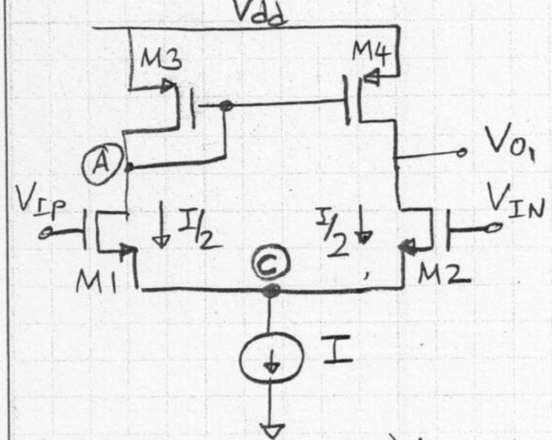
# OTA Topologies

(— Allstot)




## Single Stage OTA

Common-mode

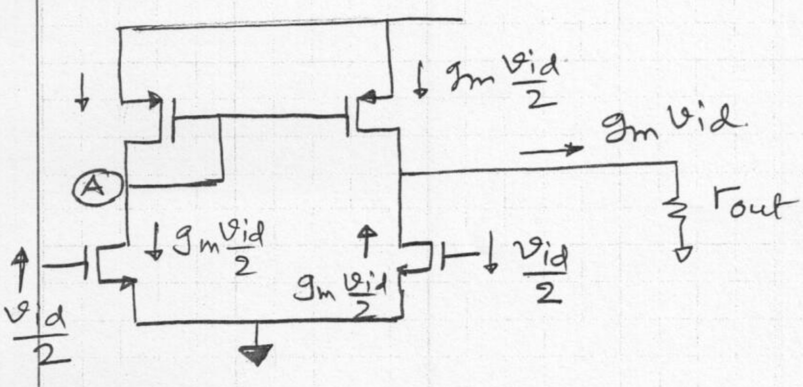
$V_{IP} = V_{IN} = V_{CM}. \quad \left(\frac{V_{dd}}{2}\right)$

ASSUME Feedback sets $V_{SD_3} = V_{SD_4}$

$$V_{SD_3} = V_{SD_4} = |V_{Tp}| + \sqrt{\frac{2\left(I/2\right)}{\mu_p C_{ox}\left(\frac{W}{L}\right)_p}}$$

$$V_{O_1} = V_{dd} - |V_{Tp}| - |V_{DSATp}|$$

Ac analysis — Node C — virtual ground node. for differential signal.



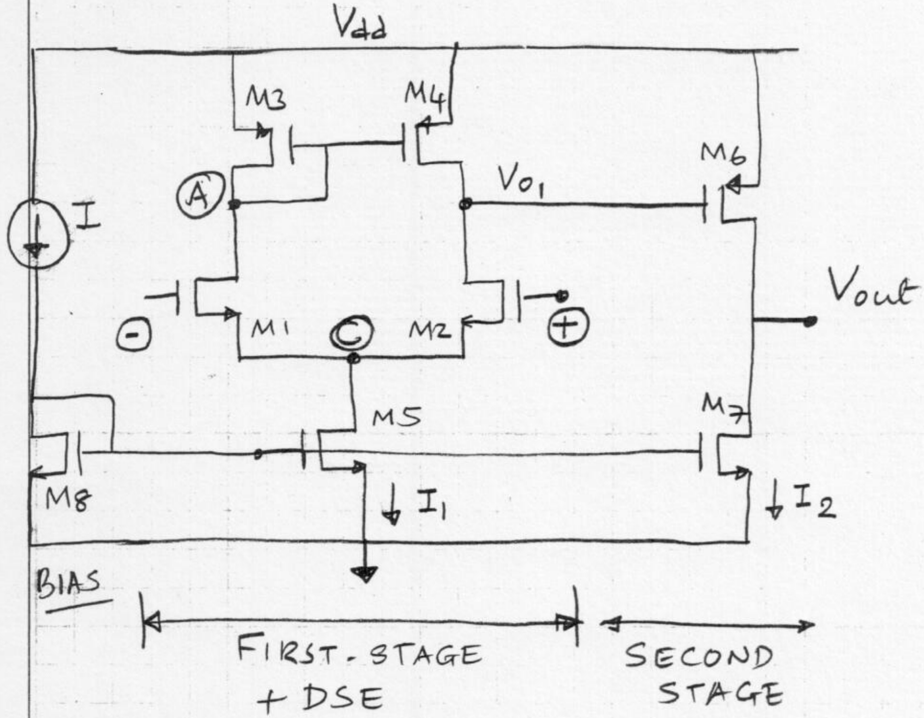

small signal o/p resistance $= \frac{1}{(g_{ds_2} + g_{ds_4})}$

$$V_{O_1} = \frac{g_{m_1} v_{id}}{g_{ds_2} + g_{ds_4}} \qquad A_v = \frac{g_{m_1}}{g_{ds_2} + g_{ds_4}} \qquad \underline{25\text{–}100}$$

