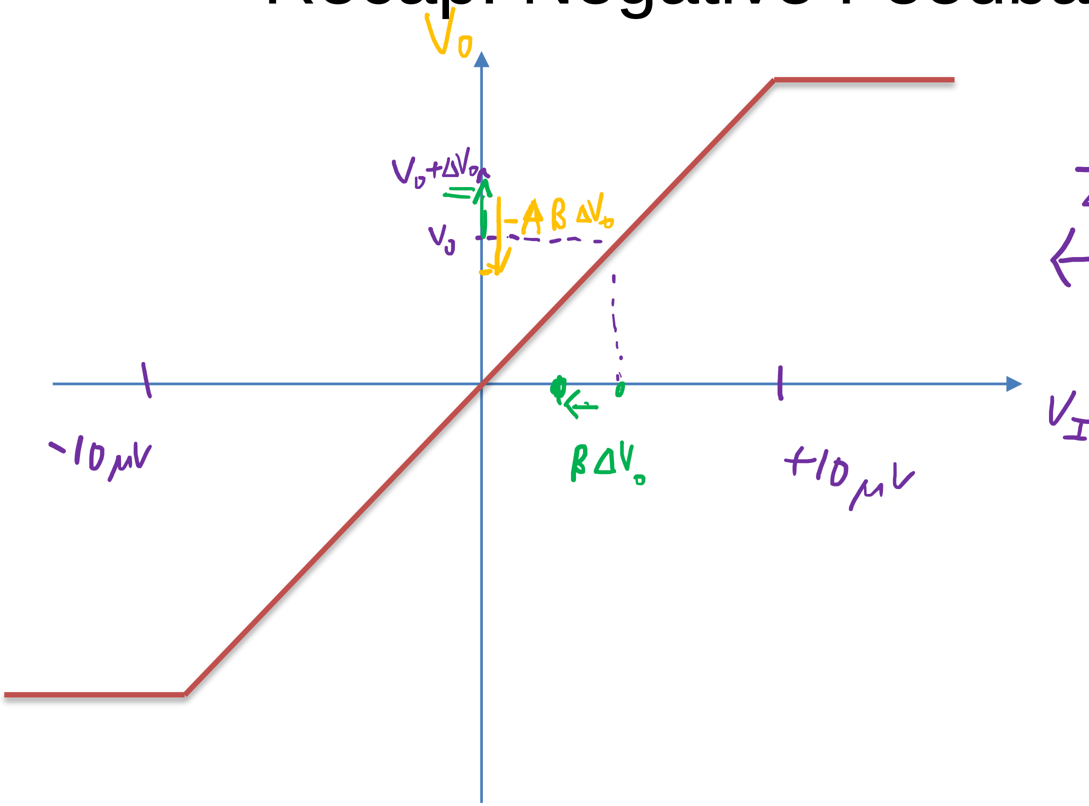
電子電工學
Lecture 9

Midterm Exam II info

Date: Nov 25, 2020 (Wed)
Time: 3:10 ~ 6:00 pm (in class)
Location: 化工系館柏林講堂/93156
Coverage: Textbook ~ Chapter 8

Recap: Negative Feedback



Zoom In

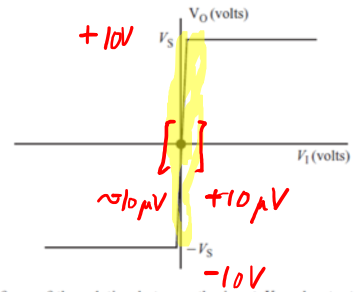


Figure 6.2 The form of the relation between the input V_I and output V_O voltages of an opamp

$V_I = V_+ - V_-$

Gain $\sim 10^5$

$V_o = A V_I$

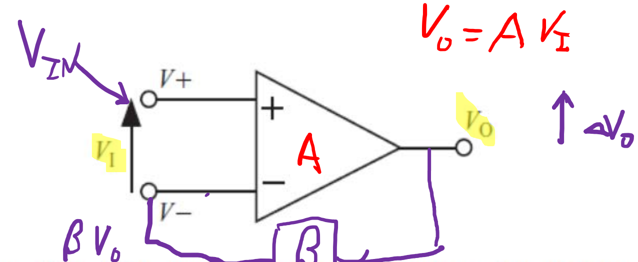


Figure 6.3 The conventional representation of an opamp

$\beta \Delta V_o$

$|\beta| < 1$

$$\begin{cases} V_I = V_{IN} - \beta V_o \\ V_o = A V_I \end{cases}$$

$$\Rightarrow V_o / V_{IN} = \frac{A}{1 + A\beta} \xrightarrow{A \to \infty} \frac{1}{\beta}$$

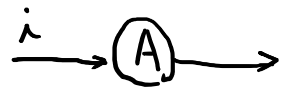
$\Rightarrow$ STABLE CIRCUIT

Example 7.3

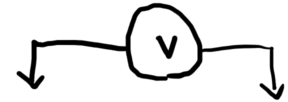
To measure upto 5 V

$R = ?$

Convert an Ammeter into a Voltmeter



$r_{in} \approx 0$



$r_{in} \to \infty$

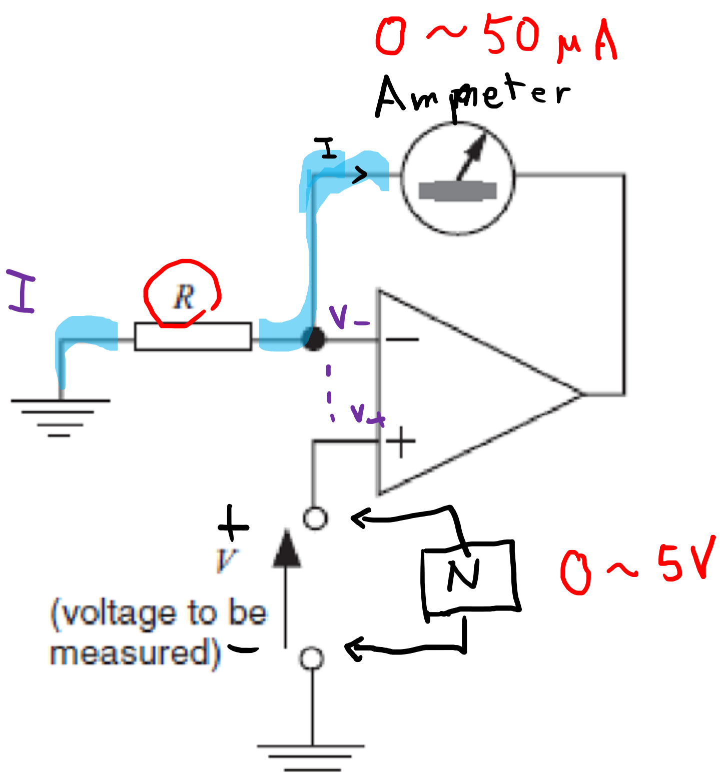


Figure 7.16 A high-input-resistance voltmeter

Negative Feedback

→ Virtual short Ckt

→ $V_- = V_+ = V$

→ $I = \dfrac{0 - V_-}{R} = -\dfrac{V}{R}$

I: 50 μA

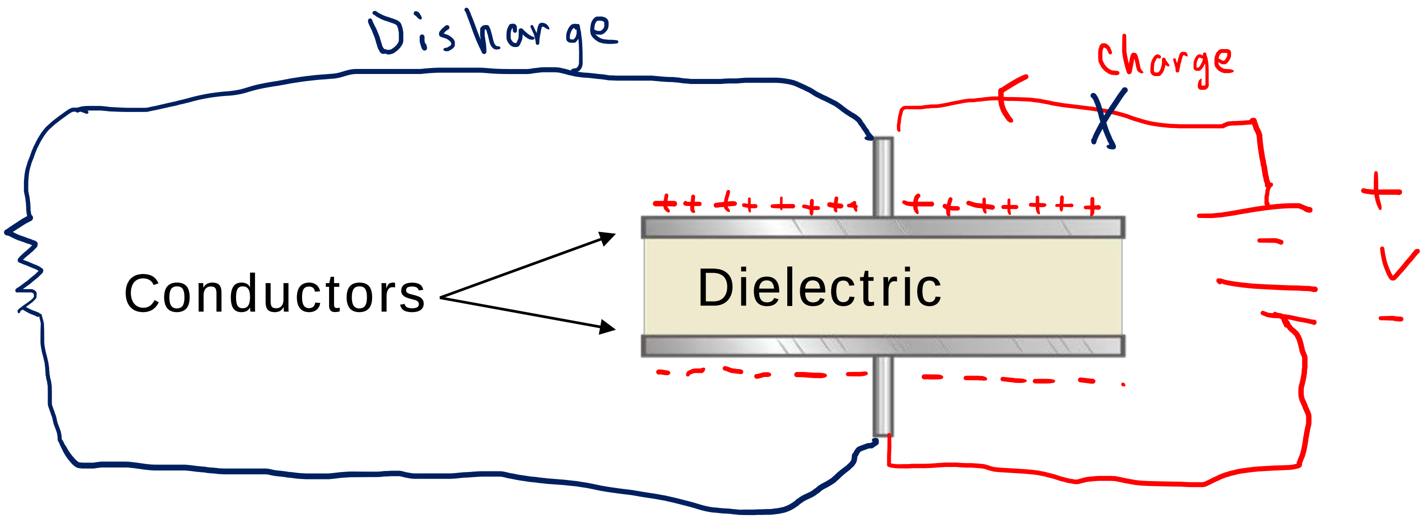
V: 5V

→ $R = \dfrac{5V}{50\,\mu A} = 100\ k\Omega$

Chapter 8

Mixed and Dynamic Opamp Circuits

Capacitor



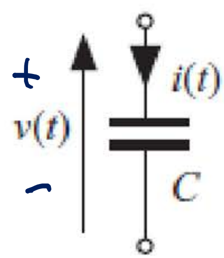


Figure 8.1 The symbol representing a capacitor. The constant C is its capacitance in farads

FIGURE 3.2 Some examples of practical capacitors.

