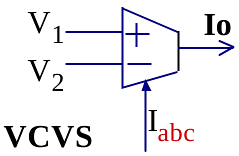
OPERATIONAL TRANSCONDUCTANCE AMPLIFIER (OTA)

First commercial OTA produced by RCA in 1969, i.e., CA3080



VCVS

$$Io = g_m(I_{abc})(V_1 - V_2)$$

The transconductance gain " g_m" is a function of the I_{abc} .

$\mathbf{g_m} = h_1 I_{abc}$ for bipolar and weak inversion MOSFETs

$\mathbf{g_m} = h_2 [I_{abc}]^{1/2}$ for MOSFETs in saturation

Operational Transconductance Amplifier (OTA)

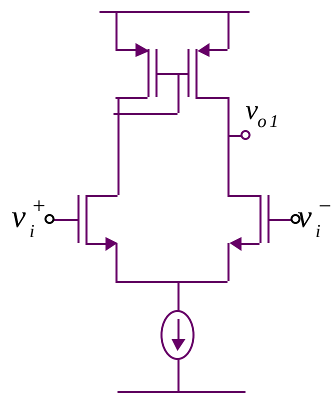
An ideal Op Amp requires high gain

$$A_v = G_m R_{out}$$

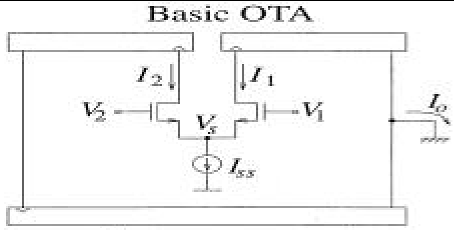
High R_{out} is desirable
if the load resistance is much higher than R_{out}

If the load is capacitor. ☺
i.e., Switched-Capacitor Circuits or
open loop continuous-time
Integrator

Simple CMOS Operational Transconductor Amplifier (OTA)



Basic OTA



$$\left.\begin{aligned} I_1 &= \beta(V_1 - V_s - V_T)^2 \\ I_2 &= \beta(V_2 - V_s - V_T)^2 \\ I_1 + I_2 &= I_{ss} \end{aligned}\right\} \Rightarrow \quad V_s = \frac{V_1 + V_2 - 2V_T}{2} \pm \sqrt{\frac{I_{ss}}{2\beta} - \left(\frac{\Delta V}{2}\right)^2}$$

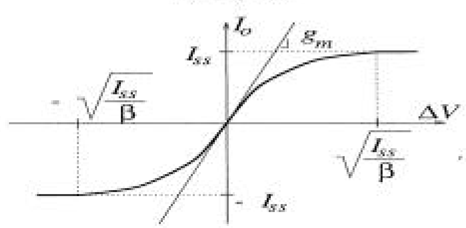
$$\Delta V = V_1 - V_2$$

$$I_o = I_1 - I_2 \quad \Rightarrow \quad I_o = \Delta V \sqrt{2 I_{ss}\beta} \sqrt{1 - \frac{\beta}{2 I_{ss}}(\Delta V)^2}$$

Linearity considerations

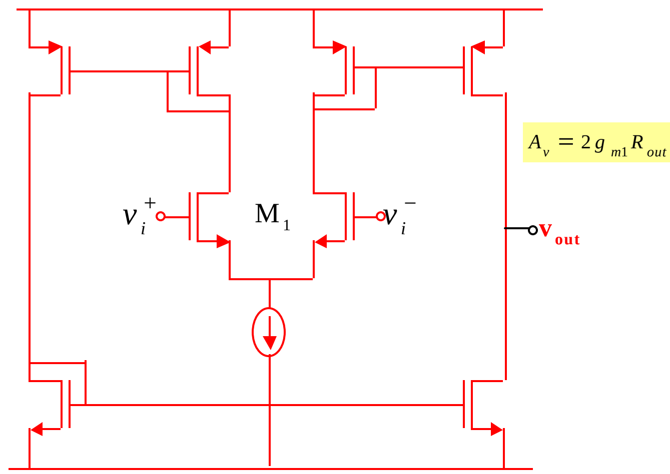
$$\beta = \frac{\mu C_{ox}}{2}\frac{W}{L}$$

