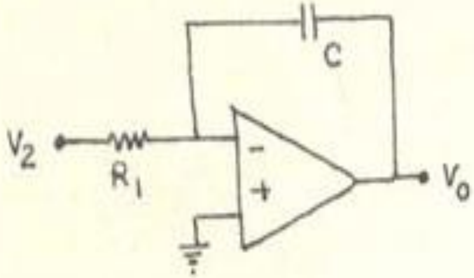
UNIT-5

(Lecture-7)

OP-AMP CIRCUITS

Inverting integrator : In Fig. 4 (a) if R_2 is replaced by a capacitor (having transformed impedance $\frac{1}{sC}$) one obtains the circuit of Fig. 5 (a) which is the inverting integrator.



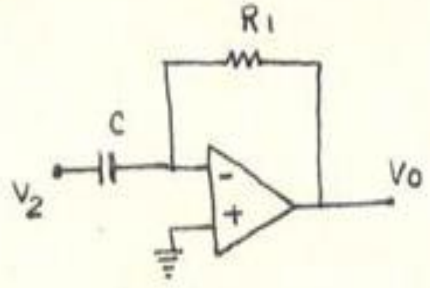


Fig. 5 (a) inverting integrator (b) inverting differentiator (Miller integrator)

Replacing R_2 in equation (6) by $\frac{1}{sC}$, the transfer function of the integrator of Fig. 5 (a) is found to be

$$V_0(s) = -\frac{1}{sCR_1} V_2(s) \quad (10)$$

or in time domain

$$V_0(t) = -\frac{1}{CR_1}\int V_2(t)\,dt \quad (11)$$

Inverting differentiator: Interchanging R_1 and C in Fig. 5 (a) leads to the circuit of Fig. 5 (b) which is inverting differentiator with

$$V_0(s) = -sCR_1 V_2(s) \qquad (12)$$

or in time domain, $$V_0(t) = -CR_1 \frac{dV_2(t)}{dt} \qquad (13)$$

Finite gain differential amplifiers: In the 3-port VCVS of Fig. 3, if a potential divider is added at the input the circuit of Fig. 6 is obtained for which

$$V_1 = \left(\frac{R_4}{R_3+R_4}\right) e_1 \qquad (14)$$

Combining (14) and (4)

$$V_o = \frac{\left(1+\frac{R_2}{R_1}\right)}{\left(1+\frac{R_3}{R_4}\right)} e_1 - \frac{R_2}{R_1} V_2 \qquad (15)$$

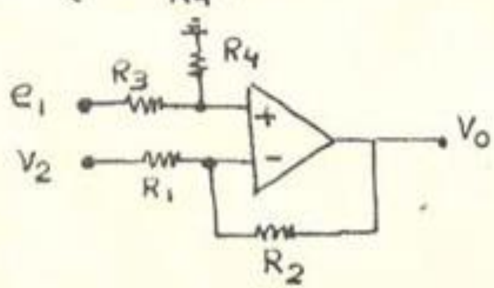


Fig. 6 K-gain differential amplifier

letting $\frac{R_2}{R_1} = \frac{\left(1+\frac{R_2}{R_1}\right)}{\left(1+\frac{R_3}{R_4}\right)} = k$ (16)

the circuit realises a k-gain differential amplifier for which the required resistor values are found to be

$$R_2 = kR_1 \; ; \; R_4 = kR_3 \qquad (17)$$

The above configuration has a limitation that the input impedances at the two input terminals are not infinite as desired. An alternative k-gain differential amplifier circuit which does possess this feature is shown in Fig. 7

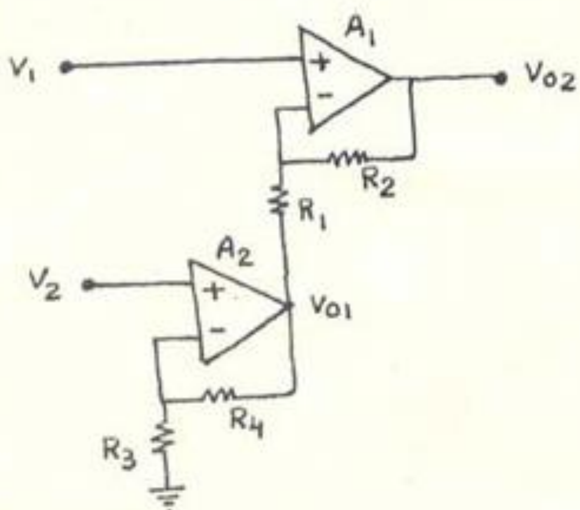


Fig. 7 Finite gain differential amplifier with infinite input impedance

In this circuit A_2 is connected as a noninverting VCVS due to which

$$V_{01}' = \left(1 + \frac{R_4}{R_3}\right) V_2 \qquad (18)$$

A_1 alongwith R_2 and R_1 realises a 3-port VCVS similar to Fig. 3, hence utilising equation (4) we can write

