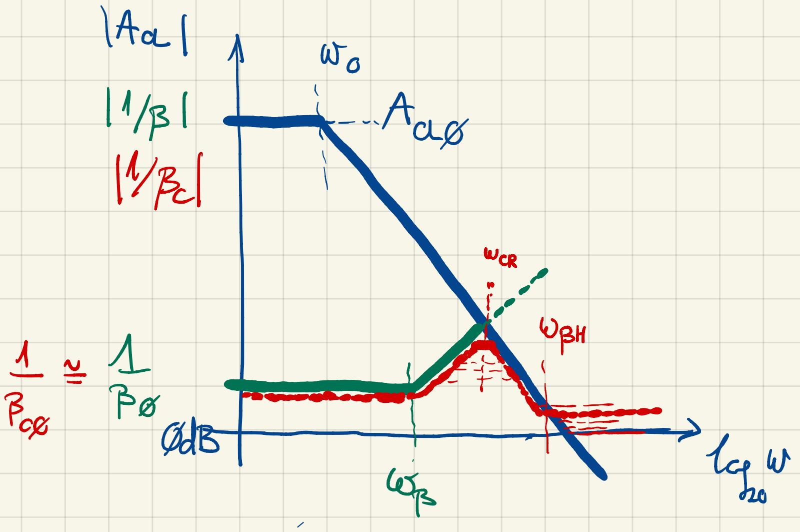
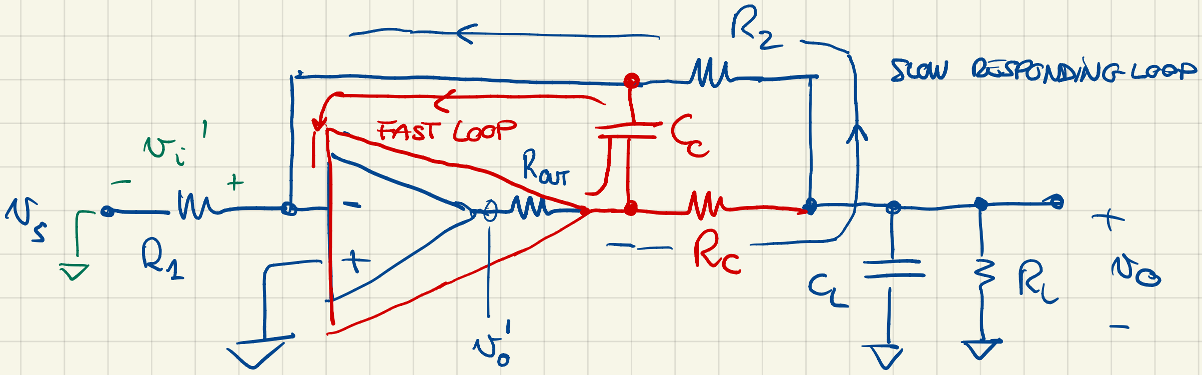


OPENING AND CLOSING RATIOS ARE ± 40 dB/dec
⇒ PM ≅ Ø ⇒ WE NEED TO APPLY
COMPENSATION!

$R_c < R_{out}$

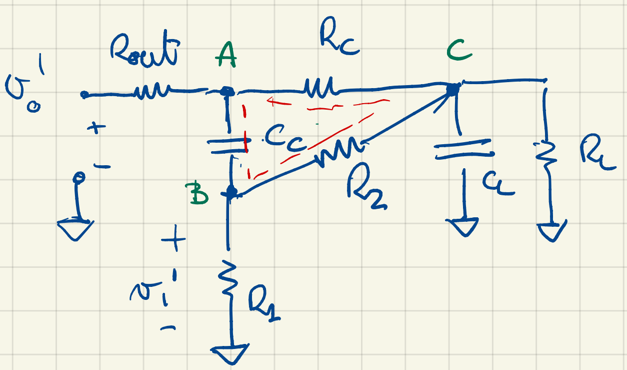
$$\omega_\beta = \frac{1}{R_L' \cdot C_L}$$

A POSSIBLE COMPENSATION NETWORK IS THE FOLLOWING



THE IDEA IS TO BY-PASS THE DELAYED FEEDBACK CREATING A FAST FEEDBACK PATH THAT STABILIZES THE AMPLIFIER TURNING IT INTO A FOLLOWER.

$$\beta_c(s) = \frac{v_i'}{v_o'}$$



$$R_\ell = R_L' // (R_c + R_{out})$$

THE EXPLICIT CALCULATION IS CUMBERSOME (TRY AS AN EXERCISE)
HINT: USE TRIANGLE TO STAR TRANSFORM.

