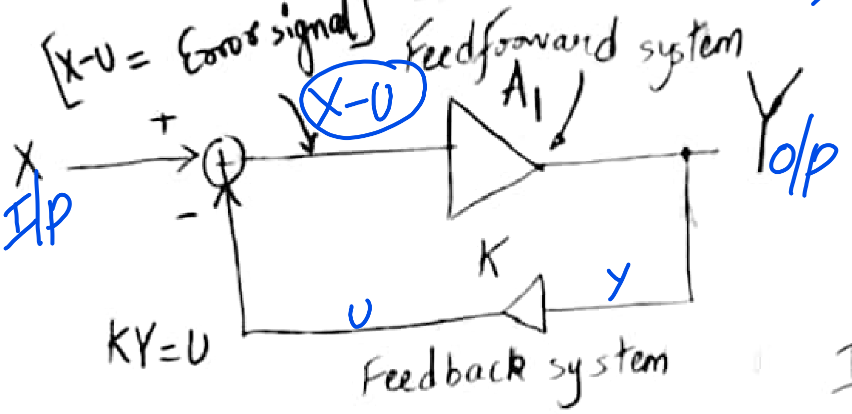
Review : (Story so far)

$K = \frac{U}{Y}$

[X-U = Error signal]



$$\frac{Y}{X} = \frac{A_1}{1+KA_1}$$

→ Open-loop gain (AoL)

→ Closed-loop gain < AoL

$KA_1 \to$ loop gain

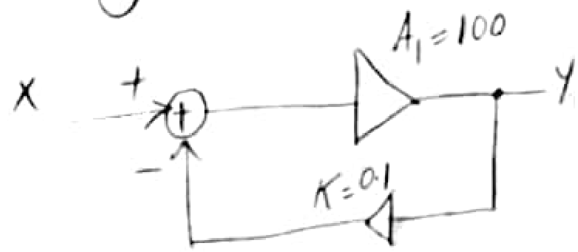
$$\text{Error} = \frac{X}{1+KA_1}$$

If error is small; $U \approx X$

Golden Rule:

- In a well-designed negative-feedback system, the feedback signal is a good copy (replica) of the input signal.

Example:-



$$\frac{Y}{X} = \frac{A_1}{1+KA_1} \approx \frac{100}{1+10} \approx \frac{100}{11}$$

$$\frac{Y}{X} \approx 9.09$$

100 → 50

↓ 9.09 ↓ 8.33

Example: II: What happens if A_1 drops to 50 in the previous example? $A_1 \approx 50$

$$\frac{Y}{X} = \frac{50}{1+5} \approx \frac{50}{6} \approx 8.33$$

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- Even though the open-loop gain changed by a factor ~~of 2~~, 02.
  the closed-loop gain changed by only 10%
  - Most important result:-
    - Significant change in A_1 leads to a minor change in closed-loop gain.

Observation: If $KA_1 \gg 1$, $\Rightarrow$

$$\boxed{\frac{Y}{X} \approx \frac{1}{K}}$$

$\Rightarrow$ Closed-loop gain is relatively independent of open-loop gain.

$\Rightarrow$ We should try to maximize KA_1.

Observation: K is usually chosen ≤ 1

- Loop gain: KA_1 : in a well-designed negative feedback system, the loop gain $\gg 1$.
  $\Rightarrow$ Closed-loop gain $\approx \frac{1}{K}$

