Non Simultaneous-conjugate-match Technique for S-band Low Noise Amplifier Design

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Abstract— The design of 2-stage low noise amplifier (LNA) working at S-band frequency is proposed by using non simultaneous-conjugate-match technique. Implementation of the technique is motivated by the circumstance that the gain of LNA designed by the familiar technique, i.e. simultaneous-conjugate-match is almost followed by arise of values in noise figure (NF) and voltage standing wave ratio (VSWR). In the design process, the ADS software is applied to determine the desired trade-off value between LNA parameters such as gain and VSWR. The 2-stage LNA which is deployed on an Arlon DiClad527 applies BJT transistors of BFP420. To achieve the impedance matching condition, microstrip lines are employed at the input and output ports. From the experimental characterization, it shows that the prototype of 2-stage LNA produces the gain of 24.32 dB at 3 GHz which is 4.56 dB lower than the simulated result.

1. INTRODUCTION

In wireless communication systems, a front-end amplifier receiver is a very critical block in radio frequency (RF) receivers due to its responsibility to recover the transmitted data out of the weak received signal which is usually accompanied by noise and interference. Thus, a front-end amplifier receiver with high performance capability is an essential device to provide sufficient power gain and low noise figure as well as good input impedance matching within the required operational frequency bands [1–3]. There are a lot of topologies and design methods of RF receiver amplifier including the utilization of RF-CMOS integrated circuit which have been investigated where some achievements in accomplishing specification and aspect of applications have been acquired [4–6]. One of the methods to obtain the match output impedance, as well as better isolation between the input and output ports is by cascading an amplifier in some stages.

In the design of low noise amplifier (LNA), there are many trade-off values involve between noise figure (NF), gain, linearity, impedance matching, and power dissipation [6, 7]. Basically, the main goal of LNA design which is usually carried out by use of a simultaneous-conjugate-match (SCM) technique is to achieve simultaneous noise and input matching at any given amount of power dissipation. The LNA should also provide low noise behavior not only at one frequency but over the whole desired working bandwidth [8]. Beside the mentioned trade-offs above, the stability is the most important thing that has to be paid more attention. To attain the desired stability as well as the stability maintenance, there are few methods that could be implemented including resistive matching, network compensation, negative feedback, balanced circuits, and traveling wave [2, 3]. For some application, however, the resistive matching method can potentially increase the noise figure and simultaneously decrease the gain of LNA, while the method of negative feedback typically produces inferior reflected wave [9, 10]. Moreover, in the LNA design based on SCM technique especially for bilateral and unilateral RF amplifier, due to the influence of reflected waves from the input port to the load and from the output port to the source, it is sometimes very difficult to achieve some condition where the LNA has maximum transducer gain. Thus, it will significantly affect in determining the desired trade-off value between gain and VSWR.

In this paper, the design of LNA is proposed by implementing a technique of non simultaneous-conjugate-match (SCM) where the amplifier will be designed at mismatch condition. The LNA which is intended to be applied for S-band application is powered by 2-stage cascaded RF transistors of BFP420 type to achieve the high gain. Prior to deployment on an Arlon DiClad527, the designed LNA is numerically characterized through the ADS software to determine the desired trade-off value. To compensate impedance mismatch, a method of network compensation is implemented using microstrip lines at the input, interstage and output ports. The dimension of microstrip lines are optimized to achieve the impedance matching condition and optimum performance of LNA with some design parameters such as gain and VSWR are used as performance indicators.

2. OVERVIEW OF NON SCM TECHNIQUE AND CIRCUIT DESIGN

In this work, the employed topology for designing 2-stage LNA powered by RF transistor of BFP420 type is common emitter topology in which the RF input signal is applied to the base of transistor and the RF output is taken from the collector. The topology is chosen in order to obtain good sensitivity and high gain. To achieve a maximum gain in the SCM technique, the reflection coefficients of amplifier at the 1st stage should satisfy the following conditions; $\Gamma_{\text{S-1}} = \Gamma^*_{\text{in-1}}$ and $\Gamma_{\text{L-1}} = \Gamma^*_{\text{out-1}}$, whilst on the 2nd stage; $\Gamma_{\text{S-2}} = \Gamma^*_{\text{in-2}}$ and $\Gamma_{\text{L-2}} = \Gamma^*_{\text{out-2}}$. Those conditions are very difficult to be obtained since according to (1) and (2), $\Gamma_{\text{in-1}}$ is influenced by $\Gamma_{\text{L-1}}$, whereas $\Gamma_{\text{out-1}}$ is influenced by $\Gamma_{\text{S-1}}$. This situation also applies for the 2nd stage of amplifier.

