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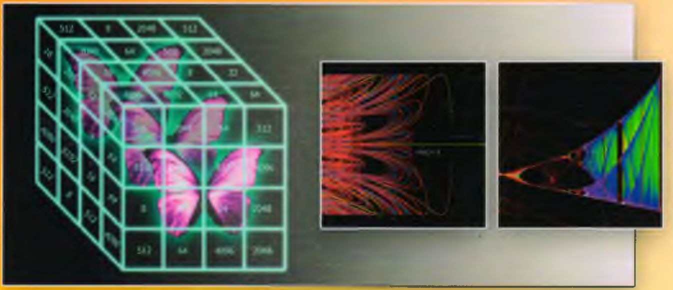

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MATHEMATICAL MODELING OF GENERATOR PARAMETERS BASED ON TRANSISTOR STRUCTURE WITH NEGATIVE RESISTANCE

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Abstract - This article is devoted to the analysis of the generator based on a transistor structure with a negative resistance in the nonlinear mode. Analytical dependencies for calculating the amplitude of oscillations, amplitude and frequency sensitivity to changes in external circuit elements, power regimes that determine the main parameters of frequency transducers of physical quantities and the stability of their operation are obtained.

Keywords - generator, negative resistance, frequency transducer of physical quantities

I. Introduction

The generator of electric oscillations is the main element of frequency transducers, therefore the consideration of its operation in a broad sense makes it possible to evaluate the dependence of the parameters of the transducers on the action of both external and internal factors. The appearance of a significant number of semiconductor devices with falling sections of volt-ampere characteristics (tunnel diodes, tunnel resonance structures, Ghana diodes, avalanche-purging diodes, lambda diodes and a number of other devices) made it possible to use them not only as switches, thresholds, amplifiers, devices, but also as a variety of sensory devices [1-3].

II. Theoretical and experimental research

The physical processes that occur in the transistor structure (Fig. 1) are rather complex, which makes it impossible to describe them by simple correct quantitative dependences [4, 5]. Therefore, the analytical description of the static volt-ampere characteristic is based on its approximation by elementary functions. The most expedient is the abstract approximation, which is not related to physical processes in the transistor structure, but relies primarily on its extreme points and the mathematical features of their neighborhood. Figure 2a shows a family of static volt-ampere characteristics of the transistor structure (Fig. 1) with negative resistance.

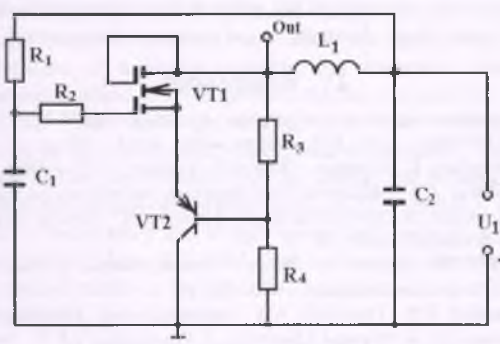

Fig.1. The electric circuit of the generator.

A piecewise linear approximation of the static volt-ampere characteristic of semiconductor structures with negative resistance by means of three-four segments was found rather widely [3]. It makes it possible to investigate rather complex transistor circuits by well-developed linear methods. With an increase in the number of linear segments, it is possible to improve the approximation of the current-voltage characteristic, but the number of complex calculation operations increases.

Therefore, when calculating the voltage-harmonic coefficients, a more accurate approximation of the volt-ampere characteristic of the transistor structure is needed. The use of approximation by a sixth-degree pair polynomial with respect to the maximum point makes it possible to obtain not only qualitative, but also good quantitative convergence of theoretical and experimental results.

Using the equations obtained in [6], and assuming that the origin is transferred to the performance point of the characteristic, the approximating functions can be written in the form:

$$I_{\sim}(y)=\sum_{n=1}^{6}a_n y^n,\ \ G(y)=\sum_{n=1}^{6}n\cdot a_n y^{n-1},\qquad (1)$$

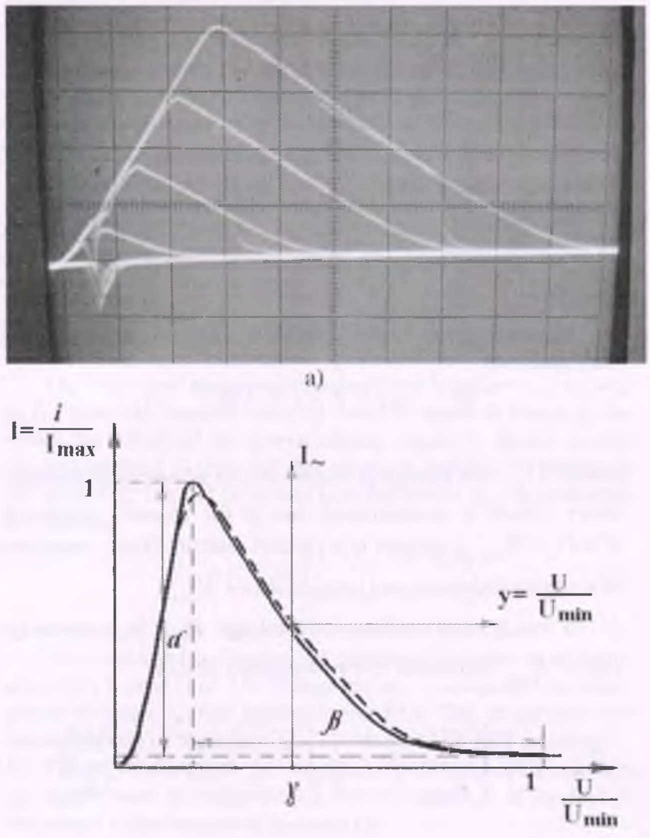

Fig.2. Static volt-ampere characteristics of the transistor structure (a) and their approximation by a polynomial of the 6th degree (b).

