ANALYSIS OF METHOD FOR IMPROVING INPUT MATCHING OF SINGLE STAGE LOW NOISE AMPLIFIER BY USING NON-UNILATERAL CHARACTERISTICS OF TRANSISTORS A DESED ENHANCED

Mihail Plamenov Tonev

Technical University of Sofia, Bulgaria
Faculty of Telecommunication, TU-Sofia, "Kl. Ohridsky" str. 8, 1000 Sofia, Bulgaria
E-mail: mihail_tonev@abv.bg

Abstract

For low noise amplifiers the most common design is input matching network to reflect in optimum reflection coefficient of transistor for obtaining the lowest possible noise figure. The optimum reflection coefficient is different from conjugate matching and this makes low noise amplifiers to have poor input matching. This problem is challenge for microware engineers and most popular decisions are discussed in [1]. In this paper was presented also one novel method for solving this problem by using non-unilateral characteristics of transistors. It is shown practically that can be achieved simultaneously good input matching and low noise figure. For evaluating influence of such matching to all parameters of amplifier is necessary to have proper mathematical model. In following paper is presented detailed analysis of low noise amplifier with improved input matching by using non-unilateral nature of transistors.

1. INTRODUCTION

In general every microwave single stage amplifier can be presented as cascade connection of input matching network, active component and output matching network. For theoretical analysis influence of DC feeding network is neglected. Generalized block diagram of single stage amplifier with all reflection coefficients is shown in fig1. Impedances Z_1 and Z_2 present source and load impedance. In general they are equal to characteristic impedance Z_0=50Ω. Parameters of designed amplifier depend on choosing reflection coefficients of input and output matching network (Γ_S and Γ_L). For low noise amplifier required reflections are:

(1) $$\Gamma_S = \Gamma_{opt}$$

(2) $$\Gamma_L = \overline{\Gamma_{out}}$$

Where Γ_{opt} is optimal reflection coefficient of transistor and Γ_{out} is output reflection coefficient of transistor with matched input. Transistor is presented as two port network which have specific input and output reflection coefficients. In fig.1 they are shown as Γ_{IN} and Γ_{OUT}.

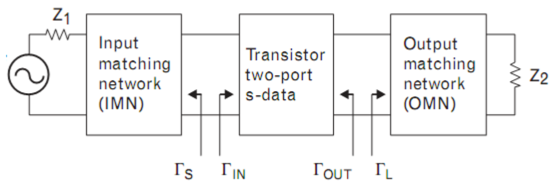

Fig. 1. Block diagram of single stage low-noise amplifier

They depend on each other but optimal reflection coefficient doesn't depend on them. This dependence is due to non-unilateral characteristics of transistors. If transistor is presented with its S-parameters, the relationship between Γ_{IN} and Γ_{OUT} is:

(3) $$\Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L}$$

Theoretically for obtaining simultaneous conjugate matching and noise figure matching is necessary to be satisfied equation (1) and:

(4) $$\Gamma_{in} = \overline{\Gamma_{opt}}$$

The input matching network is designed in order to satisfy equation (1). The output matching network will be used for satisfaction of equation (4). This means that we neglect equation (2) and output will not be conjugate matched. In general this output mismatch will lead to loss in amplifier's insertion gain but input will be conjugate matched which makes amplifier usable in applications where this is required. In this case is necessary to make tradeoff between input and output matching while noise figure remain constant.

2. SINGLE STAGE AMPLIFIER WITH IMPROVED INPUT MATCHING

In following chapter will be analysed single stage low noise amplifier with improved input matching. The NE3210 transistor manufactured by NEC Corporation will be used. The input and output matching networks will be designed using ideal components in order to obtain lowest possible noise figure and perfect input matching of amplifier at 12GHz. Theoretically designed amplifier will be simulated and optimized with "Ansoft Serenade" circuit simulator. The S matrix and noise parameters of transistor are given bellow.

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \begin{bmatrix} 0.44\angle -166.2^\circ & 0.10\angle 2.1^\circ \\ 3.91\angle 23.5^\circ & 0.21\angle -123.1^\circ \end{bmatrix}$$

$$\Gamma_{opt} = 0.29\angle 133^\circ$$

$$R_n = 4.5$$

$$F_{\min} = 1.08$$

The R_n and F_{min} are nose resistance and minimum noise figure. Values of these parameters are given from manufacturer.

