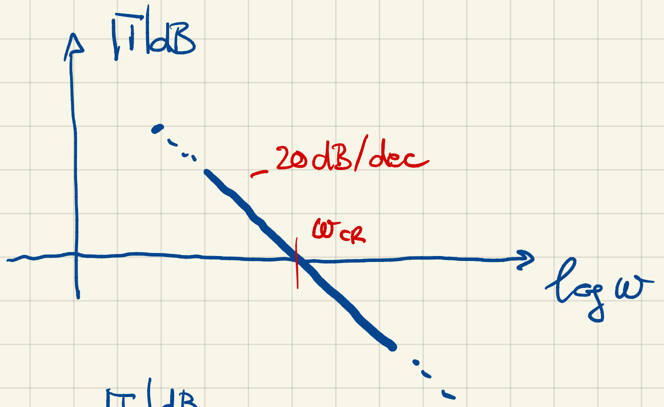
BODE PLOTS : SOME TYPICAL CASES

#1

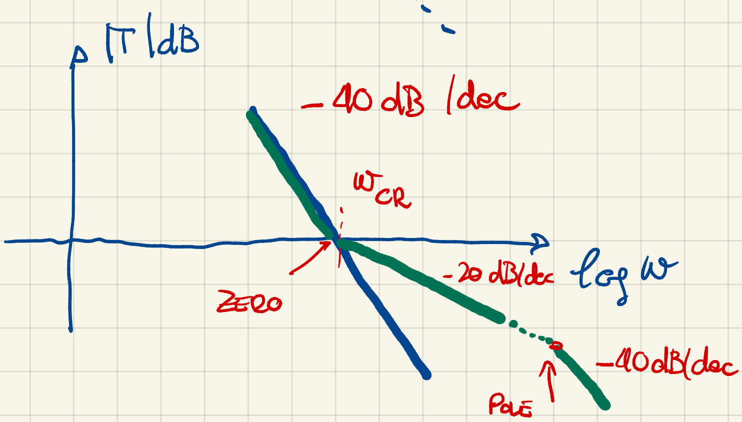


IN THIS CASE, IF ADDITIONAL POLES AND ZEROS ARE PLACED DISTANTLY FROM ω_{CR}

$$PM \cong 90^\circ$$

THE LOOP IS STABLE WITH LARGE MARGIN

#2



THE MINIMUM PHASE MARGIN IN THIS CASE CAN BE AS LOW AS ZERO

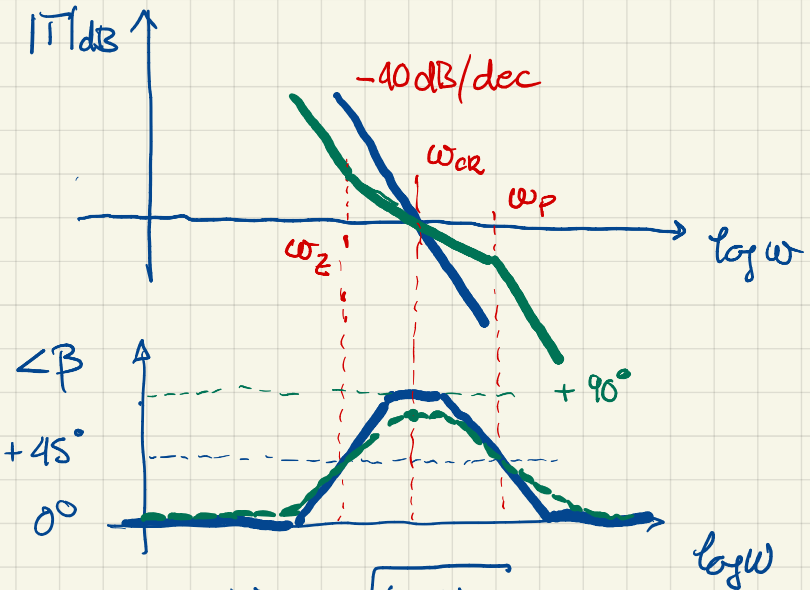
THE SYSTEM IS "FORMALLY" STABLE BUT WITH VERY SMALL PM THE TIME RESPONSE IS LIGHTLY DAMPENED AND SHOWS PERSISTENT OSCILLATIONS
$\Rightarrow$ COMPENSATION IS NEEDED.

