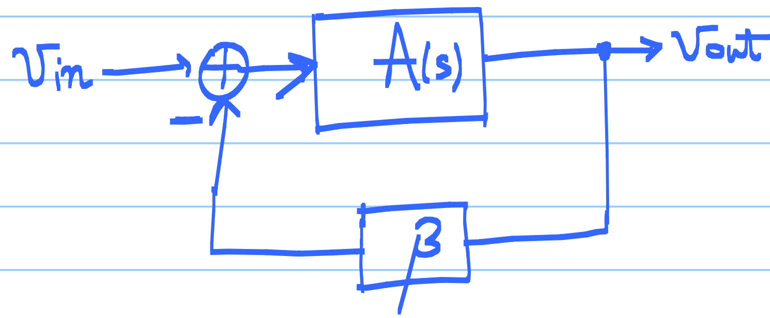
ECE 511 – Lecture 21

Note Title 4/18/2012

Saturday (4/21)
Project Help Session
MEC 206
3 pm → 4 pm



loop-gain → $A\beta$

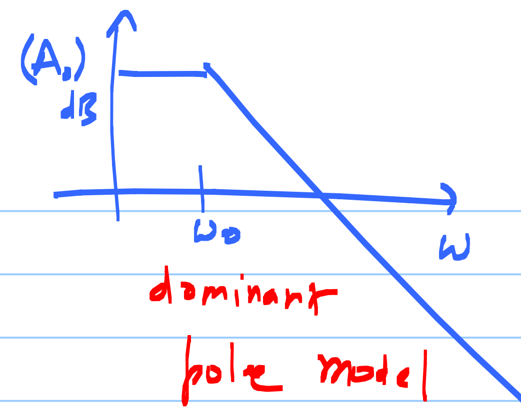
Ideal CL gain → $A_{CL} = \frac{1}{\beta}$ ← when $|A\beta| \gg 1$

finite 'A' ⟹ $A_{CL} = \frac{1}{\beta}(1 - \epsilon)$ ← gain error

$\epsilon = \frac{1}{A\beta}$

②

$$A(s) = \frac{A_0}{\left(1+\frac{s}{\omega_0}\right)}$$



$$\frac{V_{out}}{V_{in}}(s) = \frac{A(s)}{1+\boxed{\beta A(s)}}$$

$$= \frac{A_0}{(1+\beta A_0)+\frac{s}{\omega_0}} = \frac{\boxed{\left(\frac{A_0}{1+\beta A_0}\right)}}{1+\frac{s}{\omega_0(1+\beta A_0)}}$$

$\approx \frac{1}{\beta}$ for $A_0\beta \gg 1$

$$= \frac{A_{CL}'}{\left(1+\frac{s}{\omega_0(1+\beta A_0)}\right)}$$

closed loop pole (ω_{3dB})

$$\omega_{3dB} = (1+\beta A_0)\,\omega_0 \qquad A_0\beta >> 1$$

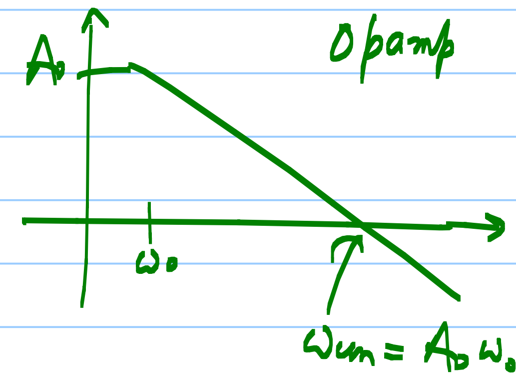
$$\simeq \beta \boxed{A_0\,\omega_0}$$

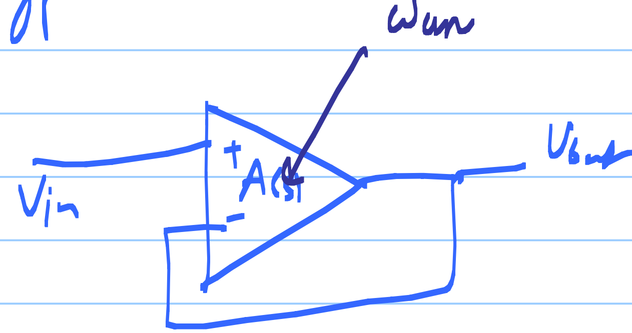
$$= \frac{1}{A_{CL}} \cdot \omega_{un}$$

