ECSE 331
Laboratory No. 4
Silicon Diodes and Their Applications

Objective:

Investigate the i-v characteristics of a silicon diode as a function of diode voltage. This investigation will apply to a signal, rectifier and Zener diode. The forward, reverse and breakdown regions of the diode and temperature dependence will be investigated. Applications of diodes as rectifiers, voltage regulators and limiters will be explored.

Equipment Required:

1. NI Elvis-II$^+$ test instrument
2. PC with ELVIS-II$^+$ software installed
3. Heat Gun
4. Aerosol Freeze Spray to cool diode
5. Hand-held thermal imager
6. Components:
    a. IN4148 signal diode
    b. 1N4005 power diode
    c. 1N5226B 3.3 V Zener diode
    d. 1.5 V battery / battery holder
    e. resistors: 10 Ω, 1 kΩ, 10 kΩ
    f. capacitors: 1 μF, 100 μF

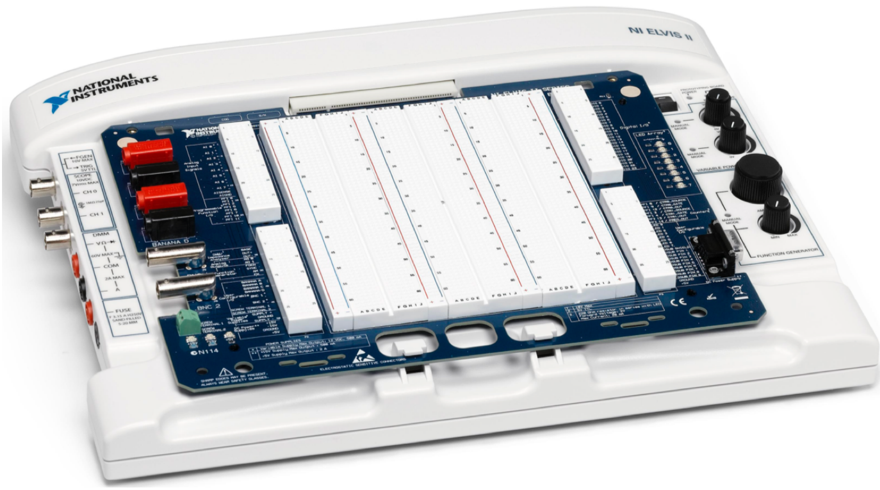
Description of the NI Elvis-II+ Test Instrument:

The National Instruments Educational Laboratory Virtual Instrumentation Suite (NI ELVIS-II$^+$) is a hands-on design and prototyping platform that integrates the 12 most commonly used instruments – including oscilloscope, digital multi-meter, function generator, bode analyzer, and more. It connects to a PC through a USB connection, providing quick and easy acquisition and display of measurements.

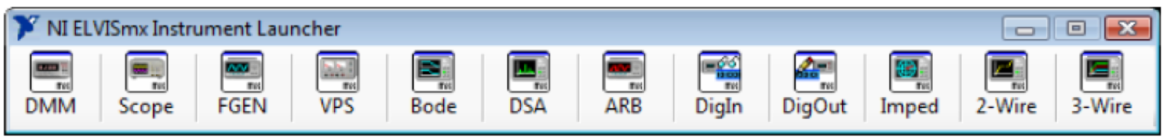
The National Instruments Educational Laboratory Virtual Instrumentation Suite consists of two main components:

1. The bench-top workstation (NI ELVIS-II$^+$), which provides instrumentation hardware and associated connectors, knobs, and LEDs as shown in Fig. 1(a). A prototyping board (breadboard) sits on top of the workstation, plugged into the NI ELVIS-II$^+$ platform, and offers hardware workspace for building circuits and interfacing experiments.
2. NI ELVIS-II$^+$ software, which includes soft front panel (SFP) instruments. Fig. 1(b) illustrates the PC screen view of the oscilloscope interface.

The Elvis-II$^+$ prototype board consists of 5 separate areas: four small prototype areas on the



(a)



(b)

Fig. 1: (a) Elvis-II$^+$ instrumentation hardware with prototyping board, and (b) menu for various virtual instrument.

peripheral of the board, and a much larger central prototype area. The boards on the peripheral are used to interface to the internal data acquisition board of the Elvis-II$^+$ system. There are marking along the perimeter of the board indicating the connection. The student was introduced to this test bench back in Laboratory 1. The student should refer back to this lab for a detailed description of the NI ELVIS-II$^+$ test system.

