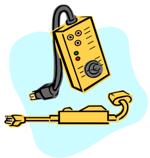
SINGLE-PHASE RECTIFIERS WITH CAPACITIVE FILTER

I. OBJECTIVES

a) To establish the dependence between the type of the rectifier (half-wave and full-wave) and the shape of the rectified voltage.
b) To determine how the load resistor and the values of the filtering capacitor influence the rectified voltage.
c) To deduce the maximum reverse voltage on the rectifying diodes.



II. COMPONENTS AND INSTRUMENTATION

For the experiment you will use an experimental board, a transformer, four rectifying diodes, two electrolytic capacitors, a resistor and a potentiometer. In order to visualise the voltages you will use a dual channel oscilloscope, a voltmeter and an ammeter for the measurement of the average values of the voltage and current.

III. THEORETICAL ASPECTS

1. Half-wave rectifiers

1.1. Half-wave recitifers with resistive load

The voltage v_I is obtained from the secondary of a transformer, with a ratio of 23:1. The primary voltage comes from the outlet and is a sinewave,with 230V effective value and 50 Hz frequency.

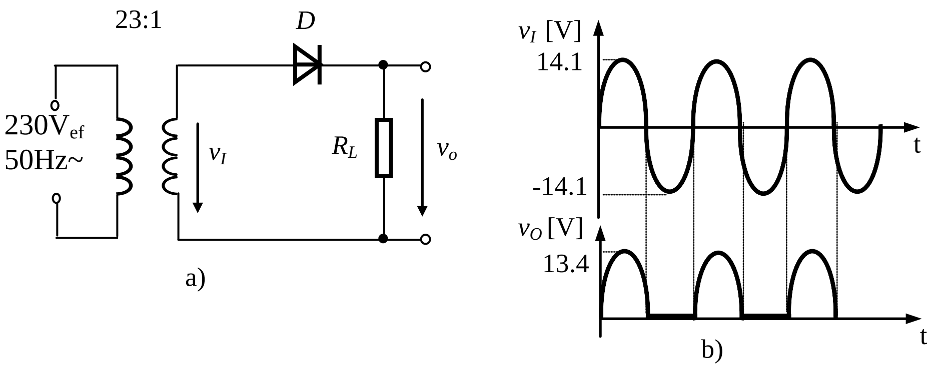


Fig. 1. Half-wave rectifier a) Circuit; b) Waveforms;

The amplitude of v_I is computed as follows:

$$n = 23 = \frac{\hat{V}_{primary}}{\hat{V}_{\sec undary}}$$

$$\hat{V}_{secundary} = \hat{V}_I = \frac{\hat{V}_{primary}}{23} = \frac{230\sqrt{2}}{23} = 14.1V$$

1.2. Half-wave rectifiers with capacitive filter

Rectifiers with D and R (for example the half-wave rectifier in Fig. 1) generate an output voltage of a single sign, but it has a considerable variation, equal to the amplitude of the input signal. To obtain a continuous voltage, we must smoothen these variations by adding a filtering capacitor (see Fig. 2).

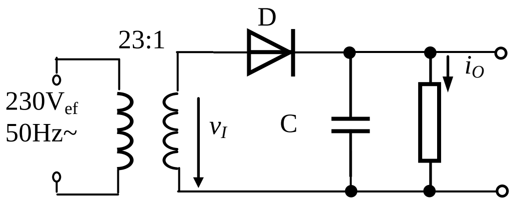


Fig. 2. Half-wave rectifier with capacitive filter

The circuit can be seen also as a positive peak detector loaded with *R*. In actual practical situations, such as the design of power supplies a load resistance will be inherently present. If the input voltage is an alternative sinusoidal one, between two consecutive peaks of v_I, the capacitor will discharge through *R* and v_O will go down, unlike the situation without *R* when v_O was constant (see Fig.2.4.2). The waveforms in steady-state regime for the circuit in Fig. 2 are plotted in Fig. 3. The time constant of the circuit, *RC*, should be much greater than the period *T* of the signal, $RC >> T$. Note that the output is no longer a constant dc voltage but it may be considered as being composed on a dc voltage on which an ac component, called *ripple,* is superimposed.