$$g_m = \sqrt{2 I_{ss}\beta}$$

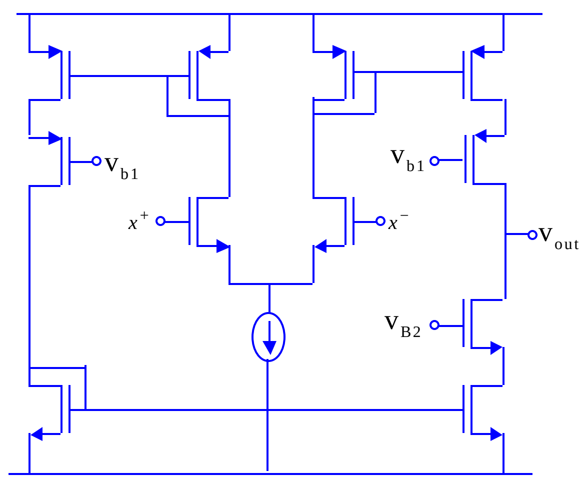


Operational Transconductor Amplifier

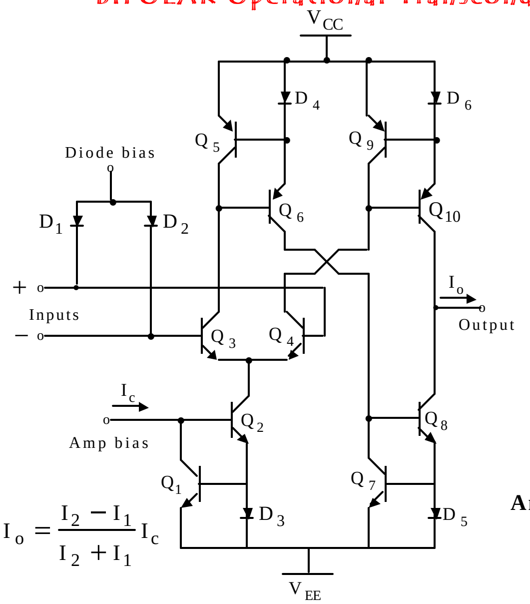
with three current mirrors



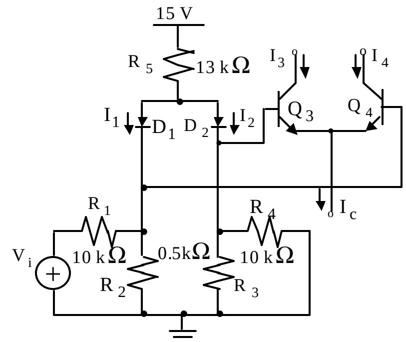
Cascode OTA



BIPOLAR Operational Transconductor Amplifiers



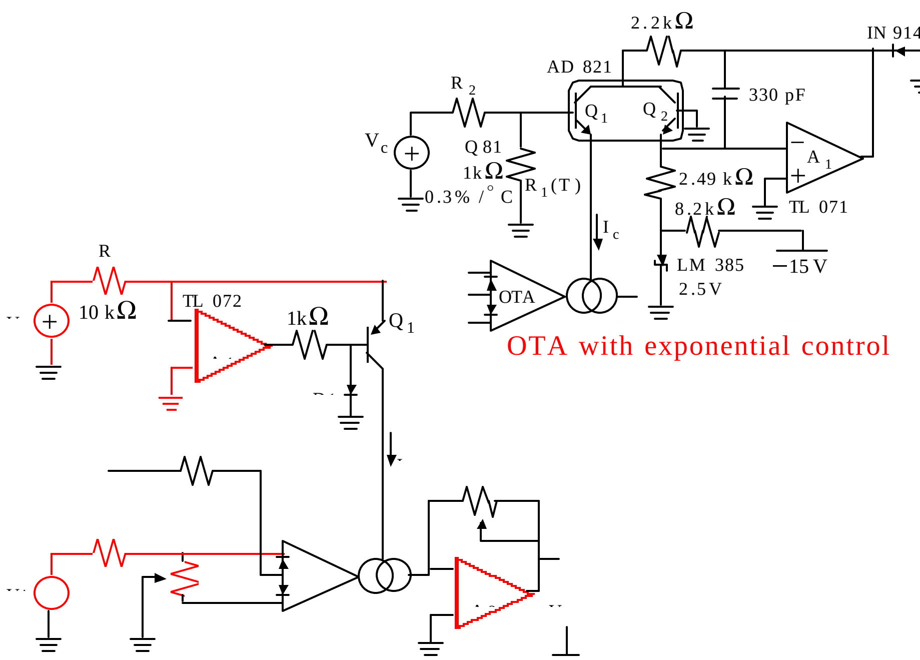
$$I_o = \frac{I_2 - I_1}{I_2 + I_1} I_c$$



