Development of Complex Curricula for Molecular Bionics and Infobionics Programs within a consortial* framework**

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**Molekuláris bionika és Infobionika Szakok tananyagának komplex fejlesztése konzorciumi keretben

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ELECTRICAL MEASUREMENTS

(Elektronikai alapmérések)

Nonlinear resistive networks (setting of the operation point)

(Nemlineáris rezisztív hálózatok (munkapontszámítás))

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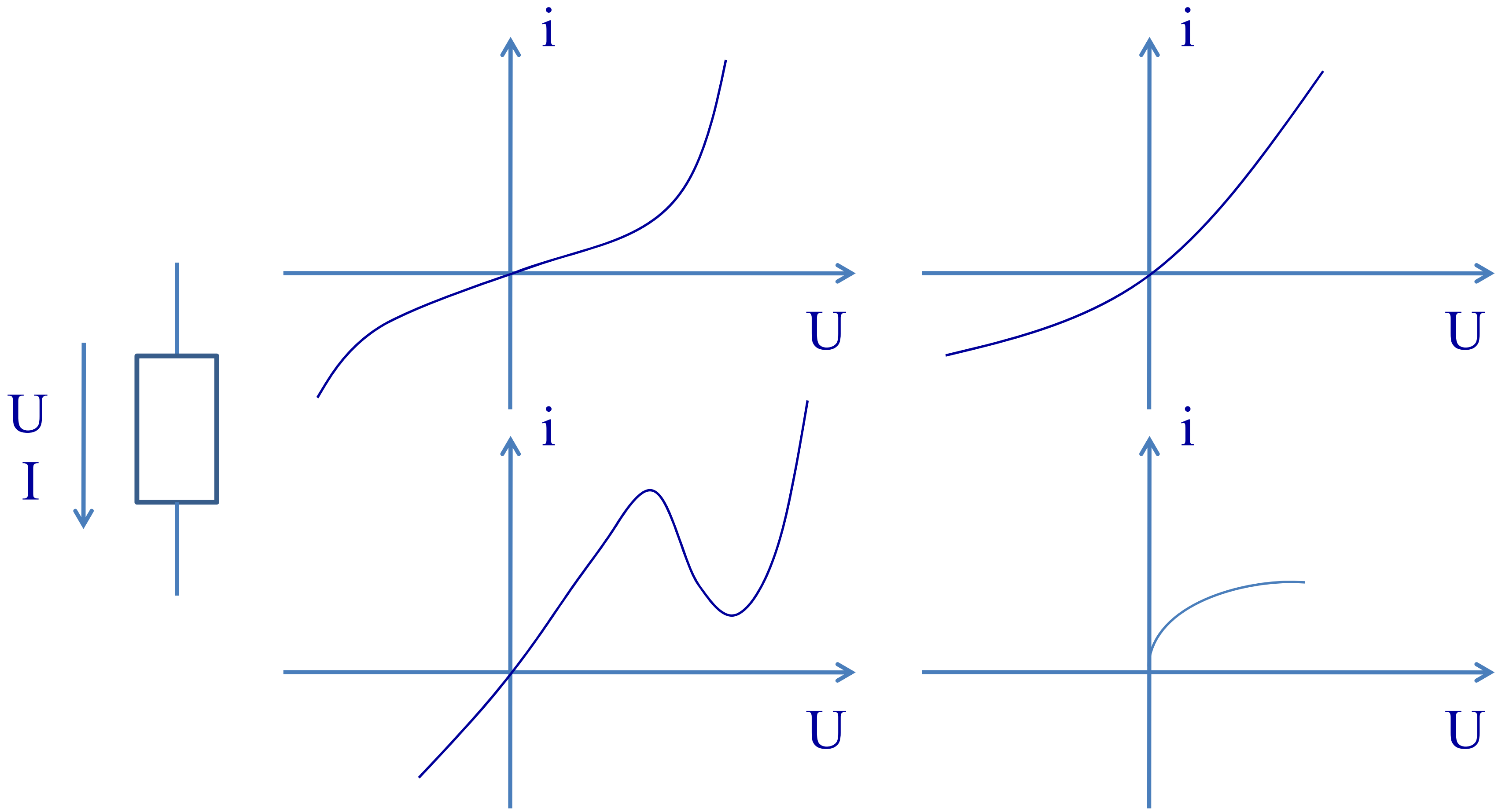
TÁMOP – 4.1.2-08/2/A/KMR-2009-0006

Nonlinear resistance

- The simplest type of non-linear networks is a nonlinear resistive network, which contains the combination of voltage sources, power supplies, linear and nonlinear invariant resistors.
- The characteristics of connection of the u voltage of the nonlinear resistance and the i current of nonlinear resistance can be given by
  $i = I(u); \quad I(0) = 0$
  voltage controlled explicit form, or
  $u = U(i); \quad U(0) = 0$
  current controlled explicit form, here U, and respectively I are functions.

Typical characteristics of a nonlinear component



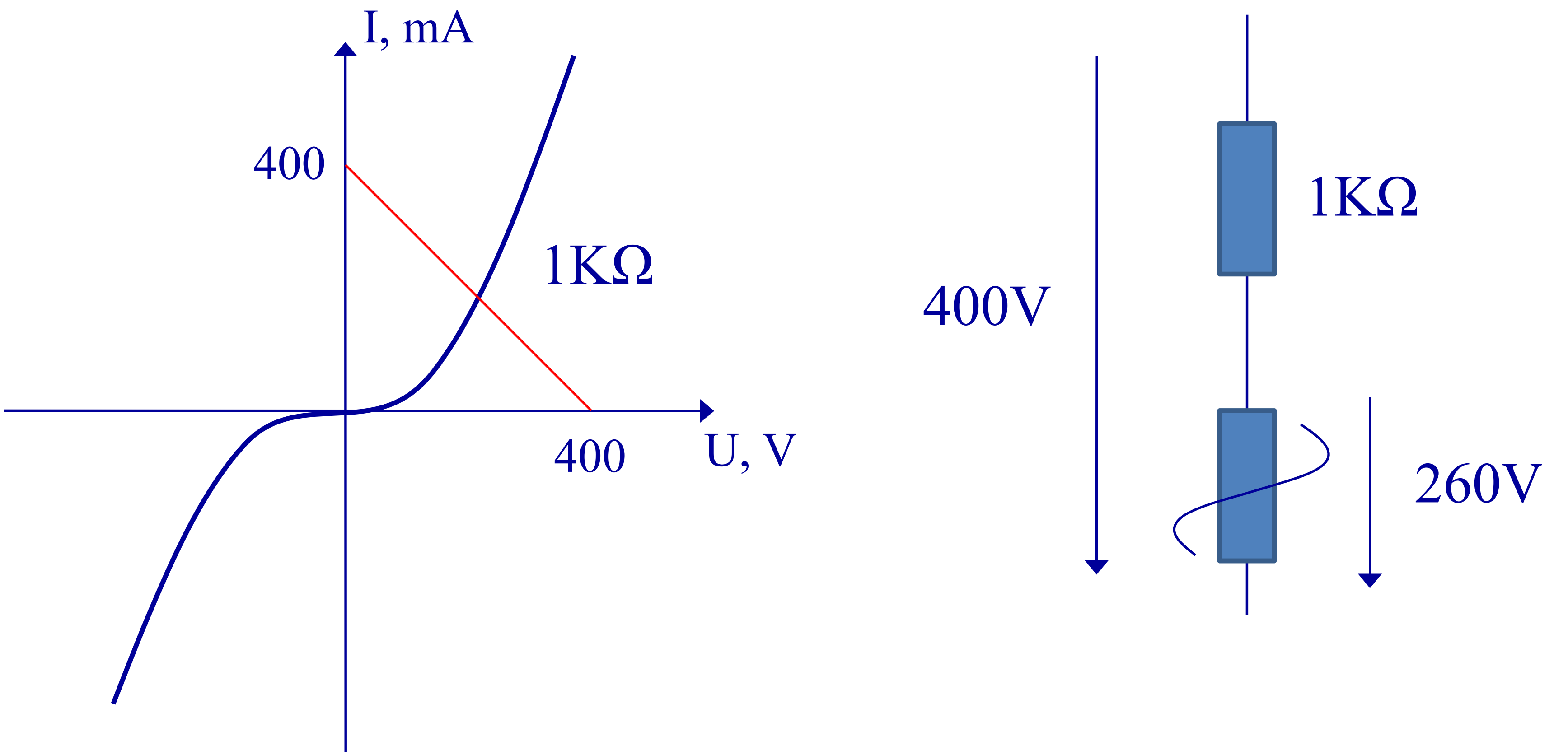
Nonlinear components

- From the equation of the p=ui follows that the nonlinear resistance is passive if the signs of U and I have symmetric reference directions, so the curve is located in the I. and III. parts of the plane.
- The non-linear characteristics can be given as a characteristic curve, or as a matrix containing numbers or as a combination of elementary functions. Covering the whole range by a close approximation with a simple function is not easy to find. Fractionally linear characteristics are often used to cover the range.

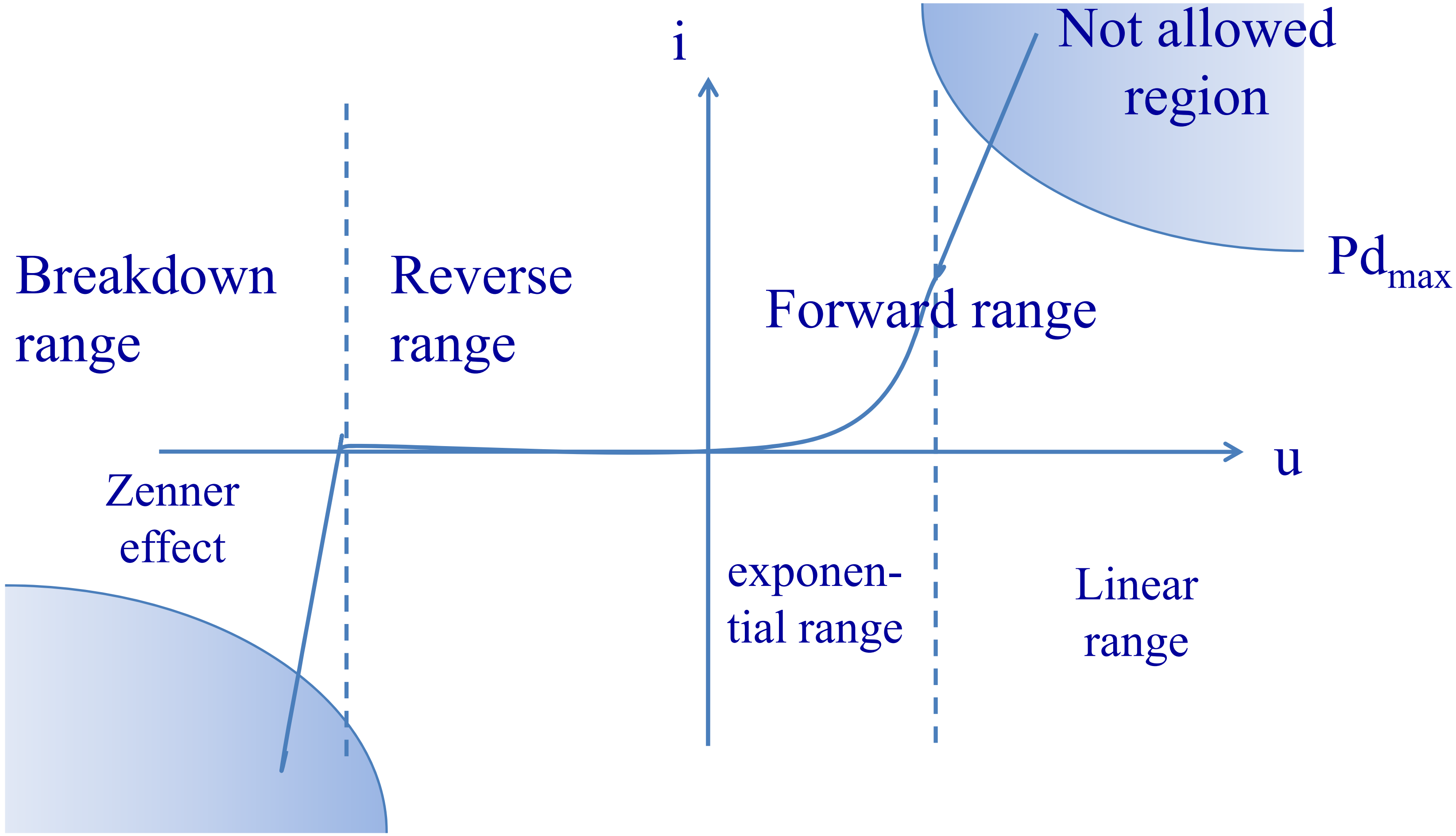
Operation point

- Consider a resistive network, which contains only one nonlinear resistor. Replace the rest of the network by the Thevenin or Norton equivalent of the corresponding non-linear resistor. This characteristic of this replacement can be given by an equation of a straight line in the given t time, where this line is called load line. The intersection points of characteristic curve of the non-linear resistance and this load line are the operation points, which can satisfy both the characteristic of non-linear resistant and the characteristic of the rest of the network.