$$g_{out_A} = g_{m_3} + g_{ds_3} + g_{ds_1} \approx g_{m_3}$$ — low imp. wide Bandwidth node.

<u>Limited gain</u> (one stage only)
D2SE included

## Two Stage OTA




BIASING — To avoid systematic offsets

(DC) $V_A = V_{o_1}$ $\quad \left\{ \text{Else } V_{os} = \dfrac{V_{o_1} - V_A}{A} \right.$ ← FIRST STAGE GAIN.

$$V_A = V_{dd} - V_{SG_3} = V_{o_1} = V_{dd} - V_{SG_6}$$

$$V_{SG_3} = V_{SG_6} \Rightarrow \text{Same } V_{dsat}.$$

$$|V_{T_3}| + \sqrt{\frac{2(I_1/2)}{\mu_p C_{ox}\left(\frac{W}{L}\right)_3}} = |V_{T_6}| + \sqrt{\frac{2(I_2)}{\mu_p C_{ox}\left(\frac{W}{L}\right)_6}}$$

Assuming $V_{T_3} = V_{T_6}$ (process matching)

$$\left(\frac{W}{L}\right)_6 = 2\left(\frac{I_2}{I_1}\right)\cdot\left(\frac{W}{L}\right)_3$$

Good design practice

$M_3, M_4, M_6$ — same L

$M_1 - M_2$ same W & L.

$M_8, M_5, M_7$ — same L.

also use unit cell design — keep W same

$$v_{o_1} = \frac{g_{m1}}{g_{ds_2} + g_{ds_4}} v_{id} \quad \& \quad v_{out} = \frac{g_{m6}\, v_{o_1}}{g_{ds_6} + g_{ds_7}}$$

$$\text{Total gain} = \frac{g_{m1}}{g_{ds_2} + g_{ds_4}} \cdot \frac{g_{m6}}{g_{ds_6} + g_{ds_7}}$$

Each high impedance node contributes a low freq pole in frequency response

Each pole → 90° phase shift

Two poles → 180° phase shift → +ve feedback

— Limit Two gain Stages. for Stability.

— <u>Need for frequency compensation</u>

Motivation to Study Feedback & Stability

→ Then comeback & figure out frequency compensation of <u>opamps</u>.

# Feedback & Stability

1927. Harold Black (Bell labs) — -ve feedback.

Advantages

1. Gain desensitization
2. Terminal impedance Modification

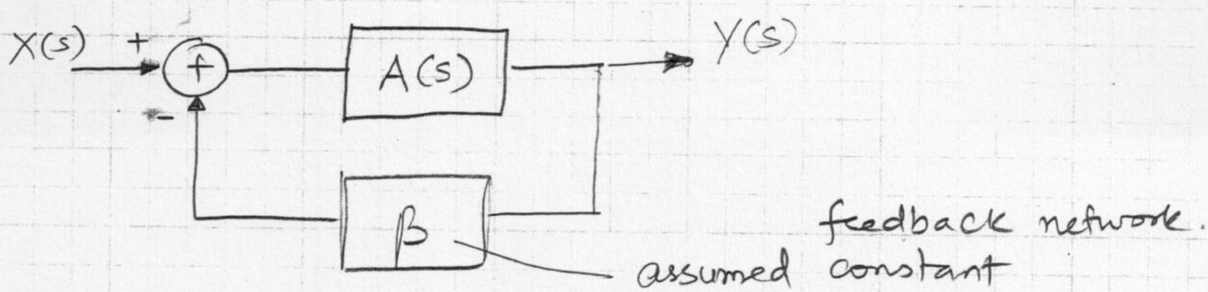
   Shunt FB ↓ impedance
   Series FB ↑ impedance

3. Bandwidth Modification. (increase in BW)
4. Nonlinearity reduction.

Disadvantages

1. Gain Reduction
2. Potential Instability.

Negative feedback example




$$\frac{Y(s)}{X(s)} = \frac{A(s)}{1+\beta A(s)}$$ Closed loop gain

$T$ = loop gain = $\beta A(s)$.

