DESIGN OF AN IMPROVED CURRENT CONVEYOR EMPLOYING A HIGH PERFORMANCE OPERATIONAL AMPLIFIER

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ABSTRACT
This paper proposes an improved current conveyor of non-inverting type especially suitable for active filter applications. The current conveyor employs a high performance operational amplifier which is the key element of good filter characteristics. The device characteristics and filter performance simulations show that the proposed circuit exhibits very good performance and offers new opportunities to be used in analog circuit design.

1. INTRODUCTION
The current conveyor can potentially provide the high accuracy, wide bandwidth, low input impedance and high output impedance characteristics needed for many current domain signal processing applications. Since its first proposal in 1968 and its reformulation named as the second generation current conveyor in 1970 [1], this circuit element continues to receive a great deal of attention and find numerous applications. It would be appropiate to consider the current conveyor as being one of the basic building blocks of current-mode design, due to its favorable balance of operational flexibility and simplicity, giving it a similar role of the operational amplifier in voltage-mode operation. However, high performance implementations have emerged only in the last decade and has enabled current conveyors to challenge traditional voltage operational amplifier applications such as active filters, amplifiers, oscillators and immitance simulators.

In active filters, the performance of the active element, of which here the current conveyor is of our concern, plays an important role in the overall performance of the filter. In this paper, we propose an improved current conveyor circuit which is suitable for continuous time active filters, and offers new opportunities to be used in analog circuit design.

2. THE CURRENT CONVEYOR CIRCUIT
Current conveyor configurations have been developed based on several techniques such as using translinear loops and unique design methods [2-4]. However, these examples show unsatisfactory performances of either terminal x, y or z impedances and current transfer ratios due to the inherent properties of the cells used. An alternative implementation of current conveyors is the use of operational amplifiers and is based on the supply current sensing technique [5,6]. An operational amplifier exists as the main gain block and complementary current mirrors are used to sense the output current of the amplifier via its power supply rails. This provides small values of input error currents and offset voltages, a voltage transfer function close to unity and also enables large output swing, low terminal x resistance values and high terminal y resistance values. However, the low bandwidth of the amplifier is a main drawback of current conveyors using this technique. The traditional use of the circuit by conventional operational amplifiers generally yield moderate performance characteristics for the current conveyor [7,8]. The characteristic values of the current conveyor are very important in obtaining filter performances near to ideal case [9-11]. Therefore, such circuits require high performance operational amplifiers which mainly determine the performance of the current conveyor.

In this paper, a simple but high performance operational amplifier has been introduced into the circuit configuration given in Fig.1a. Transistors M1-M4 and M5-M8 serve as the complementary cascode current mirrors which enable high output impedance and accurate current transfer performance. Fig.1b depicts the full circuit schematic, whereas Table 1 depicts the transistor dimensions. The operational amplifier has been used in unity gain configuration which contributes to a high performance voltage transfer characteristic. M18-

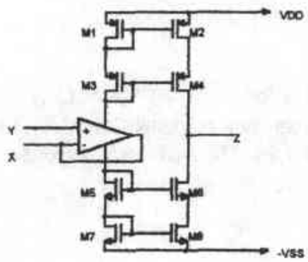
M21 and Q1-Q2 form the output stage to obtain a low output impedance [12]. Fig 2a and b demonstrate the dc voltage transfer characteristic and the unity gain frequency response of the output voltage for the operational amplifier, respectively. Supply voltages were chosen as ±5 V, whereas R=1 kΩ and C=8 pF. Simulation results given in Fig.2a yields the output voltage clipping limits as V_{Omax}= 3.51 V and V_{Omin}= -5 V. The unity gain bandwidth of the operational amplifier was obtained as f_{BW}=48 MHz from Fig. 2b, while the open-loop gain is K=56.5 dB. The input and output resistances are 872 GΩ and 8 Ω, respectively, whereas the related capacitances can be neglected.

