FACTA UNIVERSITATIS (NIŠ)
SER.: ELEC. ENERG. vol. 20, no. 2, August 2007, 215-221

The Analysis of Full-Wave Wide-Band Precision Rectifier with Modified Second Type Current Conveyor

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Abstract: The full-wave wide-band precision rectifier with modified second type current conveyor (MCCII), realized with the operational amplifier and three current mirrors (CM), is presented in this paper. The model of operational amplifier is adapted in such a way that it is possible to use supply-current sensing in supply rails of operational amplifier with SPICE program. Wilson's realization for current mirrors is used for precise current reproduction in a wide range of the amplitude values as well as frequencies.

Keywords: Rectifier, current conveyor, current mirror, operational amplifier, SPICE program.

1 Introduction

How we can use second generation of noninverting (CCII+), and inverting (CCII−) types of current conveyors to realize (design) high performance rectifiers is explained in literature [1]. Operational amplifier supply-current sensing with high quality current mirrors [2], is a technique widely used in the design CCII+ and CCII− conveyors. If we want to use the well known SPICE program [3] to analyze rectifier circuits with supply-current technique, we can not do that, so we have to adapt SPICE program or adapt a model operational amplifier and we decide to do that.

2 Modified Second Type Current Conveyor

In the ideal case, the behavior of the modified second type current conveyor [1], whose conventional symbol is given in Figure 1, can be characterized with the

Manuscript received on December 10th 2006

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following system of equations [4]:

$$i_z = |i_x|, \tag{1}$$

$$v_x = v_y, \tag{2}$$

$$i_y = 0. \tag{3}$$

where i_x, i_y, i_z and v_x, v_y are currents and voltages of x-, y-, and z-terminals, respectively. The circuit exhibits a high input impedance port (theoretical with infinite value for ideal conveyor) at Y. Port X acts as a low impedance input port (zero impedance for an ideal conveyor).

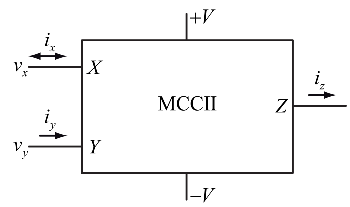


Fig. 1. Symbol of the modified second type current conveyor.

MCCII is made of one operational amplifier and the three current mirrors, as it is shown in Figure 2.

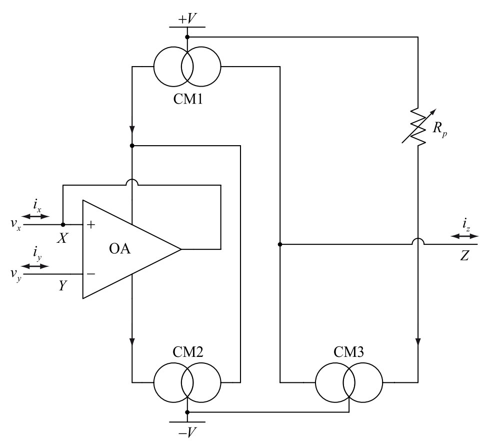


Fig. 2. MCCII made of one operational amplifier and three current mirrors.

On the basis of the characteristics of the ideal operational amplifier it can be concluded that the relations (2) and (3) are satisfied, so that only the relation (1) should be proved. The Figure 2 shows that for the positive values of current i_x, the negative supply rail of operational amplifier gives the same current on the drive side of current mirror CM2. The current must be shown on its copy side, that is connected to the drive side CM1. So, the same current ix must appear on the copy side CM1, that must be shown in total on connection Z, because the current of the copy side CM3 is fixed (determined by the value of the variable resistor R_p).

On the basis of the Figure 2 it is concluded that the positive supply rail of operational amplifier should provide the negative values of i_x. It means that the total value of current must appear on the copy side CM1, that is, on connection Z in the direction shown in the Figure 2. So whether the input current is positive or negative, the current i_z which has the same value as i_x , always has the direction as is shown in Figure 2. This is a proof of validity of the relation (1).

3 The Realization of the Precise Full-Wave Rectifier with MCCII

MCCII is very appropriate for the realization of the two-sided rectifier, because only two additional resistors are necessary, as it is shown in Figure 3.