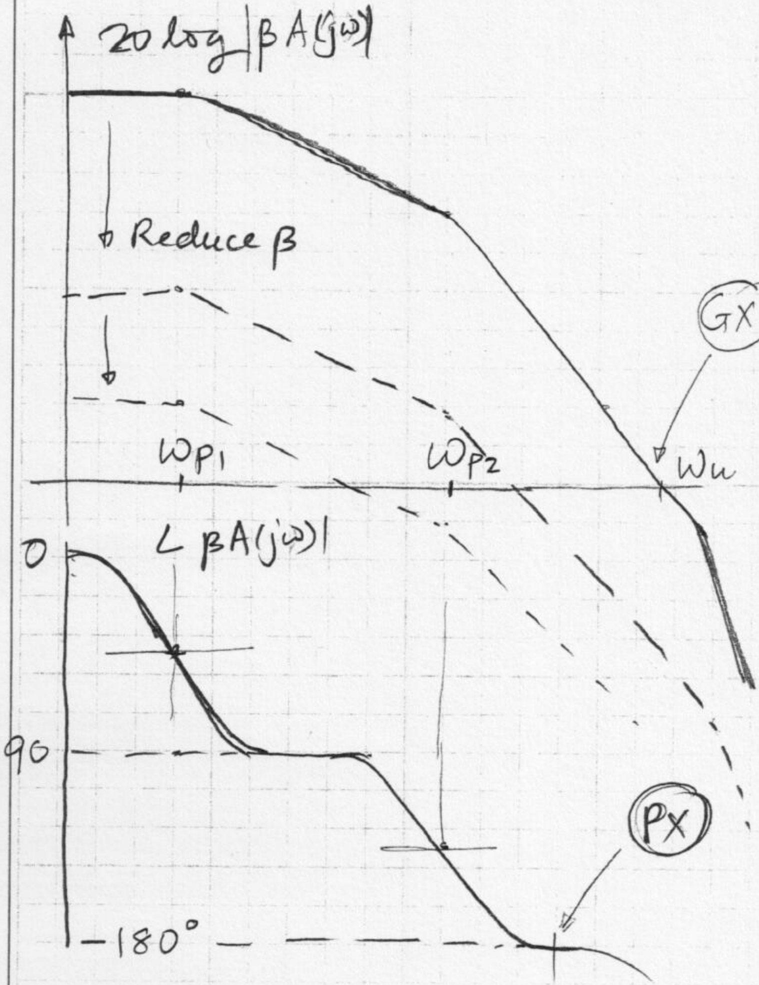
Closed loop gain goes to $\infty$ when $\beta A(s) = -1$

$|\beta A(s)| = 1$

$\angle \beta A(s) = -180°$.

Barkhausen's criteria for oscillations.

Consider Two-pole frequency response.




GX Gain Crossover freq.

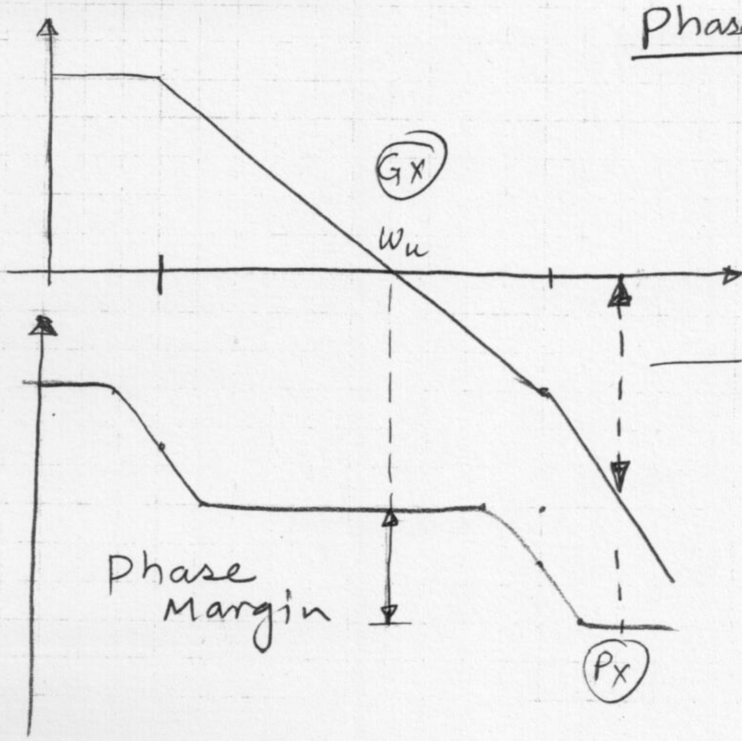
- loop gain unity

PX Phase Crossover freq.