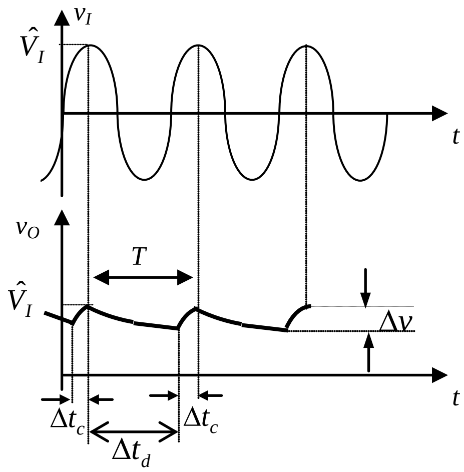


Fig. 3. Waveforms for half-wave rectifier with capacitive filter.

We specify the followings:

- The diode *D* conducts for short time intervals Δt_c, close to the positive peaks of v_I. We neglect the voltage drop across the conducting diode. The capacitor charges with an electric charge equal to the one lost on the longest duration of the discharge, Δt_d.

$$v_c(t) = (1 - e^{-\frac{t}{RC}})V_\infty + V(0) \cdot e^{-\frac{t}{RC}}$$

- When *D –(off), C* discharges through *R* and in this way v_O drops exponential with the time constant *RC.* At the end of the discharge interval Δt_d, which is almost equal with $T, v_O = \hat{V}_I - \Delta v$, where Δv is the peak to peak value of the ripple of the output voltage. If $RC >> T$, Δv is small. A special attention will be paid to this ripple Δv.

We remind the expression of the voltage across the capacitor.

$$v_c(t) = (1 - e^{-\frac{t}{RC}})V_\infty + V(0)e^{-\frac{t}{RC}}$$

Let us assume the initial time moment, t=0 as being the moment when the discharge of the capacitor begins (v_I at the maximum value), therefore $V(0) = \hat{V}_I$. V_∞ is the value at which the voltage on the capacitor could finally reach, if the input signal will disappear, $V_\infty = 0\text{V}$. The time interval in which we are interested is the one of the capacitor's discharge $t = \Delta t_d$, when the value of the voltage is:

$$v(\Delta t_d) = \hat{V}_I - \Delta v$$

We obtain:

$$\hat{V}_I - \Delta v = \hat{V}_I e^{-\frac{\Delta t_d}{RC}} \approx \hat{V}_I e^{-\frac{T}{RC}}$$

Because $RC >> T$ we can use the approximation:

$$e^{-\frac{T}{RC}} \approx 1 - \frac{T}{RC}$$

$$\hat{V}_I - \Delta v = \hat{V}_I - \frac{T}{RC}\hat{V}_I$$

$$\Delta v = \frac{T}{RC}\hat{V}_I$$

The higher the time constant RC (usually by choosing a large value for C), the smaller is the ripple, so v_O is closer to a smooth continuous voltage.

Remark: An alternative interpretation of the previous approximation is that, on the intervals Δt_d we consider that the discharge of the capacitor happens at a constant current $I_O = \frac{\hat{V}_I}{R}$. This interpretation holds as long as $\Delta v << \hat{V}_I$

$$\Delta v = \frac{T}{C} I_O = \frac{T}{RC}\hat{V}_I$$

If we want to use the frequency f of the voltage:

$$\Delta v = \frac{1}{fC} I_O = \frac{1}{fRC}\hat{V}_I$$

2. Full-wave rectifiers

2.1. Full-wave rectifiers with resistive load

The schematic of the full-wave rectifier with resistive load is depicted in Fig. 4. The input and output voltages are plotted in Fig. 5.

On the positive half cycle of v_I , D_1 and D_3 are in conduction (while D_2 and D_4 are cutoff), and on the negative half wave D_4 and D_2 are in conduction (D_1 and D_3 being cutoff).

