National Aviation University

Department of Electronics, Robotics, Monitoring and IoT Technologies

Course: "Analog and Digital Instrumentation"

Experiment 5

"Full-Wave Rectifier with Improved Performance"
Повнохвильовий випрямляч з поліпшеними
характеристиками

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OBJECTIVES

1. To study the principle of operation of the full-wave rectifier with improved performance.
2. To simulate the op-amp full-wave rectifier with improved performance using MULTISIM software.
3. To assemble the op-amp full-wave rectifier with improved performance integrator circuit on the solderless breadboard and to perform required measurements.

INFORMATION

Note: Actual lab procedure follows this information section.

The main drawback of a diode full-wave rectifier is that it cannot work properly with small voltages. For example, a bridge rectifier, like that shown in Fig. 1(a), has output voltage

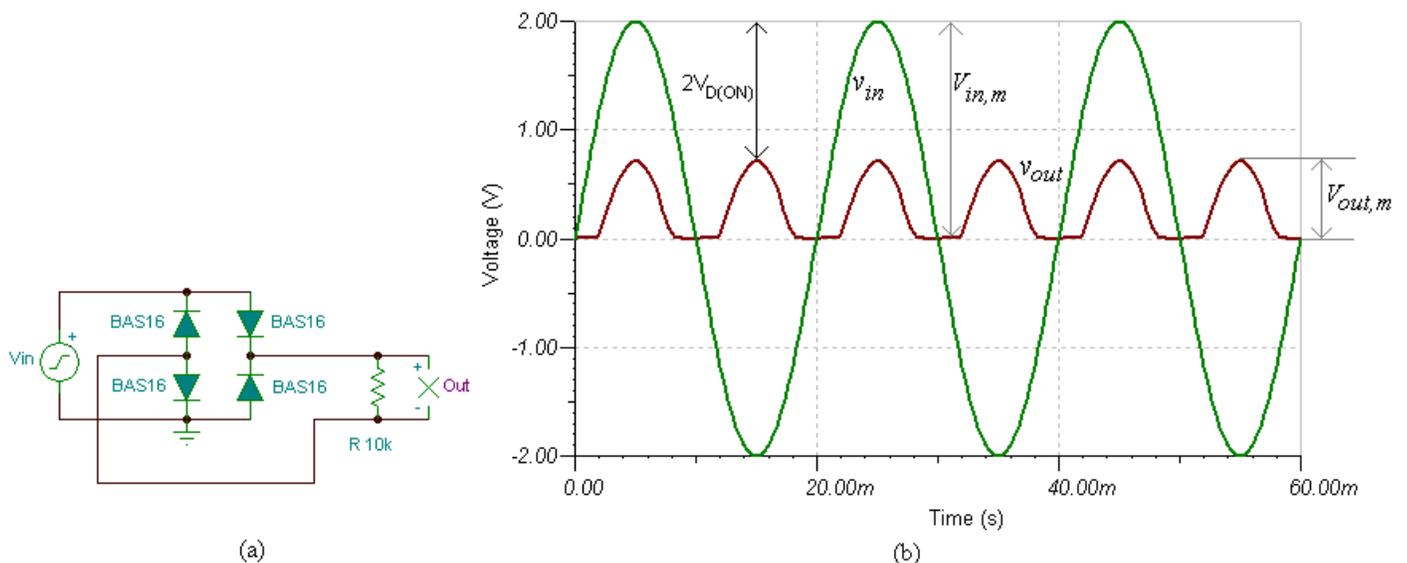$$V_{out} = V_{in,m} - 2V_{D(ON)}$$

(a)

(b)

Figure 1: Operation of a bridge rectifier with small voltages: (a) the bridge rectifier circuit, (b) the time diagrams

It means that the amplitude of the input voltage must be greater than $2V_{D(ON)}$ to provide $V_{out}>0$. If $V_{in,m} \leq 2V_{D(ON)}$ then $V_{out} = 0.$ Even if $V_{in,m}$=2V, like it is shown in Fig. 1(b), the operation of the bridge rectifier is not efficient because $V_{out,m}$ is significantly less than $V_{in,m}$.

For operating with small input signals an *op amp* full-wave rectifier with improved performance must be used. The circuit of this rectifier is shown in Fig. 2. The circuit of Fig. 2 consists of two parts. The first part includes the *op amp* OPA1, diodes D1, D2, and resistors R_A, R_F and $R_F||R_A$. This part represents a negative output, inverting half-wave rectifier.

The second part represents a two input inverting adder amplifier and includes the *op amp* OPA2 and resistors R_{A1}, R_{A2}, R_{F1}, and $R_{F1}||R_{A1}||R_{A2}$. Consider the operation of an inverting half wave-rectifier, which is separately shown in Fig. 3.
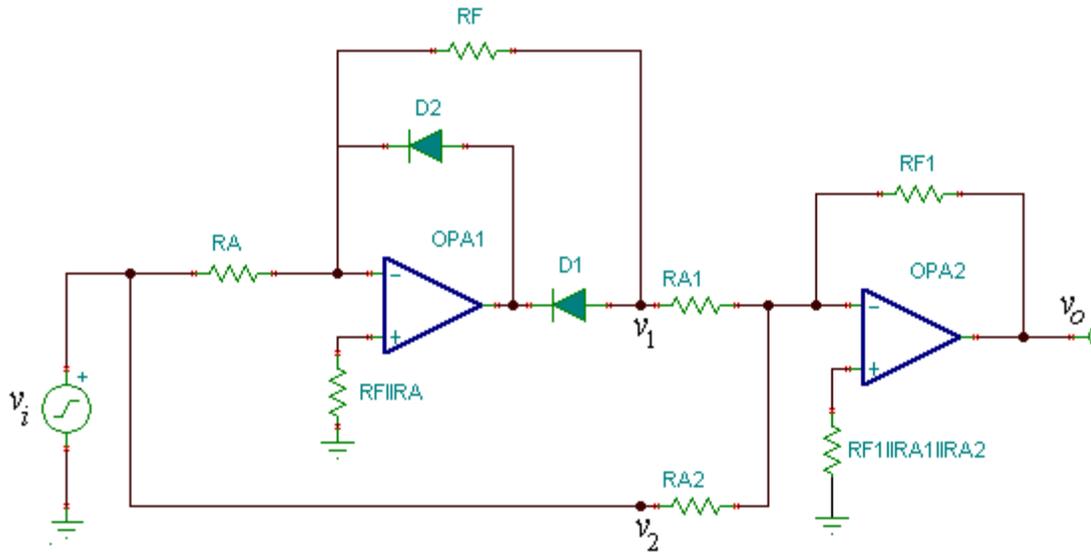
Figure 2: Operational amplifier full-wave rectifier with improved performance