Important Property: If $KA_1 \gg 1 \Rightarrow$

$\frac{Y}{X} \approx \frac{1}{K}$ and relatively indep. of A_1

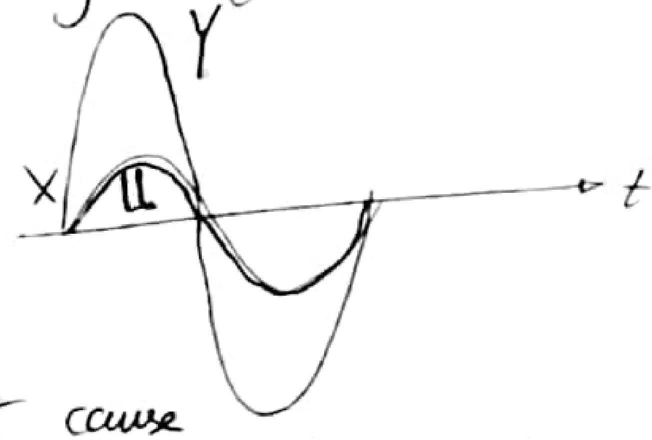
- **Summary of feedback concepts:-**

(1) We sacrifice the open-loop gain to benefit from negative feedback.

(2) The feedback signal is a good copy (replica) of the input signal.

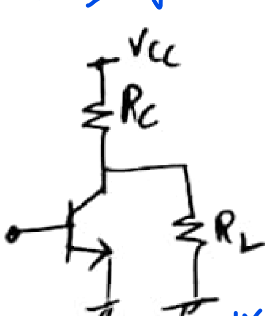
(3) $Y = \frac{U}{K}$ is a good copy of X but with a scaling factor. eg if $K = 0.1$, $Y \approx 10X$

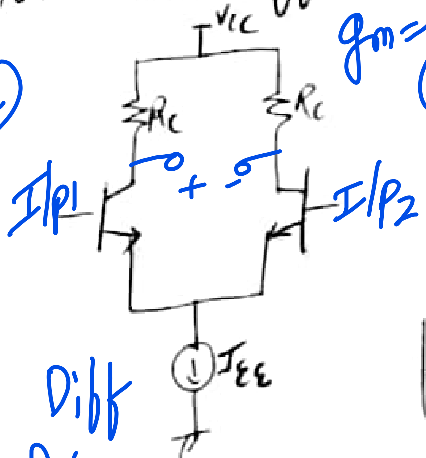
$\Rightarrow$ The loop wants to make Y a good (scaled) copy of X.



(4) If $\boxed{KA_1} >> 1$ $\Rightarrow$ Factors that cause A_1 to vary have less effect on the closed-loop gain.

$A_v = -g_m(R_C \| R_L)$





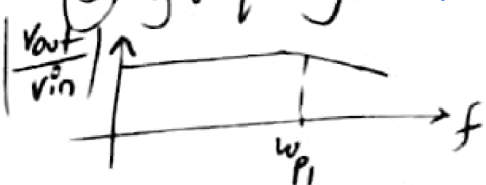
$g_m = \frac{I_C}{V_T}$

Factors that cause A_1 to vary:

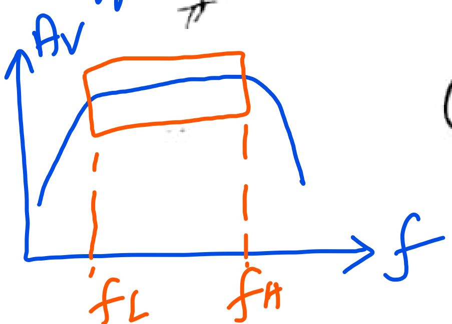
(1) Temperature.

(2) Supply voltage

(3) Frequency.



(4) load impedance ($\sim R_L$)



$BW = f_H - f_L$

- **Properties of Negative Feedback:**

$$\boxed{\frac{Y}{X} = \frac{A_1}{1+KA_1} \approx \frac{1}{K} \quad \text{if } \boxed{KA_1 >> 1}}$$

① Gain Desensitization $\Rightarrow$ $\frac{Y}{X}$ is less sensitive to temperature supply, etc than A_1 is.

$$\frac{Y}{X} = \frac{A_1}{1+KA_1} \approx \frac{1}{K} \qquad KA_1$$

$$\frac{Y}{X} = \frac{\frac{\cancel{A_1}}{K\cancel{A_1}}}{\boxed{\frac{1}{KA_1}} + 1} \approx \frac{1}{K}$$