An alternative linearization approach

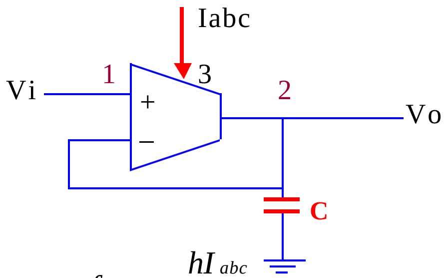
$$I_o = \frac{I_c}{12.2\text{V}} V_i$$

Bipolar OTA, LM13600 type.



Voltage-Controlled Amplifier with Linear Control.

First-Order Low-Pass using one OTA and one capacitor

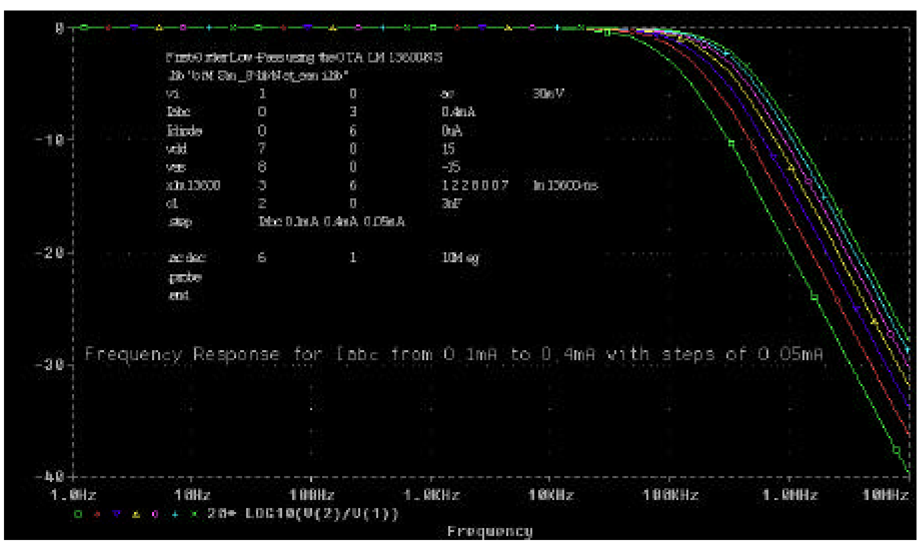


Vdd 7 0 15v
Vss 8 0 -15V

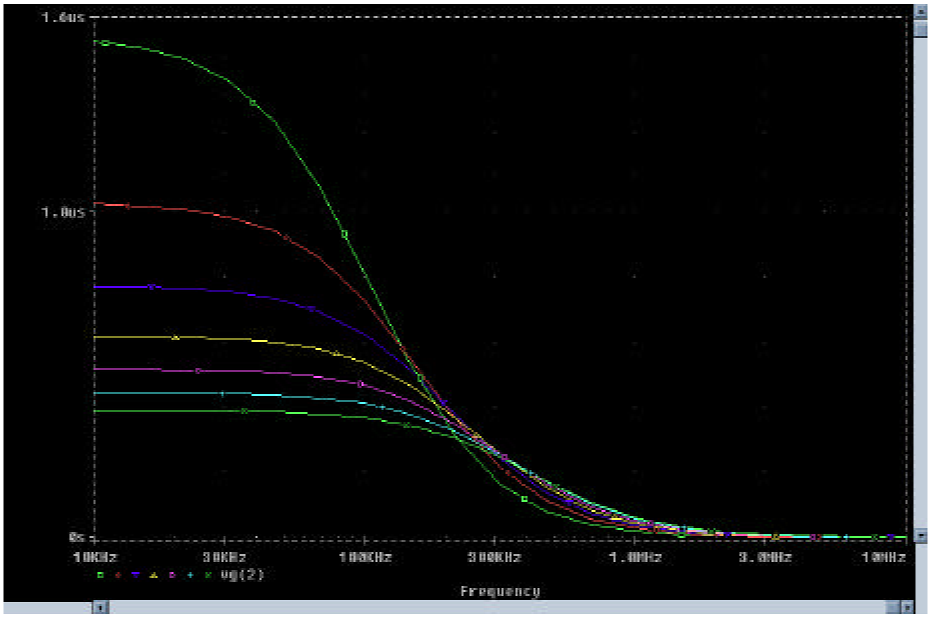
$$f_{3dB} = \frac{\eta I_{abc}}{2\pi C}$$

