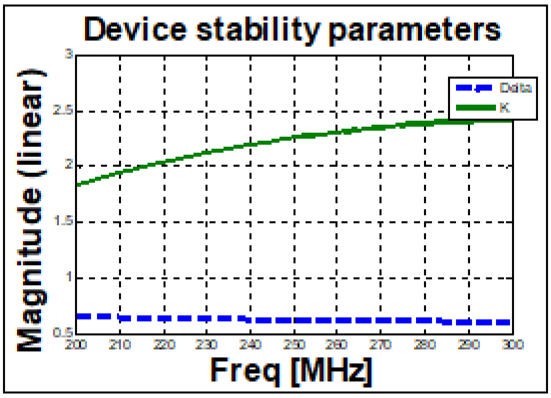

Figure 4: Device Stability Parameters

The LNA must operate in a stable region, so our first step is to plot Delta and K for the transistor being used. Use the plot method of the rfckt object to plot Delta and K as a function of frequency to see if the transistor is stable

After executing the program , from the above **Fig: 4**, the power gain and noise figure behavior across the same bandwidth, in between the Centre Frequency = 250 MHz, Bandwidth = 100 MHz., the amplifier is not unconditionally stable.

Step2: Calculate and Power Gain, Noise Figure and Stability: As the plot shows, $K > 1$ and $\Delta < 1$ for all frequencies in the bandwidth of interest. This means that the device is unconditionally stable. It is also important to view the power gain and noise figure behaviour across the same bandwidth.

Enable the data cursor and click on the constant available gain circle. The data tip displays the following data: 1. Available power gain (Ga), 2.Noise figure (NF), 3. Reference impedance(Z0), 4. Load impedance(Z1), 5. Normalized source impedance (ZS)

Ga, NF and ZS are all functions of the source impedance(Zs), Reference impedance(Z0), and the Load impedance(Z1). Together with the stability information this data allows you to determine if the gain and noise figure targets can be met.

Both the available gain and the noise figure are functions of the source impedance(Zs), Reference impedance (Z0), and the Load impedance (Z1). This is shown in **(Fig :5)**

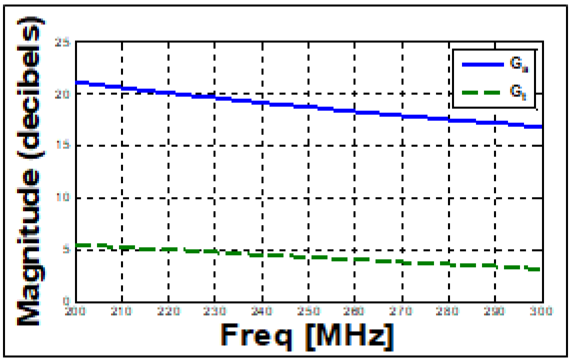

Figure 5: Available & Total Gain for Unmatched Amplifier

Step:3 Stabilize the Amplifier: One way to stabilize an amplifier is to cascade a shunt resistor at the output of the amplifier. However, this approach will also reduce gain and add noise. At the end of the example, we will verify that the overall gain and noise still meet the requirement. To find the maximum shunt resistor value that makes the amplifier unconditionally stable, use the f_{zero} function to find the resistor value that makes stability MU equal to 1. The f_{zero} function always tries to achieve a value of zero for the objective function, so the objective function should return MU-1

Step:4 Design the Input and Output Matching Network : The region of operation is between 200 and 300 MHz, so you choose a band pass topology for the matching networks which is shown here, The topology chosen, as seen in Figure 2, is a direct-coupled prototype band pass network of parallel resonator type with top coupling, that is initially tuned to the geometric mean frequency with respect to the bandwidth of operation. For the initial design all the inductors are assigned the same value on the basis of the first series inductor. As mentioned in, choose the prototype value to be unity and use standard impedance and frequency transformations to obtain de-normalized values.

