Ch. 6. Dynamic OpAmp Limitations

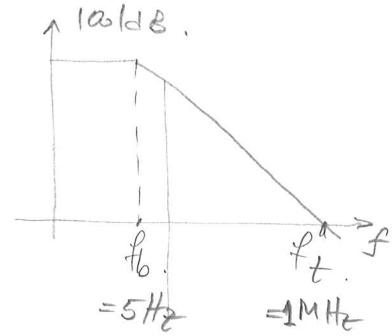
Part 2.

Last time:

- Open loop OpAmp gain (1) $a(jf) = \dfrac{a_0}{1 + j\dfrac{f}{f_b}}$
- Unity gain $\boxed{f_t = a_0 \cdot f_b}$.
- Gain Bandwidth Product:

$$\boxed{GBP = |a(jf)|_f * f = f_t = \text{const.}}$$

for $f \gg f_b$ where OpAmp behaves as integrator



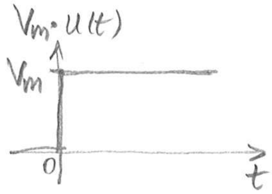
Today: First: (See previous notes)

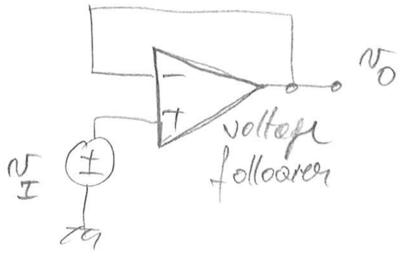
- Questions:
  - How does (1) affect the closed loop gains of
    - noninverting
    - inverting
  - How does (1) affect the input/output impedances for configurations of the negative feedback:
    - series
    - shunt

Today: Second:
- Slew Rate (transient response)
- Current-feedback amplifiers.

6.4 Transient Response

a) Rise time





$$A(jf) = \frac{1}{1 + j\frac{f}{f_t}}$$: transfer function.

$$\boxed{\text{Pole at } s = -2\pi f_t}$$

$$A(s) = \frac{\omega_t}{s + \omega_t} \quad \text{(reminder)}$$

$$v_I(t) = V_m \cdot u(t)$$

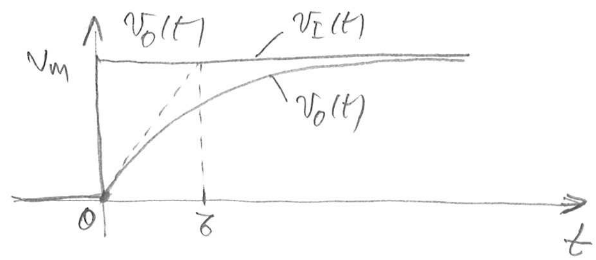
$$V_I(s) = \frac{V_m}{s}$$

$$\Rightarrow V_O(s) = V_m \cdot \frac{\omega_t}{s(s+\omega_t)} \Rightarrow$$

$$\Rightarrow V_O(s) = V_m \left[\frac{1}{s} - \frac{1}{s+\omega_t}\right]$$

$$\Rightarrow v_O(t) = V_m \cdot \left[1 - e^{-\omega_t \cdot t}\right] \cdot u(t) \qquad \omega_t = 2\pi f_t$$

$$\boxed{v_O(t) = V_m \left[1 - e^{-2\pi f_t \cdot t}\right] \cdot u(t)}$$



$$\tau = \frac{1}{\omega_t} = \frac{1}{2\pi f_t}$$

$\boxed{t_R} \triangleq \boxed{\text{Rise time}} \triangleq$ time for v_O to swing from 10% to 90% of V_m.

$$t_R = \tau \left[\ln(0.9) - \ln(0.1)\right] = \boxed{\frac{0.35}{f_t} = t_R} \quad [sec]$$

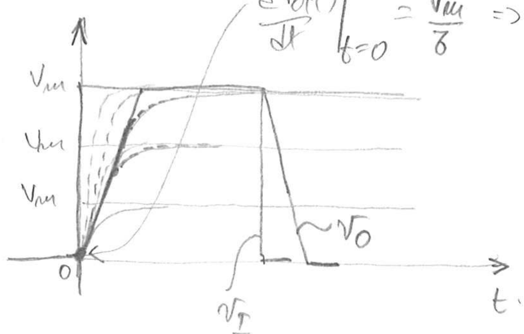
The higher f_t, the lower t_R!

Example: $\mu A741$ $t_R \cong 350\,ns$.

b) Slew rate

Slew rate: "a measure of how fast the output can change"

$$\left.\frac{dv_O(t)}{dt}\right|_{t=0} = \frac{V_m}{\tau} \Rightarrow$$ slope is proportional to V_m.



The rate at which v_O slew saturates to a constant value for increasing values of V_m!

That value is called $\boxed{\text{slew rate}} \triangleq \boxed{SR}$ $[V/\mu sec]$.

