Mathematical model of transistor equivalent of electrical controlled capacity

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Abstract – **This work the mathematical model of transistor equivalent of electrical controlled capacity based on two bipolar transistors are made. Associations of active and reactive component complete resistance with changeable temperature.**

Keywords – **transistor equivalent, electrical controlled capacity, negative differentiating resistance, complete resistance.**

I. Introduction

For further development of radio electronics and radio-engineering we must solve new actual exercises for improvement of characteristics up-to-date devices and reduction effect exterior connection in semiconductor structures, that lead to appearance negative resistance and simplified circuits of wide spread devices: filters, phase turners. Their functions are significantly multiplied [1, 2, 3].

II. Theoretical and experimental investigations

Well known circuits of transistor equivalent of capacity are (fig. 1), circuits union of two bipolar transistors, two MOS transistors or one bipolar MOS transistors.

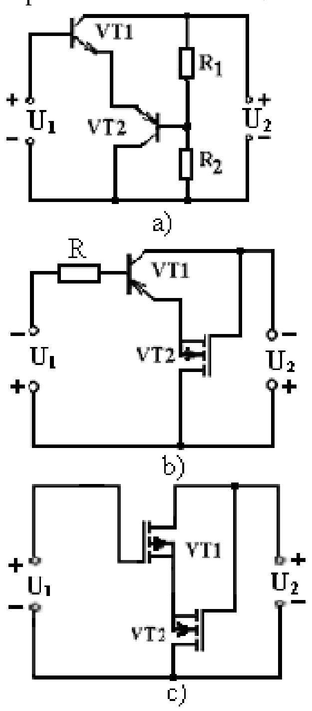

Fig. 1 Transistor equivalent of electrical controlled capacity.

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Such technical decisions establish equivalent capacity, what can be used in radio technical devices: filters, generators, amplifiers, gates, phase turners, ets. General theory and principles of work are known [3].

Let us see transistor equivalent of electrical controlled capacity fig. 1a. There is an area on its volt-ampere dependence, what is responsible for differential resistance (fig. 2). While choosing a working point on a impinged part of volt-ampere dependence we can control quantity of capacity. The application of this equivalent demands design of its mathematical model.

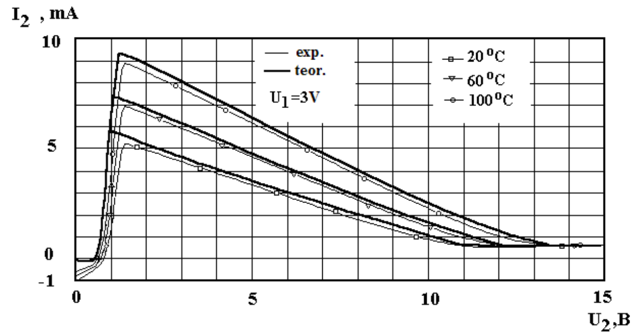

Fig. 2 Volt-ampere dependence transistor equivalent of electrical controlled capacity.

On fig. 3 an equivalent circuit of transistor equivalent of electrical controlled capacity is given. Between collectors of transistors as a result of activity of positive inverse connection is complete resistance, active component has negative value, and reactive component has capacity character.

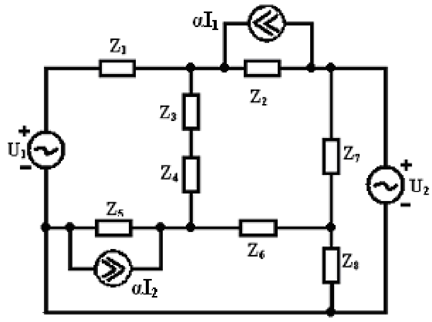

Fig. 3 An equivalent circuit transistor equivalent of electrical controlled capacity.

Complete resistance of such structure equates:

$$Z = R + jX \qquad (1)$$

Where R – active component, $X = 1/ j\omega C_{eq}$ - reactive component, $\omega = 2\pi f$.