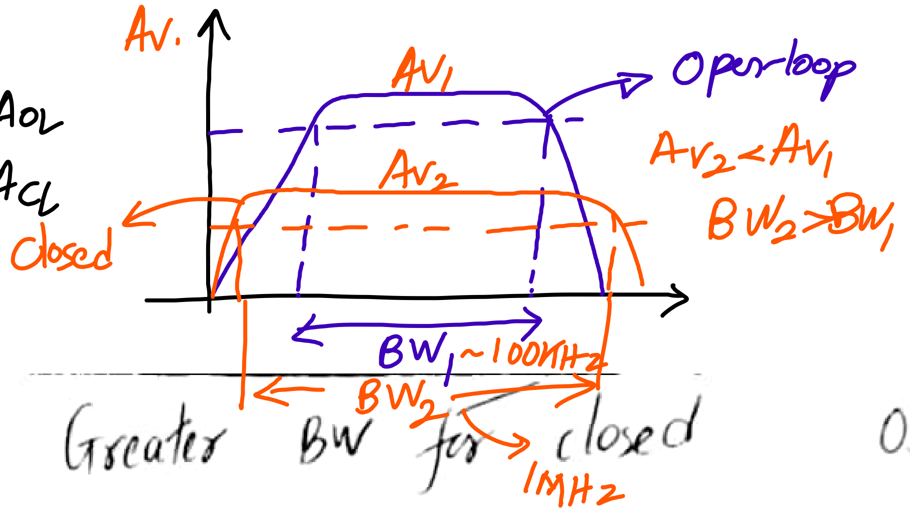
$$0 \leftarrow \frac{1}{KA_1}$$

Gain x BW = constant

Gain ↓↓

100 → A_{OL}

10 → A_{CL}



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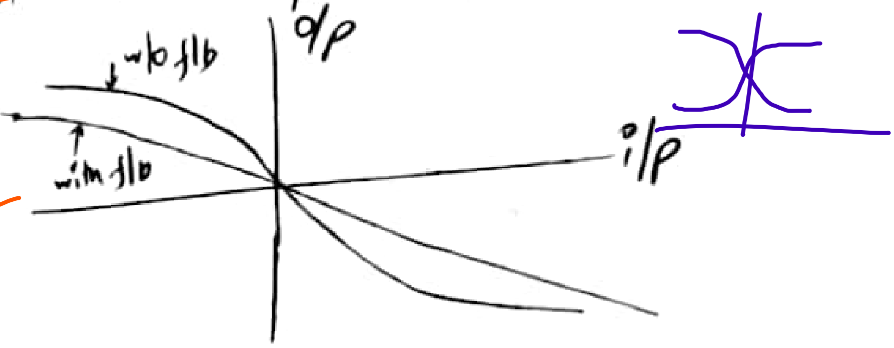
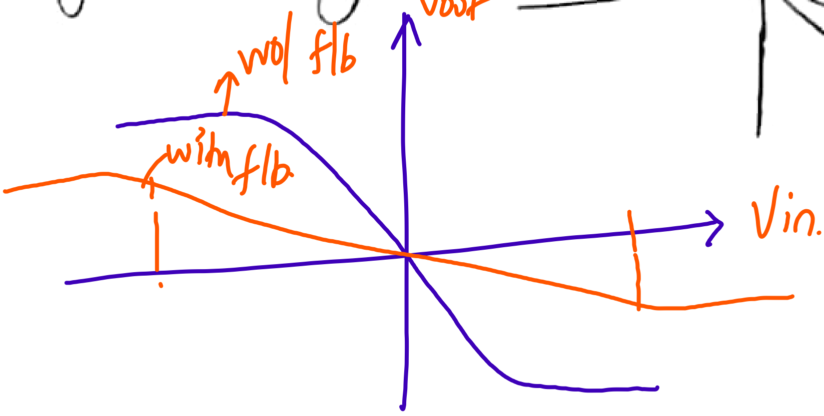
2) Bandwidth Extension: Greater BW for closed-loop system

3) Modification of Input and output impedances.

