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Schematic techniques for improving precision and radiation hardness of current feedback operational amplifiers

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Abstract. The circuit design method of increasing the accuracy of the current feedback amplifier (CFA) by incorporating dynamic shunt into the Wilson current mirror is considered.

1. Introduction
Typical integrated circuits (ICs) of CFAs have a high slew rate and settling time and low bandwidth so they are widely used in real-time mode [1,2]. The disadvantage of such amplifiers is in the order of large error in the reproduction of voltage gain with a closed loop. Their advantages are the relative independence of the bandwidth of the voltage gain with feedback ($K_u$ must be less than 10).

This paper discusses the method of improving the accuracy of CFA and reducing the response time to the impact of a single heavy charged particles by incorporating a dynamic shunt into the Wilson current mirror.

2. Description of a typical circuit and transimpedance gain in op amp CF with open loop
The block diagram of CFA is shown in Fig. 1. It consists of input and output buffers. The current mirrors (CMs) are used as the input buffer load. The CMs’ output is supplied with a reflector on the output buffer, which provides work in a low-resistance load of 100 Ohms.

![Figure 1. The block diagram of CFA](image-url)
Fig. 1 shows that the output of CFA is constantly connected through a resistor $R_F$ to the non-inverting input. This connection enables work of the op amp with the feedback in the current repeater non-inverting mode. For example, applying the positive 1V signal to the input with a small delay we get the equal 1 V signal at the output: at the same time through resistor $R_F$ flows currently $I_F = \frac{U_{out}}{R_F} = 1 \text{ mA}$.

Despite the fact that in the classical sense there is a concept of negative feedback voltage, in the scientific literature, it is referred to as the feedback current, and therefore the gain of CFA with open loop will be determined by the so-called trans-impedance [3]: $Z_i = R_i C_i$, where $R_i$ is the output resistance of CMs, $C_i$ is the stray capacitance between CMs’ output and the input of output buffer ($Z_i$ - trans-impedance gain - "resistance conversion factor" measured in V/A or Ohm). Therefore Bode diagram for the CFA is the dependence of $Z_i$ on frequency. Moreover, since $R_F$ – enabled constantly, for the experimental determination of $Z_i$ it is necessary to divide a constant and a variable component of the input signal by connecting to the output capacitor large quantities. Bode diagram for this case is shown in Fig. 2.

![Figure 2](image)

**Figure 2.** The Bode diagram of CFA with close loop ($f_a=\frac{1}{2\pi R_i C_i}$ – the dominating pole frequency, $f_A=Z_i f_a/R_{FB}$ – unity gain frequency)

### 3. Methods of increasing trans-impedance gain

The load of the input repeater (Fig. 1) is a Widlar current mirror, which allows increasing the output impedance on the order in comparison with CM, collected on two transistors. The maximum gain of this scheme is about 80 dB. Further increase in the gain can be achieved by using a static or dynamic CM, shown in Fig. 3.

![Figure 3](image)

**Figure 3.** The upper half of the Wilson current mirror with I37 shunt
From Fig. 3 it follows that Q186 transistor is arranged on a common base with a dynamic shunt, which decreases its static current n times, the output impedance (Q186 collector resistance), respectively, is increased n times compared with Widlar CM.

The gain can be described by the following expression:

\[ K_U = K_{UQ186} \cdot K_{U2}, \]  

where:

\[ K_{U2} = \frac{g_{m1}}{g_{m2}} \approx 5, \]  

\[ K_{UQ186} = (r_{Q186} \parallel R_{in.buf.}) \cdot g_{m1}. \]

Considering that \( \beta_n = \beta_p = 100, (r_{Q186} \parallel R_{in.buf.}) \approx 1000 \text{ kOhm}, I_{K186}^0 = 1mA, \) we get:

\[ K_U = 5 \cdot \frac{1000000}{25} = 200000. \]

Thus, the main problem of obtaining gain 100dB at one stage with the help of static (dynamic) shunt is solved.

4. CFA key features

The concept of the developed CFA is shown in Fig. 4, and its frequency and transient response - in Fig. 5 and 6, respectively. The Fig. 5 shows that the unity gain frequency is 2.4 GHz with a phase margin of 40°.

![Figure 4. The concept of the developed CFA](image)
5. Response to the impact of HCP

Increased bandwidth has reduced single event time (SET) from 5 ns for a typical CFA to 3 ns. However, it should be noted that the further reduction of SET after hitting hard charged particle (HCP) a single critical node (Q159) is connected with the design of the CM automatically generating additional current while the current amplification factor $\beta$ is degradation [4].
6. Conclusion
The developed CFA circuit based on Wilson CM with static (dynamic) shunt allows to improve accuracy characteristics (trans-impedance increased by 3-5 times compared with the same of Wilson CM), to expand the bandwidth to 2.5 GHz with a phase margin of 40°, and also to reduce SET from 5 to 3 ns.

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References