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Microprocessor Laboratory
Sixth Course on Basic VLSI Design Techniques
8 November - 3 December 1999

ADDITIONAL MATERIAL FOR LECTURE NOTES
by

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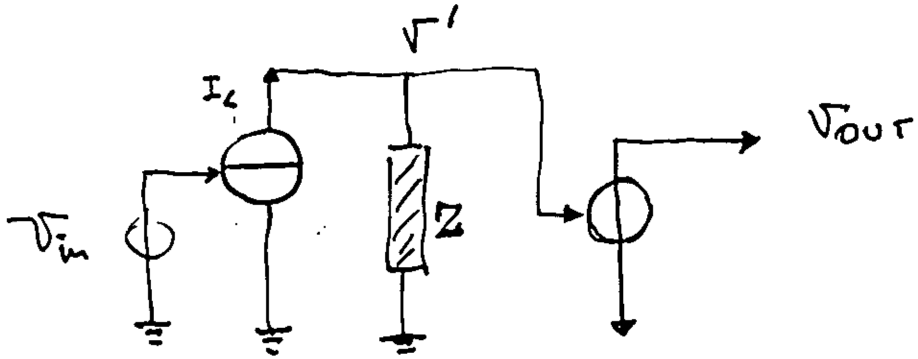
INTRODUCTION

ANY AMPLIFIER COULD BE THOUGH AS A:



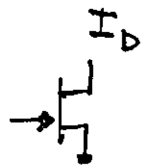
VOLTAGE CONTROLLED CURRENT GENERATOR, THAT CAN BE FOLLOWED BY VOLTAGE CONTROLLED VOLTAGE GENERATOR, NORMALLY WITH GAIN "1"

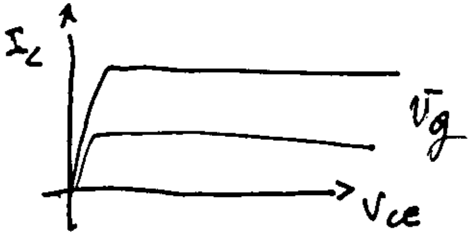
$\frac{I_L}{V_{in}} = g_m$ TRANSCONDUCTANCE [mho, siemens]

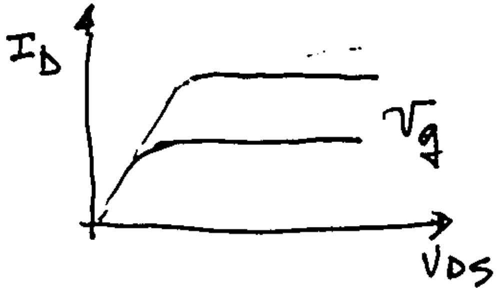
$V' = I_L * Z = V_{OUT}$

$$\frac{V_{OUT}}{V_{in}} = g_m Z$$

BASIC ENGINES TO MAKE AMPLIFIERS!







$$\frac{I_c}{V_g} = g_T = \frac{1}{r_e}$$

$$\frac{I_D}{V_g} = g_m$$

$$\frac{I_D}{V_g} = g_m$$

$$r_e = \frac{KT}{q} \frac{1}{I_c} = \frac{25\,mV}{I_c[mA]}$$

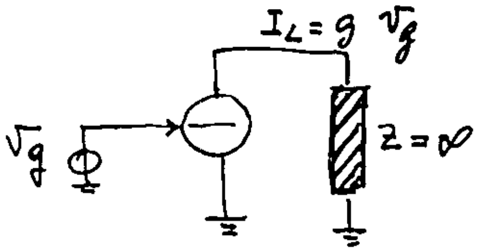
$$= 5 \div 250\ \Omega$$

$$g_T = 4 \div 200\ mS$$

$$g_m = .5 \div 20\ mS$$

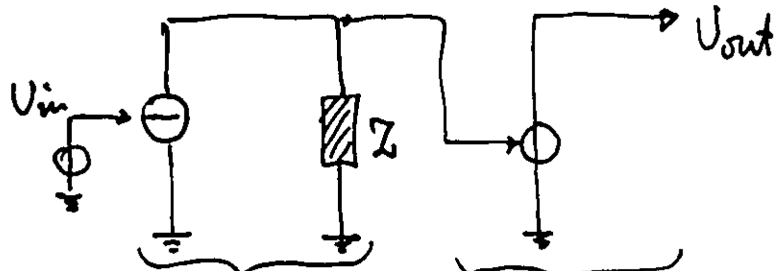
$$g_m = .05 \div 2\ mS$$

WHICH IS THE LIMIT FOR THE AMPLIFICAZION OF A SINGLE ENGINE ??



