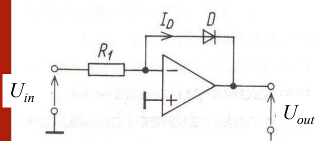
OpAmp
Some Nonlinear Applications

Logarithmic circuit



$$I_D = I_{CS}\exp\left(\frac{U_{BE}}{\varphi_T}\right)$$

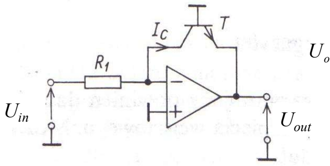
$$U_{out} = -\varphi_T \ln 10 \log \frac{U_{in}}{I_S R_1}$$

$$U_{out} \approx -(1...2)\cdot 60mV \cdot \log \frac{U_{in}}{I_S R_1}$$

Small voltage rang (2 decades) caused by:

- series resistivity of diode
- φ_T – is not a constant value (φ_T can change with current)

Logarithmic circuit



$$U_{out} = -U_{BE} = -\varphi_T \ln \frac{U_{in}}{I_{CS} R_1}$$

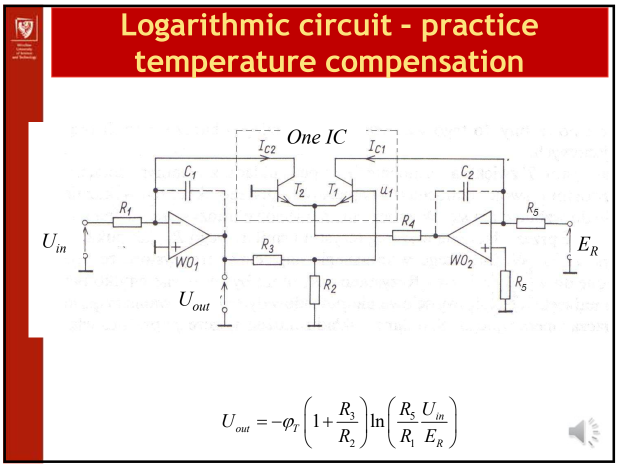
$$I_C = I_{CS}\exp\left(\frac{U_{BE}}{\varphi_T}\right)$$

Advantages:

- Wider voltage range (up to 9 decades) as φ_T is „more stable"

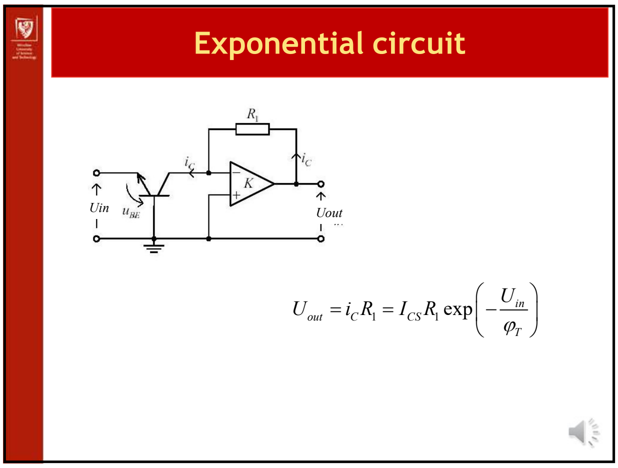
Disadvantage:

- Temperature instability



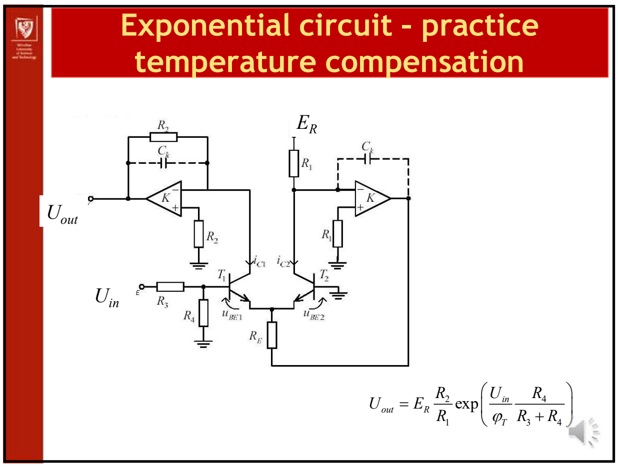
Logarithmic circuit - practice temperature compensation

$$U_{out} = -\varphi_T\left(1+\frac{R_3}{R_2}\right)\ln\left(\frac{R_5}{R_1}\frac{U_{in}}{E_R}\right)$$



