



# ROHINI

## COLLEGE OF ENGINEERING & TECHNOLOGY

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(AUTONOMOUS)

### OPERATIONAL TRANSCONDUCTANCE AMPLIFIER (OTA):

The operational amplifiers considered up to this point have been voltage amplifiers. The input signal is a voltage and the output signal is a voltage. Another type of op-amp is an operational transconductance amplifier (OTA) which produces an output current proportional to an input voltage. The constant of proportionality is the transconductance of the amplifier. Thus, the OTA is voltage controlled current source (VCCS). There is usually an additional input for a current to control the amplifier's transconductance. Ideally, the Operational Transconductance Amplifier has infinite input and output impedances, and the transconductance is assumed to be constant. However, real OTAs have noninfinite input and output impedances, and the transconductance is frequency dependent.

The IC OTAs are specially designed single chip transconductance amplifiers in which the input is voltage and the output is current such that

$$I_{\text{out}} = g_m V_d = g_m (V_1 - V_2) \quad \dots(41.1)$$

where  $g_m$  is the transconductance or gain of the OTA. The unique feature of an Operational Transconductance Amplifier is that  $g_m$  can be varied over a wide range by means of an external control current  $I_c$ . Usually,  $g_m$  is proportional to  $I_c$  so that

$$g_m = kI_c \quad \dots(41.2)$$

where

$$k = \frac{e}{2KT} \text{ and } \frac{KT}{e} = 25 \text{ mV at } 25^\circ\text{C.}$$

The typical range of  $I_c$  is 0.1  $\mu\text{A}$  to 1 mA.

Normally, OTAs are operated without feedback in linear applications. This is possible because the magnitude of the resistance attached to its output controls its output voltage. The major drawback is that if the differential input signal is not small, it may lead to distortion. Typically input signal remains below 100 mV peak-to-peak.

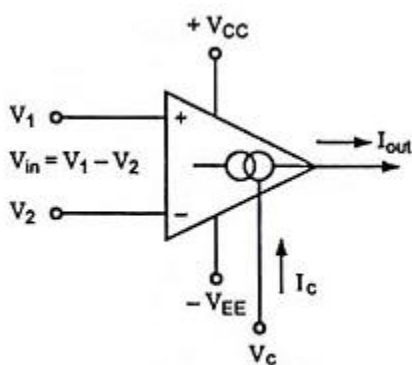


Fig. 41.1 OTA Symbol

Operational Transconductance Amplifier finds applications in implementing programmable amplifiers and integrators in audio- processing and electronic music synthesis. They are also employed as current switches in sample and hold applications. One of the important use of OTAs using VLSI technique is in neural networks. Popular OTAs are LM 3080, LMI 3600/3700 (National Semiconductor) CA 3080 (RCA) and the NE 5517 (Signetics).

The simplified internal circuit diagram of an OTA is shown in Fig. 41.2.

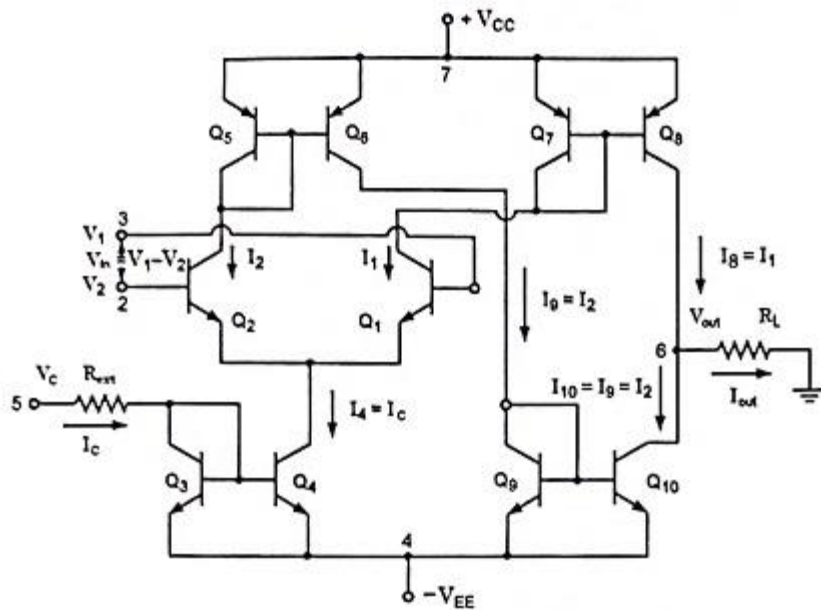


Fig. 41.2 Simplified Internal Circuit of OTA

Transistor pairs  $Q_1 - Q_2$  form a differential amplifier. Transistors  $Q_3 - Q_4$  accept the controlling current  $I_c$  whose value is being controlled by an external resistor  $R_{ext}$  and controlling voltage  $V_c$ . Since transistors  $Q_3 - Q_4$  form current mirror,

$$I_4 = I_c \quad \dots[41.3 (a)]$$

Also, transistors  $Q_5 - Q_6$  form current mirror, so that the current coming from collector of  $Q_6$  to  $Q_9$  duplicates  $I_2$ .

