REPORT ON DIODE - PARAMETERS, CHARACTERISTICS AND ITS APPLICATION.

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to
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Exercise - 2

DIODE - PARAMETERS, CHARACTERISTICS AND ITS APPLICATION

Contents

1 Purpose of the exercise

- Getting to know the properties of different types of Diodes.
- Examples of applications of diodes in electronics. Construction and testing of basic rectifier systems.

2 Theoretical basics

Diodes are two-layer, two-terminal semiconductor elements. Constructed of two layers of p-type and n-type semiconductor, they have an anode terminal (A) and a cathode terminal (K). With the positive polarity of the A-K junction (the anode potential greater than the cathode potential), the diode allows the current to flow from the anode terminal to the cathode terminal. This state is called the conduction state, in this state there is a slight voltage drop across the diode and the diode has a relatively low static resistance. In the case of negative polarity of the A-K junction, a reverse current flows through the diode with a low value, the diode is in a blocked state and it is characterized by a relatively high static resistance. When the reverse voltage exceeds the breakdown voltage, the diode goes into the breakdown state, in this state the reverse current increases sharply.

The properties of the diode are discussed on the basis of the current-voltage characteristic (static characteristic). The figure 1 shows the static characteristics of the diode.

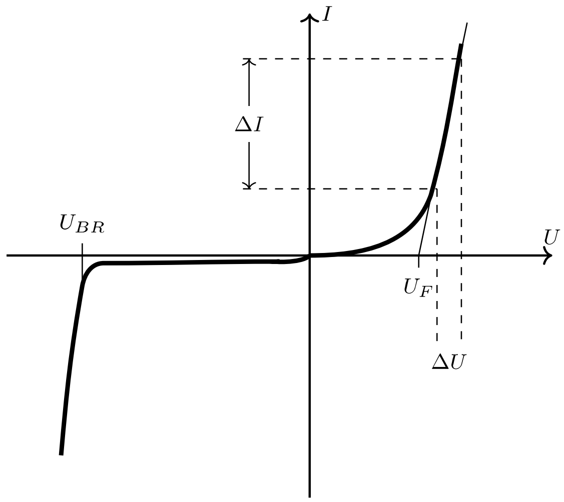


Figure 1: Static characteristics of a diode

Based on the static characteristics of the diode, the following values are determined for the diode:

- **forward voltage U_F (threshold voltage)** - it is the forward voltage which is approximately constant due to the steep forward curve slope,
- **breakdown voltage U_{BR}** - it is the limit voltage between the blocking state and the breakdown state, this voltage depends on the type of diode,
- **static resistance R_S and dynamic resistance r_D**

$$R_S = \frac{U}{I}, \quad r_D = \frac{\Delta U}{\Delta I},$$

where: U,I - voltage and current at a selected point on the characteristic , ΔU,ΔI - changes in voltage and current in the vicinity of this point.

2.1 Basic types of semiconductor diodes

2.1.1 Rectifier Diode (General Purpose)

The rectifying diode (general purpose) is used in rectifier systems, in signal circuits, in voltage limiters, in analog functional generators, etc. The symbol of the rectifying diode is shown in the figure 2. The rectifying diode works periodically in forward and reverse state.

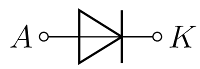


Figure 2: Rectifier diode symbol

Basic properties of a rectifier diode:

- forward voltage value U_F it does not depend much on the value of the flowing current, it depends on the type of semiconductor material and temperature,
- the value of the reverse current practically does not depend on the applied voltage, it depends on the type of semiconductor material and temperature,
- Forward current and breakdown voltage limits for a low power diode range from mA to about $1A$ and from several V to several hundred V.

2.1.2 Pulse and Schottky diodes

Pulse diode is characterized by a very high work speed, switching times are in the order of ns or mus. The basic dynamic parameters of LEDs are:

- switch-on time - the time from the moment of polarization of the junction in the forward direction until the current reaches its maximum value,
- switch-off time - the time from the moment of diode polarization in the reverse direction to the moment the current flow ceases.

Dioda Schottky'ego - a semiconductor diode where a metal-semiconductor junction is used instead of the p-n junction. The Schottky diode is characterized by: small electrical capacity of the junction - so that typical switching times are from hundreds ps to single ns, low forward voltage, about $0.3 - 0.5V$, low breakdown voltage - up to tens of V.

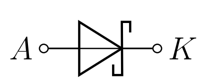


Figure 3: Schottky diode symbol

The symbol of a pulse diode is like a rectifier diode, the symbol of a Schottky diode is shown in the picture 3

2.1.3 Zener diode

In diodes, the reverse current increases rapidly after exceeding the maximum reverse voltage U_{BR}. In a zener diode, the breakdown voltage at which this surge occurs is well defined. This voltage is called the zener voltage and denoted by U_z.

Such diodes can be used to stabilize DC voltages. After exceeding the Zener voltage, the slope of the current-voltage characteristic of the Zener diode is relatively large (figure 4 - regulation region). A large change in current causes a small change in voltage. The stabilization is the better the lower the dynamic resistance of the diode - $r_z = \frac{\Delta U_z}{\Delta I_z}$.

