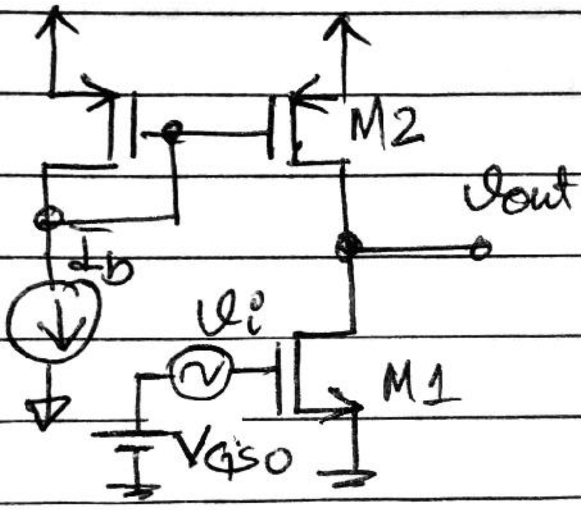
FEEDBACK

* Why feedback.

Let's look at two problems with a so-called open-loop (ie. no feedback) amplifiers eg. common-source amplifier



Problem-1 : Gain variability.

$$\text{Gain} = \frac{V_{out}}{V_{in}} = -g_{m1} \cdot (r_{ds1} \| r_{ds2})$$

Both g_m & r_{ds} vary wildly over ① process & ② temperature since μ, V_T are strong functions of process & temperature.

Problem-2 : Distortion.

The gain, $g_{m1}(r_{ds1} \parallel r_{ds2})$ is a small-signal approximation.

In reality, the transistor is non-linear and therefore the output will be distorted as the input signal grows in amplitude.

Let the time-varying input

$$v_i = V_m \sin \omega t$$

The largesignal drain current I_{DS} can be written as

$$I_{DS1} = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_T)^2$$

DC bias

$$= \underbrace{\frac{\mu_n C_{ox}}{2} \frac{W}{L}}_{\beta'} (V_{GS0} + 2 V_m \sin \omega t - V_T)^2$$

$$= \underbrace{\beta' (V_{GS0} - V_T)^2}_{\text{DC bias}} + \underbrace{\beta' \cdot 2 V_m \sin \omega t}_{g_m \cdot v_i} + \underbrace{\beta' V_m^2 \sin^2 \omega t}_{\text{Distortion}}$$

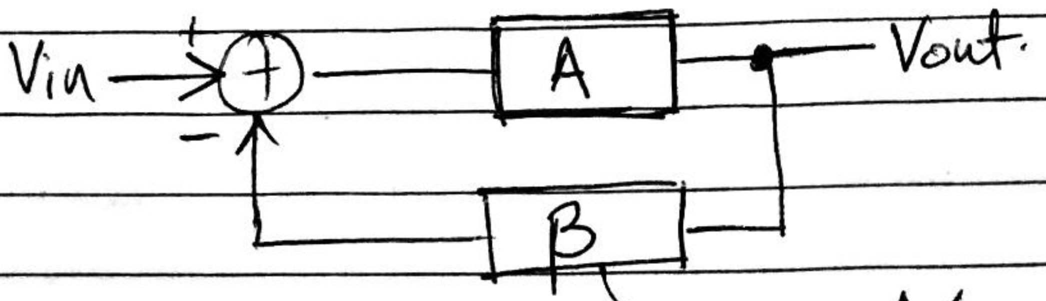
Using trignometric relation the distortion term can be expanded to

$$\beta' \cdot V_m^2 \sin^2 \omega t = \frac{\beta'}{2} V_m^2 (1 + \cos 2\omega t)$$

2nd harmonic distortion.

Therefore $V_{out} = \text{Gain} \cdot V_{in} + \underbrace{V_D}_{\text{unwanted distortion}}$

Feedback



$\beta = 1/G$
where G is the desired gain.