Operation point



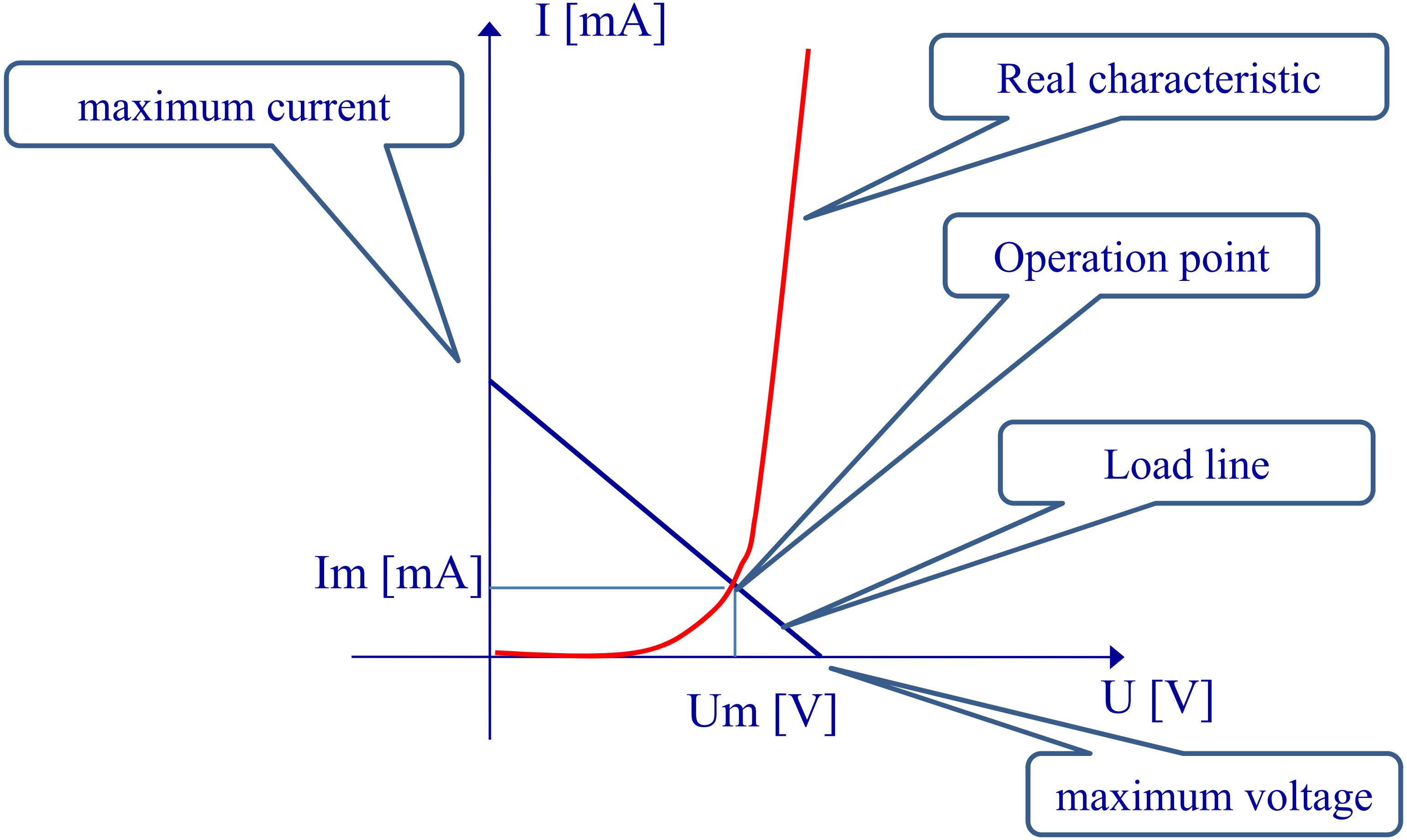
Diode characteristics - review



Diode characteristics - review

- Breakdown range: The range where the Zenner effect occurs.
- Zenner effect: If the emptied layer has a sufficiently big field strength, then it is able to tear out electrons from their ties and this way free charge carriers appear.
- Reverse range: The voltage range where there is no current in the semiconductor.
- Forward range: The voltage range where there is current in the semiconductor.
- Linear range: The part of the forward range, where the voltage-current function can be approximated linearly.
- Exponential range: The part of the forward range, where the voltage-current function can be approximated exponentially.

Diode operation point - review

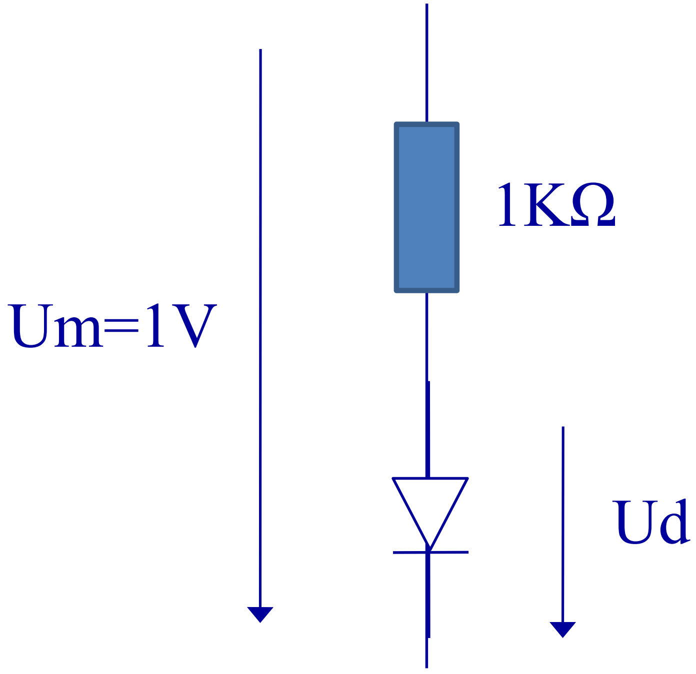


Diode operation point - review

- Operation point: All the electrical characteristics set on an electronic device. In the absence of input signal, values of the static operation point can be measured, in case of a dynamic input the current operation point is constantly changing depending on the input signal.
- Maximum current: The value of the load line of the diode in case of zero voltage value.
- Load line: The load line represents the relationship between current and voltage in the linear part of the circuit.
- Maximum voltage: The value of the load line of the diode in case of zero current value.

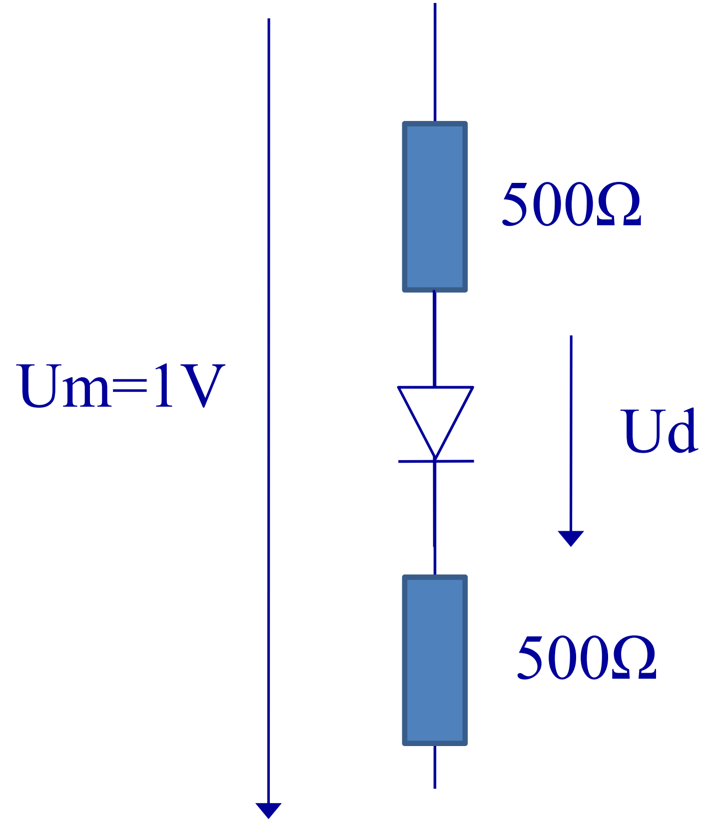
Operation point calculation

- We assume that
- Ud=0.65 V
- Voltage Um-Ud that is 350 mV
- The current is **350mV/1KΩ=350μA**



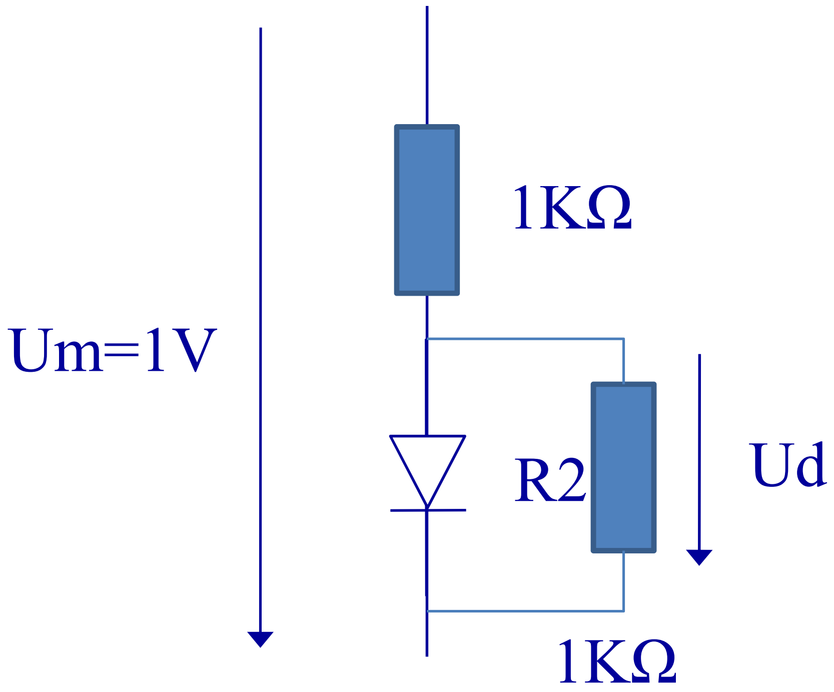
Operation point calculation

- We assume that
- Ud=0.65 V
- Voltage 350mV that is 175 mV on both resistances
- The current is **175mV/500Ω=350µA**