THEN $Z_{MAX} = Z_{OUT}$ OF THE ELEMENT.

			A_{LIMIT}
BIPOLAR	$Z_{OUT} \rightarrow$	$10^5 \div 10^6\ \Omega$	$400 \div 200'000$
J-FET	$Z_{OUT} \rightarrow$	$10^5 \div 10^6\ \Omega$	$50 \div 20'000$
C MOS	$Z_{OUT} \rightarrow$	$10^4 \div 10^5\ \Omega$	$.5 \div 200$



OTA Operational Transconductance Amplifier — OUTPUT STAGE

OPERATIONAL AMPLIFIER

THERE ARE ALSO

$A_i = \frac{i_{out}}{i_{in}}$ OCA → OP. Current Amp.

$A_T = \frac{V_{out}}{i_{in}}$ CMA → Current Mode Amp.

$A_V = V_{out}/V_{in}$ BW $= f_T$ NB @ f_T $A_V = 1$

GBW $= A_V f_b = K$ (constant) $= f_T$

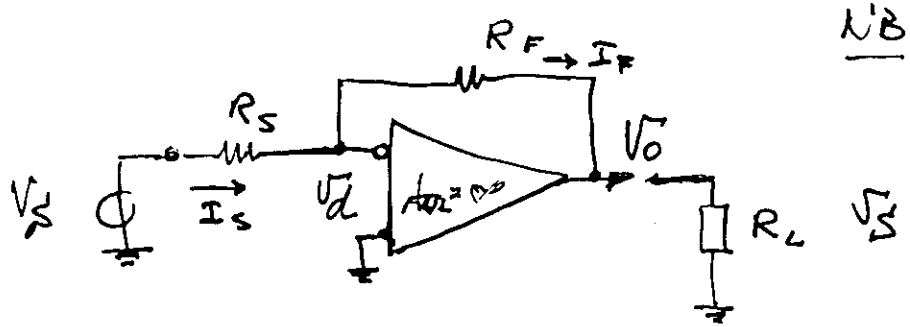
OP. AMP. REQUIREMENTS:

$A_{OL} \to \infty$ $(10^4 \div 10^5)$

$R_{inOL} \to \infty$ $(10^5 \div 10^8)$

$Z_{oOL} \to 0$ $(50 \div 200)$

IDEAL REAL LIFE



NB $\frac{V_o}{V_d} \to \infty$ THAT MEANS $V_d \to 0$

$$\frac{V_S - V_d}{R_S} = \frac{V_d - V_o}{R_F}$$ COMBINING WITH $V_d = -\frac{V_o}{A_{OL}}$

$$\boxed{A_f} = V_o/V_S = \frac{A_{OL} R_F}{R_F + R_S - A_{OL} R_S} \underset{A_{OL} \to \infty}{\simeq} -R_F/R_S \boxed{= A_{f\,ideal}}$$

& $V_d = \phi$ VIRTUAL GROUND AS $I_S \equiv I_F$

IS INFINITE A_{OL} GAIN NECESSARY TO HAVE

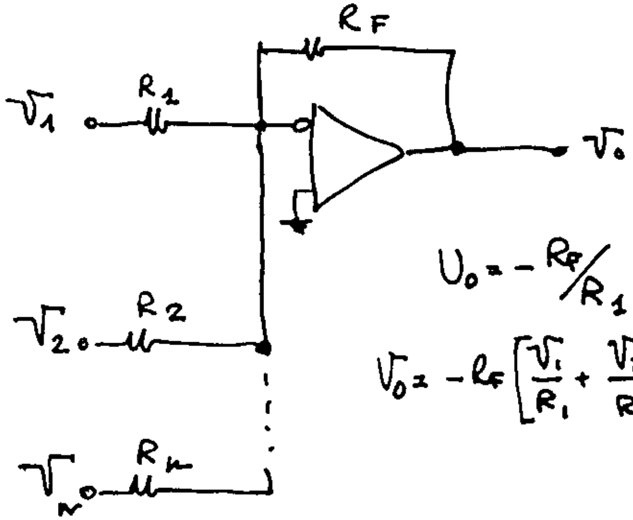
$$A_f = A_{f\,ideal} = -R_F/R_S \qquad ?$$

REMINDING THAT

$$A_f = \frac{A_{OL} R_F}{R_F + R_S - A_{OL} R_S} = \frac{A_{OL}\, R_F/R_S}{R_F/R_S + 1 - A_{OL}}$$

$$= \frac{A_{OL}\, A_{fi}}{A_{OL} - 1 + A_{fi}} = \frac{A_{fi}}{1 - 1/A_{OL} + A_{fi}/A_{OL}}$$

