The Generator of Superhigh Frequencies on the Basis Silicon Germanium Heterojunction Bipolar Transistors

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Abstract - **investigations of the hyperfrequency generator presented on the basis of the transistor structure consisting from two silicon - germanium heterojunction of bipolar transistors. The opportunity of electrical adjustment of an oscillation frequency is shown.**

Keywords - **negative resistance, oscillator, SiGe HBT**

I. Introduction

Modern integrated technologies that are moving in nanotechnology, can create ultrahigh-frequency silicon - germanium heterojunction bipolar transistors (SiGe HBT) with boundary frequencies up to 200 GHz [1]. Transistors of this type are widely used in navigation systems transceiver equipment in a wireless communication system, a wireless Internet automotive radar. Create microwave oscillators using the negative differential resistance to compensate for the energy loss in an oscillatory system, based on SiGe heterojunction bipolar transistors can dramatically increase the frequency generation and its restructuring by changing the supply voltage. The paper presents the oscillator circuit and the dependence of oscillation frequency on the power mode.

II Theoretical and Experimental Researches

Fig. 1 is a schematic diagram of the oscillator. The oscillation circuit is formed by the capacitive component of the impedance of the electrodes collector - emitter of transistor VT1 and inductance L1. Resistance R1-R4 and the constant voltage source V1, V2 enables a choice of the operating point on the falling section of the current-voltage characteristics of the device [2].

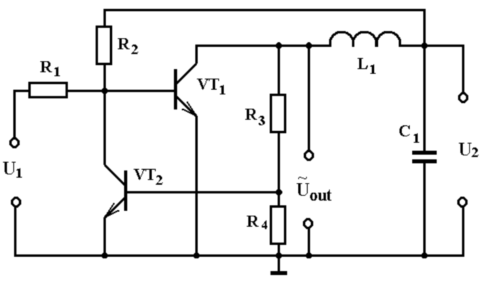

Fig. 1. Schematic diagram of the oscillator

Due to the negative dynamic resistance converts the DC power of the electric field source voltages V1 and V2 in the alternating electric field energy, ie the energy of the microwave electrical oscillations. To calculate the oscillation frequency depending on the voltage supply is necessary to know the dependence of the negative differential resistance on electrodes collector - emitter of transistor VT1 and equivalent capacitance of the tuner circuit from DC. For this purpose we use a nonlinear oscillator equivalent circuit (Fig. 2), which is based on small-signal models of SiGe heterojunction bipolar transistors [3], [4].

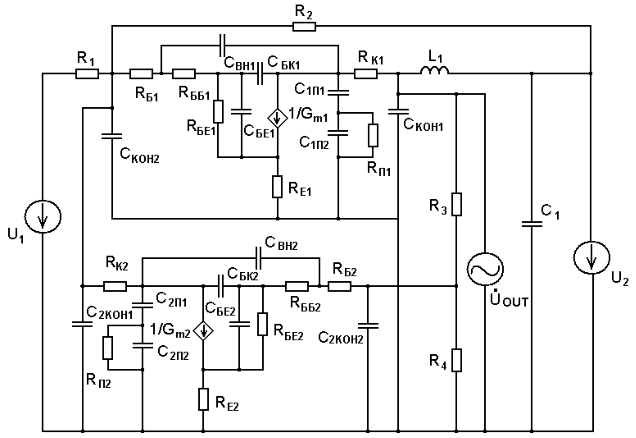

Fig.2. Non-linear equivalent circuit oscillator

Nonlinear oscillator equivalent circuit (Fig. 2) is transformed into an equivalent circuit, convenient for calculations (Fig. 3). According to the circuit (Fig. 3) is composed of equations Kirchhoff

