Nonsinusoidal Signal Generators

- rectangle, triangle, saw tooth, pulse, etc.

Multivibrator circuits:

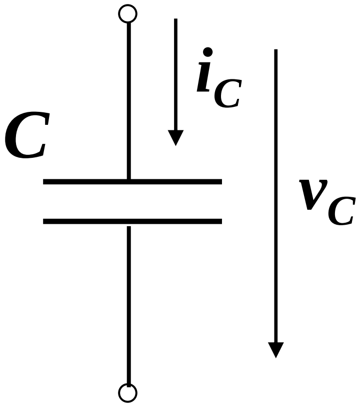
❖ **astable** – no stable states (two quasi-stable states; it remains in each state for predetermined times)

❖ monostable – one stable state, one non-stable state

❖ bistable – two stable states

- From one stable state the circuit switches in the other state under the action of a control signal (input signal).
- From one non-stable state the circuit switches in the other state automatically.

C in the time domain

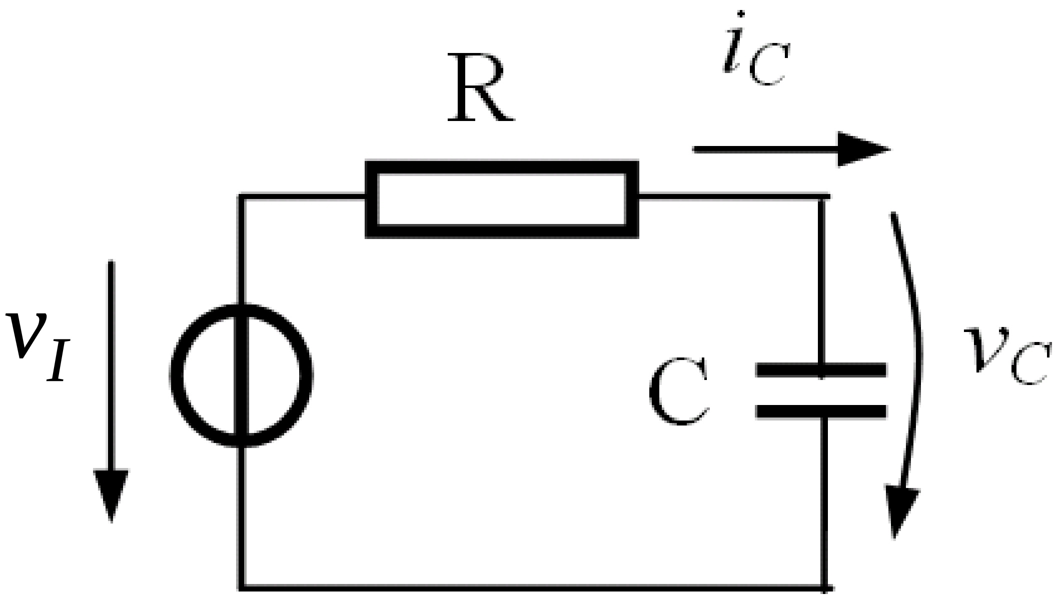


Defining relation between current and voltage

$$\boxed{C\,dv_C(t) = i_C(t)\,dt}$$

RC circuit – time domain analysis

- RC circuit with voltage source



$$R i_C(t) + v_C(t) = v_I(t)$$

$$C dv_C(t) = i_C(t) dt$$

$$i_C(t) = C \frac{dv_C(t)}{dt}$$

$$\boxed{RC \frac{dv_C(t)}{dt} + v_C(t) = v_I(t)}$$

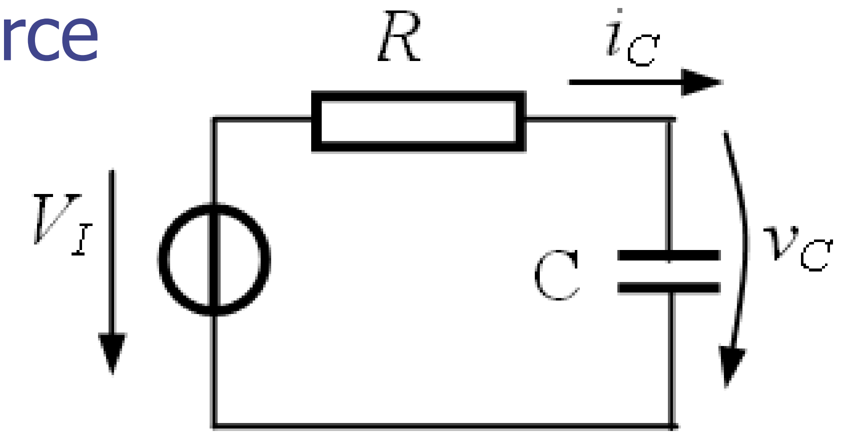
$\tau = RC$ time constant of the circuit

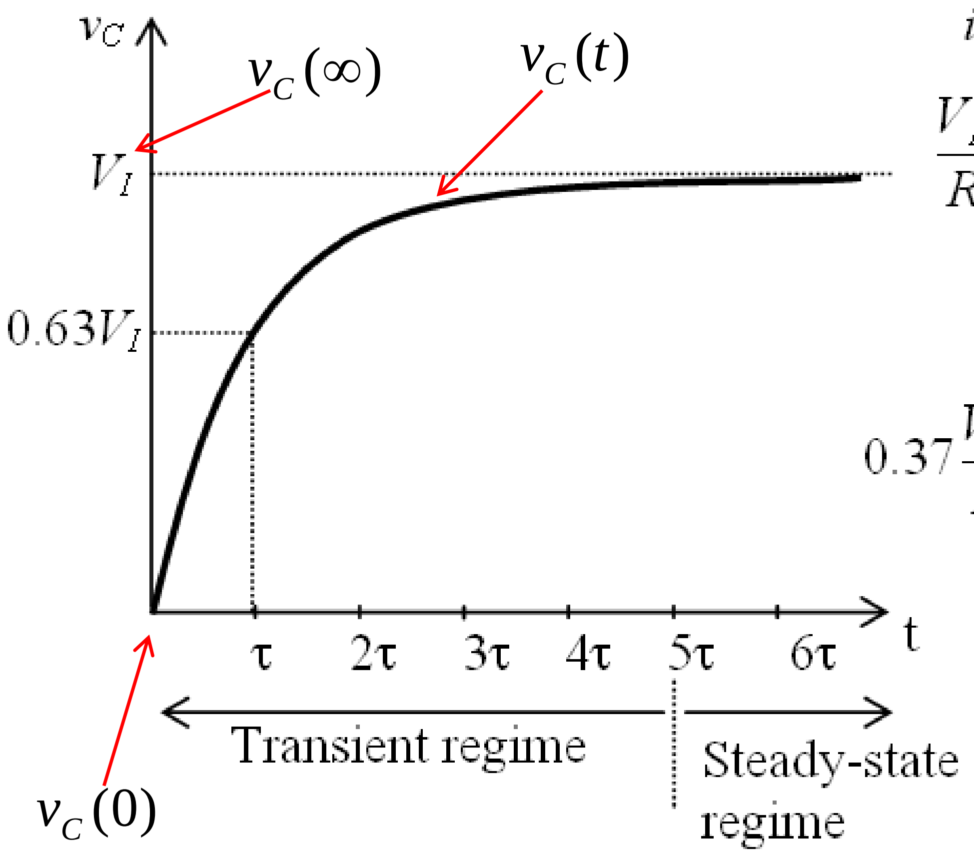
$$\boxed{v_C(t) = v_C(0) e^{\frac{-t}{\tau}} + (1 - e^{\frac{-t}{\tau}}) v_C(\infty)}$$