where $I_{\sim}(y)$ - variable component of the normalized current of the transistor structure, $G(y)=dI_{\sim}(y)/dU$ - differential conductivity,

$$
\left.\begin{aligned}
a_1 &= -2S_1(1-\gamma) - 4S_2(1-\gamma)^3 - 6S_3(1-\gamma)^5,\\
a_2 &= S_1 + 6S_2(1-\gamma)^2 + 15S_3(1-\gamma)^4,\\
a_3 &= -4S_2(1-\gamma) - 20S_3(1-\gamma)^3,\\
a_4 &= S_2 + 15S_3(1-\gamma)^2,\\
a_5 &= -6S_3(1-\gamma), \quad a_6 = S_3,\\
S_1 &= \frac{\alpha(2-3\beta^2) - \beta^6(1-\alpha)}{\beta^2(1-\beta^2)^2},\\
S_2 &= \frac{2\beta^6(1-\alpha) - \alpha(1-3\beta^4)}{\beta^4(1-\beta^2)^2},\\
S_3 &= \frac{\alpha(1-\beta^2)^2 - \beta^4}{\beta^4(1-\beta^2)^2}, \qquad y = U/U_{\min}
\end{aligned}\right\} \quad (2)
$$

In the expressions (1) - (2) the following notation is adopted:

$$\alpha = (I_{\max} - I_{\min})/I_{\max},$$

$$\beta = (U_{\min} - U_{\max})/U_{\min},$$

$$\gamma = U_0/U_{\min},$$

U_0 - the bias voltage, which is taken from the origin (Fig. 2b). For the averaged current-voltage characteristic α = 0,99077, $\beta = 0,8$, $S_1 = 0,9264$, $S_2 = 4,3615$, $S_3 = -5,2972$.

The amplitude of oscillation of the generator is determined on the basis of the energy balance: the energy absorbed by the oscillation circuit of the generator must equal the energy given by the negative resistance.

The power given by the negative resistance is determined by the expression

$$P_{NDR} = U_p I = U_p^2 / R_{Loss}, \quad (3)$$

where U_p - the voltage at which the loss of energy in the oscillatory circuit is compensated due to the negative resistance, $I = U_p / R_{Loss}$ - current in a parallel electric circuit, composed of negative resistance and loss resistance R_{Loss}.

In steady state at sinusoidal voltage P_{NDR} is equal to the power P_{Loss} consumed by the oscillatory circuit

$$P_{Loss} = \frac{1}{T}\int_0^T \frac{U^2}{R_{Loss}} dt = \frac{1}{T}\int_0^T \frac{U_m \sin\omega t}{R_{Loss}} dt = \frac{1U_m^2}{2R_{Loss}}. \quad (4)$$

Equating (3) and (4), we obtain

$$\frac{U_m^2}{2R_{Loss}} = \frac{U_p^2}{R_{Loss}},$$

where is the amplitude of the generator voltage

$$U_m = \sqrt{2}U_p.$$

If the working point moves along the falling area of the volt-ampere characteristic, then the voltage U_1 corresponds to the negative resistance R_{g1}, and the voltage U_2 – R_{g2} that allows you to write the equation

$$\frac{U_2}{U_1} = \frac{R_{g2}/R_{g1} - 1}{R_{g2}/R_{втр} - 1}. \quad (5)$$

Amplitude sensitivity is determined by the expression (5) given $U_p = U_2$ that, then

$$S_{R_{BTP}}^{U_m} = \frac{2R_{g2}}{R_{втр}(R_{g2}/R_{втр} - 1)}. \quad (6)$$

Analysis of expression (6) shows that the amplitude sensitivity of the generator increases with the approximation of values R_{g2} to $R_{втр}$, but on the other hand it reduces the effect of higher harmonic components in the voltage of the generator.

In the sinusoidal form of oscillation, the resonant frequency of the generator can also be presented as [7]

$$\omega_p = \left[1 - \frac{1}{4Q^2}\left(1 - \frac{R_{Loss}}{R_{g2}}\right)^2\right]^{1/2}. \quad (7)$$

where Q is the Q-factor of the oscillatory circuit. On the basis of (7) the frequency sensitivity is determined to change the resistance of losses

$$S_{R_{Loss}}^{\omega_p} = \frac{1}{4Q^2}\left(1 - \frac{R_{Loss}}{R_{g2}}\right)^2. \quad (8)$$

The frequency response is less, the smaller the values of the resistances R_{g2} and R_{Loss}. On the other hand, the value of the negative resistance should be such as to provide a mode of self-excitation of the generator, which means that a small frequency sensitivity has a generator that operates near the stability boundary.

III. Conclusions

Analysis of the obtained analytical expressions showed that in order to reduce the nonlinear distortions and frequency shifts that are caused by these distortions, it is necessary to decrease the value of the characteristic impedance of the generator circuit by appropriate selection of the point in the decreasing section of the current-voltage characteristic of the transistor structure.

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