SLEW RATE

OPERATIONAL AMPLIFIER DYNAMIC LIMITATIONS

INEL 5207 - SPRING 2008 - M.TOLEDO

TRANSIENT RESPONSE

- FOLLOWER (NON-INVERTING WITH UNITY GAIN)
  - FREQUENCY RESPONSE

$$A = \frac{1}{1 + j\frac{1}{f_t}}$$

  - STEP RESPONSE

$$v_O = V_m\left(1 - \exp\left(-t/\tau\right)\right) \qquad \tau = \frac{1}{2\pi f_t}$$

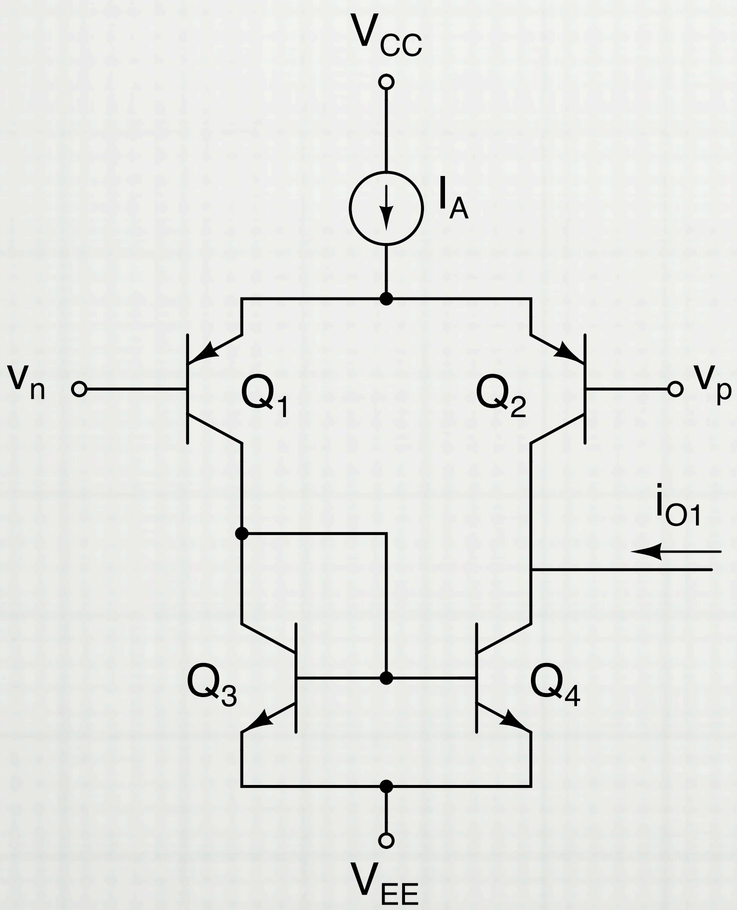
  - RISE TIME (TIME TO GO FROM 10% TO 90% OF V_M)