Constant for the opamp → $\boxed{\omega_{un} = \omega_{3dB} \cdot A_{CL}}$

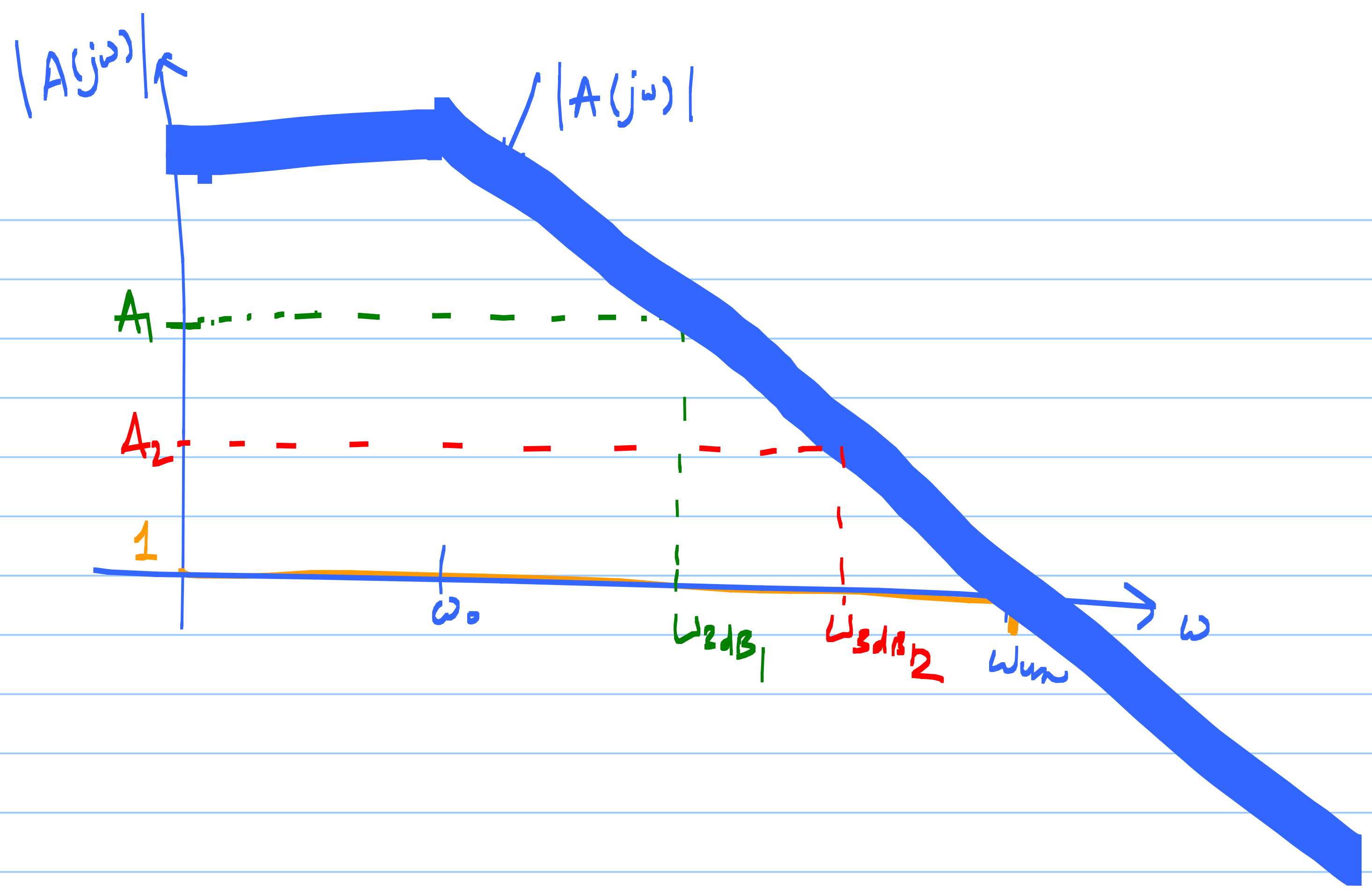
$2\pi f_{un}$

gain-BW trade off

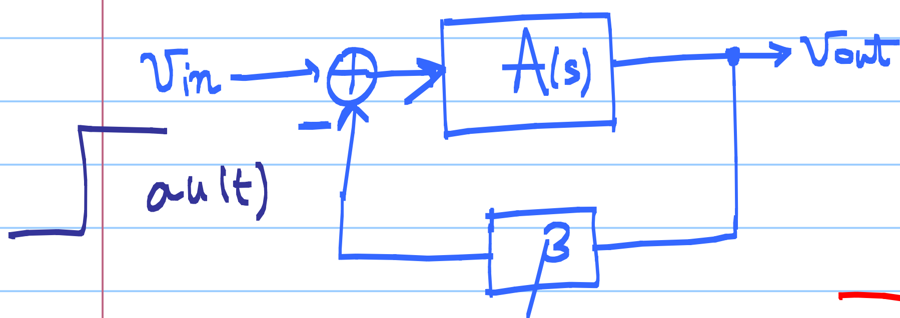




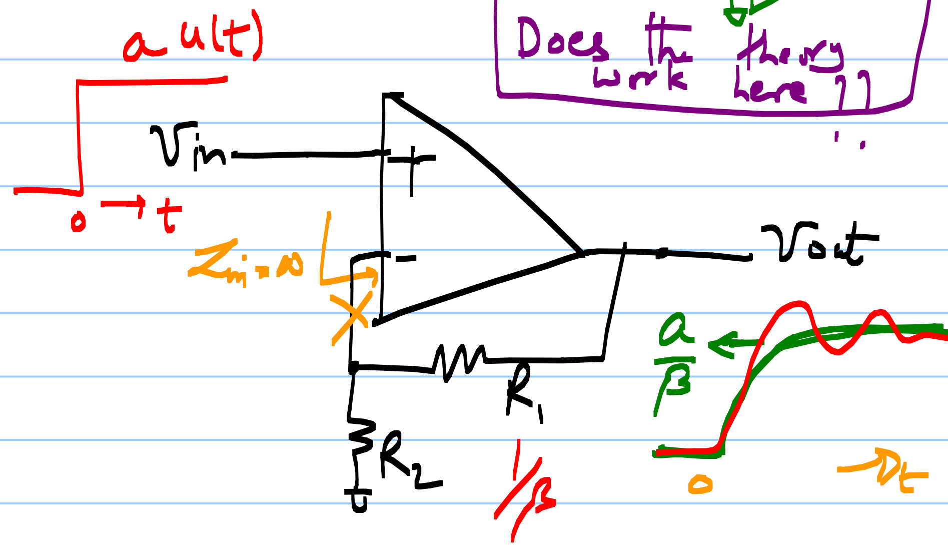
$\omega_{3dB} = \, ? = \omega_{un}$



$|A(j\omega)|$
$|A(j\omega)|$
A_1
A_2
1
ω_0
ω_{3dB_1}
ω_{3dB_2}
ω_{u_m}
ω



Does the theory work here ??



$$\beta = \frac{R_2}{R_1 + R_2}$$

$$v_{in}(t) = a\,u(t) \leftrightarrow \frac{a}{s}$$

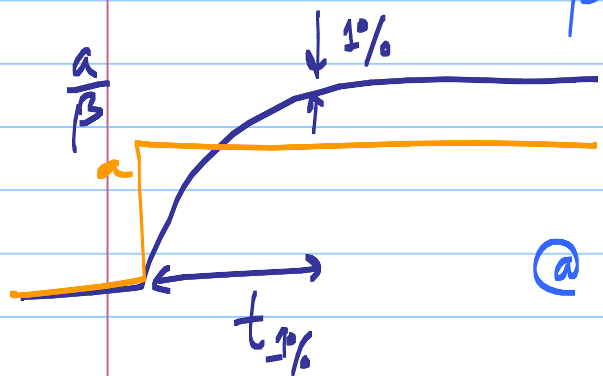
$$V_{out}(t) = \mathcal{L}^{-1}\left(\frac{a}{s}\cdot\frac{1}{\beta}\cdot\frac{1}{(1+s/\omega_{3dB})}\right)$$

$$= \frac{a}{\beta}\left[1 - e^{-t/\tau}\right]u(t)$$

← linear settling ('1st order system')

