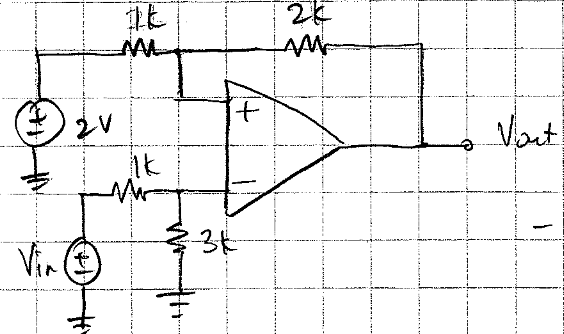
Review Problems

(±5 V supplies)

Example:

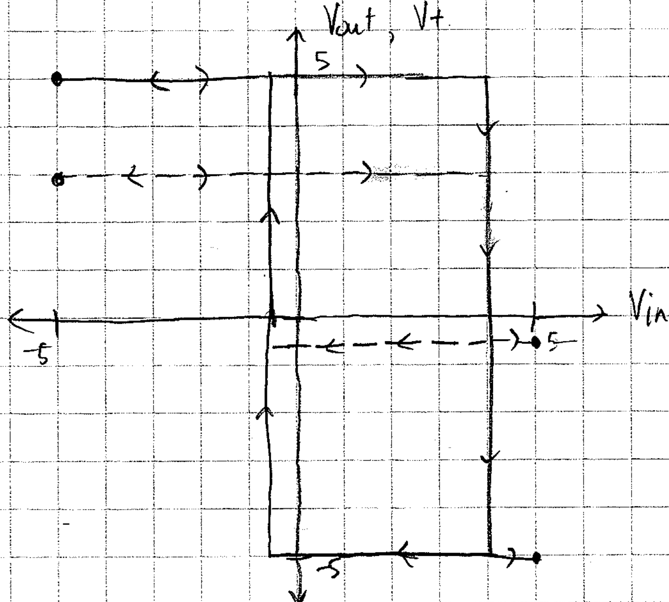


(a) Plot VTC for Vout vs. Vin and V+ vs. Vin.

- start at $V_{in} = -5\,V \rightarrow V_- = -3.75\,V$

$\rightarrow V_{out} = 5\,V$

$\rightarrow V_+ = 2 + (5-2)\frac{1}{1+2} = 3\,V$



→ Switches when $V_+ = V_-$

$\therefore 3 = V_{in} \cdot \frac{3}{4}$

$\Rightarrow V_{in} = 4\,V$

- then $V_{out} = -5\,V$, $V_+ = 2 - (5+2)\frac{1}{1+2}$

$= -0.33\,V$

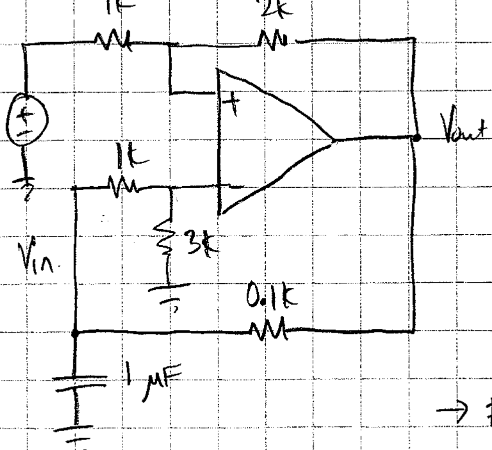
→ Now head back in other direction

- Switches when $V_+ = V_-$

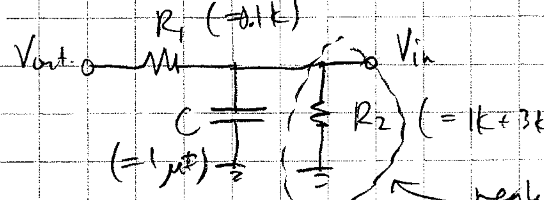
$-0.33 = V_{in} \cdot \frac{3}{4}$

$\Rightarrow V_{in} = -0.44\,V$

(b) Extra R & C are added, what is the freq. of oscillation?