4) Higher Linearity } eg





I_{CQ} $\quad g_m = \frac{I_C}{V_T}$

$A_v = -g_m(R_C \| R_L)$

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Properties of Negative Feedback :-

① Gain Densensitization :-

If A_1 (open-loop gain) changes due to various factors (temperature, supply, frequency, load impedance), the closed-loop gain does not change as much.

→ The closed-loop gain $\left(\frac{Y}{X}\right)$ of the amplifier with negative feedback is, A_f

A_f → closed-loop gain with negative f/b

$$\frac{Y}{X} = A_f = \frac{A_1}{1+A_1K} \quad — ①$$

→ Differentiating eqn ① w.r.t A_1, we have

$$\left|\frac{dA_f}{dA_1}\right| \qquad \left|\frac{dA_f}{dA_1}\right| = \frac{(1+\cancel{A_1K}).1 - \cancel{A_1K}}{(1+A_1K)^2} = \frac{1}{(1+A_1K)^2}$$

ie. $$dA_f = \frac{dA_1}{(1+A_1K)^2}$$

→ Dividing both sides by A_f, we get $\quad A_f = \frac{A_1}{1+KA_1}$

$$\frac{dA_f}{A_f} = \frac{dA_1}{(1+A_1K)^2} \times \frac{1}{A_f} = \frac{dA_1}{(1+A_1K)^{\cancel{2}}} \times \left(\frac{\cancel{1+KA_1}}{A_1}\right)$$

ie $$\boxed{\frac{dA_f}{A_f} = \frac{dA_1/A_1}{1+KA_1}} \quad — ②$$

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$$\boxed{\frac{dA_f}{A_f} = \frac{dA_1/A_1}{1+KA_1}}$$

$$\frac{dA_f/A_f}{dA_1/A_1} = \frac{1}{1+KA_1}$$ *

02

ie $$\boxed{\frac{dA_f}{A_f} = \frac{dA_1/A_1}{1+A_1K}}$$

where, $\frac{dA_f}{A_f}$ → represents the fractional / percentage change in voltage gain with f/b.

$\frac{dA_1}{A_1}$ → represents the fractional / percentage change in voltage gain without f/b.

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→ $$\boxed{\text{Sensitivity} = \left[\frac{dA_f/A_f}{dA_1/A_1}\right] = \frac{1}{1+KA_1}}$$ — (3)

→ Reciprocal of sensitivity is called "desensitivity" (D)

$$\boxed{D = 1+KA_1}$$ — Densensitivity

K or β or $\beta_{N/W}$ $\beta_{N/W}$

$$\boxed{D = 1+KA_1}$$

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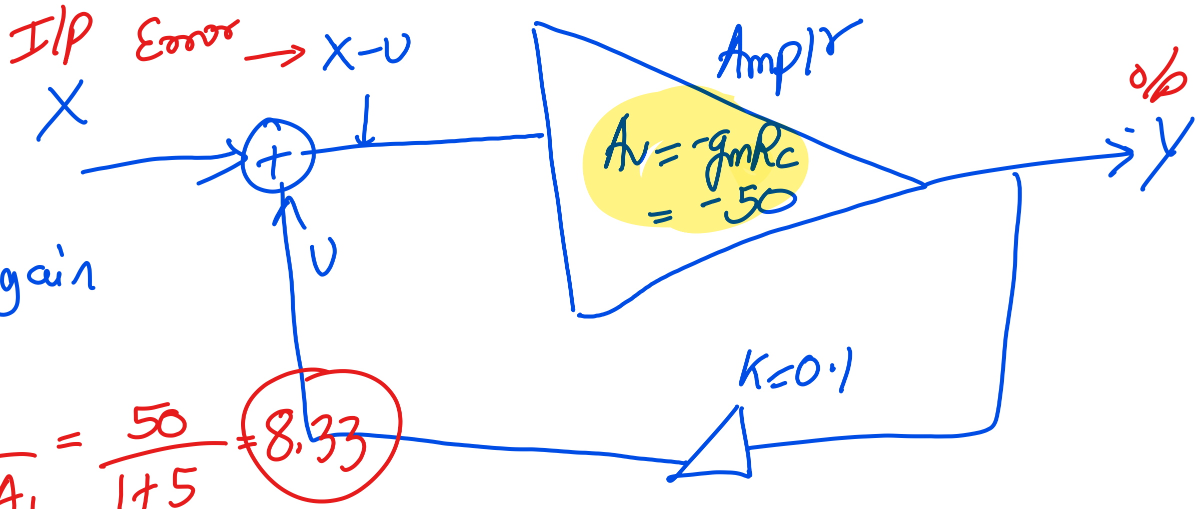

