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Analysis of Feedback Amplifier

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1. Basic Amplifier is <u>Unilateral</u>, but the Gain is evaluated with Loading of
   (i) feedback network (ii) Source & Load Resistances

2. Feedback network too is <u>Unilateral</u>. Essentially we say there is no or very little Feed forward case

Analysis steps :-

(a) Identify Topology - What is type of Feedback (Sampling) and how it mixes at the Input.

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You have a <u>Series Mixing</u> if in the input circuit, there is a circuit component (W) which is in Series with V_s. Then

$$x_f = V_f \text{ is Feedback signal}$$

You have <u>Shunt Mixing</u> at Input circuit, if there is a connection between 'Input Node' (Base or Gate) and the output circuit, then

$$x_f = I_f \quad \text{current feedback}$$

We also test for Sampling now:

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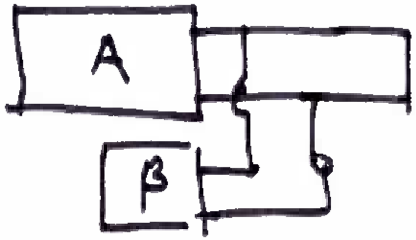
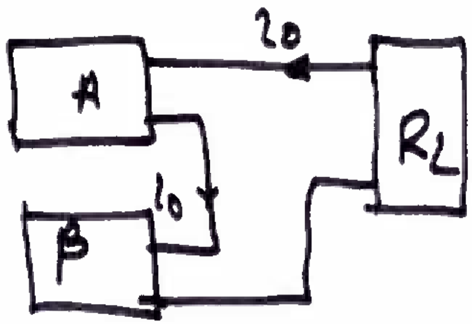
(i) Set $V_o = 0$ ($R_{load} = 0$). If now x_f becomes 'zero', then sampling is voltage kind. This is called Shunt Sampling



(ii) Set $I_o = 0$ ($R_L \to \infty$), then if $x_f = 0$, then we have current sampling or series sampling



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[2] Amplifier Without Feedback

Step (a) Find Input Circuit by

Setting $V_o = 0$ (Shunt Sampling)

$I_o = 0$ (Series Sampling)

Step (b) Find Output Circuit by

Setting $V_i = 0$ for Current Mixing (Shunt)

or $I_i = 0$ for Voltage Mixing (Series)

Then get A_{OL} from this Circuit.

(c) Evaluate β for the topology $= \frac{x_f}{x_o}$

(d) Get $A_{OL}\beta = T$ for the Amplifier

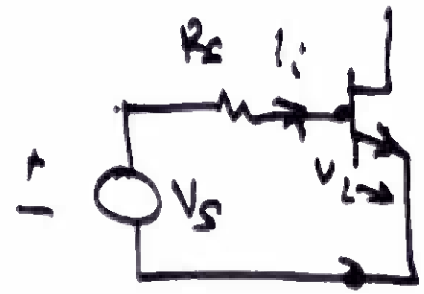
(e) Evaluate $A_{CL} = A_F$ for the Amplifier

(f) Evaluate R_{IF} and R_{OF} for the Amplifier

Since R_E is common between Input & Output circuit, this amplifier is Voltage Amplifier.

Circuit without Feedback :

Input Circuit :— Set $V_o = 0$



Output Circuit : Set $V_i = 0$ (current sampling) & $I_i = 0$ (voltage sampling)

If we make $I_i = 0$, there is dependent source in the output we have circuit with only load resistance R_E.