As to the equivalent circuit (fig. 3) we can make up a sat of equations.

$$\begin{cases} U_1 = i_1(Z_7+Z_8) - i_2 Z_7 + i_4 Z_8 \\ 0 = i_2(Z_2+Z_3+Z_4+Z_6+Z_7) - i_1 Z_7 - i_3(Z_3+Z_4) + i_4 Z_6 + Z_2 \alpha I_1 \\ U_2 = i_3(Z_1+Z_3+Z_4+Z_5) - i_2(Z_3+Z_4) + i_4 Z_5 + Z_5 \alpha I_2 \\ 0 = i_4(Z_5+Z_6+Z_8) + i_2 Z_6 + i_3 Z_5 + i_1 Z_8 + Z_5 \alpha I_2 \end{cases} \quad (2)$$

As to the solution of the set of equations (2) we can get analytical association of complete resistance from a voltage supply.

$$Z = U_1 \frac{Z_7 + 2Z_3\left(\frac{Z_7+Z_8}{Z_5 Z_8} - \frac{Z_8}{Z_5}\right) + \frac{Z_7+Z_8}{Z_8} - B\left(a + 2Z_3\left(\frac{Z_7}{Z_8 Z_5} + \frac{Z_6}{Z_5}\right) + \frac{Z_7}{Z_8}\right)}{Z_6 \alpha I_1 + \frac{U_1 Z_6}{Z_8} - 2Z_3 \alpha I_2 - \frac{2Z_3 C U_1}{Z_5 Z_8} + A\left(a - 2Z_3\left(\frac{Z_7}{Z_8 Z_5} + \frac{Z_6}{Z_5}\right) + \frac{Z_7}{Z_8}\right)} \quad (3)$$

where

$$A = \frac{U_2 - \frac{CbU_1}{Z_5 Z_8} - b\alpha I_2 + \frac{U_1 Z_5}{Z_8} + Z_5 \alpha I_2}{2Z_3 - \frac{Z_5 Z_7}{Z_8} + \left(\frac{Z_7}{Z_8 Z_5} + \frac{Z_6}{Z_5}\right)b} \qquad B = \frac{b\left(\frac{Z_7+Z_8}{Z_5 Z_8} - \frac{Z_8}{Z_5}\right) - \frac{(Z_7+Z_8)Z_5}{Z_8}}{2Z_3 - \frac{Z_5 Z_7}{Z_8} + \left(\frac{Z_7}{Z_5 Z_8} + \frac{Z_6}{Z_5}\right)b}$$

$a = z_2 + z_3 + z_4 + z_6 + z_7$, $b = z_1 + z_3 + z_4 + z_5$, $c = z_5 + z_6 + z_8$.

From (3) we can get real and unreal parts of complete resistance on electrodes collector- collector (fig 1. a).

$$\operatorname{Re} Z' = R_1 + \frac{R_1}{R_2} + 1 + \frac{2d}{r_e(d^2+e^2)}\left(\left(\frac{R_1}{R_2}+1\right) - R_2\right) + \frac{2\omega C_e e}{e^2+d^2}\left(\left(\frac{R_1}{R_2}+1\right) + R_2\right) + B'(\bar{a}' + B'' a'')$$

$$\operatorname{Im} Z' = B''\bar{a}' - B' a'' + \frac{2\omega C_e e}{e^2+d^2}\left(\left(\frac{R_1}{R_2}+1\right) + R_2\right) - \frac{2e}{r_e(d^2+e^2)}\left(\left(\frac{R_1}{R_2}+1\right) + R_2\right) \quad (4)$$

$$\operatorname{Re} Z'' = r_б \alpha I_1 + \frac{r_б U_1}{R_2} + \frac{2}{r_e}\alpha I_2 + \frac{2U_1\left(d\left(\frac{m}{r_e} + \omega C_e n\right) + e\left(\frac{n}{r_e} + m\omega Ce\right)\right)}{R_2(d^2+e^2)} + A'a' - A''a''$$

$$\operatorname{Im} Z'' = \omega Ced\alpha I_2 + \frac{d\left(\frac{n}{r_e} + m\omega C_e\right) - e\left(\frac{m}{r_e} - \omega C_e n\right)}{R_2(d^2+e^2)} + A''a' + A'a'',$$

where

$$\bar{a}' = k + \frac{R_1}{R_2} + \frac{2}{r_e(e^2+d^2)}\left(\frac{R_1 d}{R_2} + r_б d\right) + \frac{\omega Ce}{e^2+d^2}\left(\frac{R_1 e}{R_2} + r_б e\right),$$

$$a' = k + \frac{R_1}{R_2} + \frac{2}{r_e(e^2+d^2)}\left(\frac{R_1 d}{R_2} + r_б d\right) - \frac{\omega Ce}{e^2+d^2}\left(\frac{R_1 e}{R_2} + r_б e\right),$$