Capacitor

Charge (Columb)

Capacitance $C = \dfrac{q(t)}{v(t)}$

(Farad)

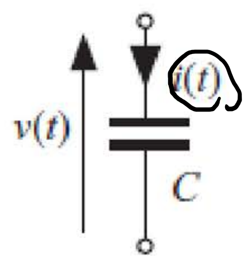
Votage (Volt)

$C = \dfrac{q(t)}{v(t)}$

$q(t) = i(t)\, t$

$q(t) = C \cdot v(t) \xrightarrow{d/dt} i(t) = C \cdot \frac{d}{d\tau} v(t)$

$v(t) = \frac{1}{C} \cdot q(t) \longrightarrow v(t) = \frac{1}{C} \int_{-\infty}^{t} i(\tau)\, d\tau$



$$\boxed{\begin{aligned} q(t) &= C \cdot V(t) \\ i(t) &= C \frac{d}{dt} V(t) \end{aligned}}$$

$V(t) = \frac{q(t)}{C}$

$= \frac{1}{C} \int_{-\infty}^{t} i(\tau) d\tau$

Figure 8.1 The symbol representing a capacitor. The constant C is its capacitance in farads

Capacitor

$$v(t) = \frac{1}{C}\int_{-\infty}^{t} i(\tau)\, d\tau$$

$$= \frac{1}{C}\left[\int_{-\infty}^{0} i(\tau)\, d\tau + \int_{0}^{t} i(\tau)\, d\tau\right]$$

$$= v(0) + \frac{1}{C}\int_{0}^{t} i(\tau)\, d\tau$$

Initial voltage of capacitor

$$v(t) = \frac{1}{C}\int_{-\infty}^{t} i(\tau)\, d\tau$$

$$= \frac{1}{C}\left[\int_{-\infty}^{0} i(\tau) d\tau + \int_{0}^{t} i(\tau)\, d\tau\right]$$

$$= v(0) + \frac{1}{C}\int_0^t i(\tau)\, d\tau$$

$$v(t) = v(0) + \frac{1}{C}\int_0^t i(\tau)\, d\tau, \quad i(\tau) = I$$

$$\underset{y}{v(t)} = v(0) + \frac{1}{C}\int_0^t I\, dt = \underset{b}{v(0)} + \underset{m}{\frac{I}{C}}\,\underset{x}{t}$$

$i(t) = I$

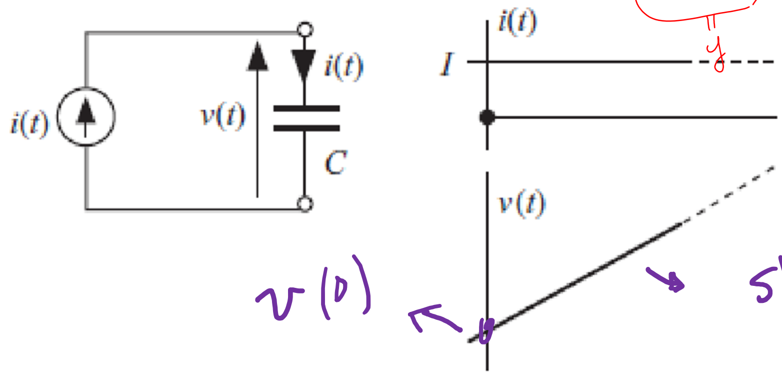


Figure 8.2 The application of a constant current to a capacitor, and the resulting voltage response

Capacitor

If $i(t) = I$ constant

$$v(t) = v(0) + \frac{1}{C}\int_0^t I \, d\tau$$

$$= v(0) + \frac{1}{C} \cdot I \cdot t$$

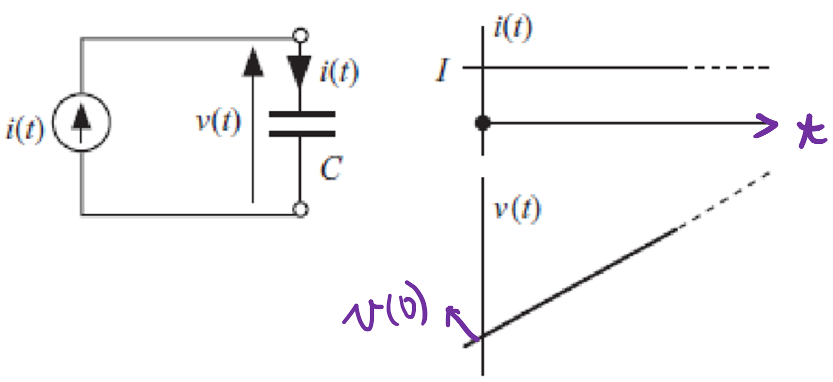


Figure 8.2 The application of a constant current to a capacitor, and the resulting voltage response

Capacitor

$$\boxed{v(t) = v(0) + \frac{1}{C}\int_0^t i(\tau)\, d\tau}$$

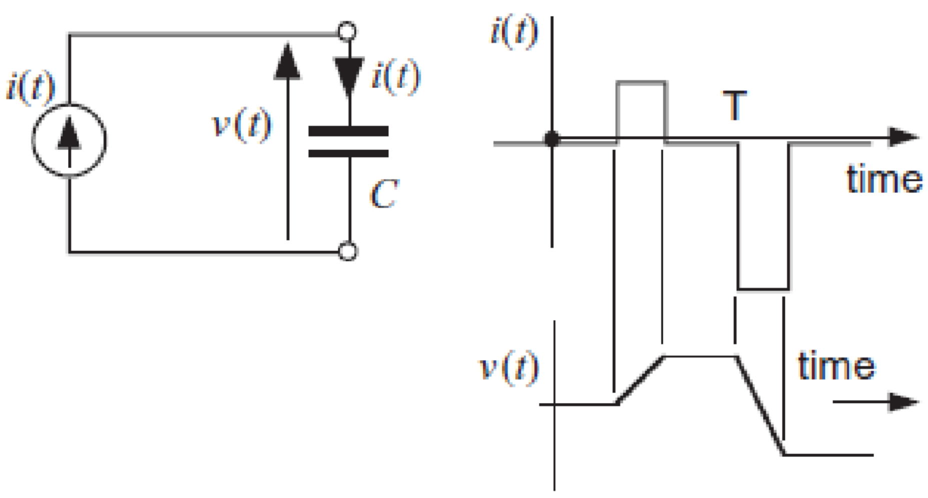


Figure 8.3 Response of a capacitor to a time-varying current source

Capacitor

$$i(t) = C\frac{dv(t)}{dt}$$

$C = \frac{q(t)}{V(t)}$ $\therefore \frac{dq(t)}{dt} = i(t)$

q(t)對時間微分是i(t)

$q(t) = CV(t)$ $\frac{d}{dt}$ ⇒ $\boxed{i(t) = C\frac{dV(t)}{dt}}$

In practice, $v(t)$ does not change abruptly!

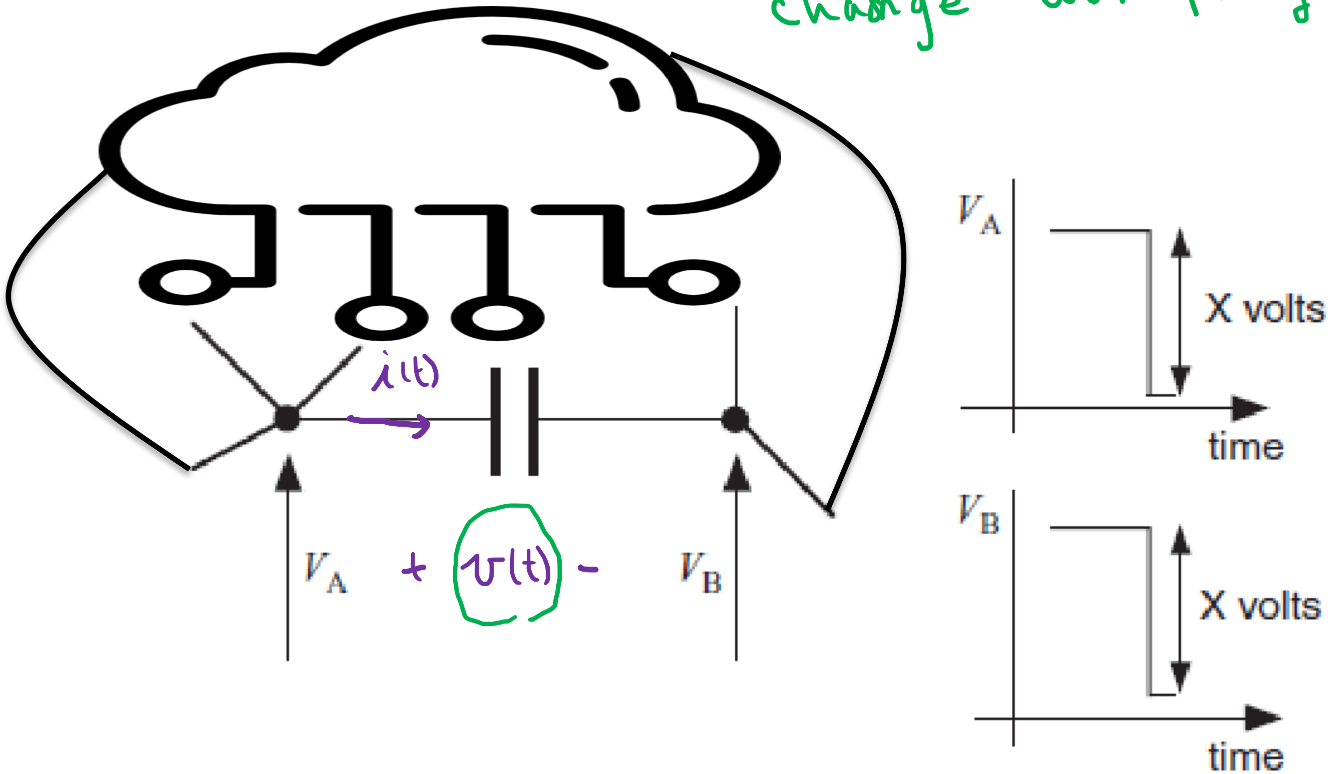


Figure 8.4 If the voltage at one teminal of a capacitor changes instantaneously, the voltage at the other terminal will exhibit the same change since, instantaneously, a capacitor voltage does not change

Capacitor

A capacitor resists change in voltage
電容會抗拒電壓改變
A inductor resists change in current
電感會抗拒電流改變

A capacitor resists change in Voltage!

