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Student Zone—August 2019 ADALM2000 Diodes and Diode Circuits

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Objective

The purpose of this activity is to investigate the current vs. voltage characteristics of a PN junction diode.

Subcategories

- 2a: Half-Wave Rectifier
- 2b. Full-Wave Rectifier
- 2c. Bridge Rectifier
- 2d. Limiter/Clamp Circuit
- 2e. AC Coupling and DC Restoration
- 2f. Variable Attenuator
- 2g. Absolute Value Circuits
- 2h. A Voltage Doubler Circuit

Materials

- ADALM2000 active learning module
- Solderless breadboard
- One resistor (1 kΩ or any similar value from 1 kΩ to 5 kΩ)
- One small signal diode (1N914 or similar)

Directions

The current vs. voltage characteristics of the PN junction diode can be measured using the ADALM2000 board and the following connections. The blue boxes indicate where to connect the ADALM2000 board. Set up the breadboard with waveform generator output W1, which is attached to one end of the resistor. The 2+ scope input is also connected here. The other end of the resistor is connected to one end of the diode, as shown in Figure 1. The 2– scope input and the 1+ scope input are connected to the second end of the resistor. The other end of the diode is connected to ground, along with the 1– scope input.

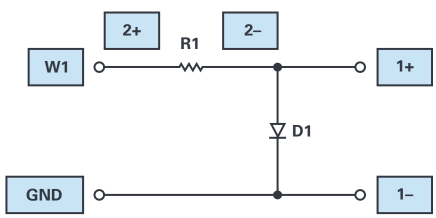


Figure 1. Connection diagram for diode I/V curves.

Hardware Setup

The waveform generator should be configured for a 100 Hz triangle wave with 6 V amplitude and 0 V offset. The differential input of Scope Channel 2 (2+, 2–) is used to measure the current in the resistor (and diode). The single-ended input of Scope Channel 1 (1+) is used to measure the voltage across the diode (1– input can be grounded). The scope should be setup with Channel 1 at 500 mV per division and Channel 2 set also at 500 mV per division. The current flowing through the diode I_D is the voltage measured by Channel 2 divided by the resistor value (1 kΩ in this example). Use the XY display mode to plot the voltage across the diode (Scope Channel 1) on the x-axis vs. the current in the diode (Scope Channel 2) on the y-axis.

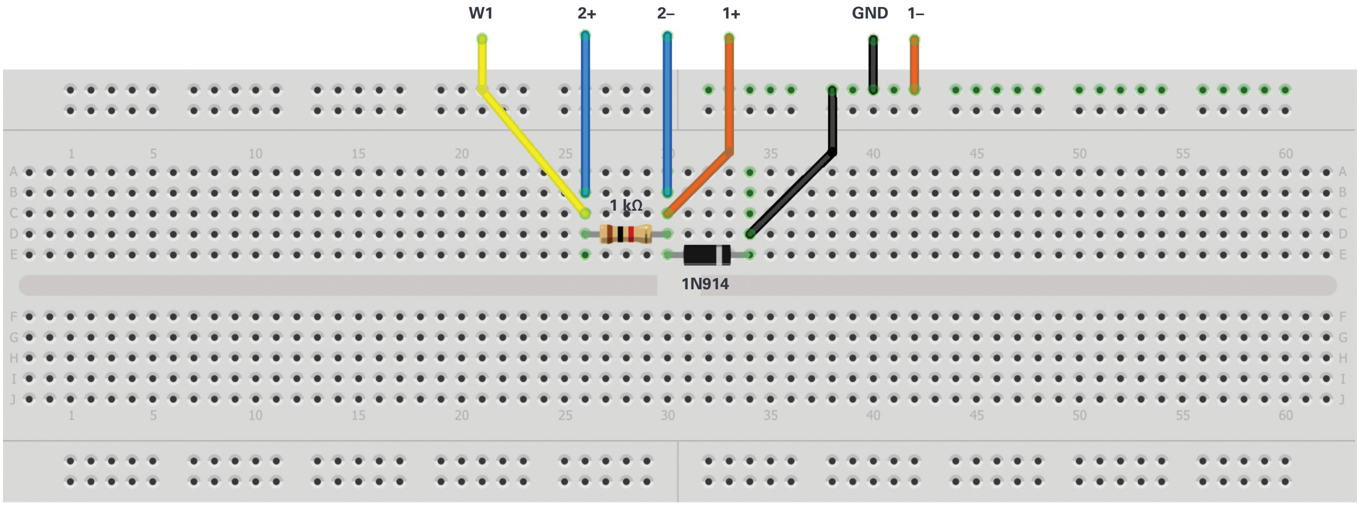


Figure 2. Current vs. voltage, linear scales.