TO COMPENSATE THE AMPLIFIER, WE CAN MODIFY THE β-NETWORK IN DIFFERENT WAYS:

1. WE CAN PLACE A ZERO IN T AT $\omega = \omega_{CR}$. BECAUSE β-NETWORKS ARE PASSIVE (MOST OF THE TIMES), WE HAVE ALSO AN ADDITIONAL POLE (AT HIGH FREQUENCY)

   WITH COMPENSATION, $\underset{\text{AFTER}}{PM} \leftarrow \underset{\text{BEFORE}}{PM} + 45^\circ$ ZERO EFFECT

2. WE CAN PLACE BOTH ZERO AND POLE AT APPROPRIATE FREQUENCIES IMPLEMENTING A LEAD-LAG COMPENSATION OR ZERO-POLE COMPENSATION.



$$\omega_{CR} = \sqrt{\omega_P \omega_Z}$$

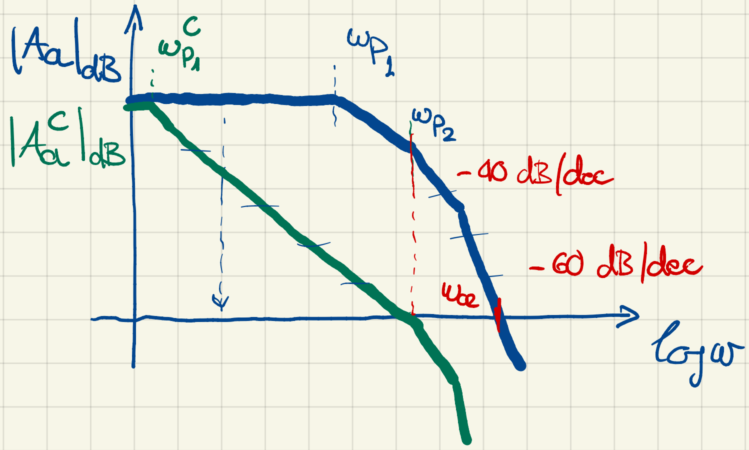
PM IS IMPROVED MORE OR LESS DEPENDING ON WHERE WE PLACE ω_Z AND ω_P.

TYPICAL DESIGN CHOICE IS TO HAVE

$$\frac{\omega_P}{\omega_{CR}} = \frac{\omega_{CR}}{\omega_Z} = 4 \Rightarrow$$

$$\underset{\text{AFTER}}{PM} \leftarrow \underset{\text{BEFORE}}{PM} + 60^\circ$$

(3)

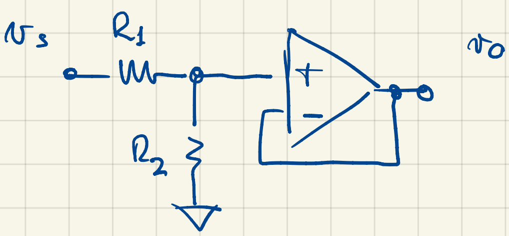


THIS IS THE TYPICAL OPAMP CASE: 3-STAGE AMPLIFIER

ASSUMING WE HAVE JUST 3-POLES (ONE PER STAGE) WE HAVE LITTLE OR NO PHASE MARGIN AT ALL EVEN WHEN β IS CONSTANT

TO SOLVE THE PROBLEM THE OPAMP IS INTERNALLY COMPENSATED BY INTENTIONALLY REDUCING ω_{p_1} (STRONGLY).

THIS WAY PHASE MARGIN CAN BE IMPROVED TO MINIMUM 45°

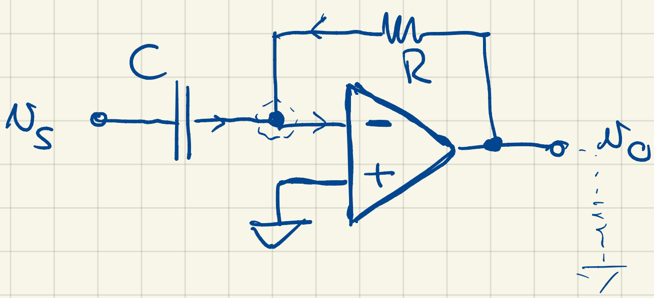


$$\frac{v_o}{v_s} = \frac{R_2}{R_1+R_2} < 1$$

IF THE OPAMP IS UNITY GAIN STABLE, THIS CONFIGURATION YIELDS A TARGET SIGNAL ATTENUATION BUT NO STABILITY ISSUES.

