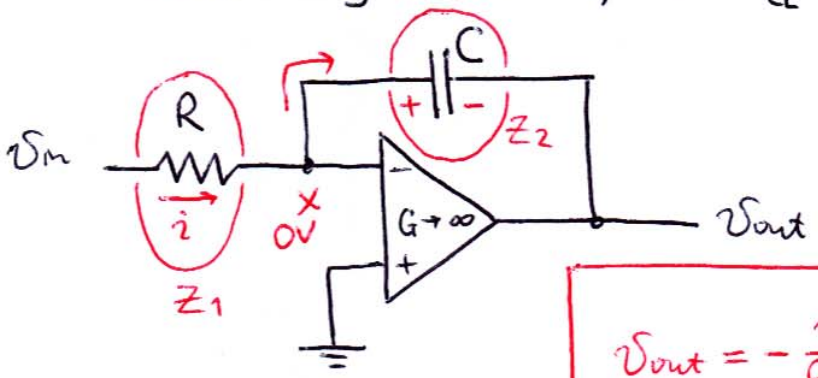
P3360/AEP3630

Lecture 12

Integrator

$v_{out} \propto \int v_{in} dt$, $\Rightarrow$ $G_{CL}(s) \propto \frac{1}{s}$ single pole @ origin



$i = \frac{v_{in}}{R}$

$v_{out} = -v_c = -\frac{Q}{C}$

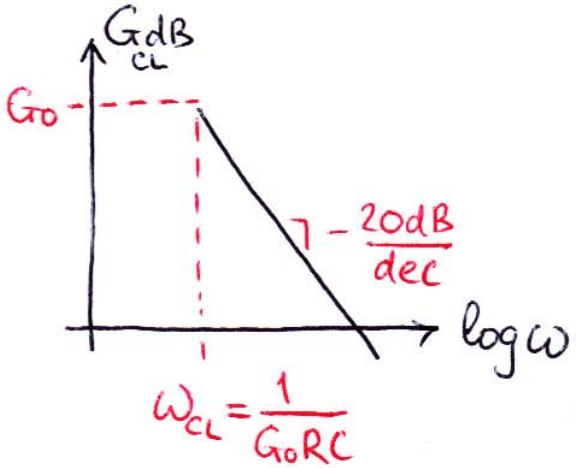
$$v_{out} = -\frac{1}{RC}\int_0^t v_{in} dt - \frac{Q(t=0)}{C}$$

AC response :

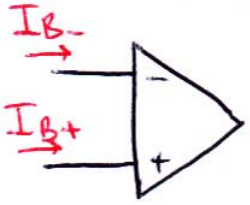
$$G_{CL}(\omega) = \frac{v_{out}}{v_{in}} = -\frac{Z_2}{Z_1} = -\frac{1}{j\omega RC}, \text{ or } G_{CL}(s) = -\frac{1}{sRC}$$

Problem 1 : $G_{CL}(\omega \to 0) \to \infty$?

ω_{CL} depends on G_0



Problem 2 : I_B needed to bias transistors inside op-amp.