Ex: $\mu A741$ $SR = 0.5 \frac{V}{\mu s}$

- SR is due to the limited current capabilities of charging / discharging $\boxed{C_c}$ mainly.
  ↑ gives a tradeoff between fast response and dominant-pole model/stability

- Critical V_{om} output-step magnitude corresponding to the onset of slew-rate limiting is such that:

$$\frac{V_{om(crit)}}{\tau} = SR. \Rightarrow \boxed{V_{om(crit)} = \frac{SR}{2\pi f_t}}$$

Example: $V_{om(crit)} = 80mV$ for $\mu A741$

ⓒ Full-power bandwidth

SR-limiting => output signal is distorted.

For a sin signal at input => $v_0 = V_{om} \cdot \sin 2\pi f t$

$$\frac{dv_0}{dt} = 2\pi f \cdot V_{om} \cdot \cos 2\pi f t \Big|_{max} = 2\pi f V_{om}$$

We need: $\left(\frac{dv_0}{dt}\right)_{max} \leq SR \iff 2\pi f V_{om} \leq SR$

$$\boxed{f V_{om} \leq \frac{SR}{2\pi}}$$ in order not to have distorsions!

trade-off between amplitude and frequency!

Definition: FPB (full-power bandwidth) = maximum frequency at which the OpAmp will yield undistorted signal at the largest possible amplitude!

$$\boxed{FPB \triangleq \frac{SR}{2\pi V_{sat}}}$$

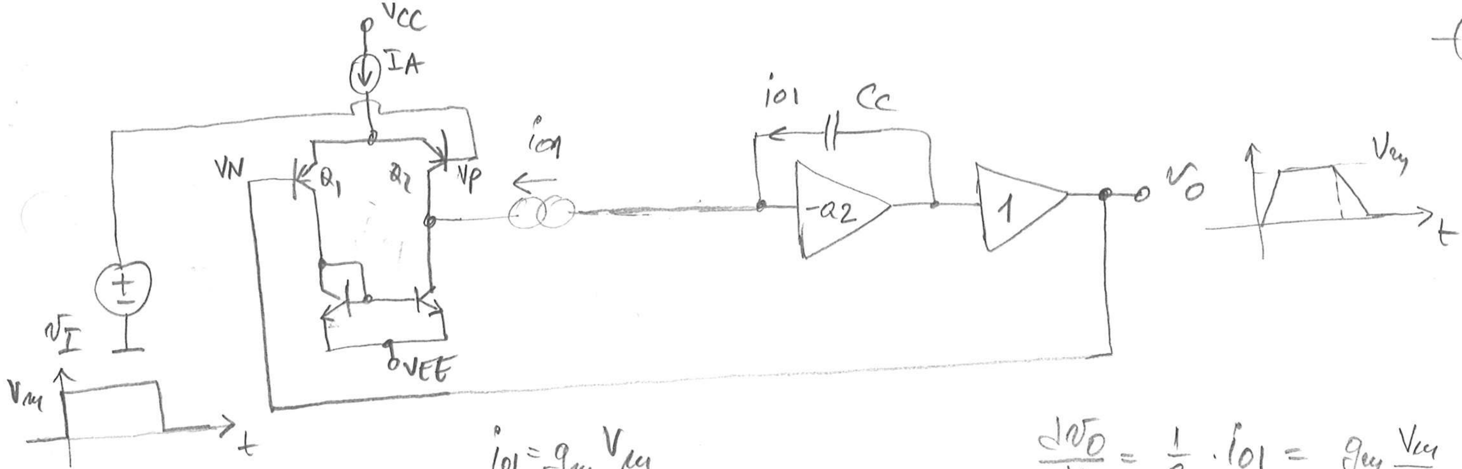
Ex: $\mu A741$

$V_{sat} = 13V$
$SR = 0.5 \frac{V}{\mu s}$ => FPB = 6.1kHz.

ⓓ The settling time $\boxed{t_s}$

Exercise!

ⓔ SR-limiting: Causes & Cures → see next page!



$i_{o1} = g_m V_{in}$

$$\frac{dv_O}{dt} = \frac{1}{C_c} \cdot i_{o1} = g_m \frac{V_{in}}{C_c}$$

(1) – Low V_{in} => $\frac{dv_O}{dt} = \frac{1}{C_c} i_{o1} = g_m \frac{V_{in}}{C_c}$

(2) – If we overdrive input => Q_1 or Q_2 will saturate and conduct I_A

=> capacitor C_c will become current starved and

$$\left(\frac{dv_O}{dt}\right)_{max} = \boxed{\frac{I_A}{C_c} = SR} \; !$$

In previous lecture we had found (see eq. 6.8) that:

$$f_t = \frac{g_{m1}}{2\pi C_c} = \frac{I_A}{8\pi V_T \cdot C_c} \Rightarrow C_c = \frac{I_A}{8\pi V_T f_t} = \boxed{\frac{g_{m1}}{2\pi f_t}}$$

$$\Rightarrow \boxed{SR = \frac{2\pi I_A \cdot f_t}{g_{m1}}}$$ tells us how to improve SR!.

ⓐ increase f_t

ⓑ decrease g_{m1}

ⓒ increase I_A.