

**Experiment-2****Diode Circuit Applications**

Introduction	The objectives of this experiment are to observe the operating characteristics of several very common diode circuits and the effects of non-ideal diode characteristics on their performance.
Precautions	None of the devices used in this set of procedures are particularly static sensitive; nevertheless, you should pay close attention to the circuit connections and to the polarity of the power supplies, diodes, and oscilloscope inputs. Some of the capacitors are electrolytics which are polar capacitors and must be installed in the correct polarity in order to function properly.
Comment	Many of the procedures in this experiment will utilize the $\pm 6.3$ VAC laboratory transformer as the signal generator for the circuits. You may wish to set up the input to your solderless breadboard so that the transformer output is always introduced at the same end of the breadboard, e.g. from the left, to help keep it better organized.

**Procedure 1 Voltage clipper circuits**

Set-Up	Using the solderless breadboard, construct the circuit shown in Fig. E2.1 using the following components: $R1 = 10\text{ k}\Omega$ 5% 1/4W $D1 = 1N4148$
--------	--

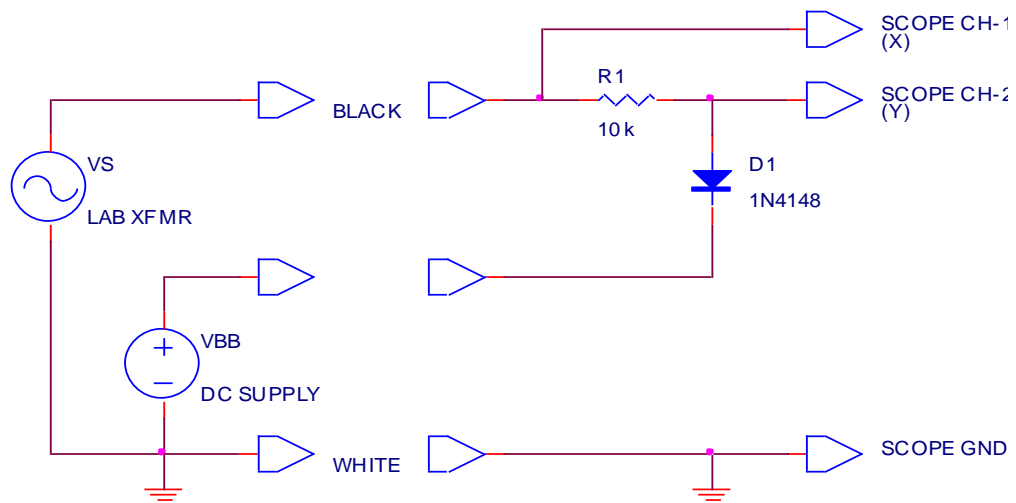


Figure E2.1

Turn the power switch OFF on the laboratory transformer and plug the unit into a 120 VAC line receptacle. Connect the transformer to the circuit board

## Experiment-2

using leads from the black and white banana jacks as shown in Fig. E2.1. This will apply a 10 V peak sinewave to the circuit once the power is turned on.

Configure a DC power supply to implement the VBB DC source in Fig. E2.1. Use a pair of squeeze-hook test leads to connect the output of the power supply to your breadboard. Initially adjust the output of the DC power supply to zero.

Connect a 10× probe to the BNC connectors on each of the two input channels of an oscilloscope. Connect the probe from Ch-1 to the free end of R1 to monitor the input signal, and connect the probe from Ch-2 to the node between R1 and D1 to monitor the output signal, as shown in Fig. E2.1. Configure the oscilloscope to display both channels with a vertical scale of 5 V/div, which includes the attenuation of the 10× probe. Set the input coupling of both channels to DC, and make sure that channel-2 is not inverted. Set the timebase to 5 ms/div. Set the trigger mode to AUTO with a source of Ch-1. Finally center both traces on the center of the screen by switching the input coupling for each channel to GND, moving each trace to the center hairline of the screen using the position controls, and then returning the input coupling switches to the DC position.

**Measurement-1** Set the output of the DC power supply initially to  $V_{BB} = 0.0$  Volts. Next, turn ON the laboratory transformer. At this point, the oscilloscope should show a sinewave input for Ch-1 and a clipped sinewave output for Ch-2. Sketch both of these signals on the same set of voltage-time axes in your notebook.

Using the built-in meter on the DC power supply, slowly increase the output voltage to change the VBB voltage from 0.0 to +10.0 Volts. Observe the effect on the output waveform. Use the meter on the DC power supply to set the VBB voltage to +4.0 V. At this setting, sketch the input and output waveforms on the same set of voltage-time axes in your notebook.