$$\dot{U}_{OUT} = (Z_3 + Z_4)i_1 + Z_3 i_3 + Z_4 i_4;$$
$$\dot{U}_{OUT} = (Z_{16} + Z_{28})i_2 + Z_{16} i_{12};$$
$$0 = (Z_{14} + Z_3 + Z_4)i_3 + Z_{14} i_{15} + Z_3 i_1 + Z_4 i_4 + Z_4 i_1;$$
$$0 = (Z_{26} + Z_4)i_4 + Z_{26} i_5 + Z_4 i_1 + Z_4 i_3;$$
$$0 = (Z_{27} + Z_{21} + Z_{24} + Z_{25} + Z_{26})i_5 + Z_{27} i_8 - Z_{21} i_6 + Z_{24} i_7 - -Z_{25} i_{16} + Z_{26} i_4;$$
$$0 = (Z_{22} + Z_{20} + Z_{21})i_6 + Z_{22} i_7 - Z_{21} i_5 + Z_{20} i_8;$$
$$0 = (Z_{22} + Z_{23} + Z_{24})i_7 + Z_{22} i_6 + Z_{24} i_5 + Z_{23} i_{16};$$
$$0 = (Z_{19} + Z_{20} + Z_{27})i_8 + Z_{19} i_9 + Z_{20} i_6 + Z_{27} i_5;$$
$$0 = (Z_{17} + Z_{18} + Z_{19})i_9 - Z_{17} i_{10} - Z_{18} i_{16} + Z_{18} i_8;$$
$$0 = (Z_1 + Z_{17})i_{10} - Z_{17} i_9;$$
$$0 = (Z_6 + Z_7 + Z_8)i_{11} - Z_6 i_{12} - Z_7 i_{17} - Z_8 i_{13};$$
$$0 = (Z_2 + Z_5 + Z_6 + Z_{15} + Z_{16})i_{12} - Z_5 i_{17} - Z_6 i_{11} - Z_{15} i_{15} + Z_{16} i_2;$$
$$0 = (Z_8 + Z_9 + Z_{10})i_{13} - Z_8 i_{11} - Z_9 i_{17} + Z_{10} i_{14};$$
$$0 = (Z_{11} + Z_{10} + Z_{13})i_{14} + Z_{11} i_{17} + Z_{10} i_{13} + Z_{13} i_{15};$$

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$$0=(Z_{13}+Z_{15}+Z_{14})i_{15}+Z_{13}i_{14}-Z_{15}i_{12}+Z_{14}i_{3};$$
$$0=(Z_{12}+Z_{15}+Z_{23}+Z_{18})i_{16}-Z_{12}i_{17}-Z_{25}i_{5}+Z_{23}i_{7}-Z_{18}i_{9};$$
$$0=(Z_{12}+Z_{5}+Z_{7}+Z_{9}+Z_{11})i_{17}-Z_{12}i_{16}-Z_{5}i_{12}-Z_{7}i_{11}-$$
$$-Z_{7}i_{11}-Z_{9}i_{13}+Z_{11}i_{14}, \tag{1}$$

where $Z_1=R_1$, $Z_2=R_2$, $Z_3=R_3$, $Z_4=R_4$, $Z_5=R_{B1}$,

$$Z_6=-j\frac{1}{\omega C_{BH1}},\; Z_7=R_{BB1},\; Z_8=-j\frac{1}{\omega C_{BK1}},\; Z_{11}=R_{E1},$$

$$Z_9=\frac{R_{BE1}}{1+(\omega R_{BE1}C_{BE1})^2}-j\frac{\omega C_{BE1}R_{BE1}^2}{1+(\omega R_{BE1}C_{BE1})^2},\; Z_{10}=1/G_{m1}$$

$$G_{m1}=G_{m01}\frac{e^{-j\omega\tau_1}}{1+j\omega\tau_2},\;\; Z_{12}=-j\frac{1}{\omega C_{1KOH2}},\;\; Z_{15}=R_{K1},$$

$$Z_{13}=\frac{R_{P1}}{1+\left(\omega C_{1P2}R_{P1}\right)^2}-j\left(\frac{1}{\omega C_{1P1}}+\frac{\omega C_{1P2}R_{P1}^2}{1+\left(\omega C_{1P2}R_{P1}\right)^2}\right)$$

$$Z_{19}=\frac{R_{P2}}{1+\left(\omega C_{2P2}R_{P2}\right)^2}-j\left(\frac{1}{\omega C_{2P1}}+\frac{\omega C_{2P2}R_{P2}^2}{1+\left(\omega C_{2P2}R_{P2}\right)^2}\right)$$

$$Z_{14}=-j\frac{1}{\omega C_{1KOH1}},\;\; Z_{16}=j\omega L_1,\;\; Z_{17}=-j\frac{1}{\omega C_{2KOH1}},$$

$$Z_{18}=R_{K2},\;\; Z_{20}=1/G_{m2},\; G_{m2}=G_{m02}\frac{e^{-j\omega\tau_1}}{1+j\omega\tau_2},$$

$$Z_{21}=\frac{R_{BE2}}{1+(\omega R_{BE2}C_{BE2})^2}-j\frac{\omega C_{BE2}R_{BE2}^2}{1+(\omega R_{BE2}C_{BE2})^2},\; Z_{27}=R_{E2},$$

$$Z_{22}=-j\frac{1}{\omega C_{BK2}},\qquad Z_{23}=-j\frac{1}{\omega C_{BH2}},\qquad Z_{24}=R_{BB2},$$

$$Z_{25}=R_{B2},\; Z_{26}=-j\frac{1}{\omega C_{2KOH2}},\;\; Z_{28}=-j\frac{1}{\omega C_1}.$$

