School of Electronics and Telecommunications
Electronics Devices – ET2015E

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Chapter 3. Pulse circuits

Outline

3.0. Pulses

3.1. Saturation mode of transistor

3.2. Saturation mode of OPAM

3.3. Comparator

3.4. Bi-stable multivibrator

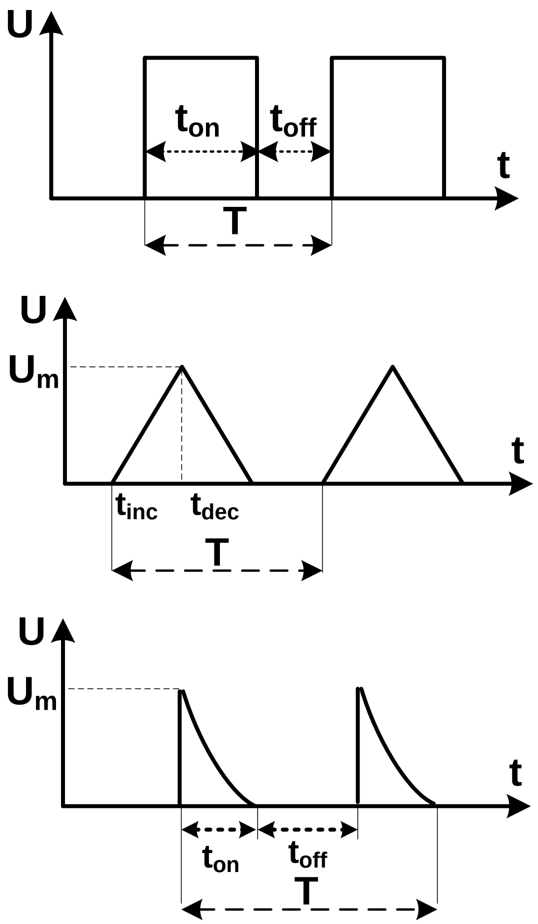
3.5. Monostate multivibrator

3.6. Astate multivibrator

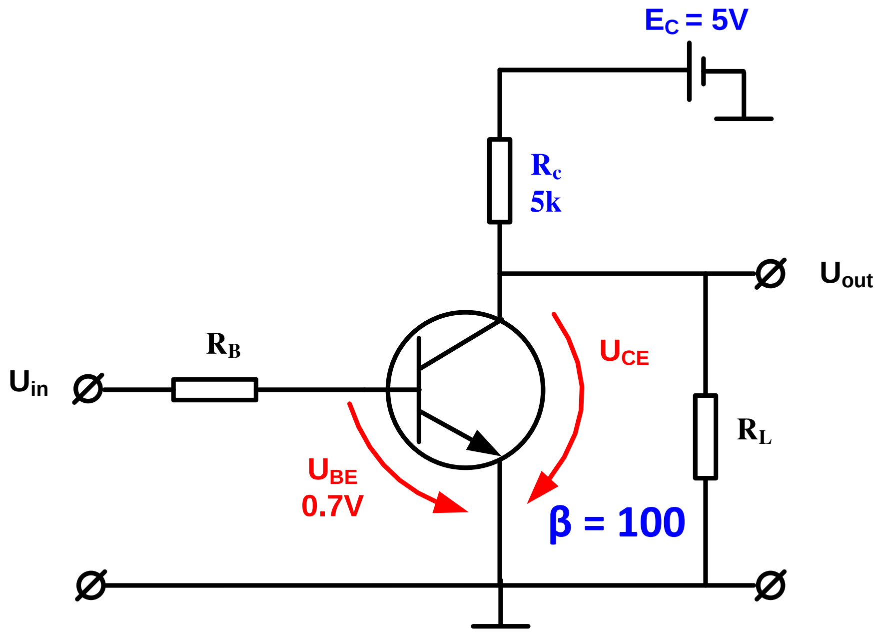
Chapter 3. Pulse circuits (cont.)

3.0. Pulses

- **Types of pulse: square, triangle, edge-trigged**
  - **t_{on}: existing time of pulse; t_{off}: non-existing time of pulse**
  - **t_{inc}: increasing ramp of pulse; t_{dec}: decreasing ramp of pulse**
- **Periodic pulse**
  - **$T = 1/f$ or $f = 1/T$**
  - **Duty cycle: t_{on}/T; Non-duty cycle: t_{off}/T; t_{on}/t_{off}**
- **One-polarity or two-polarity pulse**



3.1. Saturation mode of transistor



- **Transistor as a switch: Output in two distinguished states:**

➢ $U_{out} \geq U_H$ when $U_{in} \leq U_L$

➢ $U_{out} \leq U_H$ when $U_{in} \geq U_L$

- **Transition between two stages: 1) Pulse at the input or 2) Periodical transition based on positive feedback**

- **From EC circuit:**

➢ **Saturation:** $I_{C(sat)} = (E_C - U_{CE})/R_C \sim E_C/R_C$ ➔ $I_{B(sat)} = I_C/\beta$ ➔ $U_{CE} = U_{out} \sim 0\ V = U_L$ (Typically $U_L = 10\%E_C$)

➢ **Cut-off:** $I_{Bcut\text{-}off} = 0$ ➔ $I_{Ccut\text{-}off} = 0$ ➔ $U_{CE} = U_{out} = E_C$ (No Load). If $R_C = R_L$ ➔ $U_{out} = E_C/2$ (Typically U_H 30%E_C)

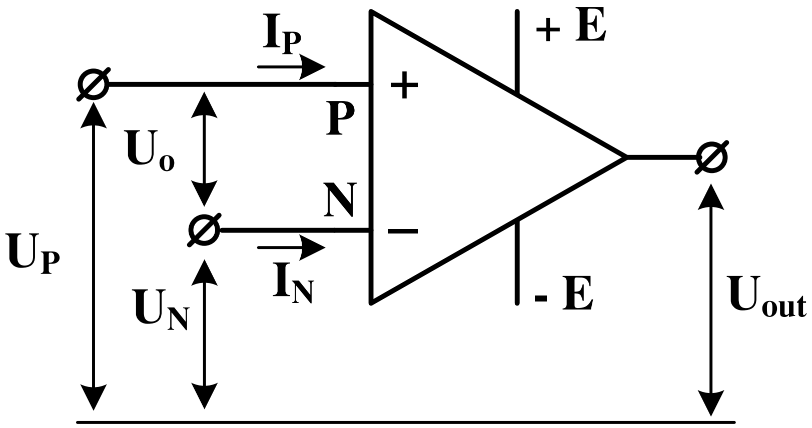
Example: 1) Determine saturated current I_B and 2) Select R_B to guarantee pulse mode of transistor