100Khz< f_{3dB} < 400KHz

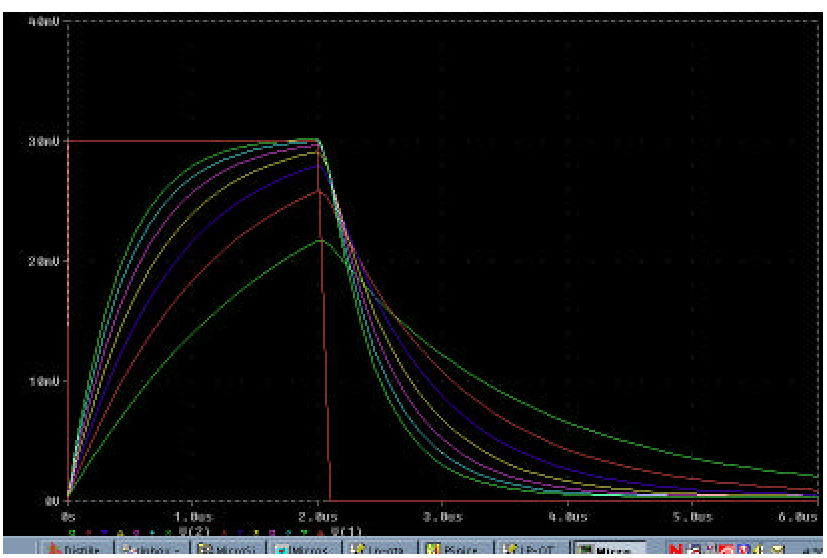
Note.- This OTA uses bipolar transistors



Group Delay for a First-Order Programmable Low Pass



Time Response (Pulse of 2Us duration)for a LP First-Order



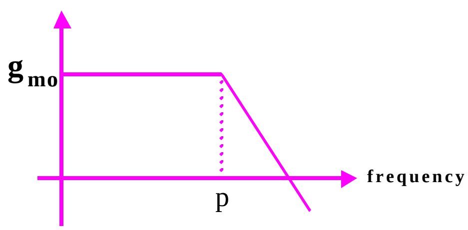
LM13600 with Iabc={0.1mA-0.4mA}

OPERATIONAL TRANSCONDUCTANCE AMPLIFIER (OTA) Frequency Dependence

$G_m = g_{mo} / (1 + s/p)$

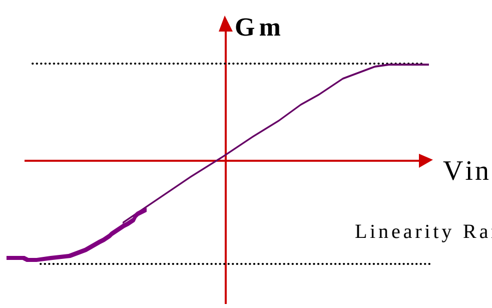
Where g_{mo} is the DC transconductance gain

p is the dominant pole which is around 10MHz to 100Mhz



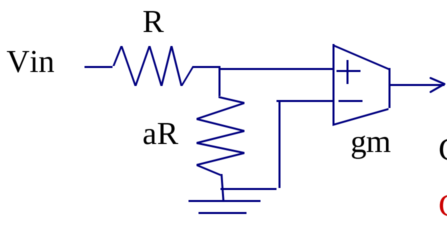
Issues about the OTA:

- Operated in open loop conditions
- High-Frequency Operation
- Poor Linearity Range



