Section 5. Technical sciences

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RESEARCH OF THE AMPLITUDE-FREQUENCY CHARACTERISTICS OF A QUASI COMPLEMENTARY EMITTER FOLLOWER ON THREE-STRUCTURAL INJECTION-VOLTAIC TRANSISTORS

Abstract. In this article shows the results of an experimental study of the amplitude-frequency characteristics of the quasi-complementary emitter followers on three structural injection-voltaic transistors.

Keywords: amplifier; the quasi-complementary emitter followers, the three-structural injection-voltaic transistor, current-voltage characteristic, amplitude-frequency characteristic**.**

I. Introduction

In the final stages of low-frequency power amplifiers, complementary and quasi-complementary emitter followers (CEF and QCEF) are widely used on powerful bipolar transistors operating in the push-pull mode of class "AB". For cascades with a large output power, it is not always possible to select a pair of complementary transistors. In this case, in the output stage, quasi-complementary emitter followers (QCEF) can be used on powerful transistors of the same type.

The main disadvantage of quasi-complementary emitter followers is the instability of the operation mode due to an increase in temperature or supply voltage values.

The main disadvantage of the complementary emitter follower [1] operating in the "AB" mode is the instability of the operating mode with increasing temperature or the supply voltage at which the 100% negative current feedback characteristic of the emitter follower disappears through the load resistor due to the fact that these external destabilizing factors are equivalent to common-mode signals. To reduce the influence of temperature and other destabilizing factors, additional local negative feedback is introduced using two resistors connected between the emitters of transistors [1]. But this method is not effective enough and reduces the power given to the load.

In [2; 3; 4; 5], an injection-voltaic transistor (IVT) made on germanium and silicon transistors, and having an extended range of stable operation, was proposed and experimentally investigated.

In [6], a complementary emitter follower is highly resistant to the action of destabilizing factors, in which injection-voltaic transistors (IVT) are used as output transistors.

The main disadvantage of a complementary emitter follower for IVT is the use of transistors made of semiconductor materials with different bandgaps, which will result in low manufacturability in the integrated design. In addition, IWT has a small range of stable operation in the field of secondary breakdown [6].

To ensure the manufacturability of manufacturing a complementary emitter follower in integral design, it is advisable to use three-structure injection-voltaic transistors (TIVT) [7] made on a homogeneous material as output transistors. TIVTs also have an extended range of stable operation in the field of secondary breakdown and an expanded range of temperature stability compared to IWT.

In [8], an efficient QCEF for TIVT was proposed, which has an extended range of stable operation with increasing temperature and increasing voltage values of power supplies.

II. Methods and experements

In [9], a quasi-complementary emitter follower is highly resistant to the influence of destabilizing factors, in which three-structure injection-voltaic transistors (TIVTs) are used as output transistors. The scheme of a quasi-complementary emitter follower at the TIVT is shown in Fig. 1, In the above diagram, the upper arm of the QCEF consists of a composite TIVT connected according to the Darlington scheme (TIVTs are connected according to the CK-CK circuit), and the lower arm also consists of a composite TIVT connected but according to the Shiklai scheme (TIVTs are connected according to the CE-CK circuit).

