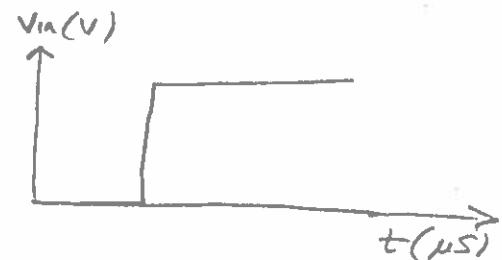
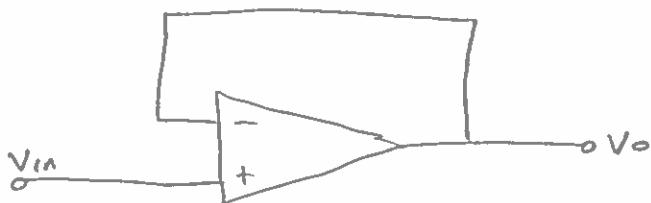


## I. Slew Rate

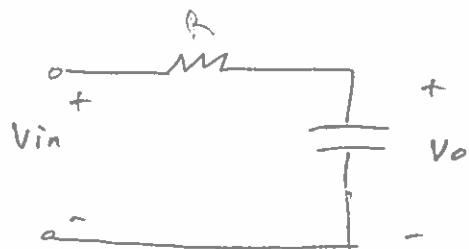
$$\text{Slew Rate (SR)} = \frac{dV_o}{dt}_{\max}$$



What is physical origin of slew rate and how is this different than bandwidth?

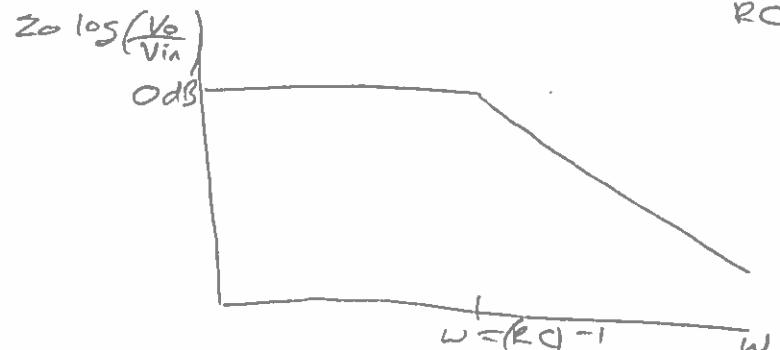


To answer this we need knowledge of internal transistor function and so we cannot directly address this question right now. Instead consider a simple RC circuit.



$$V_o = V_{in} \frac{\frac{1}{j\omega C}}{\frac{1}{j\omega C} + R}$$

$$\frac{V_o}{V_{in}} = \frac{1}{1 + j\omega CR} = \frac{1}{1 + j\omega \frac{RC}{1}}$$



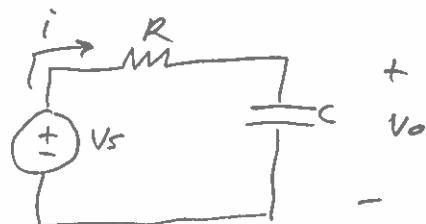
$$\text{Bandwidth } \omega = (RC)^{-1}$$

In Time-domain what is voltage across the capacitor ( $v_o$ )?

$$i = C \frac{dv_o}{dt}$$

$$\frac{dv_o}{dt} = \frac{i}{C}$$

$\parallel$   
Slew Rate



In a real circuit, the voltage source ( $V_s$ ) will be limited in how much current it can supply and this will limit the slew rate.

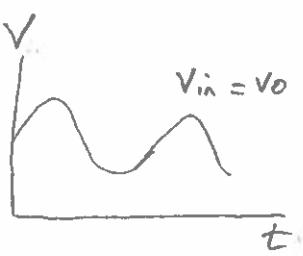
$$SR = \frac{dV_o}{dt}_{\text{max}} = \frac{i_{\text{max}}}{C}$$

$$\text{For } V_s = V_0 \cos(\omega t)$$

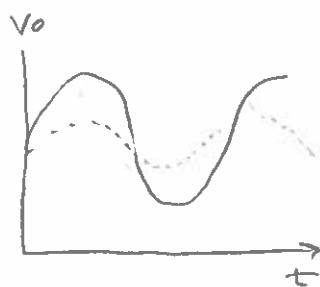
$$\frac{dV_s}{dt} = V_0 \omega \cos(\omega t) \quad \text{max slope} = V_0 \omega$$

$$\text{if } \begin{cases} V_0 \omega > i_{\text{max}}/C & (\text{SR limited}) \\ V_0 \omega < i_{\text{max}}/C & (\text{BW limited}) \end{cases}$$