- After output switches, Vin charges through R-C network:



neglect this for simplicity

→ Find $\frac{V_{in}}{V_{out}} = \frac{1/sC}{R_1 + 1/sC}$

$= \frac{1}{1 + sR_1C}$

$$= \frac{1/R_1C}{1/R_1C + s} = H(s)$$

→ Let $V_{out}(t) = u(t)$ (step)

$\therefore V_{out}(s) = \frac{1}{s}$

$\rightarrow V_{in}(s) = \frac{1}{s} \cdot H(s)$

Inverse Laplace transform: $\frac{\alpha}{s(s+\alpha)} \Longleftrightarrow (1 - e^{-\alpha t})\,u(t)$

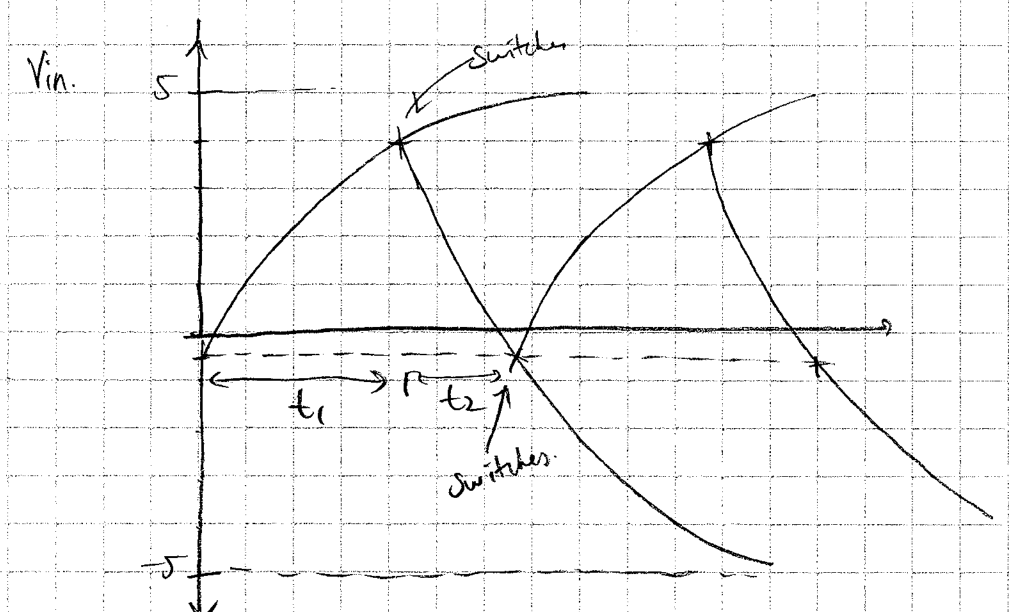
$\Rightarrow$ So, $V_{in}(t) = (1 - e^{-\alpha t})\,u(t)$ where $\alpha = \frac{1}{R_1 C}$

$= \frac{1}{100 \cdot 1E\text{-}6}$

$= 1E4.$

→ Let's plot output, assuming V_{in} starts at -0.44

- V_{out} switches to 5 V.



→ Calculate t_1, t_2: t_1: $V_{in} = -0.44 + 5.44(1 - e^{-\alpha t}) = 4$

$1 - e^{-\alpha t} = \frac{4.44}{5.44}$

$e^{-\alpha t} = 0.18$

$-\alpha t = \ln(0.18)$

$t = \frac{\ln(0.18)}{-1E4} = 1.71E\text{-}4$

t_2: $V_{in} = 4 - 9(1 - e^{-\alpha t}) = -0.44.$

$$1 - e^{-\alpha t} = \frac{4.44}{9}$$

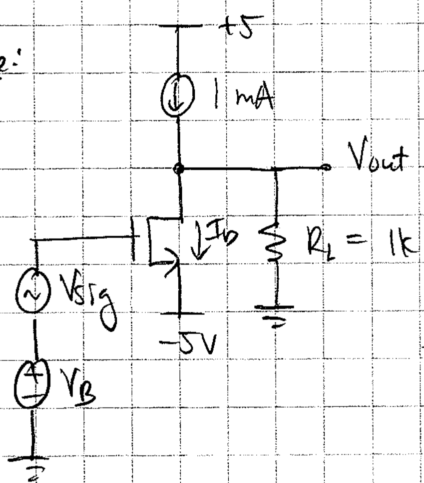
$$e^{-\alpha t} = 0.507$$

$$-\alpha t = \ln(0.507)$$

$$t = \frac{\ln(0.507)}{-1E4} = 6.79E-5$$

$$\Rightarrow f_{req} = \frac{1}{T_R} = \frac{1}{t_1 + t_2} = \frac{1}{1.71E-4 + 6.79E-5} = 4186 \text{ Hz}.$$

Next Example:



- $V_t = 1V$, $\mu_n C_{ox} \frac{W}{L} = 2E-3$

(a) Choose V_B to get $V_{out} = 0$ V for $V_{sig} = 0$.