If we assume the *op amp* is ideal, then

$$v_- = v_+ = 0$$

For negative v_i, diode D1 is OFF since $(v_1 - v_D) < 0$, and diode D2 is ON. So, $v_1 = v_-$, but $v_- = v_+ = 0$. Therefore, $v_1 = 0$. This case was simulated as shown in Fig. 4.
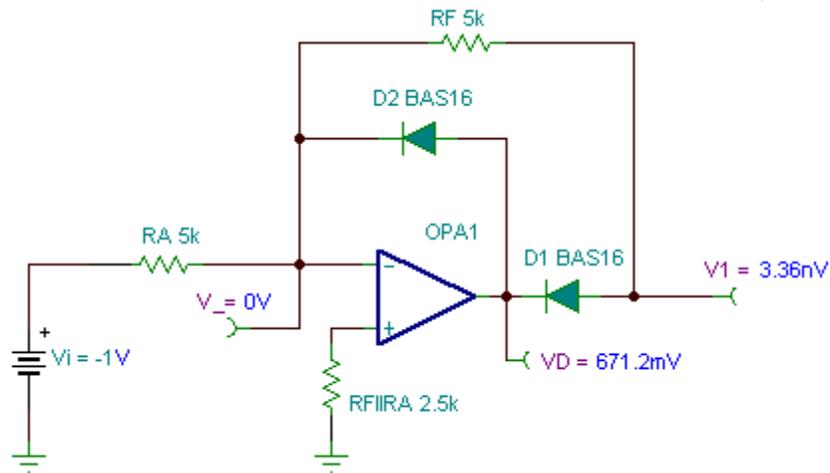

Figure 4: Simulation of the inverting half-wave rectifier operation when $v_i<0$

Alternatively, when v_i is positive diode D2 is OFF and diode D1 is ON. Indeed, assume that both diodes D1 and D2 are ON. In this case $v_D=V_{D(ON)}$ and $v_1=2V_{D(ON)}$, which is not possible because $R_A=R_F$ and $v_1=-v_i$. On the other hand, the assumption that diode D1 is ON and diode D2 is OFF results in $v_1=-v_i$:

$$\frac{v_i - v_-}{R_A} + \frac{v_1 - v_-}{R_F} = 0 \rightarrow v_+ = 0 \rightarrow v_- = v_+ = 0 \rightarrow$$

$$\frac{v_i}{R_A} + \frac{v_1}{R_F} = 0 \rightarrow v_1 = -v_i \frac{R_F}{R_A} \rightarrow R_A = R_F \rightarrow v_1 = -v_i \quad (1)$$

The expression in Eq. (1) does not depend on the diode forward voltage, $V_{D(ON)}$. Thus, because of the high open loop gain of the *op amp*, the feedback acts to cancel the diode turn-on (forward) voltage. This leads to improved performance of the rectifier.

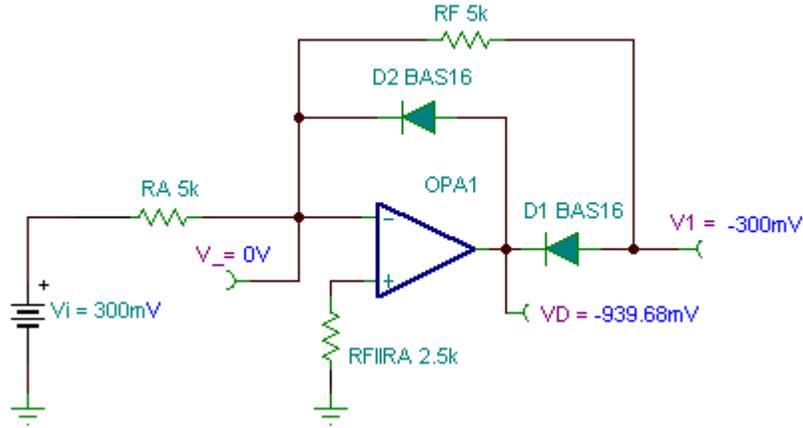In Fig. 5, the result of simulation is shown when v_i is positive.

Figure 5: Simulation of the inverting half-wave rectifier operation when $v_i > 0$

As seen from Fig. 4 and 5,

$$v_1 = \begin{cases} -v_i \Rightarrow v_i > 0, \\ 0 \Rightarrow v_i \leq 0 \end{cases} \quad (2)$$

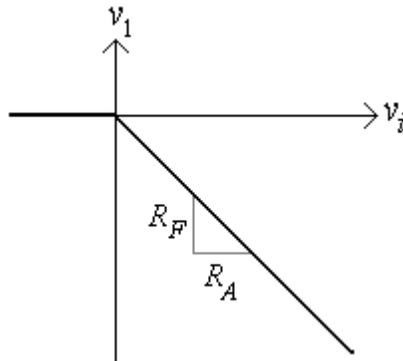The graphical presentation of Eq. (2) is shown in Fig. 6.

