SEMICONDUCTOR COMPONENTS

4th Edition

Training in Technology

hps SystemTechnik

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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List of Contents

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.
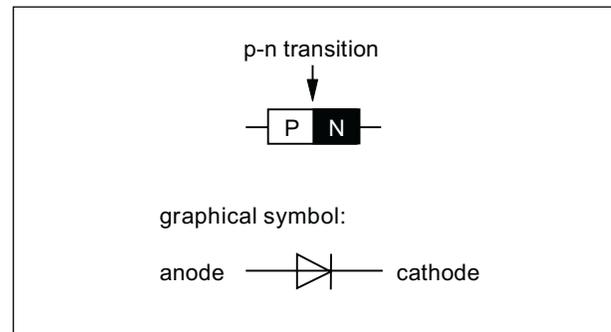
Fig. 1.1.1.1

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.
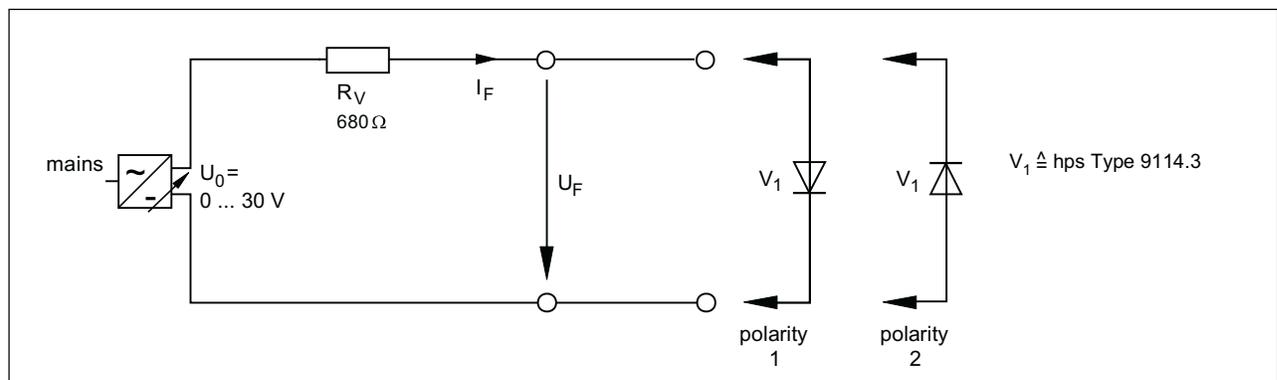
Fig. 1.1.2.1

- 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
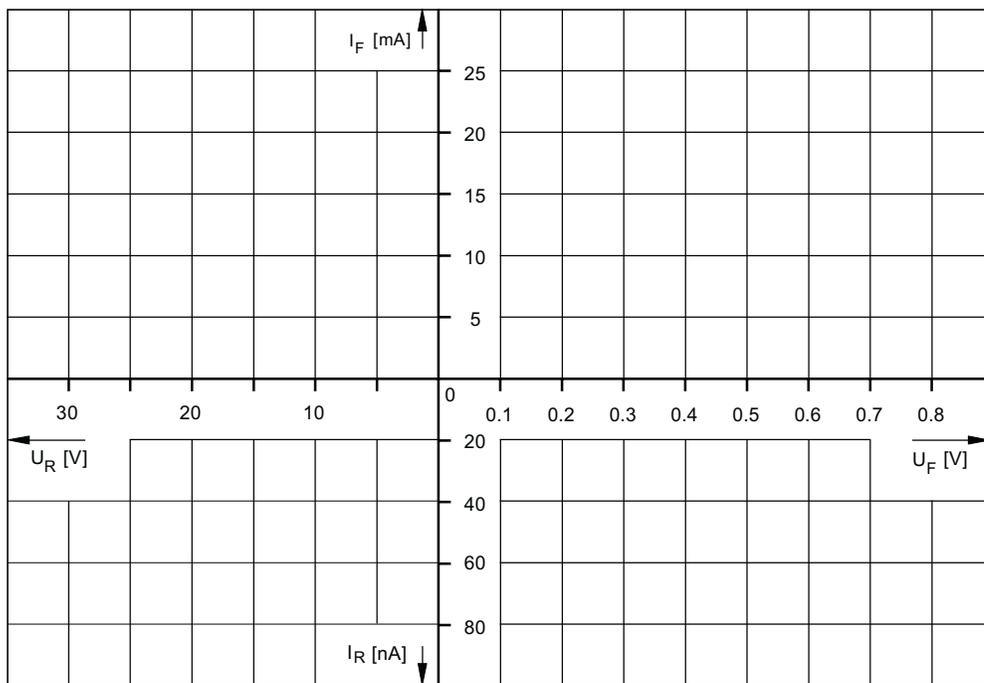
Fig. 1.1.2.2

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.

R
330 Ω

Y

X

u_{pp} = 6 V
(sine)
f = 50 Hz

G
~

V_1

$V_1 \triangleq$ hps Types:
9114.3 (silicon diode)
9114.2 (germanium diode)
9121.10.3 (gallium-arsenide diode)
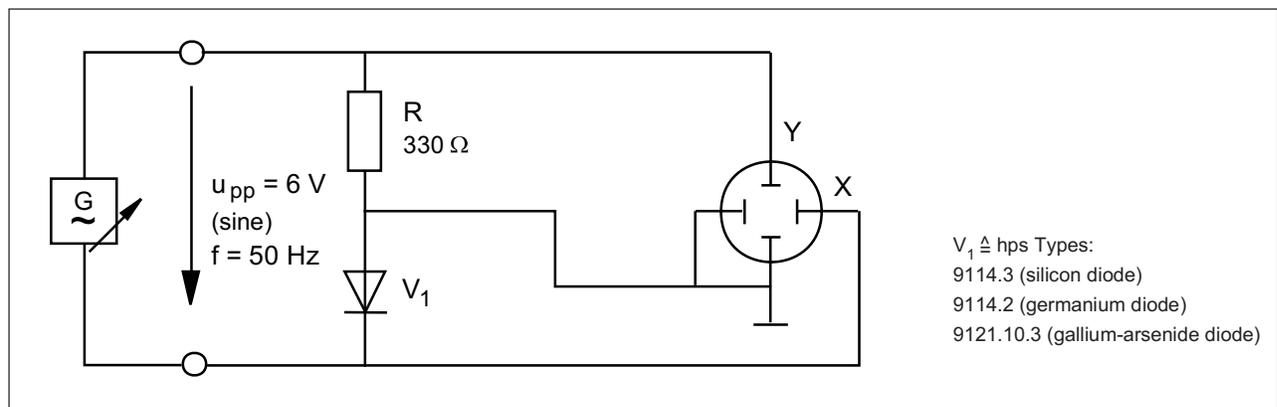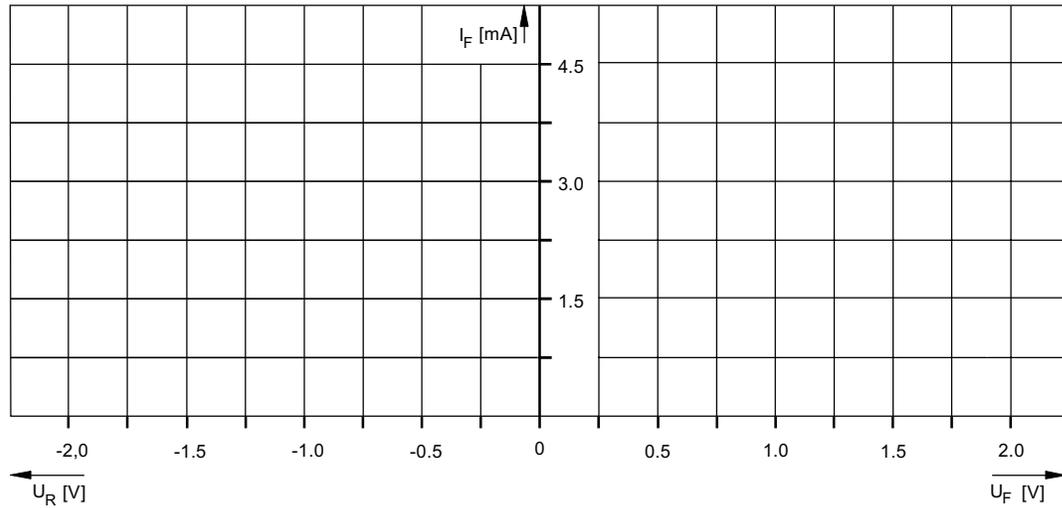
Fig. 1.2.2.1

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):

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

ΔU_F = change of on-state potential in V

ΔI_F = change of on-state current in A

ΔR_{diff} = differential internal resistance in Ω

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

Answer:

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1.3   Half-Wave Rectifier Circuit M1

1.3.1   General

In circuits in which semiconductor diodes are in-
serted a current can only flow (on-state range) when
the ap-plied current has a certain polarity. If the polar-
ity of the voltage is reversed, the off-state range of the
diode becomes effective, preventing current from flow-
ing. 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.
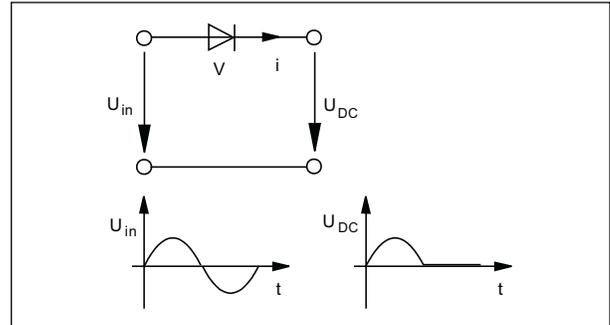
Fig. 1.3.1.1   Half-wave rectifier circuit M1

1.3.2   Experiments

◻ **Experiment**

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

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.
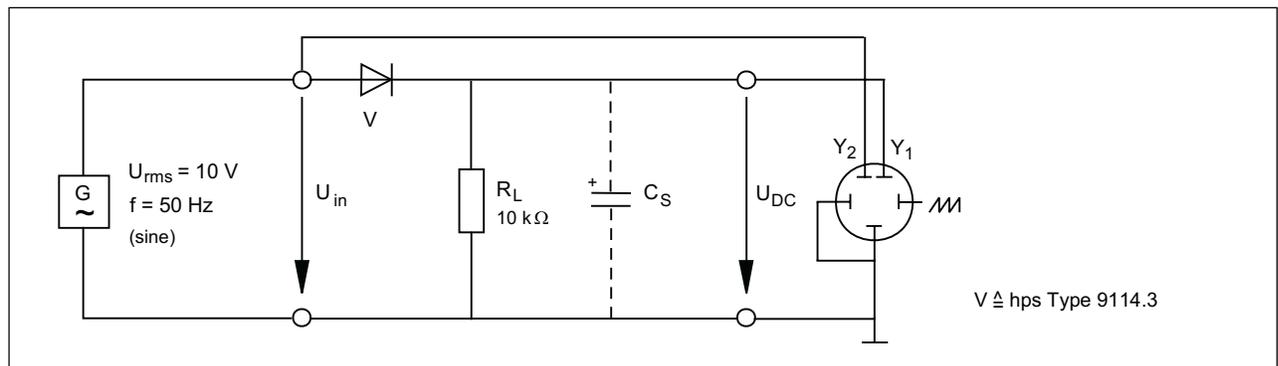
Fig. 1.3.2.1

- 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.

$- 0\ (Y_1)$
$\triangleq U_{in}$

$- 0\ (Y_2)$
$\triangleq U_{DC}$
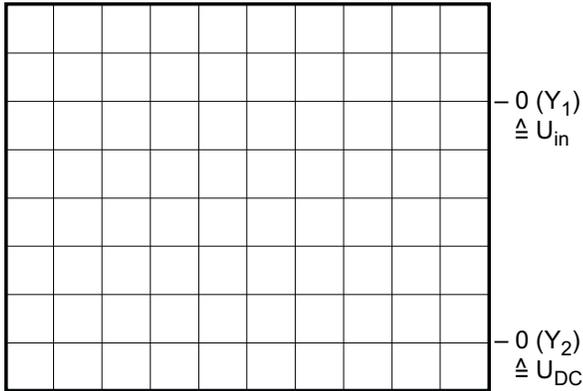
Fig. 1.3.2.2

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]				
$\dfrac{U_{DC}}{U_{in}}$ =				
$u_{rip\ pp}$ [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.

$- 0\ (Y_1)$
$\triangleq U_{in}$

$- 0\ (Y_2)$
$\triangleq U_{DC}$
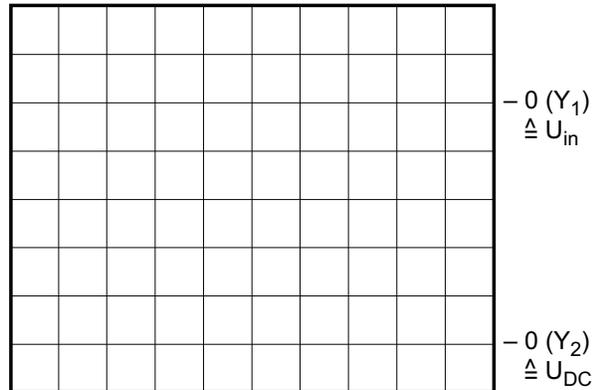
Fig. 1.3.2.3

Settings:

Y_1 = 10 V / div.

Y_2 = 5 V / div.

X = 5 ms / div.

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- 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).

$- 0\ (Y_1)$
$\triangleq U_{in}$

$- 0\ (Y_2)$
$\triangleq U_{DC}$
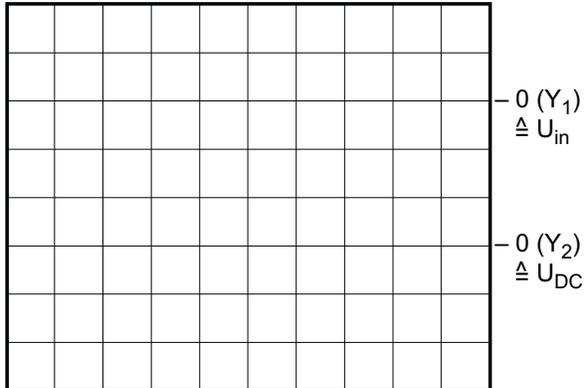
Fig. 1.3.2.4

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.
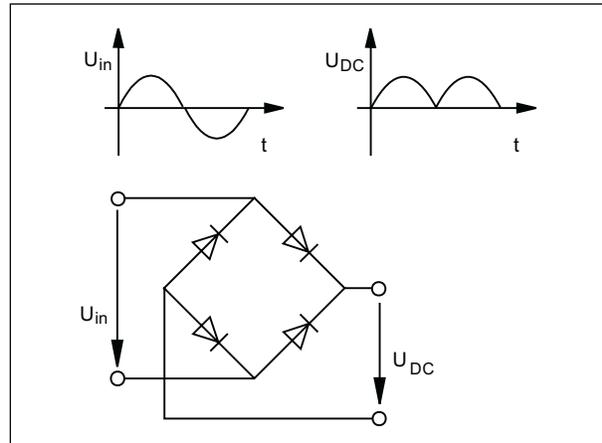
Fig. 1.4.1.1   Bridge rectifier circuit B2

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}.
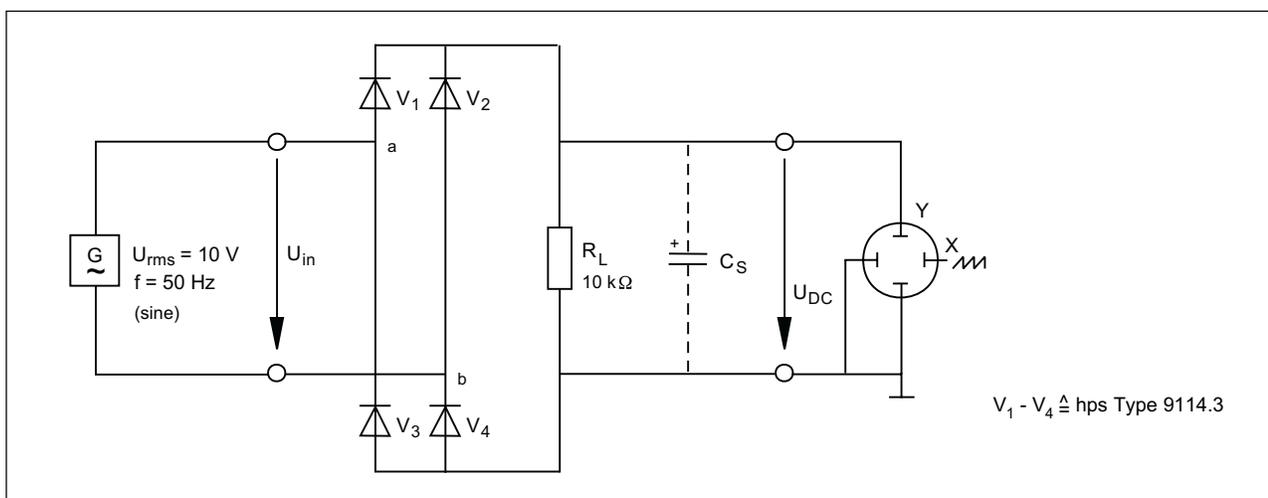
Fig. 1.4.2.1

- 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.

- Enter all evaluated values in Table 1.4.2.1.

− 0 (Y)
≙ U_{in}

− 0 (Y)
≙ U_{DC}

Fig. 1.4.2.2

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

Tab. 1.4.2.1
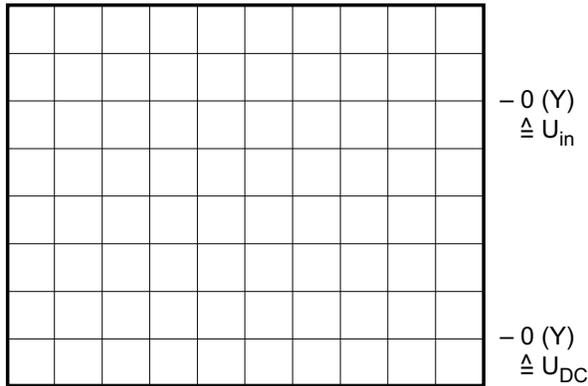
Settings:

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!

