OTA Applications
output relations by realizing resistors by \( \frac{3}{4} \)m value.

on silicon an active filter can satisfy both input and bandwidths one.

Thus frequency response of filters are limited.

Thus, for a transfer value of \( R \) (larger and smaller), the realization on silicon are limited.

Thus frequency cutoffs, one must get very small for higher frequency cutoffs. For example, an RC filter is a passive continuous filter, used in cases which have lower cutoff.

For continuous (analog) filters are mostly continuous, but also use in realization of active filters.
Such filters are also called $g_{m-C}$ continuous filters.

OTA is a device whose output could be controlled 'transconductance'.

Take an OTA as shown

\[ i_{out} = g_{M} \cdot (V_{+} - V_{-}) \]

If we put $V_{-} = 0$

Then $i_{out} = g_{M} \cdot V_{in}$
Unloaded

\[ I_{\text{out}} = g_m \cdot V_{\text{in}} \]

Loaded

\[ V_{\text{out}} = \frac{I_{\text{out}}}{j\omega C} \]

Loaded with -ve Feedback

\[ I_{\text{bias}} = g_m \cdot V_{\text{in}} \]
Low Pass Filter

\[ A(s) = \frac{V_{\text{out}}(s)}{V_{\text{in}}(s)} = \frac{9m_1 / j\omega c}{1 + \frac{9m_1}{j\omega c}} = 1 + \frac{1}{1 + \omega / \omega_0} \]

\[ \omega_0 = \frac{9m_1}{c} \]

\[ V_\text{out} = l_{\text{out}} \cdot \frac{L}{j\omega C} = \frac{9m_1}{j\omega C} \left( V_{\text{in}} - V_{\text{out}} \right) \]

\[ V_{\text{out}} \left[ 1 + \frac{9m_1}{j\omega C} \right] = \frac{9m_1}{j\omega C} V_{\text{in}} \]
\[
\text{High Pass Filter}
\]

[Diagram of a high pass filter with a transfer function and circuit representation]
"General Purpose Biquad Filter with OTA"

Combining LP & HP filter architectures as seen earlier, we can create both Band Pass and Band Reject filters.
If we put $V_2$ and $V_3$ to Ground, we get

$$V_{out1} = \frac{1}{j\omega C_1} GM (V_1 - V_{-1})$$

$$V_{out1} = \frac{1}{j\omega C_1} GM (V_{in} - V_{out2})$$

$$V_{out2} = \frac{1}{j\omega C_2} GM (V_{out1} - V_{out2})$$

$V_{out1} = V_2$

$V_{out2} = V_2 + V_{-2}$

$V_{out2} = V_1 = V_{in}$

$-\text{(1)}$

$-\text{(2)}$
Substituting (1) in (2)

\[ V_{out2} = \frac{g_m}{j\omega C_2} \left[ \frac{g_m}{j\omega C_1} (V_{in} - V_{out2}) - V_{out2} \right] \]

or \[ j\omega C_2 \cdot V_{out2} = \frac{g_m}{j\omega C_1} V_{in} \]

Taking \( g_m = g_m' \)

- \[ - \left[ + \frac{g_m'}{j\omega C_1} + 1 \right] V_{out2} \]

\[ V_{out2} \left[ 1 + \frac{g_m'}{j\omega C_1} + \frac{j\omega C_2}{g_m'} \right] = \frac{g_m'}{j\omega C_1} \cdot V_{in} \]

\[ \therefore \text{Transfer} \ V_{out2} = \frac{g_m'/(j\omega C_1)}{1 + \frac{g_m'}{j\omega C_1} + \frac{j\omega C_2}{g_m'}} = A(j\omega) \]
\[ A(s) = \frac{g_{m1}}{s c_1 + \frac{g_{m1}}{s c_1} + \frac{s c_2}{g_{m1}}} \]

\[ = \frac{g_{m1}}{s c_1 + g_{m1} + \frac{s^2 c_1 c_2}{g_{m1}}} \]

\[ = \frac{g_{m1}^2}{s^2 c_1 c_2 + s g_{m1} c_1 + g_{m1}^2} \]

\[ \Rightarrow H(s) = \frac{c}{a s^2 + b s + c} \rightarrow \text{Two Poles only. Dominant pole is cut-off frequency.} \]

\[ \therefore \text{This is a Low Pass Filter.} \]
Case II: \( V_2 = V_m \), \( V_1 = V_3 = 0 \)

\[
\text{Vout}_1 = g_{m1} (0 - \text{Vout}_2) \cdot \frac{1}{j\omega C_1} + \text{Vin}
\]

\[
\text{Vout}_1 = -\frac{g_{m1} \text{Vout}_2 + \text{Vin}}{j\omega C_1} \quad (1)
\]

\[
\text{Vout}_2 = g_{m1} (\text{Vout}_1 - \text{Vout}_2) \cdot \frac{1}{j\omega C_2} \quad (2)
\]
Substitute 1 in 2