Supply voltages were chosen to be ±10 V and Alcatel Mietec 2 μm HBiMOS process parameters have been used for the SPICE simulations of the current conveyor. The voltage transfer characteristics V_X= $V_X(V_Y)$ for open-circuited terminal x and V_Z= $V_Z(V_Y)$ for open-circuited terminal z, are given in Figs.3a and b, respectively. The voltage clipping limits at terminal x and terminal z were obtained as V_{Xmax}=4.76 V, V_{Xmin}= -7.52 V, V_{Zmax}=9.52 V and V_{Zmin}= -9.42 V. Fig.3c illustrates the I_X= $I_X(V_Y)$ characteristic for short-circuited terminal x. The lower and upper boundaries of current I_X were determined as I_{Xmin}= -69.7 μA and I_{Xmax}=1.87 mA. The I_X= $I_X(V_Y)$ and I_Z= $I_Z(V_Y)$ characteristics for terminal loads of R_X= R_Z=1 kΩ are given in Fig.3d.

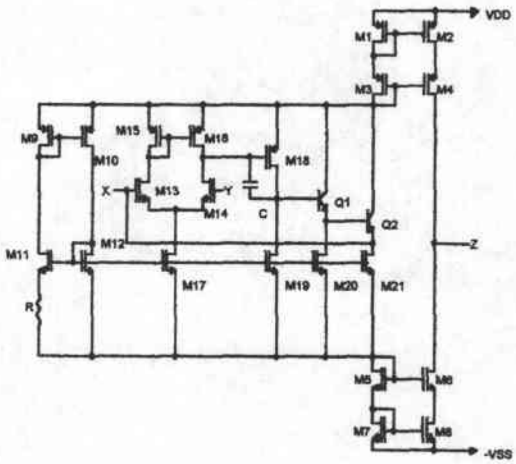
The frequency responses of the voltage gain v_x/v_y and current gain i_z/i_x are shown in Fig.3e. We obtain the values of the voltage and current transfer functions at low frequencies as k_V=0.996 and k_I=1.019, respectively, for terminal loads of R_X=10 kΩ and R_Z=10 kΩ. The 3 dB bandwidth value for the voltage transfer function is 61 MHz, while for the current transfer function it is 37 MHz.

Fig.3f shows that the impedance Z_X has a value of 3.4 Ω at low frequencies and shows a maximum of 4132 Ω at a resonant frequency of 15.8 MHz. The variation of the impedance Z_Y with frequency is given in Fig.3g. Values of r_Y=18.9 TΩ and C_Y=6 fF are obtained. Fig.4h showing the output impedance Z_Z at terminal z, gives the values of r_Z=788.4 MΩ and C_Z=151.9 fF.

The characteristic values are summarized in Table 2. The results prove that the circuit offers a very good choice for high performance analog circuit designs.

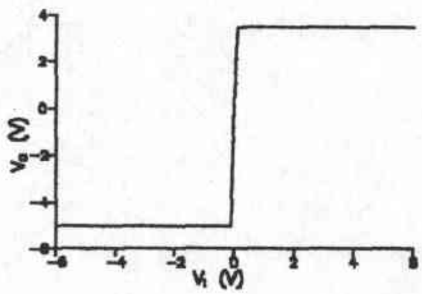


a)



b)

Fig.1. a) Current conveyor configuration b) Circuit diagram of the operational amplifier



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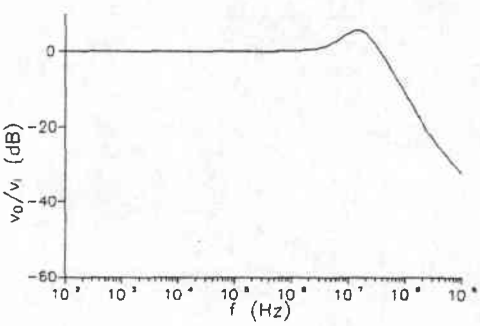

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Fig.2. Device characteristics of the operational amplifier a) dc voltage transfer characteristic b) The unity gain frequency response of the output voltage