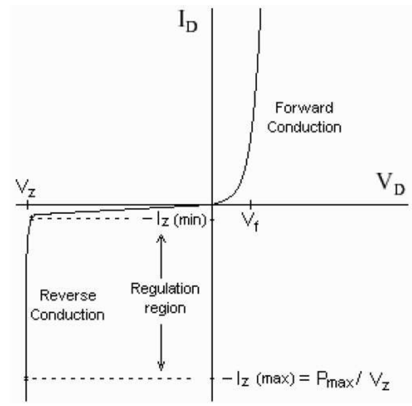


Figure 4: Current-voltage characteristics of a zener diode

The stabilizer shown in the figure 5 is designed for the worst case, i.e. with the worst combination of events in mind. The resistor should be selected so that at the lowest voltage at the input $U_{we\ min}$ and the highest current at the output $I_{out\ max}$ the difference between the input voltage and the voltage drop across the resistor R was greater than the voltage U_z. Thus, the following condition must be met:

$$U_{we\ min} - RI_{wy\ max} > U_z \Rightarrow R < \frac{U_{we\ min} - U_z}{I_{wy\ max}}.$$

The diode dissipates the power $P_d = U_z I_z$. In the worst case, the diode has to dissipate power:

$$P_{d\ max} = U_z I_{z\ max} = U_z \left[\frac{U_{we\ max} - U_z}{R} - I_{wy\ min} \right].$$

The resistor dissipates the power $P_r = \frac{(U_{we} - U_z)^2}{R}$. In the worst case, the resistor has to dissipate the power:

$$P_{r\ max} = \frac{(U_{we\ max} - U_z)^2}{R}.$$

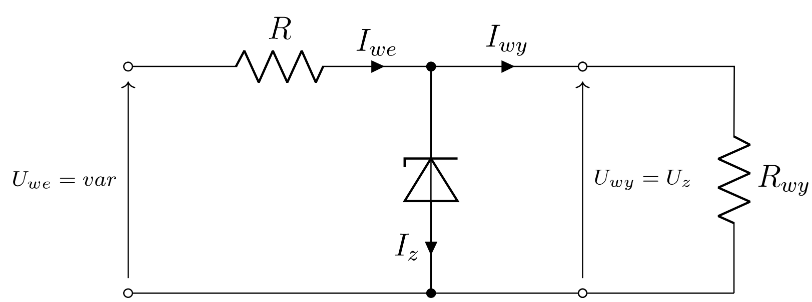


Figure 5: Stabilizer with a zener diode

2.1.4 Light emitting diode - LED

A LED (Light Emitting Diode) is a special case of a diode. During the positive polarity of the A-K junction, the current flowing through the diode produces a quantum of electromagnetic radiation, and thus - the phenomenon of electroluminescence.

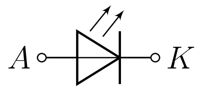


Figure 6: Symbol diody LED

The main parameters of the LED: quantum efficiency, luminous efficiency, wavelength of the emitted light, spectral width, output power, cut-off frequency, maximum forward current measured in milliamperes, maximum reverse voltage.

2.1.5 Other types of diodes

Photodiode - a semiconductor device working as a photo detector. In the absence of polarity, the photodiode works as a source of electric current, when illuminating the diode in the junction, an electromotive force is generated (the so-called photovoltaic phenomenon). When the photodiode is biased in the reverse direction, the photodiode behaves like a resistor whose resistance depends on the illumination.

Capacitive diode - with reverse polarity the diode shows the characteristics of a capacitor, the capacitive effect is exposed in relation to a conventional rectifying diode.

2.2 Rectifier circuits

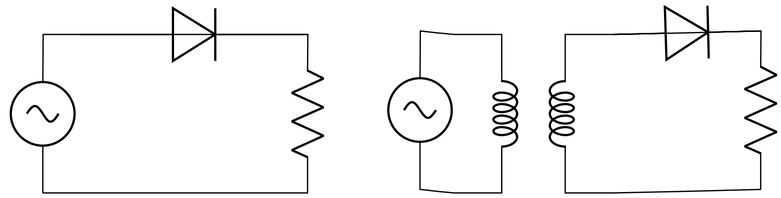
Rectifier - a power electronics system that converts AC energy into DC energy.

Diode rectifier - unregulated AC to DC unregulated converter. The rectifier diodes conduct unidirectional current when the anode voltage is positive in relation to the cathode. Rectified voltage is pulsating (the value changes, but the direction does not change).

Number of pulses - the number of ripples p in the rectified voltage, measured in the period of the supply voltage (the number of rectified half-periods of the voltage per one period of the supply voltage). As the number of p pulses increases, the rectified voltage ripple amplitude decreases.

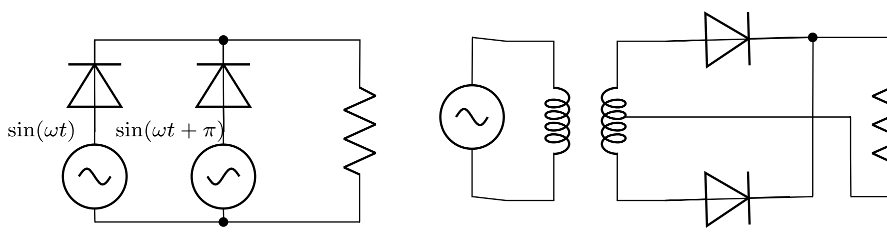
Unidirectional rectifier - a rectifier that draws unidirectional current from the power supply (gets the constant current component from a sinusoidal power source)

Bi-directional rectifier - a rectifier that draws bi-directional AC current from the power supply with zero average value (does not draw DC component from the power source). This is the property of **bridge layouts**.



