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Designing the low noise 2 GHz amplifier for the RF receivers

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Abstract: *This article studies the design of a low noise amplifier in the frequency of 2GHz. The circuit designed has the maximum gain suitable for the lowest noise value. The source and load matching circuit of this low noise amplifier is designed using microstrip lines. Considering the importance of stability in amplifiers design, firstly, the transistor stability factors are surveyed in this article. After that, the design of the source and load matching circuits will be studied. At the end, the method used for biasing the surveying piece would be analyzed.*

Keywords: *S parameter, stability, low noise amplifier, microstrip lines, noise figure*

I. Introduction

One of the most important and complicated parts in the theory of analog circuits is amplifying the input signal by one or multistage transistor circuits [1]. Low noise amplifiers are normally used for sufficiently amplifying the receiving signals in order to overcome the noises in the next phases [2]. There are three reasons for utilizing low noise amplifiers. The first one is to provide appropriate isolation between the local oscillator or mixer and the antenna. The second reason is to improve the deletion of image frequency and the last reason is to provide a suitable base for selecting the desired signals [3]. NE68019 transistor is used in this design which its manufacturer is NEC Electronics company. This NPN silicon transistor has a low noise, high gain, and low price which is highly appropriate to be used in this design. The use of S parameters of the mentioned transistor with collector-emitter voltage of V_{CE} = 6V and collector current of I_C = 5mA have been set to be the basis of this design. Resonant frequency of this transistor is 10 GHz. ADS software is used for necessary simulations in this design and MATLAB software is used for furnishing mathematical computations and diagrams.

II. Research method

2.1. Stability analysis

The first step to design an amplifier is surveying its stability factor. Regarding the dependency of Γ_{in} and Γ_{out} to the source and load matching circuits, the stability of the amplifiers depends on Γ_S and Γ_L introduced by matching circuits. Generally, two types of stability are existed which the first one is conditional stability and the other one is unconditional stability. *K-Δ* test, equations 1 and 2, is used for surveying the stability conditions and the $\boldsymbol{\mu}$ test, equation 3, is utilized to analyze the amount of stability. WhenK > 1 and <1|Δ|, the piece is stable without any conditions [1][4].

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

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

$$(3)\ \mu=\frac{1-|S_{11}|^2}{\left|S_{22}-\Delta\ S_{11}^*\right|+|S_{12}\ S_{21}|}$$

Figure 1 demonstrates the stability diagram in terms of the frequency for the transistor. In the frequency of 2 GHz, **0|Δ|/33=, K = 1/09, and μ = 1/05** which shows the transistor unconditional stability.

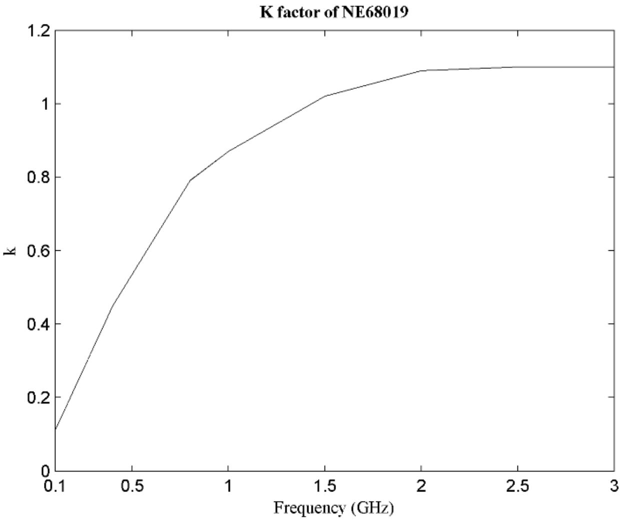

Figure 1: Stability factor diagram based on the frequency for NE68019 transistor.