Procedure

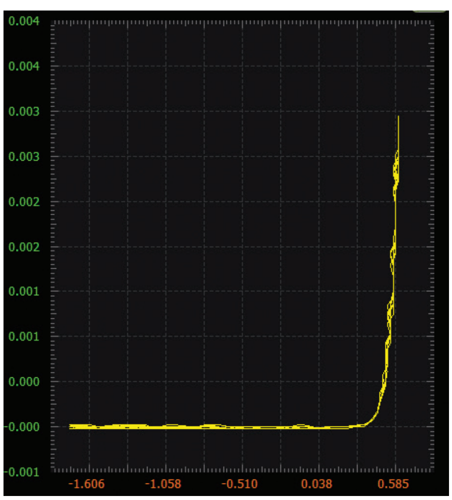


Figure 3. Current vs. voltage (linear scales Scopy plot).

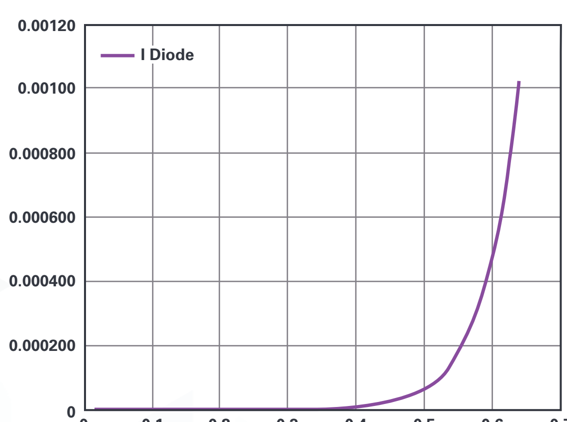


Figure 4. Current vs. voltage (linear scales Excel plot).

Load the captured data into a spreadsheet program like Excel and calculate the diode current I_D. Plot the current vs. the voltage across the diode. The diode voltage and current relationship is logarithmic. If plotted on a log scale, the line should be straight, as seen in Figure 5.

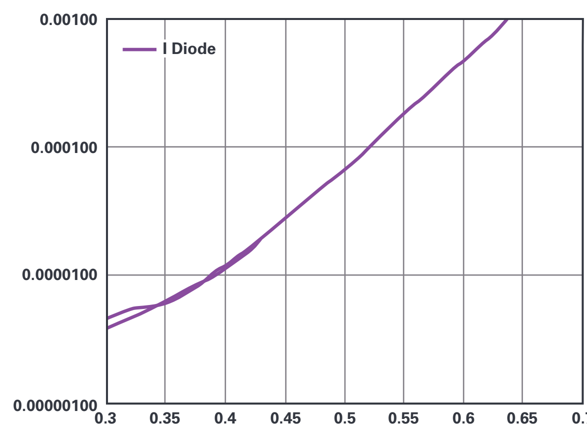


Figure 5. Current vs. voltage on a log scale.

Questions

What is the mathematical expression for the diode current I_D given the voltage across the diode V_D?

Further Exploration on Diode Characteristics

Measure the diode characteristics, V_D at a fixed I_D, of multiple 1N914 diodes; there should be four included in the ADALP2000 analog parts kit and you can ask to exchange some with a lab-mate to get even more samples. Calculate the mean and coefficient of variation (CV) of your measurements (CV is defined as the standard deviation divided by the mean as a percentage). Discuss the amount of variation you observe, which is often a measure of what semiconductor engineers call process variation.

Replace the 1N914 diodes with a light emitting diode (LED). You should have red, yellow, green, and infrared LEDs in the ADALP2000 analog parts kit. Do the LEDs have similar mathematical expressions for the diode current I_D given the voltage across the diode V_D as the 1N914? In what way are they similar and in what way are they different? Do the red, yellow, and green LEDs turn on at the same forward voltage?

2a. Half-Wave Rectifier

Objective

The purpose of this activity is to investigate the use of a diode as a half-wave rectifier.

Materials

- One resistor (4.7 kΩ or any similar value)
- One small signal diode (1N914 or similar)

Directions

Set up the breadboard with waveform generator output W1 attached to one end of the diode. The other end of the diode is connected to one end of the load resistor, as shown in Figure 6. The other end of the resistor is connected to ground. The single-ended input of Scope Channel 2 (2+) is also connected to the end of the resistor not connected to ground (2– input can be grounded).

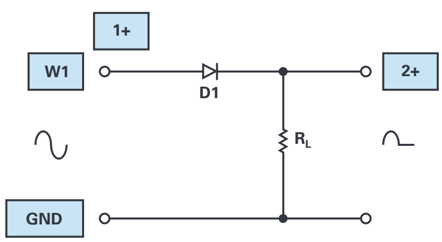


Figure 6. Connection diagram for a half-wave diode rectifier.

Hardware Setup

The waveform generator should be configured for a 100 Hz sine wave with 6 V amplitude and 0 V offset. Scope Channel 2 (2+) is used to measure the voltage across the load resistor R_L. Both scope channels should be set to 500 mV per division.

Procedure

Plot the two waveforms using the oscilloscope feature from the Scopy tool.