The value for the capacitor in the parallel trap is set using this inductor value to make it resonate at the geometric mean frequency. Please note that there are many ways of designing the initial matching network. This example shows one possible approach. This is shown in **(Fig :6)**

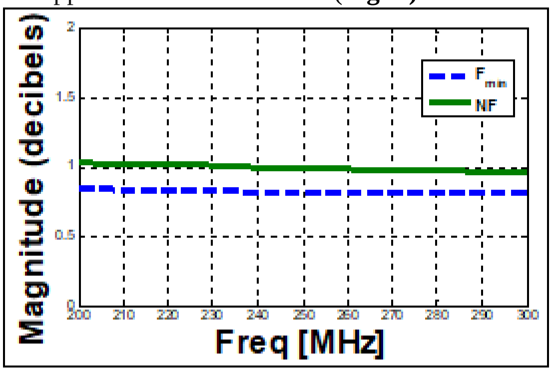

Figure 6: F_{min} & NF for unmatched Amp

The plot shows, the target requirement for both gain and noise figure have been met. To understand the effect of optimizing with respect to only the transducer gain, use the first choice for the cost function (which involves only the gain term) within the objective function shown above. This is shown in **(Fig:7)**

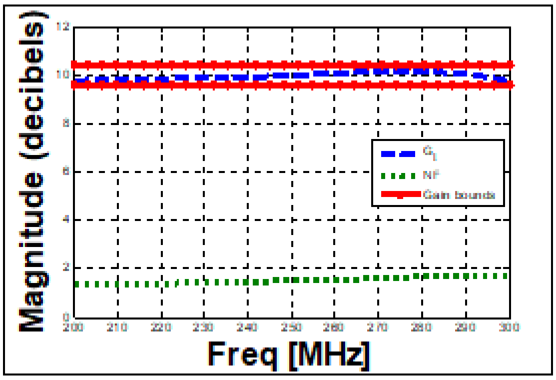

Figure 7: G_t, NF Under Optimized Condition

Step:6 Verify the Design: This plot, shows the power gain across the 100-MHz bandwidth. It indicates that the transducer gain varies linearly between 5.5 dB to about 3.1 dB and achieves only 4.3 dB at band centre. It also suggests there is sufficient headroom between the transducer gain Gt and the available gain Ga to achieve our target Gt of 10 dB.

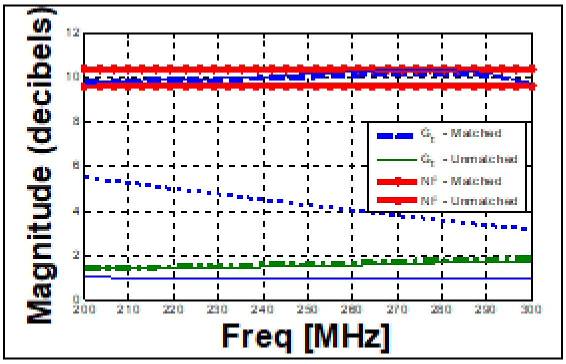

Figure 8: G_t, NF Matched & Unmatched

The results of optimization can be viewed by plotting the transducer gain and the noise figure across the bandwidth, and comparing it with the unmatched amplifier. Plot the noise figure around the design frequency range. The noise figure is ≤ 10 dB in the design, which also meets the requirement in the specification. The Centre Frequency = 250 MHz, Bandwidth = 100 MHz above that of the amplifier, which demonstrates added noise by the shunt resistor. The plot shows, the target requirement for both gain and noise figure have been met. To understand the effect of optimizing with respect to only the transducer gain, use the first choice for the cost function (which involves only the gain term) within the objective function shown above.

3. Result and Discussion

For practical verification, the same above procedure is repeated in the designed Broadband matching network for different (Centre Frequency = 350 MHz, Bandwidth = 200MHz) and

(Centre Frequency = 400 MHz, Bandwidth = 250 MHz) then the results are verified and tabulated in Table :1

- For the Centre Frequency = 350 MHz, Bandwidth = 200MHz parameters under matching and un-matching conditions are shown in **Fig : 8 & Fig : 9.** Similarly the **Fig 10.** Shows that the G_t and G_{mag} are matched at 200-350 MHz.

