23 SECOND GENERATION CURRENT CONTROLLED CONVEYOR

Second generation current controlled conveyor (CCCII) is another useful building block as it provides electronic control of filter parameters. CCCII is a combination of a voltage follower, current follower and an electronically controllable resistance, $R_x$, at terminal $x$. The equivalent circuit representation of CCCII is shown in Fig. 2.6.

![Fig. 2.6 Circuit representation of CCCII.](image)

23.1 A PRACTICAL CCCII

The performance of a practical CCCII differs from an ideal one at higher frequencies because of finite impedances at various terminals of CCCII. The circuit representation of a non ideal CCCII is shown in Fig. 2.7.

![Fig. 2.7 Non ideal CCCII with its parasitic impedances and voltage and current transfers.](image)
It is similar to CCII except that the input resistance $R_x$ is controllable by $I_0$ and an inductance $L_x$ is added in series at $x$ terminal of Fig. 2.4 in order to take into account variation of the impedance at port $X$ as a function of frequency [108].

23.2 TRANSLINEAR IMPLEMENTATION OF CCCII+, CCCII- AND MOCCCII

The schematic representation of a CCCII [13] is shown in Fig 2.8(a). The translinear loop is biased by dc current $I_0$ using the current mirrors formed by transistors $Q_5$ to $Q_7$ and $Q_{10}$ and $Q_{11}$. Using the analysis as done in the section 2.2, it may be shown that the circuit of Fig. 2.8(a) has a resistance at $x$ terminal which is electronically controllable. A current controlled conveyor with negative current transfer (CCCII-) can be obtained by adding cross coupled current mirrors in order to reverse the sign of the current $i_x(t)$ as shown in Fig. 2.8(b). A multiple output current controlled conveyor (MOCCCII) can be obtained by simply inserting current mirrors for multiple positive and negative current transfers. Figure 2.9 shows a MOCCCII having four $z$ terminals with two terminals having positive current transfer and other two with negative current transfer.

![Fig. 2.8(a) Translinear implementation of CCCII+](image-url)

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24 CONVERTING ACTIVE RC CIRCUITS TO CURRENT CONVEYOR BASED CIRCUITS

A wide variety of voltage mode continuous time circuits are available in the literature and the techniques of transformation have received considerable attention in generating new circuits from present well-developed voltage mode ones. Among the transformation techniques, adjoint transformation and inverse transformation are two of the most popular ones. The basis of conversion used in this thesis is adjoint principle [1],
According to this principle, a network $N_1$ can be replaced by an adjoint network $N_2$ (Fig. 2.10) if the input voltage excitation of network $N_1$ is changed to output current response and its voltage output response is changed to input current excitation. The resulting transfer functions of these networks $N_1$ and $N_2$ are identical.

$$\left. \frac{V_{\text{out}}}{V_{\text{in}}} \right|_{N_1} = \left. \frac{I_{\text{out}}}{I_{\text{in}}} \right|_{N_2}$$

![Diagram](image.png)

**Fig. 2.10** Inter reciprocal networks $N_1$ and $N_2$.

The networks so obtained are inter-reciprocal to one another. When the networks $N_1$ and $N_2$ are identical, for example in case of passive networks, the networks are called reciprocal. The adjoint of a given network can be constructed by replacing each element in the network by another according to the list given in Fig. 2.11.

The impedance levels in the corresponding nodes of both the networks should be identical in order to maintain identical transfer functions for both the original network $N_1$ and adjoint network $N_2$. Therefore, the signal flow is reversed in the adjoint network. The voltage source is converted to a current sensing element as both behave as short circuits, and a voltage sensing element is converted to a current source.
Fig. 2.11 Some electrical elements and their corresponding adjoint elements.

Figure 2.12 shows a class of active networks with an op amp connected as infinite gain voltage amplifier and a four terminal passive network with no grounded internal node. The adjoint transformation method [110] generates unity gain CCII circuits from infinite gain op amp based circuits. The nullator representation of the original circuit of Fig. 2.12 is shown in Fig. 2.13(a). The terminals 2 and 3 can be chosen as the output port of this network. The output can be taken as $V_{out} = V_2 - V_3$, as it does not change transfer function.