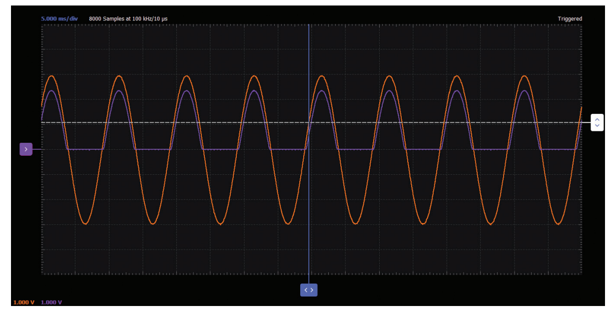


Figure 8. Half-wave rectified waveform.

Questions

Why is the peak value of the rectified output less than the peak value of the ac input and by how much? At what point in the input waveform does the rectified waveform become positive; that is, something other than zero? What happens if the direction of the diode is reversed? Repeat the experiment with the direction of the diode reversed.

Further Exploration

Replace the 1N914 diode with a light emitting diode. You probably need to increase the AWG1 amplitude to 10 V to accommodate the higher forward voltage drop of the LED.

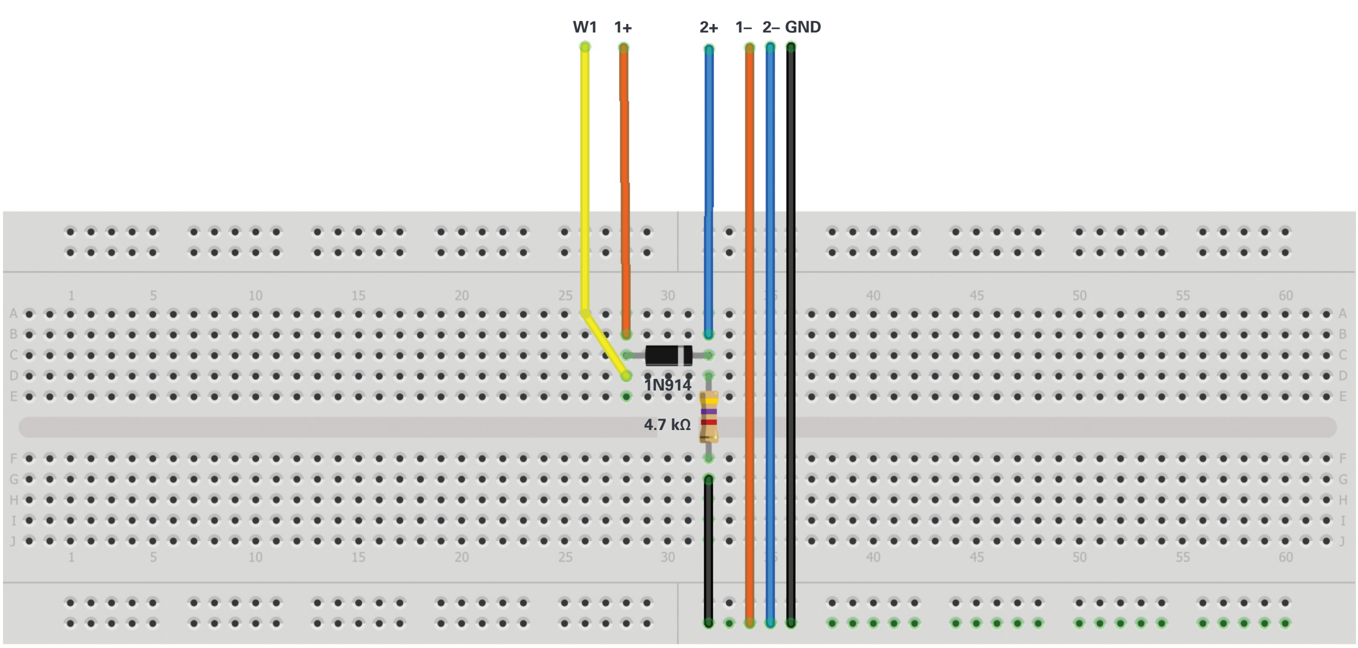


Figure 7. Half-wave diode rectifier breadboard circuit.

- 1. How does the waveform for the rectified output compare to your earlier results with the 1N914 diode? By how much does the forward-bias voltage drop increase?
- 2. Experiment with the three different waveform shapes while the waveform generator remains set to 100 Hz and pay attention to the brightness of the LED. Discuss your observations of waveform shape and brightness and relate these observations to your measured effective dc values for each waveform shape.
- 3. Reduce the waveform generator frequency, and experiment with values as low at 0.2 Hz (one cycle every five seconds). Discuss the behavior of the LED optical intensity for each of the three waveform shapes when the waveform generator frequency is 1 Hz or less.
- 4. At what frequency does the flashing LED stop flickering and begin to appear as a constant intensity?

2b. Full-Wave Rectifier

Objective

The purpose of this activity is to investigate the use of two diodes as a full-wave rectifier.

Materials

- One resistor (4.7 kΩ or any similar value)
- Two small signal diodes (1N914 or similar)

Directions

Set up the breadboard with W1 attached to one end of the first diode, D1, and W2 to one end of the second diode, D2. Both diodes should face in the same direction. The other end of each diode is connected to one end of the load resistor, as shown Figure 9. The other end of the resistor is connected to ground. The single-ended input of Scope Channel 2 (2+) is connected to the junction of the resistor and the two diodes.