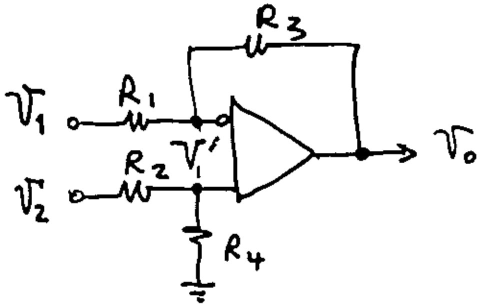
$$\simeq \frac{A_{fi}}{1 + A_{fi}/A_{OL}} \xrightarrow[A_{OL} \to \infty]{} A_{fi} \quad \text{OR FOR } A_{OL} \gg A_{fi}\,!$$



$$U_0 = -R_F/R_1 \; V_1$$

$$V_0 = -R_F\left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \dots + \frac{V_n}{R_n}\right]$$

Σ WITHOUT COUPLING OF V_x, AS THE SUMMING NODE AS ZERO VOLTAGE.



FROM $V' = \frac{V_2}{R_2+R_4} * R_4$

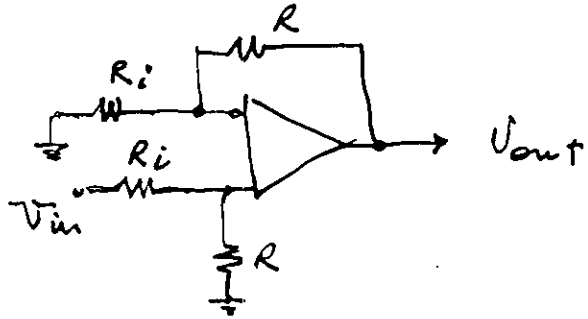
$$\frac{V_1 - V'}{R_1} = \frac{V' - V_0}{R_3}$$

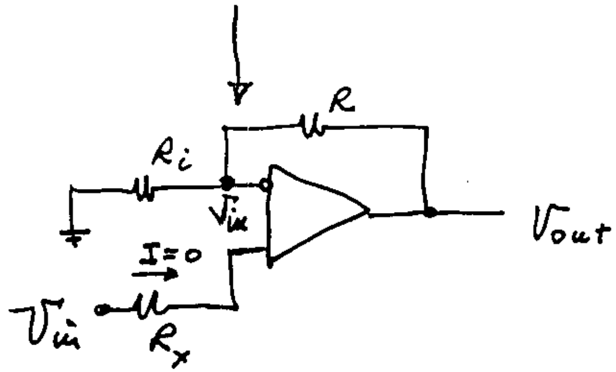
$$V_0 = V_2 \frac{R_4}{R_2+R_4}\,\frac{R_1+R_3}{R_1} - V_1 \frac{R_3}{R_1}$$

IF $R_1 = R_2 = R_i$

$R_3 = R_4 = R$

$$V_0 = (V_2 - V_1)\, R/R_i$$





$$\frac{V_{out} - V_{in}}{R} = \frac{V_{in}}{R_i}$$

$$V_{out} = (1 + R/R_i)\, V_{in}$$

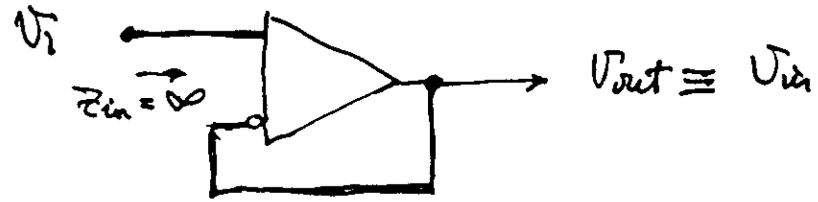
$$Z_{in} \Rightarrow \infty$$

$$A_{f+} = 1 + R_F/R_S \geq 1$$

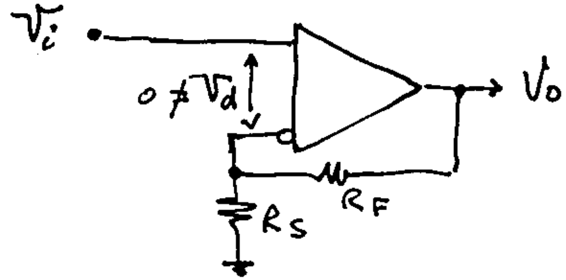
WHILE

$$A_{f-} = -R_S/R_S$$ NEGATIVE BUT "ANY" VALUE

$A_{f+} = 1$ if R_F/R_S THAT MEANS $R_S = \infty$ THEN R_F DON'T CARE, THEN:



AGAIN IN THE ASSUMPTION $A_{OL} = \infty$. DO WE NEED IT?



