Design of LNA at 2.45 GHz for "Health Monitoring System"

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Abstract— In this paper, the design of a two stage Low Noise Amplifier (LNA) for the frequency 2.45 GHz is used for Health Monitoring System. The NE3510M04 IC is transistor used in the LNA which is a Hetero Junction Field Effect Transistor (HJ-FET) for L-S band developed by California Eastern Laboratories (CEL) on Roger's RO 4003C substrate. This paper gives a brief idea of the design step and simulation. Based on the simulation in Advanced Design Simulation (ADS) software a gain of 24.141 dB with an input and output return loss of -25.993 dB and -29.889 dB respectively at 2.45 GHz is attained. The result With these parameters the two stage LNA is apt for the first stage of the receiver in Health Monitoring System.

Index Terms—Low Noise Amplifier, health Monitoring System, Noise Figure, Reflection Coefficient for source and load, NE3510M04, Roger's RO 4003C substrate.

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1 Introduction

Quite often we come across in the media that people in the rural areas die due to diseases. The reason for this is that, there are not much medical facilities in the rural area and people have to travel long distance before they reach a well equipped hospital for better treatment which they may not be able to afford. Moreover, very few doctors prefer to work in rural areas.

During emergency conditions when the person requires a doctor, one would have to go to the nearest city hospital and there may not be adequate ambulance services to those areas. In these conditions, the person would die untreated. In order to handle this situation a "Health Care Monitoring System" was proposed to be introduced in each house.

Fig. 1. Health Care Monitoring System

A Health Care Monitoring System comprises of a patient unit, sensors, doctor unit, nurse unit and a medicine dispensing unit as shown in fig1.The sensors measure parameters that a doctor would require when a person falls ill like blood pressure, body temperature, heart rate etc. These parameters are sent wirelessly to the patient unit and then the patient unit would send the data through wireless sensor network (WSN) to the doctor unit. The doctor would send his prescription back to the patient unit. If the condition is serious, the message will be send to the nurse unit in order to help the patient. Based on the prescription received by the doctor appropriate medicine would eject out from the medicine dispensing box that is provided in every house.

As shown in fig. 1, a transceiver block is required to send the data and normally in RF receivers the first block is the LNA (Low Noise Amplifier).LNA is used to amplify extremely low level signals without the introduction of noise thereby preserving the signal-to-noise ratio for signal with low power[6][7]. LNA is a class A amplifier where output current flows for the entire cycle of the input applied. The LNA mainly consists of three blocks, they are the input impedance matching network, the amplifier and the output impedance matching network.

In this paper a LNA (Low Noise Amplifier) is designed using NE 3510M04 which is a Hetero Junction Field Effect Transistor (HJ-FET) for L-S band developed by California Eastern Laboratories (CEL) on Roger's RO 4003C substrate. The factors that must be considered for the design of LNA are low noise, matching, moderate gain and stability without oscillating in its required frequency range [2].
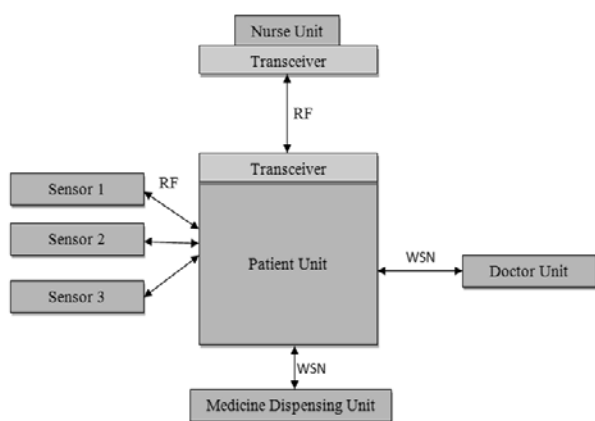
Along with the above factors power consumption and layout design size needs to consider [1].

The simulation is done in ADS software which is an electronic design automation software used in the RF and microwave domain. ADS provide the S-parameter, noise figure and the stability of the device. S-parameter provides the input and output impedance matching and its gain.