Figure 6: Transfer characteristic of the rectifier shown in Fig. 3

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The operation of the negative half-wave rectifier was simulated by Tina 7 (Industrial version) and shown in Fig. 7.

As seen from Fig. 7, a 0.3V sinusoidal voltage was applied to the rectifier input. The output voltage is negative half-wave rectified voltage with the same amplitude.
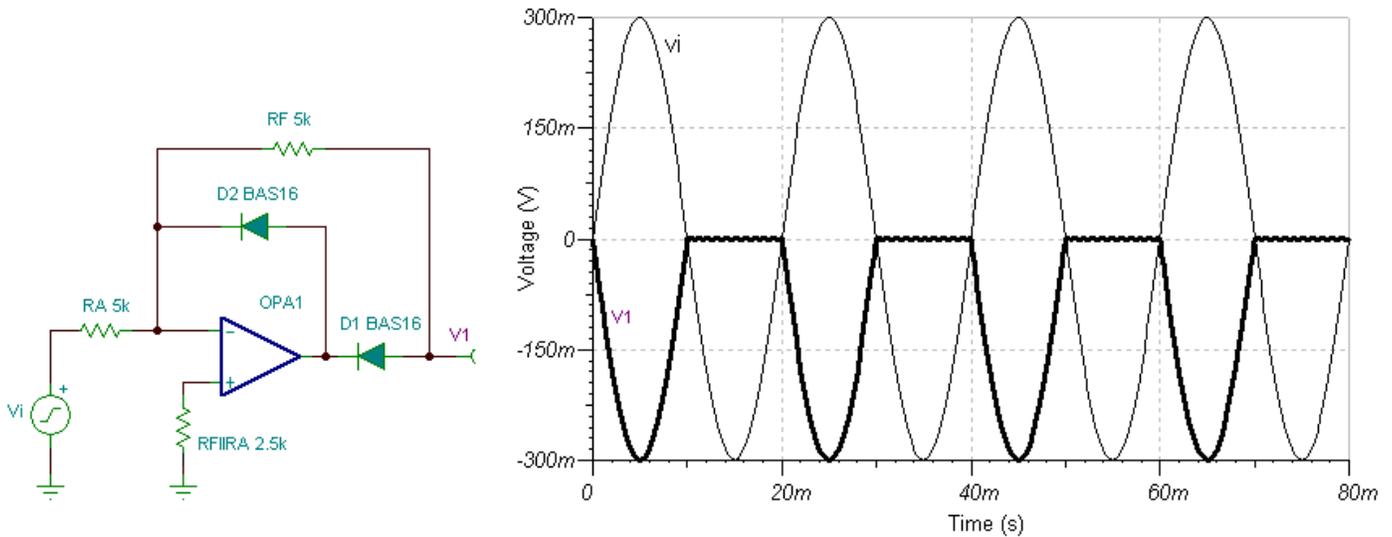

Figure 7: Simulation of the negative half-wave rectifier operation with a small input signal

Now we return back to the full-wave rectifier circuit of Fig. 2. To explain the operation of this circuit we note that the mathematical operation of taking the absolute value is the same as that of reversing the sign of the negative part of the signal. If the half-wave rectified output is doubled and the original signal is subtracted from this, the result is the full-wave rectified waveform. This is easily proved by considering the two operating conditions separately. First, suppose that the input is positive. Then the half-wave output is equal to the input, and the difference described above becomes (тепер повернемося до схеми повноперіодного випрямляча на Рис. 2. Щоб пояснити роботу в цій схемі відзначимо, що математична операція взяття абсолютного значення така ж як зміна знака негативної частині сигналу. Якщо напівволновий випрямленний вихід подвоюється, та вихідний сигнал віднімається від нього, то в результаті виходить двохнапівперіодна випрямлена форма хвилі. У цьому легко переконатися, якщо окремо розглянути два робочих режима. По-перше, припустимо, що вхід позитивний. Тоді вихід напівхвилі дорівнює входу, і різниця, описана вище, стає)

$$2v_i(t) - v_i(t) = v_i(t)$$

Thus, the output is equal to the input. Now if the input is negative, the half-wave output is zero, and the difference becomes
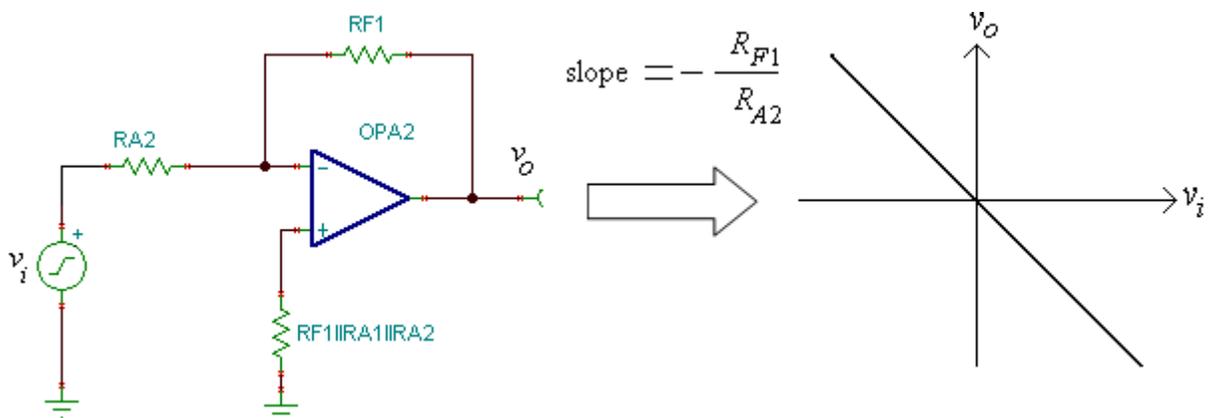
$$2 \times 0 - v_i(t) = -v_i(t)$$

