HIGH ACURACCY CURRENT-MODE PRECISION RECTIFIER BASED ON UNITY-GAIN CELLS

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Abstract. *In this paper a new current-mode full-wave precision rectifier is presented. The circuit uses a single current follower, a reduced number of passive components and provides output signals as voltage or/and as current. With a little modification the circuit can handle voltage as well as currents without performance alteration. The main features of the proposed circuit consist in its very good transient response, including at high frequency, and the increased accuracy.*
Keywords: *current-mode operation, precision rectifier, current-mode devices, current follower, unity gain cells.*

Introduction

Current-mode operation has proved its advantages over the conventional voltage-mode operation in a lot of application areas, not only in linear circuits as active filters [1][2] or transconductance amplifiers [3][4], but also in non-linear circuits as triggers [5], relaxation oscillators [6] or precision rectifiers [7][8]. Among these advantage we may cite the wider dynamic range, the better linearity over the full operation range, the much low temperature sensitivity and the lower power supply voltages [9]. A special class of current-mode devices, namely "unity gain cells" includes the simplest one, the voltage followers (VF) and current followers (CF). Initially, they was designed to be used as voltage buffers, respectively as current buffers, but as time goes on they have fond the usefulness in some linear applications too [10][11]. In order to preserve the overall performances of the current-mode circuits that use voltage followers, these are built using translinear technology. Such realisation, which is a component part of OPA660 transadmitance operational amplifier [4], is reproduced in fig.1. The bias circuits were omitted in this example. As for the symbol, in current-mode operation there are accepted two representations, depicted in fig.2.

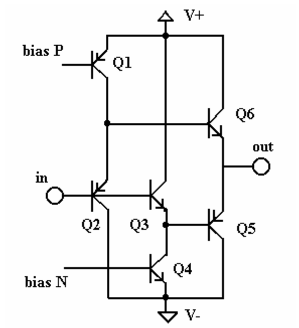

Fig.1 A translinear implementation of a voltage follower

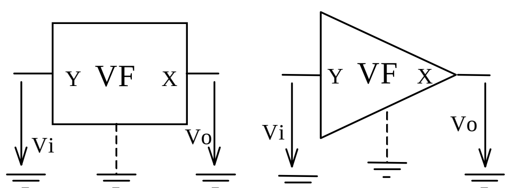

Fig. 2 The symbols of current-mode voltage follower

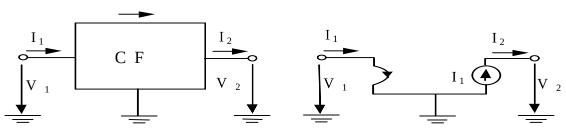

Fig. 3 The symbol and the equivalent circuit of the current follower

The notation for the input and the output are borrowed from the current conveyor that was the first current-mode device implemented [12].

The current follower is the simplest current-mode device and its symbol and equivalent circuit, with the port signals, are shown in fig.3. With the references in fig.3, the functional equation of the CF is given by eqn.1.

$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_2 \\ I_1 \end{bmatrix} \qquad (1)$$

A variant of CF is the Double Output CF (DOCF), which has two outputs, the currents that flow through them having opposite signs and being both equal to the input, as magnitude. The ports of DOCF are noted as shown in fig.4: the input with X, the direct output with Z+ and the reversed output with Z- (opposite to the notation of current conveyor).

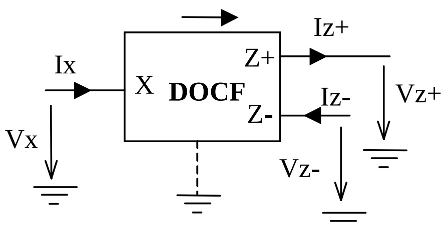

Fig. 4 DOCF symbol and port signals

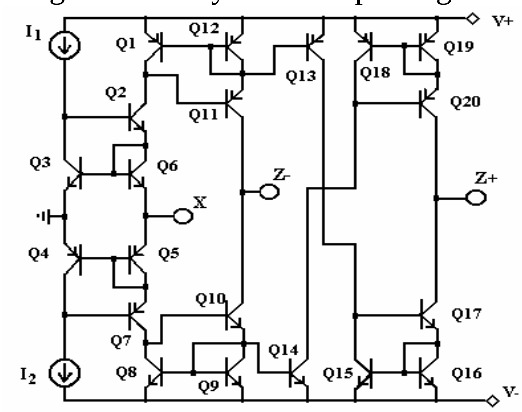

Fig. 5 DOCF scheme

The functional equation modifies as follows:

$$\begin{bmatrix} V_x \\ I_{z+} \\ I_{z-} \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ -1 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_{z+} \\ V_{z-} \end{bmatrix} \qquad (2)$$

In fig.5 we give the scheme of the DOCF, in bipolar technology, which was used to perform SPICE simulations. To increase the accuracy of DOCF, simply current mirrors were replaced with Wilson current mirrors.