LET'S ANALYSE SOME OPAMP CONFIGURATIONS WHERE THERE CAN BE STABILITY PROBLEMS EVEN WHEN THE OPAMP IS INTERNALLY COMPENSATED, UNITY GAIN STABLE

TIME DIFFERENTIATOR



IF THE OPAMP IS IDEAL WE KNOW THAT

$$A_v = \frac{v_o}{v_s} = -sRC$$

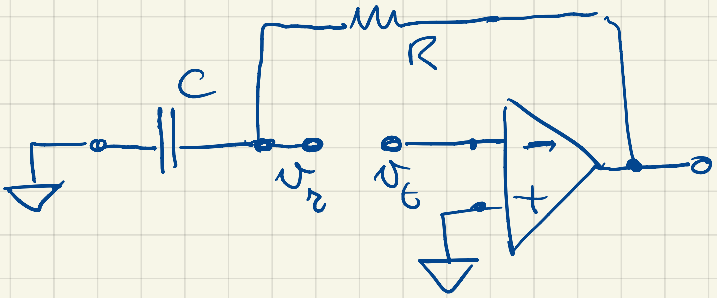
BUT WHAT CAN WE SAY WHEN A_{OL}^{OPAMP} IS:

$$A_{ol} = \frac{A_{ol0}}{1+\frac{s}{\omega_0}}$$

INTERNALLY COMPENSATED, UNITY GAIN STABLE OPAMP.

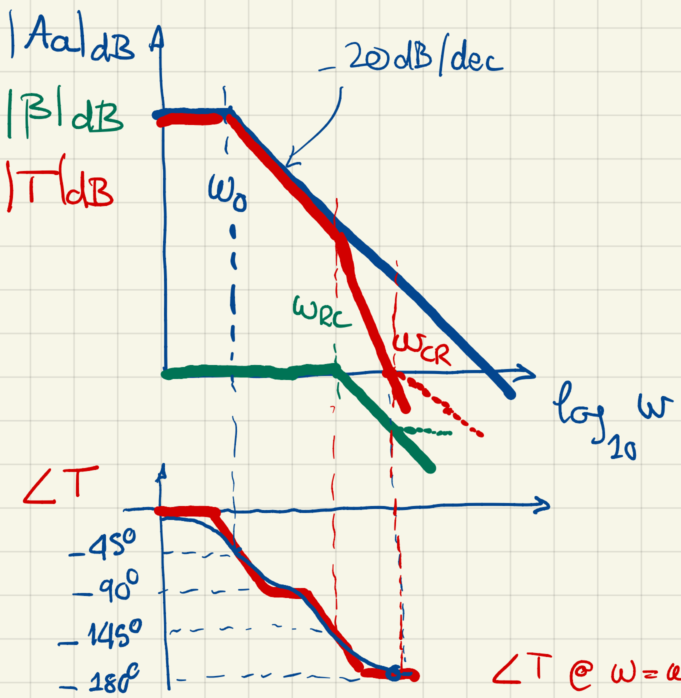
THE MOST STRAIGHTFORWARD WAY TO ANALYSE THE PROBLEM IS

TO USE **DIRECT LOOP INSPECTION**



$$T = -\frac{v_r}{v_t} = -\left(-\frac{A_{ol0}}{1+\frac{s}{\omega_0}}\cdot\frac{\frac{1}{sC}}{R+\frac{1}{sC}}\right) = \underbrace{\frac{A_{ol0}}{1+\frac{s}{\omega_0}}}_{A_{ol}}\cdot\underbrace{\frac{1}{1+sRC}}_{\text{CAN BE OUR }\beta\text{ NETWORK}}$$

ONCE WE HAVE T WE CAN DISCUSS STABILITY $\quad A_{ol}(s)\cdot\beta(s)$



$\angle T$ @ $\omega = \omega_{CR} \cong \varnothing$

$$\omega_{RC} = \frac{1}{RC} > \omega_0$$

$$\omega_{CR} > \omega_{RC} > \omega_0$$

PM IS GOING TO BE $\cong 0^0$ IN THE WORST CASE.