(inductor) (current)

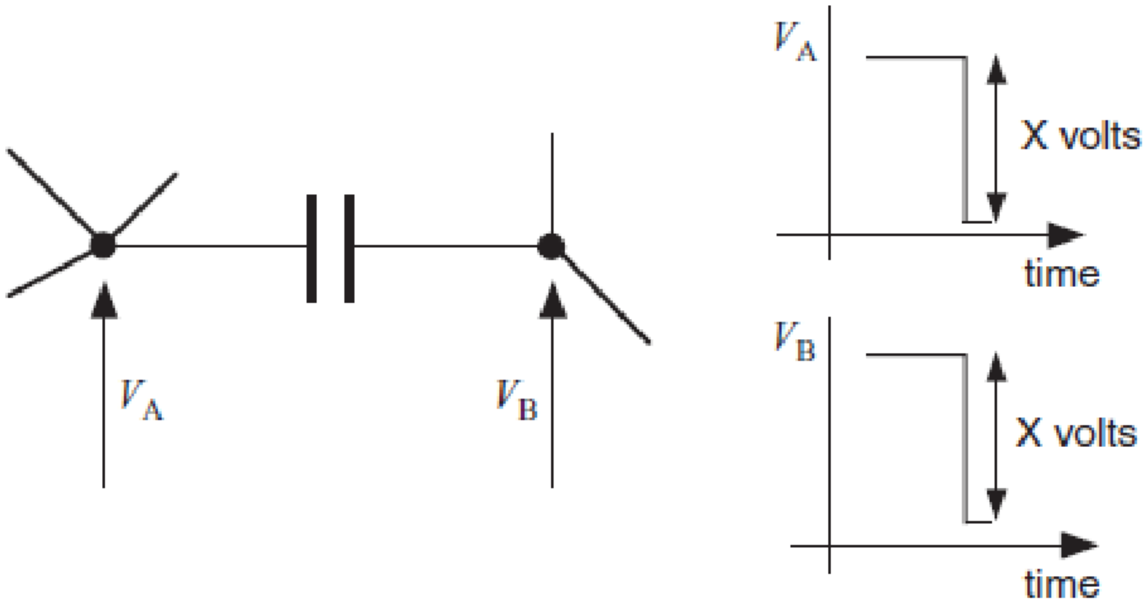


Figure 8.4 If the voltage at one teminal of a capacitor changes instantaneously, the voltage at the other terminal will exhibit the same change since, instantaneously, a capacitor voltage does not change

Integrator 積分器

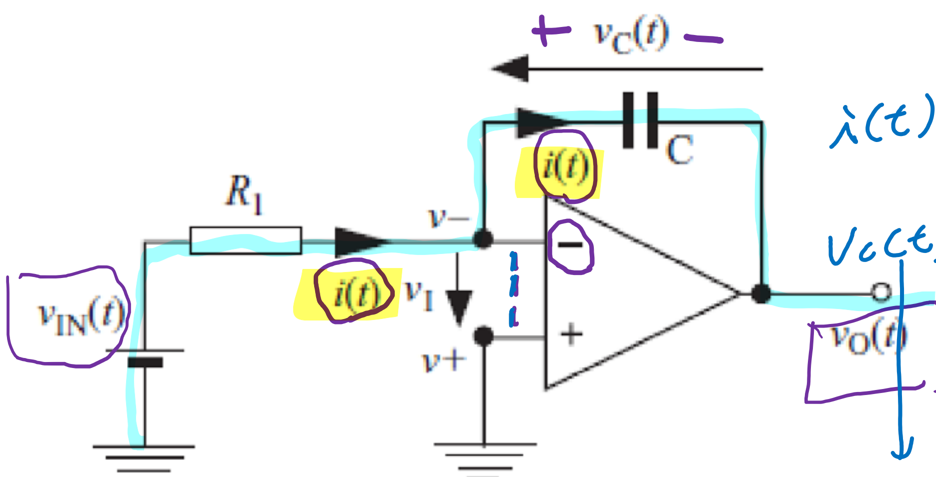
Negative Feedback $\rightarrow V_I = 0 \therefore V_- = V_+ = 0$

$\Rightarrow$ Virtual short ckt $\quad V_- = V_+ = 0$

$$i(t) = \frac{V_{IN}(t) - V_-}{R_1} = \frac{V_{IN}(t)}{R_1}$$

$$v_c(t) = v_c(0) + \frac{1}{C}\int_0^t i(\tau)\,d\tau$$

$$= v_c(0) + \frac{1}{R_1 C}\int_0^t v_{IN}(\tau)\,d\tau$$



$$i(t) = \frac{V_{IN}(t) - 0}{R_1} = \boxed{\frac{V_{IN}(t)}{R_1}}$$

代入

$$V_c(t) = V_c(0) + \frac{1}{C}\int_0^t i(t)\,dt$$

$$= V_c(0) + \frac{1}{R_1 C}\int_0^t V_{IN}(t)\,dt$$

$$V_- - V_o(t) = -V_o(t)$$

$$V_o(t) = -V_c(0) - \frac{1}{R_1 C}\int_0^t V_{IN}(t)\,dt$$

Figure 8.5 An integrating circuit

Integrator

$$V_o(t) = -\cancel{V_c(0)}^{\,0} \boxed{-\frac{1}{R_1 C}} \int_0^t V_{IN}(\tau)\,d\tau$$

$$\underbrace{\frac{1}{R_1 C}}_{\text{constant } k}$$

$$\overset{0}{\parallel}$$

$$\therefore\ V_o(t) = k \int_0^t V_{IN}(\tau)\,d\tau$$

$$V_o(t) = v_- - v_c(t)$$

$$= -\underbrace{v_c(0)}_{0} - \underbrace{\frac{1}{R_1 C}}_{k \ \text{constant}} \int_0^t v_{IN}(\tau)\,d\tau$$

If $v_c(0) = 0$

$$\Rightarrow \boxed{v_o(t) \propto \int_0^t v_{IN}(\tau)\,d\tau}$$

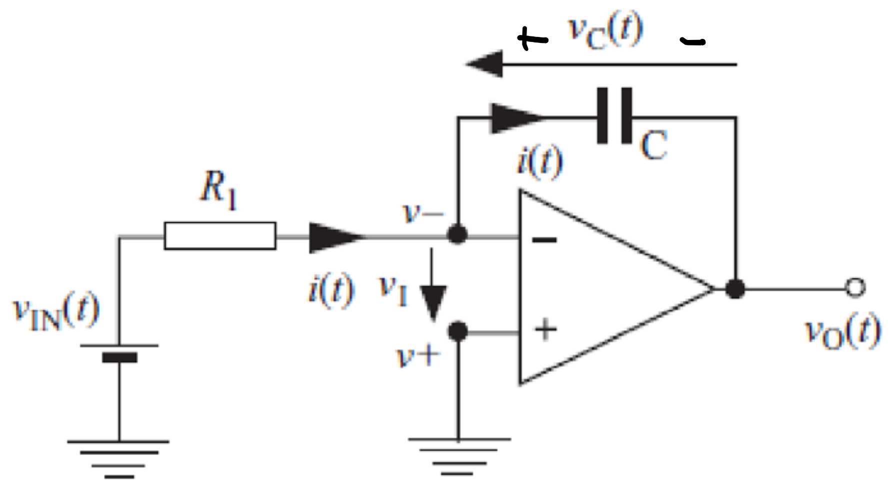


Figure 8.5 An integrating circuit

Example 8.1

$10^4\,\Omega$ $\quad 10^{-6}\,F$

$1\,\mu F$

$10\,k\Omega$

$$\boxed{v_o(t) = v_o(0) - \frac{1}{R_1 C}\int_0^t v_{IN}(\tau)\,d\tau}$$

$$= v_o(0) - 100\int_0^t v_{IN}(\tau)\,d\tau$$

(-6)

$$V_o(t) = V_o(0) - \boxed{\frac{1}{R_1 C}}\int_0^t V_{IN}(\tau)\,d\tau$$

$$V_o(t) = -6 - 1000t$$

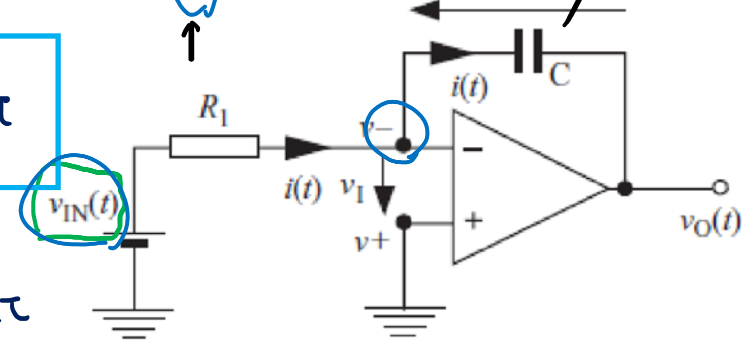


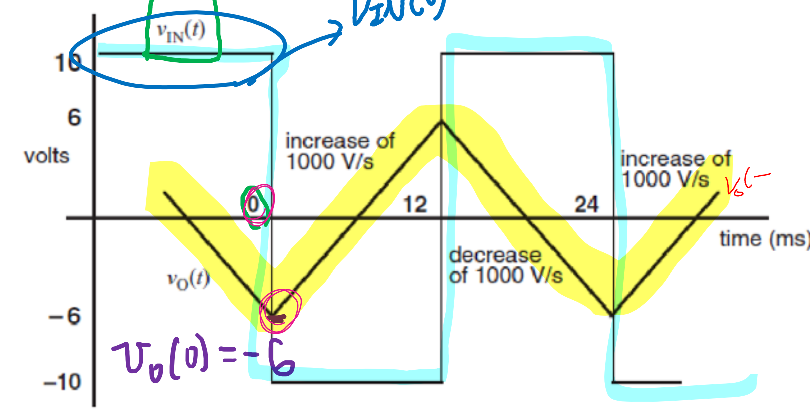
Figure 8.5 An integrating circuit

$i(t) = \frac{V_{IN}(t)}{R_1}$

$V_{IN}(0) =$

$+10(0)$

$V_{IN}(t)$



$v_o(0) = -6$

Figure 8.6 The input and output voltages of the integrator of Figure 8.5 (numerical values refer to Example 8.1)