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Example of Source/Emitter Follower

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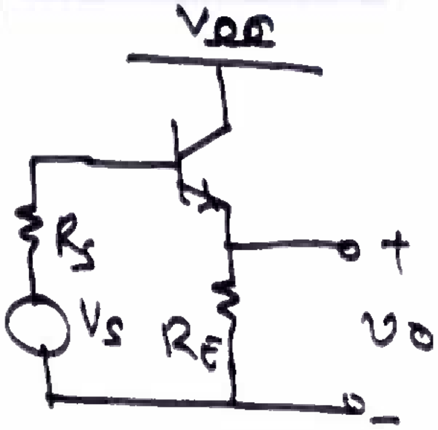

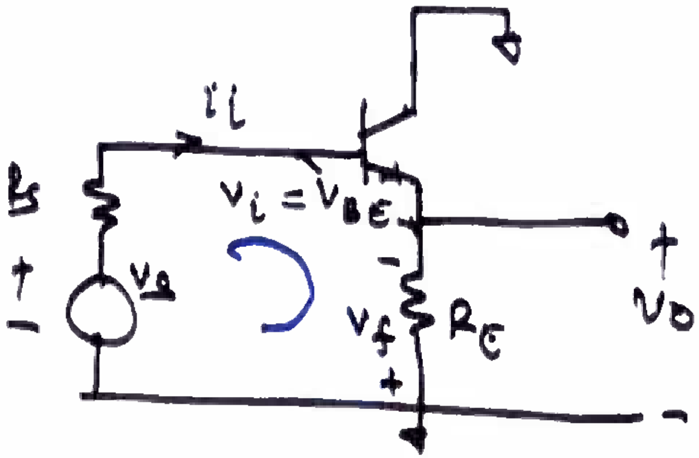

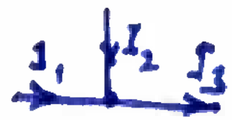

If we ~~want~~ make $v_o = 0$, $v_f = 0$ Hence Input has series Mixing and shunt Sampling

∴ It is Series-Shunt Amplifier

For Shunt Sampling

$$R_{OF} = \frac{R_O}{1+T}$$

$R_O = r_o$ for our Voltage Amplifier.

$$= \frac{r_o}{1 + \frac{\beta R_{OE}}{r_\pi + R_s}} = \frac{r_o(r_\pi + R_s)}{r_\pi + R_s + \beta R_{OE}}$$

$$\simeq \frac{R_s + r_\pi}{\beta} = \frac{2K}{100} = 20\,\Omega$$

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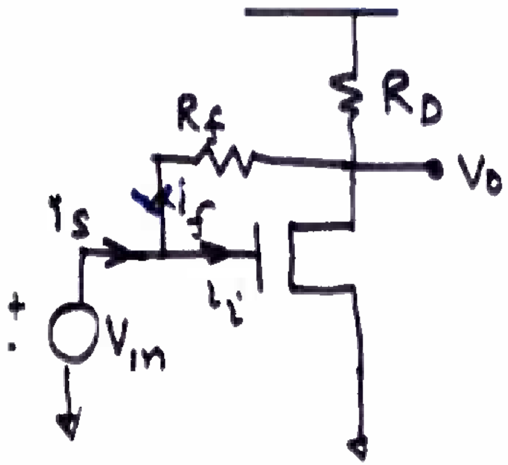
Shunt - Shunt Amplifier



R_f sums currents at Gate Node

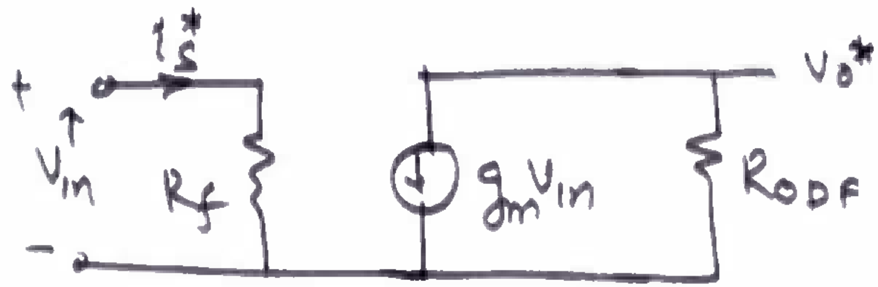
$$i_i = i_s - i_f$$

Since 'Input' circuit 'node' is connected to 'output' node through R_f, then feedback has <u>Shunt Mixing</u>

If we make $V_o = 0$, then there is no feedback.