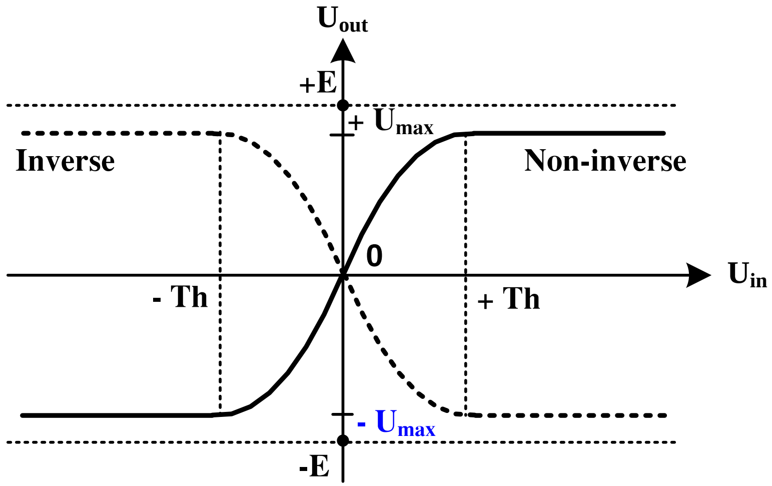
1) $U_H = 0.3E_C = 1.5V = U_{in}$; $U_L = 0.1E_C = 0.1V$; $I_{C(sat)} \sim 5V/5K = 0.1mA$ ➔ $I_{B(sat)} = 0.1mA/100 = 10\mu A$

2) For deep saturation ➔ Select $I_B = 10I_{B(sat)} = 100\ \mu A$ ➔ $R_B = (U_{in} - U_{BE})/I_B = (1.5V - 0.7V)/100\ \mu A = 8k\Omega$

3.2. Saturation mode of OPAM

- Transfer characteristic: Saturation area and $U_{out} = \pm U_{max}$
  - ➢ Since $K_{OPAM} = \infty$ (ideal)
  - ➢ $U_P – U_N = U_{out}/K_{OPAM} = 0$
    - ✓ If $U_P > U_N$: Positive saturation
    - ✓ If $U_P < U_N$: Negative saturation
- In high speed transition: Delay between states $\pm U_{max}$





3.3. Comparator

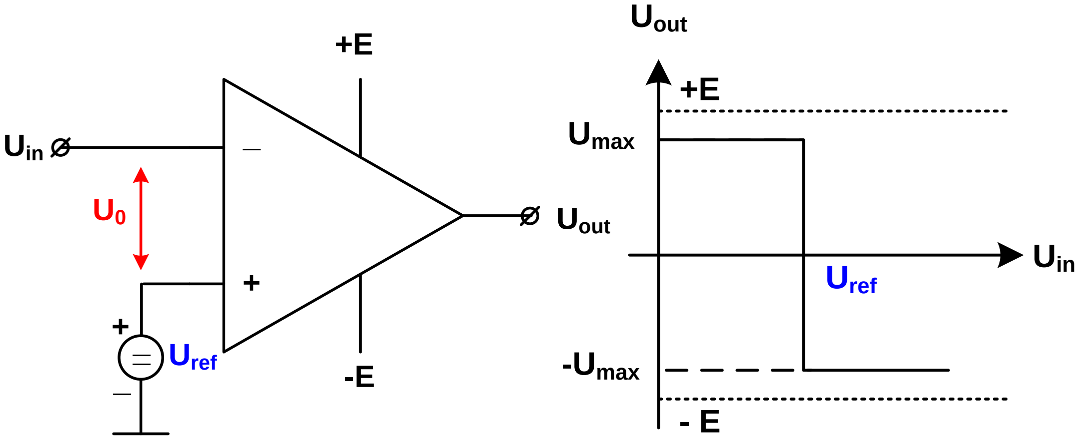
- **Inverse and non-inverse; operating in saturation mode**

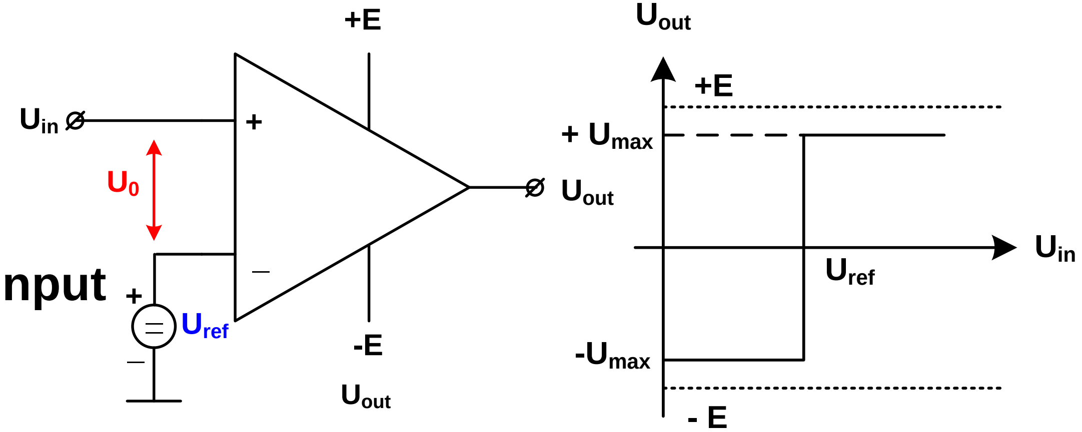
➢ **Inverse: (-) input compared with U_{ref} in (+) input**

✓ **If $U_0 = U_{ref} – U_{in} > 0$ ➔ $U_{in} < U_{ref}$ ➔ U_{out} from + U_{max} -> - U_{max}**

✓ **If $U_0 = U_{ref} – U_{in} < 0$ ➔ $U_{in} > U_{ref}$ ➔ U_{out} from - U_{max} -> + U_{max}**

✓ **Transfer characteristic: based on inverse amplifier**



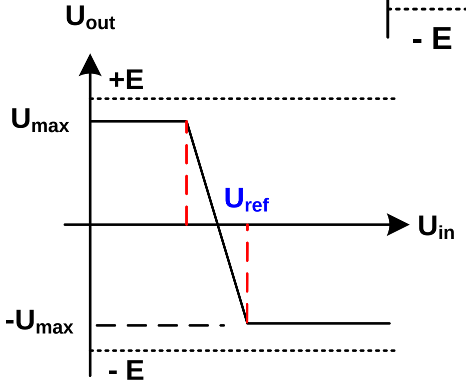


➢ **Non-Inverse: Non-Inverse (+) input compared with U_{ref} in (-) input**

✓ **If $U_0 = U_{in} – U_{ref} > 0$ ➔ $U_{in} > U_{ref}$ ➔ U_{out} from - U_{max} -> + U_{max}**

