Experiment 1

Recording the Current - Voltage Characteristics of a Diode

1- Objects of the Experiment

- Studying the characteristics of a diode.
- Determining the value of cut-in voltage.
- Determining the value of the reverse-bias saturation current
- Determining the value of the emission coefficient

2- Principles

The diode is a device formed from a junction of n-type and p-type semiconductor material. The lead connected to the p-type material is called the **anode** and the lead connected to the n-type material is the **cathode**. In general, the cathode of a diode is marked by a solid line on the diode (see Figure 1).

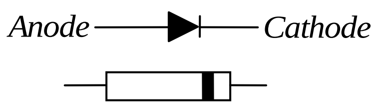

Figure 1. *The symbol for a diode compared to an actual diode package*

An ideal diode acts as a unilateral switch. It has a voltage-current characteristic as shown in the Figure 2. When forward biased the diode acts as a short circuit. When reverse biased, it acts as an open circuit. No power is dissipated in an ideal diode biased in either direction since either the voltage across it is zero (forward biased) or the current through it is zero (reverse biased).

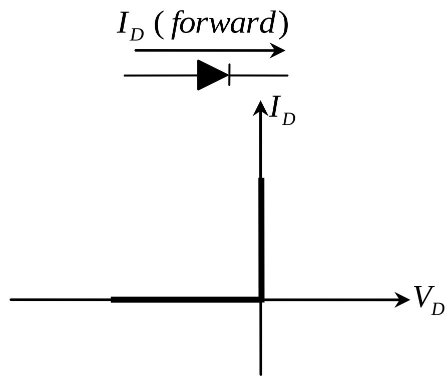

Figure 2. *Ideal diode*

A more realistic approximation to a real diode is a series circuit containing an ideal diode, a battery and a resistor (see Figure 3). This model is called as *piecewise linear model* or *small signal equivalent model*. The battery introduces a small cut-in voltage, V_γ, that must be exceeded before the diode begins conducting under forward bias conditions. The value of V_γ is determined by the type of semiconductor used in the p-n junction. The resistor approximates the semiconductor resistance under forward bias and determines the amount of dissipation in the diode.

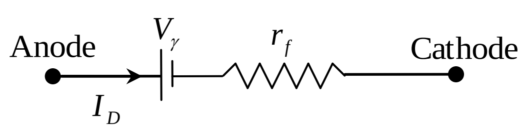

Figure 3. *Real diode in forward bias*

When a real diode is reverse biased a minuscule leakage current, I_S, flows through the device. This current can be effectively ignored as long as the reverse breakdown voltage of the diode is not exceeded (see Figure 4). At potentials greater than the reverse breakdown voltage, charge is pulled through the p-n junction by the strong electric fields in the device and a large reverse current flow. This usually destroys the device.

Real diodes have internal resistance called forward diode resistance, r_f, which can be found as follow (see Figure 4):

$$Slope\ of\ tangent\ line = \frac{1}{r_f}$$ (Equation 2)

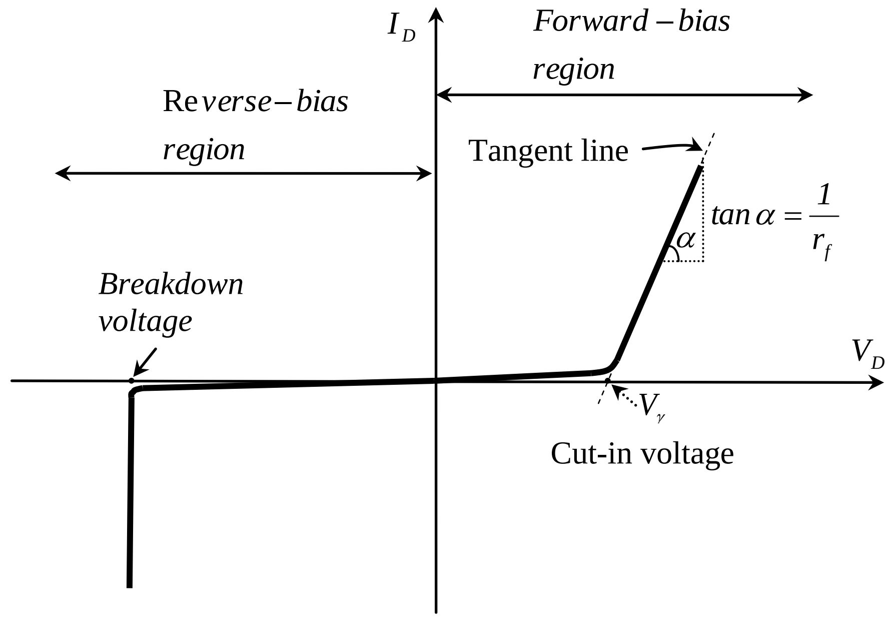

Figure 4. *Real diode characteristics*

The voltage current relationship of semiconductor diode is expressed as

$$I_D = I_S e^{\left(\frac{V_D}{nV_T}-1\right)} \cong I_S e^{\left(\frac{V_D}{nV_T}\right)}$$ (Equation 2)

$$where \quad \begin{cases} I_S\ :reverse\text{-}bias\ saturation\ current \\ V_T\ :thermal\ voltage, V_T\,(at\ 300K) = 0.026V \\ n : emission\ coefficien\ t\ or\ ideality\ \ factor \end{cases}$$

The relationship given in this equation is valid for both forward and reverse bias; however, it fails to be valid when the reverse bias voltage reaches a value that causes breakdown. The parameters I_S and n can be found experimentally. For this purpose the straight line portion of I - V curve on a semi logarithmic plot is extrapolated to intercept the current axis at $V_D = 0$ (see Figure 5). I_S is read from the graph and n is calculated from the slope.

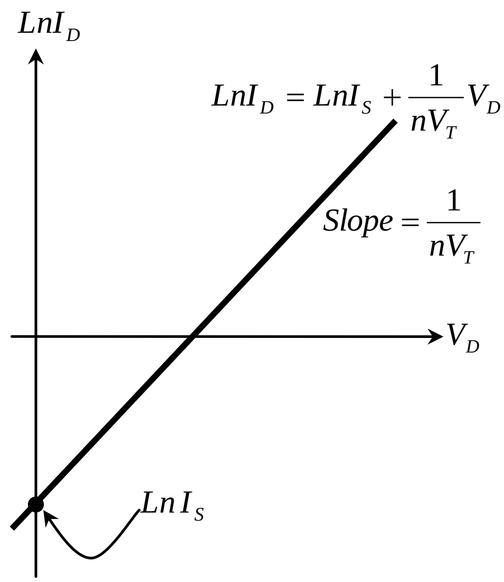

Figure 5. *Determination of reverse-bias saturation current (I_S) and emission coefficient (n) of Si-diode*

3- Equipments

1 Plug-in board 297 X 300	726 50
1 STE Resistor 100 Ω, 2 W	577 32
1 STE Si-Diode 1N4007	578 51
1 AC/DC stabilizer (-15 V)...(+15 V) / 1 A	726 88
2 Digital Multimeters	
Connecting Leads 100 cm	500 441
1 Potentiometer 220 Ω, 3W	577 90

4- Setup

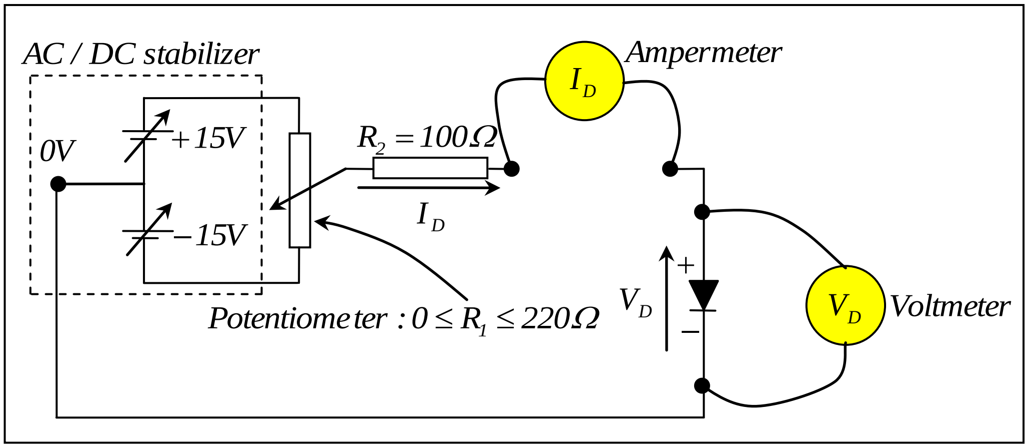

Figure 6. *Setup for determining I_D-V_D characteristics.*

5- Carrying out the experiment

5-1- I-V characteristic of a Silicon (Si) diode

- - Turn the potentiometer's button at the maximum position.

- - Turn the AC/DC stabilizer's button at zero position.

- Set up the experiment as shown in the Figure 6. Plug in the Si-Diode, so that the tip of the triangle points from plus to minus (in the direction of the current, "forward direction"). Pay attention to the measuring range and polarity of the multimeters.

- Turn the button of the AC/DC stabilizer until you reach a value close to 30mA in the ampermeter. The current I_D should not exceed 30 mA. After this operation, don't touch the button.

- Turn the potentiometer's button to position 0

- Carefully increase resistance R_1 of the potentiometer and observe current I_D.

- For different pairs of voltage V_D and current I_D fill table 1.

Table 1. *I-V characteristics of a Si-diode*

V_D (V)	$I_D(mA) \le 30mA$
-3	
-1	

0	
0.1	
0.16	
0.18	
0.23	
0.26	
0.28	
0.32	
0.35	
0.38	
0.43	
0.57	
0.67	

- Fill the first two columns of Table 2 with different pairs of voltage V_D and current I_D from Table 1 such that $10 < I_D(mA) \leq 30mA$

Table 2. *Si-Diode in conducting-state (forward) direction*

V_D (V)	$10 < I_D(mA) \leq 30mA$	$Ln(I_D)$	$Ln(I_D).V_D$	V_D^2
$\overline{V_D} =$	$\bar{I}_D =$	$\overline{Ln(I_D)} =$	$\overline{V_D.Ln(I_D)} =$	$\overline{V_D^2} =$

Part 1

1) Prepare a sheet of graph paper for plotting I_D versus V_D (Table 1). You should make I_D the vertical axis and V_D the horizontal axis. Each axis should be labeled and appropriate units indicated. The graph should have a title.

2) Plot your data on the graph.

3) Trace a smooth curve joining the different points.

4) Determine the value of cut-in voltage V_γ (see Figure 4)

5) Determine the value of r_f by using Equation 1.

<u>Part 2</u>

1) Prepare a sheet of graph paper for plotting $Ln(I_D)$ versus V_D (Table 2). You should make $Ln(I_D)$ the vertical axis and V_D the horizontal axis. Each axis should be labeled and appropriate units indicated. The graph should have a title.

2) Plot your data on the graph.

3) Draw a best fit line to the points on your graph <u>by using the method of least square (See Apendix).</u>

The equation of the best fit line is: $Ln(I_D) = mV_D + b$

4) Determine the slope ***<u>m</u>*** of your best fit line, and the y-intercept ***<u>b</u>***.

5) Find the relationship between m and I_S (see equation in Figure 5).

6) Find the relationship between b and n (see equation in Figure 5).

7) Determine the values of I_S *and n.*

6- Conclusion

Make a general conclusion about the experiments and the results obtained.

Experiment 2

Half-Wave Rectifier Circuit

1- Objects of the Experiment

- Recording the output voltage for an Ohmic load resistance
- Representing the output voltage as a function of the charging capacitor.
- Representing the output voltage as a function of the load resistor.

2- Principles

Rectification is the process of converting an alternating (AC) voltage into one that is limited to one polarity. The diode is useful for this function because of its nonlinear characteristics, that is, current exists for one voltage polarity, but is essentially zero for the opposite polarity. Rectification is classified as half-wave or full-wave.

Figure 1 shows a power transformer with a diode and a resistor connected to the secondary of the transformer. We will use the piecewise linear approach in analysing this circuit, assuming the diode forward resistance $r_f = 0$ when the diode is "on".

The input signal, v_I, is, in general, a 220 V (rms), 60 Hz AC signal. Recall that the secondary voltage, v_S, and primary voltage, v_I, of an ideal transformer are related by

$$\frac{v_I}{v_S} = \frac{N_1}{N_2} \qquad \text{(Equation 1)}$$

where N_1 and N_2 are the number of primary and secondary turns, respectively.

The ratio N_1/N_2 is called the transformer turns ratio. The transformer turns ratio will be designed to provide a particular secondary voltage, v_S, which in turn will produce a particular output voltage v_O.

For $v_S < 0$, the diode is reverse biased, which means that the current is zero and the output voltage is zero. As long as $v_S < V_\gamma$, the diode will be nonconducting, so the output voltage will remain zero. When $v_S > V_\gamma$, the diode becomes forward biased and a current is induced in the circuit. In this case, we can write

$$i_D = \frac{v_S - V_\gamma}{R} \qquad (\text{for } v_s \rangle V_\gamma) \qquad (\text{Equation 2})$$

$$v_O = R\,i_D = v_S - V_\gamma \qquad (\text{for } v_s \rangle V_\gamma) \qquad (\text{Equation 3})$$

If a capacitor is added in parallel with the load resistor of a half-wave rectifier to form a simple filter circuit (Figure 2), we can begin to transform the half-wave sinusoidal output into a DC voltage. The voltage across the capacitor follows the initial portion of the signal voltage (the positive half of the output sine wave). When the signal voltage reaches its peak and begins to decrease, the voltage across the capacitor also starts to decrease, which means the capacitor starts to discharge. The only discharge current path is through the resistor. If the RC time constant is large, the voltage across the capacitor discharges exponentially with time. During this time period, the diode is cut off.

3- Equipments

1 resistor 100Ω / 2W	577 32
1 resistor 1kΩ / 2W	577 44
1 resistor 10kΩ / 0.5W	577 56
1 electrolytic capacitor 10μF / 35V	578 37
1 Electrolytic capacitor 47μF / 35V	578 38
1 Electrolytic capacitor 100μF / 16V	578 39
1 Si-diode 1N4007	578 51
1 Two-oscilloscope	
1 Power supply unit	726 961
1 Plug-in board 297X300	72650

1 Measuring cable BNC/4mm	575 24
1 Set of bridging plugs 19mm	501 48
1 Set of connecting leads	501 532

4- Setup

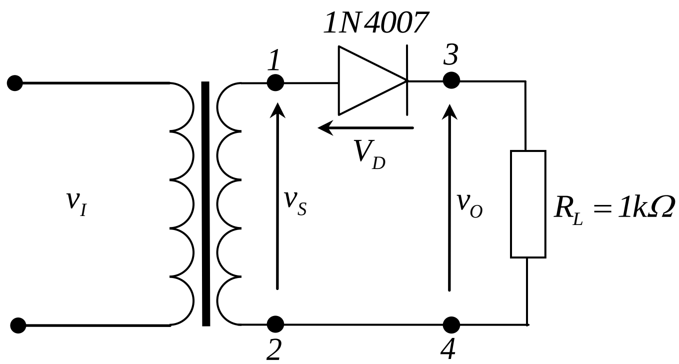

***Figure 1**. Half-wave rectifier circuit*

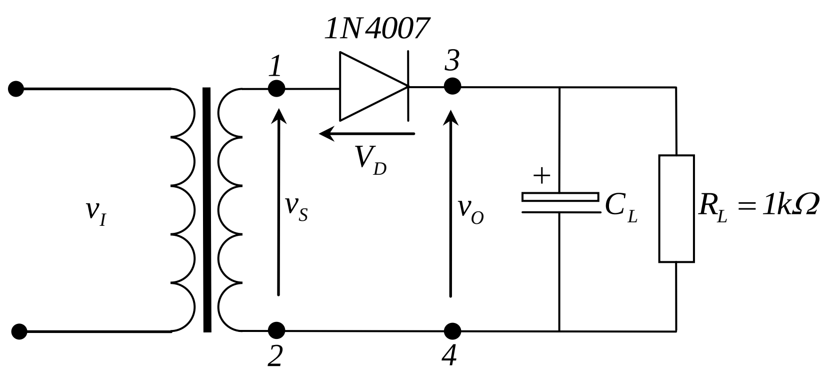

***Figure 2.** Half-wave rectifier with an RC filter*

5- Carrying out the experiment

5-1- Representing the output voltage $v_O(t)$ for an Ohmic load resistance

- Assemble the circuit as shown in Figure 1 and apply an AC voltage of V_S = $6V$ to terminals 1 and 2.

- Use channel 1 of the oscilloscope to measure the peak-to-peak value of the transformer voltage at terminals 1 and 2.

- Transfer the graph into a sheet of graph paper. Each axis should be labeled and appropriate units indicated.

- Determine the amplitude (peak value) V_S and the frequency f of the transformer voltage $v_S(t)$

- Use the second oscilloscope channel to measure the output voltage $v_O(t)$ and enter this into the same sheet of graph paper.

- Determine the amplitude (peak value) V_O and the frequency f of the output voltage $v_O(t)$

- Calculate the amplitude of the output voltage V_O (from Equation 3) and compare the calculated value with the measured value. Give reasons for any deviations which may occur.

5-2- Representing the output voltage as a function of the charging capacitor

- Assemble the circuit without the capacitor as shown in Figure 2 and apply an AC voltage of $V_S = 6V$ to terminals 1 and 2.

- Without the capacitor, record the output voltage $v_O(t)$ on the oscilloscope.

- Transfer the graph into a sheet of graph paper.

- Connect the capacitors C_{L1} = 10µF, C_{L2} = 47µF and C_{L3} = 100 µF (Polarity must be correct) to terminals 3 and 4 (parallel to the load resistor) as in Figure 2 one after the other.

- Record the output voltages $v_O(t)$ of the different capacitors on the oscilloscope.

- Transfer the graphs into the same sheet of graph paper. Each axis should be labeled and appropriate units indicated. Label the output voltages according to the appropriate capacitor.

- Comment on the relationship between the output voltage ripple and the capacitance value of the capacitor.

5-3- Representing the output voltage as a function of the load resistor

- Connect the capacitor C_L = 47 µF between the terminals 3 and 4 shown in Figure 2.

- Connect the load resistors R_{L1} = 100Ω, R_{L2} = 1kΩ and R_{L3} = 10kΩ parallel to the capacitor one after the other.

- Display the corresponding output voltage $v_O(t)$ on the oscilloscope.

- Transfer the graphs into a sheet of graph paper. Each axis should be labeled and appropriate units indicated. Label the output voltages according to the appropriate load resistor.

- Comment on the relationship between the output voltage ripple and the load resistor value. Give reasons for this.

6- Conclusion

Make a general conclusion about the experiments and the results obtained.

Experiment 3

Full-wave Rectifier Circuit

1- Objects of the Experiment

- Recording the output voltage for an Ohmic load resistance
- Representing the output voltage as a function of the charging capacitor.
- Representing the output voltage as a function of the load resistor.

2- Principles

The full-wave rectifier inverts the negative portions of the input sinusoid v_S so that a unipolar output signal is generated during both halves of v_S. One example of a full-wave rectifier circuit appears in Figure 1. The input to the rectifier consists of a power transformer, in which the input is normally a 220 V (rms), 60 Hz AC signal, and the two outputs are from a center-tapped secondary winding that provides equal voltages v_S, with the polarities shown. When the input line voltage is positive, both output signal voltages v_S are also positive.

The primary winding connected to the 220 V AC source has N_1 windings, and each half of the secondary winding has N_2 windings. The value of the v_S output voltage is $120(N_2/N_1)$ volts (rms). The **turns ratio** of the transformer (N_1/N_2) can be designed to "step down" the input line voltage to a value that will produce a particular DC output voltage from the rectifier.

During the positive half of the input voltage cycle, both output voltages v_S are positive, therefore, diode D_1 is forward biased and conducting and D_2 is reverse biased and cut off. The current through D_1 and the output resistance produce a positive output voltage. During the negative half cycle, D_1 is cut off and D_2 is forward biased, or "on", and the current through the output resistance again produces a positive output voltage.

For a sinusoidal input voltage, we can determine the output voltage versus time as follow:

- when v_S is positive, then for $v_S > v_\gamma$, D_1 is on and the output voltage is

$$v_O = v_S - V_\gamma \qquad \text{(Equation 1)}$$

where $V_\gamma = 0.7V$ the cut-in voltage

- when v_S is negative, then for $v_S < -v_\gamma$, or $-v_S > v_\gamma$, D_2 is on and the output voltage is

$$v_O = -v_S - V_\gamma \qquad \text{(Equation 2)}$$

Since a rectified output voltage occurs during both the positive and negative cycles of the input signal, this circuit is called a **full-wave rectifier**.

If a capacitor is added in parallel with the load resistor of a full-wave rectifier to form a simple filter circuit (Figure 2), we can begin to transform the full-wave sinusoidal output into a DC voltage. The voltage across the capacitor follows the initial portion of the signal voltage (the positive half of the output sine wave). When the signal voltage reaches its peak and begins to decrease, the voltage across the capacitor also starts to decrease, which means the capacitor starts to discharge. The only discharge current path is through the resistor. If the RC time constant is large, the voltage across the capacitor discharges exponentially with time. During this time period, the diode is cut off.

3- Equipments

1 resistor 100Ω / 2W	577 32
1 resistor 1kΩ / 2W	577 44
1 resistor 10kΩ / 0.5W	577 56
1 electrolytic capacitor 10µF / 35V	578 37
1 Electrolytic capacitor 47µF / 35V	578 38

1 Electrolytic capacitor 100µF / 16V	578 39
1 Si-diode 1N4007	578 51
1 Two-oscilloscope	
1 Power supply unit	726 88
1 Plug-in board 297X300	72650
1 Measuring cable BNC/4mm	575 24
1 Set of bridging plugs 19mm	501 48
1 Set of connecting leads	501 532

4- Setup

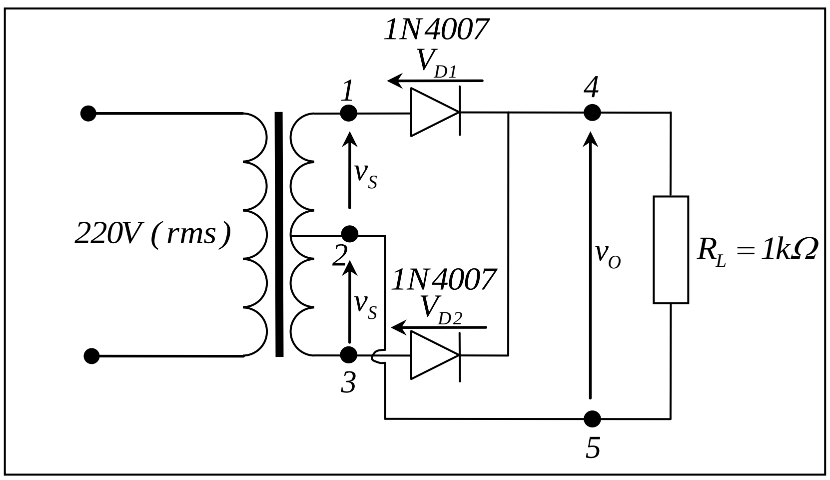

Figure 1. *Full-wave rectifier circuit with center-taped transformer*

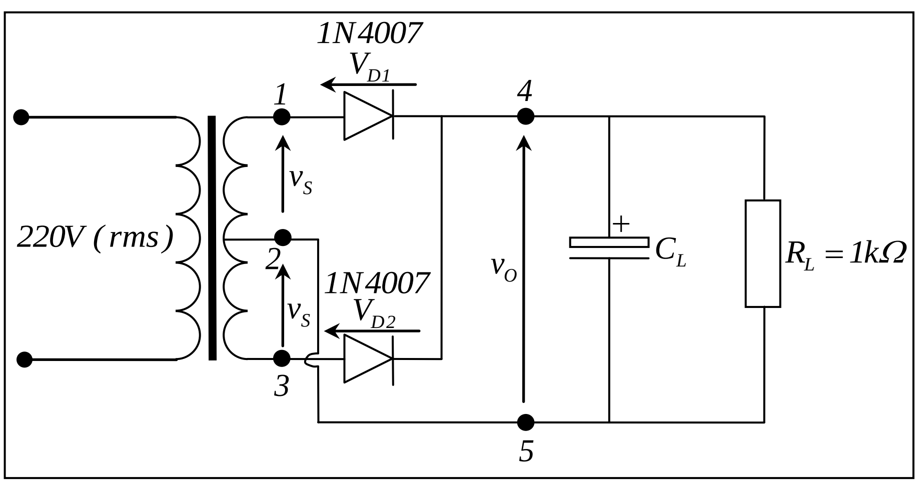

Figure 2. *Full-wave rectifier circuit with center-taped transformer and RC filter*

5- Carrying out the experiment

5-1- Representing the output voltage $v_O(t)$ for an Ohmic load resistance

- Assemble the circuit as shown in Figure 1 and apply an AC voltage of $v_S(max) = 2X6V$ to terminals 1 and 3.
- Use channel 1 of the oscilloscope to measure the peak-to-peak value of the transformer voltage at terminals 1 and 3.
- Transfer the graph into a sheet of graph paper. Each axis should be labeled and appropriate units indicated.
- Determine the amplitude (peak value) $v_S(max)$ and the frequency f of the transformer voltage $v_S(t)$
- Use the second oscilloscope channel to measure the output voltage $v_O(t)$ and enter this into the same sheet of graph paper.
- Determine the amplitude (peak value) $v_O(max)$ and the frequency f of the output voltage $v_O(t)$
- Calculate the amplitude of the output voltage $v_O(max)$ and compare the calculated value (Equation 1) with the measured value. Give reasons for any deviations which may occur.

5-2- Representing the output voltage as a function of the charging capacitor

- Assemble the circuit without the capacitor as shown in Figure 2 and apply an AC voltage of $v_S(max) = 2X6V$ to terminals 1 and 3.
- Without the capacitor, record the output voltage $v_O(t)$ on the oscilloscope.
- Transfer the graph into a sheet of graph paper.
- Connect the capacitors C_{L1} = 10µF, C_{L2} = 47µF and C_{L3} = 100 µF (Polarity must be correct) to terminals 4 and 5 (parallel to the load resistor) as in Figure 2 one after the other.
- Record the output voltages $v_O(t)$ of the different capacitors on the oscilloscope.

- Transfer the graphs into the same sheet of graph paper. Each axis should be labeled and appropriate units indicated. Label the output voltages according to the appropriate capacitor.

- Comment on the relationship between the output voltage ripple and the capacitance value of the capacitor.

5-3- Representing the output voltage as a function of the load resistor

- Without the capacitor, record the output voltage $v_O(t)$ on the oscilloscope.

- Transfer the graph into a sheet of graph paper.

- Connect the capacitor C_L = 47 μF between the terminals 4 and 5 shown in Figure 2.

- Connect the load resistors R_{L1} = 100Ω, R_{L2} = 1kΩ and R_{L3} = 10kΩ parallel to the capacitor one after the other.

- Display the corresponding output voltage $v_O(t)$ on the oscilloscope.

- Transfer the graphs into the same sheet of graph paper. Each axis should be labeled and appropriate units indicated. Label the output voltages according to the appropriate load resistor.

- Comment on the relationship between the output voltage ripple and the load resistor value. Give reasons for this.

6- Conclusion

Make a general conclusion about the experiments and the results obtained.

Experiment 4

Capacitor Filter Circuit

1- Objects of the Experiment

- Representing the ripple voltage on the load voltage.
- Determining the ripple voltage as a function of the charging capacitor and the load resistor.

2- Principles

Another example of a full-wave rectifier circuit appears in Figure 1. This circuit is a **bridge rectifier**, which still provides electrical isolation between the input alternating current powerline and the rectifier output, but does not require a center-tapped secondary winding (as the case of Figure 1 in Experiment 3). However, it does use four diodes, compared to only two in the previous experiment.

During the positive half of the input voltage cycle, v_s is positive, D_3 and D_2 are forward biased, D_1 and D_4 are reverse biased, and the direction of the current (solid line arrows) is as shown in Figure 1. During the negative half-cycle of the input voltage, v_s is negative, and D_1 and D_4 are forward biased, D_3 and D_2 are reverse biased. The direction of the current (dashed line arrows), shown in Figure 1, produces the same output voltage polarity as before. Because two diodes are in series in the conduction path, the magnitude of v_o is two diode drops less than the magnitude of v_s:

$$v_0 = |v_s| - 2V_\gamma \quad (\mathit{for}\ |v_s| \geq 2V_\gamma) \qquad \text{(Equation 1)}$$

3- Equipments

1 resistor 100Ω / 2W	577 32
1 resistor 1kΩ / 2W	577 44
1 resistor 10kΩ / 0.5W	577 56
1 electrolytic capacitor 10μF / 35V	578 37

1 Electrolytic capacitor 47μF / 35V	578 38
1 Electrolytic capacitor 100μF / 16V	578 39
4 Si-diode 1N4007	578 51
1 Two-oscilloscope	
1 multimeter	
1 Power supply unit	726 88
1 Plug-in board 297X300	72650
1 Measuring cable BNC/4mm	575 24
1 Set of bridging plugs 19mm	501 48
1 Set of connecting leads	501 532

4- Setup

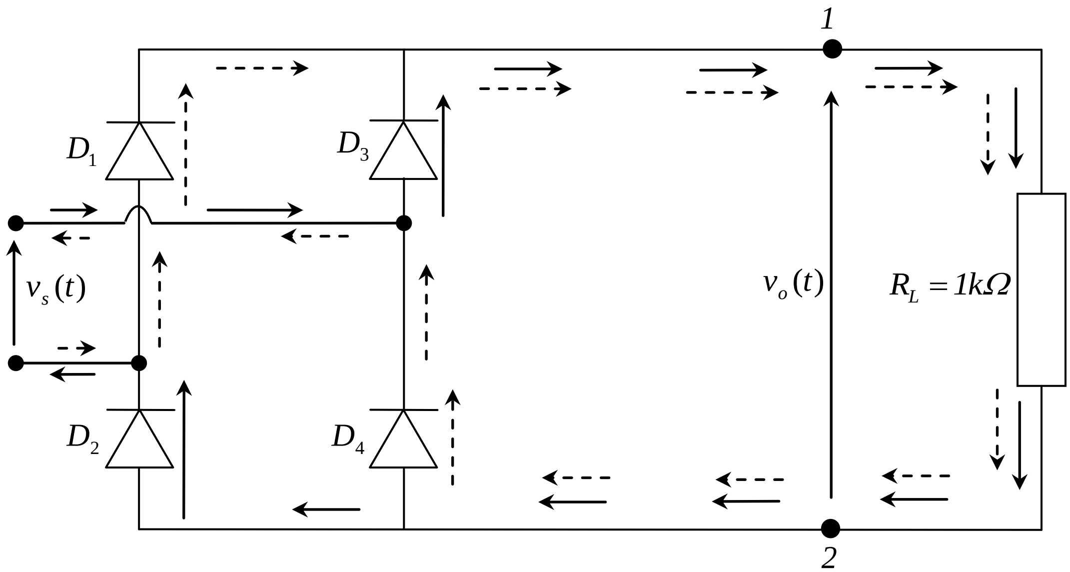

Figure 1. A full-wave bridge rectifier. The circuit showing the current direction (solid line arrows) for a positive input cycle, and the current direction (dashed line arrows) for a negative input cycle.

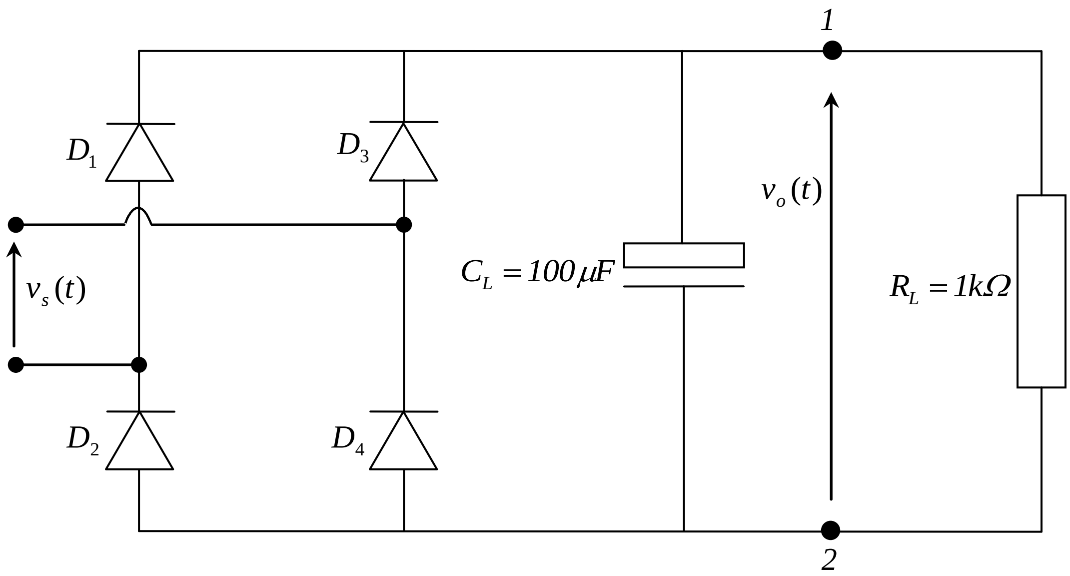

Figure 2. A full-wave bridge rectifier with an RC filter

5- Carrying out the experiment

5-1- Representing the ripple voltage on the load voltage

- Assemble the circuit as shown in Figure 1 and apply an AC voltage of V_s=*12V*, *f*=*60Hz*.

- Use channel 1 of the oscilloscope to measure the voltage $v_o(t)$ across the load resistor.

- Transfer the graph into a sheet of graph paper. Each axis should be labeled and appropriate units indicated.

The voltage $v_o(t)$ across the load resistor is a pulsating DC voltage, which is made up from a DC and an AC voltage component. The AC voltage component, which is superpositioned onto the DC voltage is designated the ripple voltage.

- Determine the peak-to-peak value of the ripple voltage from the graph ($V_{r\,pp}$ =??)

I5-2- Determining the ripple voltage as a function of the charging capacitor and the load resistor

- Measure the value of V_M (amplitude of $v_o(t)$) and the peak-to-peak value of the ripple voltage $V_{r\,pp}$ for the combination of charging capacitor and load resistor as given in Table 1. Enter the values in Line 1 of Table 1.

Table 1.

		$R_L = 1k\Omega$			$C_L = 100\mu F$	
		$C_L = 10\mu F$	$C_L = 47\mu F$	$C_L = 100\mu F$	$R_L = 100\Omega$	$R_L = 10k\Omega$
1	$V_{rpp}(V)$					
	$V_M\ (V)$					
2	$V_{rpp}(V)$ (Eq. 2)					
3	*Percent error (%)*					

- Describe the ripple voltage dependence on the charging capacitor.
- Describe the ripple voltage dependence on the load resistor.

- The peak-to-peak value of the ripple voltage can be calculated **approximately** using the expression below:

$$V_{rpp} = \frac{V_M}{2\,f\,RC} \qquad \text{(Equation 2)}$$

- Calculate the ripple voltages for the values given in Table1 and enter your results into Line 2 in the table
- Calculate the percent errors for the values given in Table 1 and enter your results into Line 3 in the table.

6- Conclusion

Make a general conclusion about the experiments and the results obtained.

Experiment 5
Zener-Diode Characteristics

1- Objects of the Experiment:

- Recording the current-voltage characteristic $I_Z = f(V_Z)$ of a Zener diode.
- Determining the quiescent point $Q(V_Z, I_Z)$
- Determining the differential resistance of a Zener diode.

2- Principles

Zener diodes are semiconductor diodes which are operated in the reverse direction via a series resistor connected upstream. The resistor serves to limit the current, i.e. to protect the diode.

When the applied voltage U exceeds a particular voltage V_{Z0} (breakdown voltage), which is dependent on the diode type, the barrier junction conducts and the current I_Z greatly increases. This happens for two reasons:

1- When the electric field strength exceeds approximately $2x10^5$V/cm in the barrier junction, which is only several μm thick, electrons in the crystal are ripped out of their fixed bonds and become available as charge carriers (as do the holes left behind). This process is known as the **<u>Zener effect</u>**. The Zener effect is only effective for diodes with a breakdown voltage (V_{Z0}) of up to approximately 6V.

2- The charge carriers of the reverse current experience such a strong acceleration under the high field that they collide with valence electrons at high speed, knocking them out of their fixed bonds. These electrons are then in turn accelerated and so the cycle is continually repeated. This effect is known as the **<u>avalanche effect</u>** because the number of charge carriers climbs in such a dramatic manner. The avalanche effect occurs in diodes with a breakdown voltage (V_{Z0}) greater than 6V.

The voltage V_Z of a Zener diode is not completely constant in the breakdown region; it is dependent on the current I_Z and the temperature.

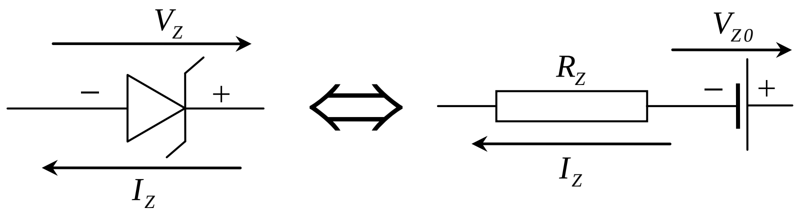

Figure 1. Circuit symbol of a Zener diodel and its equivalent circuit diagram for $V_Z > V_{Z0}$.

The breakdown voltage V_{Z0} can be calculated using the expression below for $V_Z > V_{Z0}$ (temperature effects have been ignored)

$$V_Z = V_{Z0} + r_Z I_Z \qquad with \qquad r_Z = \frac{\Delta V_Z}{\Delta I_Z}$$

3- Equipments

1 resistor 1Ω / 2W	
1 resistor 330Ω / 2W	577 380
1 Zener diode ZPD 9	578 55
2 multimeters	
1 Power supply unit	726 88
1 Plug-in board 297X300	72650
1 Set of bridging plugs 19mm	501 48
1 Set of connecting leads	501 532

4- Setup

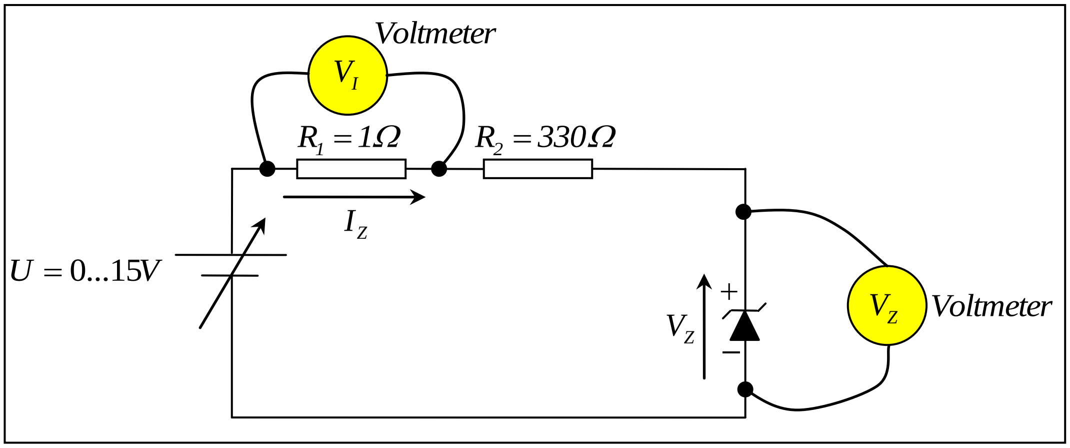

Figure 2.

5- Carrying out the experiment

5-1- Recording the current-voltage characteristic $I_D = f(V_D)$ of a Zener diode

- Assemble the circuit as shown in Figure 2 and carry out the measurements for the voltages given in Table 1.

Table 1

ZPD 9	
V_Z (V)	**I_Z (mA)=V_I/R_1**
1	
3	
5	
7	
8	
9	
9.5	
10	
10.5	
11	
12	

13	
14	

- Prepare a sheet of graph paper for plotting I_Z versus V_Z. You should make I_Z the vertical axis and V_Z the horizontal axis. Each axis should be labeled and appropriate units indicated. The graph should have a title.
- Plot your data on the graph and draw the corresponding current-voltage characteristic $I_Z=f(V_Z)$.
- What function does the series resistor R_2 have?
- Determine the breakdown voltage V_{Z0} of the diode by drawing a tangent to the approximately linear part of the curve and reading the voltage from the voltage axis where the tangent intersects it.

5-2- Determining the quiescent point $Q(V_Z, I_Z)$ and the differential resistance r_Z

The quiescent point or Q-point of a circuit is determined by the components used and the operating voltage. The Q-point is given by the intersection of the Zener diode characteristic with the series resistor characteristic (load line). The Zener diode characteristic is given by the manufacturer in a data manual or it can be determined by measurement. Two points are required in order to be able to construct the load line:

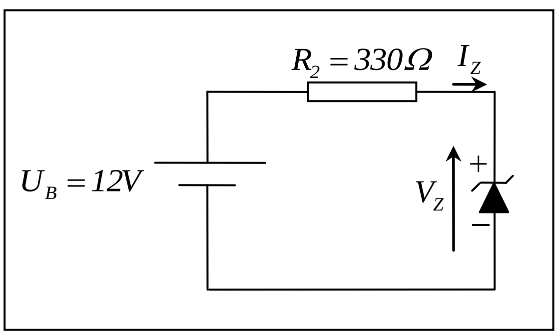

Figure 3

$$U_B = (R_1 + R_2)I_Z + V_Z \qquad \text{(Equation 1)}$$

$$U_B - V_Z = (R_1 + R_2) I_Z \qquad \text{(Equation 2)}$$

$$I_Z = -\frac{1}{R_1 + R_2} V_Z + \frac{U_B}{R_2} \qquad \text{(Equation 3)}$$

These two points A(V_{Z1},I_{Z1}), and B(V_{Z2},I_{Z2}) can be determined from Equation 3 and Figure 3. Plotting points A and B and tracing the line connecting the two points gives the load line.

- Construct the load line for the circuit shown in Figure 3 in the same sheet of graph paper and label the quiescent point (the quiescent point is the intersection between the I-V characteristics of Zener diode and the load line)
- Give the quiescent point Q(V_Z,I_Z).
- Draw a tangent to the Zener diode characteristic at the quiescent point and construct a right-angled triangle using the tangent.
- Determine the differential resistance r_Z from the intersections at the axes.

6- Conclusion

Make a general conclusion about the experiments and the results obtained.

Experiment 6

Voltage Stabilization with Zener Diode

1- Objects of the Experiment:

- Representing the output voltage characteristic $V_z = f(U)$ as a function of the Zener diode used.
- The influence of the load resistance and load current on the output voltage.
- Stabilizing a pulsing DC voltage.

2- Principles

Zener diodes are used in the assembly of simple circuits for voltage stabilization. Because of the slope of the characteristic in the breakdown region, large changes in the diode current only cause small changes in the diode voltage V_Z.

The voltage V_Z should remain as constant as possible during fluctuations in the input voltage U and variations of the load resistance R_L and thus the load current I_L (see Figure 3).

A change in the Zener current I_Z can be caused by a change ***a)*** in the input voltage U and ***b)*** in the load current I_L. In both cases a small Zener diode differential resistance is important for good stabilization of the output voltage.

3- Equipments

1 resistor 1Ω / 2W	
1 resistor 100Ω / 2W	577 32
1 resistor 330Ω / 2W	577 380
1 Potentiometer 1kΩ / 2W	577 92
1 Electrolytic capacitor 100µF / 35V	578 39
1 Si diode 1N4007	578 51
1 Zener diode ZPD 9	578 55
1 Two-oscilloscope	

2 multimeters	
1 Power supply unit	726 88
1 Plug-in board 297X300	72650
1 Measuring cable BNC/4mm	575 24
1 Set of bridging plugs 19mm	501 48
1 Set of connecting leads	501 532

4- Setup

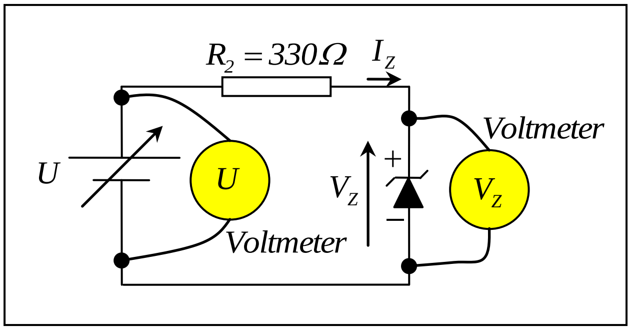

Figure 1. Circuit representing the output voltage characteristic $V_Z = f(U)$

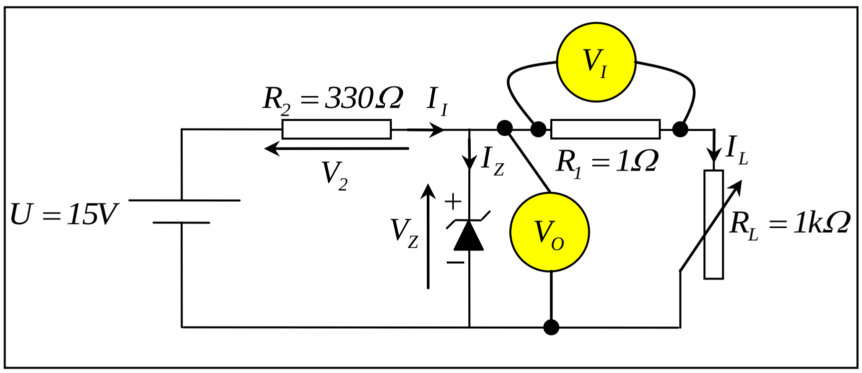

Figure 2. Circuit showing the influence of load resistance and load current on the output voltage

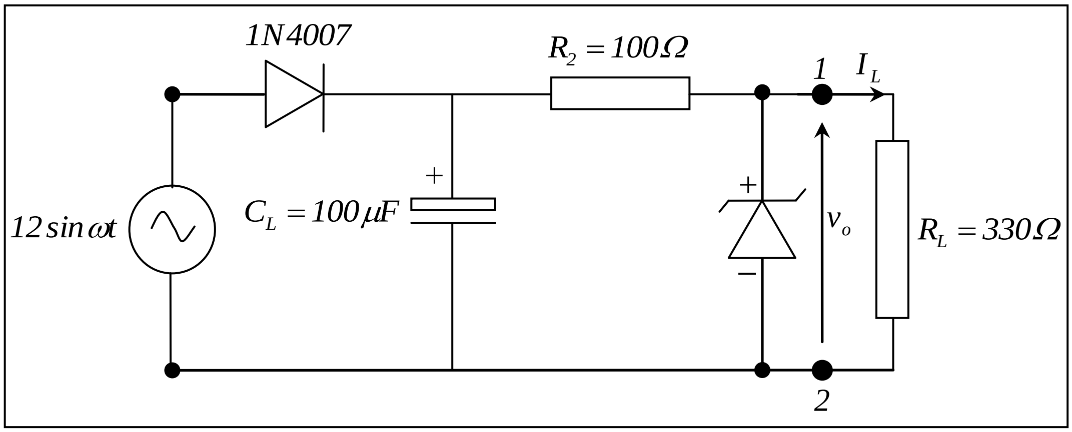

Figure 3. *Circuit for stabilizing the pulsing DC voltage*

5- Carrying out the experiment

5-1- Representing the output voltage characteristic V_Z = f(U) as a function of the Zener diode

- Assemble the circuit as shown in Figure 1 and measure the output voltages corresponding to the input voltages given in Table 1.

Table 1.

U (V)	**V_Z (V)**
1	
3	
5	
7	
8	
8.5	
9	
9.3	
9.6	
10	
10.5	
11	

12	
13	
14	

- Prepare a sheet of graph paper for plotting *U* versus V_Z. You should make V_Z the vertical axis and *U* the horizontal axis. Each axis should be labeled and appropriate units indicated. The graph should have a title.
- Plot your data and draw the graph for $V_Z = f(U)$.
- Explain the shape of the curve.

5-2- Influence of load resistance and load current on the output voltage

- Supply the circuit shown in Figure 2 with an operating voltage U = 15V. Using potentiometer R_L, set the load currents given in Table 2 and measure the output voltages $V_O \approx V_Z$.
- Enter the output voltage values and the load resistances R_L into Table 2.

Table 2

I_L (mA) = V_I/R_1	$V_O \approx V_Z$ (V)	R_L (Ω)
45		
40		
35		
30		
25		
20		
15		
10		

- Prepare a sheet of graph paper for plotting V_O versus R_L. You should make V_O the vertical axis and R_L the horizontal axis. Each axis should be labeled and appropriate units indicated. The graph should have a title.
- Plot your data and draw the graph for $V_O = f(R_L)$.

- Determine the smallest possible load resistor value (R_{Lmin}) which gives a stable output voltage from the characteristic.

5-3- Stabilizing a pulsing DC voltage

- Assemble the circuit as shown in Figure 3 (**without Zener diode**) and supply it with a sinusoidal AC voltage U=12V, f = 60Hz.
- Record the voltage v_o across the load resistance on the oscilloscope
- Prepare a sheet of graph paper for plotting v_o versus time t. You should make $\boldsymbol{v_o}$ the vertical axis and ***t*** the horizontal axis. Each axis should be labeled and appropriate units indicated. The graph should have a title.
- Draw the graph for $v_o = f(t)$ (without Zener diode)
- Connect the Zener diode as shown in Figure 3 and record the characteristic once more on the oscilloscope.
- Draw the graph for $v_o = f(t)$ (with Zener diode) in the same sheet of graph paper.
- Describe the influence of the Zener diode on the voltage across the load resistor.

6- Conclusion

Make a general conclusion about the experiments and the results obtained.

Experiment 7

Bipolar Transistor Characteristics

1- Objects of the Experiment:

- Base-emitter diode characteristic for open collector.
- Representing the relationship I_C (I_B) with V_{CE} as parameter (V_{CE} = constant).
- Measurement methods for determining the relation between V_{CE} and I_C.

2- Principles

There are two types of bipolar transistors: npn transistors doping and pnp transistors doping as shown in Figure 1.

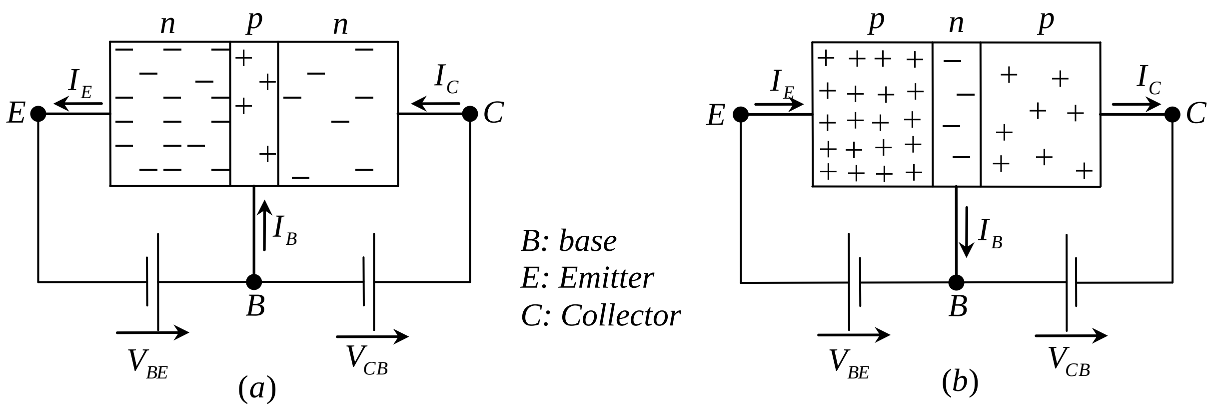

Figure 1. *(a) npn transistors doping; (b) pnp transistors doping*

Emitter: this zone emits charge carriers into the middle zone (base).

Collector: This zone collects charge carriers.

I_B causes a flood of charge carriers in the weekly-doped base. The vast majority of these charge carriers are removed via the collector by V_{CB}.

I_C is dependent on I_B and $I_C >> I_B$: a small base current can control a relatively large collector current I_C.

3- Equipments

1 resistor 1kΩ / 2W	577 44
1 resistor 100Ω / 2W	577 32
1 resistor 10kΩ / 0.5W	577 56
1 Potentiometer 10kΩ / 1W	577 925
1 Potentiometer 1kΩ / 1W	577 92
1 Transistor BD 137, NPN	578 67
1 multimeters	
1 Power supply unit	726 88
1 Plug-in board 297X300	72650
1 Set of bridging plugs 19mm	501 48
1 Set of connecting leads	501 532

4- Setup and carrying out the experiment

4-1- Base-emitter diode characteristic for open collector

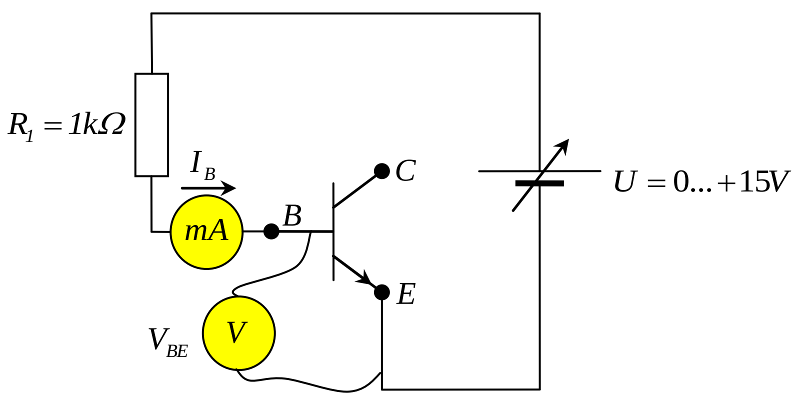

Figure 1. Base-emitter diode characteristic for open collector

The characteristic of $I_B = f(V_{BE})$ is called the transistor input characteristic.

- Assemble the circuit as shown in Figure 1.

- Measure the relation between I_B and V_{BE} and enter the values in Table 1.

Table 1

V_{BE} (V)	I_B (mA)
0.1	

0.3	
0.5	
0.6	
0.65	
0.7	
0.75	
0.8	

- Prepare a sheet of graph paper for plotting I_B versus V_{BE}. You should make I_B the vertical axis and V_{BE} the horizontal axis. Each axis should be labeled and appropriate units indicated. The graph should have a title.
- Plot your data from Table 1 and draw the graph of $I_B = f(V_{BE})$.

4-2- Control characteristic and current amplification

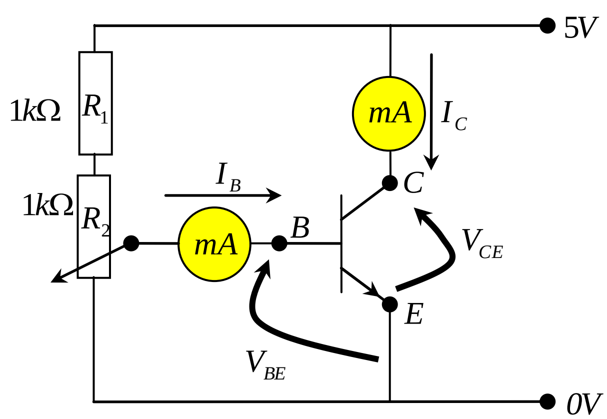

Figure 3.

The base voltage V_{BE} is set using potentiometer R_2. This controls the base current I_B which then in turn causes the current I_C.

- Assemble the circuit as shown in Figure 3.
- Adjust the potentiometer in both directions.
- Measure the collector currents witch correspond to the base currents given in Table 3. Enter these values into the second column.

Table 3.

I_B (μA)	I_C (mA)
10	
20	
50	
80	
100	
200	
300	
500	

- Prepare a sheet of graph paper for plotting I_C versus I_B (Table 3). You should make I_C the vertical axis and I_B the horizontal axis. Each axis should be labeled and appropriate units indicated. The graph should have a title.

- Plot your data on the graph.

- Draw best fit line to the points on your graph. The best fit line must be drawn by using method of least squares

- Determine the slope of your line.

- Roughly describe the relationship between I_B and I_C.

4-3- Transistor output characteristic

- Assemble the circuit as shown in Figure 4.

- Set a base current $I_B = 100\ \mu A$ using the base potentiometer (10kΩ). You must maintain the base current at a constant magnitude.

- Set the voltage V_{CE} given in Table 4 using the collector potentiometer (1kΩ), measure the corresponding value V_2 and calculate V_1 in each case. (Make sure that I_B is reset as required.)

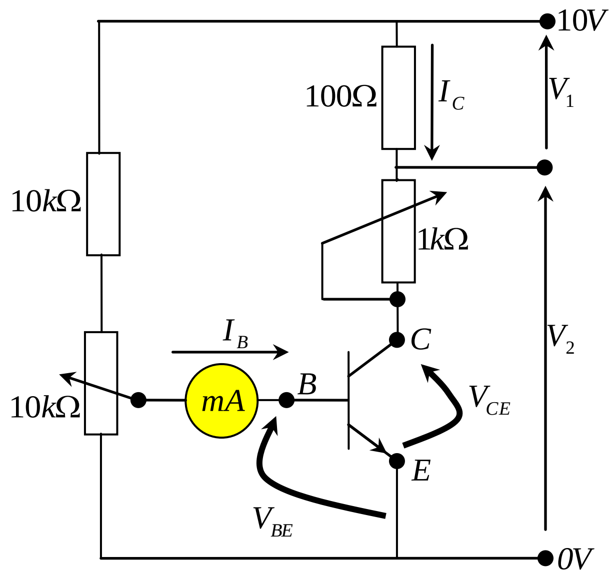

Figure 4. Measurement method for determining the relationship between V_{CE} and I_C.

- Calculate the corresponding collector currents and enter V_1 and I_C values in Table 4.
- Repeat the procedure for the base currents $I_B = 200\ \mu A$, $I_B = 300\ \mu A$, $I_B = 400\ \mu A$, and $I_B = 500\ \mu A$ (Tables 5 – 8).

Table 4.

$I_B = 100\ \mu A$			
V_{CE} (V)	V_2 (V)	V_1 (V)	I_C (mA)
0			
….			
….			
….			
….			
….			
0.6			

Table 5.

$I_B = 200\ \mu A$			
V_{CE} (V)	V_2 (V)	V_1 (V)	I_C (mA)
0			
….			
….			
….			
….			
….			
0.6			

Table 6.

$I_B = 300\ \mu A$			
V_{CE} (V)	V_2 (V)	V_1 (V)	I_C (mA)
0			
….			
….			
….			
….			
….			
0.6			

Table 7.

$I_B = 400\ \mu A$			
V_{CE} (V)	V_2 (V)	V_1 (V)	I_C (mA)
0			
….			
….			
….			
….			
….			
0.6			

Table 8.

$I_B = 500\ \mu A$			
V_{CE} (V)	V_2 (V)	V_1 (V)	I_C (mA)
0			
….			
….			
….			
….			
….			
0.6			

- Prepare a sheet of graph paper for plotting I_C versus V_{CE} (Table 4-8). You should make I_C the vertical axis and V_{CE} the horizontal axis. Each axis should be labeled and appropriate units indicated. The graph should have a title.
- Plot your data on the graph.
- Describe the curve of the parameter $I_B = 100\ \mu A$.
- Compare the high base current curves with the low ones.

5- Conclusion

Make a general conclusion about the experiments and the results obtained.

Experiment 8

Field Effect Transistor (FET)

1- Objects of the Experiment:

- Study the drain current - voltage characteristics for n-channel JFET.
- Representing the relationship between drain current, I_D, and gate to source voltage, V_{GS}, for the transistor biased in the saturation region.

2- Principles

The acronym 'FET' stands for **field effect transistor**. It is a three-terminal unipolar solid-state device in which current is controlled by an **electric field.**

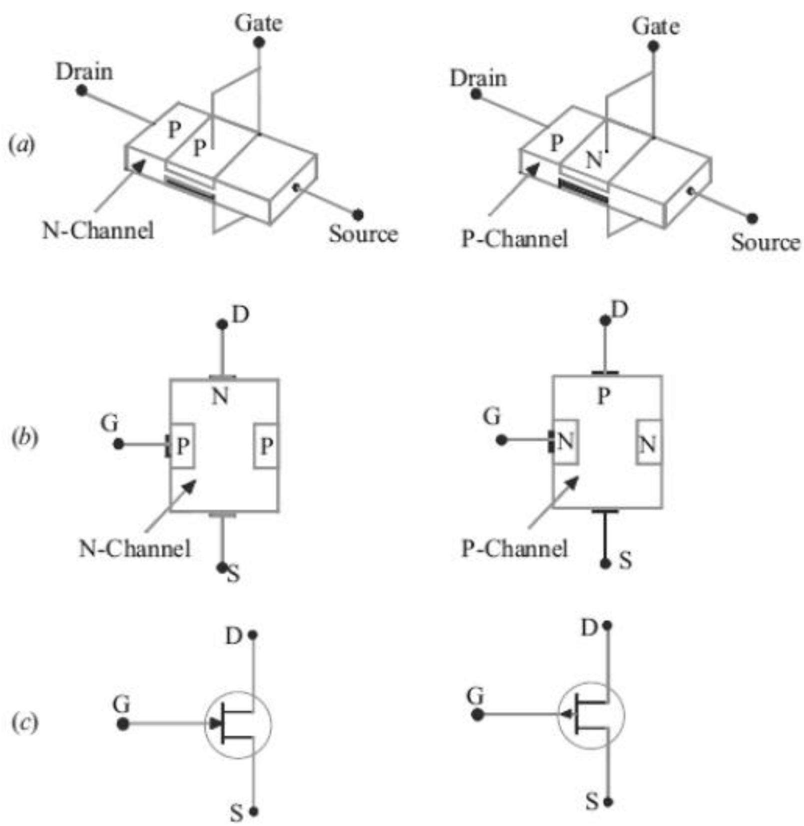

Fig. 1 FET construction

As shown in Fig.1, it can be fabricated with either an N-channel or P-channel though N-channel is generally preferred. For fabricating an N-channel JFET, first a narrow bar of