2. LNA DESIGN PROCESS

The basic amplifier can be modeled using the circuit as shown in fig 2 where a matching circuit is used on both sides of the transistor to transform the input and output impedance Z_O to the source and load impedance Z_S and Z_L [1].
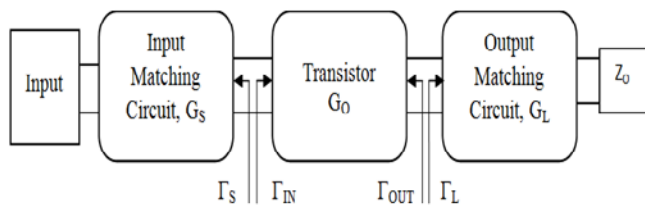
Fig. 2. Block diagram of a transistor amplifier

Based on the fig 2, the transducer power gain can be calculated from the gain factor of the input and output matching network and the transistor itself [4].

$$G_S = \frac{1 - |\Gamma_S|^2}{|1 - \Gamma_{IN}\Gamma_S|^2} \qquad (1)$$

$$G_O = |S_{21}|^2 \qquad (2)$$

$$G_L = \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2} \qquad (3)$$

$$G_T = G_S \, G_O \, G_L \qquad (4)$$

where

G_S = effective gain factor for input (source) matching network

G_O =effective gain factor of transistor

G_L = effective gain factor for output (load) matching network

The following are the design procedure followed for the design of LNA.

2.1 Specification

The LNA should work for the following specification

- Frequency range   = 2.4 – 2.5 GHz
- Gain   >20 dB
- Noise Figure   < 1dB
- Reflection coefficient for source < -15 dB
- Reflection coefficient for load   < -15 dB
- Power supply   =3 V

Based on the given specification NE 3510M04 which is a Hetero Junction Field Effect Transistor (HJ-FET) for L-S band developed by California Eastern Laboratories (CEL) was found appropriate. The substrate used is Roger's RO 4003C having the specification as follows:

- Dielectric constant   =3.38 ± 0.05
- Dissipation factor   = 0.0021
- Standard thickness   =1.524 mm
- Standard copper cladding   =17μm

2.2 Bias Circuit Design

According to the datasheet of NE3510M04, a minimum noise figure with a high gain is provided when V_{DS} =2V and I_D = 10mA at 2 GHz so this point is chosen as the quiescent point of NE3510M04.

2.3 Stability Consideration

Stability is one of the important factor that is to be considered in an amplifier as reflected waves occur which would create self oscillation in certain frequency range and we will not an amplified signal [3] which means that the input or output port impedance will has a negative real part [1]. This means that $|\Gamma_{IN}| > 1$ or $|\Gamma_{OUT}| > 1$ because it depends upon input and output port impedance.

In order to check whether the amplifier is unconditionally stable, it should meet the sufficient and necessary conditions that are

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}S_{21}|} > 1 \qquad (5)$$

$$|\Delta| < 1 \qquad (6)$$
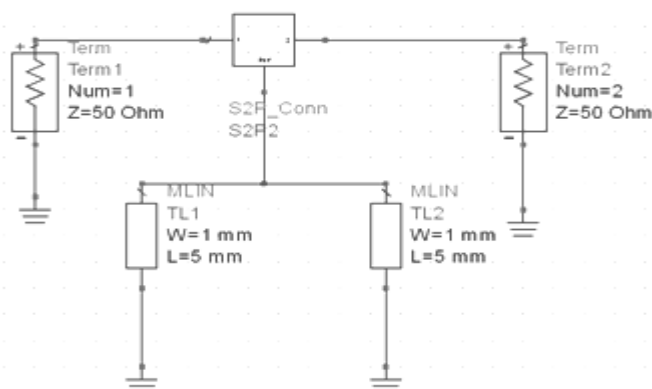
where k is the rolett factor.

Fig.4. Circuit for Stability

NE 3510M04 is not stable at all frequency, in order to make it stable at 2.4-2.5 GHz, a small microstrip line is added in between the source and ground of the device as shown in fig. 4. The microstrip line acts as a negative feedback which itself acts as an inductor connected in between the source and ground. The length of the microstrip line is determined using the tuning tool and the by checking the stability factor provided in ADS.

