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The output stage of an operational amplifier on GaAs n-channel field-effect and GaAs p-n-p bipolar transistors with nonlinear negative feedback

Zhuk A. A.¹, Prokopenko N. N.¹, Pakhomov I. V.¹, Titov A. E.²

¹ Don State Technical University, Rostov-on-Don, Russia

² Southern Federal University, Rostov-on-Don, Russia

*E-mail: Alexey.zhuk96@mail.ru, ORCID: 0000-0002-7116-5924.

Abstract:

A new circuit of the output stage of an operational amplifier implemented on GaAs n-channel field-effect transistors with a control p-n junction and GaAs bipolar p-n-p transistors is investigated. Its peculiarity consists in the presence of a nonlinear negative feedback that stabilizes the drain current of the output transistor with an n-channel at a negative input voltage. The basic equations for the static mode of the output stage are given. The results of modeling in the LTspice simulation software of 3 modifications of the proposed circuit solutions are discussed.

Keywords: operational amplifier, output stage, GaAs JFET, GaAs BJT, analog microcircuitry, LTspice.

1. Introduction

A significant number of circuits of output stages (OS) of operational amplifiers (Op-Amp) are known, which are implemented on complementary bipolar (BJT) and field-effect (JFET, CMOS, SOI, SOS, etc.) transistors [2-28]. The above-mentioned OS circuit solutions are most popular in analog microcircuits implemented on the basis of standard technological processes [2-28].

In modern microcircuitry technology, there are a number of instrumentation tasks for extreme operating conditions (exposure to low temperatures and penetrating radiation). To solve them, it is promising to use circuit solutions, including Op-Amp with OS, based on GaAs basic matrix crystals [29].

The features of the existing GaAs technological processes [30-33] impose significant restrictions on the OS circuitry of this subclass. This is due to the types of transistors being implemented and their characteristics. In particular, the GaAs technological process of the “Minsk Scientific Research Institute of Radio Materials” (<https://mniirm.by>) is focused on the manufacture of analog circuits containing only field-effect GaAs transistors with a control p-n junction and bipolar

GaAs p-n-p transistors. Thus, there are a number of restrictions on the circuitry of analog devices when using this technological process.

The purpose of the article is to consider the proposed GaAs OS circuitry of this subclass and perform their computer modeling in the LTspice simulation software.

The purpose and novelty of the article is to consider the proposed GaAs circuitry of the OS of the Op-Amp and perform its computer simulation in the LTspice simulation software.

Fig. 1 shows a scheme of a well-known silicon OS, which was used as a prototype of the proposed GaAs OS [1].

Fig. 1 – Scheme of the well-known BiJTJFet silicon OS Op-Amp [1]

A significant disadvantage of the OS in Fig. 1 is that it cannot be implemented on the basis of technological processes that allow creating only GaAs JFET field-effect transistors with a control p-n junction and GaAs bipolar p-n-p transistors (<https://mniirm.by>).

2. The scheme of the proposed OS

Fig. 2 shows the scheme of the proposed OS [1]. The resistor R_{load} in Fig. 2 and further simulates the properties of the OS load.

Fig. 2 – Scheme of GaAs OS Op-Amp [1]

If a positive input voltage $u_{in}^{(+)}$ is applied to the OS input in Fig. 2, then an output current $i_{load}^{(+)}$ is formed in the load R_{load} , the maximum value of which $I_{load..max}^{(+)}$ is determined by the maximum permissible current of the source of the field-effect transistor J1. In this case, using the J5 transistor, the base of the output bipolar transistor J2 is locked along the circuit, which can be excluded from further consideration of the operation of the circuit in this mode. When several elementary field-effect transistors are switched on in parallel as a J1 transistor (or its channel width is increased), the numerical values of the maximum current $I_{load..max}^{(+)}$ can be increased to the set values.

With a negative increment of the input voltage OS, the current in the load R_{load} is provided by the output bipolar transistor J2. Due to the decrease in the drain

current of the field-effect transistor J1, the static collector current of the bipolar transistor J5 decreases, which leads to an increase in the base current of the output transistor J2 and the output current in the load R_{load} with a negative $u_{in}^{(-)}$. As a consequence, the maximum negative current in the load R_{load} will be determined by the maximum drain current of the transistor J3:

$$I_{load.max}^{(-)} = \beta_2 I_{d.3}, \quad (1)$$

where, β_2 is the current gain of the base of the transistor J2; $I_{d.3} = U_{gs.3}/R_1$ is the static current of the J3; $U_{gs.3}$ is gate-source voltage of the J3 field-effect transistor.

At the same time, due to the negative feedback, the current of the source of the field-effect transistor J1 practically does not change ($I_{s.1} \approx \text{const}$) and, consequently, the increment of the output voltage in this OS mode corresponds to the increment of its input voltage $u_{in}^{(-)}$. As a consequence, the maximum negative current in the load R_{load} will be determined by equation (1).