The oscilloscope can also be used to directly display the voltage transfer characteristics (VTC) of this circuit. Do not change any of the connections from those of Fig. E2.1 and simply reconfigure the oscilloscope to display Ch-1 versus Ch-2 in an X-Y mode. Ground the inputs to both channels by setting the coupling switches to GND, and then switch the oscilloscope into the X-Y mode. (On Tektronix oscilloscopes, all you need to do is push the X-Y button in; on Hewlett-Packard oscilloscopes, you will need to access the X-Y mode through the MATH function menu.) Use the position controls to move the dot onto the cross-hairs in the exact center of the screen. Change the input coupling on each of the two channels back to DC and the display should now show the VTC. Sketch the VTC shown on the oscilloscope screen in your notebook.

## *Experiment-2*

Now examine how the VTC is affected by the various circuit elements. You may wish to switch the oscilloscope back and forth between displaying the VTC and displaying the actual waveforms to better appreciate what is happening in the circuit and how this is represented on the VTC. (On Tektronix oscilloscopes, you can do this by simply pushing the X-Y button in and out.) First, change the value of VBB by adjusting the voltage upward and downward on the DC power supply. Keep the maximum value of VBB to less than 10 V or so. Second, change the polarity of VBB by reversing the squeeze-hook test leads. Third, reverse the polarity of the diode D1. Play around with these modifications until you fully understand the role that each plays in determining the VTC and the output waveforms.

### Question-1

The circuit shown in Fig. E2.1 is termed a positive-peak positive-level clipper. In your notebook draw circuits, VTC's, and output waveforms (assuming a sinusoidal input) for each of the four cases of:

- (a) a positive-peak positive-level clipper,
- (b) a negative-peak positive-level clipper,
- (c) a positive-peak negative-level clipper, and
- (d) a negative-peak negative-level clipper.

## Procedure 2 Voltage limiter circuits

Comment	Clipping circuits keep a voltage from exceeding some set value. Limiters restrict the voltage to a specific range.
Set-Up	<p>This procedure calls for the construction of several voltage limiter circuits and you will use the following components:</p> <p>R1 = 100 <math>\Omega</math> 5% 1/4 W resistor</p> <p>R2 = 1.0 k<math>\Omega</math> 5% 1/4 W resistor</p> <p>D1, D2, D3, D4 = 1N4007 diode</p> <p>D5, D6 = 1N4732 (4.7 V) zener diode</p> <p>The basic circuit you will build is shown in Fig. E2.2a.</p>

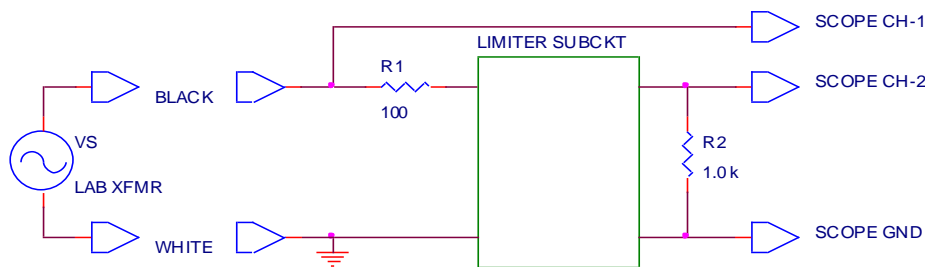


Figure E2.2a

The four diode limiter subcircuits are shown in Fig. 2.2b.

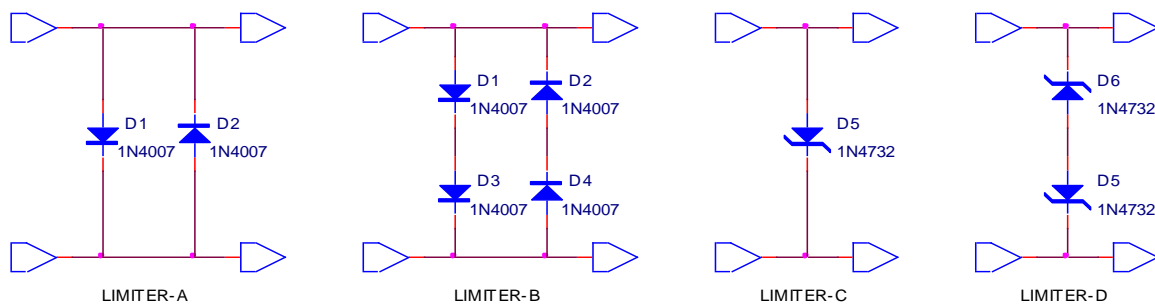


Figure E2.2b

Note that each limiter circuit appears in parallel with the load resistor R2. The purpose of R1 is to limit the current drawn from the transformer when the diode limiters turn on.