CONCLUSION: **THE CIRCUIT NEEDS TO BE COMPENSATED.**

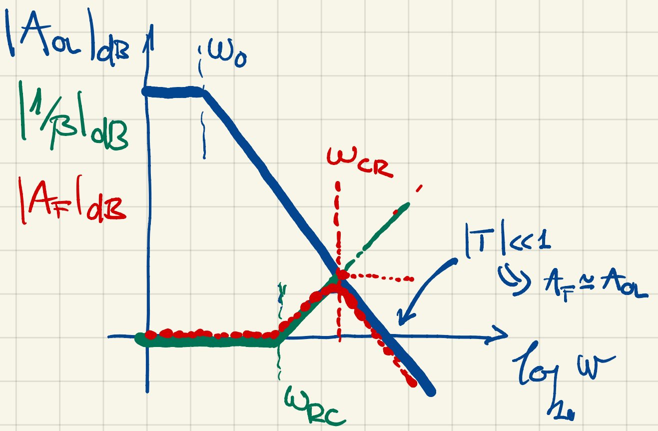
A DIFFERENT WAY OF LOOKING AT THIS STABILITY ISSUES IS TO USE BODE PLOTS OF A_{ol} AND $1/\beta$. WHY?

BECAUSE KONSIDERING FREQUENCIES WHERE $|T| >> 1$ WE SEE THAT

$$A_F = A_{iv} = \frac{A_{ol}}{1+T} = \frac{A_{ol}}{1+\beta A_{ol}} \underset{|T|>>1}{\cong} \frac{1}{\beta} \quad \text{THE TARGET FREQUENCY RESPONSE}$$

SO IT IS NORMALLY EASIER TO PLOT $1/\beta$ INSTEAD OF β, AS THE FORMER IS SPECIFIED BY DESIGN.

THE BEDE PLOTS CHANGE ACCORDINGLY



ON THIS TYPE OF PLOT, WE CAN DEFINE

CLOSING RATIO: DIFFERENCE BETWEEN THE SLOPE OF A_{OL} AND THAT OF $1/\beta$ FOR $\omega < \omega_{CR}$

AND

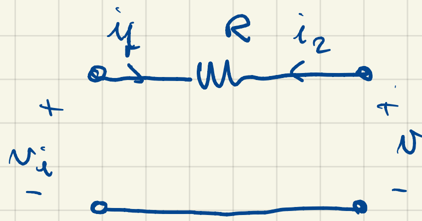
OPENING RATIO: DIFFERENCE BETWEEN THE SLOPE OF $1/\beta$ AND THAT OF A_{OL} FOR $\omega > \omega_{CR}$

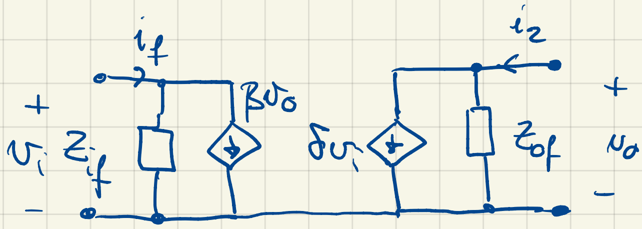
IN THIS CASE, CLOSING RATIO IS $-20-(+20) = -40$ dB/dec
AND THE OPENING RATIO IS $+20-(-20) = +40$ dB/dec
BOTH INDICATE SMALL PM VALUES CAN BE EXPECTED.

ANOTHER ANALYTICAL APPROACH IS TO USE **FEEDBACK THEORY**.
BASED ON THAT:

FEEDBACK TOPOLOGY IS **VOLTAGE SENSING – CURRENT MIXING**
SO THIS IS A TRANS-RESISTANCE AMPLIFIER

THE β-NETWORK IS THE CIRCUIT PART CONNECTING THE OUTPUT NODE (WHERE WE MEASURE VOLTAGE) TO THE INPUT NODE (WHERE WE MIX CURRENTS). SO IT IS RESISTOR R





$$Z_{if} = \left.\frac{v_i}{i_f}\right|_{v_o=\emptyset} = R \qquad Z_{of} = \frac{v_o}{i_2} = R$$

$$\beta = \left.\frac{i_f}{v_o}\right|_{v_i=0} = -\frac{1}{R} \qquad \delta = \left.\frac{i_2}{v_i}\right|_{v_o=0} = -\frac{1}{R}$$

$Z_{out} \cong \emptyset$ (OPAMP is "ALMOST" IDEAL)