- 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.


− 0 (Y)
≙ U_{in}

− 0 (Y)
≙ U_{DC}

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

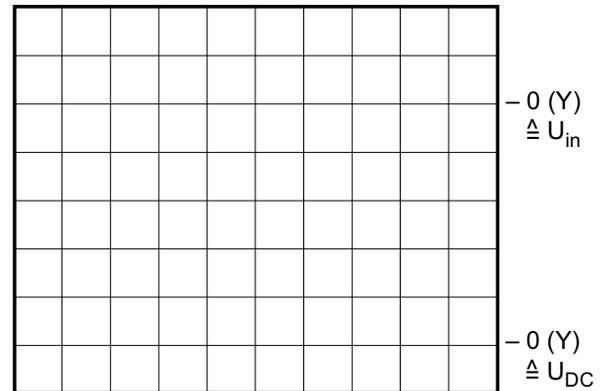Zener diodes – called after their discoverer Carl Zener – are silicon diodes whose on-state characteristic is the same as that of rectifier diodes.
Zener diodes differ from rectifier diodes in the relatively low breakdown voltages in the off-state or backward range (Z-voltage). When the breakdown voltage 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
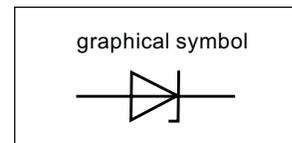
Fig. 2.1.1.1

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.
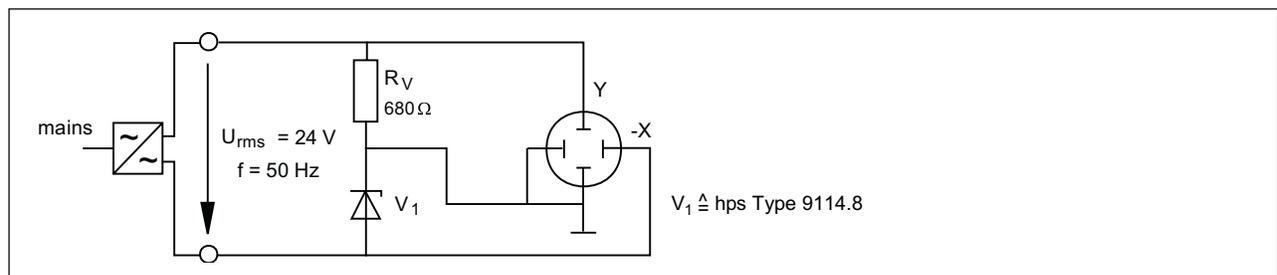
Fig. 2.1.2.1

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.

– 0 (Y)

Fig. 2.1.2.2

I
0 (X)
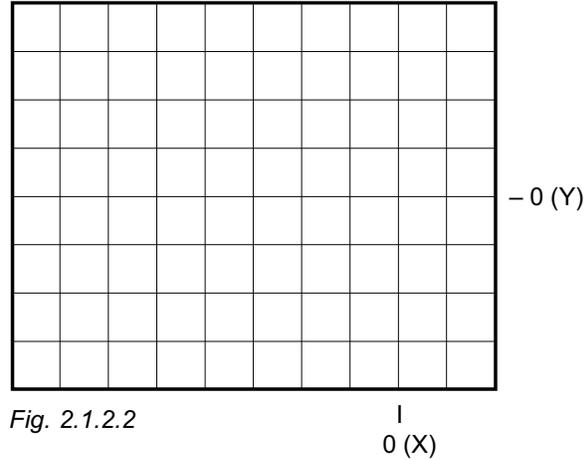
Settings:
Y   = 10 V / div.
-X = 2 V / div.

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:

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

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}.
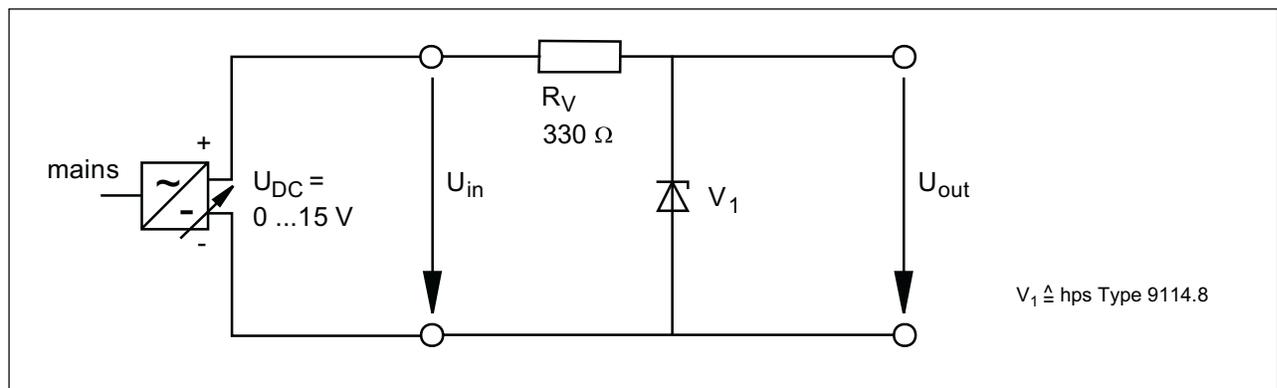
Fig. 2.2.2.1

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
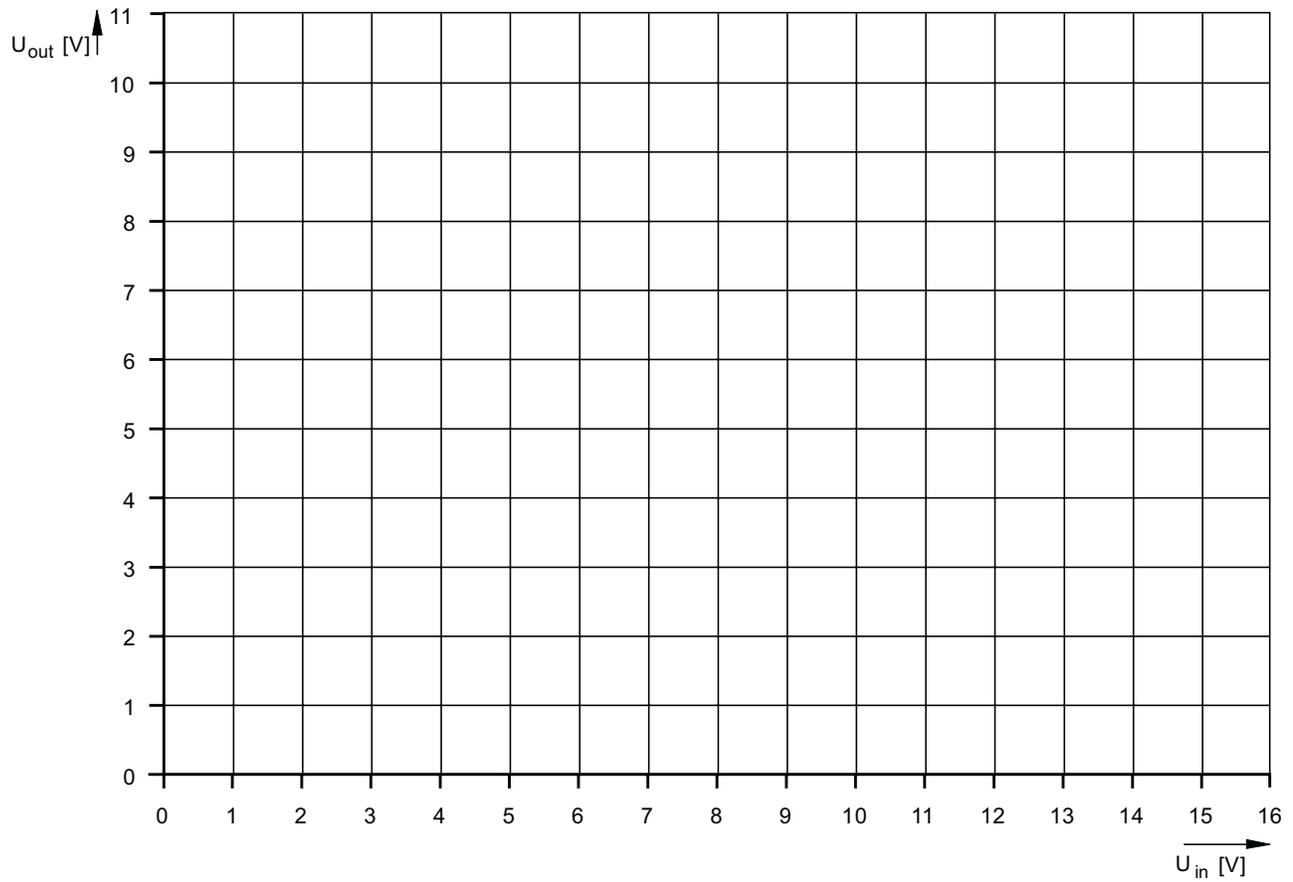
Fig. 2.2.2.2

❒ 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

Within the figure:
R_V 330 Ω
mains
$U_{DC} = 0...15\ V$
U_{in}
V_1
U_{out}
I_Z
$V_1 \triangleq$ hps Type 9114.8
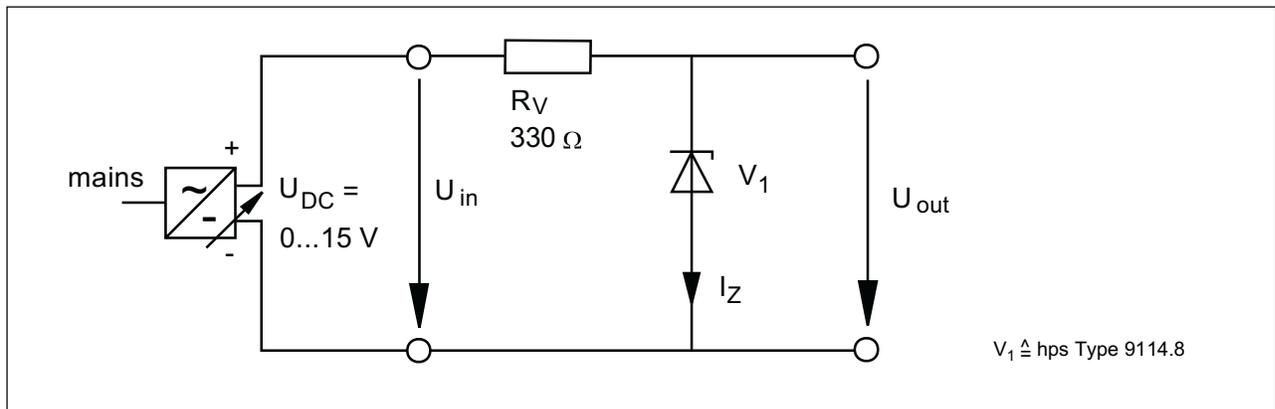
U_{in} [V]	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
I_Z [mA]																

Tab. 2.2.2.2
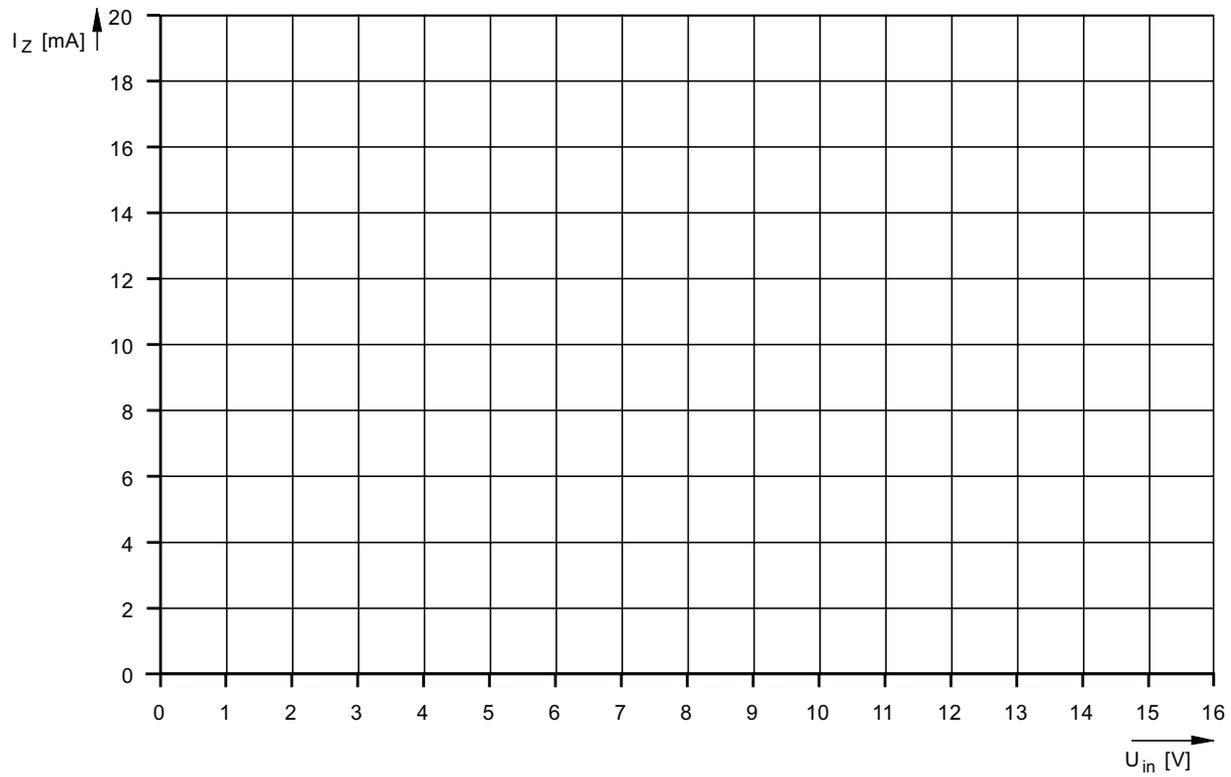
Fig. 2.2.2.4

□ 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.
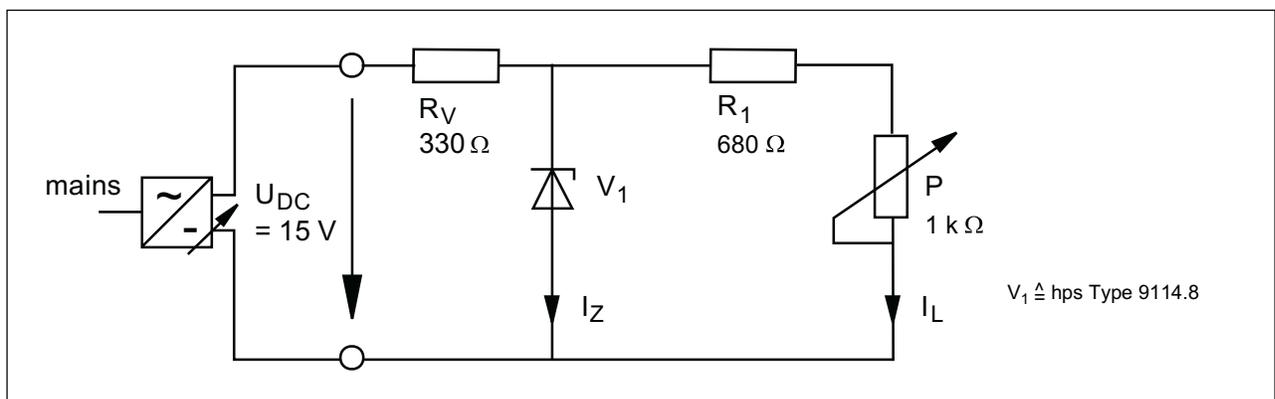
Fig. 2.2.2.5

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
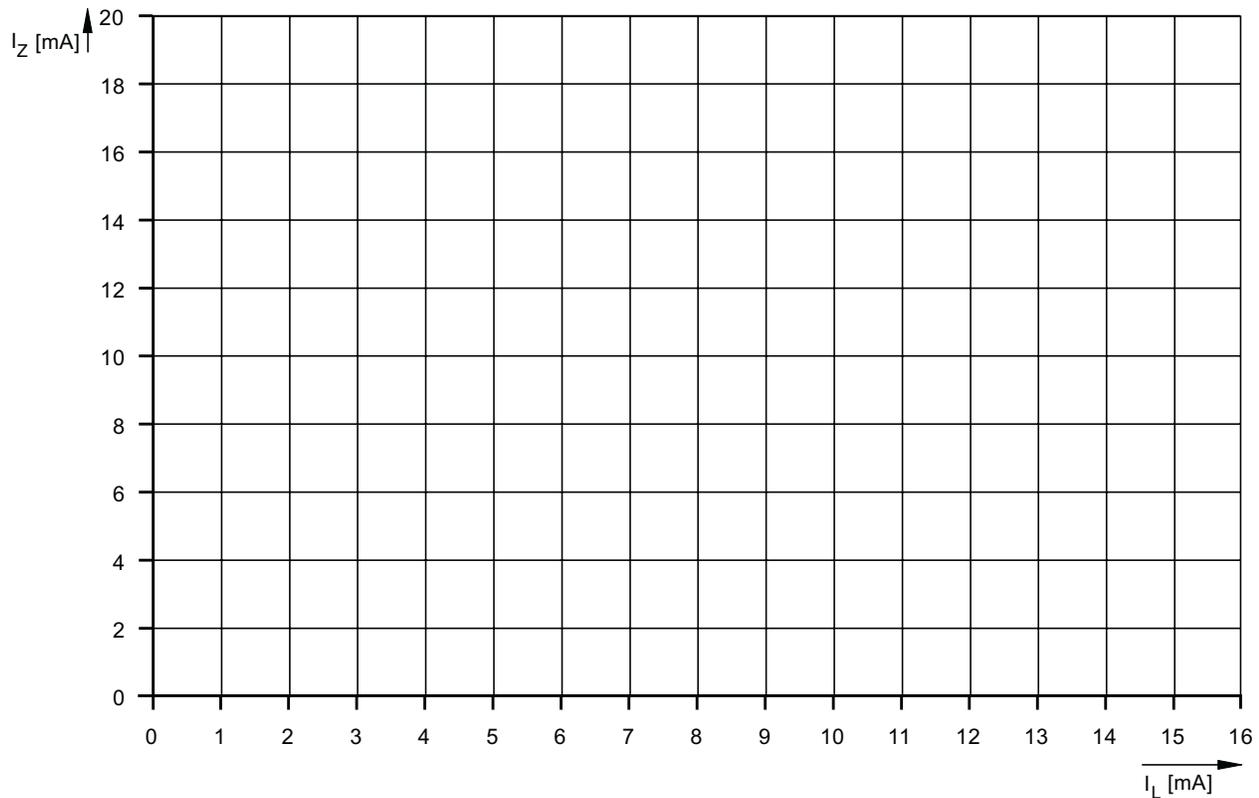
Fig. 2.2.2.6

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.

