LOW NOISE MICROWAVE AMPLIFIERS WITH IMPROVED INPUT MATCHING APPLICABLE IN ACTIVE ARRAY ANTENNAS

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Abstract

The difference between the optimal input reflection coefficient for achieving minimal noise figure and those needed for perfect matching is usually a challenge for low noise amplifiers design. Normally amplifiers designed to achieve lowest possible noise figure have very poor input reflection coefficient. This may cause a lot of problems in case of their application as a component in modern active phased array antennas and can be a reason for significant performance degradation. One of the possible solutions is to use balanced amplifier configuration in order to improve input and output matching. The main disadvantages of this solution are degradation of the noise figure due to the losses in the input hybrid and a bigger occupied space.

Another approach for solving the problem is presented in this paper. The non – unilateral properties of the transistors are used in order to obtain minimum noise figure and at the same time conjugate matching. Practical circuits and achieved performance are discussed in details.

INTRODUCTION

As known in general for every radio-communications receiver first stage of input amplifier is matched to achieve minimal noise figure. This often leads to poor input return loss of the receiver and when it is directly connected to the receiving antenna may cause problems. Usually microwave antennas are designed to be matched at their output to 50 ohms. When they see different impedance, for example as those of poorly matched low-noise amplifier, their characteristics might be changed. This is true especially concerning phased antenna arrays. Good example for such mismatch sensitive system is active antenna arrays used in modern mobile satellite communications. Such type of antennas must provide dynamic polarization control while on move. In order to support such functionality antennas must comprise dual port antenna elements receiving signals with two orthogonal linear polarizations and two independent summation feed circuits. In order to achieve good isolation between these summation circuits and to avoid phase and amplitude errors in antenna aperture it is need to ensure good matching between all feed line components inside the antenna. So if low noise amplifiers at the antenna outputs are not well matched to their characteristic impedance it may cause significant degradation of the most important antenna parameters, such as gain and cross-polarization isolation.

Two possible solutions of the mentioned above problem are known in practice. The first possible solution is to connect isolator between antenna and the receiver. This completely solves the problem with poor input matching of the receiver but degrades its nose figure performance because of the insertion loss introduced by the isolator. From another side using isolator with low insertion loss will significantly increase price of the device, which is another factor that restrict using isolators. Another less expensive solution is to use balanced amplifiers. Balancing technique is well known method for improving return loss of low noise amplifiers, but it also degrades noise performance due to the input hybrid device loss. Other disadvantages of balanced amplifiers are twice bigger power consumption and twice bigger occupied space compared to single ended amplifier. These disadvantages sometimes can make them not applicable.

Another approach, using a novel matching technique allowing achieving simultaneously low noise figure and good matching for such type of amplifiers is described in the presented paper.

MICROWAVE TRANSISTOR AS TWO PORT NETWORK

At microwave frequencies transistors are usually presented as two port networks, which are characterized with S-parameters. Such two port network with defined load and source impedances is presented schematically on Fig.1.

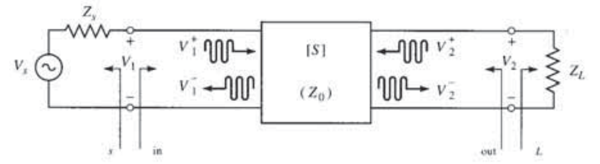

Fig. 1. Two-port network with specific source and load impedances

The three types of power gains for an arbitrary two-port network connected to source and load impedances, Z_S and Z_L may be defined as follows:

- Power Gain = G = P_L/P_{in} is the ratio of power dissipated in the load Z_L to the power delivered to the input of the two-port network. This gain is independent of Z_S.
- Available Gain = G_A = P_{avn}/P_{avs} is the ratio of the power available from the two-port network to the power available from the source. It depends on Z_S but not on Z_L.
- Transducer Power Gain=G_T=P_L/P_{avs} is the ratio of the power dissipated in the load to the power delivered to the input of two port network. This depends on both Z_S and Z_L.