$$\omega_{\beta_c} \overset{R_\ell \ll R_{out}}{\cong} \omega_\beta$$

$$\beta_{c\emptyset} = \frac{R_1}{R_1+R_2} \cdot \frac{\overbrace{R_L // (R_1+R_2)}^{R_L'}}{R_{out} + R_c + R_L // (R_1+R_2)} \overset{R_{out}+R_c \ll R_L'}{\cong} \beta_0$$

FIRST DESIGN CRITERION : KEEP $\beta_\phi \cong \beta_{C\phi}$ AND $\omega_\beta \cong \omega_{\beta c}$

BOTH CAN BE ACHIEVED WHEN $R_C \ll R_{out}$.

$$\beta_{C+\infty} = \frac{R_C /\!/ R_1 /\!/ R_2}{R_{out} + R_C /\!/ R_1 /\!/ R_2} \cong \frac{R_C}{R_{out} + R_C} \cong \frac{R_C}{R_{out}} < 1 \rightarrow \text{CHOICE OF } R_C$$

SECOND DESIGN CRITERION IS TO PLACE THE HIGH FREQUENCY POLE AT $\omega_{\beta H}$ SO THAT

$$A_{OL\phi} \cdot \omega_\phi = \omega_{\beta H} \cdot \frac{1}{\beta_{C+\infty}} \Rightarrow \omega_{\beta H} = A_{OL\phi}\, \omega_\phi \cdot \beta_{C+\infty}$$

$$\omega_{\beta H} = \frac{1}{C_C\, R_{CC}} \quad \text{WHERE } R_{CC} = R_C /\!/ R_{out} + R_1 /\!/ R_2$$

$$C_C = \frac{1}{R_{CC} \cdot \omega_{\beta H}} \longrightarrow \text{CHOICE OF } C_C$$

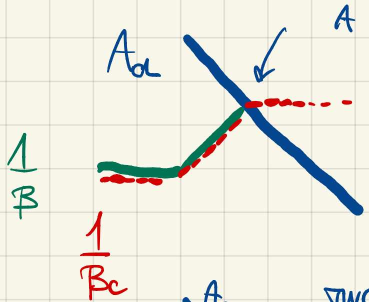
SUMMARY

COMPENSATED OPAMPS $\left(A_{OL}(s) = \frac{A_{OL\phi}}{1 + s/\omega_\phi} \right)$ DO NOT POSE TOO MANY STABILITY PROBLEMS

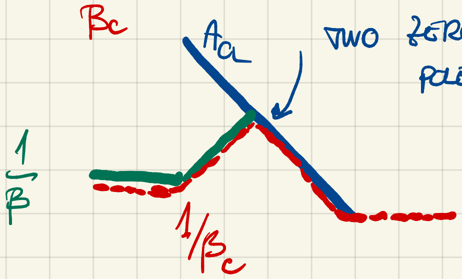
PROBLEMS ARISE MOSTLY FROM HIGH PASS FREQUENCY RESPONSE OR FROM CAPACITIVE LOADS