The first step in low noise amplifier design is synthesizing input matching network. From equation (1) and transistor parameters we find required reflection coefficient. The input characteristic impedance is 50Ω. We use interactive smith chart to synthesize matching network as shown in fig. 2. This network contains two components – parallel capacitor and series inductance. Schematic diagram of transistor with synthesized noise matching network at 12GHz is shown in fig. 3. This is theoretical circuit and we use ideal components. So with this matching noise figure of transistor is equal to Fmin = 0.34 dB at 12 GHz.

After transistor input is noise matched, second step in amplifier design is to match the output. In general output matching network have to satisfy equation (2) in order to obtain conjugate matching at the output and maximize insertion gain. But if we neglect this parameters and our aim is good input matching we can use equation (3) to find output reflection coefficient which will satisfy (4). From (3) and (4) we find:

$$\Gamma_L = \frac{S_{11} - \overline{\Gamma_{opt}}}{S_{12}S_{21} - S_{11}S_{22} + S_{22}\overline{\Gamma_{opt}}} \quad (5)$$

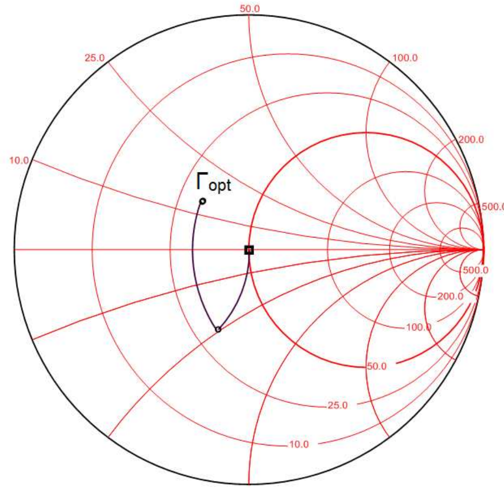

Fig. 2. Synthesizing input matching network using interactive smith chart

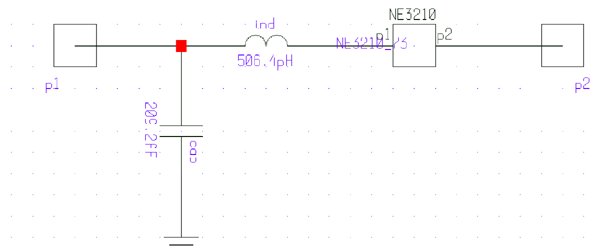

Fig. 3. Transistor connected to input noise matching network at 12GHz.

To obtain this reflection coefficient the output of transistor must be loaded with impedance:

$$Z_L = \frac{Z_0 - Z_0\Gamma_L}{\Gamma_L + 1} \quad (6)$$

From equations (5), (6) and transistor parameters given above we find required output reflection coefficient and load impedance for obtaining conjugate matched input.

$$\Gamma_L = 0.789\angle -48.89$$

$$Z_L = 104.6\angle -67.46$$

To synthesize output matching circuit is used interactive smith chart as shown in fig. 4.

Synthesized network contains two components – series inductance and parallel capacitance. Theoretically designed amplifier using ideal components is shown schematically in fig. 5.

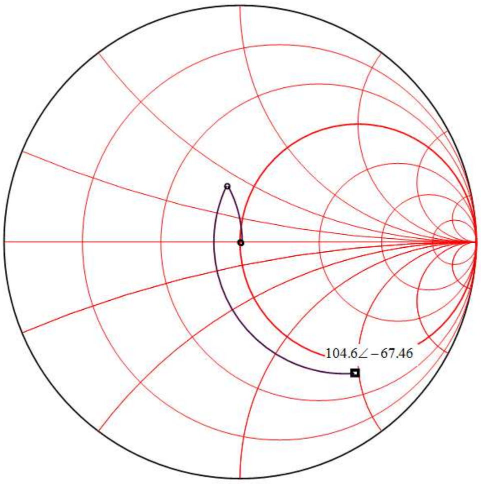

Fig. 4. Synthesizing output matching network using interactive smith chart

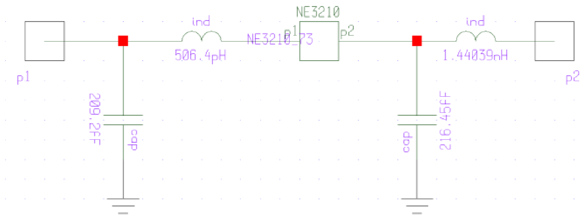

Fig. 5. Schematic diagram of single stage low noise amplifier with improved input matching