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Thus, the output is equal to the negative of the input. The composite output is then the absolute value of the input. This form of full-wave rectifier is realized in Fig. 28. The step-by-step conversion of an input periodical voltage into a full-wave rectified output voltage is shown in Fig. 8.
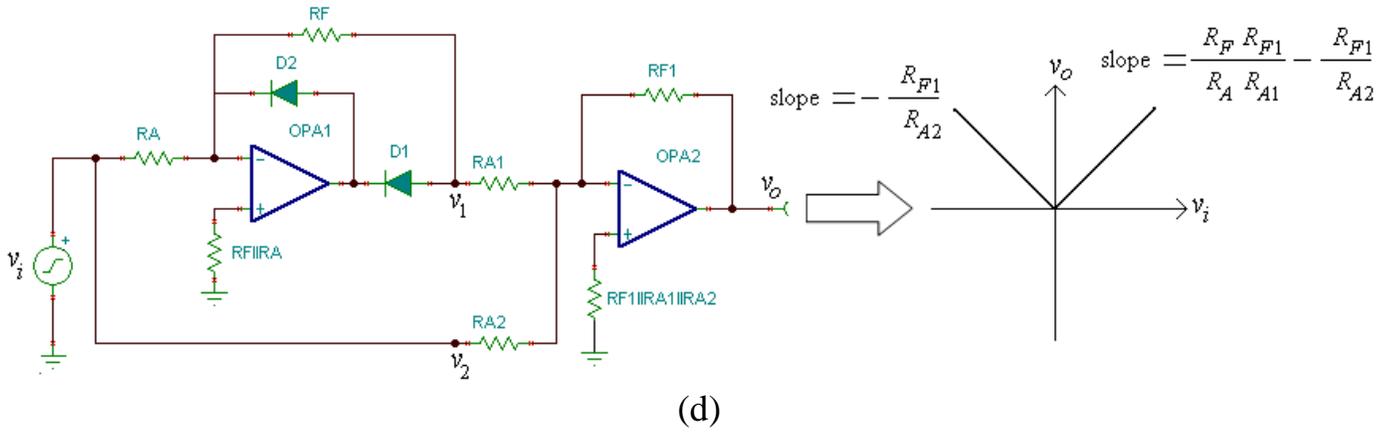

(a)

(b)

(c)

(d)
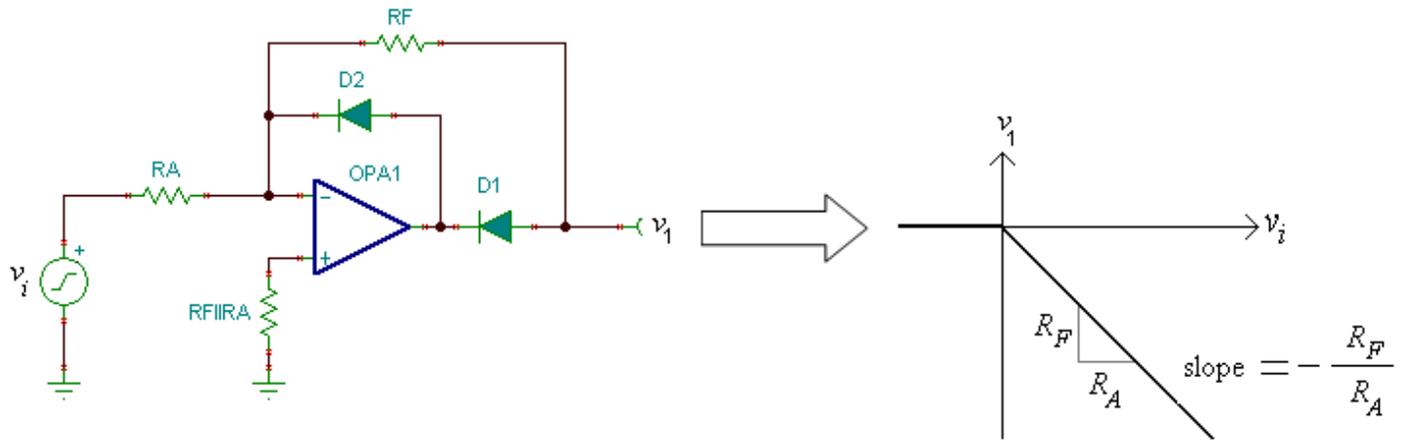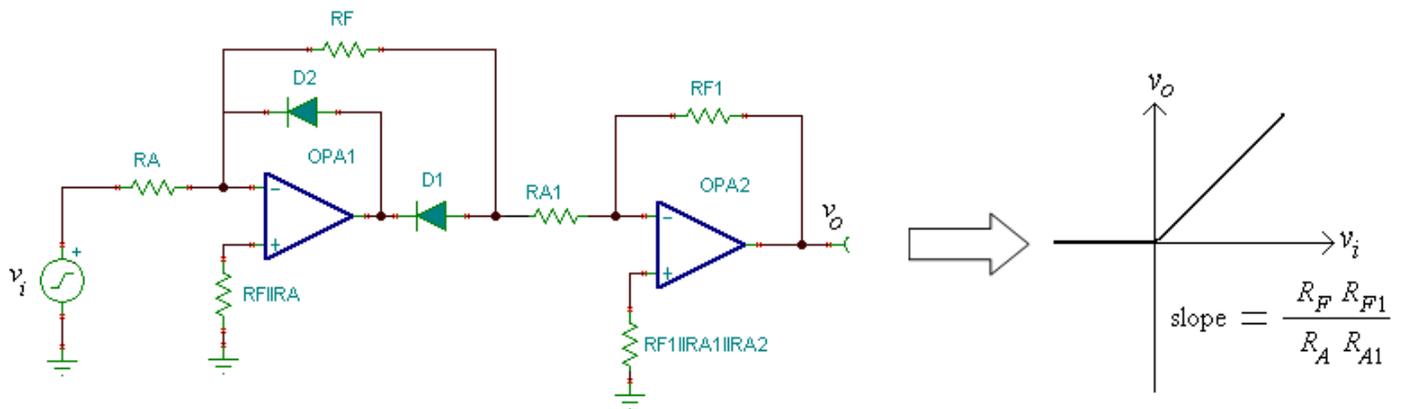
Figure 8: Step-by-step conversion of an input periodical voltage into a full-rectified output voltage