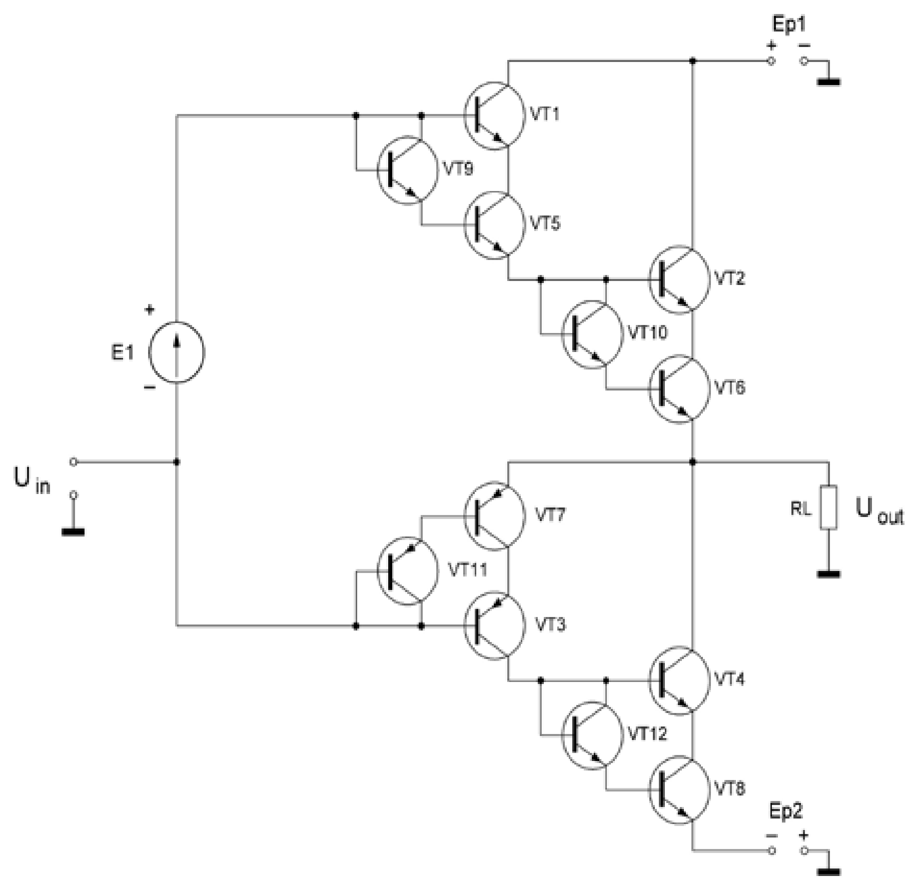

Figure 1. Scheme of a quasi-complementary emitter follower at TIVT

Thus, the quasi-complementary emitter follower on the TIVT consists of four TIVT (two in the upper and two in the lower arms). Let us consider in more detail TIVT (Fig. 2). TIVT consists of three transistor structures [7].

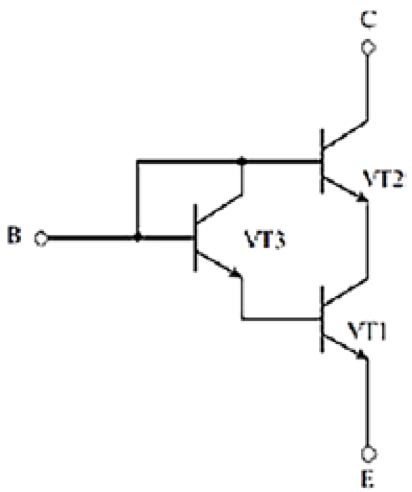

Figure 2. The scheme of the TIVT

The collector potential VT1 is always lower than the base potential of the second and third transistor structures by the value of the forward voltage of the emitter-base junction of the second structure. Consequently, the intersection of the characteristics of the first and second structures at any values of U_{KE} and U_{EB}, due to the displacement $U_{EB3} = U_{KE3}$, will be in the horizontal section of the injection-voltaic regime (Fig. 3). The first and third structures play the role of an ideal stable current generator feeding the emitter of the second transistor structure.

The data used is from the results of The results of studies of TIVT show [7] that TIVT stably operate at higher values of the collector-emitter reverse voltage UKE (2–3 times higher than the maximum allowable) than in the case of individual structures. The power dissipated on the collector exceeds the passport value of the maximum permissible power for the VT2 transistor by more than 3 times.

