Model of the Operational Conveyor based on Current-steering output stage

Slobodan Djukic[1] and Milan Veskovic[2]

Abstract – **This study presents the improved version of the operational conveyor based on current-steering output stage. Related to the previous study the improvement refers to the fact that the required precise current distribution to the two equal parts should be performed by the Wilson's current mirrors. The suggested operational conveyor has very good voltage and current transfer characteristics, and has constant gain-bandwidth product close to 2MHz. Also, it does not require the transistors with matched characteristics. The results of the simulation circuit with the PSPICE program are also presented in this study. The operational conveyor uses the standard electronic components and is suitable for the implementation in the integrated technics.**

Keywords – **Current-mode processing technicque, current mirror, current conveyor, operational conveyor, PSPICE simulation**

I. Introduction

The concept of the current conveyor (CCI) was introduced by Sedra and Smith, back in 1970. [1], and the possibility of its application in the implementation of the full-wave precision rectifier for the small signals is presented in the literature [2-5]. However, the area of application of the current conveyor is much broader. The symbol of the negative second type current conveyor ($CCII^-$) is shown in Figure 1, and it can be mathematically described by the following matrix equation:

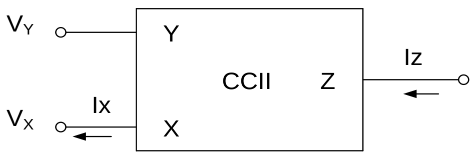

Fig. 1. Symbol of the second type current conveyor (negative)

$$\begin{vmatrix} I_y \\ V_x \\ I_z \end{vmatrix} = \begin{vmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & \pm 1 & 0 \end{vmatrix} \cdot \begin{vmatrix} V_y \\ I_x \\ V_z \end{vmatrix} \quad (1)$$

or with three linear equations:

$$V_x = V_y\,, \quad (2)$$

$$I_y = 0\,, \quad (3)$$

$$I_z = \pm\, I_x\,. \quad (4)$$

The voltage signal Vy is connected to the high-resistance input Y and it buffers with the unity gain at the input X and the current Ix is mapped to the output Z. The problem is that the resistance r_X, which is recognized by the inverting input of the conveyor, is not zero. This resistance is small but it does not have a constant value and it affects the error of the voltage transfer function.

This current conveyor can be mathematically described by the following matrix equation [5]:

$$\begin{bmatrix} I_Y \\ V_Y \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & r_x & 0 \\ 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} V_X \\ I_X \\ V_Z \end{bmatrix} \quad (5)$$

or with three linear equations:

$$I_Y = 0 \quad (6)$$

$$V_Y = V_X + r_x\, I_X \quad (7)$$

$$I_Z = -I_X \quad (8)$$

The concept of operational conveyor (OC) introduced by Gift [6] completely eliminates the resistance r_X, and it consists of the voltage operational amplifier (VOA), which works with the current conveyor (CCII) in a feedback loop, as shown in figure 2.

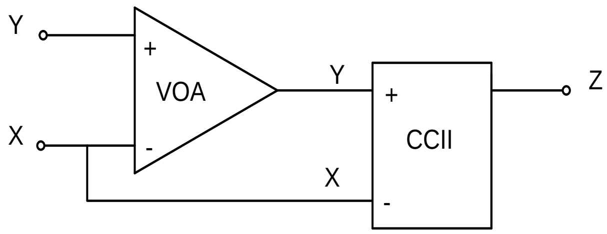

Fig. 2. Operational conveyor with CCII used as a feedback circuit

The operational conveyor can be represented as a circuit with three connectors, as shown in Figure 3.

[1]Slobodan Djukić is with Faculty of Technical Science Čačak, University of Kragujevac, Svetog Save 65, 32000 Čačak, Serbia E-mail: slobodan.djukic@ftn.kg.ac.rs.

[2]Milan Vesković is with Faculty of Technical Science Čačak, University of Kragujevac, Svetog Save 65, 32000 Čačak, Serbia E-mail: Milan.veskovic@ftn.kg.ac.rs.

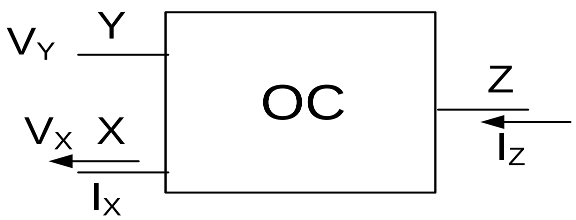

Fig. 3. Symbol of the operational conveyor

Figure 4 shows the concept of the operational conveyor, with the voltage operational amplifier and current-steering output stage as the feedback circuit.