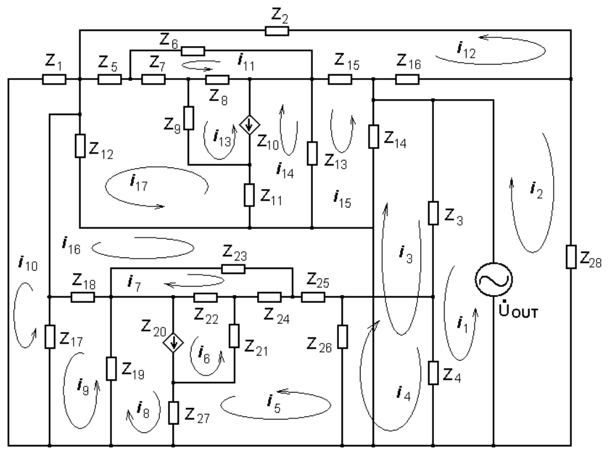

Fig.3. Conversion nonlinear oscillator equivalent circuit for AC

The system of equations (1) is calculated in a computing environment «Matlab 7.1» on the PC. The parameters of the equivalent circuit of the generator required for the calculation were taken from [3, 4]. So, as the oscillator circuit implements an oscillating system, energy losses which are compensated by negative resistance turn to the definition of transformation function ie the dependence of frequency from voltage and sensitivity. These calculations can be made on the basis of an equivalent circuit, which is shown in Fig. 4.

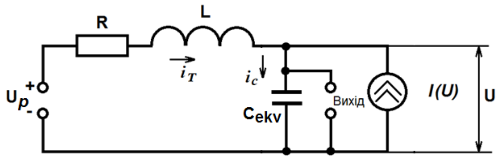

Fig.4. Equivalent circuit of the oscillator

The diagram (Fig. 4), the total inductance *L* and the inductance terminal of the circuit, the capacitance *C* includes an external capacitance *C1*, and the internal capacitance of transistors VT1 and VT2 at the collector-emitter electrode. The resistance *R* includes all the resistance loss of the circuit. The current source of *I(U)* simulates the falling portion at the output voltage characteristic of the device.

The equivalent circuit of the oscillator (Fig. 4) is described by Kirchhoff

$$U_p=Ri_T+L\frac{di_T}{dt}+U, \tag{2}$$

$$i_T=C_{ekv}\frac{dU}{dt}+I(U). \tag{3}$$

From the equations (2) and (3) are defined by components

$$\frac{di_T}{dt}=\frac{U_p-i_T-U}{L}, \tag{4}$$

$$\frac{dU}{dt}=\frac{i_T-I(U)}{C_{ekv}}. \tag{5}$$

At equilibrium, a DC current and voltage do not change over time, where

$$\left.\frac{di_T}{dt}\right|_{i_T=i_{T0}}=0,\qquad \left.\frac{dU}{dt}\right|_{U=U_0}=0. \tag{6}$$

If you use conditions (6) from (4) and (5) define

$$U_P=i_{to}R-U_0=0, \tag{7}$$

$$i_{T0}-I(U_0)=0. \tag{8}$$

Circuit condition in accordance with (7) and (8) can be realized at one point of the incident-sectional area and the current-voltage characteristics of the load line

$$R=\frac{U_p-U_0}{I(U_0)}, \tag{9}$$

which is a state of equilibrium DC schemes investigated.

For a review of the circuit in a dynamic mode in the equation (4) and (5) introduce the variables which have the form

$$u=U-U_0,\qquad i=i_T-i_{T0}. \tag{10}$$

Nonlinear static voltage-current characteristic of the circuit near the equilibrium point will replace the linear function

$$I(U_0+u)=I(U_0)+u/R_g, \tag{11}$$

where R_g - negative differential resistance at the point of equilibrium.