Linearity Range from 50mV to 200 mV

Linearization of OTA by means of Attenuation



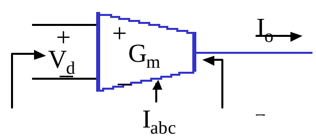
$$Gm_{effective} = a\,gm/(1+a)$$

$$Gm = bgm$$

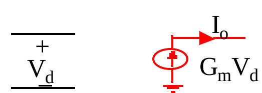
$$b = a/(1 + a)$$

Basic Building Blocks

• The Operational Transconductor Amplifier (OTA)--its input is voltage; its output is current. It is a voltage-controlled current source.



Symbol



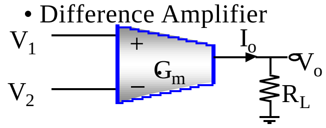
Macromodel of Ideal OTA

$G_m = G_m(I_{abc})$

Fundamental Operations

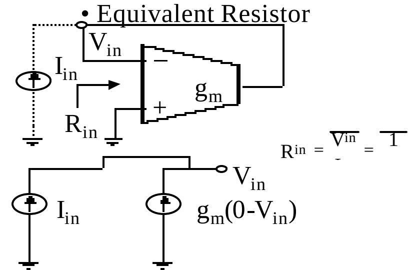
Observe that in contrast to Op Amp, the OTA is often used in a open-loop fashion.

• Difference Amplifier

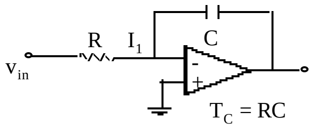
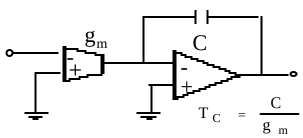
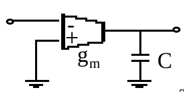


$I_o = G_m(V_1 - V_2)$

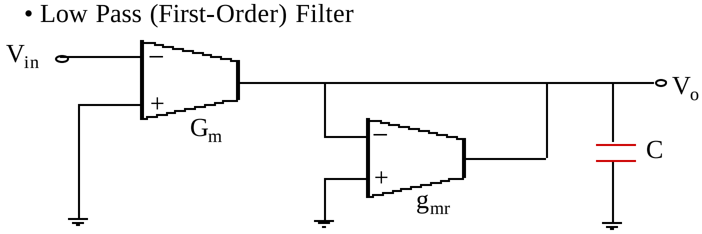
• Equivalent Resistor



INTEGRATORS

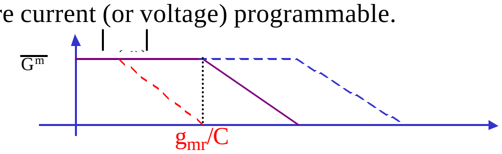
Implementation	Remarks
 $T_C = RC$ MOSFET-C, $T_C = \frac{C}{K(V_{C1} - V_{C2})}$	• Non-ideal op amp effects i.e., A_o, GB • Frequency limitations $\omega_o = \frac{1}{T_C} < GB$, i.e., $\omega_o \leq \frac{GB}{30}$ • Need of buffered op amp • Limited MOSFET's gate volt.
 $T_C = \frac{C}{g_m}$	• Increased tunability • No loading effect • Still GB effects • No parasitic cap. effects
 $T_C = \frac{C}{g_m}$	• Need linear components • Excellent frequency resp. • MOSFET OTA tuning range of several octaves • BiCMOS OTA wider tuning range • Suffer parasitic cap. effects

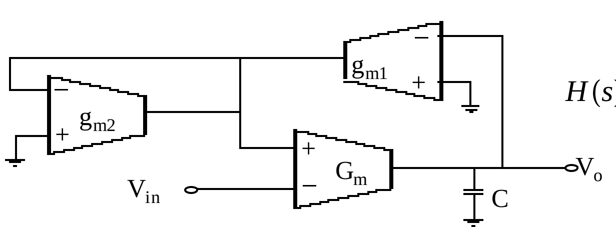
- Low Pass (First-Order) Filter



$H(s) = \frac{V_o(s)}{\;} = \frac{-G_m/g_{mr}}{\;}$

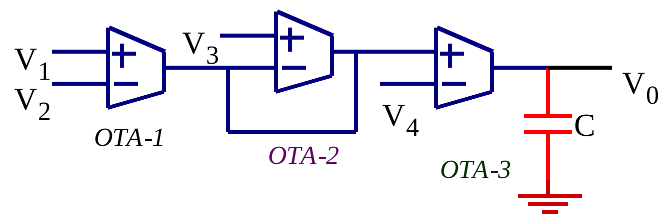
Remember that OTAs are current (or voltage) programmable.