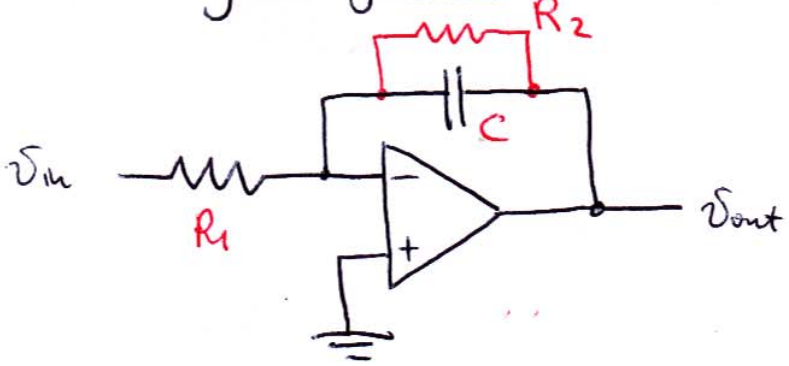
e.g. 741 $|I_B| \sim 20$nA

3140 $|I_B| \sim 10$pA

$\Rightarrow$ will charge the cap / offset DC

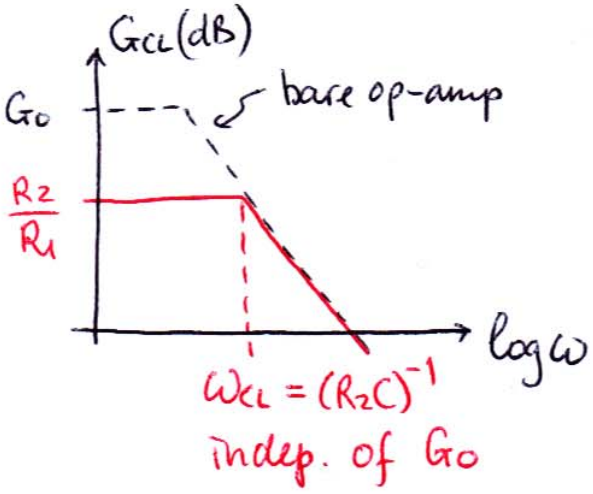
Solution

Leaky integrator



$$G_{CL}(\omega) \approx -\frac{R_2 \| Z_C}{R_1}$$

$$G_{CL}(\omega) = -\frac{R_2}{R_1}\frac{1}{1+j\omega R_2 C}$$

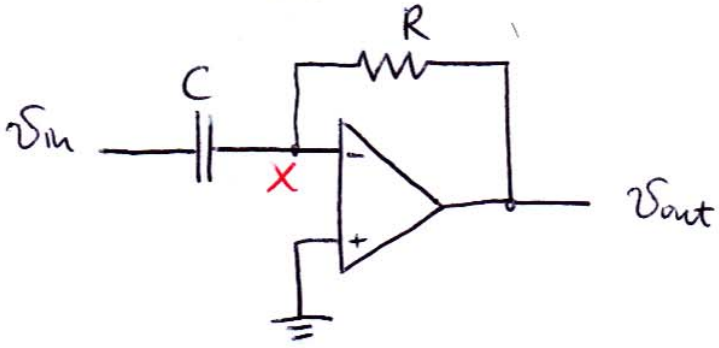


Pros: fixed Probs 1 & 2

Cons: integrates only $\omega \gg \omega_{CL} = (R_2 C)^{-1}$

Differentiator

$v_{out} \propto \frac{d}{dt} v_{in}$, $\Rightarrow$ $G_{CL}(s) \propto s$ single zero @ origin



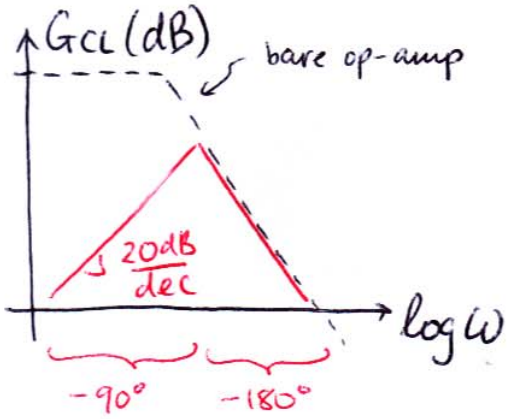
$$v_{in} = v_C = \frac{Q}{C} \;;$$

$$i = \frac{dQ}{dt} = C\frac{dv_{in}}{dt}$$

$$\boxed{v_{out} = -iR = -RC\frac{dv_{in}}{dt}}$$

AC response:

$$G_{CL}(\omega) = -\frac{R}{1/j\omega C} = -j\omega RC \;, \text{ or } G_{CL}(s) = -sRC$$



Problem : output may "ring"

Q: why?

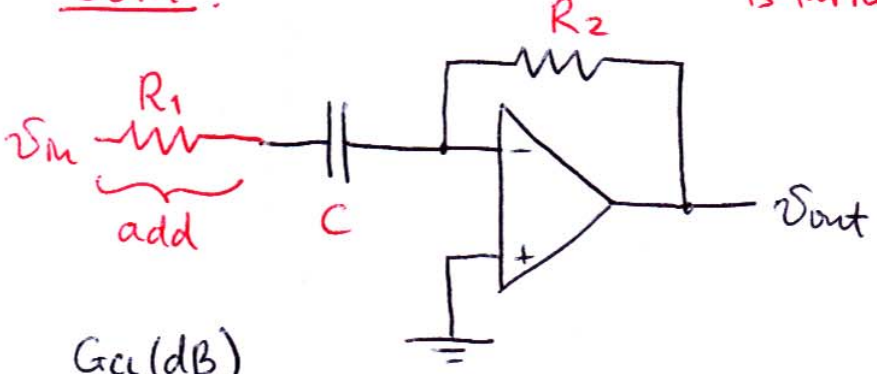
F.B. : $-90°$ phase lag

op.-amp : $-90°$ phase lag (comp.)

$\Rightarrow -180°$ total phase lag,

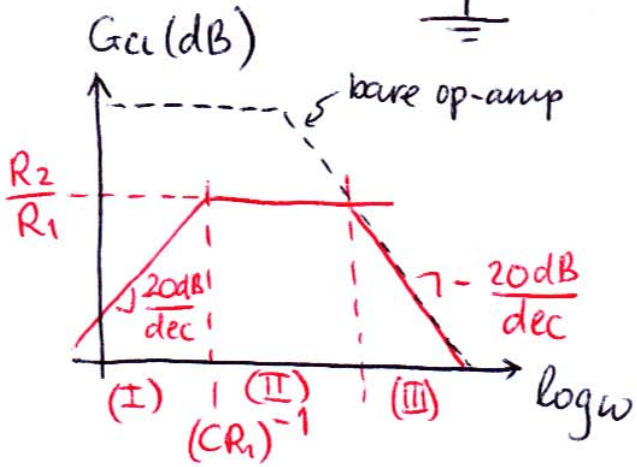
"−" is turned into "+" F.B. (oscillations)