The curve of Fig. 8(a) shows v_1 as function of v_i. This dependence can be represented as

$$v_1 = \left\{ \begin{array}{l} -\dfrac{R_F}{R_A} v_i \Rightarrow v_i > 0, \\ 0 \Rightarrow v_i \leq 0 \end{array} \right\} \tag{3}$$

In Fig. 8(b) is shown the output voltage due to v_i through OPA1 and OPA2 (upper connection). For this connection the output is

$$v_o\big|_{v_2=0} = \left\{ \begin{array}{l} \dfrac{R_F R_{F1}}{R_A R_{A1}} v_i \Rightarrow v_i > 0, \\ 0 \Rightarrow v_i \leq 0 \end{array} \right\} \tag{4}$$

Figure 8(c) shows the output voltage as a function of v_i through OPA2 (lower connection). This is given by

$$v_o\big|_{v_1=0} = -\dfrac{R_{F1}}{R_{A2}} v_i \tag{5}$$

To obtain the total output voltage, we add Fig. 8(b) and Fig. 8(c) to obtain the curve shown in Fig. 8(d). Since *op amp* OPA2 with resistors R_{A1}, R_{A2} and R_{F1} represent an inverting summing circuit, then

$$v_o = -\dfrac{R_{F1}}{R_{A1}} v_1 - \dfrac{R_{F1}}{R_{A2}} v_2 \tag{6}$$

Substituting v_1 from Eq. (3) into Eq. (6) and taking into account that $v_2=v_i$ results in the following expression for v_o:

$$v_o = \frac{R_F R_{F1}}{R_A R_{A1}} v_i - \frac{R_{F1}}{R_{A2}} v_i \tag{7}$$

To make full-wave rectifier symmetrical (that is, magnitude of the slope is the same for both positive and negative v_i), the resistors are selected so that

$$\frac{R_{F1}}{R_{A2}} = \frac{R_F R_{F1}}{R_A R_{A1}} - \frac{R_{F1}}{R_{A2}}$$

