Non-sinusoidal Signal Generators

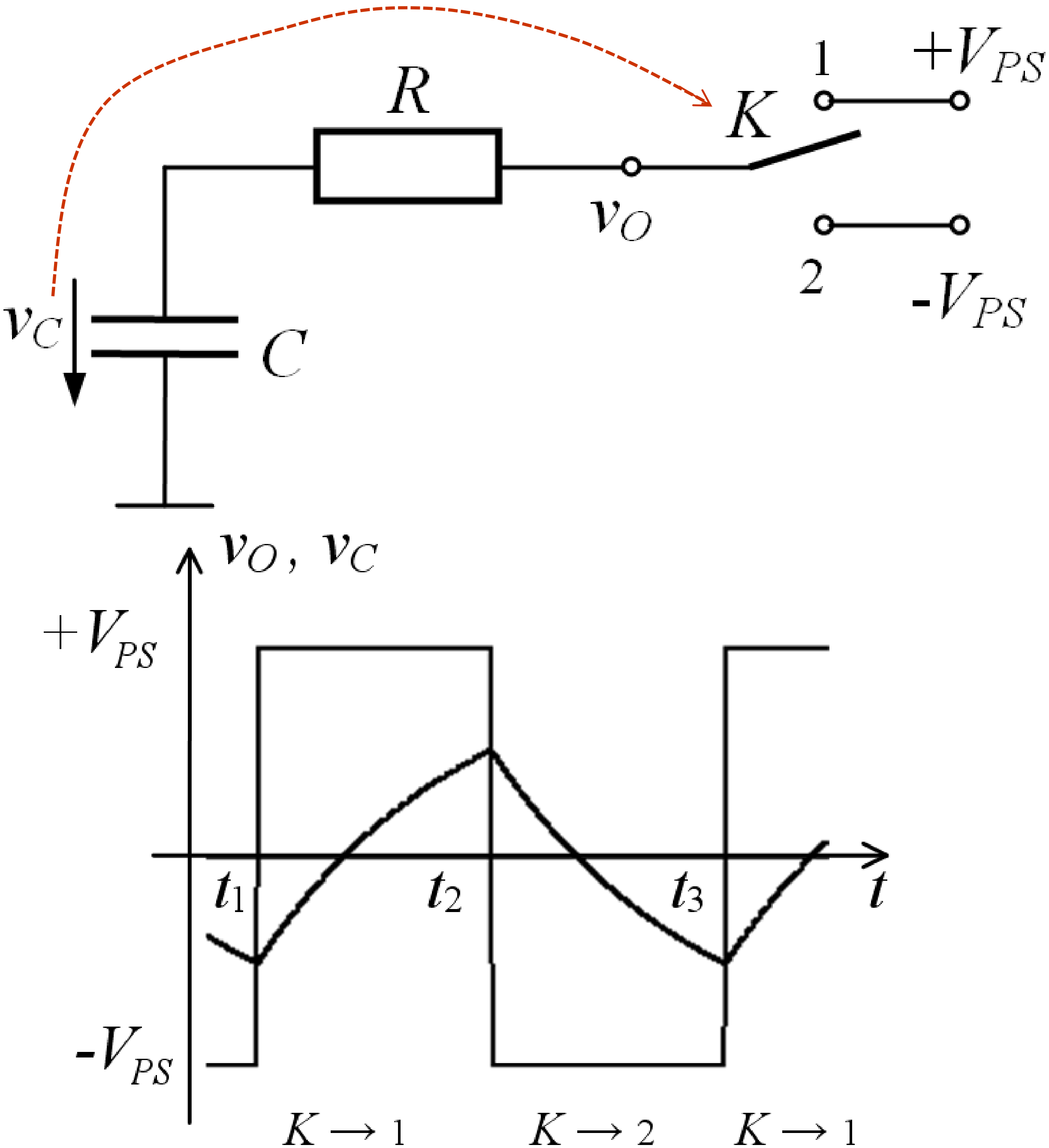
- rectangle, triangle, saw tooth, pulse, etc.

  Multivibrator circuits:

  - **astable** – no stable states (two quasi-stable states; it remains in each state for a predetermined times)
  - monostable – one stable state, one unstable state
  - bistable – two stable states

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

Astable multivibrators (Relaxation oscillators)

