
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.

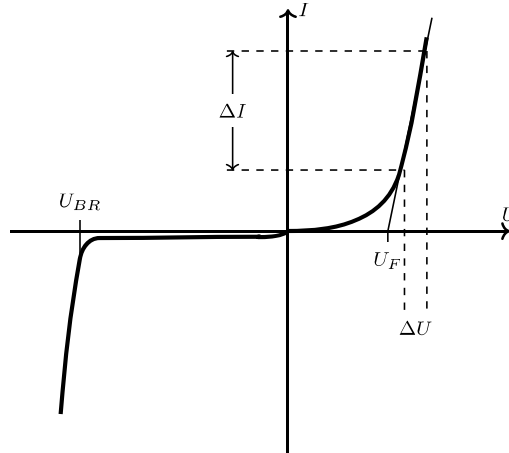


Figure 1: Static characteristics of a diode

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, $\Delta U, \Delta I$ - 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.

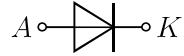


Figure 2: Rectifier diode symbol

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 .

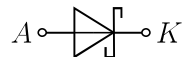


Figure 3: Schottky diode symbol

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 - $r_z = \frac{\Delta U_z}{\Delta I_z}$.

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:

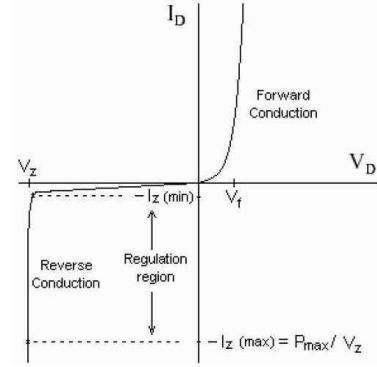


Figure 4: Current-voltage characteristics of a zener diode

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

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:

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

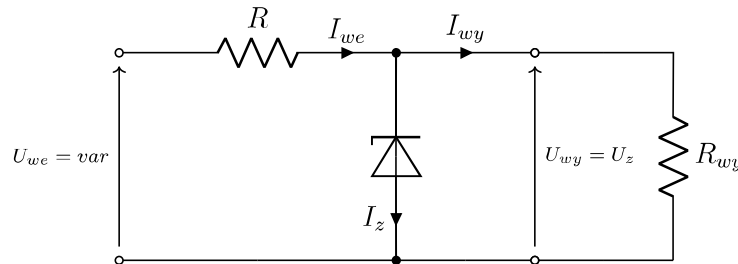


Figure 5: Stabilizer with a zener diode

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.

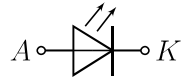


Figure 6: Symbol diody LED

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**.

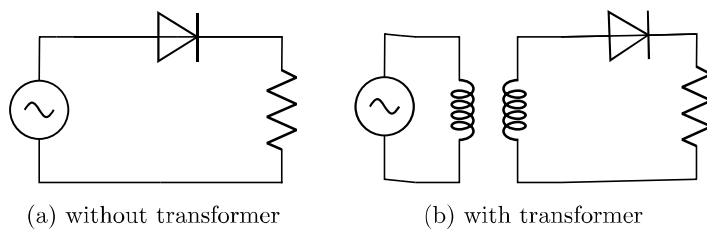


Figure 7: Single-phase, single-pulse, unidirectional system

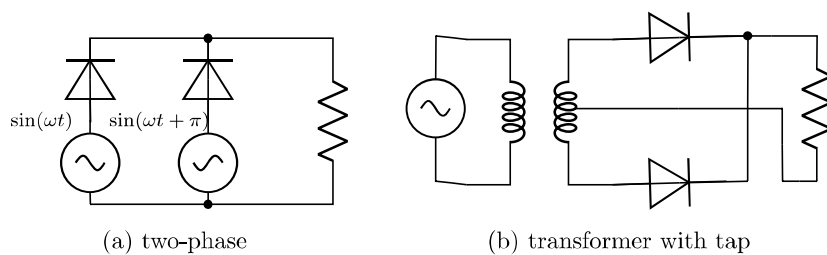


Figure 8: Two-pulse, unidirectional system

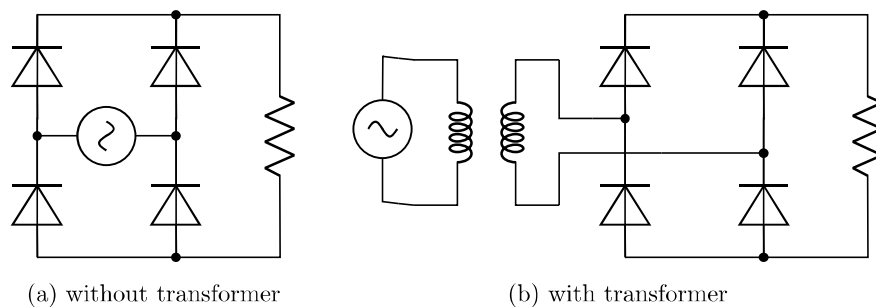


Figure 9: Single-phase, two-pulse, two-way, bridge system (Graetz bridge)

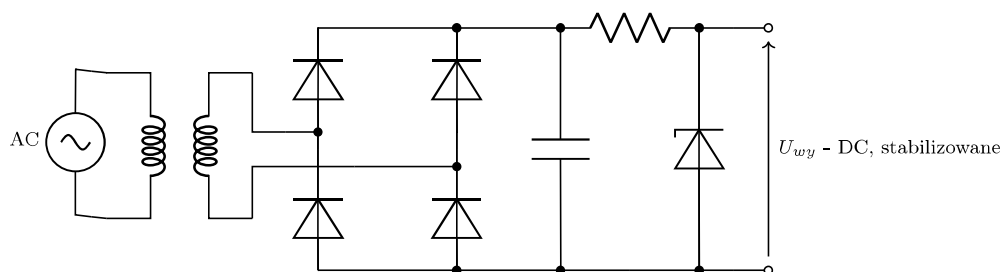


Figure 10: DC power supply with a transformer and a stabilization system for the output voltage

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 $I_{CH1max} = 100mA$. By changing the input voltage U_{we} in range $U_{we} \in (0 : 15V)$ determine the characteristics $I = f(U)$ 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.

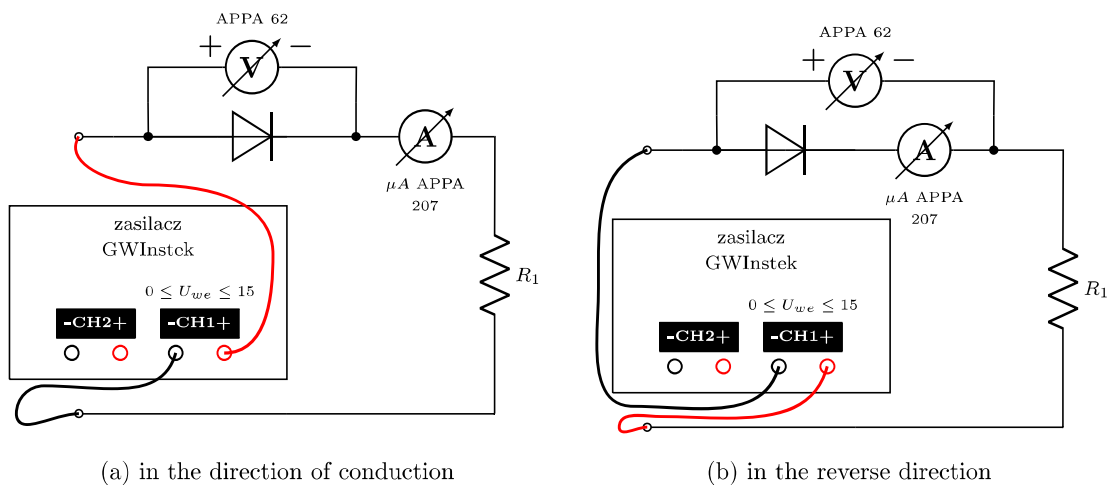


Figure 11

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 $f = 500\text{Hz}$ 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 $INVERT \rightarrow ON$, then $PROBE \rightarrow CURRENT \rightarrow 5\text{V/A}$. 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.

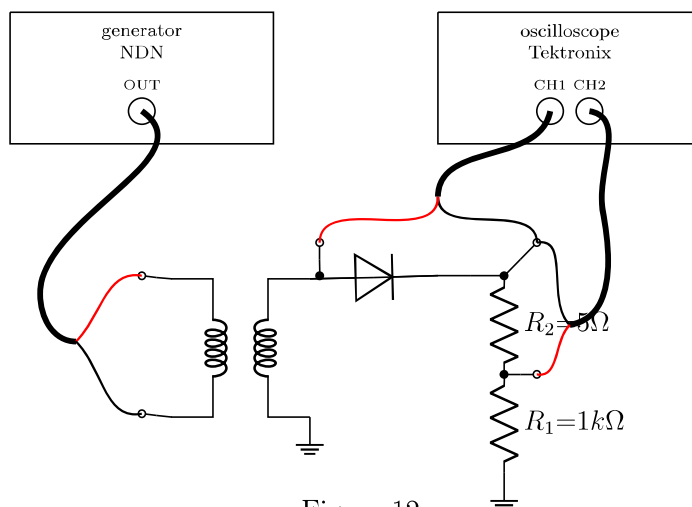


Figure 12

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.

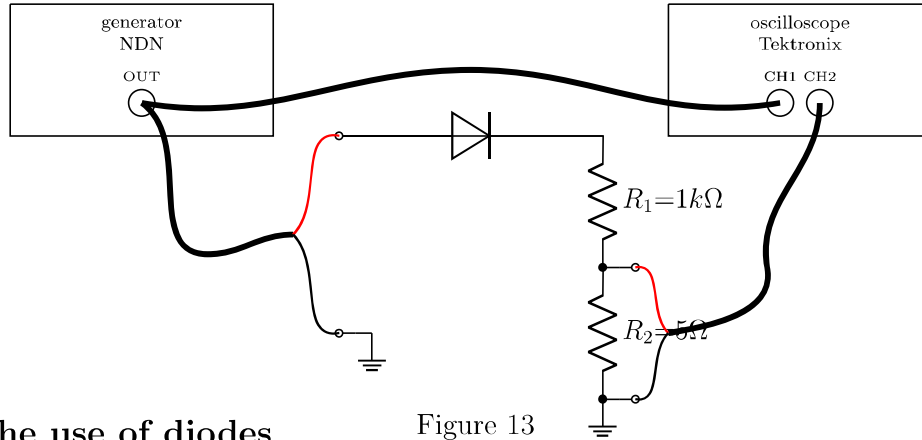


Figure 13

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.

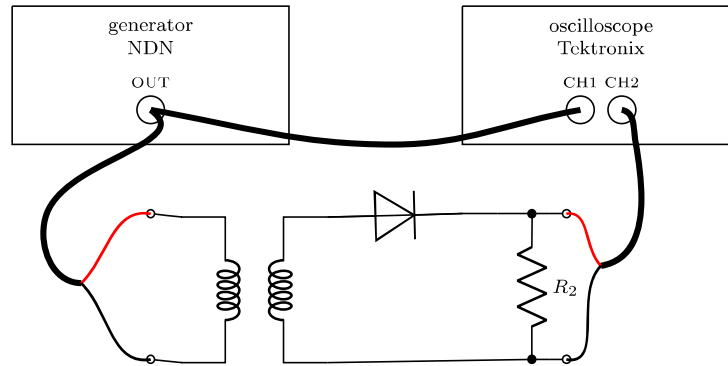


Figure 14: One-pulse, unidirectional system

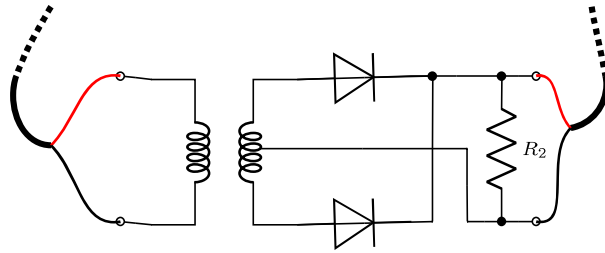


Figure 15: Two-pulse system, transformer with tap

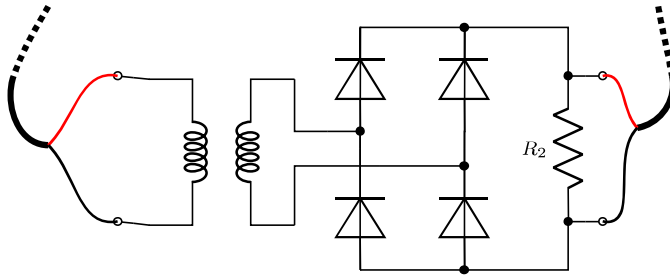


Figure 16: Two-pulse, bidirectional (bridge) system

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

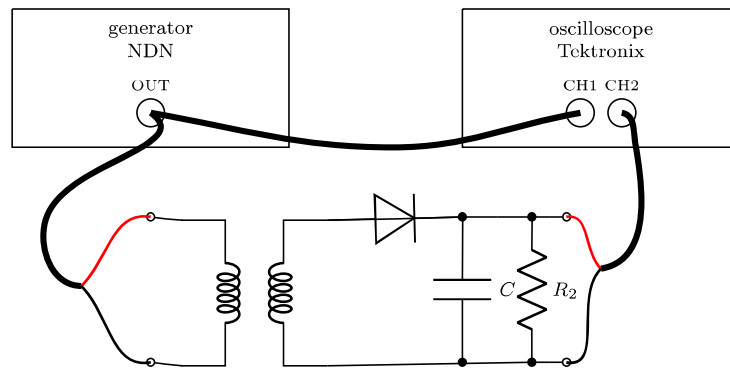


Figure 17: Single-pulse, unidirectional system with a filtering capacitor

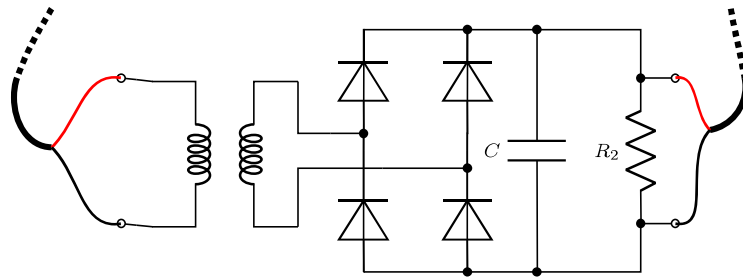


Figure 18: Bridge with filter capacitor

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

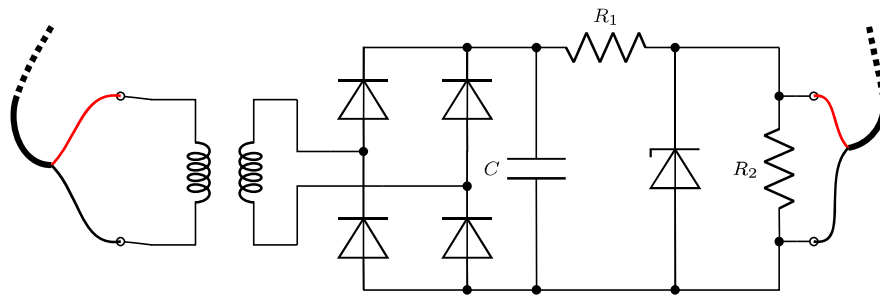


Figure 19: Bridge with filter capacitor and zener diode

Conclusion

In this exercise, we investigated the static characteristics of various diodes, including the 1N4002, 1N5818, and Zener diodes (0.5W, 4.3V, and 9.1V), and LEDs (Red and White). The main objective was to understand the forward and reverse behaviors of these diodes by analyzing their voltage-current (I-V) characteristics.

1.1N4002 Diode:

- The 1N4002 diode demonstrated typical rectifying behavior with a forward voltage range from 0.6V to 0.71V and corresponding current range from 1.36mA to 14.9mA. This indicates its suitability for low-current rectification purposes in general electronic circuits.

2.1N5818 Diode:

- The Schottky diode 1N5818 showed a lower forward voltage range (0.2V to 0.25V) compared to the 1N4002, with a current range from 2mA to 15.2mA. This characteristic makes it ideal for applications requiring low forward voltage drops and fast switching.

3.Zener Diodes:

- The Zener diodes (0.5W, 4.3V, and 9.1V) displayed typical forward voltages around 0.72V to 0.81V, with current ranges from 1.7mA to 14.7mA. Zener diodes are primarily used for voltage regulation, and their forward characteristics align with their function as reverse-biased voltage stabilizers.

4.LEDs:

- The Red LED exhibited a forward voltage range from 1.6V to 1.9V, with a current range from 0.3mA to 13.8mA. The White LED required higher forward voltages (2.0V to 2.9V) for currents ranging from 0.001mA to 12.3mA. LEDs operate at higher forward voltages due to their electroluminescent properties, which are material-dependent. The exercise provided a comprehensive understanding of the static characteristics of various diodes, highlighting their forward and reverse behaviors. By examining these characteristics, we can select appropriate diodes for specific electronic applications, ensuring optimal performance and efficiency. This foundational knowledge is crucial for designing and analyzing electronic circuits involving diodes.

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; D035 | | | | Diode D . . .Diode: Zener; 0,5W; 9,1V; D035 | | | |
| 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 |