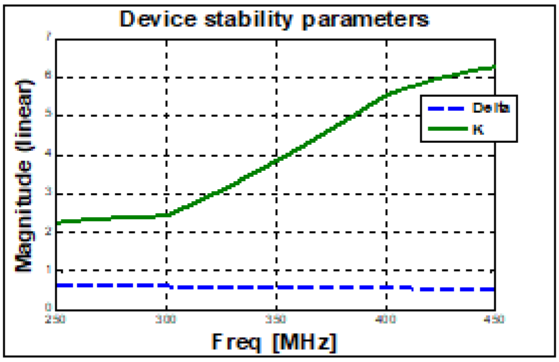

Figure 9: Device Stability Parameters at fc=350MHz, BW=200MHz

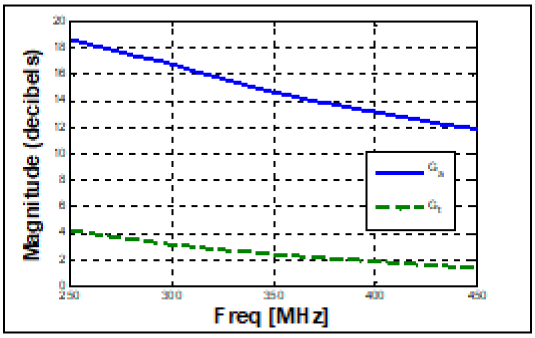

Figure 10: Available & Total Gain for Unmatched Amplifier at fc=350MHz, BW=200MHz

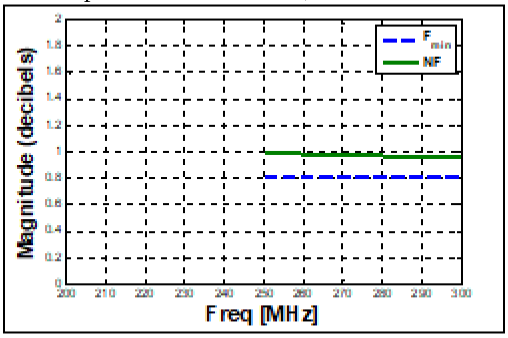

Figure 11: F_{min} & NF for unmatched Amp at fc=350MHz, BW=200MHz

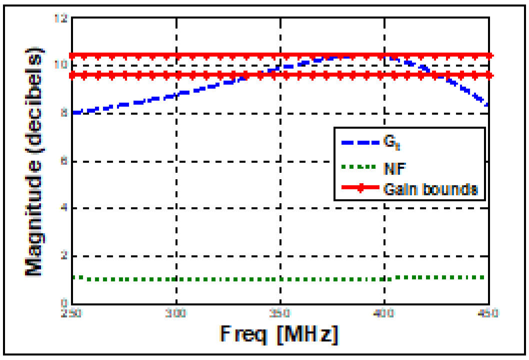

Figure 12: G_t, NF Under Optimized Condition at fc=350MHz, BW=200MHz

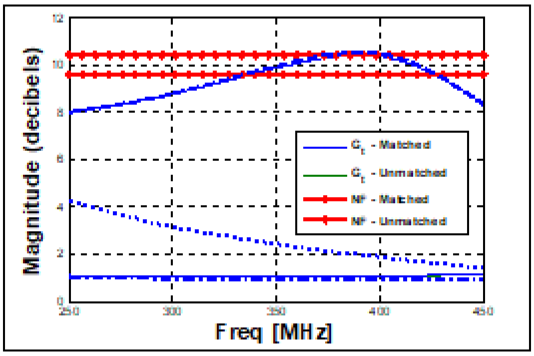

Figure 13: G_t, NF Matched & Unmatched Condition at fc=350MHz, BW=200MHz

- For the Centre Frequency = 400 MHz, Bandwidth = 250 MHz parameters under matching and un-matching conditions are shown in **Fig : 11 & Fig : 12.** Similarly the **Fig 13.** Shows that the G_t and Gmag are matched at 250-400 MHz.