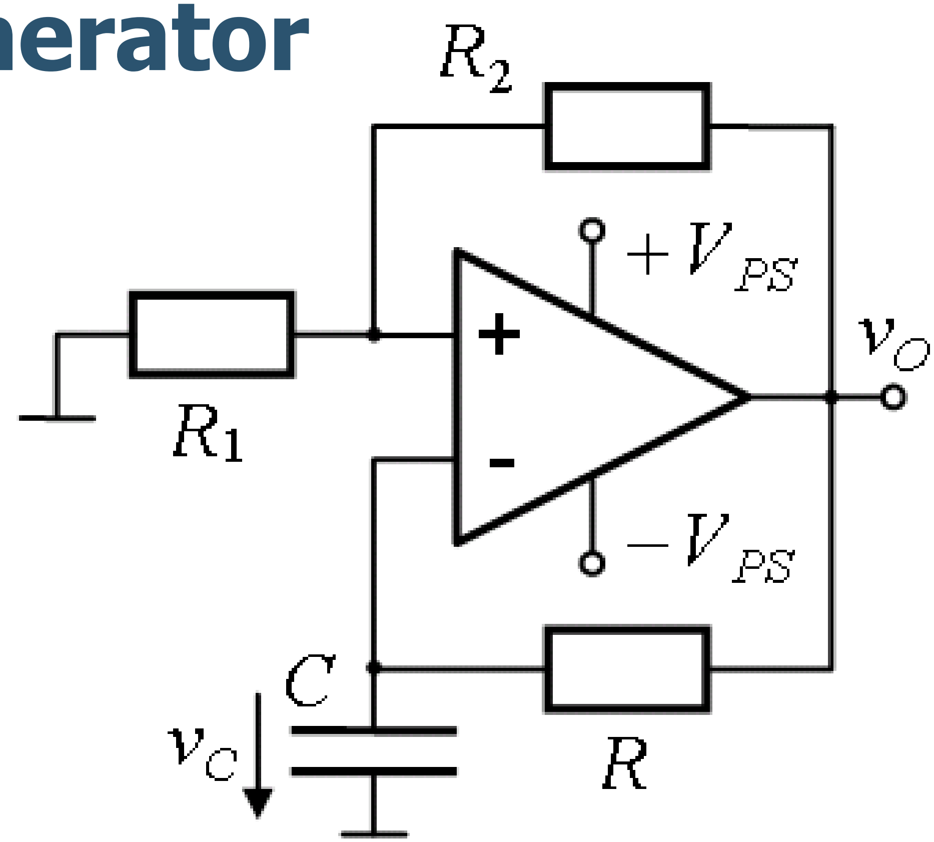


Operating principle

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

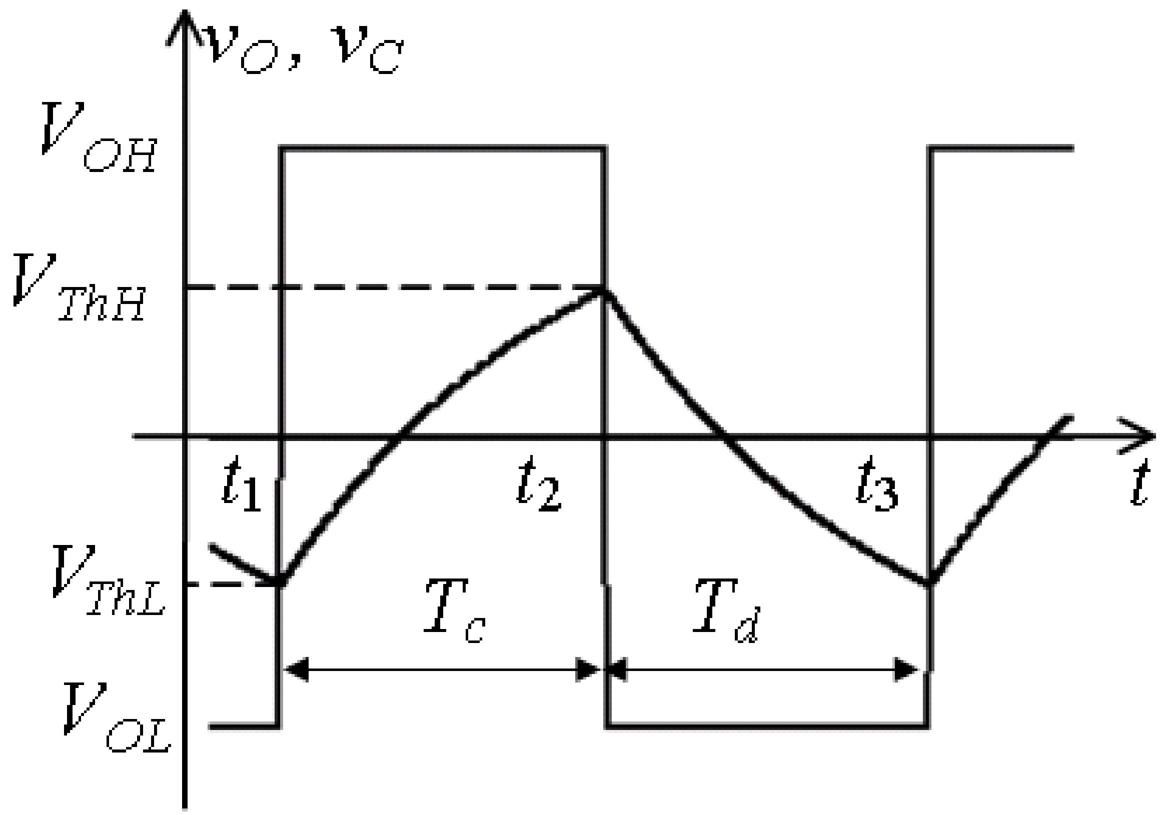
- if the voltage across the capacitor is fed to a PF comparator, a **rectangular wave** is obtained

Rectangular signal generator



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

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

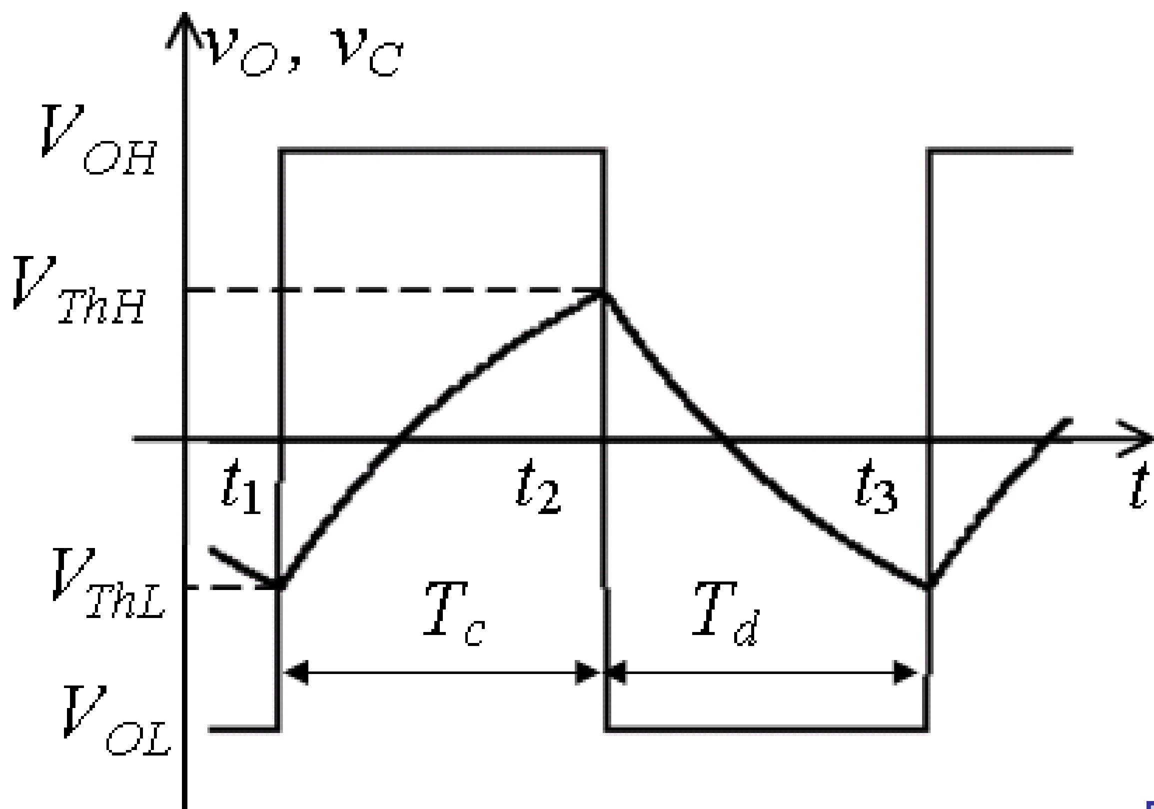


$$V_{ThL} = \frac{R_1}{R_1 + R_2} V_{OL} = rV_{OL}$$

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

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

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



$$T = T_c + T_d$$

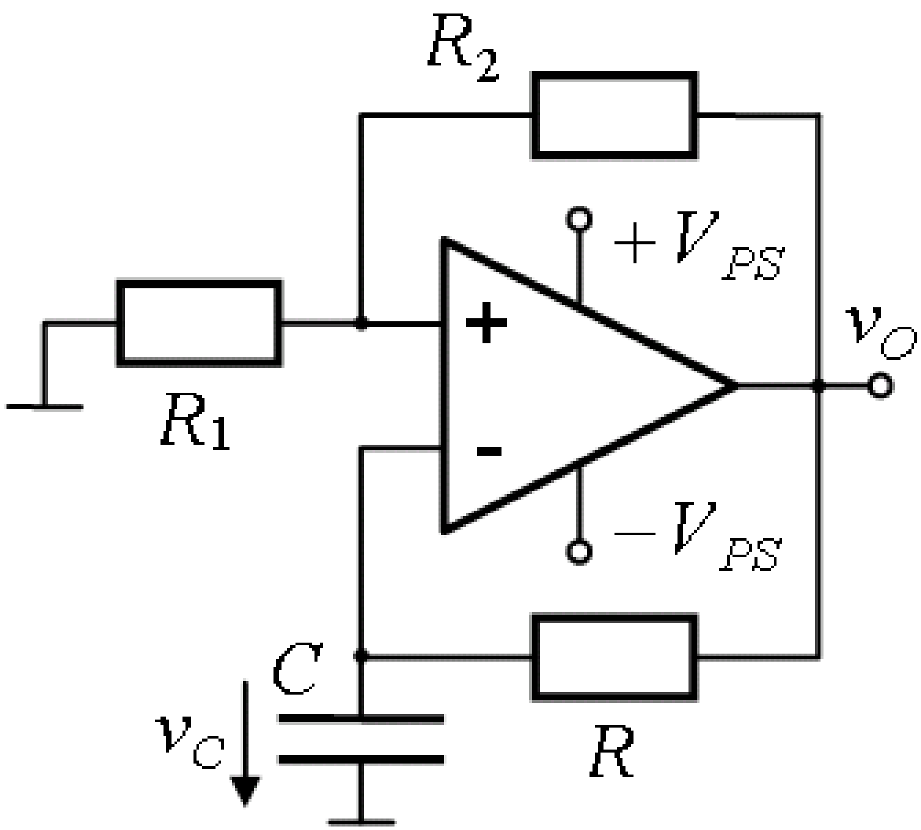
Generally $V_{OH} = -V_{OL}$

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

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

If $R_1 = R_2$

$$T = 2RC \ln 3 \approx 2.2RC$$



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)

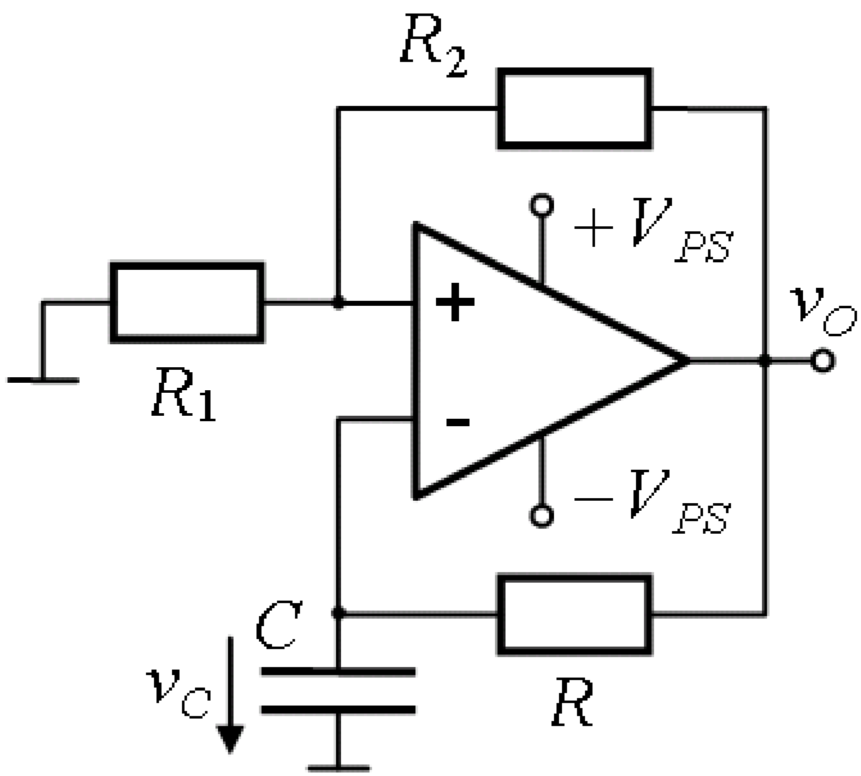
$$V_{ThL} = \frac{R_1}{R_1 + R_2} V_{OL} = \frac{10}{10+20}(-12) = -4\text{V}$$

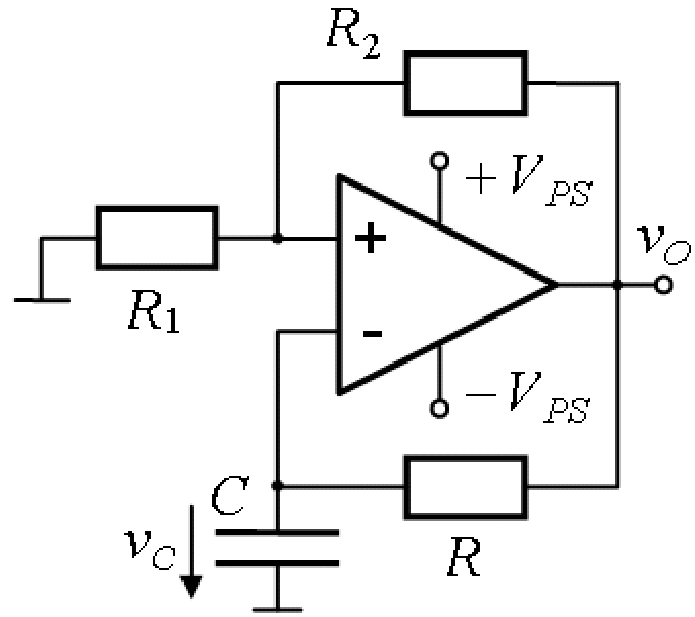
$$V_{ThH} = \frac{R_1}{R_1 + R_2} V_{OH} = \frac{10}{10+20} \cdot 12 = 4\text{V}$$

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

$$T = 2RC \ln\frac{1+r}{1-r} = 2 \cdot 7.5\text{k}\Omega \cdot 10\text{nF} \cdot \ln\frac{1+1/3}{1-1/3} = 104\mu\text{s}$$

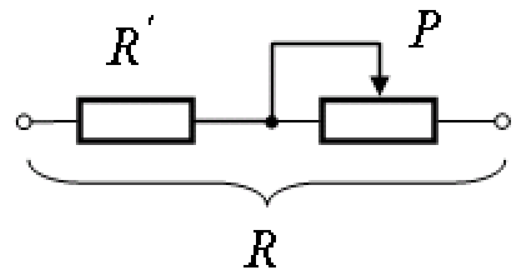
$$f = \frac{1}{T} = \frac{1}{104} = 9.6\text{kHz}$$





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

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



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

Select R'=8.87 kΩ (1%).

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

$$R' + P = 90\,\text{k}\Omega; \quad P = 90 - 8.87 = 81.13\,\text{k}\Omega$$

Select P =100 kΩ

Checking for numerical values

How can the astable multivibrator circuit be enhanced to generate a pure triangular signal?

In the astable circuit the capacitor is charged/discharged in a series RC circuit under a constant voltage => variable current

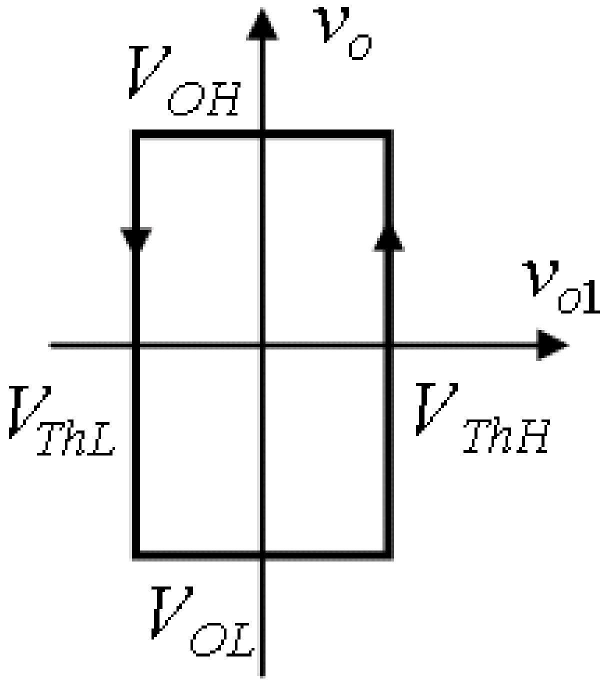
$$C dv_c = i_c dt; \;\; v_c(t) = \frac{1}{C}\int_{t_1}^{t_2} i_c dt$$

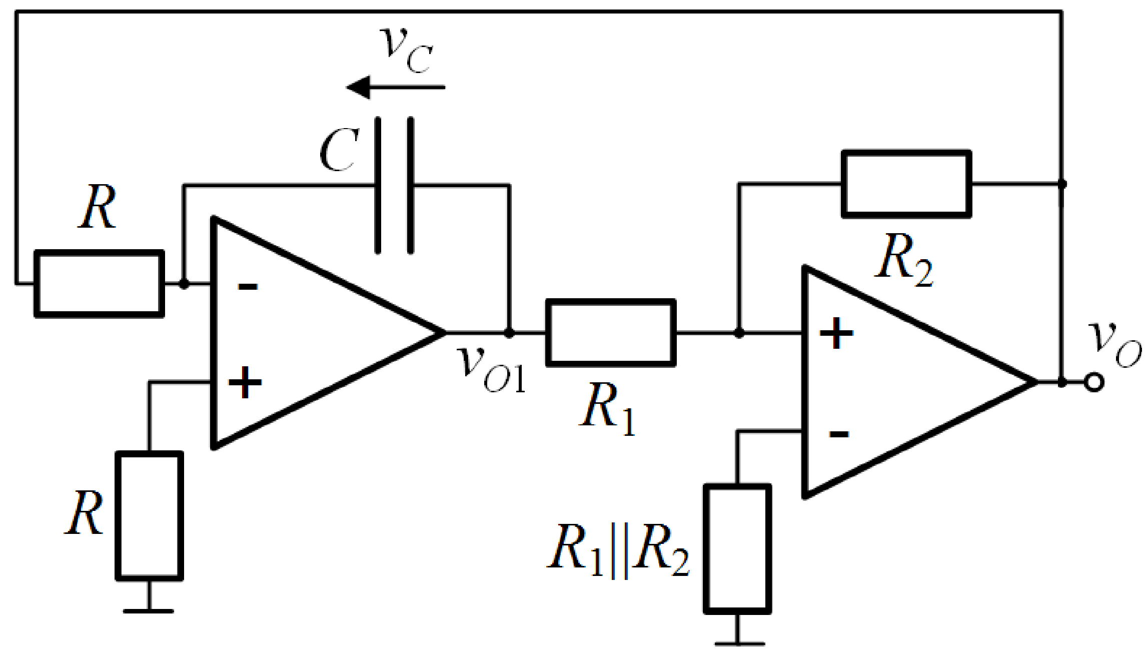
If one can set $i_c = I_C = \text{cst.}$ $\quad v_c(t) = \frac{1}{C} I_c t \Big|_{t_1}^{t_2}$

It results a linear variation in time of the voltage across the capacitor

To obtain a triangular signal, the capacitor should be charged / discharge under a constant current

Rectangular and triangular signal generator

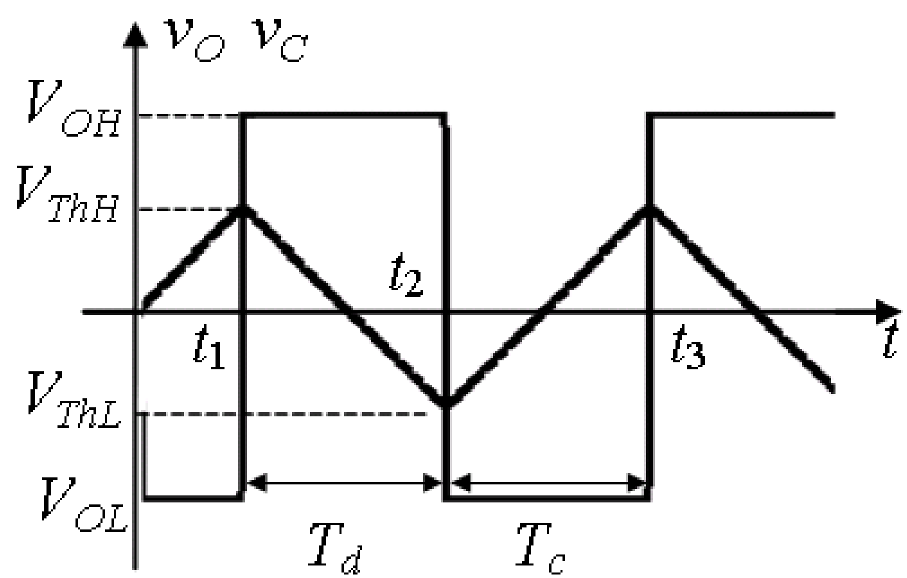


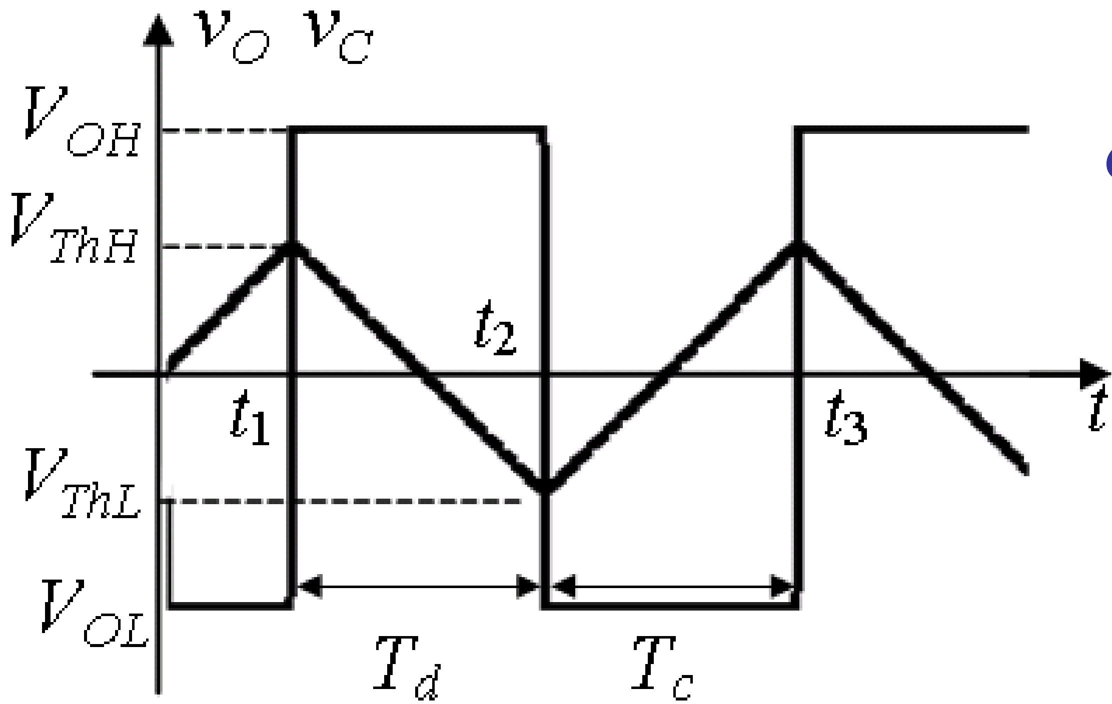


$$v_{o1}(t) = v_C(t)$$

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

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





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

discharge

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

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

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

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

$$T = T_d + T_c$$

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

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

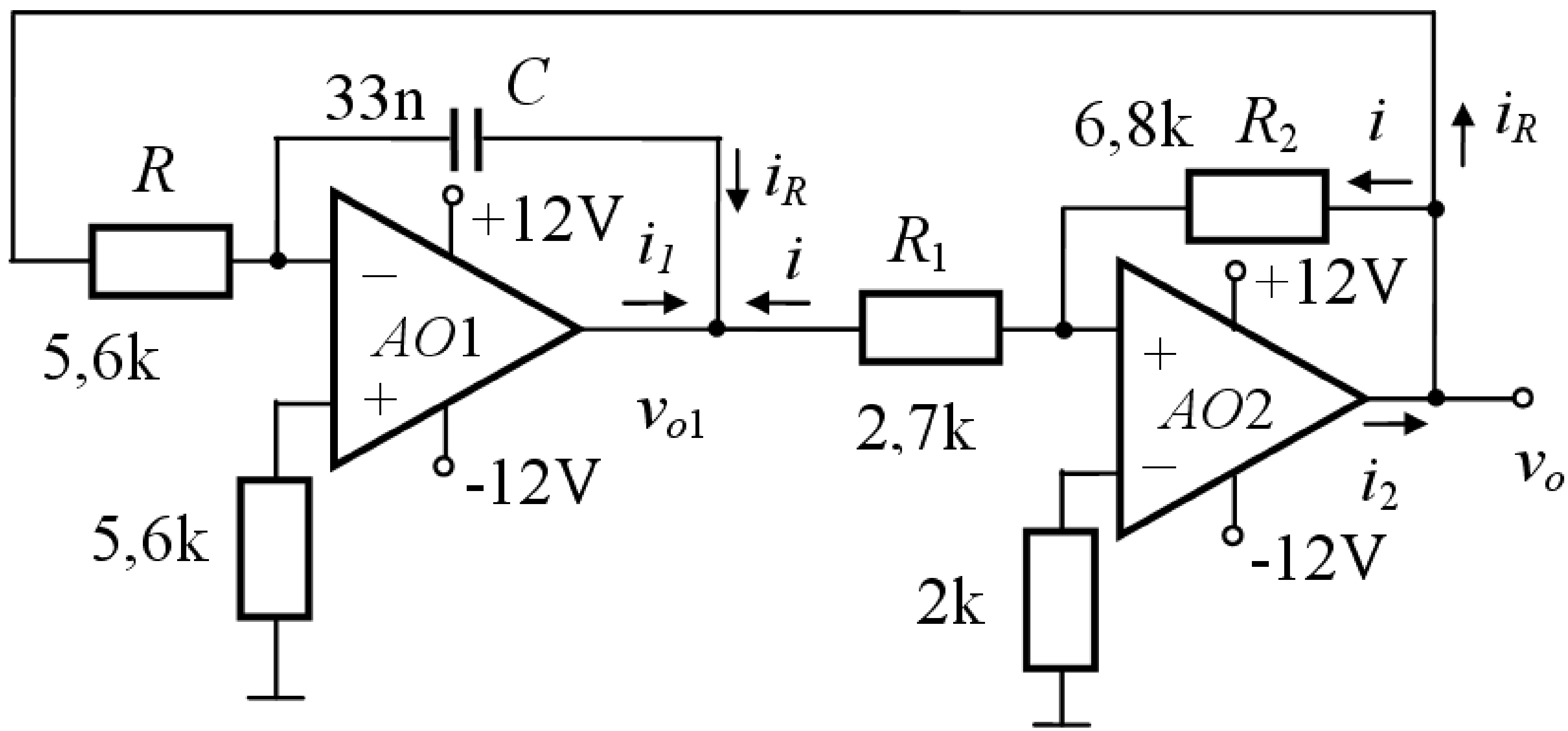
$$T = 2RC\frac{V_{ThH} - V_{ThL}}{V_{OH}} = 4RC\frac{R_1}{R_2}$$

If $R_1 = R_2$

$$T = 4RC$$

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

Problem

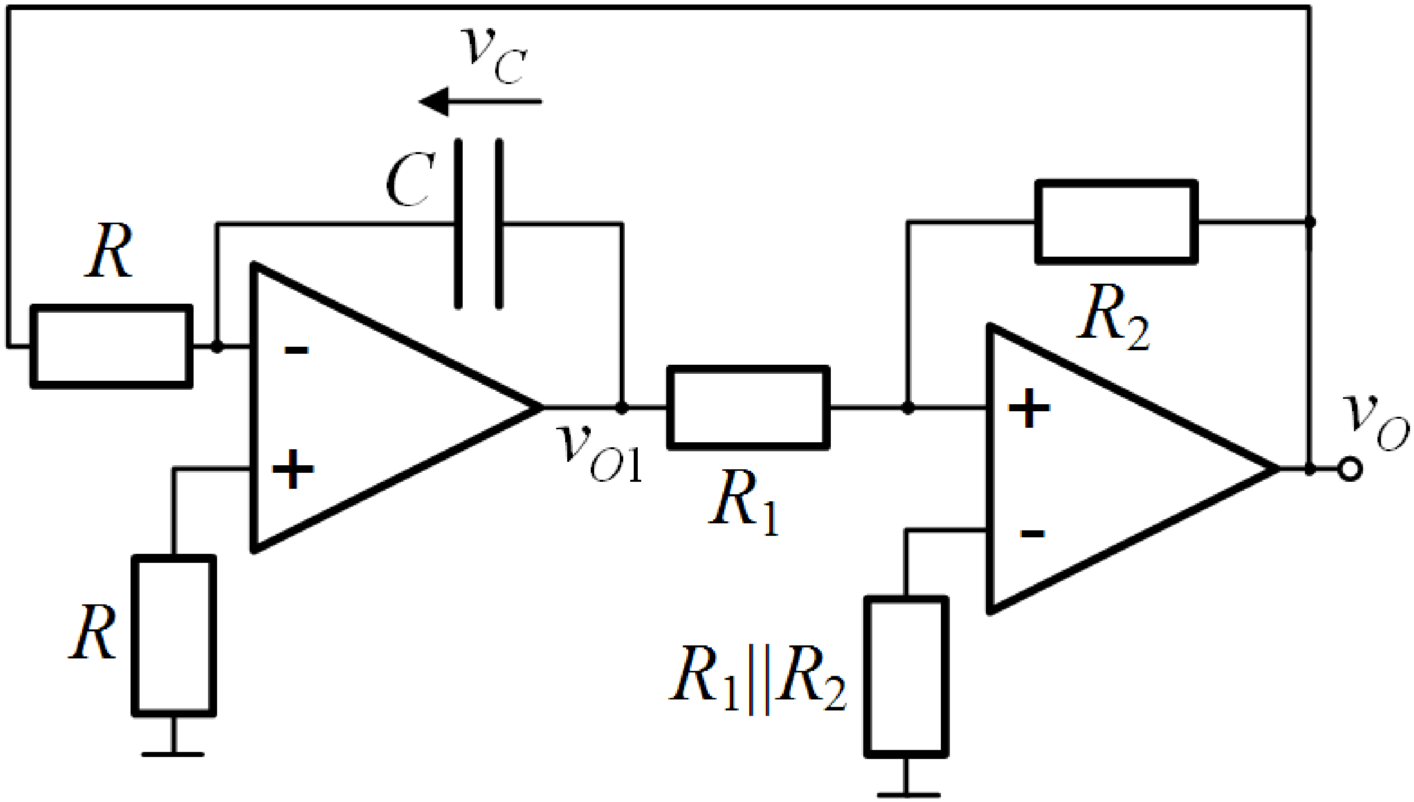


At saturation the output voltage of *AO2* is within 1V of the supply

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?



Frequency adjustment

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

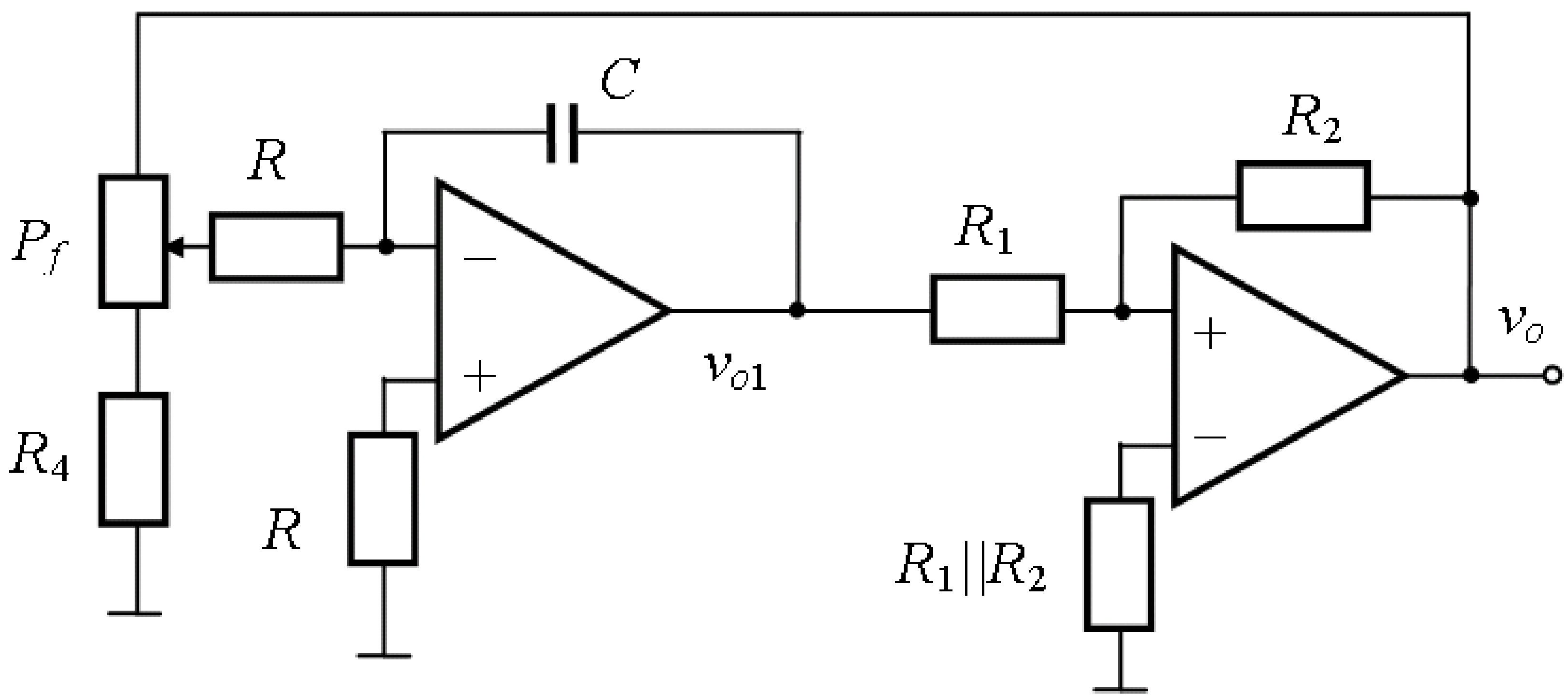
$$\Delta t = \frac{C\Delta v_C}{i_C}$$

- Range adjustment: switching *C*
- Continuous adjustment: adjusting the current trough *C*

$$|\, i_C \,| = \frac{V_O}{R} \quad (V_O = V_{OL} \text{ or } V_O = V_{OH})$$

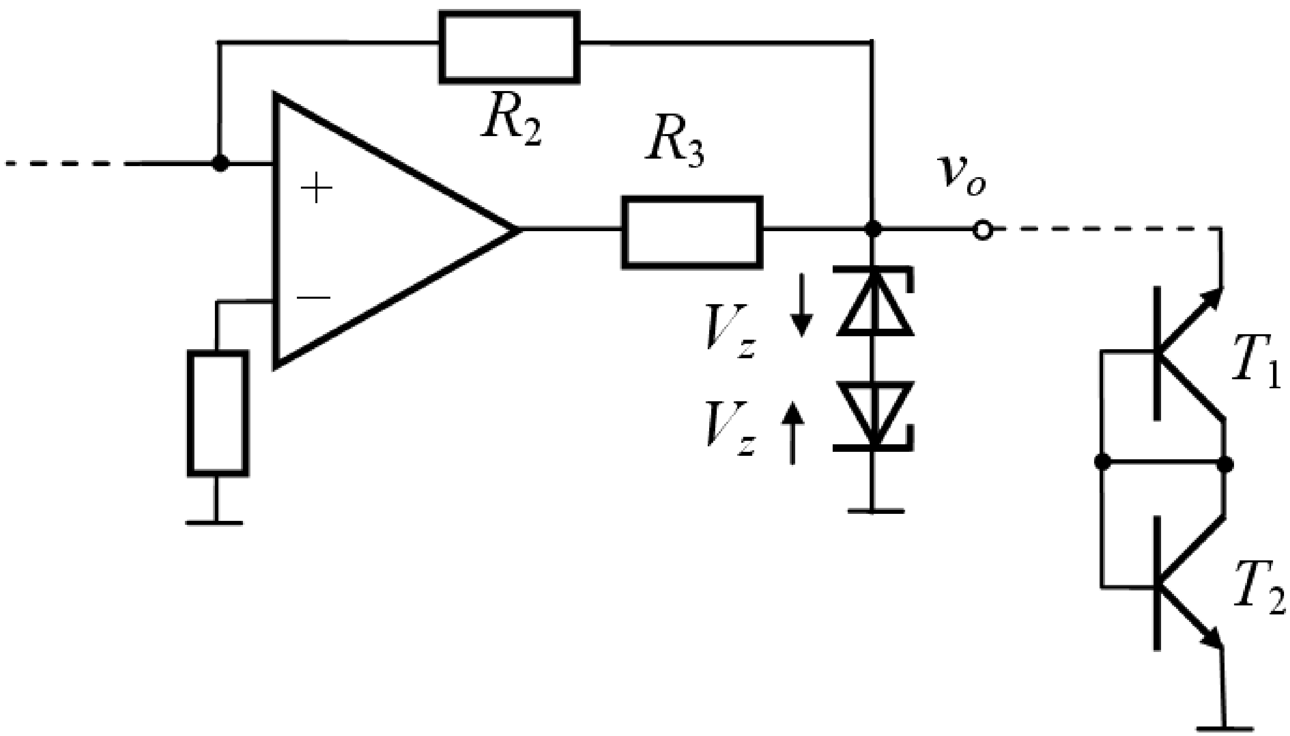
- *R* – adjustable (*R'* +*P*)
- Adjust the voltage applied across *R*

Frequency adjustment -
adjust the voltage applied across *R*



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

The independence of the supply voltage

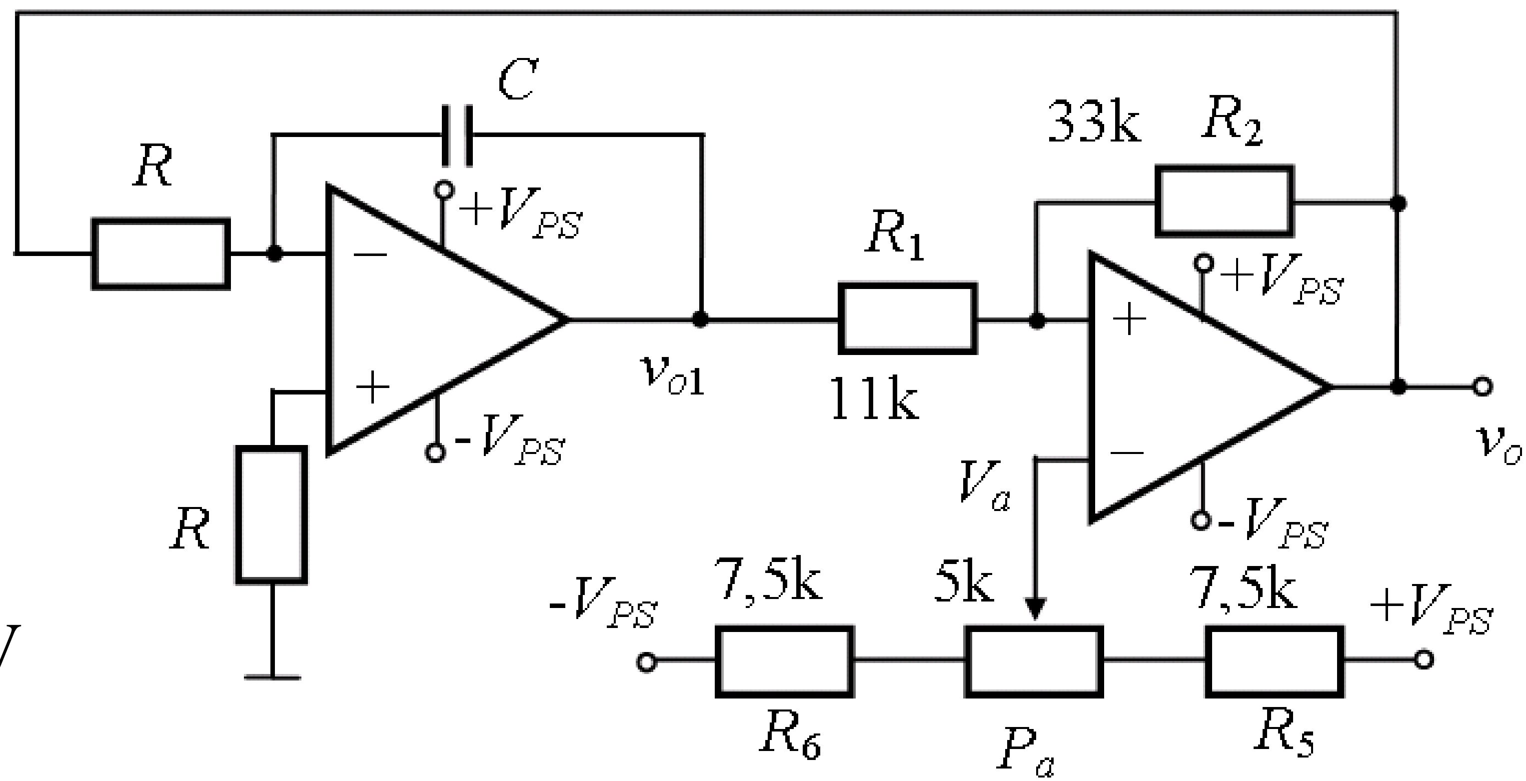


$$V_{OH} = V_Z + 0{,}7\text{V}; \qquad V_{OL} = -V_Z - 0{,}7\text{V}$$

What is the role of R_3?

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) .

Offset adjustment of the triangular voltage



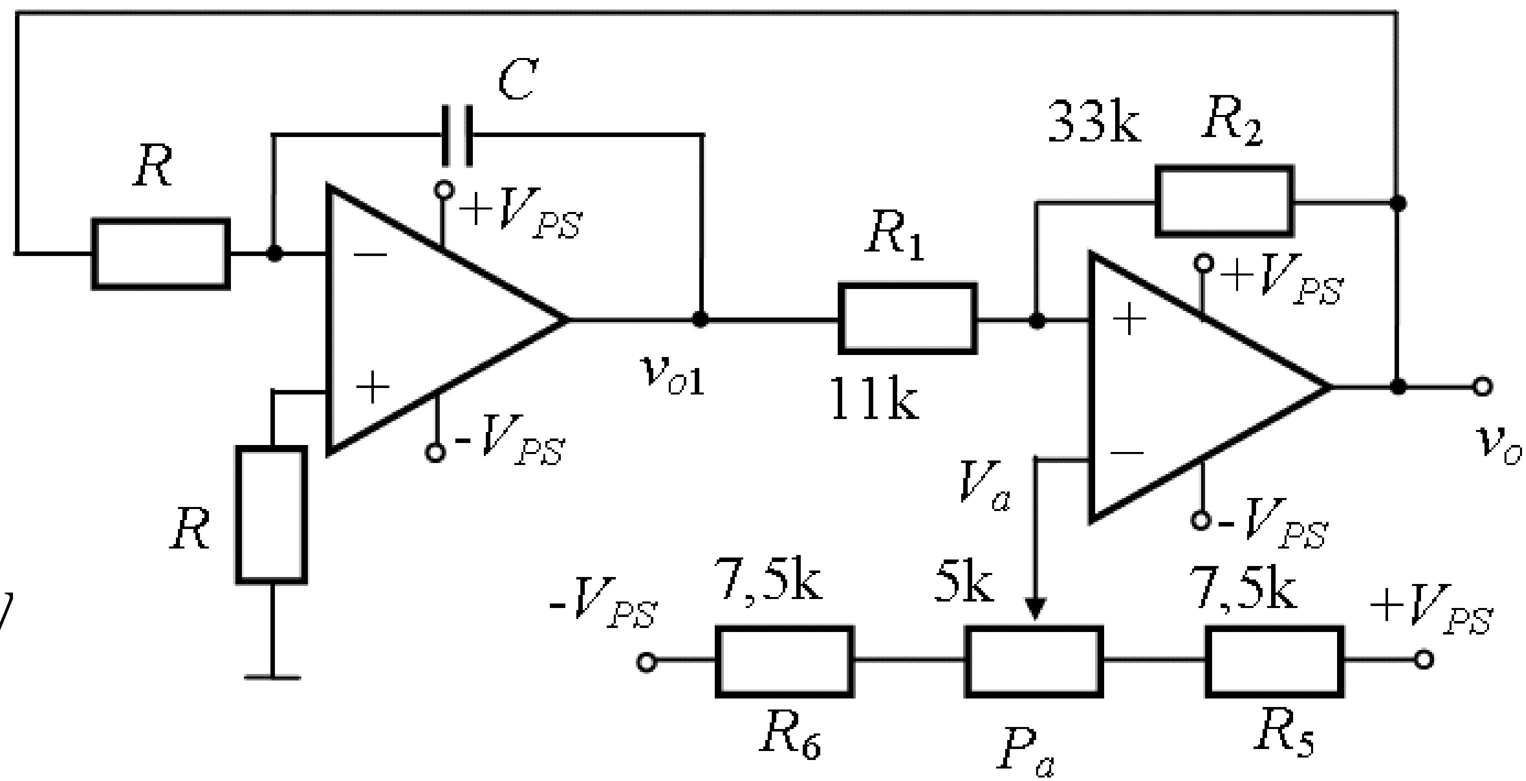
$\pm V_{PS} = \pm 15\text{V}$

Based on the translation of hysteresis for the PF comparator.

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

$$V_{a\max} = \frac{P_a + R_6}{R_5 + P_a + R_6}V_{PS} + \frac{R_5}{R_5 + P_a + R_6}\left(-V_{PS}\right) = \frac{15}{4}\text{V} = 3.75\,\text{V}$$

Offset adjustment of the triangular voltage



$\pm V_{PS} = \pm 15\text{V}$

$$V_{a\min} = \frac{R_6}{R_5 + P_a + R_6} V_{PS} + \frac{P + R_5}{R_5 + P_a + R_6}\left(-V_{PS}\right) = -\frac{15}{4}\text{V} = -3{,}75\text{V}$$

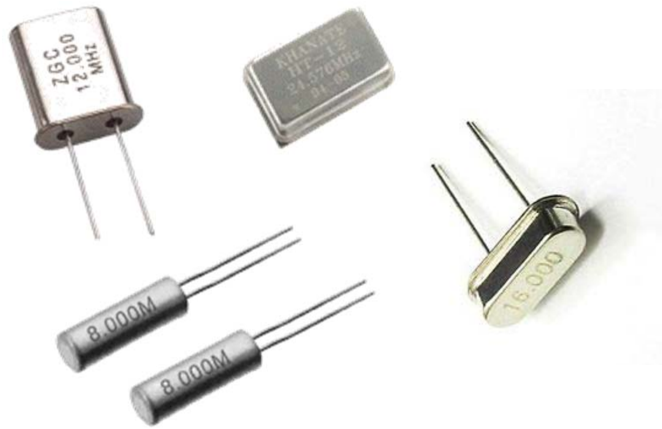
The offset can be adjusted between

$$V_{o1\max} = \left(1 + \frac{11}{33}\right) \cdot \frac{15}{4} = 5\text{V}; \qquad V_{o1\min} = \left(1 + \frac{11}{33}\right) \cdot \left(-\frac{15}{4}\right) = -5\text{V}$$

