Integrators with current conveyors

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Abstract: - The present paper is concerned with integrators with current conveyors that can be employed for voltage integration. These connections find application in particular in A/D converters. Some feasible connections of integrators with current conveyors are shown, and simulations are performed that use a macromodel of the universal current conveyor that was designed and produced under the designation UCCX0349. It can thus be expected that the agreement between simulation and practical results will be considerable.

Key-Words: - universal current conveyor, integrator

1 Introduction

The connection of inverting integrator with an active element, the operational amplifier, is common knowledge. The transfer function of integrator is given by the relation

$$H(s) = \frac{V_{out}}{V_{in}} = -\frac{1}{sC_1R_1}. \qquad (1)$$

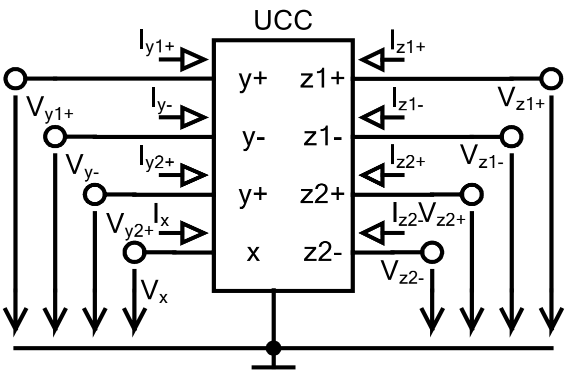
The time dependence of integrator output voltage is given, above all, by the magnitude of time constant $\tau = R_1C_1$ and is described by the expression

$$V_{out} = -\frac{1}{\tau}\int V_{in}(t)\,\mathrm{d}t. \qquad (2)$$

The output voltage waveform of an integrator with classical operational amplifier is distorted primarily by two negative effects, which are given by the real properties of the operational amplifier itself. What comes to show in the output voltage waveform are the rate error and the forward transfer, which affect the precision of integration. The rate error is caused by the final rate of operational amplifier and the integrator output voltage does not respond instantaneously to input voltage changes. The forward transfer is responsible for considerable switching peaks at the instant the direction of integration is changed. The peaks are caused by the feedback capacitor, which at the moment of voltage change represents a short circuit, and the transferred voltage appears on the output resistor of operational amplifier. The voltage peak magnitude is given by the magnitude of inner resistance of amplifier.

It is thus obvious that classical operational amplifiers are not convenient for the design of precise integrators. From among active elements, current conveyors can be seen as suitable to employ. The present situation is particularly opportune since a new component, the universal current conveyor (UCC), is available. In the design of integrator with current conveyors we will therefore utilize the universal current conveyor. This element enables the realization of a number of current conveyors, and it was produced as a customized integrated circuit, designated UCCX 0349. The UCCX device was designed on the CMOS 0.35 μm technology in AMI Semiconductors. A macromodel of UCCX 0349 was created, which is more convenient for computer simulation than a model on transistor level. Though the macromodel is simpler, in the simulation and examination of the properties of circuits with current conveyors it offers greater advantages. This model was made use of in the simulations given below. This element can work in a frequency band of up to tens of MHz. The definition of this element is given in Fig. 1.

An appropriate interconnection of terminals enables realizing the following current conveyors:CCI+/-, ICCI+/-, CCII+/-, ICCII+/-, CCIII+/-, and ICCIII+/-.



$$V_x = V_{y1+} - V_{y-} + V_{y2+},$$
$$I_{y1+} = I_{y-} = I_{y2+} = 0,$$
$$I_{z1+} = I_{z2+} = I_x,$$
$$I_{z1-} = I_{z2-} = -I_x.$$

Fig. 1: Universal Current Conveyor, symbol and definition relations

2 Connection of integrators with current conveyors

The universal current conveyor can be used to produce various integrator connections. In these connections, input terminals y+, y-, y+ can be made very good use of: they enable realizing an integral of the sum or difference of input voltages. Voltage inputs y+, y-, y+ provide much variability in the connection of input voltages. A summing or differencing integrator can thus be realized or voltage is applied to one input and then integrated while to another input a voltage is temporarily applied that clears the voltage across the integration capacitor. This is usual, for example, in A/D converters. Employing different inputs is of much advantage because if integrator with classical operational amplifiers is used, voltage summing is very problematic and capacitance discharging/by capacitance must be realized with the aid of a reference current source. In the simulations performed a voltage applied to one input is integrated while a voltage applied to another input is cleared by the integration capacitor. In the first part of the integration process the voltage examined is integrated and then such a reference voltage V_{ref} is temporarily applied to another suitable input of universal current conveyor that the integrator is cleared. The settings in the simulated circuits are: R_1 = 1kΩ, C_1 = 1nF, V_m = 0.1V, and V_{ref} = 1V.

Let us now use an analogy to the application of operational amplifier (OA) and current conveyor. The integration capacitor is thus connected in the feedback branch. The connection of this integrator is shown in Fig. 2.

