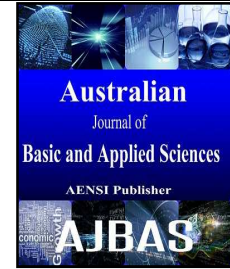




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Design Of Band Pass Filter Embedded With Low Noise Amplifier For Ism Band Applications

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ABSTRACT

In modern society demand of wireless communication growing rapidly due to the technology's compact size, portability and selectivity. The proposed paper work is designing the required ISM band (Industries scientific and Medicines band) 2.45 GHz by BPF(Band Pass Filter) embedded with LNA(Low Noise Amplifier) by matching network. Embedding can change the structure and combine the function of the circuits and simplify the connection between the components. Frequency spectrum is a natural resource and need to be distributed with deep attention. The engineering community is in high favour to design devices which is compatible with ISM Band since it is unlicensed and it's free uses. Cordless phone, wireless LAN, Bluetooth and Wi-Fi are operated in 2.4GHz -2.5 GHz. Performances of different designs are compared with respect to noise figure, gain, input and output reflection coefficient. In the design process, a single stage LNA is designed by transistor ATF-58143. Maximally flat band-pass (BPF) filters were designed with lumped components and distributed elements. Afterwards, BPF is integrated with the LNA at the front side of LNA to get a compact Band-Pass Filtered Low-Noise Amplifier with better performance.

INTRODUCTION

In wireless communications, receivers need to be able to detect and amplify incoming low power signals without adding much noise. Therefore, to filter out the unwanted signal, a Band-Pass filter (BPF) is placed before low noise amplifier (LNA)'s placement. A low noise amplifier (LNA) is often used as the first stage of these receivers. To design an LNA embedded with Band-Pass Filter (BPF), with trade-off or suitable compromise between gain and noise is always a matter of challenge. There are two methods to improve the Performance of RF front-end, including system level packaging of RF systems (passive and active components or subsystems are integrated into one device to realize the system in one package) and co-design for RF front-end (the traditional 50 ohm interface between the LNA and band-pass filter is removed to realize multi-function in one device). The co design can essentially change the structure of the circuit, combine the function of the circuits and simplify the connection between the components.

In this paper, a method of co-designing the Band Pass Filter with Low Noise Amplifier is presented and the design formulae are also provided. First, BPF is designed. Second, using the traditional method, the LNA operating at frequency band is designed. Finally, the BPF is combined into Low Noise Amplifier with help of matching network. In order to verify the method, BPF with LNA operating at 2.4 GHz is designed and simulated.

Design Methodology:

Since the objectives of the work is design a Band Pass Filter with Low Noise Amplifier for 2.4 GHz application, where the major performance is obtain the minimum noise figure and high gain. In wireless

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communications, receivers need to be able to detect and amplify incoming low power signals without adding much noise. Therefore, to filter out the unwanted signal, a Band Pass filter (BPF) is placed before low noise amplifier (LNA)'s placement. There are two methods to improve the performance of RF front-end, including system-level packaging of RF systems and co-design for RF front-end. The co design can essentially change the structure of the circuit, combine the function of the circuits and simplify the connection between the components. By co-design, the noise figure was improved significantly. Harmonic suppression is improved effectively.

Band Pass Filter:

In RF transmitter and receiver, filters are key components which is used to selectivity pass or reject signals based on frequency. A Band-Pass Filter (BPF) which is used to reject unwanted frequency bands and pass a narrow pass-band. In this work design band pass filter at 2.45GHz frequency and filter ripple factor (IL) is 0.1 dB. Insertion loss method used to design band pass filter. First step of filter design is determine filter order. In this method determine filter order form given below formula

Filter order determination:
 $IL = 1 + a_m^2 \omega'^{2n} ; \omega' = \omega / \omega_c$ (1)

Ripple magnitude:
 $r_m = 10 \log(a_m^2 + 1)$ (2)

Using ripple magnitude determined a_m value
 Stop-band attenuation at
 $f'_x = 10 \log[1 + a_m^2 \cos^2 h^2(n \cos h^{-1} \omega'_x)]$ (3)

Filter order is 4 and characteristic impedance of the filter is 50 ohm
 Second step of the filter design is determine filter element

Series arm g_k
 $L_k = \frac{g_k Z_L}{(\omega_2 - \omega_1)}$ (4)