These definitions differ primarily in the way the source and load are matched to the two-port device. If the input and output are both conjugate matched, then the gain is maximized and $G = G_A = G_T$. Equations for these gains and reflection coefficients in terms of the S parameters of the active device can be defined, referring to Fig.1, as follows:

$$(1) \qquad G = \frac{P_L}{P_{in}} = \frac{|S_{21}|^2\left(1-|\Gamma_L|^2\right)}{\left(1-|\Gamma_{in}|^2\right)|1-S_{22}\Gamma_L|^2}$$

$$(2) \qquad G_A = \frac{P_{avn}}{P_{avs}} = \frac{|S_{21}|^2\left(1-|\Gamma_S|^2\right)}{|1-S_{11}\Gamma_S|^2\left(1-|\Gamma_{out}|^2\right)}$$

$$(3) \qquad G_T = \frac{P_L}{P_{in}} = \frac{|S_{21}|^2\left(1-|\Gamma_S|^2\right)\left(1-|\Gamma_L|^2\right)}{|1-\Gamma_S\Gamma_{in}|^2|1-S_{22}\Gamma_L|^2}$$

Where

$$(4) \qquad \Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0},\ \Gamma_S = \frac{Z_S - Z_0}{Z_S + Z_0}$$

And

$$(5a) \qquad \Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L}$$

$$(5b) \qquad \Gamma_{out} = \frac{Z_{out} - Z_0}{Z_{out} + Z_0} = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1-S_{11}\Gamma_S}$$

In general to obtain good input matching it is necessary input reflection coefficient of two port network Γ_{in} to be close to zero. From equation 5a can be seen that Γ_{in} depends on active component parameters (S_{11}, S_{21}, S_{12}) and on load reflection coefficient Γ_L. This means that we can manipulate input reflection coefficient of two port network by changing load impedance.

DESIGN OF MICROWAVE LOW-NOSE AMPLIFIER (LNA) WITH IMPROVED INPUT MATCHING

The main goal in designing low nose amplifiers is obtaining proper reflection coefficient from input matching network. This coefficient must coincide with optimum reflection coefficient for obtaining minimum noise figure of active component. Usually this coefficient is different from conjugate machining and this is the reason Γ_{in} of LNA's not to be zero. It is possible to design proper input matching network and then to choose load impedance, which will minimize input reflection coefficient of the two port network. In this case amplifier will be simultaneously matched for obtaining minimum nose figure and conjugate matched with source. In general for single stage amplifier this will worse output matching. The problem can be solved by adding second stage in amplifier configuration. Then using inter-stage matching circuit we can chose proper reflection coefficient to make $\Gamma_{in} = 0$ and then output matching circuit can be designed to make $\Gamma_{out} = 0$.

The approach, presented above was proven by designing microwave LNA, suitable for using in Ku band satellite communications working in frequency band from 10.7GHz to 12.8GHz. It was designed on Arlon 25N substrate with 0.51mm thickness, dielectric constant 3.38 and loss tangent 0.0025. Used transistors are NE3210 low noise hetero-junction FET, manufactured by NEC. The S-parameters of transistors and capacitors, provided by manufacturers were putted in simulator and circuit simulation was performed.

The first step in design is to define input matching circuit. In Fig. 2 reflection coefficients of input matching circuit and optimum reflection coefficient of transistor are shown. As can be seen, there is coincidence between them which means that transistor is matched for obtaining minimum noise figure.

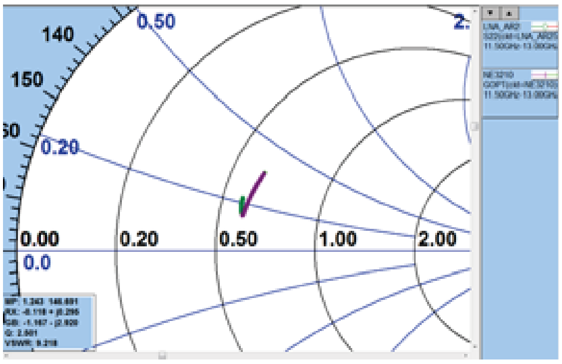

Fig. 2. Reflection from input matching circuit and transistor Γ_{opt}

Once input of the amplifier is matched, the inter-stage and output matching circuit can be designed, using optimization procedure in order to achieve good input and output matching. Simulated S-parameters and noise figure of LNA model are shown in fig. 3 and fig. 4.