$$V_{02} = \left(1 + \frac{R_2}{R_1}\right) V_1 - \frac{R_2}{R_1} V_{01} \qquad (19)$$

substituting (18) in (19) we obtain

$$V_{02} = \left(1 + \frac{R_2}{R_1}\right) V_1 - \frac{R_2}{R_1}\left(1 + \frac{R_4}{R_3}\right) V_2 \qquad (20)$$

For obtaining k-gain, $\left(1 + \frac{R_2}{R_1}\right) = \frac{R_2}{R_1}\left(1 + \frac{R_4}{R_3}\right) = k$ (21)

In other words, resistor values must be chosen according to

$$R_2 = (k-1) R_1 \; ; \; R_3 = (k-1) R_4 \qquad (22)$$

Negative impedance Convertor: The circuit realisation of the NIC is shown in Fig. 8

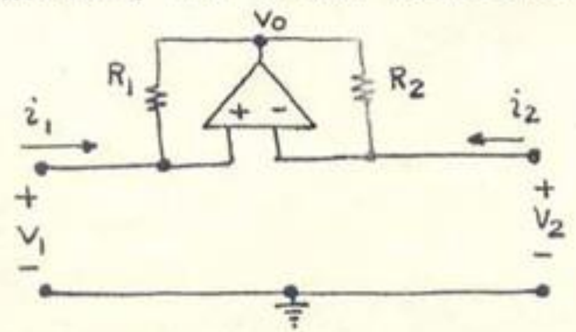


Fig. 8 op-amp realisation of the NIC

Routine analysis gives $i_1 = \frac{V_1 - V_0}{R_1}$ (23)

$$i_2 = \frac{V_2 - V_0}{R_2} \quad (24)$$

Due to the property of the ideal op-amp

$$V_1 = V_2 \quad (25)$$

From (23)−(24) $\frac{i_1}{i_2} = \frac{R_2}{R_1}$ (26)

Thus, the transmission matrix of the circuit is given by

$$\begin{bmatrix} v_1 \\ i_1 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & -\frac{R_2}{R_1} \end{bmatrix} \begin{bmatrix} v_2 \\ -i_2 \end{bmatrix} \quad (27)$$

From the above transmission matrix it is seen that the circuit is a NIC with

$$A = 1, \quad |D| = \left| \frac{R_2}{R_1} \right| \quad (28)$$

so that upon terminating port 2 into Z_L impedance looking at port 1 is given by

$$Z_{in} = -\left(\frac{R_1}{R_2}\right) Z_L \quad (29)$$

Current Controlled Voltage Sources: The circuit is shown in Fig. 9. Since noninverting input terminal is connected to ground, due to infinite gain, the inverting input terminal is forced to have ground potential (virtual ground) due to which $v_m = 0$.

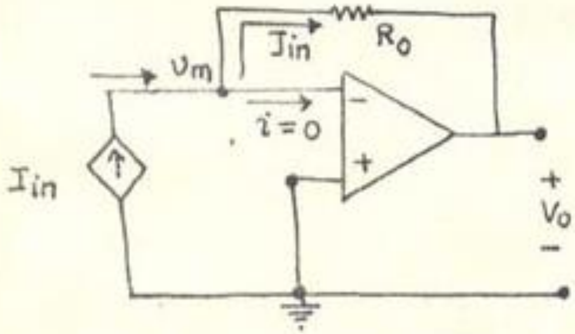


Fig. 9 CCVS

Also, due to infinite z_{in}, no current is drawn by the op-amp input terminal.

Hence,
$$I_{in} = \frac{0 - V_o}{R_0}$$

or
$$V_o = -R_0 I_{in} \tag{30}$$

and the circuit acts as an inverting CCVS.