A_1

$A_v = -50$ ↳ open-loop gain

$$\frac{Y}{X} = \frac{A_1}{1+KA_1} = \frac{50}{1+5} = 8.33$$

$\beta = K = 0.1$

N1: An amplifier has an open-loop gain (A_1) of 1000 and a feedback ratio (K) of 0.04. If the open-loop gain changes by 10% due to temperature, find the % change in gain of the amplifier with feedback.

$\frac{dA_1}{A_1} = 10\%$ $\frac{dA_f}{A_f}$?

Solⁿ: Given: $A_1 = 1000$, $K = 0.04$, $\frac{dA_1}{A_1} = 10\% = 0.1$

$$\frac{dA_f}{A_f} = \frac{dA_1}{A_1} \times \frac{1}{1+A_1K} = 0.1 \times \frac{1}{1+1000\times 0.04} = 0.25\%$$

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2) * An amplifier has voltage gain with f/b of 100. If the gain without f/b changes by 20% and the gain with f/b should not vary more than 2%, determine the value of open-loop gain and feedback ratio.

A_f

A_1 K

Soln:- Given :- $A_f = 100$, $\frac{dA_f}{A_f} = 2\% = 0.02$

$\frac{dA_1}{A_1} = 20\% = 0.2$

$A_1 ? K ?$

$\rightarrow \frac{dA_f}{A_f} = \frac{dA_1}{A_1} \times \frac{1}{1+KA_1}$ $\Rightarrow 0.02 = 0.2 \times \frac{1}{1+KA_1}$

ie $1+KA_1 = \frac{0.2}{0.02} = 10$

$\frac{Y}{X} \Rightarrow A_f$

gain with f/b

ie $\underline{D = 10 = 1+KA_1}$

Now, $A_f = \frac{A_1}{1+KA_1} \Rightarrow 100 = \frac{A_1}{10}$

ie $\underline{A_1 = 1000}$ ---> open-loop gain

$A_1 > 1$

$\rightarrow 1+KA_1 = 10$

ie $KA_1 = 9$

$k = \frac{9}{1000} = \underline{0.009}$ → f/b ratio

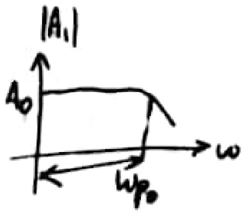
$K < 1$

(2) Bandwidth Extension:

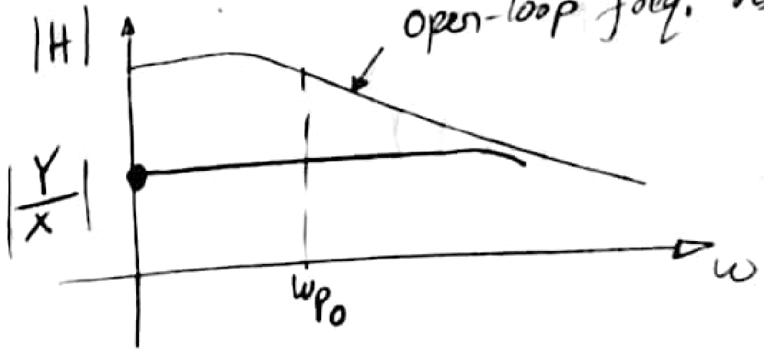
As an example, $A_1(s)$

$$A_1(s) = \frac{A_0}{1 + s/\omega_{p_0}}$$

open-loop ampl'r



$$\underline{BW = \omega_{p_0}}$$



$$\frac{Y}{X}(s) = \frac{A_1}{1+KA_1} = \frac{\dfrac{A_0}{1+s/\omega_{p_0}}}{1+K\cdot\left(\dfrac{A_0}{1+s/\omega_{p_0}}\right)}$$