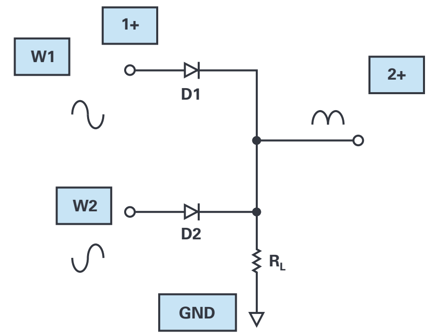


Figure 9. Connection diagram for a full-wave diode rectifier.

Hardware Setup

The first waveform generator, W1, should be configured for a 100 Hz sine wave with 6 V amplitude and 0 V offset. The second AWG generator, W2, should be configured also for a 100 Hz sine wave with 6 V amplitude and 0 V offset but with the phase set to 180°. The single-ended input of Scope Channel 2 (2+) is used to measure the voltage across the load resistor. Both scope channels should be set to 500 mV per division.

Procedure

Plot the two waveforms using the oscilloscope provided by the Scopy tool. If both 0° and 180° phases of the ac input are available, then a second diode can fill in the missing half-wave of the input and produce the full-wave rectified signal, as shown in Figure 11. Again, the forward voltage of the diodes is apparent, and the output waveform does not come to a sharp point at the zero crossing due to the non-zero turn on voltage of the diodes.

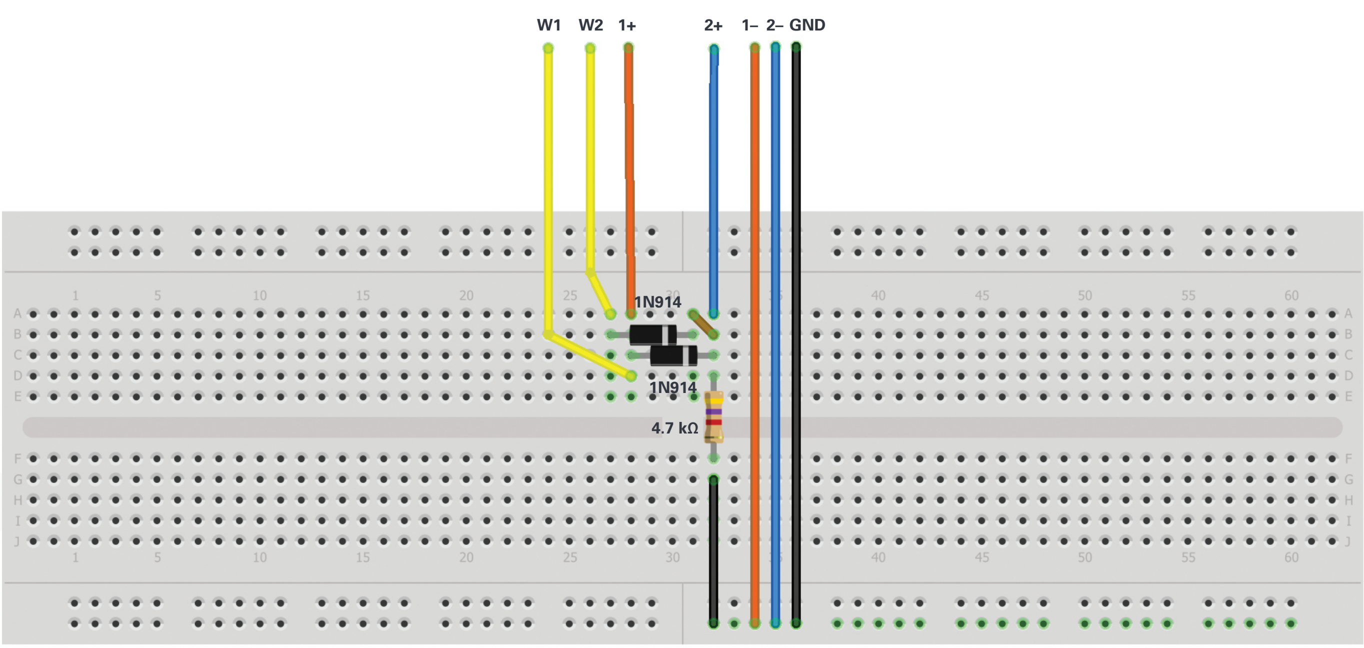


Figure 10. Full-wave diode rectifier breadboard circuit.

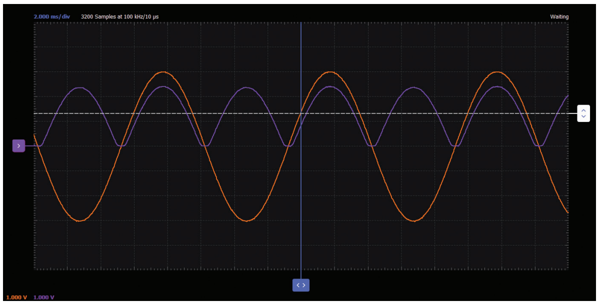


Figure 11. Full-wave rectified waveform.