Practical Information for the Student:

In performing this experiment, you will construct several building blocks of modern transistor circuits. On doing so, keep the following points in mind:

1. In the figures, more positive voltages are always shown closer to the top of the page, so that current flows in the circuit from top to bottom.
2. Keep all connecting leads as short as possible and pushed down to the surface of the circuit board. You want to avoid a "*rat's nest*" of wiring whereby unwanted coupling capacitances and series inductances are created. These parasitics can prevent your circuit from working correctly.
3. Use different color wires in your circuit. The standard convention is red for positive supply voltages, blue for negative supply voltages and black for ground. Use colors that are different than these for signals. If you use a single color for everything, your circuit should still work. However, the debug process will be much more difficult if something goes wrong. It is important for the student to understand that when asked to design a circuit it is not limited to just the arrangement and component selection for the circuit but also to the fact that the

design may not work the first time it is assembled. In general, all design will require at least two iterations before one can declare success!

4. In understanding circuits, as well as designing them, keep in mind that that there are two *interleaved* problems: the dc design, which establishes the operating points, and the ac design, which is responsible for how the circuit responds to signals. The student must design both problems at the same time; if you make a change to one, be sure that you haven't changed the other.

Write-Up Requirements:

A good laboratory report should contain a **brief** description of what the experiment was about, including circuit diagrams, and what you did, your data, your results, and anything else called for in the assignment, such as questions inserted in the laboratory. Answers to these questions require observations that need to be made at the time you do the experiment.

The laboratory report should be written using the IEEE paper style consisting of a double-column single-space format, and must adhere to the following:

1. Title page - Title of the assignment/project, authors' name, and course name.
2. Abstract - Abstract of the assignment/project report.
3. Introduction
4. Main body of the assignment/project report including figures.
6. Conclusions
7. References
8. Appendices

Procedure:

I. i-v Characteristics Using a Curve Tracer

Critical to one's understanding of any electronic device is the concept of its transfer characteristic. In the case of a silicon diode, we're interested in how the diode current changes with respect to its terminal voltage. This is referred to as its i-v characteristic. In this part of the laboratory, the student will construct an instrument referred to as a curve-tracer and use it to measure the i-v characteristics of a silicon diode. This instrument must be capable of sourcing a voltage signal while at the same time measure the corresponding current that it delivers. To accomplish this, the student will use the function generator capability of the Elvis-II$^+$ to generate a triangular voltage waveform. A pseudo current probe using a 10-Ω sense resistor and a difference amplifier will be used to create a voltage equal to 10 times the diode current. The A and B channels of the oscilloscope will then enable one to display these two signals; one as the x-axis, the other the y-axis.

Construct the circuit shown in Fig. 2 using the 741 op-amp and the 1N4148 signal diode. The pin-outs for these components can be found in Figs. 3 and 4. Verify that the current sensing op-amp circuit operates as expected without the diode present by replacing the diode with a 100 Ω resistor. Using the function generator feature of the Elvis-II$^+$ test system, set it to generate a saw-tooth waveform over a –2 V to +2 V signal range. Connect the V_X node to the channel A of your Scope and the V_Y to channel B. As the voltage V_Y is 10-times larger than the current, either scale the input by a factor of ten, or simply keep track of the y-axis units and adjust any plot accordingly. Set the Scope to plot channel A versus B, so that an i-v characteristic will appear on your screen. Capture your results and confirm that the i-v characteristics displayed indeed corresponds to a 10 kΩ resistor. Next, replace the 100 Ω resistor by the 1N4148 signal diode. *Capture your results and identify the following attributes of the diode: (1) cut-in voltage, and (2) slope of the i-v characteristic at a diode voltage drop of 0.7 V or the reciprocal of the ac diode resistance. In your report, superimpose the diode behavior predicted by the piece-wise linear model onto the measured i-v curve for the diode. What is the maximum voltage difference between the actual i-v curve and that predicted by the piecewise linear model over a voltage range from -2 to +2 V? Is the piece-wise linear approximation a good model?*

Repeat the above procedure but this time use the 1N4005 power rectifier diode instead of the 1N4148 signal diode. Superimpose the two i-v plots and compare. *Are there significant differences?*

Reverse the direction of the diode in Fig. 2 and display the i-v transfer characteristic of the diode? *Comment on what you see.*

II. Diode Temperature Effects

In this part of the laboratory, you will measure the temperature effects of the diode. This will require access to a hot-air blowgun, a can of freeze spray (spray-on cooling agent) and a hand-held thermal imager. These are available in the microelectronics laboratory Rm 4090 of the Trottier building.