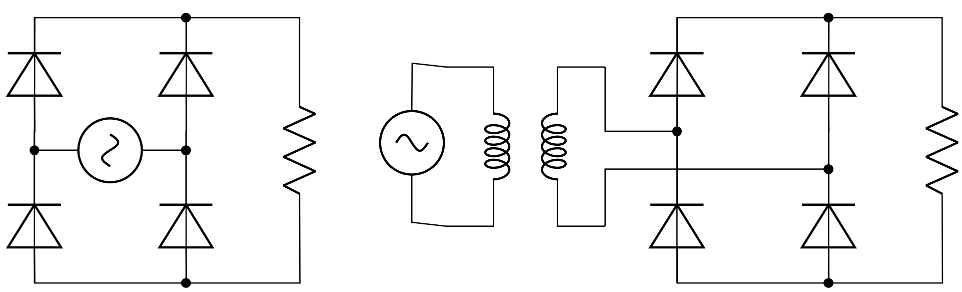
(a) without transformer (b) with transformer

Figure 7: Single-phase, single-pulse, unidirectional system



(a) two-phase (b) transformer with tap

Figure 8: Two-pulse, unidirectional system



(a) without transformer (b) with transformer

Figure 9: Single-phase, two-pulse, two-way, bridge system (Graetz bridge)

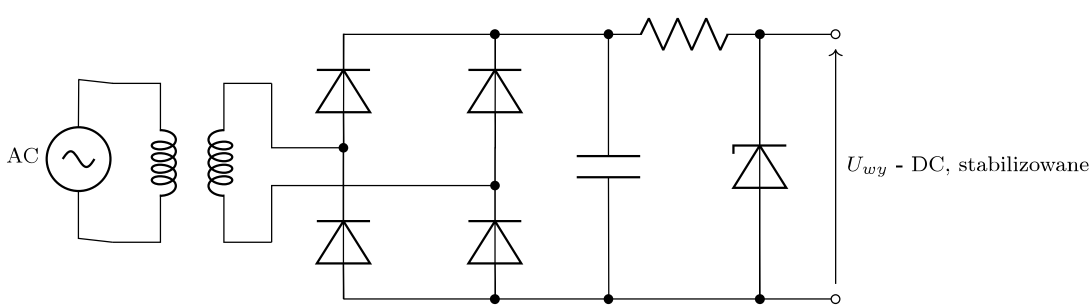


Figure 10: DC power supply with a transformer and a stabilization system for the output voltage

3 The course of the exercise

Use the plate for measurements **E1 i E2**. The symbols or values of the elements used on the test plates are shown in the table 1.

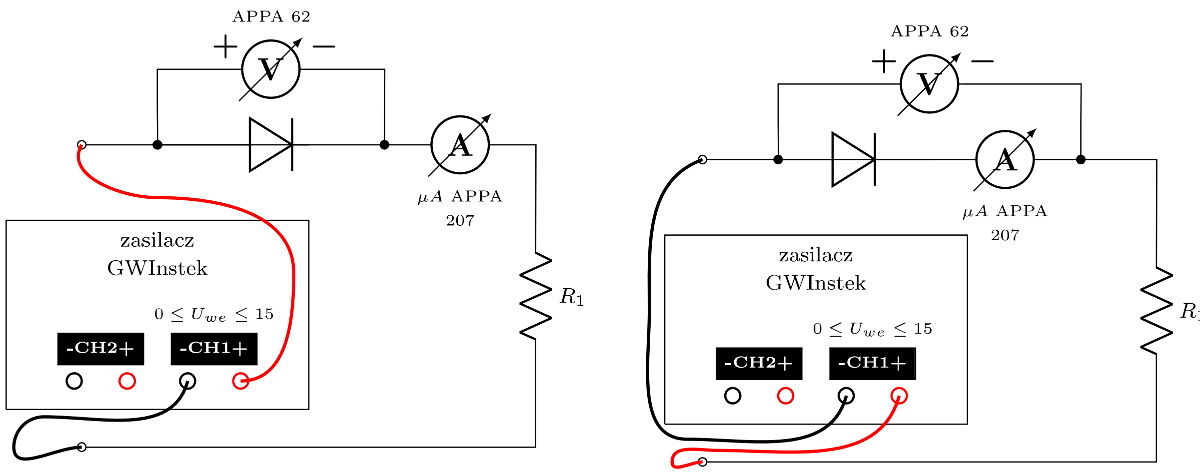
Tabela 1: Table of parameters of test plates E1 and E2

Board E1	
Designation and Symbol / Value	
R1	$1k\Omega$
R2	$5\Omega 1\%$
D1	1N4002
D2	1N5818
D3	Diode: Zener; 0,5W; 4,3V; DO35
D4	Diode: Zener; 0,5W; 9,1V; DO35
D5	LED
D6	LED

Board E2	
Designation and Symbol / Value	
R1	500Ω
R2	$12k\Omega$
C1	$1\mu F$
C2	$100\mu F$
D1-D4	1N4002
DZ	Diode Zener; 0,5W

3.1 Determination of static characteristics

Connect the circuit as shown in the picture 11a. On channel one of the power supply (CH1), set the current limit to $\boldsymbol{I_{CH1max} = 100mA}$. By changing the input voltage U_{we} in range $\boldsymbol{U_{we} \in (0 : 15V)}$ determine the characteristics $\boldsymbol{I = f(U)}$ **in forward direction**. Then change the polarity of the power supply (figure 11b) and determine the characteristics **in the reverse direction** . Perform the characteristics for three selected Diodes . Record the results in the table 2 and mark it on the figure 20.



(a) in the direction of conduction

(b) in the reverse direction

Figure 11

3.2 Observation of characteristics on an oscilloscope

Connect the circuit as shown in the picture 12. On the generator, set the maximum amplitude, frequency $f = 500Hz$ and select the triangular waveform. Set the DC coupling on the first and second channels of the oscilloscope and set the zero levels of both signals to zero of the oscilloscope. On the second channel of the oscilloscope, select $INWERT \rightarrow ON$, then $PROBE \rightarrow CURRENT \rightarrow 5V/A$. Set the oscilloscope to the XY mode (select the $DISPLAY \rightarrow XY$ option). Record the characteristics for the selected LEDs.

NOTE! Pay attention to the order in which the resistors are connected.

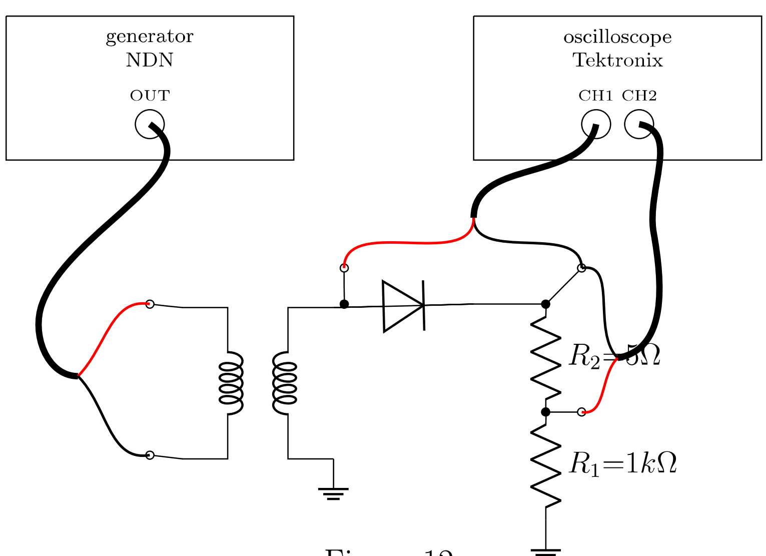


Figure 12

3.3 Dynamic operation of LEDs

Connect the circuit as shown in the picture 13. Set on the generator **square wave**. On the second channel of the oscilloscope, select $INWERT \rightarrow OFF$, then $PROBE \rightarrow CURRENT \rightarrow 5V/A$. Set the oscilloscope to YT mode (choose $DISPLAY \rightarrow YT$ option). Observe the moment of switching on and then the moment of switching off individual LEDs. For the tested LEDs, measure the switch-on time and the switch-off time.

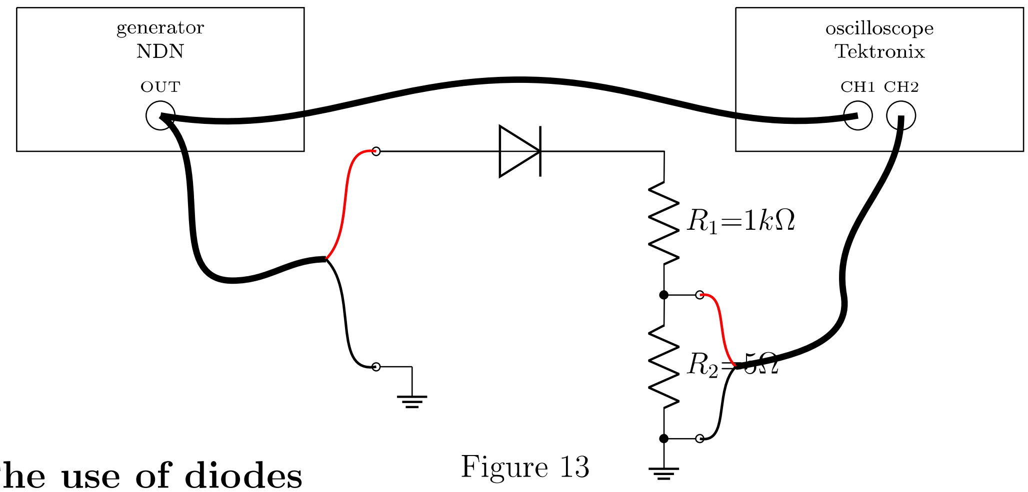


Figure 13

3.4 The use of diodes

Build and test the circuits from the drawing from 14 to 19 on the test board $E2$. At the input of each circuit, give a sinusoidal wave from the generator with the frequency $500Hz$ and the voltage
$U_{pk-pk} = 20V$. On channel one and two, select $PROBE \rightarrow VOLTAGE \rightarrow x1$. Observe the voltage waveform at the input and the voltage waveform at the output on the oscilloscope.

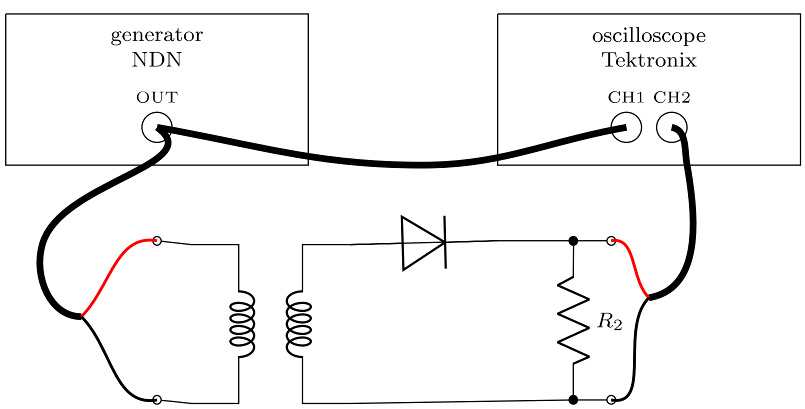


Figure 14: One-pulse, unidirectional system

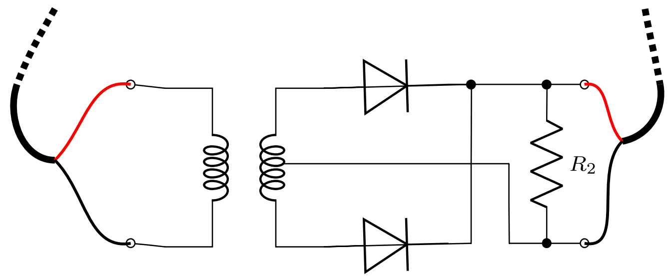


Figure 15: Two-pulse system, transformer with tap

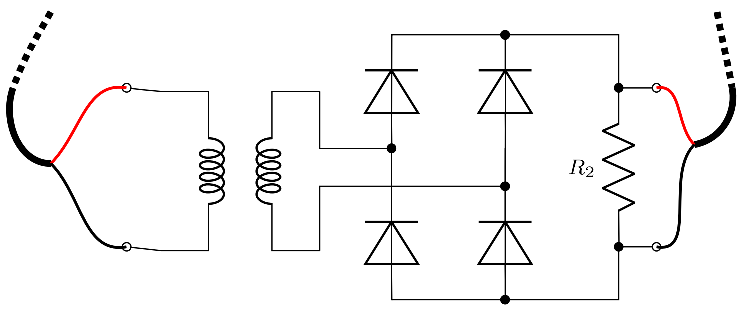


Figure 16: Two-pulse, bidirectional (bridge) system

Note. For the circuit shown in Figure 17 and 18, record the waveforms for the two capacitance values of the C capacitor.

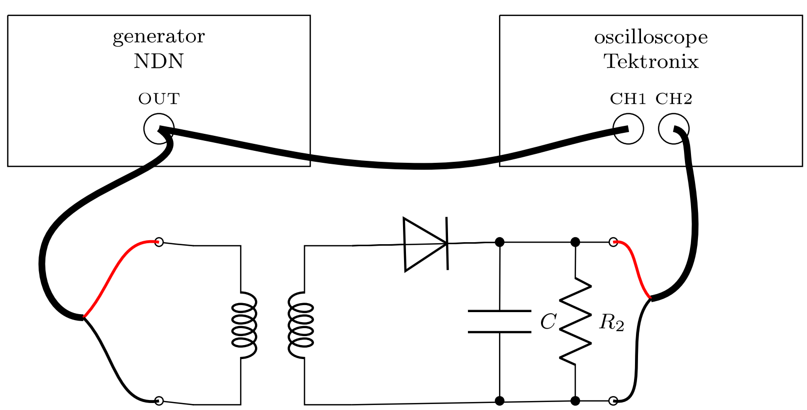


Figure 17: Single-pulse, unidirectional system with a filtering capacitor

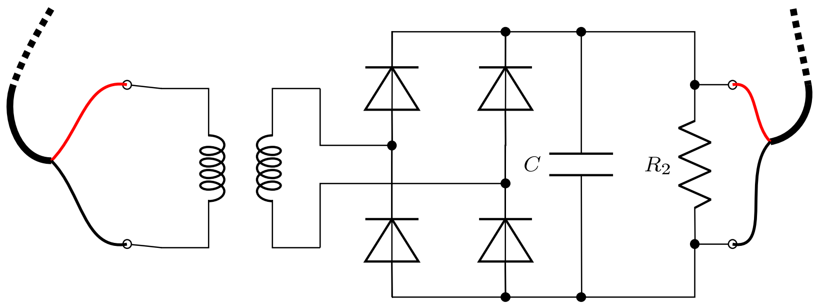


Figure 18: Bridge with filter capacitor

Note. For the circuit shown in Figure 19 record the waveforms for two different zener diodes.

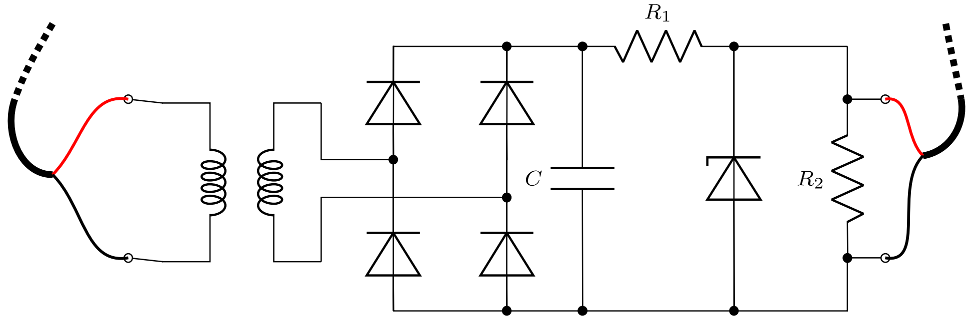


Figure 19: Bridge with filter capacitor and zener diode

4 Report

4.1 Static characteristics

On the basis of the obtained measurements, plot the static characteristics and compare with the characteristics obtained on the oscilloscope. Determine the forward voltages U_F and dynamic resistance r_D for the tested diodes. Find the zener voltage U_z and the dynamic resistance r_z for the zener diodes. Compare the obtained results with the catalog values.

4.2 Dynamic operation of Diodes

Interpret the process of switching on and off the tested diodes, and compare the tested diodes in terms of dynamic parameters (switch-on and switch-off times).

4.3 The use of diodes

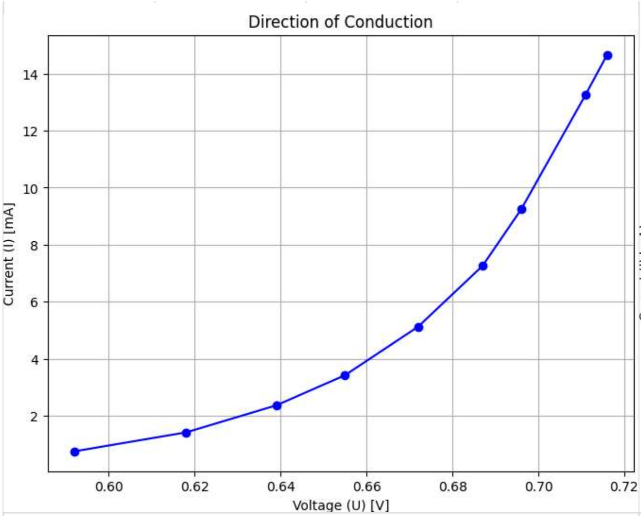
Compare the tested rectifier systems. Describe the effect of using a capacitor at the rectifier output and a zener diode.

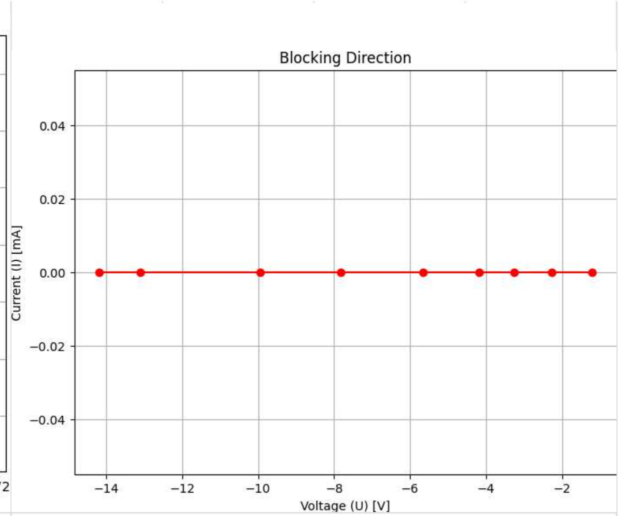
5 Necessary equipment

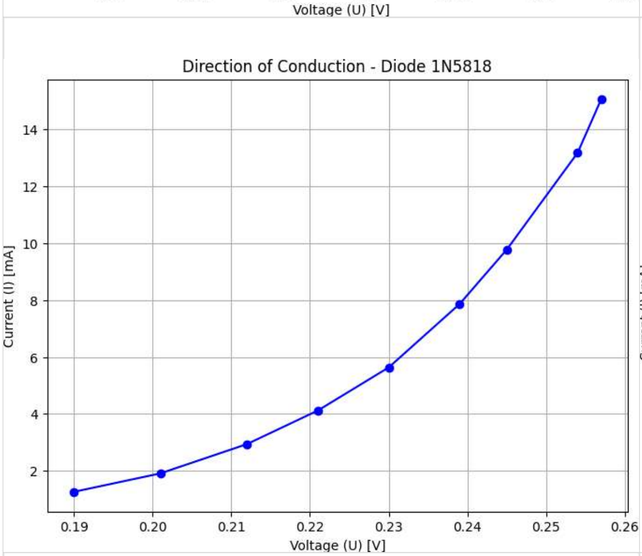
- scientific calculator
- pendrive $1GB$ or a camera for recording waveforms from an oscilloscope
- protocol

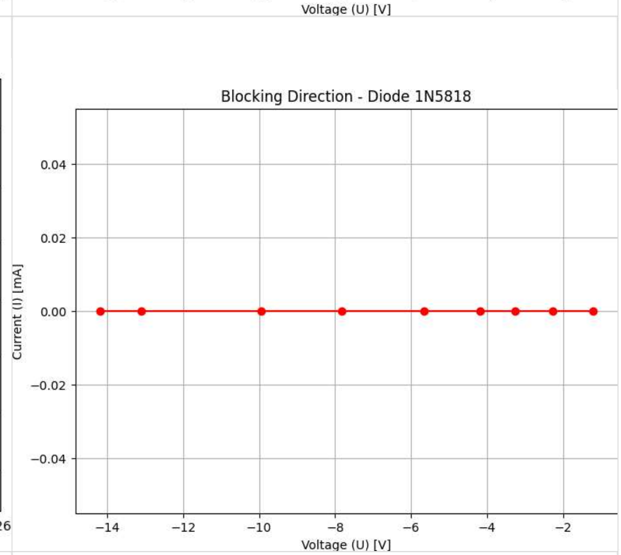
Tabela 2: Static characteristics

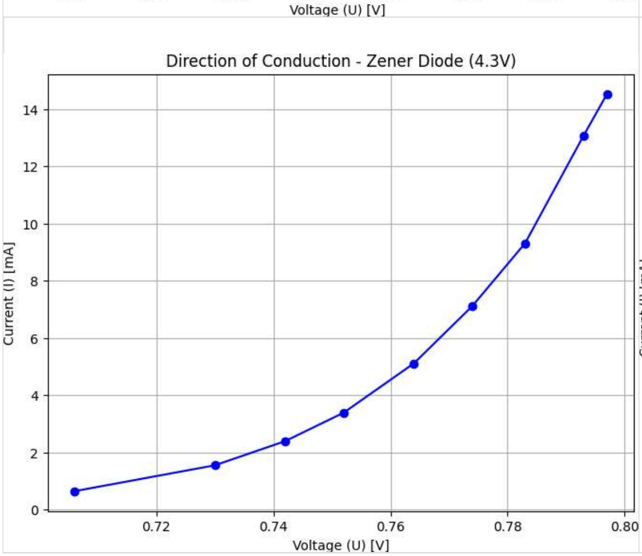
Diode D . . .1N4002				**Diode D . . .1N5818**			
Direction of conduction		Blocking direction		Direction of conduction		Blocking direction	
U [V]	*I[mA]*	*U [V]*	*I[mA]*	*U [V]*	*I[mA]*	*U [V]*	*I[mA]*
0.592	0.761	-1.199	0	0.19	1.261	-1.199	0
0.618	1.425	-2.27	0	0.201	1.91	-2.27	0
0.639	2.372	-3.26	0	0.212	2.939	-3.26	0
0.655	3.429	-4.17	0	0.221	4.119	-4.17	0
0.672	5.127	-5.66	0	0.23	5.632	-5.66	0
0.687	7.258	-7.83	0	0.239	7.86	-7.83	0
0.696	9.239	-9.94	0	0.245	9.775	-9.94	0
0.711	13.257	-13.1	0	0.254	13.176	-13.1	0
0.716	14.657	-14.195	0	0.257	15.064	-14.195	0
Diode D . . .Diode: Zener; 0,5W; 4,3V; DO35				**Diode D . . .Diode: Zener; 0,5W; 9,1V; DO35**			
Direction of conduction		Blocking direction		Direction of conduction		Blocking direction	
U [V]	*I[mA]*	*U [V]*	*I[mA]*	*U [V]*	*I[mA]*	*U [V]*	*I[mA]*
0.706	0.642	-1.67	-0.001	0.64	0.584	-1.74	-0.001
0.73	1.547	-2.02	-0.004	0.723	1.426	-2.5	-0.002
0.742	2.391	-2.93	-0.112	0.74	2.238	-3.15	-0.002
0.752	3.385	-3.47	-0.537	0.755	3.315	-4.37	-0.002
0.764	5.109	-3.94	-1.83	0.771	4.927	-5.55	-0.001
0.774	7.117	-4.2	-3.783	0.785	7.034	-7.68	-0.001
0.783	9.308	-4.33	-5.621	0.796	9.208	-9.07	-0.242
0.793	13.071	-4.47	-9.008	0.81	13.244	-9.13	-4.515
0.797	14.524	-4.52	-10.682	0.814	14.484	-9.15	-5.962
Diode D . . .LED (Red)				**Diode D . . .LED (White)**			
Direction of conduction		Blocking direction		Direction of conduction		Blocking direction	
U [V]	*I[mA]*	*U [V]*	*I[mA]*	*U [V]*	*I[mA]*	*U [V]*	*I[mA]*
1.392	0.002	-1.199	0	1.35	0.001	-1.199	0
1.639	0.349	-2.27	0	2.08	0.001	-2.27	0
1.709	1.287	-3.26	0	2.62	0.643	-3.26	0
1.748	2.321	-4.17	0	2.69	1.464	-4.17	0
1.794	4.014	-5.66	0	2.77	3..063	-5.66	0
1.841	6.177	-7.83	0	2.85	5.054	-7.83	0
1.877	8.092	-9.94	0	2.9	6.731	-9.94	0
1.94	11.721	-13.1	0	2.99	10.791	-13.1	0
1.962	13.121	-14.195	0	3.01	12.113	-14.195	0

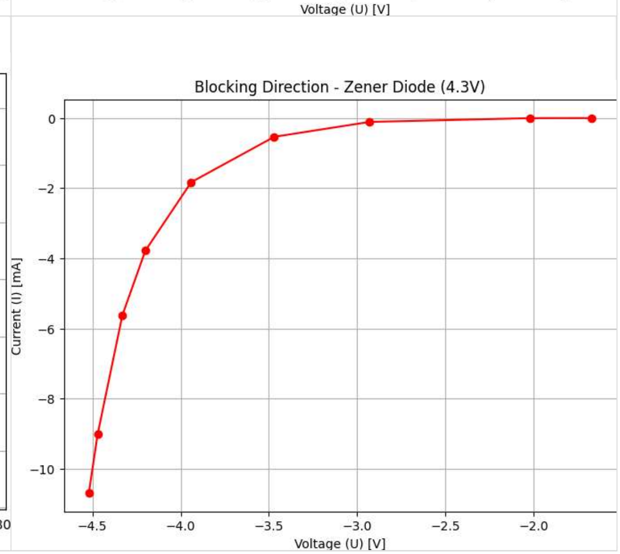

Direction of Conduction
Current (I) [mA]
2 4 6 8 10 12 14
0.60 0.62 0.64 0.66 0.68 0.70 0.72
Voltage (U) [V]

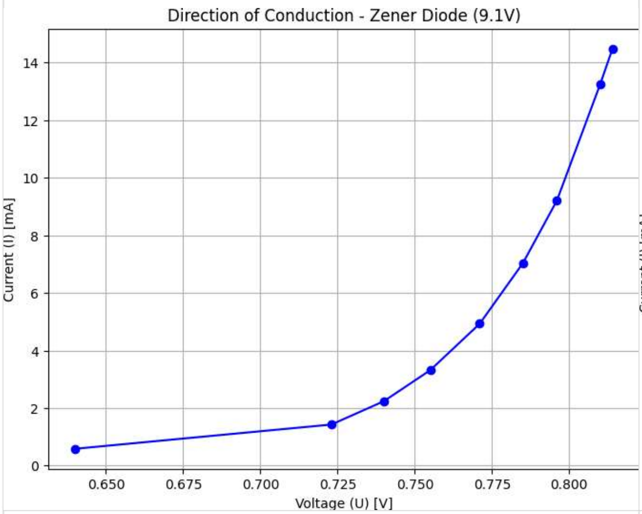

Blocking Direction
Current (I) [mA]
0.04 0.02 0.00 −0.02 −0.04
−14 −12 −10 −8 −6 −4 −2
Voltage (U) [V]