Exponential circuit

$$U_{out} = i_C R_1 = I_{CS} R_1 \exp\left(-\frac{U_{in}}{\varphi_T}\right)$$



Exponential circuit - practice temperature compensation

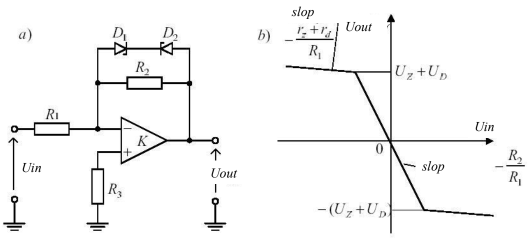
$$U_{out} = E_R \frac{R_2}{R_1}\exp\left(\frac{U_{in}}{\varphi_T}\frac{R_4}{R_3+R_4}\right)$$

Voltage limiter

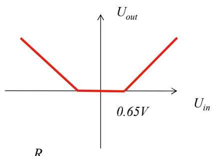
$$u_{wy} = f(u_{we})$$

$$U_{out} = \begin{cases} U_{out\,min}; & for \quad U_{in} < U_{in\,min} \\ A_V U_{in}; & for \quad U_{in\,min} < U_{in} < U_{in\,max} \\ U_{out\,max}; & for \quad U_{in} > U_{in\,max} \end{cases}$$