$$v_d = v_i - \frac{V_o}{R_S + R_F} \cdot R_S$$

$$v_{OUT} = A_{OL} v_d = A_{OL} v_i - A_{OL} \frac{v_o}{R_S + R_F} R_S$$

$$A_{f+} = \frac{v_{OUT}}{v_{in}} = \frac{A_{OL}}{1 + A_{OL} \, {R_S}/{(R_S+R_F)}} \xrightarrow[A_{OL} \to \infty]{} = \frac{R_S + R_F}{R_S} = A_{fi}$$

$$A_{f+} = \frac{A_{OL}}{1 + {A_{OL}}/{A_{fi}}} \qquad A_{f+} = A_{fi} \quad \text{IF } A_{OL} \to \infty \text{ OR } A_{fi} \ll A_{OL}$$

LET'S CALCULATE THE REAL UNITY GAIN FOR $A_{OL} = 5 * 10^4$

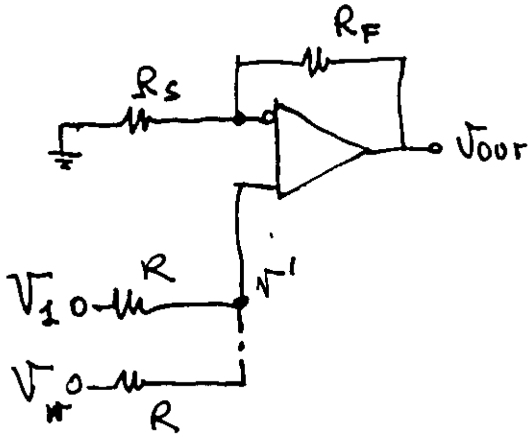
$$A_f = \frac{A_{OL}}{1 + A_{OL}} = \frac{5 * 10^4}{1 + 5 * 10^4} = .9999800004 \approx$$

AND FOR $A_{OL} = 1000$

$$A_f = \frac{10^3}{1 + 10^3} = .99900$$ STILL QUITE GOOD.

CAN WE MAKE NON INVERTING SUM ?

YES, BUT...



$$V_1' = \frac{V_1}{R + \frac{R}{N-1}} \cdot \frac{R}{N-1} = \frac{V_1}{N}$$

$$\cdot \quad \cdot \qquad \cdot$$

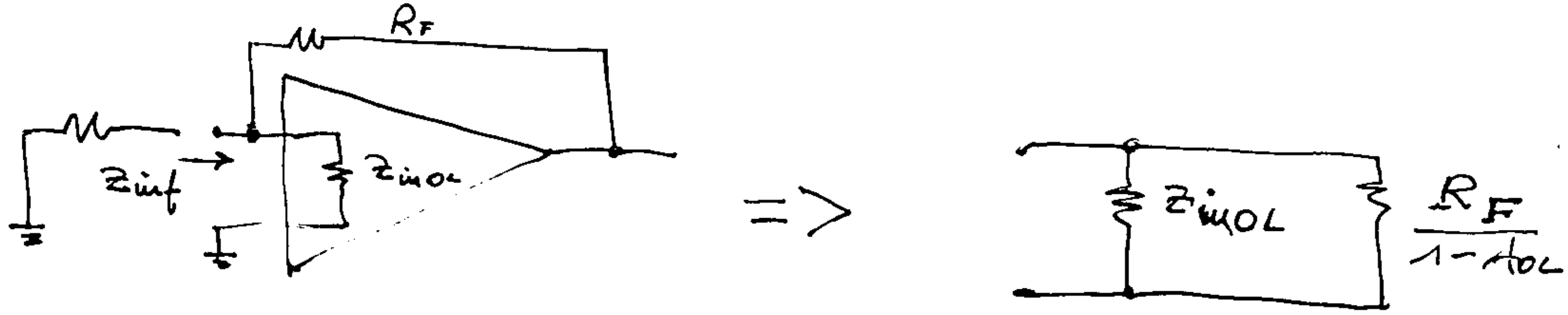
$$V_N' = \frac{V_N}{N}$$

$$V_o = \left(1 + R_F/R_S\right) \frac{1}{N}\left(V_1 + V_2 + \cdots V_N\right)$$

EACH GENERATOR V_N SEES THE OTHERS, SO ITS LOAD IS NOT CONSTANT!

LET'S USE ANOTHER METHOD TO CALCULATE MORE PRECISELY THE Z_{inf}, INPUT IMPEDANDE WITH FEEDBACK.