The idea is: Put a large gain block A in the so-called feed-forward path which can vary wildly and sample the output with accurate multiplier β which $1/G$ the desired gain and subtract it from the input to result in $G = \frac{V_{out}}{V_{in}} = 1/\beta$

$\therefore G > 1 \therefore \beta < 1$ which easily reliazable through simply a resistor divider.

$$\frac{V_{out}}{V_{in}} = \frac{A}{1+\underbrace{\beta \cdot A}_{\text{Loop gain} = L \text{ or } T}} = \underset{\substack{\text{closed-loop} \\ \text{gain}}}{A_{CL}} = \underset{\substack{\text{desired} \\ \text{gain}}}{G}$$

closed-loop gain OR desired gain

It can be seen from the above equation that for large A

$$\frac{V_{out}}{V_{in}} \approx \frac{1}{\beta}$$

Gain sensitivity:

Now let's see how much $V_{out}/V_{in} = A_{CL}$ varies for variation in A.

$$\frac{dA_{CL}}{dA} = \frac{d}{dA}\left(\frac{A}{1+\beta A}\right) = \frac{1}{(1+\beta A)^2}$$

The gain sensitivity S_A can be defined as

$$S_A = \frac{dA_{CL}/A_{CL}}{dA/A} = \frac{1}{1+\beta A} = \frac{1}{1+L} = \frac{1}{1+T}$$

$$\because \beta \cdot A \gg 1 \Rightarrow \underline{S_A \ll 1}$$

Example

Let desired gain $A_{CL} = 10$

$\Rightarrow \beta = 1/10$

& Let $A = 1000$

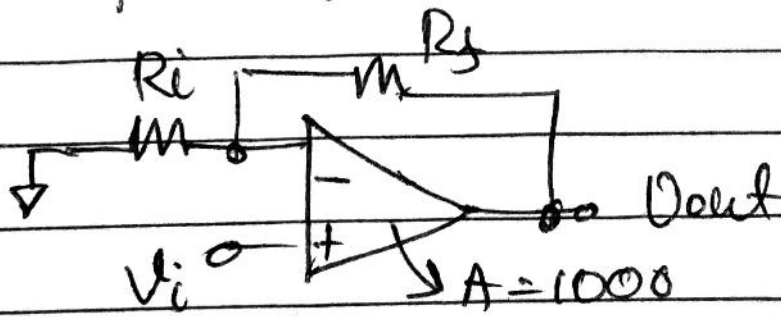
$$S_A = \frac{1}{1+100} \approx 0.01$$

Now let's say A varies by $\pm 10\%$

i.e 1000 ± 100 (900 – 1100)

then closed-loop gain A_{CL} varies by $0.01 \times 10\% = \underline{0.1\%}$

Op-Amp example:

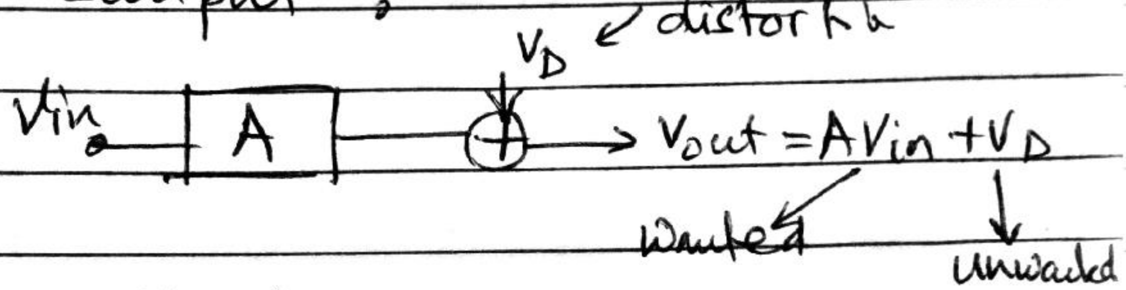


For $\frac{V_{out}}{V_i} = 10$ $\quad \beta = \frac{1}{R_f/R_i} = \frac{1}{10}$

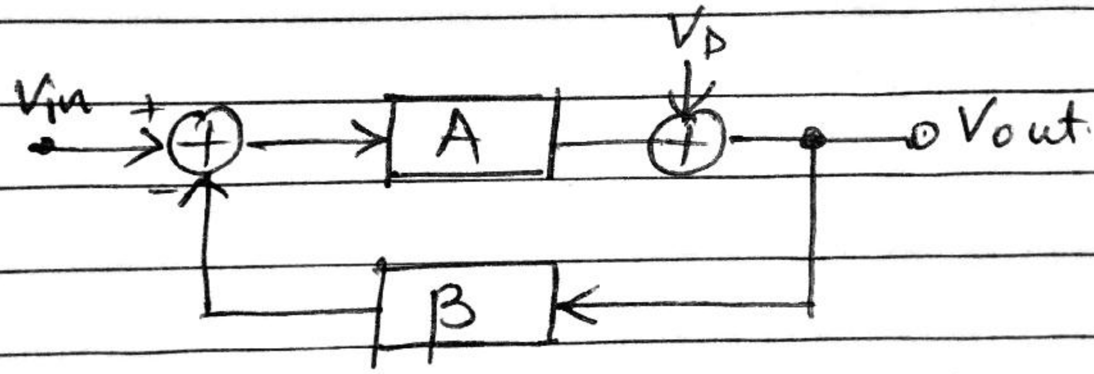
$\Rightarrow R_f/R_i = \underline{10}$ ← ratio of resistors variability is low.

Feedback improving distortion

The distortion can be modeled as the linear amplifier with an unwanted signal added at the output:



With feedback

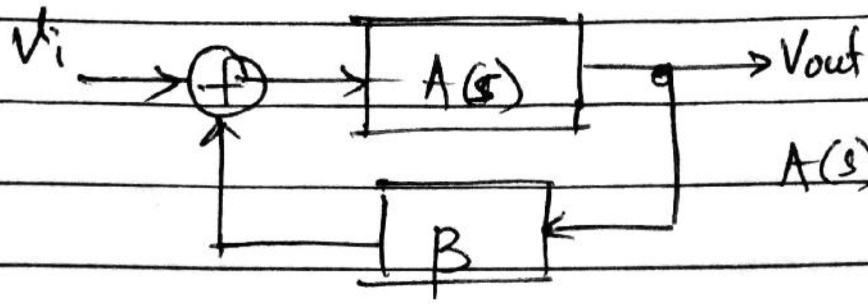


If we want to find the distortion in V_{out}:

$$\left.\frac{V_{out}}{V_D}\right|_{V_{in}=0} = \frac{1}{1+\beta A} \cong \frac{1}{\beta A} \approx 0$$

$$\therefore V_{out} = \frac{V_{in}}{\beta} + \cancel{\frac{V_D}{\beta A}}^{\approx 0}$$

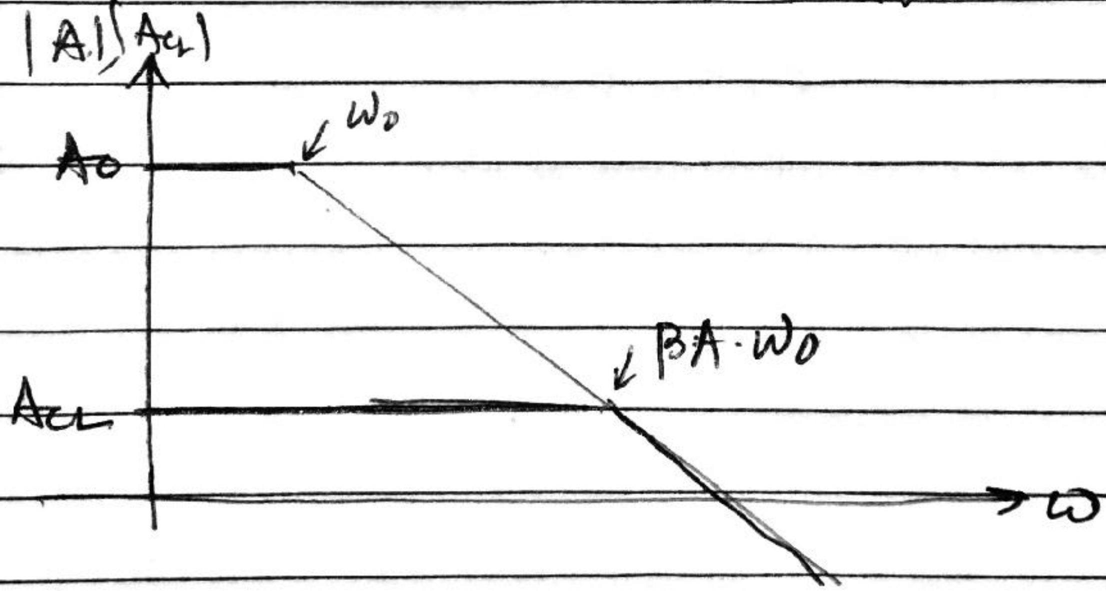
Gain-Bandwidth Trade-Off.