Fig. 2.12 Op amp based network.
The application of adjoint transformation on topology of Fig. 2.13(a) gives the topology of Fig. 2.13(b). Choosing node 3 as ground node, a CCII based implementation as shown in Fig. 2.13(c) is obtained. Similarly the application of adjoint transformation on topology of Fig. 2.13(b) gives the nullator topology of Fig. 2.13(d) and its corresponding CCII based implementation is shown in Fig. 2.13 (e).

Fig. 2.13 Nullator – norator representation and generation of CCII based networks.

A damped voltage integrator based on op amp is shown in Fig. 2.14(a) in which the nodes 1, 2, 3 and 4 of network N of Fig. 2.12 are marked. Fig. 2.14(b) and (c) shows the CCII based current integrator and CCII based voltage integrator using the steps discussed earlier.
Fig. 2.14 (a) Damped voltage integrator with op amp (b) current integrator with CCII and (c) voltage integrator with CCII.

25 SENSITIVITY

The designer has to select the best circuit from the numerous available configurations, given the fact that in practice, the components used for realization of filter may deviate from their nominal design values. There may be initial inaccuracy in the circuit elements owing to tolerances in the fabrication process. The component values also tend to drift due to environmental effects such as humidity and temperature variations, and chemical changes which occur as circuit ages. As coefficients in the filter transfer function depend on circuit elements, it is expected that a filter will deviate from its ideal behavior. The size of error, however, depends on how large the component tolerances are, and how sensitive the circuit’s performance is to these parameters. The concept of sensitivity is one of the important criteria for comparing various circuit configuration and establishing their practical utility in meeting specified requirements. The sensitivity computations [23, 24] not only allow the designer to select better circuits
from the available ones, but also permits one to conclude whether a chosen filter circuit satisfies and will keep on satisfying the desired specifications.

In general, performance criteria $P$, such as quality factor or a pole or zero frequency, will depend on component $x$, which could be $R$, $C$, $\alpha$ or $\beta$ etc., i.e. $P = P(x)$. If $P$ stands for the magnitude or phase of the transfer function $H(s)$, then $P$ is also function of frequency, so $P = P(s, x)$. The parameter, $S^p_x$, gives the sensitivity of $P$ to a small change in a single parameter $x$ and is defined mathematically as

$$S^p_x = \frac{x_0}{P(s, x_0)} \frac{\partial P(s, x)}{\partial x} \bigg|_{x_0}$$  \hspace{1cm} (2.5.1)

where $x_0$ is nominal value of the component.

The relative change or variability in the performance measure $P$, is expressed as

$$\frac{\Delta P}{P} = S^p_x \frac{dx}{x}$$  \hspace{1cm} (2.5.2)

and is $S^p_x$ times of the relative change of the circuit parameter $x$ on which $P$ depends.

Thus, good circuits should have small sensitivities to their elements; and for acceptable performance deviation $\frac{\Delta P}{P}$, the circuits can be assembled from the elements with larger tolerances $\frac{dx}{x}$. The components of a good circuit, if vary during operation, the circuit performance is less likely to drift out of the acceptable range of specification.

2.6 CONCLUSION

This chapter presents various types of current conveyors and concepts related to them. The second generation current conveyor being the most versatile element compared
to other available current conveyors in the literature and provides extension into electronic tunable regime is presented in detail. Thereafter, various nonidealities that can affect the transfer function are described. The translinear realization of second generation current conveyor, current controlled current conveyor and multiple output current controlled current conveyor are elaborated. The adjoint principle and transformation method for specific type of active RC circuits conversion into equivalent current conveyor circuits are presented. The chapter ends with the emphasis on the concept of sensitivity that provides the measure of the change in some performance parameter of the transfer function resulting from some change in the nominal values of one or more elements of the network.