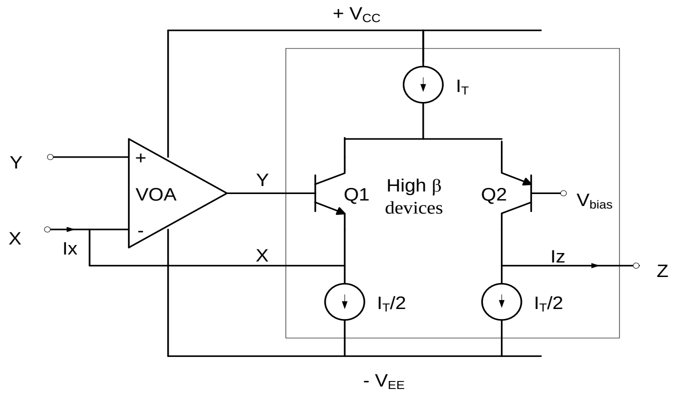

Fig. 4. Operational conveyor with CCII used as a feedback circuit – basic formulation

Good voltage transfer characteristic between the terminals Y and X is provided by the usage of the negative feedback with the voltage operational amplifier. In order to keep the error in the voltage transmission function as small as possible, it is necessary that the current I_T is as higher, so that the input resistance of the transistor Q_1 be smaller comparing to the output resistance of current sources. The increasing of the current Ix at port X for some amount causes the decrease of the current of the transistor Q_1 by the same amount, which then causes an increase in current through the transistor Q_2, which causes an increase at the output for the same amount. The same can be concluded for the reduction of current Ix, so it can be concluded that the relation Ix = -Iz is valid. Transistors Q_1 and Q_2 should have a large current gain, in order to ensure the equality of their emitter and collector currents. It is important to notice that it is necessary to provide the exact division of the current I_T into two equal parts, which is not easy, given the fact that the current I_T should be variable. Figure 4 shows that in the feedback loop of the voltage operational amplifier there is a current conveyor. The question is whether the level of the current steering stage (bounded by rectangle) is in fact the current conveyor? The answer is positive, and for the following reasons:

a) Its voltages Vx and Vy are roughly equal (they differ for the base-emitter voltage of the transistor Q_1)

b) Its current Iy value is about zero because it is the transistor Q_1 base current, and it has great current amplification,

c) It has already been demonstrated that the Ix = Iz

II. DISCRETE VERSION OF THE OPERATIONAL CONVEYOR REALISATION

The complete scheme of the operational conveyor is presented in Figure 5. In relation to the literature [5], we performed the improvement in terms of the exact division of the current I_T into two equal parts using Wilson's current mirrors, but the current mirror of the unit amplifier can also be used [7]. The usage of discrete components requires their patient matching by their characteristics, although there are those ready-made components, such as CA3096AE (transistor arrays) [8]. To set the current I_T, the variable resistor R_2 is used, and for the elimination of the offset voltage at the output terminal, the variable, resistor R_3 is used. This is also an improvement as compared to the literature [8] because there is one resistor less.

III. PSPICE SIMULATION

In order to test the characteristics of the operational conveyor, it is presented as a voltage amplifier such as the excitation generator Vin is linked via the resistor Rin to the input X of the operational conveyor, and the Y connection to the ground, while the output Z through the load R_l is also conected to the ground. The supply voltages are Vcc =$-V_{EE}$ = 5V, while the used transistors are 2n4014 (npn) and 2n4059 (pnp). Current amplification of the both transistor is approximately 180. For the value of the current I_T=2mA the following values are used for the resistors R_2 = 4.6 kΩ and R_3= 200 kΩ approximately. For the voltage operational amplifier we used TL082. The resistance r_X of such operational conveyor is below 10 Ω, which practically means that it does not exist, or that the first matrix equation which describes its behavior is valid. We have made another simulation with uA741 and get little larger value for r_X .

Figure 6 shows the frequency dependence of the output impedance of the operational conveyor for the different values for the current I_T. It is noticed that it has a constant value (the order of magnitude of 80 kΩ) to the limit frequency which in this case is in the order of a few tens of kilohertz size. Based on Figure 6 it can be concluded that the output impedance consists of the parallel connection of resistance and capacitance that can be seen at the port Z of the operational conveyor. It would be good if the magnitude of the output impedance module had as higher value as possible, which can be achieved by reducing the value of the set current I_T, but then the scope of the possible changes of the current Iz at the output, reduces, which is not good.