For this next step, return to the curve tracer set-up involving the 1N4148 signal diode shown in Fig. 2. Display the i-v characteristic for the 1N4148 signal diode using your function generator/oscilloscope curve-tracer setup. Let us assume that this measurement was made at room temperature but to get a more precise temperature reading, use the hand-held thermal imager and determine the temperature of the diode. Now, using the can of freeze spray, blow the cooling agent directly onto the diode, while at the same time exercising the i-v characteristics of the diode. Measure the temperature of the diode and record this information along with the i-v characteristics. Now, repeat this procedure but this time use the hot-air blowgun, blow hot air onto the diode. Avoid heating up the op-amp circuit. This will raise the temperature of the diode. Measure the temperature of the diode and record this information along with the i-v characteristics. Compare the three plots taken at the three different temperatures. *How do they compare? How do you expect the i-v characteristics to change with temperature? Provide an explanation with supporting theory.*

III. Zener Diodes

In this part of your laboratory you will investigate the i-v characteristics of the 1N5226B Zener diode. Using your curve-tracer circuit, place the Zener diode into the test port as shown in Fig 5. and sweep the saw tooth waveform output to produce a signal that varies between –5 V to +2 V. *At what voltage does this Zener diode breakdown? Estimate the ac resistance of the Zener diode inside its breakdown region?*

Do not dismantle your i-v curve tracer circuit, as you will need this test setup later in part VI of this laboratory.

IV. Rectifiers

Connect the half-wave rectifier circuit shown in Fig. 6 using the 1N4005 power rectifier diode and a 1-kΩ load. Apply a 60 Hz, 5 V amplitude sinewave as input. Observe the output voltage across the load resistor using your oscilloscope. Display both the output and input signals on the same plot. *How do they compare?*

Insert a 1-μF capacitor across the load resistor of the rectifier circuit as shown in Fig. 7. Maintain the same 60 Hz input signal as before. Observe the output voltage across the load resistor using your oscilloscope. Display both the output and input signals on the same plot. *How do they compare? How much ripple is present in the output signal? What is the frequency of the ripple? What is the amplitude of the ripple?* Increase the capacitance to 100 μF and repeat the experiment. *Did the frequency or amplitude of the ripple change? If so, how much? Can you provide an equation to describe the ripple?*

V. Voltage Regulation Using Zener Diode

In this part of the laboratory the student will compare two different ways to reduce a DC level from a fixed DC supply. Using the half-wave rectifier of part IV with C = 100 uF, replace the 1-kΩ load resistor with a voltage divider circuit to produce an output voltage level of 3.3 V as shown in Fig. 8(a). Maintain the sum of the two resistors at approximately the 1-kΩ level so that the rectifier circuit behaves the same way as in part IV. Observe the output voltage at the output of the voltage divider using your oscilloscope. *What is the average value of the output and how much ripple is present at this output? How does this amount of ripple compare with the amount of ripple present in your previous measurement of the rectifier of part IV?*

Next, replace the resistor divider with the 1N5333 Zener diode and a series resistor of approximately 1 kΩ as shown in Fig. 8(b). Observe the output voltage across the Zener diode using your oscilloscope. *What is the average value of the output and how much ripple is present at this output? How does this amount of ripple compare with the amount of ripple present in your previous measurement involving the resistor-divider network? Which provides the smallest AC ripple?*

VI. Limiter Circuit Using Diodes

Place a 1.5 V battery cell in series with the 1N4148 signal diode and interface it to the curve-tracer circuit as shown in Fig. 9. Adjust the saw tooth waveform generator to produce an output signal that varies between –2 V to +3 V. Display the i-v characteristic of the two back-to-back diodes arrangement using the oscilloscope. *At what voltage does the diode-battery arrangement turn on?*

Connect two 1N4148 signal diodes in reverse directions and interface it to the curve-tracer circuit shown in Fig. 10. Adjust the saw tooth waveform generator to produce an output signal that varies between –2 V to +2 V. Display the i-v characteristic of the two back-to-back diodes arrangement using the oscilloscope. *Comment on how this circuit would be used? Is this useful for large signals, small signals or both?*

This concludes this lab.