Circuit description

The already known precision rectifiers employ only current conveyors of different types [7][8]. In succession we propose a very simple current-mode full-wave rectifier which uses only one DOCF, four diodes and, optional, one or two resistors. The circuit schematic is presented in fig. 6.

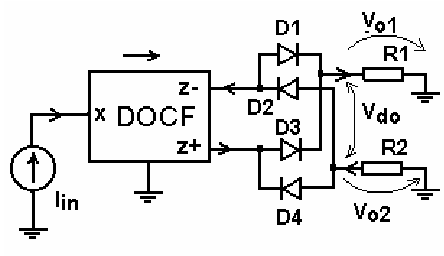

Fig. 6 First full-wave precision rectifier scheme

When the input current is positive, D1, D3 diodes are ON and D2, D4 diodes are OFF. When the polarity of the input current changes, D1, D3 diodes are OFF and D2, D4 diodes are ON. Thus, into R1 flows the positive full-wave rectified current since the negative one flows into R2. If the outputs of the rectifier must be currents, R1 and R3 are not necessary, the outputs of the diode-bridge being connected straight to the ground. When the output must be a voltage, one or both resistors are required. It is advisable that the value of the resistors be chosen as small as possible in order to improve the accuracy at high frequency due to the pole that the resistor and the output capacity of the bridge form. We must notice that it is possible to double the output voltage if consider the differential output Vdo.

In the real case, the functioning of the DOCF is described by the equation 3, where α and β are real quantities smaller than 1 but very close to it. Typical values are α=0.96 and β=0.98.

$$\begin{bmatrix} V_x \\ I_{z+} \\ I_{z-} \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 \\ \alpha & 0 & 0 \\ -\beta & 0 & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_{z+} \\ V_{z-} \end{bmatrix} \qquad (3)$$

As a consequence, the expressions for Vo1 and Vo2 are:

$$V_{o1} = \begin{cases} I_{in}\alpha R_1 \mid I_{in} \geq 0 \\ -I_{in}\beta R_1 \mid I_{in} < 0 \end{cases} \quad (4)$$

$$V_{o2} = \begin{cases} -I_{in}\alpha R_2 \mid I_{in} \geq 0 \\ I_{in}\beta R_2 \mid I_{in} < 0 \end{cases} \quad (5)$$

The error of the output current on the two alternations may be computed as

$$\frac{V_{o1} \mid I_{in} \geq 0}{V_{o2} \mid I_{in} < 0} = \frac{\alpha}{\beta} \quad (6)$$

which means an error of 2% for the values considered. This error is more than acceptable and is smaller than that provided by other circuits [8]. The differential output voltage is

$$V_{do} = V_{o1} - V_{o2} = \begin{cases} \alpha(R_1 + R_2)I_{in} \mid I_{in} \geq 0 \\ -\beta(R_1 + R_2)I_{in} \mid I_{in} < 0 \end{cases} \quad (7)$$

Assuming that $R_1 = R_2 = R$:

$$V_{do} = \begin{cases} 2\alpha RI_{in} \mid I_{in} \geq 0 \\ -2\beta RI_{in} \mid I_{in} < 0 \end{cases} \quad (8)$$

This is the only situation when matching components are required.
The circuit can work with voltage input signals if a single resistor is added to its input, as shown in fig.7. If the input impedance of the rectifier is critical and/or the input voltage is very small (under 100mV) this solution may be not acceptable.

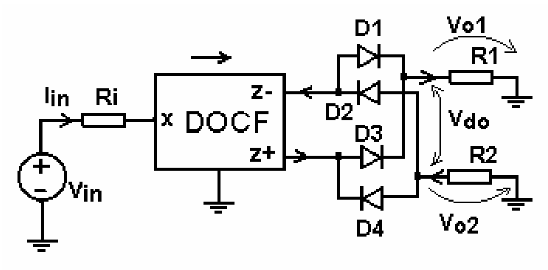

Fig. 7 Voltage input / current or voltage output current-mode precision rectifier

The circuit depicted in fig.8 solves this drawback by employing an additional voltage follower, which ensure the required high input impedance for the rectifier.