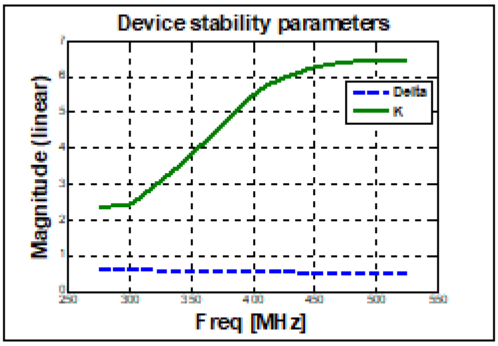

Figure 14: Device Stability Parameters at fc=400MHz, BW=250MHz

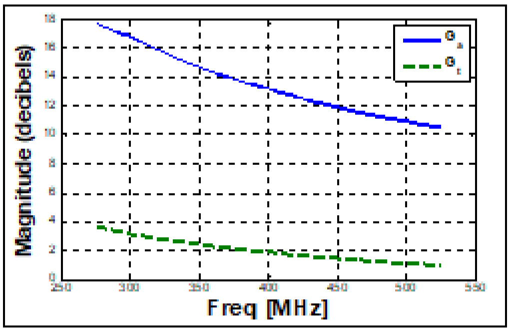

Figure 15: Available & Total Gain for Unmatched Amplifier at fc=400MHz,Bw=250MHz

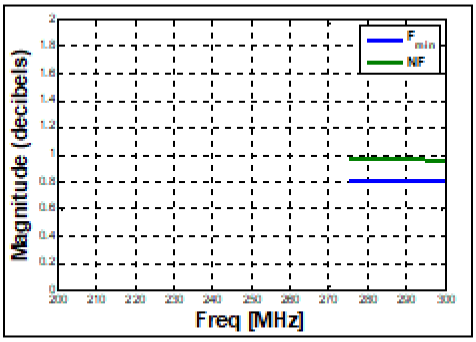

Figure 16: F_{min} & NF for unmatched Amp at fc=400MHz, BW=250MHz

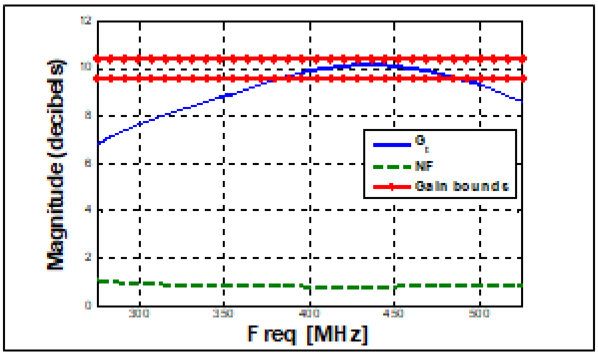

Figure 17: G_t, NF Under Optimized Condition at fc=400MHz, BW=250MHz

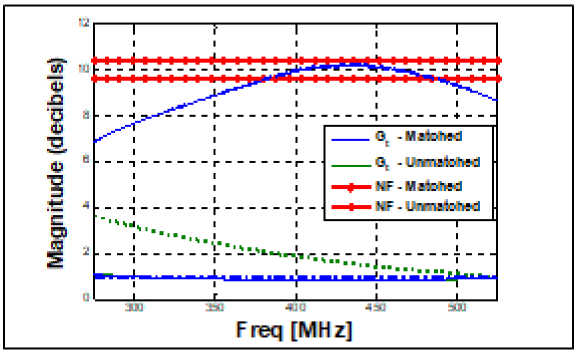

Figure 18: G_t, NF Matched & Unmatched Condition at fc=400MHz, Bw=250MHz

Table 1: Lumped Parameter Under Optimized Condition

S.NO	Fc MHz	BW MHz	Input matching network				Output matching network			
			L1	L2	L3	Cin	L1	L2	L3	Cout
1	250	100	0.5722	0.9272	0.3546	6.8526e-12	0.0517	0.1275	0.0581	5.4408e-12
2	350	200	0.0049	0.2718	0.3608	7.9926e-12	0.5067	0.8265	0.3316	4.1942e-12
3	400	250	0.0006	0.1627	0.1468	9.2650e-12	0.5496	0.5420	0.2314	4.8603e-12

4. Conclusion

In this paper the author discussed about the procedure for designing the Broadband matching network under various RF frequencies by LNA and also analyzed its the performance as Noise Figure, stability Factor, using RFTOOL box. Designing input and output matching networks by LNA is an important part of RF amplifier design. Here we have analyzed the Noise figure, Reflection factors and the placement for different frequencies. In each matching network at a specified frequency, the Zs and Z_L can be calculated easily by Matlab. The Matlab RFTOOL box is an efficient tool for effective designing and analyzing the matching network by LNA.

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