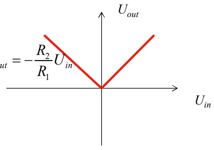
Signal limiter



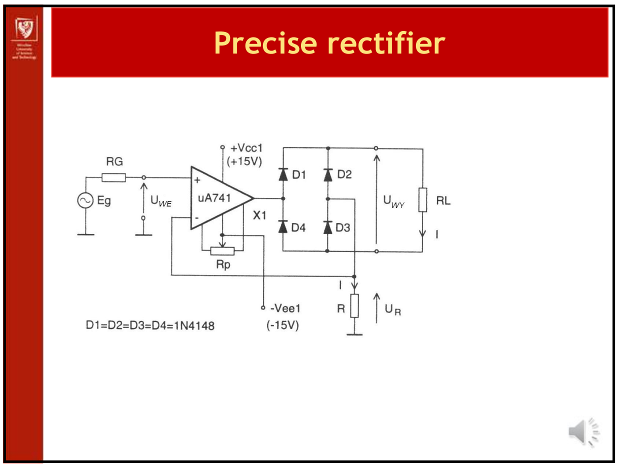
Precise rectifier



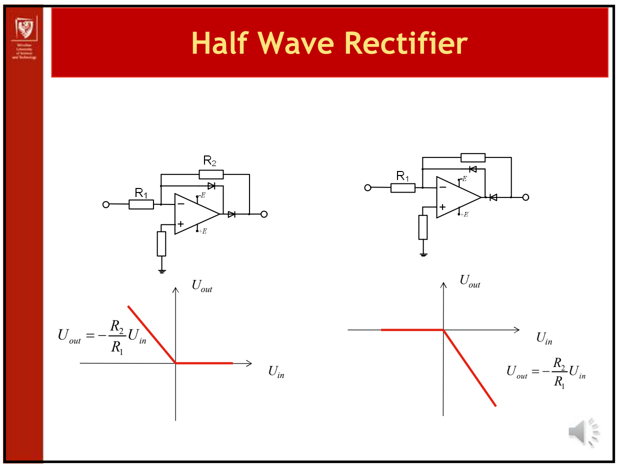
$$U_{out} = -\frac{R_2}{R_1} U_{in}$$



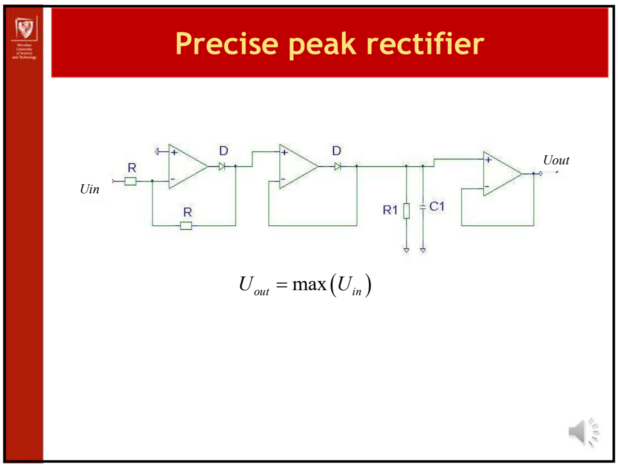
$$U_{out} = -\frac{R_2}{R_1} U_{in}$$



Precise rectifier

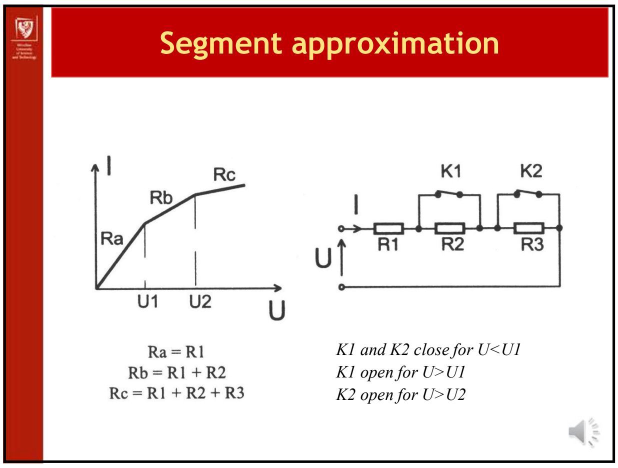


Half Wave Rectifier



Precise peak rectifier

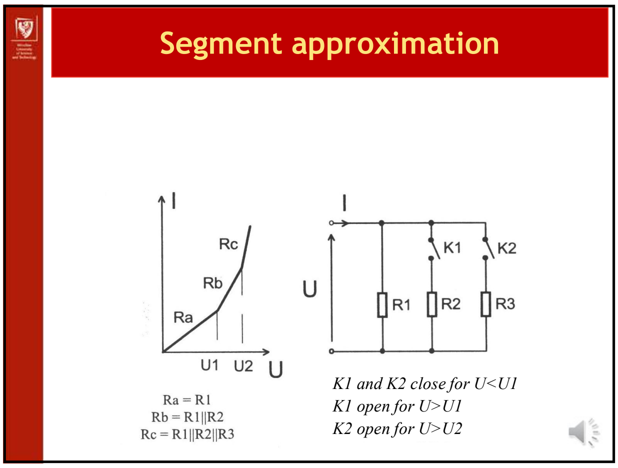
$$U_{out} = \max\left(U_{in}\right)$$



Segment approximation

Ra = R1
Rb = R1 + R2
Rc = R1 + R2 + R3

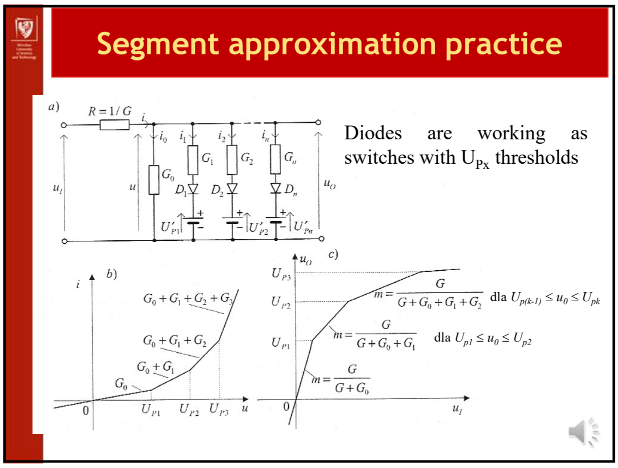
K1 and K2 close for U<U1
K1 open for U>U1
K2 open for U>U2