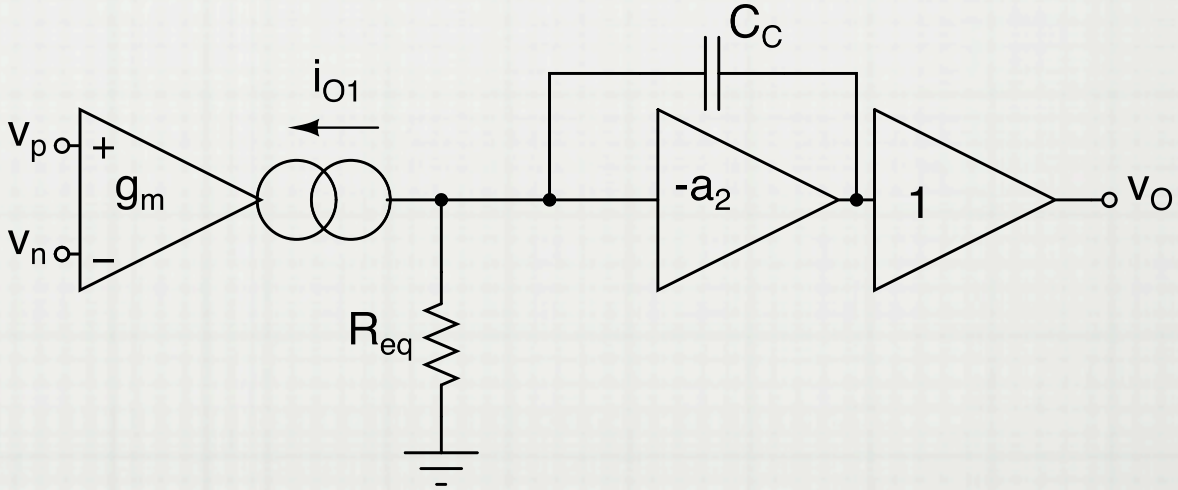
$$t_r = \frac{0.35}{f_t}$$

CURRENT STARVING

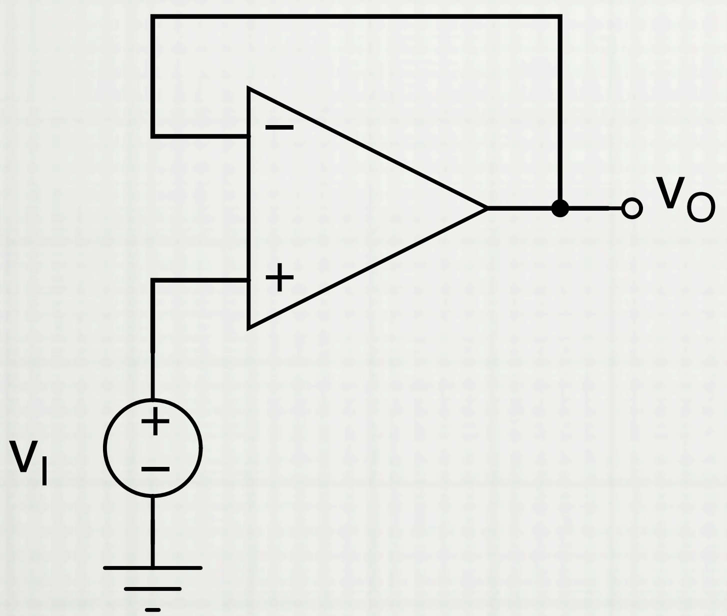
i_{O1} is limited to $\pm I_A$. Output can not change faster than