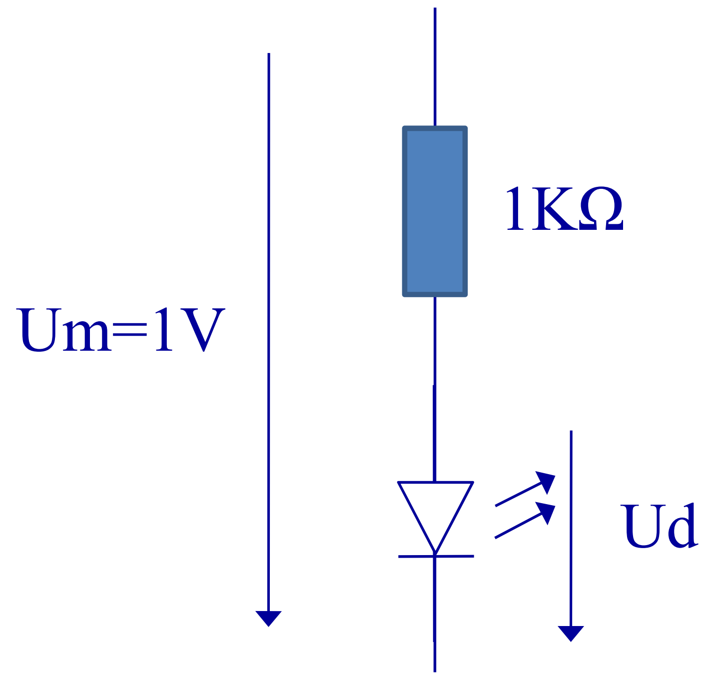
Operation point calculation

- We assume that
- Ud=0.65 V
- Voltage 350mV
- The current is **350µA**
- $\mathbf{I_{R2}}$**=Ud/R2=650 µA**



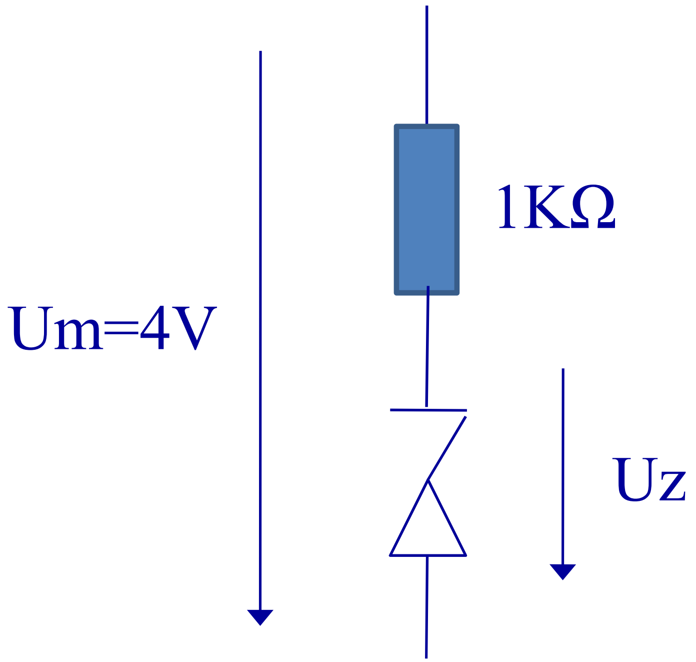
Operation point calculation

- We assume that
- Ud=2.00 V
- Voltage Um-Ud that is -1V
- The current is = **0A!**



Operation point calculation

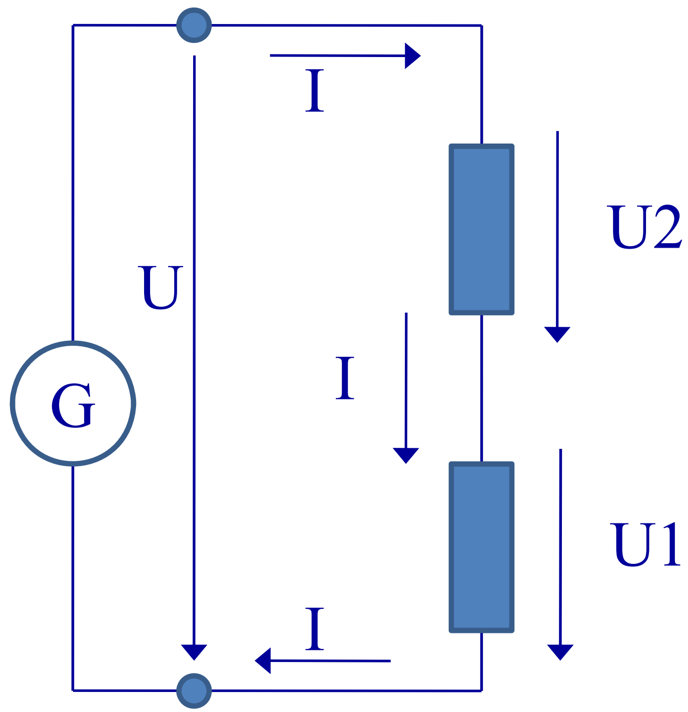
- We assume that
- Ud=2.7 V
- Voltage Um-Ud that is 1.3V
- The current is 2.3V/1K Ω=**1.3mA**



Kirchhoff's voltage law

$$U = U1+U2$$

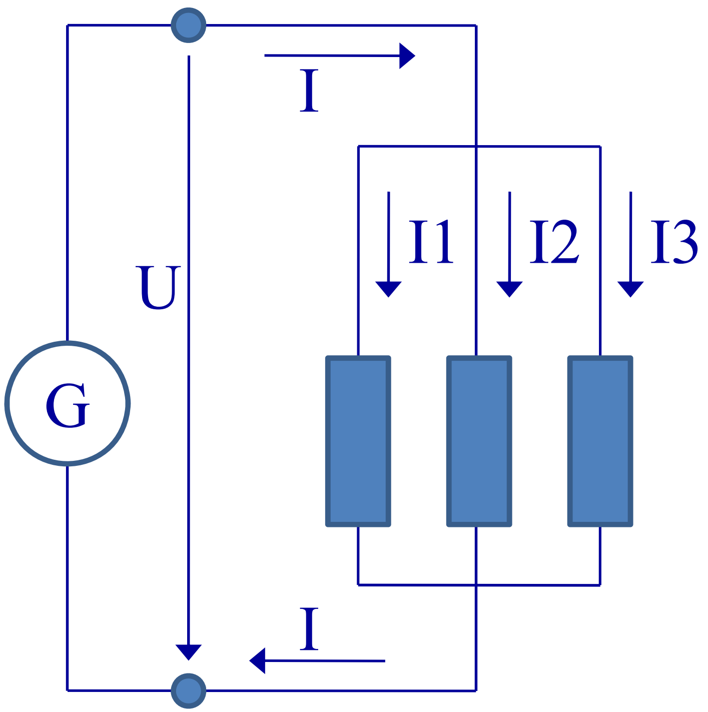
$$\sum U = 0$$



Kirchhoff's current law

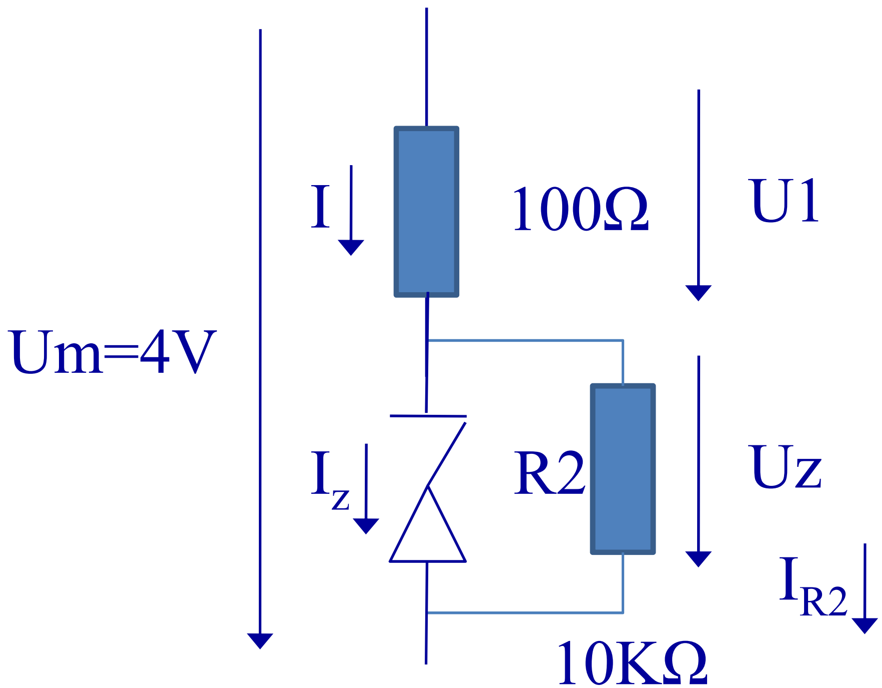
I = I1+I2+I3

$$\sum I = 0$$



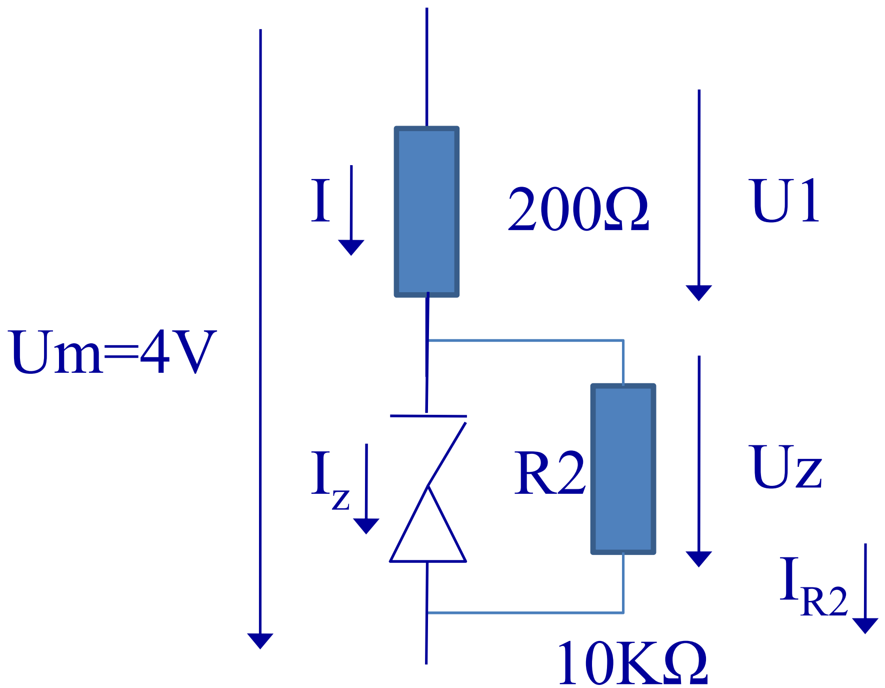
Operation point calculation

- We assume that
- Uz=2.7 V
- U1=1.3V
- The current is **I=1.3V/100 Ω =13mA**
- **I_{R2}=2.7V/10K Ω =270µA**
- **I_z=I-I_{R2} =12.73mA**