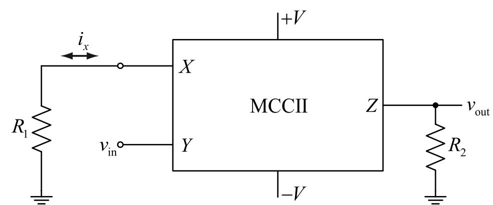


Fig. 3. The full-wave rectifier with MCCII.

On the basis of the Figure 3 and the relations for MCCII it is concluded that the current on connector X is:

$$i_x = \frac{v_{\text{in}}}{R_1} \tag{4}$$

while the current on the output connector is:

$$i_z = |i_x| = \frac{|v_{\text{in}}|}{R_1}, \tag{5}$$

and the voltage on the output connector Z is:

$$v_{\text{out}} = R_2 i_z = |v_{\text{in}}| \frac{R_2}{R_1}. \tag{6}$$

If resistors are properly selected ($R_1 = R_2$), then:

$$v_{\text{out}} = |v_{\text{in}}|. \tag{7}$$

That represents analytical expression of an ideal rectifier.

Taking into consideration the realization of MCCII, it is concluded that the operation of this rectifier is based on supply-current sensing technique in the positive and negative rails of the operational amplifier. It is known that the program SPICE cannot track the current in input power-supply leads of operational amplifier, because the program SPICE operates with functional and not physical model. This function can be realized in two ways: by adding already calculated transistor currents in operational amplifier (which implies the modification of SPICE program) or by correcting the model for operational amplifier [5] which the existing program package can track the current in the supply leads. The operational amplifier is corrected in a certain way to provide the ability of sensing the current in supply leads of operational amplifier, as is shown in the [6], on the basis of which the complete scheme of the two sided rectifier with MCCII can be drawn. The scheme is adapted for the SPICE analysis (Figure 4).

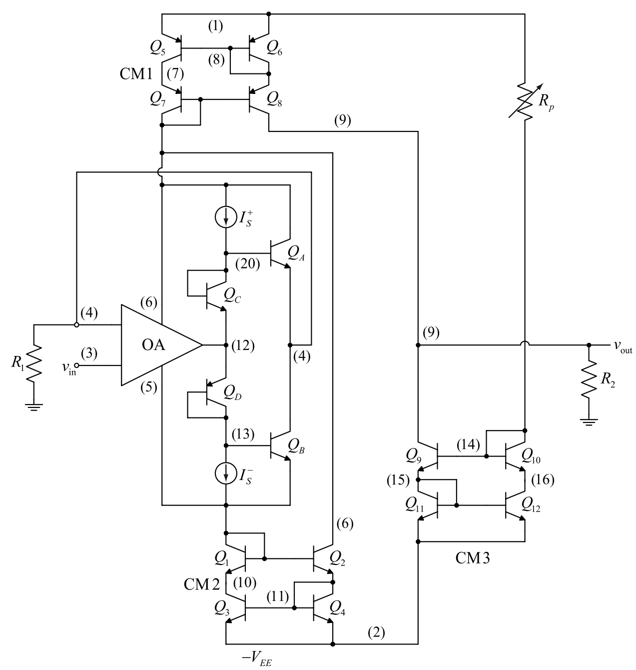


Fig. 4. Full-wave rectifier modeling for SPICE analysis.

The diode connected transistors Q_C and Q_D are used in order to decrease cross-over distortion. These transistors are identical to Q_A and Q_B transistors. Wilson's realization with four transistors for current sources is used so that the transfer characteristic of the current mirrors [7] would be better, i.e. that the current on copy side should be more like the current on the drive side in the wider range of current values and wider frequency range as it is shown in the Figure 4.

The way of determining current sources I_S^+ and I_S^- is explained in the literature [5]. When $v_{\text{in}} > 0$, the input current is obtained by transistor Q_A, while for $v_{\text{in}} < 0$ the input current is obtained by transistor Q_B. This functions well as long as the input current is much stronger than the direct current of polarization I_S. Most problems occur when the input current becomes equal or weaker than I_S. The current distribution between transistors Q_A and Q_B becomes non-linear ([8], Figure 4). In order to provide as good a rectifier as possible the following condition should be fulfilled:

$$I_{\max} > \frac{|v_{\text{in}}|}{R_1} \gg I_S, \tag{8}$$

where $I_{\max}$ is the maximum allowable output current of operational amplifier.