$$A(s) = \frac{A_0}{\frac{s}{\omega_0} + 1}$$

$$\frac{V_{out}}{V_{in}} = A_{CL} \cong \frac{1/\beta}{\frac{s}{\omega_0 \cdot \underbrace{\beta A}} + 1}$$

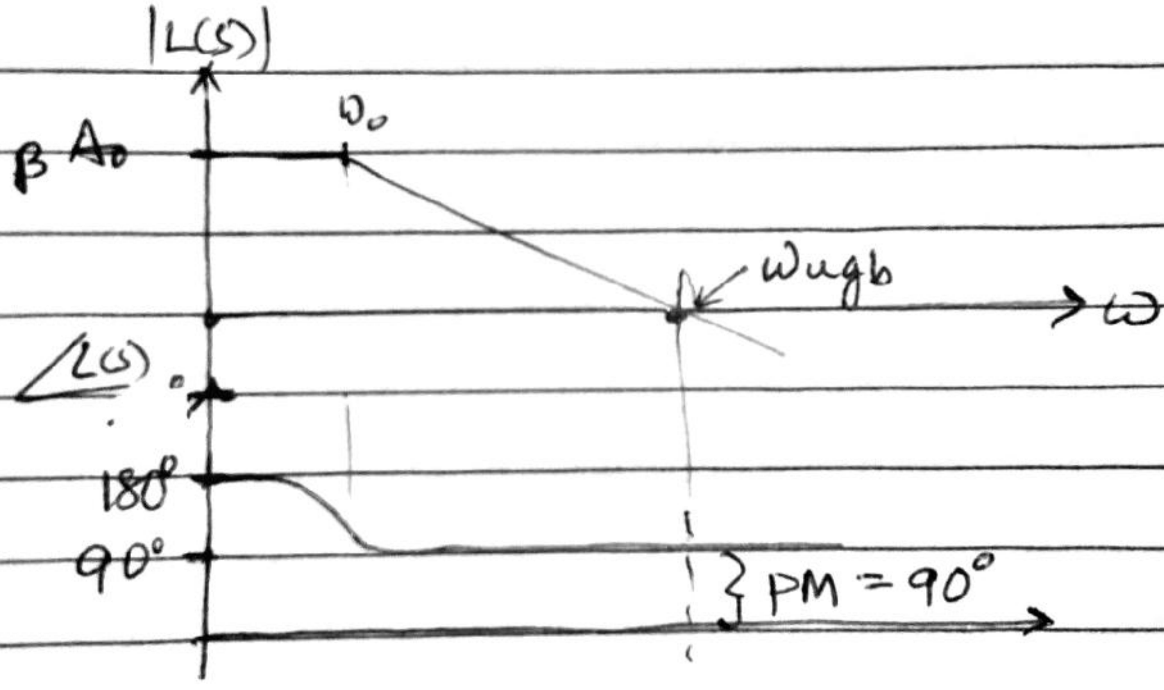
BW extension.



STABILITY CRITERIA.

* All poles of $A_{CL}(S) = \frac{V_{out}}{V_{in}}(s)$ should be in the left-half plane.

* The stability criteria is evaluated easily from the Bode Plot of the loop-gain $L(s) = \beta \cdot A(s)$



Stability criteria:

① Phase Margin (PM) $> 0^\circ$ but should be typically more than 45°

$$PM = 180^\circ - \angle L(j\omega) \Big|_{\text{at } \omega = \omega_{ugb} \ \& \ \beta A_0 = 1}$$

② Gain Margin (GM) $<$ 0 dB
and typically desired < -10 dB

GM = Gain @ ω when $\angle L(j\omega) = 0^\circ$