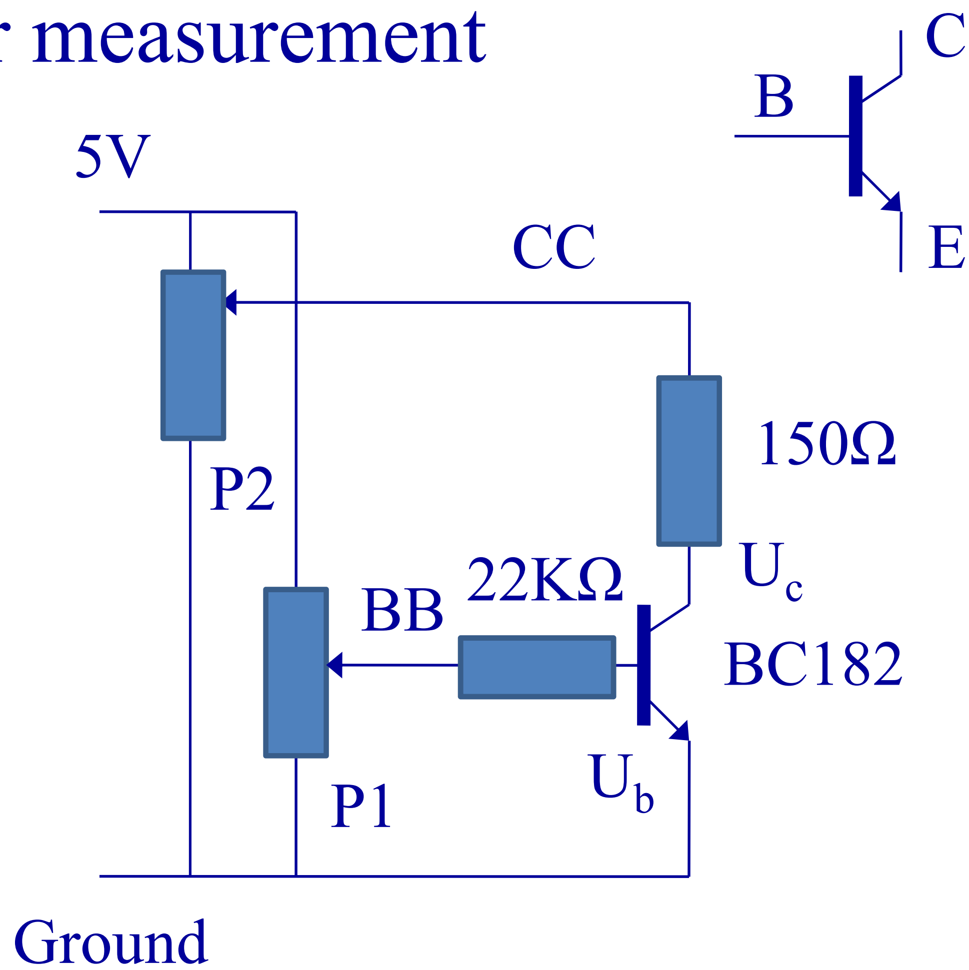
Operation point calculation

- We assume that
- Uz=2.7 V
- U1=1.3V
- The current is
  I=1.3V/200 Ω =6.5mA
- **I_{R2}=2.7V/10K Ω =270µA**
- **I_z=I-I_{R2} =6.23mA**



Circuit for measurement

- $I_b=(U_{bb}-U_b)/22K\ \Omega$
- $I_c=(U_{cc}-U_c)/150\ \Omega$
- To be depicted: $I_c(U_{ce})$ in the case of I_b = constant

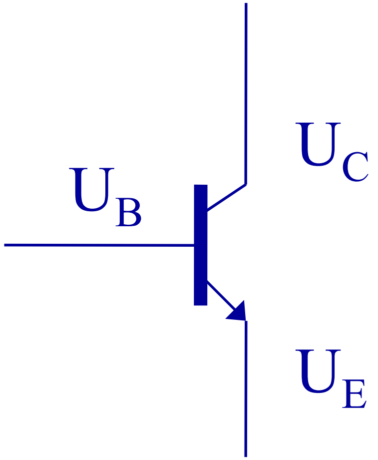


Bipolar transistor

(BE: open, CB: open)

Saturation mode:

- $i_C = ß \cdot i_B$
- $U_{BE} = 0.65$ V
- $U_{CE} = Vsat \approx 0.2$ V

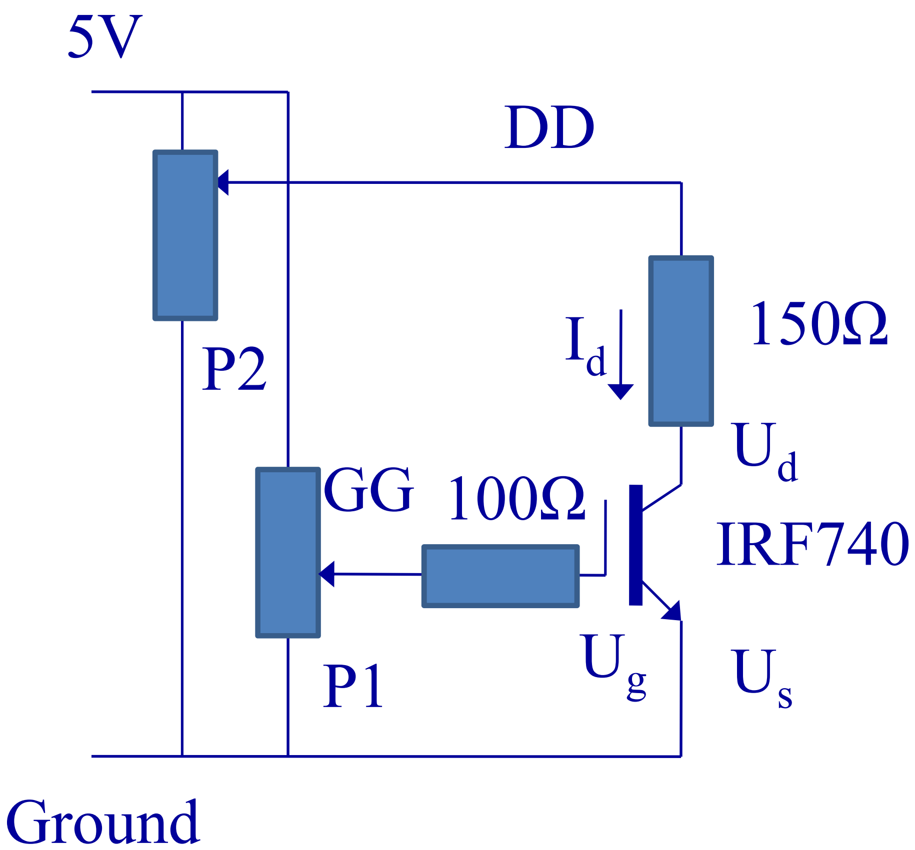


Bipolar transistor

- The transistor can be managed as a four-pole if we duplicate one of its three terminals. The common point of the input and the output is the ground. Thus, from an AC point of view we can distinguish three basic circuits: the common emitter, common collector, common base.
- To operate the transistor, an appropriate base-emitter voltage signal (in case of silicon it is approx. 0.65 V) should be provided. The direction of the collector-base voltage should be closed. The direct voltage and direct current are related to the operation point. The changes around the operation point are for the alternating mode. During operation, direct current and alternating current quantities can be measured.

Circuit for measurement

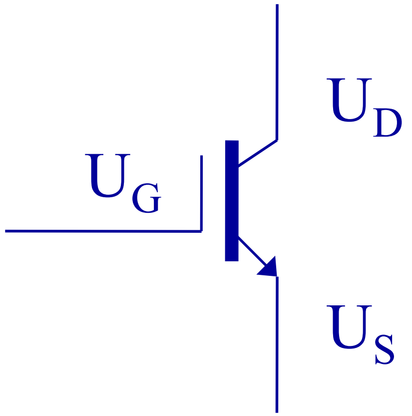
- We do not measure current!
- $U_{gg} = U_g$!!!
- $I_d=(U_{DD}-U_d)/150\ \Omega$
- To be depicted: in the case of $I_d(U_{ds})$ U_{gs} = constant



MOS transistor

- Saturation mode $U_{DS} \geq (U_{GS}-V_T)$
  $I_D=K/2 \cdot (U_{GS}-V_T)^2$

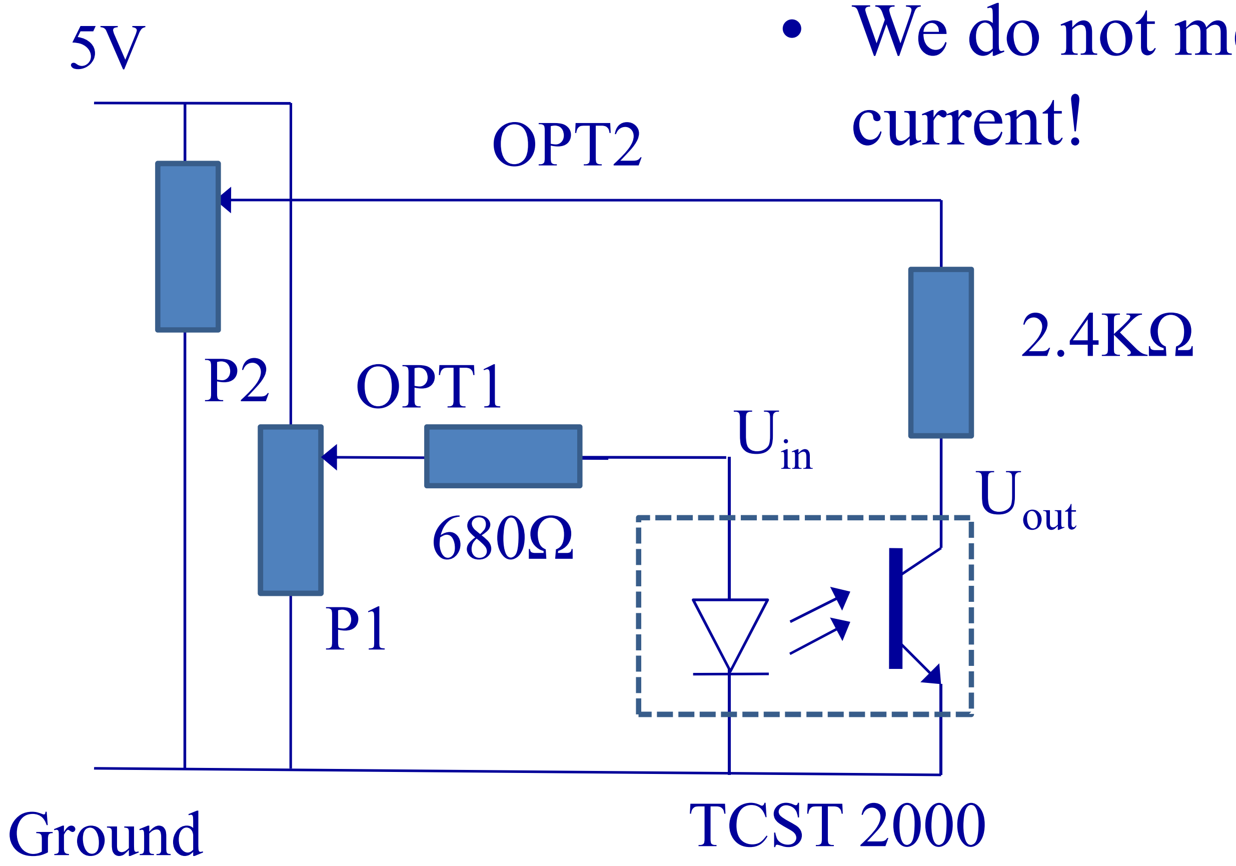
- Triode mode $U_{DS} \leq (U_{GS}-V_T)$
  $I_D=K((U_{GS}-V_T) \cdot U_{DS}-U_{DS}^2 /2)$



where V_T is the threshold voltage and K is usually given

Optocoupler

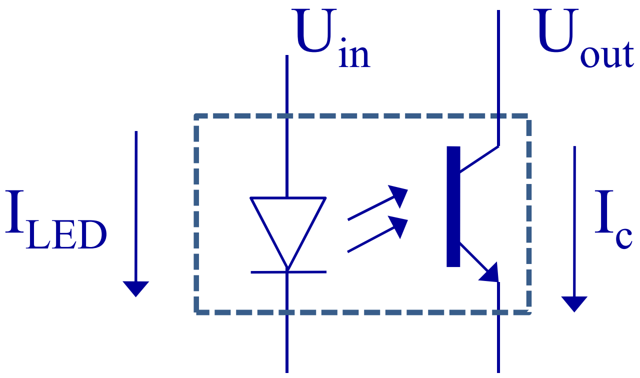
- We do not measure current!