If we consider 0.7V across the conducting diodes, the amplitude of the output voltage is with 2·0.7V=1.4V less than the amplitude of the input voltage.

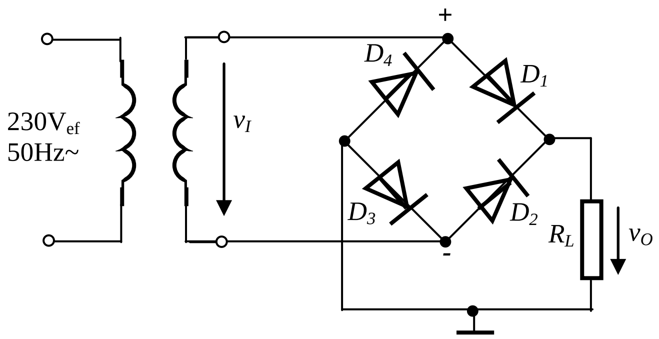


Fig. 4. Full-wave diode bridge rectifier

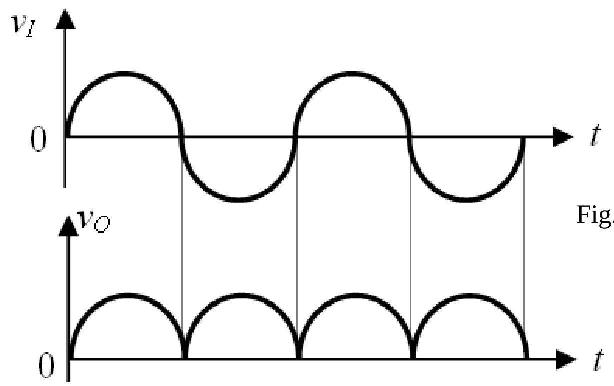


Fig. 5. Full-wave diode bridge rectifier - waveforms

2.1. Full-wave rectifiers with capacitive filters

In the case of a full-wave rectifier with capacitive filter (Fig. 6.), the reasoning is the same, just that the discharge time of the capacitor is shorter, approximately half of a period (Fig. 7).

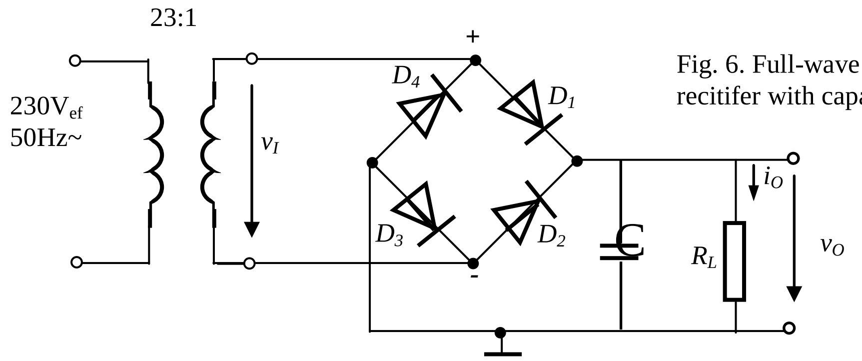


Fig. 6. Full-wave diode bridge recitifer with capacitive filter

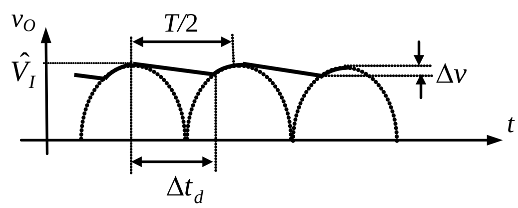
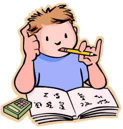


Fig. 7. Full-wave rectifier with capacitive filter - waveforms

In this case we have the relationship:

$$\Delta v = \frac{\hat{V}_I}{2\,fRC} \qquad \text{or} \qquad \Delta v = \frac{1}{2\,fC} I_O$$

Using the same capacitance, in the case of full-wave rectifier, the output ripple will be two times smaller.