$$a'' = L - \frac{\omega Ce}{d^2+e^2}\left(\frac{R_1 d}{R_2} + r_б d\right) + \frac{r}{r_e(e^2+d^2)}\left(\frac{R_1 e}{R_2} + r_б e\right).$$

$$\operatorname{Re} Z = \frac{\operatorname{Re} Z' \operatorname{Re} Z'' + \operatorname{Im} Z' \operatorname{Im} Z''}{(\operatorname{Re} Z'')^2 + (\operatorname{Im} Z'')^2} \quad (5)$$

$$\operatorname{Im} Z = \frac{\operatorname{Re} Z' \operatorname{Im} Z'' + \operatorname{Im} Z' \operatorname{Re} Z''}{(\operatorname{Re} Z'')^2 + (\operatorname{Im} Z'')^2} \quad (6)$$

The set of equations (2) is solved by the numerical method on personal computer at usage the software package “MathLab 6.5”. The dependence of active component of complete resistance from temperature is represented on fig. 4. The results of theoretical and experimental dependences of reactive component of complete resistance from temperature are represented on fig. 5.

From the schedule (fig. 4 and fig. 5) it is visible, that active and reactive component of complete resistance of bipolar transistor structure has quit large change of quantity, for active component it achieves from 2kOhm to 10kOhm, while voltage supply may change from 3V to 5V, for reactive component it achieves from 82kOhm to 112kOhm, while voltage controllable may change from 3V to 5V. It gives us an opportunity to change equivalent capacity in wide band. When voltage supply is equal 2V it changes from 300pF to 1600pF, while voltage controllable achieves from 3V to 5V.

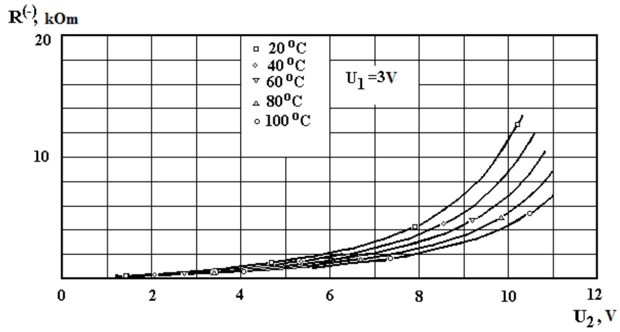

Fig. 4 An dependence of active component of complete resistance from temperature.

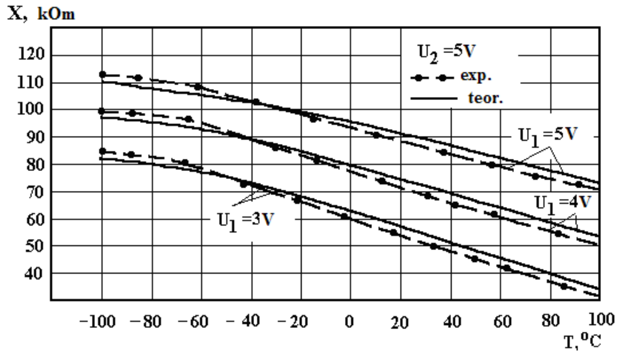

Fig. 5 Theoretical and experimental dependences reactive component of complete resistance from temperature.

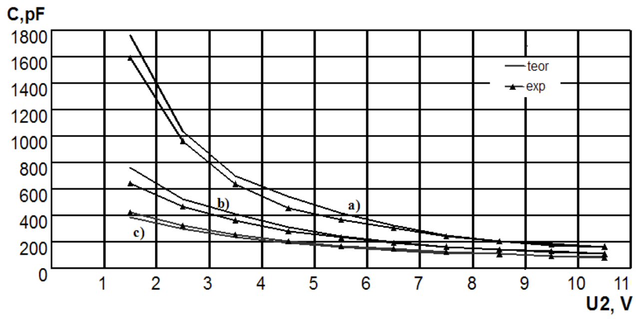

Fig. 6 Volt-farad dependence transistor equivalent of capacity from a voltage supply a) U_1=3V, b) U_1=4V, c) U_1=5V.

The made up theoretical and experimental investigations temperature conditions of work of electrical controlled capacity, based on two bipolar transistors shows that optimal temperature gamut is -60C, +60C. The results of theoretical and experimental investigations are coincided, what confirms the adequacy of made up mathematical model.

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