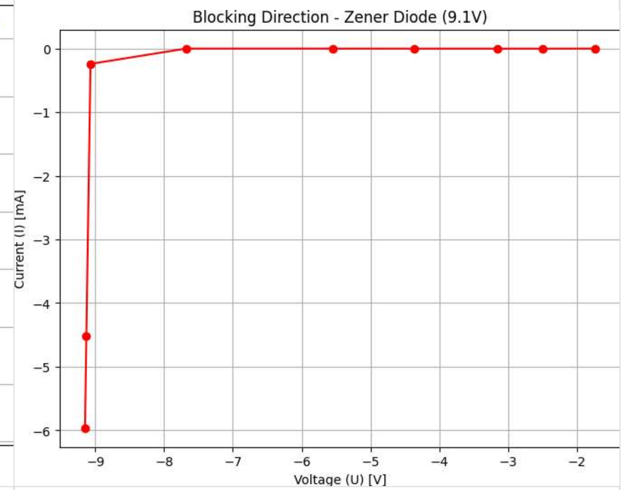

Direction of Conduction - Diode 1N5818
Current (I) [mA]
2 4 6 8 10 12 14
0.19 0.20 0.21 0.22 0.23 0.24 0.25 0.26
Voltage (U) [V]

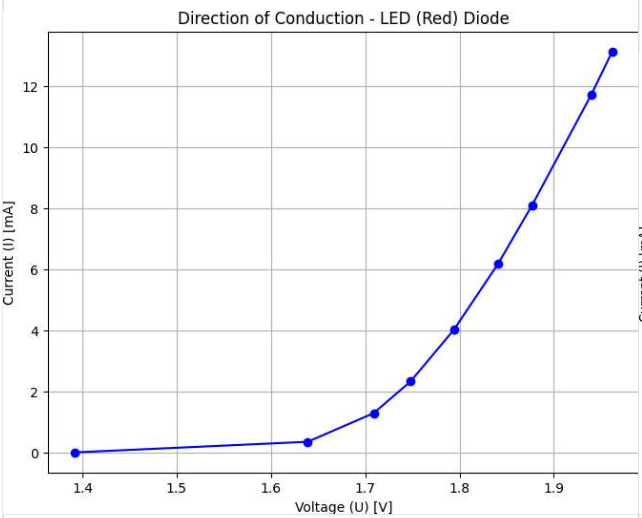

Blocking Direction - Diode 1N5818
Current (I) [mA]
0.04 0.02 0.00 −0.02 −0.04
−14 −12 −10 −8 −6 −4 −2
Voltage (U) [V]


Direction of Conduction - Zener Diode (4.3V)
Current (I) [mA]
0 2 4 6 8 10 12 14
0.72 0.74 0.76 0.78 0.80
Voltage (U) [V]

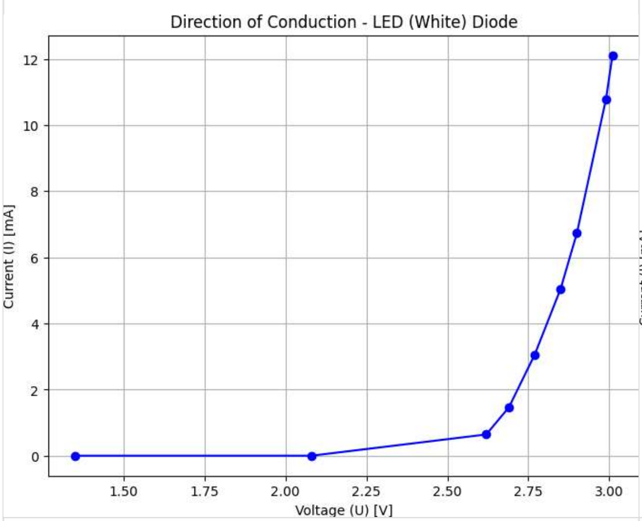

Blocking Direction - Zener Diode (4.3V)
Current (I) [mA]
0 −2 −4 −6 −8 −10
−4.5 −4.0 −3.5 −3.0 −2.5 −2.0
Voltage (U) [V]

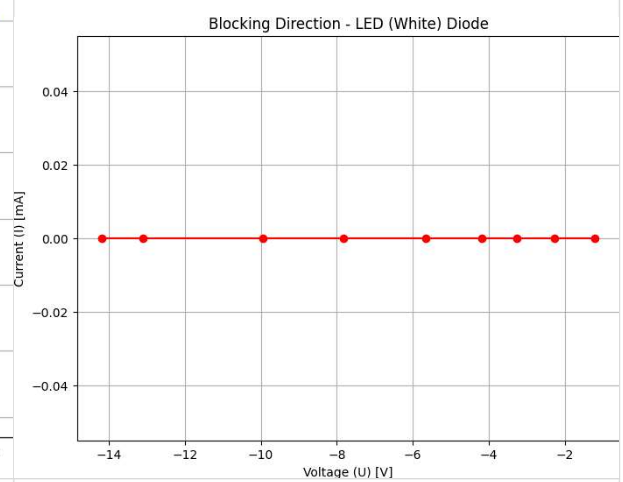

Direction of Conduction - Zener Diode (9.1V)
Current (I) [mA]
Voltage (U) [V]


Blocking Direction - Zener Diode (9.1V)
Current (I) [mA]
Voltage (U) [V]


Direction of Conduction - LED (Red) Diode
Current (I) [mA]
Voltage (U) [V]


Blocking Direction - LED (Red) Diode
Current (I) [mA]
Voltage (U) [V]


Direction of Conduction - LED (White) Diode
Current (I) [mA]
Voltage (U) [V]


Blocking Direction - LED (White) Diode
Current (I) [mA]
Voltage (U) [V]