COMPENSATION CAN BE IMPLEMENTED IN TWO WAYS

1. A ZERO IS ADDED TO β-NETWORK TO REDUCE OPENING AND CLOSING RATIOS

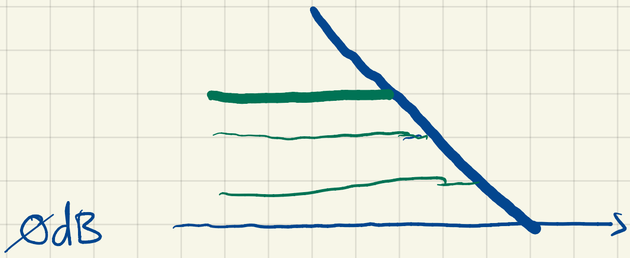


2. TWO ZEROS (AND AN ADDITIONAL, HIGH FREQUENCY POLE) ARE ADDED MAKING OPENING AND CLOSING RATIOS EQUAL TO ZERO.



WE DO NOT HAVE ANY STABILITY PROBLEM WHEN

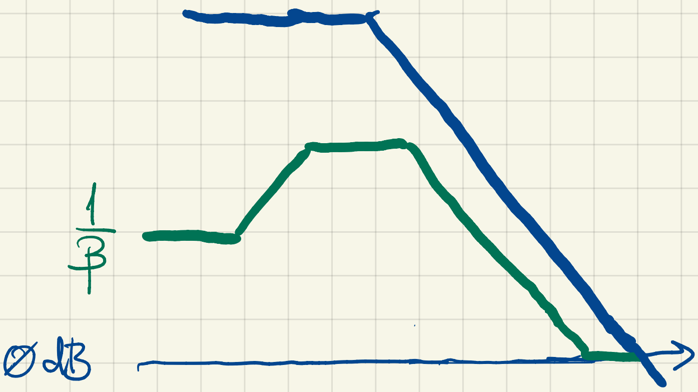
1. THE TARGET GAIN IS CONSTANT



OPENING AND CLOSING RATIOS ARE ALWAYS EQUAL TO $\mp$ 20 dB/dec

PM IS LARGE (90°)

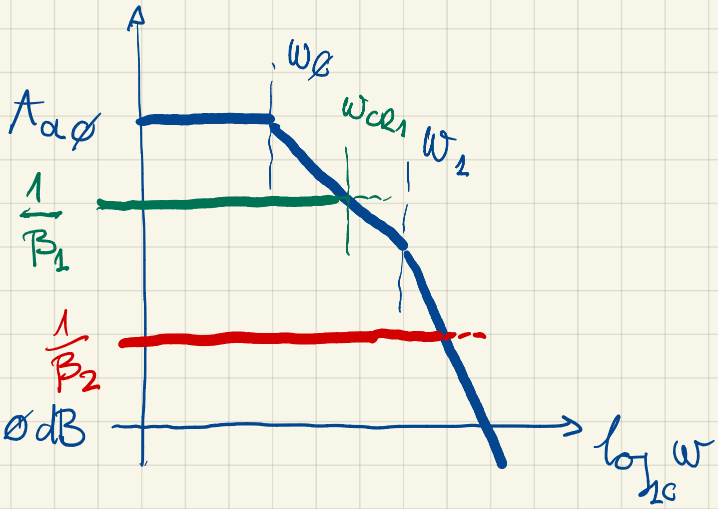
2. THE TARGET GAIN IS FREQUENCY DEPENDENT, BUT DOES NOT INTERSECT $A_\alpha(s)$ WITH CLOSING RATIO ≤ -40 dB/dec



THE PHASE MARGIN IS ALWAYS LARGE BECAUSE POLES OF β DO NOT CAUSE INTERSECTIONS WITH LARGE OPENING AND CLOSING RATIOS

WHAT IF THE OPAMP WE ARE USING IS JUST PARTIALLY COMPENSATED, NON UNITY GAIN STABLE?

THE TYPICAL CASE IS
$$A_\alpha(s) = \frac{A_{\alpha\emptyset}}{\left(1+\frac{s}{\omega_\emptyset}\right)\left(1+\frac{s}{\omega_1}\right)}$$

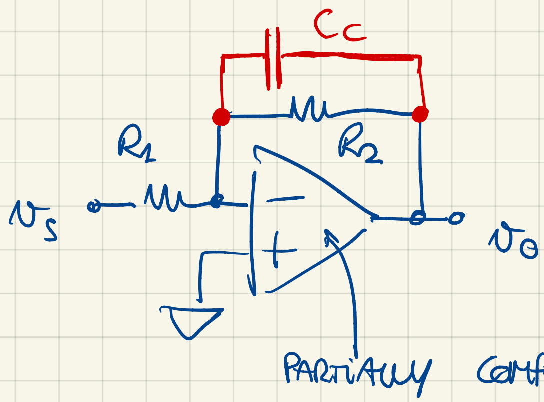


β_1 YIELDS A STABLE AMPLIFIER WITH CONSTANT GAIN $1/\beta_1$

β_2 YIELDS VERY LOW STABILITY MARGIN.

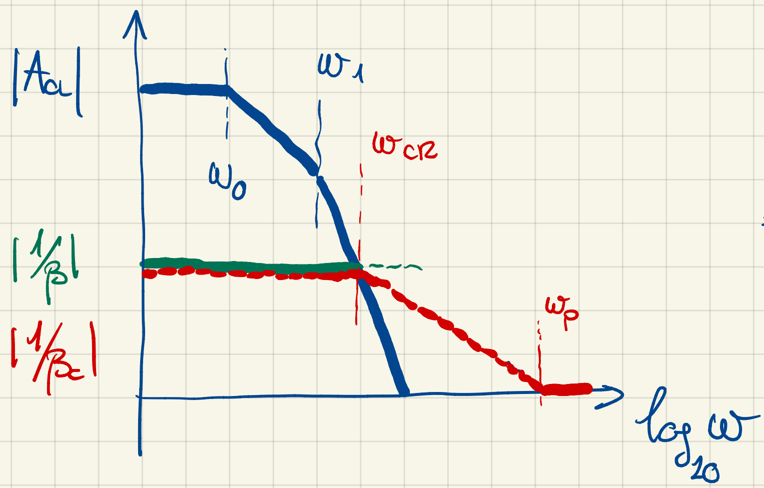
HOW DO WE SOLVE THE PROBLEM? COMPENSATING THE FEED BACK NETWORK.