- need $I_D = 1 \text{ mA} = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_t)^2$

$$1E-3 = 1E-3 \cdot (V_{GS} - V_t)^2$$

$$V_{GS} - V_t = 1 \text{ V}$$

$$V_{GS} = 2 \text{ V}.$$

$\rightarrow$ Need $V_B = -3$ V.

(b) For $V_{sig} = 0.7 \cdot \sin(\omega t)$, find min. & max of V_{out}.

- V_{GS} varies from 1.3 V to 2.7 V.

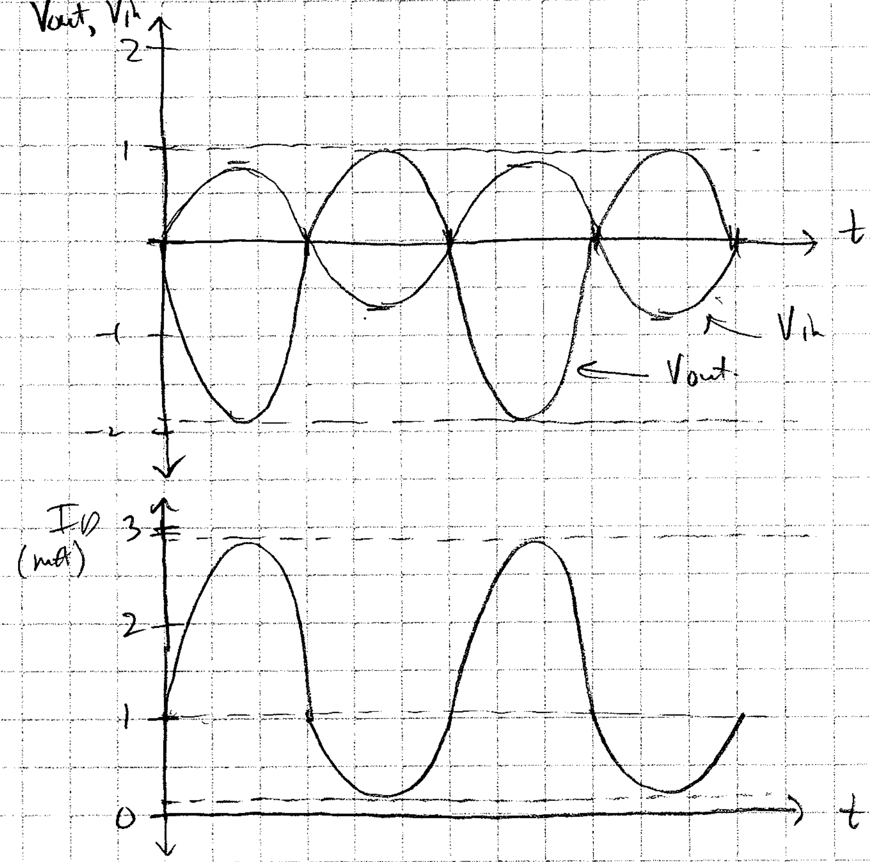
$\rightarrow$ $V_{GS} = 1.3$ V: $I_D = 1E-3(0.3)^2 = 0.09$ mA.

$\rightarrow$ $V_{out} = (1 \text{ mA} - 0.09 \text{ mA}) 1k = 0.91$ V.

$\rightarrow$ $V_{GS} = 2.7$ V: $I_D = 1E-3(1.7)^2 = 2.89$ mA

$\rightarrow$ $V_{out} = (1 \text{ mA} - 2.89 \text{ mA}) \cdot 1k = -1.89$ V.

(c) Plot V_{in}, V_{out}, I_D



(d) Calculate efficiency → Power from supplies:

- positive supply: $P = I \cdot V = 1\,mA \cdot 5\,V = 5\,mW$
- negative supply: Avg. current $\approx \left(\frac{2.89 + 0.09}{2}\right) = 1.49\,mA$

$P = I_{avg} V = 1.49\,mA \cdot 5\,V = 7.45\,mW$.

→ Power to Load: $P = \frac{V_{rms}^2}{R} = \left[\frac{(0.91)^2}{2 \cdot 1E3} + \frac{(1.89)^2}{2 \cdot 1E3}\right] \cdot 0.5$

$= 1.1\,mW$

→ Efficiency $\eta = \frac{1.1}{7.45} = 14.8\,\%$

(e) Why so much distortion?

C.S. small signal: $A_v = g_m \cdot R_L$ depends on g_m

C.D. small signal: $A_v = \frac{g_m \cdot R_L}{1 + g_m \cdot R_L} \approx 1$

doesn't depend on g_m