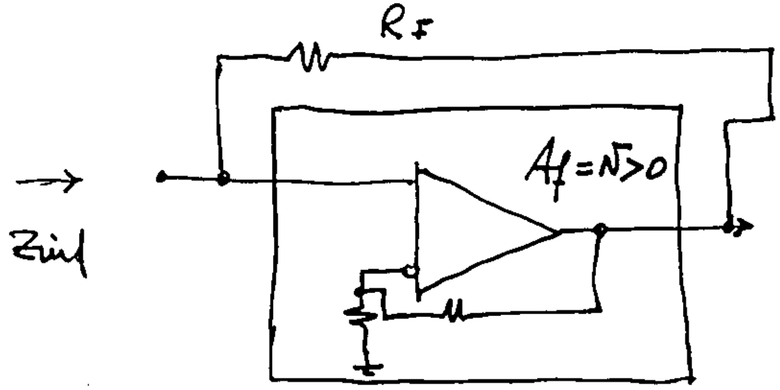
WE USE THE MILLER EFFECT



$$Z_{inf} = Z_{inOL} \,//\, \left[\frac{R_F}{1-A_{OL}} \right]$$

$$= \frac{Z_{inOL}\, R_F}{R_F + Z_{inOF}\,(1-A_{OL})} \rightarrow \frac{R_F}{1-A_{OL}} \rightarrow \emptyset$$

BUT THIS HOLDS FOR ANY SIGN OF A_{OL} EVEN FOR $A_{OL} > 0$ ...

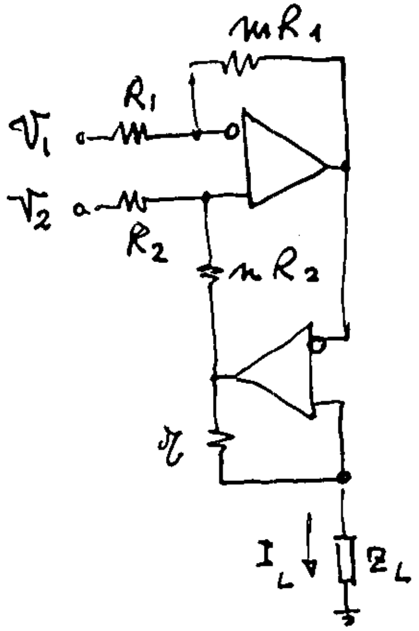


$$Z_{inf} = \frac{Z_{inOL} \; R_F}{R_F + Z_{inOL}\,(1 - A_{OL})}$$

$Z_{inOL} = \infty$ NOW AND $A_{OL} = N > 0$ THEN (REMEMBER $A_{OL} > 1$ ALSO)

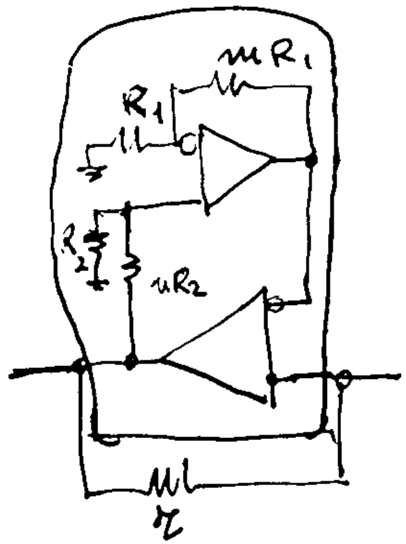
$$Z_{inf} = \frac{-R_F}{N - 1} \leq \emptyset \quad !$$

WE CAN USE IT TO GENERATE INFINITE IMPEDANCES!



WE WANT TO MAKE A VOLTAGE $(V_2 - V_1)$ CURRENT GENERATOR.

THE IMPEDANCE SEEN FROM LOAD Z_L MUST BE ∞.



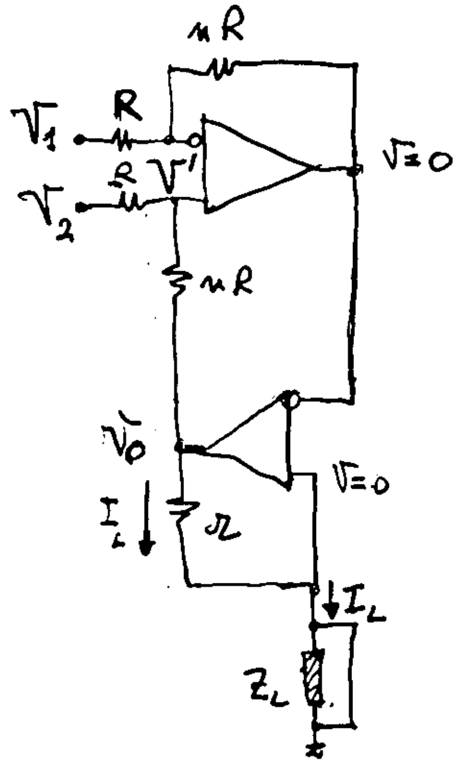
$$Z_{inf} = \frac{Z_{inf}\, R_F}{R_F + Z_{iOL}(1 - A_{OL})}$$

