PAPER • OPEN ACCESS

Formation of synergetic effects in integrated circuits operational amplifiers based on the current dynamic cascades

View the article online for updates and enhancements.

IOP ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Formation of synergetic effects in integrated circuits operational amplifiers based on the current dynamic cascades

A A Lebedev[1], I I Liakhchilina[1] and N M Klokov[1]
[1]National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe shosse 31, 115409 Moscow, Russian Federation

Corresponding author e-mail address: Lebedev741@mail.ru

Abstract. In this paper, the existing IC developments (Bazes operational amplifier with an automatic set of modal current, current feedback operational amplifier (CFA), a two-channel operational amplifier with an accurate combination of AFC areas of low and high-frequency channels) from the standpoint of synergistic effect is analyzed. New architectural, structural and circuit solutions to improve the accuracy, speed and radiation characteristics with the help of directional formation of synergistic effect (SE) proposed by the authors are also considered. A number of criteria to ensure future product improvement compared to commercially available are presented.

1. Introduction

Currently, there are several major developments in the creation (design) of industrial ICs wide application [1-4]. These include the following developments: a high-speed current feedback operational amplifier (op amp) (CFA), which successfully solved the problem of the relative independence of the gain and bandwidth of negative feedback amplifier (NFA) [5]; wideband amplifier [1] with automatic modal current in CMOS technology, as well as wideband op amp with accurate combination Bode diagram plots of low-frequency and high-frequency amplifier stages.

The new approach connected to use of controlled macrocells of current cascades [6] in order to expand their functionality and to use of local negative feedback, proposed in [5].

2. The presence of synergy effects, their analysis and use to improve the quality of industrial op amp IC

Improvement of the technical characteristics mentioned in the introduction can be considered (examined) from the perspective of synergistic effect.

In synergy dynamic systems are combined, and the new entity is not equal to the sum of the parts and forms a system of another organization or system level. An indication of this is the amplifier [2] (let's call it Bazes amplifier), in which SEFF is achieved by ring connection of two gain stages. This allows setting a single ring current by automatic tuning the resistances of current sources formed by the diode-connected transistors in the NMOS and PMOS, respectively. Bazes amplifier is a three-stage structure; the first two stages have feedback of -3 dB, for a total of -6 dB. Stability of Bazes amplifier covered by feedback is achieved by inserting local negative feedback. This allows, on the one hand, to expand the bandwidth at a gain of 32 dB and on the other hand, receive the phase margin of 80-85 °.

3. Methods of improving accuracy and speed parameters of industrial grade LM124 bipolar op amp IC

In this paper, the use of main architectural, structural and circuit solutions, viewed from the perspective of the SE is proposed.

The main difference of proposed solutions is connected to the organization of an improved (compared to conventional) op-amp architecture, in which instead of one differential cascade (DC) a parallel connection of two stages with a common mid-point is used. This midpoint is fed with in-phase component of the output signal, which allows weakening the dependence of the dynamic offset on the impact of the input common-mode signal.

a)   b)
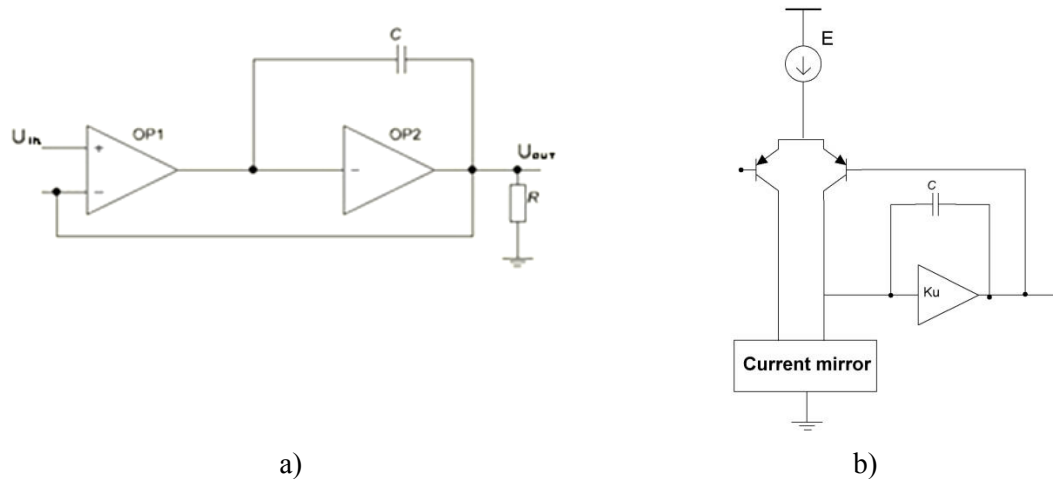
Figure1. LM124 op amp: a - a standard LM124 op amp architecture, b - a standard LM124 op amp structural organization.