- 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.

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.
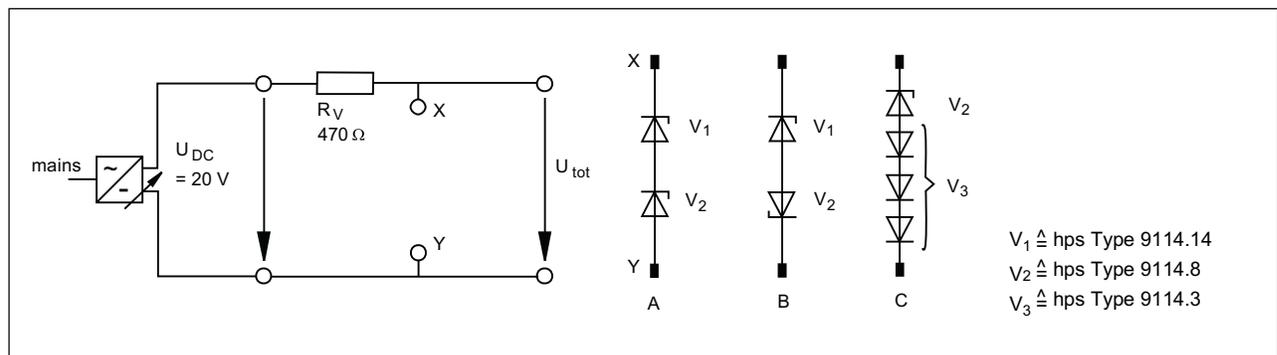
Fig. 2.3.2.1

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

Tab. 2.3.2.1

U = 3.3 V (hps Type 9114.14)	$-3 \cdot 10^{-4} \cdot K^{-1}$	-0.99 mV / K
U = 10 V (hps Type 9114.8)	$+8 \cdot 10^{-4} \cdot K^{-1}$	+8 mV / K
U = 0.7 V (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 con-nected 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 ad-just 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 Ta-ble 2.4.2.1.

- Subsequently reverse the polarity of the input volt-age 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.
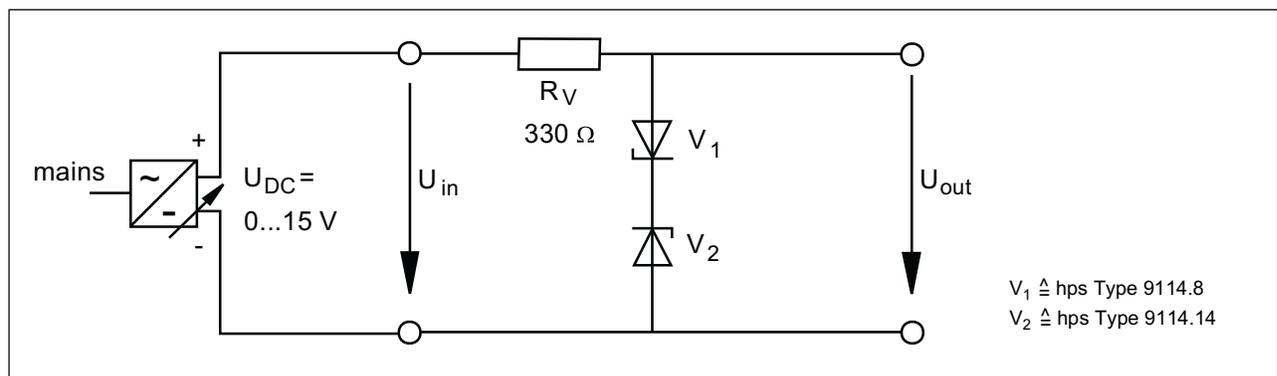
Fig. 2.4.2.1

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
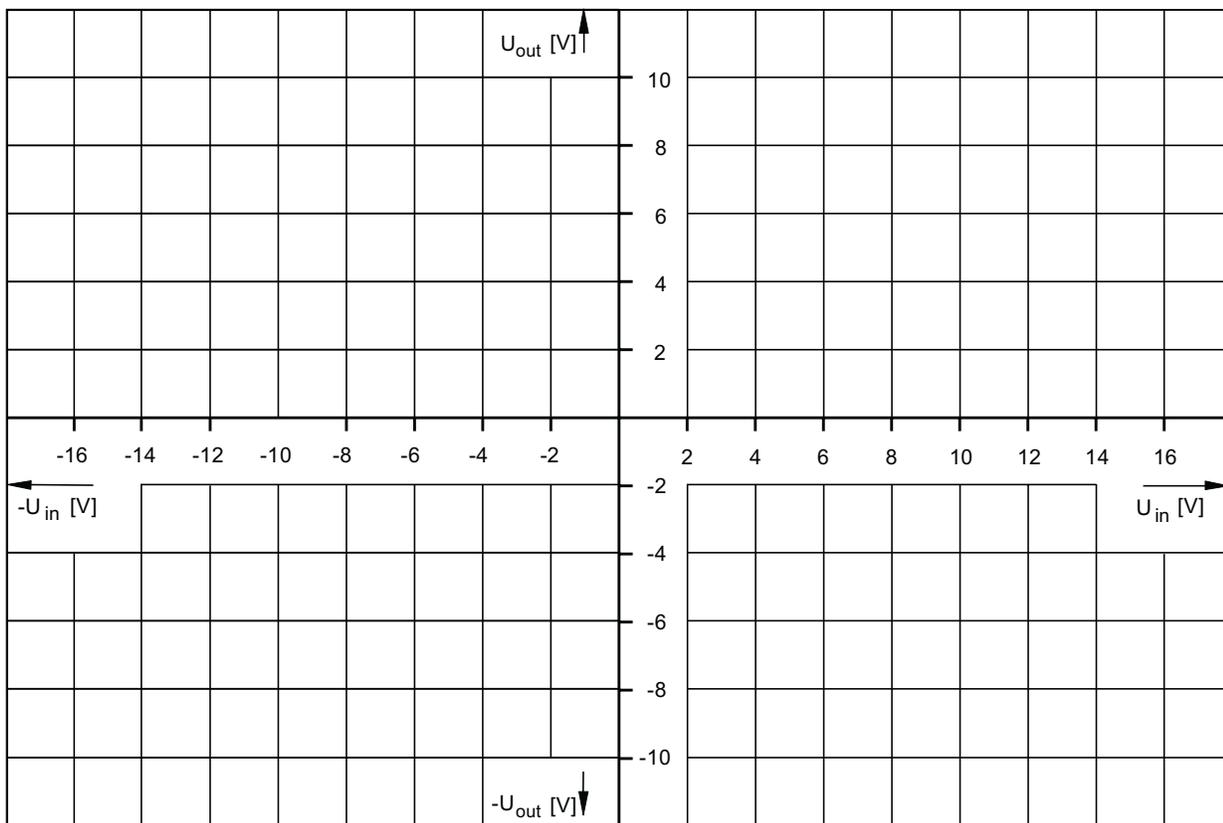
Fig. 2.4.2.2

□ **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.
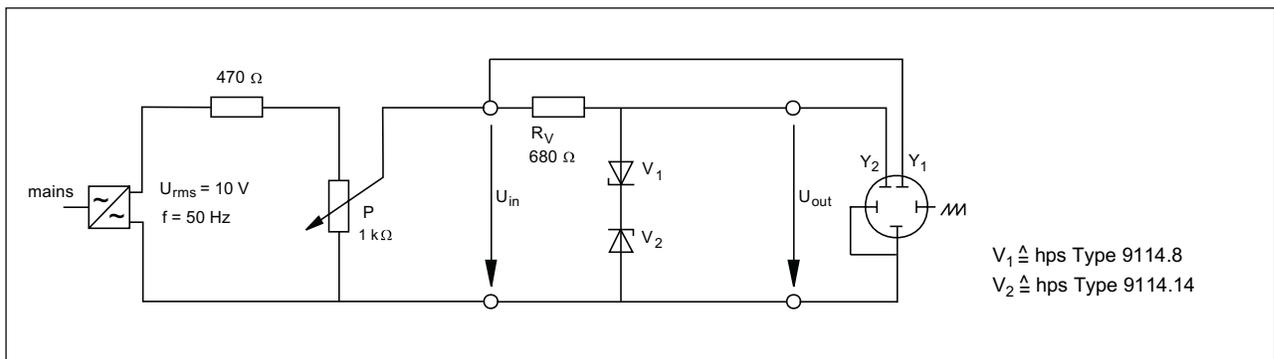
Fig. 2.4.2.3
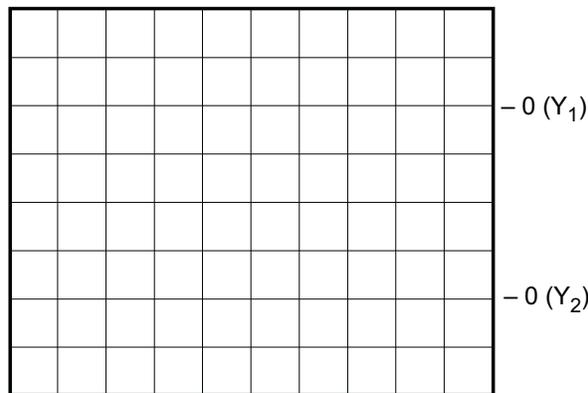
Fig. 2.4.2.4
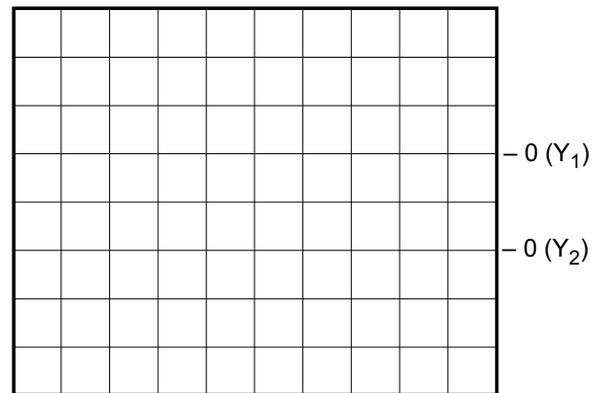
Fig. 2.4.2.5

| **Settings:**	**Remarks:**
X = 5 ms / div.	Y_1 = input voltage U_{in}
Y_1 = 2 V / div.	Y_2 = output voltage U_{out}
Y_2 = 2 V / div.	

Settings:	**Remarks:**
X = 5 ms / div.	Y_1 = input voltage U_{in}
Y_1 = 20 V / div.	Y_2 = output voltage U_{out}
Y_2 = 5 V / div.	

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!

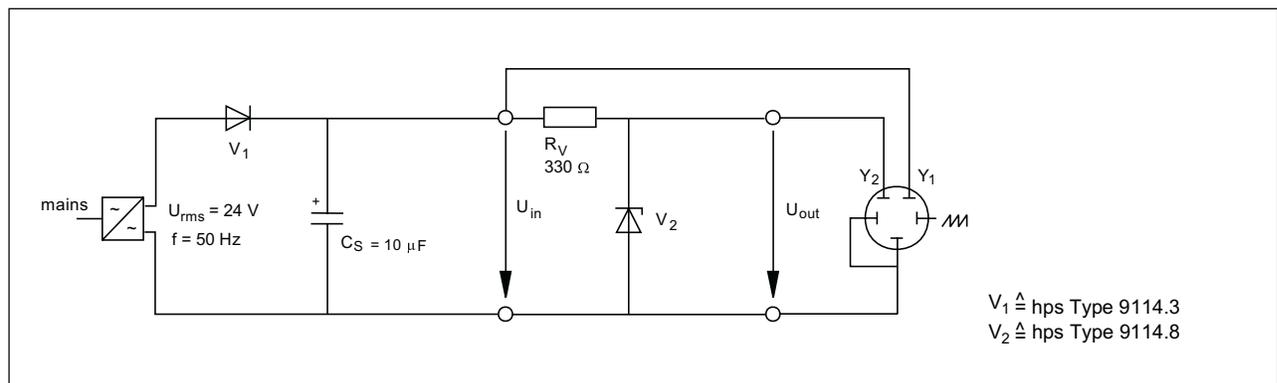• Subsequently set the inputs of the oscilloscope to AC (Y_2 = 0.1 V/div.). The DC components of both voltages are then suppressed and only the ripple parts are displayed. Plot the graph of voltages U_{in} and U_{out} on diagram 2.5.2.3.
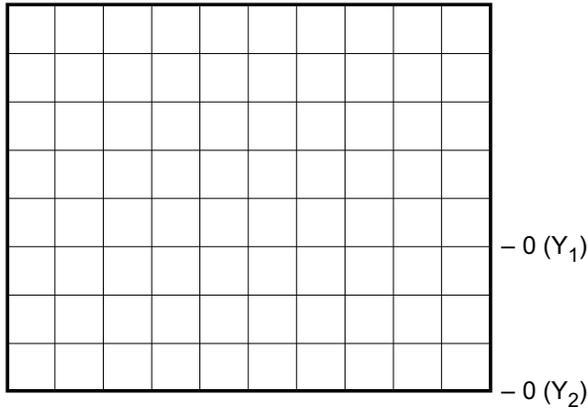
Fig. 2.5.2.1

Fig. 2.5.2.2

Fig. 2.5.2.3

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}

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 1: How high is the ripple voltage ΔU_{in} on the smoothing capacitor C_S (measure in Fig. 2.5.2.2)?

Anwer:

ΔU_{in} =

ΔU_{in} = peak-to-peak value of the input voltage U_{in}

Question 2: How high is the ripple voltage ΔU_{out} on the Zener diode (measure in Fig. 2.5.2.3)?

Answer:

ΔU_{out} =

ΔU_{out} = peak-to-peak value of the output voltage U_{out}

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.

graphical symbol

Fig. 3.1.1.1
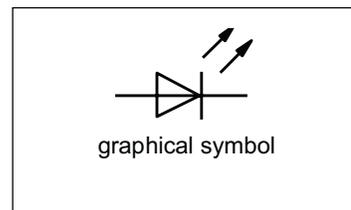
3.1.2   Experiments

❐ **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

I
0 (X)
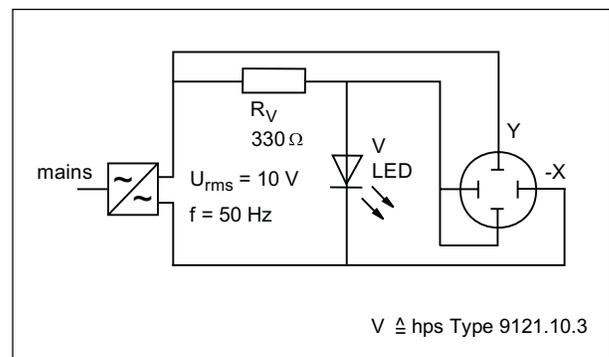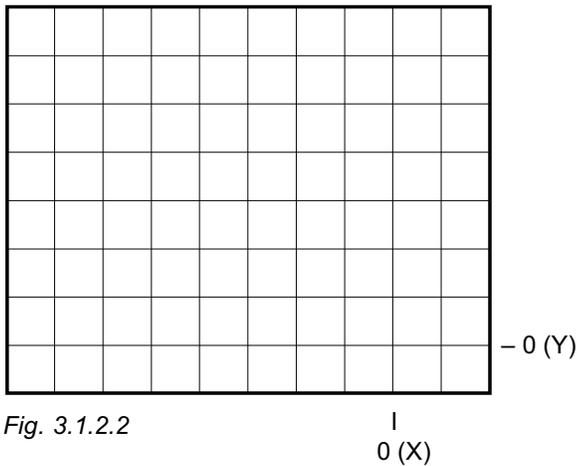
Settings:

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.
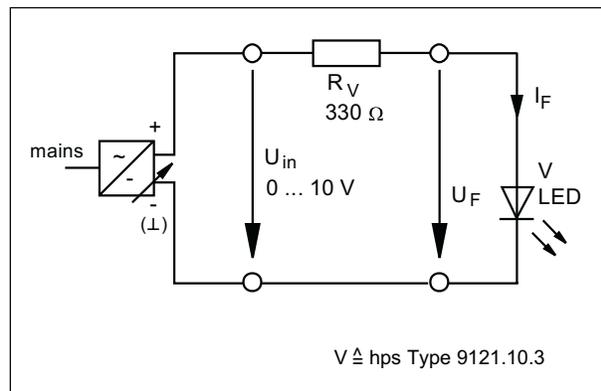
Fig. 3.1.2.3

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.
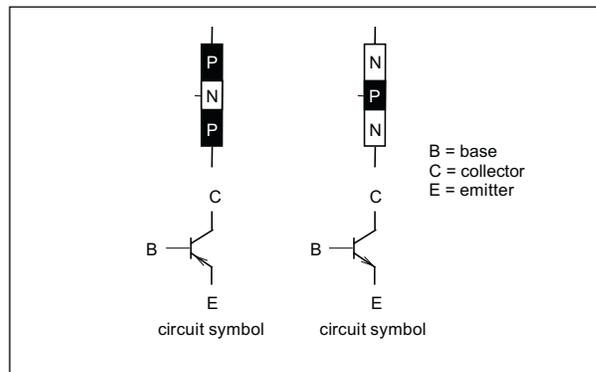
Fig. 4.1.1.1

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.