$$R_F = r \qquad Z_{iOL} = \infty$$

$$Z_{inf} = \frac{r}{1 - A_{OL}}$$ TO HAVE $Z_{inf} = \infty$

A_{OL} MUST BE $= 1$

THAT MEANS $\boxed{m = n}$ CONDITION TO HAVE I_L INDEPENDENT FROM Z_L. BUT WHICH IS THE VALUE OF I_L ?



$$V' = \frac{V_1}{R+nR} \cdot nR = \frac{V_1\, n}{1+n}$$

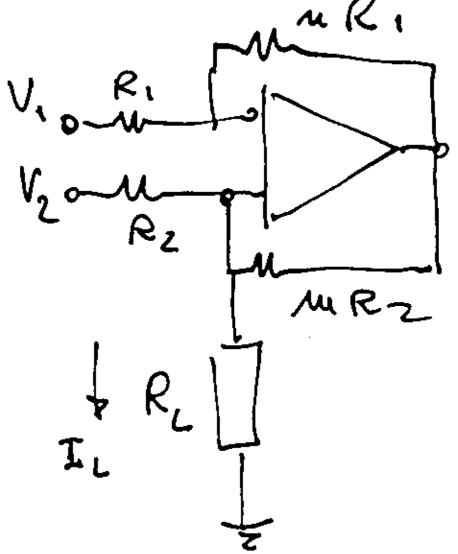
$$V' = \frac{V_2 - V_0}{R+nR} \cdot nR + V_0 = \frac{V_2 - V_0}{1+n}\, n + V_0$$

$$V_1 \frac{n}{1+n} = \frac{V_2\, n}{1+n} - V_0 \left[\frac{n}{1+n} - 1 \right]$$

$$= \frac{V_2\, n}{1+n} + V_0 \left[\frac{1}{1+n} \right]$$

$$V_0 = (V_1 - V_2)\, n$$

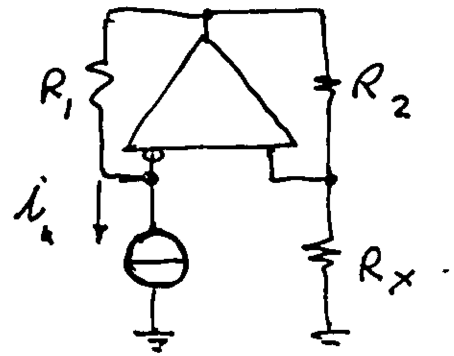
$$\boxed{I_L = \frac{V_0}{r} = \frac{V_1 - V_2}{r}\, n}$$



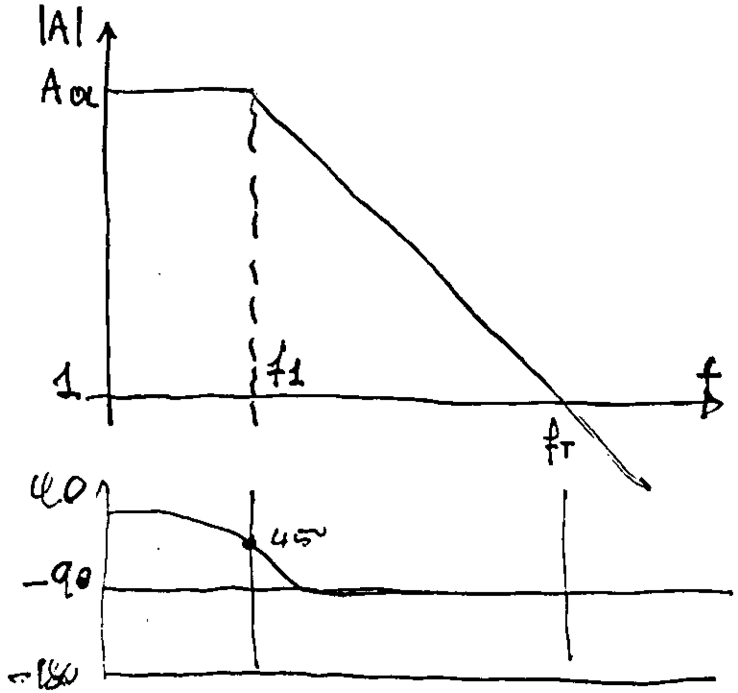
TRY TO FIND THE CONDITION TO HAVE $I_L = f(V_1, V_2)$