Soln :



assuming $G_{OL} \to \infty$

$$G_{CL}(\omega) = -R_2 \frac{j\omega C}{1+j\omega C R_1}$$



(I) $-90°$ phase lag

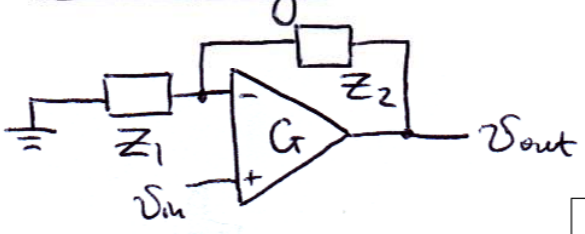
(II) bring phase back to $0°$

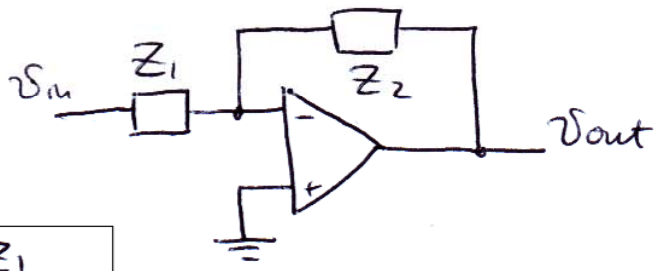
(III) Int. Comp. : $-90°$ phase lag

Pros: no $180°$ phase change
$\Rightarrow$ no "+" F.B.

Cons: differentiates only
$\omega \ll (CR_1)^{-1}$

Stability





$$H = \frac{Z_1}{Z_1 + Z_2}$$

$$G_{CL} = \frac{1}{H}\frac{GH}{1+GH} \qquad G_{CL} = -\left(\frac{1}{H}-1\right)\frac{GH}{1+GH} \qquad (4)$$

GH = loop gain $= |GH|e^{j\varphi}$

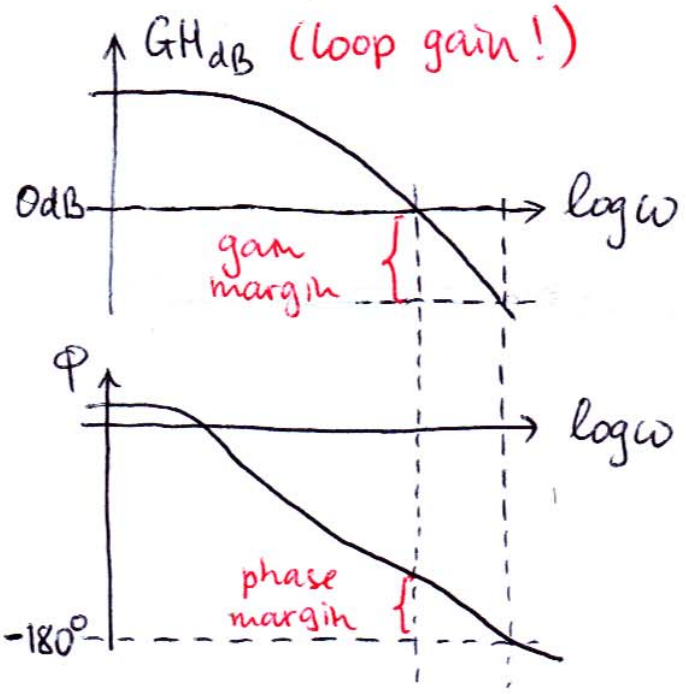
If @ some freq $\varphi = \pm 180°$, $GH = -|GH|$

$\Rightarrow$ turn negative into positive F.B.

if $|GH|<1$ @ $\varphi(\omega) = -180°$, $\Rightarrow$ may ring but will damp

if $|GH|>1$ @ $\varphi(\omega) = -180°$, $\Rightarrow$ self-sustained oscillations

Phase & gain margins



$$G_{CL} = \frac{1}{H}\frac{GH}{(1+GH)} = 0 \quad \text{(stay away from!)}$$

if $GH = -1$

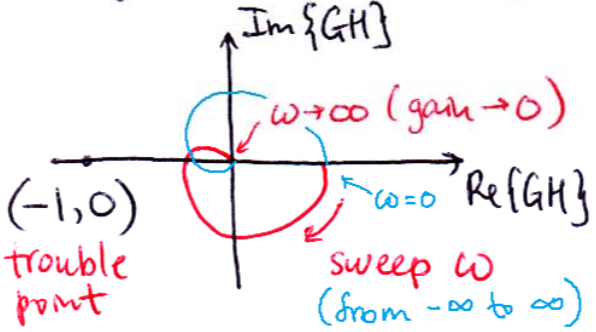
Rule of thumb for loop gain:

phase margin $> 45°$

gain margin $>$ 10-12 dB

Nyquist plots

plot $GH(\omega)$ on complex plane



Nyquist criterion of stability:

if Nyquist curve encompasses (-1,0)

$\Rightarrow$ circuit is unstable