$$\Gamma_{\text{in}} = S_{11} + \frac{S_{12}S_{21}\Gamma_{\text{L}}}{1 - S_{22}\Gamma_{\text{L}}} \tag{1}$$

$$\Gamma_{\text{out}} = S_{22} + \frac{S_{12}S_{21}\Gamma_{\text{S}}}{1 - S_{11}\Gamma_{\text{S}}} \tag{2}$$

Whilst in the non-SCM technique, it is unnecessary to calculate Γ_{in} and Γ_{out} for designing matching impedance network. Therefore, it can simplify the mathematical calculations for gain circles on Smith chart for given value of Z_{L} and Z_{S}. Since the LNA is designed at a condition of mismatch, therefore the impedance mismatch factor (M) expressed in (3) will be used for each stage, i.e., M_1 and M_2 for the 1st and 2nd stage of amplifier respectively, to determine the VSWR of each stage. If the impedance mismatch factor equals 1, as expressed in (4) it means that the VSWR equals 1, too. Or in other words, the RF power signal from the source is fully transferred by the amplifier. In other hand, if the LNA is at a condition of mismatch or mathematically expressed by VSWR > 1 or $M < 1$, it indicates that some of RF power signal is reflected to the source which is important in designing impedance matching network. To obtain the maximum power transfer (G_{T}) so that the LNA has a high gain, it can be calculated by making a relationship between the operating power gain (G_{P}) and the impedance mismatch factor (M), as expressed in (3).

$$G_{\text{T}} = \underbrace{\frac{(1 - |\Gamma_{\text{L}}|^2)|S_{21}|^2}{|1 - S_{22}\Gamma_{\text{L}}|^2(1 - |\Gamma_{\text{in}}|^2)}}_{G_{\text{P}}} \cdot \underbrace{\frac{(1 - |\Gamma_{\text{S}}|^2)(1 - |\Gamma_{\text{in}}|^2)}{|1 - \Gamma_{\text{in}}\Gamma_{\text{S}}|^2)}}_{M} \tag{3}$$

$$\text{VSWR} = \frac{1 + \sqrt{1 - M}}{1 + \sqrt{1 + M}} \tag{4}$$

Based on the common emitter topology, the circuit design of 2-stage LNA equipped with dc bias and dc current block at the input and output ports is shown in Figure 1. The quiescent point (Q) for transistor in both stages is designed at $I_{\text{c}} = 10\,\text{mA}$, $\beta = 100$, $V_{\text{be}} = 0.7\,\text{Volt}$, $V_{\text{ce}} = 2\,\text{Volt}$ and $V_{\text{cc}} = 5\,\text{Volt}$. By using the ADS software, the amplifier confirms to have a good stability