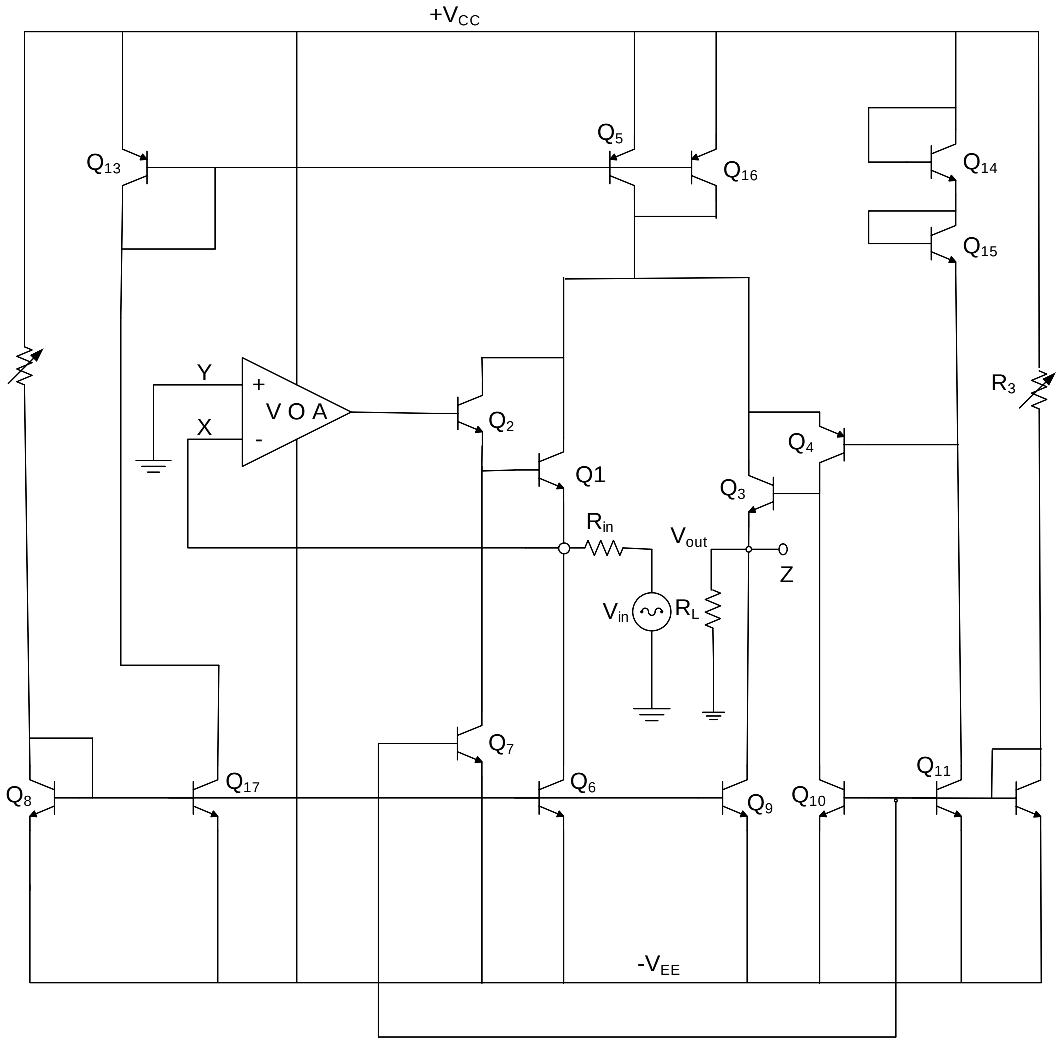

Fig 5. Discrete version of the proposed operational conveyor

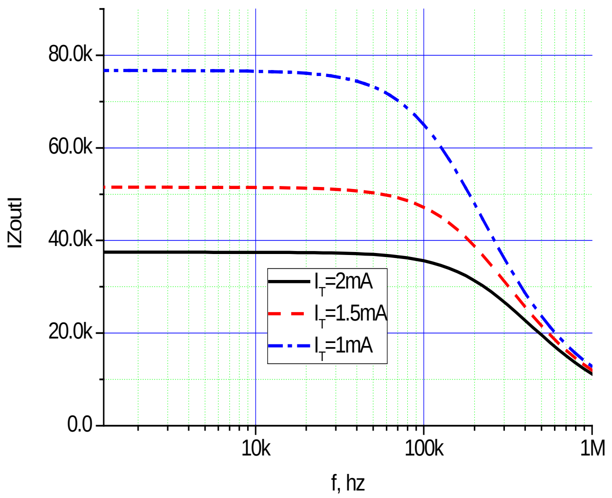

Fig. 6 Output impedance curves of the operational conveyor for different current I_T.