2.2. Matching circuits design

Generally, concerning the frequency increase and wavelength decrease, adverse and parasitic effects of the circuit separate elements are further taken into account in comparison to the past. Regarding this issue, distributed components are used instead of the compressed ones [1]. In this amplifier, microstrip lines are used to design the source and load matching circuits. These lines are designed so as to have the impedance characteristic of Z_0= 50Ω in addition to playing the role of an inductor or a capacitor [5]. The use of a transfer line with specific length in the form an open circuit (a stub) paralleled with another transition line with specific distance from the source and load is the matching approach used in this article [4]. In order to design this low noise amplifier, the lowest noise in the source and the highest proportional power gain in the load are expected which these considerations will be included in the design. The noise figure of a double valve amplifier is furnished through the equation 4 which depends on Fmin ،R_n, and Γ_{opt}. These values named noise parameters are provided by the piece manufacturer.

$$F = F_{min} + \frac{R_N}{Z_0} \frac{\left|G_S - G_{opt}\right|^2}{\left(1-\left|G_S\right|^2\right)\left|1+G_{opt}\right|^2} \quad (4)$$

Figure 2 presents the minimum noise figure diagram in terms of the frequency.

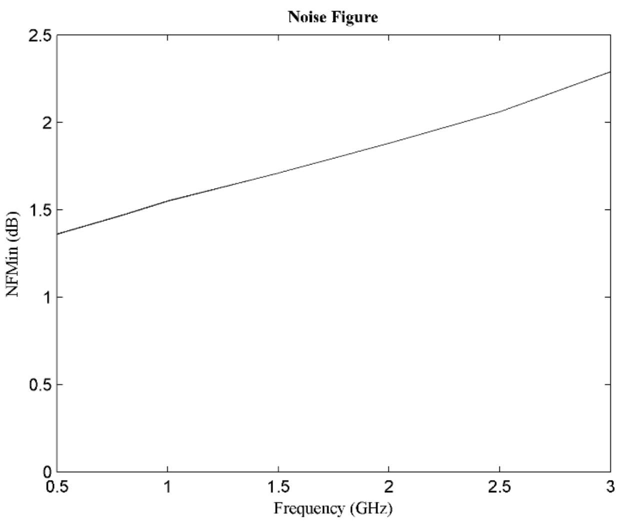

Figure 2: The lowest noise figure diagram in terms of the frequency for NE68019 transistor.

Concerning equation 4, in the frequency of 2 GHz, noise figure has its minimum value when:

$$(5) \quad \Gamma_S = \Gamma_{opt} = 0/36\angle 77$$

And we have

$$(6)\ F = F_{min} = 1/88\,\text{dB}$$

Therefore, the power gain of this amplifier's source matching circuit, $G_{S_{NF_{min}}}$ is furnished through equation 7 when the lowest noise is existed in the frequency.

$$(7)\ G_{S_{NF_{min}}} = \frac{1}{1-|\Gamma_S|^2} = 0/60\,\text{dB}$$

Considering equation 5, the minimum gain of the load matching circuit, $G_{L_{max}}$ is obtained by equations 8 and 9.

$$(8)\ \Gamma_L = \Gamma_{out}^* = \left(S_{22} + \frac{S_{12}\,S_{21}\,\Gamma_S}{1-S_{11}\,\Gamma_S}\right)^* = 0/47\angle 65/40$$

$$(9)\ G_{L_{max}} = \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} = 1/52\,\text{dB}$$

The transistor power gain in the frequency of 2 GHz, G_0 is obtained by equation 10.

$$(10)\ G_0 = |S_{21}|^2 = 8/90\,\text{dB}$$

The amplifier total gain in the frequency of 2 GHz, G_T is presented by equation 11.

$$(11)\ G_T = G_{S_{NF_{min}}}\ G_0\ G_{L_{max}} = 11/02\,\text{dB}$$

According to the values obtained for Γ_S and Γ_L in addition to the simulations done by ADS software, the low noise amplifier AC circuit is like figure 3 which contains the size of microstrip lines as well. Rogers company RO4003 fiber has been used to design the circuit. Regarding the data sheet provided by the manufacturer, it is better to consider the dielectric coefficient to be ε_r= 3/55 in the designs. Furthermore, the fiber has dielectric thickness of H = 20mil, conductor thickness of T= 2mil, and loss tangent of TanD = 0/0027.

