A Low Noise Amplifier with High Image Rejection and Selectivity

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***Abstract*- A low noise amplifier (LNA) with bandpass filtering and image rejection capability has been proposed. The circuit is implemented on low cost FR4 substrate. Co-simulations show that the proposed structure provides a power gain of 11.49 dB with noise figure 2.67 dB at 2.4GHz and two transmission zeros at 2 GHz and 3 GHz, respectively. As a result, it holds the image rejection capability for the intermediate (IF) frequencies 200MHz and 300MHz, respectively. The simulated results are verified by measurements. Measurements show that the image frequency is suppressed by 32.5 dB and 41.4 dB for the IF 200 MHz and 300 MHz, respectively.**

I. INTRODUCTION

In the receiver chain for any wireless system, low noise amplifier (LNA) plays an important role in the overall performance of the receiver. Its function is to amplify weak signal with minimum possible added noise. It necessitates enough amplification as well as minimum noise figure. Since LNA is used as the first stage of microwave receiver, the noise performance of whole cascaded system depends on the gain and noise figure of LNA.

In wireless systems, the application of superheterodyne receiver architecture is widespread because of its high selectivity and sensitivity [1]. But the image frequency signal is its main problem. It requires proper filtering of the image signal. To address the problem, some of the recent researches have been focused on the development of image rejection notch filter [2], [3]. A typical superheterodyne receiver is shown in Fig. 1. The first bandpass filter (BPF) is used toselect the desired band of signal. In addition, a separate image rejection filter is required to remove the image frequency from the signal especially for the smaller intermediate frequency (IF). In the present work as shown in the same figure, a BPF is integrated with the LNA to get amplification only over the desired signal band as well as to remove the image frequency. Thus, it saves implementation area. Moreover, it has high image rejection capability for two different IFs.

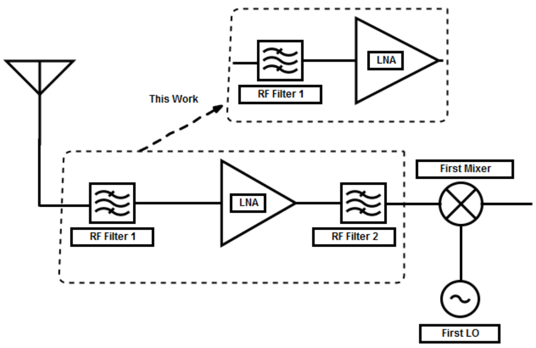

Figure 1. A typical superheterodyne receiver and the present work.

II. LNA DESIGN WITH INTEGRATED BPF

A. LNA Design

Low noise figure, moderate gain, stability and matching are the most important factors for the design of a LNA [4]. So, the choice of the transistor is a very important task. In this design, Agilent's ATF-54143 enhancement mode p-HEMT [5] has been selected because of its high dynamic range and low noise. Next step is to bias this selected transistor at appropriate point. The bias point (V_{ds}, I_{ds}) is selected from datasheet of transistor at which it gives optimum gain and noise figure. According to this, a DC bias network is designed along with a radio frequency choke. The choke inductance value is chosen to suppress the 2.4 GHz signal at least by 15 dB.

The Rollet's stability condition for unconditional stability of LNA are given by [6]

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

$$\Delta = |S_{11}S_{22} - S_{12}S_{21}| < 1 \qquad (2)$$

The noise figure of a two-port amplifier can be expressed as

$$F = F_{\min} + \frac{R_N}{G_S}|Y_s - Y_{opt}|^2 \qquad (3)$$

where $Y_S = G_S + jB_S$ = source admittance presented to transistor, Y_{opt} = optimum source admittance that results in minimum noise figure, F_{min} = minimum noise figure of transistor attained when $Y_S = Y_{opt}$, R_N = equivalent noise resistance of transistor, G_S = real part of source admittance. It shows that the noise figure of the amplifier is dependent on the source impedance but not on the load impedance. Generally, it is not possible to obtain both minimum noise figure and maximum gain for an amplifier simultaneously. Thus to obtain a usable trade-off between these quantities, constant noise figure and gain circles are plotted and the corresponding source impedance in the stable region of the amplifier is found out. A single stub matching network is used to match this impedance with the port impedance of 50 Ω.