Noninverting CCVS can be obtained in two different ways as shown in Fig. 10 :(i) by

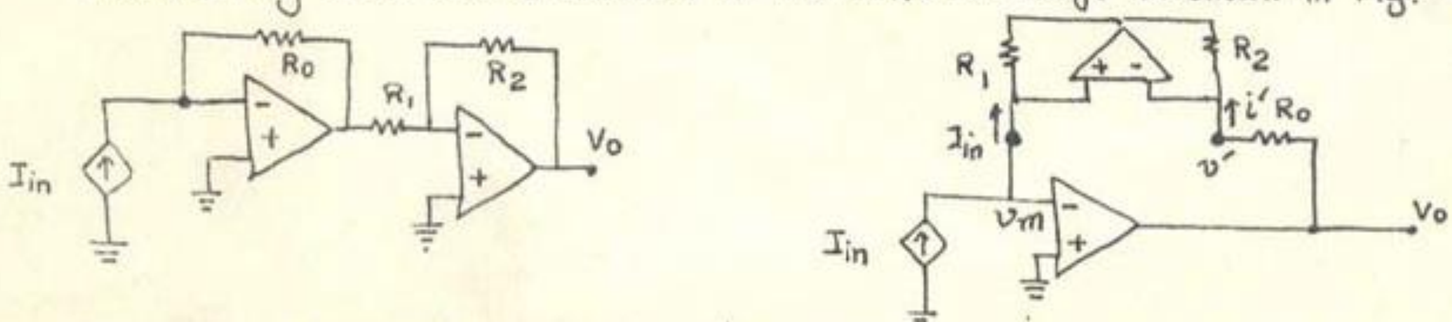


Fig. 10 Noninverting CCVS structures

cascading an inverting VCVS so that

$$V_0 = -(R_0 I_{in})\left(-\frac{R_2}{R_1}\right) = +\left(\frac{R_0 R_2}{R_1}\right) I_{in} \quad (31)$$

(ii) by putting a NIC with $A = 1$, $D = -\frac{R_2}{R_1}$ in the feed back path. Analysis gives

$$V_0 = i' R_0 + v' = i' R_0 = \left(\frac{R_1}{R_2}\right) I_{in} \; R_0 = +\left(\frac{R_1 R_0}{R_2}\right) I_{in} \quad (32)$$

(since $v' = v_m = 0$ and $i' = -\frac{R_1}{R_2} I_{in}$)

Voltage-Controlled-Current-sources : Consider the circuit shown in Fig. 11 (a). By judicious redrawing it can be rearranged as in Fig. 11 (b) where it is easy to recognise an NIC terminated into R realising a $-R$ at input port of NIC. consequently, we obtain the equivalent circuit of Fig. 11 (c). Analysis of this equivalent circuit gives

$$I_{out} = \frac{V_L}{-R} + \frac{V_L - V_{in}}{R} = -\frac{V_{in}}{R} \quad (33)$$

Hence, the circuit of Fig. 11 (a) is an Inverting VCCS.