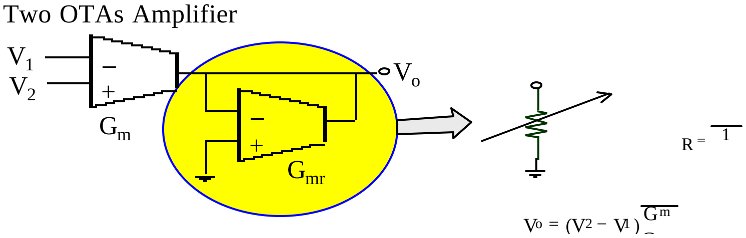
$$H(s) = \frac{V_o(s)}{V_{in}(s)} = \frac{-G_m}{sC + G_m g_{m1}/g_{m2}}$$

Example of Multiple OTAs Circuit



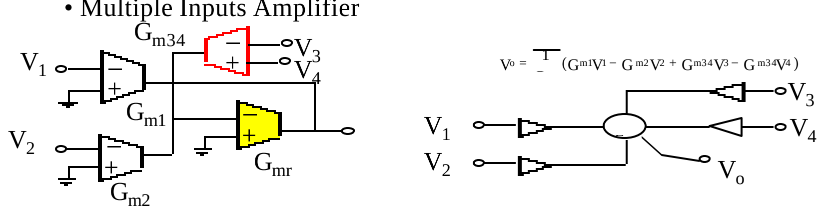
$$Vo = gm_1(V_1 - V_2)gm_3/sCgm_2 + (V_3 - V_4)gm_3/sC$$

- Two OTAs Amplifier

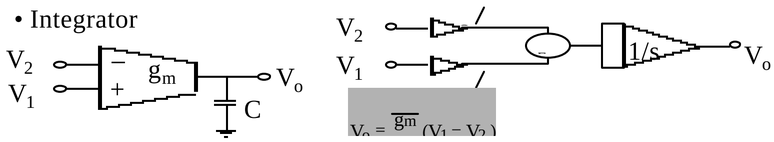


Observe that both inverting and non-inverting amplifiers are simultaneously available. If only one is needed, the other input is grounded.