↳ single-pole opamp model

$$\tau = \frac{1}{\omega_{3dB}} = \frac{1}{\omega_{un}\cdot 1/\beta}$$



@ $t = t_{1\%}$

$$1 - e^{-t/\tau} = 0.99$$

$$\Rightarrow \boxed{t_{1\%} = 4.6\,\tau} \simeq 5\,\boxed{\tau}$$

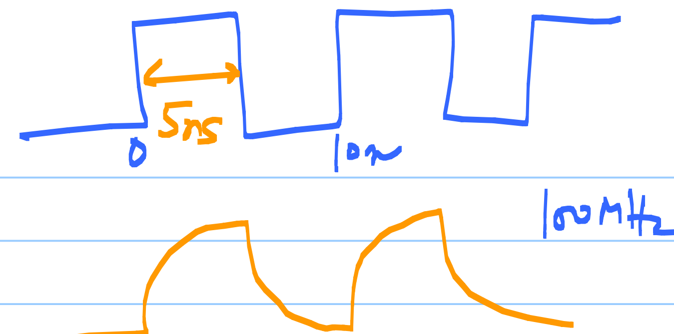
ω_{3dB}

↓

ω_{un}

for 1% settling of 5ns

$$\frac{1}{\beta} = 10$$



$$\omega_{un} = \frac{1}{\beta} \cdot \omega_{3dB}$$

$1/\tau$

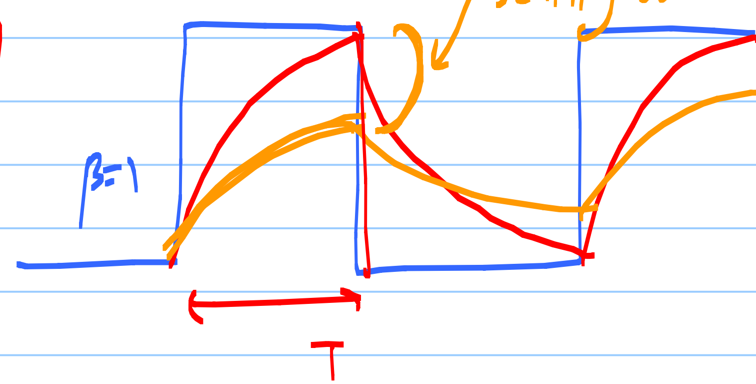
$$= \frac{1}{\beta\tau}$$

$$\tau = \frac{5ns}{4.7} = 1.09\,ns$$

$$= 9.21 \times 10^{9}\ rad/s$$

$$f_{un} = \frac{\omega_{un}}{2\pi} = \boxed{1.47\ GHz}$$

$A_0\beta \uparrow \Rightarrow \varepsilon \downarrow$

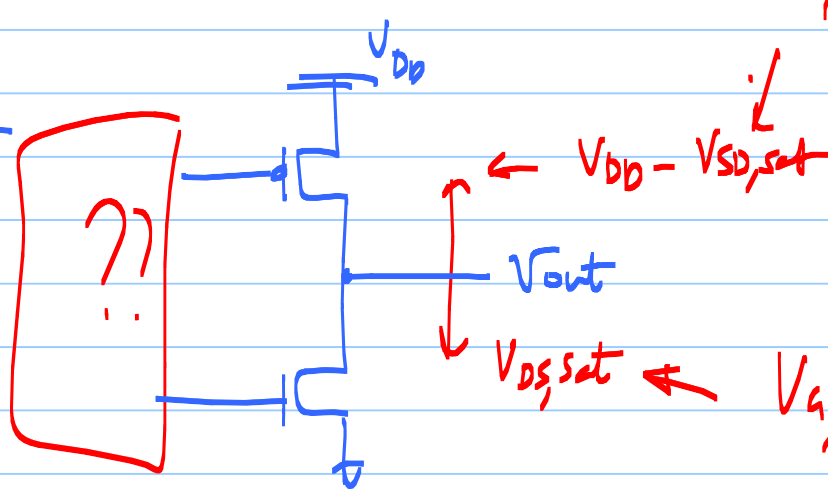


③ Large-signal BW

↳ transient simulations for large signals

AC analysis doesn't help much.

④ Output swing



"V_{ov}"

$V_{GS} - V_{THN}$

"V_{ov}"

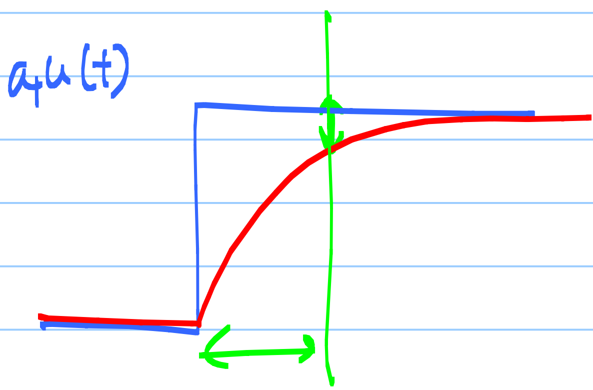
trade-off with

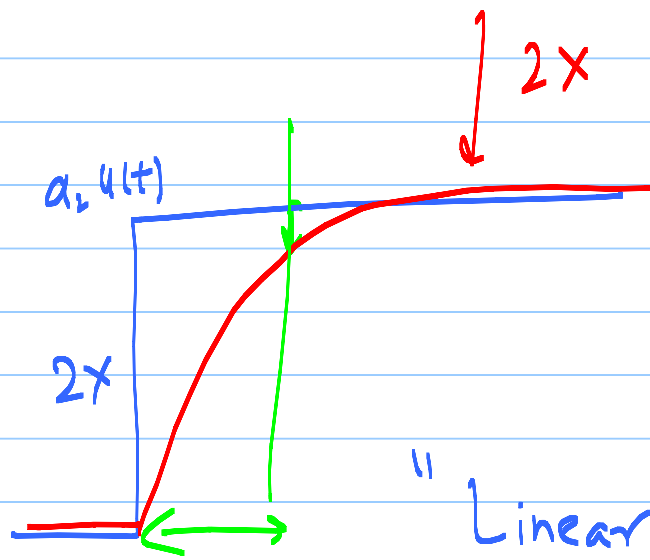
$V_{ov} \leftarrow f_T$ (speed)

$$f_T \propto \frac{V_{ov}}{L} \leftarrow$$

⑤ Slewing.