✓ **If $U_0 = U_{in} – U_{ref} < 0$ ➔ $U_{in} < U_{ref}$ ➔ U_{out} from + U_{max} -> - U_{max}**

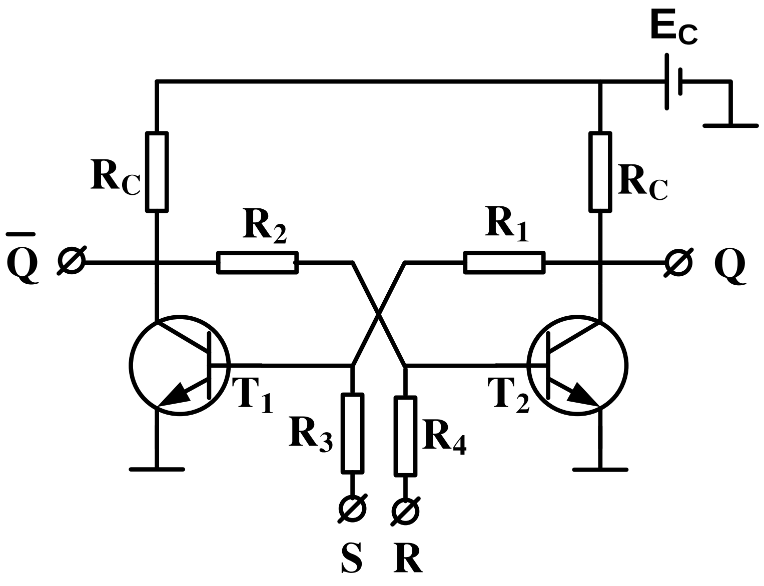
✓ **Transfer characteristic: based on non-inverse amplifier**



- **Transition delay**

3.4. Bi-stable multivibrator:

- **Symmetrical:** RS Trigger using transistor
- **Unsymmetrical:** Schmitt trigger using transistor and OPAM



a) Symmetrical bi-stable multivibrator: RS trigger using Transistor

- Transition between two output stages U_H (1) and U_L(0): apply a pulse

➢ **State 1**: RS = 10 ➔ T_1 saturated ($\overline{Q} = 1$) and T_2 off ($Q = 0$)

➢ **State 0**: RS = 01 ➔ T_2 saturated ($Q = 1$) and T_1 off ($\overline{Q} = 0$)

➢ **Forbidden state:** RS = 11 ➔ T_1 and T_2 are simultaneously saturated or off

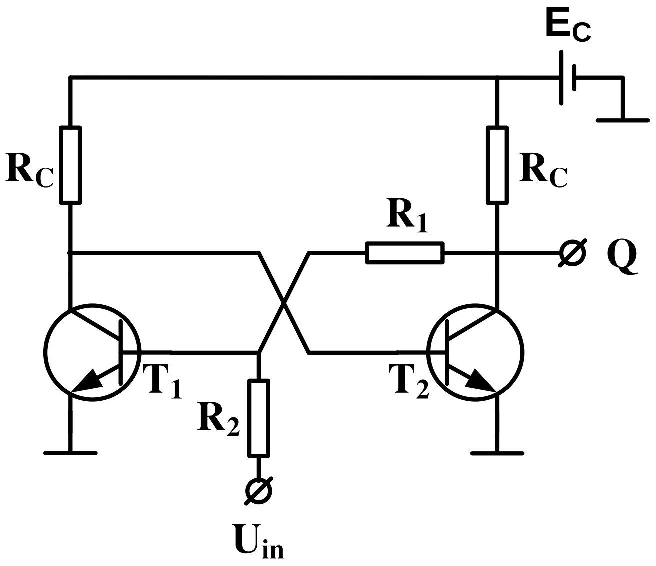
R_n	S_n	Q_{n+1}	$\overline{Q_{n+1}}$
0	0	Q_n	$\overline{Q_n}$
0	1	1	0
1	0	0	1
1	1	x	x

- **Operation:**

➢ Apply a pulse to S (S = 1): T_1 saturates ➔ $\overline{Q} = U_L = 0$ ➔ Feedback to T_2 ➔ T_2 off ➔ $Q = U_H = 1$ ➔ State 1

➢ Apply a pulse to R (R = 1): T_2 saturates ➔ $Q = U_L = 0$ ➔ Feedback to T_1 ➔ T1 off ➔ $\overline{Q} = U_H = 1$ ➔ State 0

b1) Unsymmetrical bi-stable multivibrator using transistor:



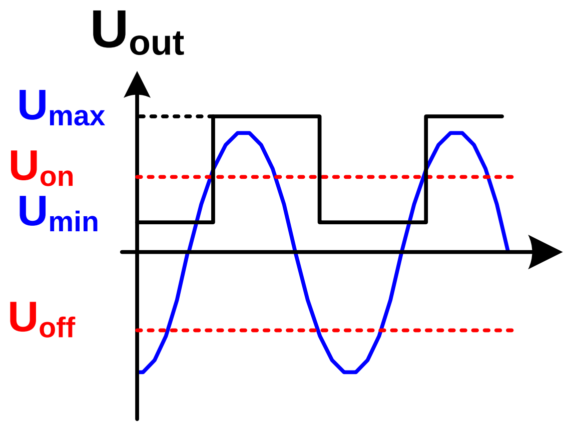
- Schmitt trigger using Transistor

➢ Initial U_{in} increasing from negative value: T_1 off, T_2 saturated

➔ $U_{out} = U_{CE(sat)} = U_{min}$

➢ U_{in} reaches U_{on}: T_1 saturated leads to T_2 off because of feedback

➔ U_{out} changes state from U_{min} to U_{max}

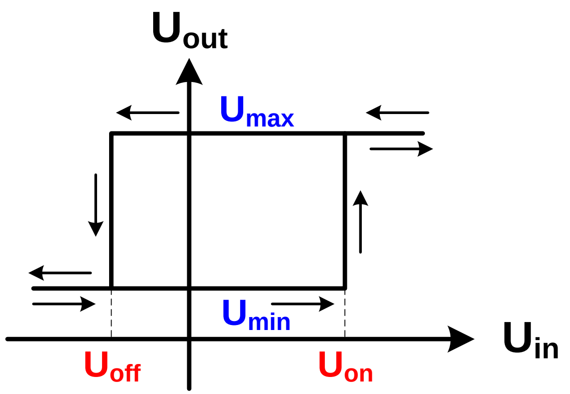


➢ U_{in} decreases from positive value: T_1 saturated and T_2 off

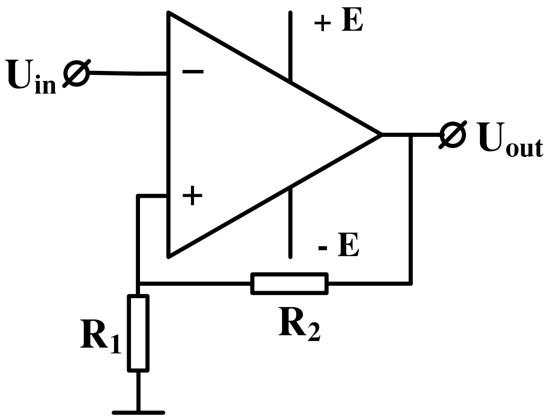
➔ $U_{out} = U_{max}$

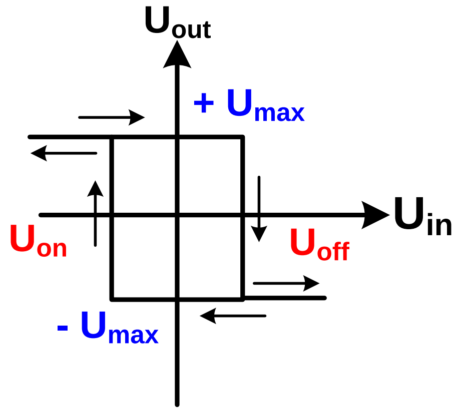
➢ U_{in} reaches U_{off}: T_1 off leads to T_2 saturated

➔ U_{out} changes state from U_{max} to U_{min}



EXAMPLE: U_{in} is a sin wave ➔ Output signal?



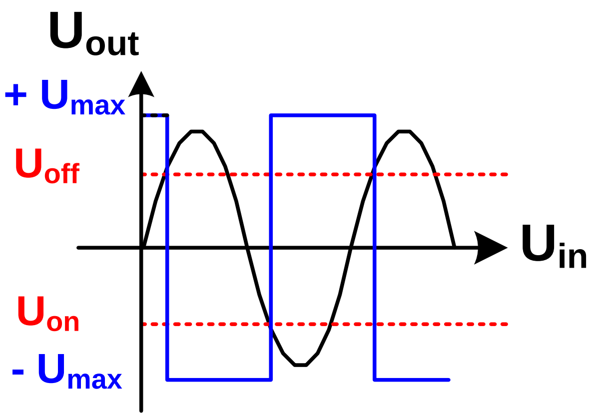


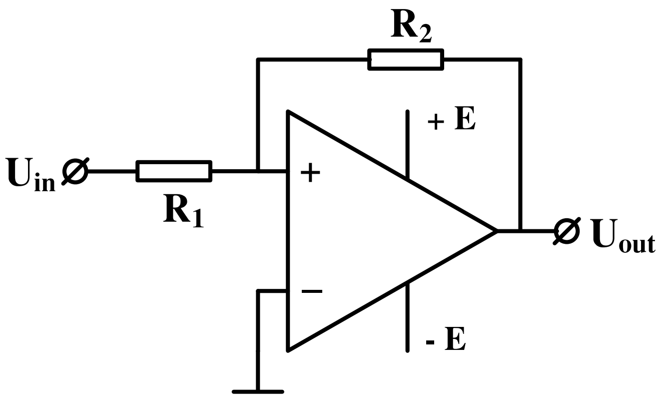
b2) Unsymmetrical bi-stable multivibrator using OPAM:

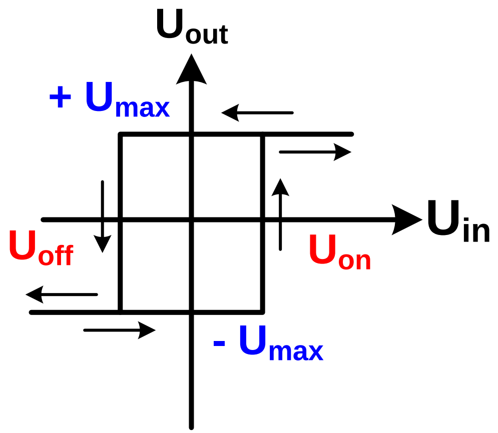
- **Inverse Schmitt trigger: using OPAM**

- **Inverse comparator-based operation:** $U_{out} = \pm U_{max}$
- **Since** $U_{out} = \pm U_{max} \Rightarrow U_P = U_{out}R_1/(R_1+R_2)$
- **And** $U_{in} = U_N = U_P \Rightarrow U_{in} = \pm U_{out}R_1/(R_1 + R_2)$ **or** $U_{in} = \pm U_{max}R_1/(R_1 + R_2) = \pm U_{ref} = \pm\beta U_{max}$, **where** $\beta = R_1/(R_1 + R_2)$
- **Once** $U_0 = U_P - U_N$ **zero-crosses,** U_{out} **changes between** $- U_{max} \Leftrightarrow + U_{max}$
- **Transfer characteristic: refer to that of inverse comparator, where** $U_{on} = - U_{ref}$ **or** $U_{off} = + U_{ref}$
- **Switching delay:** $$\Delta U_{delay} = \frac{R_1}{R_1 + R_2}\left[U_{max} - \left(-U_{max}\right)\right] = \frac{R_1}{R_1 + R_2} 2U_{max}$$

EXAMPLE: **Sin input signal applied to inverse Schmitt trigger. Investigate the output signal .**





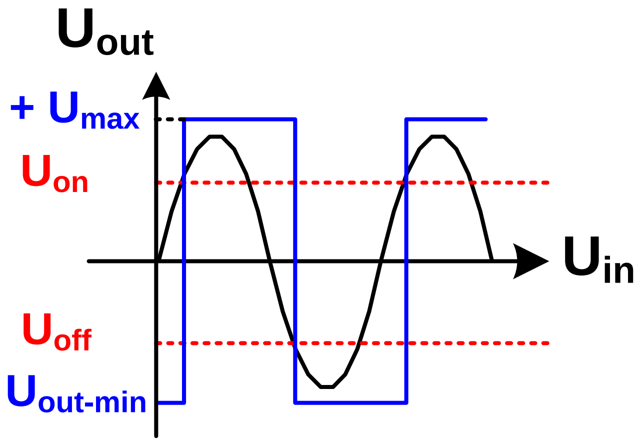


- **Non-inverse Schmitt trigger: using OPAM**

- **Inverse comparator-based operation: $U_{out} = \pm U_{max}$**
- **Since $U_{out} = \pm U_{max}$ ➔ Let's determine $\pm U_{ref}$**
- **Since $(U_{in} - U_P)/R_1 = (U_P - U_{out})/R_2$ and $U_P = U_N = 0$**