Segment approximation

Ra = R1
Rb = R1||R2
Rc = R1||R2||R3

K1 and K2 close for U<U1
K1 open for U>U1
K2 open for U>U2



Segment approximation practice

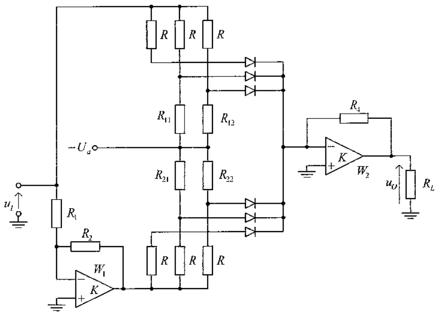
Diodes are working as switches with U_{Px} thresholds

$m = \dfrac{G}{G + G_0 + G_1 + G_2}$ dla $U_{p(k-1)} \le u_0 \le U_{pk}$

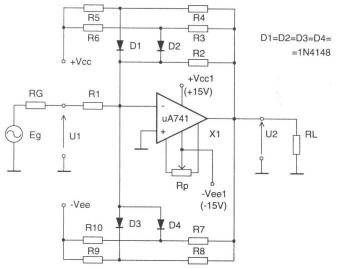
$m = \dfrac{G}{G + G_0 + G_1}$ dla $U_{p1} \le u_0 \le U_{p2}$

$m = \dfrac{G}{G + G_0}$

Segment approximation of square function (parabolic)



Segment approximation triangle to sin shaper



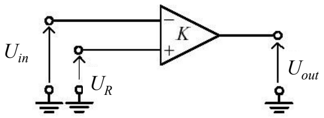
Problems

- *Log exp functions*
- *Voltage limiters*
- *Rectifier*
- *Segment approximation*

Comparators

U.Tietze, Ch.Schenk, E.Gamm, Electronic Circuits. Handbook for Design and Application, 2nd Edition, Springer : Chapter 6.5.1

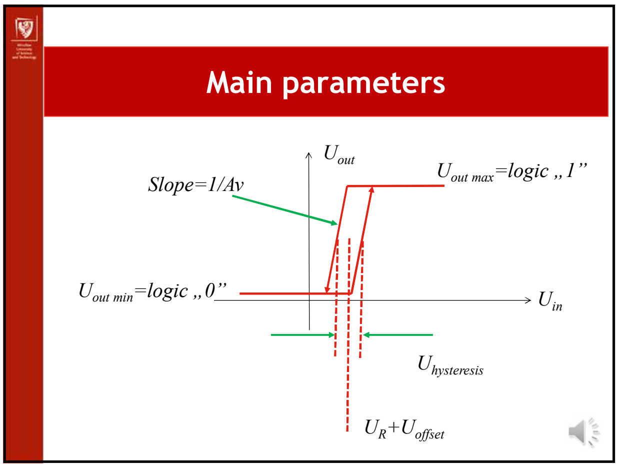
Definition



$$U_{out} = \begin{cases} 1 & for \quad U_{in} < U_R \\ 0 & for \quad U_{in} > U_R \end{cases}$$

Main parameters

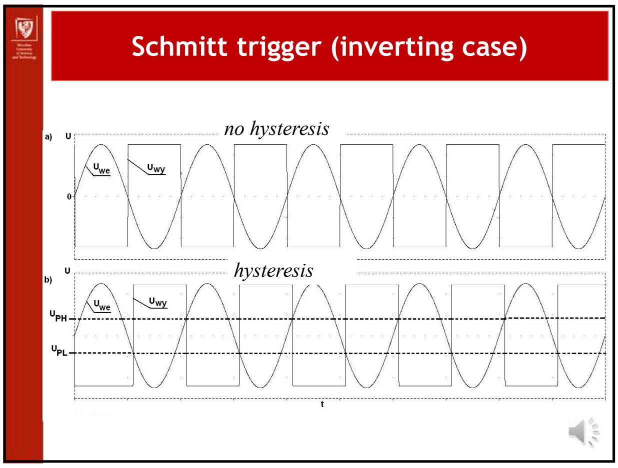
- gain Av [V/V],
- CMRR,
- SR,
- offset,
- sensitivity (min U_{in1}-U_{in2}),
- with/without hysteresis
- time delay,
- maximum input voltages (common, differential)
- output voltages (logic levels),
- maximum output current,.