small input



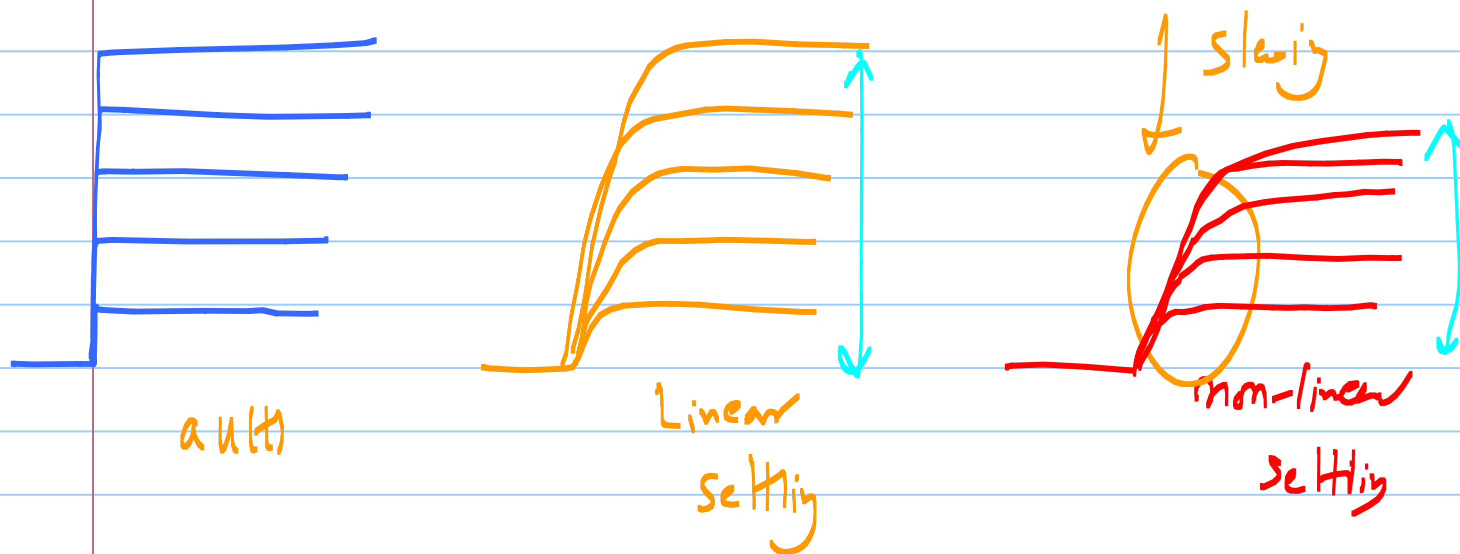


"Linear settling"