  ➔ $U_{in} = - U_{out}(R_1/R_2) = \mp U_{max}(R_1/R_2) = \mp U_{ref}$
- **Once $U_{in} - U_{ref}$ zero-crosses, U_{out} changes between $- U_{max} \rightarrow + U_{max}$ and vice versa**
- **Transfer characteristic: refer to that of non-inverse comparator, where $U_{on} = + U_{ref}$ or $U_{off} = - U_{ref}$**
- **Switching delay:** $$\Delta U_{delay} = \frac{R_1}{R_2}\left[U_{max} - \left(-U_{max}\right)\right] = \frac{R_1}{R_2} 2U_{max}$$

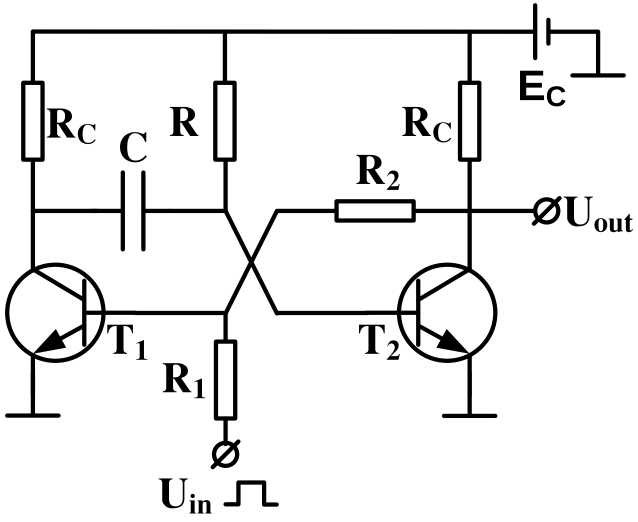
EXAMPLE: Sin input signal applied to non-inverse Schmitt trigger. Investigate the output signal .

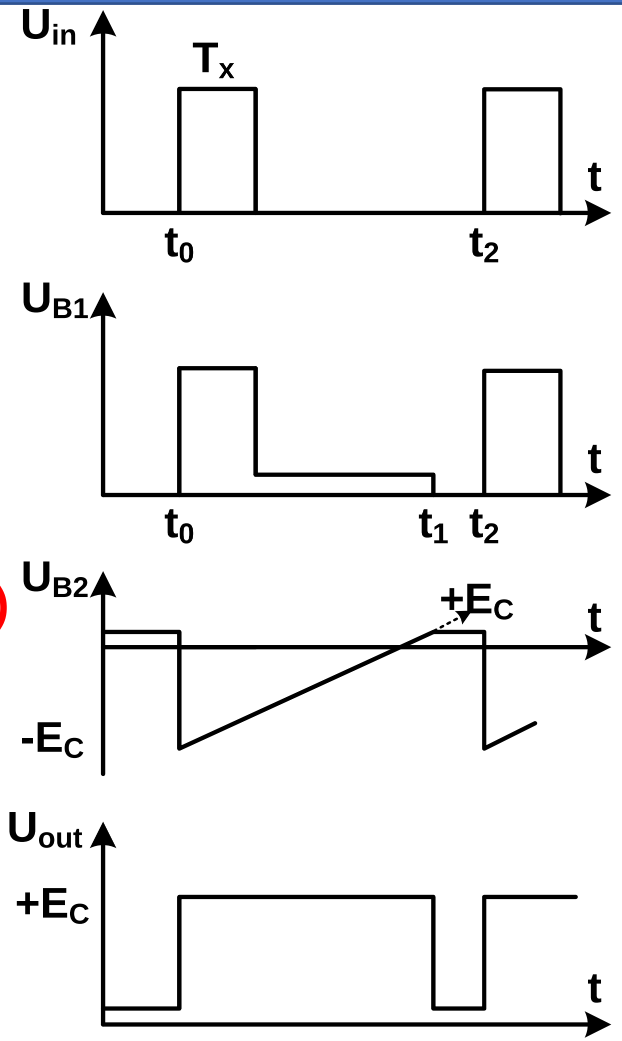


3.5. Monostate multivibrator:

- Using transistor

➢ Stable state: T_1 off, T_2 saturated (0)





➢ At t_0, U_{in} as a pulse is applied across R_1 to B_1

➔ T_1 is saturated ➔ U_{C1} decreases from E_C to 0 and passing across RC to B_2

➢ Therefore U_{B2} decreases from U_{BE} → $-E_C$ resulting T_2 off and $U_{C2} = E_C$ (unstable)

➢ Equation for B_2 while C charging is expressed as: $U_{B2} = E_C[1-2e^{(-t/RC)}]$

✓ $U_{B2} = -E_C$ at $t = t_0$ ➔ $t_0 = 0$

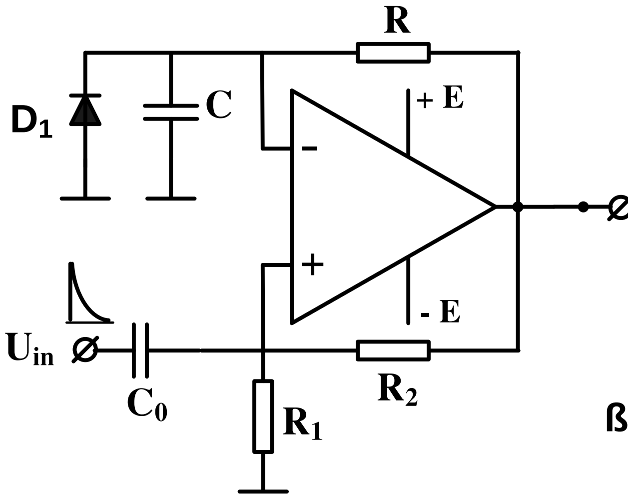
✓ $U_{B2} = 0$ at t_1 ➔ $t_1 = -RC\ln[(E_C-U_{B2})/2E_C] \sim RC\ln(E_C/2E_C) \sim RC\ln 2 \sim 0.7RC$

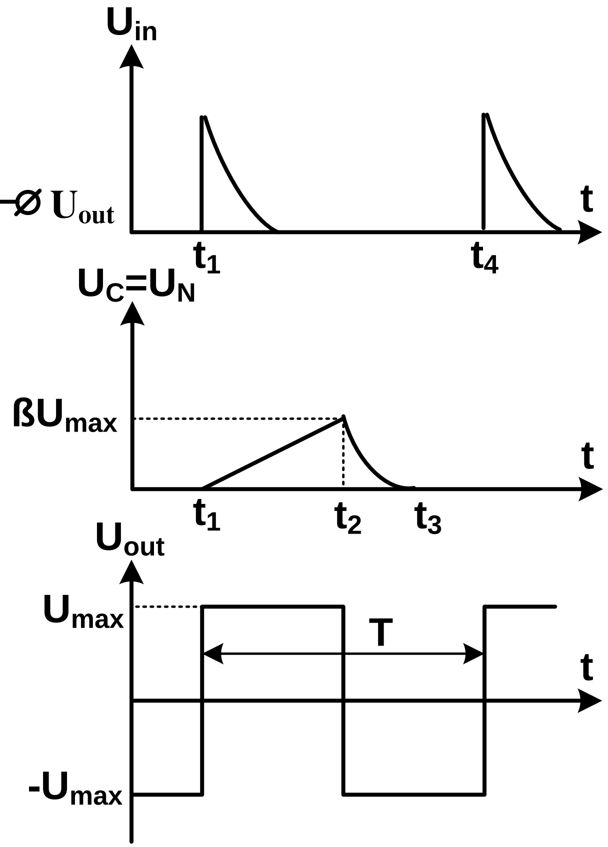
➢ Existing pulse time (duty cycle): $t_{pulse} = t_1 - t_0 = 0.7RC$

➢ After t_1, T2 is saturated again the output fed back across R_1R_2 to B_1 ➔ T_1 off ➔ Stable state

Chapter 3. Pulse circuits (cont.)