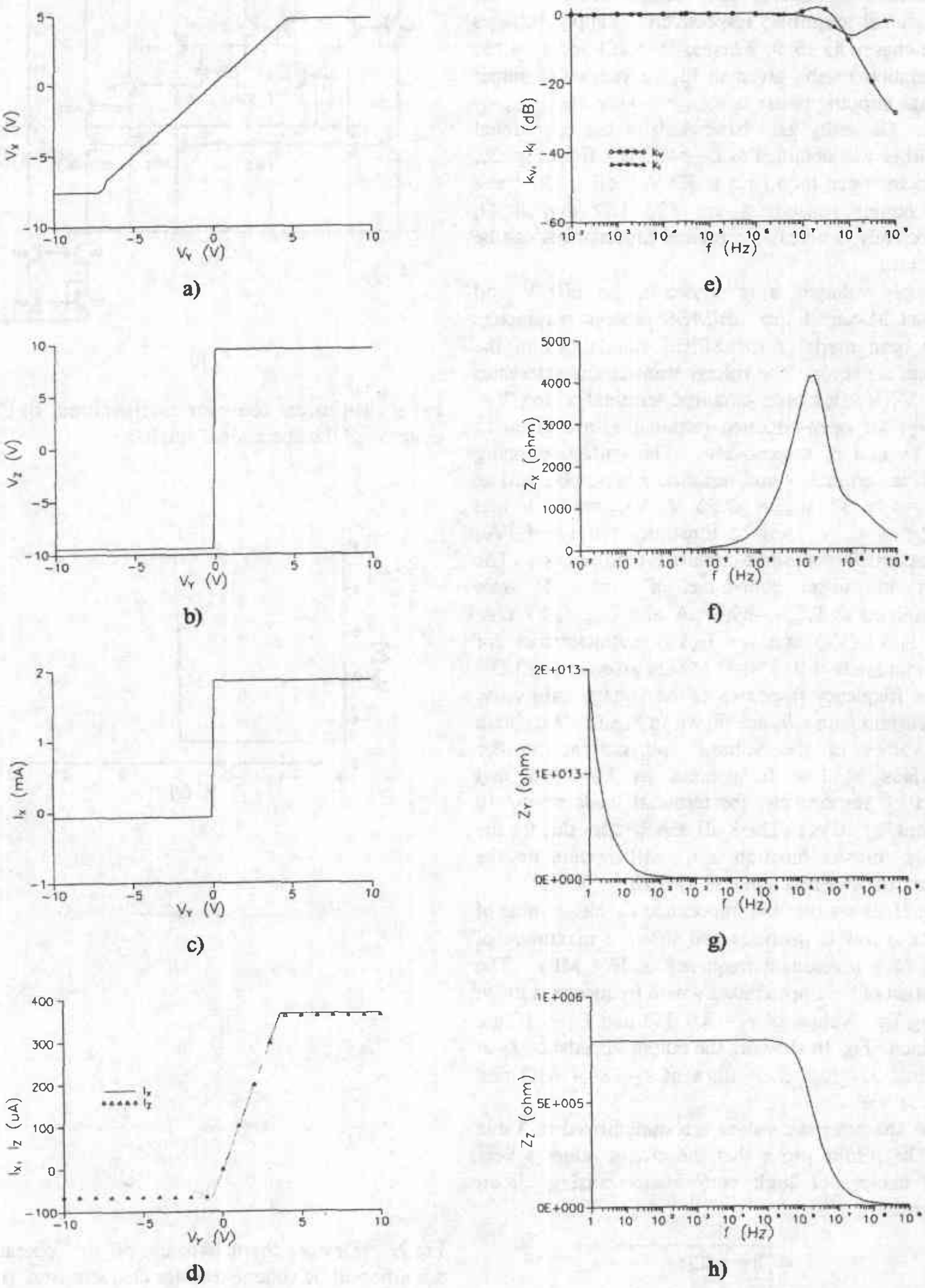


Fig.3. **Device characteristics of the current conveyor a) $V_X=V_X(V_Y)$ for $R_X=\infty$ b) $V_Z=V_Z(V_Y)$ for $R_Z=\infty$ c) $I_X=I_X(V_Y)$ for $R_X=0$ d) $I_X=I_X(V_Y)$, $I_Z= I_Z(V_Y)$ for $R_X=R_Z=1\ k\Omega$ e) Frequency responses of v_x/v_y and i_z/i_x for $R_X=R_Z=10\ k\Omega$ f) Frequency response of Z_X g) Frequency response of Z_Y h) The frequency response of Z_Z**

Table 1. Transistor dimensions of the current conveyor given in Fig.1b

Transistor	W [µm]	L [µm]	AD, AS [µm²]	PD, PS [µm]
M1	80	2	520	173
M2	80	2	520	173
M3	80	2	520	173
M4	80	2	520	173
M5	20	2	130	53
M6	20	2	130	53
M7	20	2	130	53
M8	20	2	130	53
M9	100	2	650	213
M10	100	2	650	213
M11	40	2	260	93
M12	40	2	260	93
M13	20	2	130	53
M14	20	2	130	53
M15	50	2	325	113
M16	50	2	325	113
M17	40	2	260	93
M18	100	2	650	213
M19	40	2	260	93
M20	40	2	260	93
M21	40	2	260	93