Hence we have Shunt Sampling

Hence Amplifier without feedback has eq. circuit as



$$\frac{1}{R_{ODf}} = \frac{1}{r_o} + \frac{1}{R_f} + \frac{1}{R_D}$$

$$\therefore \quad A_{OL} = \frac{v_o^*}{i_s^*} = \frac{v_o^*}{v_{in}} \cdot \frac{v_{in}}{i_s^*} = -g_m R_{ODF} \cdot R_f$$

$$R_i^* = R_f \quad \& \quad R_o^* = R_{ODF}$$

$$\text{Feedback factor } \beta = \frac{i_f^*}{v_o^*} = \frac{1}{R_f}$$

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$$\therefore A_{CL} = \frac{V_o}{i_s} = \frac{A_{OL}}{1 + A_{OL}\beta}$$

$$= -\frac{g_m R_{ODF} \cdot R_f}{1 + g_m R_{ODF} \cdot R_f \cdot \frac{1}{R_f}}$$

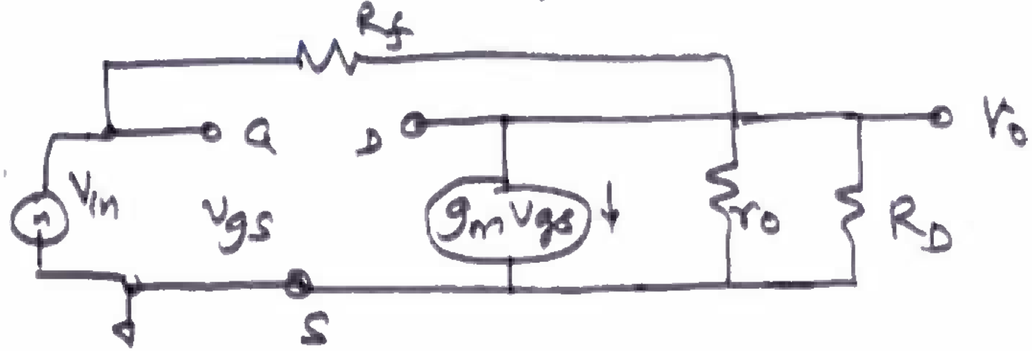
$$= -R_f \quad \text{if} \quad g_m R_{ODF} >> 1$$

Voltage Gain

$$A_{VCL} = \frac{V_o}{V_{in}} = \frac{V_o}{i_s} \cdot \frac{i_s}{V_{in}} = \cancel{A_{CL} \cdot \frac{1}{R_f}}$$

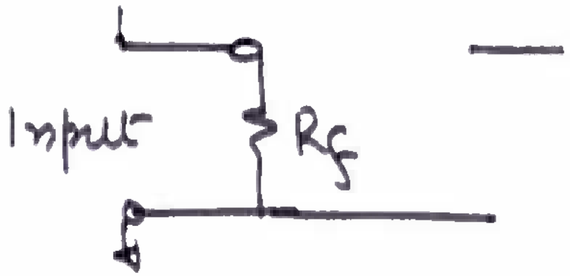
$$= -\frac{g_m R_{ODF} \cdot R_f}{1 + g_m R_{ODF}} \cdot \frac{1}{R_f} = \frac{-g_m R_{ODF}}{1 + g_m R_{ODF}}$$

ac equivalent circuit is

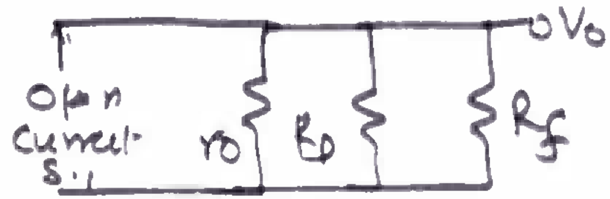


Open loop Amplifier will then be :