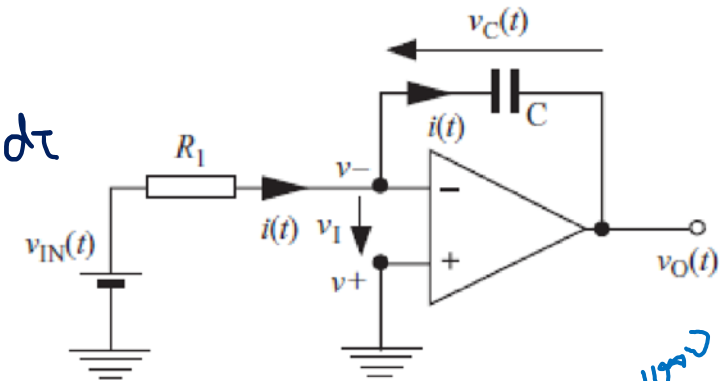
Example 8.1

For $0 < t < 12$ ms

$V_{IN}(t) = -10\ V$

$$v_o(t) = v_o(0) - 100 \int_0^t (-10)\, d\tau$$

$$= -6 + 1000t$$



$\frac{12}{t} = 1000$

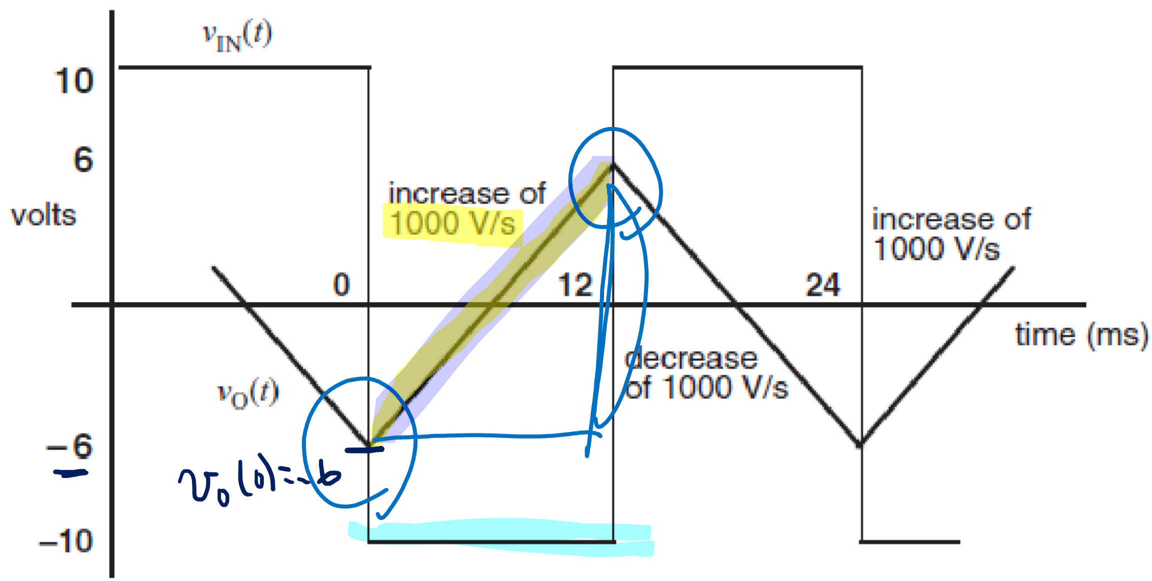


Figure 8.6 The input and output voltages of the integrator of Figure 8.5 (numerical values refer to Example 8.1)

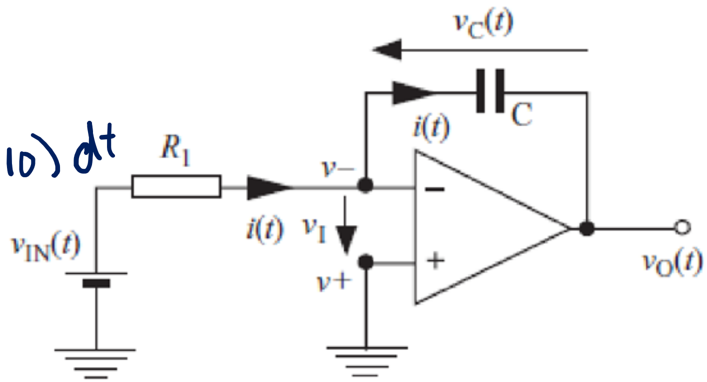
Example 8.1

For $12 < t < 24$ ms

$V_{IN}(t) = +10\text{ V}$

$$v_o(t) = v_o(12\,\text{ms}) - 100\int_{12\,\text{ms}}^{t} (+10)\,dt$$

$$= 6 - 1000(t-12)$$



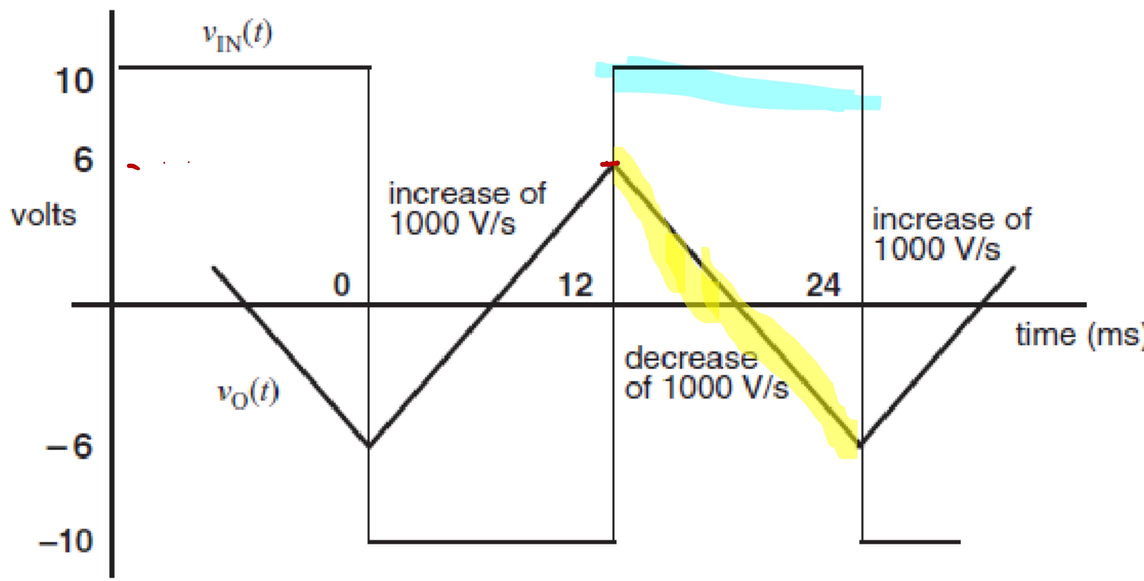


Figure 8.6 The input and output voltages of the integrator of Figure 8.5 (numerical values refer to Example 8.1)

Example 8.2

Dynamic Opamp Ckt

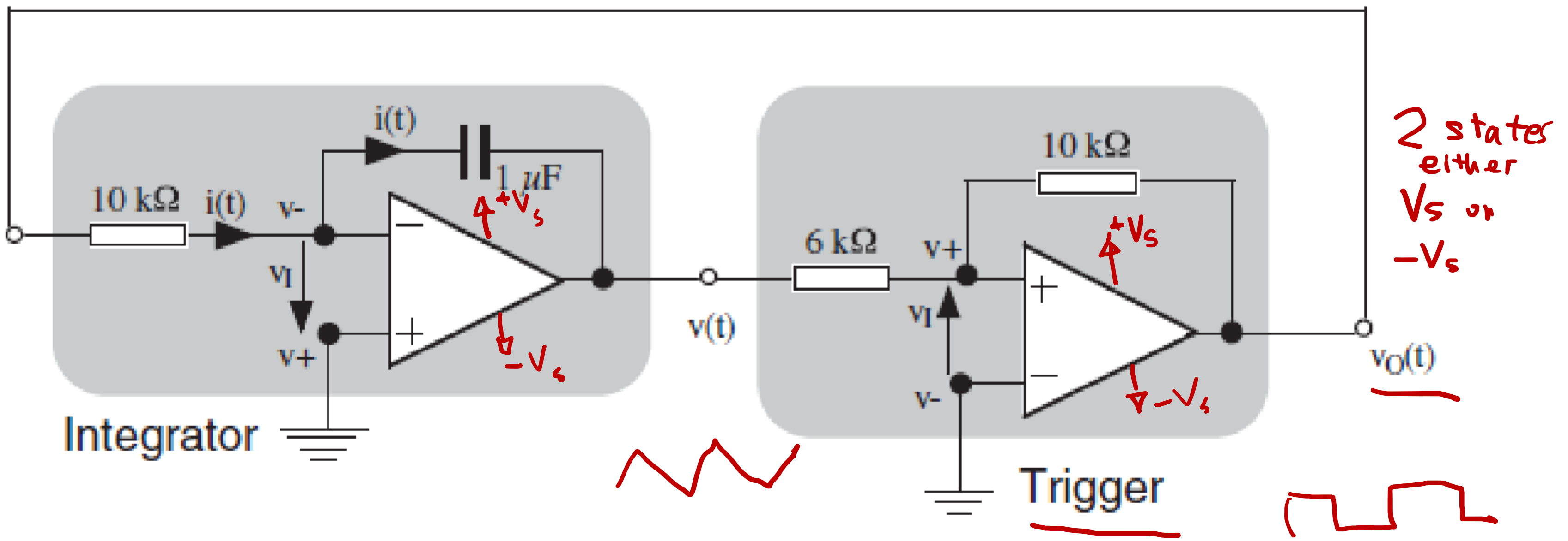


Figure 8.7 The circuit analysed in Example 8.2

Trigger circuit

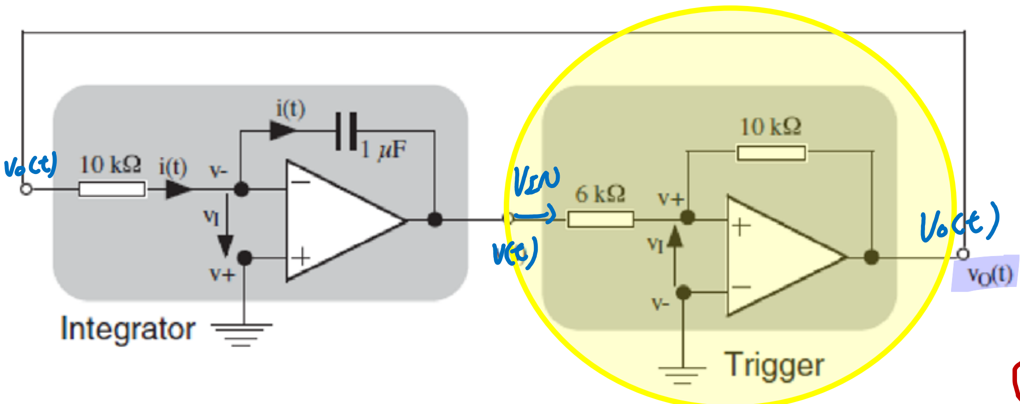


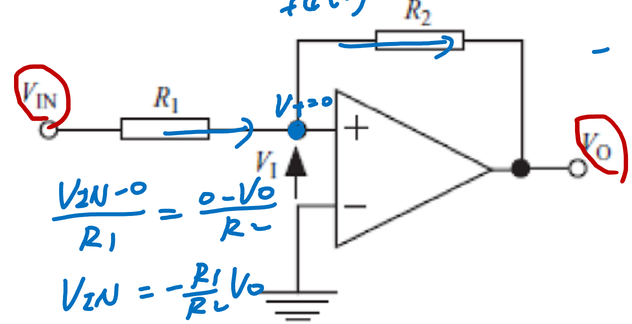
Figure 8.7 The circuit analysed in Example 8.2

When $V_0(t) = +V_s \Rightarrow V_{th} = -\frac{R_1}{R_2} V_s$

$\begin{cases} V_{IN} > V_{th} \Rightarrow V_0 = +V_s \\ V_{IN} \downarrow < V_{th} \Rightarrow V_0 = -V_s \end{cases}$ → State Reverse

$+V_s$: $V_{th} = -\frac{R_1}{R_2} V_s$ $-4(V)$ $\begin{cases} V_{IN} > V_{th} & +V_s \\ V_{IN} < V_{th} & -V_s \end{cases}$

$-V_s$: $V_{th} = \frac{R_1}{R_2} V_s$ $+4(V)$ $\begin{cases} V_{IN} < V_{th} & -V_s \\ V_{IN} > V_{th} & +V_s \end{cases}$



$V_+ = 0$

$\frac{V_{IN} - 0}{R_1} = \frac{0 - V_0}{R_2}$

$V_{IN} = -\frac{R_1}{R_2} V_0$

When $V_0(t) = -V_s \Rightarrow V_{th} = +\frac{R_1}{R_2} V_s$

$\begin{cases} V_{IN} < V_{th} \Rightarrow V_0 = -V_s \\ V_{IN} \uparrow > V_{th} \Rightarrow V_0 = +V_s \end{cases}$

↓ State reverse

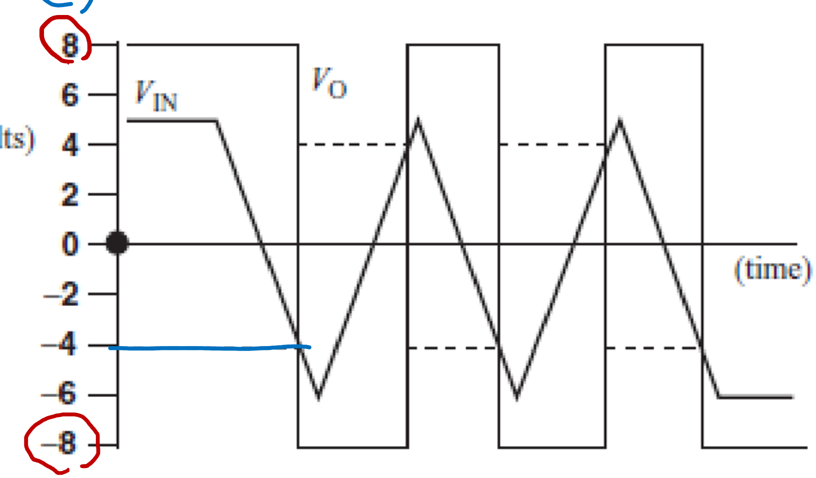
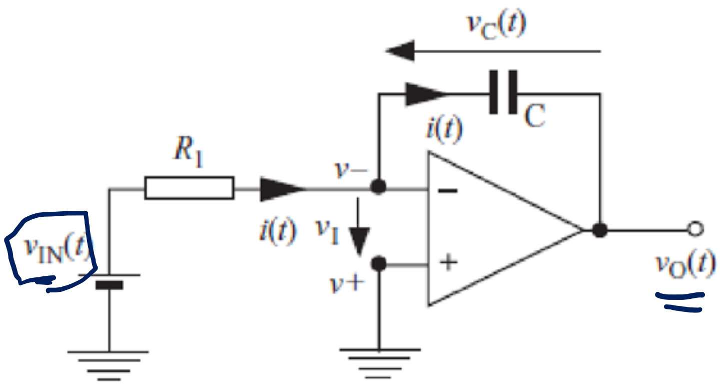


Figure 6.15 The waveform of the output voltage of the trigger circuit of Figure 6.13(a)

Integrator



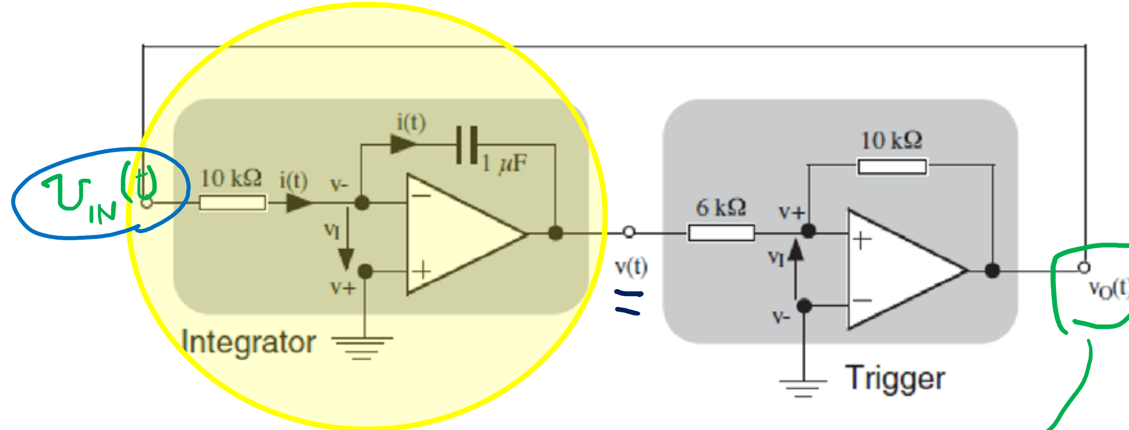


Figure 8.7 The circuit analysed in Example 8.2

$$v_O(t) = v_O(0) - \frac{1}{R_1 C}\int_0^t v_{IN}(\tau)\,d\tau$$

2 states

$$\begin{cases} +V_s \\ -V_s \end{cases}$$

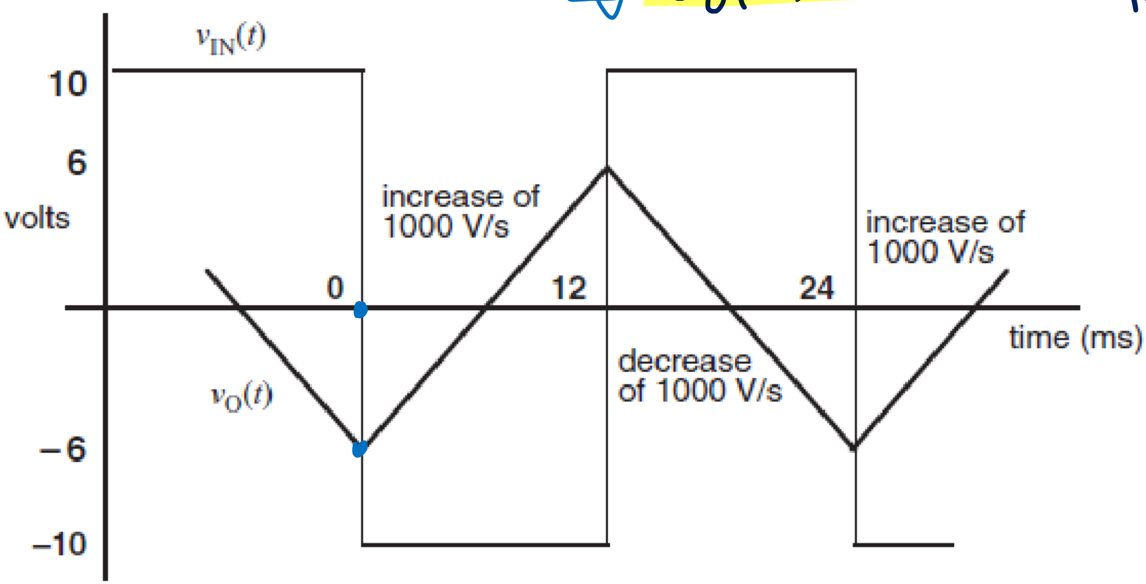


Figure 8.6 The input and output voltages of the integrator of Figure 8.5 (numerical values refer to Example 8.1)

Example 8.2 (1)

$+V_s$

For state $v_o(t) = \boxed{+10\ V}$

Integrator

$$v(t) = v(0) - \frac{1}{RC}\int_0^t v_o(\tau)\,d\tau$$

$$= v(0) - 1000t$$

Trigger

$$V_{th} = -\frac{6}{10} \times 10 = -6\ V$$

If $v(t) > V_{th} \Rightarrow v_o(t) = +10V$

If $v(t)\downarrow < V_{th} \Rightarrow v_o(t) = -10V$

V_{IN}

State reverse

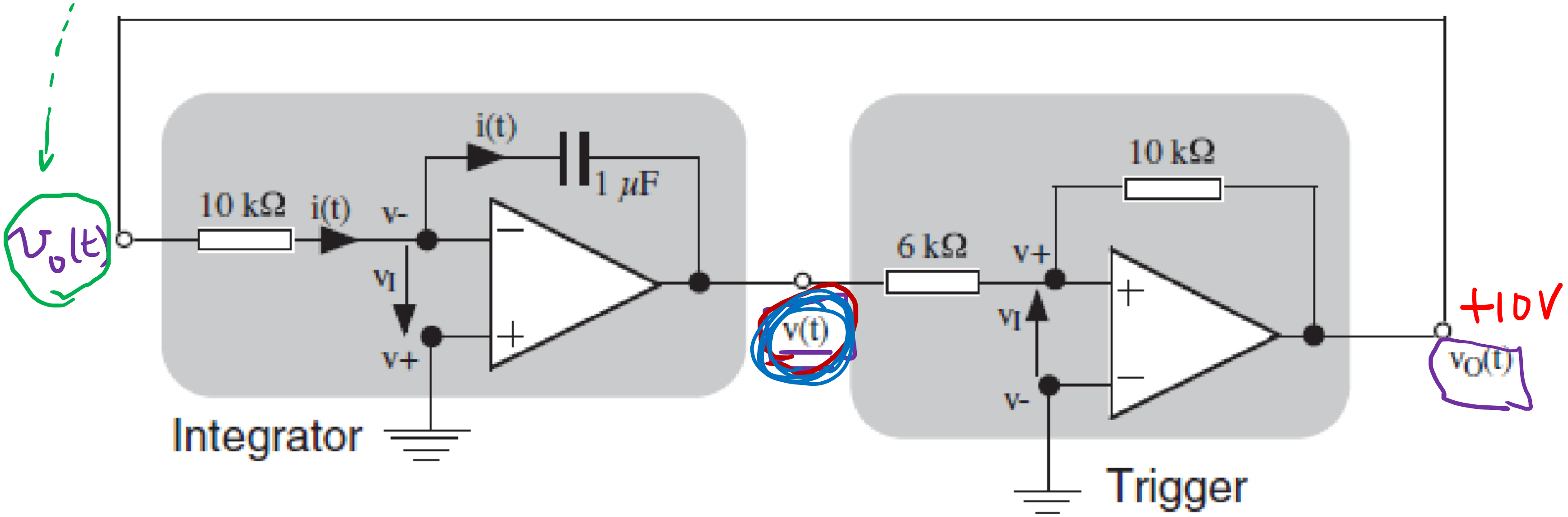


Figure 8.7 The circuit analysed in Example 8.2

Example 8.2 (2)

$V(t) = V(0) - \frac{1}{R_1 C}\int_0^t V_{IN}(t)\,dt$

$V_{IN}(t) = V_O(t) = -10(V)$

For state $v_O(t) = -10V$

Integrator

$v(t) = v(0) + 1000t$

Trigger $V_{th} = +6V$

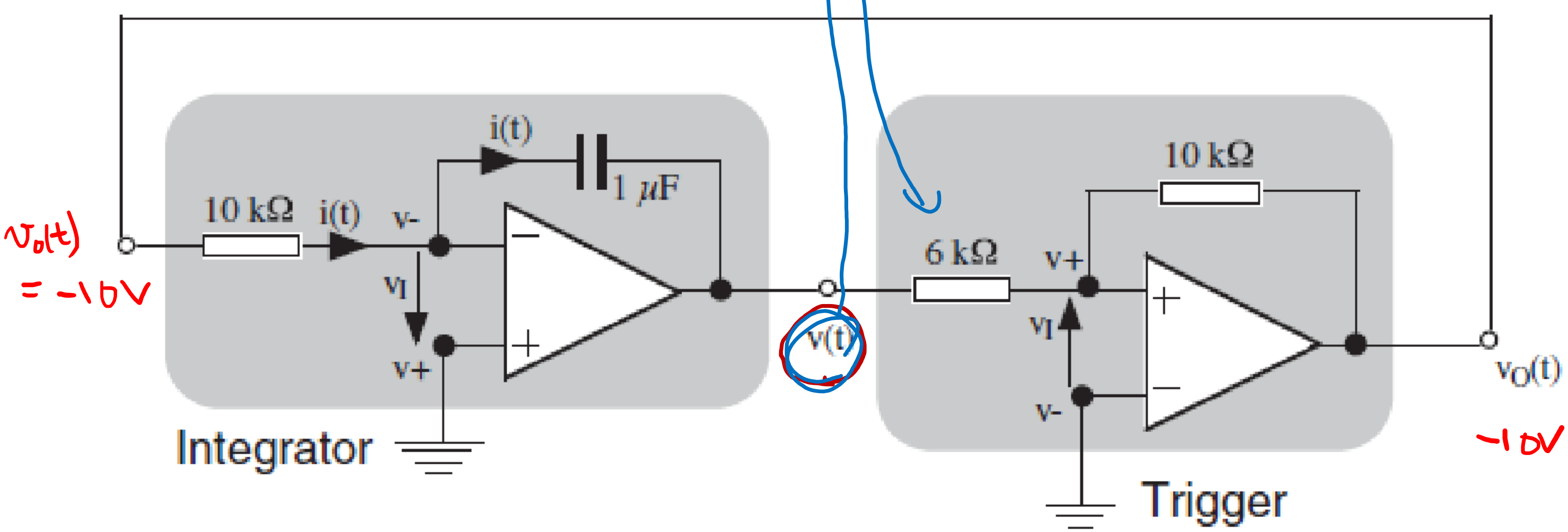
$v(t) < V_{th} \Rightarrow V_O(t) = -10V$ $-V_s$

$v(t)\uparrow > V_{th} \Rightarrow V_O(t) = +10V$ $+V_s$

$v(t) = V_{IN}$

State reverse

$v_O(t) = -10V$



-10V

Figure 8.7 The circuit analysed in Example 8.2

Example 8.2 (3)

T = period = 24 ms

f = frequency = $\frac{1}{\text{period}}$

= $\frac{1\,\text{s}}{24\,\text{ms}}$ = 41.6 (Hz)

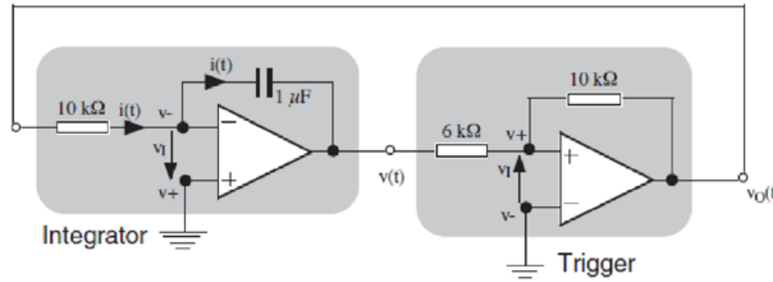


Figure 8.7 The circuit analysed in Example 8.2

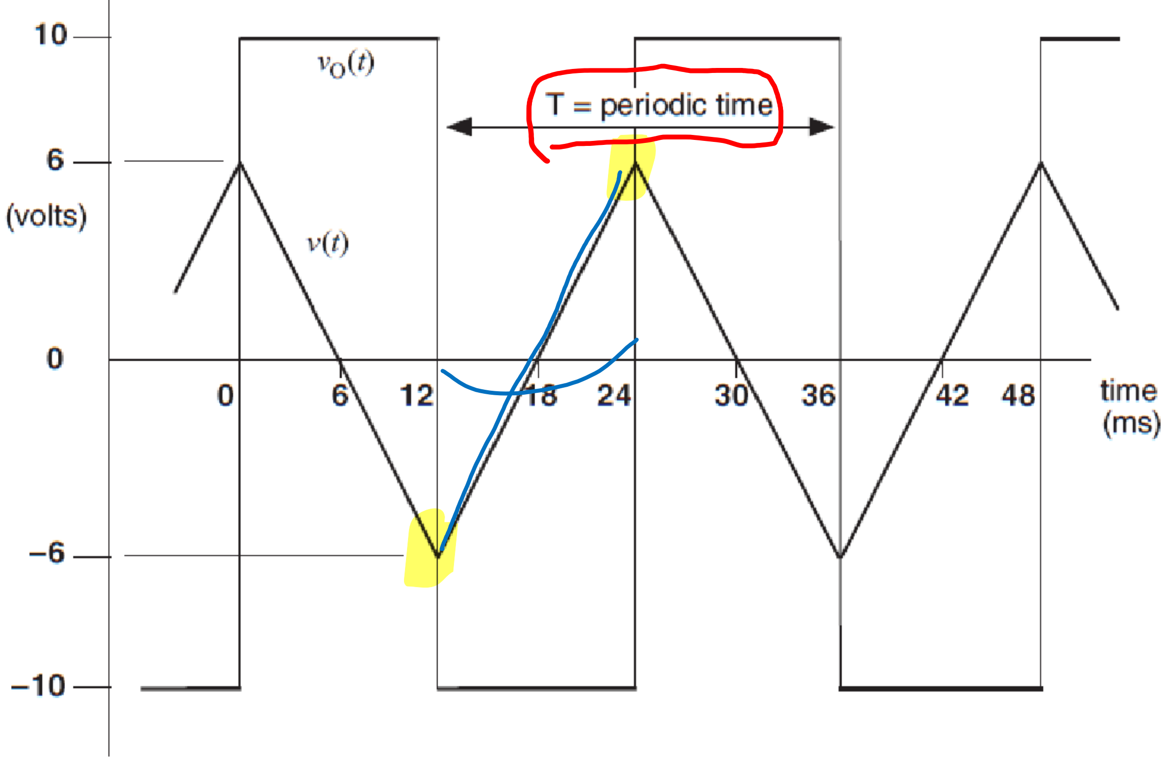


Figure 8.8 The voltages v_O and v in the circuit of Figure 8.7

Asymmetrical oscillator

If $V_o = +10V \rightarrow i(t) = 1.5\ mA$

If $V_o = -10V \rightarrow i(t) = -0.5\ mA$

$$v(t) = v(0) + \frac{1}{C}\int_0^t i(\tau)\,d\tau$$

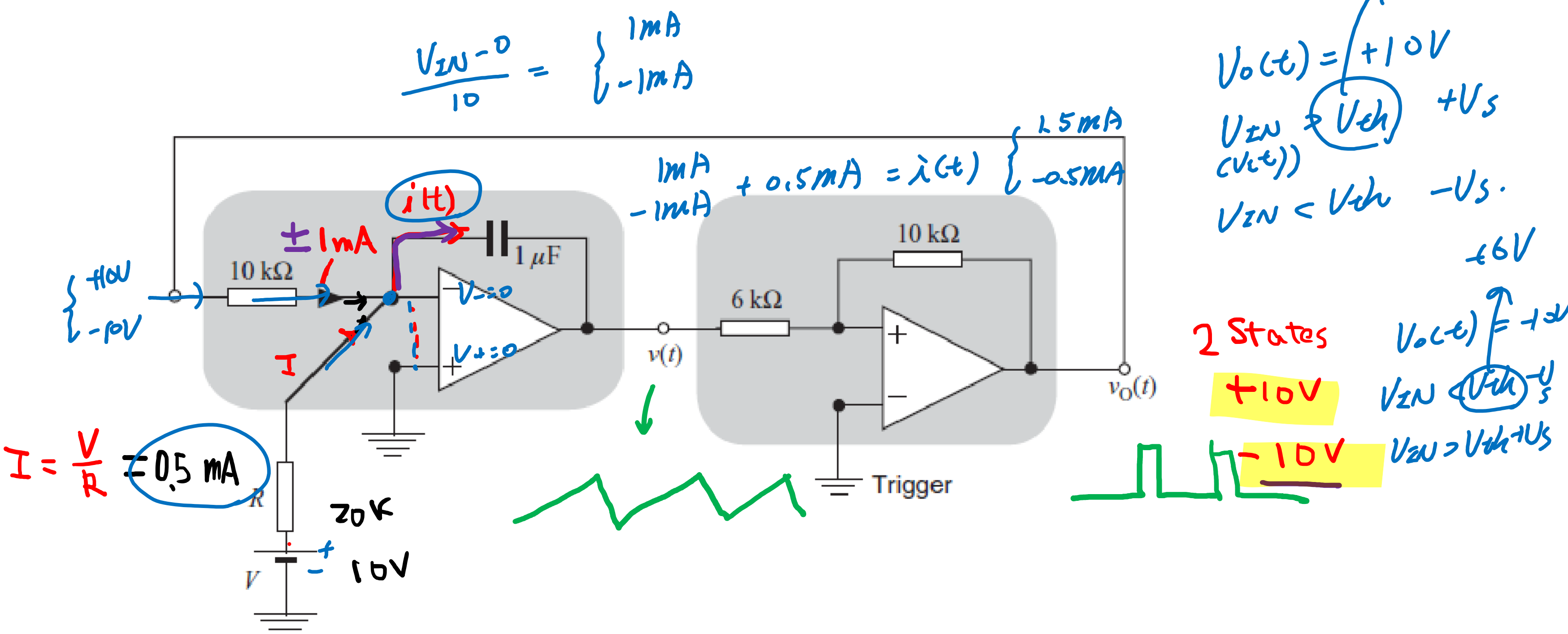


Figure 8.9 Modification to the circuit of Figure 8.7, resulting in asymmetrical waveforms

LAB 3. Asymmetrical Oscillator

Build an asymmetrical oscillator on the online simulator. For the opamps, set ‘Max Output’ to 10 and ‘Min Output’ to -10. Display $v(t)$ and $v_o(t)$. Export as text file and submit.

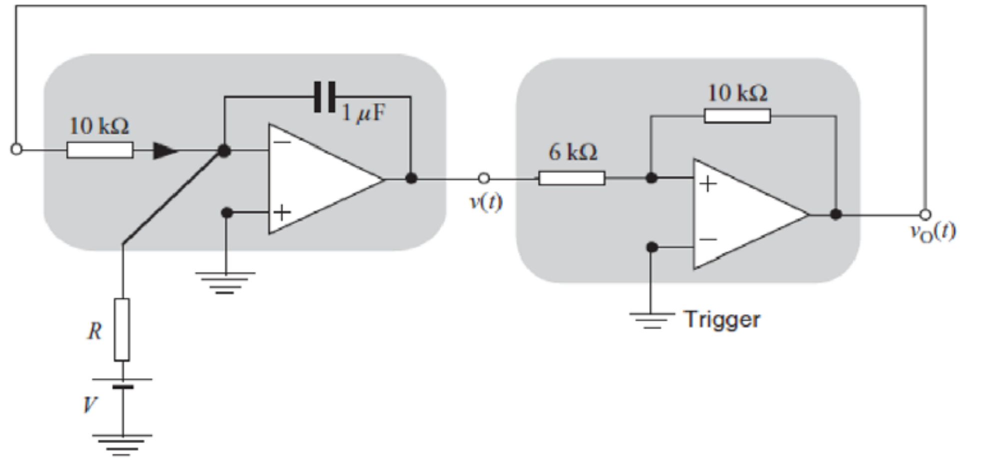


Figure 8.9 Modification to the circuit of Figure 8.7, resulting in asymmetrical waveforms

Suppose your student ID is

E(NN) 0 (BBB) (CC)

Set the Voltage Source

V = 1.NN

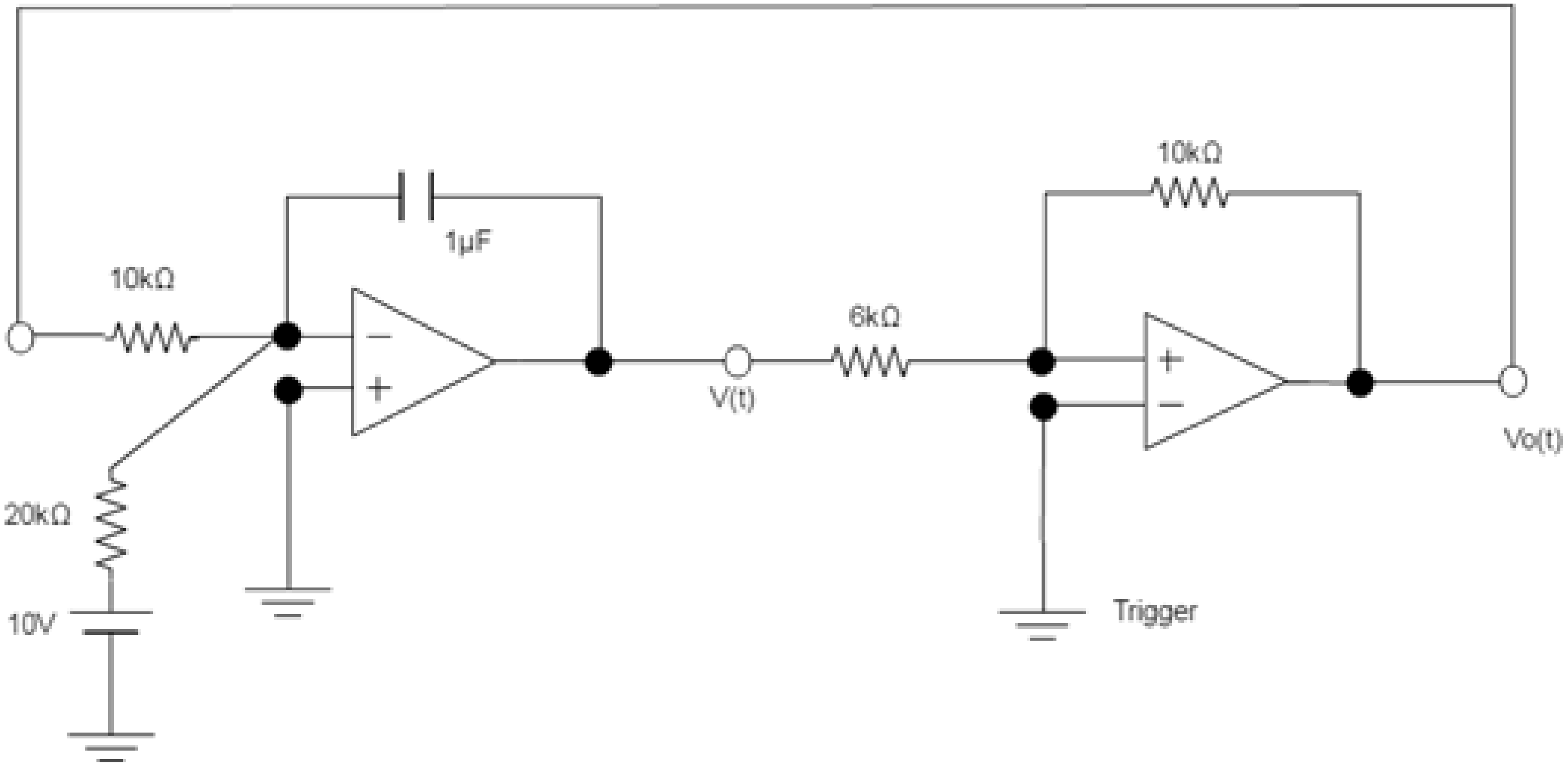
Set the resistor

R= 2.*CC* KΩ

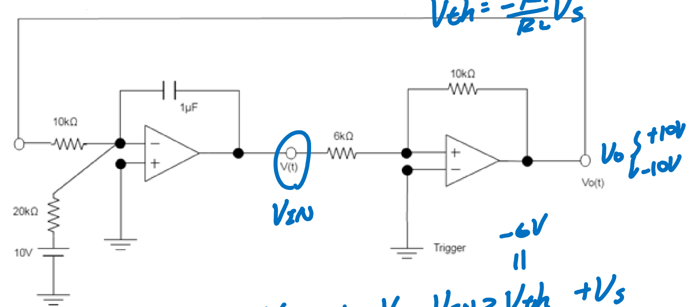
Example: ID E34048154
NN=34, Voltage=1.34
CC=54, R=2.54 K

Quiz

Assume that the limits to $\boxed{V_O \text{ are } +10 \text{ and } -10 \text{ V}}$, $V_O(0)=10$ V, $V(0)=6$ V. For the following circuit, draw the voltage waveforms of $V(t)$ and $V_O(t)$, respectively, for $0 < t < 80$ ms. What is the period of the waveform $V_O(t)$?



Quiz Review



For $V_o(t) = +10\,V$

$v_c(t) = v_c(0) + \frac{1}{C}\int_0^t i(\tau)\,d\tau$

$C = 10^{-6}\,F$, $i = 1.5\,mA$

$= v_c(0) + 1500\,t$

$v(t) = 0 - v_c(t) = -v_c(0) - 1500t$

$v(t)$: $6V \longrightarrow -6V$

$\Delta = \frac{(-6)-(+6)}{-1500} = 8\,\mu S$

$-6V = V_{th}$

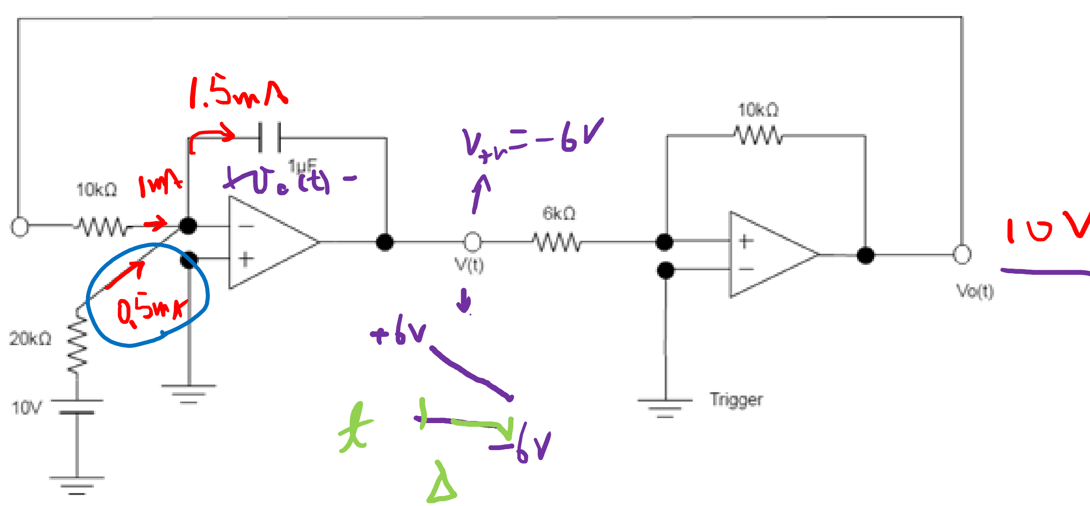
$V_o = +10V$: $V_{IN} > V_{th} + V_s$, $V_{IN} < V_{th} - V_s = -6V$

$V_o = -10V$: $V_{IN} < V_{th} - V_s$ ($6V$), $V_{IN} > V_{th} + V_s = 6V$

$V(t) = V(0) + \frac{1}{C}\int_0^t i(t)\,d\tau$

$\begin{cases} V_{IN} = +10V \Rightarrow +1mA \\ V_{IN} = -10V \Rightarrow -1mA \end{cases}$

$\Rightarrow i(t) \begin{cases} 1.5mA \\ -0.5mA \end{cases}$



Quiz Review

For state $V_o(t) = -10V$

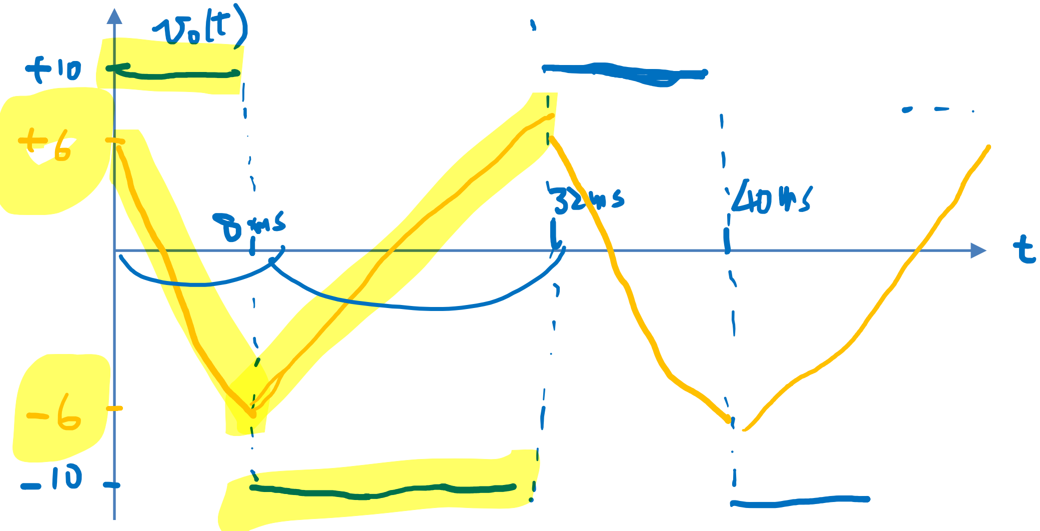
$i(t) = -0.5 \text{ mA}$

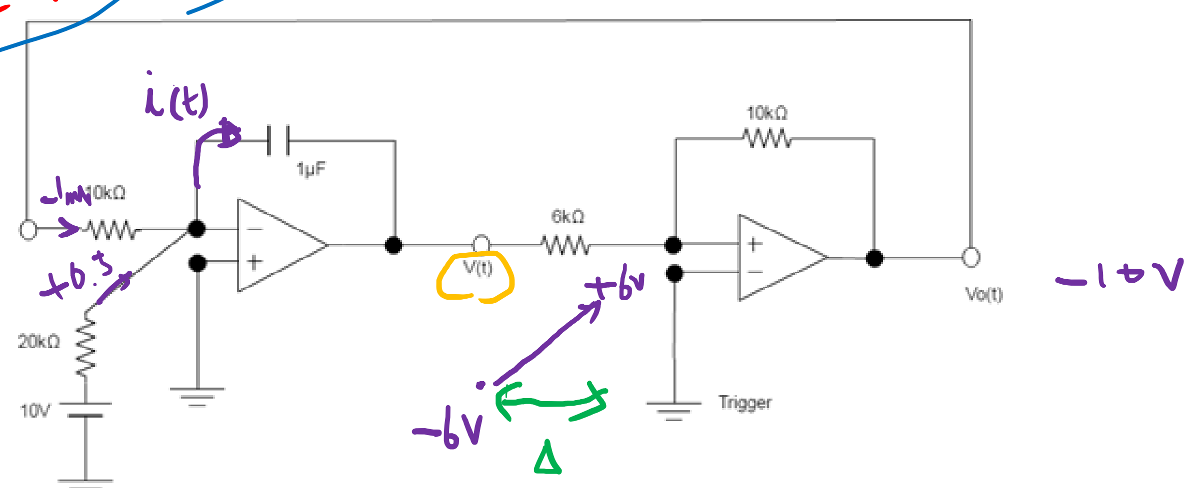
slope $= +500 \text{ V/s}$

$$\Delta = \frac{6-(-6)}{500} = 24 \text{ ms}$$

Period $= 8 \text{ ms} + 24 \text{ ms}$

$= 32 \text{ ms}$





* Dependent Source
    * Nodal
    * Superposition
    * Thevenin
* Load-Line Analysis

* Opamp

    Positive Feedback
    Negative Feedback

* Capacitor → Oscillator