Questions

What happens if the direction of the diodes is reversed? Repeat the experiment with the direction of both diodes reversed.

What happens if the direction of one diode is opposite of the other? Repeat the experiment with the direction of one diode (D1) reversed.

How could both 0° and 180° phases be created from a single source (such as a transformer)?

Further Exploration

Replace D1 and D2 with red and green LEDs. Increase the amplitude of AWG1 to 10 V (to accommodate the higher turn on voltage of the LEDs). Slow the frequency of AWG1 to 5 Hz or less. Are the two LEDs ever both on at the same time?

- 1. How does the waveform for the rectified output compare to your earlier results with the 1N914 diodes? By how much does the forward-bias voltage drop increase?
- 2. Experiment with the three different waveform shapes while the waveform generator is set to 100 Hz, pay attention to the brightness of the LEDs. Discuss your observations of waveform shape and brightness and relate these observations to your measured effective dc values for each waveform shape.
- 3. Reduce the waveform generator frequency, and experiment with values as low at 0.2 Hz (one cycle every five seconds). Discuss the behavior of the LED optical intensity for each of the three waveform shapes when the waveform generator frequency is 1 Hz or less.
- 4. At what frequency do the flashing LEDs stop flickering and begin to appear as a constant intensity?

2c. Bridge Rectifier

Objective

The purpose of this activity is to investigate the use of four diodes as a bridge rectifier.

Materials

- One resistor (4.7 kΩ or any similar value)
- Four small signal diodes (1N914 or similar)

Directions

Four diodes can be arranged in a bridge configuration to provide a full-wave rectification from a single ac phase, as shown in Figure 12. However, it can also be seen that only the ac input or the load can be referenced to ground.

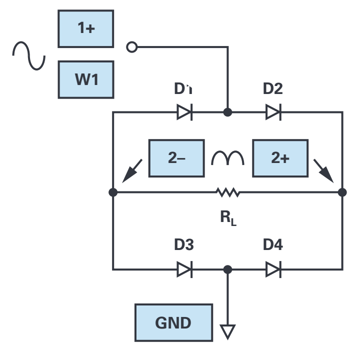


Figure 12. Connection diagram for diode bridge rectifier.

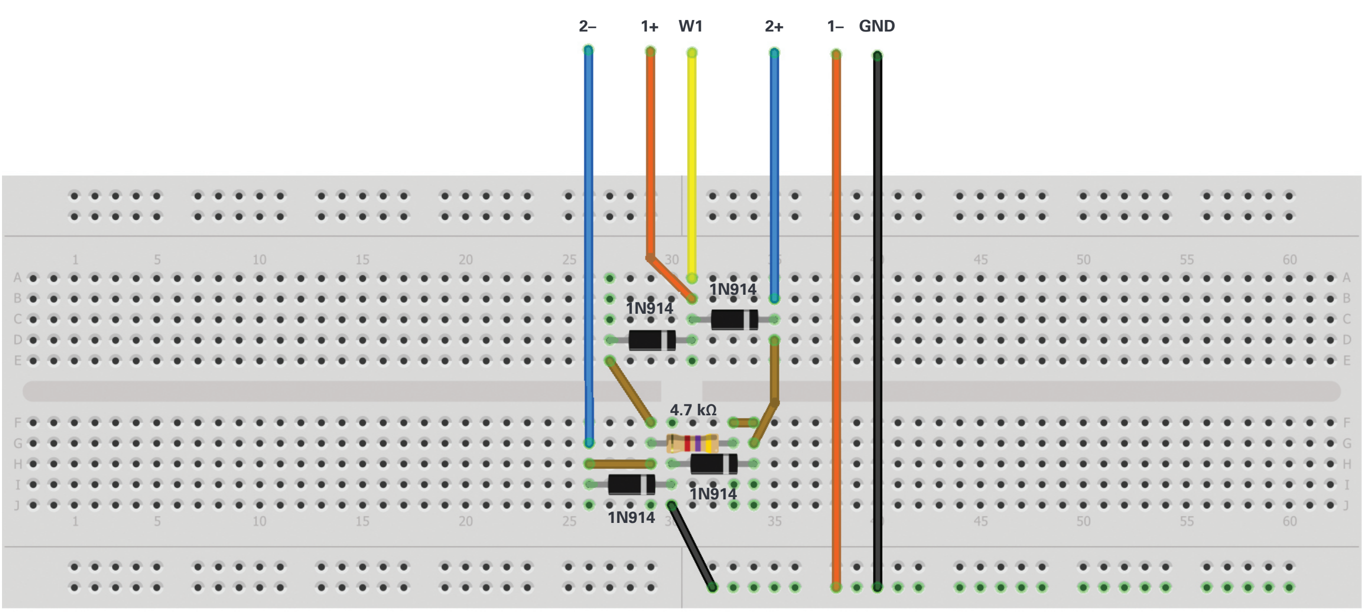


Figure 13. Diode bridge rectifier breadboard circuit.