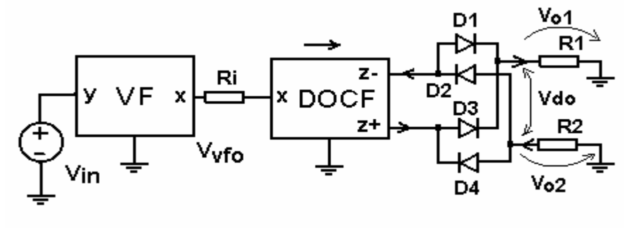

Fig. 8 High input impedance current-mode precision rectifier

To ensure the correct circuit functioning, the value of resistor Ri must be chosen in the range:

$$\frac{V_{vfo}^{\max}}{I_{vfo}^{\max}} \leq Ri \leq \frac{V_{vfo}^{\max}}{I_B} \quad (9)$$

where V_{vfo}^{MAX} represents the absolute magnitude of the output voltage of CF, $I_{vfo}^{\max}$ is the maximum current available at the CF output and I_B is the value of the bias current of the input stage in DOCF (I_1, I_2 in fig. 5)

Simulation results

In order to verify the circuit functioning, many SPICE simulations were performed. Some results are presented bellow. In fig.9 we reproduce the output current through R1 for the circuit depicted in fig. 6. The input current has the magnitude of 100uA and the frequency of 100KHz and of 1MHz respectively.
The transient response of the high input impedance rectifier is displayed in fig.10.
On the top are displayed the input voltage (Vin) and the output voltage of the voltage follower (Vvfo) since on the bottom is displayed the current through R1.
It is clear that the response of the proposed circuits is very good, even at 1 MHz, where no operational amplifier can perform similar responses.

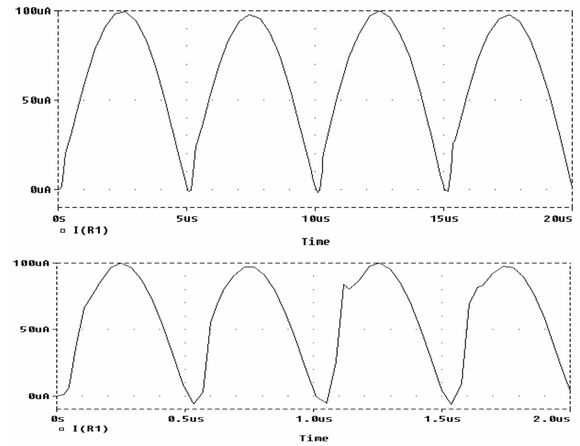

Fig. 9 The output current at 100KHz (above) and 1MHz (bellow)

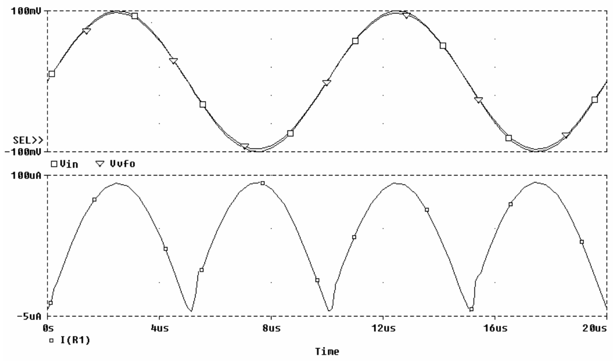

Fig. 10 The transient response of the high input impedance precision rectifier.

For simulation we have chosen next components and values: VF and DOCF are of the type given in fig.1 and fig.5; bias current of DOCF: $I_1 = I_2 = 1mA$; $R_1 = R_2 = 10$ ohms; Ri = 1Kohm; D1…D4 of BA482 type. Voltage supply: ±10V.

Conclusions

The current-mode precision rectifiers presented are very simple, they use as active devices only unity gain cells. Due to the reduced number of external passive components they are suitable for integration. The accuracy ensured is very good even at high frequency. Also, with a single exception, the circuits require no component matching. Furthermore, the circuits provide outputs signals as currents or voltages as well.

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