$C_k = \frac{(\omega_2 - \omega_1)}{(g_k Z_L \omega_0^2)}$ (5)

Shunt arm g_k
 $L_k = \frac{Z_L}{g_k (\omega_2 - \omega_1)}$ (6)

$C_k = \frac{g_k (\omega_2 - \omega_1)}{(Z_L \omega_0^2)}$ (7)

Filter element values from above formulas

$L_1=521.91\text{pH}$, $C_1=8.11\text{pF}$, $L_2=48.98\text{nH}$, $C_2=86.47\text{fF}$, $L_3=216.183\text{pH}$, $C_3=19.59\text{pF}$, $L_4=20.28\text{nH}$, $C_4=208.76\text{fF}$

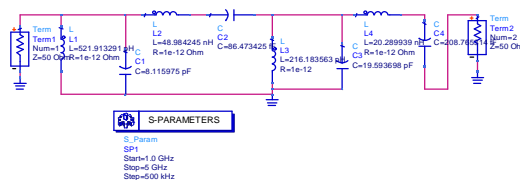


Fig. 1: Band Pass filter using lumped component

Series resonator have low impedance for desired frequency bandwidth which is 2.4 to 2.5 GHz and parallel resonator will give high impedance to desired bandwidth to stop signal from the ground

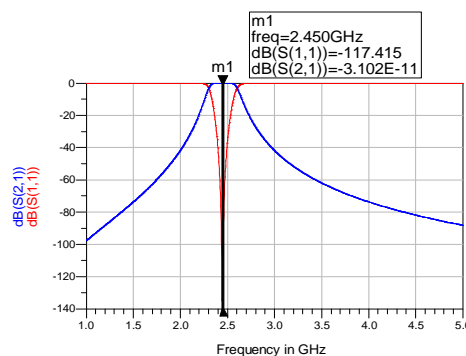


Fig. 2: Simulation result of Input reflection and forward transmission coefficient

X-axis, frequency and along to Y-axis input reflection coefficient and forward transmission are plotted respectively. The value of S_{11} is -117.415 dB and S_{21} is -3.1dB at the central frequency which is 2.45 GHz. Band-Pass filter is showing very appropriate results for S_{11} & S_{21} individually but when this BPF is attached with the LNA circuit using matching network then it is needed to further optimization to get better results for whole BPF-LNA.

Band pass filter design using distributed component

Here, first determine distributed component value for all lumped component in the above lumped design of filter.

The theoretical value of distributed component calculated and defined as,

The effective dielectric constant of a micro strip line is given approximately by

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12d/W}} \tag{8}$$

The characteristic impedance can be calculated as

$$Z_0 = \frac{60}{\sqrt{\epsilon_e}} \ln\left(\frac{8d}{W} + \frac{W}{4d}\right) \text{ for } \frac{W}{d} \leq 1 \tag{9}$$

$$\sqrt{\epsilon_e} \left[\frac{W}{d} + 1.393 + 0.667 \ln\left(\frac{W}{d} + 1.444\right) \right] \text{ for } \frac{W}{d} \geq 1 \tag{10}$$

For a given characteristic impedance Z_0 and dielectric constant, the W/d ratio can be

Found as

$$\frac{W}{d} = \frac{8e^A}{e^{2A} - 2} \text{ for } \frac{W}{d} \geq 1 \tag{11}$$

$$\frac{2}{\pi} \left[B - 1 - \ln(2B - 1) + \frac{\epsilon_r - 1}{2\epsilon_r} \left\{ \ln(2B - 1) + 0.39 - \frac{0.61}{\epsilon_r} \right\} \right] \text{ for } \frac{W}{d} \geq 1 \tag{12}$$

Where,

$$A = \frac{Z}{60} \frac{\sqrt{\epsilon_r + 1}}{2} + \frac{\epsilon_r - 1}{\epsilon_r + 1} \left(0.23 + \frac{0.11}{\epsilon_r} \right)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}}$$

The schematic design of Band Pass Filter using distributed component is given in figure 3.

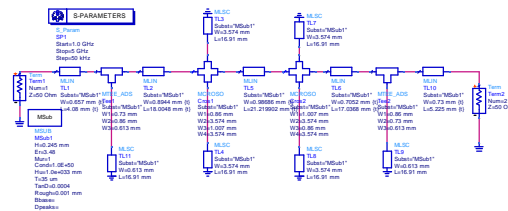


Fig. 3: Schematic of Band Pass Filter using distributed component

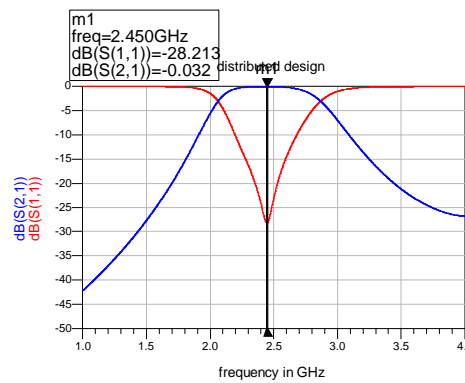


Fig. 4: Result of band pass filter distributed design

If we use Roger’s substrate (Rogers 4350B) with $\epsilon_r=3.48$, and $H=0.254$ mils to build the filter. . The value is obtained as S_{11} is -28.415 dB and S_{21} is -0.031dB at the central frequency which is 2.45 GHz as given figure 4

Low Noise Amplifier:

The design of Low Noise Amplifier involves selection of active devices, DC analysis and device characterization, Biasing condition, Stability analysis, Design of input and output matching, Performance Optimization and impedance matching. The first stage of LNA design process is selection of transistor.

A. Selection of active devices:

Most of these design conditions can be met

Carefully selecting a transistor, The AVAGO Technologies’ ATF58143 is chosen for designing BPF-LNA. Agilent Technologies’s ATF-58143 is a high dynamic range, low noise E-PHEMT housed in a 4-lead SC-70 (SOT-343) surface mount plastic package. The combination of high gain, high linearity and low noise makes the ATF-58143 ideal as low noise amplifier for cellular/ PCS/WCDMA base stations, wireless local loop, and other applications that require low noise and high linearity performance in the 450 MHz to 6 GHz frequency range

B. Stability Analysis:

S2P file is used to check the stability of the transistor. First the S2P file is run alone and it is found that in the whole bandwidth (BW) i.e. from 2.4 GHz to 2.5 GHz, the transistor is unstable, because the value of stability factor is: $K < 1$. Stability of an amplifier refers to its resistance to oscillations. Oscillation occur when any one of the present a negative resistance which occurs when $|r_{in}| > 1$ or $|r_{out}| > 1$.

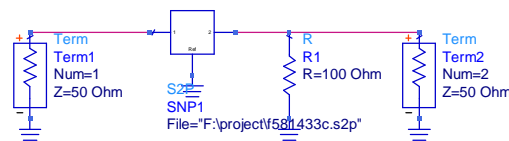


Fig. 5: Schematic for stability analysis

In order to make it stabled a shunt resistor (R1) ism connected to the drain as shown in the figure 5.The stability analysis is performed and stability factor $K=1.634$

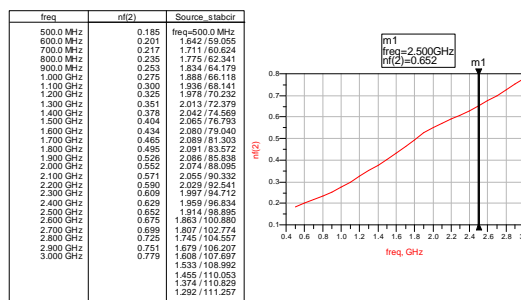


Fig. 6: Stability Analysis for ATF 58143

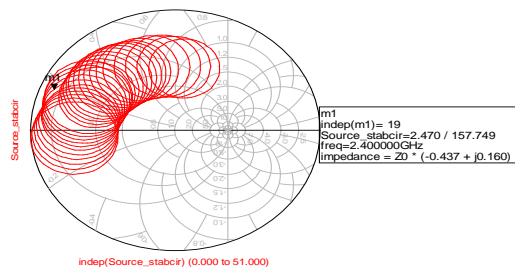


Fig. 7: Stability Circle for ATF 58143

The necessary and sufficient condition for unconditional stability are:

$$K > 1, |\Delta| < 1$$

$$1 - |S_{11}|^2 > |S_{12} S_{21}| \tag{13}$$

$$1 - |S_{22}|^2 > |S_{12} S_{21}| \tag{14}$$

Where,

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12} S_{21}|}$$

$$\Delta = S_{11} S_{22} - S_{12} S_{21}$$

C. Design of Input and Output matching network:

The input matching network can be designed to

Match the large signal input impedance of the RF active device with the 50 ohm source impedances. The large signal input impedance of the power transistor consists of two parts, resistance R_{in} and reactance X_{in} .

$$Z_{in} = R_{in} + jX_{in} \tag{14}$$

Input matching network improves the net input power delivered to the RF device. The output matching network for the LNA is designed to transform the impedance of 50 ohm to the load impedance Z_L or to the load reflection coefficient. The amplifier circuit was simulated after adding the input and output matching circuit using ADS.

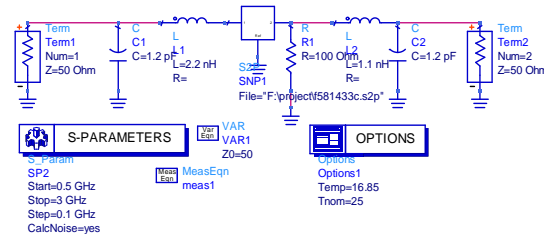
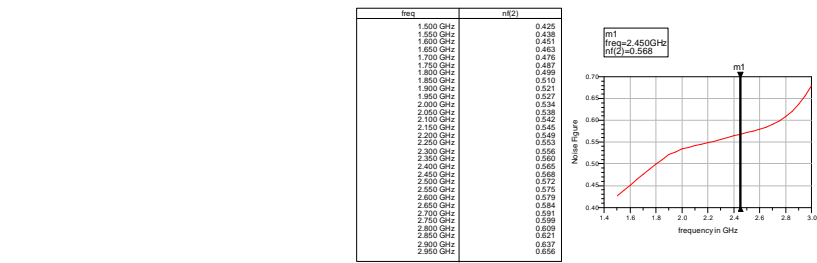
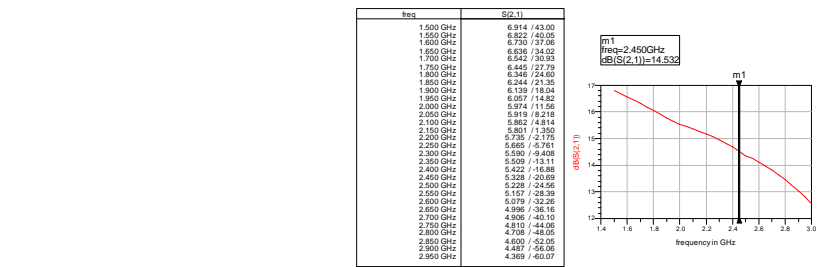


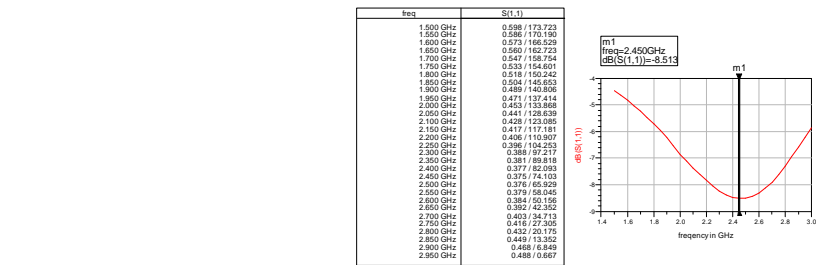
Fig. 8: Schematic design for matching network of LNA



(a) Noise figure Vs frequency



(b) Forward transmission coefficient Vs Frequency



(c) Input reflection coefficient Vs Frequency

Fig. 9: Simulation result of LNA matching network

The input and out matching network combined with network of LNA is designed using ADS and impedance matching was performed to obtain the Gain (S_{21}) of 14.532 dB, Input reflection coefficient (S_{11}) of -8.513 dB and Noise Figure (NF) of 0.568.

The input and out matching network combined with active biasing network of LNA is designed the simulation results are given by figure 10.

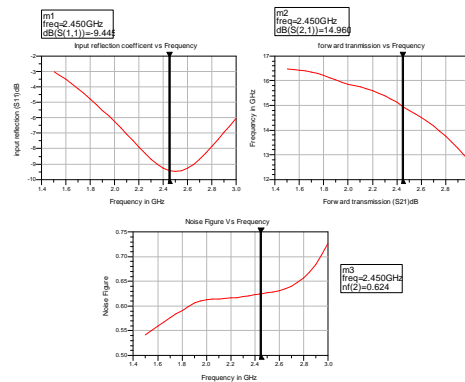


Fig. 10: Simulation Result of LNA

The impedances matching and biasing network added and processed LNA has a noise figure of 0.624, optimum gain (S_{21}) of 14.96 dB with input return loss (S_{11}) of -9.445 dB

Co-Design Of Bpf With Lna:

In this section, BPF-LNA is designed using lumped components. Order 4 lumped-filter with maximally flat response was connected with LNA through matching network. The BPF-LNA co-design presents a great challenges because of its simultaneous requirement of high gain, low noise figure, good matching and stability at the lowest current draw from amplifier. The design requires 3.3 V supply voltage. The co-design circuit of NPF-LNA given by figure 11.

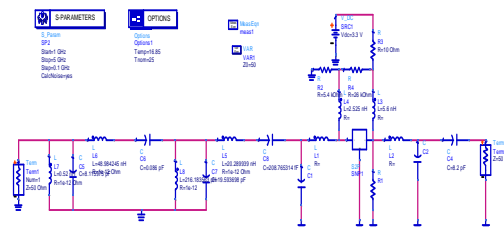


Fig. 12: Design BPF-LNA using lumped component

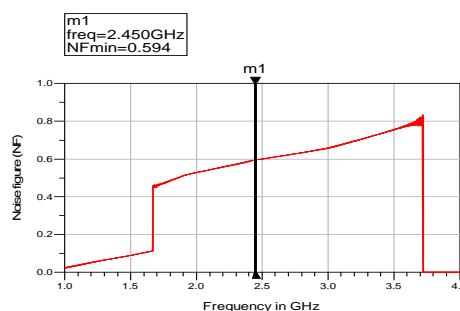


Fig. 13: Simulation result of noise figure

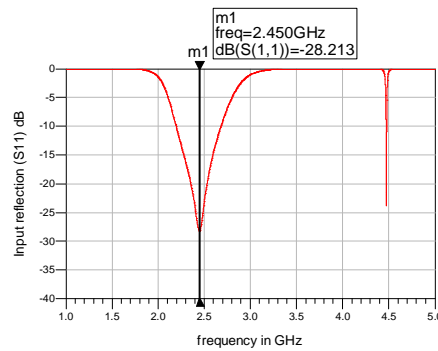


Fig. 14: Simulation result of return loss (S11)

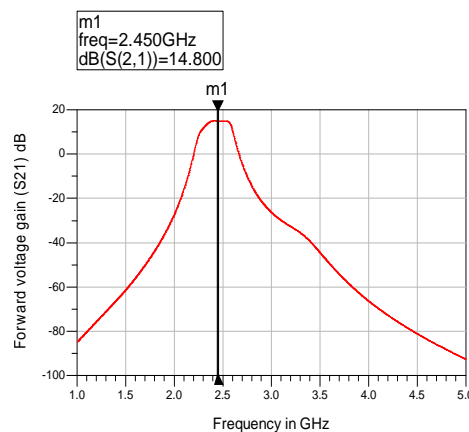


Fig. 15: Simulation result of gain (S21)

The proposed BPF-LNA has a minimum noise figure (NF) of 0.594, with return loss (S11) of -28dB and forward voltage gain (S21) of 14.800 dB.

Table 1: summary of simulation result of 2.45 GHz BPF-LNA

PARAMETER	VALUE
RF Frequency	2.45GHz
Power Supply	3.3 volts
Noise Figure (NF)	0.594
Gain (S21)	14.800 dB
Return Loss(S11)	-28 dB

Conclusion:

The Co-design of Band Pass Filter embedded with Low Noise Amplifier for ISM band application is presented in this paper. LNA stand-alone and BPF-LNA with lumped and distributed components are designed using ATF-58143, and their performances are compared. Optimization was performed according to get the desired responses in the design. In BPF-LNA lumped design the optimum value of input reflection coefficient and gain are -28.213 dB and 14.8 dB respectively. BPF-LNA distributed design has a input reflection coefficient and gain of - 5.923 dB and 14.2dB. Furthermore, throughout the whole design, transistor was stable. The optimization work gives a closer and wide view of all the relevant result.

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