STANDARD SOLUTION



PLACE A COMPENSATION CAPACITOR SO THAT A ZERO IS ADDED TO THE β-NETWORK

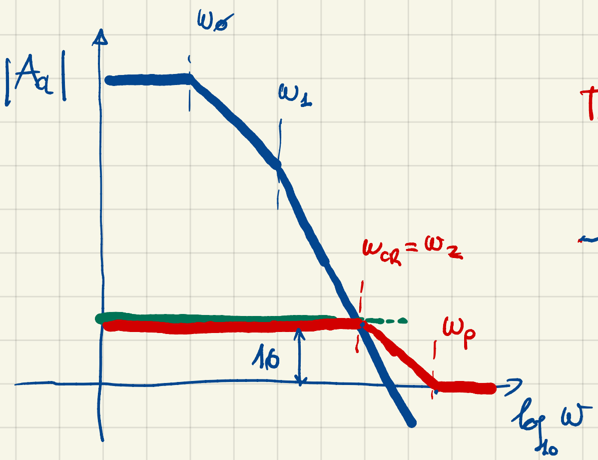
IF $1+\frac{R_2}{R_1}$ $\left(=\frac{1}{\beta}\right)$ IS LOWER THAN SOME LIMIT, PM IS LOW.

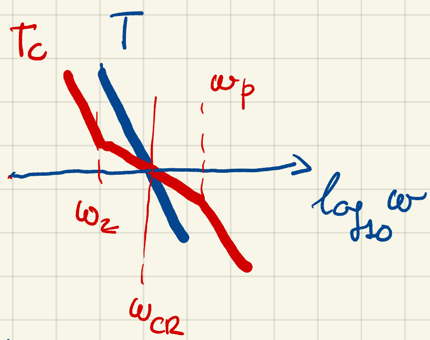


THANKS TO C_C OPENING AND CLOSING RATIOS ARE $\pm$ 20 dB/dec $\Rightarrow$ PM IS LARGER (MINIMUM ΔPM $= +45°$)

THIS TECHNIQUE FAILS TO PROVIDE LARGE PM VALUES WHEN THE TARGET GAIN IS RELATIVELY LOW.

EXAMPLE



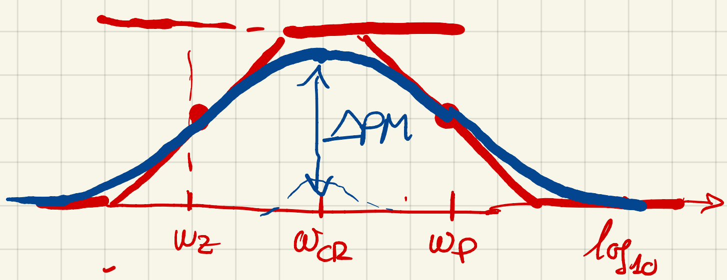


$\frac{\omega_{CR}}{\omega_z} = \frac{\omega_p}{\omega_{CR}} = 4$ $\quad \Delta PM = +60°$

16 IS THE MINIMUM GAIN COMPATIBLE WITH $\Delta PM = +60°$

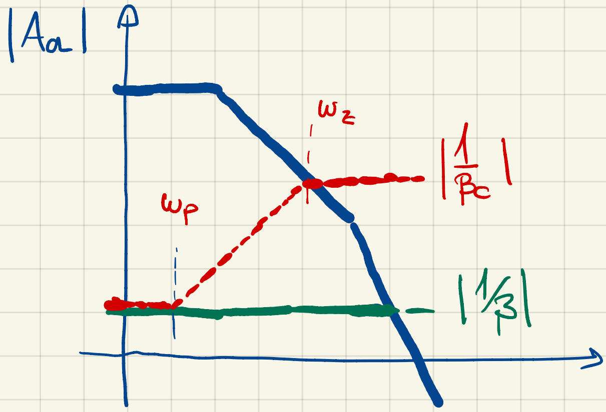
16 IS 24 dB !

