Today – More op-amp circuits

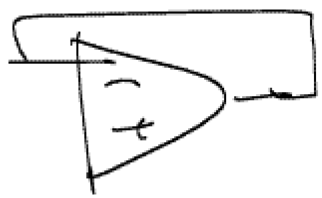
Administrivia ⟹ My office hours today are
5:00 – 9:00 (not 5:00 – 7:00)
[in 277 Cory]

Today → (1) Finish driving point characteristics of
nonlinear oscillator
[For details, look at EE100 webpage for Summer 06,
you can get to it from the EE100 homepage
↳ Click on EE100 Fall Homepage & then again
click EE100 Summer Homepage. look under lecture notes]

(2) More op-amp circuit examples

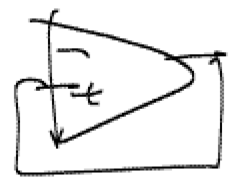
[hold off on the mathematical explanation of feedback]

Negative feedback



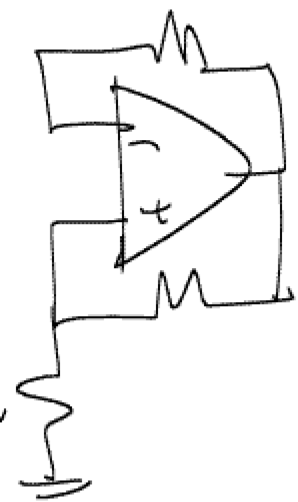
Amplifiers

positive feedback

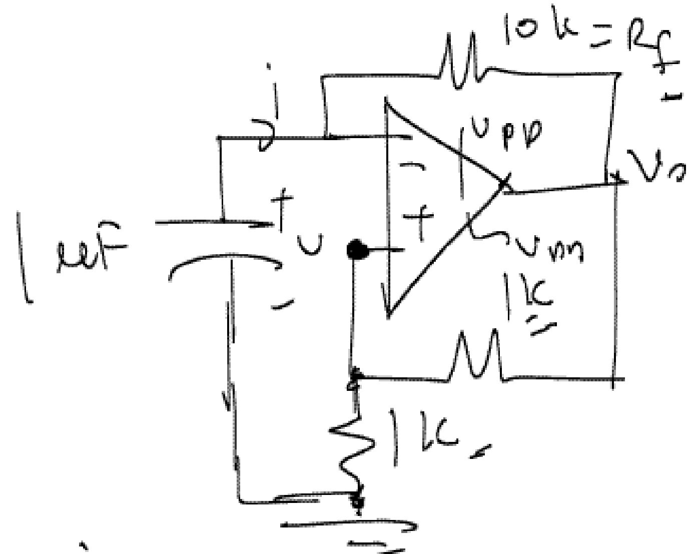


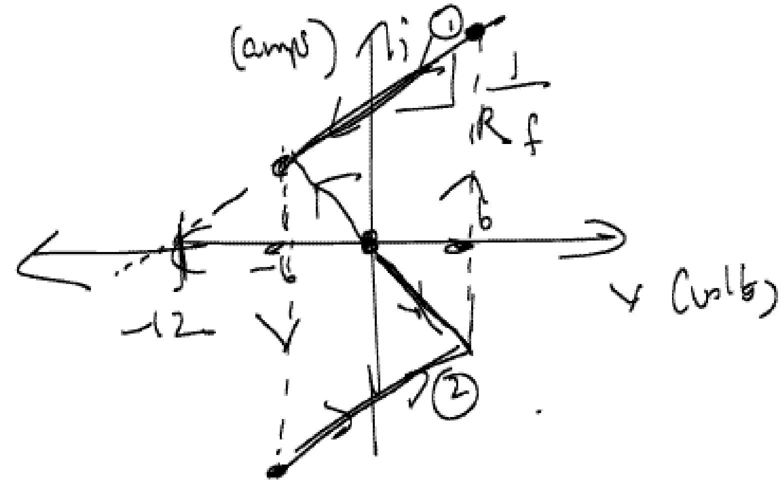
Oscillators

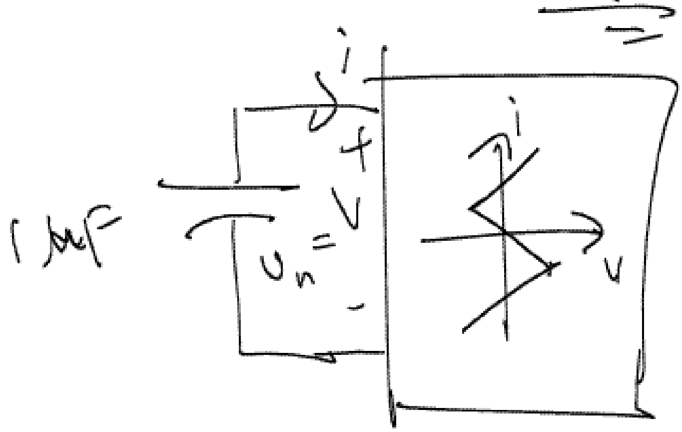
Both



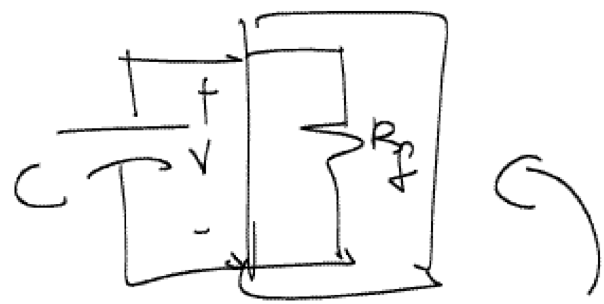
Recall:







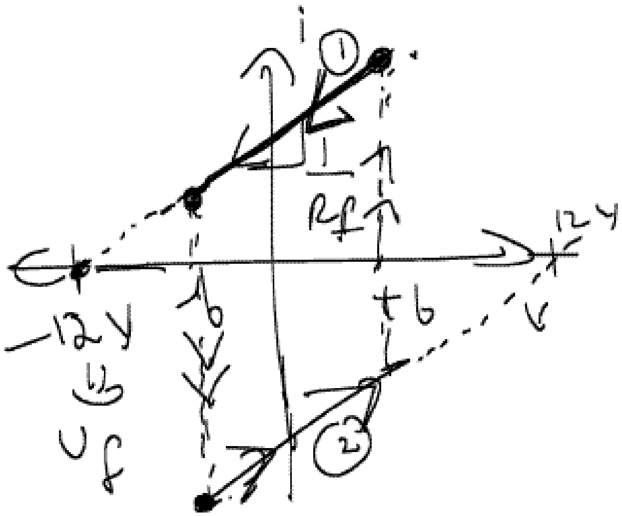
Region (1)



RC Circuit

$$v(t) = v_f + (v_i - v_f)\, e^{-t/R_f C}$$

(Important)



$v_i = 6$ V

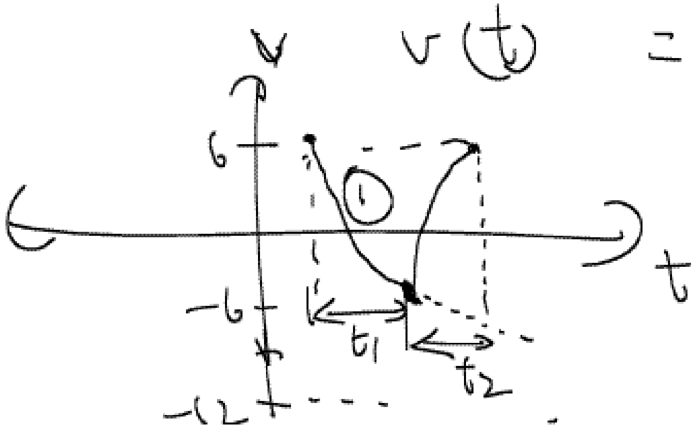
$v_f \triangleq$ capacitor is fully charged