2.4 Input Matching Network

Input matching is required to match the load impedance and the transmission line so that maximum power is transferred as shown in fig. 5.But as we design the input impedance we observe that we do not get maximum gain with minimum noise figure. It is also known that the first stage of the LNA should have minimum noise figure. Hence the priority is given to minimize the noise figure, in order for that the reflection coefficient of the transistor must terminate with suitable reflection coefficient of the source (Γ_{opt}).
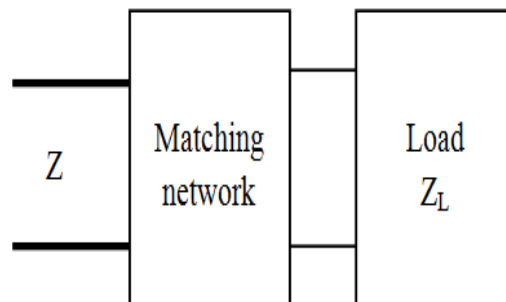

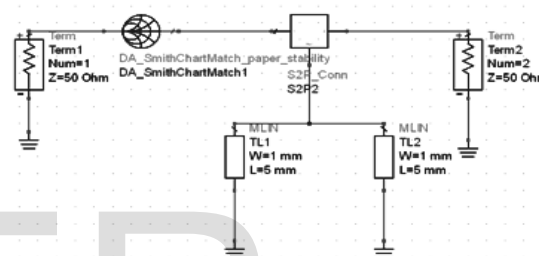Fig. 5. Block Diagram of Input Matching Network

Fig. 6. Input Impedance Matching using Smith Chart Utility

For the input impedance matching, DA_SmithChartMatch in ADS is used to get a rough idea of the input impedance and then tuning tool provided in ADS is used to provide a better match as in fig 6.The matching is done using lumped elements.

2.5 Output Matching Network

The output impedances matching is used to attain maximum gain with a flat gain curve and a low input VSWR [3][9].Here also the DA_SmithChartMatch in ADS is used to get a rough idea of the output impedance and then tuning tool provided in ADS is used to get an appropriate balance in the S_{11}, S_{21}, S_{22} and noise figure. While adjusting the parameters gain is considered for the matching the output impedance so as to get maximum gain[8].

2.6 Minimum noise figure design and maximum gain design

Noise figure is an important factor in a LNA as it should have a low noise figure in order to amplify the low level signal without the introduction of noise[10]. Noise figure (F) is reduced using the Friis formula as given below.

$$F = \frac{SNR_{IN}}{SNR_{OUT}} \qquad (7)$$

$$F = F_1 + \frac{F_2 - 1}{G_1} \qquad (8)$$

where F_1 = Noise Figure of first stage
F_2 = Noise Figure of second stage
G_1 = Gain of the first stage

Based on the equation, the first stage of the LNA contributes to majority of the noise figure. Therefore it is essential to reduce the noise figure of the first stage.

But as we minimize the noise figure of the first stage the gain of the first stage reduces and hence priority is used to increase the gain of the second stage of the LNA[5]. The result gain is calculated by adding the resultant gains in dB as given below

$$G_{max} = G_1 + G_2 \qquad (9)$$

where G_1 = resultant gain of first stage
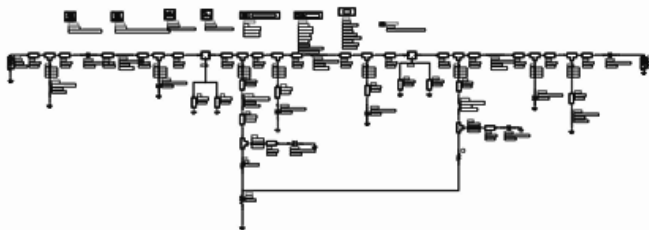G_2 = resultant gain of second stage

3 SIMULATION RESULTS

Fig.7 Schematic of LNA

From fig. 7 shows the schematic of the LNA. Fig. 8 shows the s-parameters of the device and fig. 9 shows the stability and noise figure of the device. As shown in fig.8