Hardware Setup

The waveform generator should be configured for a 100 Hz sine wave with 6 V amplitude and 0 V offset. The scope channel 2 (2+, 2–) is used to measure the voltage across the load resistor, R_L. Both scope channels should be set to 500 mV per division.

Procedure

Plot the two waveforms using the oscilloscope provided by the Scopy tool. The disadvantage of this circuit is that now two diode drops are in series with the load and the peak value of the rectified output is less than the ac input by 1.2 V rather than the 0.6 V in the previous circuits.

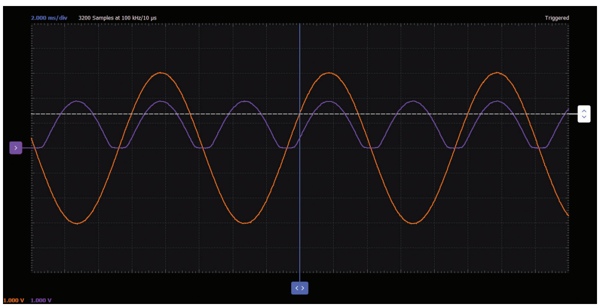


Figure 14. Full-wave bridge rectifier waveforms.

Questions

How would you reconfigure this circuit to allow one end of the load resistor to be connected to ground rather than how it is shown Figure 8 with one end of the ac source grounded?

Further Exploration

Replace all four diodes D1, D2, D3, and D4 with red and green LEDs. Increase the amplitude of AWG1 to 10 V (to accommodate the higher turn on voltage of the LEDs). Slow the frequency of AWG1 to 5 Hz or less. Are two of LEDs ever both on at the same time? If so, which two?

- 1. How does the waveform for the rectified output compare to your earlier results with the 1N914 diodes? By how much does the forward-bias voltage drop increase?
- 2. Experiment with the three different waveform shapes while the waveform generator is set to 100 Hz, pay attention to the brightness of the LEDs. Discuss your observations of waveform shape and brightness and relate these observations to your measured effective dc values for each waveform shape.
- 3. Reduce the waveform generator frequency, and experiment with values as low at 0.2 Hz (one cycle every five seconds). Discuss the behavior of the LED optical intensity for each of the three waveform shapes when the waveform generator frequency is 1 Hz or less.
- 4. At what frequency do the flashing LEDs stop flickering and begin to appear as a constant intensity?

2d. Limiter/Clamp Circuit

Objective

The purpose of this activity is to investigate the use of diode as an amplitude limiting or clamp circuit.

Materials

- One 10 kΩ resistor (or any similar value)
- Two small signal diodes (1N914 or similar)

Directions

Set up the breadboard with the waveform generator output (W1) attached to one end of the 10 kΩ resistor, as shown in Figure 15. One diode (D1) is connected between the other end of the 10 kΩ resistor and the output of the second function generator. The second diode D2 is connected between ground and the top of D1 as shown. Scope Channel 2 (2+) is connected to the common connection of the resistor and the two diodes.

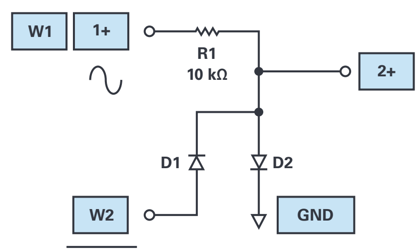


Figure 15. Connection diagram for a diode clamp.