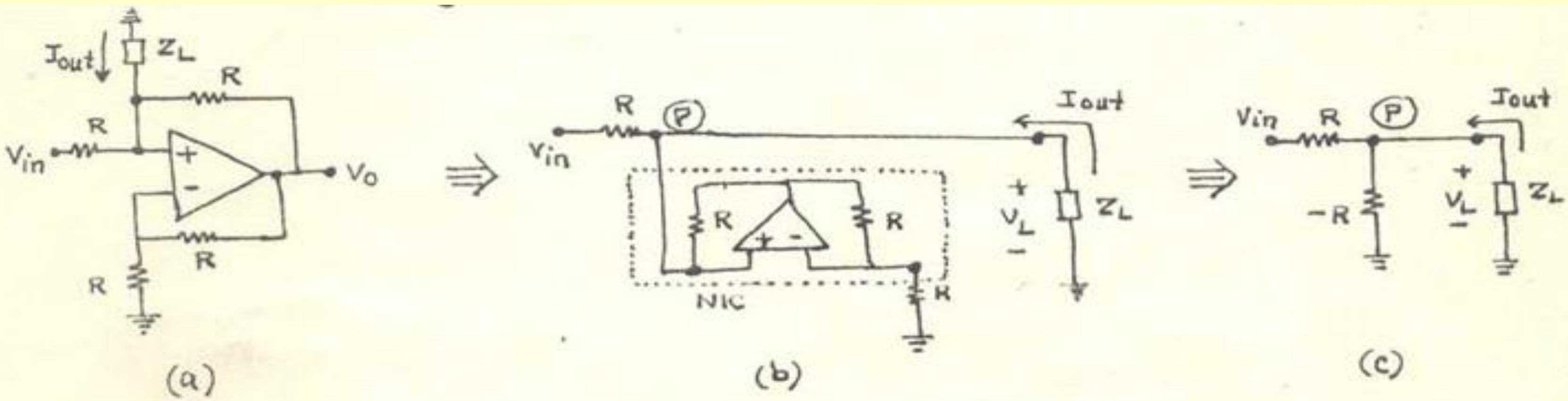


Fig. 11 Inverting VCCS

A slightly different arrangement giving a noninverting VCCS is shown in Fig. 12 (a)

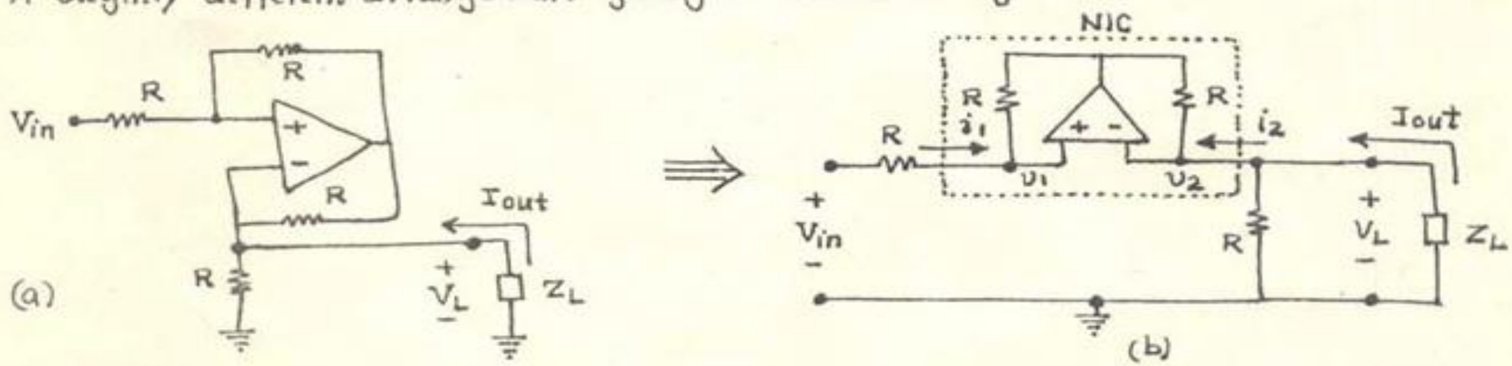


Fig. 12 Noninverting VCCS

With some arrangement the circuit can be redrawn as in Fig. 12 (b) where once again we can identify an NIC. For the NIC

$$v_1 = v_2 = v_L \qquad (34)$$

also as the two resistors of NIC are identical, $i_1 = i_2$ (35)

but $i_1 = \frac{V_{in} - V_1}{R}$; $i_2 = i_{out} - \frac{V_2}{R} = i_{out} - \frac{V_1}{R}$ (using (34)), (36)

substituting (35) into (36) we get

$$\frac{V_{in} - V_1}{R} = i_{out} - \frac{V_1}{R}$$

$$\text{ie} \quad i_{out} = + \frac{V_{in}}{R} \tag{37}$$

Current Controlled current Sources : op-amp realisation of CCCS can be obtained by cascading CCVS and VCCS as shown in Fig. 13 .

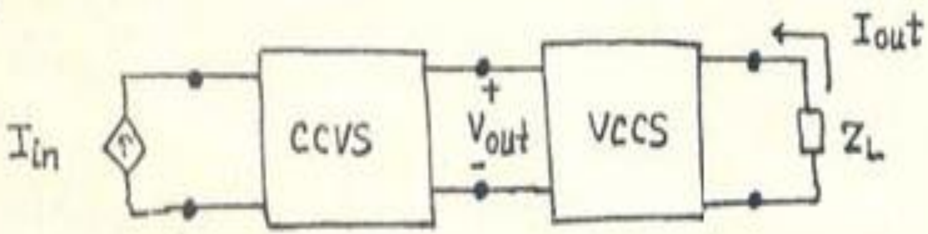


Fig. 13 Realisation of CCCS