Obviously, the qualitative rectifier demands operational amplifier with minimal value of I_S. Contrary to rectifiers used in the technique of voltage processing with the operational amplifiers and diodes where the feedback is broken off during the transition from the positive into the negative half period, this situation enables the feedback to be continuously shut down which prevents the distortion of the output signal.

4 SPICE Analysis

In the rectifier shown in the Figure 4 an operational amplifier TL082 that uses FET transistors at differential entry points is applied. The measured polarization currents are $I_S = I_S^+ = I_S^- = 0.44\,\text{mA}$. In the separate part of the operational amplifier, the transistors 2N2221A (NPN) and 2N4258 (PNP) are used while the same transistors were also used in the current mirrors. The resistor R_p was used to set the output voltage to zero and adjusted to $4.7\,\text{m}\Omega$, while the remaining two resistors are set to $R_1 = 50\,\Omega$ and $R_2 = 55\,\Omega$. Nominally these two resistors should be equal, but this small difference in value is due to the adjustment of the unitary ratio on the rectifier voltage transferring function. The electrical voltage is $V_{CC} = 10\,\text{V}$ and $V_{EE} = -10\,\text{V}$.

Figure 5 shows the transferring characteristic $V_{\text{out}} = f(V_{\text{in}})$ of the rectifier presented in Figure 4 for the range of input voltage from $-500\,\text{mV}$ to $500\,\text{mV}$.

It is notable that the transferring characteristic shown in the Figure 5 does not have a sharp knee when the input voltage is around zero, as it is expected. This is due to the fact that the relation (8) is not satisfied, so in this range the suggested model does not function well.

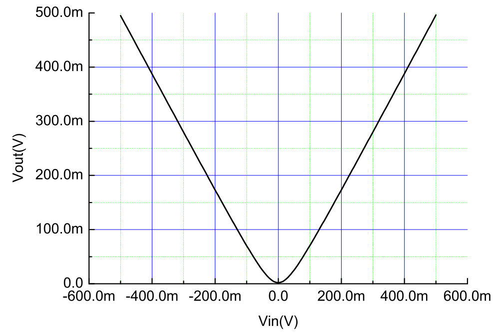
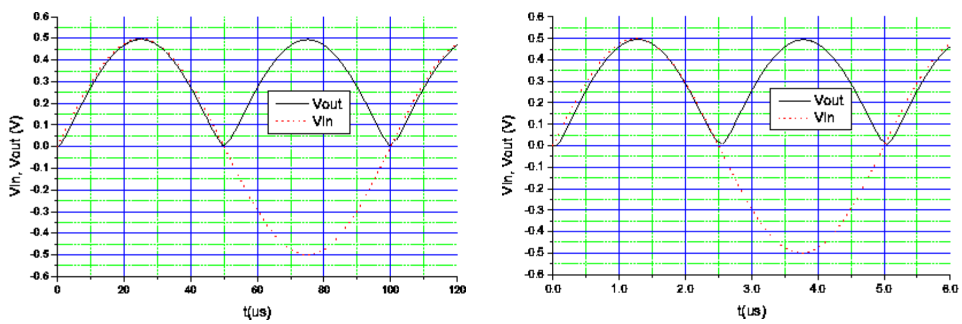


Fig. 5. Transferring characteristic of the rectifier shown in Figure 4.

Figure 6 shows the temporal pattern of the voltage on the rectifier output shown in the Figure 4 at two different frequencies: $f = 10\,\text{kHz}$ and $f = 200\,\text{kHz}$.



(a) (b)

Fig. 6. Rectifier response for frequencies $f = 10\,\text{kHz}$ (a) and $f = 200\,\text{kHz}$ (b).

In reference [8] the rectifier output with the same operational amplifier as the one obtained in the technique of voltage processing is presented. It can be noted that the output signal on frequencies $f = 200\,\text{kHz}$ is considerably distorted. On the basis of Figure 6 it can be concluded that the rectifier shown in Figure 4 functions well in the wide range of frequencies, even up to the frequency of full voltage.

5 Conclusion

In this study, it is proposed MCCII with the adapted model of operational amplifier accommodated for supply-current sensing in the voltage leads. The suggested rectifier, based on this MCCII operates well as long as the relation (8) is fulfilled. Besides, operational amplifier with the weakest direct current of polarization I_S

should be chosen in order to ensure the correct functioning of the rectifier even for small input currents. One should pay attention to the fact that the current amplification of the adapted model of operational amplifier is larger due to the two additional transistors at the output.

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