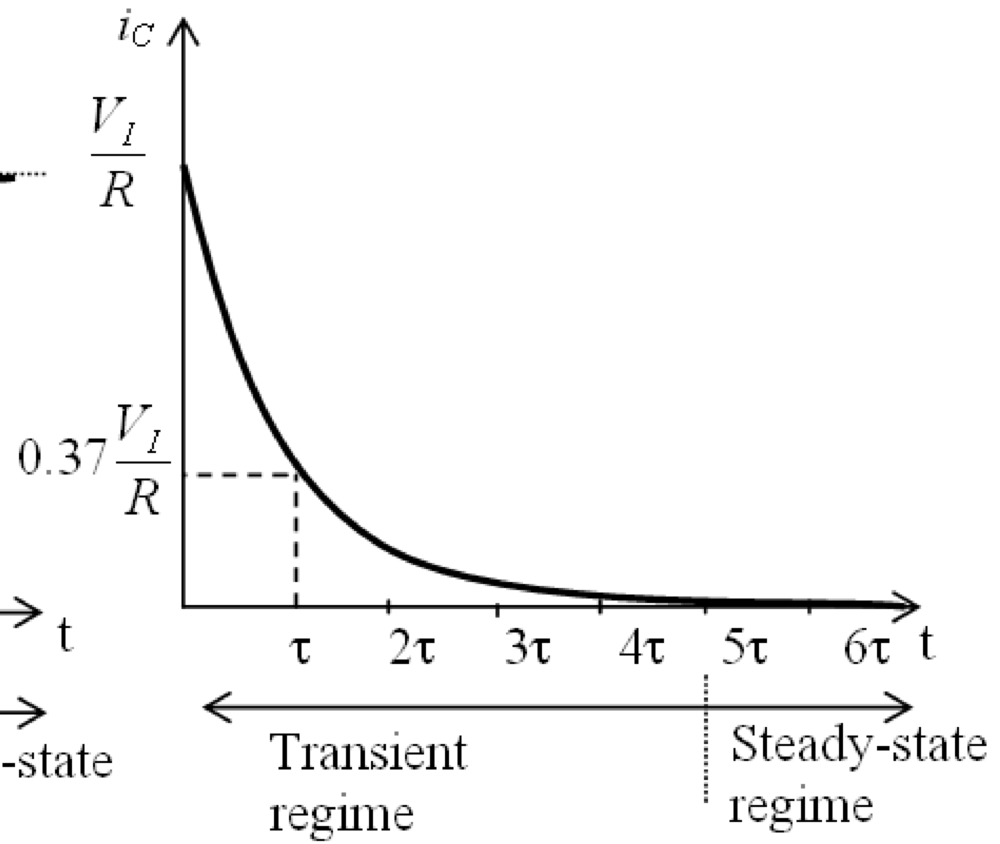
RC circuit with dc voltage source

$$v_C(t) = v_C(0)e^{\frac{-t}{\tau}} + (1 - e^{\frac{-t}{\tau}})v_C(\infty)$$

$$v_C(0) = 0; \qquad v_C(\infty) = V_I; \qquad \tau = RC$$





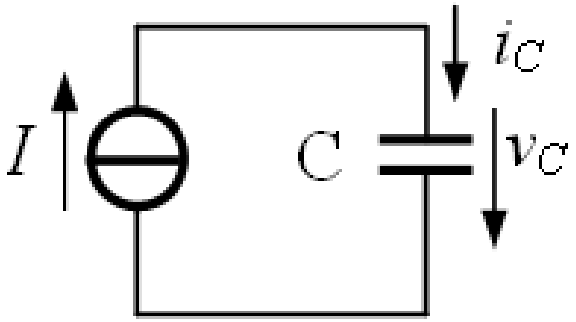


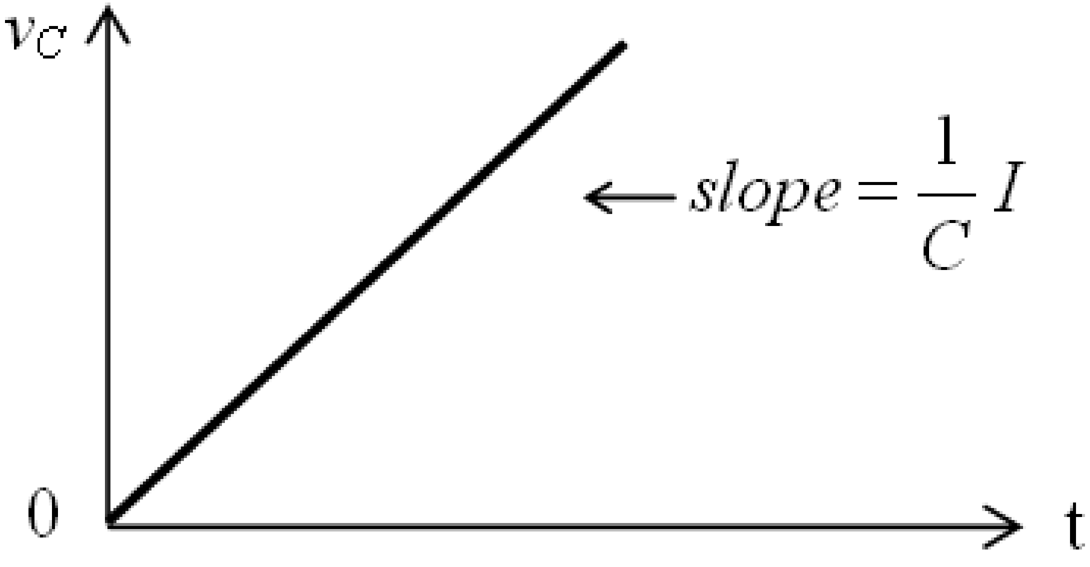
➢ Charging the *C* with a constant current

$$C dv_c(t) = i_c(t) dt$$

$$v_C(t) = \frac{1}{C}\int_0^t i_C(t)dt + v_C(0)$$

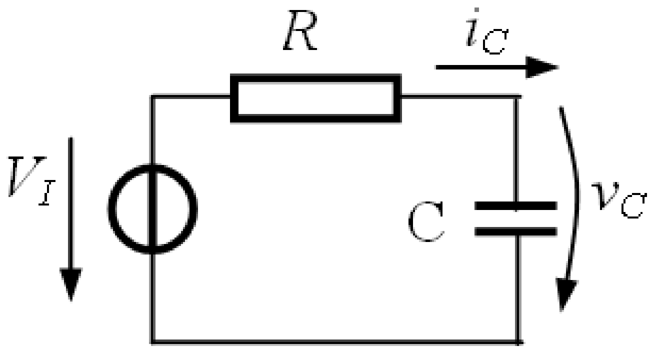
$$\boxed{v_C(t) = \frac{1}{C} It + v_C(0)}$$



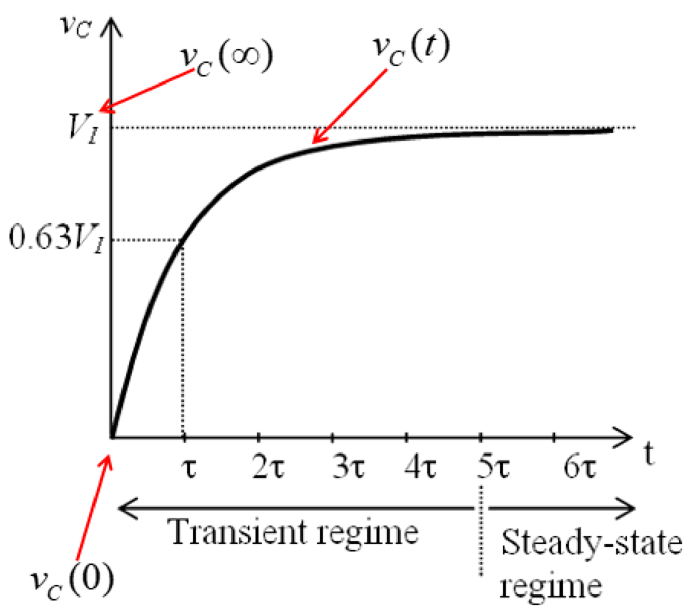


Charging the capacitor - summary

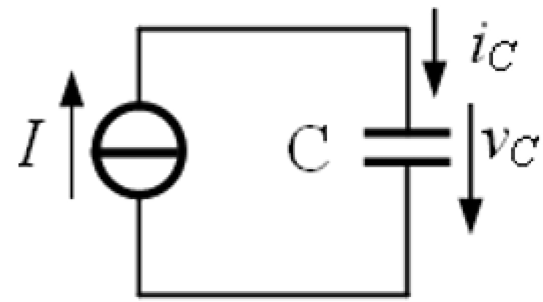
- with a ***R* and a DC voltage source**