Scenario #1  
 $\omega \ll (RC)^{-1}$   
 $V_0 \omega \ll i_{\text{max}}/C$

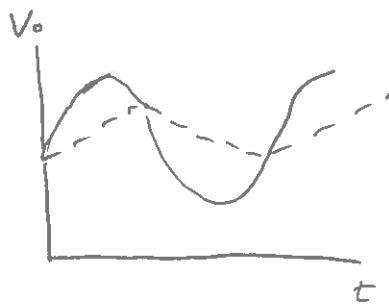


Scenario #2  
 $\omega \gg (RC)^{-1}$   
 $V_0 \omega \gg i_{\text{max}}/C$

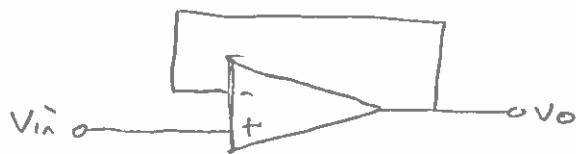


(ignoring phase shift)

Scenario #3  
 $\omega \ll (RC)^{-1}$   
 $V_0 \omega \gg i_{\text{max}}/C$



## II. Slew Rate example #1



Question

$$SR = 40 \text{ v}/\mu\text{s}$$

What is highest frequency in which a 20 volt peak-to-peak sinusoid can be produced at output?

Answer

$$V_o = 10 \sin(2\pi f t)$$

$$\left. \frac{dV_o}{dt} \right|_{max} = 10 (2\pi f)$$

$$SR = 40 \text{ v}/\mu\text{s} = 10 (2\pi f_{max}) / 1 \times 10^6$$

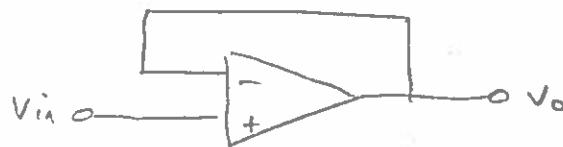
$$f_{max} = \frac{40}{2\pi} \times 10^6$$

$$f_{max} = 637 \text{ kHz}$$

### III. Slow Rate Example #2

#### Full-power Bandwidth ( $f_M$ )

The frequency at which an output sinusoid with amplitude equal to the rated output voltage max begins to show distortion due to slew-rate limiting.



$$V_{in} = V_{o,\max} \sin \omega_m t$$

$$SR = \frac{dV_{in}}{dt}_{\text{max}} = V_{o,\max} \omega \cos \omega_m t$$

$$\text{Max slope} = V_{o,\max} \omega_m$$

Then,

$$SR = V_{o,\max} \omega_m$$

$$SR = V_{o,\max} 2\pi f_m$$

$$f_m = \frac{SR}{2\pi V_{o,\max}}$$

We need to buffer a 500 kHz sinusoid with 10 V<sub>p-p</sub> amplitude which op-amp will work without distorting output signal

#### Op-Amp #1

$$f_{3dB} = 250 \text{ kHz}$$

$$SR = 1000 \text{ V}/\mu\text{s}$$

$$V_{o,\max} = 20 \text{ V}$$

No,  $f_{3dB}$  too low!

#### Op-Amp #2

$$f_{3dB} = 600 \text{ kHz}$$

$$SR = 1 \text{ V}/\mu\text{s}$$

$$V_{o,\max} = 10 \text{ V}$$

$$f_m = \frac{1 \times 10^6}{2\pi(10)} = 16 \text{ kHz}$$

No!

#### Op-Amp #3

$$f_{3dB} = 600 \text{ kHz}$$

$$f_M = 400 \text{ kHz}$$

$$V_{o,\max} = 20 \text{ V}$$

$$400 \text{ kHz} = \frac{SR}{2\pi(20)}$$

$$SR = 50 \text{ V}/\mu\text{s}$$

$$WV_{p-p} = 31 \text{ V}/\mu\text{s}$$

$$V_{o,\max} = 20 \text{ V}$$

#### Op-Amp #4

$$f_{3dB} = 10 \text{ MHz}$$

$$SR = 1000 \text{ V}/\mu\text{s}$$

$$V_{o,\max} = 20 \text{ V}$$

Yes!

But probably expensive.

Op-Amp #3  
a better choice.