

The Current-Feedback OTA (CFB OTA)

Part of this work was completed at the Signal and Information Processing Laboratory, ETH Zürich.

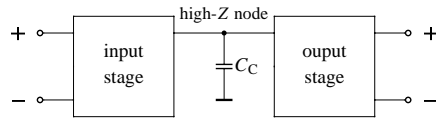
Abstract of the paper — The current-feedback OTA (CFB OTA) recently appeared in a new classification of operational amplifiers. It is dual to the operational floating amplifier (OFA), so all OFA circuits can readily be transposed into CFB OTA circuits. This paper discusses the theoretical basis of the CFB OTA, shows its relation to the OFA, and compares their performance in a simple V-I converter by showing how both can be built with the same two transistor stages. The advantages and disadvantages of the CFB-OTA implementation are discussed as well, but the main advantage of introducing the CFB OTA is that its introduction is virtually for free: most current opamps from the literature can be converted into CFB OTAs by re-wiring their input stage, without adding or re-sizing a single transistor.

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Operational Amplifiers

Operational Amplifiers consist of an input stage, a gain stage, and an output stage.

The simplest gain stage is a high-impedance node to which a compensation capacitor is connected.



BLOCK DIAGRAM OF AN OPERATIONAL AMPLIFIER.

Both the input stage and the output stage can have two high-impedance terminals, two low-impedance terminals, or one of each. Therefore there are voltage (V), current (I), and hybrid (H) input and output stages.

The H input stage can be understood as an extended I input stage whose analogue ground voltage is not fixed, but can be set through an additional terminal. The V output can also be extended to a hybrid stage. It copies the current flowing into the voltage output terminal to an additional current output terminal. This technique is called *output current sensing* or *supply current sensing*.

The centre node of every opamp is a high-impedance node, therefore all input stages need a high-impedance output (current output) and all output stages need a high-impedance input (voltage input). The opamp stages must perform the following functions:

	input stage	output stage
V	single-ended OTA	voltage buffer
I	current buffer	balanced-output OTA
H	CCII±	CCII-

FUNCTIONS OF THE OPAMP STAGES.

The nine possible combinations of stages are:

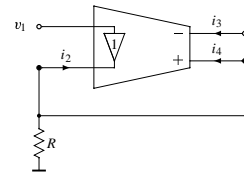
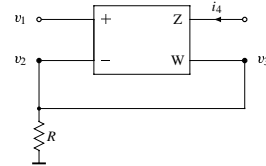
CLASS	COMMON NAME
V-I	operational transconductance amplifier (OTA)
V-V	operational amplifier (opamp)
V-H	operational floating amplifier (OFA)
I-I	current-mode opamp
I-V	operational transresistance amplifier (OTRA)
I-H	floating OTRA
H-I	current-feedback OTA (CFB OTA)
H-V	current-feedback opamp (CFB opamp)
H-H	operational floating conveyor (OFC)

COMMON NAMES OF THE NINE OPERATIONAL AMPLIFIERS.

To our knowledge, the current-feedback OTA (CFB OTA) has not been discussed yet in the literature.

Current-Feedback OTA and Operational Floating Amplifier

In this paper, the CFB OTA and the OFA are compared by using them in a very simple application: A V-I converter.



LINEAR VOLTAGE-TO-CURRENT CONVERTER WITH OFA (TOP) AND CFB OTA (BOTTOM).

Equations

Without the feedback and the feedback resistor R , the OFA is described by

$$i_1 = i_2 = 0, \quad v_3 = A_v(v_1 - v_2), \quad i_4 = -i_3, \quad A_v \rightarrow \infty,$$

and the CFB OTA is described by

$$i_1 = 0, \quad v_2 = v_1, \quad i_3 = -A_i i_2, \quad i_4 = A_i i_2, \quad A_i \rightarrow \infty.$$

(Positive currents are flowing into the amplifier terminals.)

Duality

The CFB OTA and the OFA are dual. Transposing a circuit containing OFAs will result in a circuit containing CFB OTAs, and vice versa. Thus all applications that were theoretically derived for the OFA can be transposed into applications of the CFB OTA.

Construction

Both circuits can be built using the two stages shown on the right plus a compensation capacitor.

The OFA has the single-output OTA as its input stage, and the CCII as its output stage. The terminal Y of the CCII is connected to the high-impedance point, its terminal X and Z are the terminals W and Z of the OFA. $C_C = 9$ pF.

The CFB OTA has the CCII at its input stage and the balanced-output OTA as its output stage; Z is connected to V_+ . $C_C = 2.5$ pF.