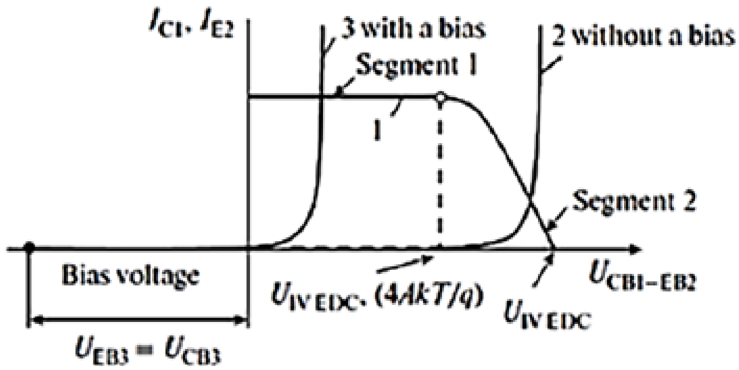

Figure 3. I – V characteristic illustrating the operation of the TIVT. Output I – V characteristic (curve 1) VT_1 and output I – V characteristics (curve 2 – without bias and curve 3 – with bias voltage) VT_2

In [10], a mathematical model of TIVT in a common emitter circuit was proposed and theoretically investigated. Output characteristics of TIVT in active mode, with UKE> UBE, is described by the expression:

$$I_K = I_{K2} = \alpha_{N1}\alpha_{N2}I_{E01}(1+\gamma(U_{KE}-U_{BE1}))\exp(b_{E1}U_{BE1}) \quad (1)$$

where

$$U_{BE1} = \frac{1}{b_{E1}+b_{BE3}}\left[\ln\left[\frac{I_{E03}}{(1-\alpha_{N1})I_{E01}}\right]+b_{E3}U_{BE}\right]$$

– the voltage at the emitter junction of the transistor VT_1;

α_{N1}, α_{N2} – transmission coefficients of emitter currents of transistors VT_1, VT_2;

I_{E01}, I_{E03} – saturation currents of emitter junctions of transistors VT_1, VT_3;

γ – s the coefficient describing the modulation of the base width (Earley effect);

b_{E1}, b_{E2} – are the ideality parameters of the I – V characteristic of emitter junctions VT_1, VT_3.

$$I_K = I_{K2} = \alpha_{N1}\alpha_{N2}I_{E01}\exp(b_{E1}U_{BE1}) - -I_{K02}\exp(b_{K2}(U_{BE}-U_{KE})) \quad (2)$$

where I_{K02} – saturation current of the collector junction of the transistor VT_2;

b_{K2} – is the ideality parameter of the I – V characteristic of the collector junctions of the transistor VT_2.

Input characteristics of TIVT in active mode, with $U_{KE} > U_{BE}$, is described by the following expression for the base current:

$$I_B = [1-\alpha_{N1}\alpha_{N2}]I_{E01}(1+\gamma(U_{KE}-U_{BE1}))\exp(b_{E1}U_{BE1}) \quad (3)$$

To determine the current gain of the TIVT, we will use Figure 4.

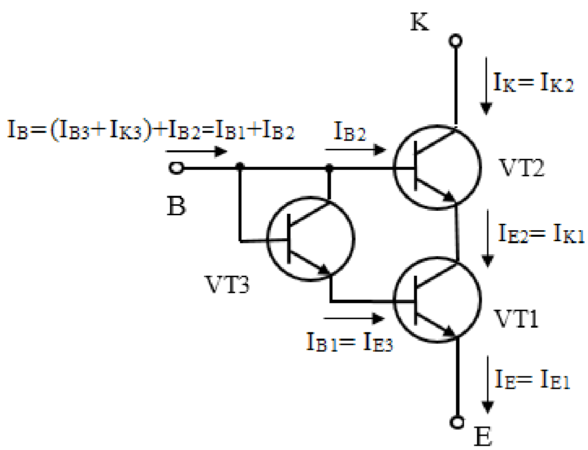

Figure 4. Current distribution in an injection-voltaic transistor

Fig. 4 shows that the current gain of the TIVT is determined by the following expression:

$$\beta_{TIVT} = \frac{\partial I_K}{\partial I_B}\bigg|_{U_{KE=const}} = \frac{\Delta I_K}{\Delta I_B} = \frac{\Delta I_K}{\Delta I_{B1}+\Delta I_{B2}} = \frac{1}{\frac{1}{\frac{\Delta I_K}{\Delta I_{B1}}}+\frac{1}{\frac{\Delta I_K}{\Delta I_{B2}}}} = \frac{1}{\frac{1}{\beta_1}+\frac{1}{\beta_2}} = \frac{\beta_1\beta_2}{\beta_1+\beta_2} \quad (4)$$