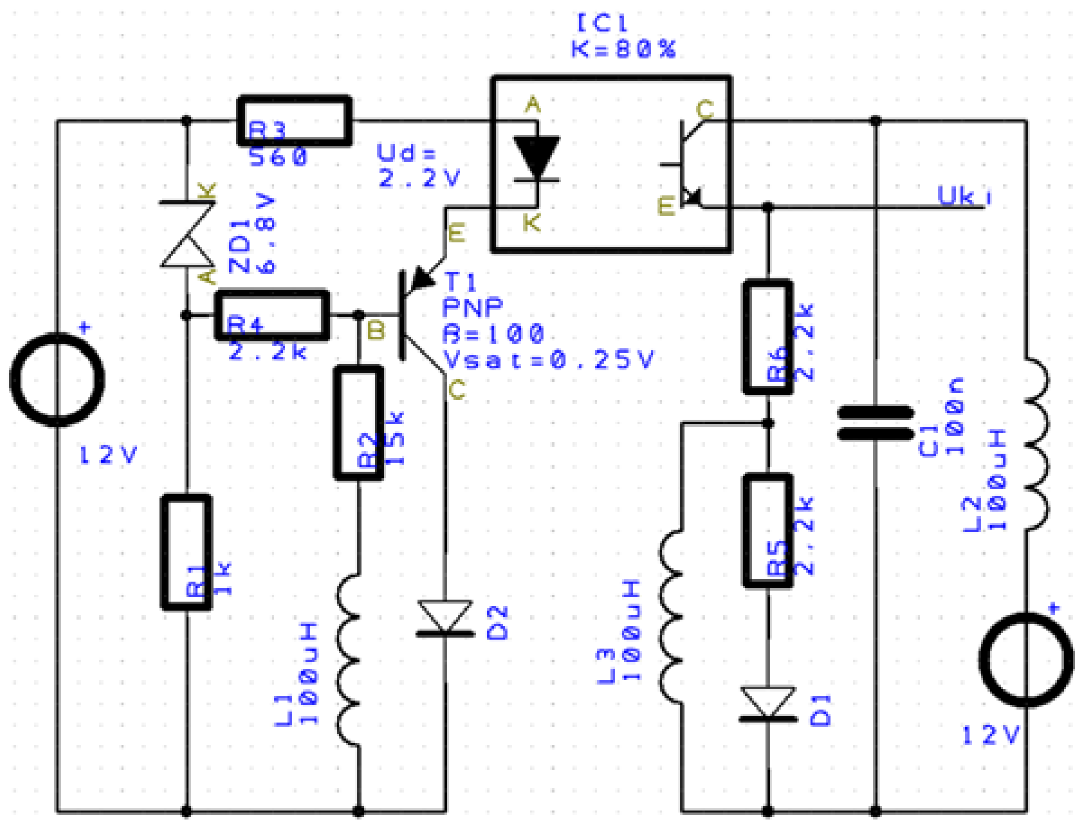
Optocoupler

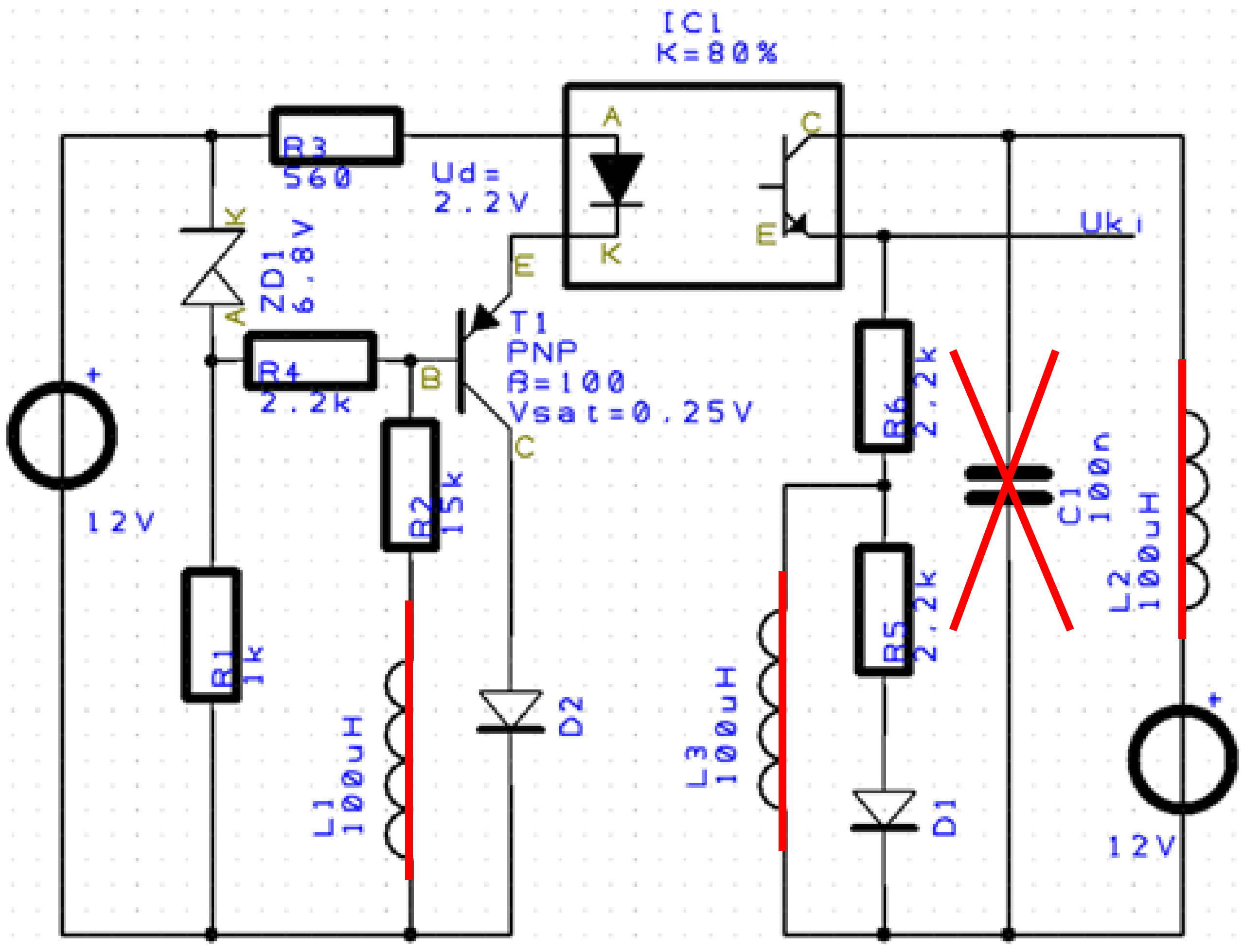
- Linear mode

$$I_c = K_{opto} \cdot I_{LED}$$

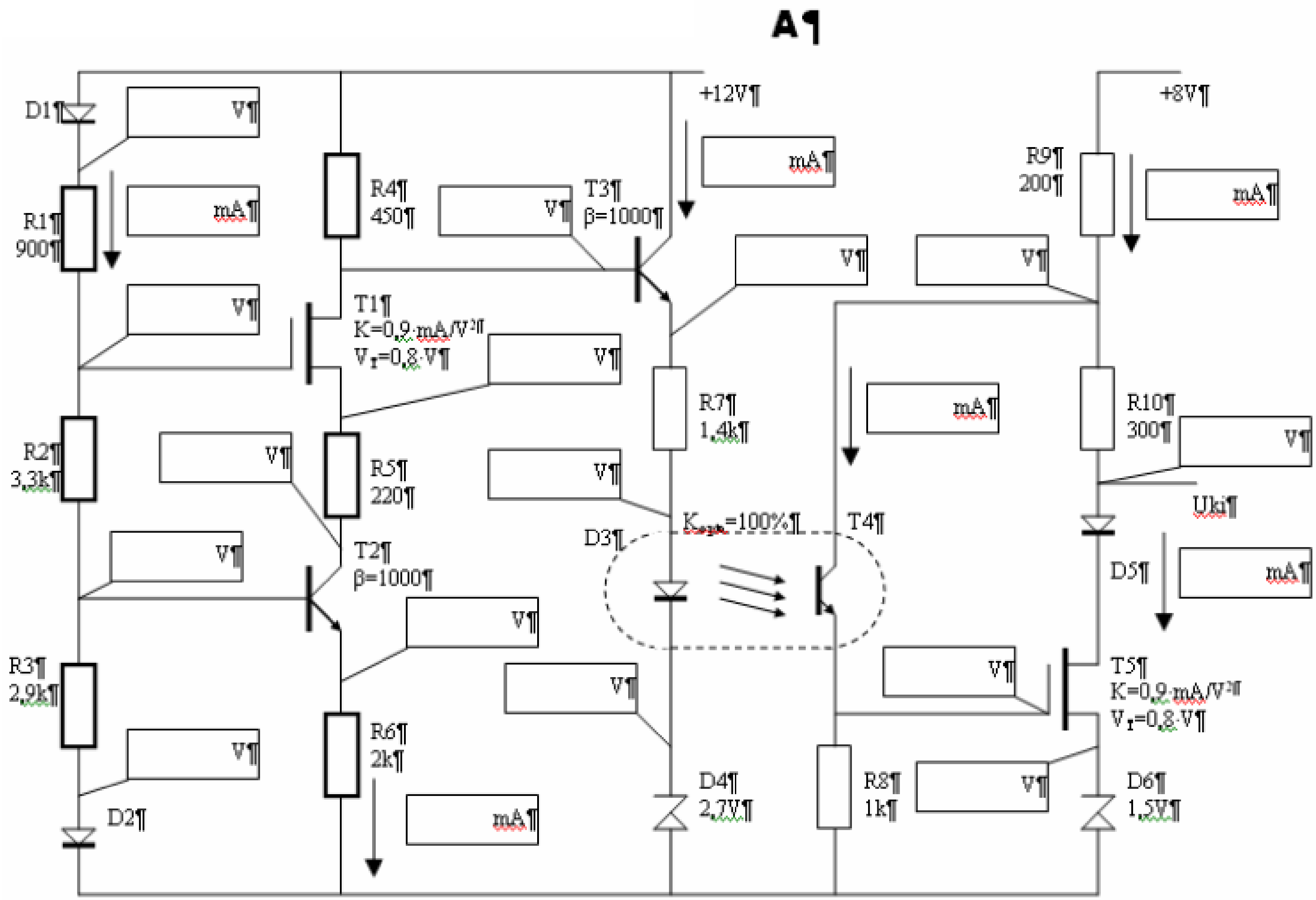


Operation point calculation




IC1
K=80%
A
C
E
K
Ud=
2.2V
Uki
R3
560
ZD1
6.8V
K
A
R4
2.2k
B
T1
PNP
B=100
Vsat=0.25V
E
C
R2
15k
R1
1k
12V
L1
100uH
D2
R6
2.2k
R5
2.2k
C1
100n
L2
100uH
L3
100uH
D1
12V

Electrical Measurements: Nonlinear resistive networks

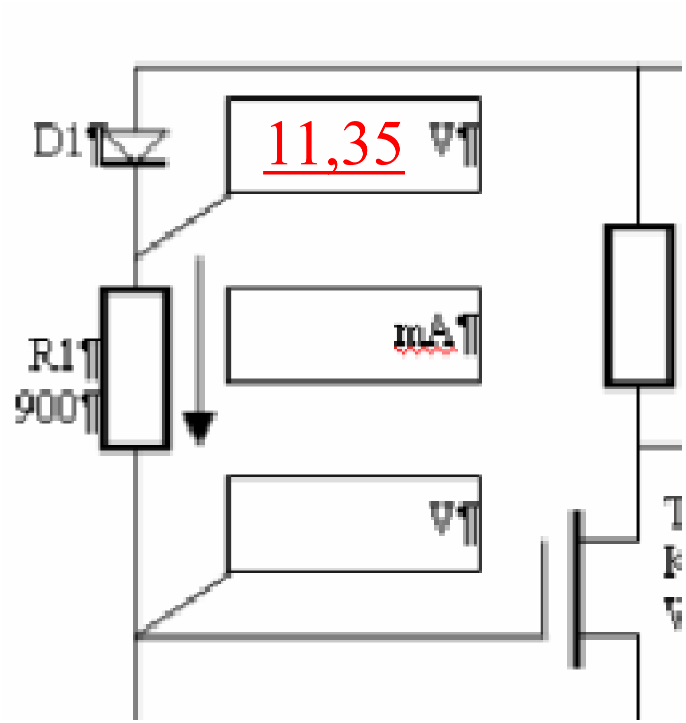


Solution process

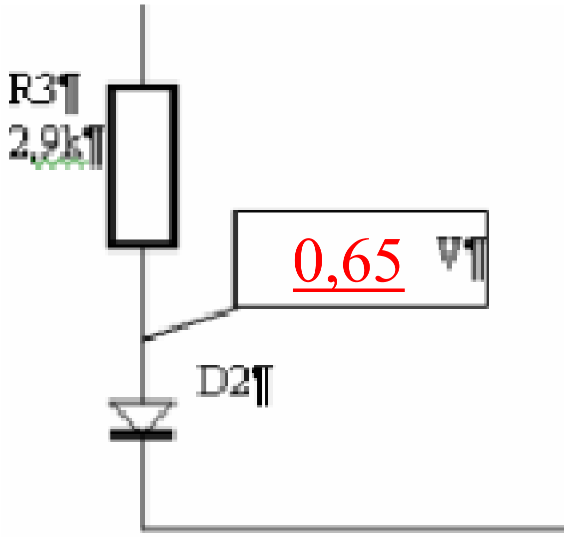
- First step, since we are dealing with DC circuits, we can replace the capacitors with splits and coils with shortcuts.
- It is assumed that the diodes are opened mode and this can change if we get a contradiction.
- Usually the voltage of the diodes are given, in case of opened mode we can assume that this is 0.65V.
- We use the calculation rules related to the cases of serial and parallel resistors.
- We use Kirhoff's voltage and current laws.
- The basis current of the bipolar transistor usually can be negligibled.