$$\frac{a}{\beta}\left(1-\underbrace{e^{-t/\tau_s}}_{\text{settling}}\right)$$

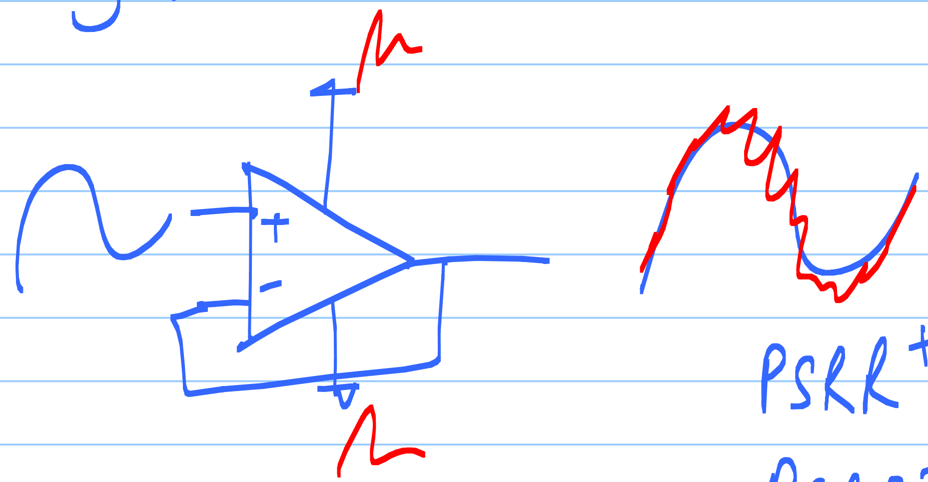

non-linear settling
slewing

$\beta = 1$



(9) Noise & offset → ECE 614

(10) Supply rejection



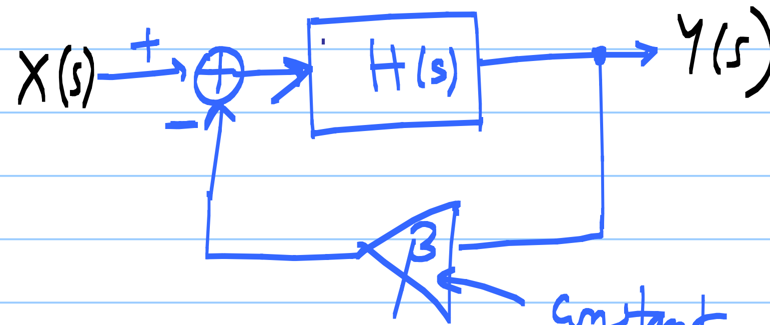