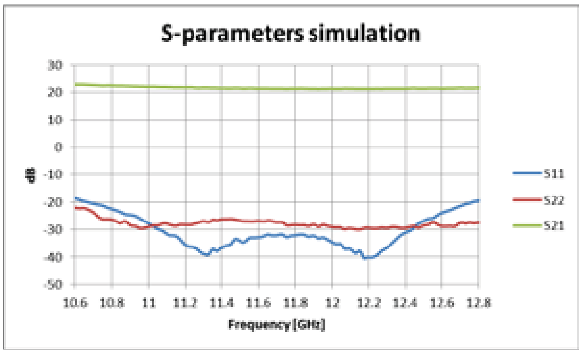

Fig. 3. Simulated S-parameters of LNA

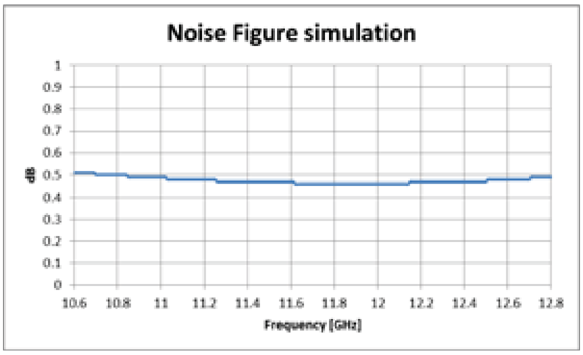

Fig. 4. Simulated noise Figure of LNA

The input and output reflection coefficients are lower than 0.1 and noise figure is lower than 0.5 dB. Simulated amplifier has low noise figure and good matching with source and load. To gain real inside how circuit works the simulated layout of amplifier was manufactured and measured. Measurement results are presented graphically in Fig. 5 and Fig. 6. Some difference between measured and simulated results may be caused by the tolerances in component parameters and by reflections from input and output connectors used for measurements. Measured input reflection coefficient is lower than 0.13 and measured noise figure is about 0.65 dB.

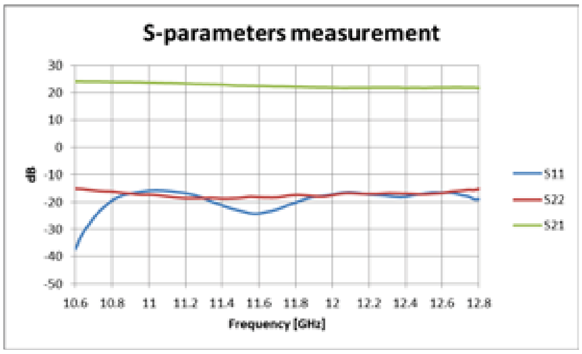

Fig. 5. Measured S-parameters of LNA

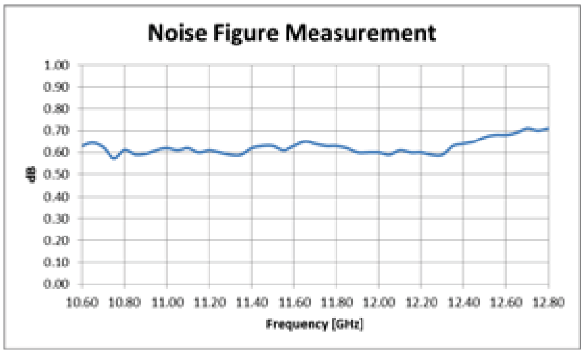

Fig. 6. Measured noise Figure of LNA

CONCLUSION

A design of microwave low-noise amplifier with improved input matching was presented in this paper. As was explained this is critical parameter for some communication systems. Practically the proposed method for enhancing this parameter, by using non-unilateral characteristic of microwave transistors was proved by model measurements.

References

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