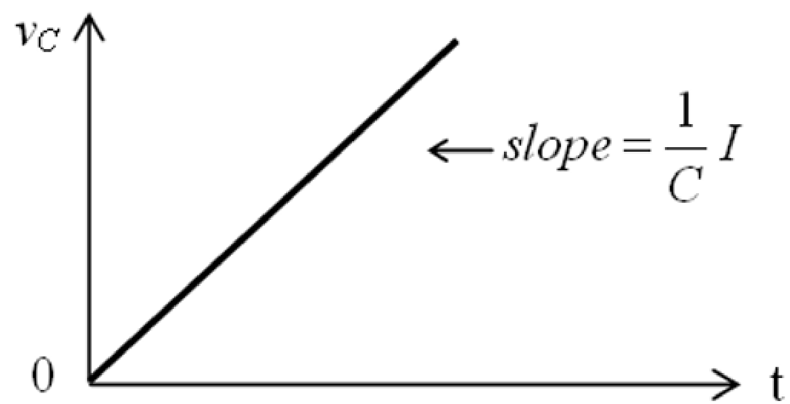
$$v_C(t) = v_C(0)e^{\frac{-t}{\tau}} + (1-e^{\frac{-t}{\tau}})v_C(\infty)$$



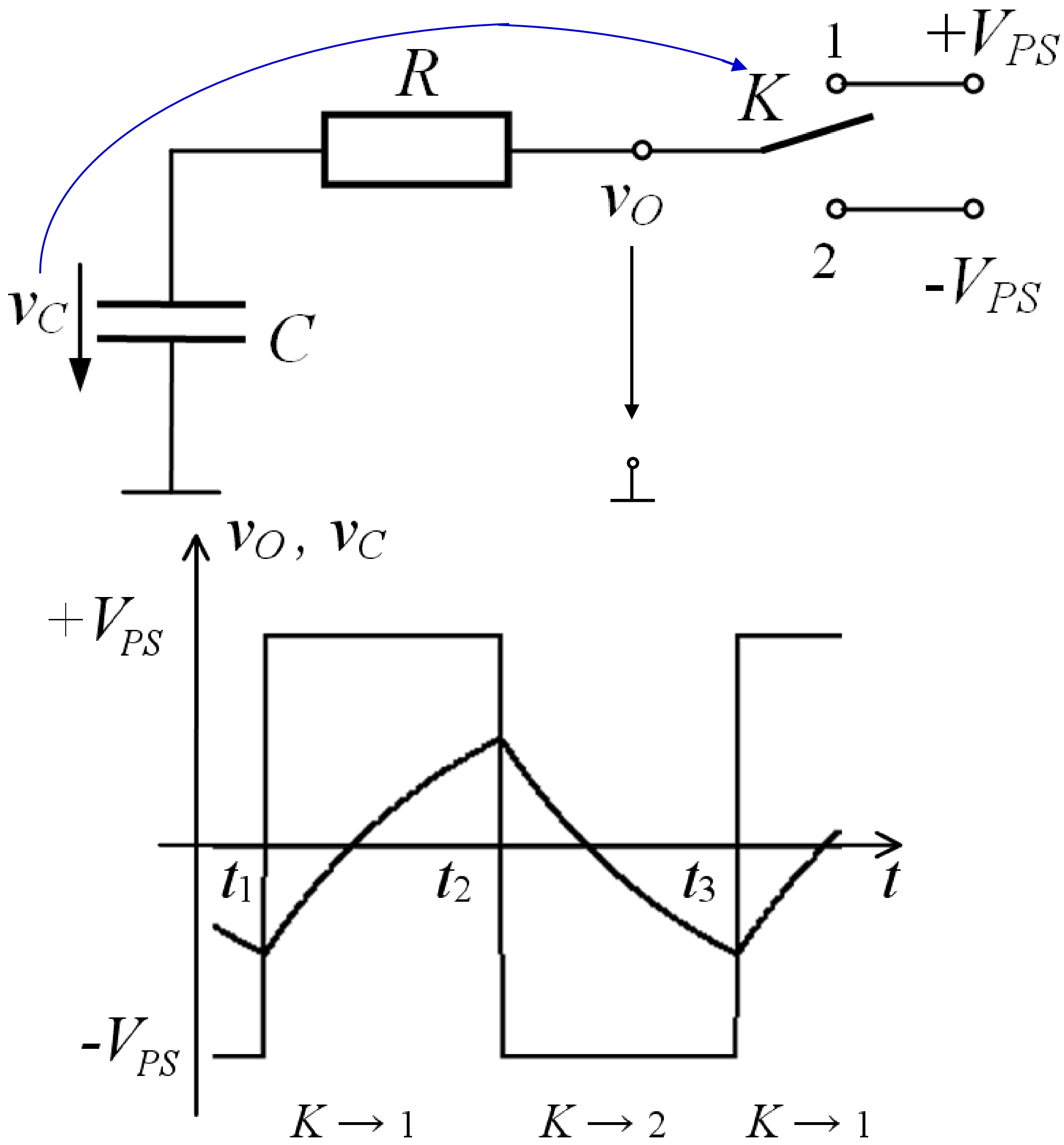
- with a **constant current** source



$$v_C(t) = \frac{1}{C}It + v_C(0)$$



Astable multivibrators (Relaxation oscillators)



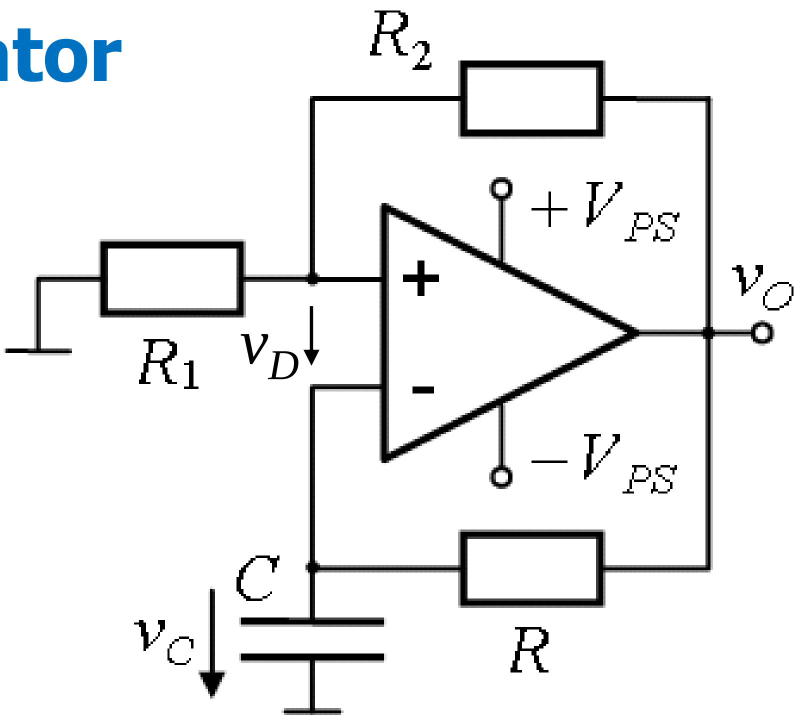
Operating principle

- the time variation of the voltage across the capacitor is exponential

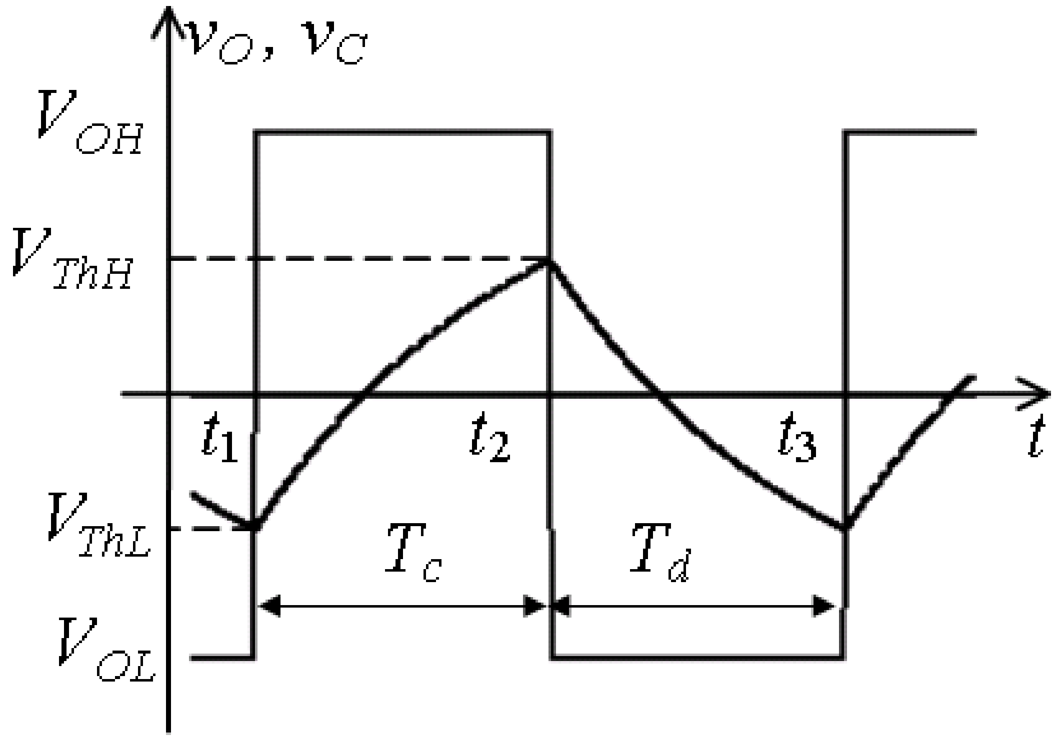
- if the voltage across the capacitor is fed to a PF comparator, a **rectangular wave** is obtained