In Fig. 9 and Fig. 10 are shown the rectifier circuit and time diagrams of voltages corresponding to the circuits shown in Figures 8 (a), (b), (c), and (d) when $R_A=5k\Omega$, $R_F=5k\Omega$, $R_{A1}=100k\Omega$, $R_{A2}=200k\Omega$, and $R_{F1}=200k\Omega$.
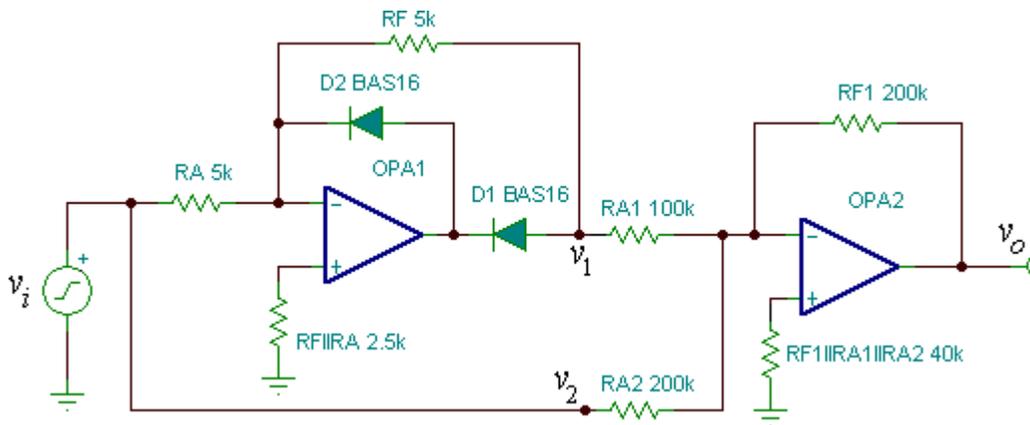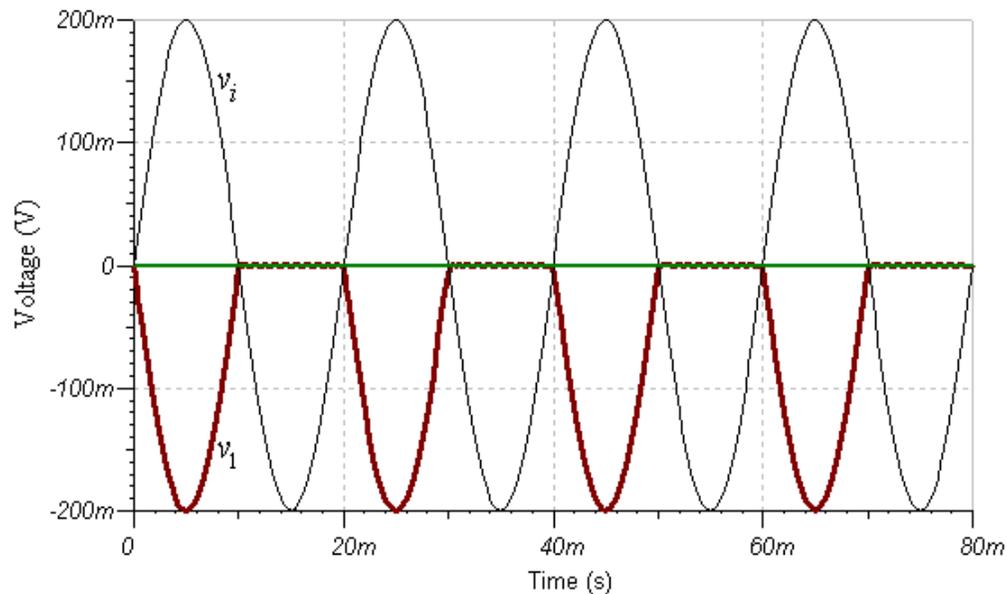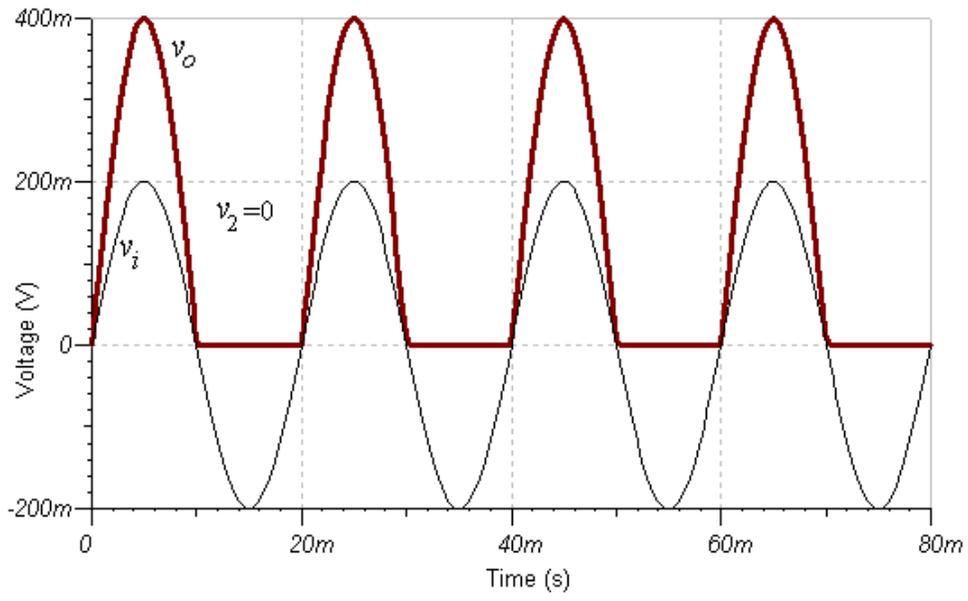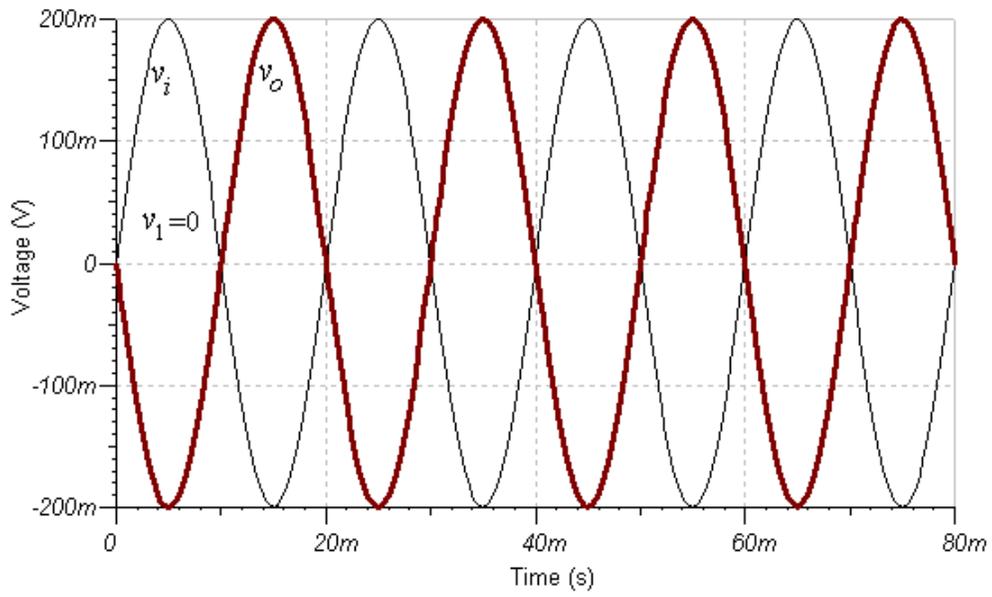

Figure 9: Improved full-wave rectifier circuit with selected resistor values
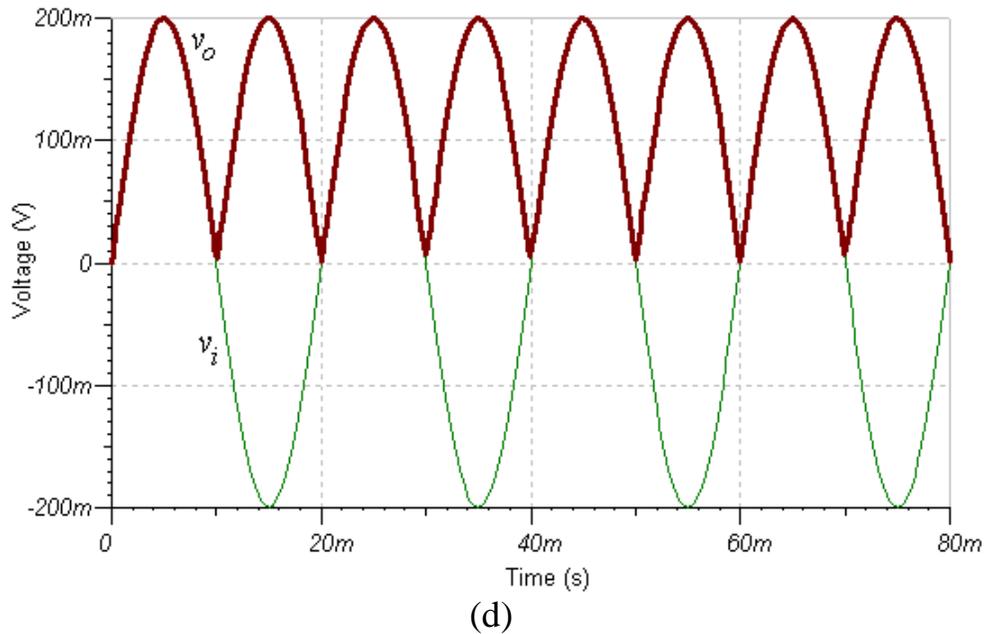