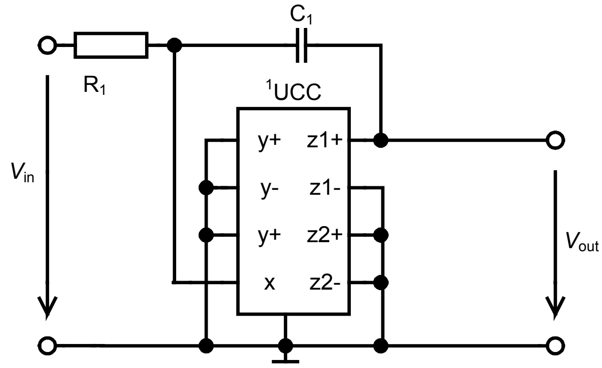


Fig. 2: Integrator with UCC – analogy to the application of OA

The transfer is given by the relation

$$H(s) = \frac{V_{out}}{V_{in}} = -\frac{1}{2sC_1R_1}. \quad (3)$$

Integrator output voltage vs. time is given in Fig. 3. As can be seen, the output voltage is affected by the so-called forward transfer (a voltage jump at the instant when input voltage polarity is changed), which appears in integrators with operational amplifiers. This effect greatly affects the precision of integration. In spite of realizing a given function, this connection is absolutely unsuitable for use in measuring technology and does not yield any advantage.

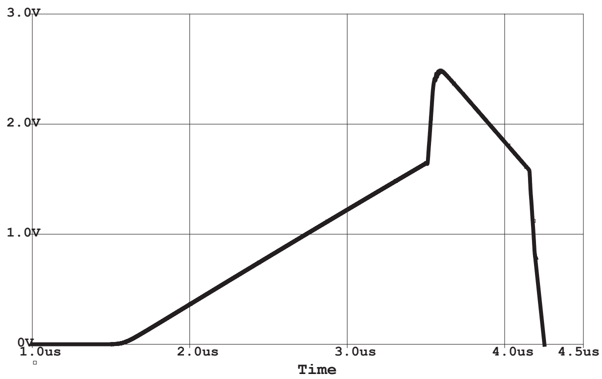


Fig. 3: Output voltage waveform of the integrator in Fig. 2.

Another familiar integrator connection is given in Fig. 4. The integration capacitor is no longer connected in feedback so that the input part is thus separated from the output part, which is of advantage.

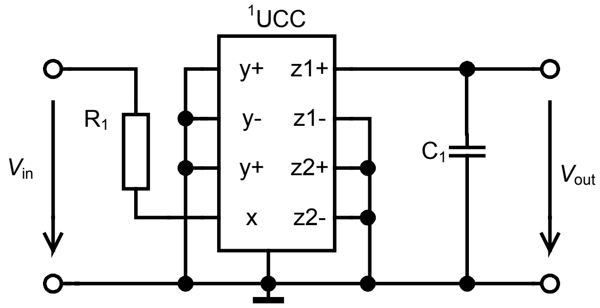


Fig. 4: Integrator with UCC.

The transfer function is given by relation (1). Output voltage vs. time is shown in Fig. 5.

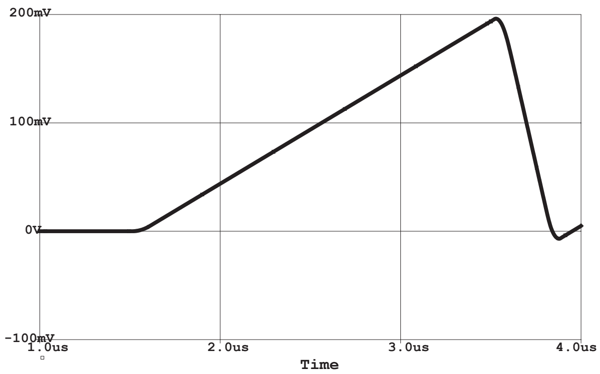


Fig. 5. Output voltage vs. time for integrator connected as in Fig. 4.

The waveform obtained gives very good results and this connection appears to be suitable for use in converters. The integrator rate error comes to be shown. A disadvantage is that the value of resistor R_1 is added to the internal resistance of the input voltage source and the integrator time constant is thus affected.