\[ V_{out\ 2} = \frac{g_{m1}}{jwC_2} \left[ -\frac{g_{m1} V_{out\ 2} + V_{in}}{jwC_1} - V_{out\ 2} \right] \]

\[
\left[ 1 + \frac{jwC_2}{g_{m1}} + \frac{g_{m1}}{jwC_1} \right] V_{out} = V_{in}
\]

\[
\left[ 1 + \frac{sc_2}{g_{m1}} + \frac{g_{m1}}{sc_1} \right] V_{out} = V_{in}
\]

\[
\frac{V_{out}}{V_{in}} = A(s) = \frac{1}{1 + \frac{sc_2}{g_{m1}} + \frac{g_{m1}}{sc_1}}
\]

\[
A(s) = \frac{g_{m1} s_{c_1}}{s c_2 + s g_{m1} c_1 + g_{m_1}^2} = \frac{g_{m1} s_{c_1}}{a s^2 + bs + c}
\]
\[ H(s) = \frac{S}{as^2 + bs + c} \] is for Bandpass filter core.

1. If we set \( V_2 = V_{in} \) & \( V_1 = V_3 = 0 \)

The two OTA architecture behaves as a Bandpass filter.

Similarly, if \( V_3 = V_{in} \) & \( V_1 = V_2 = 0 \), we get

\[ A(s) = \frac{s^2 c_1 c_2}{s^2 c_1 c_2 + s c_1 g_{m1} + g_{m1}^2} \] which is a transfer function for Highpass filter.
OTA as Voltage Amplifier

\[ I_0 = g_m (V^+ - V^-) = -g_m V^- \]

\[ \frac{V_{in} - V^-}{R_1} = I_1 = I_2 = \frac{V_- - V_{out}}{R_2} \]

But \[ I_0 = -I_2 \]

\[ \therefore \frac{V_- - V_{out}}{R_2} = g_m V_- \quad \text{or} \quad \frac{V_{out}}{R_2} = V_- \left( \frac{1}{R_2} - g_m \right) \]

\[ \text{or} \quad V_- = \frac{V_0}{1 - g_m R_2} \]
Also \( I_1 = \frac{V_{in} - V_-}{R_1} = \frac{V_{in}}{R_1} - \frac{V_{out}}{R_1 (1 - g_m R_2)} \)

\[
I_2 = \frac{V_- - V_{out}}{R_2} = \frac{V_{out}}{R_2 (1 - g_m R_2)} - V_{out}
\]

\[
= \frac{V_{out}}{R_2} \left[ \frac{1}{1 - g_m R_2} - 1 \right] = \frac{V_{out}}{R_2} \cdot \frac{g_m R_2}{1 - g_m R_2}
\]

\[
= V_{out} \frac{g_m}{1 - g_m R_2}
\]

Equating \( I_1 = I_2 \)

\[
\frac{V_{in}}{R_1} - \frac{V_{out}}{R_1} \left(1 - g_m R_2 \right) = \frac{g_m}{1 - g_m R_2} \cdot V_{out}
\]
\[ V_{in} = \frac{1 + g_m R_1}{1 - g_m R_2} \frac{V_{out}}{V_{in}} = \frac{1 - g_m R_2}{1 + g_m R_1} \]

If \( g_m R_2 \rightarrow g_m R_1 \gg 1 \)

Then \[ \frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1} \]

Same as OPAMP based Amplifier.
Fully Differential OPAMP

Fully differential (outputs) Amplifiers have certain advantages over single ended OPAMPS.

1. Larger Output Swings as \( V_{out} \) & \( V_{out} \) are independently handled

2. May result in better or superior frequency performance as 'No' Miller capacitance is used
The biggest advantage of fully Differential System is Rejection of Noise overriding at parasitic capacitances both at the Input and Output.

\[ V_- = V_- + V_N, \quad V_+ = V_+ + V_N \]
\[ V_+ - V_- = \overline{V_+ - V_-} \]

Same wave \( \text{Vout}^+ - \text{Vout}^- = \text{Vout}^+ - \text{Vout}^- \)
However to achieve these better properties we need to create a 'COMMON MODE FEEDBACK' circuit (CMFB) which maintains

For Fully Differential OPAMP, the Open-Loop Gain (DC) $A_{oLdc}$ is

$$A_{oL} = \frac{V_{out}^+ - V_{out}^-}{V_+ - V_-}$$

If we have Single-ended OPAMP, then

$$A_{oL} = \frac{V_{out}^+}{V_+ - V_-}$$
we can say $V_o = -V_e$
e xtending this to differ ential case

we get $V_e = V = -V_e$

for $-V_e$ or $+V_e$ inputs, then

say currents don’t enter in opamp

but is very very large, $-V_e$

Here we invoke the rule that

we use in single-ended opamp based amplifier.

we use $-V_e$ feedback similar to that

and $+V_e$...

Hence if we only consider one of the

output $V_o$ in fully differential case
This is equivalently saying, a Differential Amplifier can be realised by two single ended Amplifiers.

Due to difference in input connectivity in two OPAMPS, the Phase Margin for two differs a lot and hence Bandwidth observed for this case is very much limited.