(a)

(b)

(c)

8

(d)

Figure 10: Time diagrams illustrating the operation of a full-wave rectifier with improved performance: (a) conversion of v_i into v_1 (Eq. 3), (b) conversion of v_i into v_o when $v_2=0$ (Eq. 4), (c) conversion of v_i into v_o when $v_1=0$ (Eq. 5), (d) complete conversion of v_i into v_o (Eq. 7)

EQUIPMENT

1. Digital multimeter UT33B
2. Solderless breadboard BB830T
3. Oscilloscope HAMEG HMO1024
4. Sinusoidal generator
5. Power Supply +12V, 0, -12V
6. Resistors: 2×1.0 kΩ 2×3.8 kΩ, 5×100 kΩ
7. Diodes: 2×1N4007
8. Operational amplifiers: 2×UA741 (УД708)
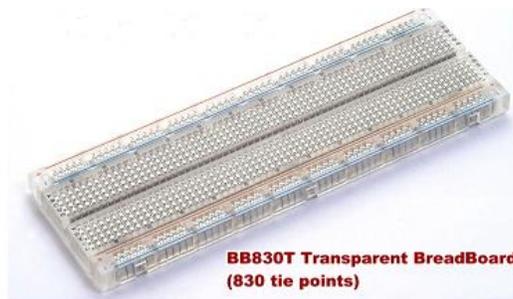
PROCEDURE

The pin connections for the 8 pin DIP package uA741 (УД708) op-amp are given in Fig. 11. Throughout this experiment use the external DC Power Supply Unit with **+12V, 0, -**

12V jacks. The initial location of each uA741 chip and connections to +12V, 0, -12V terminals of the power supply are shown in Fig. 11.
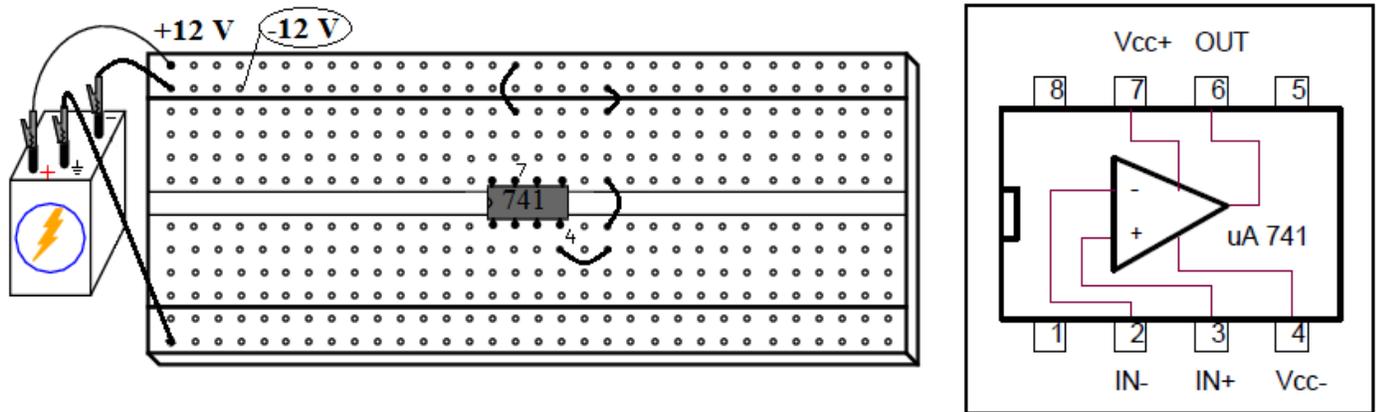

Figure 11: Initial location of uA741 chip on the solderless breadboard

<u>To use the Power Supply Unit:</u>

• Turn the Power Supply ON. This will set both positive and negative power sources respectively to **+12V** and **–12V**. Measure these voltages with digital multemeter.

• Turn the Power Supply OFF before connecting to the circuits.

• Connect the **+12V** terminal of the Power Supply to the V_{CC}^+ of your circuit as shown in Fig. 11. Connect the **-12V** terminal of the Power Supply to the V_{CC}^- of your circuit as shown in Fig. 11. Connect the **COM** terminal of the Power Supply to the ground of your circuit as shown in Fig. 4.

Procedure steps:

1. Build the circuit of Figure 12 using two 8-pin uA741 (УД708) op-amp and resistors.

2. Apply a 1kHz sinusoidal voltage with amplitude 100 mV from the **Signal Generator** to the input and use the dual trace oscilloscope to observe both input and output waveforms. Measure the amplitude of the output voltage and make a photograph by your camera.

3. Apply a 1kHz sinusoidal voltage with amplitude 500 mV from the **Signal Generator** to the input and use the dual trace oscilloscope to observe both input and output waveforms. Measure the amplitude of the output voltage and make a photograph by your camera.

4. Apply a 1kHz sinusoidal voltage with amplitude 1.0 V from the **Signal Generator** to the input and use the dual trace oscilloscope to observe both input and output waveforms. Measure the amplitude of the output voltage and make a photograph by your camera.