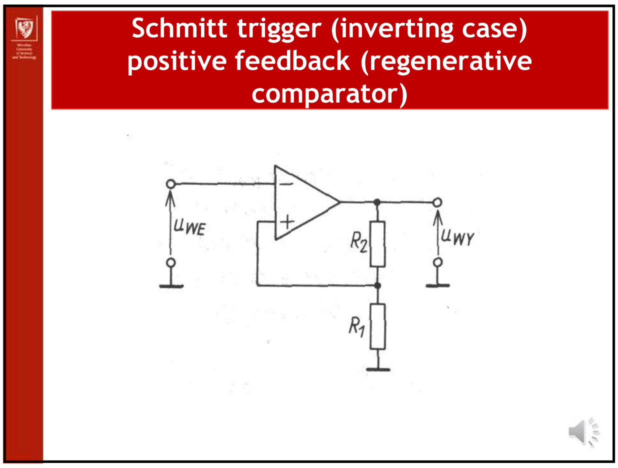
Main parameters

Comparators by function

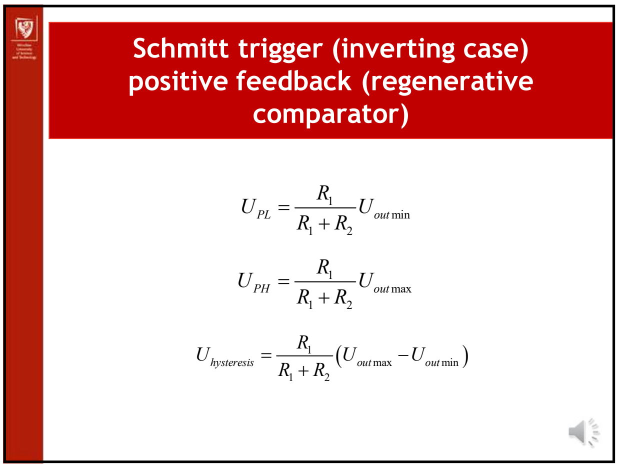
- Zero voltage detector ($U_R = 0V$),
- Level discriminator ($U_R \neq 0V$),
- Window comparator ($U_{R1} < U_R < U_{R2}$)
- Schmitt trigger (with hysteresis and positive feedback).



Schmitt trigger (inverting case)



Schmitt trigger (inverting case) positive feedback (regenerative comparator)

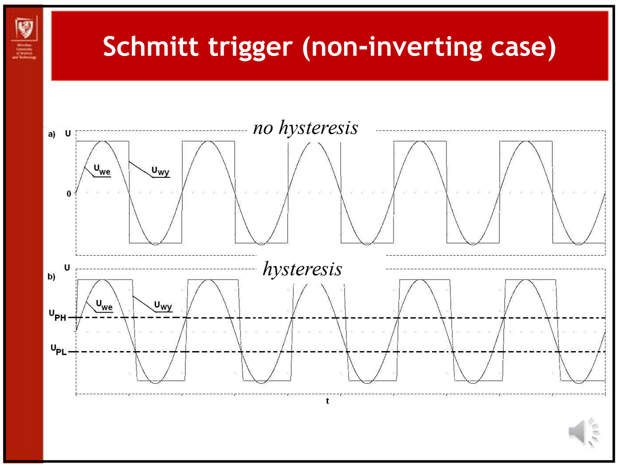


Schmitt trigger (inverting case) positive feedback (regenerative comparator)

$$U_{PL} = \frac{R_1}{R_1 + R_2} U_{out\,\min}$$

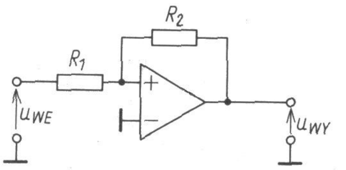
$$U_{PH} = \frac{R_1}{R_1 + R_2} U_{out\,\max}$$

$$U_{hysteresis} = \frac{R_1}{R_1 + R_2} \left(U_{out\,\max} - U_{out\,\min} \right)$$