Measurement-2	<p>Turn the power switch OFF on the lab transformer and plug it into the 120 VAC receptacle. Connect the black and white outputs of the lab transformer, the oscilloscope probes and their grounds as shown in Fig. E2.2a. Using the first limiter circuit of two diodes connected in parallel with the load resistor, display the VTC of this circuit by setting the oscilloscope in its X-Y mode in the same manner as in the previous procedure (use vertical and horizontal scales of 1 or 2 V/div., as appropriate). Sketch a copy of the VTC in your lab</p>
---------------	--

## *Experiment-2*

notebook, labeling both axes with tick marks and a voltage scale. It is also a good idea to jot down the channel settings like the coupling, filtering, or averaging that you may have set. Explore the effect of each diode by first pulling one out of the breadboard and then the other.

Next, add another 1N4007 diode in series with each of the existing diodes to create the second limiter circuit B. Sketch a copy of the VTC in your lab notebook.

Next, remove all the 1N4007 diodes and replace them with a single 1N4732 zener diode with its anode connected to R1. This is the third limiter circuit C. Sketch a copy of the VTC in your lab notebook.

Finally, add a second opposing 1N4732 zener diode in series with the existing zener diode to produce the fourth limiter circuit D. Sketch a copy of the VTC in your lab notebook as well.

### Question-2

- (a) Draw the VTC for the fourth limiter circuit if the zener diodes were connected in anti-parallel, rather than in anti-series as shown. Explain your result.
- (b) Redraw Fig. E2.2b in your notebook and indicate in the figure which way current flows when  $V_{in} = +3.0\text{ V}$  and when  $V_{in} = -3.0\text{ V}$ .
- (c) Using only 1N4007 and 1N4732 diodes, design a limiter circuit that will restrict the voltage across a load resistor to the range of about  $-9.4$  to  $+2.0\text{ V}$ .

### Procedure 3 Precision half-wave rectifier

**Comment** Half-wave rectifiers are simply clipping circuits that clip very close to zero. When  $V_{BB}$  was set to zero in the clipper of Procedure 1, the diode turn-on voltage created an offset of nearly a volt in the clipping level. This procedure illustrates a means for cancelling out this diode turn-on voltage with that of another identical diode, eliminating the need for accurate adjustment of the  $V_{BB}$  supply to zero out the clipping level. Balancing and cancellation techniques such as this are commonplace in analog circuit design.

**Set-Up** Construct the circuit of Fig. E2.3 using the following components:

$R1 = 470\ \Omega$  5% 1/4 W resistor

$R2 = 10\ \text{k}\Omega$  5% 1/4 W resistor

$R3 = 100\ \Omega$  5% 1/4 W resistor

$D1, D2 = 1\text{N}4007$  diode

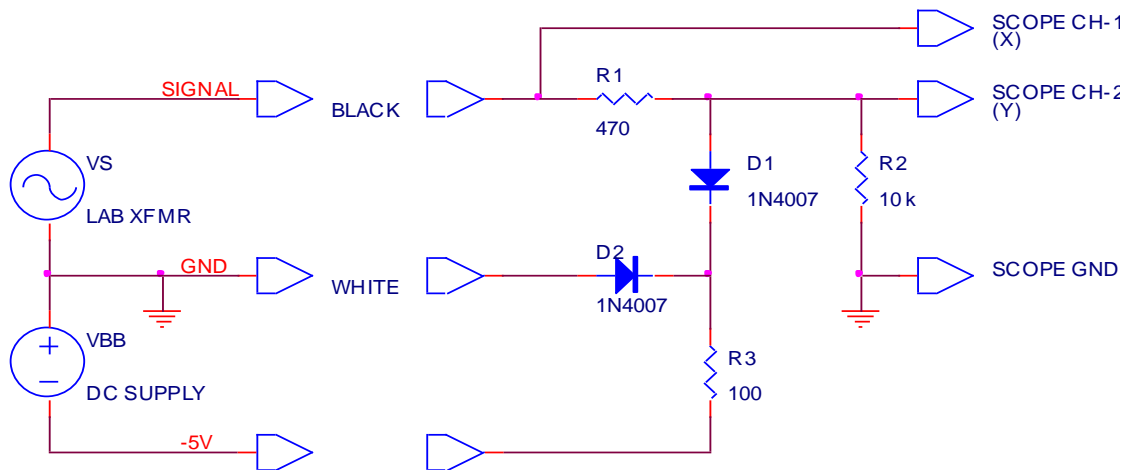


Figure E2.3

Turn the power switch OFF on the lab transformer and plug it into the 120 VAC receptacle. Connect the black and white outputs of the lab transformer, the oscilloscope probes and their grounds as shown in Fig. E2.3. Connect the circuit as shown and set  $V_{BB} = -5.0\ \text{V}$ .

**Measurement-3** Display the VTC of this circuit by setting the oscilloscope to its X-Y mode in the same manner as in the previous procedure (use vertical and horizontal scales of 2 V/div.). Sketch a copy of the VTC in your lab notebook, labeling both axes with tick marks and a voltage scale. Switch to the time domain and display the voltage measured with both channels vs. time on the oscilloscope. Sketch both output waveforms in your notebook.

**Question-3**

- What is the purpose of resistors  $R1$  and  $R3$  in this circuit?
- Explain why  $D1$  and  $D2$  should be identical diodes.

## Experiment-2

(c) The above circuit is a precision positive half-wave rectifier. Design a precision negative half-wave rectifier.

### Procedure 4 *Half-wave rectifier and capacitive filtering*

---

**Comment** Rectification of an AC power source followed by capacitive filtering is the most common method for creating a DC source of power. Capacitively filtered rectifiers are an essential subcircuit of all DC power supplies. This and the next two procedures examine a few of the most common circuit topologies.

**Set-Up** Disconnect the DC power supply and turn it off, since it will not be needed for any of the remaining procedures. Disconnect the lab transformer and the oscilloscope probes and disassemble the circuit of the Procedure 1. Leave the oscilloscope running in its previous configuration.

Construct the circuit shown in Fig. E2.4 on a solderless breadboard using the following parts:

D1 = 1N4007

R1 = 1.0 k $\Omega$  5% 1/4 W

C1 = 10  $\mu$ F 25 V electrolytic \*\*\*

C2 = 33  $\mu$ F 25 V electrolytic \*\*\*

\*\*\* Leave space for, but do not yet install C1 or C2 until called for in the measurements.

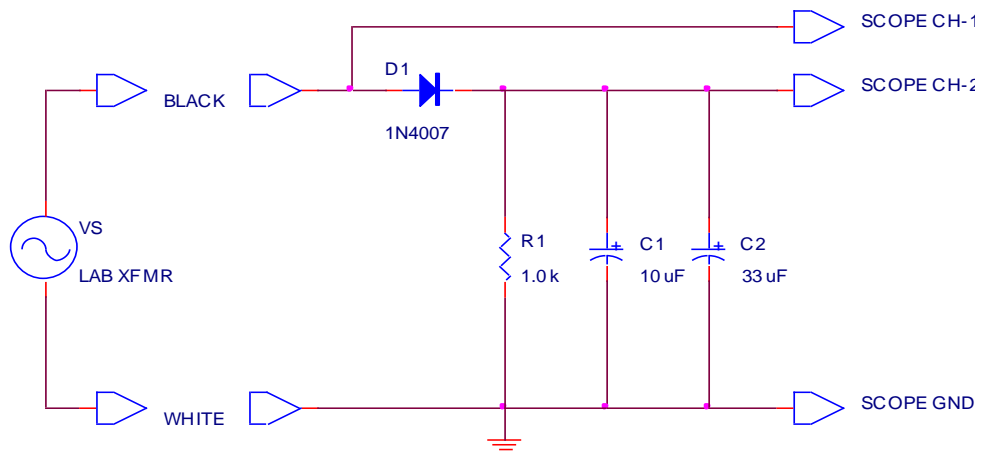


Figure E2.4

Connect the black and white outputs of the laboratory transformer, the oscilloscope probes, and their grounds to the breadboarded circuit as shown in Fig. E2.4. Adjust the oscilloscope to display both the input and output waveforms as a function of time. The display should show two complete

## Experiment-2

cycles of each waveform with the timebase at 5 ms/div. The laboratory transformer should supply a 10 V peak sinewave to the circuit, which should appear 4 divisions tall on the oscilloscope screen, with the vertical range switches set to give 5 V/div with a 10× probe.

Measurement-4 Sketch the output of the half-wave rectifier in your notebook, labelling both the voltage and time axes with tick marks obtained from the scale factors on the oscilloscope. Determine the minimum and maximum voltage output.

Next, connect capacitor C1 in parallel with R1 and repeat the measurement. Carefully note that C1 is an electrolytic capacitor which must be installed in the correct polarity. The capacitor will have some marking which indicates the (+) and (-) leads. Make sure that the (+) lead is connected to the cathode of the diode, as shown in Fig. E2.4. On the same set of axes as the previous measurement, sketch the output waveform in your notebook. Note the minimum and maximum values of the waveform.

Next, connect capacitor C2 in parallel with R1 and C1. Note that C2 is also an electrolytic capacitor and must be installed in the correct polarity. The addition of C2 has the effect of increasing the total capacitance from 10  $\mu\text{F}$  to 43  $\mu\text{F}$ . Repeat the measurement and sketch the half-wave rectifier output on the same axes as before. Again note the minimum and maximum values of the waveform.

Question-4

- (a) Compute the minimum voltage that the output voltage across R1 falls to when both capacitors C1 and C2 are present. Use an analytical approach which equates the RC decay of the output when the diode is off to the sinusoidal input voltage when the diode is on. Use a model for D1 which only involves a turn-on voltage of  $V_\gamma$ , and use a value for  $V_\gamma$  that you measured in Experiment 1 for the 1N4007 diode.
- (b) Using the same model for D1, compute the maximum voltage that the output voltage across R1 rises to.
- (c) From your calculated minimum and maximum output voltages, compute the ripple voltage and the time duration over which the diode conducts.
- (d) Compare the results of your calculation with the measured values of ripple voltage for the circuit.



### Procedure 5 Full-wave bridge rectifier and capacitive filtering

#### Set-Up

Disconnect the laboratory transformer and oscilloscope channel-1 probe from the breadboarded circuit of Procedure 2. Remove diode D1 and replace it with four 1N4007 diodes (D1-D4) which form a full-wave bridge rectifier as shown in Fig. E2.5. Note carefully the polarity of each of the four diodes in the bridge. Temporarily remove capacitors C1 and C2; they will be re-installed later in the measurements. The circuit of Fig. E2.5 uses the following components:

D1, D2, D3, D4 = 1N4007

R1 = 1.0 k $\Omega$  5% 1/4 W

C1 = 10  $\mu$ F 25 V electrolytic

C2 = 33  $\mu$ F 25 V electrolytic

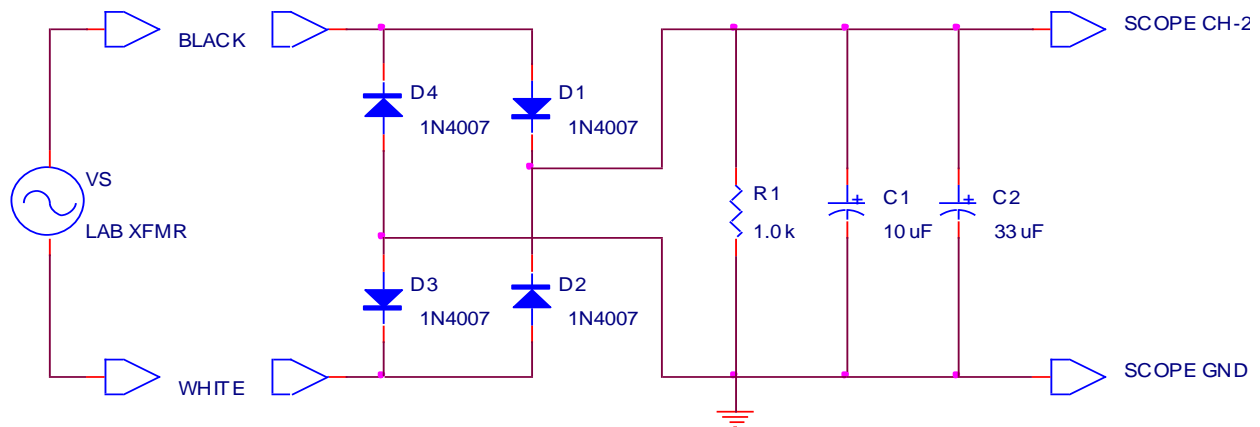


Figure E2.5

Connect the black and white banana jack outputs of the laboratory transformer to the diode bridge on the breadboard as shown in Fig. E2.5. Turn the lab transformer ON to supply a 10 V peak sinewave to the circuit.

#### Measurement-5

Adjust the oscilloscope to display two complete cycles of the Ch-2 input. Set the timebase to 5 ms/div and the trigger source to Ch-2. Sketch the output of the full-wave bridge rectifier in your notebook, labeling both the voltage and time axes with tick marks obtained from the scale factors on the oscilloscope. Determine the minimum and maximum voltage output.

Next, connect electrolytic capacitor C1 in parallel with R1 and repeat the measurement. Once again, be sure to install electrolytic capacitor C1 in the correct polarity. On the same set of axes as the previous measurement, sketch the output waveform in your notebook. Note the minimum and maximum values of the waveform.

## *Experiment-2*

Next, connect electrolytic capacitor C2 in parallel with R1 and C1, again paying attention to its polarity. Repeat the measurement and sketch the full-wave bridge rectifier output on the same axes as before. Again note the minimum and maximum values of the waveform.

### Question-5

- (a) Compute the minimum voltage that the output voltage across R1 falls to when both capacitors C1 and C2 are present. Use an analytical approach which equates the RC decay of the output when the diode is off to the sinusoidal input voltage when the diode is on. Use a model for D1 which only involves a turn-on voltage of  $V_\gamma$ , and use a value for  $V_\gamma$  that you measured in Experiment 1 for the 1N4007 diode.
- (b) Using the same model for D1, compute the maximum voltage that the output voltage across R1 rises to.
- (c) From your calculated minimum and maximum output voltages, compute the ripple voltage and the time duration over which the diodes in the bridge each conduct.
- (d) Compare the results of your calculation with the measured values of ripple voltage for the circuit.
- (e) Discuss briefly the advantages and disadvantages of full-wave versus half-wave rectification for the conversion of AC to DC power.

## Procedure 6 Zener diode voltage regulator

**Comment** A “regulator” is any contraption which is used to hold a dynamic variable at a constant value and compensate for changes in other dynamic variables which may affect it. A voltage regulator is designed to keep the output voltage of a circuit at a constant value, independent of the input voltage and also independent of the load current. A zener diode is the simplest form of such a voltage regulator. In this procedure you will add a zener diode voltage regulator to the filtered, full-wave bridge rectifier of Procedure 5 in order to remove the remaining ripple voltage.

**Set-Up** Disconnect the channel-2 oscilloscope probe from the breadboarded circuit of Procedure 5, but leave the remainder of the circuit connected. Add the components R2, D5, and RL as shown in Fig. E2.6 below. The lab transformer should be still connected to apply a 10 V peak sinewave to the breadboard using the black and white banana jacks. The overall circuit of Fig. E2.6 uses the following parts:

D1, D2, D3, D4 = 1N4007

R1 = 1.0 k $\Omega$  5% 1/4 W

C1 = 10  $\mu$ F 25 V electrolytic

C2 = 33  $\mu$ F 25 V electrolytic

R2 = 1.0 k $\Omega$  5% 1/4 W

D5 = 1N4732 (4.7 V) zener

RL = 10 k $\Omega$  potentiometer

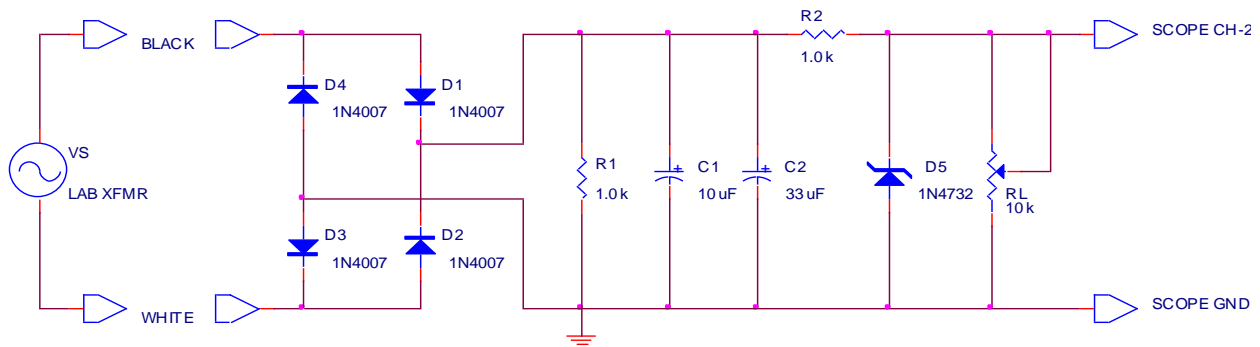


Figure E2.6

The middle lead on the potentiometer RL is the wiper, that is, the moveable terminal represented by the arrow in Fig. E2.6. The potentiometer RL is used in the above circuit to simulate the effect of a varying load resistance. Familiarize yourself with the proper directions to turn the knob on RL to increase or to decrease the load current.

## Experiment-2

Connect the channel-2 probe of the oscilloscope to the cathode (banded end) of D5, as shown in Fig. E2.6, and adjust the oscilloscope to display the output waveform.

**Measurement-6** Adjust the load resistance  $R_L$  over the extent of its range and observe the output voltage on the oscilloscope. Sketch the output waveforms in your notebook for the two most obvious cases of where the regulator is regulating the output voltage and where the regulator has “dropped-out” because of excessive load current.

Next, the regulation properties of the circuit will be determined by measuring the DC output voltage under specific load current and input voltage conditions. Remove the 10 k $\Omega$   $R_L$  potentiometer from the circuit. This condition now corresponds to no load, or open-circuit output conditions. Use the bench DMM to measure the DC output voltage under these circumstances. Now, add a 4700  $\Omega$  5% 1/4 W resistor in parallel with D5 (where  $R_L$  used to be) and remeasure the DC output voltage with the DMM. Replace the 4700  $\Omega$  load resistor with a 1000  $\Omega$  5% 1/4 W resistor and remeasure the DC output voltage. Finally replace the 1000  $\Omega$  load resistor with a 470  $\Omega$  5% 1/4 W resistor and remeasure the DC output voltage. Record each of these readings in a table in your notebook.

Now, reconnect the laboratory transformer to apply a 20 V peak sinewave to the circuit using the black and red banana jacks. Repeat the above measurements of the DC output voltage using the DMM with load conditions of: (1) no load, (2) 4700  $\Omega$  load, (3) 1000  $\Omega$  load, and (4) 470  $\Omega$  load. Record these readings in your notebook. You may also wish to re-examine the voltage waveforms at this higher input voltage level.

**Question-6**

- (a) Using the measured values of the DC output voltage (the voltage across D5), compute the load regulation for the zener diode regulator as: Load Regulation =  $\Delta V_{out} / \Delta I_{load}$ .
- (b) Compute the line regulation for this zener diode regulator as: Line Regulation =  $\Delta V_{out} / \Delta V_{in}$ . For  $\Delta V_{in}$ , use the change in the rms input voltage from the laboratory transformer.
- (c) Explain how both of these performance measures are related to the characteristics of the zener diode D5.

## Procedure 7 Voltage clamper circuits

### Set-Up

Disconnect the lab transformer leads and the oscilloscope probes and then completely disassemble the breadboarded circuit of Procedure 6. Assemble on a solderless breadboard the circuit of Fig. E2.7 below using the following parts:

C1 = 10  $\mu$ F 25 V electrolytic

D1 = 1N4007

R1 = 10 k $\Omega$  5% 1/4 W

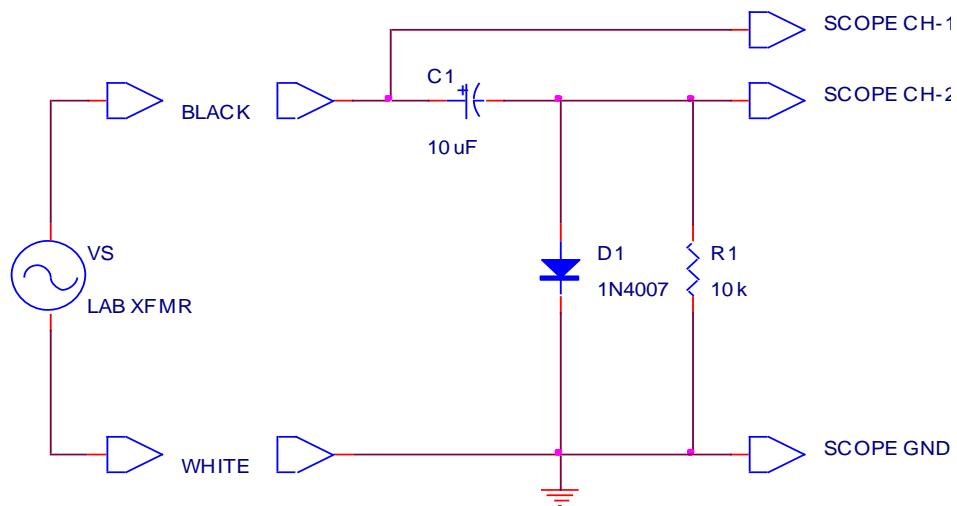


Figure E2.7

Connect the black and white banana jack outputs of the lab transformer to the breadboard as shown in Fig. E2.7 to apply a 10 V peak sinewave to the circuit. Keep the lab transformer turned OFF while you are making connections to the circuit. Connect 10 $\times$  oscilloscope probes from channel-1 and channel-2 of the oscilloscope to the points indicated in Fig. E2.7. Connect the oscilloscope ground leads as shown.

### Measurement-7

Configure the oscilloscope to display two complete cycles of the waveforms. Set the timebase to 5 ms/div and set the trigger source to Ch-1. Adjust the vertical scale for both channels to produce 5 V/div on the screen. Adjust the vertical position of each channel so that the zero voltage level corresponds to the center cross-hair on the oscilloscope screen. Do this by first grounding the input to a channel by setting the coupling switch to GND, moving the horizontal line vertically to the exact center of the screen with the vertical position control, and then returning the coupling switch to DC. Note that the difference between the channel-1 and channel-2 voltages is equal to the voltage across the capacitor C1. Record these waveforms in your notebook with sketches that are ticked off with proper scale factors. Use the bench DMM to measure the voltage across capacitor C1. Record this voltage and its polarity on a schematic of the clamper circuit in your notebook.