WHEN THE TARGET GAIN IS LOWER, THIS TECHNIQUE



NO LONGER ALLOWS ΔPM TO BE $+60^\circ$.

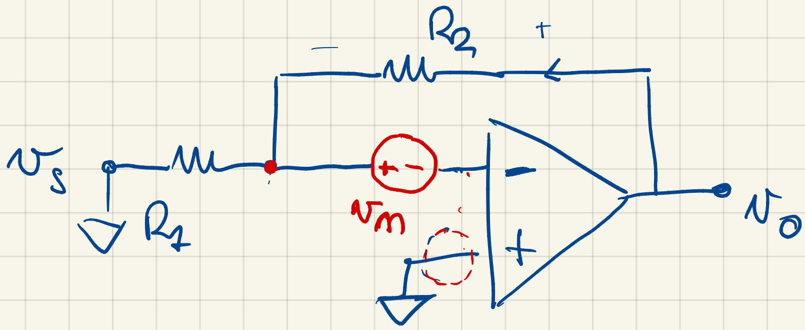
OF COURSE, THERE IS AN ALTERNATIVE STRATEGY



THIS IS THE SO-CALLED

NOISE GAIN COMPENSATION

ΔPM CAN BE AS HIGH AS $+90^\circ$



THE TERM NOISE GAIN NG DERIVES FROM

$$1+\frac{R_2}{R_1}$$

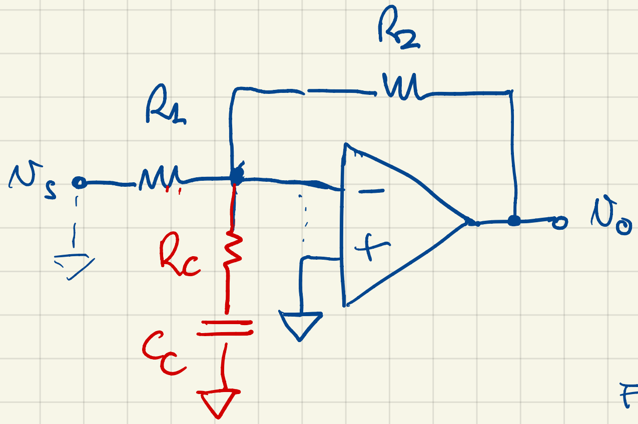
BEING THE AMPLIFICATION OF NOISE.

v_m IS NOISE

$$\frac{v_o}{v_m} = 1+\frac{R_2}{R_1}$$

← THIS IS THE "NOISE GAIN"

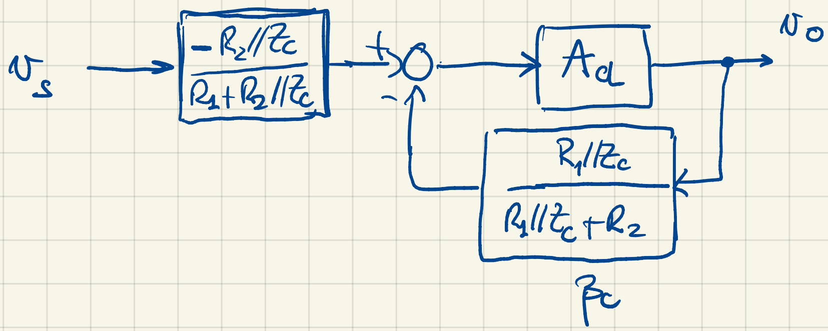
IN THE INVERTING CONFIGURATION NG COMPENSATION LOOKS LIKE THIS:



$$\beta = \frac{v_-}{v_o} = \frac{R_1}{R_1+R_2}$$

$$\beta_c = \frac{v_-}{v_o} = \frac{R_1 /\!/ Z_c}{R_1 /\!/ Z_c + R_2}$$

FROM LOOP INSPECTION



FOR $|T| >> 1$

$$A_v = \frac{v_o}{v_s} \simeq -\frac{R_2 // Z_C}{R_1 + R_2 // Z_C} \cdot \frac{R_2 + R_1 // Z_C}{R_1 // Z_C} = -\frac{R_2}{R_1}$$

PROVE AS EXERCISE

HINT:
$$\frac{R_2 // Z_C}{R_1 + R_2 // Z_C} = R_1 // R_2 // Z_C \cdot \frac{1}{R_1}$$

$$\frac{R_2 + R_1 // Z_C}{R_1 // Z_C} = \frac{R_2}{R_2 // R_1 // Z_C}$$

∎