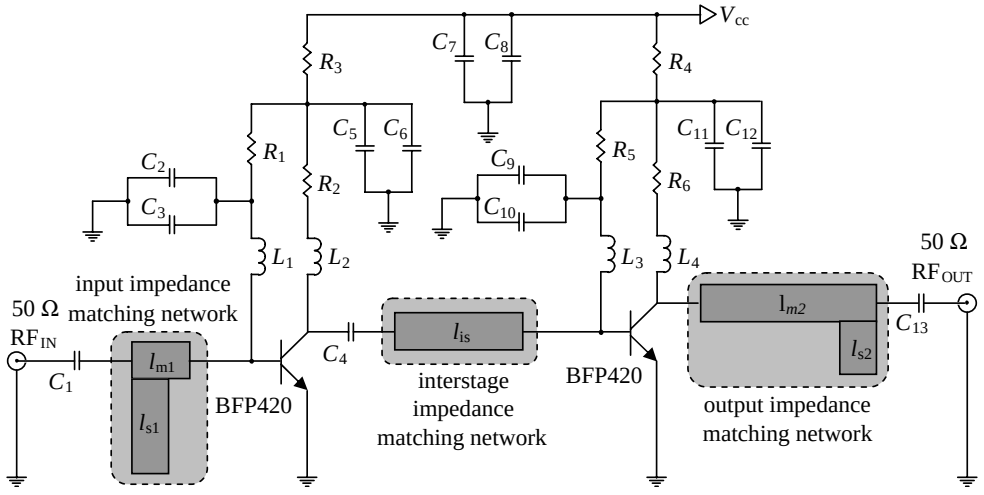

Figure 1: Circuit design of 2-stage low noise amplifier.

with the S-parameter values at frequency of 3 GHz as follows; $S_{11} = 0.540\angle 162.904°$ dB, $S_{12} = 0.075\angle 48.295°$ dB, $S_{21} = 4.240\angle 63.908°$ dB and $S_{22} = 0.151\angle -137.164°$ dB. Furthermore, the values of Z_L and Z_S can also be determined and are $23.95\text{-}j6.65\,\Omega$ and $36.55\text{-}j10.7\,\Omega$, respectively.

Since the input and output ports are set to be 50 Ω, therefore impedance matching networks are required to compensate the impedance mismatch. To minimize parasitic effects which may cause oscillation of amplifier, microstrip lines are applied as the impedance matching network for the input, interstage and output ports of LNA. After conducting some parametrical studies to obtain the optimum dimension of microstrip lines, the length of microstrip line (l_{m1}) and stub (l_{s1}) for the input port is 4.65 mm and 7.56 mm, respectively, and the length of microstrip line for the interstage (l_{is}) is 10.2 mm. Whereas for the output port, the length of microstrip line (l_{m2}) and stub (l_{s2}) is 14.02 mm and 4.2 mm, respectively.

3. REALIZATION AND CHARACTERIZATION

Figure 2 shows the picture of realized 2-stage LNA prototype which is deployed on an Arlon DiClad527 dielectric substrate with SMD (surface-mount device) components for resistors, inductors and capacitors. Two SMA connector types are soldered at the input/output ports of LNA for experimental characterization. The results of experimental characterization for gain, $VSWR_{IN}$ and $VSWR_{OUT}$ are depicted in Figures 3, 4 and 5, respectively. It is noticeable that the measurement of noise figure could not be performed in this work due to the unavailability of noise source instrument. In addition, simulated results of gain, $VSWR_{IN}$ and $VSWR_{OUT}$ are also plotted together in each respected figure as comparison.

From Figure 3, in despite of measured gain is lower than the simulated one, however it has similar tendency for all observed frequency ranges. It shows that the measured gain at frequency of 3 GHz is 24.32 dB, whilst the simulated one is 28.88 dB. The discrepancy is possibly affected by the different parameter of Arlon DiClad527 dielectric substrate, i.e., dielectric loss, used for realizing

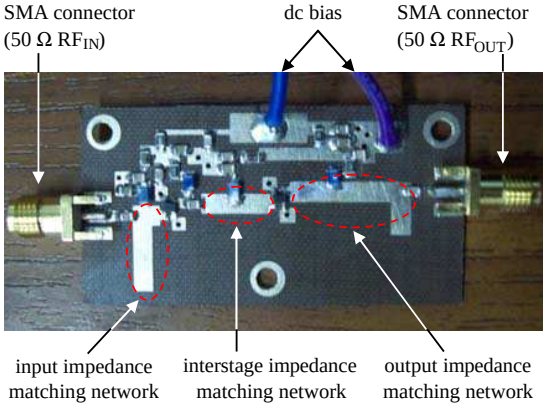

Figure 2: Picture of realized 2-stage low noise amplifier prototype.