Integrator connection using a CCI+ is shown in Fig. 6. The transfer function is given by the relation

$$H(s)=\frac{V_{out}}{V_{in}}=\frac{1}{sC_1R_1}. \quad (4)$$

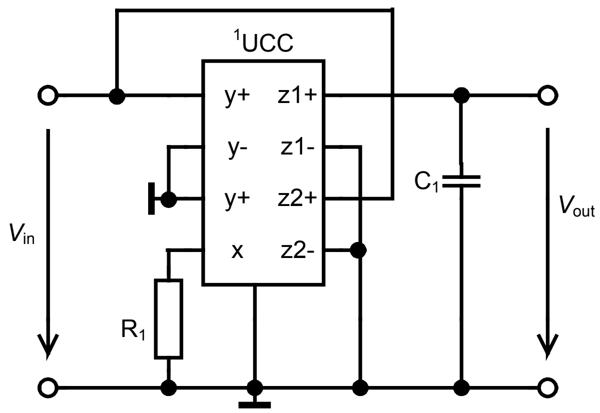


Fig. 6: Integrator with UCC connected as CCI+

The output voltage vs. time is similar to that in Fig. 5, but the output voltage is inverted. With this connection it is of advantage that the resistor is connected to the ground potential and that it does not affect the input circuits.

Another connection of the integrator with ICCI+ can be seen in Fig. 7. In this case it is a lossy integrator and its transfer function is given by the relation

$$H(s)=\frac{V_{out}}{V_{in}}=\frac{1}{1+sC_1R_1}. \quad (5)$$

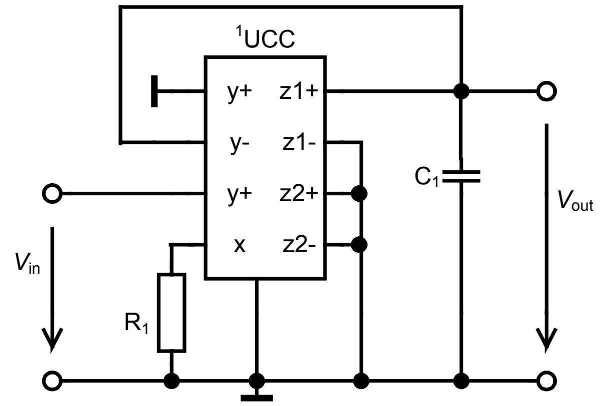


Fig. 7: Lossy integrator with UCC connected as ICCI+

Output voltage vs. time is shown in Fig. 8, where it is obvious that capacitor charging is not linear. This connection is therefore not convenient for precise applications.

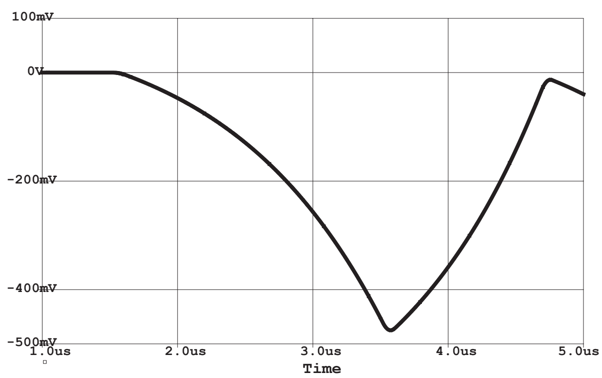


Fig. 8: Lossy integrator output voltage vs. time, connected as in Fig. 7

Fig. 9 gives the connection of integrator with a UCC connected as an ICCII+. Its transfer function is given by relation (1). A possible modification is the connection realizing an ICCII- or CCII+/-. The output voltage vs. time is equivalent to that in Fig. 5. The connection with CCII+/- and ICCII+/- is very simple and yields a number of possible input voltage connections. From the very definition of UCC it can be seen that summing and differencing integrators can be realized, thus providing for a number of applications.

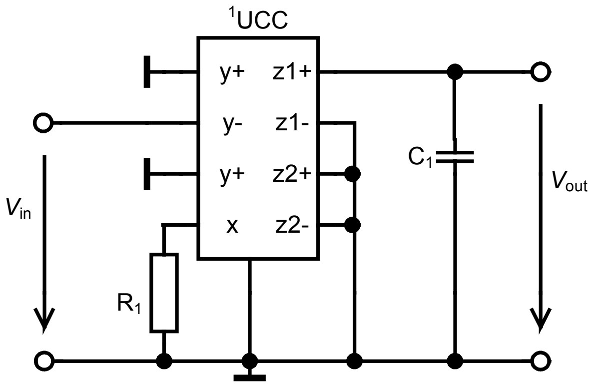


Fig. 9: Integrator with UCC connected as ICCII+

3 Conclusion

In the paper, a number of possible connections of integrators with current conveyors are shown. The UCC element, the universal current conveyor, is employed here, which is available for experimental work. Also available is its c omparatively exact macromodel for computer simulation, which was used to test the functionality of the integrators presented. It can be seen that when current conveyors are employed, analogous connections with classical elements cannot be taken into consideration. Not all these connections can be employed in precise applications either. However, it can be said that integrators with current conveyors have some properties that are of advantage. Given a suitable connection, the forward transfer does not on principle show; current conveyors are able to work on higher frequencies. The universal element opens up new possibilities in voltage integration and it can be expected that in view of the properties of the realized current conveyor the achievable cut-off frequencies and integration precision will be substantially higher.

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