B. Filter Design

A bandpass filter (BPF) is designed using two open-loop resonators. The filter structure is shown in Fig. 2. The advantage of this configuration is that two transmission zeros are created around the passband [7] if the tapped line feeding scheme is used. The positions of transmission zeros are determined by length of the arms L_1 and L_2. The simulated frequency response of the designed filter is shown in Fig. 3. The finite element method of ADS from Keysight has been used for all of the full-wave simulations. A 0.8 mm thick FR4 substrate of permittivity 4.4 and loss tangent 0.022 is used for the filter implementation. The filter shows a passband of bandwidth 340 MHz around the operating frequency 2.4 GHz and two transmission zeros at 2 GHz and 3 GHz. The transmission zeros are obtained at the frequencies at which the length of the arms is a quarter wavelength. Thus, locations of the transmission zeros can be tuned by proper selection of the tapping position. Here, the corresponding lengths are 51 mm and 11 mm, respectively. The bandwidth of the passband can be controlled by changing the separation between the resonators.

C. Integrated LNA Design

The complete circuit of the proposed integrated LNA is shown in Fig. 4. It consists of the filter and LNA with DC biasing network and matching network. For ATF-54143, *S* is for source, *G* for gate and *D* for drain connection. This circuit is designed for ADS co-simulation where layout as well as lumped components can be simulated simultaneously. It can be noted that there is no requirement of DC blocking capacitor at the input end as the chosen coupled resonator based filter configuration is serving the same purpose. Co-simulated *S*-

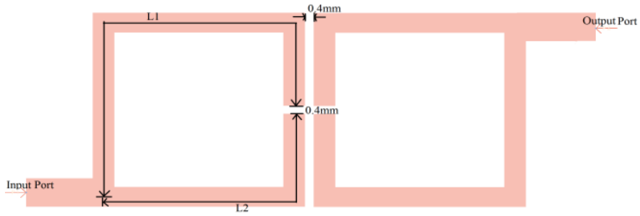

Figure 2. Filter structure.

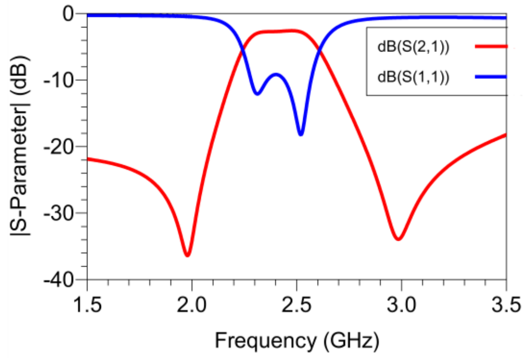

Figure 3. Simulated *S*-parameters of the designed filter.

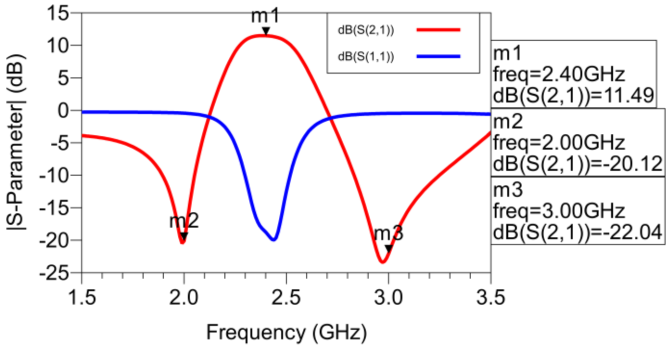

Figure 5. Simulated *S*-parameters of integrated LNA.

parameters, *K*-Δ stability and noise figure are shown in Fig. 5, Fig. 6 and Fig. 7, respectively. It can be seen that *K* is greater than one and Δ is less than one for the frequency range of interest. The power gain at 2.4 GHz is 11.49 dB and there are two transmission zeroes at 2 GHz and 3 GHz with depth of -20.68 dB and -21.49 dB, respectively. In Fig. 7, the blue line shows the minimum possible noise figure for the circuit and