Schmitt trigger (non-inverting case)

Schmitt trigger (non-inverting case) positive feedback (regenerative comparator)



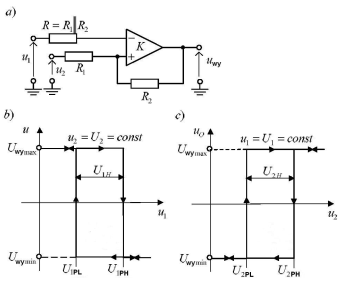
Schmitt trigger (inverting case) positive feedback (regenerative comparator)

$$U_{PL} = -\frac{R_1}{R_2} U_{out\,\min}$$

$$U_{PH} = -\frac{R_1}{R_2} U_{out\,\max}$$

$$U_{hysteresis} = -\frac{R_1}{R_2}\left(U_{out\,\max} - U_{out\,\min}\right)$$

Schmitt trigger - general case



Schmitta trigger - universal

Inverting case:

$$U_{1PL} = \frac{R_2}{R_1 + R_2} U_2 + \frac{R_1}{R_1 + R_2} U_{out\,\min}$$

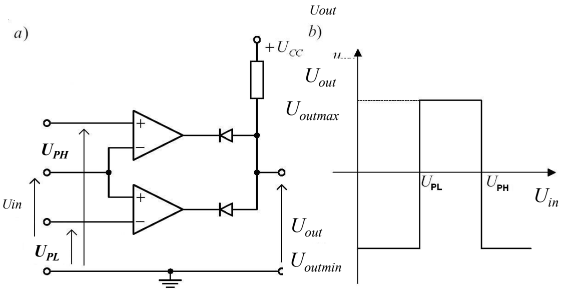
$$U_{1PH} = \frac{R_2}{R_1 + R_2} U_2 + \frac{R_1}{R_1 + R_2} U_{out\,\max}$$

Non-inverting case:

$$U_{2PL} = \frac{R_1 + R_2}{R_2} U_1 - \frac{R_1}{R_2} U_{out\,\max}$$

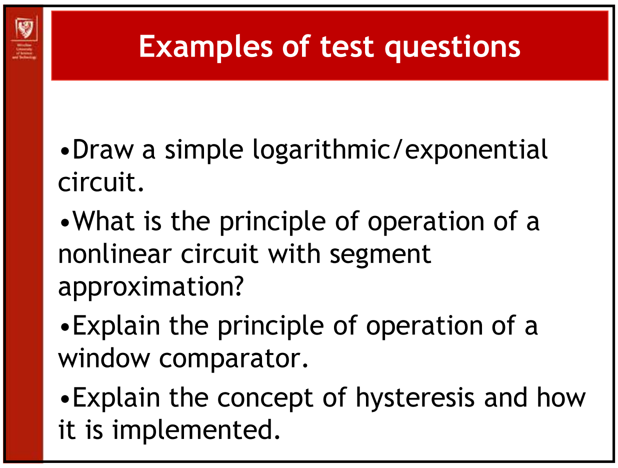
$$U_{2PH} = \frac{R_1 + R_2}{R_2} U_1 - \frac{R_1}{R_2} U_{out\,\min}$$

Window comparator



Summary

- Comparator – definition
- Comparator – parameters
- Comparator types:
  - zero detector,
  - level detector,
  - Schmitt trigger, hysteresis
  - window comparator



Examples of test questions

- Draw a simple logarithmic/exponential circuit.
- What is the principle of operation of a nonlinear circuit with segment approximation?
- Explain the principle of operation of a window comparator.
- Explain the concept of hysteresis and how it is implemented.