Figure 7 shows the amplification of the operational conveyor in the function of frequency, based on which we conclude that the amplification change does not change the bandwidth range, and that the constancy of the product of the amplification and the bandwidth range does not apply to this operational conveyor

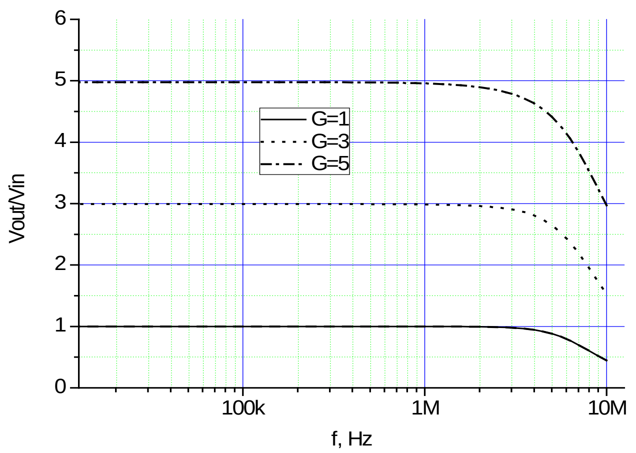

Fig. 7. Frequency response of the operational conveyor for different gain G

Figure 8 and Figure 9 show the current and voltage transfer function of the conveyor. It can be seen that the transfer characteristics of the observed ranges are practically ideal

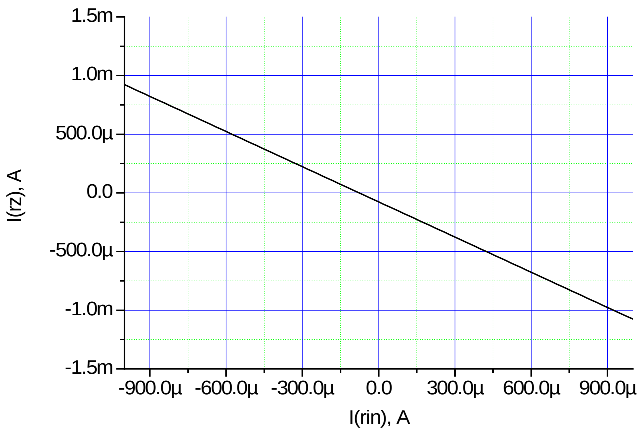

Fig. 8. Current transfer characteristic of the operational conveyor.

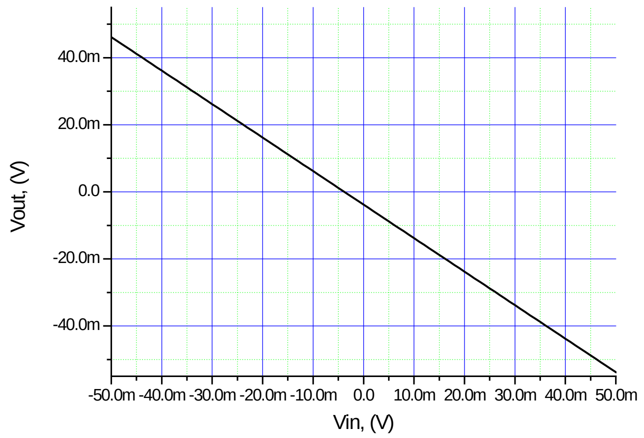

Fig. 9. Voltage transfer characteristic of the operational conveyor

IV. CONCLUSION

The proposed implementation of the operational conveyor based on the current steering output and current mirrors, has excellent current and voltage transfer function, because a resistance at the inverting input of the operational amplifier has a negligible value. The transient behavior of that discrete version of the operational conveyor is very well-behaved, with a well- damped response giving a constant gain-bandwidth product close to 2 MHz. Limitation of the gain-bandwidth product is primarily caused by the f_T of the pnp transistors.

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