a)   b)
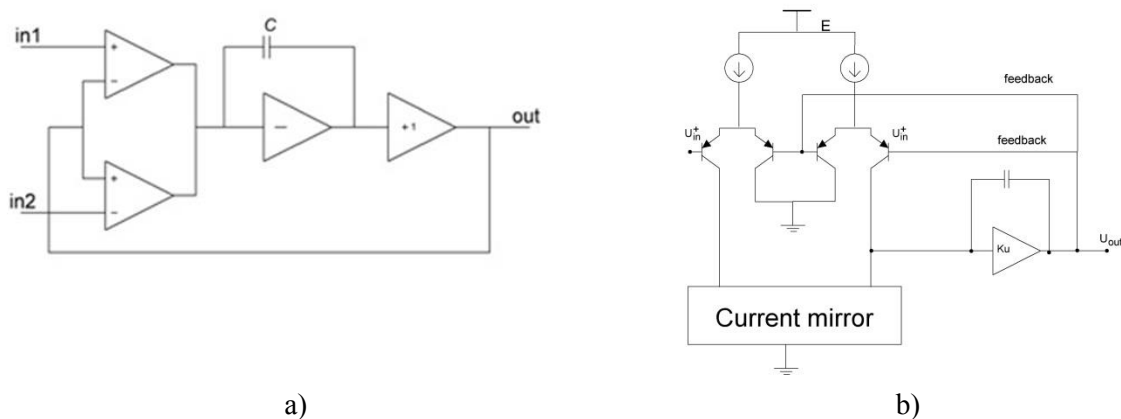
Figure2. Proposed op amp with extended bandwidth, increased slew rate and high resistance to HCP and the effect of in-phase signal: a - proposed op-amp architecture, b - proposed op amp structural organization.

Fig. 1 shows a standard LM124 op-amp architecture and structural organization. The disadvantage of this architecture is a hard relationship between accuracy, frequency and speed characteristics. Also, the in-phase component of the signal shift results in an undesirable constant component at the output of op amp. This shift can be described by the following simplified equation:

$$\Delta U_{out} = K_{dd}(\Delta U_{ind} + \frac{\Delta U_{insp}}{K_{ds}}) \tag{1}$$

where ΔU_{ind} - differential component of the input signal ΔU_{insp} - in-phase component of the input signal, K_{dd} - differential signal gain, K_{ds} - input to differential transmission coefficient. It can be shown [3] that the inverse of common mode rejection ratio (CMRR) for the typical architecture of the op amp is evaluated using the following expression:

$$\frac{1}{CMRR} = \Delta\mu = \mu_m \frac{\Delta\mu}{\mu_m} \tag{2}$$

Where
$$\mu_m = \frac{1}{W}\left(\frac{dW}{dU_{dd}}\right) = 5 \cdot 10^{-4} \tag{3}$$

For the proposed architecture in Fig. 2 for AC common-mode the following relation [3].

$$\frac{\Delta\mu}{\mu_m} = \frac{\Delta U_{dd}}{U_{dd}} \tag{4}$$

Then CMRR = 5×10^5. Thus, the proposed architecture of the input DC allows to increase the CMRR on order and weakens the rigid relationship between static and dynamic zero offset voltage, and also to reduce the response to the impact of HCP by doubling the current signal supplied to the input of the intermediate stage.