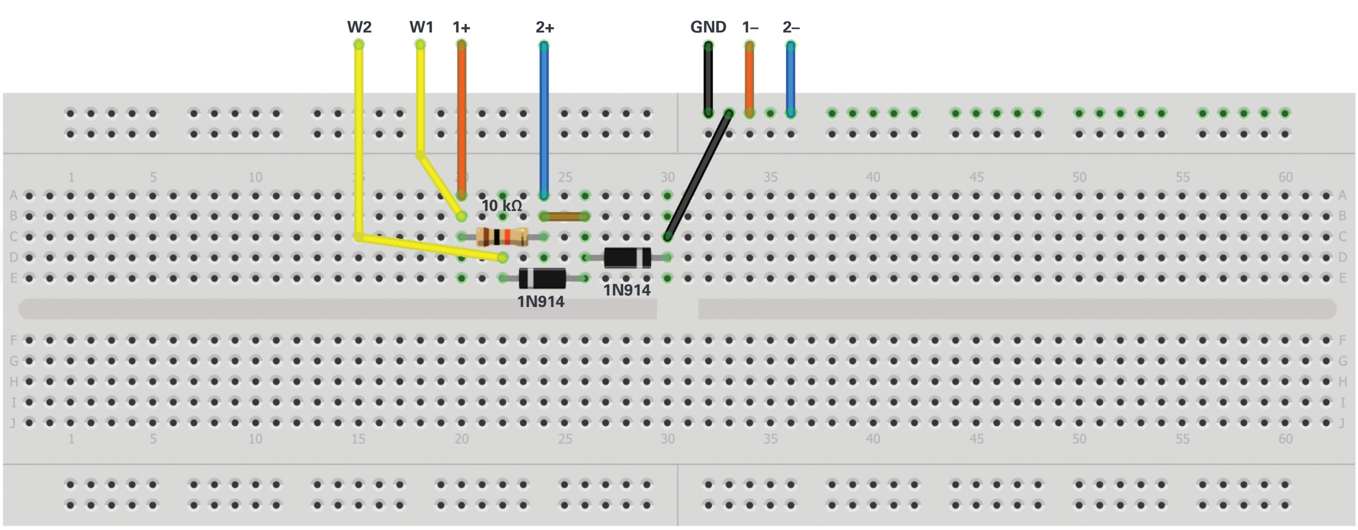


Figure 16. Diode clamp breadboard circuit.

Hardware Setup

The first waveform generator should be configured for a 100 Hz sine wave with 6 V amplitude and 0 V offset. The second waveform generator should be configured with 0 V amplitude and 0 V offset to start. The offset of the second generator will be varied and the effect on the output signal observed. Scope Channel 2 (2+) is used to measure the clamped/limited voltage and should be set to 500 mV/div.

Procedure

With the dc offset value of Waveform Generator 2 set to zero, observe the minimum and maximum values of the voltage seen on Scope Channel 2 (2+). Adjust the dc offset of Generator 2 between –2 V and +2 V and observe the minimum and maximum voltage seen on the scope. Reverse the direction of both diodes, D1 and D2. Repeat the sweep of the dc offset and observe the minimum and maximum voltages seen on the scope. How do the two sets of measurements compare?

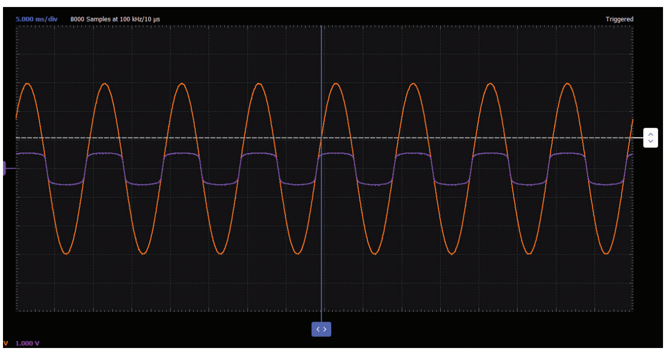


Figure 17. Diode clamp waveforms.

Questions

What happens to the voltage limits if both diodes, D1 and D2, are connected to the second generator output?

2e. AC Coupling and DC Restoration

Objective

The purpose of this activity is to investigate ac coupling and the use of a diode as a dc restoration circuit. Many signals contain a dc component. Often this dc must be removed and perhaps restored to a different dc level later in the signal path.

Materials

- One 1.0 µF capacitor (or any similar value)
- One small signal diode (1N914 or similar)

Directions

Set up the breadboard with W1 attached to one end of the 1.0 µF capacitor, as shown in Figure 18. The diode (D1) is connected between the other end of the 1.0 µF capacitor and the output of the second waveform generator, W2. The single-ended input of Scope Channel 2 (2+) is connected to the common connection of the capacitor and the diode.

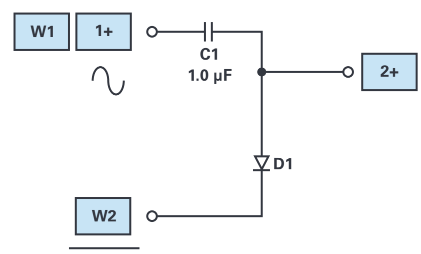


Figure 18. Connection diagram for dc restoration circuit.

Hardware Setup

The first waveform generator should be configured for a 1 kHz sine wave with 2 V amplitude and 0 V offset to start. The offset will be varied and the effect on the output observed. The second waveform generator should