1. Astable multivibrator-rectangular signal generator

$$v_C(t) = v_C(0)e^{-\frac{t}{\tau}} + \left(1 - e^{-\frac{t}{\tau}}\right)v_C(\infty)$$



$$v_D(t) = v^+ - v^- = \frac{R_1}{R_1 + R_2}v_O(t) - v_C(t)$$

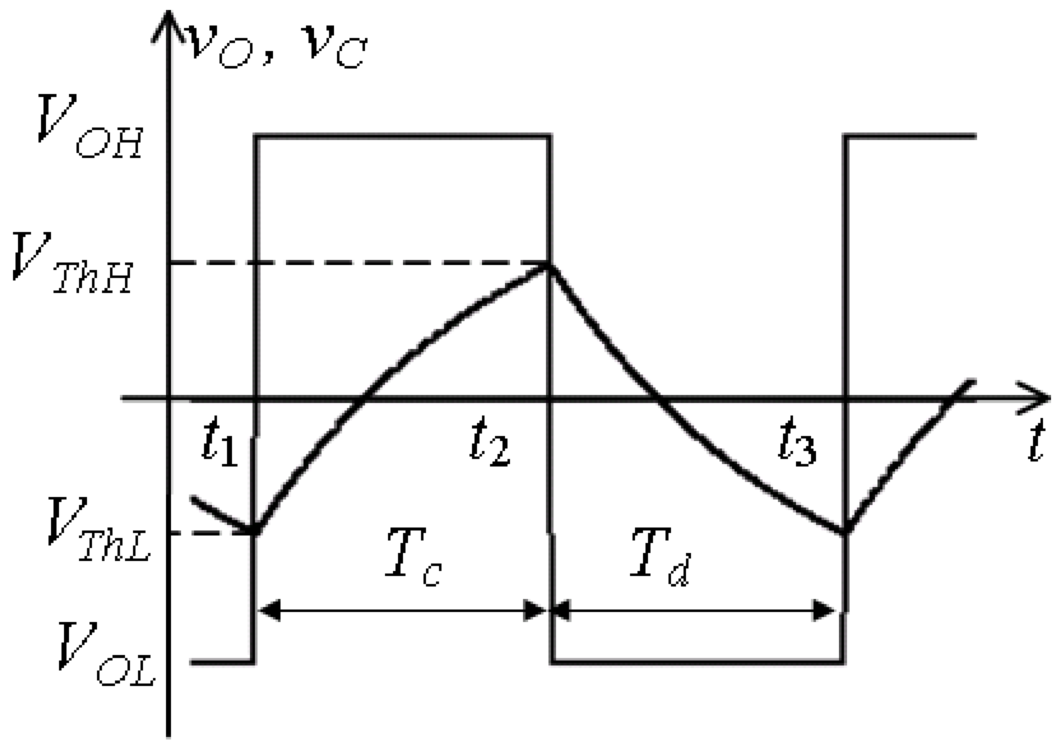


$$V_{ThL} = \frac{R_1}{R_1 + R_2}V_{OL} = rV_{OL}$$

$$V_{ThH} = \frac{R_1}{R_1 + R_2}V_{OH} = rV_{OH}$$

$$t \in (t_1,\ t_2) \qquad V_{ThH} = V_{ThL} e^{-\frac{T_c}{\tau}} + \left(1 - e^{-\frac{T_c}{\tau}}\right) V_{OH}; \quad T_c = \tau \ln \frac{V_{OH} - rV_{OL}}{(1-r)V_{OH}}$$

$$t \in (t_2,\ t_3) \qquad V_{ThL} = V_{ThH} e^{-\frac{T_d}{\tau}} + \left(1 - e^{-\frac{T_d}{\tau}}\right) V_{OL}; \quad T_d = \tau \ln \frac{rV_{OH} - V_{OL}}{(r-1)V_{OL}}$$



$$T = T_c + T_d$$

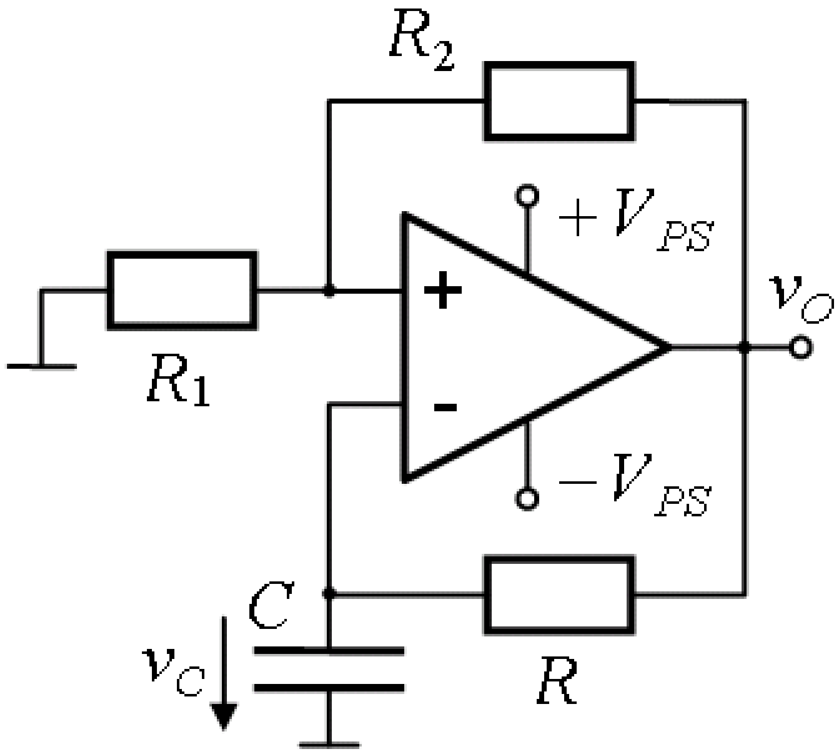
Generally $V_{OH} = -V_{OL}$

$$T_c = T_d = \frac{T}{2} = \tau \ln \frac{1+r}{1-r}$$

$$\boxed{T = 2RC \ln \frac{1+r}{1-r}}$$

If $R_1 = R_2$

$$\boxed{T = 2RC \ln 3 \approx 2{,}2RC}$$



Problem

$\pm V_{PS} = \pm 12\text{V}$, R_1=10kΩ, R_2=20kΩ, R=7.5kΩ and C=10nF. The op amp is a rail-to-rail type.

a) What are the minimum and maximum values for the voltage across the capacitor?

b) What is the frequency of the rectangular signal?

c) Modify the circuit for an adjustable frequency between f_{min}=0.8kHz and f_{max}=8kHz?

a)

$$V_{ThL} = \frac{R_1}{R_1 + R_2} V_{OL} = \frac{10}{10+20}(-12) = -4\text{V}$$

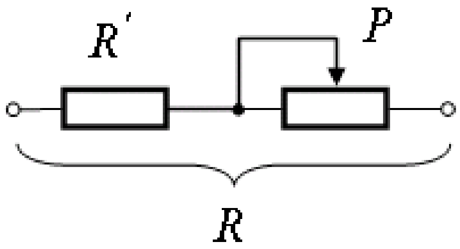
$$V_{ThH} = \frac{R_1}{R_1 + R_2} V_{OH} = \frac{10}{10+20} \cdot 12 = 4\text{V}$$

b) $$r = \frac{R_1}{R_1 + R_2} = \frac{10}{10+20} = \frac{1}{3}$$

$$T = 2RC \ln\frac{1+r}{1-r} = 2\cdot 7.5\text{k}\Omega \cdot 10\text{nF} \cdot \ln\frac{1+1/3}{1-1/3} = 103.5\mu\text{s}$$

$$f = \frac{1}{T} = \frac{1}{166} = 9.7\text{kHz}$$

c) $$T = 2RC\ln\frac{1+r}{1-r} = 2RC\ln 2 = 1.386\,RC$$



$$T_{\min} = \frac{1}{f_{\max}} = 1.386R'\text{C}$$

$$R' = \frac{1}{1.386\, f_{\max} C} = \frac{1}{1.386\cdot 8\text{kHz}\cdot 10\text{nF}} = 9\text{k}\Omega$$

R'=8.87kΩ (1%).