Multiply by N^r & D^r by $\times\left(1+\frac{s}{\omega_{p_0}}\right)$

$$\frac{Y}{X}(s) = \frac{A_0}{1+KA_0+s/\omega_{p_0}}$$

Divide N^r & D^r by loop gain

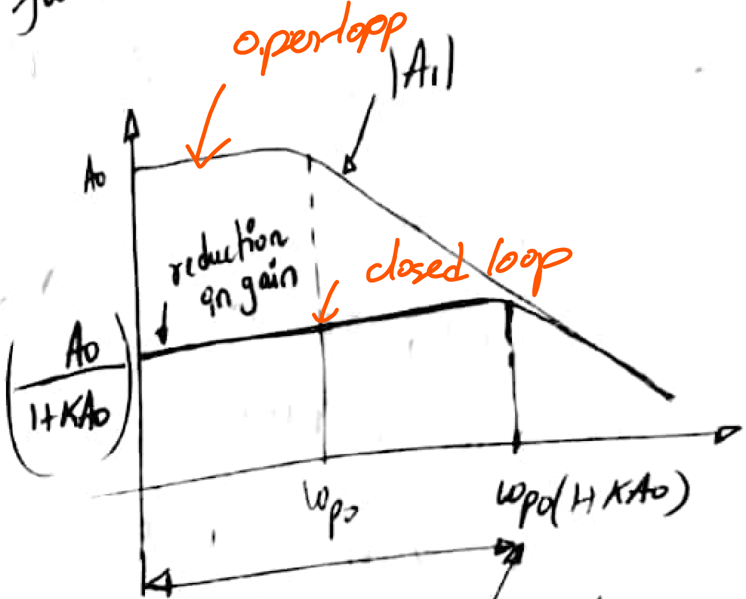
$$\boxed{\frac{Y}{X}(s) \approx \frac{\dfrac{A_0}{1+KA_0}}{1+\dfrac{s}{(1+KA_0)\,\omega_{p_0}}}}$$

- Transfer function

If $s=0 \Rightarrow \frac{Y}{X} = \frac{A_0}{1+KA_0}$

Pole freq $\Rightarrow$ Closed-loop pole :-

$$\boxed{-\omega_{p_0}(1+KA_0)}$$



new pole

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$BW_{new} = \omega_{p_0}(1+KA_0)$

BW with feedback

BW extension with negative feedback.

$$\boxed{BW_f = BW(1+KA_1)}$$

A_1

An amplifier has a mid-band gain of 125 and a bandwidth of 250KHz (BW)

$K = 4\% = 0.04$

a) If 4%, negative feedback is introduced, find the new bandwidth (BW_f) and gain. (A_f)

(BW_f) new

b) If the bandwidth is to restricted to 1MHz, find the feedback ratio K'

Soln: Given: $A_1 = 125$, $\boxed{BW = 250KHz}$, $K = 4\% = 0.04$

a) $\boxed{BW_f = BW(1+KA_1)} = 250 \times 10^3 (1 + 125 \times 0.04)$

$= 1.5 \text{ MHz}$

Bandwidth with f/b $\rightarrow BW_f$

$$\boxed{BW_f = BW(1+KA_1)}$$

Gain with feedback;