So that,

$$I_9 = I_2 \quad \dots[41.3 (b)]$$

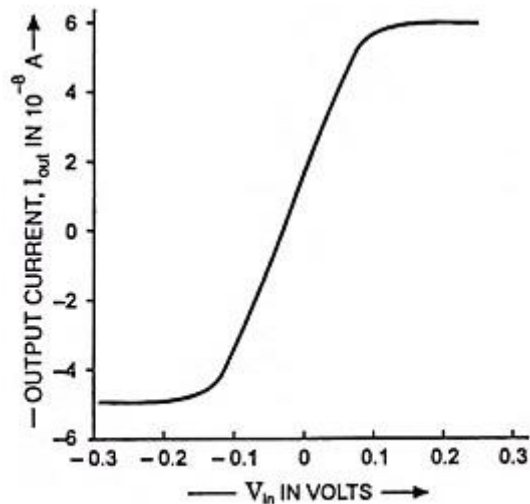


Fig. 41.3 OTA Transfer Characteristic

Again transistors  $Q_9 - Q_{10}$  form current mirror pair so that

$$I_{10} = I_9 = I_2 \quad \dots(41.4)$$

The transistors  $Q_7 - Q_8$  form current mirror pair and collector current of  $Q_8$  duplicates  $I_1$  so that

$$I_8 = I_1 \quad \dots(41.5)$$

Now, at the output, applying Kirchoff's current law, we have,

$$I_8 = I_{out} + I_{10} \quad \dots(41.6)$$

$$\text{or } I_{out} = I_8 - I_{10} = I_1 - I_2 \quad \dots(41.7)$$

The voltage gain of the amplifier can be expressed as

$$A = \frac{V_{out}}{V_{in}} = \frac{I_{out} R_L}{V_{in}} = g_m R_L \quad \dots(41.8)$$

The transconductance  $g_m$  can be calculated as [behaving like diode]

$$I_1 = I_s [\exp(V_1/V_T) - 1] \quad \dots(41.9)$$

$$\text{and } \cong I_s \exp(V_1/V_T)$$

$$I_2 = I_s [\exp(V_2/V_T) - 1] \cong I_s \exp(V_2/V_T) \quad \dots(41.10)$$

where

$I_s$  = Reverse saturation current of transistor  $Q_1$  or transistor  $Q_2$  (assuming same characteristics)

and  $V_T$  = Volt equivalent of temperature

$$= \frac{kT}{e} = \frac{T}{11,600} \quad (\text{where } T \text{ is in K})$$

Now the controlling current is given as

$$I_c = I_1 + I_2 = I_s \left[ \exp\left(\frac{V_1}{V_T}\right) + \exp\left(\frac{V_2}{V_T}\right) \right]$$

$$\text{or } I_s = \frac{I_c}{\exp\left(\frac{V_1}{V_T}\right) + \exp\left(\frac{V_2}{V_T}\right)}$$

$$\begin{aligned} \text{and } I_{\text{out}} = I_1 - I_2 &= I_s \left[ \exp\left(\frac{V_1}{V_T}\right) - \exp\left(\frac{V_2}{V_T}\right) \right] \\ &= \frac{I_c}{[e^{V_1/V_T} + e^{V_2/V_T}]} [e^{V_1/V_T} - e^{V_2/V_T}] \end{aligned}$$

Multiplying numerator and denominator by  $\exp\left(-\frac{V_1 + V_2}{2V_T}\right)$

$$\left( -\frac{V_1 + V_2}{2V_T} \right)$$

we have,

$$\begin{aligned}
I_{\text{out}} &= I_c \frac{\left[ e^{\left(\frac{V_1}{V_T} - \frac{V_1 + V_2}{2V_T}\right)} - e^{\left(\frac{V_2}{V_T} - \frac{V_1 + V_2}{2V_T}\right)} \right]}{\left[ e^{\left(\frac{V_1}{V_T} - \frac{V_1 + V_2}{2V_T}\right)} + e^{\left(\frac{V_2}{V_T} - \frac{V_1 + V_2}{2V_T}\right)} \right]} \\
&= I_c \frac{\left[ e^{\left(\frac{V_1 - V_2}{2V_T}\right)} - e^{-\left(\frac{V_1 - V_2}{2V_T}\right)} \right]}{\left[ e^{\left(\frac{V_1 - V_2}{2V_T}\right)} + e^{-\left(\frac{V_1 - V_2}{2V_T}\right)} \right]} \\
I_{\text{out}} &= I_c \tanh \left( \frac{V_1 - V_2}{2V_T} \right) \quad \dots(41.11)
\end{aligned}$$

The above equation depicts that output current  $I_{\text{out}}$  is a function of differential voltage  $V_{\text{in}}$  i.e.,  $(V_1 - V_2)$ . Thus a transconductance amplifier normally computes a tan-hyperbolic. For smaller range of inputs the output current behaves linearly and smoothly shifts to saturation. Transfer characteristic of OTA is given in Fig. 41.3.

Equation (41.11) can be assumed as

$$\begin{aligned}
I_{\text{out}} &\approx I_c \frac{V_1 - V_2}{2V_T} \quad \because [\text{for small values of } \theta, \tanh \theta \approx \theta] \\
\text{or } \frac{I_{\text{out}}}{V_{\text{in}}} &\approx \frac{I_c}{2V_T}
\end{aligned}$$

Transconductance,

$$g_m = \left| \frac{\partial I_{\text{out}}}{\partial V_{\text{in}}} \right| = \frac{I_c}{2V_T} \quad \dots(41.12)$$

The voltage gain,

$$A = g_m R_L = \frac{I_c R_L}{2V_T} \quad \dots(41.13)$$

Thus, the voltage gain of the Operational Transconductance Amplifier is controlled externally by a controlling current  $I_c$ .

At  $T = 27^\circ\text{C} = 300\text{ K}$

$$V_T = 25\text{ mV}$$

$$\therefore g_m = \frac{I_c}{2 V_T} = \frac{I_c}{2 \times 25 \times 10^{-3}\text{ V}} = 20 I_c \text{ per volt} \quad \dots(41.14)$$

$$\therefore I_{\text{out}} = (20 I_c) V_{\text{in}} \quad \dots(41.15)$$