Conjugate input matching and minimum noise figure at the same time were reached but is necessary to be analysed how this type of matching is influencing to amplifier gain. The total transducer gain of amplifier can be written as:

$$G_T = G_S G_0 G_L \tag{7}$$

Where G_S is gain from source matching network, G_0 is transistor gain and G_L is gain from output network. The effective gains G_S and G_L of matching networks might be grater then unity. This is because unmatched transistor would incur power loss due to reflections at the input and output of transistor, and the matching sections can reduce this loss.

$$G_S = \frac{1-|\Gamma_{opt}|^2}{|1-\Gamma_{in}\Gamma_{opt}|^2} = 0.38dB \tag{8}$$

$$G_0 = |S_{21}|^2 = 11.48dB \tag{9}$$

$$G_L = \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} = -4.62dB \tag{10}$$

Using equations (7), (8), (9) and (10) is calculated transducer gain of amplifier.

G_T=7.6dB. From equation (10) is seen that 4.62dB of amplifier's gain are lost by mismatching in output network. This is main problem in presented method for improving input matching of low noise amplifiers. Practically conjugate matched input will never be required. Parameter of amplifiers that is related to input matching is called input return loss of amplifier:

$$RL = 20\log\left|\frac{VSWR-1}{VSWR+1}\right|, dB \tag{11}$$

The VSWR is voltage standing wave ratio. For most applications -20dB return loss is sufficient. This means that input VSWR must be lower than 1.2. In fig.6 is shown graphically area of input reflections that satisfy this requirement.

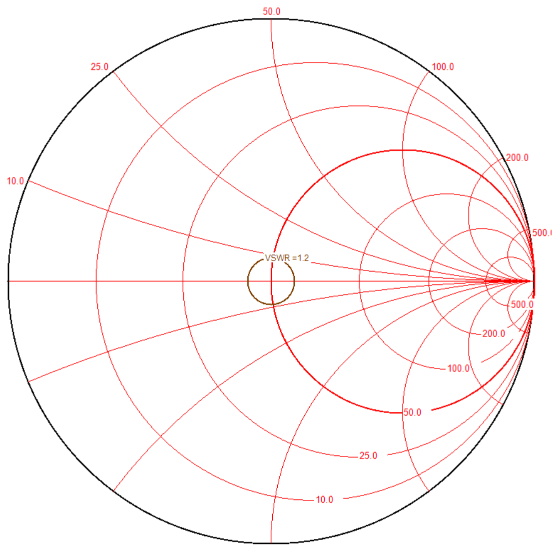

Fig. 6. Area of input reflections that satisfy practical requirements for input return loss

For amplifier's design might be chosen every input reflection coefficient inside the circle shown in fig. 6

$$\Gamma = \frac{Z_{opt} - \overline{Z_{in}}}{Z_{opt} + Z_{in}} \tag{12}$$

Z_{opt} is optimal impedance for low noise figure matching and Z_{in} is input impedance of transistor loaded with output matching network. From equation (12) we find Z_{in} and then:

$$\Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \tag{13}$$

When value for Γ_{in} is found we use (5) and (6) to find parameters of output network. With choosing proper value of Γ we can significantly reduce loss in gain due to output mismatch. Optimization procedure can be used to find the best values Z_{in}. With using linear optimization procedure in "Ansoft serenade" circuit simulator was found that if Z_{in}=27-j10.1 then loss in gain due to output mismatch will be reduced with about 3dB. Parameters of designed amplifier are: RL=-20dB, G_T=10.5dB, NF= F_{min} = 0.35dB.

Conclusion

A method for improving input return loss of microwave low-noise amplifiers was presented in this paper. For improving this parameter was used non-unilateral nature of transistors. A single stage low nose amplifier was analyzed and designed. The results shows that the input of amplifier can be simultaneously conjugate and noise matched but output matching will be poor and amplifier gain will be reduced. Some tradeoffs between input and output matching can be done and amplifier will meet most of the practical requirements. Further improvement of performance will be by adding second stage.

References

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