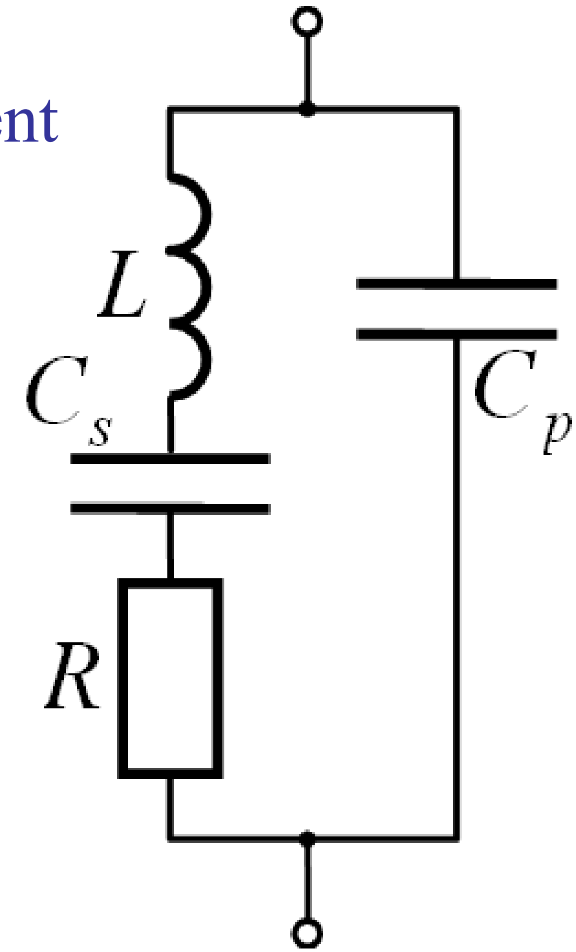
Specialized integrated circuits for signals generation

- 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) - timer

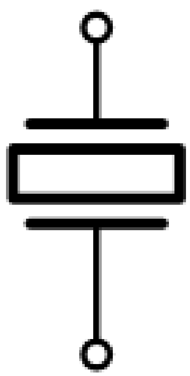
Quartz-crystal



equivalent electric circuit



circuit symbol

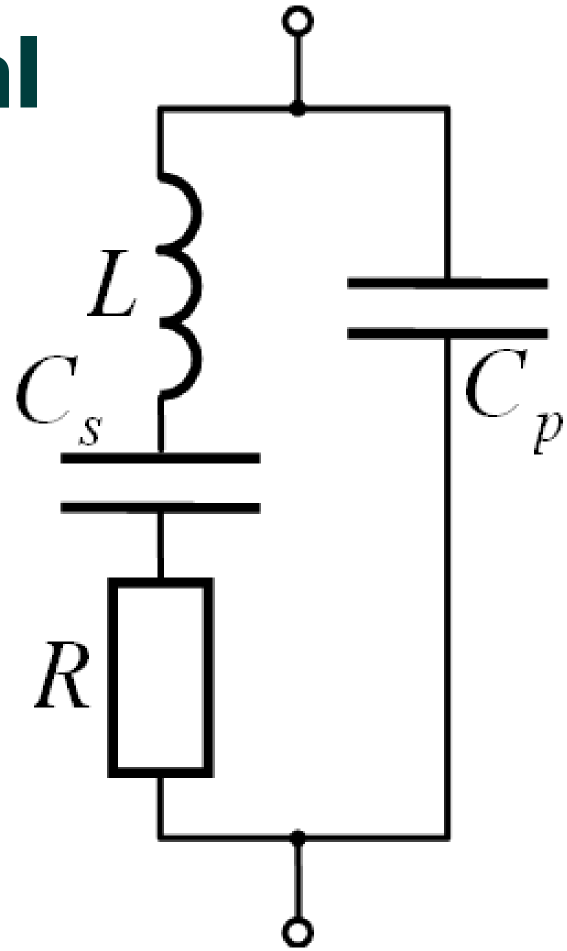


Quartz is amongst one of the most common minerals in the Earth's continental crust.

It has a hexagonal crystal structure made of trigonal crystallized silica (silicon dioxide, SiO_2)

Quartz-crystal

equivalent electric circuit



$$C_p \gg C_s$$

R – very low value *can be neglected*

- Series resonance

$$f_s = \frac{1}{2\pi\sqrt{LC_s}}$$

- Parallel resonance

range: tens of KHz … hundreds of MHz

$$f_p = \frac{1}{2\pi\sqrt{L\left(\frac{C_p C_s}{C_p + C_s}\right)}}$$

$$f_p \approx \frac{1}{2\pi\sqrt{LC_s}} = f_s$$

Quartz-crystal oscillator

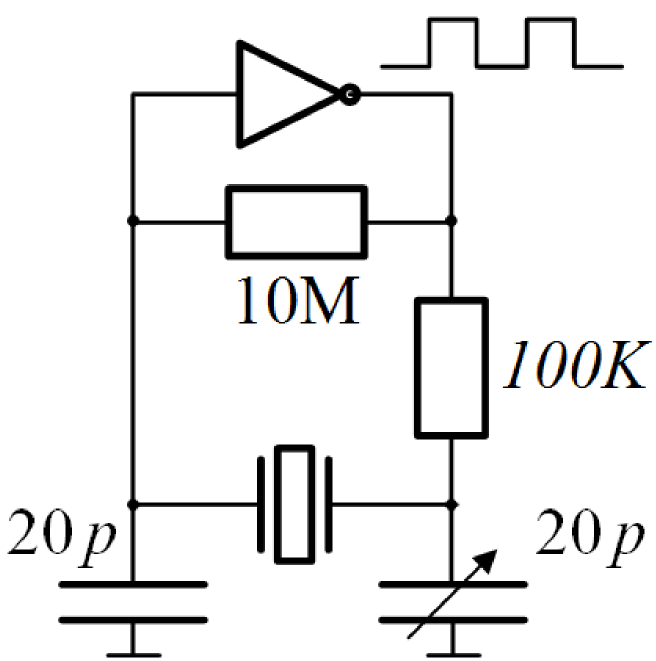
f_0=1, 2, 4, 5, … , 20MHz

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

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

The crystal oscillator circuit sustains oscillation by taking a voltage signal from the quartz resonator, amplifying it, and feeding it back to the resonator. The rate of expansion and contraction of the quartz is the resonant frequency, and it is determined by the cut and size of the crystal.

Clock generator

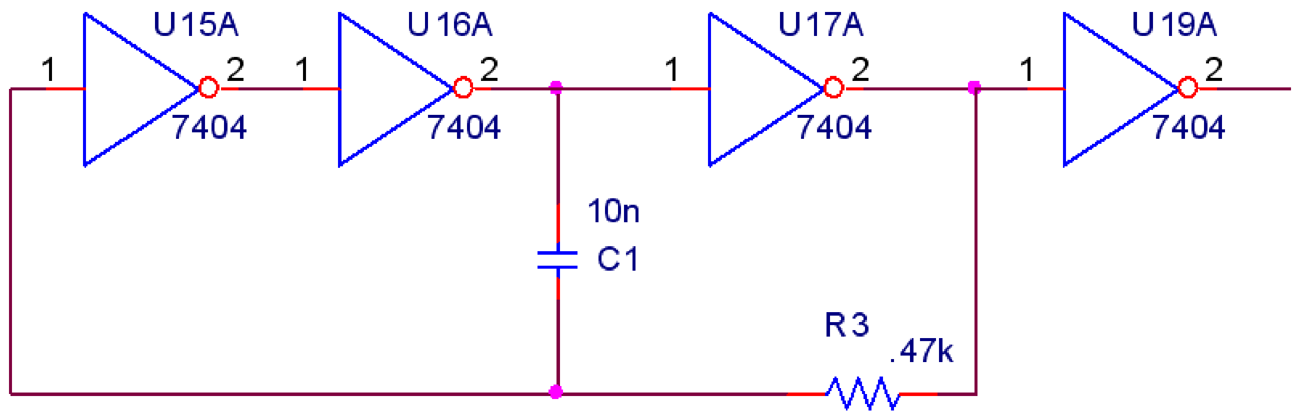


During startup, the circuit around the crystal applies a random noise (ac) signal to it, and purely by chance, a tiny fraction of the noise will be at the crystal's resonant frequency.

The crystal will therefore start oscillating in synchrony with that signal. As the oscillator amplifies the signals coming out of the crystal, the crystal's frequency will become stronger, eventually dominating the oscillator's output. Natural resistance in the circuit and in the quartz crystal filter out all the unwanted frequencies.

Other clock generators

- NOT gates oscillator



- Ring oscillator

$$f = \frac{1}{2t_d \cdot n}$$

t_d - delay time of one invertor