$$\boxed{A_f = \frac{A_1}{1+KA_1}} = \frac{125}{1+125 \times 0.04} = 20.83$$

gain with f/b

$K' \rightarrow$ new feedback ratio

b) $BW_f = (1+A_1K)BW$

ie $1 \times 10^6 = (1+125K') \times 250 \times 10^3$

ie $(1+125K') = \frac{10^6}{250 \times 10^3} = 4$

$$K' = \frac{3}{125} = 0.024 = 2.4\%$$

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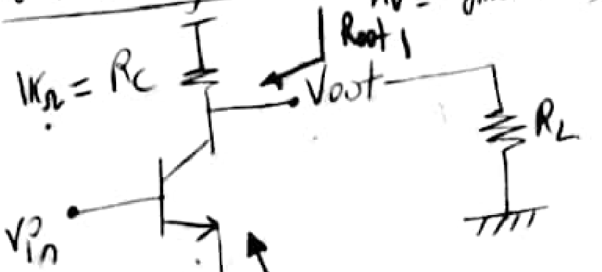
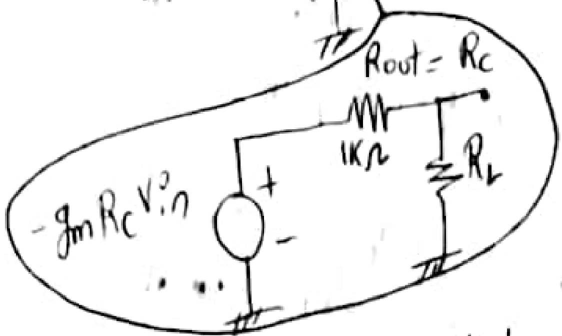
Modification of Input and output impedances: (Read) 07

without feedback

$A_V = -g_m(R_C \| R_L)$





Thevenin's equivalent

If $R_L = 1K\Omega \Rightarrow$ the gain drops by a factor of 2
$\Rightarrow$ the output voltage swing drops by a factor of 2.

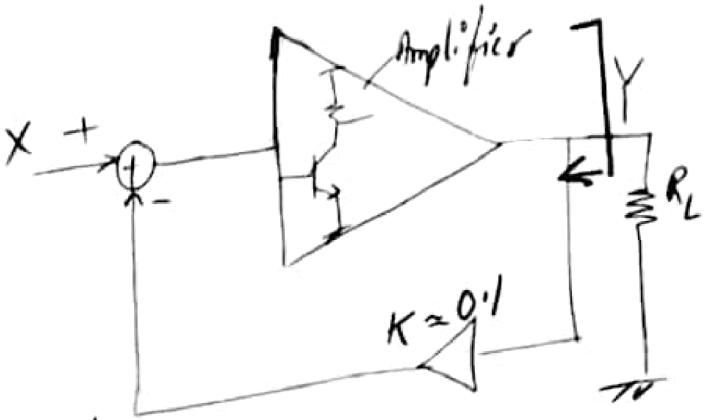
eg

$A_V = -50$ (w/o Load)

$A_V = -25$ (with $R_L = 1K\Omega$)

– open-loop system

with feedback



without R_L

$$A_V = \frac{50}{1+5} = 8.33$$

with $R_L = 1K\Omega$,

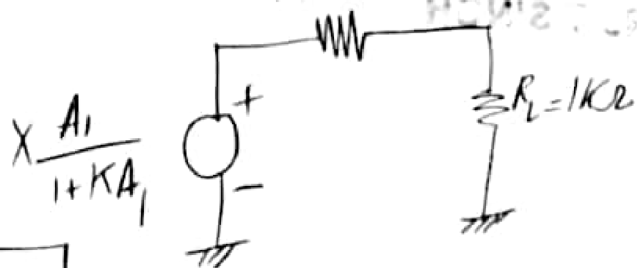
$$A_V = \frac{25}{1+2.5} = \frac{25}{3.5} = 7.2$$

→ gain drop by may be by 15%

This circuit is less sensitive to load impedance.