Comparison

Both circuits were simulated with BSIM 3v3 models that had proved to be reliable in two previous chip fabrication runs.

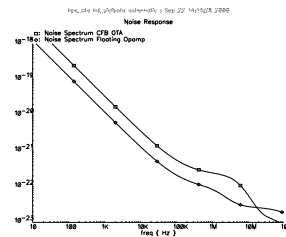
Transfer Function

The C_C were chosen such that the two circuits have the same AC transfer function magnitude and a DC transconductance of 520 μ S.

The simulated AC transfer functions show that the CFB-OTA circuit has the smaller phase lag. This is so because the outputs of the CFB OTA are symmetrical, and the phase lag is compensated by feedback, whereas the large phase lag in the OFA circuit is there because the current mirrors M61-M93 are outside the feedback loop. Of course, phase lag compensation by feedback has implications on the maximum speed of the circuit. The C_C of the CFB OTA circuit cannot be made much smaller without compromising the stability of the circuit, whereas the OFA circuit could still be made much faster by decreasing the value of C_C .

Harmonic Distortion and noise

In the OFA circuit, the high-gain feedback makes the voltage difference between the two inputs very small, whereas in the CFB-OTA circuit, the feedback makes the current i_2 very small. Thus the OFA circuit will have the more accurate voltage transfer function from v_1 to v_2 , while the CFB-OTA circuit will have better linearity, because the voltage buffer conducts only very little current. For the same reason, the output current noise of the voltage buffer will play a larger role in the CFB-OTA circuit than in the OFA circuit, so the CFB-OTA circuit will be noisier.



NOISE SPECTRA OF BOTH CIRCUITS.

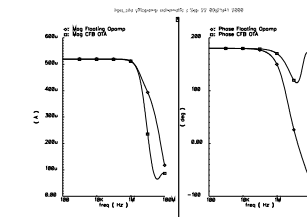
Simulations confirm this qualitative analysis. Transient simulations with both circuits show that the THD for a 100-kHz signal reaches 1% for an input signal magnitude of 7.8 mV in the CFB-OTA circuit and only 2.5 mV in the OFA circuit, which is a factor of 10 dB lower. Looking at noise, one finds, as expected, that the CFB OTA circuit is noisier than the OFA circuit. The factor between the two noise spectra shown below is 8 dB, thus if one looks at the SNR at 1% THD, the CFB-OTA circuit is only 2 dB better than the OFA circuit.

Transistor Dimensions

M11, M21, M31, M41	15 × 1.8 μ m
M12, M22	600 × 0.6 μ m
M13	45 × 7.2 μ m
M33, M43	45 × 1.8 μ m
M51	13.5 × 1.8 μ m
M52, M62	600 × 0.6 μ m
M53, M63, M73	
M83, M93	45 × 1.8 μ m
M61, M71, M81, M91	15 × 1.8 μ m

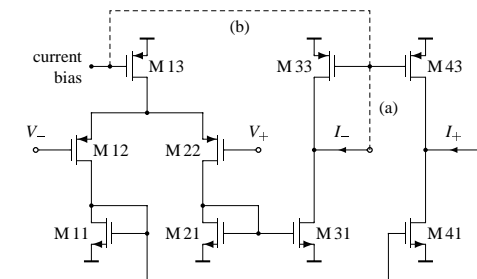
SIZES OF ALL TRANSISTORS IN THE CIRCUITS.

Bias Current: 40 μ A per branch.

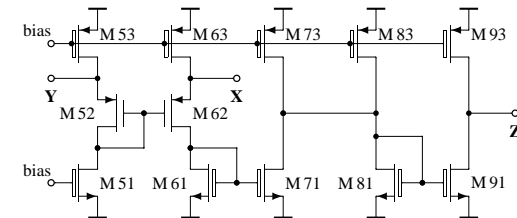


AC TRANSFER FUNCTION OF BOTH CIRCUITS.

Circuits used for the simulation



TRANSISTOR SCHEMATIC OF THE OFA.



TRANSISTOR SCHEMATIC OF THE CCII.

Conclusion

Theoretical discussions and simulations of an application example show that the CFB OTA can have advantages over the operational floating amplifier (OFA). Specifically, a V-I converter built with a CFB OTA is much more linear than the same circuit built with an OFA. Although it is not in any general way better than any of the other operational amplifiers, the CFB OTA may have advantages in specific applications. Its introduction is almost for free, because most current opamps found in the literature can be used as CFB OTAs without adding or re-sizing a single transistor.