ⓐ Input Circuit : we set $V_o = 0$ (Shunt Sampling), then



(b) Output Circuit : We set $V_{in} = 0$



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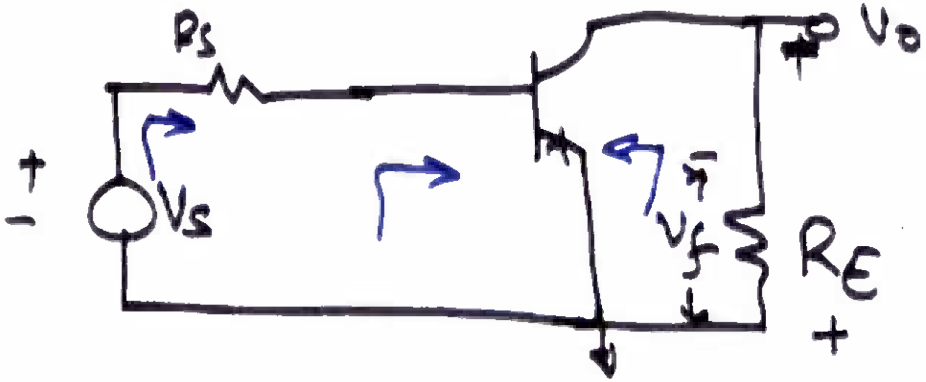
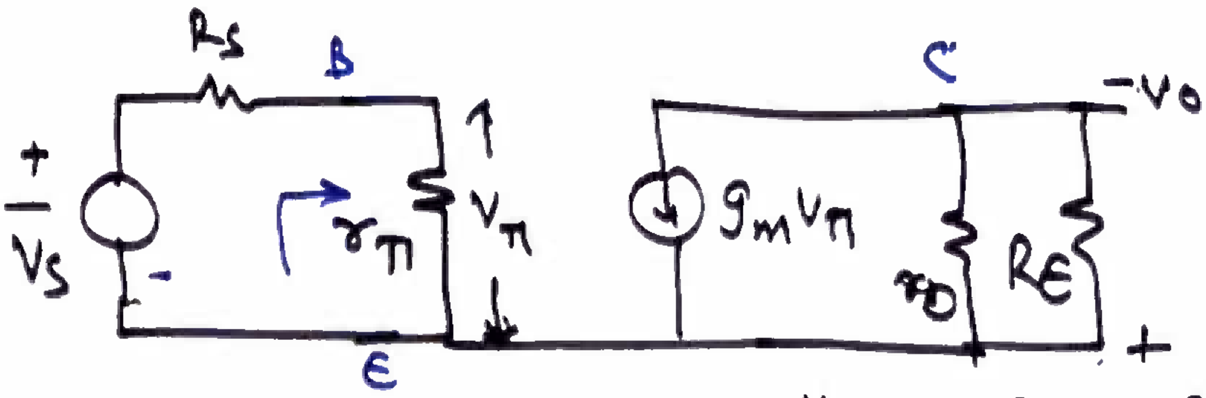
Hence Amplifier without Feedback has the Circuit





$$V_\pi = \frac{r_\pi}{r_\pi + R_s} V_s$$

$$R_{oE} = r_o \parallel R_E$$

$$\therefore A_{OL} = \frac{V_o}{V_s} = + \frac{r_\pi}{r_\pi + R_s} \cdot g_m R_{oE}$$

$$\beta = \frac{V_f}{V_o} = 1$$

$$\therefore \; T = A_{OL}\beta = \frac{g_m r_\pi R_{OE}}{r_\pi + R_s} = \frac{\beta R_{OE}}{r_\pi + R_s}$$

Then feedback Gain $A_{CL} = A_f$

$$= \frac{A_{OL}}{1+T} = \frac{\beta R_{OE}/(r_\pi + R_s)}{1 + \frac{\beta R_{OE}}{r_\pi + R_s}}$$

$$= \frac{\beta R_{OE}}{r_\pi + R_s + \beta R_{OE}}$$

$$R_{iF} = (1+T) R_i$$

We have $R_i = r_\pi$

$$\therefore \; R_{iF} = r_\pi \cdot \left[1 + \frac{\beta R_{oe}}{(r_\pi + R_s)} \right]$$

$$= r_\pi + \frac{r_\pi}{r_\pi + R_s} \cdot \beta R_{OE} \simeq r_\pi + \beta R_{OE}$$