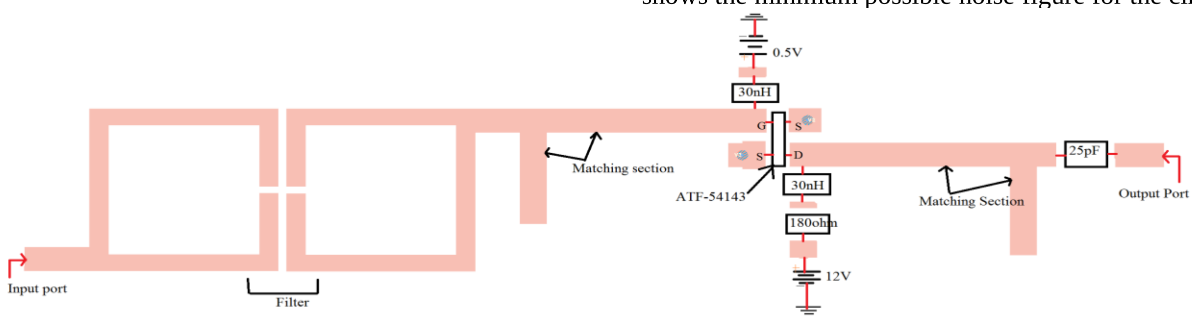

Figure 4. Circuit of the integrated LNA

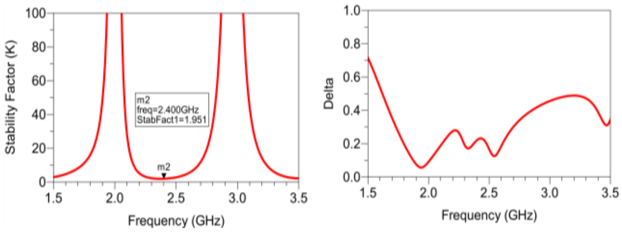

Figure 6. *K*-Δ test based on simulated *S*-parameters.

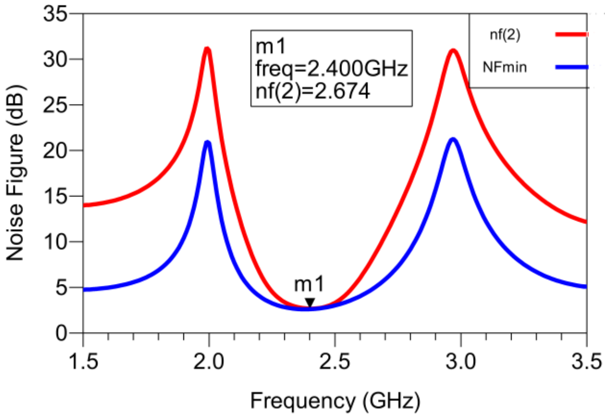

Figure 7. Simulated noise figure of the integrated LNA.

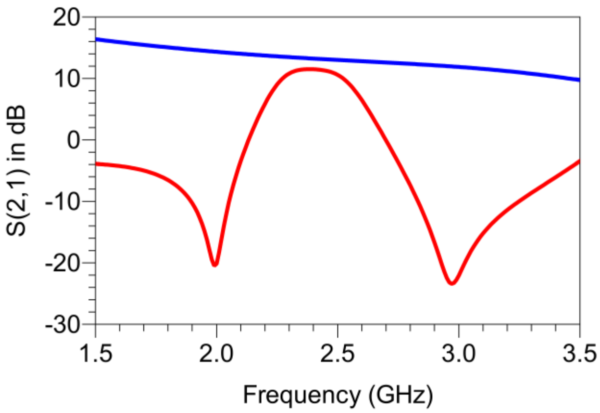

Figure 8. Simulated transmission response of the LNA with (red) and without filter (blue).

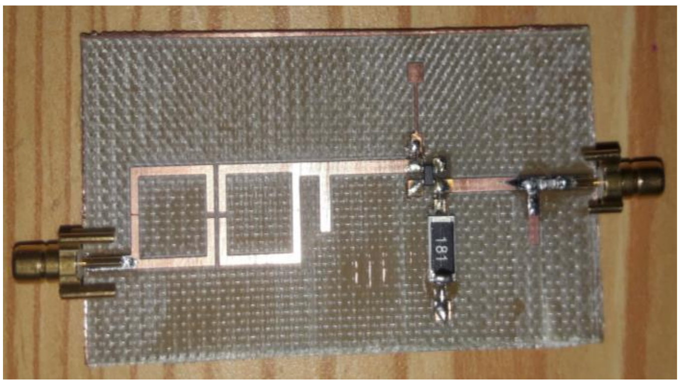

Figure 9.A photograph of the fabricated circuit.