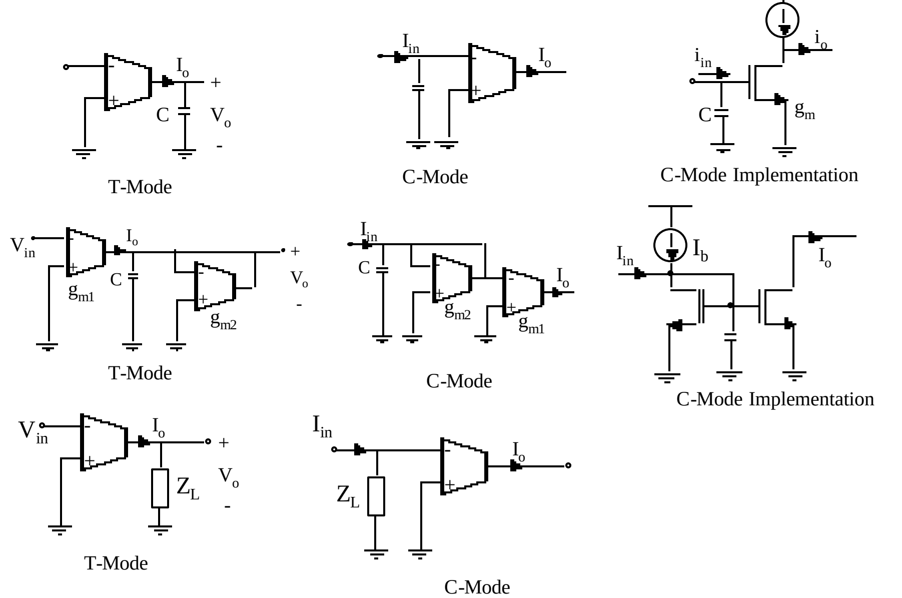
- Multiple Inputs Amplifier

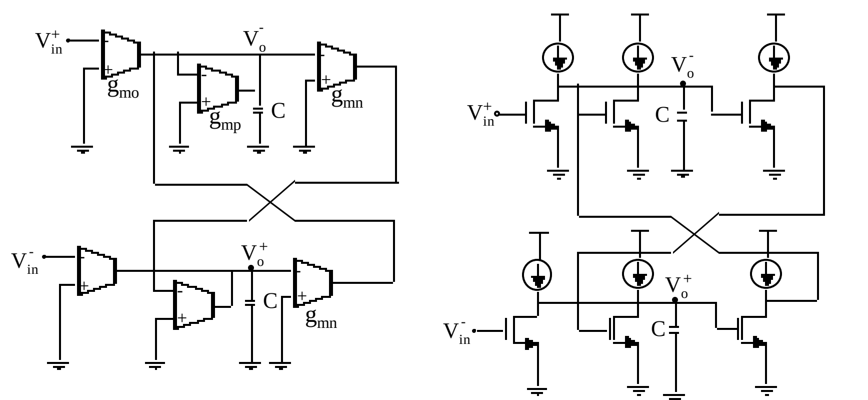


- Integrator



How to map a Transconductance-Capacitor Circuit to a Current-Mode Circuit?

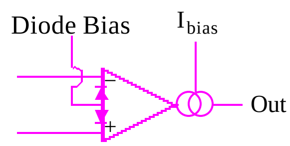




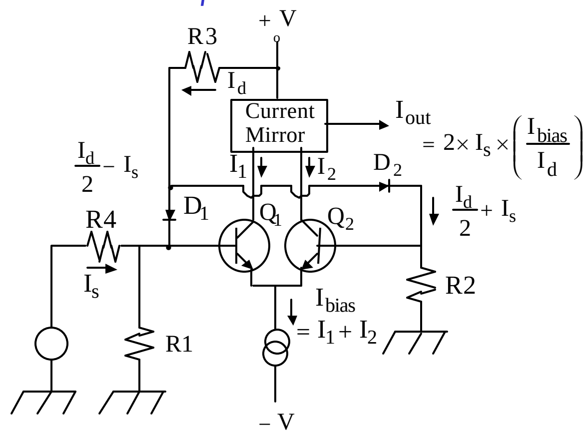
Pseudo-Differential Voltage-Mode Implemented with Transconductors

$$A_{dm} = \frac{g_{mo}/C}{S + (g_{mN} - g_{mP})/C}$$

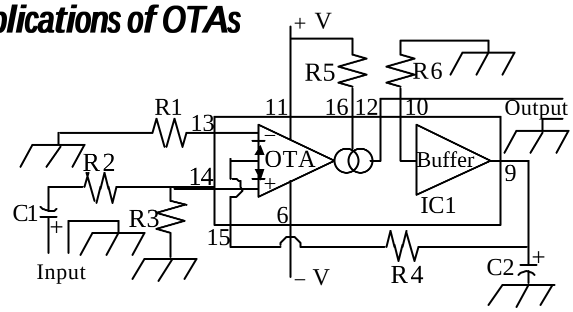
$$A_{cm} = \frac{g_{mo}/C}{S + (g_{mN} + g_{mP})/C}$$



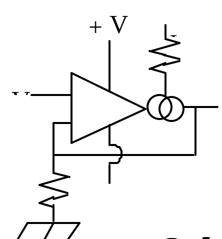
LM 13600 simplified version

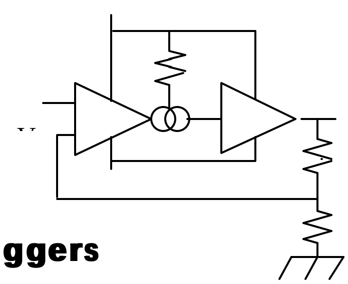


Applications of OTAs



Automatic Gain Control (AGC) Amplifier





Schmitt Triggers

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