– closed-loop system

Rout = ? < 1KΩ



Key point

$\boxed{R_{out2} < R_{out1}}$

o/p impedance of negative feedback is less than w/o feedback

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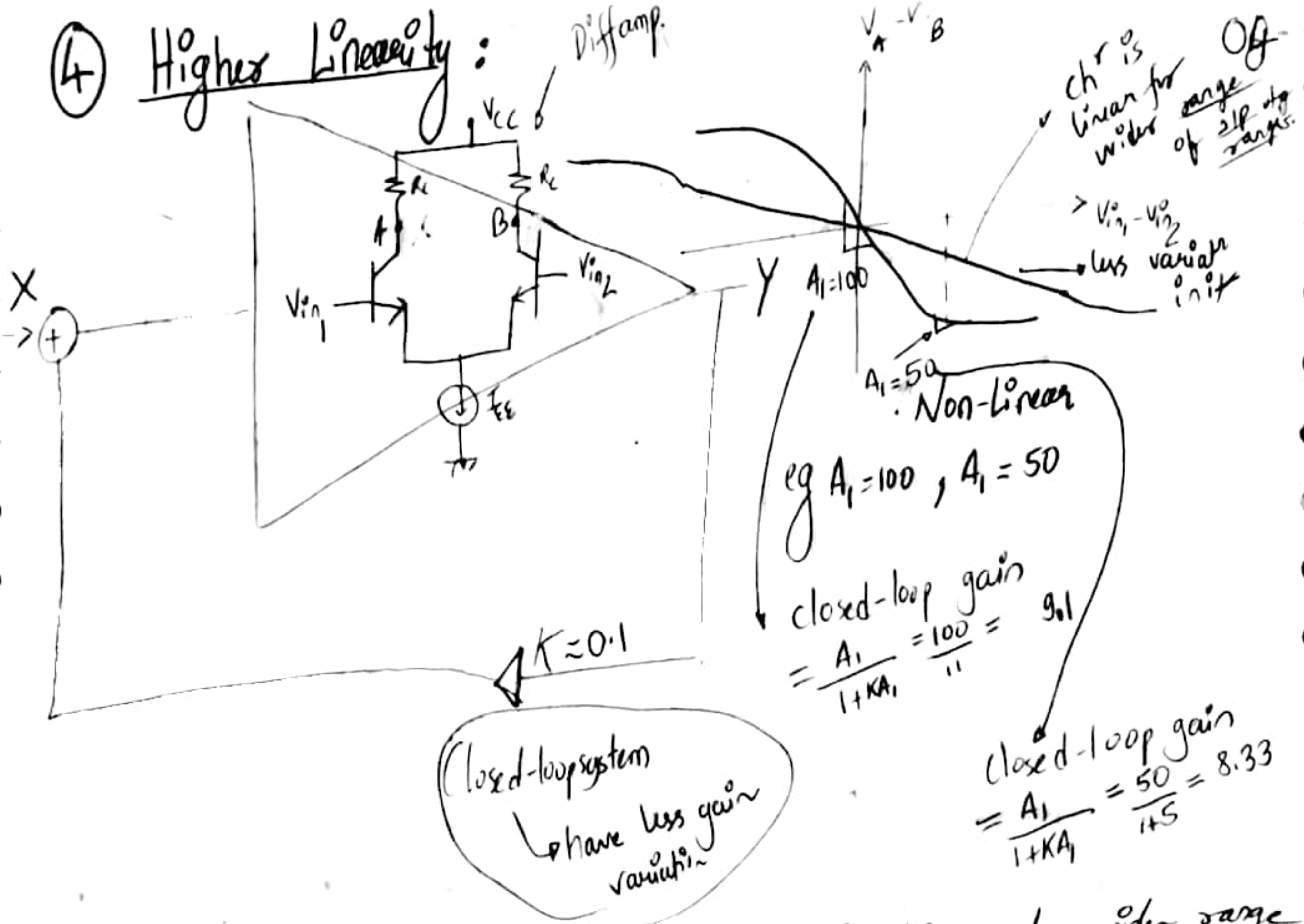
(4) Higher Linearity :



eg $A_1 = 100$, $A_1 = 50$

closed-loop gain $= \frac{A_1}{1+KA_1} = \frac{100}{11} = 9.1$

closed-loop gain $= \frac{A_1}{1+KA_1} = \frac{50}{1+5} = 8.33$

→ Higher linearity means that characteristics is linear for wider range of i/p' voltages.