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$$R_{if} = \frac{V_{in}}{i_s} = \frac{R_f}{1 + g_m R_{oDF} \cdot R_f / R_f}$$

$$= \frac{R_f}{1 + g_m R_{oDF}}$$

$$\therefore \quad A_{VCL} = -\frac{g_m R_{oDF} R_f}{1 + g_m R_{oDF}} \cdot \frac{1 + g_m R_{oDF}}{R_f}$$

$$= -g_m R_{oDF}$$

Stability

$$A_{CL} = \frac{A_{OL}}{1+T}$$

If $T > 0$ (+tive), we have negative feedback.
Then $A_{CL}(s) < A_{OL}(s)$ and feedback stabilises $A_{CL}(s)$.

If $T < 0$, we have Positive Feedback, then
$A_{CL}(s) > A_{OL}(s)$ This leads to Instability

Even without signal, small noise at input is amplified and Positive feedback increases input to Amplifier, thus increasing output further. In a typical case the system may oscillate.

We can find Stability condition in Negative Feedback Amplifier by observing Bode's Plots for Closed Loop Gain Transfer Function

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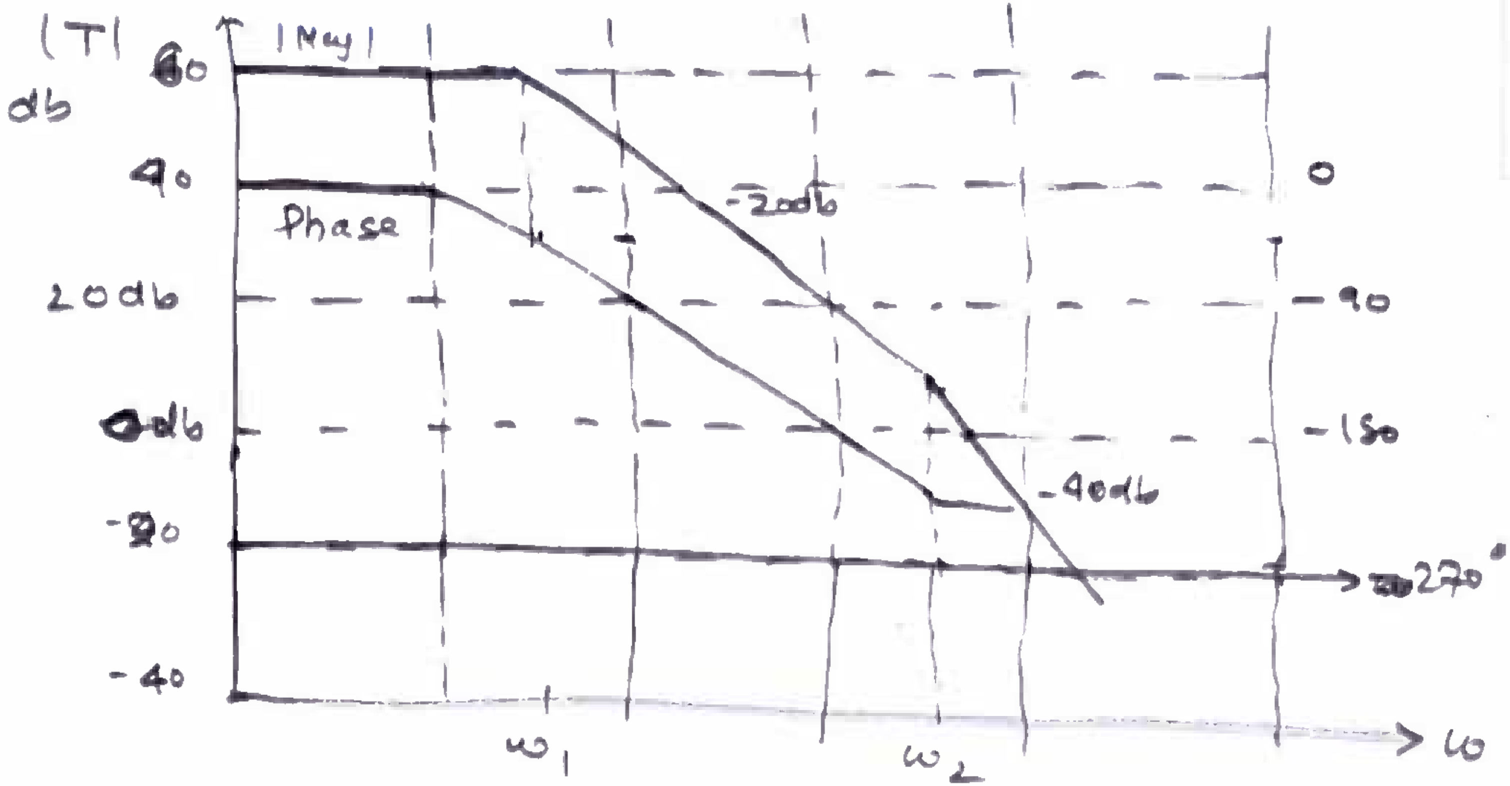
Phase Margin & Gain Margin