the simulated values of S_{11} = -37.421 dB which is less than -15dB, S_{21} = 24.2 dB which is greater than 20 dB and S_{22} = -28.8 dB which is less than -15 dB. All the s-parameter value satisfies the specification provided. According to fig.9, the noise figure is 0.813 dB which is less than 1dB for 2.45 GHz and the stability factor is greater than 1 and the delta value
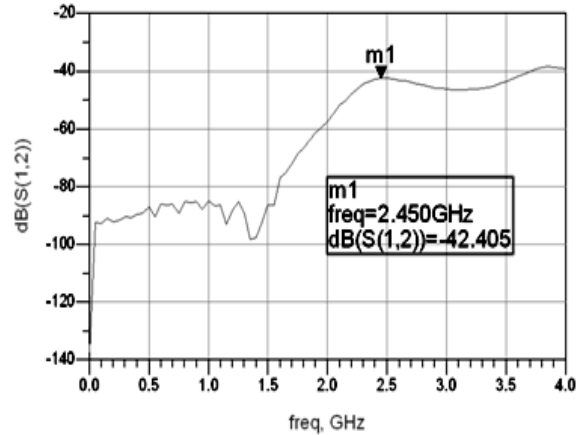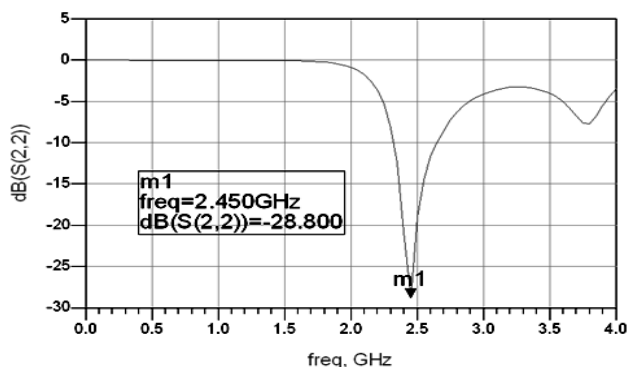
is less than 1.
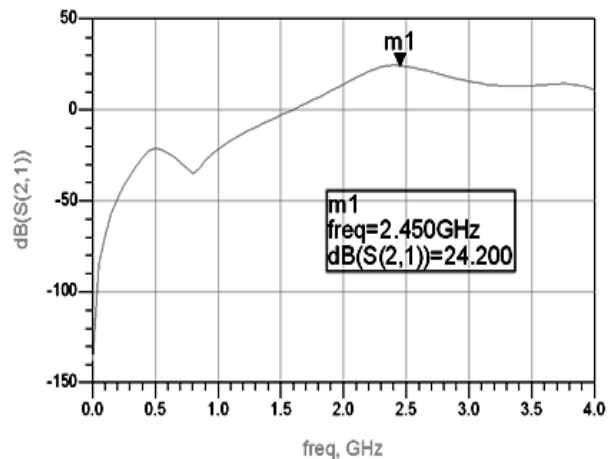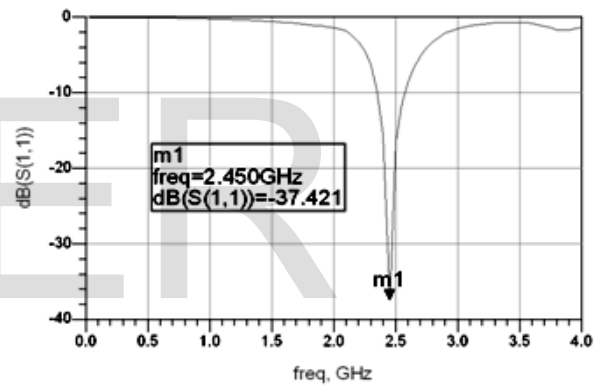
Fig.8 Simulated S-parameter of the device

freq	delta	NFmin	StabFact1
2.100 GHz	0.677	0.899	3.322
2.150 GHz	0.592	0.894	3.852
2.200 GHz	0.490	0.884	3.914
2.250 GHz	0.384	0.859	3.875
2.300 GHz	0.262	0.840	3.884
2.350 GHz	0.153	0.837	4.065
2.400 GHz	0.122	0.817	4.004
2.450 GHz	0.123	0.813	4.122
2.500 GHz	0.112	0.802	4.153
2.550 GHz	0.070	0.798	4.234
2.600 GHz	0.012	0.790	4.381

Fig.9 Simulated values of noise figure and stability and delta

This is then compared to the device ATF54143 which provides a gain of 16.3 dB with a noise figure of 0.8 dB [3]. With a cascaded structure of two stage LNA using NE 3510M04 provides a better gain with a low noise figure as shown in fig.9 and fig.8.

Substrate	Device	Gain (dB)	Noise figure(dB)	Frequency GHz
FR4	ATF54143	16.3	0.8	2.4-2.5
Rogers RT/Duroid 4003C	NE3510M04	24.2	0.813	2.45
Rogers RT/duroid 5880	**FHX76LP**	57	1.16	**5.75 – 5.85**
FR4		7.78	**1.53**	**5-6**

4 CONCLUSION

In this paper the design and simulation of LNA is discussed. For the design of a LNA a device is selected based on the specification required. Then, biasing is done in order to get maximum gain and minimum noise figure. Using the DA_SmithChartMatch the input and output

matching networks are attained. After that, the tunning parameter is used to finally tune to 50Ω load.

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