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 valu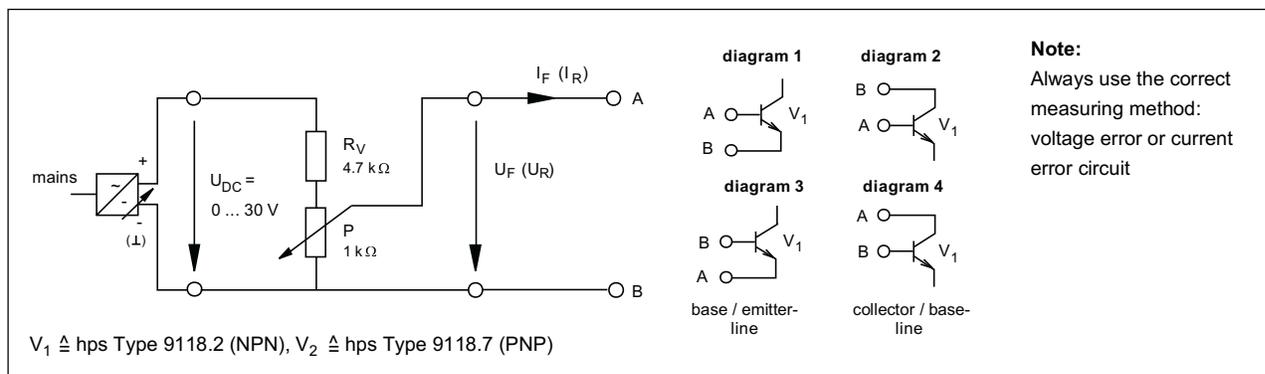es in Table 4.1.2.2. On the diagram (Fig. 4.1.2.2), plot a graph showing the dependence of the current I_R on the voltage U_R.

- 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)*
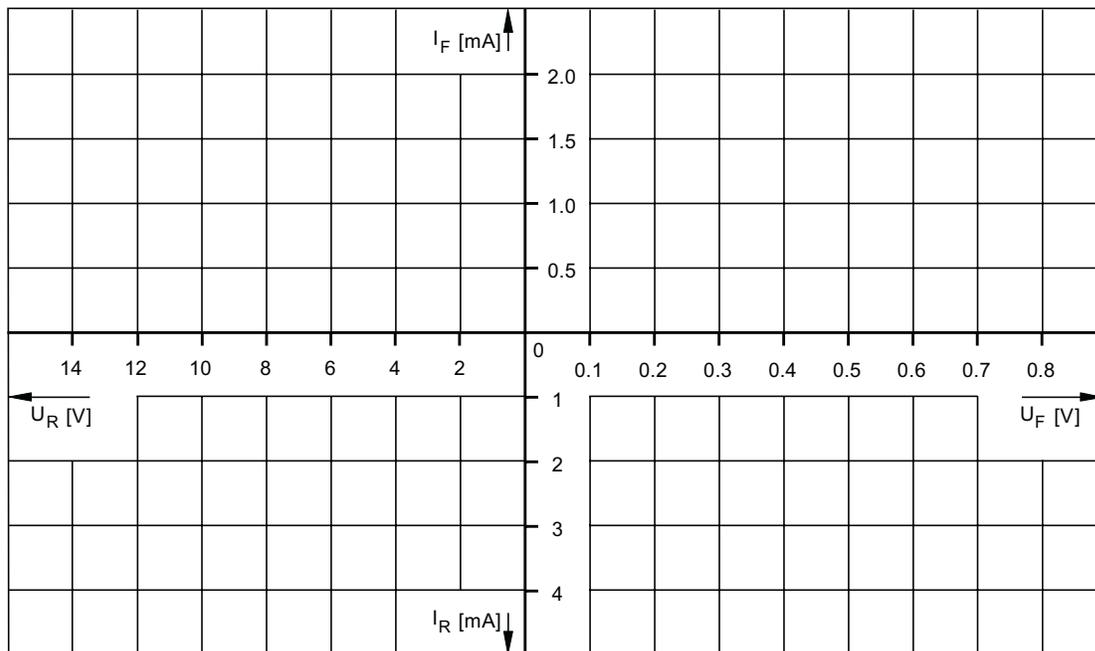
Fig. 4.1.2.2

* 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.

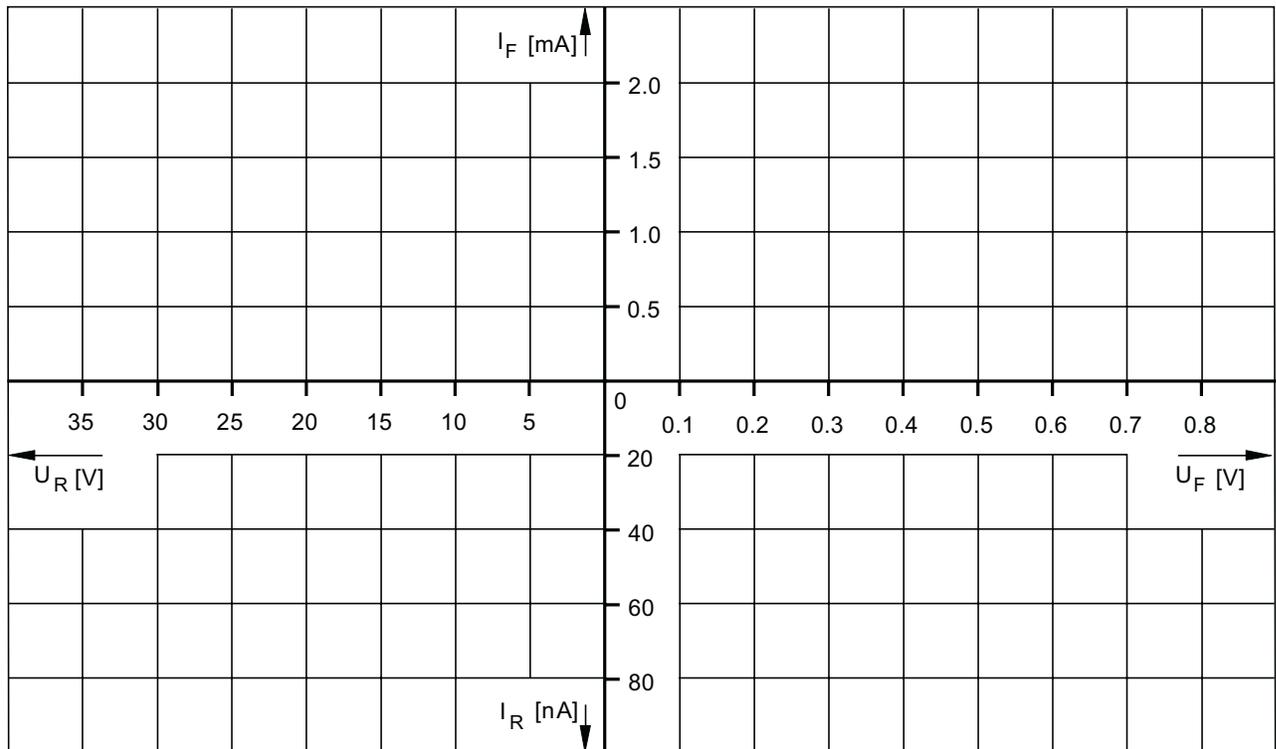|	**Polarity**	**N-P-N Type**	**P-N-P Type**
Base/Emitter Line (conducting or blocked)	base + / emitter - (polarity 1)		
	base - / emitter + (polarity 3)		
Collector/Base Line (conducting or blocked)	collector - / base + (polarity 2)		
	collector + / base - (polarity 4)		

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.

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

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

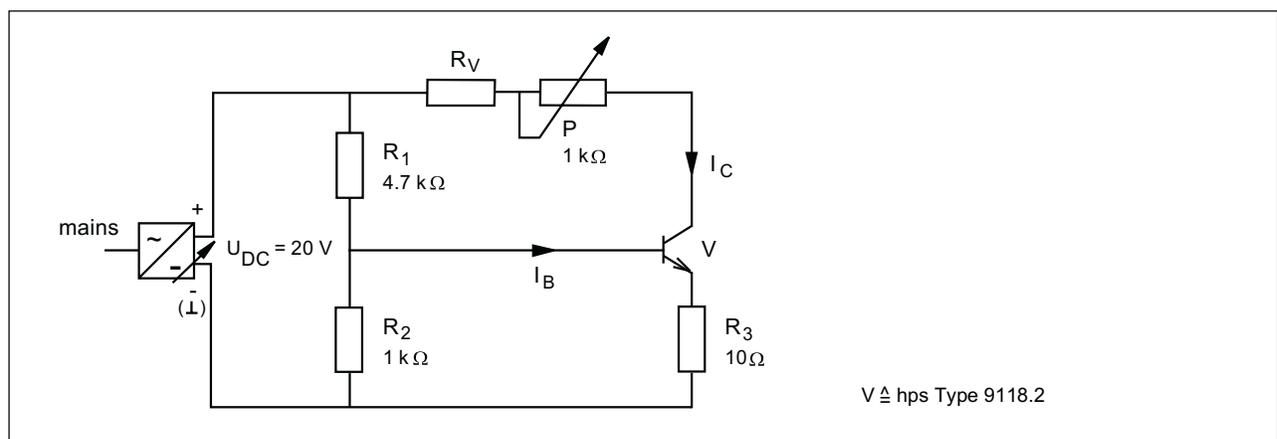- On the diagram (Fig. 4.2.2.2), plot a graph showing the dependence of the base current I_B on the collector current I_C (at a constant base/emitter voltage).

$I_B = f(I_C)$, 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
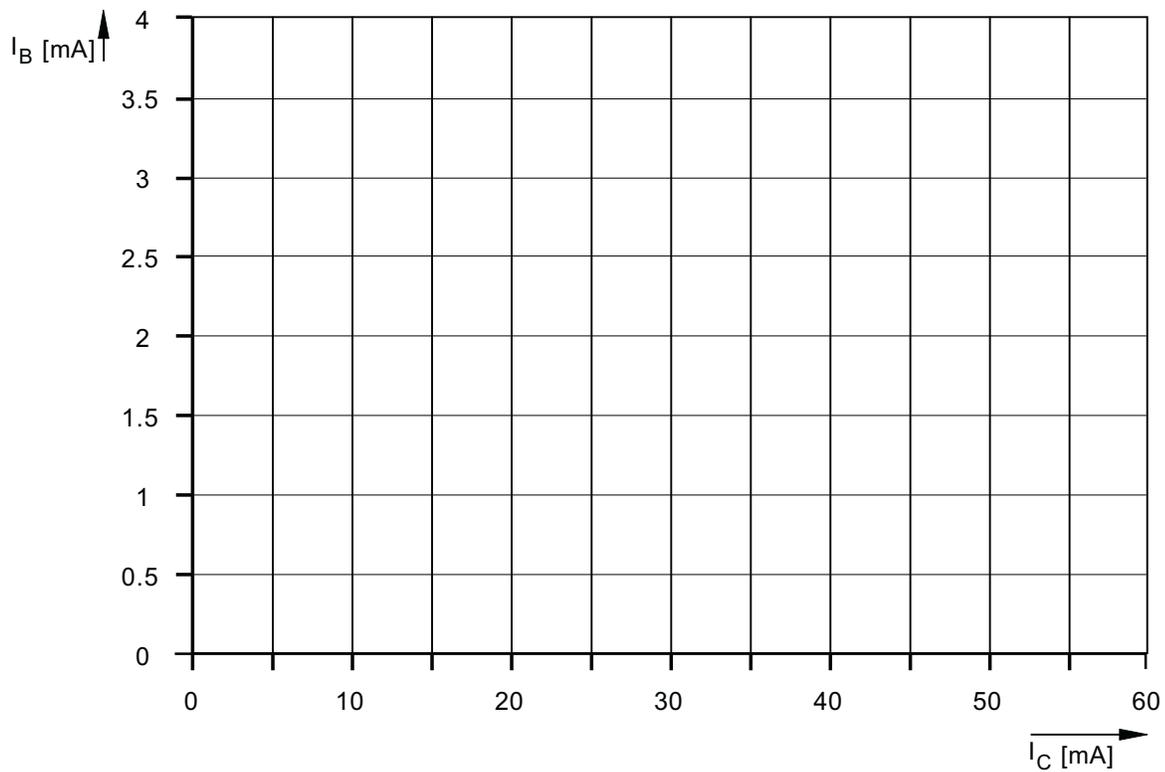
Fig. 4.2.2.2

❏ 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.

$I_C = f (I_B)$
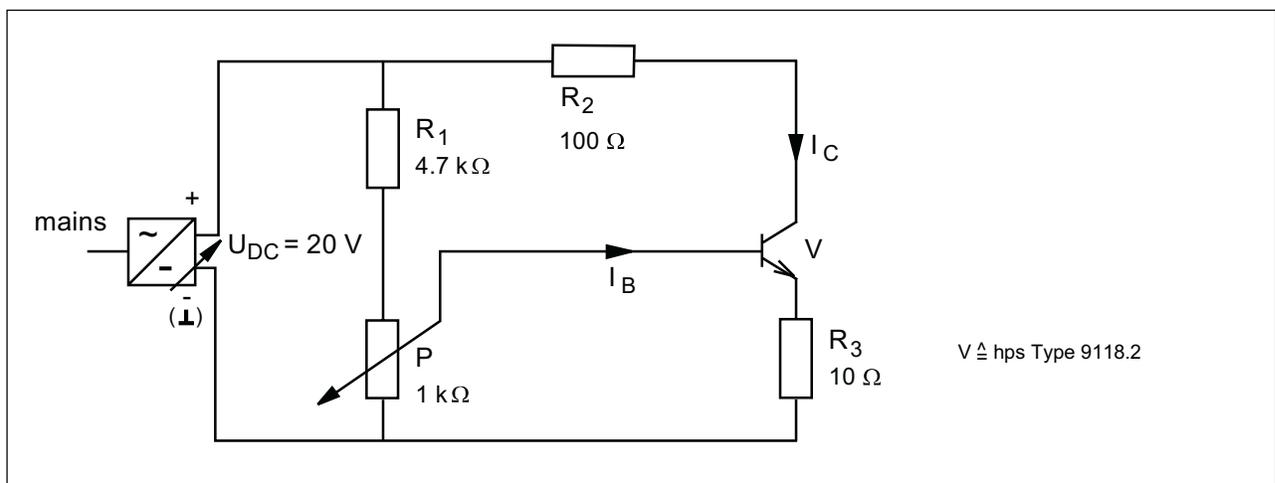
Fig. 4.2.2.3

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
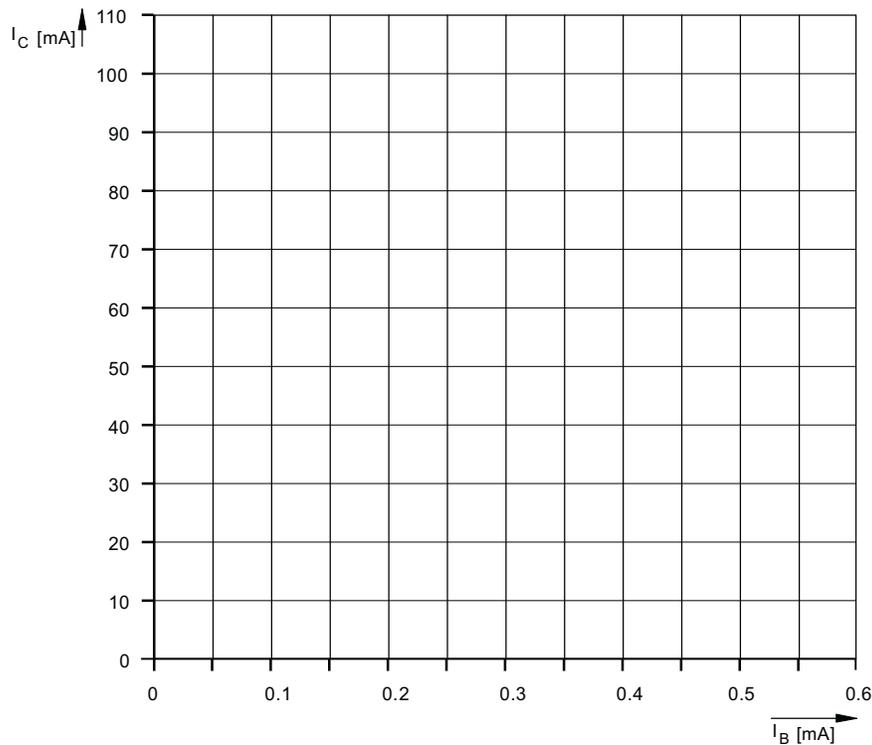
Fig. 4.2.2.4

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:

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

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

Answer:

Small signal current gain when ΔI_C = 40 mA - 20 mA:

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

Small signal current gain when ΔI_C = 80 mA - 70 mA:

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

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).
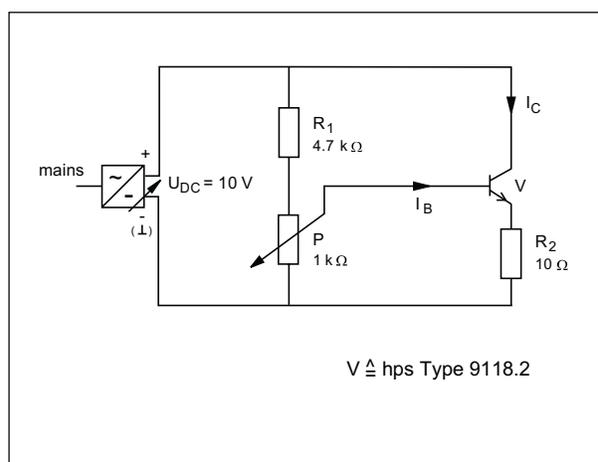
Note:
Considerable deviations in the measured values occur in these and the following measurements due to self-heating of the transistor. Steps cannot be taken to stabilize temperatures, since these would falsify the basic characteristic curves. It is therefore advisable to reduce the currents to zero 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).
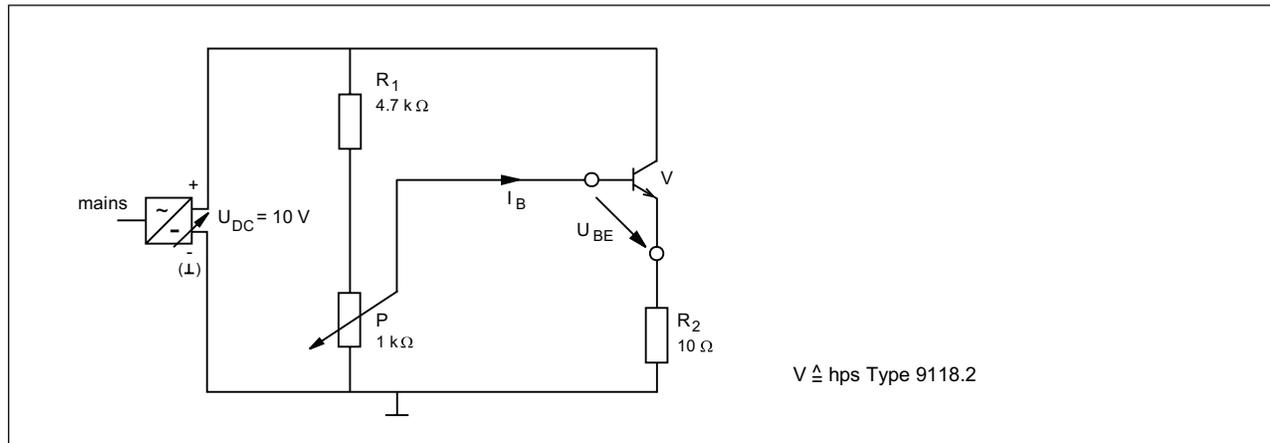
Fig. 4.3.2.2

- 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).
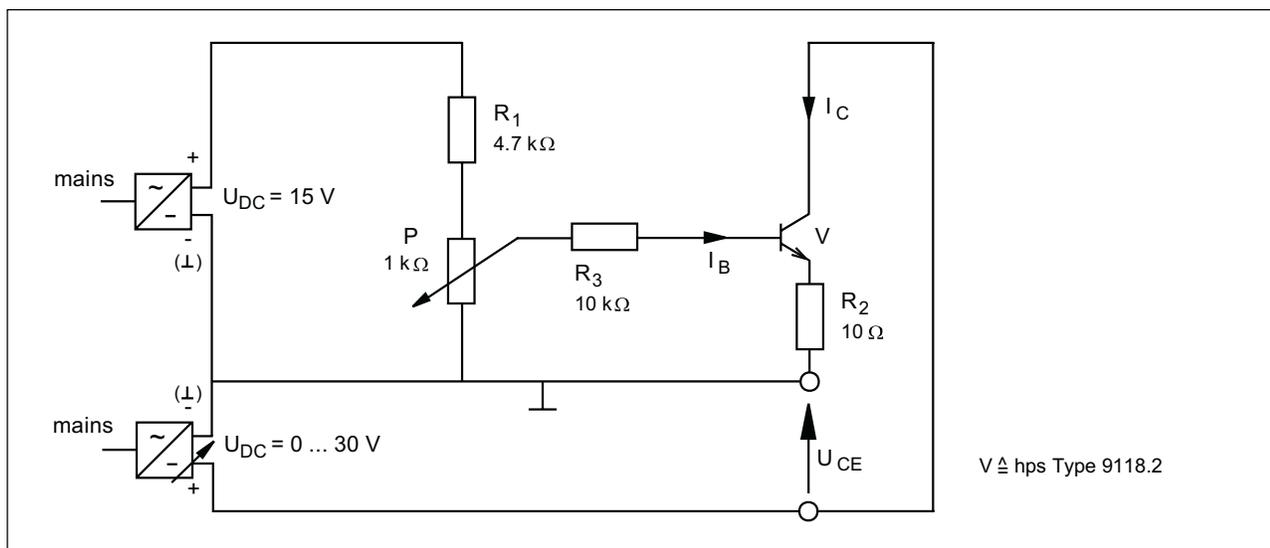

Fig. 4.3.2.3

- 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

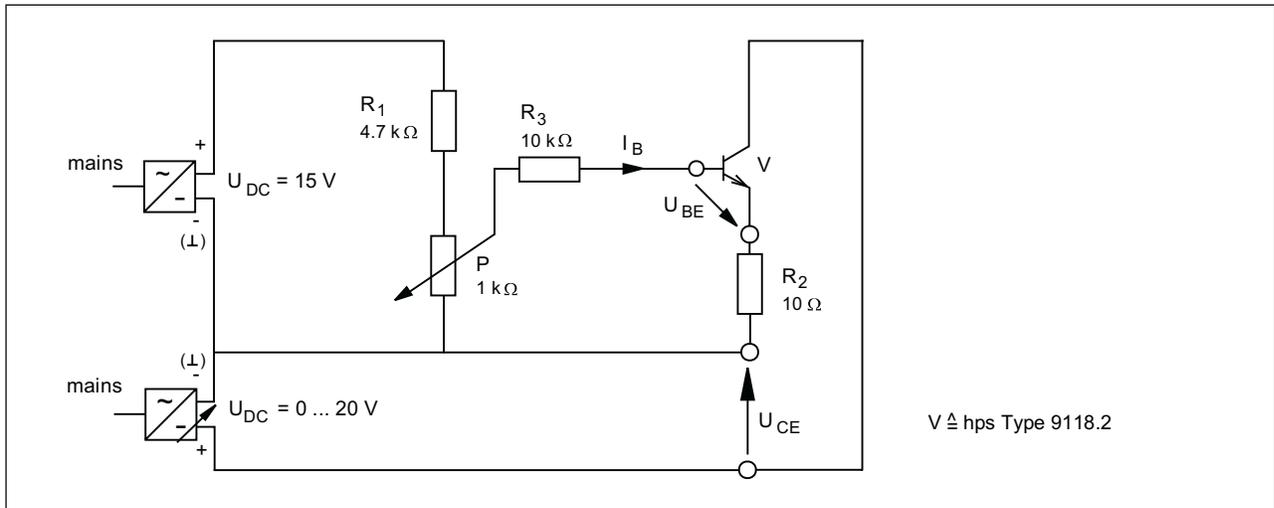
Question 1: What function does resistor R_2 have in the emitter line?

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

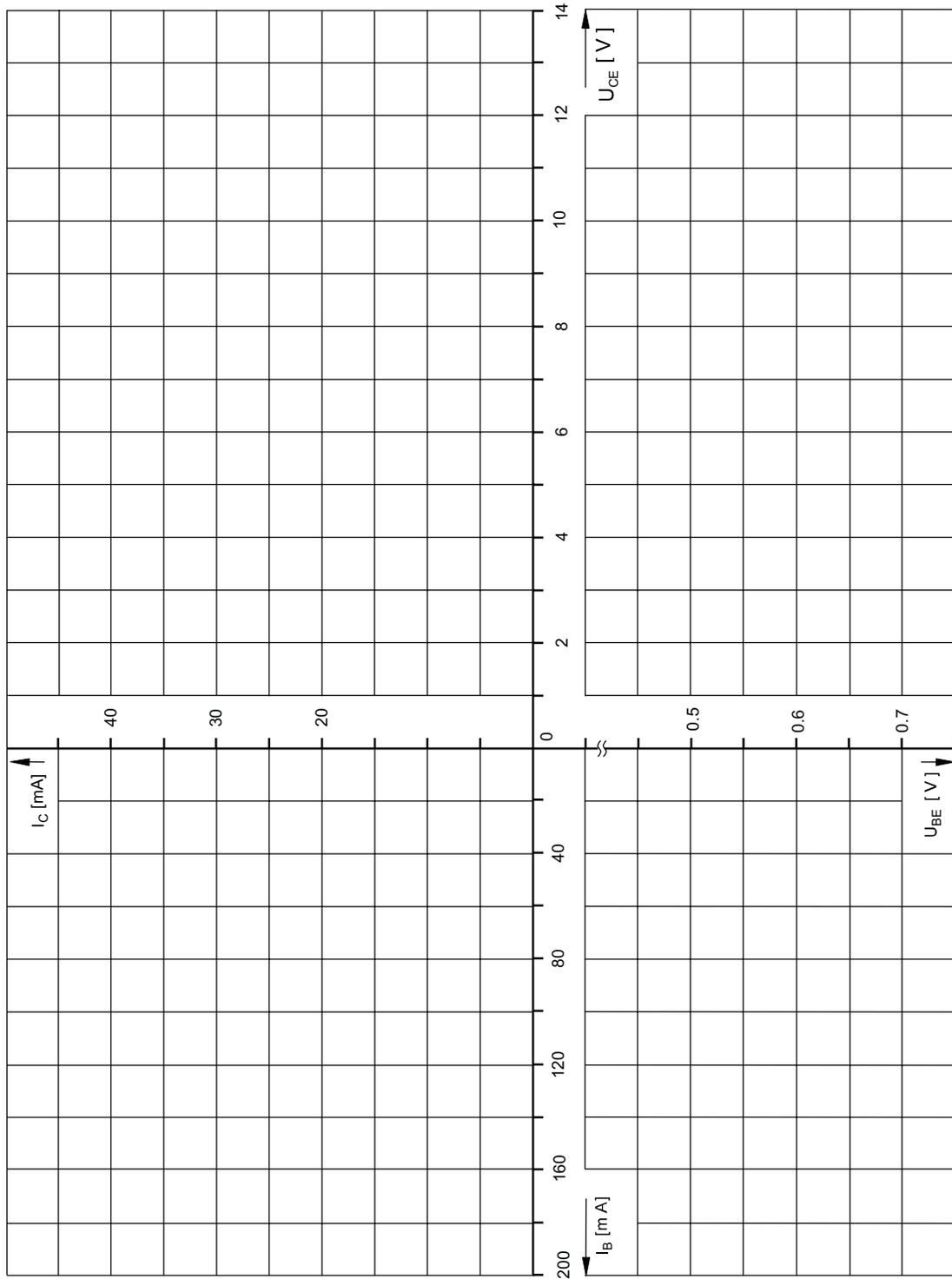| U_{CE} [V]	2	4	6	8	10	12	14
U_{BE} [V] at I_B = 20 μA							
U_{BE} [V] at I_B = 40 μA							
U_{BE} [V] at I_B = 60 μA							

Tab. 4.3.2.4

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.
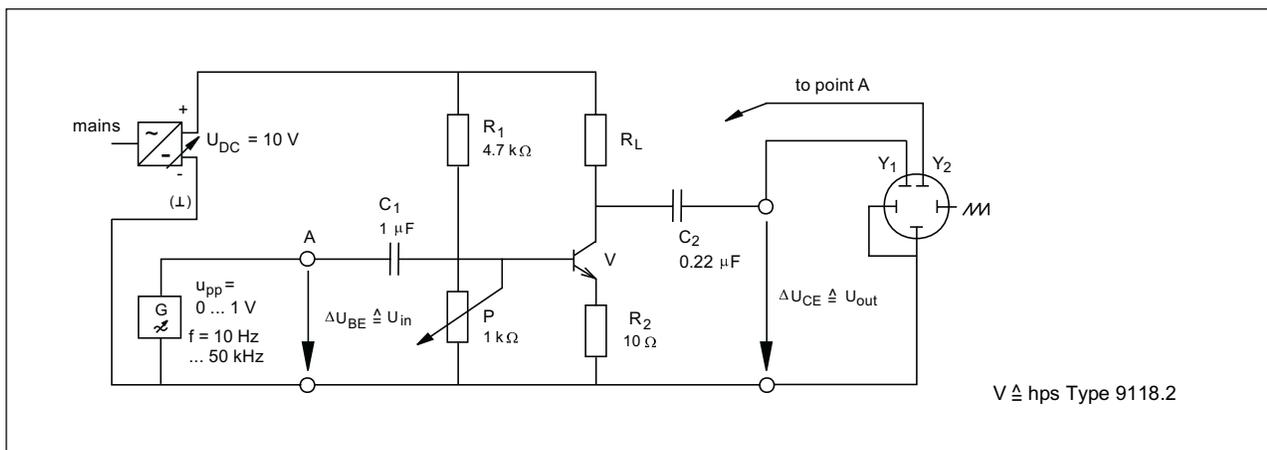

Fig. 4.4.2.1

- 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.
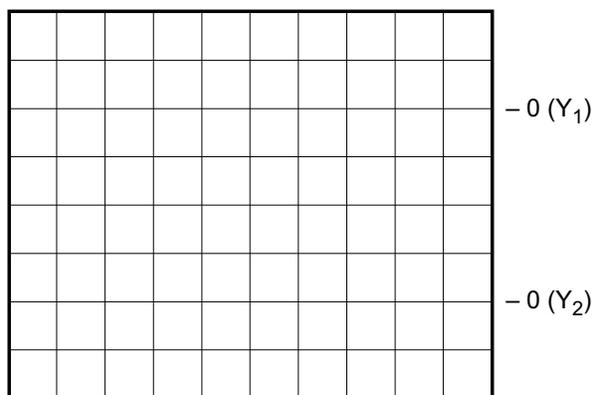
— 0 (Y₁)

— 0 (Y₂)

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

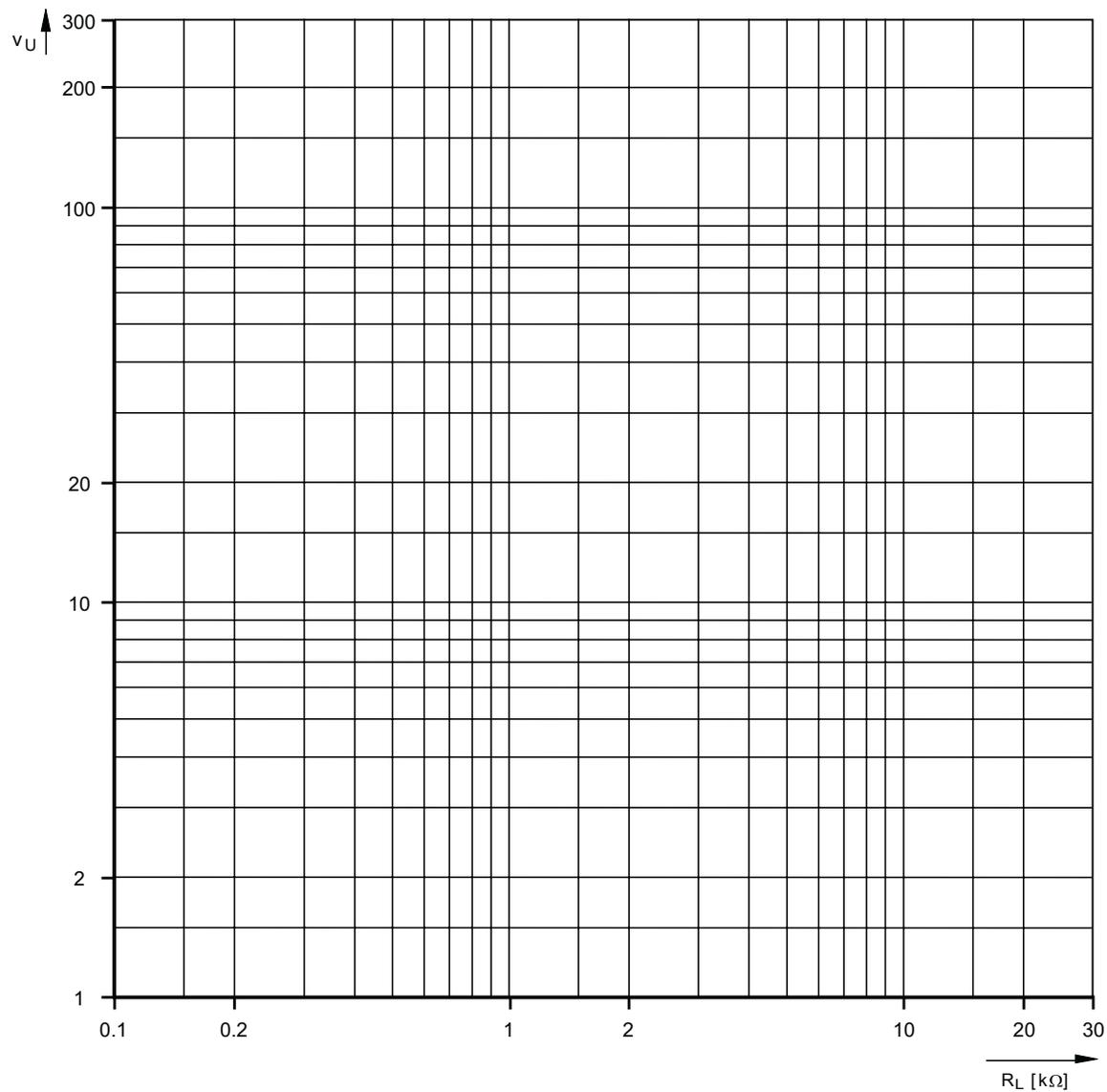- In the next experiment, measure the influence of the load resistance on the upper cut-off frequency. To do this, set the output voltage when f = 1 kHz to a fixed value, which is equated to 100 %. Then increase the frequency until the output voltage has dropped back to 70.7 %.
  The frequency at which 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.