Table 2. Characteristic values of the proposed current conveyor

V_{Xmax}	4.76 V
V_{Xmin}	-7.52 V
V_{Zmax}	9.52 V
V_{Zmin}	-9.42 V
I_{Xmax}	1.87 mA
I_{Xmin}	-69.7 µA
k_V	0.996
f_V	61 MHz
k_I	1.019
f_I	37 MHz
r_X	3.4 Ω
R_P	4132Ω
f_P	15.8 MHz
r_Y	18.9 TΩ
C_Y	6 fF
r_Z	788.4 MΩ
C_Z	151.9 fF

3. APPLICATION OF THE CURRENT CONVEYOR TO A FILTER

In this section, the current conveyor proposed will be introduced to a current-mode active filter in order to demonstrate the filter performance [13]. Fig.4 depicts the filter circuit in bandpass configuration. The transfer function of the filter in terms of circuit components can be given as follows:

$$\frac{I_2}{I_1} = \frac{\frac{1}{C_1 R_2} s}{s^2 + \frac{R_2 + R_3}{R_2 R_3 C_4} s + \frac{1}{C_1 R_2 R_3 C_4}}$$

The component values for the filter have been obtained for a maximally flat Butterworth filter, with unity gain; thus $Q = 1/\sqrt{2}$ and H=1. For f_O =100 kHz; the component values are C_1 =100 pF, R_2 =10 kΩ, R_3 =10 kΩ, C_4 =200 pF. The simulation results for the frequency response of the filter demonstrated in Fig.5a shows that the proposed current conveyor provides a very good performance. The large-signal behavior of the filter is simulated for an input sinusoidal signal of 100 kHz, which yields a maximum input signal amplitude of 70 µA, provided that 1% distortion for the output signal is acceptable. The result is depicted in Fig.5b.

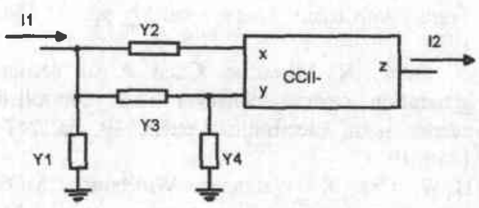
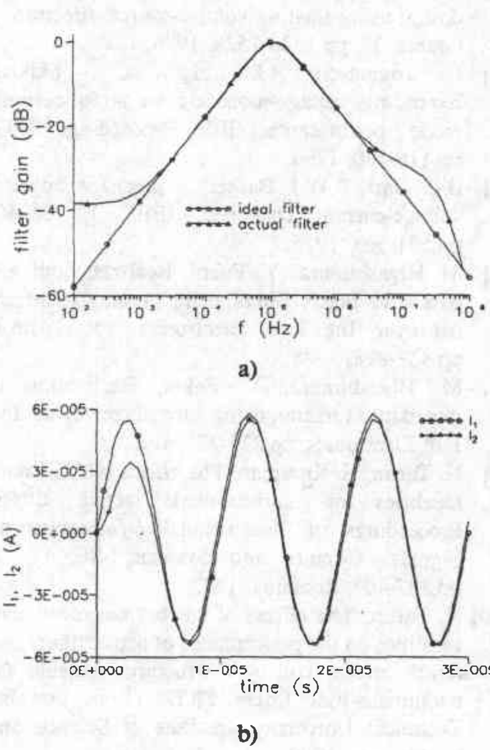


Fig.4. The bandpass filter configuration



a)

b)

Fig.5. a) The frequency response of the filter b) The large-signal behavior of the filter

4. CONCLUSION

An improved current conveyor especially suitable for active filter applications is proposed in this paper. An operational amplifier exists as the main gain block and complementary cascode current mirrors are used to sense the output current of the amplifier via its power supply rails. This provides small values of input error currents and offset voltages, a voltage transfer function close to unity and also enables large output swing, low terminal x resistance values and high terminal y resistance values. The complementary cascode current mirrors enable high output impedance and accurate current transfer performance. The device characteristics and filter performance simulations show that the proposed circuit proves to be an offer for high performance analog circuit designs.

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