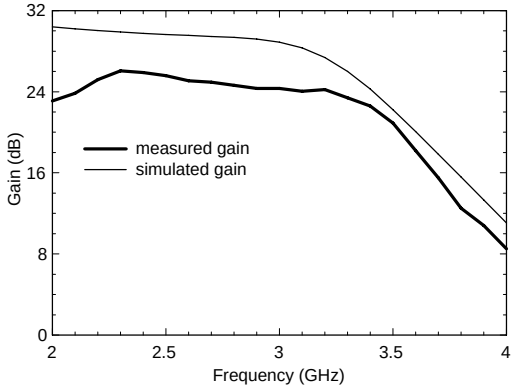

Figure 3: Measured gain of 2-stage LNA prototype with simulated result as comparison.

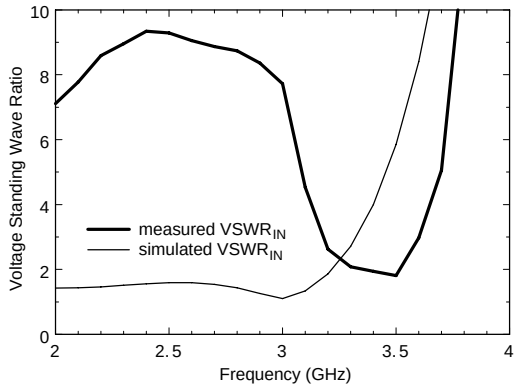

Figure 4: Measured $VSWR_{IN}$ of 2-stage LNA prototype with simulated result as comparison.

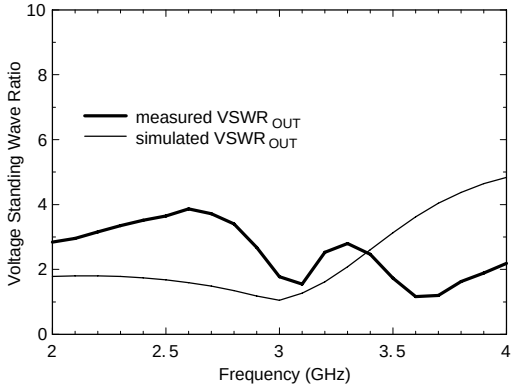

Figure 5: Measured $VSWR_{OUT}$ of 2-stage LNA prototype with simulated result as comparison.

the prototype which has value higher than in the simulation. When the value of dielectric loss is higher, some amount of energy from the input port that should be actually transmitted to the output port is absorbed by the dielectric substrate causing the decrease of measured gain.

The different results of experimental characterization are also found for the value of VSWR at the input and output ports as plotted in Figures 4 and 5, respectively. In general, both VSWR values are shifted to higher frequency range affecting the VSWR values at frequency of 3 GHz. The measured $\mathrm{VSWR_{IN}}$ and $\mathrm{VSWR_{OUT}}$ at frequency of 3 GHz are 7.72 and 1.78, respectively, whilst the simulation is 1.1 and 1.05, respectively. The difference in measured results of VSWR is probably evoked by the different value of relative permittivity of dielectric substrate used in the realization. For the results indicted in Figures 4 and 5, the actual value of relative permittivity seems to be lower than in the simulation. If the actual relative permittivity is lower, thus the impedance of impedance matching networks, i.e., microstrip lines, reacts to move to be bigger resulting the increase of VSWR.

4. CONCLUSION

The design of 2-stage LNA for S-band frequency application has been demonstrated by use of non-SCM technique and realized on an Arlon DiClad527 dielectric substrate for experimental characterization. It has been shown that utilization of non-SCM technique in the design of 2-stage LNA could reduce the flow of design process due to unnecessary to calculate Γ_{in} and Γ_{out} for designing matching impedance network. From characterization results, it has been demonstrated that the realized 2-stage LNA prototype has produced gain of 24.32 dB at frequency of 3 GHz with the values of $\mathrm{VSWR_{IN}}$ and $\mathrm{VSWR_{OUT}}$ of 7.72 and 1.78, respectively. Although the experimental characterization result in some frequencies was worse than the design and has needed to be improved, in general the prototype of 2-stage LNA has shown acceptable performance and similar tendency with the simulated one. It should be noted that parameters of involved materials in the design process should be taken into account to avoid the discrepancies which may occur in the realization. In addition, a further investigation on the performance improvement of 2-stage LNA designed based on non-SCM technique is still underway where the result will be reported later.

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