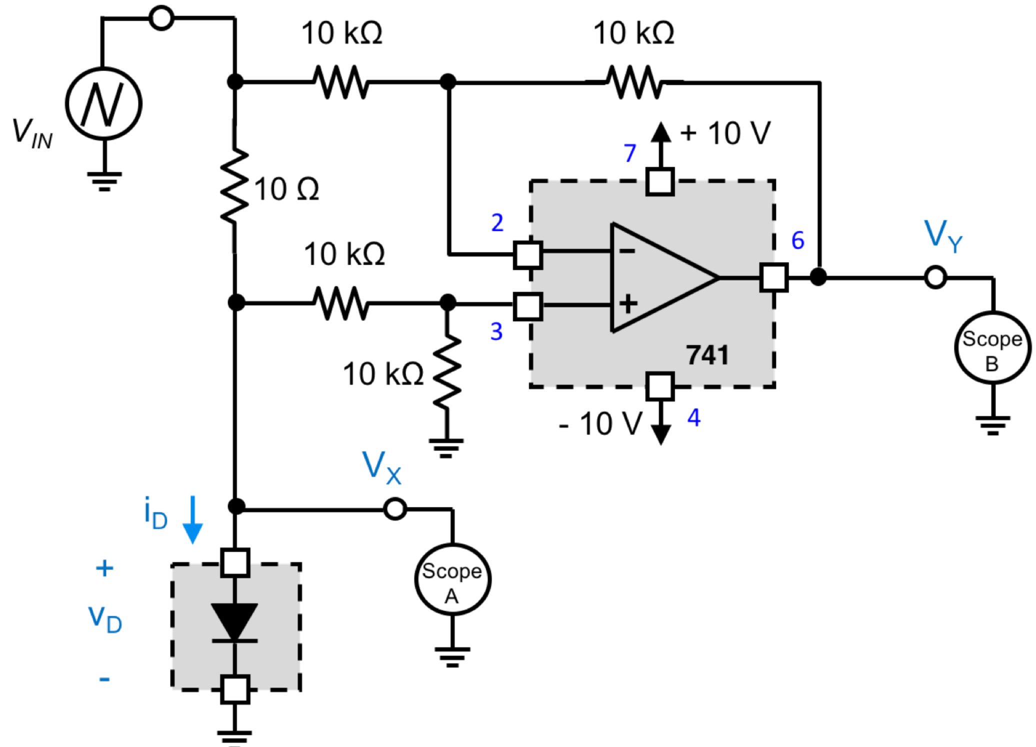


Fig. 2: Curve-trace set-up for measuring the diode i-v characteristic.

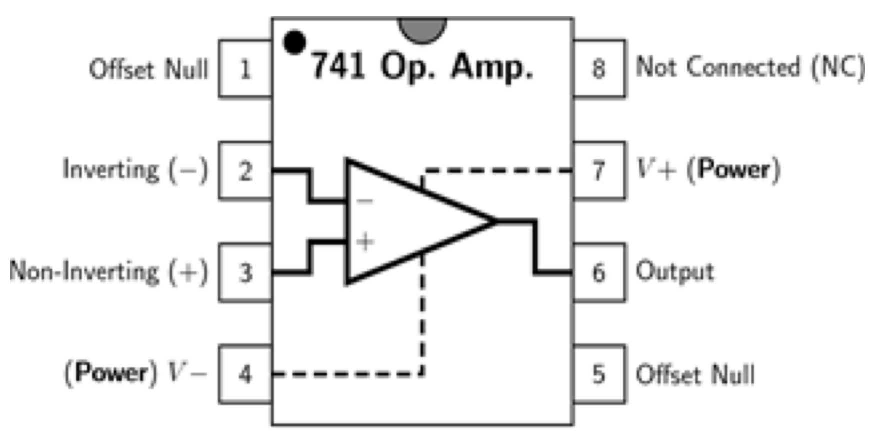
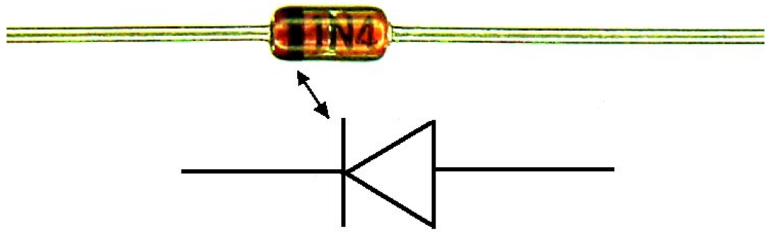