IV. PREPARATION

1.P. SINGLE-PHASE HALF-WAVE RECTIFIER

1.1.P. SINGLE-PHASE HALF-WAVE RECTIFIER WITH RESISTIVE LOAD

- How do the waveforms for v_S, v_O and i_O look like for the circuit shown in Fig. 8 .if the transformer's ratio is n = 23?
- How can you compute the average value (DC component) V_0 of the output voltage?
- What is the value of the output voltage ripple ΔV_O (the difference between the maximum and minimum value)?
- What is the value of the maximum reverse voltage on the rectifying diode?

1.2.P. SINGLE-PHASE HALF-WAVE RECTIFIER WITH CAPACITIVE FILTER

- How do the waveforms for v_S and v_O look like, for the circuit shown in Fig. 9?
- Compare the output voltage ripple for this circuit with the one obtained at 1.1.P.

2.P. SINGLE-PHASE FULL-WAVE RECTIFIER

2.1.P. SINGLE-PHASE FULL-WAVE RECTIFIER WITH RESISTIVE LOAD

All the points below refer to the circuit shown in Fig. 10.

- What are the states (on/off) of the four diodes, for the positive wave of the v_s voltage?
- How do the waveforms of v_S and v_O look like?
- Compare the output voltage ripple for this circuit with the one obtained at 1.1.P.

2.2.P. SINGLE-PHASE FULL-WAVE RECTIFIER WITH CAPACITIVE FILTER

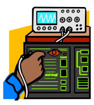
- How does the output voltage look likes for the circuit in Fig. 11?
- Compare the output voltage ripple for this circuit with the one obtained at 2.1.P.

V. EXPLORATIONS AND RESULTS

Notes: The sinusoidal voltage, which should be rectified in this experiment, is obtained from the transformer, T_r , as you can see in Fig. 8. The voltage source used as rectifier is a floating one. Because the primary of the transformer is connected to the voltage from the main network, be careful ***not to touch*** *this part of the transformer when it is plugged in, because you can be* ***electrocuted!!!***

1. SINGLE-PHASE HALF-WAVE RECTIFIER

1.1 SINGLE-PHASE HALF-WAVE RECTIFIER WITH RESISTIVE LOAD



Exploration

Build the circuit shown in Fig. 8.

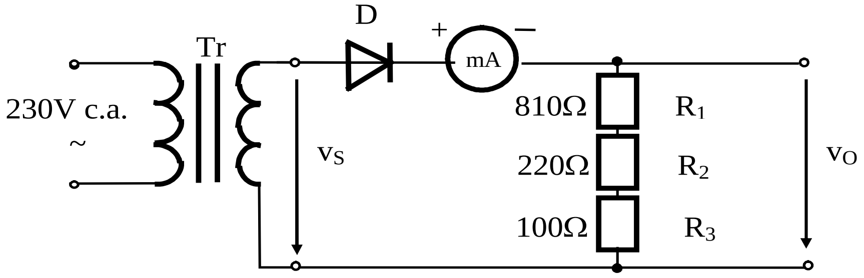


Fig. 8. Single-phase half-wave rectifier

For three combinations of the load resistance, ($R_1 + R_2 + R_3$, R_2+R_3, R_3), do the following:

- With the dual channel oscilloscope, calibrated, set on Y-t mode, visualise v_S and v_O.
- With a DC voltmeter, measure the value of the dc component of V_O.
- Measure (read) the output voltage ripple, ΔV_O, from the oscilloscope.
- With the dc miliammeter set on **200mA**, measure the dc component of I_O (load current).

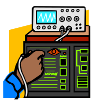
Results

- $v_S(t)$ and $v_O(t)$ for the load resistance $R_1 + R_2 + R_3$
- Fill in Table 1 – the rows with C = 0μF.