- loop phase shift 180°

For stability GX must occur before PX

Measure of Stability




Phase Margin PM

$= 180° - \angle T(\omega_u)$

$= 60°$ (max. flat gain)

$= 70°$ (fast settling)

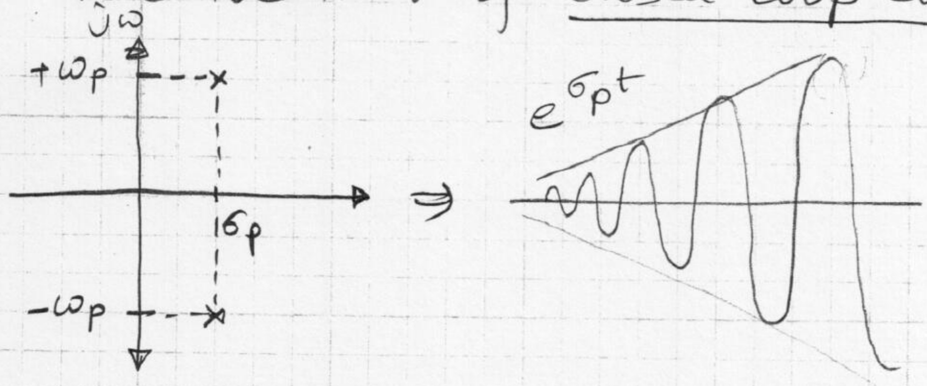
Gain Margin GM

$GM = -20 \log |T(\omega_{-180°})|$

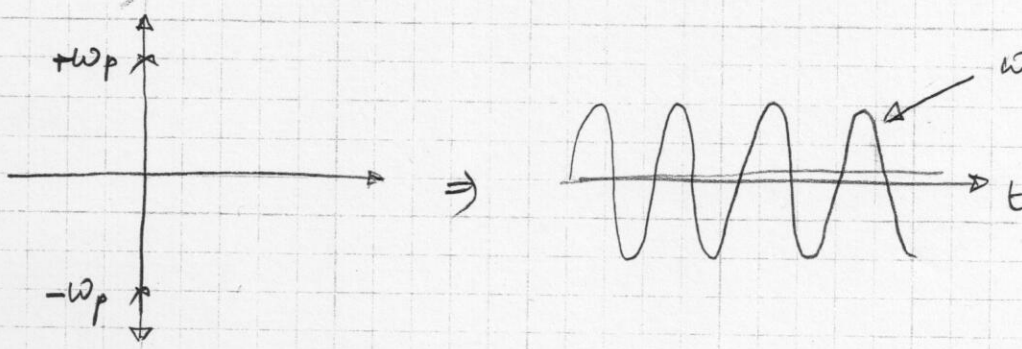
$= 12$ dB (typ).

## Pole location of Closed Loop System $\frac{Y(s)}{X(s)}$

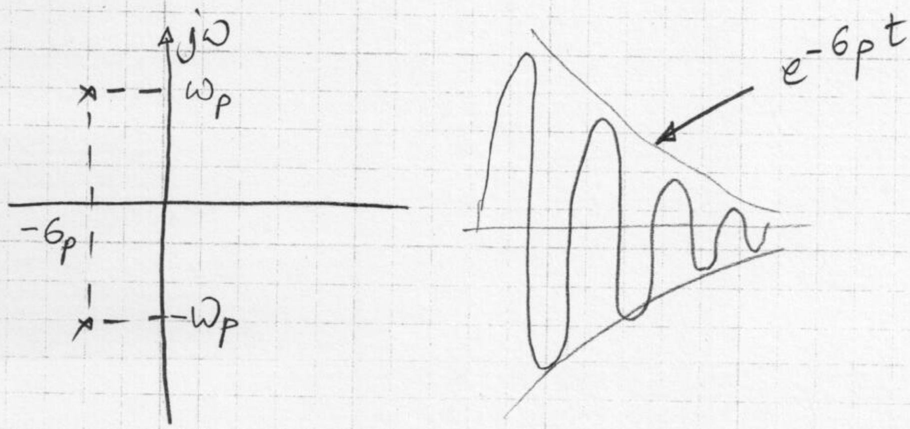
Not $T(s)$ Loop Gain




Freq domain Time domain




unstable oscillating




(stable)