2.3. Bias circuit

Generally, there are two methods to bias the circuit which are active biasing and passive biasing. Passive biasing may result in some disadvantages including the transistor's sensitivity, parameters change, and low thermal stability [1]. Active bias circuit is used in this design in which Q_1 low frequency transistor provides the bias current of Q_2 high frequency transistor. R_3 transistor connected to the emitter of Q_1 transistor leads to stability increase. In the case Q_1 and Q_2 transistors have thermal characteristics close to each other, the biased circuit would have favorable thermal stability. It has been tried to take these considerations into account. Thus, Farchild semiconductor company MMBT3904 transistor is used to increase the stability in this circuit. Figure 4 shows the biased circuit utilized in this design and the values specified on that are the results of ADS simulation. For theoretical calculations, a voltage is assigned to Q_1 transistor collector which leads to freedom in the current selection. If Q_1 transistor collector voltage, V_{c1} is considered 3V and its emitter voltage, V_{E1} is considered 1V, the followings would be furnished for the designed bias circuit.

$$(12)\ I_1 = I_{C1} + I_{B1} + I_{B2} = 1/06\,\text{mA}$$

$$(13)\ R_4 = \frac{V_{C1} - V_{BE2}}{I_{B2}} = 44\,\text{K}\Omega$$

$$(14)\ R_1 = \frac{V_{CC} - V_{C1}}{I_1} = 5/7\,\text{K}\Omega$$

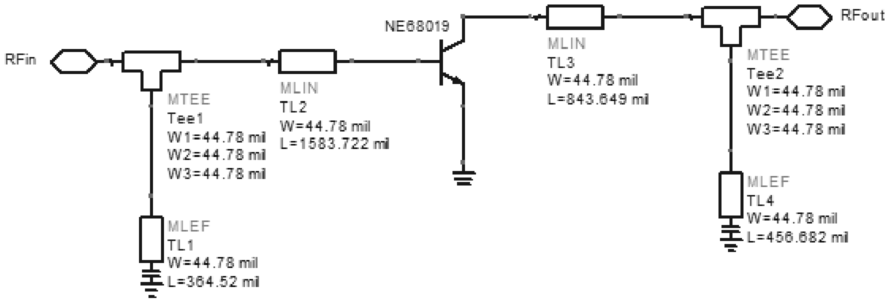

Figure 3: The AC circuit of the low noise amplifier designed in 2GHz frequency

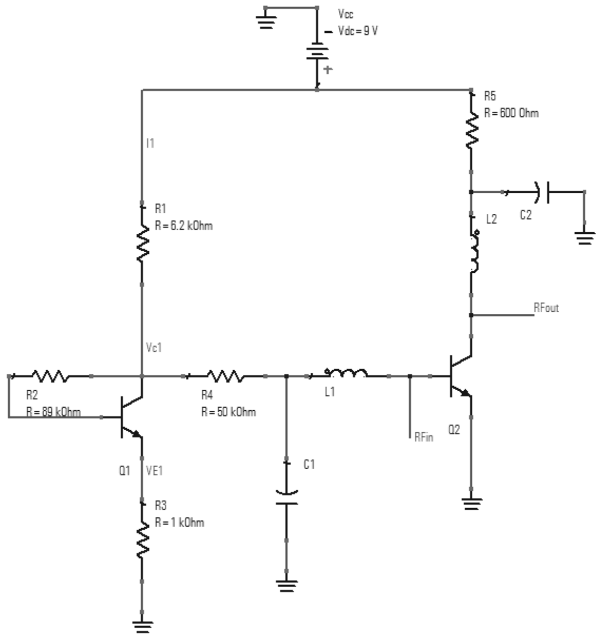

Figure 4: The schematic of NE68019 transistor active bias circuit using MMBT3904 transistor

$$R_2 = \frac{V_{C1} - V_{BE1} - V_{E1}}{I_{B1}} = 85/7\,\mathrm{K}\Omega \qquad (15)$$

$$R_3 = \frac{V_{E1}}{I_{C1} - I_{B1}} = 1\mathrm{k}\Omega \qquad (16)$$

If Vcc voltage is 9:

$$R_5 = \frac{V_{CC} - V_{CE2}}{I_{C2}} = 600\ \Omega \qquad (17)$$

With a suitable approximation, it can be seen that the values furnished theoretically are close to the results obtained by the simulations.

III. Conclusion

This article presented a method for designing a low noise amplifier in 2GHz frequency using the transistor S parameters. Regarding the unconditional stability of the high frequency transistor used, its source and load matching circuits have been designed by microstrip lines so as the amplifier has the lowest noise of 1.88 dB and highest power gain of 11/02 dB. The active bias circuit presented in this paper leads to the amplifier stability increase. The circuit designed in this survey is in the building stage and due to the accurate computations and simulations done, it is expected to have favorable results after it is built and experimented.

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