$\Rightarrow i = 0 \Rightarrow -12$ V

$R_f = 10$ k, $C = 1$ uF

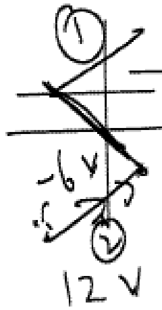
$$\therefore \underset{[\text{Region } ①]}{v(t)} = -12 + (6 - [-12])e^{-t/10ms}$$

$$v(t) = -12 + 18e^{-t/10ms}$$



$\therefore v(t_1) = -6$ V

$$\Rightarrow -12 + 18e^{-t_1/10ms} = -6$$



Region (1) & (2)
⇒ op-amp is saturated
⇒ $v_o = \pm 12\ V$

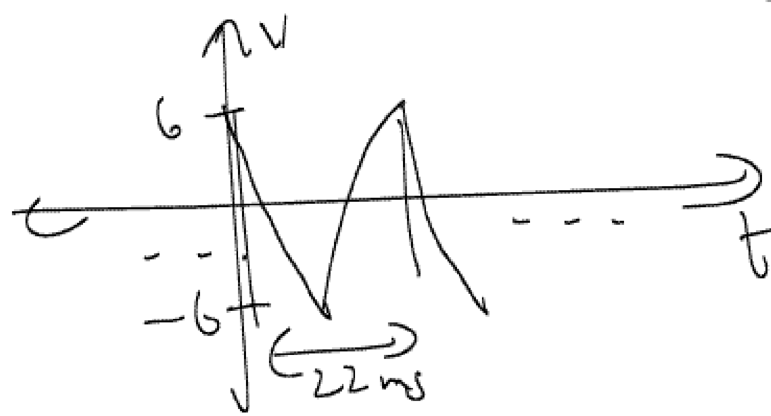
$$\Rightarrow \quad 18 e^{-t_1/10\,ms} = 6$$

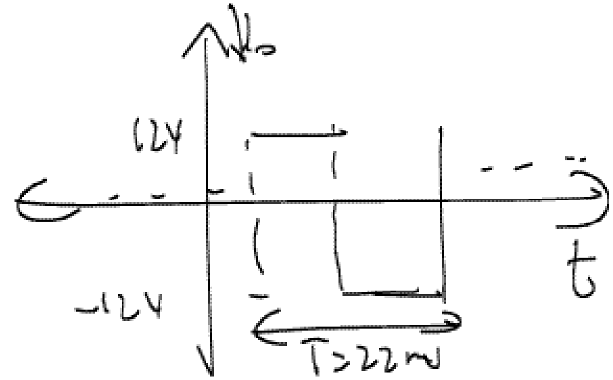
$$\Rightarrow \quad t_1 = -10\,ms \cdot \ln\left[\frac{6}{18}\right]$$

$$\Rightarrow \quad t_1 = 11\ ms$$

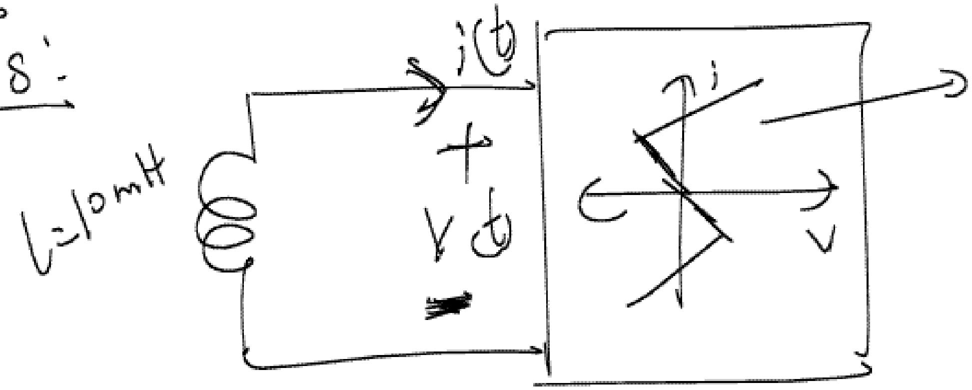
By symmetry, $t_2 = t_1 = 11\ ms$

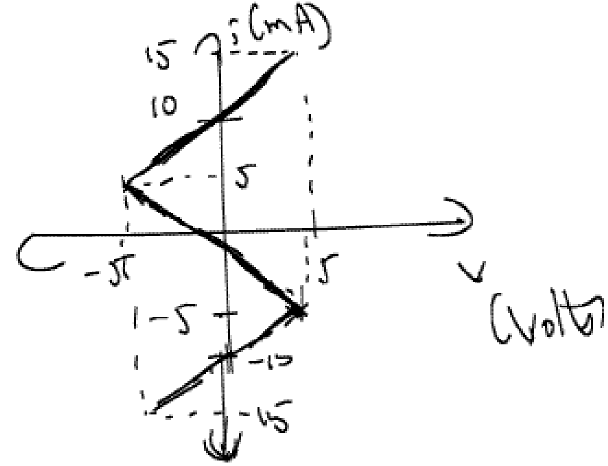
$T = 22\,ms \Rightarrow$ $\boxed{f = 45.45\ Hz}$





Eg:





(Q:) What happens?

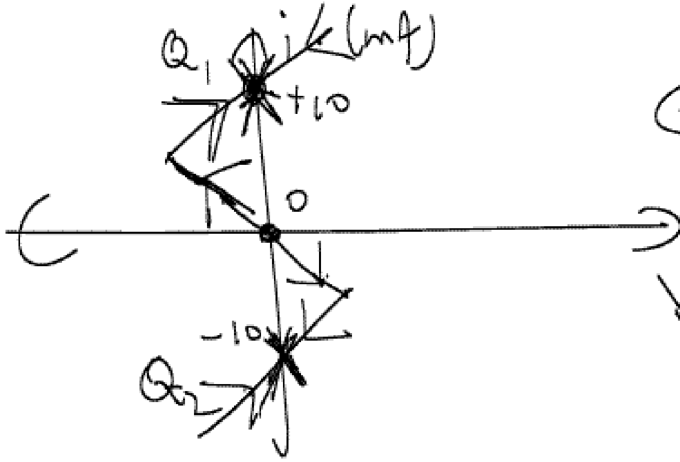
Start by writing i-v relationship:

$$v(t) = -L\frac{di}{dt}$$

eq. points

$$\frac{di}{dt} = 0 \Rightarrow -\frac{v}{L} = 0 \Rightarrow \boxed{v = 0}$$

stability



dynamic route

$v > 0$, $i' < 0$
$v < 0$, $i' > 0$
($C > 0$)

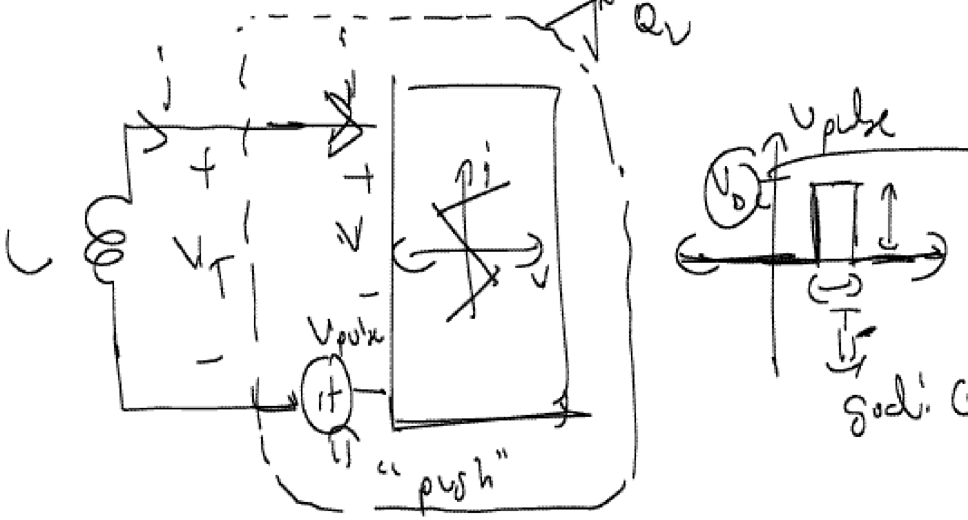
i. $(0, 10\text{ mA})$, $(0, -10\text{ mA})$] ⇒ stable equilibria

$(0, 0)$ ⇒ unstable equilibrium

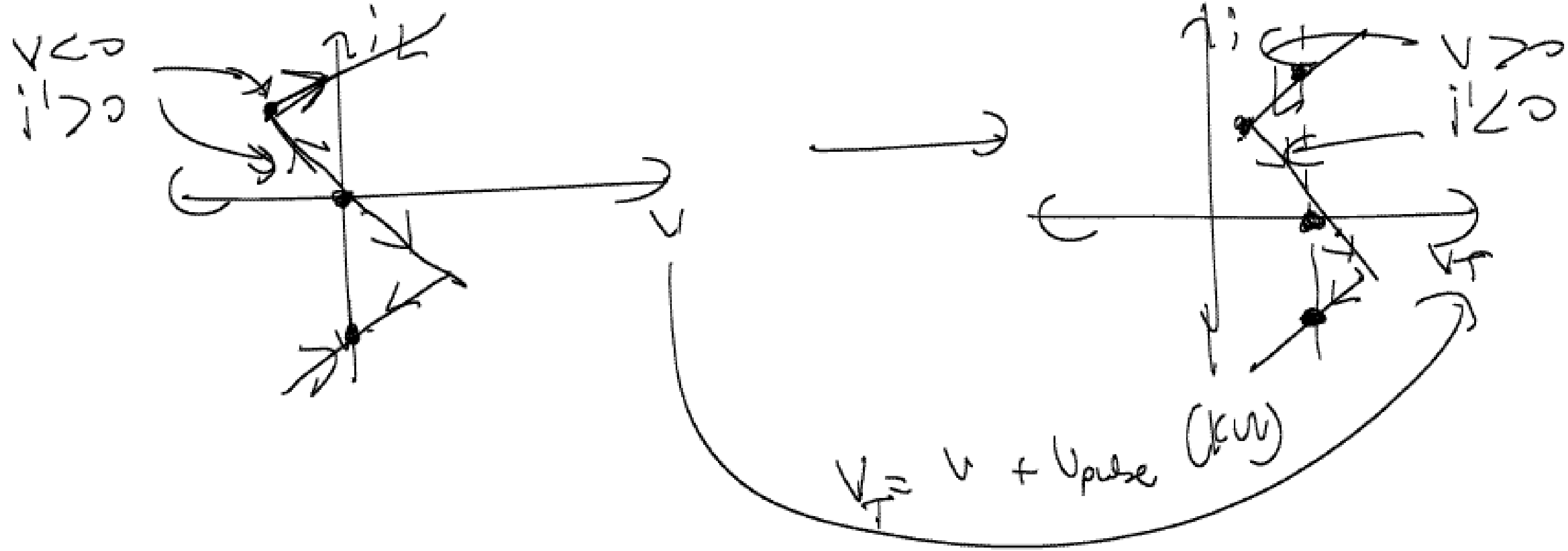
This circuit is useful as "memory" ⇒ two stable states → $(0, 10\text{ mA}) \Rightarrow$ "1"
$(0, -10\text{ mA}) \Rightarrow$ "0"] Basis of a computer memory [aka flip-flop]

(Natural question): How do I switch from Q_1 to Q_2?

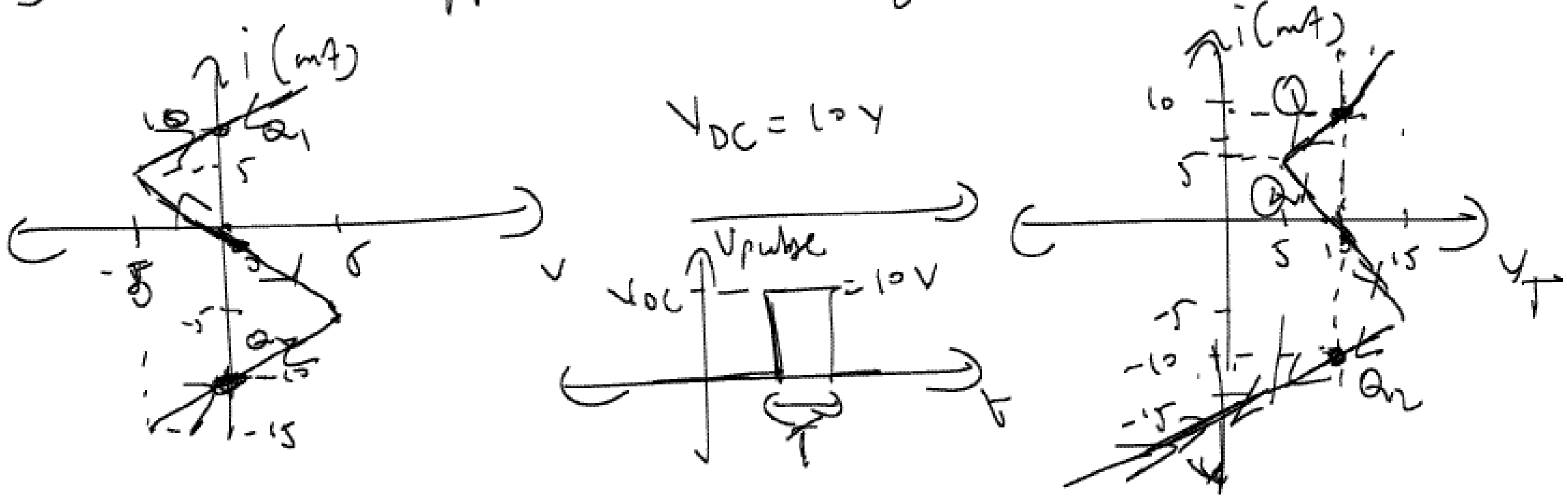
Analogy:



goal: calculate T and V_0



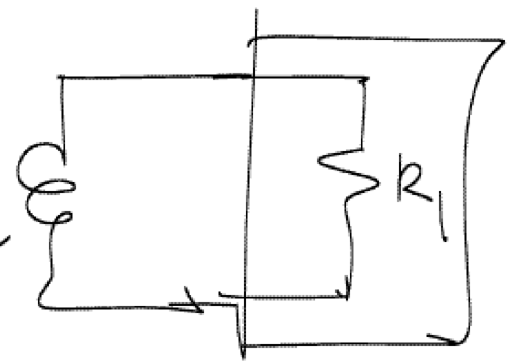
(Q:1) What happens if V_{DC} = 10 V

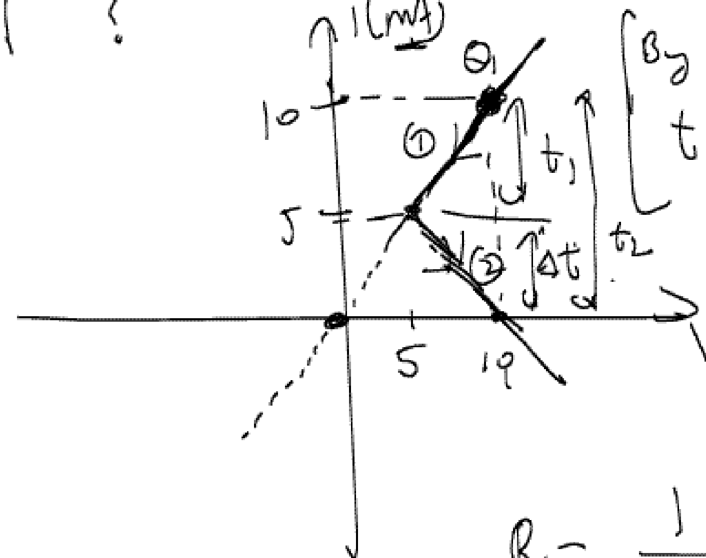


(Q:2) What is minimum T ?

Region ①:

10 mH = L





By symmetry $t_1 = \Delta t$

Inductor ⇒ use i(t)

⇓

Region ①: $i(t) = i_f + (i_i - i_f)\, e^{-t/(L/R_1)}$

$i_i = 10\text{ mA}$, $i_f = 0$

extrapolate to y-axis since V = 0 if inductor is fully charged.

$R_1 = \frac{1}{\Delta} = \frac{1}{\frac{5\text{mA}}{5\text{V}}} = 1\text{k}$

$$\therefore\ i_{Region1}(t) = 10\, e^{-t/10\,\mu s}\ mA$$

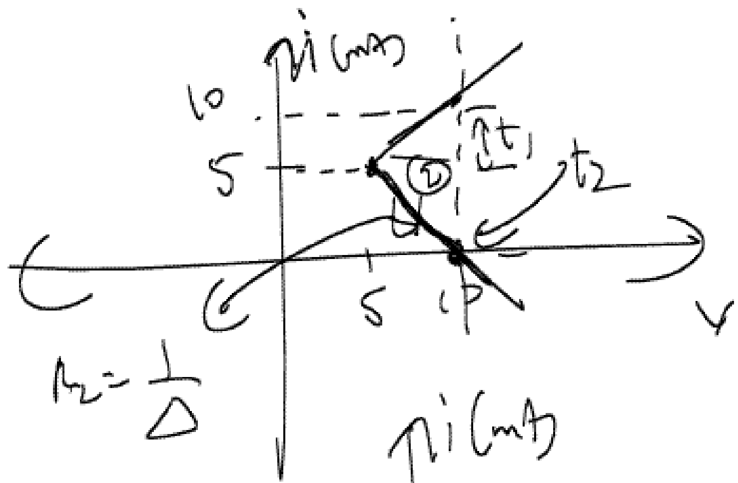
$$i_{Region1}(t_1) = 5\ mA$$

$$\Rightarrow\ 10\, e^{-t_1/10\,\mu s}\ \cancel{mA} = 5\ \cancel{mA}$$

$$\Rightarrow\ t_1 = \left[-\ln\left(\frac{5}{10}\right) \cdot 10\,\mu s\right]$$

$$= -\left[-0.69\right] \cdot 10\,\mu s = \underline{6.9\ \mu s}$$

Lets do region ②, little tricky because slope is negative!