**Example** One pole amplifier

$$A(s) = \frac{A_0}{\left(1 + \frac{s}{\omega_{p_1}}\right)}$$

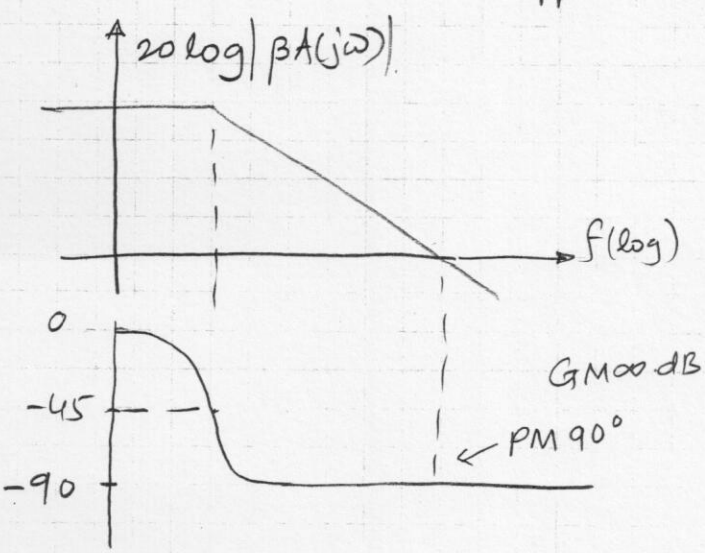
$\beta$ constant

Loop Gain $T(s) = \dfrac{\beta A_0}{\left(1 + \frac{s}{\omega_{p_1}}\right)}$

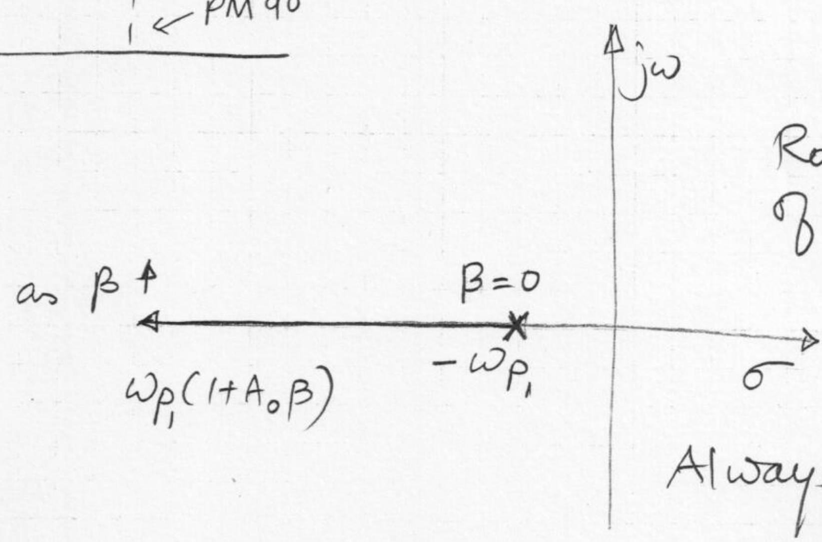
Closed loop gain

$$\frac{Y(s)}{X(s)} = \frac{\frac{A_0}{\left(1 + \frac{s}{\omega_{p_1}}\right)}}{1 + \frac{A_0 \beta}{\left(1 + \frac{s}{\omega_{p_1}}\right)}} = \frac{A_0}{\left(1 + \frac{s}{\omega_{p_1}} + A_0\beta\right)}$$

$$\frac{Y(s)}{X(s)} = \frac{A_0 / (1 + A_0\beta)}{1 + \frac{s}{\omega_{p_1}(1 + A_0\beta)}}$$ ← used for Root locus.




Unconditionally Stable




Root locus of closed loop response.

Always <u>Stable</u>