Table 1

	R_L [Ω] / C [μF]	$R_1+R_2+R_3$	R_2+R_3	R_3
	0			
I_O [mA]	100			
	1000			
	0			
V_O [V]	100			
	1000			
	0			
ΔV_O[V]	100			
	1000			

1.2 SINGLE-PHASE HALF-WAVE RECTIFIER WITH CAPACITIVE FILTER



Exploration

Build the circuit shown in Fig. 9.

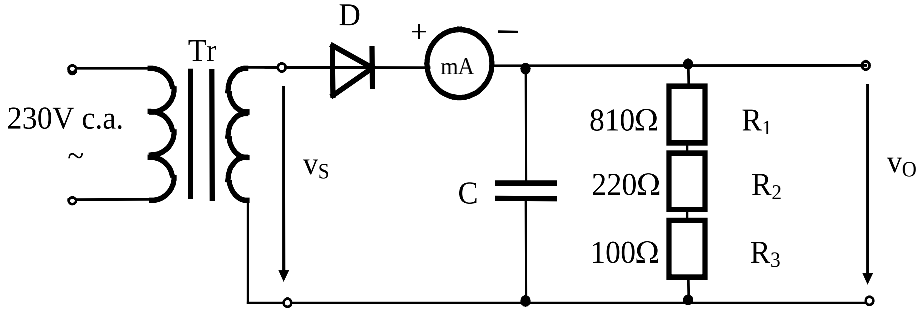


Fig. 9. Single-phase half-wave rectifier with capacitive filter

a) C=100µF
Follow the steps from experiment 1.1.
b) C=1000µF
Follow the steps from experiment 1.1.

Results

a) C=100µF

- $v_S(t)$ and $v_O(t)$ for the load resistance $R_1 + R_2 + R_3$
- Fill in Table 1 – the rows with C = 100µF.

b) C=1000µF.

- Fill in Table 1 – the rows with C = 1000µF.

2. SINGLE-PHASE FULL-WAVE RECTIFIER

2.1 SINGLE-PHASE FULL-WAVE RECTIFIER WITH RESISTIVE LOAD

Exploration
Build the circuit shown in Fig. 10.

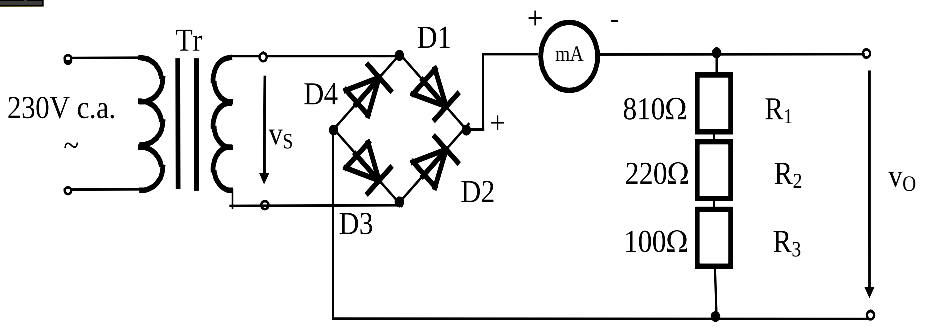


Fig. 10. Single-phase full- wave rectifier

For three combinations of the load resistance, ($R_1 + R_2 + R_3$, R_2+R_3, R_3), do the following:

- With the dual channel oscilloscope, calibrated, set on Y-t mode, visualise v_S and v_O.
- With a DC voltmeter, measure the value of the dc component of V_O.
- Measure (read) the output voltage ripple, ΔV_O, from the oscilloscope.
- With the dc miliammeter set on **200mA**, measure the dc component of I_O (load current).

Results

- $v_S(t)$ and $v_O(t)$ for the load resistance $R_1 + R_2 + R_3$
- Fill in Table 2 (identical to Table 1) – the rows with C = 0µF.

2.2 SINGLE-PHASE FULL-WAVE RECTIFIER WITH CAPACITIVE FILTER

Exploration
Build the circuit shown in Fig. 11.