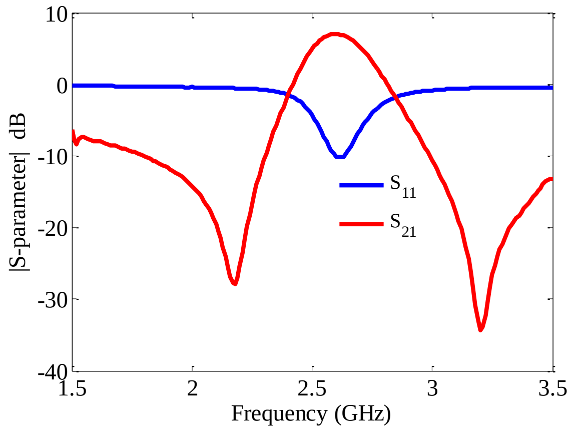

Figure 10. Measured *S*-parameters.

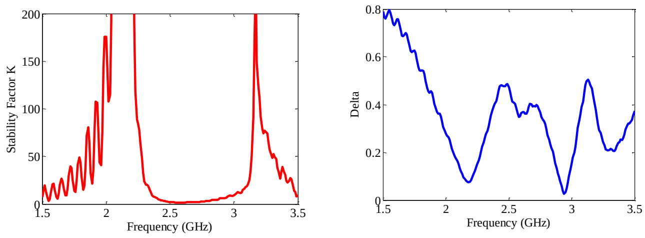

Figure 11. *K*-Δ test based on measured *S*-parameters.

the red line is for its actual noise figure. We can see that at 2.4 GHz the minimum and actual noise figures are same i.e. 2.67dB.A comparison of the power gain with and without the integrated filter is shown in Fig. 8. It illustrates that the proposed integrated LNA structure improves the selectivity by passing the desired signal at 2.4 GHz with minimal attenuation and suppressing the image frequency. The total area occupied by the circuit is $0.74\lambda_g \times 0.16\ \lambda_g$, where λ_g is the microstrip line guided wavelength at 2.4 GHz for the present substrate.

III. Fabrication and Measurements

The designed structure as shown in Fig. 4 is fabricated using the same FR4 substrate and the commercially available SMD components are placed at the respective positions. The inductor and capacitors are chosen so that the operating frequency (2.4 GHz) is well below their self-resonant frequencies given in the manufacturer datasheet. A photograph of the integrated circuit is shown in Fig. 9. Measured *S*-parameters are plotted in Fig. 10. *K*-Δ test has been performed using the measured *S*-parameters and are shown in Fig. 11. It shows that the LNA is stable over the frequency range of interest. Measured maximum power gain is obtained as 7.1dB at 2.6GHz. A reason of gain reduction is the degradation of impedance matching at 2.6 GHz. Single stub matching network provides narrowband matching and it was designed based on the *S*-parameters of the p-HEMT under the chosen bias condition at 2.4 GHz. In addition, there is connector loss due to the SMA to microstrip line transition. However, two transmissions zeros are clearly visible at 2.2GHz and 3.2GHz with values -25.4dB and -34.3dB, respectively.

IV. CONCLUSION

A low noise amplifier with high image rejection capability and selectivity has been presented. A bandpass filter using a pair of open-loop resonators is used to obtain the characteristic. The filter creates a pair of transmission zeros when the arms of the resonators become a quarter wavelength. It is possible to find a suitable tapping position to provide the required external quality factor as well as to place the transmission zeros at the desired location. A slight change of the resonator width may be required for this purpose. The rectangular occupying area of the structure is $0.74\lambda_g \times 0.16\ \lambda_g$, where λ_g is the microstrip line guided wavelength at 2.4 GHz. Measurements show that the image frequencies corresponding to the intermediate frequencies 200 MHz and 300 MHz are suppressed by -25.4 dB and -34.3 dB, respectively. The co-simulated noise figure of the proposed structure is 2.67 dB.

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