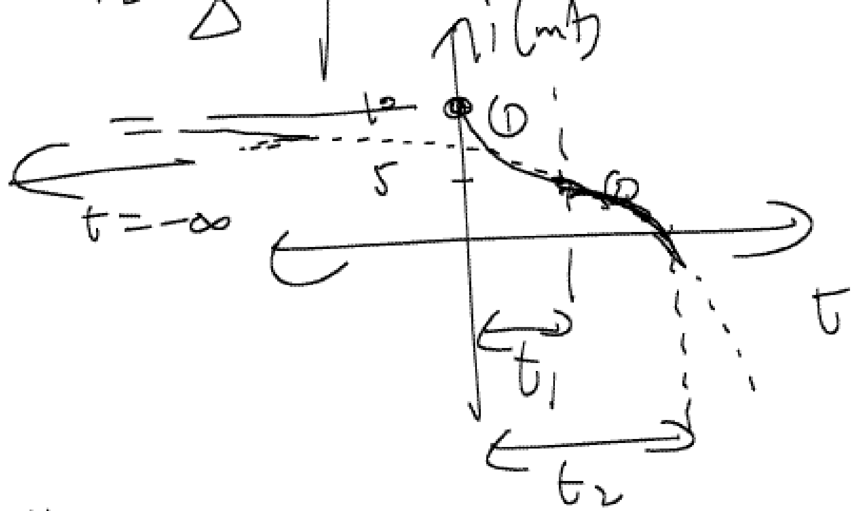


$R_2 = \frac{1}{\Delta}$

$$i_{Region ②}(t) = i_f + (i_i - i_f)e^{\frac{-(t-t_1)}{(L/R_2)}}$$

$i_i = 5$ mA

$R_2 = -1\,k\Omega$



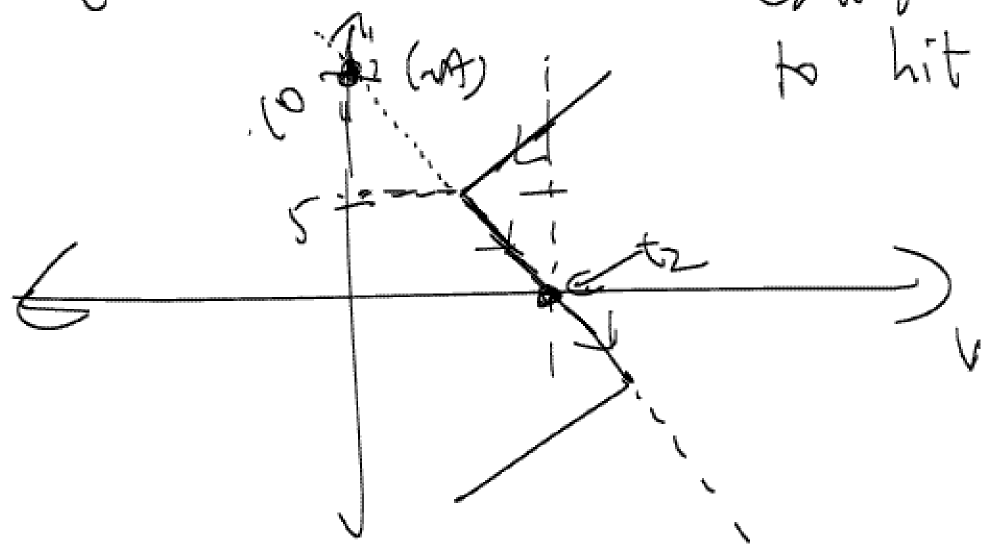
$$i_{Region ②}(t) = i_f + (i_i - i_f)e^{\frac{-(t-t_1)}{-10\,\mu s}}$$

$$= i_f + (i_i - i_f)e^{\frac{(t-t_1)}{10\,\mu s}}$$

Notice $i_f \neq \lim_{t\to\infty} i_{region ②}(t)$

"Trick" → But mathematically, $i_f = \lim_{t\to -\infty} i_{Region ②}(t)$

Physically: $t \to -\infty$ "means" extrapolate "backwards" to hit y-axis.



$i_f = 10$ mA

$$\therefore \quad i_{region ②}(t) = 10 + (5-10)e^{-\frac{(t-t_1)}{10\ \mu s}}$$

$$i_{region ②}(t_2) = 0$$

$$\Rightarrow \quad 10 - 5e^{\frac{(t_2 - t_1)}{10\,us}} = 0$$

$$\Rightarrow \quad 10 = 5e^{(t_2 - t_1)/10\,us}$$

$$\Rightarrow \quad (t_2 - t_1) = \boxed{10\,us \ln(2)}$$

$$t_2 = 6.9\,us + 6.9\,us$$

$$\boxed{t_2 = 13.8\,us}$$

$$\boxed{T > 13.8\,us}$$

Next time → More nonlinear op-amp example

→ Intro to diodes