Fig. 3: 741 Pin-Out



(a)

(b)

Fig. 4: Diode Pin-Out: (a) 1N4148 signal diode (b) 1N4005 power rectifier diode.

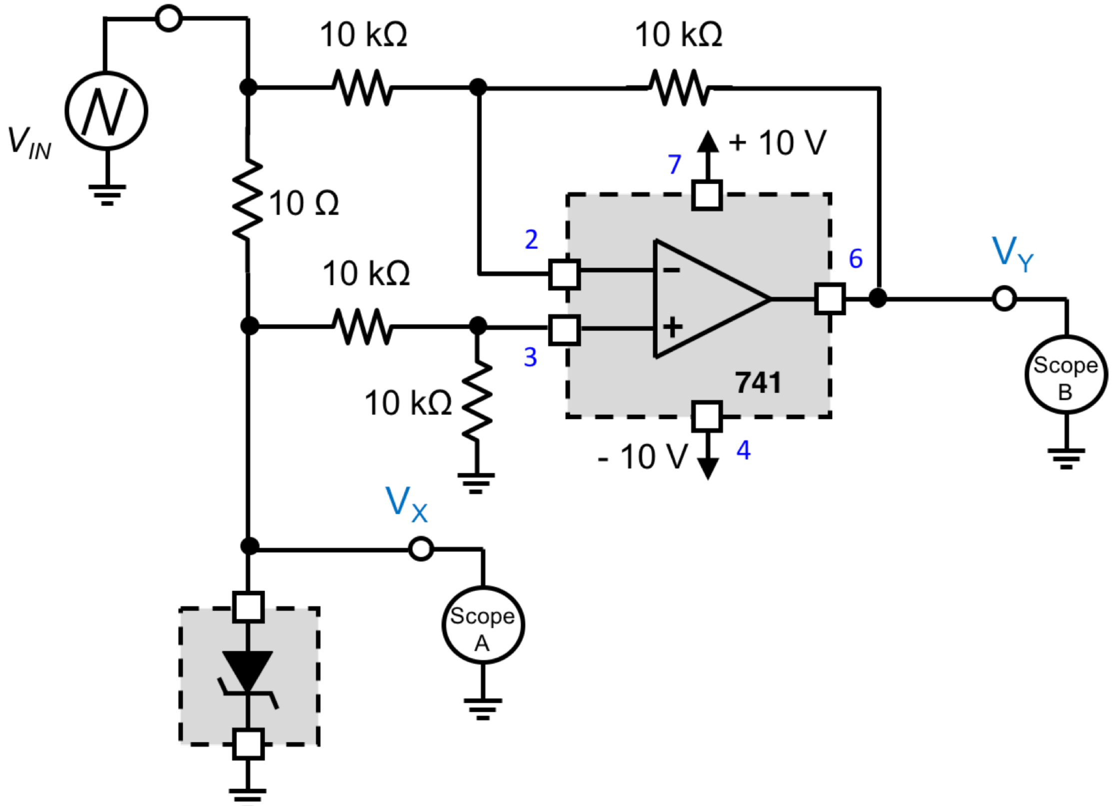


Fig. 5: Capturing the i-v characteristic of a 3.3 V Zener diode.

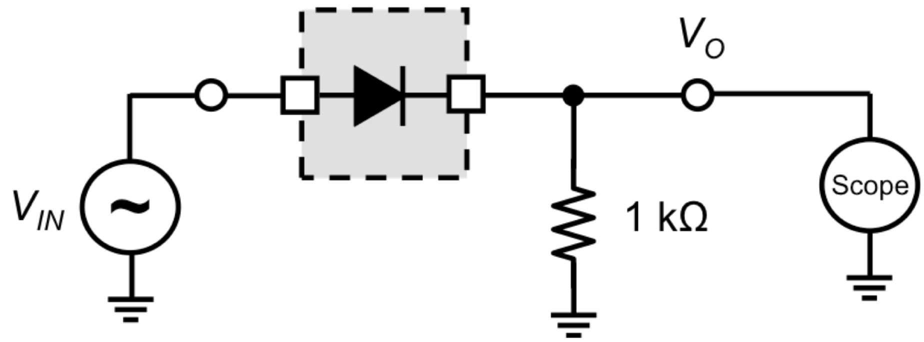


Fig. 6: Half-wave rectifier circuit.

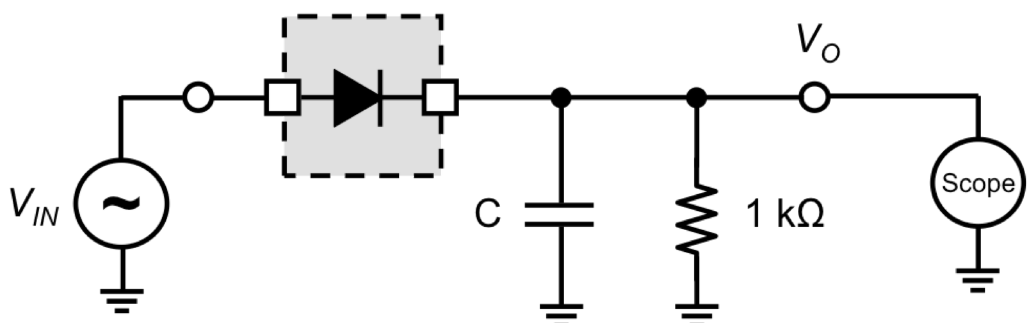
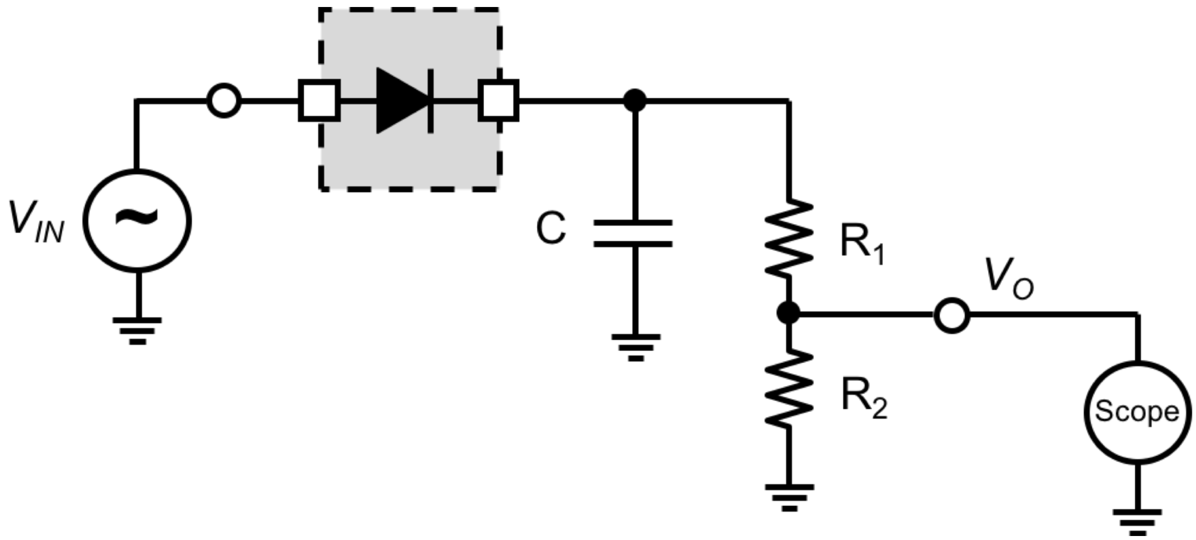
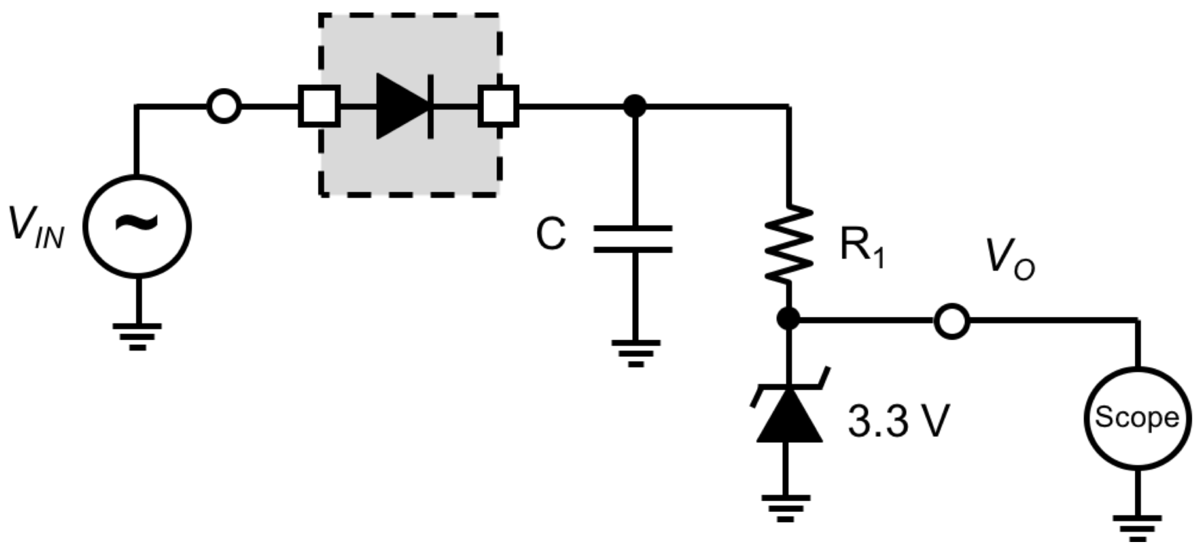


Fig. 7: Half-wave rectifier circuit with peak-detector.



(a)



(b)

Fig. 8: Voltage reference using: (a) resistor divider, (b) Zener diode.

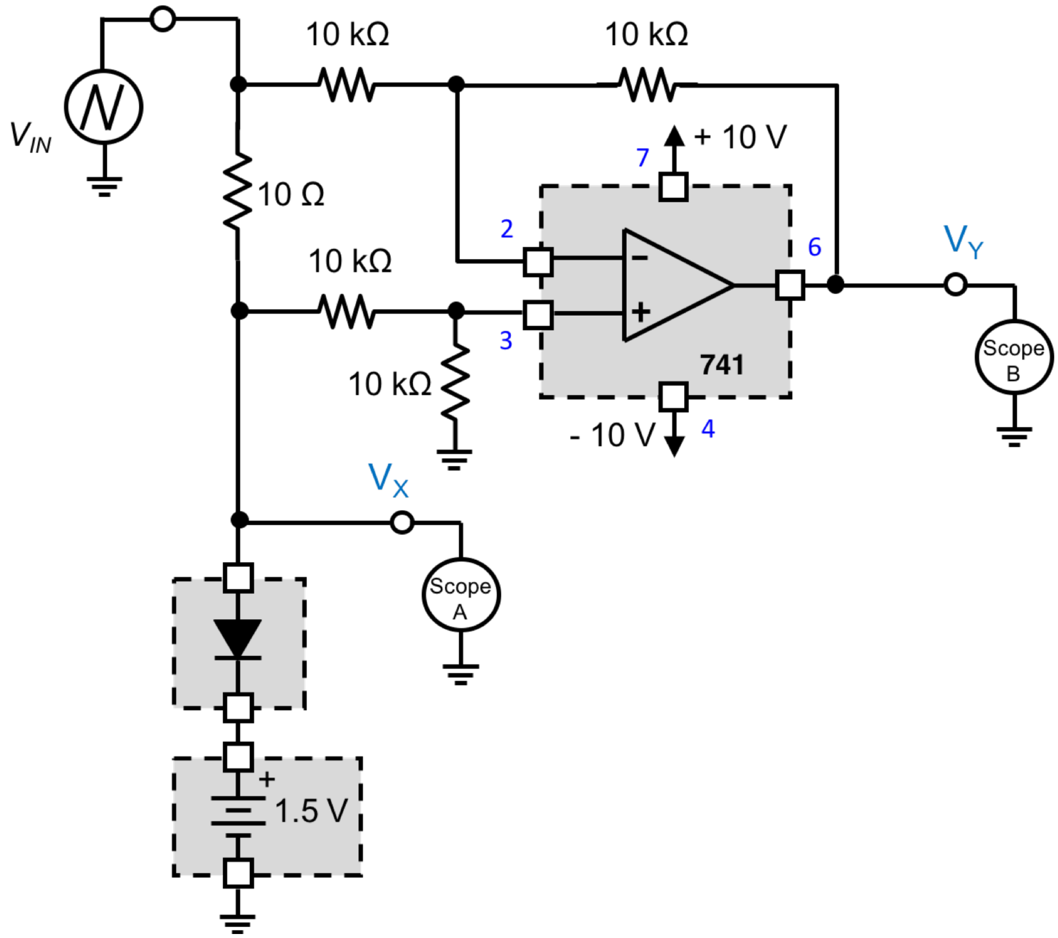


Fig. 9: Capturing the i-v characteristic