Nonlinear capacitance on electrodes first collector - emitter transistors VT1 and VT2 near the equilibrium believe constant, which is independent of voltage. Accordingly, the condition of equation (4) and (5) are converted into linear with constant coefficients

$$\frac{di}{dt}=-\frac{Ri}{L}-\frac{u}{L}, \qquad \frac{du}{dt}=\frac{i}{C_{ekv}}-\frac{u}{R_g C_{ekc}}. \qquad (12)$$

Combining equations (12) allows you to get a second order differential equation, which describes the oscillation process in autogenerator

$$\frac{d^2u}{dt^2}+\left(\frac{R}{L}-\frac{1}{R_g C_{ekv}}\right)\frac{du}{dt}+\frac{u}{LC_{ekv}}\left(1+\frac{R}{R_g}\right)=0. \qquad (13)$$

The solution of equation (13) has the form

$$u(t)=A\exp\left[-\frac{1}{2}\left(\frac{R}{L}+\frac{1}{R_g C_{ekv}}\right)+\sqrt{\frac{1}{4}\left(\frac{1}{R_g C_{ekv}}+\frac{R}{L}\right)^2-\frac{1}{LC_{ekv}}\left(1+\frac{R}{R_g}\right)}\right]t+$$
$$+B\exp\left[-\frac{1}{2}\left(\frac{R}{L}+\frac{1}{R_g C_{ekv}}\right)-\sqrt{\frac{1}{4}\left(\frac{1}{R_g C_{ekv}}+\frac{R}{L}\right)^2-\frac{1}{LC_{ekv}}\left(1+\frac{R}{R_g}\right)}\right]t, \qquad (14)$$

where A and B the coefficients are determined from initial conditions.

Two components of the equation (14) describe a batch process, the amplitude of which increases exponentially. Terms of occurrence of sinusoidal oscillations in the system described by the inequalities

$$\left(\frac{1}{R_g C_{ekv}}+\frac{R}{L}\right)<0, \qquad \frac{1}{LC_{ekv}}\left(\frac{R}{R_g}+1\right)>0. \qquad (15)$$

Thus, the occurrence of fluctuations in the resonance frequency of the autogenerator in the test will take place when the conditions (15). The resonant frequency is determined by the reactive component of the impedance at the output, which at the resonant frequency is zero (Fig. 4). The current source $I(U)$ at the operating point changes by device. Thus, the dependence of the resonance frequency from voltage by the expression

$$F(U)=\frac{1}{2\pi R_g(U)C_{ekv}}\sqrt{\frac{R_g^2(U)C_{ekv}}{L}-1}. \qquad (16)$$

The sensitivity is determined on the basis of expressions (16) and has the form

$$S_U^F=-\frac{1}{2}\frac{\sqrt{\frac{R_g^2(U)C_{ekv}}{L}-1}\left(\frac{dR_g(U)}{dU}\right)}{\pi R_g^2(U)C_{ekv}}+\frac{1}{2}\frac{\frac{dR_g(U)}{dU}}{\pi L\sqrt{\frac{R_g^2(U)C_{ekv}}{L}-1}}. \qquad (17)$$

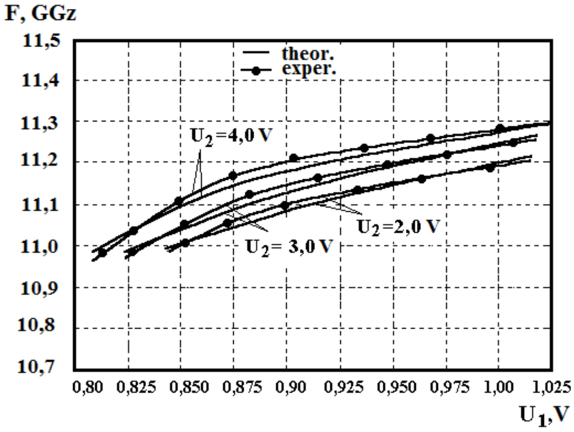

Fig.5. Dependence of the frequency generator by changing the control voltage U1

Fig. 5 shows the dependence of the oscillator frequency by varying the voltage U1 at different values of U2. As can be seen from the graph, its dependence on voltage the non-linear, this is due to the nonlinear dependence of the equivalent capacitance of the autogenerator oscillating. Changes in voltage from 0.825 V to 1.025 V it leads to a change in frequency of 350 MHz.

III. Conclusion

The scheme of the oscillator based on the transistor structure consisting of two silicon-germanium heterojunction bipolar transistors are proposed. On the basis of solutions of equations of oscillatory dependence of the oscillator output voltage is obtained from the time, of occurrence of the condition of sinusoidal oscillations in the system, the frequency dependence of the generation of the control voltage, the equation sensitivity. Changing the control voltage from 0.825 V to 1.025 V results in a change in the frequency of 350 MHz

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