OR

④ CALCULATE I_L ON R_x AS A FUCTION OF R_1 & R_2

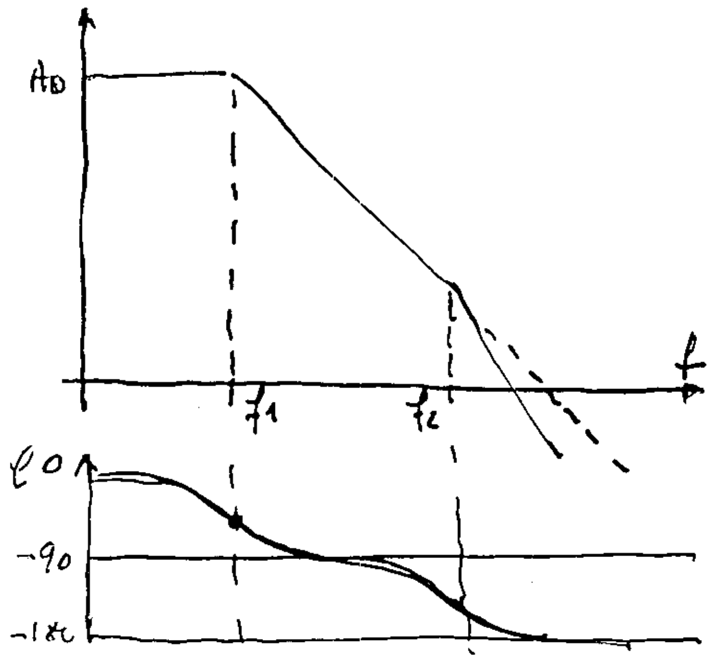


Single pole system



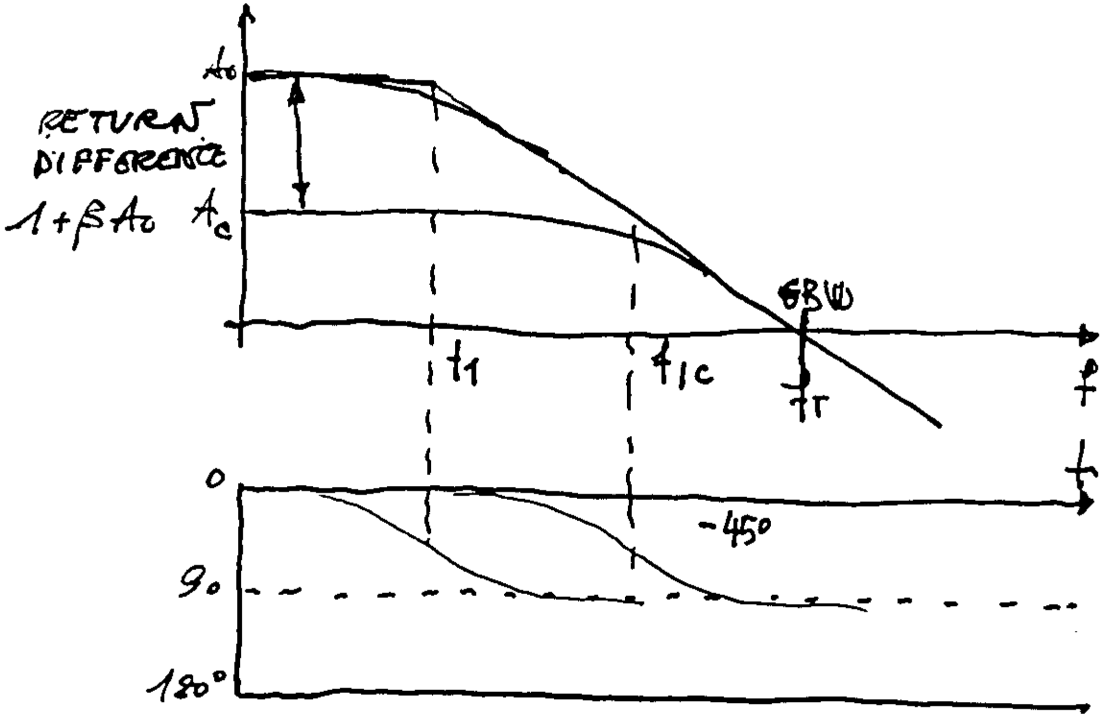
$$A = \frac{A_0}{1 + j\, f/f_1}$$

Two pole system



$$\frac{A_0}{(1+j\, f/f_1)\,(1+j\, f/f_2)}$$

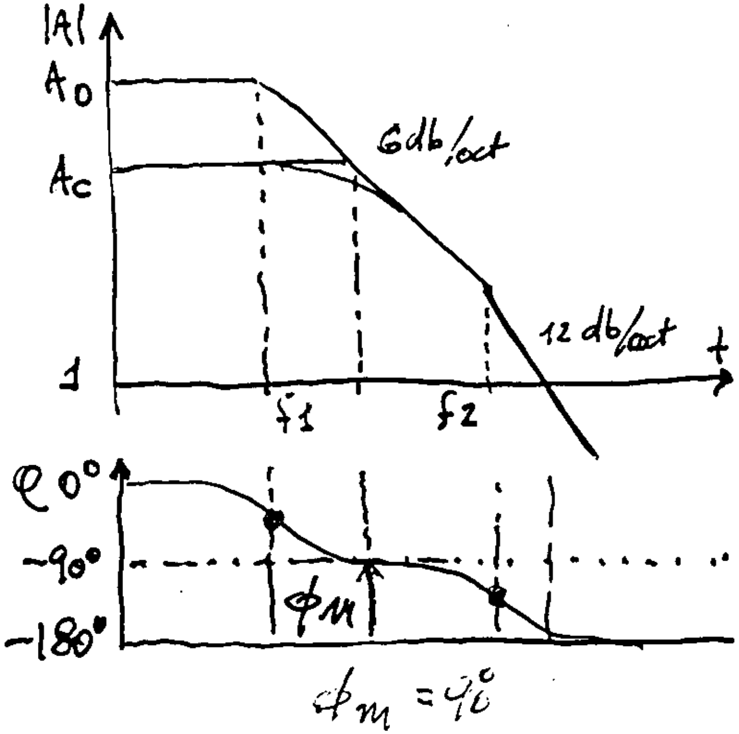
CLOSED LOOP GAIN A_C IN A ONE-POLE SYSTEM

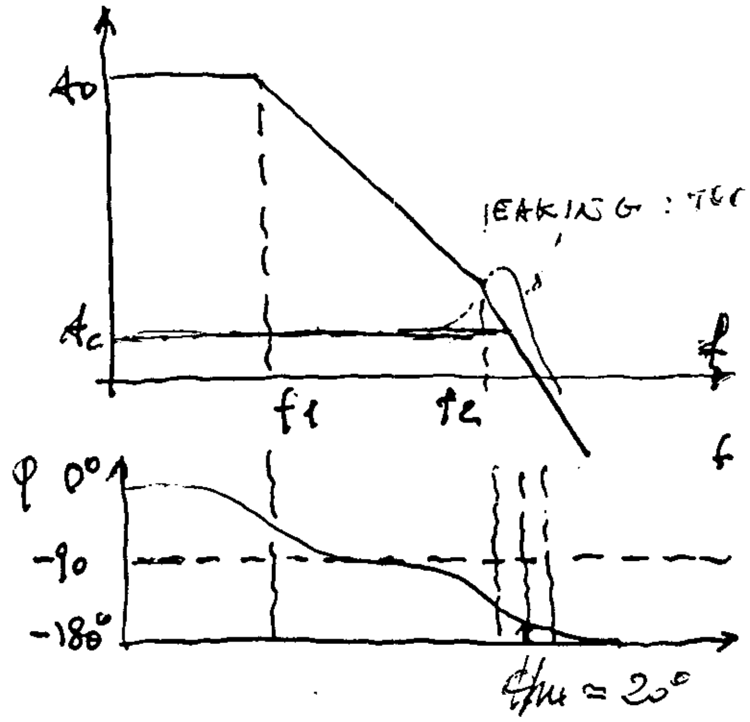


$$A_0 f_1 = 1 * f_T$$
$$A_C f_{1C} = f_T$$

GBW

TWO POLES SYSTEM WITH DIFFERENT CLOSED LOOP GAIN A_c





ALMOST READY TO OSCILLATE

THE CRITERION FOR STABILITY AGAINST OSCILLATION AL CLOSED LOOP IS:

THE OPEN LOOP PHASE SHIFT MUST BE LESS THAN 180°

AT THE FREQUENCY AT WHICH THE LOOP GAIN (IN THE

FEEDBACK CONFIGURATION) IS UNITY.

NB $A_c = \dfrac{A_0}{1+\beta A_0}$ $\qquad 1+\beta A_0$ RETURN DIFFERENCE

$\qquad\qquad\qquad\qquad\qquad \beta A$ LOOP GAIN

$$\underset{A_0 \to \infty}{\simeq} \frac{1}{\beta}$$

THE HARDEST CONDITION IS THEN THE AMPLIFIER CONNECTED AS FOLLOWER AS LOOP GAIN EQUALS THE OPEN LOOP GAIN AT THE f WHERE THE PHASE SHIFT IS 180°.