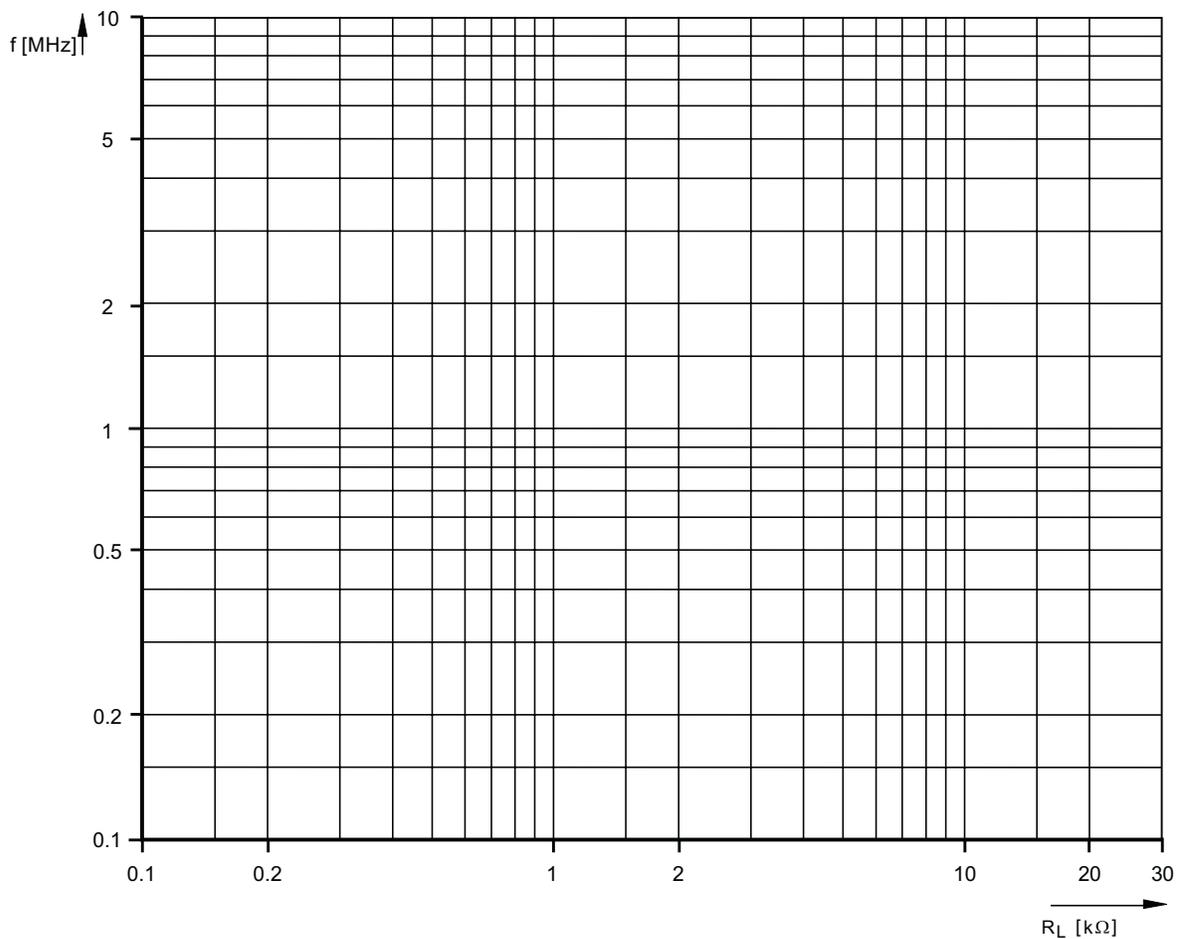*Fig. 4.4.2.4*

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).
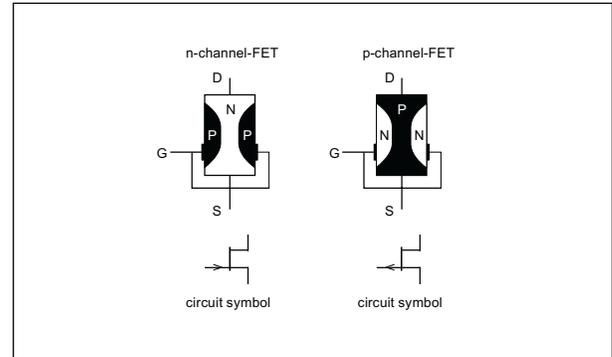

Fig. 5.1.1.1

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.
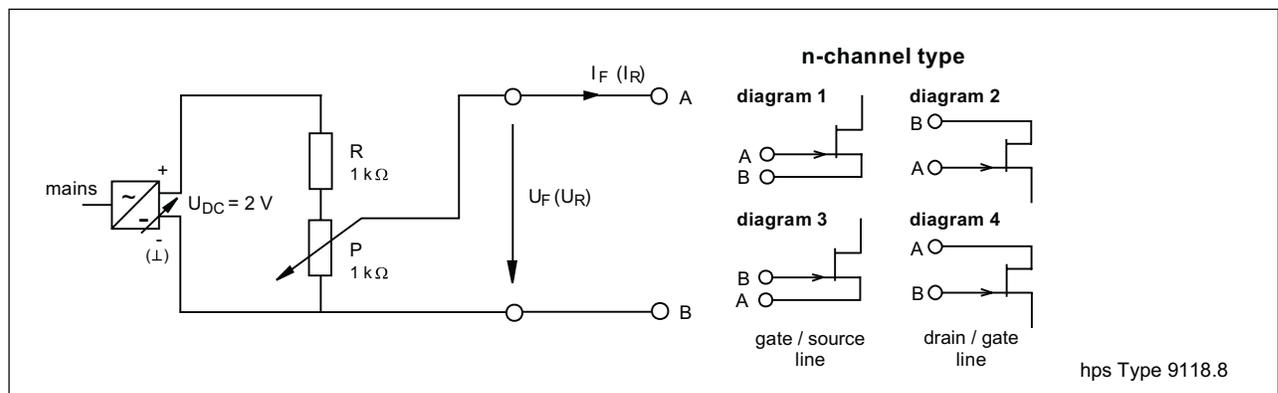

Fig. 5.1.2.1

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.
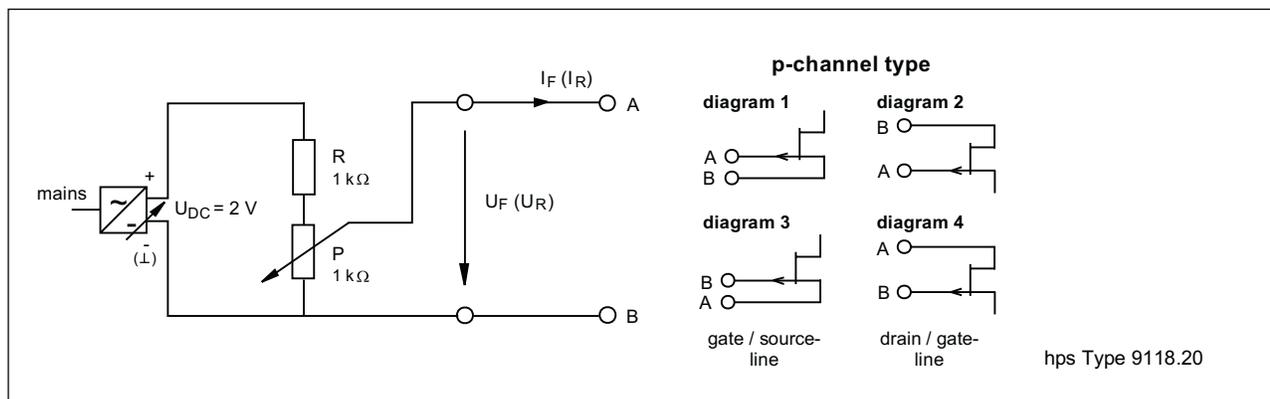

Fig. 5.1.2.2

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.
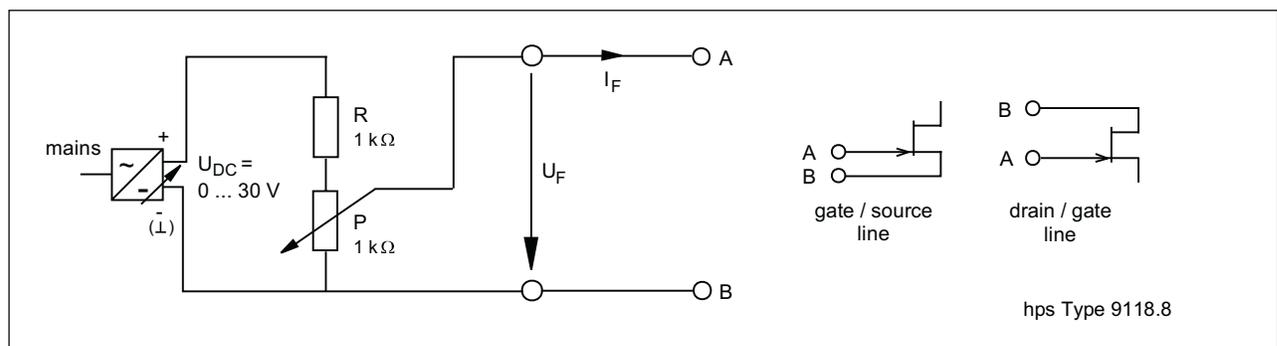
• Repeat the measurements with the drain/gate line and enter the current values I_F in Table 5.2.2.2.

• 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

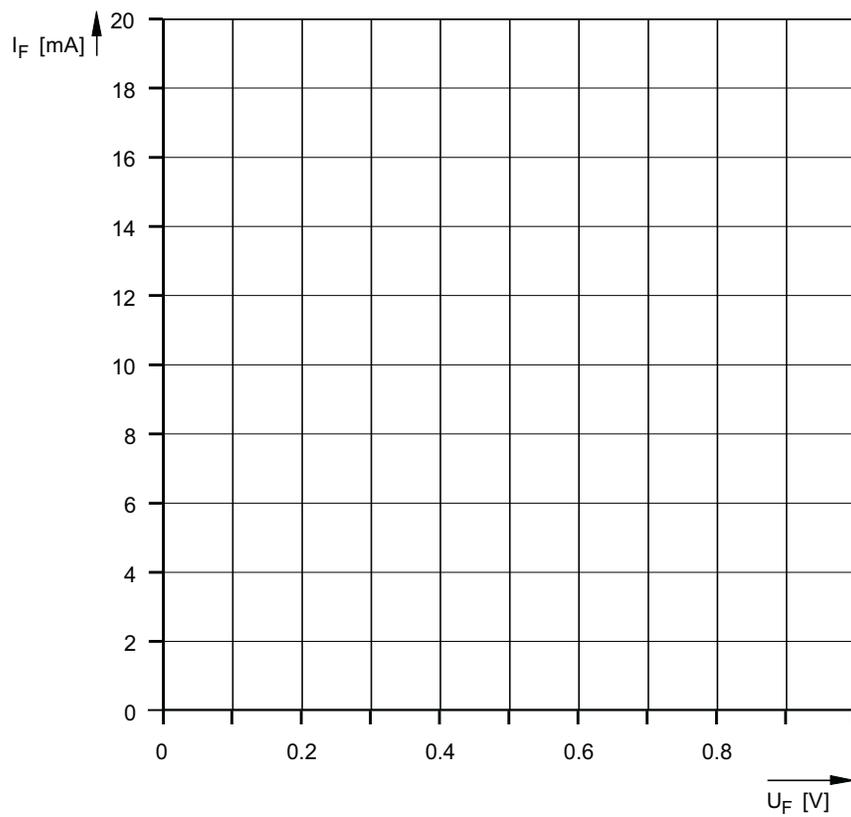*Fig. 5.2.2.2*

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

ΔI_D = drain current change in mA

ΔU_{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.
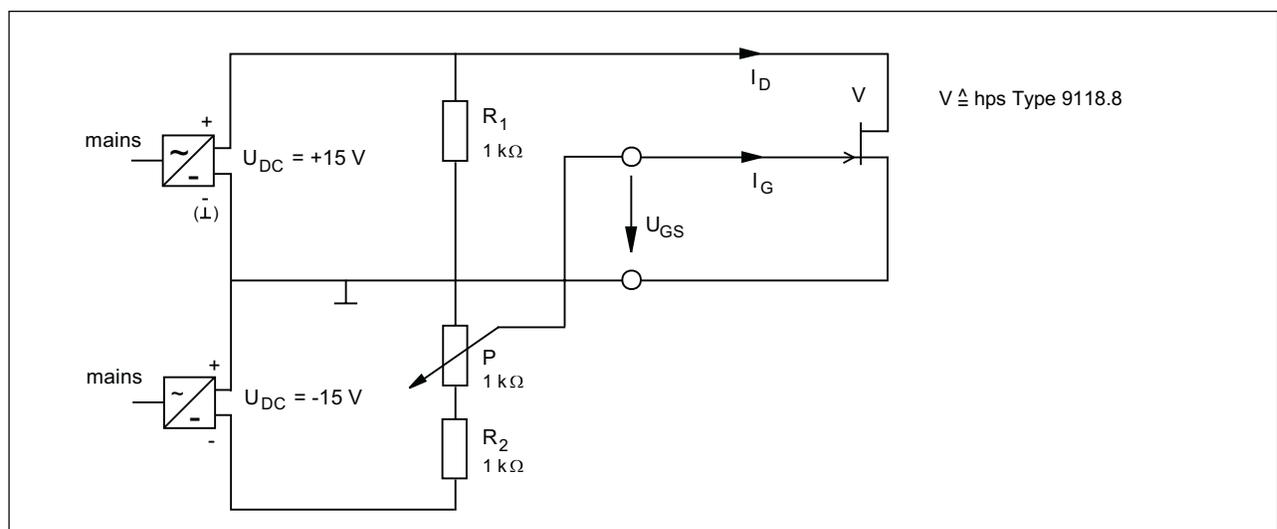

Fig. 5.3.2.1

- Plot a graph showing the dependence of the gate current I_G on the gate/source voltage U_{GS} on the diagram (Fig. 5.3.2.2).

$I_G = f(U_{GS})$

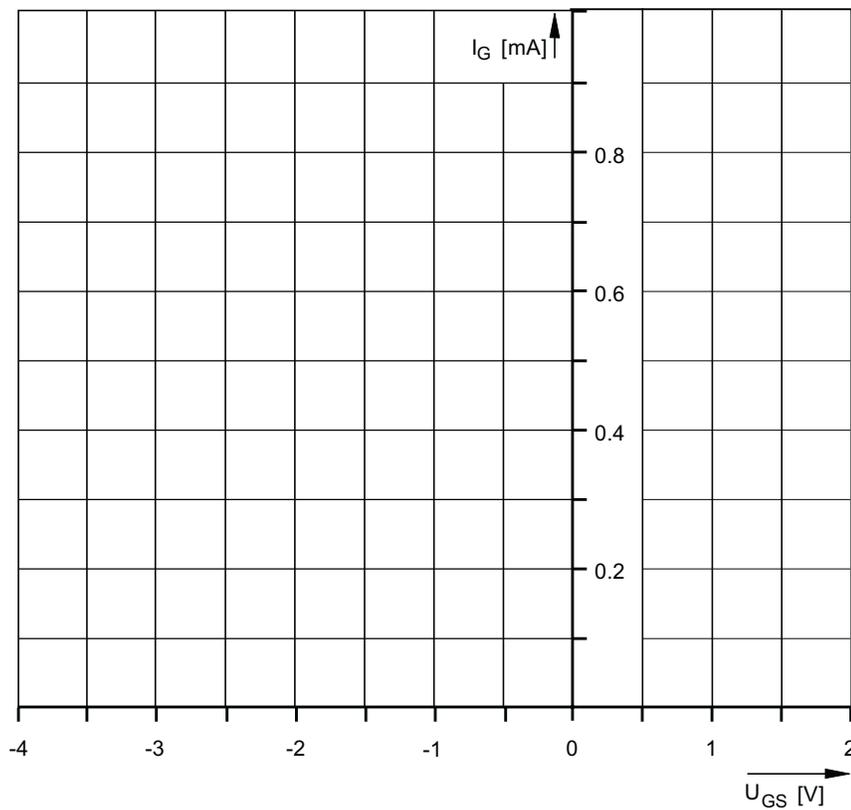| U_{GS} [V]	-4	-3	-2	-1	0	+0.5	+0.6	+0.7	+0.75
I_G [mA]									

Tab. 5.3.2.1 $U_{DS} = 15$ V

Fig. 5.3.2.2

- Plot a graph showing the dependence of the drain current I_D on the gate/source voltage U_{GS} on the diagram (Fig. 5.3.2.3): $I_D = f (U_{GS})$

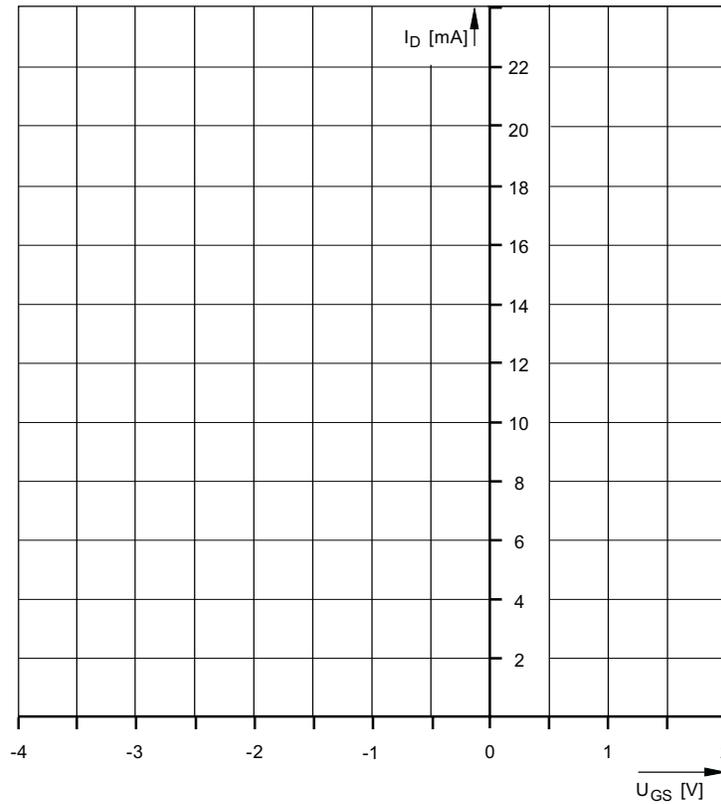| U_{GS} [V]	-4	-3	-2	-1	0	+0.5	+0.6	+0.7	+0.75
I_D [mA]									

Tab. 5.3.2.2 $U_{DS} = 15$ V

Fig. 5.3.2.3

Question 1: How great is the steepness S of a FET when the gate/source voltage change $U_{GS} = 1.5$ V and the corresponding drain current change $\Delta I_D = 4.5$ mA?