of a diode and a 1.5 V voltage source called a limiter circuit.

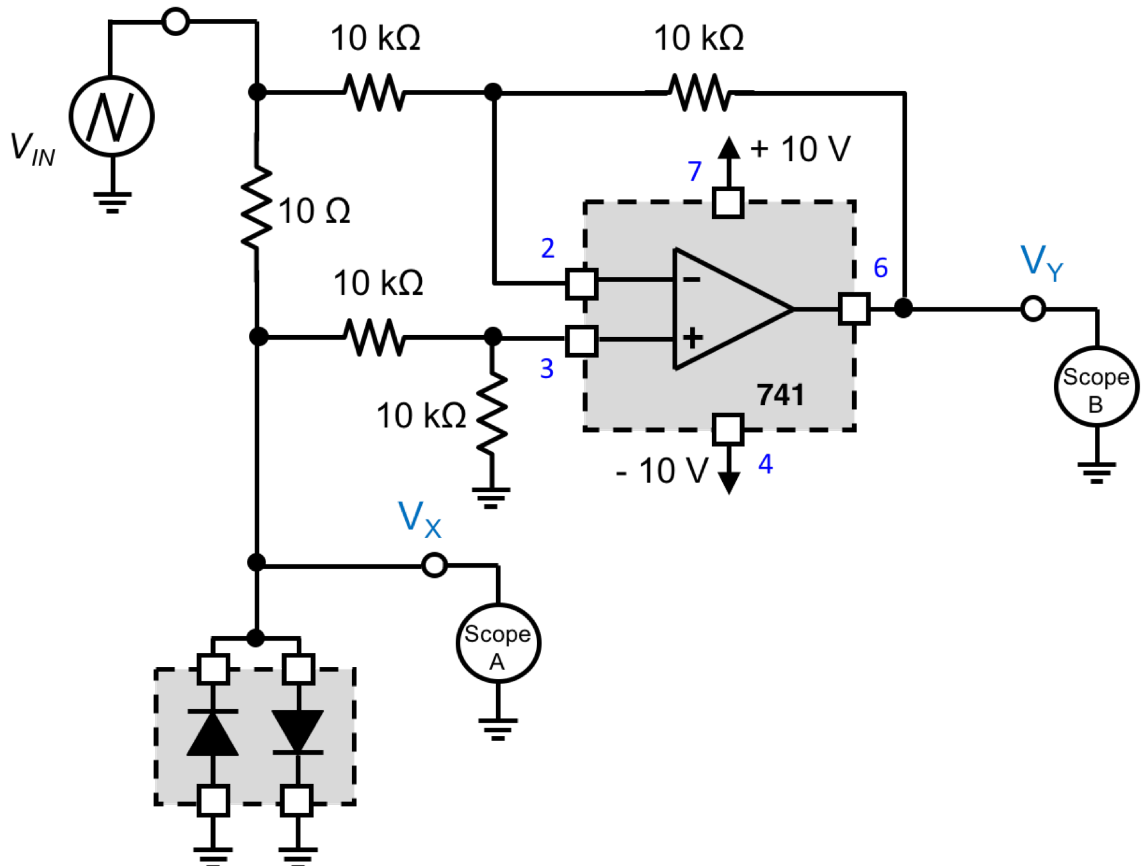


Fig. 10: Capturing the i-v characteristic of two back-to-back diodes forming another type of limiter circuit.