$$\phi_M = \angle T(j\omega_0) + 180^\circ \quad ; \quad GM = -20 \log T(j\omega_0)$$

Stability in Feedback Amplifiers

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$$A_{CL}(s) = \frac{A_{OL}(s)}{1+T(s)}$$

We see that 'zeros' of $(1+T(s))$ are poles of $A_{CL}(s)$, and Any Poles of $A_{OL}(s)$ are not common to $T(s)$

We assume A_{OL} makes system stable, then on s-plane ($\sigma + jw$ plane) then Poles of A_{OL} will be on the Left Half Plane

Typical

$$A_{CL}(s) = \frac{A_{F0}}{1 + \frac{a_1 s}{1+T_0} + \frac{a_2 s^2}{1+T_0} + \frac{a_3 s^3}{1+T_0}}$$

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Generalised Expressions for T.F. & Stability

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$$A_{CL}(s) = \frac{A(s)}{1 + A(s)\beta(s)}$$

as $s = j\omega$

$$A_{CL}(j\omega) = \frac{A(j\omega)}{1 + A(j\omega)\,\beta(j\omega)}$$

The Loop Gain $= T = A(j\omega)\beta(j\omega)$ is a complex Fn.

$$T(j\omega) = A(j\omega)\,\beta(j\omega)$$

$$= |A(j\omega)\,\beta(j\omega)|\, e^{j\phi(\omega)}$$ Amplitude & Phase

If $\phi(\omega) = 180^\circ$ for a Frequency, $T(j\omega) =$ Negative Real No.

Thus A_{CL} will increase as .

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If $|T(j\omega)| = 1$ at $\omega = \omega_{180^\circ}$

Then $A_{CL} = \frac{A(s)}{0} = \infty$

$\therefore$ Amplifier becomes Oscillator.