Answer:

Question 2: When is the field-effect transistor controlled without power?

Answer:

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5.4 Output Characteristics of the FET

5.4.1 General

Semiconductor manufacturers specify for FETs not only the control characteristic but also the more significant output characteristics which show the dependence of the drain current on the drain/source voltage at different constant gate/source voltages.

The output characteristics are recorded without load resistance (static values). The load resistance used in practice is drawn as a straight line in the characteristic field and provides information on the voltage gain.

5.4.2 Experiments

☐ **Experiment 1**

Statically measure the dependence of the drain current on the drain/source voltage at different gate/source voltages.

$I_D = f(U_{DS})$

Procedure

- Set up the circuit according to Fig. 5.4.2.1. Set the gate/source voltage U_{GS} and the drain/source voltage U_{DS} as shown in Table 5.4.2.1 and measure the corresponding drain current I_D with the multimeter.
Reverse the polarity of the power supply unit voltage (15 V) to measure the drain/source voltage when $U_{GS} = 0.5$ V.
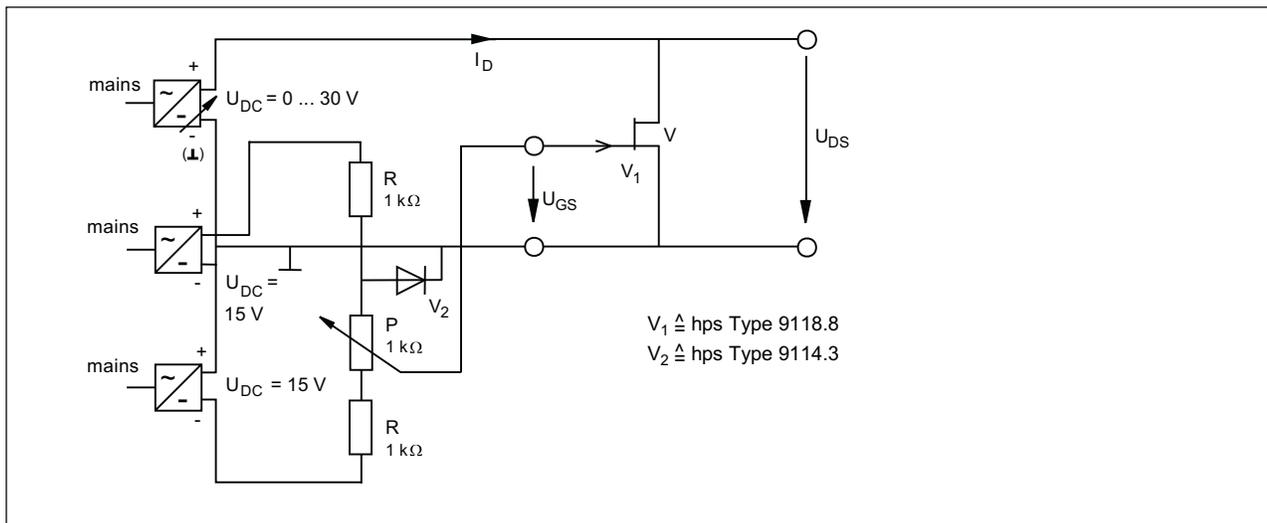Enter the drain current values I_D in Table 5.4.2.1.

Fig. 5.4.2.1

U_{DS} [V]	0	0.5	1	1.5	2	3	4	6	8	10	12	14	16	18	20
I_D [mA] at U_{GS} = -2 V															
I_D [mA] at U_{GS} = -1 V															
I_D [mA] at U_{GS} = 0 V															
I_D [mA] at U_{GS} = 0.5 V															

Tab 5.4.2.1

- On the diagram (Fig. 5.4.2.2), plot a graph showing the dependence of the drain current I_D on the drain/source voltage U_{DS} at different gate/source voltages U_{GS}.
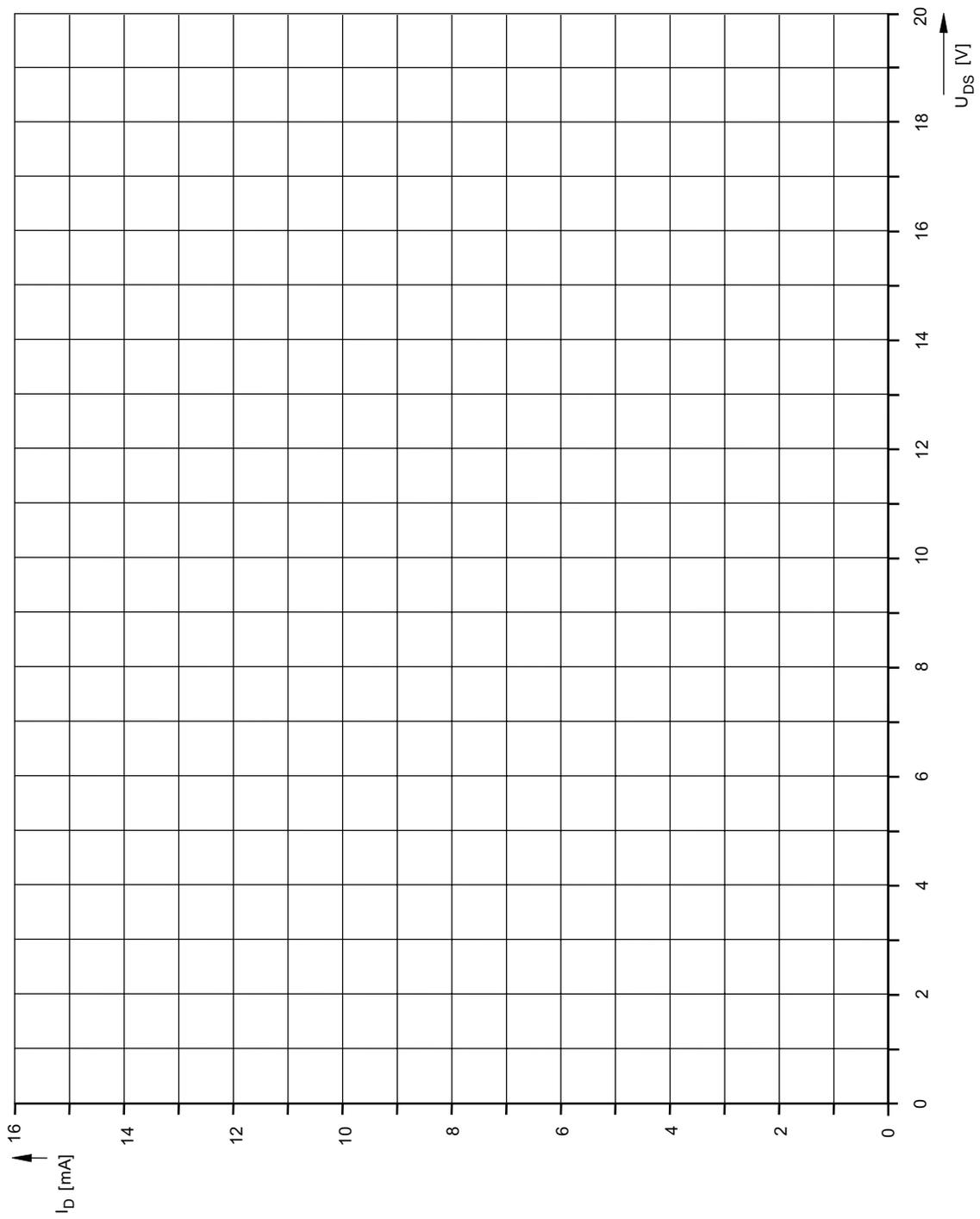
I_D [mA]

16

14

12

10

8

6

4

2

0
0   2   4   6   8   10   12   14   16   18   20

U_DS [V]

Fig. 5.4.2.2

❒ **Experiment 2**

Examine the influence of the load resistance on the field-effect transistor.

Procedure

- Set up the circuit according to Fig. 5.4.2.3. Set the load resistance R_L and different input voltages U_{in} as shown in Table 5.4.2.2, and measure the corresponding output voltage U_{out} with the multimeter.

  Enter all results in Table 5.4.2.2.

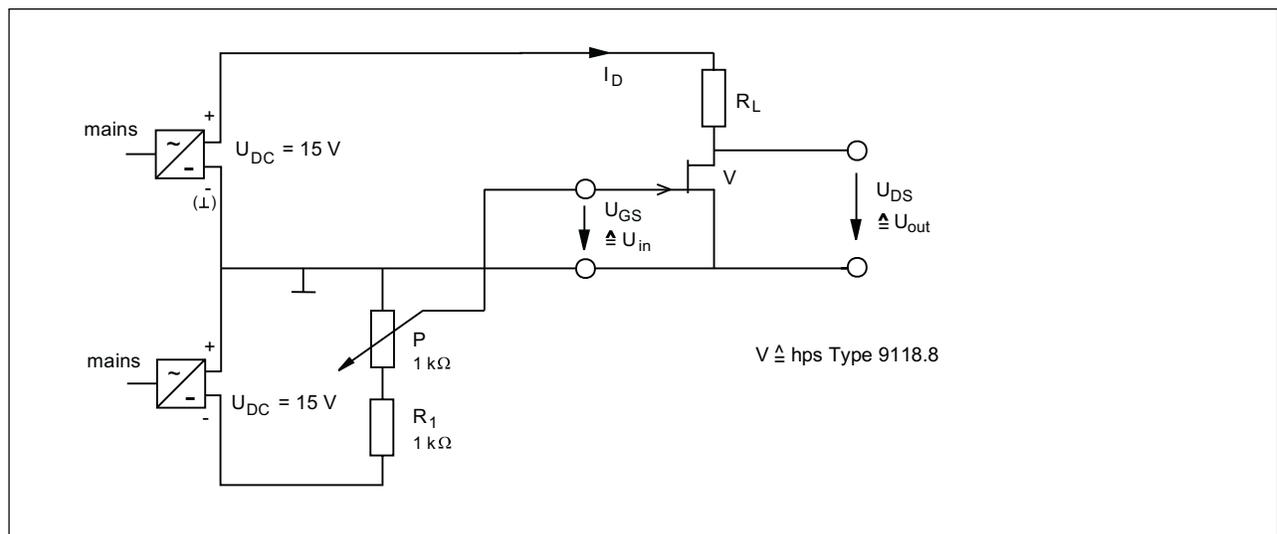- Then use the following formula to calculate the gain v with the different load resistances R_L:

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

$$\Delta U_{out} = U_{out\ 1} - U_{out\ 2}$$

$$\Delta U_{in} = U_{in\ 1} - U_{in\ 2}$$

Fig. 5.4.2.3

R_L [kΩ]	1	2 x 1	4.7	10	22
-$U_{in\,1}$ [V]	0.5	1.0	1.5	2.0	2.5
-$U_{in\,2}$ [V]	1.0	1.5	2.0	2.5	3.0
$U_{out\,1}$ [V]					
$U_{out\,2}$ [V]					
ΔU_{in} [V]					
ΔU_{out} [V]					
v = ΔU_{out} / ΔU_{in}					

Tab. 5.4.2.2

- On the diagram (Fig. 5.4.2.4), plot a graph showing the dependence of the voltage gain v on the load resistance R_L.

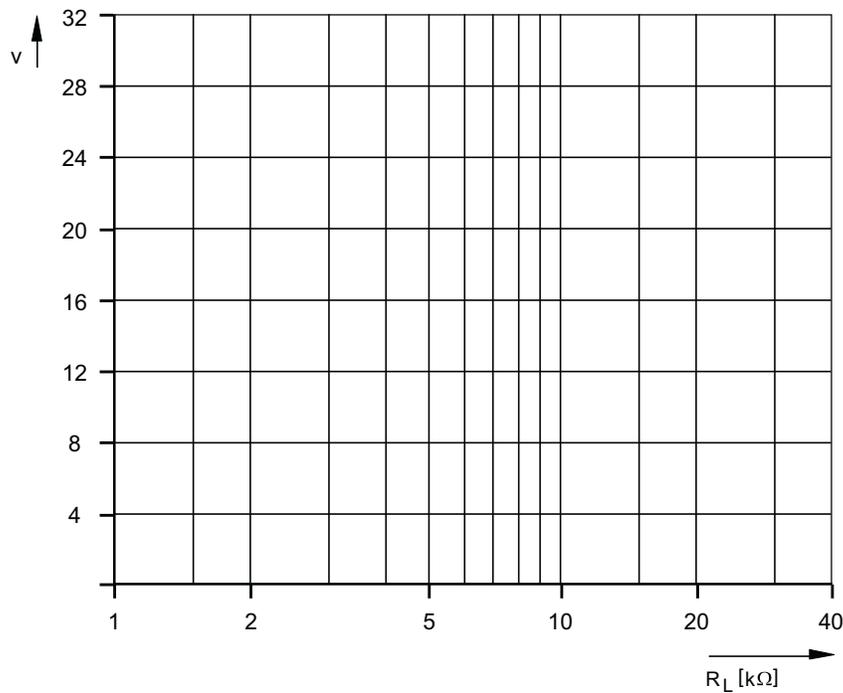- On the diagram (Fig. 5.4.2.2), draw in the load resistance line for R_L = 2 kΩ.

Fig. 5.4.2.4

Question 1: How does the gain factor v behave as the load resistance R_L increases?

Answer:

Question 2: How large is the gain factor v when U_{in} = -1 V -(-2 V)? Refer to Fig. 5.4.2.2.

Answer:

Question 3: What do the negative results for U_{out} signify?

Answer:

Notes:

6.   MOSFET (IG FET)

6.1   Control Effect of the Gate in the Self-Inhibiting MOSFET

6.1.1   General

The gate of a MOSFET (MOS field-effect transistor) is insulated from the channel by a thin layer of crystal.
It therefore has no rectifying properties, unlike the junction FET.

Electrical charge can be applied to the gate from outside to control the channel flow between source and drain.

In practice, a distinction is made between self-inhibiting types (enhancement types) and self-conducting types (depletion types).
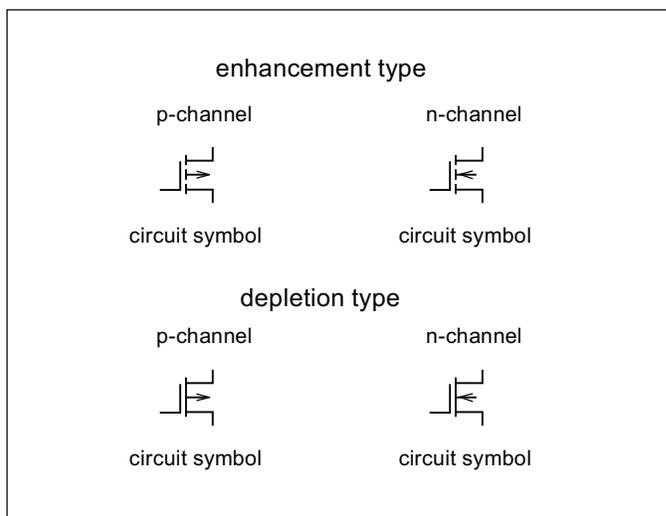

Fig. 6.1.1.1

The following experiments should be carried out with an enhancement type.

6.1.2   Experiments

❐ Experiment

Measure and investigate the control effect of the gate on the drain current in a self-inhibiting MOSFET and construct the control characteristic.

The properties and dependences of the p-channel type are also fundamentally valid for n-channel types if the operating and gate/source voltage polarities are reversed.

Procedure

- Apply a drain/source voltage $-U_{DS}$ = 10 V to the circuit (Fig. 6.1.2.1). Adjust the gate/source voltage $-U_{GS}$ in steps as shown in Table 6.2.2.1 and measure each corresponding drain current $-I_D$ with the multimeter.
  Enter the drain values $-I_D$ in Table 6.1.2.1.