$PSRR^+$

$PSRR^-$

Stability & Frequency Compensation

Closed-loop TF

$$\frac{Y}{X}(s) = \frac{H(s)}{1+\boxed{\beta H(s)}}$$ ← open-loop TF

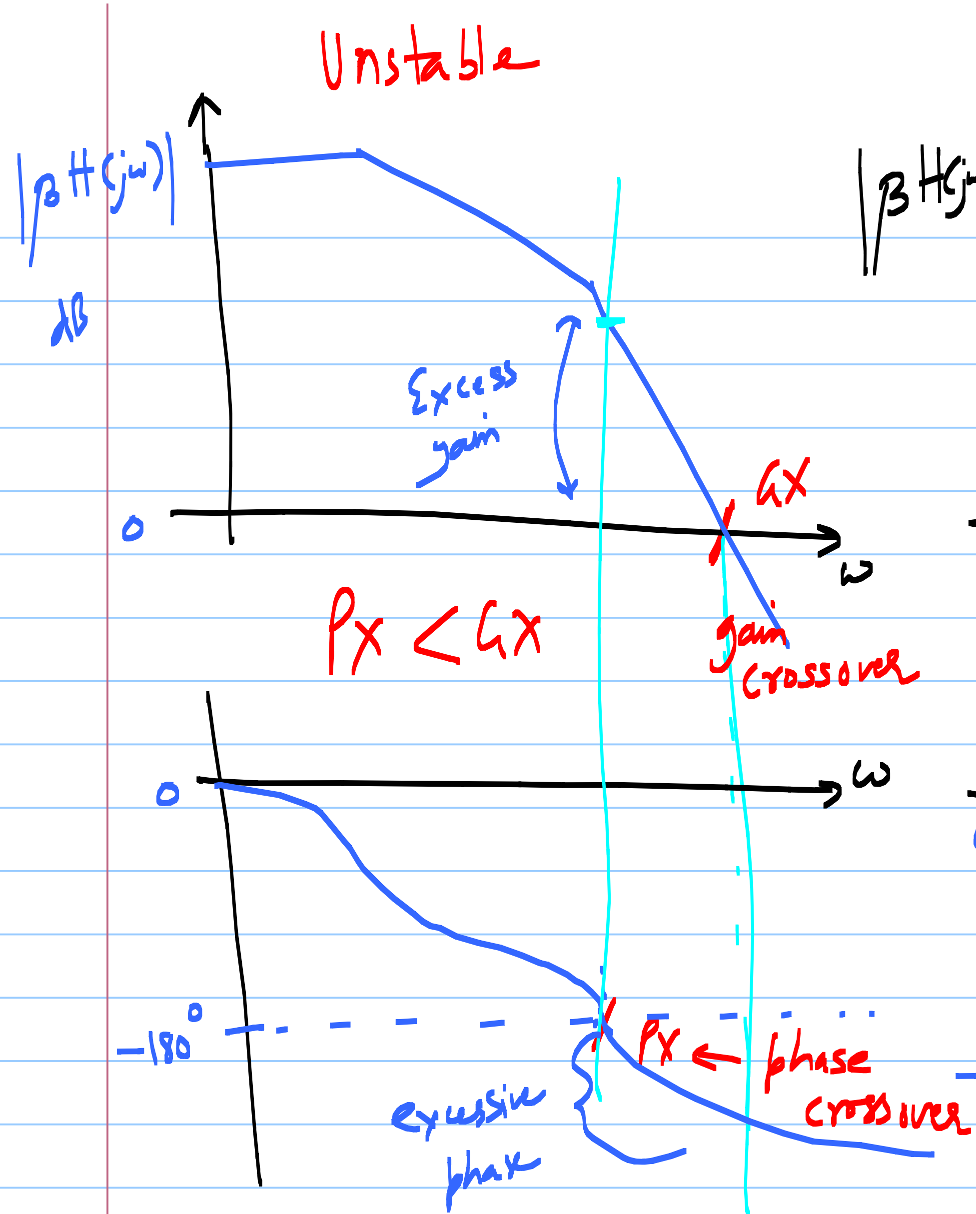


If $\beta H(s=j\omega_1) = -1 \Leftarrow A_{cL}(s) = \infty$

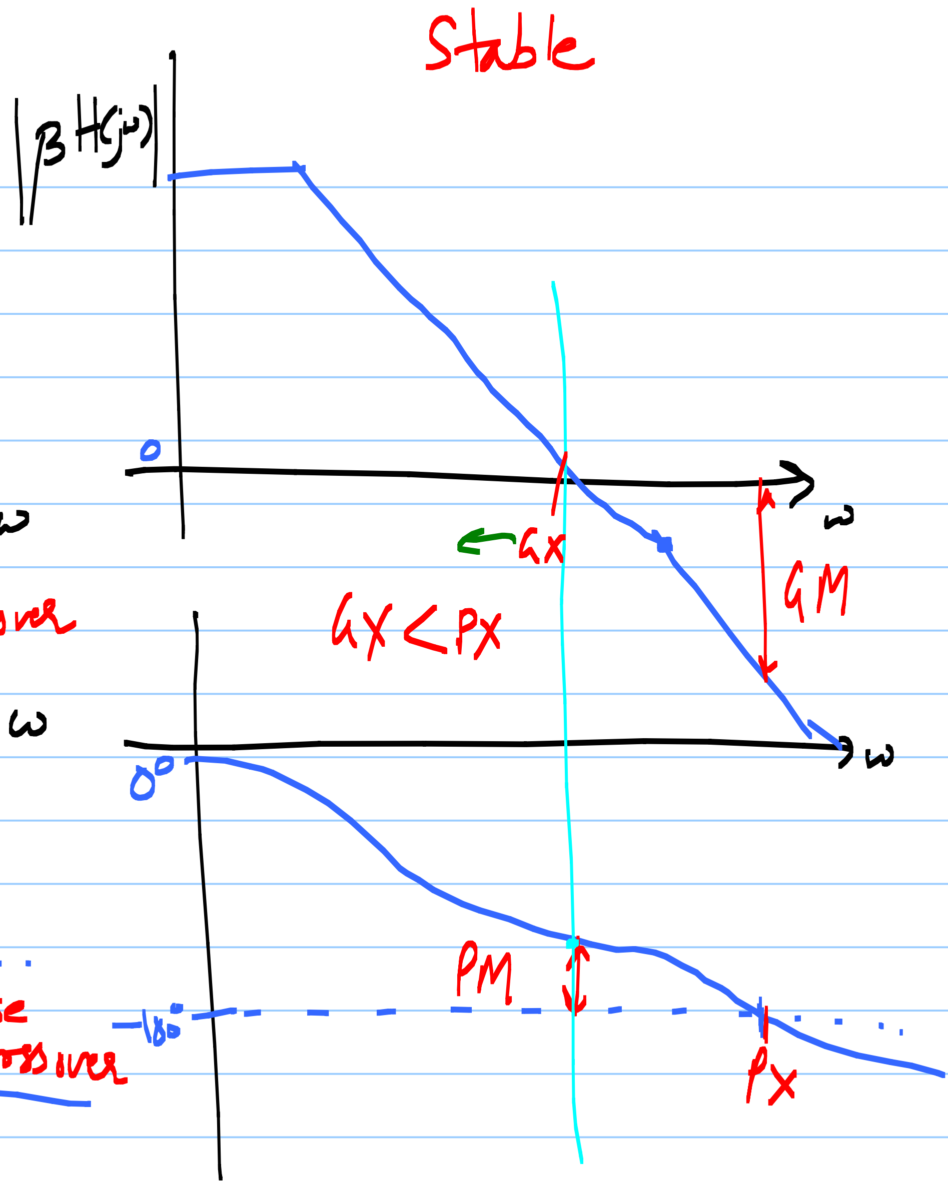
$\beta \leq 1$

↳ circuit starts oscillating at ω_1

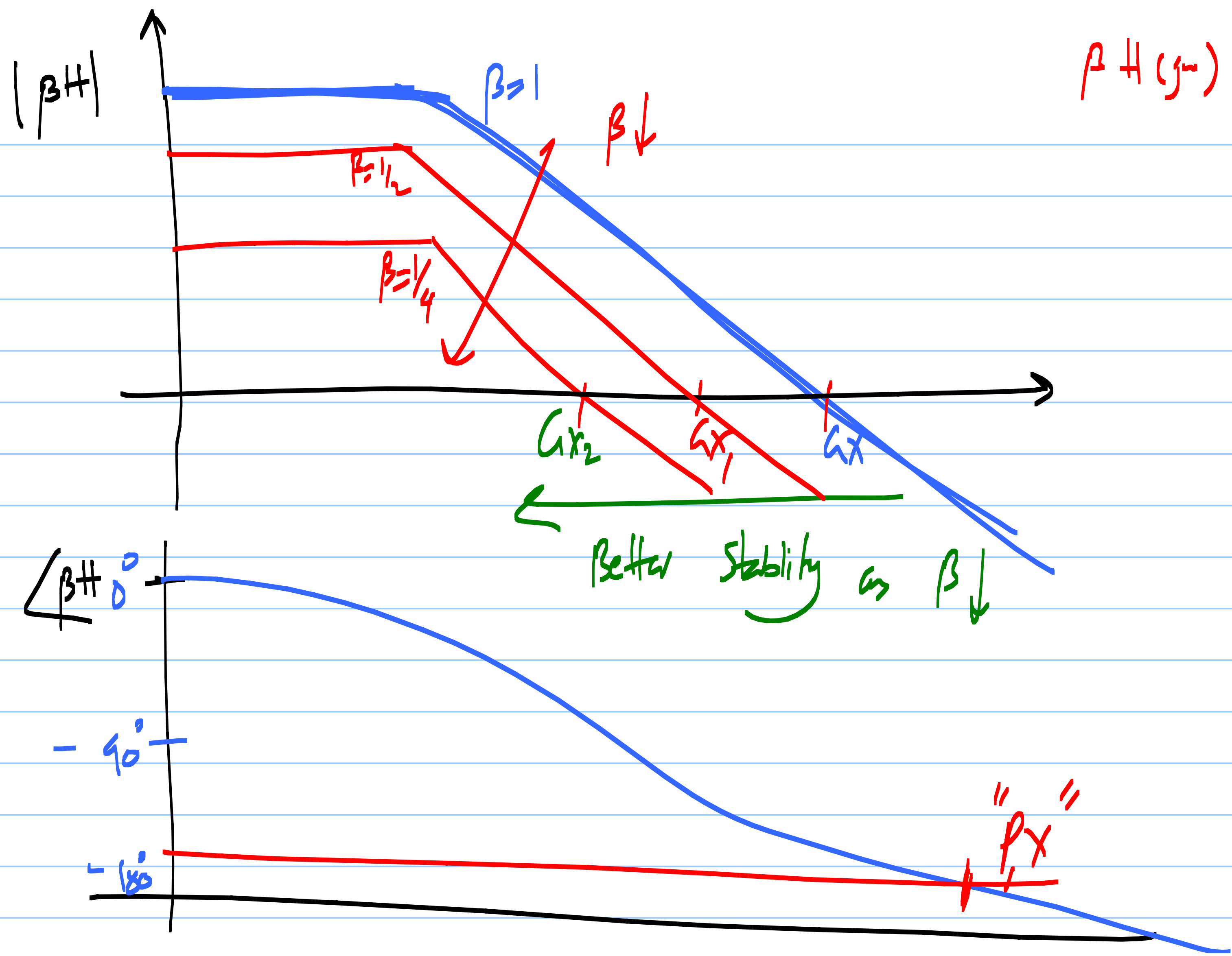
⇒ Here
$$\left[\begin{array}{l} |\beta H(j\omega_1)| = 1 \\ \angle \beta H(j\omega_1) = 180^\circ \end{array}\right.$$
⟶ Barkhausen's Criterion