4. Dynamic current stages and the formation of synergistic effect based on them

In this section the dynamic current cascades are discussed, such as current mirror (CM) with automatic magnification (threw) the modal current while the degradation of the gain current β (further - Radiation-resistant reflector current Radiation Hardness Current Mirror (RHCM)), as well as a two-tier current reflector (current mirror) with a current collector to increase the dynamic output resistance and hence voltage gain.

Radiation-resistant current reflector shown in Fig. 6. Formed by including the amplifier stage arranged in a common base between points 1 and 2 of. In [5] the principles of analog circuits by replacing the one-loop current reflector structure by a two-tier structure Fig. 3 are discussed, which allows implementing the function:

$$I_w = \sqrt{\left(I_x^2 - I_y^2\right)} \tag{5}$$

An indispensable condition for the proper functioning is supply of variable sources of current I_x, I_y to a low-impedance inputs. This function was derived using translinear principle to the existing CM applications.

Returning to Widlar CM automatic increase of modal current at a current gain degradation β was tasked. Such formulation of the problem requires the inclusion of an amplifier stage with a common base and installation of the AC voltage on the basis of zero in the gap between points 1 and 2. The complete circuit is shown in Fig. 6, and its characteristic output current dependence on β in Fig. 5 In the resulting circuit, transmission factor is K_u:

$$K_u = 1 + \frac{\beta - 2}{\beta^2 + 2} \tag{6)}$$
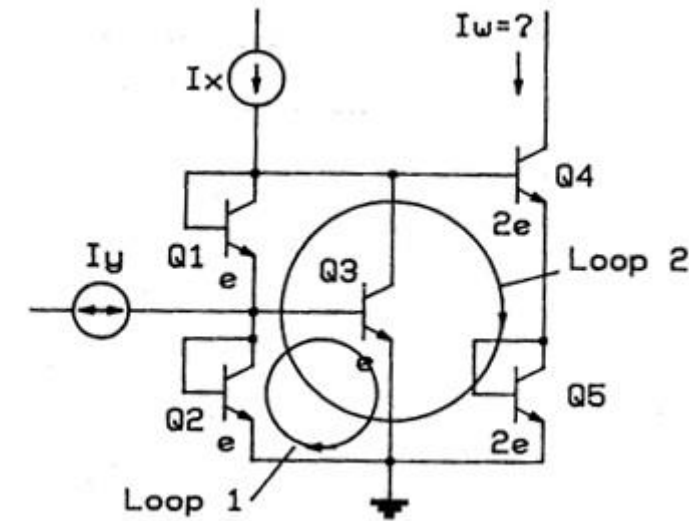
Figure 3. Two-loop structure CM shown by Toumazou.

From the diagram, it follows that the inclusion of a common base stage between points 1 and 2 produces a local positive feedback wherein unity loop gain is less than 1 which provides circuit stability when used as an input stage, either as an active collector load. Thus, the structure organization of the op amp on the basis of the proposed radiation-resistant CM reduces shift of the operating point at the output and thus extend the life cycle of a spacecraft in Earth orbit for 1 - 2 years.
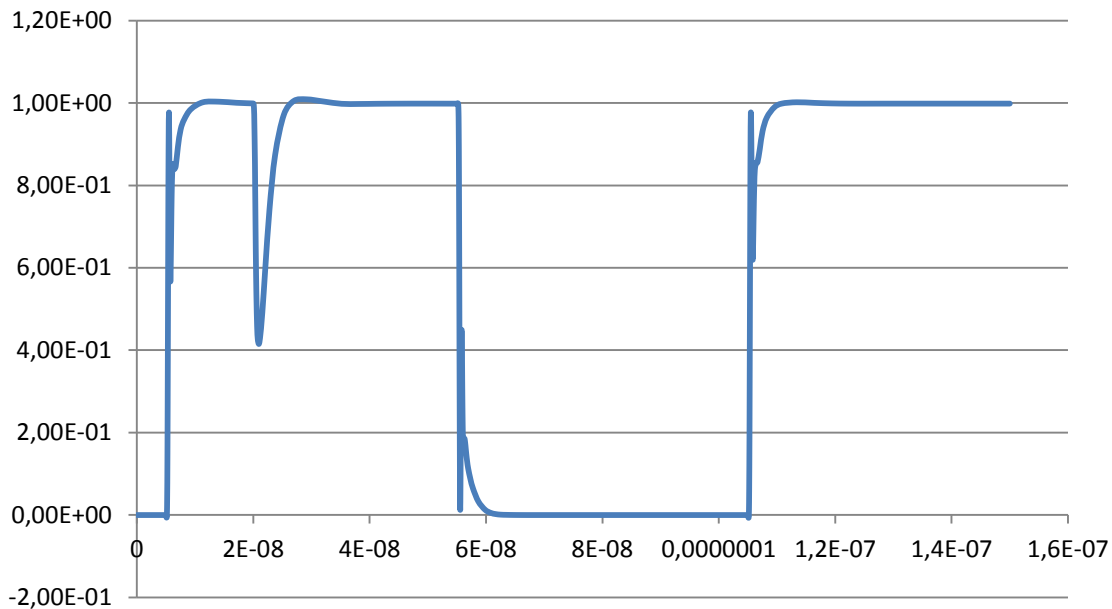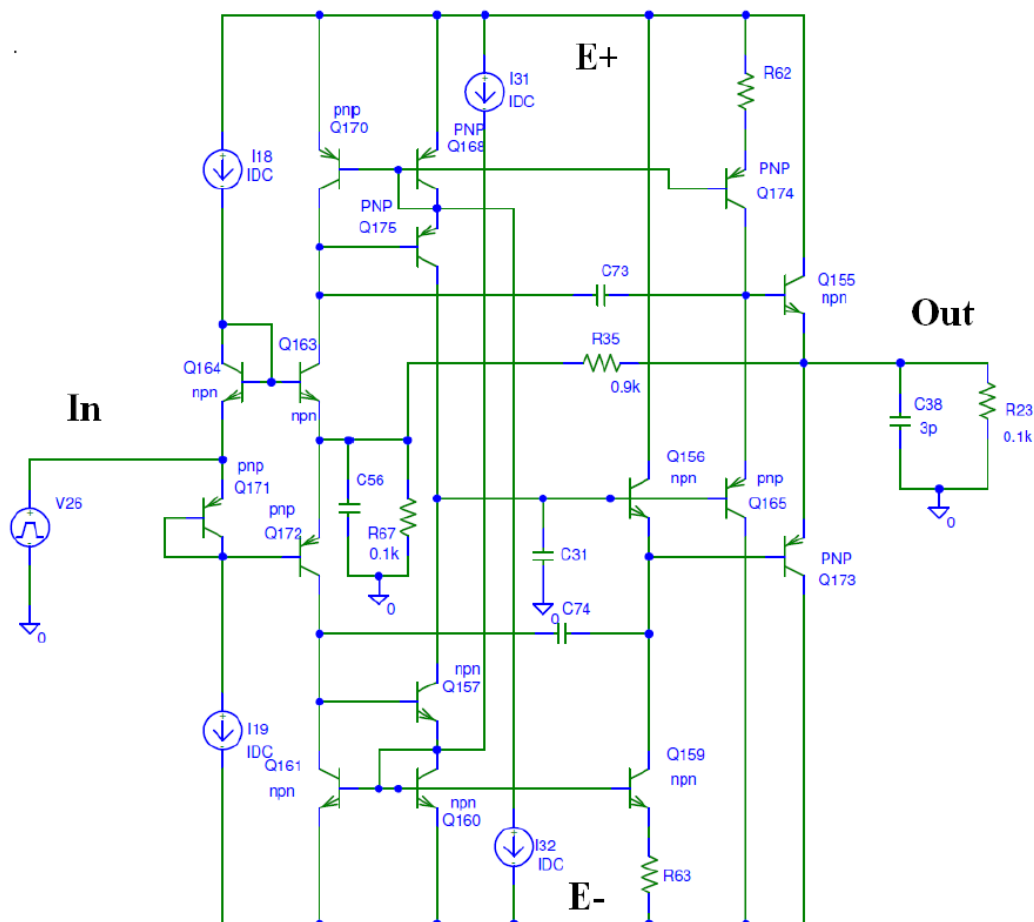

Figure 4. Transient Response to HCP.

As a result, the obtained dependence reflects the improvement of scheme's characteristics: no emissions on the transient response, reducing SET to 3 ns while reducing the amplitude of the HCP reaction.
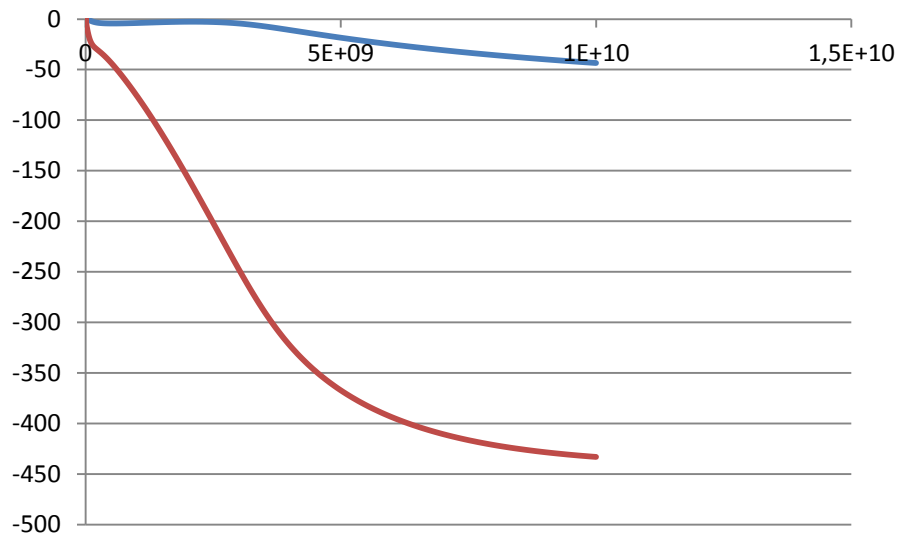
Figure 5. Frequency response (phase response and frequency response).

Figure 6. A simplified scheme of developed op amp with current feedback.

5. Discussion

It can be affirmed that improving accuracy, frequency and radiation characteristics is directly related to the formation of synergistic effect (SE), which self-formation can be described by the following criteria:

1. The presence of a local positive feedback, providing structure self-organizing in the predetermined direction to forming of SE.

2. Insertion of the dynamic current element (cascade) controlled by feedback.

3. The ability to control the system as a whole using negative feedback.

4. Maintaining stability of an op amp as long as the transfer constant loop gain less than one.

5. The openness of the system and communication with the external environment to maintain the energy of self-formation.

Thus, it is possible to predict the characteristics and parameters of the designed product.

References

[1]   Roche N J-H, Perez S, Mekki J et al 2011 *IEEE Trans. Nucl. Sci.* **58** 2980
[2]   Bazes M 1991 *IEEE JSSC* **26** 165
[3]   Soclof S 1985 *Analog Integrated Circuits (Los Angeles: Prentice-Hall)*
[4]   Lebedev A A, Nazarenko A E., Vakhnenko M S et al *2016 IOP Conf. Series: Mat. Sci. Eng.* **151** 012038
[5]   Toumazou C, Lidgey F J, Haigh D G 1990 *Analogue IC design: the current-mode approach*, (London: Six Hills Way) 23
[6]   Lebedev A A, Felitsyn V A, Komleva V A and Komlev A A 2016 *Proc. on Int. Federation for Medical and Biological Engineering (Chisinau)*(Springer) **55** 23