In a particular case, if the current gains of transistors VT_1 and VT_2 are equal $\beta_1 = \beta_2 = \beta$, then the current gain of the TIVT is determined by the expression:

$$\beta_{TIVT} = \beta / 2 \quad (5)$$

The upper arm of the quasi-complementary emitter follower circuits on the TIVT (Fig. 1) consists of two TIVT connected according to the Darlington scheme. As is known [11], the total current gain β for a composite transistor connected according to the Darlington circuit is equal to the product of the current gains of individual transistors. Thus, the total current gain β for a composite TIVT connected according to the Darlington scheme is also equal to the product of the current gain of individual TIVT:

$$\beta_{DTIVT} = \beta_{TIVT1}\beta_{TIVT2} = \frac{\beta_1\beta_2\beta_3\beta_4}{(\beta_1+\beta_2)(\beta_3+\beta_4)} \quad (6)$$

With equal current gains of all transistors $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta$ the total current gain βDIVT for a composite TIVT connected according to the Darlington scheme:

$$\beta_{TIVT} = \beta^2 / 4 \quad (7)$$

The lower arm of the quasi-complementary emitter follower circuits on the TIVT (Fig. 1) consists of two TIVT connected according to the Shiklai scheme. The total current gain β for a composite TIVT connected according to the Shiklai scheme is also equal to the product of the current gain of individual TIVT:

$$\beta_{ShTIVT} = (\beta_{TIVT1}+1)\beta_{TIVT2} \cong \beta_{TIVT1}\beta_{TIVT2} \quad (8)$$

It should be noted that large fluctuations in currents and voltages in power amplifiers and the nonlinearity of the transistor characteristics jointly affect the parameters of the amplifier. And small-signal analysis, assuming the linearity of the transistor, becomes invalid. Consequently, in amplifiers of a large signal, graphical methods of analysis are more often used [11].

To implement the investigated QCEF at TIVT (Fig. 1), different-type transistors based on silicon KT-315Г (VT_1, VT_2, VT_4, VT_5, VT_6, VT_8, VT_9, VT_{10}, VT_{12}) with n-p-n and KT-361Г structures were used by industry (VT_3, VT_7, VT_{11}) with p-n-p structure. To study the amplitude and frequency characteristics of the QCEF at the TIVT, a bipolar power supply of 20 V was selected as a power source and active load $R_L = 620$ Ohm.

III. Results

In Fig. 5, shows the combined transfer characteristic of the investigated QCEF to TIVT in mode

"B". In the investigated QCEF on the TIVT, as well as in the known schemes, near the zero input voltage, the current in the open TIVT is very small, and the internal resistance is large.

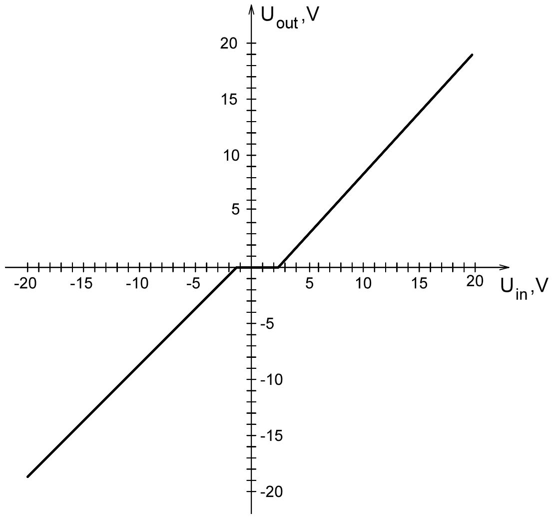

Figure 5. Combined transfer characteristic of QCEF to TIVT in mode "B"

As a result, the increase in voltage at the load in this area is less than the change in input voltage. This is the reason for the appearance of a break in the characteristic near zero. The resulting distortion of the output voltage is called transient distortion [1]. To eliminate transient distortion, as is known, a small quiescent current is passed through transistors, that is switch to the "AB" operating mode.

In the QCEF circuit under study, to switch to the "AB" operating mode, the transistor quiescent current is 1mA, which is set using bias voltage source E_1.

In Fig. 6, shows the amplitude characteristic (AC) of the QCEF on a TIVT, at a quiescent current of transistors I_0 = 1 mA and applying a harmonic signal with a frequency of 1 kHz to the input of the QCEF on a TIVT.

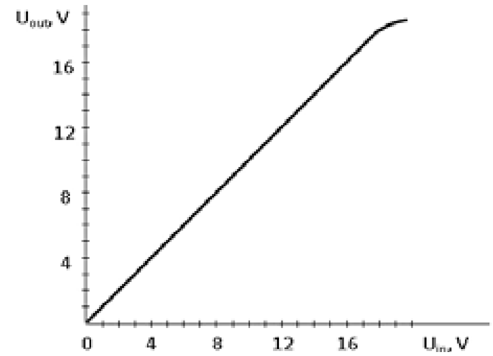

Figure 6. The amplitude characteristic of the QCEF at the TIVT at $E_{P1} = E_{P2}$ = 20V, I_0 = 1mA, f_0 = 1kHz and R_L = 620 Ohm

The amplitude characteristic of the circuit under study is linear enough for practical use and has the same bend characteristics at high input voltages, as in the circuits of well-known QCEFs on bipolar transistors. This is also explained by the nonlinearity of the current-voltage characteristics of injection-voltaic transistors.

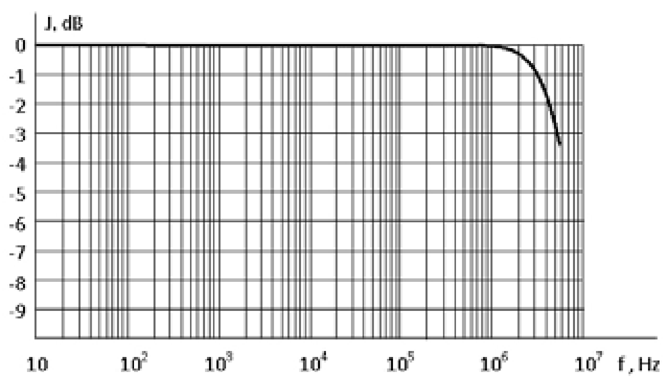

Figure 7, shows the amplitude-frequency characteristic (AFC) of the investigated schemes as a function of the relative gain of the frequency J = φ(f), which has the same form as the well-known QCEF circuits on single bipolar transistors

Figure 7. The amplitude-frequency characteristic of the QCEF at the TIVT at $E_{P1} = E_{P2}$ = 20 V, I_0 = 1 mA, f_0 = 1 kHz, U_{MIN} = 6 V and R_L = 620 Ohm. From Fig. 7, shows that the amplitude-frequency

characteristic of the investigated QCEF scheme at the TIVT is uniform without "peaks" and "troughs" and the upper cutoff frequency at the level of –3 dB relative gain is 5 MHz.

IV. Conclusion

The developed quasi-complementary emitter follower has a fairly good uniform amplitude-frequency response in a wide frequency range. The study of AFC, AC confirms the practical feasibility of using QCEF on TIVT for building powerful output stages of transformerless power amplifiers.

Thus, the use of TIVT as amplifying elements in QCEF makes it possible to build powerful output stages of transformerless power amplifiers with high operational reliability in changing operating conditions, highly stable to destabilizing factors (inconsistency of the supply voltage and temperature). The proposed QCEF can be used in the final stages of power amplifiers, radio technical devices, industrial, information and automotive electronics.

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