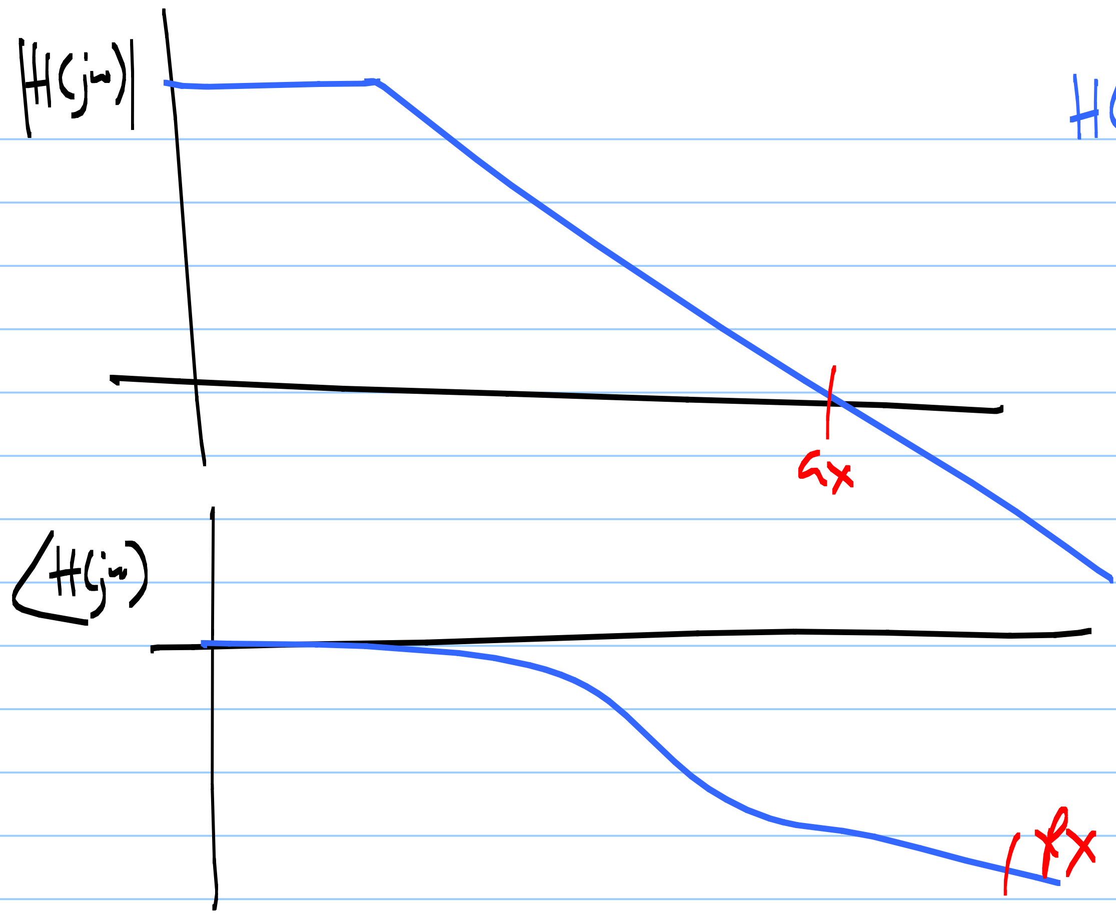
Unstable
$|\beta H(j\omega)|$
dB
Excess gain
GX
0
ω
PX < GX
gain crossover
0
ω
-180°
excessive phase
PX
phase crossover



Stable
$|\beta H(j\omega)|$
0
ω
GX
GM
GX < PX
0°
ω
PM
-180°
PX



|βH|
β=1
β↓
β=1/2
β=1/4
βH(jω)
Gx2
Gx1
Gx
Better Stability as β↓
∠βH
0°
-90°
-180°
"Px"



H(jω) should have sufficient PM + GM

$H(j\omega) \leftarrow$ "stable" sufficient PM/GM

$\Rightarrow \beta H(j\omega) \leftarrow$ stable for $\forall\, \beta \leq 1$

$$\Rightarrow \frac{H(j\omega)}{1 + \beta H(j\omega)} \Rightarrow A_{cL}(j\omega) \leftarrow \text{is stable}$$