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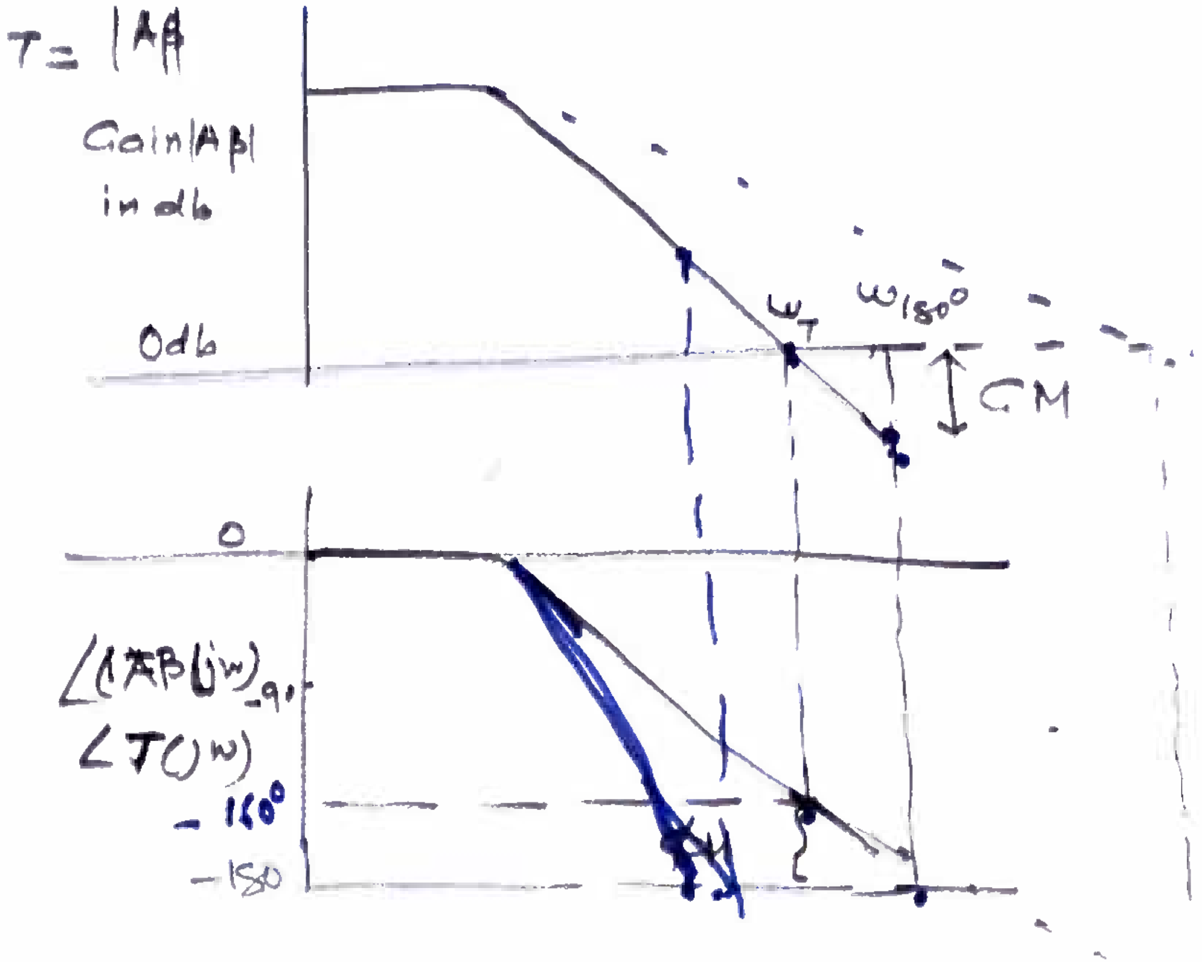
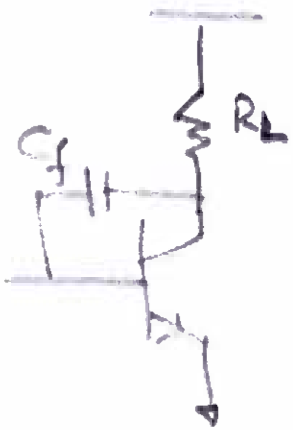

T = |Aβ|
Gain |Aβ| in db
0db
ωT
ω180°
GM
0
∠(AB(jω)
-90
∠T(jω)
-180°
-180
PM

Compensation

(1) Miller Compensation & Pole splitting



$$\omega'_{p_1} \simeq \frac{1}{g_m R_2 C_f R_1}$$

$$\omega'_{p_2} \simeq \frac{g_m C_f}{C_1 C_2 + C_f (C_1 + C_2)}$$

$$= \frac{g_m}{\frac{C_1 C_2}{C_f} + (C_1 + C_2)}$$

Without feedback

$$\omega_{p_1} = \frac{1}{R_1 C_1}$$

$$\omega_{p_2} = \frac{1}{R_2 C_2}$$