The research of the temperature difference effect on the sensitivity of the LNA parameters

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Abstract. There is an investigation of the functional characteristics changes of a low noise amplifier under the influence of temperature changes with helping of a mathematical modelling in particular CAD AWRDE Microwave Office. The relative changes of the functional characteristics of electrical parameters of a low noise amplifier at the fixed frequency as a result of influence of the environment temperature are researching. As a result, temperature changes have a greater impact on the reflection coefficient than on the noise figure and gain.

Microwave solid-state amplifiers are the most important semiconductor devices, determining the main characteristics of the modern radar systems. The sensitivity of the microwave receivers in the modern communication systems is determined by the LNA. The ambient noise level and natural interference in the microwave range is significantly lower than in the HF and VHF ranges. In this case, the noise parameters of receivers determine the quality of reflection low power signals.

For the successful RF module design and operating in the conditions of the external factors effect it is necessary to determine kinetics of the low-noise amplifiers functional characteristics.

The research of the low-noise amplifier functional characteristics under the temperature difference effect carried out by the mathematical modeling.

To research the low-noise amplifier characteristics sensitivity the model of the Ka-Band MMIC LNA was designed in Microwave Office. To research the kinetics of the functional characteristics under the influence of temperature changes the standard model of the non-linear element pHEMT was used.

The developed LNA model has the following parameters: operating frequency:
- \( f_0 = 30 \) GHz;
- gain: \( G \geq 20 \) dB;
- noise figure : \( \text{NF} \leq 5 \) dB;
- the input reflection coefficient: \( S_{11} \leq -10 \) dB;
- the output reflection coefficient: \( S_{22} \leq -5 \) dB;
- substrate material: GaAs; nominal relative dielectric constant: \( \varepsilon = 12,9 \);
- dielectric loss tangent: \( \tan \delta = 1 \cdot 10^{-5} \);
- substrate thickness : \( H = 100 \) mm;
- plating thickness: \( T = 3 \) microns.

Researching the sensitivity of the functionally complete devices electrical parameters to external effects (e.g. ambient temperature) analysis should begun from the research of the sensitivity of its elements (mainly active). We investigate the effect of ambient temperature on the transistor electrical parameters.
There are dependences of the saturation current (IDSS – triangular markers) and maximum drain current (Idmax – square markers) of 100 microns gate width pHEMT from ambient temperature in Figure 1. The graphs show that the maximum current with temperature rising from -80 °C to +115 °C decreases by 10 % and the saturation current – 3 %. Herewith the essential changes in the cutoff voltage are not detected. The change in I-V characteristics leads to a change in the bias condition of the transistor, consequently, the changing of the functional parameters such as gain and noise figure.

It should be noted that aside from choosing of the transistor bias condition the designer use transistor parameters such as $F_{\text{min}}$, $R_n$, $G_{\text{opt}}$, $G_a$, where $F_{\text{min}}$ – minimum noise factor at the optimum input reflection coefficient; $R_n$ – noise temperature; $G_{\text{opt}}$ – optimum reflection coefficient of the input corresponding to the minimum of the noise factor; $G_a$ – maximum available gain of the transistor. The first three parameters are included in the noise matrix of the transistor. Following the definitions, it can be stated that any changings of the transistor parameters will also change the noise parameters of the LNA.

The ambient temperature dependences of $F_{\text{min}}$, $R_n$, $G_a$, as a result of mathematical modeling are presented in Figure 1, "b". With the increasing of the temperature from -80 °C to +115 °C $F_{\text{min}}$ and $R_n$ monotonically increased by 34 % and $G_a$ decreased by 14 %.

**Figure 1** The dependence of the maximum current and pHEMT transistor saturation current on the temperature

**Figure 2.** Dependence of the noise parameters of the transistor array on the ambient temperature at a fixed frequency of 30 GHz
Further it was designed monolithic integrated circuit of the LNA, which layout is presented on the Figure 3. The results of the electromagnetic simulations in the temperature range from -80 °C to +115 °C across the all frequency range and on the fixed frequency are shown in Figures 4, 5.

Figure 3. The layout of monolithic integrated circuit of the three-stage LNA

Figure 4. Dependencies of the gain, noise and reflection of the monolithic integrated circuit at ambient temperatures ranging from -80 °C to 115 °C

Further it was designed monolithic integrated circuit of the LNA, which layout is presented on the Figure 3. The results of the electromagnetic integrated circuit in the temperature range from -80 °C to +115 °C across the all frequency range and on the fixed frequency are shown in Figures 4, 5.
Figure 5. Dependence of the gain, noise and reflection of the monolithic integrated circuit of LNA on the ambient temperatures on the fixed frequency of 30GHz.

Analyzing the obtained results on the fixed frequency, we can conclude about the meaning of the scattering of the main electrical parameters of LNA as a result of entertainment temperature influence. There are data about relative errors of the electrical parameters LNA changes.

| Name of parameter | Symbol | min   | nom  | max   | R   | δR   |
|-------------------|--------|-------|------|-------|-----|------|
| Environment temperature, °C | $T_A$ | -80   | 25   | 115   |     |      |
| The reflection coefficient on the input, dB | $S_{11}$ | -15,83 | -18,9 | -22,91 | 7,08 | 0,37 |
| The reflection coefficient at the output, dB | $S_{22}$ | -8,896 | -10,09 | -11,42 | 2,524 | 0,25 |
| Gain, dB | $G$ | 2,899 | 3,136 | 3,467 | 0,568 | 0,18 |
| Noise figure, dB | NF | 23,43 | 21,6 | 19,66 | 3,77 | 0,17 |

Finally it is shown a bar chart (Figure 6) of relative errors of the electrical parameters LNA changes under the expose of temperature changes. Based on this graph we can conclude that temperature changes have stronger influence on the LNA adjustment than on the gain and noise figure. Analogically it can be shown the influence of the other factors on the amplifier characteristics.

Figure 6. The bar chart of the relative error of the main electrical parameters of the monolithic integrated circuits of LNA under the environment temperature changes.
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