5. Apply a 1kHz sinusoidal voltage with amplitude 2.0 V from the **Signal Generator** to the input and use the dual trace oscilloscope to observe both input and output waveforms. Measure the amplitude of the output voltage and make a photograph by your camera.
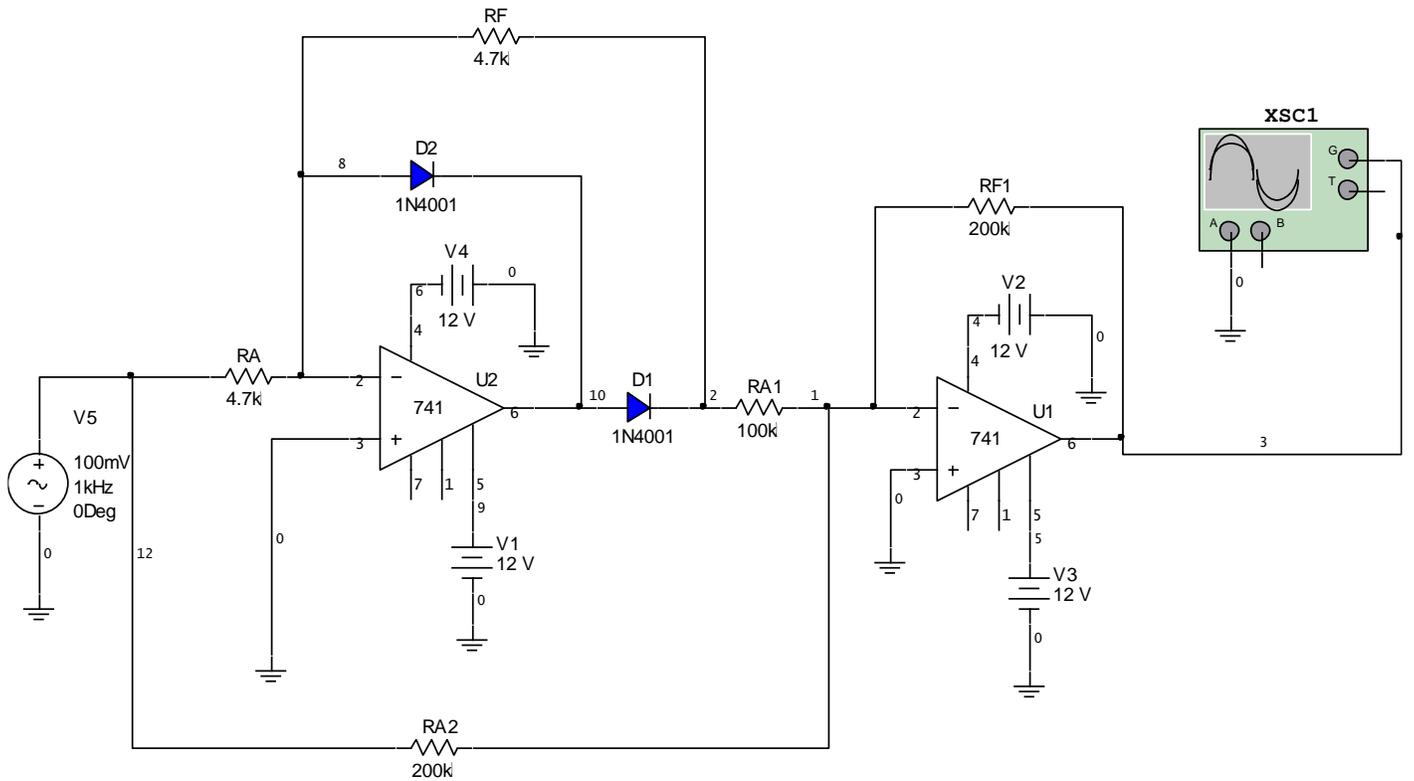
(a)
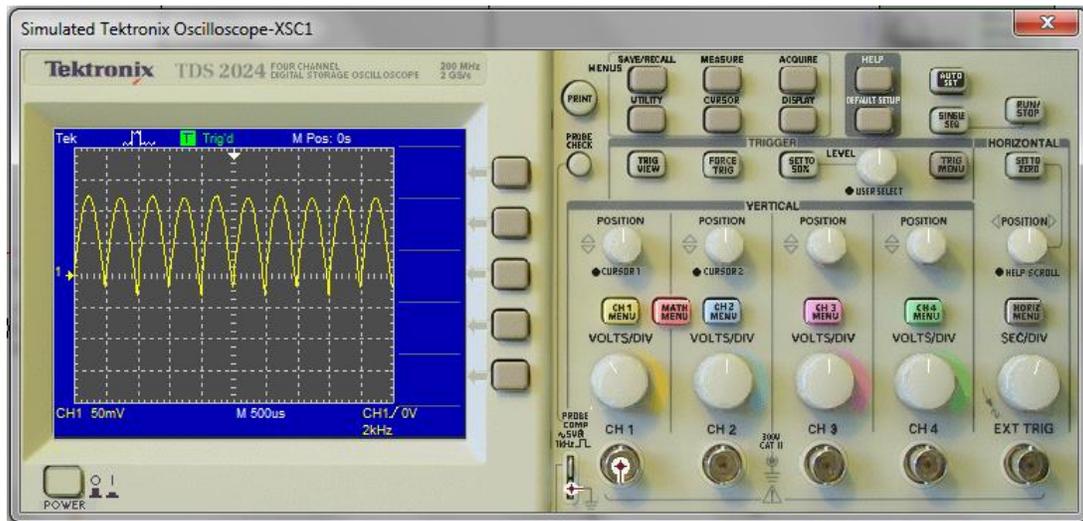
(b)

Figure 12: Improved full-wave rectifier circuit with resistor values used in the experiment (a) and displayed rectified voltage (b)

REFERENCE

1. A.S. Sedra and K.S. Smith, "Microelectronic circuits", 5th ed., New York: Oxford University Press, 2004, 1283 p.