N-type semiconductor material is taken and then two P-type junctions are diffused on opposite sides of its middle part [Fig.1 (a)]. These junctions form two P-N diodes or gates and the area between these gates is called channel. The two P-regions are internally connected and a single lead is brought out which is called gate terminal. Ohmic contacts (direct electrical connections) are made at the two ends of the bar-one lead is called source terminal S and the other drain terminal D. When potential difference is established between drain and source (V_{DS}), current (I_D) flows along the length of the 'bar' through the channel located between the two P regions. The current consists of only majority carriers which, in the present case, are electrons. P-channel JFET is similar in construction except that it uses P-type bar and two N type junctions. The majority carriers are holes which flow through the channel located between the two N-regions or gates.

Following FET notation is worth remembering:

- **Source**: it is the terminal through which majority carriers enter the bar. Since carriers come from it, it is called the source.
- **Drain**: it is the terminal through which majority carriers leave the bar i.e. they are drained out from this terminal. The drain to source voltage, V_{DS}, drives the drain current I_D.
- **Gates**: these are two internally-connected heavily-doped impurity regions which form two P-N junctions. The gate-source voltage VGS reverse biases the gates.
- **Channel**: it is the space between two gates through which majority carriers pass from source-to-drain when V_{DS} is applied.

Schematic symbols for N-channel and P-channel JFET are shown in Fig.1 (c). It must be kept in mind that gate arrow always points to N-type material.

We will consider the following two characteristics:

- **Drain characteristics**: it gives relation between I_D and V_{DS} for different values of V_{GS} (which is called running variable).
- **Transfer characteristics**: It gives relation between I_D and V_{GS} for different values of V_{DS} in the saturation region.

We will analyze these characteristics for an N-channel JFET connected in the common-source mode as shown in Fig. 2.

3- Equipment

1 Power supply unit	727 88
1 resistor 1kΩ / 2W	577 44
1 resistor 47kΩ / 0.5W	577 64
1 potentiometer 10 kΩ / 1W	577 925
1 potentiometer 100 kΩ / 1W	577 96
1 FET transistor BF 244	578 77
3 multimeters	
1 Plug-in board 297X300	72650
1 Set of bridging plugs 19mm	501 48
1 Set of connecting leads	501 532

4- Setup and carrying out the experiment

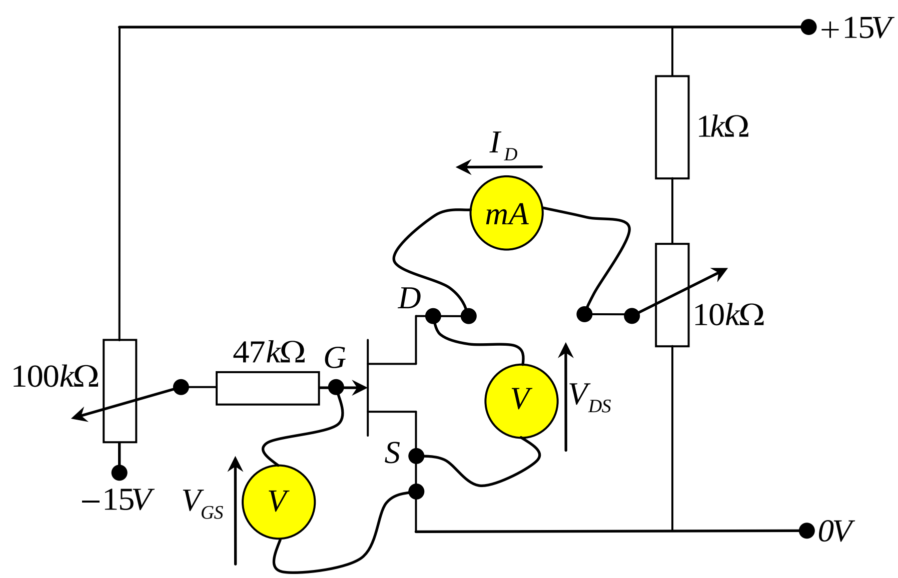

Figure 2.

4-1- Study the drain voltage-current characteristic:

- Assemble the circuit as shown in Figure 2

- Set a gate voltage V_{GS} = -1.3V by using the 100kΩ potentiometer

- Measure the relation between I_D (multimeter) and V_{DS} (multimeter) and enter the values in Table 1.

Table 1

V_{DS} (V)	I_D (mA)
0	
0.2	
0.5	
1	
1.5	
2	
2.5	
3	
3.5	
4	
4.5	
5	

-Repeat measuring for different value of V_{GS}=(-1V, -0.6V, -0.3V, 0.0V, 0.2V, 0.4V)

- Prepare a sheet of graph paper for plotting I_D versus V_{DS}. You should make I_D the vertical axis and V_{DS} the horizontal axis. Each axis should be labeled and appropriate units indicated. The graph should have a title.

- Plot your data from Table 1 and draw the graph of $I_D = f(V_{DS})$.

4-2- Representing the relationship between I_D and V_{GS} .

- Directly from the graph fill Table 2 by taking the drain voltage V_{DS} at a fixed value in saturation region

Table 2.

V_{GS} (V)	***I_D(mA)***
-1.3	
-1.0	
-0.6	
-0.3	
0.0	
0.2	
0.4	

- Prepare a sheet of graph paper for plotting I_D versus V_{GS}. You should make I_D the vertical axis and V_{GS} the horizontal axis. Each axis should be labeled and appropriate units indicated. The graph should have a title.
- Plot your data from Table 1 and draw the graph of $I_D = f(V_{GS})$.

5- Conclusion

Make a general conclusion about the experiments and the results obtained.

Appendix

Method of Least Squares

Linear regression using least squares permits determination of the best fit line by minimizing the sum of the squares of deviations of individual *y* values from the fitted straight line. It can be shown that the slope, *m*, and y-intercept, *b*, are given by

$$m = \frac{\sum x_i y_i - \frac{1}{n}\left(\sum x_i\right)\left(\sum y_i\right)}{\sum\left(x_i^2\right) - \frac{1}{n}\left(\sum x_i\right)^2}, \qquad b = \frac{\sum y_i - m\sum x_i}{n}$$

where *n* represents the number of points (data pairs) $(x_i, y_i),\ i = 1, \ldots, n$

Example

A student recorded the speed of an object as a function of time and obtained the following data:

i	Time (s) (x_i)	Speed (m/s) (y_i)	Time^2 (x_i^2)	Speed^2 (y_i^2)	Time x Speed $(x_i y_i)$
1	1.0	0.45	1.0	0.203	0.450
2	2.0	0.81	4.0	0.656	1.620
3	3.0	0.91	9.0	0.828	2.730
4	4.0	1.01	16.0	1.020	4.040
5	5.0	1.36	25.0	1.850	6.800
6	6.0	1.56	36.0	2.434	9.360
7	7.0	1.65	49.0	2.723	11.55
8	8.0	1.85	64.0	3.423	14.80
9	9.0	2.17	81.0	4.709	19.53
	$\sum x_i = 45$	$\sum y_i = 11.77$	$\sum\left(x_i^2\right) = 285$	$\sum\left(y_i^2\right) = 17.846$	$\sum x_i y_i = 70.88$

- The slope, m, is determined as indicated above:

$$m = \frac{\sum x_i y_i - \frac{1}{n}\left(\sum x_i\right)\left(\sum y_i\right)}{\sum\left(x_i^2\right) - \frac{1}{n}\left(\sum x_i\right)^2} = \frac{70.880 - \frac{1}{9}(45.0)(11.77)}{285.0 - \frac{1}{9}(45.0)^2} = 0.20 m/s^2$$

- The y-intercept, b, is determined as:

$$b = \frac{\sum y_i - m\sum x_i}{n} = \frac{11.77 - 0.20(45.0)}{9} = 0.31 m/s$$