- Using OPAM





➢ Stable state: $U_{out} = - U_{max}$

➢ At $t < t_1$: $U_{out} = - U_{max}$ and $U_C = U_N = 0$ ➔ Stable state

➔ $U_P = U_{out}R_1/(R_1 + R_2) = - U_{max}R_1/(R_1 + R_2) = +\beta U_{max}$, D -FB

➢ At $t = t_1$: a pulse > βU_{max} applied to P (+)

➔ Output changes from $– U_{max} \rightarrow + U_{max}$ (unstable), and $U_P = + \beta U_{max}$

➢ From t_1 to t_2: C is charged to $+ \beta U_{max}$, D is isolated because of RB

➢ At $t = t_2$: Since $U_N = U_P = U_C$ ➔ $U_0 = U_P – U_N$ zero-crosses ➔ C discharges until t_3

➔ U_{out} changes from $+ U_{max} \rightarrow - U_{max}$ ➔ stable state

➢ $U_C(t) = U_{max}(1-e^{(- t/RC)})$. At $t = t_1$: $U_C(t_1) = 0$; At $t = t_2$: $U_C(t_2) = \beta U_{max} = RC\ln(1+ R_1/R_2)$ ➔ $t_{pulse} = t_2–t_1 = RC\ln(1+ R_1/R_2)$

➢ At t_3, C discharges: $UC(t) = U_C(\infty)\ [U(\infty) – U_C(0)]e^{(-t/RC)}$, where $U(\infty) = - U_{max}$, $U_C(0) = U_C(t_2) = +\beta Umax$

➢ $U_C(t_3) = 0$ ➔ t_3 = C discharges and $t_3 = - RC\ln[(-U_{max} – 0)/(-U_{max} - \beta U_{max}) = RC\ln(1 + \beta)$

3.6. Astable multivibrator

- Using transistor

➢ Periodical change between the stages 1 and 0

➢ At t< t_0: C_1 is charged to E_C ➔ Stage 1

➢ For $T_1 = t_1 - t_0$: T_1 off, T_2 saturated; C_1 discharges as:

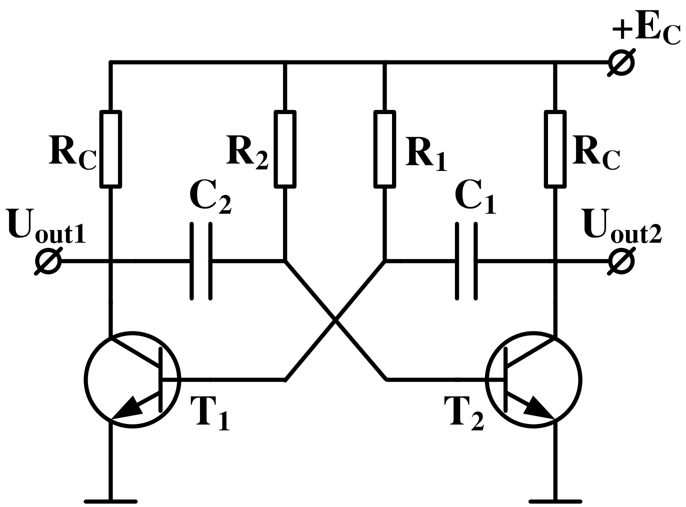
+ C_1 → T_{CE2} → R_1 → - C_1 ➔ U_{B1} goes negative to $-E_C$

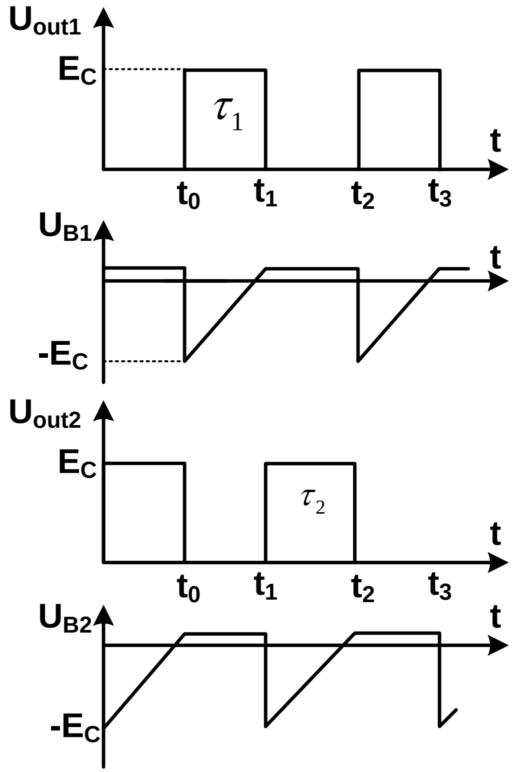
➢ At the same time: C2 is charged to + EC as: + E_C → R_C → T_{CE2} → - E_C

➔ at t_1: T_1 saturated, T_2 off ➔ A new state established ➔ Stage 0

➢ For $T_2 = t_2 - t_1$: T_1 off, T_2 saturated; C_2 in turn discharges, operating in similar manner

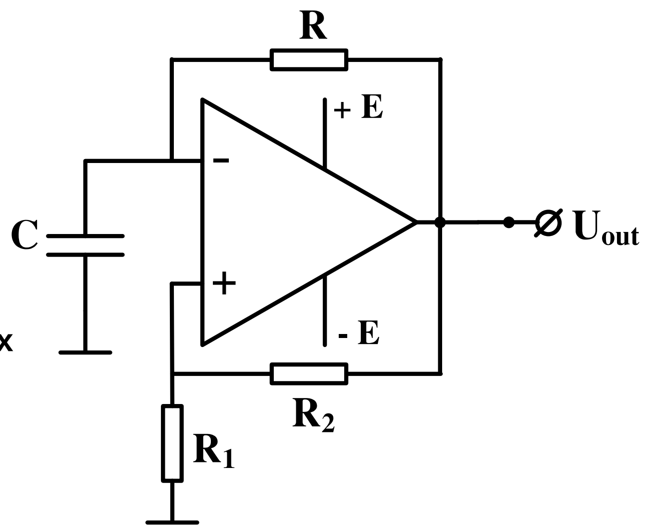
➢ Time interval between the stages: $T_1 = 0.7R_1C_1$; $T_2 = 0.7R_2C_2$