- On the diagram (Fig. 6.1.2.2), plot a graph showing the dependence of the drain current $-I_D$ on the gate/source voltage $-U_{GS}$. This gives the control characteristic of the MOSFET.
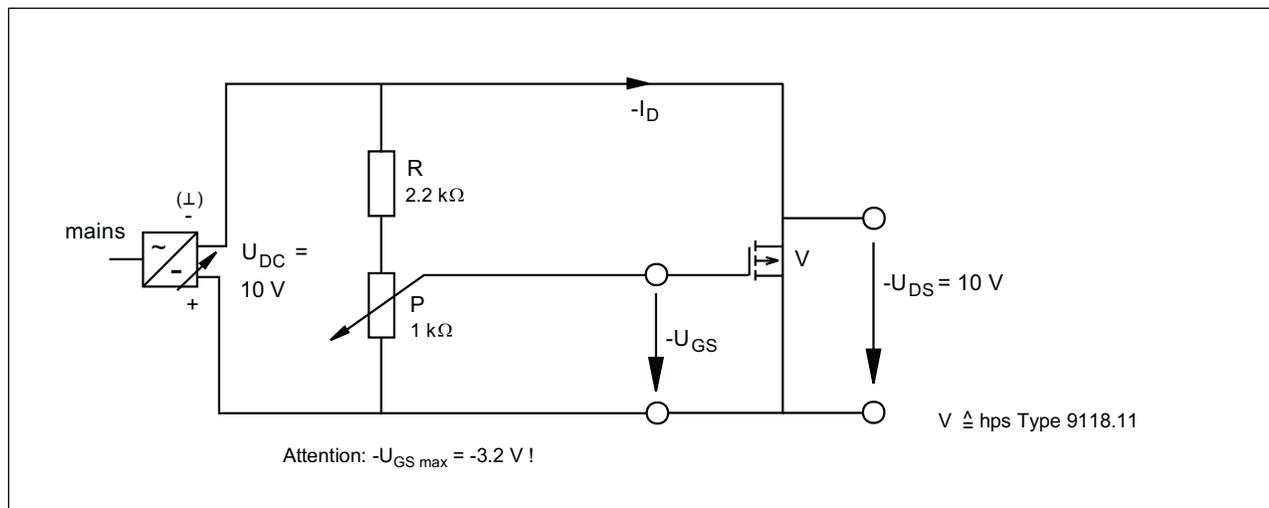 $I_D = f(U_{GS})$

Fig. 6.1.2.1

-U_{DS} = 10 V								
-U_GS [V]	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0
-I_D [mA]								

Tab. 6.1.2.1

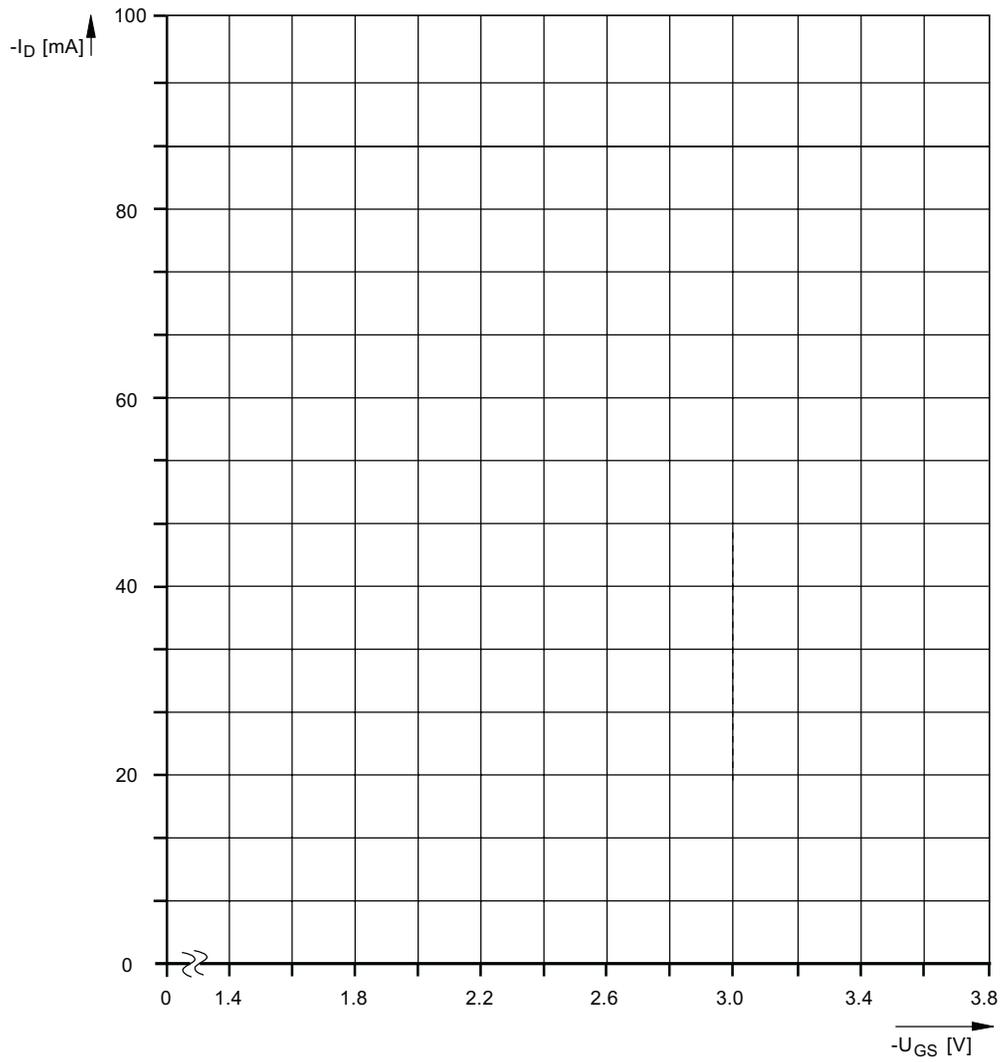*Fig. 6.1.2.2*

Question 1: When is the channel between source and drain built up?

Answer:

Question 2: What is the course of the characteristic $I_D = f(U_{GS})$ above a gate/source voltage of $U_{GS} = -2.7$ V?

Answer:

Question 3: What is the steepness of the MOSFET when the gate/source voltage is $\Delta U_{GS} = 0.2$ V (see Fig. 6.2.2.2: between -3.0 and -3.2 V)?

Answer:

Steepness:

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

6.2   Output Characteristics of the Self-Inhibiting MOSFET

6.2.1   General

For the MOSFET also, the output characteristics are the most informative of all the characteristics.

They show the dependence of the drain current on the drain/source voltage for different gate/source voltages.

The characteristics are recorded without load resistance (static characteristics), and after drawing in the straight line for the load resistance they allow the user to read off the values actually arising during practical application.

6.2.2   Experiments

☐ **Experiment 1**

In an experiment, measure the dependence of the drain current on the drain/source voltage at different constant gate/source voltages. Then construct the output characteristics.

Procedure

- Set up the circuit as shown in Fig. 6.2.2.1. Set the gate/source voltages U_{GS} and drain/source voltages U_{DS} as listed in Table 6.2.2.1 and measure the corresponding drain current I_D with the multimeter.
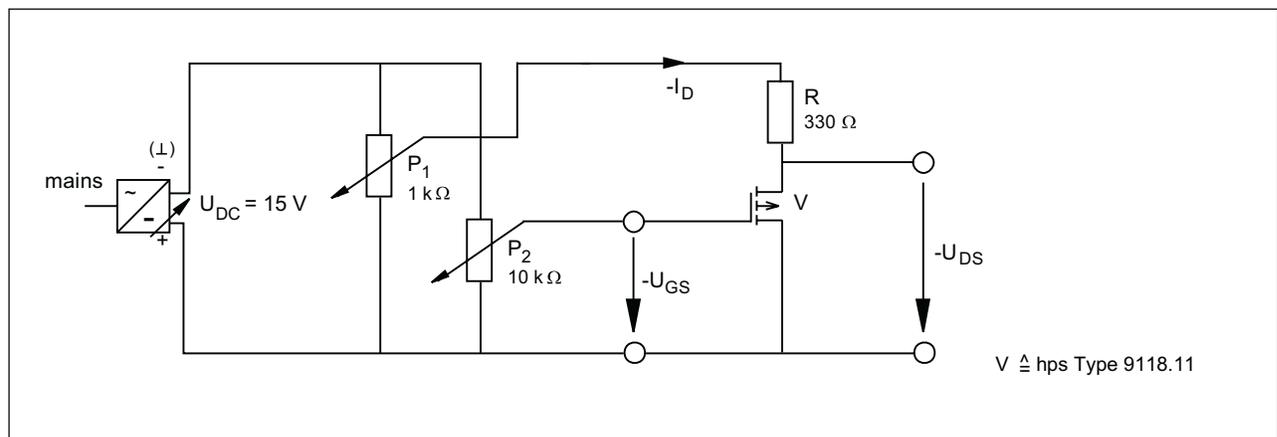 Enter the values of the drain current I_D in Table 6.2.2.1.

Fig. 6.2.2.1

-U_{DS} [V]	0	0.25	0.5	1	1.5	2	2.5	3	3.5	4
-I_D [mA] at U_{GS} = -3.0 V										
-I_D [mA] at U_{GS} = -3.1 V										
-I_D [mA] at U_{GS} = -3.2 V										
-I_D [mA] at U_{GS} = -3.3 V										
-I_D [mA] at U_{GS} = -3.4 V										

Tab. 6.2.2.1

- On the diagram (Fig. 6.2.2.2), plot a graph showing the dependence of the drain current I_D on the drain/source voltage U_{DS} for each of the gate/source voltages.
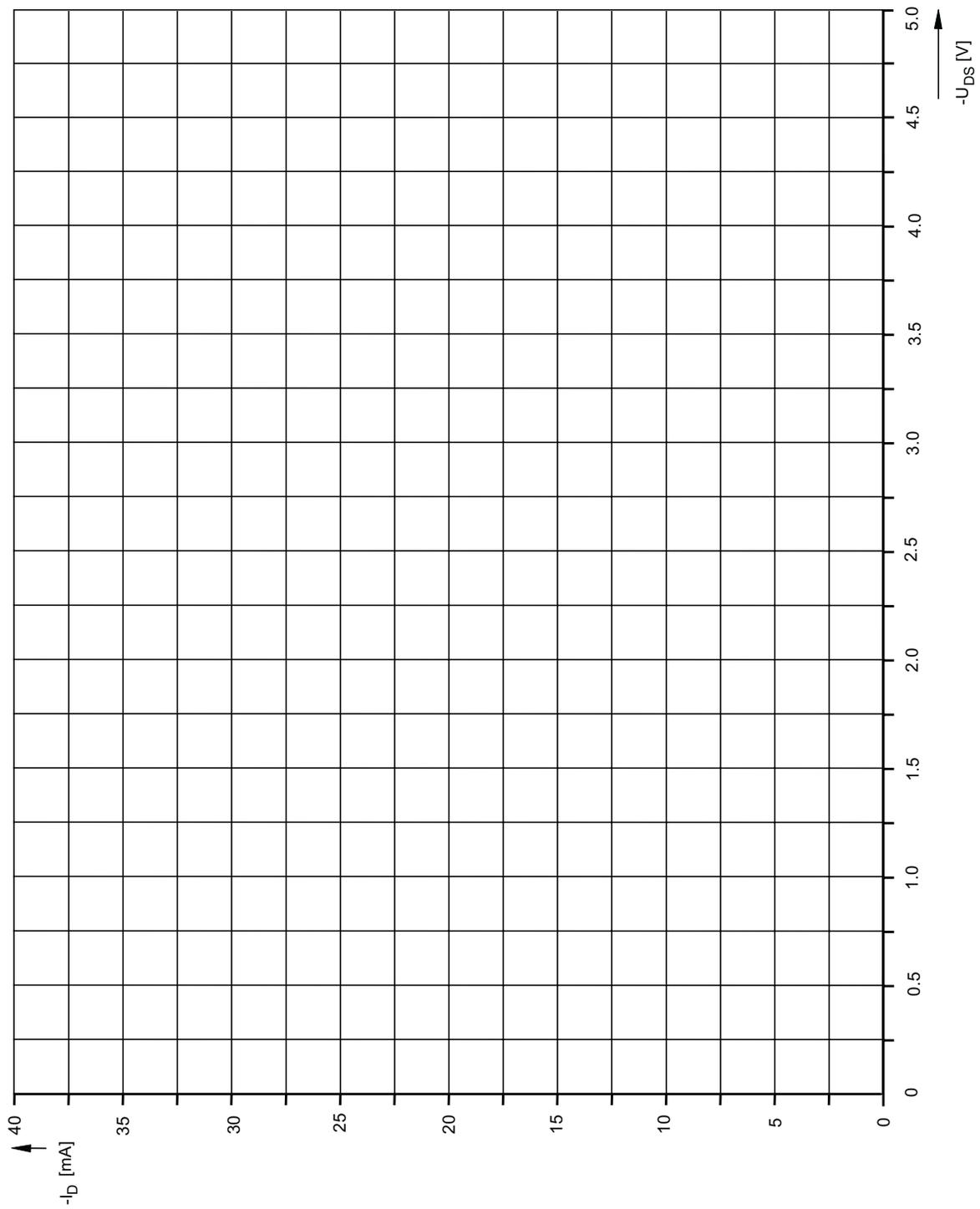
Fig. 6.2.2.2

❐ **Experiment 2**

In a further experiment, examine the influence of the load resistance on the MOSFET.

Procedure

- Set up the circuit as shown in Fig. 6.2.2.3. With the load resistance values R_L listed in Table 6.2.2.2 and varying input voltages U_{in}, measure the corresponding output voltage U_{out} with the multimeter. Enter all results in Table 6.2.2.2.

- Then use the following formula to calculate the gain v with the different load resistance values R_L:

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

$$\Delta U_{out} = U_{out\ 1} - U_{out\ 2}$$
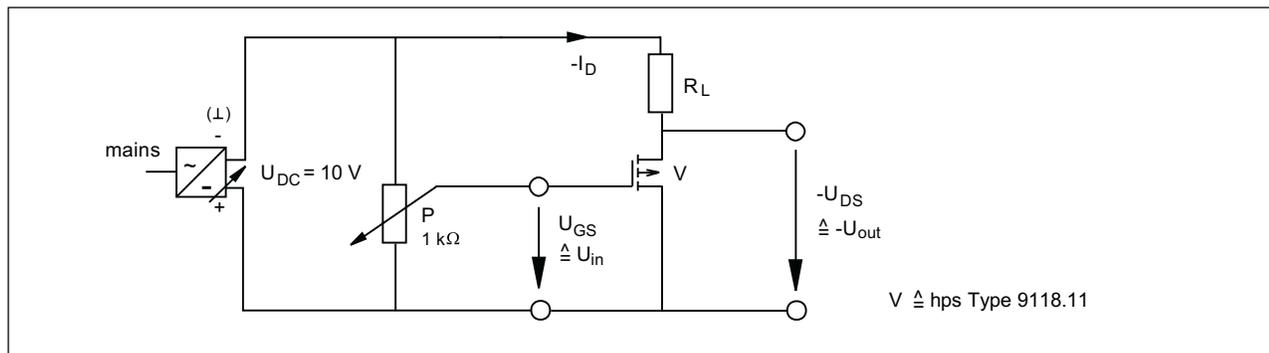
$$\Delta U_{in} = U_{in\ 1} - U_{in\ 2}$$

Fig. 6.2.2.3

R_L [kΩ]	0.33	0.68	1
$-U_{in\ 1}$ [V]	2.7	2.7	2.7
$-U_{in\ 2}$ [V]	3.1	3.1	3.1
$-U_{out\ 1}$ [V]			
$-U_{out\ 2}$ [V]			
ΔU_{in} [V]			
ΔU_A [V]			
$v = \Delta U_{out} / \Delta U_{in}$			

Tab. 6.2.2.2

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- On the diagram (Fig. 6.2.2.4), plot a graph showing the dependence of the voltage gain v on the load resistance R_L.

$v = f (R_L)$

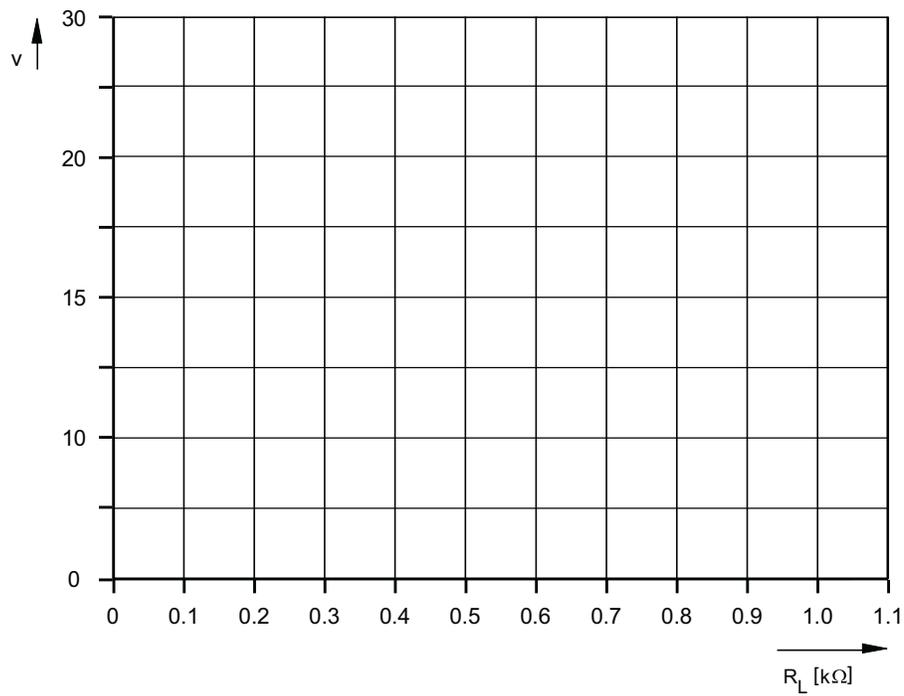*Fig. 6.2.2.4*

Question 1: How does the voltage gain v change with increasing load resistance R_L?

Answer:

Question 2: How large is the voltage gain when the load resistance R_L = 1 kΩ?

Answer:

Input voltage change:

$$\Delta U_{in} = U_{in\,1} - U_{in\,2} =$$

Output voltage change:

$$\Delta U_{out} = U_{out\,1} - U_{out\,2} =$$

Gain factor:

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

Question 3: What do the negative values for U_{out} indicate?

Answer: