# SEMICONDUCTOR COMPONENTS

4th Edition

Training in Technology

hps SystemTechnik

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0.6.2

# Introduction

The present manual

## SEMICONDUCTOR COMPONENTS

serves for conducting basic experiments with hps training systems, giving an insight into the properties and characteristics of the most important semiconductor components.

The different subjects are divided as follows:

- General / basic principles
- Section of experiments, including the task (experiment) and the procedure of the experiment

The chapter „General“ offers a short description on the subject of the respective experiment. A detailed theoretical description has purposely been omitted here because of the large extent of the subject.

We refer you to the text books recommended by book-stores for studying the theory and as accompanying experiment material.

All tables and diagrams necessary for solving the tasks set in the experiments are included. There is an extensive solutions section in the appendix for checking your own answers to the tasks and questions set in the experiments.

hps SystemTechnik offer several training systems for conducting the experiments, designed to suit individual requirements.

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**Foil**

Front view of the ELECTRONIC BOARD (Type 1018) . . . . . . . . . . F 1

# 1. Rectifier Diodes

## 1.1 Effect of the P-N Junction in Diodes

### 1.1.1 General

Diodes are bipolar semiconductor components and consist of an n-conducting and a p-conducting layer. As free charge carriers, electrons are predominant in the n-conducting layer and holes in the p-conducting layer. The p-n junction between the two has an internal diffusion potential which prevents the union of the free charge carriers. The diode is thus blocked.

By applying an external voltage the blocking effect can be increased or eliminated. The semiconductor diode transmits the current in one direction and blocks it in the other direction.

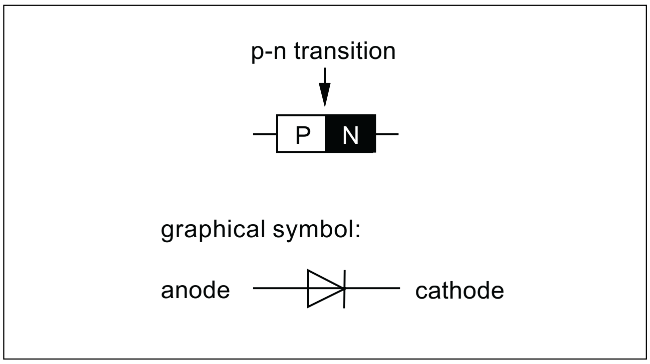


*Fig. 1.1.1.1*

### 1.1.2 Experiments

❒ **Experiment**

Investigate the effect of the p-n junction of a rectifier diode on the current flowing through in dependence on the applied voltage and its polarity.

**Procedure**

- Apply the DC voltages $U_F$ listed in Table 1.1.2.1 to the diode as shown in Fig. 1.1.2.1 (polarity 1), measure the corresponding current $I_F$ and enter the values in Table 1.1.2.1. For this purpose, use the current error measuring.

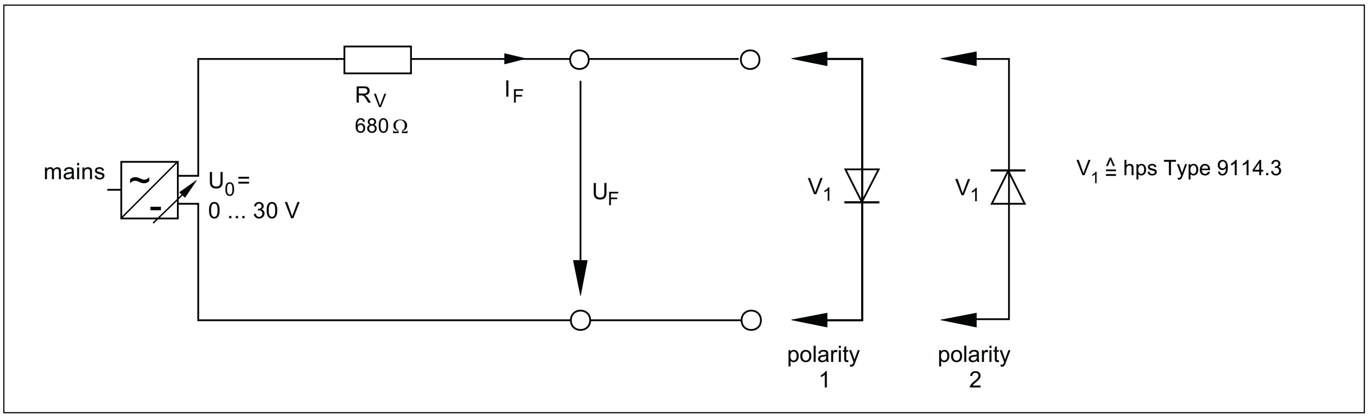


*Fig. 1.1.2.1*

- Then reverse the polarity of the diode (polarity 2) and repeat the experiment with the voltage values given in Table 1.1.2.2. Doing this, the preceding voltage divider $R_V$ / P must be removed and the voltage must be set directly on the power supply unit. For this purpose, use the voltage error measuring.
  Accurate measurement of the off-state current $I_R$ is only possible with a highly sensitive multimeter (100 nA full swing).
- Transpose the measured values from the two tables into the diagram of Fig. 1.1.2.2 to plot the diode characteristic.

| **$U_F$ [V]** | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.65 | 0.7 | 0.75 |
|---|---|---|---|---|---|---|---|---|---|---|
| **$I_F$ [mA]** | | | | | | | | | | |

*Tab. 1.1.2.1*

| **$U_R$ [V]** | 0 | 2.5 | 5 | 10 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|---|---|---|
| **$I_R$ [nA]** | | | | | | | | |

*Tab. 1.1.2.2*

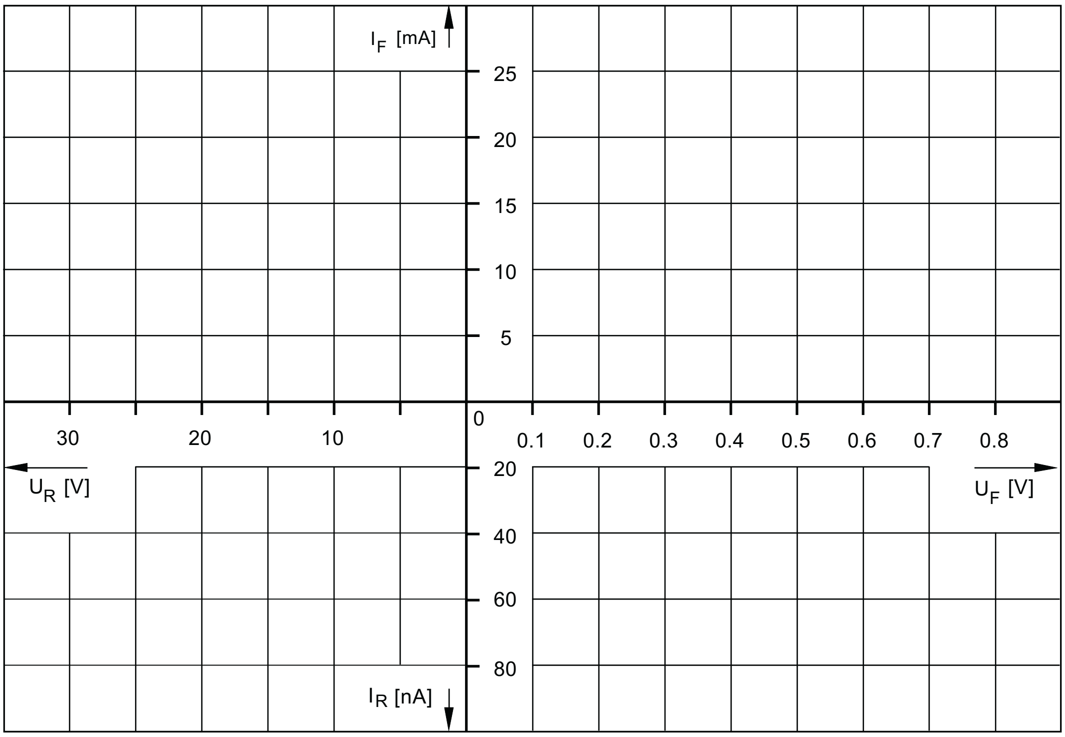


*Fig. 1.1.2.2*

**Question:** What do you call the voltage at which the diode becomes conductive?

**Answer:**

## 1.2 Characteristic Curves for Diodes of Different Semiconductor Materials

### 1.2.1 General

The diode characteristic can be displayed in full on the oscilloscope monitor if the diode is fed with an AC voltage whose momentary value alternates periodically between zero and its peak values.

The diode potential is applied to the inverting X-amplifier, the diode current is tapped as a proportional voltage at a series-connected resistor and applied to the Y amplifier.

### 1.2.2 Experiments

❒ **Experiment**

Record the characteristics of a silicon diode, of a germanium diode and of a gallium-arsenide diode (LED) with the oscilloscope.

**Procedure**

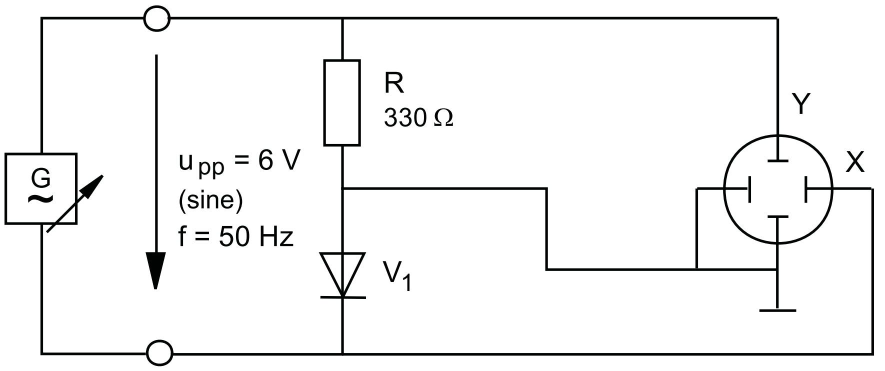
- Set up the circuit as shown in Fig. 1.2.2.1 and record the voltage course at the silicon diode, the germanium diode and at the gallium-arsenide diode (LED) with the oscilloscope (X/Y representation).

  **Note:** Since both voltages are poled oppositely in relation to the reference point, one of the two deflection amplifiers (e. g. X-amplifier) must invert.

  When using oscilloscopes without inverting facilities, a mirror-inverted image is obtained.

  **Attention:** The generator output or the oscilloscope inputs must be potential-free to prevent short-circuiting of the measuring voltages through the common ground.

- Draw the course of the curve of the three diodes into diagram 1.2.2.2.



$V_1$ ≙ hps Types:
9114.3 (silicon diode)
9114.2 (germanium diode)
9121.10.3 (gallium-arsenide diode)

*Fig. 1.2.2.1*

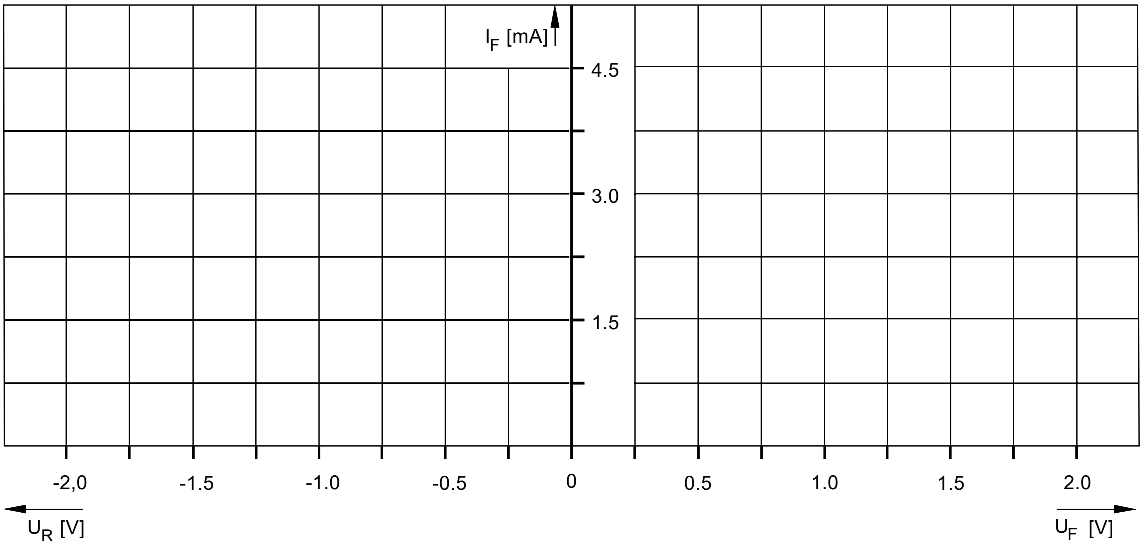


*Fig. 1.2.2.2*

**Question 1:** How do the characteristic data of the individual diodes basically differ?

**Answer:**

Threshold voltages:

Silicon diode: . . . . . . . . . . . . . . . . . .

Germanium diode: . . . . . . . . . . . . . . . . . .

Gallium-arsenide-diode (LED): . . . . . . . . . . . . . . . . . .

**Question 2:** Approximately how large are the internal differential resistances of the individual diodes with a voltage change of 1.5 ... 4.5 mA?

**Answer:**

The internal differential resistances $R_{diff}$ are:

**Silicon diode:**

$$R_{diff} = \frac{\Delta U_F}{\Delta I_F} =$$

**Germanium diode:**

$$R_{diff} = \frac{\Delta U_F}{\Delta I_F} =$$

**Gallium-arsenide-diode (LED):**

$$R_{diff} = \frac{\Delta U_F}{\Delta I_F} =$$

$\Delta U_F$ = change of on-state potential in V

$\Delta I_F$ = change of on-state current in A

$\Delta R_{diff}$ = differential internal resistance in $\Omega$

**Question 3:** What is the advantage of dynamic characteristic recording as opposed to the static method?

**Answer:**

## 1.3 Half-Wave Rectifier Circuit M1

### 1.3.1 General

In circuits in which semiconductor diodes are inserted a current can only flow (on-state range) when the ap-plied current has a certain polarity. If the polarity of the voltage is reversed, the off-state range of the diode becomes effective, preventing current from flowing. If circuits such as these are fed with AC voltage, current only flows at the half-wave at which the diode is in the on-state. The other half-wave is suppressed. The current in the circuit only flows in one direction.

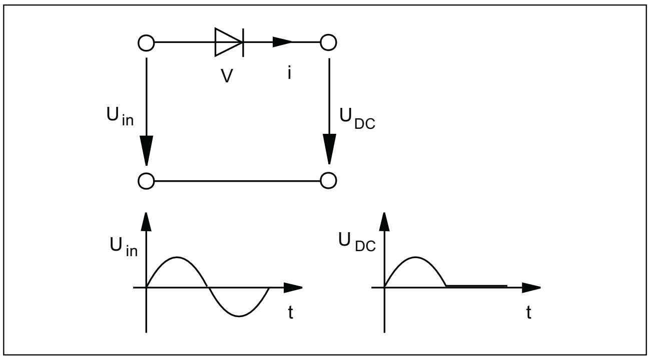


*Fig. 1.3.1.1 Half-wave rectifier circuit M1*

### 1.3.2 Experiments

**❒ Experiment**

The rectifying effect of a semiconductor diode is to be investigated in a half-wave rectifier circuit and its properties examined with the multimeter and the oscilloscope.

**Procedure**

- Set up the circuit according to Fig. 1.3.2.1 (without smoothing capacitor). The input voltage $U_{in}$ and the DC voltage $U_{DC}$ are to be measured with a multimeter and the ratio $U_{DC}$ to $U_{in}$ to be calculated.

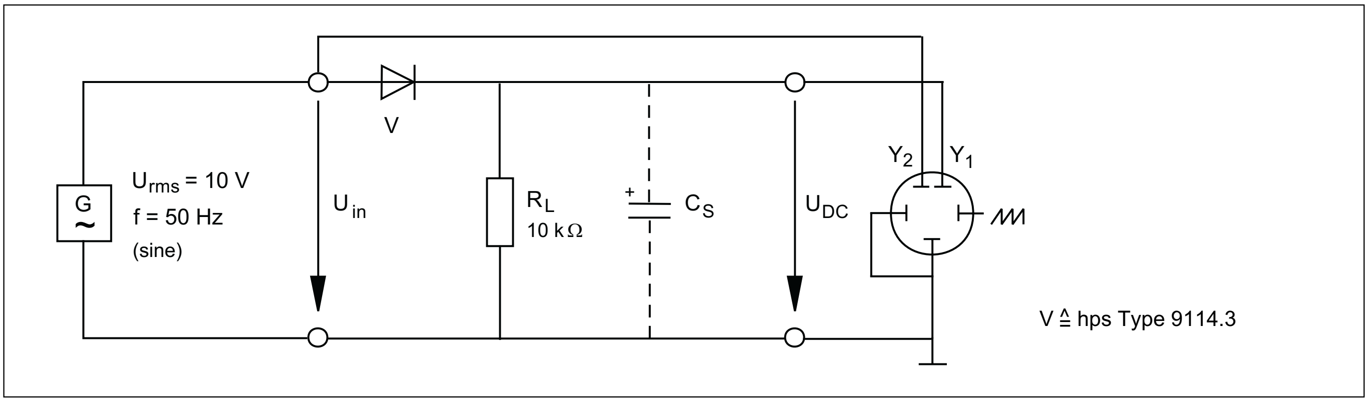


*Fig. 1.3.2.1*

- Then the input voltage $U_{in}$ and the DC voltage $U_{DC}$ are to be recorded with the oscilloscope and their curve shape to be entered into the diagram of Fig. 1.3.2.2.

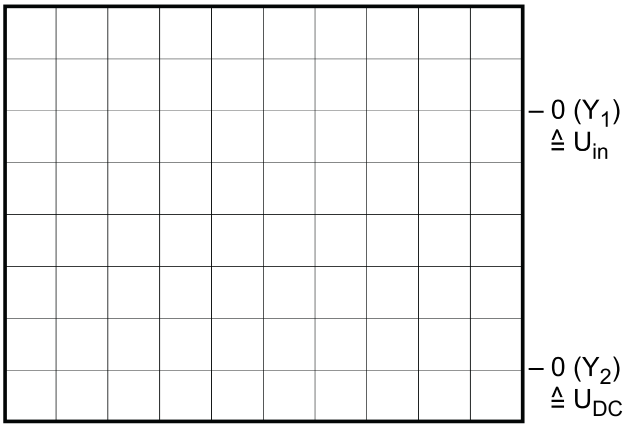


*Fig. 1.3.2.2*

**Settings:**

$Y_1$ = 10 V / div.
$Y_2$ = 5 V / div.
X = 5 ms / div.

- Evaluate the peak-to-peak value and the frequency of the ripple voltage $U_{rip}$ from the oscilloscope diagram (Fig. 1.3.2.2).
  **Note:** The ripple voltage is the AC voltage share of the pulsing DC voltage $U_{DC}$.

- Subsequently connect the smoothing capacitors $C_S$ in parallel to the load resistor $R_L$ as per Table 1.3.2.1 and repeat the measurings.

  **Attention:** Pay attention to the polarity in electrolytic capacitors!

- Enter all evaluated values into Table 1.3.2.1.

| **Half-wave rectifier circuit M1** | | | | |
|---|---|---|---|---|
| **$C_S$ [µF]** | **without** | **10** | **100** | **470** |
| **$U_{in}$ [V]** | | | | |
| **$U_{DC}$ [V]** | | | | |
| **$\frac{U_{DC}}{U_{in}}$ =** | | | | |
| **$u_{rip\ pp}$ [V]** | | | | |
| **$f_{rip}$ [Hz]** | | | | |

*Tab. 1.3.2.1*

- Plot the curve of input voltage $U_{in}$ and of DC voltage $U_{DC}$ which results using the smoothing capacitor 10 µF on the grid of Fig. 1.3.2.3.

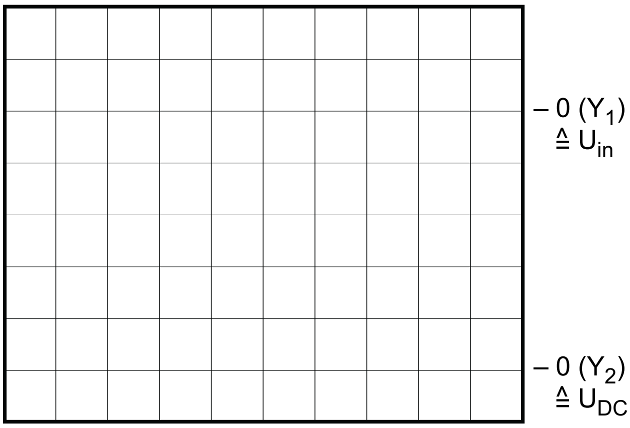


*Fig. 1.3.2.3*

**Settings:**

$Y_1$ = 10 V / div.
$Y_2$ = 5 V / div.
X = 5 ms / div.

- Finally reverse the polarity of the diode in the circuit (Fig. 1.3.2.1) and oscilloscope the voltages $U_{in}$ and $U_{DC}$ without smoothing capacitor.

- Enter the curve shapes of the two voltages into the diagram (Fig. 1.3.2.4).

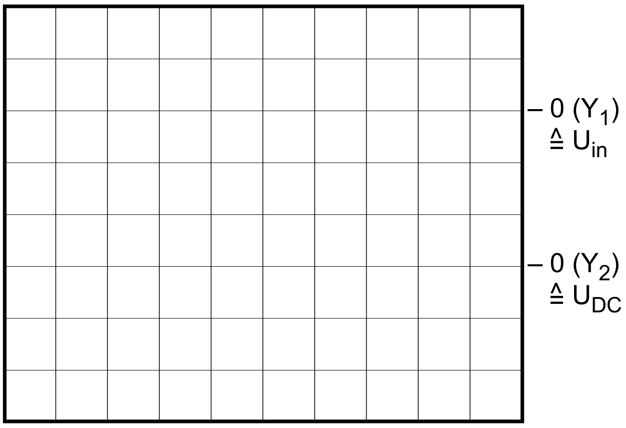


*Fig. 1.3.2.4*

**Settings:**

$Y_1$ = 10 V / div.
$Y_2$ = 5 V / div.
X = 5 ms / div.

---

**Question 1:** What is the frequency of the ripple voltage $U_{rip}$?

---

**Answer:**

---

**Question 2:** What happens if the polarity of the diode in the circuit (Fig. 1.3.2.1) is reversed?

---

**Answer:**

---

**Question 3:** At which connection of the diode is the plus pole of the resultant DC voltage $U_{DC}$?

---

**Answer:**

---

**Question 4:** What is the off-state voltage effective on the diode with smoothing capacitor $C_S$?

---

**Answer:**

---

**Question 5:** What effect does the smoothing capacitor have on the peak-to-peak value of the ripple voltage?

---

**Answer:**

# 1.4 Bridge Rectifier Circuit B2

## 1.4.1 General

The half-wave rectifier circuit only makes use of one half-wave of the AC voltage. This has the disadvantage of a low DC voltage and a high ripple.

This disadvantage is avoided with the bridge rectifier circuit B2: the opposite half-waves are reversed in polarity and added to the DC voltage.

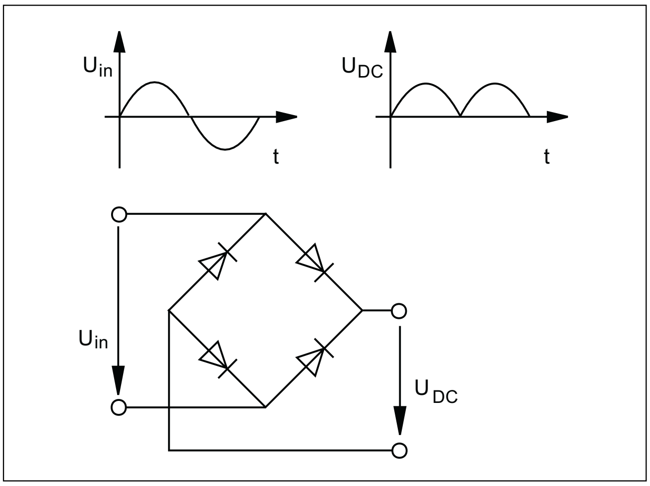


*Fig. 1.4.1.1 Bridge rectifier circuit B2*

## 1.4.2 Experiments

**❒ Experiment**

Measure the properties of a bridge rectifier with the oscilloscope and the multimeter.

**Procedure**

- Set up the circuit according to Fig. 1.4.2.1 (without smoothing capacitor). Measure the input voltage $U_{in}$ and the DC voltage $U_{DC}$ with a multimeter and calculate the ratio $U_{DC}$ to $U_{in}$.

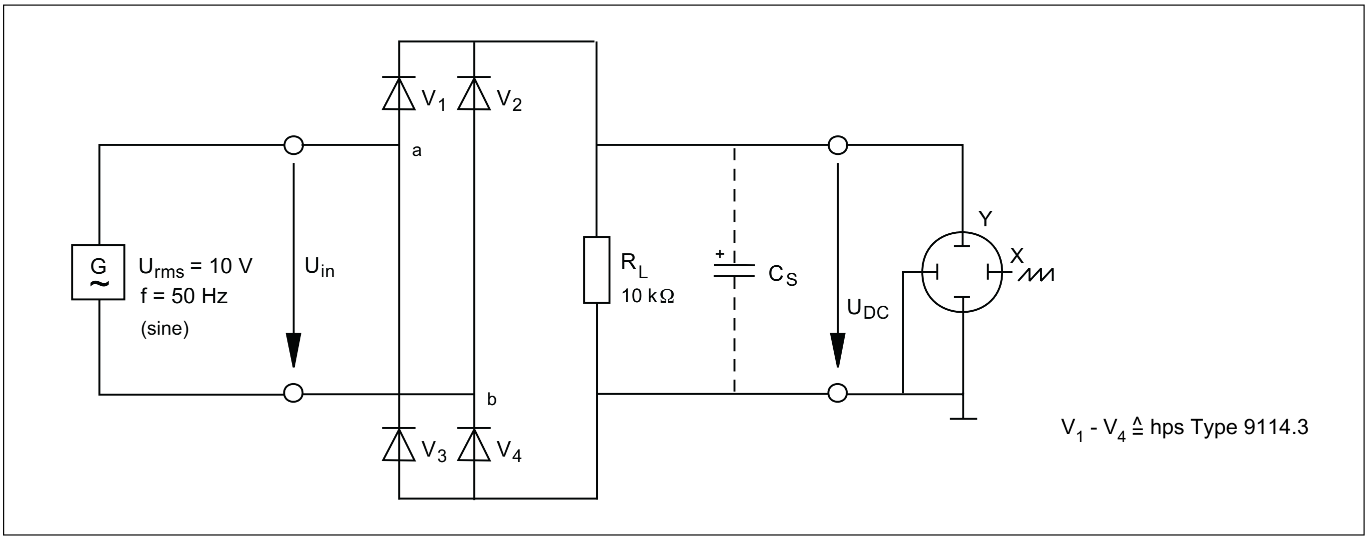


*Fig. 1.4.2.1*

- Record the input voltage $U_{in}$ and the DC voltage $U_{DC}$ are to be recorded with the oscilloscope and plot the curve on the grid of Fig. 1.4.2.2.

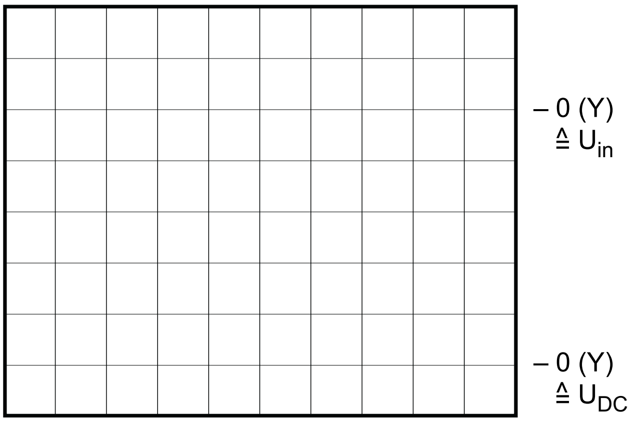


*Fig. 1.4.2.2*

**Settings:**

Y = 10 V / div.

X = 5 ms / div.

- Evaluate the peak-to-peak value and the frequency of the ripple voltage $U_{rip}$ from the oscilloscope diagram (Fig. 1.4.2.2).

  **Note:** The ripple voltage is the part of the AC voltage of the pulsing DC voltage $U_{DC}$.

- Subsequently connect the smoothing capacitors $C_S$ in parallel to the load resistor $R_L$ as per Table 1.4.2.1 and repeat the measurings.

  **Attention:** Pay attention to the polarity in electrolytic capacitors!

- Enter all evaluated values in Table 1.4.2.1.

| Bridge rectifier circuit B2 | | | | |
|---|---|---|---|---|
| **$C_S$ [µF]** | **without** | **10** | **100** | **470** |
| **$U_{in}$ [V]** | | | | |
| **$U_{DC}$ [V]** | | | | |
| **$\frac{U_{DC}}{U_{in}}$ =** | | | | |
| **$u_{rip\ pp}$ [V]** | | | | |
| **$f_{rip}$ [Hz]** | | | | |

*Tab. 1.4.2.1*

- Plot the curve of the input voltage $U_{in}$ and of the DC voltage $U_{DC}$, which results using the smoothing capacitor 10 µF on the grid of Fig. 1.4.2.3.

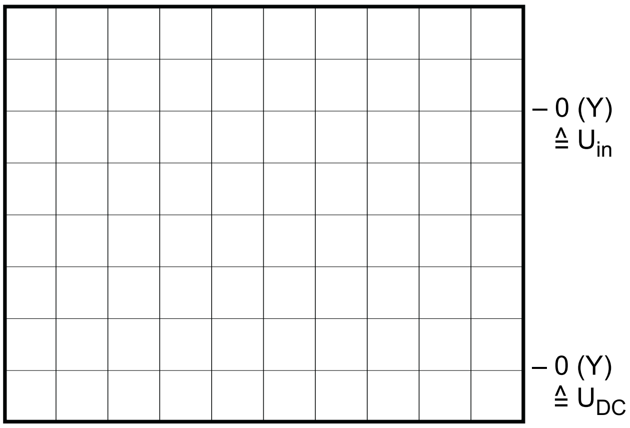


*Fig. 1.4.2.3*

**Settings:**

Y = 10 V / div.

X = 5 ms / div.

**Question 1:**
What is the ratio of the DC voltage $U_{DC}$ to the applied effective input voltage $U_{in}$ (without smoothing capacitor)?

**Answer:**

**Question 2:** Which is the frequency of the ripple voltage $U_{rip}$?

**Answer:**

# 2. Zener Diodes

## 2.1 On-State and Off-State Characteristics of Zener Diodes

### 2.1.1 General

Zener diodes – called after their discoverer Carl Zener – are silicon diodes whose on-state characteristic is the same as that of rectifier diodes.
Zener diodes differ from rectifier diodes in the relatively low breakdown voltages in the off-state or backward range (Z-voltage). When the breakdown voltage is exceeded, the current in reverse direction rises steeply (Z-effect). Whereas this reverse current must be prevented under all circumstances in rectifier diodes, Zener diodes are operated in reverse direction.

$$R_V = \frac{U_{op} - U_Z}{I_Z + I_L}$$

$U_{op}$ = applied operating voltage
$U_Z$ = Zener voltage of the used type of diode
$I_Z$ = average admissible Z-current
$I_L$ = current across load resistor $R_L$ acting parallelly to the Zener diode $R_L$

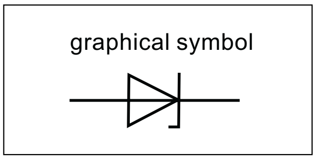


*Fig. 2.1.1.1*

The properties of Zener diodes make them suitable for voltage-stabilising and voltage-limiting.

### 2.1.2 Experiments

**❒ Experiment**

Plot the characteristic of a Zener diode and determine the Z-voltage with the oscilloscope.

**Procedure**

- Apply a sinusoid AC voltage of $U_{rms}$ = 24 V; f = 50 Hz to the circuit (Fig. 2.1.2.1).
- Switch the oscilloscope to X/Y representation.
  **Note:** Since the two voltages are poled oppositely in relation to the reference point, one of the two deflection amplifiers (e. g. the X-amplifier) must invert. Oscilloscopes without inverting facilities give mirror-inverted images.

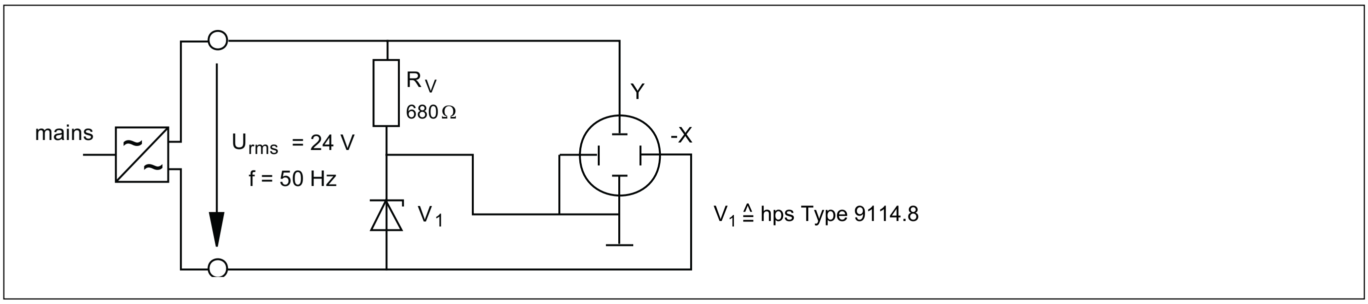


*Fig. 2.1.2.1*

**Attention:**
The power supply unit or generator output or the oscilloscope inputs must be potential-free to avoid short-circuiting through the common ground.

- Enter the obtained oscilloscope image in diagram 2.1.2.2.

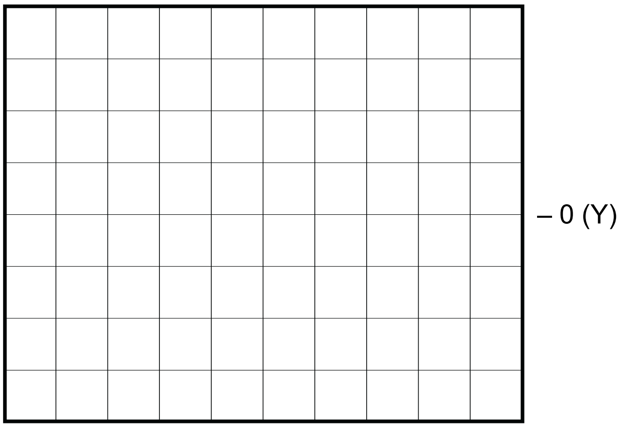


*Fig. 2.1.2.2*

**Settings:**

Y = 10 V / div.

-X = 2 V / div.

---

**Question 1:** What is the value of the Z-voltage $U_Z$?

**Answer:**

$U_Z =$

---

**Question 2:** What is the maximum current $I_Z$?

**Answer:**

$I_{Z\ max} = \frac{U_R}{R} =$

---

**Question 3:** What is the value of the threshold voltage $U_{th}$?

**Answer:**

$U_{th} =$

## 2.2 DC Voltage-Limiting with Zener Diodes

### 2.2.1 General

The steep current rise in the backward range of Zener diodes makes it possible to use the Zener diode for limiting DC voltage.
To do this, a resistor at which the difference between the unstable input voltage and the limited output voltage drops out is connected in series. The limited output voltage is equal to the Z-voltage and depends on the chosen type of Zener diode.

### 2.2.2 Experiments

❒ **Experiment 1**

Investigate the dependence of the output voltage on the input voltage in a limiter circuit assembled with Zener diodes.

**Procedure**

- Set up the circuit according to Fig. 2.2.2.1, setting the DC voltages $U_{in}$ as per Table 2.2.2.1 one after the other.
  Measure the according output voltages with a multimeter and enter the voltages in Table 2.2.2.1.
- Plot a graph on diagram (Fig. 2.2.2.2) showing the dependence of output voltage $U_{out}$ on input voltage $U_{in}$.

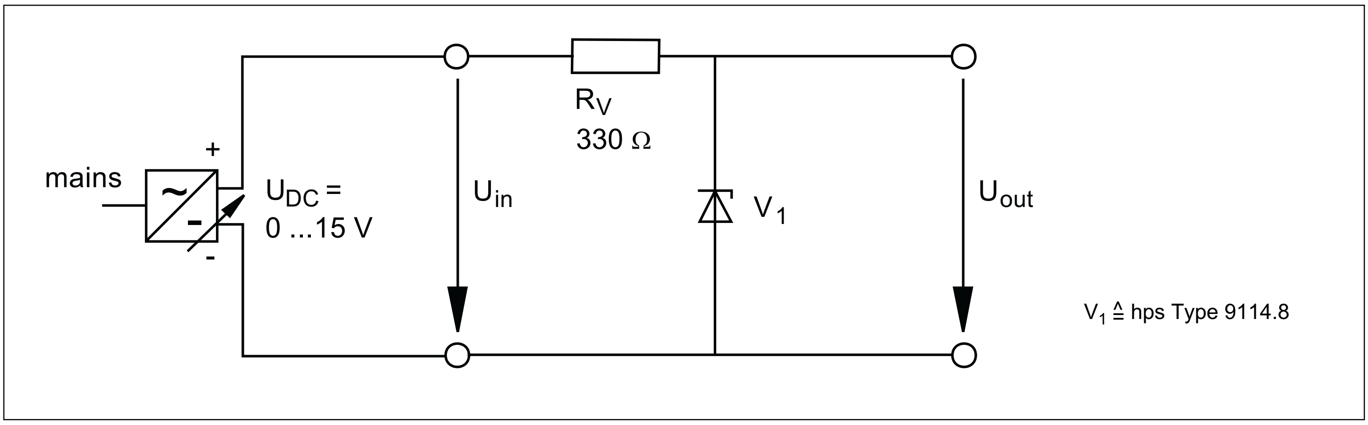


*Fig. 2.2.2.1*

| $U_{in}$ [V] | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $U_{out}$ [V] | | | | | | | | | | | | | | | | |

*Tab. 2.2.2.1*

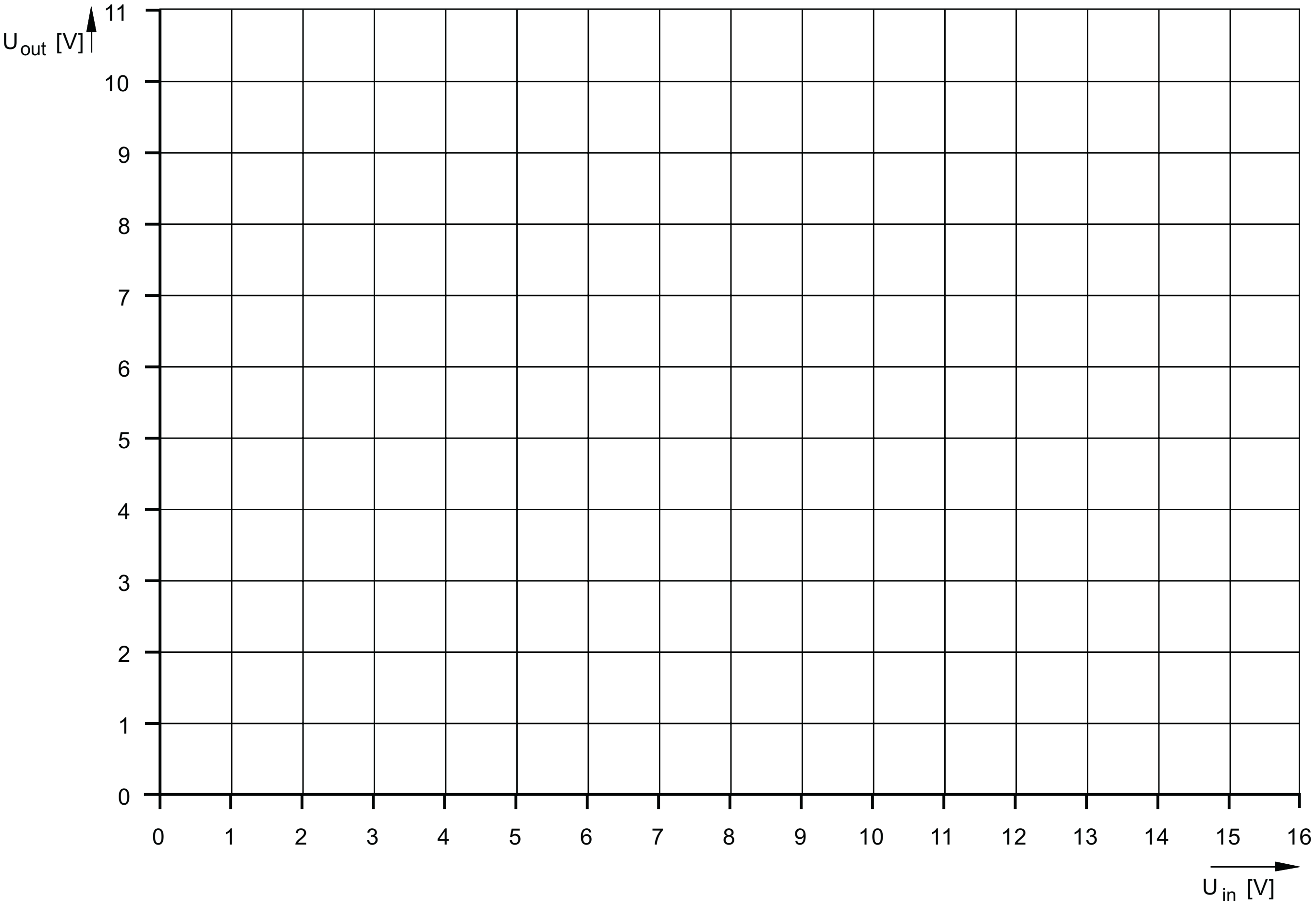


*Fig. 2.2.2.2*

### ❒ Experiment 2

Investigate the dependence of the Z-current $I_Z$ on the input voltage in a limiter circuit assembled with Zener diodes.

### Procedure

- Set up the circuit according to Fig. 2.2.2.3, setting the DC voltages $U_{in}$ as per Table 2.2.2.2 one after the other.
  Measure the according Z-currents $I_Z$ with a multimeter and enter the currents in Table 2.2.2.2.
- Plot a graph on diagram 2.2.2.4 showing the dependence of the Z-current $I_Z$ on the input voltage $U_{in}$.

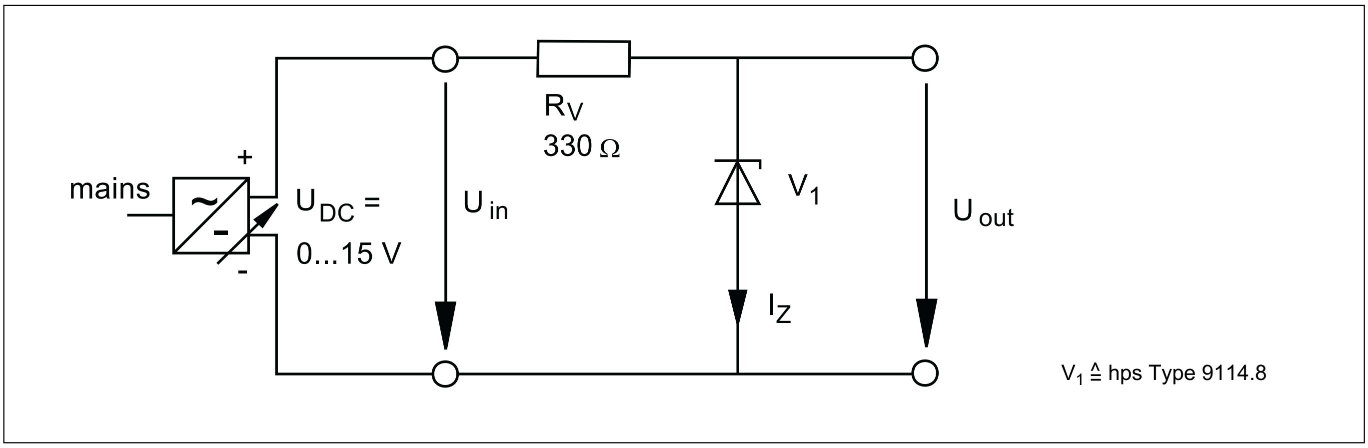


*Fig. 2.2.2.3*

| **$U_{in}$ [V]** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$I_Z$ [mA]** | | | | | | | | | | | | | | | | |

*Tab. 2.2.2.2*

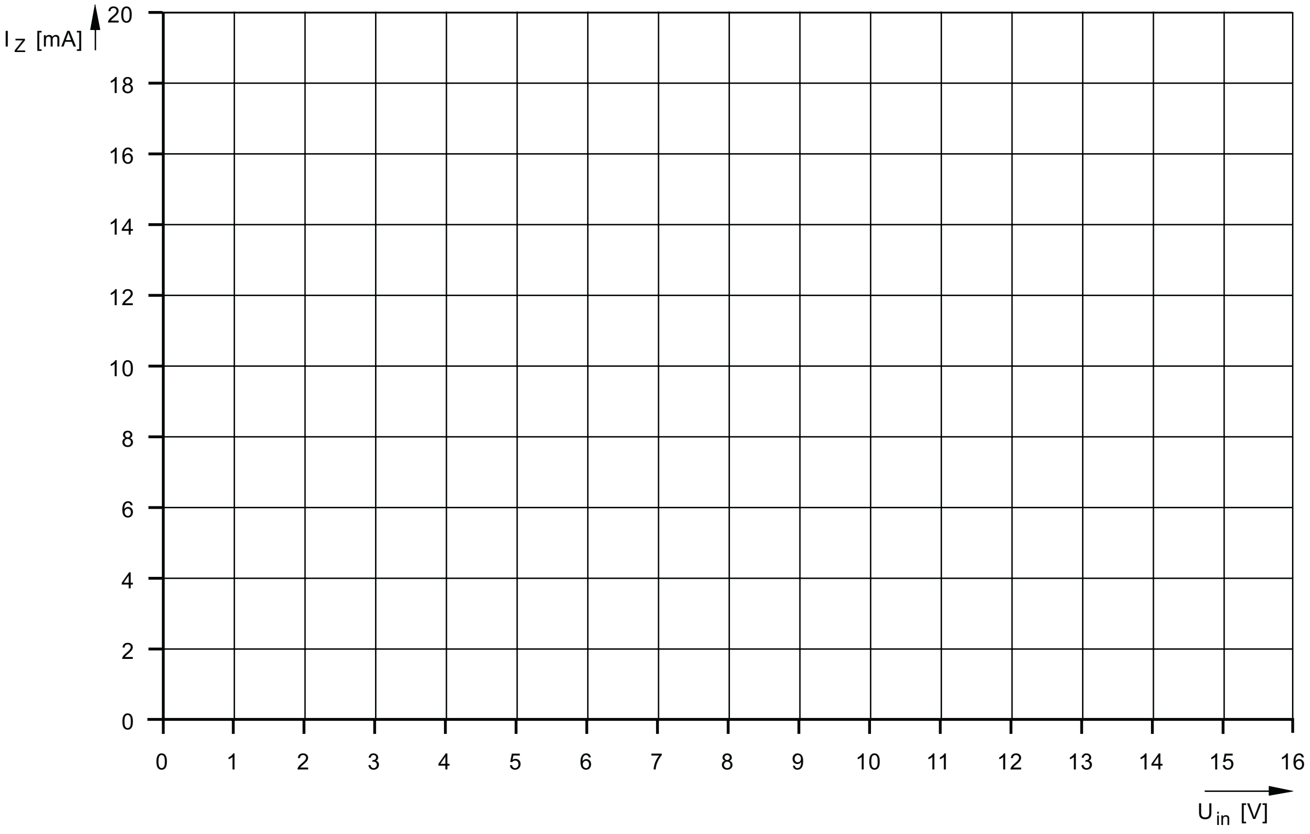


*Fig. 2.2.2.4*

### ❒ Experiment 3

Measure the influence of load current $I_L$ on the Z-current statically.

**Procedure**

- Set up the circuit according to Fig. 2.2.2.5 and set the load currents $I_L$ as shown in Table 2.2.2.3 with potentiometer P.

  **Note:**
  Resistor $R_1$ must be increased to 1 kΩ, 2.2 kΩ, 4.7 kΩ and 10 kΩ with low load currents.

- Plot a graph on diagram (Fig. 2.2.2.6) showing the dependence of the Z-current $I_Z$ on the load current $I_L$.

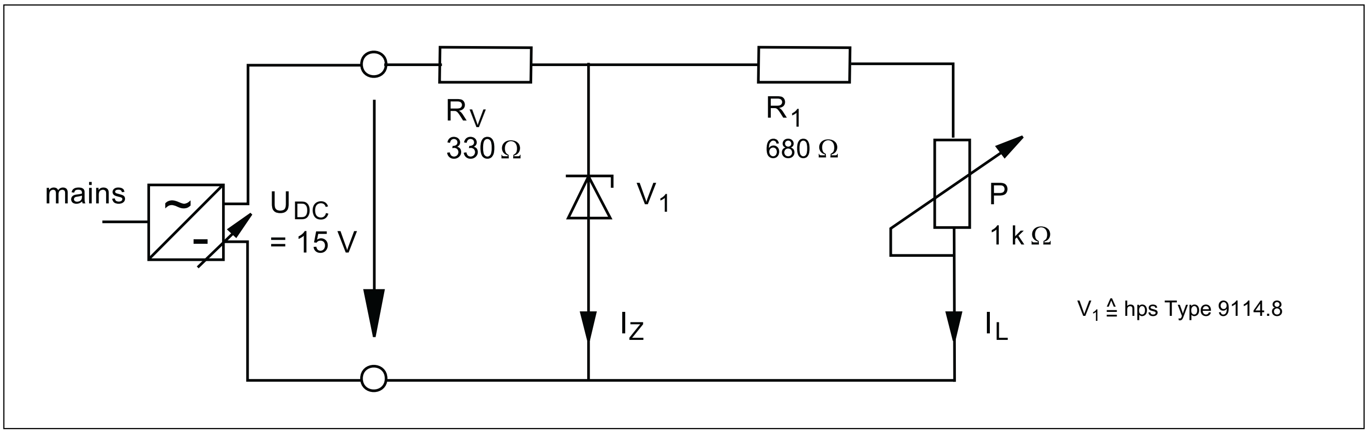


*Fig. 2.2.2.5*

| **$I_L$ [mA]** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$I_Z$ [mA]** | | | | | | | | | | | | | | | | |

*Tab. 2.2.2.3*

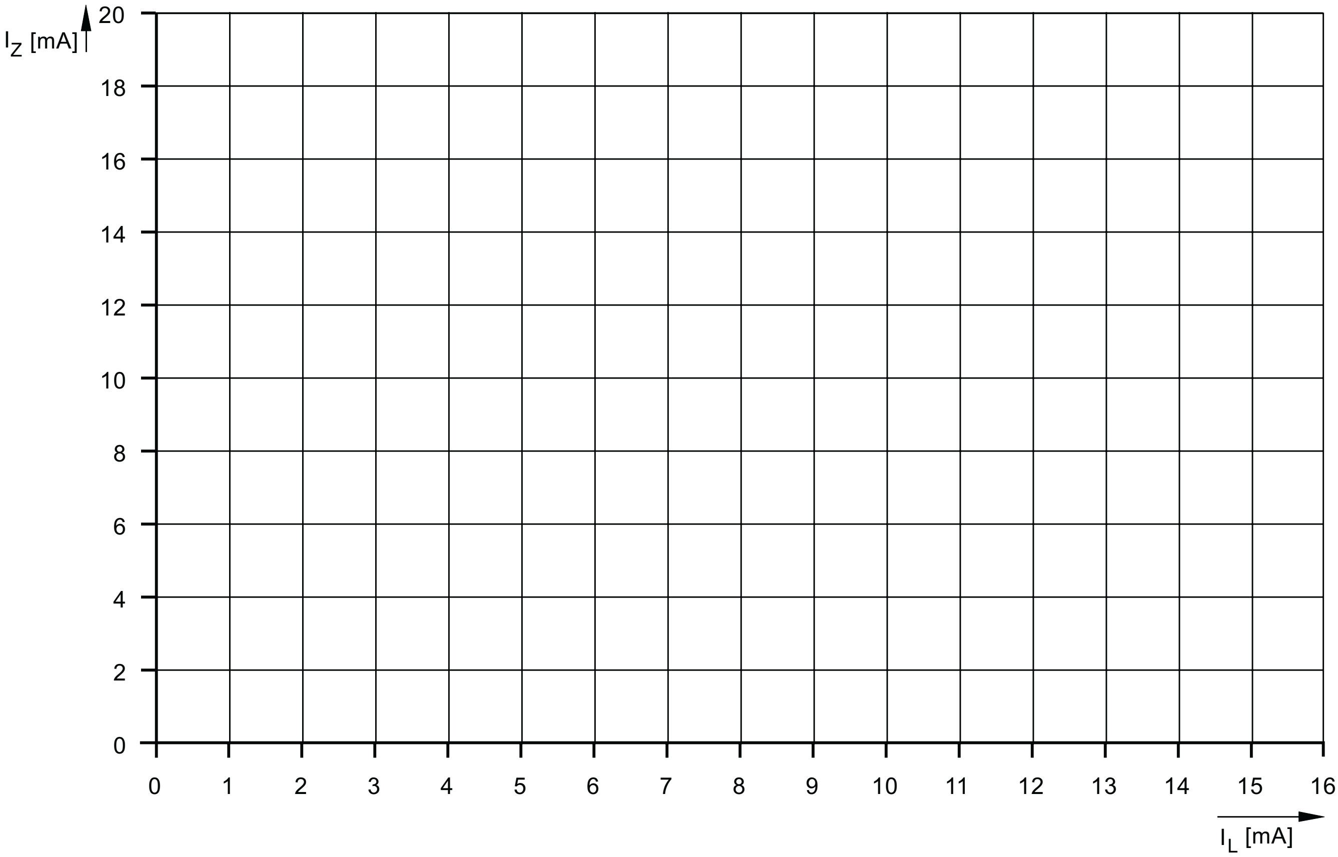


*Fig. 2.2.2.6*

**Question 1:** Under what circumstances does the output voltage remain constant in a limiter circuit with Zener diode?

**Answer:**

**Question 2:** When does the Z-current $I_Z$ begin to flow?

**Answer:**

**Question 3:** Under what circumstances is the limiting effect maintained even under load?

**Answer:**

## 2.3 Series and Series-Opposed Circuit of Zener Diodes

### 2.3.1 General

Zener diodes can be connected in series whereby their voltages are added. This series circuit is useful to combine Zener diodes with positive and negative temperature coefficients in such a way that the total Z-voltage is as temperature-independent as possible.

For the same reason, rectifier and Zener diodes can be connected in series (see Fig. 2.3.2.1).

### 2.3.2 Experiments

❐ **Experiment**

Connect different Zener and rectifier diodes in series and series-opposed, measure their total voltages and calculate their temperature coefficients.

**Procedure**

- Set up the circuit according to Fig. 2.3.2.1, connecting the series connections consisting of Zener and rectifier diodes as per Fig. 2.3.2.1 A ... C. Doing this, measure voltage $U_{tot}$ with the multimeter and enter the measured voltages into Table 2.3.2.1.
- Then calculate the temperature-dependent voltage changes of the different circuits and enter the values into Table 2.3.2.1 using the manufacturer specifications of Table 2.3.2.2 as a basis.

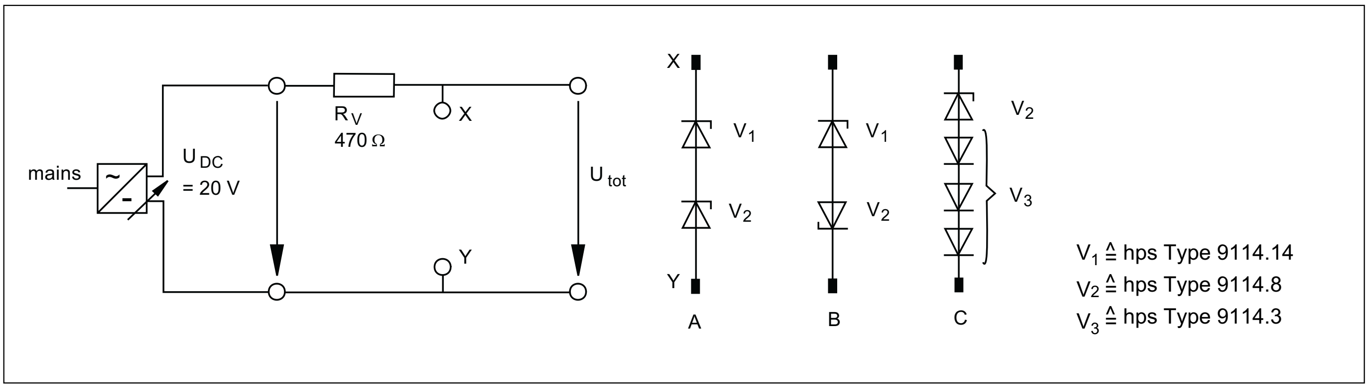


*Fig. 2.3.2.1*

| Circuit | $U_{tot}$ [V] | $\Delta U / \Delta \vartheta$ [mV / K] |
|---|---|---|
| A | | |
| B | | |
| C | | |

*Tab. 2.3.2.1*

| | | |
|---|---|---|
| U = 3.3 V<br>(hps Type 9114.14) | $-3 \cdot 10^{-4} \cdot K^{-1}$ | -0.99 mV / K |
| U = 10 V<br>(hps Type 9114.8) | $+8 \cdot 10^{-4} \cdot K^{-1}$ | +8 mV / K |
| U = 0.7 V<br>(hps Type 9114.3) | $-3 \cdot 10^{-4} \cdot K^{-1}$ | -2.4 mV / K |

*Tab. 2.3.2.2*

---

**Question 1:** How is the temperature-dependent voltage change $\Delta U/\Delta\vartheta$ obtained?

---

**Answer:**

---

**Question 2:** What is the value of the total temperature-dependent voltage change with the respective series circuit?

---

**Answer:**

**Series circuit A:** $\Delta U/\Delta\vartheta = (\Delta U_1/\Delta\vartheta) + (\Delta U_2/\Delta\vartheta) =$

**Series circuit B:** $\Delta U/\Delta\vartheta = (\Delta U_1/\Delta\vartheta) + (\Delta U_2/\Delta\vartheta) =$

**Series circuit C:** $\Delta U/\Delta\vartheta = (\Delta U_1/\Delta\vartheta) + (\Delta U_2/\Delta\vartheta) + (\Delta U_3/\Delta\vartheta) + (\Delta U_4/\Delta\vartheta) =$

---

**Question 3:** In circuit C, would there be any advantage in using a single diode with $U_Z = 12$ V for which the manufacturer specifies a Z-voltage of between 11.4 V and 12.7 V and a Z-voltage temperature coefficient of $\alpha = +9 \cdot 10^{-4} \cdot K^{-1}$ ?

---

**Answer:**

## 2.4 AC Voltage Limitation and Overvoltage Protection with Zener Diodes

### 2.4.1 General

As long as the voltage active on a Z diode is less than the Z-voltage, no Z-current is flowing. This does not cut in until the value of the Z-voltage is equalled or exceed-ed.
These components therefore provide facilities for protecting other components (e. g. MOS components) against high voltages.

To prevent a rectifying effect caused by the low threshold voltage of the on-state range, two Zener diodes are connected series-opposed and thus a voltage-limiting effect which is independent of the polarity is obtained.

### 2.4.2 Experiments

**❐ Experiment 1**

Record the characteristic $U_{out} = f(U_{in})$ of two series-opposed Zener diodes.

**Procedure**

- Set up the circuit according to Fig. 2.4.2.1 and adjust the DC voltages $U_{in}$ one after the other as shown in Table 2.4.2.1.
  Measure the respective output voltages $U_{out}$ with the multimeter and enter the voltage values in Table 2.4.2.1.
- Subsequently reverse the polarity of the input voltage $U_{in}$ and repeat the measurings above. Enter the respective output voltages $U_{out}$ in Table 2.4.2.2.
- Show the dependence of the output voltage $U_{out}$ on the input voltage $U_{in}$ by plotting a graph in the grid of diagram 2.4.2.2.

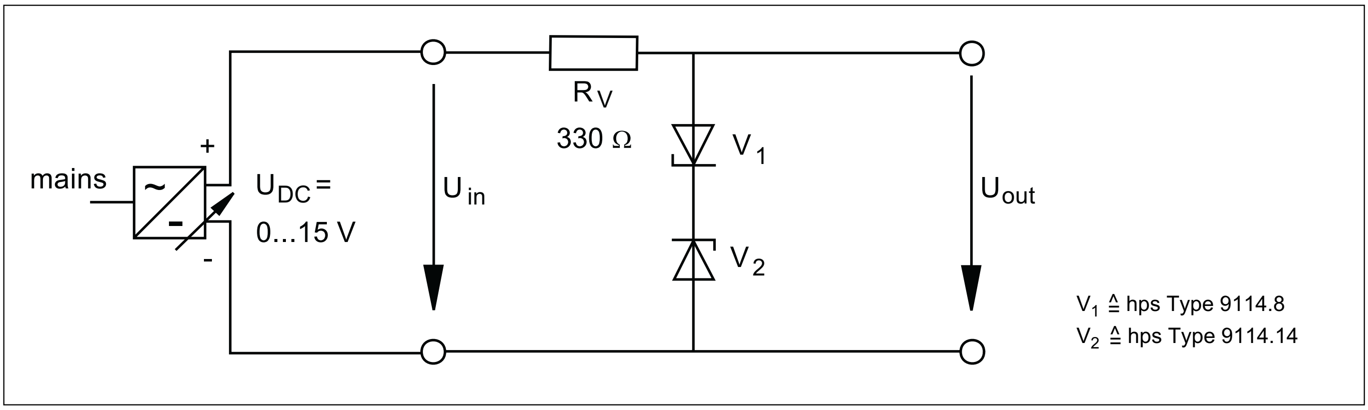


*Fig. 2.4.2.1*

| $U_{in}$ [V] | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $U_{out}$ [V] | | | | | | | | | | | | | | | | |

*Tab. 2.4.2.1*

| $-U_{in}$ [V] | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $-U_{out}$ [V] | | | | | | | | | | | | | | | | |

*Tab. 2.4.2.2*

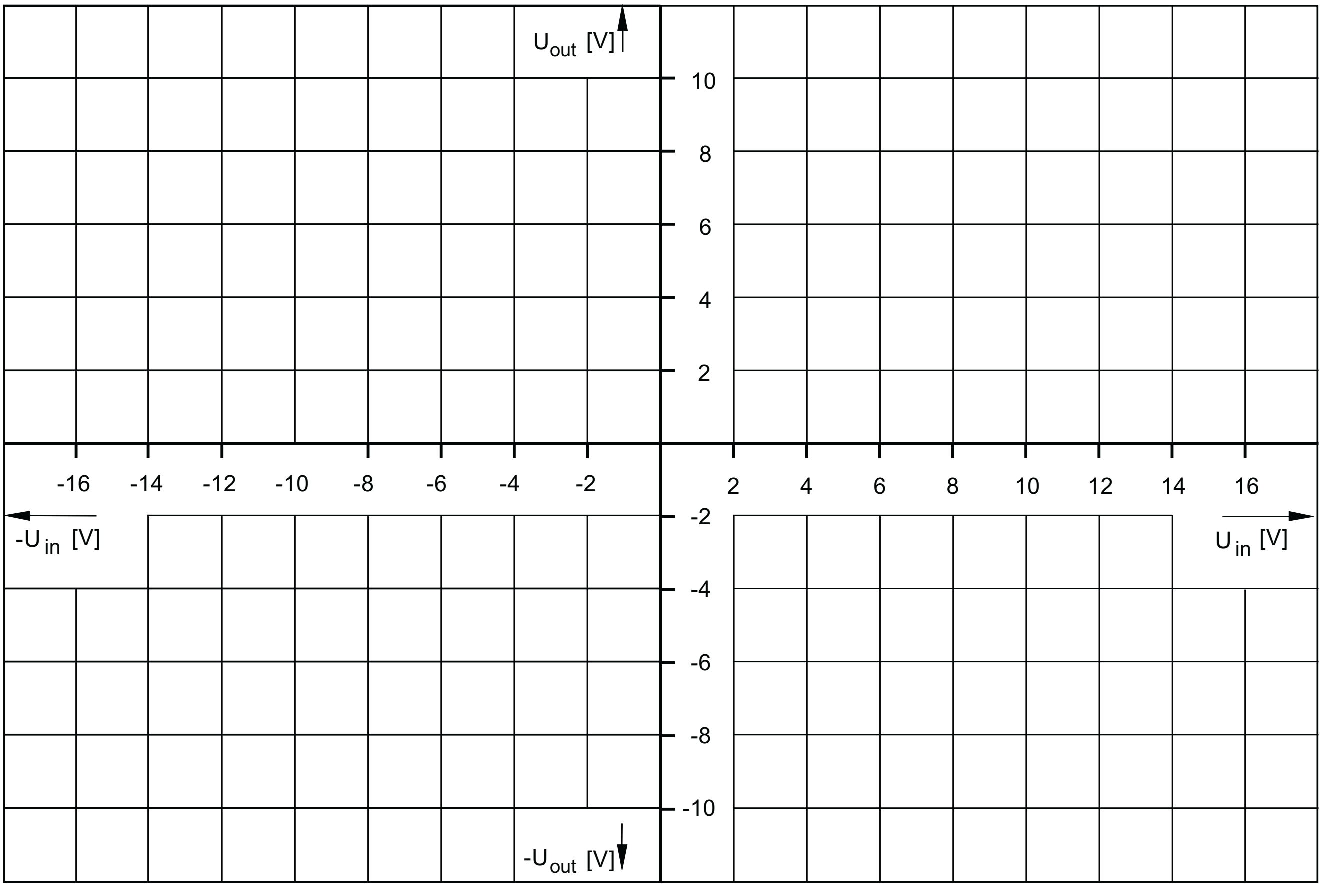


*Fig. 2.4.2.2*

### ❒ Experiment 2

Examine the voltage limiting effect of two series-opposed Zener diodes with an oscilloscope.

**Procedure**

- Apply a sinusoid AC voltage $U_{rms}$ = 10 V; f = 50 Hz to the circuit (Fig. 2.4.2.3) and set an input voltage of $U_{in\ rms}$ = 2 V with the potentiometer.
- Record the input voltage $U_{in}$ and the output voltage $U_{out}$ with the oscilloscope and plot a graph in diagram of Fig. 2.4.2.4.
- Then increase the input voltage to $U_{in\ rms}$ = 10 V.
- Repeat the measurings above and enter the values in the diagram of Fig. 2.4.2.5.

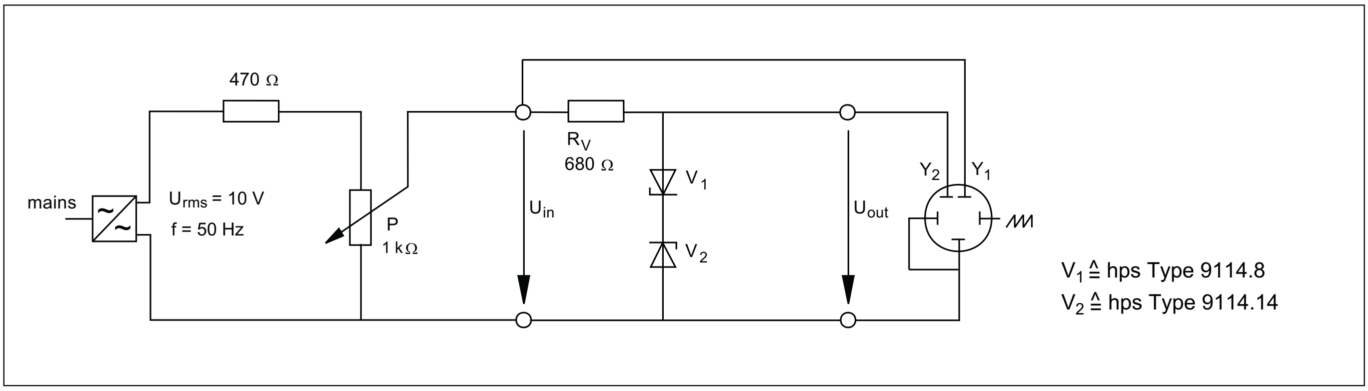


*Fig. 2.4.2.3*

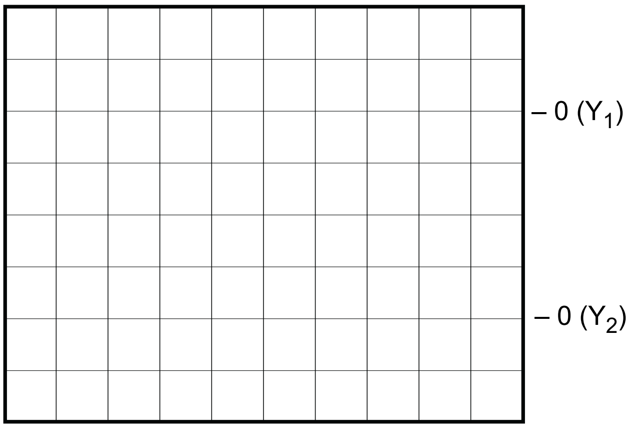


*Fig. 2.4.2.4*

**Settings:**

X = 5 ms / div.
$Y_1$ = 2 V / div.
$Y_2$ = 2 V / div.

**Remarks:**

$Y_1$ = input voltage $U_{in}$
$Y_2$ = output voltage $U_{out}$

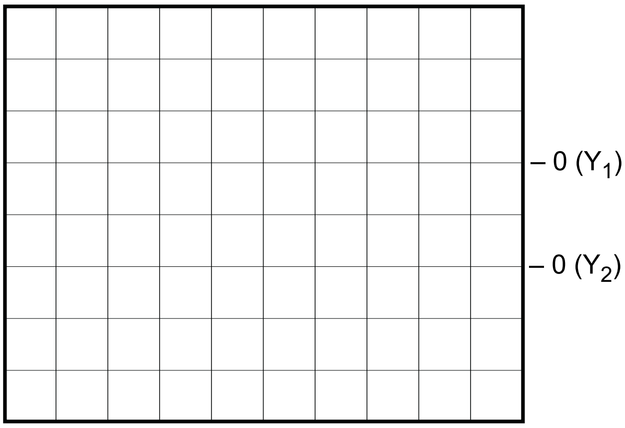


*Fig. 2.4.2.5*

**Settings:**

X = 5 ms / div.
$Y_1$ = 20 V / div.
$Y_2$ = 5 V / div.

**Remarks:**

$Y_1$ = input voltage $U_{in}$
$Y_2$ = output voltage $U_{out}$

**Question 1:** Give a possible application for a Zener diode.

**Answer:**

**Question 2:** What is the advantage of the series-opposed connection of two Zener diodes?

**Answer:**

# 2.5 Voltage Stabilization with Zener Diodes

## 2.5.1 General

Zener diodes not only stabilize long-term voltage fluctuations, but also short-term fluctuations as they are caused by the residual ripple of a rectified, presmoothed AC voltage.

## 2.5.2 Experiments

### ❒ Experiment

Examine the stabilizing effect of a Zener diode on a DC voltage with pronounced ripple.

To do this, rectify an AC voltage with a rectifier diode and slightly presmooth it with a charging capacitor.

### Procedure

- Set up the circuit according to Fig. 2.5.2.1, oscilloscope the two voltages $U_{in}$ and $U_{out}$ and plot the curve on the grid of diagram 2.5.2.2. The inputs on the oscilloscope should be set to DC.

  **Attention:** Pay attention to the polarity of electrolytic capacitors!

- Subsequently set the inputs of the oscilloscope to AC ($Y_2$ = 0.1 V/div.). The DC components of both voltages are then suppressed and only the ripple parts are displayed. Plot the graph of voltages $U_{in}$ and $U_{out}$ on diagram 2.5.2.3.

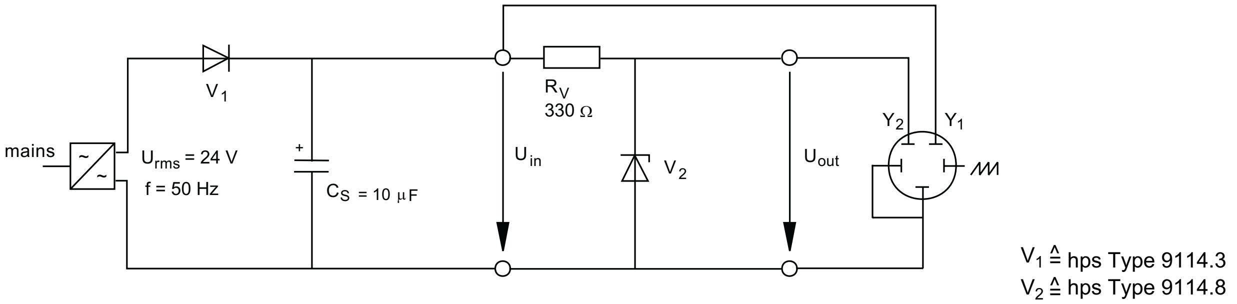


*Fig. 2.5.2.1*

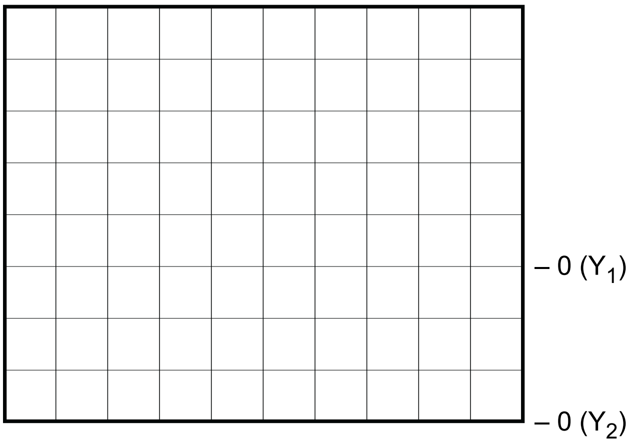


*Fig. 2.5.2.2*

**Settings:**

X = 5 ms / div.
$Y_1$ = 10 V / div.
$Y_2$ = 5 V / div.
(inputs on DC)

**Remarks:**

$Y_1$ = voltage $U_{in}$
$Y_2$ = voltage $U_{out}$

---

**Question 1:** How high is the ripple voltage $\Delta U_{in}$ on the smoothing capacitor $C_S$ (measure in Fig. 2.5.2.2)?

**Anwer:**

$\Delta U_{in}$ =

$\Delta U_{in}$ = peak-to-peak value of the input voltage $U_{in}$

**Question 2:** How high is the ripple voltage $\Delta U_{out}$ on the Zener diode (measure in Fig. 2.5.2.3)?

**Answer:**

$\Delta U_{out}$ =

$\Delta U_{out}$ = peak-to-peak value of the output voltage $U_{out}$

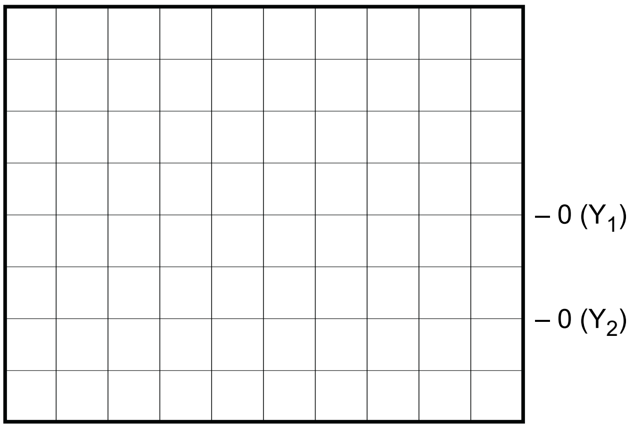


*Fig. 2.5.2.3*

**Settings:**

X = 5 ms / div
$Y_1$ = 5 V / div.
$Y_2$ = 0.1 V / div.
(inputs on AC)

**Remarks:**

$Y_1$ = voltage $U_{in}$ without DC component
$Y_2$ = voltage $U_{out}$ without DC component

**Question 3:** What is the value of the smoothing factor G (absolute stabilizing factor)?

**Answer:**

$$G = \frac{\Delta U_{in}}{\Delta U_{out}} =$$

$G$ = smoothing factor

**Question 4:** What is the value of the relative stabilizing factor S?

**Answer:**

$$S = \frac{\Delta U_{in} \cdot U_{out}}{\Delta U_{out} \cdot U_{in}} = G \cdot \frac{U_{out}}{U_{in}} =$$

$S$ = relative stabilizing factor

Measure the voltages $U_{in}$ and $U_{out}$ with the multimeter.

# 3. Diodes with Special Properties

## General

In practice there is a number of special diodes available in addition to the standard diodes examined here:

Tunnel diode, Backward diode, Schottky diode, PIN diode, Impatt diode, Trapatt diode

Their special properties can only be investigated with expensive measuring set-ups and with special measuring equipment which is uncommon in the training sec-tor. The following experiments therefore treat only the light-emitting diodes (LEDs) and the variable capacitance diodes (varicaps).

## 3.1 LEDs

### 3.1.1 General

In the case of semiconductor diodes made of intermetallic connections such as gallium-arsenide or gallium phosphide, a part of the fed electrical energy is converted not into heat as in other semiconductor components, but into light beams with a much shorter wavelength. The colour of the radiated light can be determined by choosing appropriate materials and by doping. It may be infrared, red, yellow, orange, green or even blue.

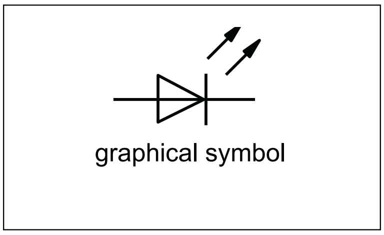


*Fig. 3.1.1.1*

### 3.1.2 Experiments

**❐ Experiment 1**

Record the characteristic of an LED with the oscilloscope.

**Procedure**

- Apply a sinusoid AC voltage $U_{rms} = 10$ V; f = 50 Hz to the circuit (Fig. 3.1.2.1) and oscilloscope the dependence of the current on the voltage with the oscilloscope in X/Y representation.
- Plot the oscilloscope image on the diagram (Fig. 3.1.2.2).

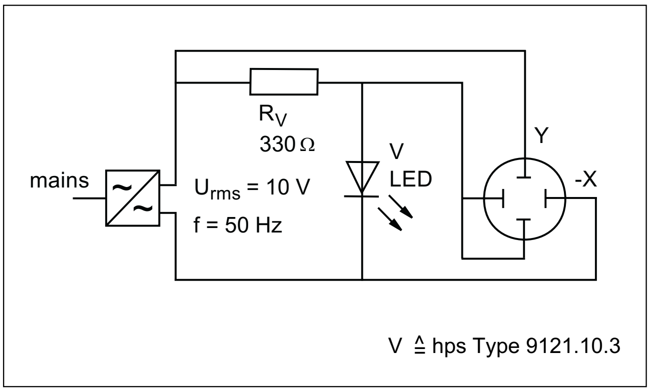


*Fig. 3.1.2.1*

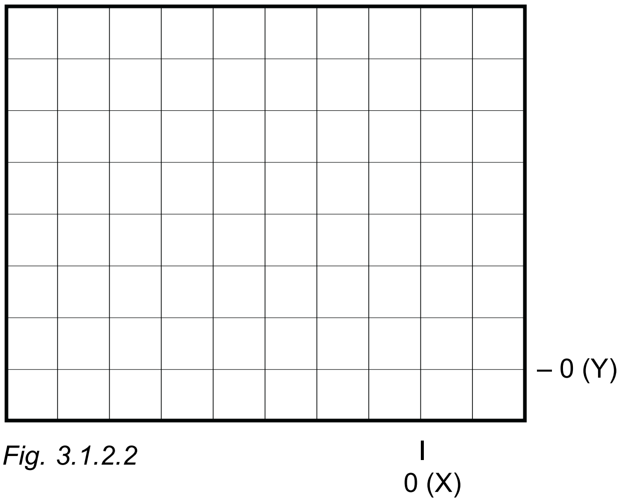


*Fig. 3.1.2.2*

**Settings:**

Y = 2 V / div.
-X = 2 V / div.

**Note:**
Since the two voltages are poled oppositely in relation to their reference points, one of the two deflection amplifiers of the oscilloscope (e. g. the X-amplifier) must invert. With oscilloscopes without inverting facility a mirror-inverted image is displayed.

**Attention:**
The power supply unit and the oscilloscope may not have a common ground.

### ❒ Experiment 2

The influence of the diode voltage $U_F$, the diode current $I_F$ and the polarity on the light emission of an LED is to be examined.

**Procedure**

- Set up the circuit as shown in Fig. 3.1.2.3 and adjust the DC voltage $U_{in}$ in steps according to Table 3.1.2.1.
  Measure the diode voltage $U_F$ and the diode current $I_F$ with the multimeter and find out the light emission of the LED (none, low, middle, bright). Enter the values to be evaluated in Table 3.1.2.1.
- Subsequently reverse the polarity of the diode and observe the light emission.

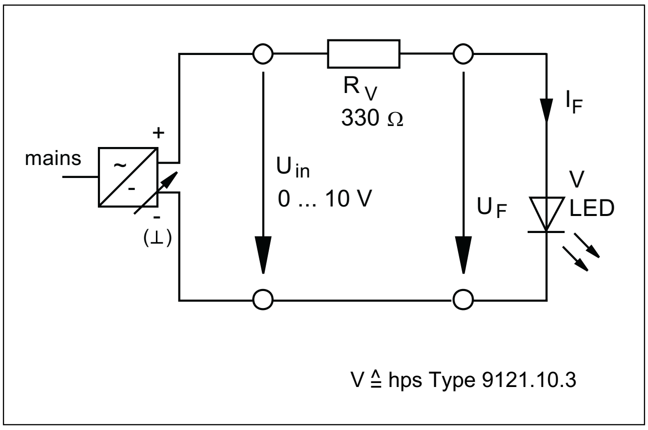


*Fig. 3.1.2.3*

| $U_{in}$ [V] | $U_F$ [V] | $I_F$ [mA] | light emission |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |

*Tab. 3.1.2.1*

**Question 1:** What is the minimum current required by the LED for weak light emission?

**Answer:**

**Question 2:** How does the light emission increase in the range between 15 mA and 20 mA?

**Answer:**

**Question 3:** How does the light emission behave when operating voltage polarity is reversed?

**Answer:**

**Question 4:** An LED is to be operated with an operating voltage of 5 V. What dropping resistance is necessary for a current of 15 mA?

**Answer:**

**Notes:**

# 4. Bipolar Transistors

## 4.1 Testing the Layers and the Rectifying Behaviour of Bipolar Transistors

### 4.1.1 General

Transistors are three-pole semiconductor components in which either a thin p-conducting layer is embedded between two n-conducting layers (n-p-n transistor) or a thin n-conducting layer between two p-conducting layers (p-n-p transistor).

The p-n junctions between the middle layer (base) and the two outer layers (emitter and collector) have a rectifier effect which can be investigated as with any rectifier diode.

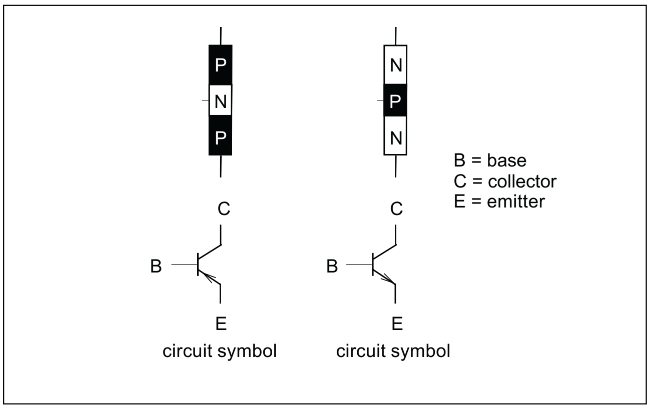


*Fig. 4.1.1.1*

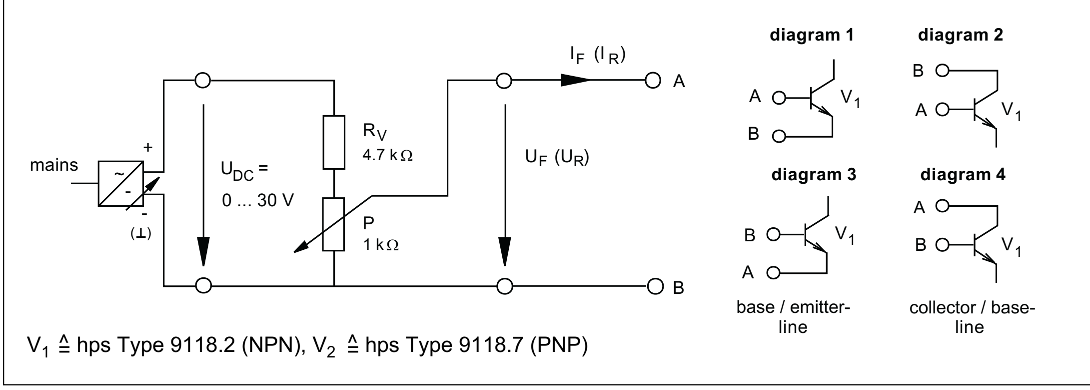
### 4.1.2 Experiments

**☐ Experiment**

Examine the effect of the p-n junctions of an n-p-n transistor on the current flowing through it, in relation to the applied voltage and its polarity.
Repeat the experiment with a p-n-p transistor, and demonstrate the basic differences between this and the n-p-n transistor.

**Procedure**

- Set up the circuit as shown in Fig. 4.1.2.1 (diagram 1). Using potentiometer P in conjunction with the multimeter, set the voltages $U_F$ consecutively according to Table 4.1.2.1. Measure each corresponding current $I_F$ and enter the values in Table 4.1.2.1. On the diagram (Fig. 4.1.2.2), plot a graph showing the dependence of the current $I_F$ on the voltage $U_F$.



**Note:**
Always use the correct measuring method: voltage error or current error circuit

*Fig. 4.1.2.1*

- Set up the circuit as shown in Fig. 4.1.2.1 (diagram 2). Set the voltages $U_F$ consecutively according to Table 4.1.2.3. Measure each corresponding current $I_F$ and enter the values in Table 4.1.2.3. On the diagram (Fig. 4.1.2.3), plot a graph showing the dependence of the current $I_F$ on the voltage $U_F$.
- For the next set of measurements, remove potentiometer P from the circuit (Fig. 4.1.2.1) and set the voltage directly on the power supply unit. Resistor $R_V$ should remain connected for safety reasons.
- Set up the circuit as shown in Fig. 4.1.2.1 (diagram 3). Set the voltages $U_R$ consecutively according to Table 4.1.2.2. Measure each corresponding current $I_F$ and enter the values in Table 4.1.2.2. On the diagram (Fig. 4.1.2.2), plot a graph showing the dependence of the current $I_R$ on the voltage $U_R$.
- Set up the circuit as shown in Fig. 4.1.2.1 (diagram 4). Set the voltages $U_R$ consecutively according to Table 4.1.2.4. Measure each corresponding current $I_R$ (multimeter with 0.1 -µA measuring range required) and enter the values in Table 4.1.2.4. On the diagram (Fig. 4.1.2.3), plot a graph showing the dependence of the current $I_R$ on the voltage $U_R$.

* Because of transistor tolerances, the voltage values UF in the vicinity of the threshold voltage may have to be specified differently.

| **$U_F$ [V]** | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.65 | 0.7 | 0.75* | 0.76* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **$I_F$ [mA]** | | | | | | | | | | | |

*Tab. 4.1.2.1* Diagram 1 (base/emitter line)

| **$U_R$ [V]** | 0 | 2 | 4 | 6 | 8 | 8.1 | 8.2 | 8.3 |
|---|---|---|---|---|---|---|---|---|
| **$I_R$ [mA]** | | | | | | | | |

*Tab. 4.1.2.2* *Diagram 3 (base/emitter line)*

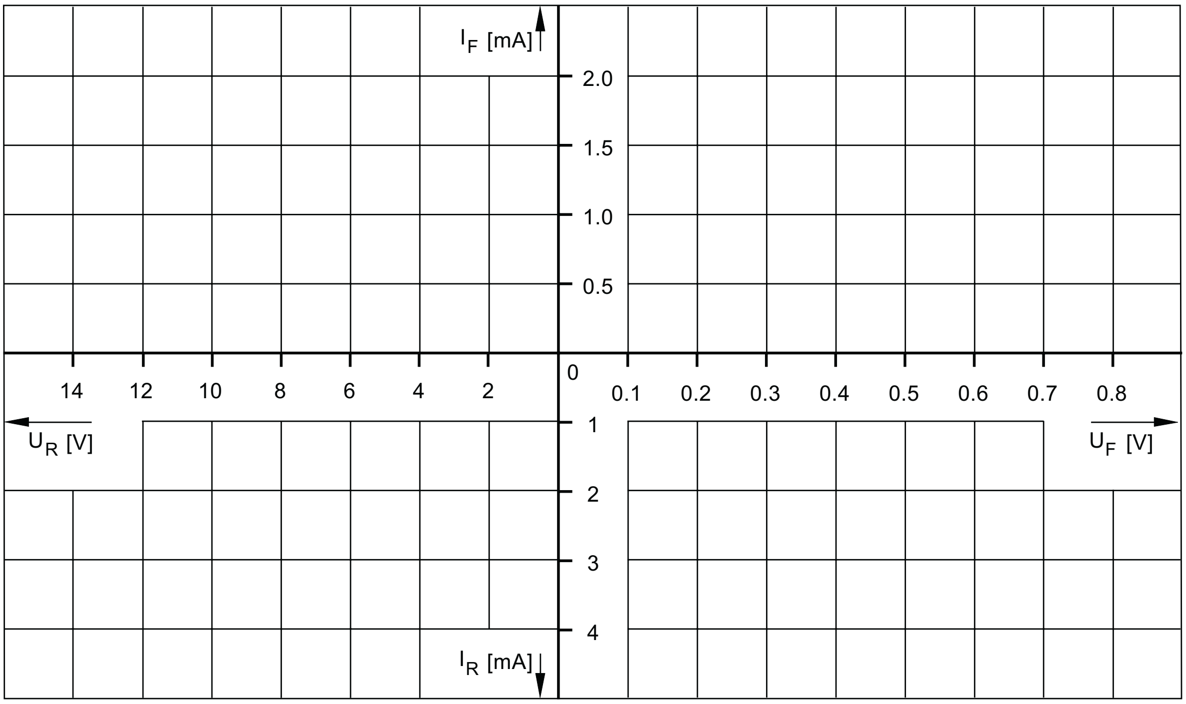


*Fig. 4.1.2.2*

* Because of transistor tolerances, the voltage values $U_F$ in the vicinity of the threshold voltage may have to be specified differently.

| **$U_F$ [V]** | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.65 | 0.7 | 0.75 | 0,8* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **$I_F$ [mA]** | | | | | | | | | | | |

*Tab. 4.1.2.3* *Diagram 2 (collector/base line)*

| **$U_R$ [V]** | 0 | 5 | 10 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|---|---|
| **$I_R$ [nA]** | | | | | | | |

*Tab. 4.1.2.4* *Diagram 4 (collector/base line)*

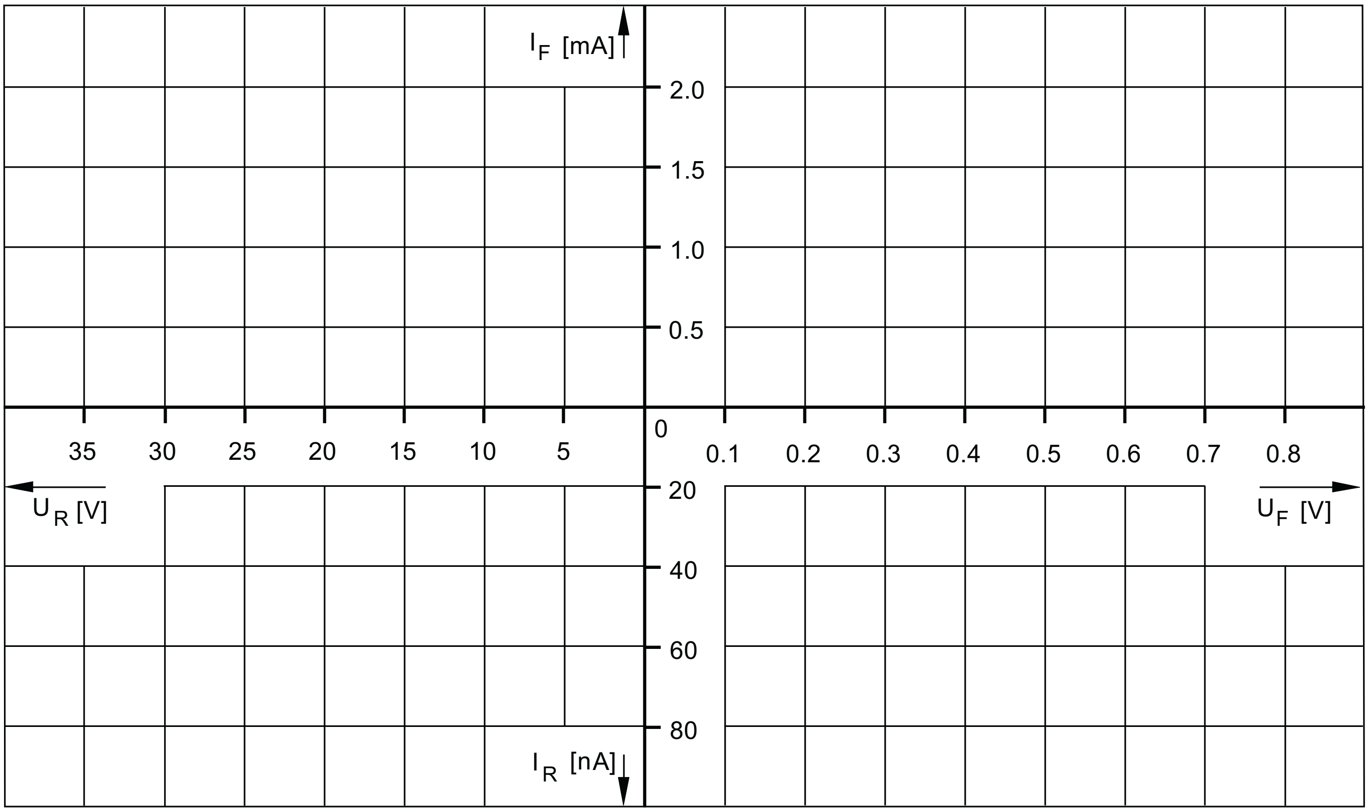


*Fig. 4.1.2.3*

- Then repeat the measurements with a p-n-p transistor in such a way as to demonstrate at which base/emitter line polarity and at which collector/base line polarity the junctions of p-n-p and n-p-n transistors are conducting or blocked. Enter the results in Table 4.1.2.5.

| | **Polarity** | **N-P-N Type** | **P-N-P Type** |
|---|---|---|---|
| Base/Emitter Line (conducting or blocked) | base + / emitter - (polarity 1) | | |
| | base - / emitter + (polarity 3) | | |
| Collector/Base Line (conducting or blocked) | collector - / base + (polarity 2) | | |
| | collector + / base - (polarity 4) | | |

*Tab. 4.1.2.5*

---

**Question 1:** What are the basic properties common to both p-n junctions of a transistor?

**Answer:**

---

**Question 2:** What properties differentiate the p-n junction between base and emitter from the p-n junction between base and collector?

**Answer:**

---

**Question 3:** What must be taken into consideration when switching a circuit over from n-p-n transistors to p-n-p transistors?

**Answer:**

## 4.2 Current Distribution in the Transistor and Control Effect of the Base Current

### 4.2.1 General

Charge carriers, which are accelerated from the emitter through the conducting p-n junction into the extremely thin base zone, penetrate the opposite, blocked p-n junction between collector and base and can drain to the collector. The base current $I_B$ is smaller by the amount of this collector current $I_C$ than the emitter current $I_E$.

$$I_B = I_E - I_C$$

On the other hand, the value of the collector current is influenced by the base current. The ratio between the two currents is known as the current gain factor B.

$B = \frac{I_C}{I_B}$ The small signal current gain $\beta$ is: $\beta = \frac{\Delta I_C}{\Delta I_B}$

The wiring of a transistor's connections with negative or positive operating voltage depends on the transistor layering. In n-p-n transistors, base and collector are positive in relation to the emitter, in p-n-p transistors negative.

### 4.2.2 Experiments

**❒ Experiment 1**

Examine the influence of the collector current on the base current statically. Carry out the experiment with an n-p-n transistor.

**Procedure**

- Apply a DC voltage of $U_{DC}$ = 20 V to the circuit shown in Fig. 4.2.2.1. Measure the base current $I_B$ with interrupted collector line (potentiometer removed) and enter its value in Table 4.2.2.1.
- Replace the potentiometer and set the collector current values listed in Table 4.2.2.1 Enter the corresponding base current values in Table 4.2.2.1.

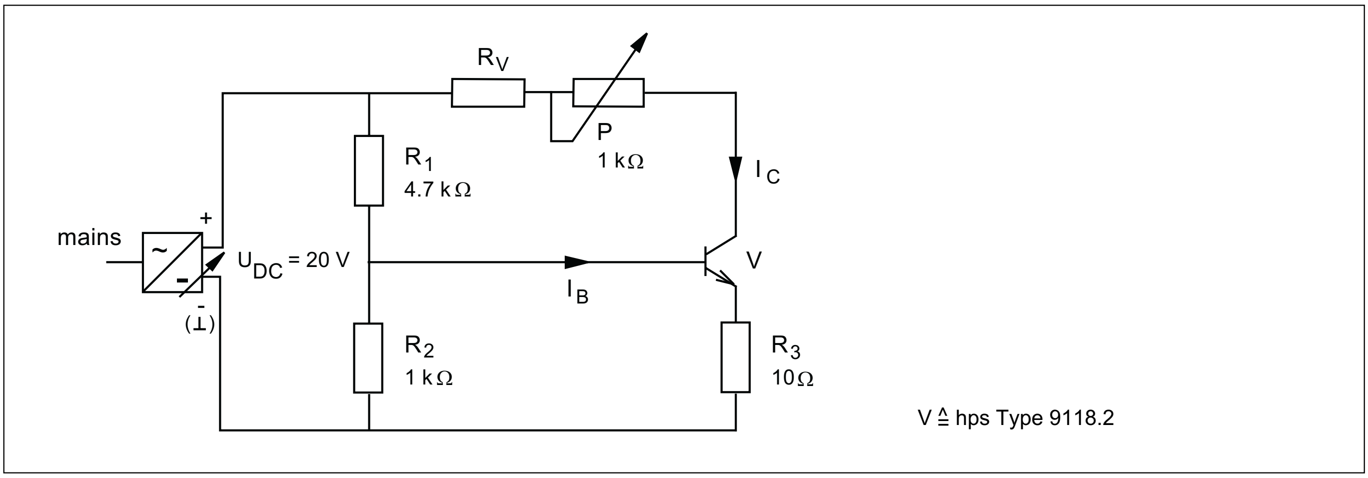


*Fig. 4.2.2.1*

- On the diagram (Fig. 4.2.2.2), plot a graph showing the dependence of the base current $I_B$ on the collector current $I_C$ (at a constant base/emitter voltage).

  $I_B = f(I_C)$, $U_{BE}$ constant

| **$R_V$ [Ω]** | ∞ | 1000 | 680 | 470 | 470 | 330 | 220 |
|---|---|---|---|---|---|---|---|
| **$I_C$ [mA]** | 0 | 20 | 25 | 30 | 40 | 50 | 60 |
| **$I_B$ [mA]** | | | | | | | |

*Tab. 4.2.2.1*

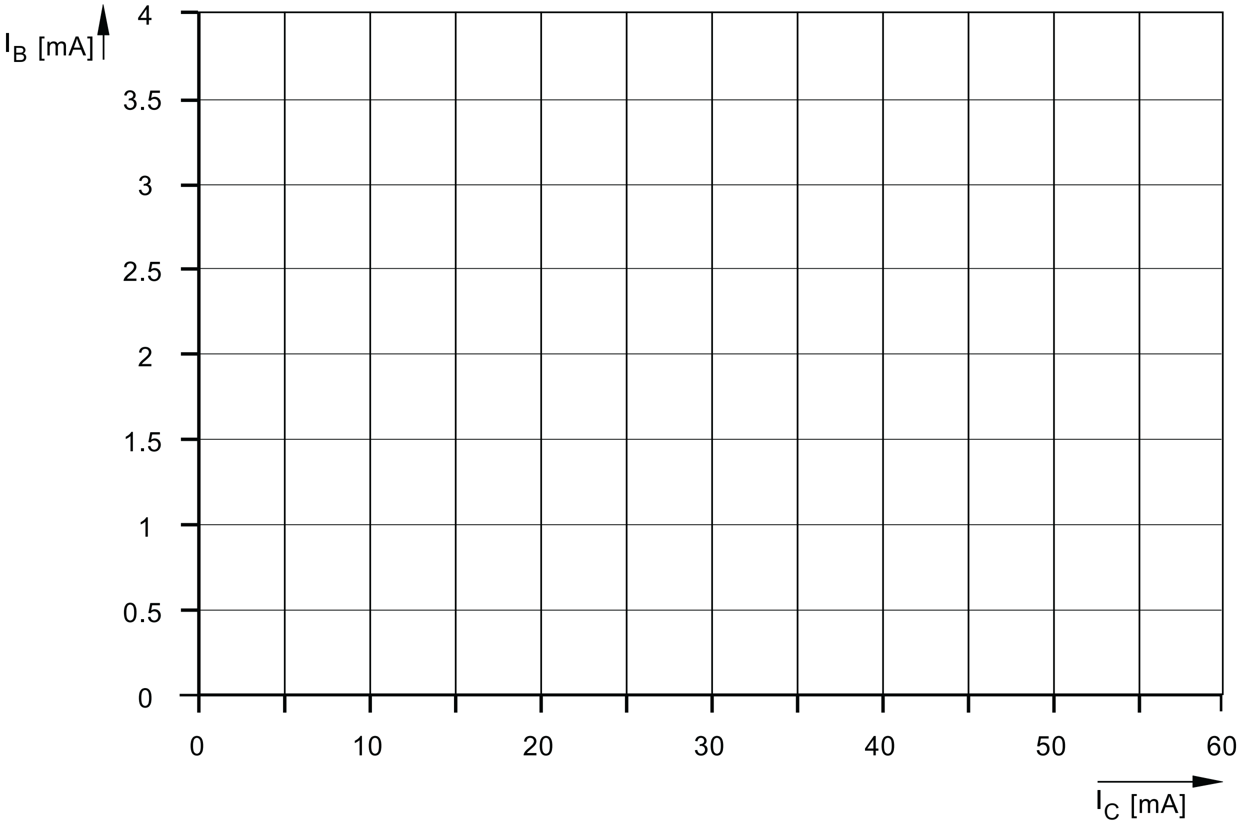


*Fig. 4.2.2.2*

### ❒ Experiment 2

Examine the influence of the base current on the collector current statically. Carry out the experiment with an n-p-n transistor.

**Procedure**

- Set up the circuit as shown in Fig. 4.2.2.3. Using the potentiometer, vary the base current according to the values given in Table 4.2.2.2. Measure the corresponding collector currents $I_C$ and enter the values in Table 4.2.2.2.

- On the diagram (Fig. 4.2.2.4), plot a graph showing the dependence of the collector current on the base current.

  $I_C = f(I_B)$

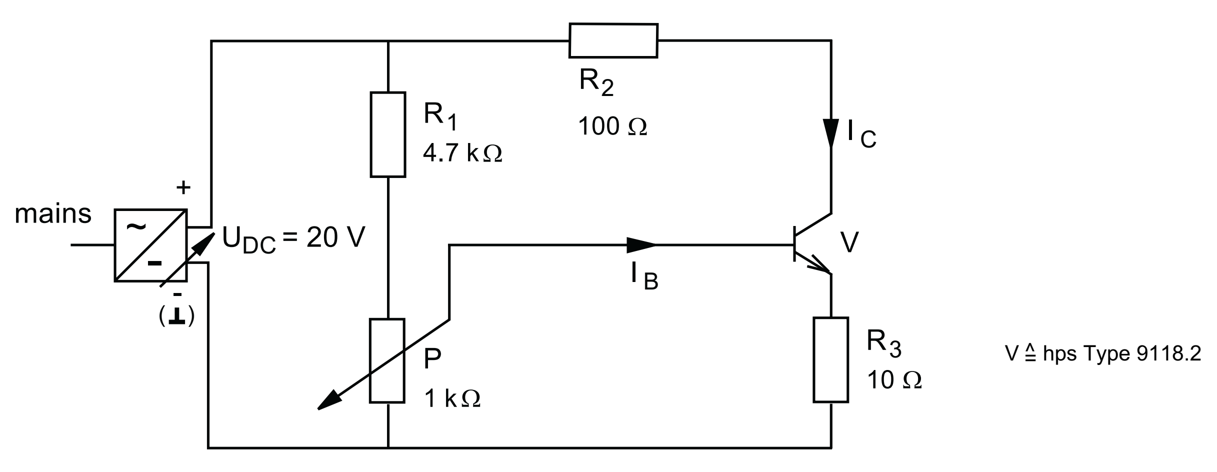


*Fig. 4.2.2.3*

| $I_B$ [mA] | 0 | 0.05 | 0.1 | 0.15 | 0.2 | 0.25 | 0.3 | 0.35 | 0.4 | 0.45 | 0.5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $I_C$ [mA] | | | | | | | | | | | |

*Tab. 4.2.2.2*

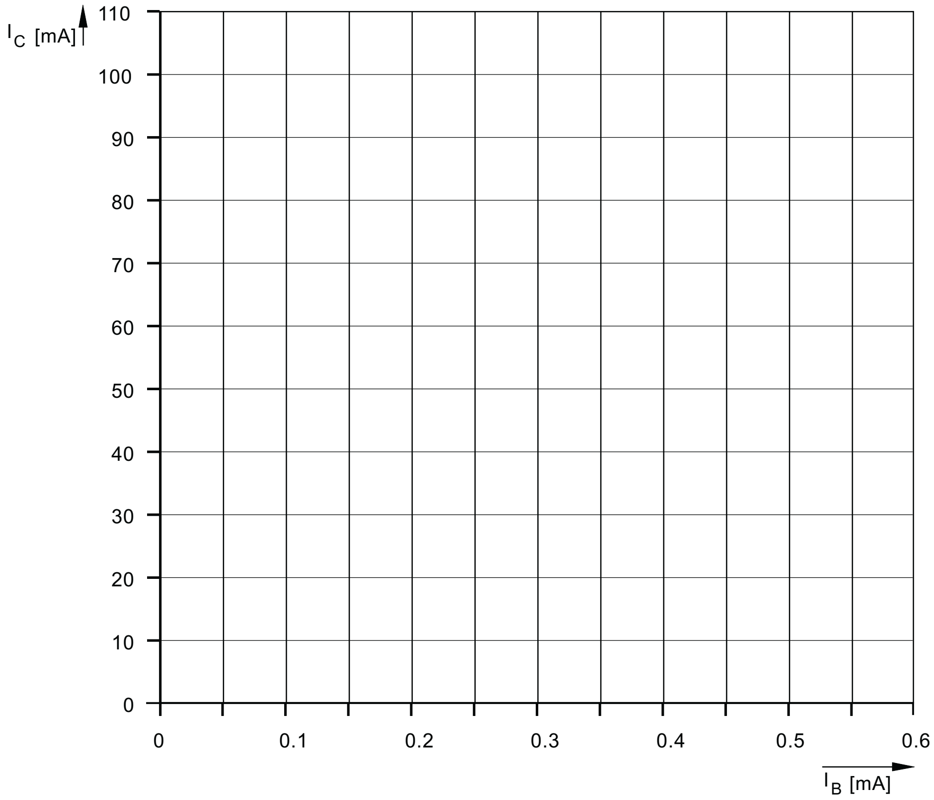


*Fig. 4.2.2.4*

**Question 1:** What does the characteristic (Fig. 4.2.2.4) demonstrate?

**Answer:**

**Question 2:** What is the current gain factor B when $I_C$ = 55 mA (see Fig. 4.2.2.4)?

**Answer:**

$B = \frac{I_C}{I_B} =$

**Question 3:** What is the small signal current gain β (see Fig. 4.2.2.4)?

**Answer:**

Small signal current gain when $\Delta I_C$ = 40 mA - 20 mA:

$\beta = \frac{\Delta I_C}{\Delta I_B} =$

Small signal current gain when $\Delta I_C$ = 80 mA - 70 mA:

$\beta = \frac{\Delta I_C}{\Delta I_B} =$

# 4.3 Characteristics of the Transistor

## 4.3.1 General: The transistor properties can be represented by 4 characteristics:

### Input Characteristic

The input characteristic shows the base current $I_B$ dependent on the base/emitter voltage $U_{BE}$ (with short-circuit output).

### Output Characteristic

The output characteristic shows the dependence of the collector current $I_C$ on the collector/emitter voltage $U_{CE}$ at different constant base currents.

### Control Characteristic

The control characteristic provides information on the dependence of the collector current $I_C$ on the base current $I_B$.

### Feedback Characteristic

The feedback characteristic shows the dependence of the base/emitter voltages $U_{BE}$, corresponding to the different constant base currents, on the collector/emitter voltage $U_{CE}$.

## 4.3.2 Experiments

❒ **Experiment**

Measure the electrical values of a transistor and draw the four characteristic fields of the transistor (four-quad-rant representation).

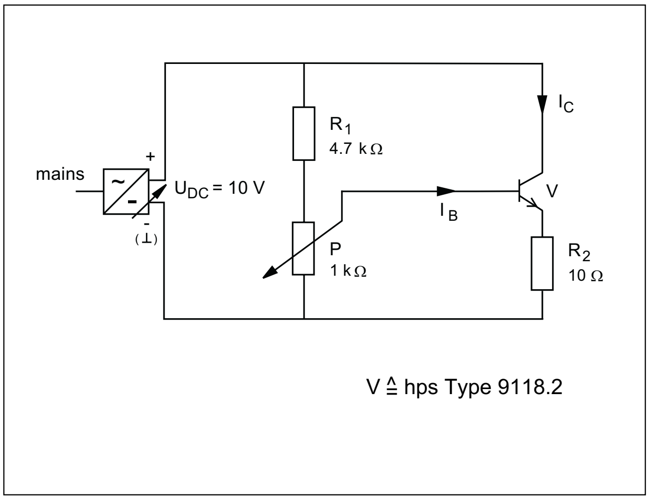


*Fig. 4.3.2.1*

**Procedure**

- Set up the circuit according to Fig. 4.3.2.1. Using the potentiometer, set the base currents $I_B$ consecutively according to Table 4.3.2.1. Measure the corresponding collector currents $I_C$ and enter their values in Table 4.3.2.1. Plot a graph showing the dependence of the collector current on the base current $I_C = f(I_B)$ in the second quadrant of the diagram (Fig. 4.3.2.5).

  **Note:**
  Considerable deviations in the measured values occur in these and the following measurements due to self-heating of the transistor. Steps cannot be taken to stabilize temperatures, since these would falsify the basic characteristic curves. It is therefore advisable to reduce the currents to zero for approx. 30 seconds after every measurement and to read the values quickly after resetting. Temperature-related dispersions of measured values can be compensated by interpolation when plotting the curves.

- Modify the circuit according to Fig. 4.3.2.2. Using the potentiometer, set the base/emitter voltages $U_{BE}$ consecutively according to Table 4.3.2.2. Measure the corresponding base currents $I_B$ and enter their values in Table 4.3.2.2. Plot a graph showing the dependence of the base current on the base/emitter voltage $I_B = f(U_{BE})$ in the third quadrant of the diagram (Fig. 4.3.2.5).

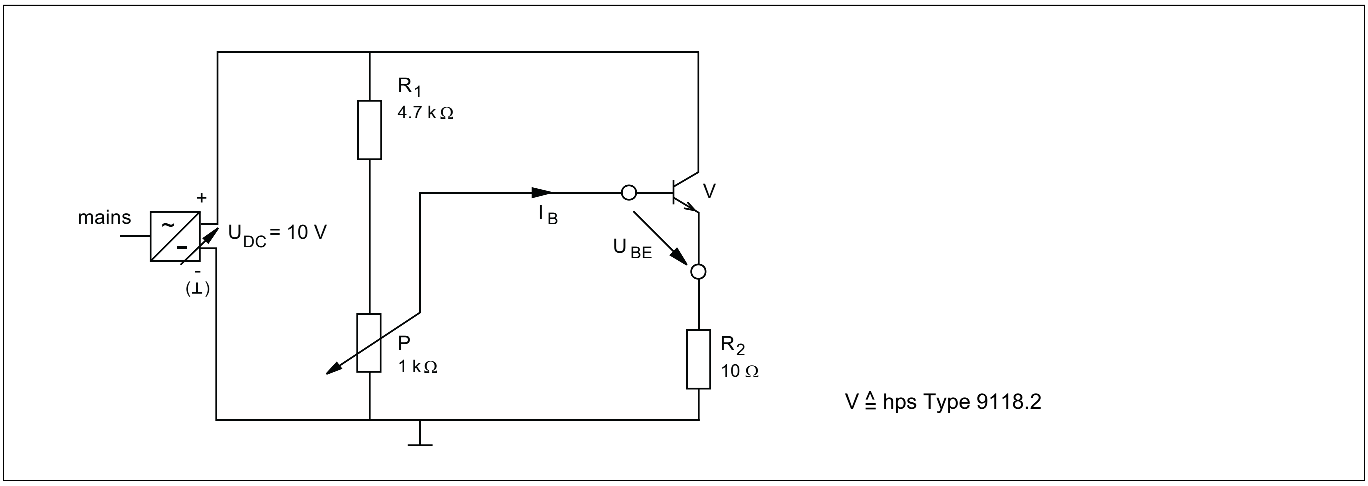


*Fig. 4.3.2.2*

- Then modify the circuit according to Fig. 4.3.2.3. Measure the collector current $I_C$ with varying base currents $I_B$ and collector/emitter voltages $U_{CE}$, according to Table 4.3.2.3. Enter the values in Table 4.3.2.3. Plot a graph showing the dependence of the collector current on the collector/emitter voltage $I_C = f(U_{CE})$ with varying base currents in the first quadrant of the diagram (Table 4.3.2.5).

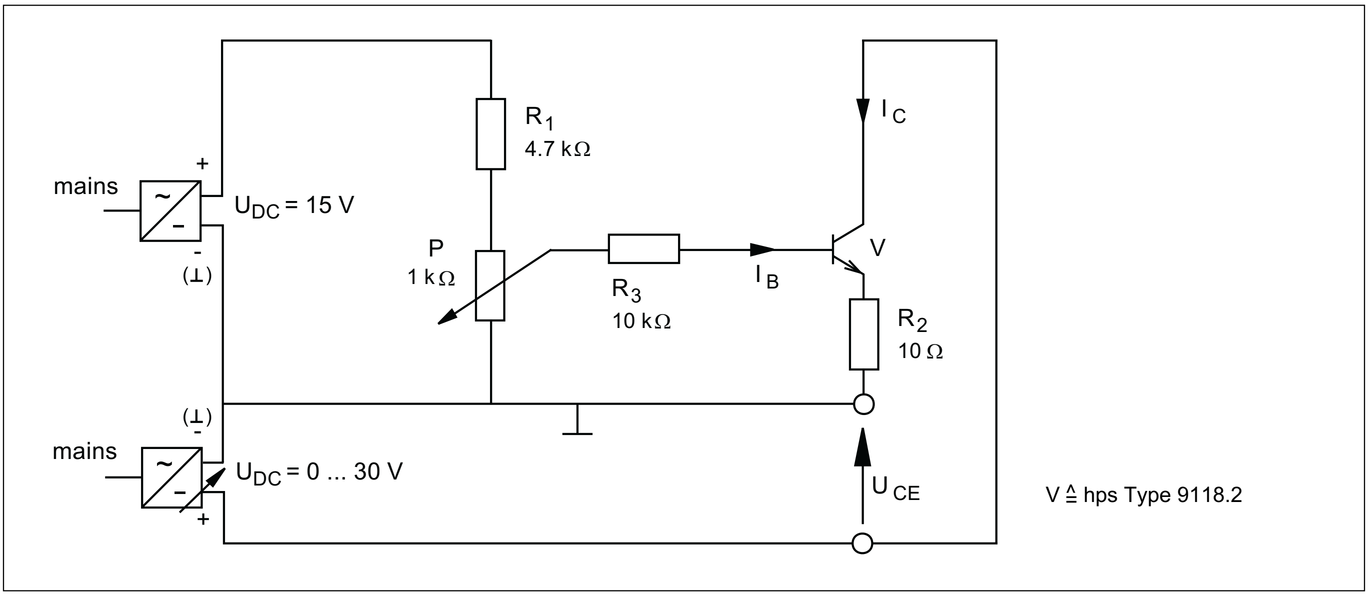


*Fig. 4.3.2.3*

- Then modify the circuit according to Fig. 4.3.2.4. Measure the base/emitter voltages $U_{BE}$ with varying base currents $I_B$ and collector/emitter voltages $U_{CE}$, according to Table 4.3.2.4.
  Enter the values in Table 4.3.2.4. Plot a graph showing the dependence of the base/ emitter voltage on the collector/emitter voltage $U_{BE} = f(U_{CE})$ with varying base currents in the fourth quadrant of the diagram (Table 4.3.2.5).

- Finally, examine the influence of resistor $R_2$. To do this, set a collector current of $I_C$ = 3 mA in the circuit shown in Fig. 4.3.2.1, bypass the resistor briefly (approx. 2-3 seconds) and at the same time observe the two ammeters.

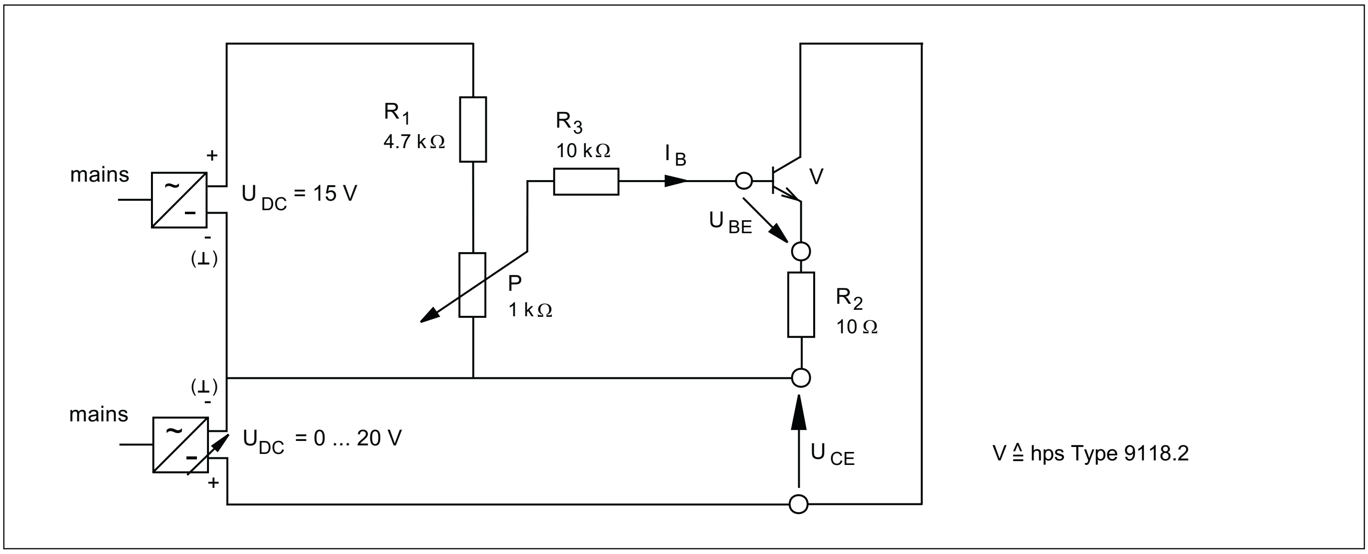


*Fig. 4.3.2.4*

---

**Question 1:** What function does resistor $R_2$ have in the emitter line?

**Answer:**

---

**Question 2:** With what value can collector current $I_C$ be controlled?

**Answer:**

| $U_{CE}$ = 10 V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $I_B$ [µA] | 0 | 20 | 40 | 60 | 80 | 100 | 120 | 140 | 160 |
| $I_C$ [mA] | | | | | | | | | |

*Tab. 4.3.2.1*

| $U_{CE}$ = 10 V | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $U_{BE}$ [V] | 0 | 0.5 | 0.6 | 0.65 | 0.7 | approx. 0.71 | approx. 0.71 | approx. 0.71 | approx. 0.71 | approx. 0.71 |
| $I_B$ [µA] | | | | | | | | | | |

*Tab. 4.3.2.2*

| $U_{CE}$ [V] | 0 | 0.2 | 0.5 | 2 | 4 | 6 | 8 | 10 | 12 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|
| $I_C$ [mA] at $I_B$ = 20 µA | | | | | | | | | | |
| $I_C$ [mA] at $I_B$ = 40 µA | | | | | | | | | | |
| $I_C$ [mA] at $I_B$ = 60 µA | | | | | | | | | | |
| $I_C$ [mA] at $I_B$ = 80 µA | | | | | | | | | | |

*Tab. 4.3.2.3*

| $U_{CE}$ [V] | 2 | 4 | 6 | 8 | 10 | 12 | 14 |
|---|---|---|---|---|---|---|---|
| $U_{BE}$ [V] at $I_B$ = 20 µA | | | | | | | |
| $U_{BE}$ [V] at $I_B$ = 40 µA | | | | | | | |
| $U_{BE}$ [V] at $I_B$ = 60 µA | | | | | | | |

*Tab. 4.3.2.4*

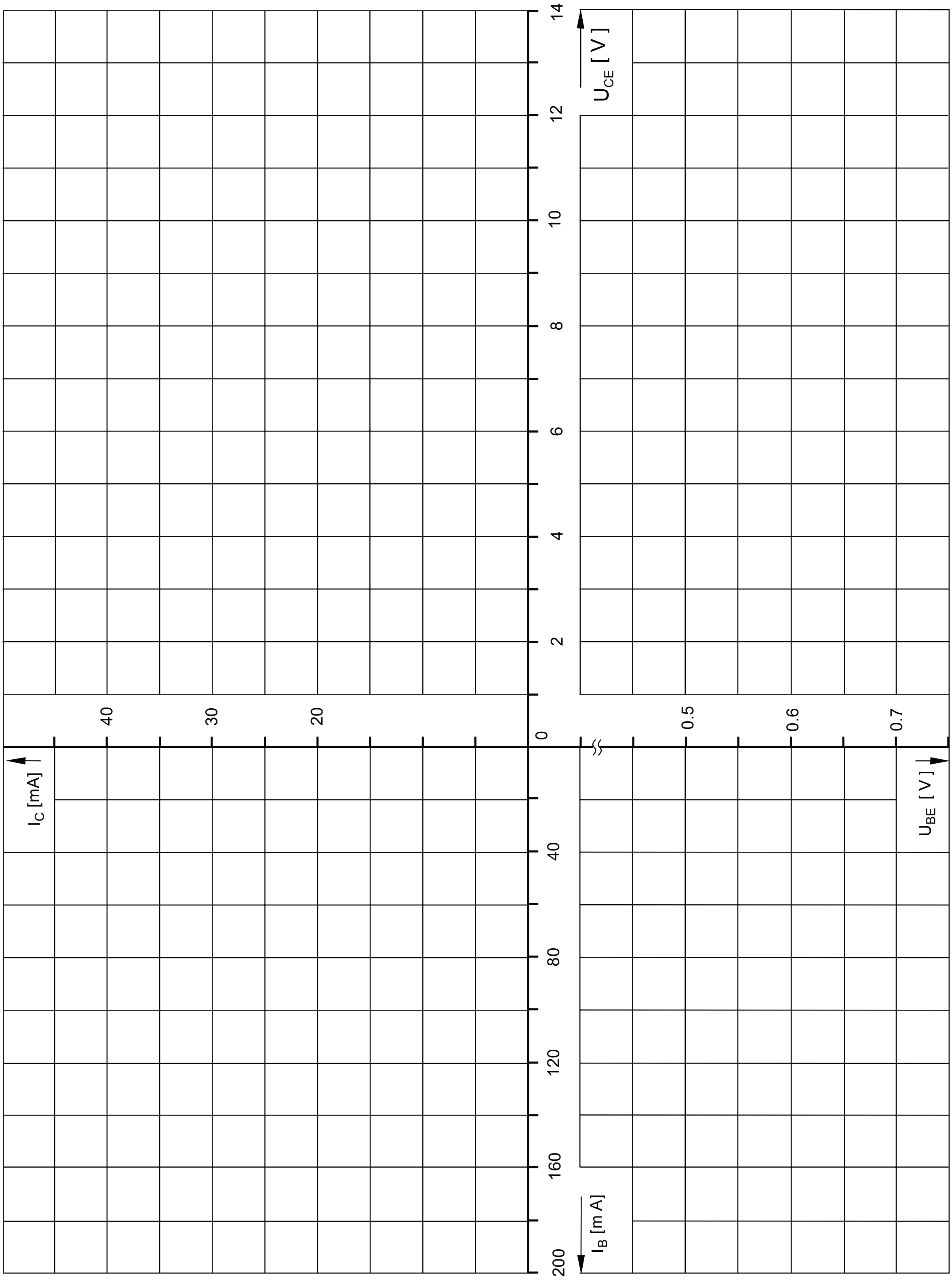

14
12
10
8
6
4
2
0
$U_{CE}$ [ V ]
40
30
20
0.5
0.6
0.7
$I_C$ [mA]
$U_{BE}$ [ V ]
40
80
120
160
200
$I_B$ [m A]

*Fig. 4.3.2.5*

# 4.4 Influence of the Load Resistance on the Transistor Properties

## 4.4.1 General

The change in collector current $I_C$ of a transistor caused by the base current $I_B$ is converted into a voltage change $U_{CE}$ on a series-connected load resistor $R_L$. The base current change $I_B$ is caused by a change in the base/emitter voltage $U_{BE}$.

The ratio of the two voltage changes gives the voltage gain of the transistor:

$$v_U = \frac{\Delta U_{CE}}{\Delta U_{BE}}$$

Since the collector/emitter voltage change $U_{CE}$ depends on the load resistor $R_L$. this resistor also influences the voltage gain.

## 4.4.2 Experiments

❒ **Experiment**

Use experiments to examine the influence of the load resistance on the voltage gain and the frequency behaviour of a transistor amplifier.

**Procedure**

- Set up the circuit according to Fig. 4.4.2.1.
  f = 1 kHz
  $R_L$ = 100 Ω

  Operate the transistor as an AC voltage amplifier. Capacitors $C_1$ and $C_2$ keep DC voltage components away from the input and output.

**Note:**
Before carrying out each actual measurement, adjust the collector rest current with the potentiometer so that the amplitude shown on the oscilloscope monitor is as large and sinusoidal as possible (operating point setting).

- Apply AC voltages $U_{in}$ (f = 1 kHz) to the input (point A) with varying load resistance $R_L$ according to Table 4.4.2.1, and measure the corresponding output voltage $U_{out}$ with the oscilloscope.

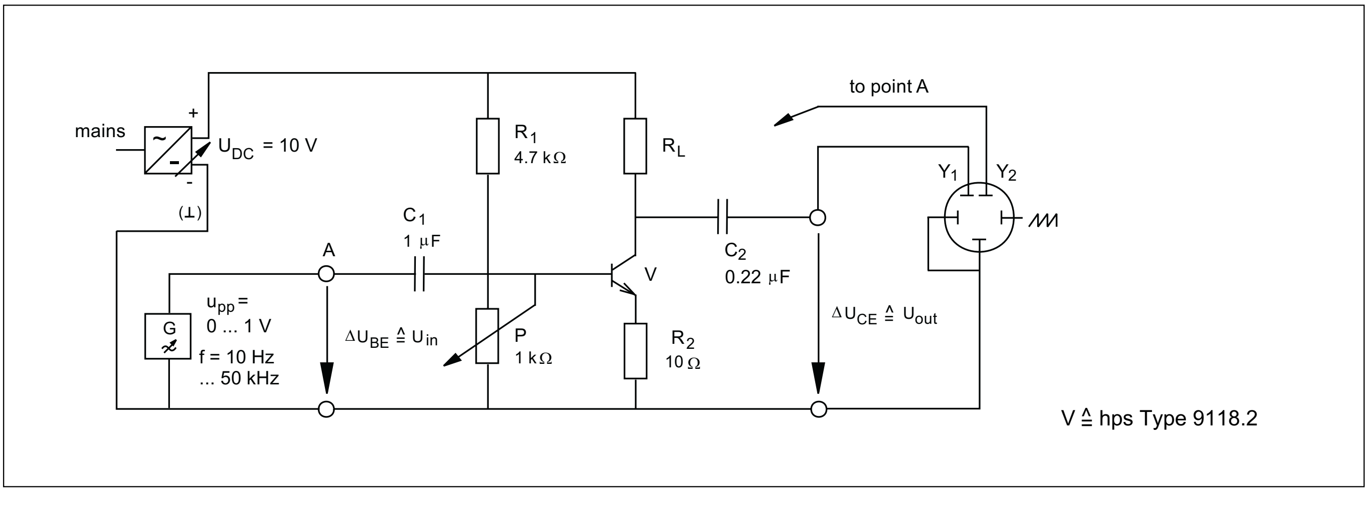


*Fig. 4.4.2.1*

- Then calculate the gain factor using the following formula:

$$v_U = \frac{U_{out}}{U_{in}}$$

- Enter the values in Table 4.4.2.1.

- Plot the curve of input voltage $U_{in}$ and output voltage $U_{out}$ (when $R_L$ = 4.7 kΩ) on the grid (Table 4.4.2.2).

- Plot a graph on the diagram (Fig.4.4.2.3) showing the dependence of the gain factor on the load resistance.

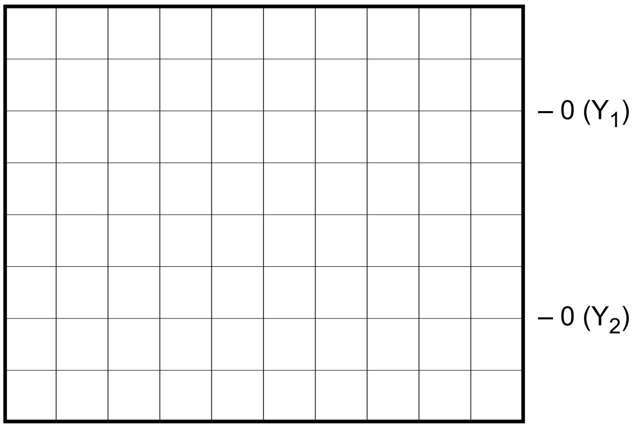


*Fig. 4.4.2.2*

| **Settings:** | **Remarks:** |
|---|---|
| X = 0.1 ms / div. | $Y_1$ = input voltage $U_{in}$ |
| $Y_1$ = 20 mV / div. | $Y_2$ = output voltage $U_{out}$ |
| $Y_2$ = 2 V / div. | |

| $R_L$ [kΩ] | 0.1 | 0.47 | 1 | 4.7 | 10 | 22 |
|---|---|---|---|---|---|---|
| $U_{in\ pp}$ [mV]* | 400 | 200 | 100 | 40 | 20 | 20 |
| $U_{out\ pp}$ [V] | | | | | | |
| $v_U$ | | | | | | |

*Tab. 4.4.2.1* * These voltage values must be reduced depending on the transistor type

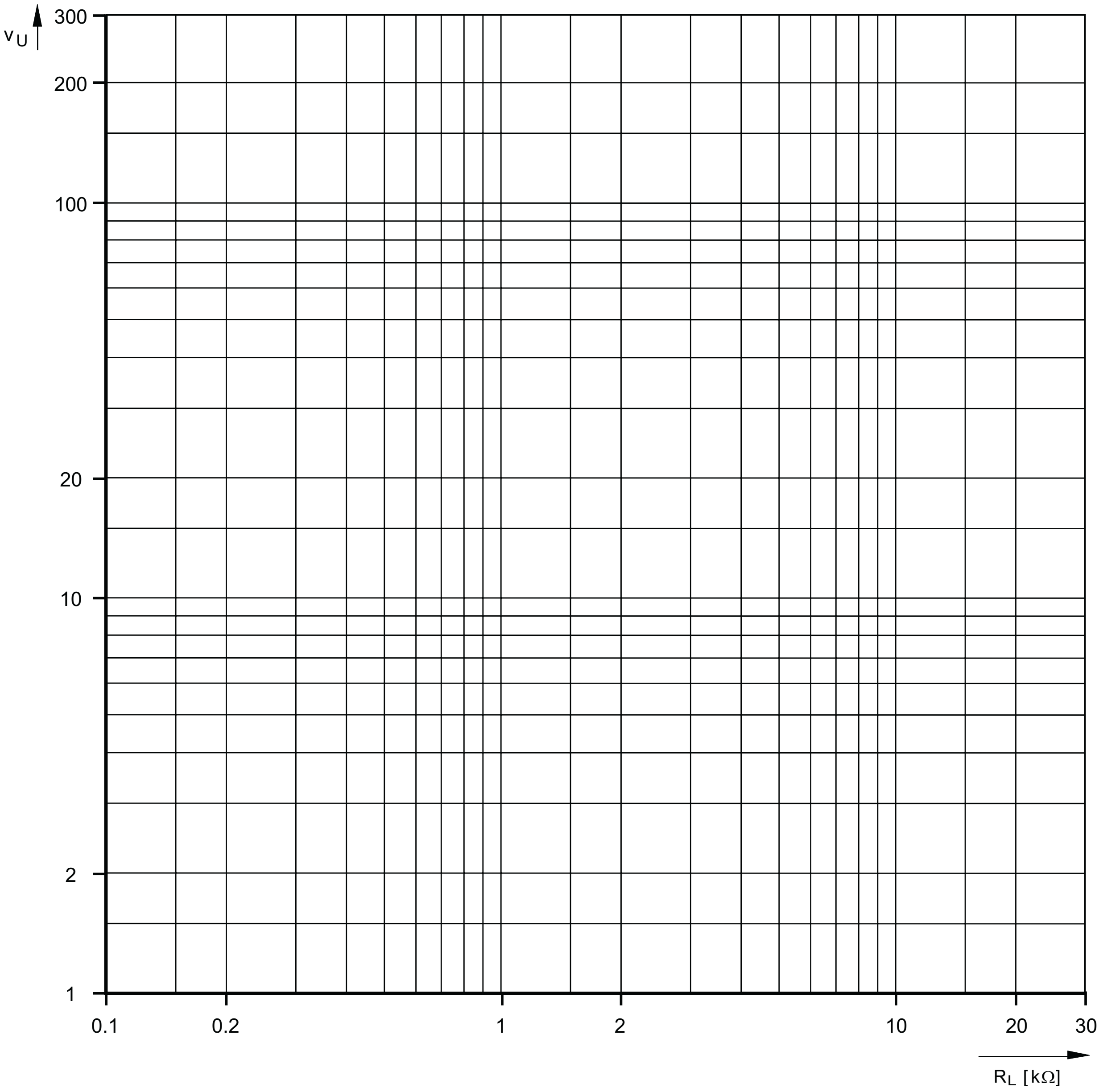


*Fig. 4.4.2.3*

- In the next experiment, measure the influence of the load resistance on the upper cut-off frequency. To do this, set the output voltage when f = 1 kHz to a fixed value, which is equated to 100 %. Then increase the frequency until the output voltage has dropped back to 70.7 %.
  The frequency at which this occurs is the upper cut-off frequency. Determine the upper cut-off frequency for each load resistance shown in Table 4.4.2.2 and enter its value in Table 4.4.2.2. Care should be taken to ensure that the set input voltage $U_{in}$ does not overdrive the transistor.

- Plot a graph to show the dependence of the upper cut-off limit on the load resistance on the diagram (Fig. 4.4.2.4).

| **$R_L$ [kΩ]** | 0.1 | 0.47 | 1 | 4.7 | 10 | 22 |
|---|---|---|---|---|---|---|
| **$f_{up}$ [kHz]*** | | | | | | |

*Tab. 4.4.2.2* * A function generator with a frequency range between 100 kHz and 5 Mhz is required for this experiment.

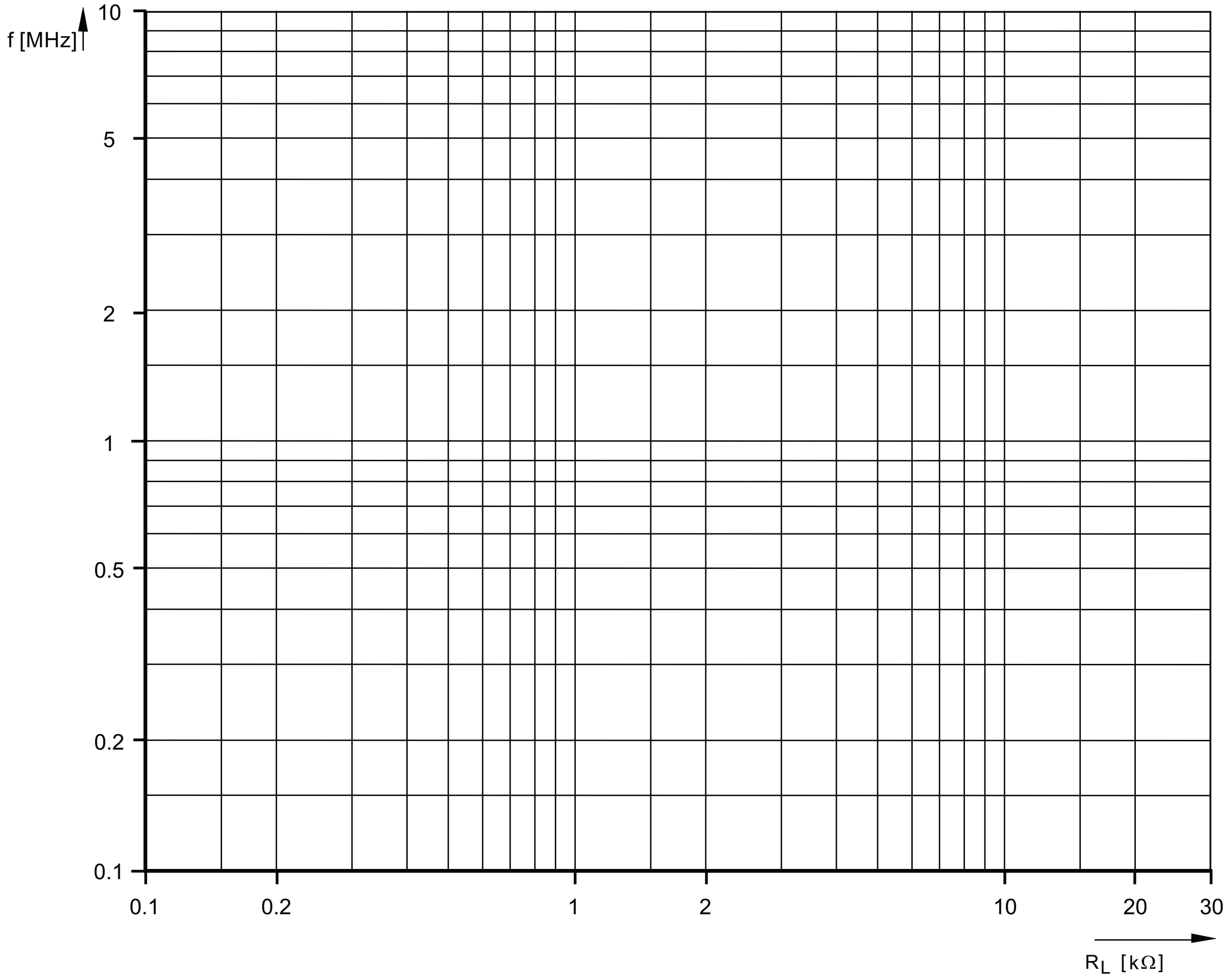


*Fig. 4.4.2.4*

**Question 1:** What influence does the load resistance have on the gain factor?

**Answer:**

**Question 2:** What influence does the load resistance have on the upper cut-off frequency?

**Answer:**

**Question 3:** How large is the phase shift between the input and output voltages?

**Answer:**

# 5. Unipolar Transistors (Junction Field-Effect Transistors)

## 5.1 Testing the Layers and the Rectifying Behaviour of FETs

### 5.1.1 General

With field-effect transistors (FETs), the charge-carrier currents do not negotiate p-n junctions between different conductive layers but flow in a uniform channel. This is why they are called unipolar transistors. The charge-carrier currents are controlled by electrodes (gates), which are isolated from the channel either by p-n junctions (junction FET) or by crystal layers (MOSFET).

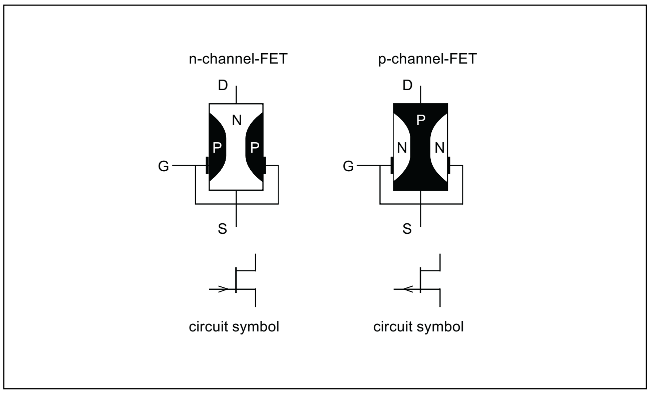


*Fig. 5.1.1.1*

### 5.1.2 Experiments

**❐ Experiment**

Investigate the properties of the p-n junctions between the gate electrodes and the main electrodes (source and drain) of an n-channel FET. Using the multimeter, measure the dependence of the current on the applied voltage. Then repeat the experiment with a p-channel FET.

**Procedure**

- Set up the circuit according to Fig. 5.1.2.1 (diagram 1) and use the multimeter to determine whether the p-n junction is conducting or blocked.
  Repeat the measurement (diagrams 2, 3 and 4).
  Enter the results (conducting/blocked) in Table 5.1.2.1.

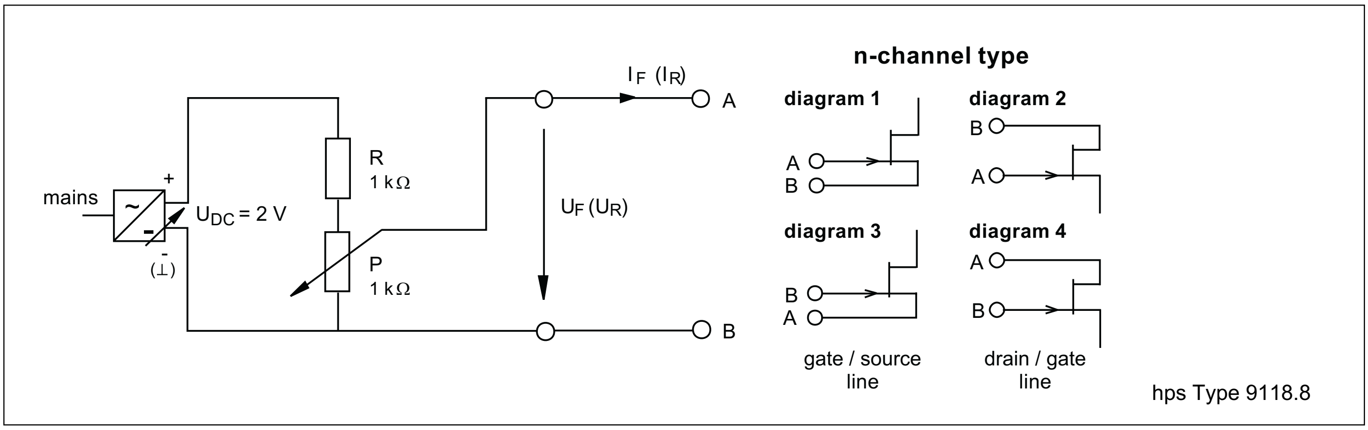


*Fig. 5.1.2.1*

| **Diagram** | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| **N-channel type** | | | | |
| **P-channel type** | | | | |

*Tab. 5.1.2.1*

- Then replace the n-channel FET with a p-channel FET (Fig. 5.1.2.2). Determine the states of the p-n junctions by measuring the currents (diagrams 1 to 4) and enter the results in Table 5.1.2.1.

  **Note:**
  With the Field Effect Transistor 2 N 3820 (Type 9118.20) tolerances > 100% may occur.

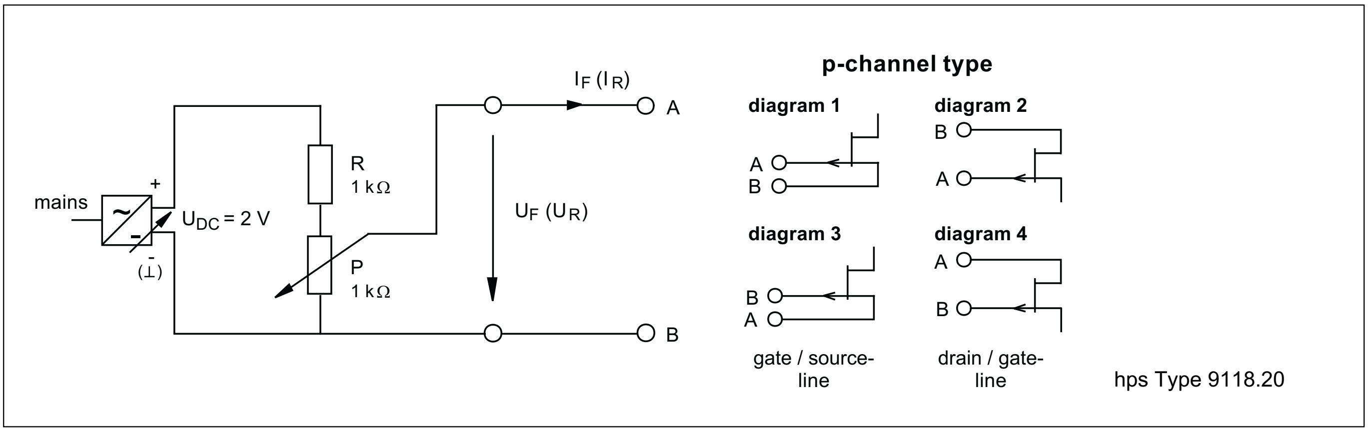


*Fig. 5.1.2.2*

---

**Question 1:** When are the p-n junctions of the n-channel FET blocked?

**Answer:**

---

**Question 2:** When are the p-n junctions of the p-channel FET blocked?

**Answer:**

## 5.2 On-State Characteristic of the Gate P-N Junctions for FETs

### 5.2.1 General

There is a rectifying effect between the gate and the channel of a junction FET. Although this is of no practical significance, its on-state characteristic must be known in order to understand certain features of the control behaviour of FETs.

### 5.2.2 Experiments

☐ **Experiment 1**

Measure and examine the on-state characteristic of the p-n junctions between the gate and the channel connections of a junction field-effect transistor. This experiment is only to be carried out on an n-channel FET. Its results are also valid for p-channel types, except that the polarity is reversed.

**Procedure**

- Set up the circuit according to Fig. 5.2.2.1 (with gate/source line). Set the voltages $U_F$ consecutively according to Table 5.2.2.1. Measure the corresponding currents $I_F$ with the multimeter and enter their values in Table 5.2.2.1.
- Repeat the measurements with the drain/gate line and enter the current values $I_F$ in Table 5.2.2.2.
- Plot a graph showing the on-state characteristics of the p-n junctions $I_F = f(U_F)$ on the diagram (Fig. 5.2.2.2).

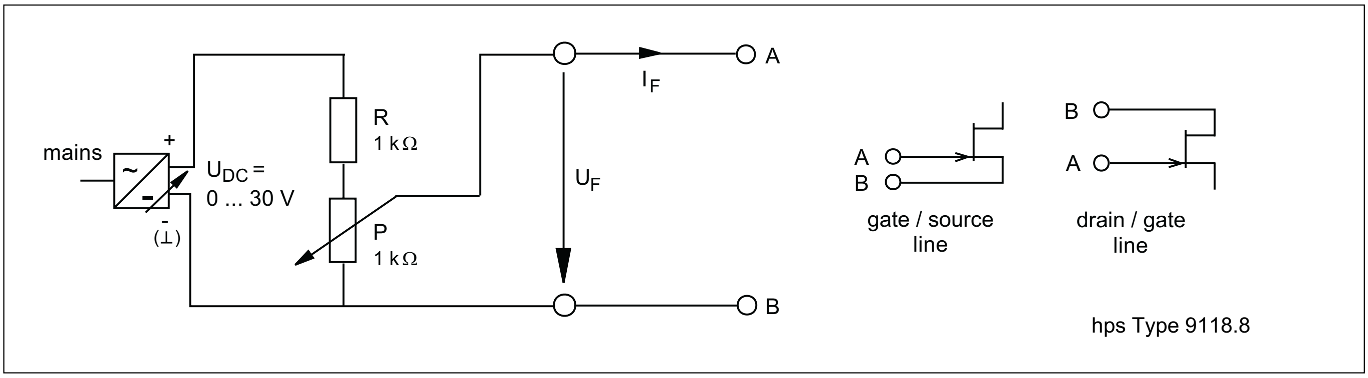


*Fig. 5.2.2.1*

| Gate/source line | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$U_F$ [V]** | 0 | 0.2 | 0.4 | 0.6 | 0.7 | 0.75 | 0.8 | 0.85 | 0.9 | 1.0 |
| **$I_F$ [mA]** | | | | | | | | | | |

*Tab. 5.2.2.1*

| Gate/drain line | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$U_F$ [V]** | 0 | 0.2 | 0.4 | 0.6 | 0.7 | 0.75 | 0.8 | 0.85 | 0.9 | 1.0 |
| **$I_F$ [mA]** | | | | | | | | | | |

*Tab. 5.2.2.2*

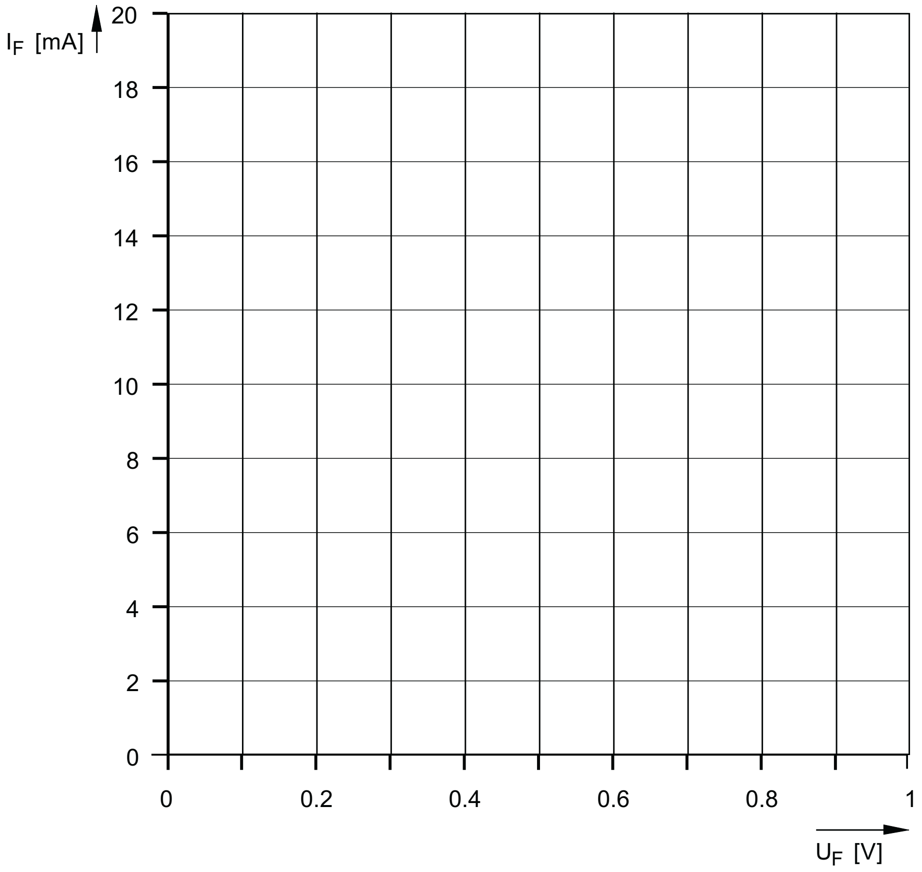


*Fig. 5.2.2.2*

---

**Question:** What is the significance of the deviations between the two on-state characteristics?

---

**Answer:**

## 5.3 Control Effect of the Gate with N-Channel FETs

### 5.3.1 General

The current flowing through the channel of the field-effect transistor (source/drain) can be controlled with the gate potential. Unlike bipolar transistors, no power is required for this as long as the p-n junction between the gate and the channel remains blocked.
The input characteristic or control characteristic of a FET identifies the relationship between the gate/source voltage $U_{GS}$ and the drain current $I_D$.
This can be used to determine the grade of steepness S, which is a direct gauge for the voltage gain:

$$S = \frac{\Delta I_D}{\Delta U_{GS}}$$

S = steepness in mA/V

$\Delta I_D$ = drain current change in mA

$\Delta U_{GS}$ = gate/source voltage change in mA

### 5.3.2 Experiments

**❒ Experiment**

Experiment to examine the influence of the gate/source voltage on the gate current and the drain current. Construct the control characteristics:

$I_G = f(U_{GS})$; $I_D = f(U_{GS})$

**Procedure**

- Set up the circuit according to Fig. 5.3.2.1 and adjust the gate/source voltage $U_{GS}$ in steps according to Table 5.3.2.1.
  Measure each corresponding gate current $I_G$ and drain current $I_D$ with the multimeter and enter the values in Table 5.3.2.1 or 5.3.2.2 as applicable.

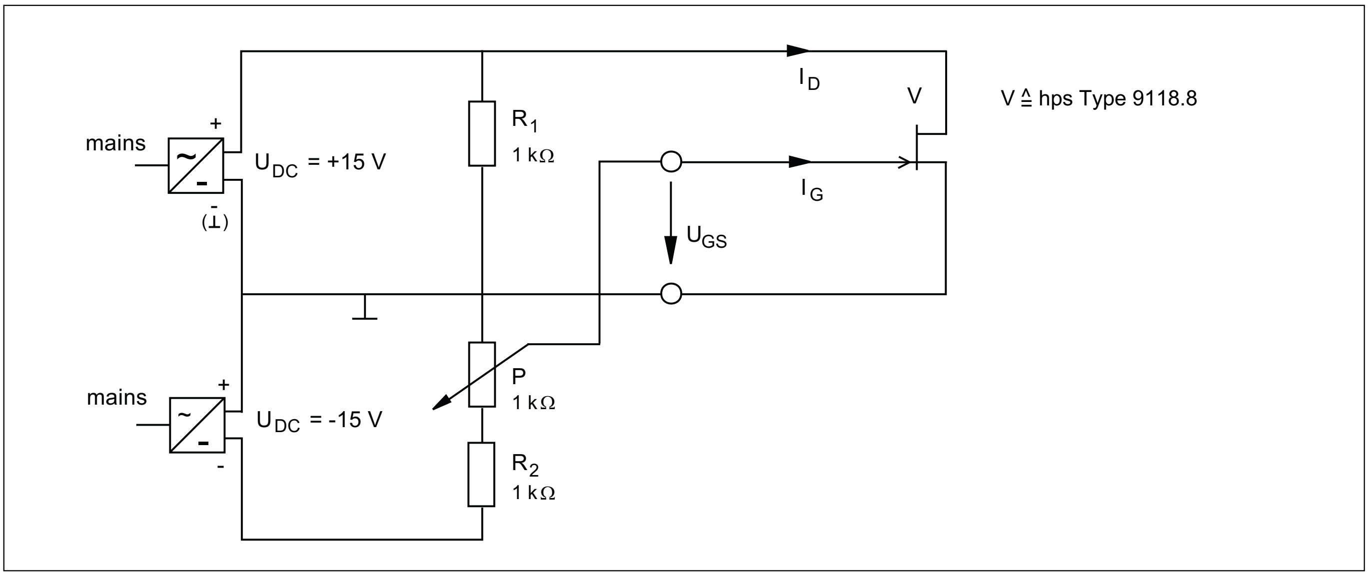


*Fig. 5.3.2.1*