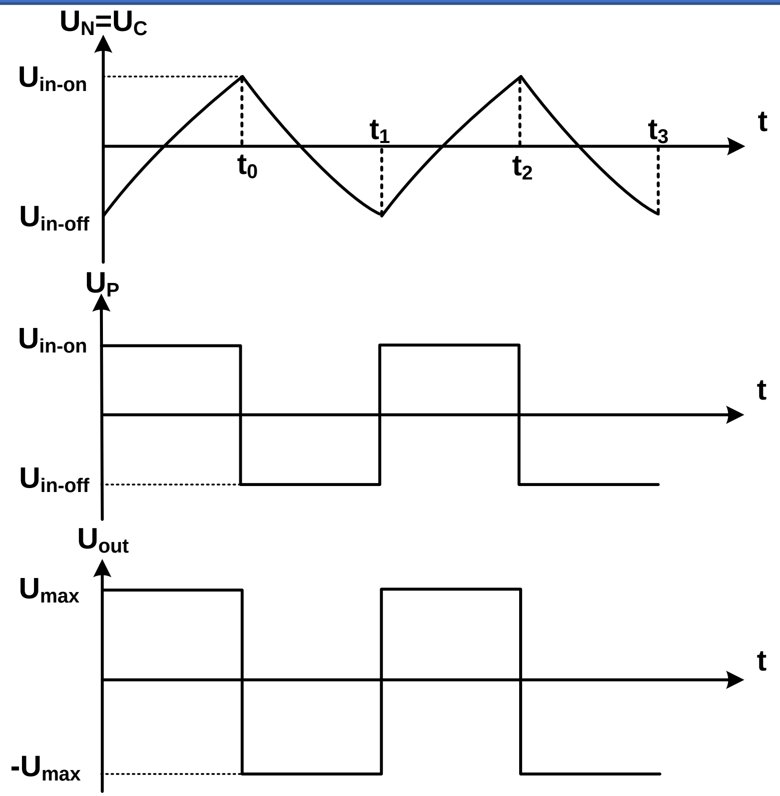




Chapter 3. Pulse circuits (cont.)

- Using OPAM





- Periodical change between the stages 1 and 0

  Output voltage switches stages between $\pm U_{max}$

- $U_P = U_{out}R_1/(R_1 + R_2) = \pm U_{max}R_1/(R_1 + R_2)$

- Since $U_C(t) = U_{max}[1 + (1 + \beta)e^{-(t/RC)}] = U_N$, where $\beta = R_1/(R_1+R_2)$

➔ Stage change occurs when $U_0 = U_P - U_P$ zero-crosses after elapsing time:

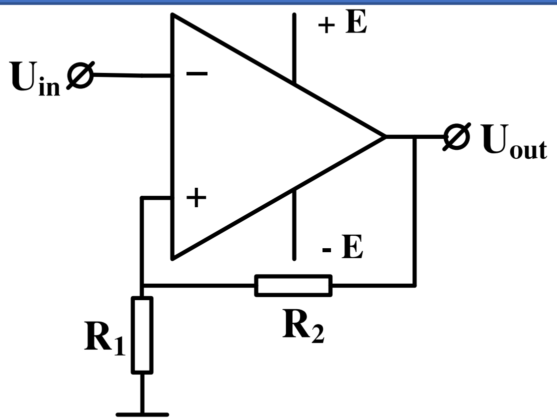
$$\tau = RC\ln\left(\frac{1+\beta}{1-\beta}\right) = RC\ln\left(1+\frac{2R_1}{R_2}\right)$$

- The period of output signal: $$T = 2\tau = 2RC\ln\left(1+\frac{2R_1}{R_2}\right)$$

- If $R_1 = R_2$: $$T = 2RC\ln 3 \approx 2.2RC$$

Chapter 3. Pulse circuits (cont.)

EXAMPLE 1: $E = +15V$; $\pm U_{max} = \pm 12V$, $R_1 = 10k\Omega$, $R_2 = 30k\Omega$. $U_{in}(t)$ – a triangle signal with amplitude ±6V, T = 20ms



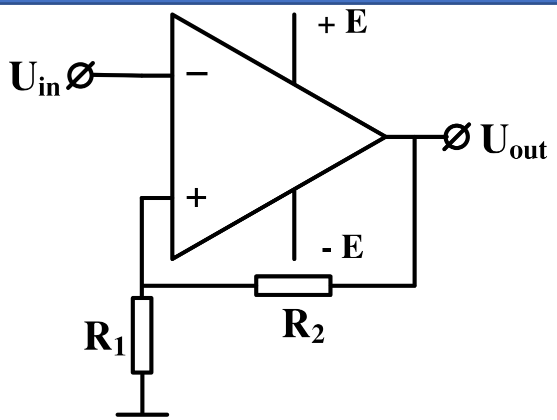
1. Illustrate transfer curves: a) ideal OPAM (trans delay = 0); b) real OPAM with trans delay rate of 0.5μs/V

2. Demonstrate $U_{out}(t)$ and its parameters. Determine time transfer delay between $U_{out}(t)$ and $U_{in}(t)$ if ideal OPAM

3. Add a voltage limiter + register at output to limit output amplitude between $0.6V \leq U_{out\_m} \leq +5V$, if $I_{out} = 10mA$

Chapter 3. Pulse circuits (cont.)

EXAMPLE 1: $E = +15V$; $\pm U_{max} = \pm 12V$, $R_1 = 10k\Omega$, $R_2 = 30k\Omega$. $U_{in}(t)$ – a triangle signal with amplitude ±6V, T = 20ms



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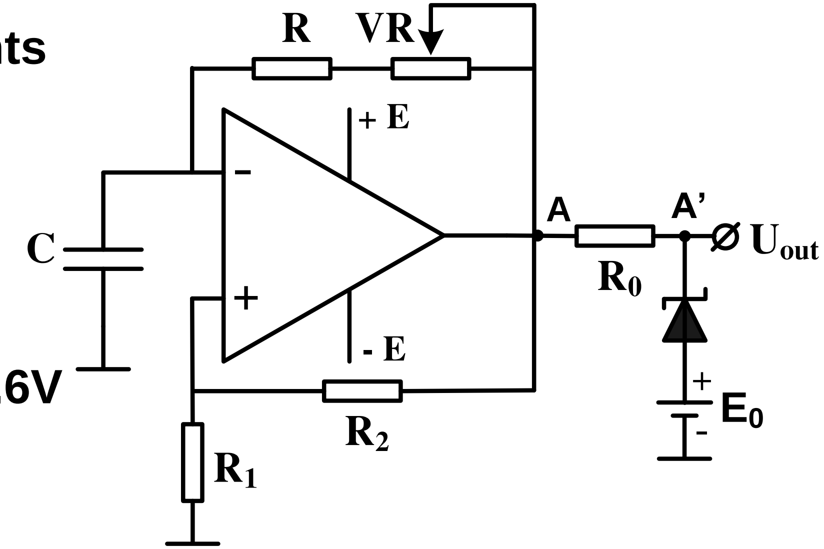
Chapter 3. Pulse circuits (cont.)

EXAMPLE 2: **a) Determine function of this circuit and signals at N, P, A points with given ± U_{max}**

b) If R = 10kΩ, VR = 0 → 10kΩ, $R_1 = R_2$ = 9.1kΩ, C = 0.1μF, ±U_{max} = ±12V.

Determine frequency range of signal at A when adjusting VR.

c) Determine signal at A' and R_0 without load, if U_Z = +5V, I_Z = 10mA, E_0 = +3.6V



Chapter 3. Pulse circuits (cont.)

- **Using OPAM**

Chapter 3. Pulse circuits (cont.)

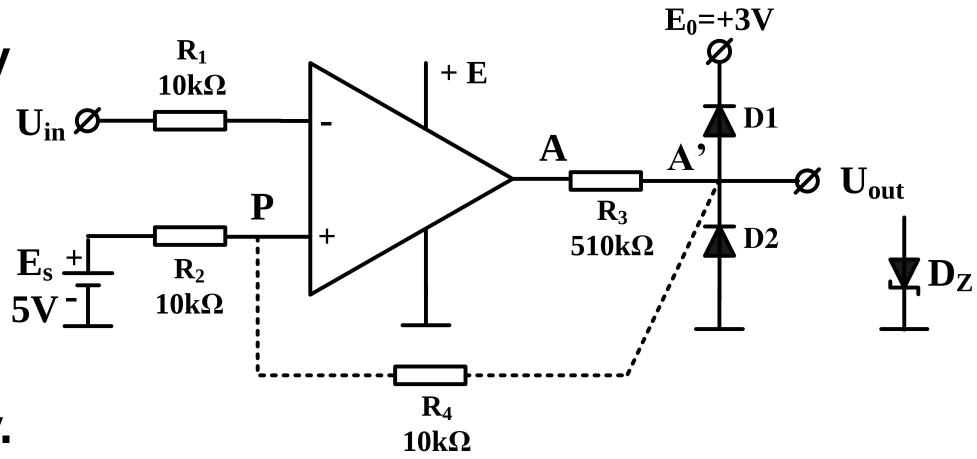
EXAMPLE 3: Given $\pm U_{max} = \pm 12V$, $U_{D1} = U_{D2} = 0.6V$, without R_4 initially

a) Determine function and transfer characteristic

b) If polarity of E_0 is subject to change, investigate transfer char.

c) If D_2 is replace by D_z. Investigate transfer characteristic.

d) Connect R_4. Determine transfer characteristic and switching delay.



Chapter 3. Pulse circuits (cont.)

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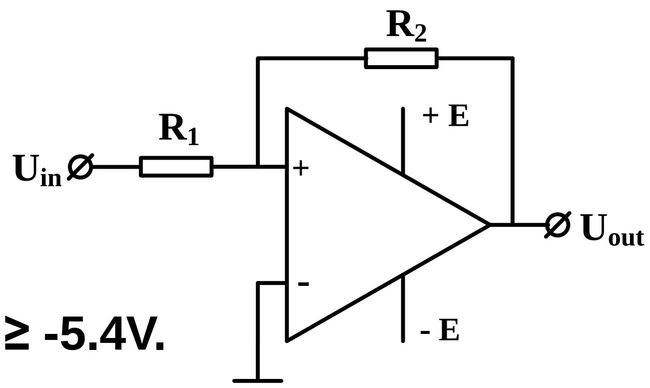


Example 4: **$E = +15V$; $\pm U_{max} = \pm 12V$, $R_1 = 10k\Omega$, $R_2 = 20k\Omega$. $U_{in}(t)$ – a triangle signal with amplitude ±6V, T = 30ms**

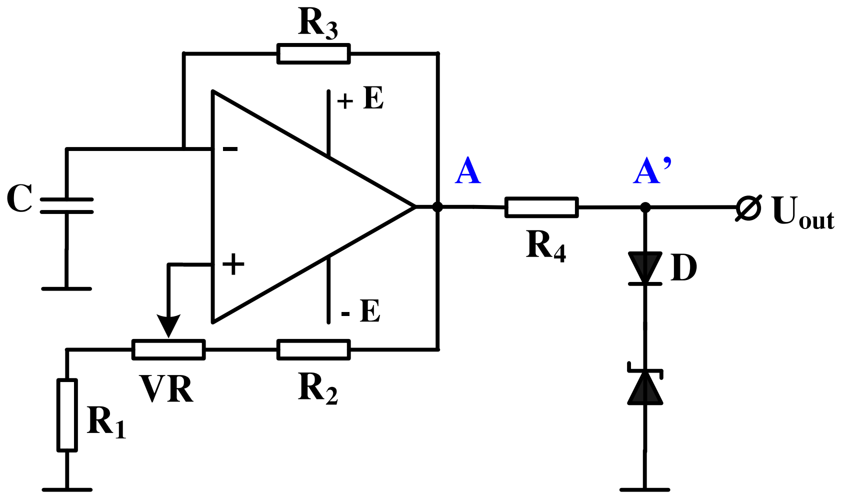
1. Determine output waveform $U_{out}(t)$ and its parameters: amplitude, period, delay

2. Add a voltage limiter at output to limit output amplitude between $+0.6V \geq U_{out\_m} \geq -5.4V$.

3. Determine time delay of output switching, if practical OPAM has transfer time dalay of 20 ns/V

Chapter 3. Pulse circuits (cont.)

Example 5: E = +15V; $\pm U_{max} = \pm 12V$, $R_1 = 15k\Omega$, $R_2 = 60k\Omega$, $R_3 = 20k\Omega$,
VR = 0 → 40kΩ, C = 0.001µF, $I_Z = 10mA$



1. Determine role of VR and frequency range of output while adjusting VR
2. VR at the right end. Illustrate signals at N, P, A points
3. Explain operation mechanism of R_4, D, D_Z. Determine R4, assuming that the load is very large. Select appropriate Dz to get output of +5V.