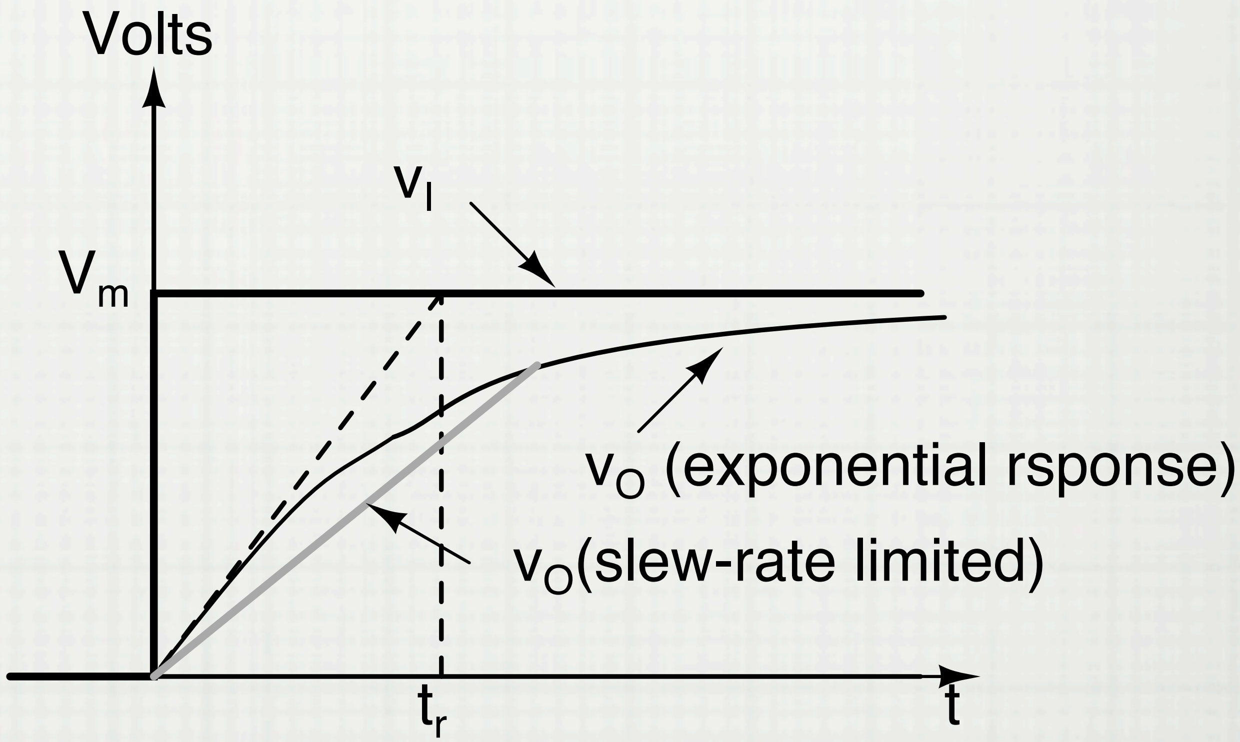
$$SR = \frac{I_A}{C_C}$$



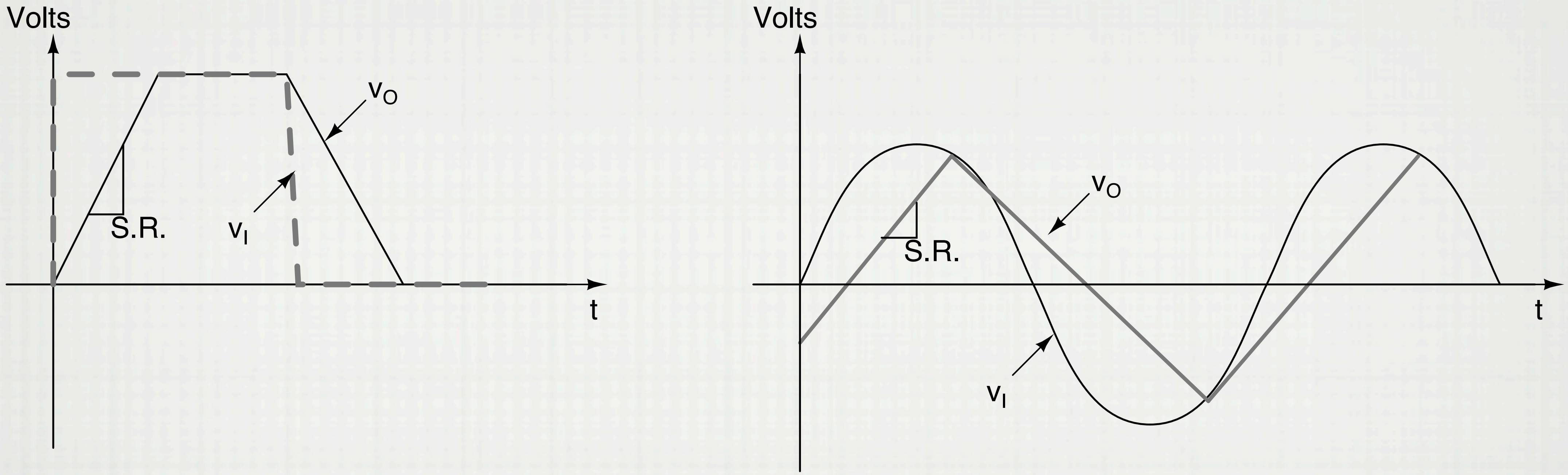


EXPONENTIAL & SLEW-RATE LIMITED STEP RESPONSE





HIGHER-ORDER POLES WOULD INTRODUCE "RINGING" - I.E. SMALL OSCILLATIONS ON RESPONSE



- Expected output: $v_{O,expected} = Av_I$
- If $\boxed{\frac{dv_{O,expected}}{dt} > S.R.}$ then $\boxed{\frac{dv_O}{dt} = S.R.}$
- If $\boxed{\frac{dv_{O,expected}}{dt} \leq S.R.}$ then the response is exponential.

For an input step, the critical output size $V_{om,crit}$ beyond which the output becomes slew-rate limited, is

$$\begin{aligned} v_{O,expected} &= V_{om}\left(1 - \exp\left(-1/\tau\right)\right) \\ \frac{dv_{O,max}}{dt} &= \frac{V_{om(crit)}}{\tau} = S.R. \\ V_{om(crit)} &= \tau \times S.R. = \boxed{\frac{S.R.}{2\pi f_B}} \end{aligned}$$

where $\boxed{\tau = \frac{1}{2\pi f_B}}$, f_B is the closed-loop bandwidth i.e.

- $f_B = f_t$ for unity gain,
- $f_B = \beta f_t$ for non-unity gain, where β is the non-inverting amplifier feedback factor.
- $V_{om} = \mid A \mid \times V_{im}$ where V_{im} is the size of the input step and A is the (inverting or non-inverting) amplifier gain

When the input is a step and $V_{om} > V_{om(crit)}$,

- initially v_O changes linearly

$$v_O(t) = SR \times t \;\; \forall \;\; t < t_1$$

- for $t > t_1$ where t_1 is defined by

$$V_{om} - v_O(t_1) < V_{om(crit)}$$

the output changes back to a linear response and.

$$V_O(t) = V_{om} - (V_{om} - v_O(t_1)) \exp^{-(t-t_1)/\tau}$$

For an input sinusoid,

- non-slew-rate limited output signal $v_O = V_{om} \sin 2\pi f t$
- v_O rate of change would be $\frac{dv_O}{dt} = 2\pi f V_{om} cos 2\pi f t$
- maximum rate of change is at $t = 0$, $\left(\frac{dv_O}{dt}\right)_{max} = 2\pi f V_{om}$
- thus for $V_{om} = V_{om,crit}$ beyond which the output becomes slew-rate limited,

$$2\pi f V_{om,crit} = S.R.$$

or

$$\boxed{V_{om(crit)} = \frac{S.R.}{2\pi f}}$$

- observe that $V_{om} =\mid A \mid \times V_{im}$ where V_{im} is the size of the input sinusoid and A is the (inverting or non-inverting) amplifier gain

Given desired V_{om} we find the maximum frequency of sinusoid with undistorted output:

$$f_{max} = \frac{SR}{2\pi V_{om}}$$

Full-power bandwidth (FPB): maximum frequency at which the opamp will yield an undistorted sinusoidal output with the largest possible amplitude. Assuming saturation at $\pm V_{sat}$,

$$FPB = \frac{SR}{2\pi V_{sat}}$$