Solution process

- The emitter - collector voltage of the bipolar transistor can not be calculated directly.
- If we know the voltages at the poles of a resistance, the voltage difference can be calculated easily.
- We use Ohm's law. If at least two are known out of the voltage of the resistance, the resistance value and the current, then the third can be calculated on the basis of the formula $U = IR$.
- It is assumed that the MOS transistor is in satruation mode, if we get a contradiction in the calculation, change the assumption (triode mode).

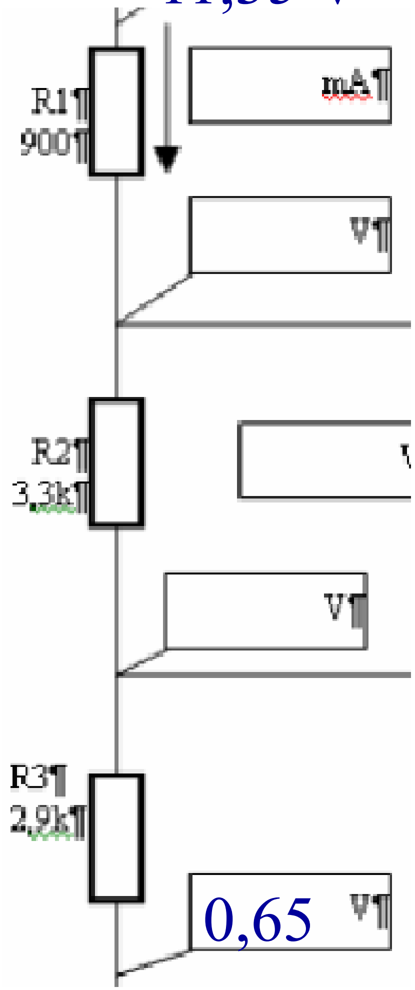


$U_d = 0{,}65\ V$



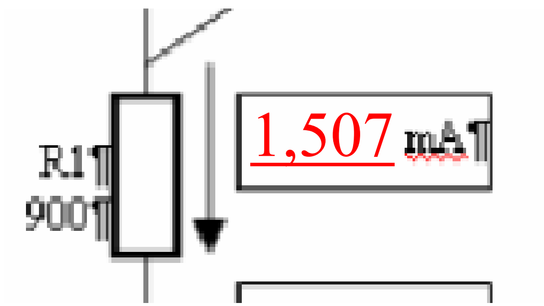
Electrical Measurements: Nonlinear resistive networks

11,35 V

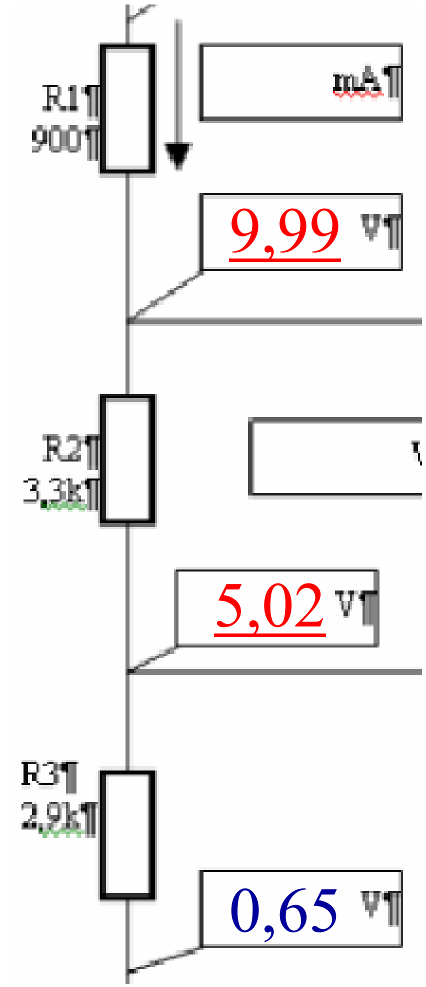


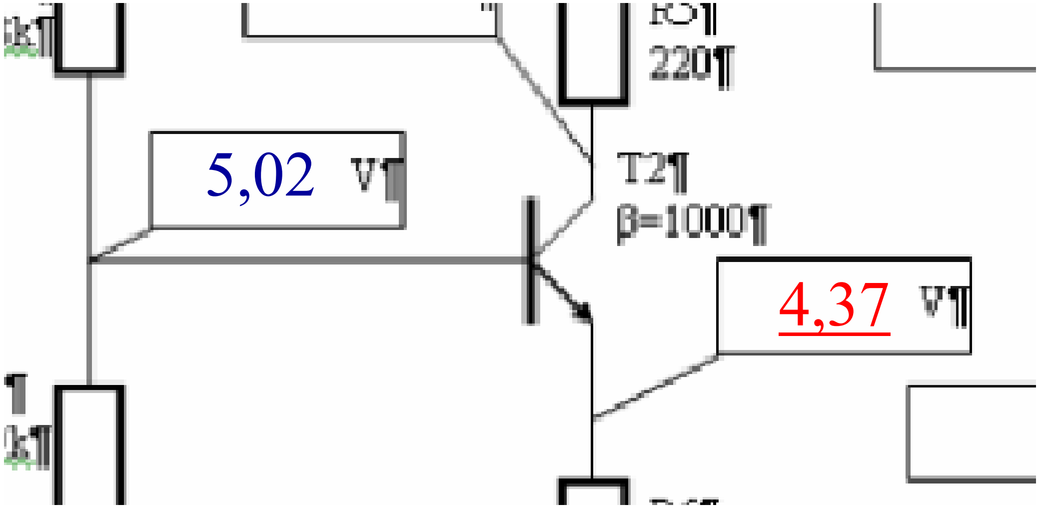
R=R1+R2+R3=7.1K Ω

I=U/R=10,7V/R=1,7mA

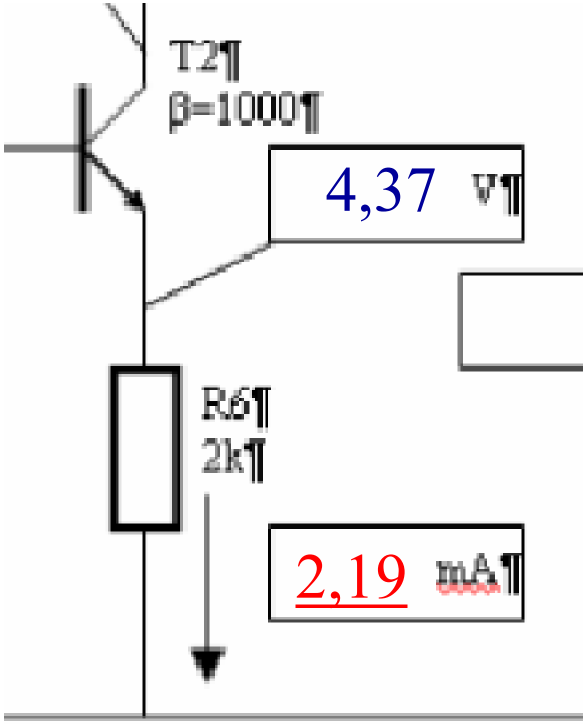


U=I*R



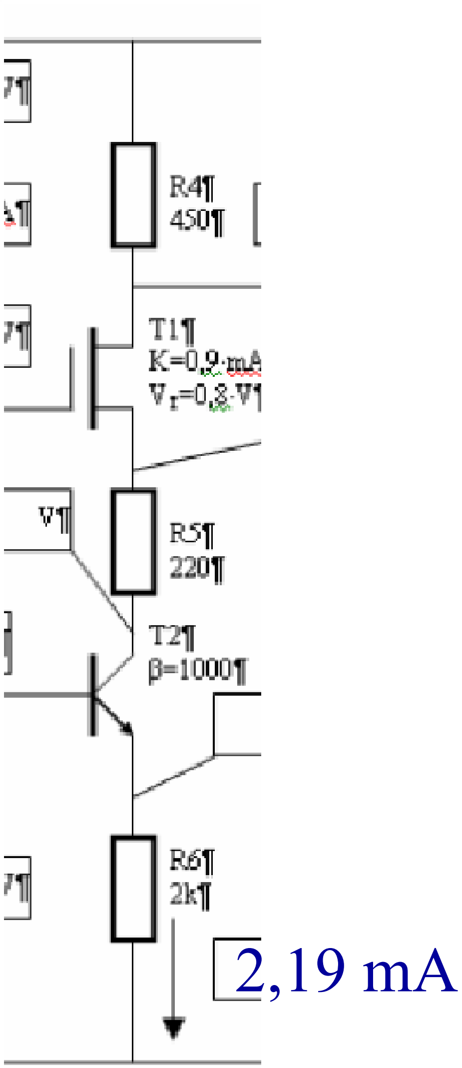


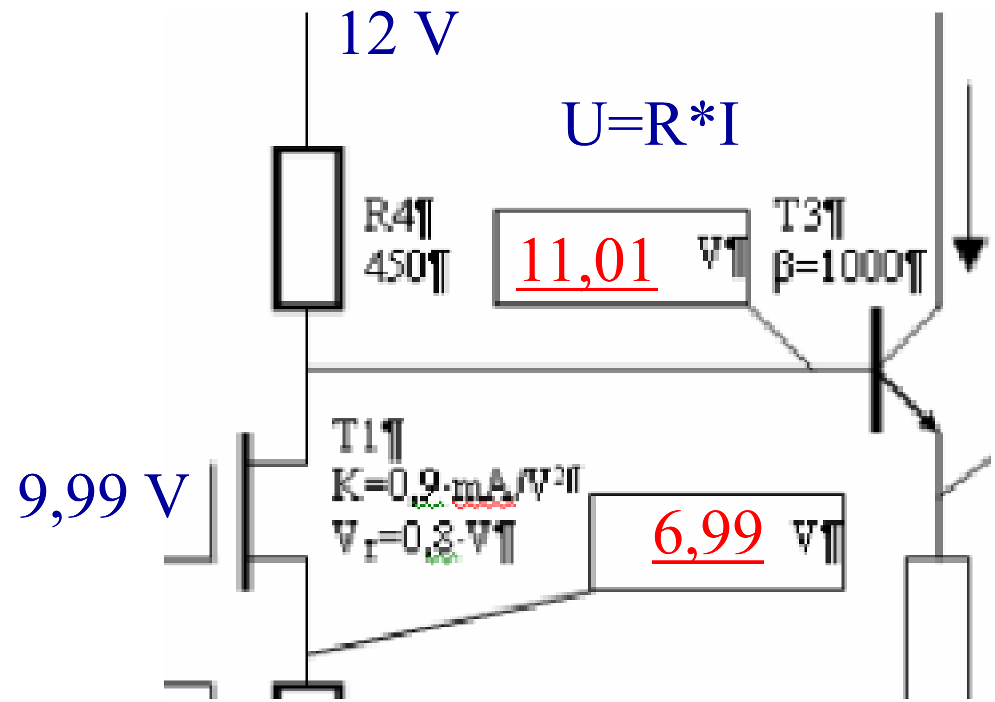
I=U/R



- Saturation mode: $i_C = ß \cdot i_B$
- $U_{BE} = 0.65$ V
- Saturation: $U_{CE} = Vsat \approx 0.2$ V

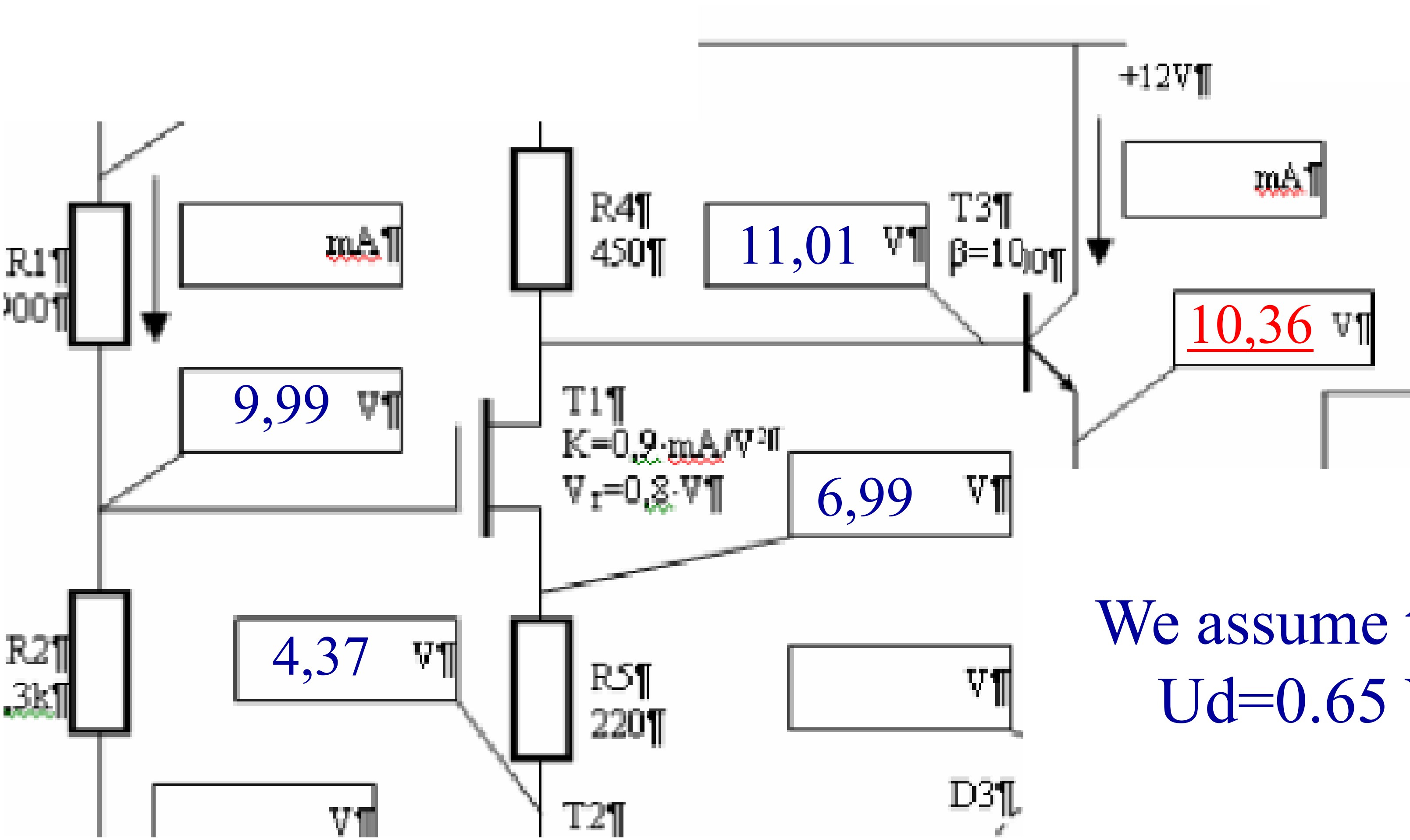
Electrical Measurements: Nonlinear resistive networks



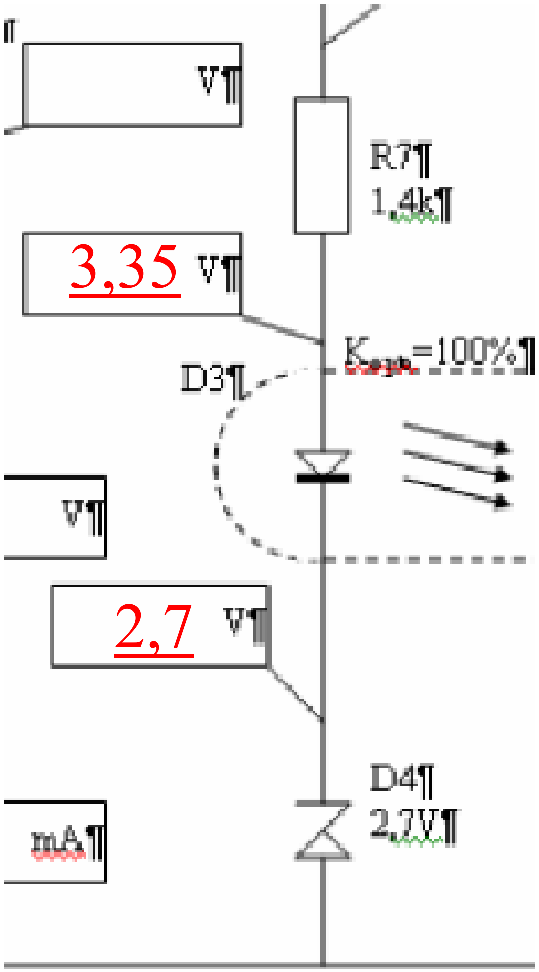


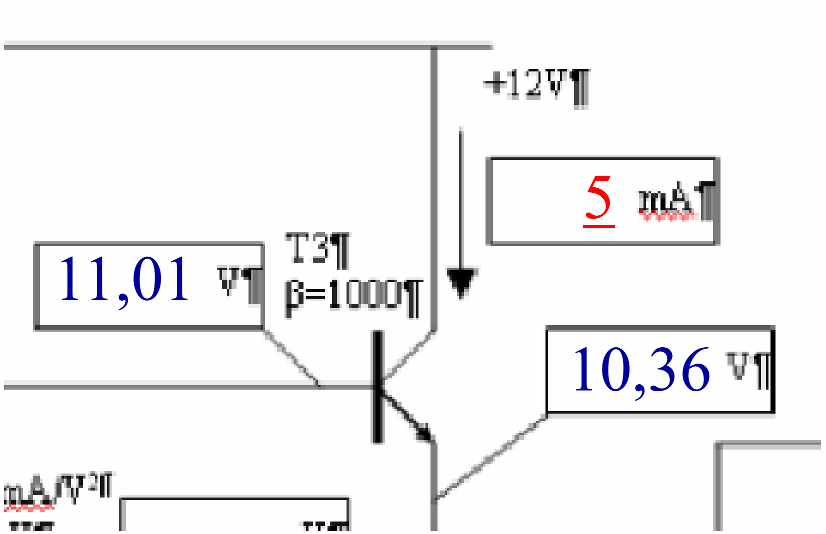
$U_{DS} \geq (U_{GS}-V_T)$, $I_D=K/2 \cdot (U_{GS}-V_T)^2$

-> $U_{GS}=3V$

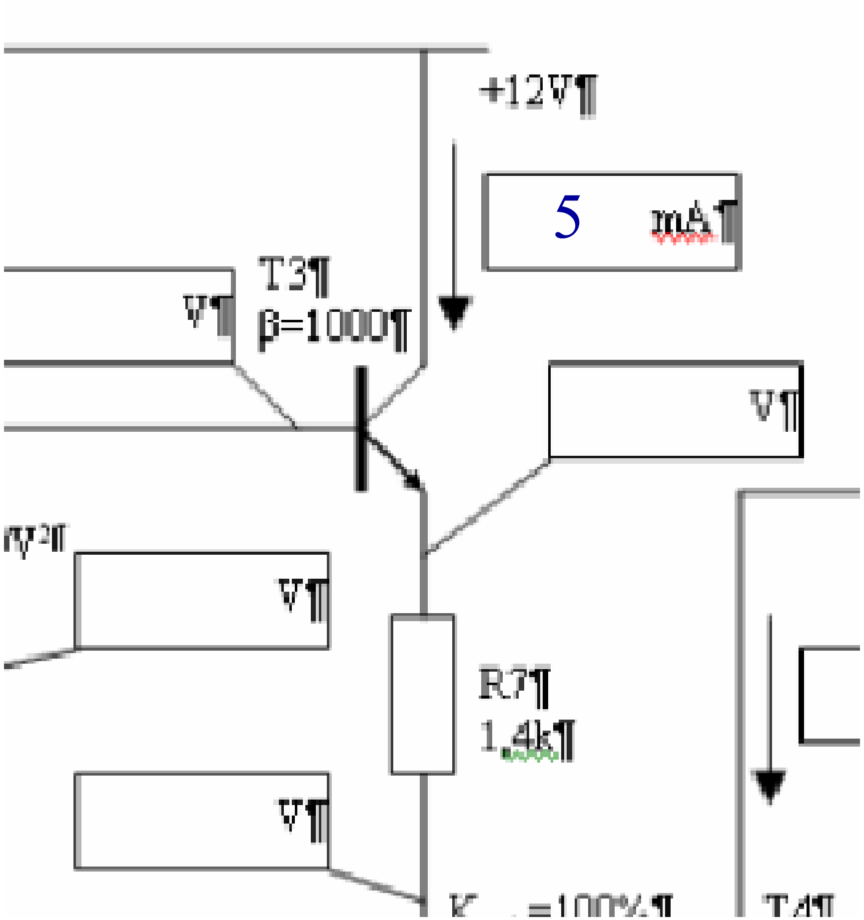


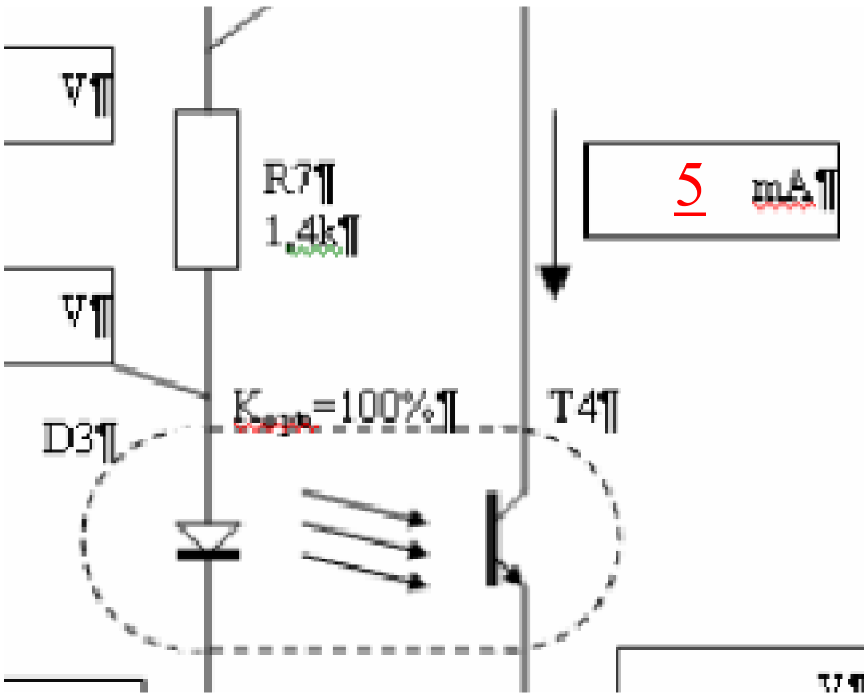
We assume that
Ud=0.65 V



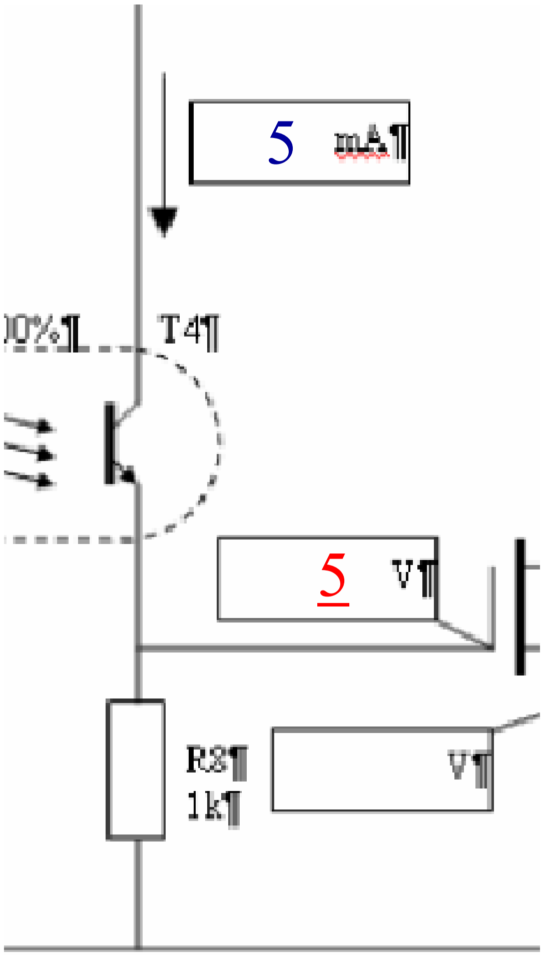


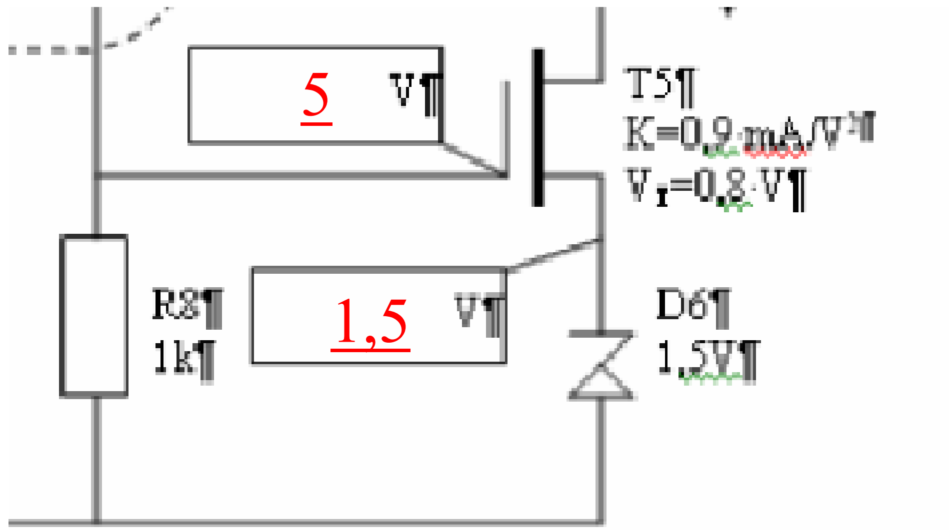
I=U/R = (10,36 – 3,35) / 1,4 = 5 mA





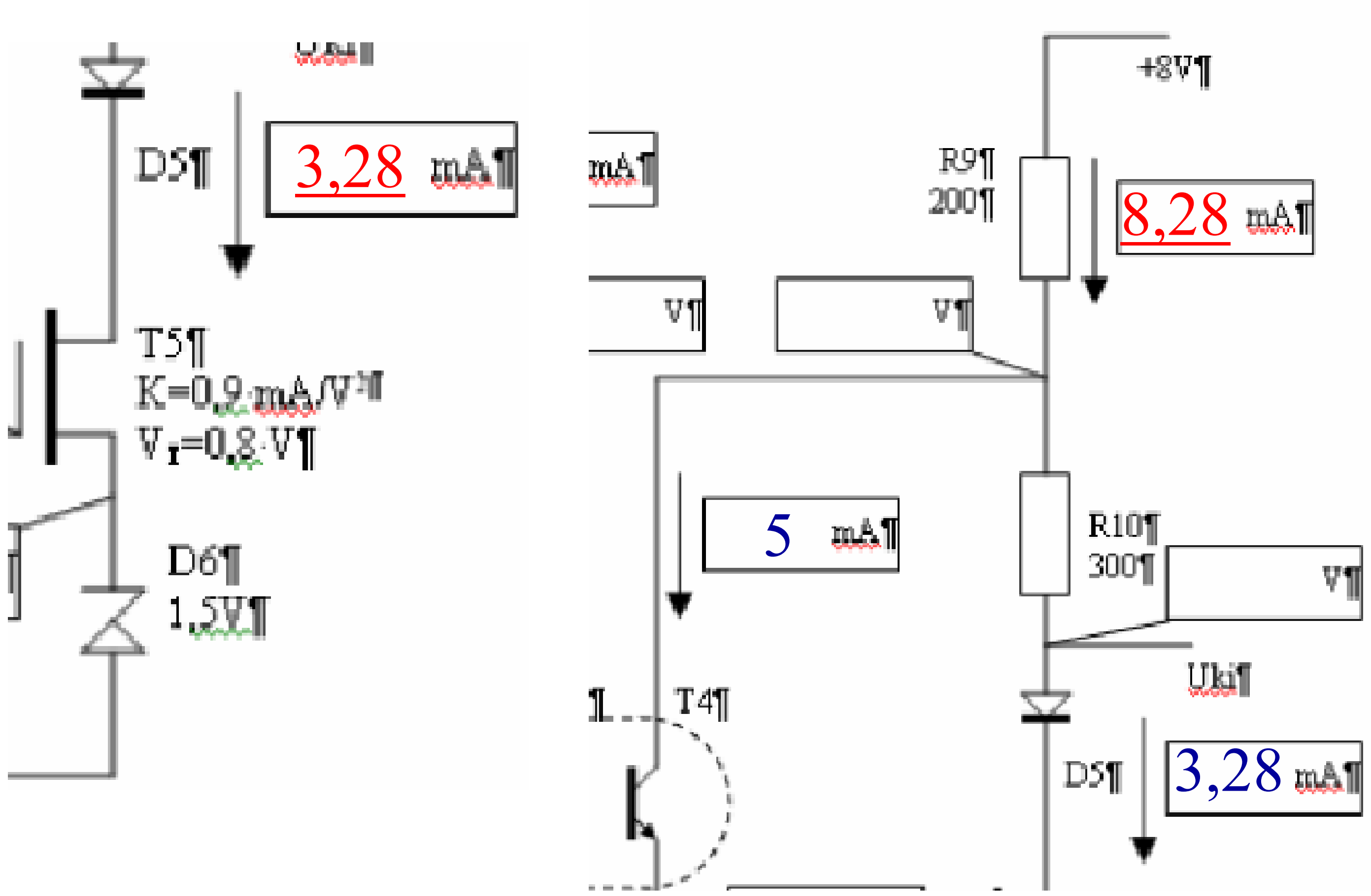
$$I_c = K_{opto} \cdot I_{LED}$$



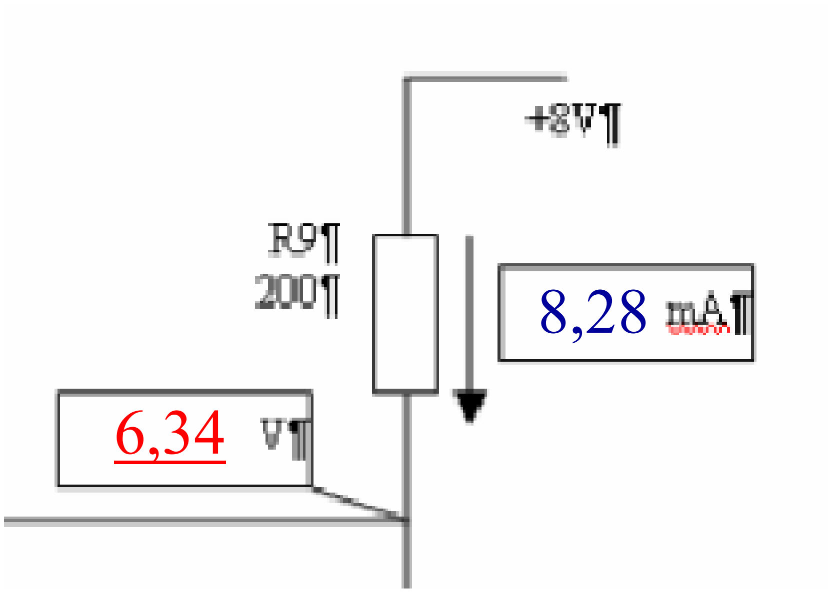


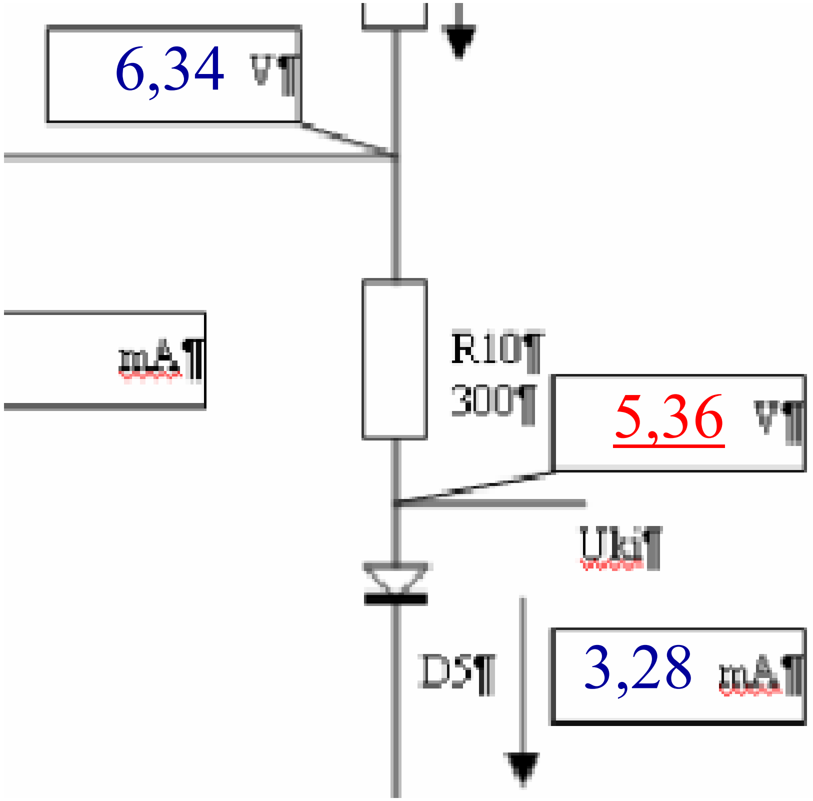
U=R*I

U_{GS}=3,5V



$U_{DS} \geq (U_{GS}-V_T)$, $I_D = K/2 \cdot (U_{GS}-V_T)^2$ -> $I_D = 3{,}28$ mA





U=R*I