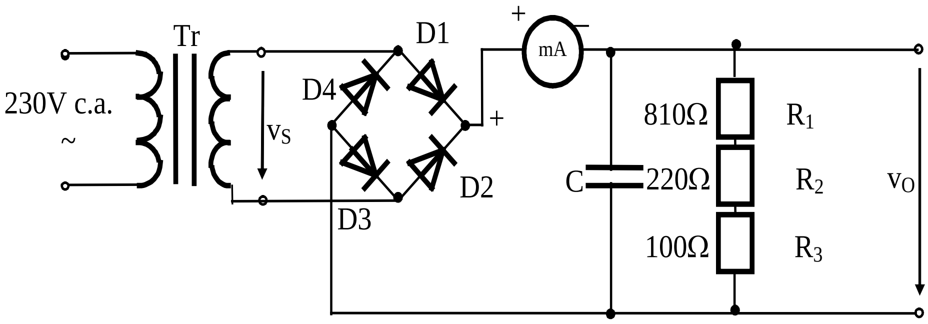


Fig. 11. Single-phase full-wave rectifier with capacitive filter

a) C=100µF

Follow the steps from experiment 2.1.

b) C=1000µF

Follow the steps from experiment 2.1.

Results

a) C=100µF

- $v_S(t)$ and $v_O(t)$ for the load resistance $R_1 + R_2 + R_3$
- Fill in Table 2 – the rows with C = 100µF.

b) C=1000µF.

- Fill in Table 2 – the rows with C = 1000µF.

REFERENCES

1. Oltean, G., Electronic Devices, Editura U.T. Pres, Cluj-Napoca, ISBN 973-662-220-7 , 2006
2. Sedra, A. S., Smith, K. C., Microelectronic Circuits, Fifth Edition, Oxford University Press, ISBN: 0-19-514252-7, 2004
3. http://www.bel.utcluj.ro/dce/didactic/ed/ed.htm

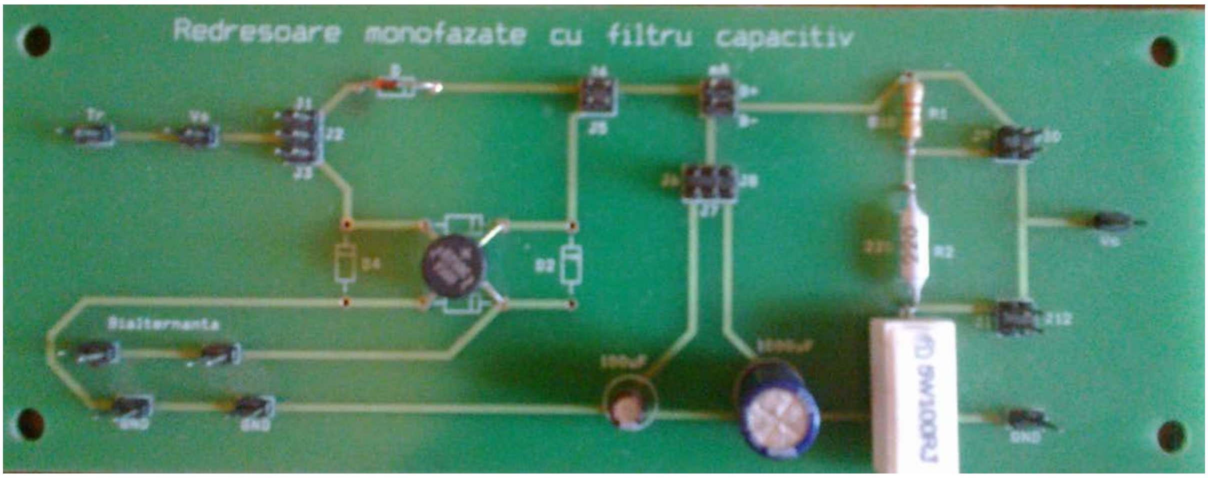


Fig. 12. Experimental assembly