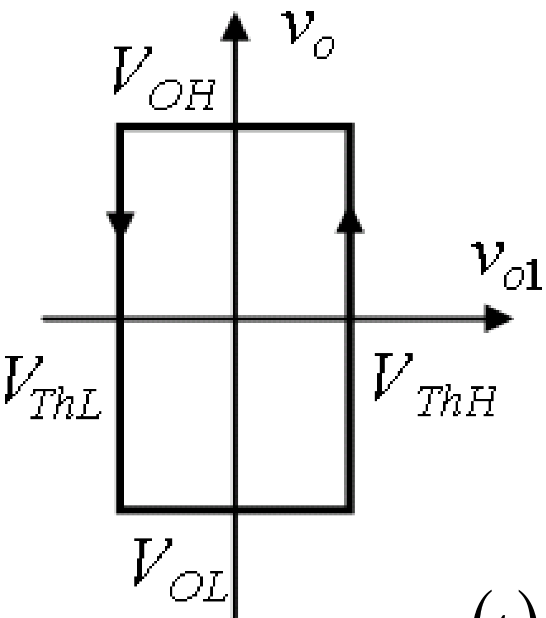
$$T_{\max} = \frac{1}{f_{\min}} = 1.386\left(R' + P\right)\text{C}$$

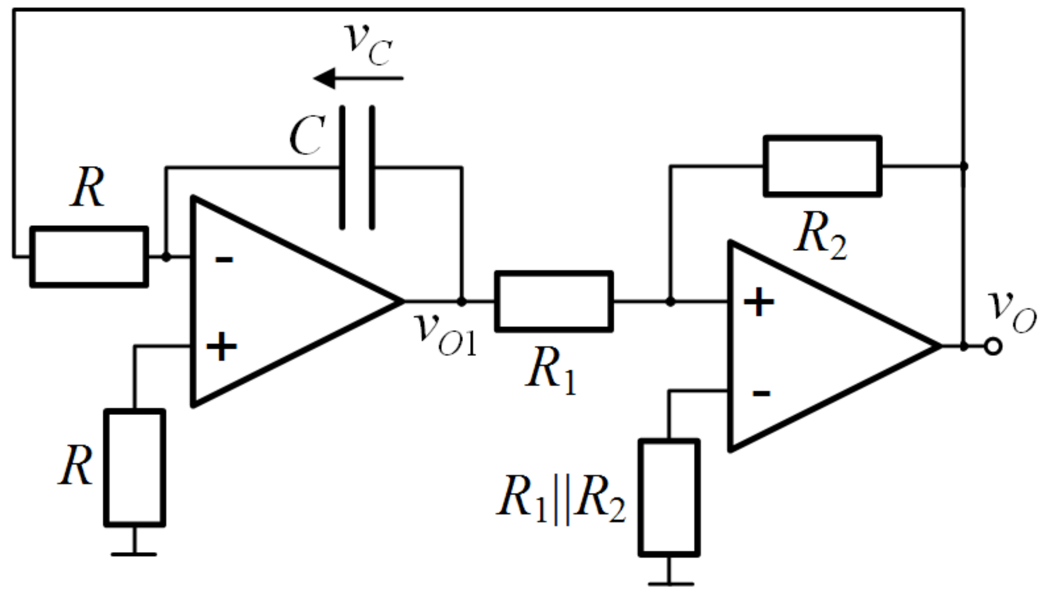
$$P = 9R' = 9\cdot 8.87 = 79.8\text{k}\Omega$$

P=100kΩ

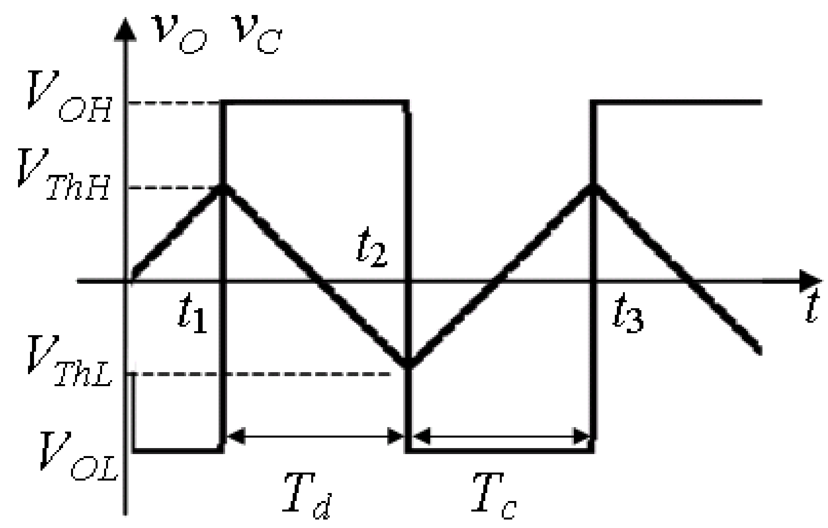
2. Astable multivibrator with an integrator and a comparator

Rectangular and triangular signal generator



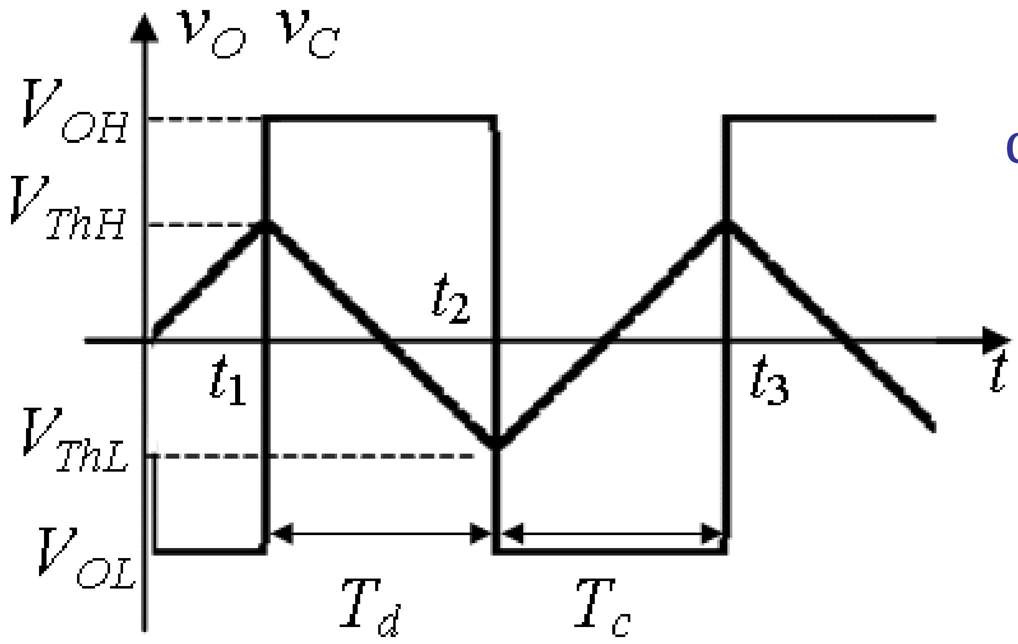


$$v_{o1}(t) = v_C(t)$$



$$V_{ThL} = -\frac{R_1}{R_2} V_{OH}$$

$$V_{ThH} = -\frac{R_1}{R_2} V_{OL}$$



$$C\Delta v_C = i_C \Delta t$$

discharge $$i_C = \frac{0 - V_{OH}}{R} = -\frac{V_{OH}}{R}$$

$$\Delta v_C = V_{ThL} - V_{ThH};$$

$$\Delta t = t_2 - t_1 = T_d$$

$$T_d = RC\frac{V_{ThH} - V_{ThL}}{V_{OH}}$$

$$T = T_d + T_c$$

In general $V_{OH} = -V_{OL}$

$$T_c = RC\frac{V_{ThH} - V_{ThL}}{-V_{OL}}$$

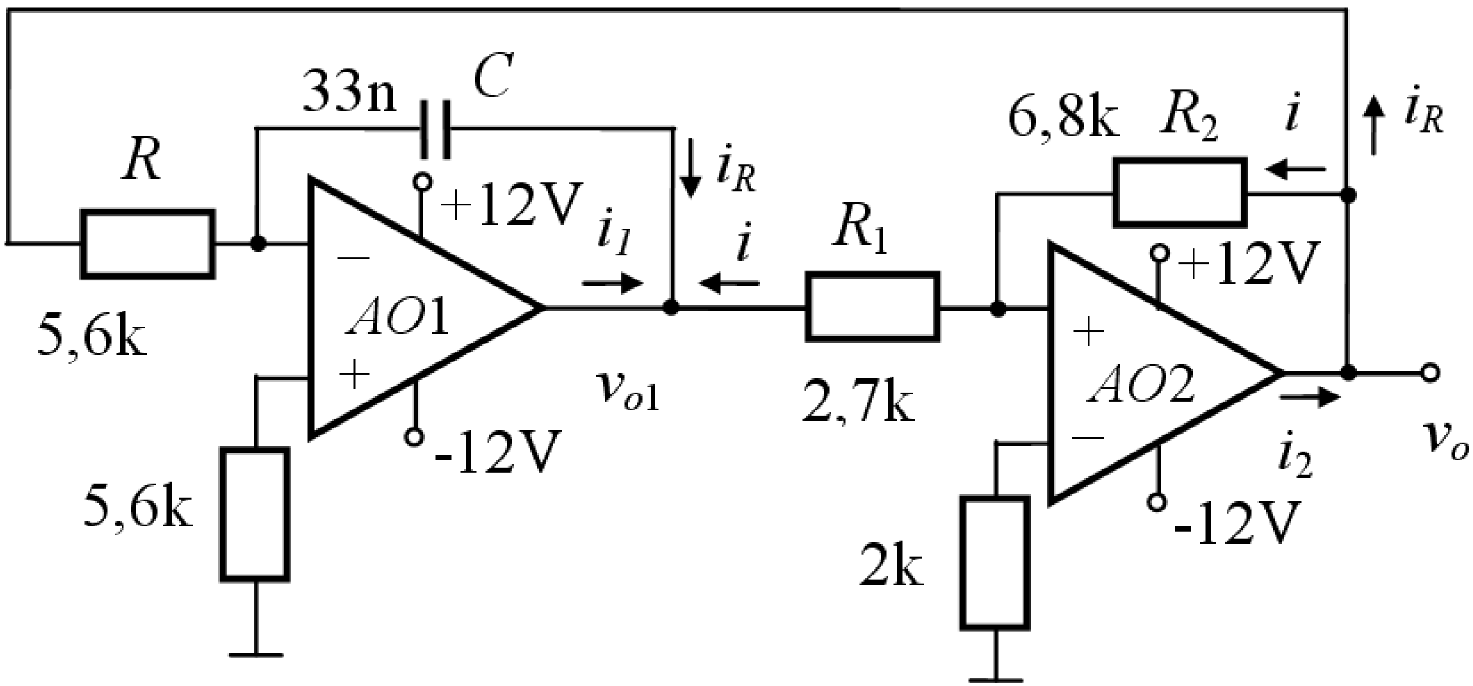
$$\boxed{T = 2RC\frac{V_{ThH} - V_{ThL}}{V_{OH}} = 4RC\frac{R_1}{R_2}}$$

If $R_1 = R_2$

$$\boxed{T = 4RC}$$

$$f = \frac{1}{4RC}$$

Problem



At saturation, the output voltage of op-amps is within 1V of the supply

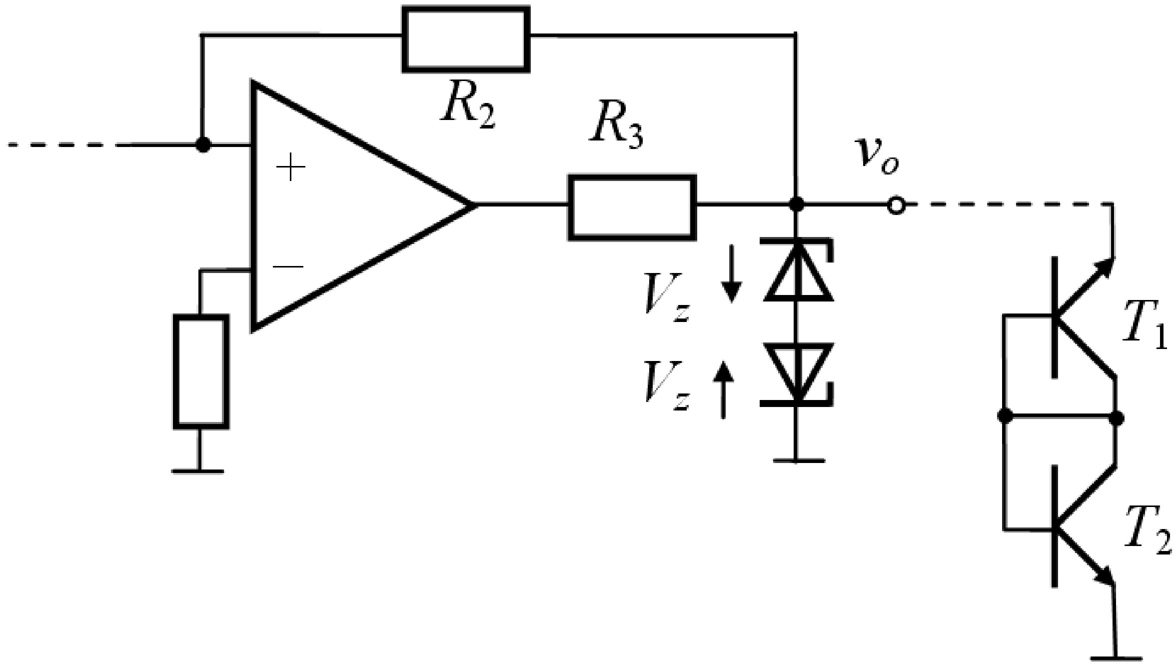
a) What is the amplitude of the triangular voltage?

b) What is the oscillation frequency?

c) What is the maximum value of the current to the output of each op amp?

The independence of the supply voltage

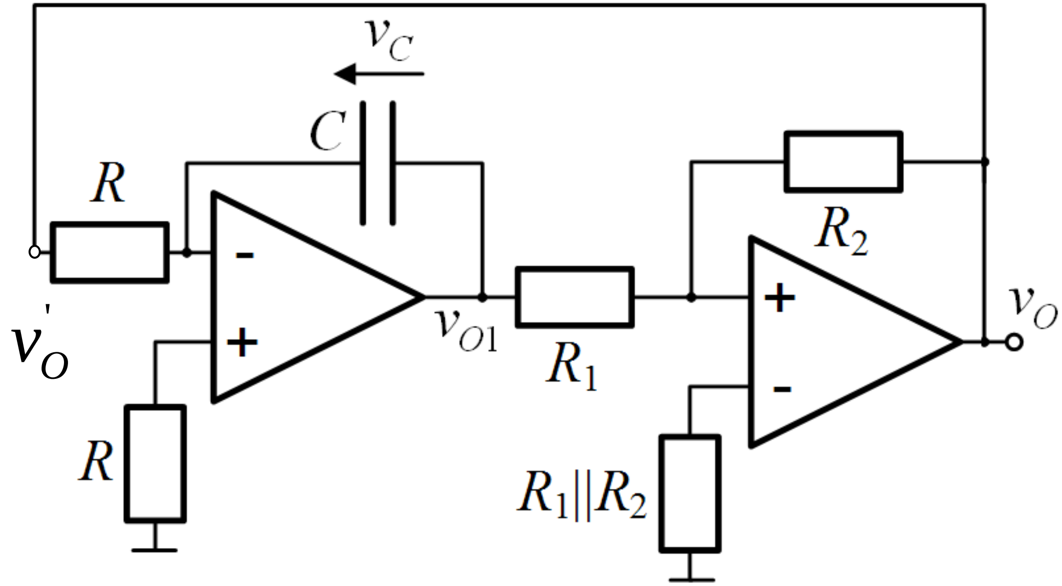
OPTIONAL



$$V_{OH} = V_Z + 0{,}7\text{V}; \qquad V_{OL} = -V_Z - 0{,}7\text{V}$$

The reverse-biased base to emitter junction behaves as a Zener diode, regulating the voltage at a voltage dependent on the transistor type and on the emitter current (5V … 8V) .

Frequency adjustment



$$T = 2RC\frac{V_{ThH} - V_{ThL}}{V_{OH}}$$

$$V_{ThL} = -\frac{R_1}{R_2}V_{OH};\quad V_{ThH} = -\frac{R_1}{R_2}V_{OL};\quad V_{OH} = -V_{OL};\quad V_{ThH} - V_{ThL} = 2\frac{R_1}{R_2}V_{OH}$$

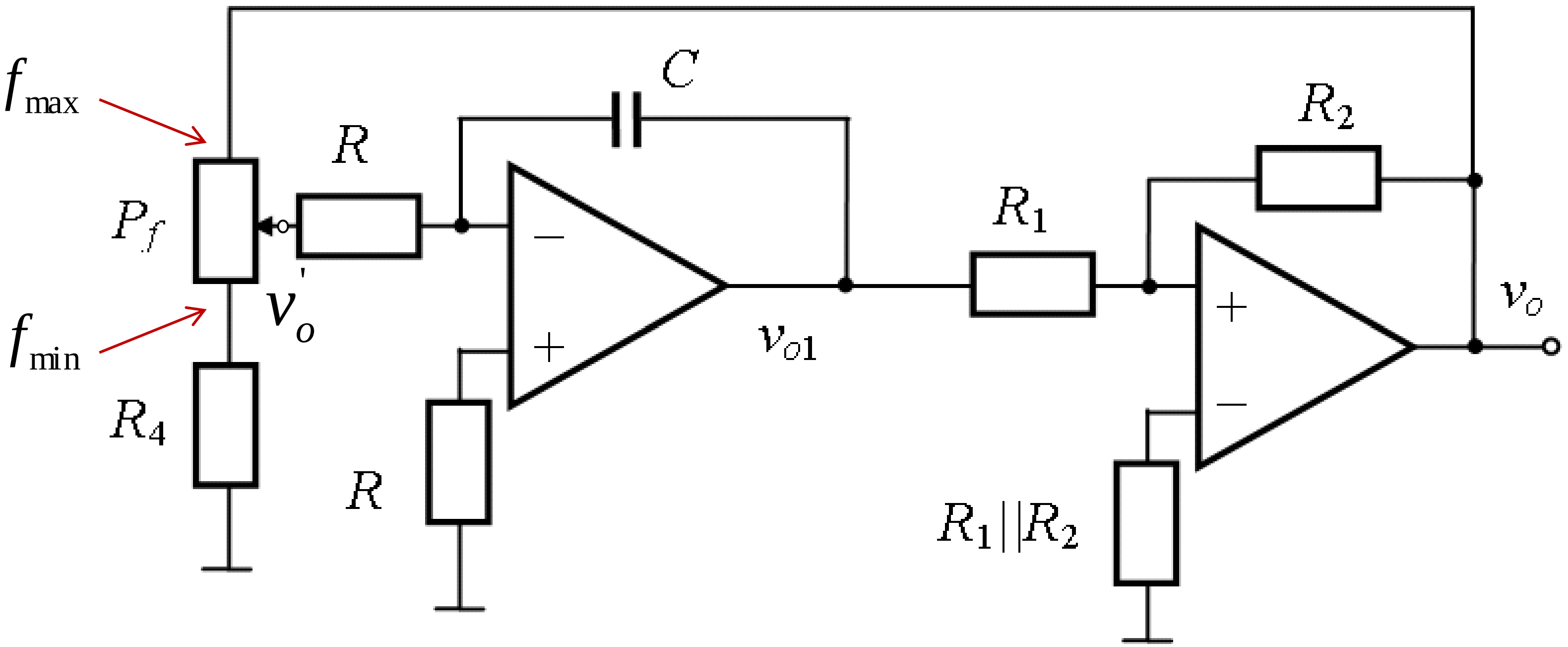
v_O

$$T = 2RC\frac{2\frac{R_1}{R_2}V_{OH}}{V_{OH}} = 4RC\frac{R_1}{R_2}\frac{V_{OH}}{V_{OH}'} \qquad f = \frac{1}{4RC}\frac{R_2}{R_1}\frac{V_{OH}'}{V_{OH}}$$

v_O'

If V_{OH}' can be adjusted, then the period (frequency) can be adjusted

Frequency adjustment - cont.



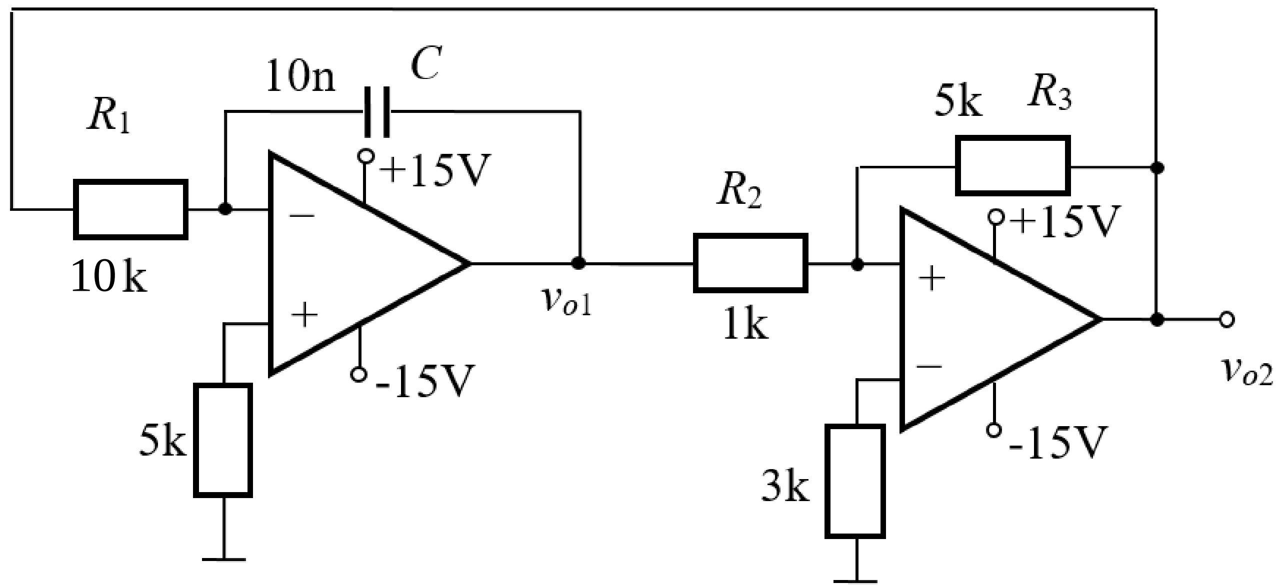
$$\text{If } v_o' = v_o;$$

$$\text{If } v_o' = \frac{R_4}{R_4 + P_f} v_o;$$

$$f_{max} = \frac{1}{4RC}\frac{R_2}{R_1};$$

$$f_{min} = \frac{1}{4RC}\frac{R_2}{R_1}\frac{R_4}{R_4 + P_f}$$

Problem

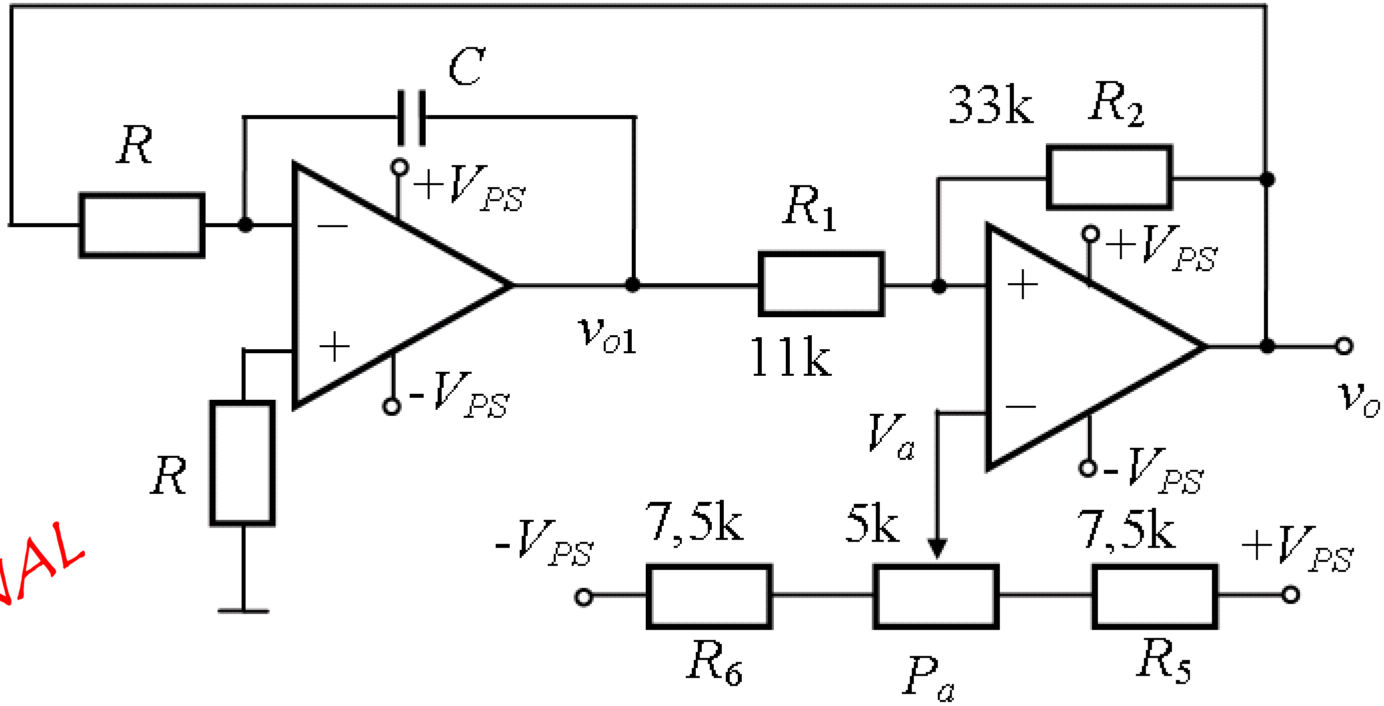


Consider rail-to-rail op-amps

a) What is the oscillation frequency?

b) Modify the circuit to obtain an adjustable frequency in the range of [5; 25] kHz.

Offset adjustment of the triangular voltage



OPTIONAL

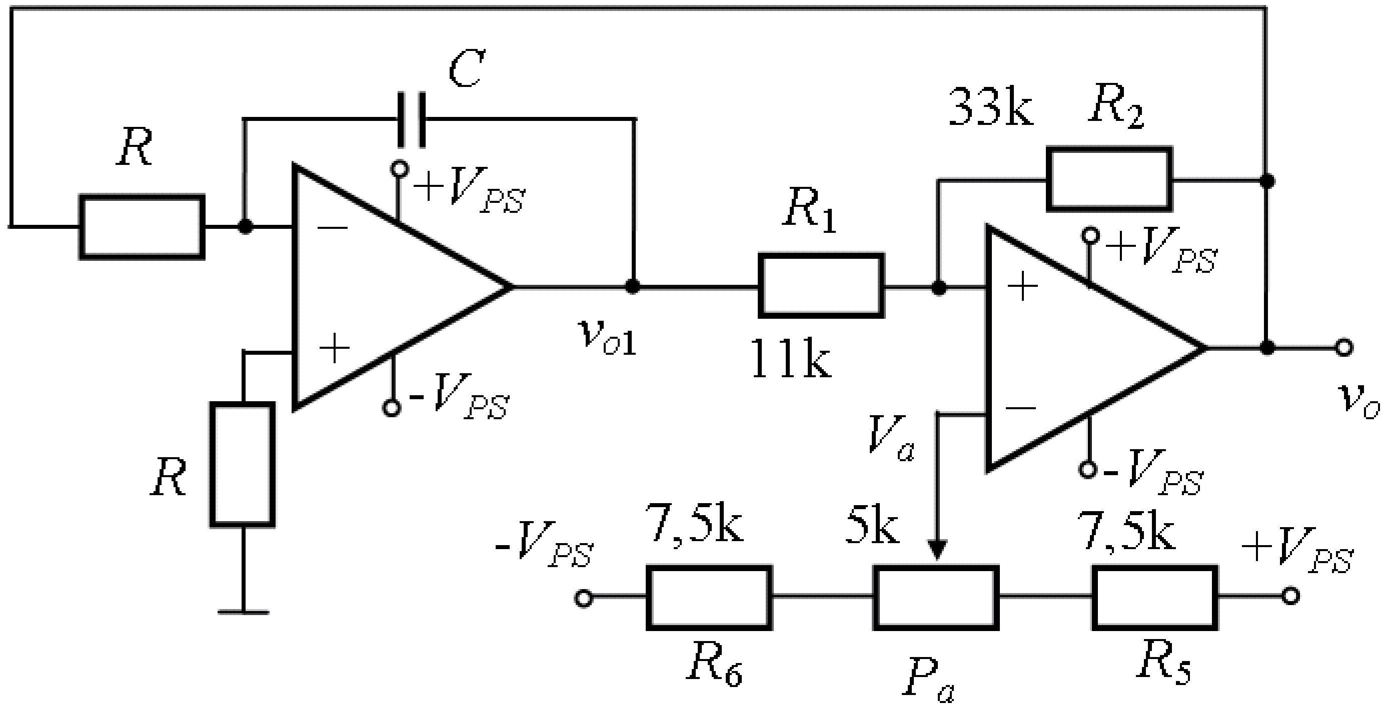
From *Pa* one can move the hysteresis along the horizontal axis, thus adjusting the offset (dc level) of the triangular voltage.

$$V_{ThL} = \left(1 + \frac{R_1}{R_2}\right)V_a - \frac{R_1}{R_2}V_{OH} \qquad V_{ThH} = \left(1 + \frac{R_1}{R_2}\right)V_a - \frac{R_1}{R_2}V_{OL}$$

$$V_{a\max} = \frac{P_a + R_6}{R_5 + P_a + R_6}V_{PS} + \frac{R_5}{R_5 + P_a + R_6}\left(-V_{PS}\right) = 3.75\text{V}$$

OPTIONAL

Offset adjustment of the triangular voltage



$$V_{a\min} = \frac{R_6}{R_5 + P_a + R_6} V_{PS} + \frac{P + R_5}{R_5 + P_a + R_6}\left(-V_{PS}\right) = -3{,}75\mathrm{V}$$

The offset can be adjusted between

$$V_{o1\max} = \left(1 + \frac{11}{33}\right) \cdot 3{,}75 = 5\mathrm{V};$$

$$V_{o1\min} = \left(1 + \frac{11}{33}\right) \cdot (-3{,}75) = -5\mathrm{V}$$

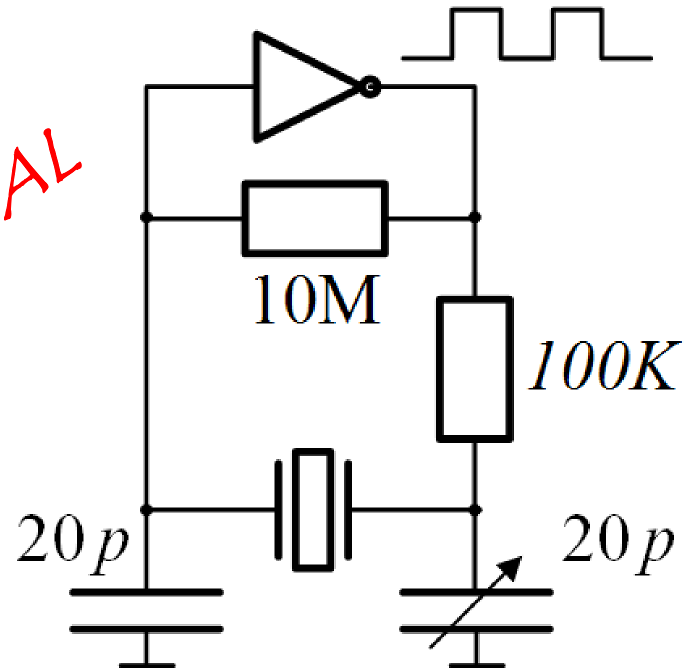
Specialized integrated circuits for signals generation

- NE566 - Function generator VCO, square, triangular - 1MHz
- AD9833 - Low power, programmable waveform generator: sine, triangular, and square wave. No external components. Frequency and phase are software programmable. 3-wire serial interface. Power-down function (SLEEP). 0 MHz to 12.5 MHz output frequency range .
- 555 - highly stable device for generating accurate time delays or oscillation (astable and monostable)

Clock generators

- Quartz-crystal oscillator

OPTIONAL



f_0=1, 2, 4, 5, … , 20MHz

f_0=14,31818MHz - video adapter in personal computers

f_0=32,768KHz - digital wristwatch, divide by 2^{15} to get 1Hz

- NOT gates oscillator