In static mode ($R_{load} = 1 \text{ M}\Omega$, $u_{in} = 0$), the following currents and voltages are set in Fig. 2:

$$U_{eb.5} + I_{d.3}R_3 = U_{eb.6} + R_4(I_{e.6} + I_{thr}), \quad (2)$$

where $U_{eb.5}$, $U_{eb.6}$ – the emitter-base voltages of bipolar transistors J5, J6; I_{thr} – through current OS at $R_{load} = 1 \text{ M}\Omega$; R_1 , R_3 , R_4 – resistance of resistors R1, R3, R4; $I_{e.6}$ – static current of the emitter of the bipolar transistor J6.

It follows from equation (2) that for $I_{d.3} = \text{const}$, $I_{e.6} = \text{const}$, $U_{eb.5} \approx U_{eb.6}$, due to the choice resistance of resistors R3, R4 in the circuit in Fig. 2, the set values of the through current I_{thr} are set.

The peculiarity of the proposed OS scheme in Fig. 2 is the presence of a general negative feedback relative to the Out, which ensures a high linearity of the amplitude characteristic – the absence of a dead zone characteristic of the well-known OS class "AB".

Fig. 3 shows the scheme of the proposed GaAs OS Op-Amp for the case when transistors J3, J4 are made according to a cascode structure. This increases the loop gain along the negative feedback circuit of the OS, and reduces the influence of voltage instabilities on the power supply's buses.

Fig. 3 – Cascode structure of GaAs OS Op-Amp

A source voltage repeater (VR) is introduced into the circuit in Fig. 4, which increases the loop gain along the negative feedback circuit of the OS, and also allows you to obtain higher values of the maximum current in the load $I_{load..max}^{(-)}$.

Fig. 4 – Scheme of GaAs OS Op-Amp with high $I_{load..max}^{(-)}$

To reduce the numerical values of the resistance of the resistor R4, the bipolar transistor J6 in the circuits in Fig. 3 and Fig. 4 can be made in the form of parallel inclusion of several elementary bipolar transistors. In this case, the numerical values of the resistance of the resistor R4 can be measured in tens or hundreds of ohms.

3. Computer simulation results

Fig. 5 shows a scheme for modeling GaAs OS in Fig. 2 in an LTspice simulation software at $t=27^\circ\text{C}$, $R_1=350\ \Omega$, $R_2=150\ \Omega$, $R_3=11.5\ \text{k}\Omega$, $R_4=5.4\ \text{k}\Omega$, $+v_{cc}=-v_{ee}=10\ \text{V}$, $R_{\text{load}}=1\ \text{M}\Omega$, static voltage at the input OS V1 = -1.2 V.

Fig. 5 – Scheme for modeling GaAs OS in Fig. 2 in the LTspice simulation software

Fig. 6 shows the amplitude characteristic of the OS in Fig. 5 at $t=27^\circ\text{C}$, $R_1=350\ \Omega$, $R_2=150\ \Omega$, $R_3=11.5\ \text{k}\Omega$, $R_4=5.4\ \text{k}\Omega$, $+v_{cc}=-v_{ee}=10\ \text{V}$, $R_{\text{load}}=5\ \text{k}\Omega/20\ \text{k}\Omega/1\ \text{M}\Omega$, static voltage at the input OS V1 = -1.2 V.

Fig. 6 – Amplitude characteristic of the OS of Fig. 5 at $t=27\text{ }^{\circ}\text{C}$

Fig. 7 shows the scheme for the simulation of GaAs OS in Fig. 4 in the LTspice simulation software at $t=27\text{ }^{\circ}\text{C}$, $R1=350\text{ }\Omega$, $R2=150\text{ }\Omega$, $R3=5.4\text{ k}\Omega$, $R4=11.5\text{ k}\Omega$, $R5=5\text{ k}\Omega$, $R_{\text{load}}=1\text{ M}\Omega$, $+v_{\text{cc}}=-v_{\text{ee}}=10\text{ V}$, the static voltage at the input OS $V1=-1.17\text{ V}$.

Fig. 7 – Scheme for simulating the GaAs OS of Fig. 4 in the LTspice simulating software

Fig. 8 shows the amplitude characteristic OS in Fig. 7 at $t=27\text{ }^{\circ}\text{C}$, $R_1=350\text{ }\Omega$, $R_2=150\text{ }\Omega$, $R_3=5.4\text{ k}\Omega$, $R_4=11.5\text{ k}\Omega$, $R_5=5\text{ k}\Omega$, $+V_{CC}=-V_{EE}=10\text{ V}$, $R_{load}=2\text{ k}\Omega/20\text{ k}\Omega/1\text{ M}\Omega$, static voltage at the input OS $V_1=-1.17\text{ V}$.

Fig. 8 – Amplitude characteristic of the OS of Fig. 7 for $t=27\text{ }^{\circ}\text{C}$

4. Conclusion

Computer modeling (Fig. 5 – Fig. 8) shows that the proposed GaAs OS [1], whose circuitry is adapted for use in the low temperature range and the effects of penetrating radiation [28], has significant advantages in comparison with the known options for constructing OS when they are implemented on silicon JFET field-effect transistors with a control p-n junction and bipolar p-n-p transistors.

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