## Experiment-2

**Question-7** The circuit of Fig. E2.7 is termed a negative voltage clamper. Draw the circuit for a positive voltage clamper and discuss any necessary polarity changes on both the diode and/or the capacitor.

### Procedure 8 Voltage multiplier circuits

**Comment** Cascading voltage clamper circuits one after the other produces a very common circuit that can be used to multiply DC voltages. These circuits find extensive use in high-voltage and switch-mode power supplies.

**Set-Up** Disconnect the Ch-2 oscilloscope probe from the breadboarded circuit of Procedure 7 and then remove resistor R1. The laboratory transformer inputs and the Ch-1 oscilloscope probe do not need to be moved.

Add additional diodes and capacitors to the breadboard to produce the circuit shown in Fig. E2.8 below. Be very careful to install each diode and each capacitor in the correct polarity. The parts used in this circuit are:

D1, D2, D3, D4 = 1N4007

C1, C2, C3, C4 = 10  $\mu$ F 25 V electrolytic

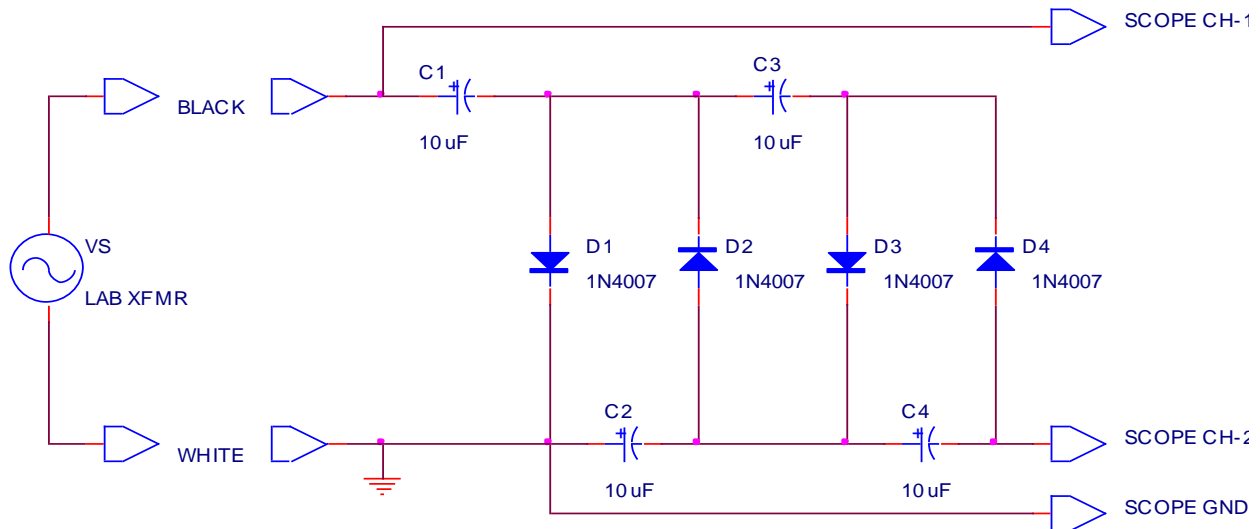


Figure E2.8

**Measurement-8** Adjust the vertical position of both oscilloscope channels so that the zero voltage level is aligned to the center cross hair on the screen. Draw a schematic of the multiplier circuit in your notebook, and then place a little sketch of the voltage waveform existing at each end of each diode (8 nodes total) beside each of the nodes in your schematic. Use the Ch-2 oscilloscope probe to sample each of these waveforms. Measure the DC output voltage that appears at the node between D4 and C4, as shown in Fig. E2.8. This is

## Experiment-2

the actual output terminal of the multiplier. Use the bench DMM to measure the voltage existing across each capacitor and record these values and their polarities on the schematic in your notebook.

### Question-8

The circuit of Fig. E2.8 is generically termed a negative even multiplier. If the peak input voltage is  $V_m$ , then this particular circuit delivers an output voltage of  $-4(V_m - V_\gamma)$ , where  $V_\gamma$  is the turn-on voltage of the diodes. Thus, the circuit is more specifically termed a negative voltage quadrupler. In your notebook, draw the schematics for a positive voltage doubler circuit which provides  $+2(V_m - V_\gamma)$ , and for a positive voltage tripler circuit which provides  $+3(V_m - V_\gamma)$ . Be very careful to consider the necessary polarities on both the diodes and the capacitors. If you have time, you might try out your designs on the breadboard to prove that they work properly.