Computer simulation of a push-pull power amplifier

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Abstract. The paper presents the results of computer simulation of power amplifiers based on bipolar and complementary Darlington transistors. It is shown that the constant voltage gain is ensured by changing the current gain in the range from 10^3to10^5.

1 Introduction

The paper presents the results of research on the development of power amplifiers based on bipolar transistors and power amplifiers based on complementary compound Darlington bipolar transistors [1]. The source material for this work was the results of works [2], devoted to the search for patterns of shaping the main characteristics of amplifying elements and a universal method for calculating power amplifiers with given indicators. The proposed methods of analysis made it possible to reveal previously unknown facts that lead to signal distortions when it is amplified.

The purpose of the research is to experimentally elucidate the possibilities of the proposed computer simulation of a class AB push-pull power amplifier of the method for calculating power amplifiers with specified performance characteristics.

2 Methods

At the first stage of this search, the active mode and the saturation mode of the bipolar transistor are considered, since these are the modes that are characteristic of class A, A, AB, BиG [3] power amplifiers.

At the second stage of studying the characteristics of a push-pull class AB power amplifier, the simulation of electronic circuits is carried out using modeling programs Lab view, Signal Express, Multi Sim, Ulti board National Instruments.

At the third stage, for experimental research, integrated microassemblies of bipolar transistors of the BD139/BD140andMJ802/MJ4502 types were used as the proposed push-pull class AB power amplifier.

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3 Results and discussion

The emitter current of a drift less bipolar transistor (BT) in active mode is determined by

$$I_E = [I_{00} + gU_{BC}]\{[exp(b(U_{EC} - U_{BC}) - cI_E)] - 1\} \quad (1)$$

where I_{00}[mA], b [V^{-1}], c[$^{-1}$], g [mS] – are the parameters of the drift less BT mathematical model.

Similarly for drift BT

$$I_E = I_0\left\{\left[exp\left((b_E + \chi U_{BC})\left((U_{EC} - U_{BC}) - \mu U_{BC}\right)\right)\right] - 1\right\} \quad (2)$$

Where I_0[mA], b[V^{-1}], χ[V^{-2}], μ[V^{-1}] – are the parameters of the drift BT mathematical model.

The threshold voltages base-collector $V_{BC\,th}$and emitter-collector $V_{EC\,th}$, determined at $I_E = 0$ by equations (1) and (2), will take the form, respectively, for a driftless BT.

$$V_{BC\,th} = V_{EC} \quad (3)$$

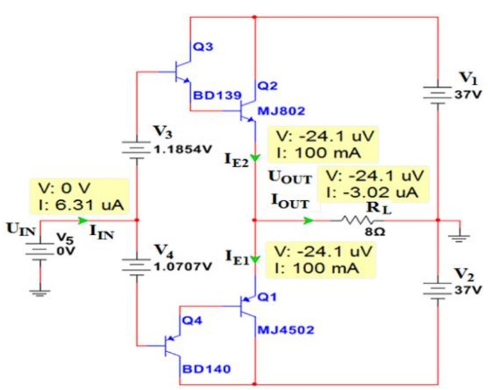
$$V_{EC\,th} = V_{BC} \quad (4)$$

And for drift BT

$$U_{BC\,th} = -\frac{b_E + \mu - \chi U_{EC}}{2\chi} + \sqrt{\left(\frac{b_{EC} + \mu - \chi U_{EC}}{2\chi}\right)^2 + \frac{b_E U_{EC}}{\chi}} \quad (5)$$

Table 1. Class AB power amplifier bias parameters

I_q, (mA)	V_3, (V)	V_4, (V)	V_{IO}, (V)
5	1.0515	0.9097	1.9612
10	1.0816	0.9465	2.0281
25	1.1218	0.9955	2.1173
50	1.1529	1.0328	2.1857
75	1.1717	1.0549	2.2266
100	1.1854	1.0707	2.2561
250	1.2322	1.1215	2.3536
500	1.2731	1.1610	2.4341



a) *b)*

Fig.1. Electrical circuit for studying the characteristics of a class AB push-pull power amplifier based on transistors BD139/BD140, MJ802/MJ4502 (a) and bias parameters (b)

$$U_{EC\,th} = 1 - \frac{\mu}{b_E - \chi U_{BC}} \tag{6}$$

Consider the theoretical construction of the load characteristic of a push-pull amplifying stage of class AB, the diagram of which is shown in Fig.1a. Fig.1b shows Table 1 with fixed values of the amplifier bias for the quiescent current in the range from 5 to 500 mA.

Dependences of the output current and voltage (1), emitter currents of the upper (2) and lower (3) arms on the differences between the input and output voltages of the amplifier $V_{IN} - V_{OUT}$ at $V_1=V_2=\pm 37$V, $R_L=8\ \Omega$ and quiescent current $I_q=100$ mA are shown on different scales in Fig.2.

Note that the output current of the amplifier is determined by the difference between the emitter currents

$$I_{OUT} = I_{E1} - I_{E2}.$$

According to the developed method [3], Fig. 3 shows the combined load characteristic of the amplifier in question, which makes it possible to visually combine its four parameters $V_{IN}, I_{IN}, I_{OUT}, V_{OUT}$.Here, curve 1 reflects the relationship between the output current and voltage and the input voltage. Curve 2 shows the dependence of the input current on the input voltage.These relationships are determined at given values of the input voltage.For example, with $V_{IN} = 20\ V$ and input current $I_{IN} = 0.2\ mA$, output current $I_{OUT} = 2.5A$, and $V_{OUT} = 20\ V$.

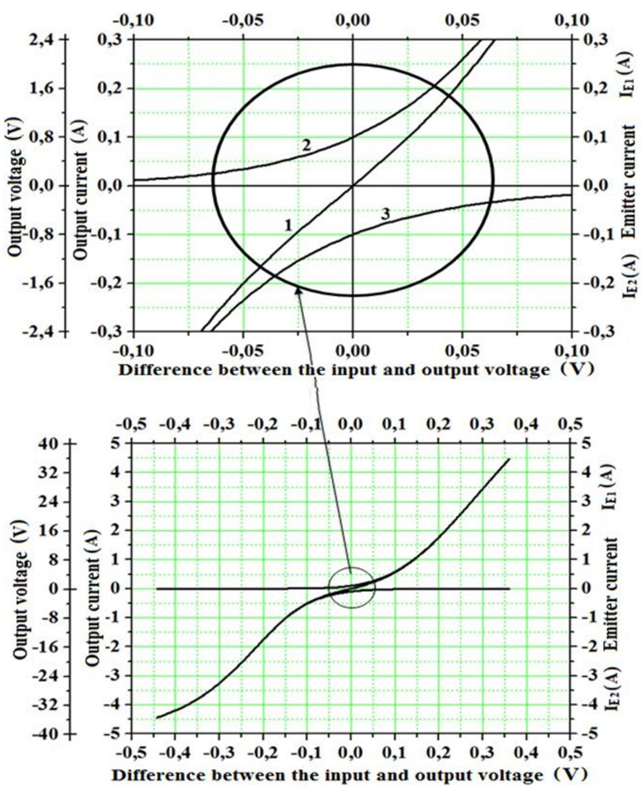


Fig. 2. Dependences of the output current (1), emitter currents of the upper (2) and lower arms (3) on the difference between the input and output voltages of a class AB power amplifier at $V_1=V_2=\pm 37$ V, $R_L=8\ \Omega$ and $I_q=100$mA.

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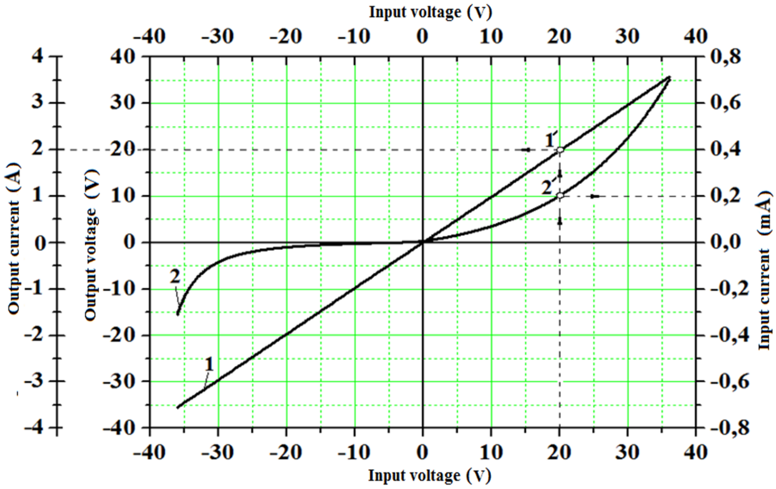
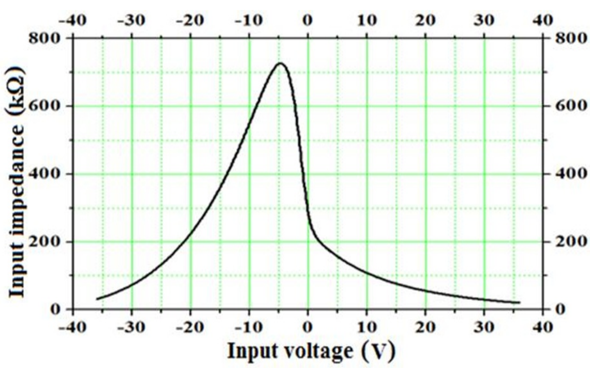
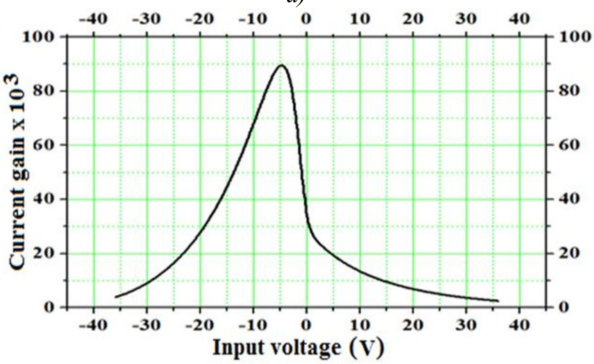


Fig. 3. Combined load characteristic of a class AB push-pull power amplifier at $V_1=V_2=\pm37$ V, $R_L=8\ \Omega$ and $I_q=100$ mA.

In addition, the combined load characteristic makes it possible to obtain the dependences of the input (Fig. 4a) and output (Fig. 4c) resistances, as well as the current gain (Fig. 4b) on the input Voltage. The asymmetry of these dependences is associated with the non-identity of the composite transistors, and the constancy of the voltage gain is ensured by changing the current gain in the range from 10^3до 10^5.



a)



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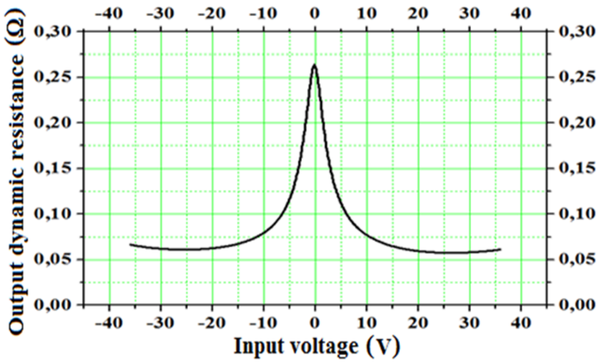


c)

Fig. 4. Dependences of the input resistance (a), current gain (b) and output dynamic resistance (c) on the input voltage of the class AB power amplifier at $V_1=V_2=\pm 37V$, $R_L=8\ \Omega$ and $I_q=100mA$.

On the other hand, the voltage gain depends on the value of the quiescent current I_q, which is determined by the given bias voltage $V_{IO} = V_3 + V_4$ (see Fig.1b Table 1).

The graphs of the output current depending on the difference between the input and output voltages of the amplifier are shown in Figure 5. It follows from the given family of dependencies that in the range of the amplifier quiescent current from 5 to 500 mA, the nonlinearity of the characteristic approaches a linear dependence.

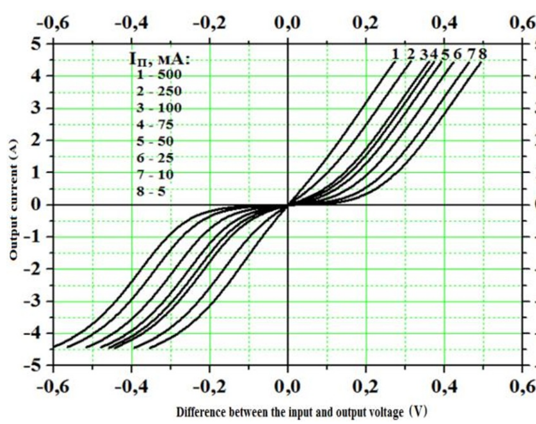


Fig. 5. Dependences of the output current (1, 2, 3, 4, 5, 6, 7, 8) on the difference between the input and output voltages of a class AB power amplifier on transistors BD139/BD140, MJ802/MJ4502 at $V_1=V_2=\pm 37$ V, $R_L=8\ \Omega$.

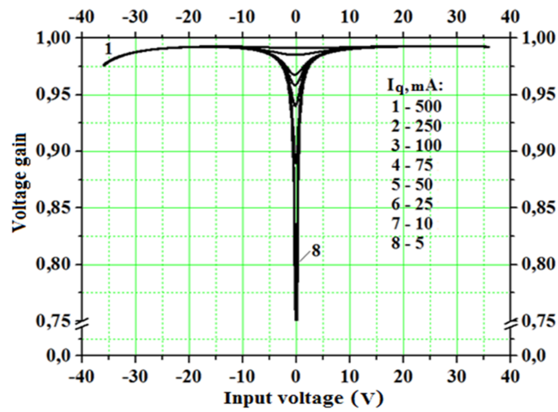
This means that as the quiescent current I_q increases, the internal resistance of the amplifier approaches zero and becomes practically unchanged.For example, at $I_q = 500\, mA$ the dependence of the output current on the difference $(V_{IN} - V_{OUT})$ becomes almost linear, and the internal resistance is 60 mΩ. The damping factor at $R_L=8\ \Omega$ is

$$DF = \frac{R_L}{R_{OUT}} = \frac{\Delta I_{OUT} \cdot R_L}{\Delta(V_{IN} - V_{OUT})} = 130.$$

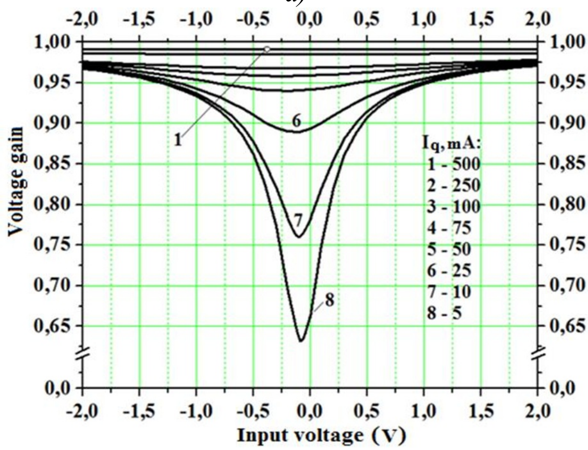
Note that a sufficiently high value of DF was obtained in an amplifier without deep feedback. With its use, DF increases significantly.

These changes can be most clearly demonstrated using graphs of the dependence of the gain on the input voltage of the amplifier in the range of ±36V, shown in Figure. 6a and ±2V in Figure. 6b at fixed values of the quiescent current I_q.

So, in the range of changes $U_{IN} = \pm 2\ V$ at $I_q = 5\ mA$, the voltage gain changes from 0.6 to 0.97, while for $I_q = 100\ mA$, K_V changes only from 0.970 to 0.974. At a quiescent current of 500 mA, the gain K_V is almost constant at 0.985.



a)



b)

Fig. 6. Dependences of the gain of a push-pull class AB power amplifier on the input voltage in the range of ±36 V (a) and ±2 V (b) at fixed values of the quiescent current**.**

The theoretical studies carried out were fully confirmed by us experimentally. The scheme of experimental studies of the cascade of a class AB power amplifier at $V_1=V_2=37$ V, $R_L=8\ \Omega$ is shown in Fig.7.

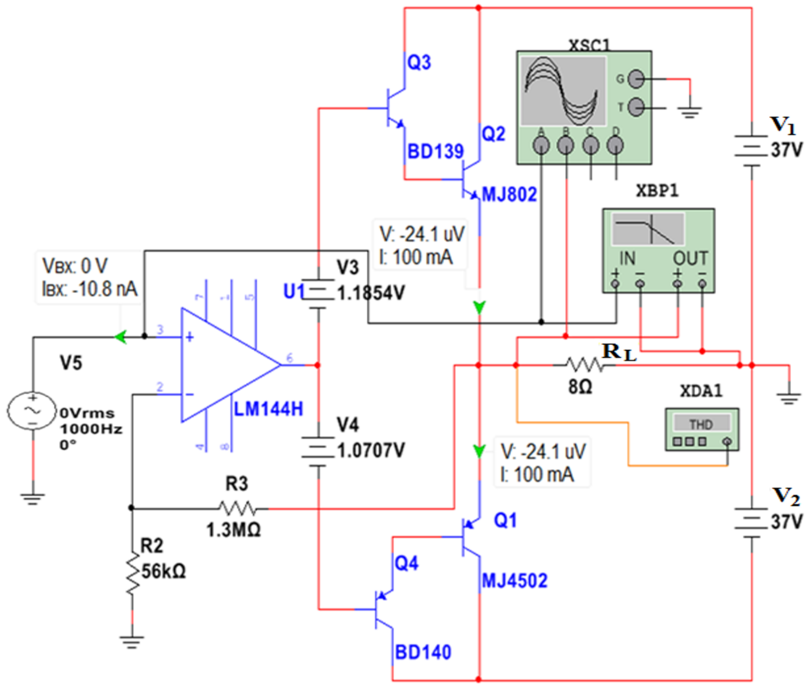
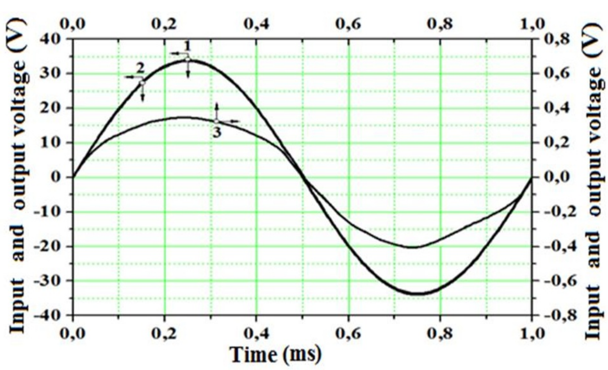


Fig. 7. Scheme for studying a class AB power amplifier based on transistors BD139/140 and MJ802/4502, with R_L=8 Ω.

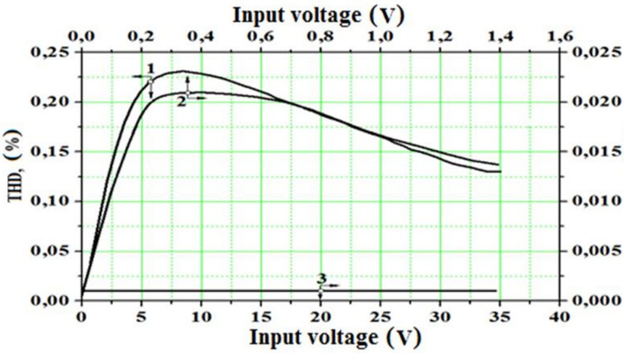
The research results are shown in Fig.8. The repetition of input $V_{IN}(\omega t)$ and output $V_{OUT}(\omega t)$ voltage shapes (Fig. 8a; curves 1 and 2) and significant voltage distortions at the emitter junction $V_{BE}(\omega t)$ (Figure. 8a; curve 3) are experimentally confirmed.

Fig. 8b shows the experimental results of the dependence of the total harmonic distortion factor THD on the input signal amplitude $V_{IN}(\omega t)$. Studies have shown that THD changes from 0.001 to 0.225% in the range of $V_{IN}(\omega t)$ from 0.1 to 35V, with $K_V =$ 1(Figure.8b, curve 1) without the use of an operational amplifier (OA).

The use of an op amp with deep feedback at $K_v = 24.2$. THD changes from 0.001 to 0.0225% in the range of $V_{IN}(\omega t)$ from 0.1 to 1.4 V. If 100% deep feedback is implemented, i.e. $K_V = 1$, then THD=0.002% (Fig.8 b, curve 2 and 3).



a)



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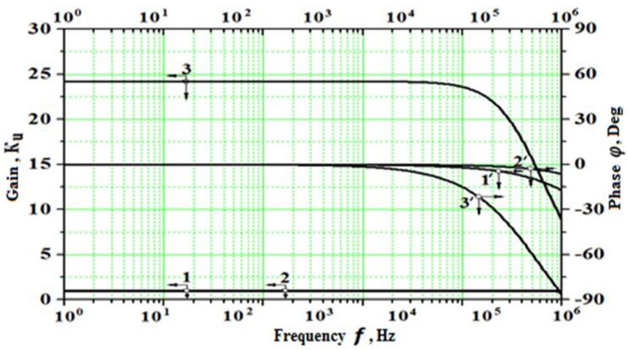

c)

Fig. 8. Timing diagrams of the class AB power amplifier stage: voltages $V_{IN}(t)$, $V_{OUT}(t)$, $(V_{IN}-V_{OUT})(t)$ (a); dependence of the coefficient of total harmonic distortion THD on the voltage amplitude U_{IN} (b) and the gain K_V and phase φ on the frequency (c): 1,2,3-frequency response and 1′,2′,3′-phase response.

The results of studying the behavior of the frequency response (curve 1) and phase response (curve 2) (Fig. 8c) are shown in the frequency range from 1 to $10^6 Hz$. The frequency response decreases from 0.998 to 0.999, and the phase response from 0 to -15 degrees, with $K_{\mathrm{V}} = 1$.

4 Conclusions

It has been established that in a class AB power amplifier based on bipolar transistors:

- input impedance $R_{d,IN}$, current gain K_i, and output impedance $R_{d,OUT}$ of a class AB amplifier in small signal mode are non-linearly dependent on input voltage;
- the asymmetry of these dependences is associated with the non-identity of the composite transistors, and the constancy of the voltage gain is ensured by changing the current gain in the range from 10^3 to 10^5. For example, for a push-pull power amplifier based on composite transistors BD139/BD140, MJ802/MJ4502, the numerical values of $R_{d,IN}$increase from $20\ k\Omega$ to $740\ k\Omega$, K_i from $5 \cdot 10^3$ to $8.8 \cdot 10^4$ and $R_{d,OUT}$ from $0.06\ \Omega$ to $0.260\ \Omega$;
- in the large signal mode, the voltage gain K_{v} depends on the value of the quiescent current I_{th}, which is determined by the specified bias voltage $V_{IO} = V_3 + V_4$;
- in the range of the quiescent current I_{th} of the amplifier from $5\ mA$ to $500\ mA$, the nonlinearity of the transfer characteristic in terms of voltage $K_{\mathrm{v}} = f(V_{IN})$approaches a

linear dependence;

- in the range of changes $V_{IN} = \pm 2\ V$ at $I_q = 5\ mA$, the voltage gain K_V changes from 0.6 to 0.97, while for I_q=100 mA, K_V changes only from 0.970 to 0.974. At a quiescent current I_q=500 mA, the gain K_V is almost constant and equal to 0.985.For example, for the specified power amplifier at $I_q = 500\ mA$, the dependence of the output current on the difference $(V_{IN} - V_{OUT})$ becomes almost linear, and the internal resistance is 60 mΩ;
- damping factor DF=130.

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