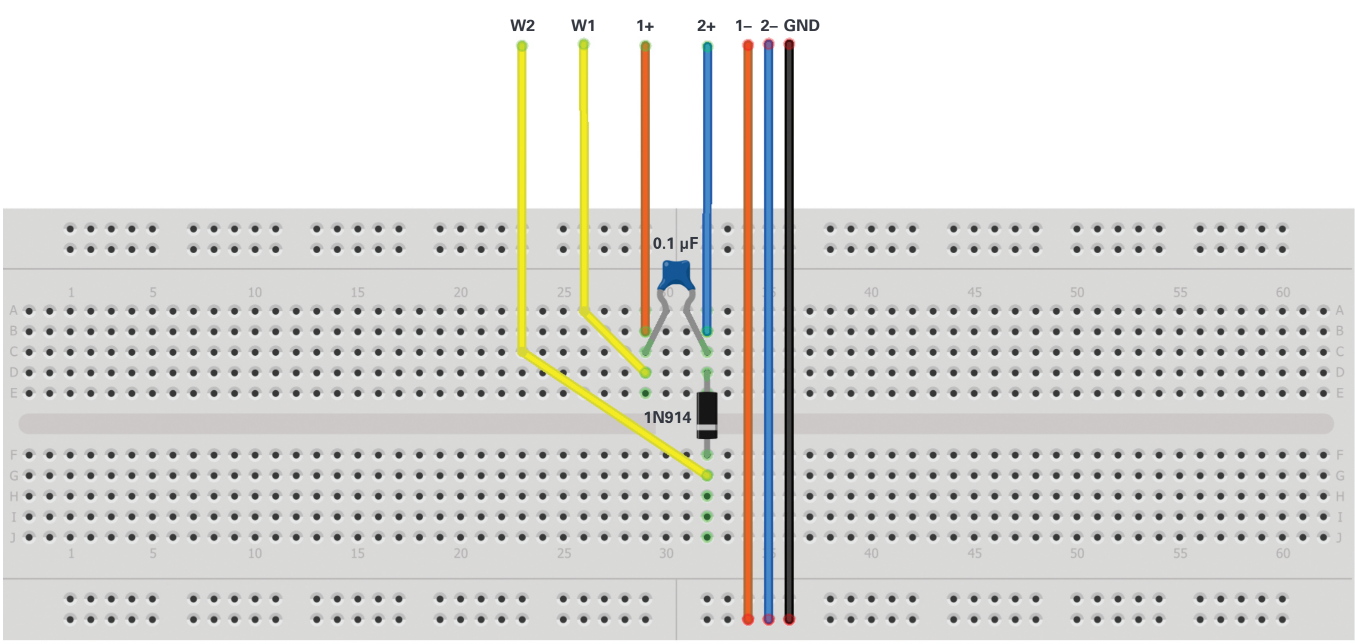


Figure 19. DC restoration breadboard circuit.

be configured with 0 V amplitude and 0 V offset to start. The offset will be varied and the effect on the output observed. Scope Channel 2 (2+) is used to measure the voltage and should be set to 500 mV/div.

Procedure

Plot the two waveforms using the oscilloscope provided by the Scopy tool.

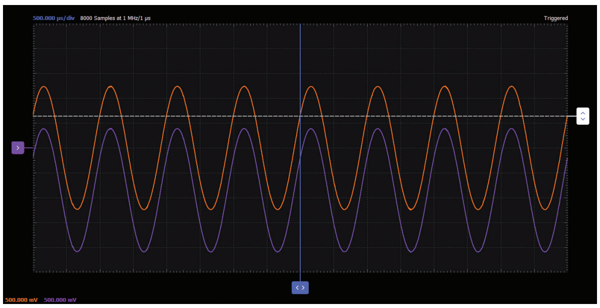


Figure 20. DC restoration waveforms.

Replace diode D1 in the circuit with a 10 kΩ resistor. Using the measurement tab on the scope, read and record the positive and negative peak values and mean value of Channel 2 (2+) as the offset of Waveform Generator channel 1 is changed between –1 and +1 volt. Now set Waveform Generator channel 1 to a square wave again with 2 V amplitude value. As done before, read and record the positive and negative peak values and the mean value as the duty cycle of the square wave is changed between 10% and 90%. Now remove the 10 kΩ resistor and put diode D1 back in place. Repeat the same measurements, adjusting the dc offset and duty cycle, that were just taken with resistor. How do they compare? Reverse the direction of diode D1 and again repeat these same measurements. How do they compare to the previous two?

Questions

What happened when the direction of D1 was reversed? What is the effect of setting different dc values for the output of Generator 2 (W2)?

2f. Variable Attenuator

Objective

The goal of this activity is to build, characterize, and analyze a small signal variable attenuator using a diode.

Materials

- One 2.2 kΩ resistor
- One 4.7 kΩ resistor
- One 10 kΩ resistor
- One 5 kΩ variable resistor, potentiometer
- Two 0.1 µF capacitors
- One small signal diode (1N914 or similar)

Directions

Set up the breadboard with the first waveform generator attached to one end of the 0.1 µF capacitor, as shown in Figure 22. Resistor R1 is connected between the second end of C1 and the junction of D1, R2, and C2. The other end of D1 is connected to ground. The second end of resistor R2 is connected to the wiper of the potentiometer R3. The ends of R3 are connected to ground and Vp (5 V) respectively. Scope Channel 2 (2+) is connected to the common connection of capacitor C2 and load resistor R4.

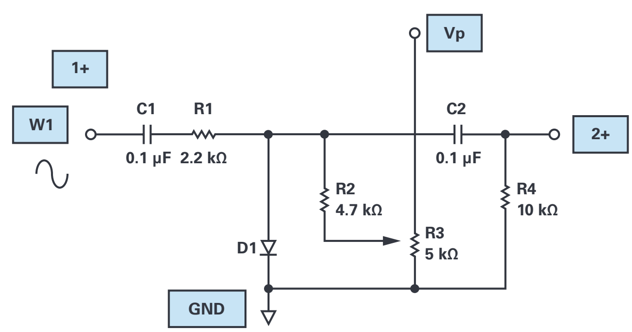


Figure 21. Connection diagram for variable attenuator.

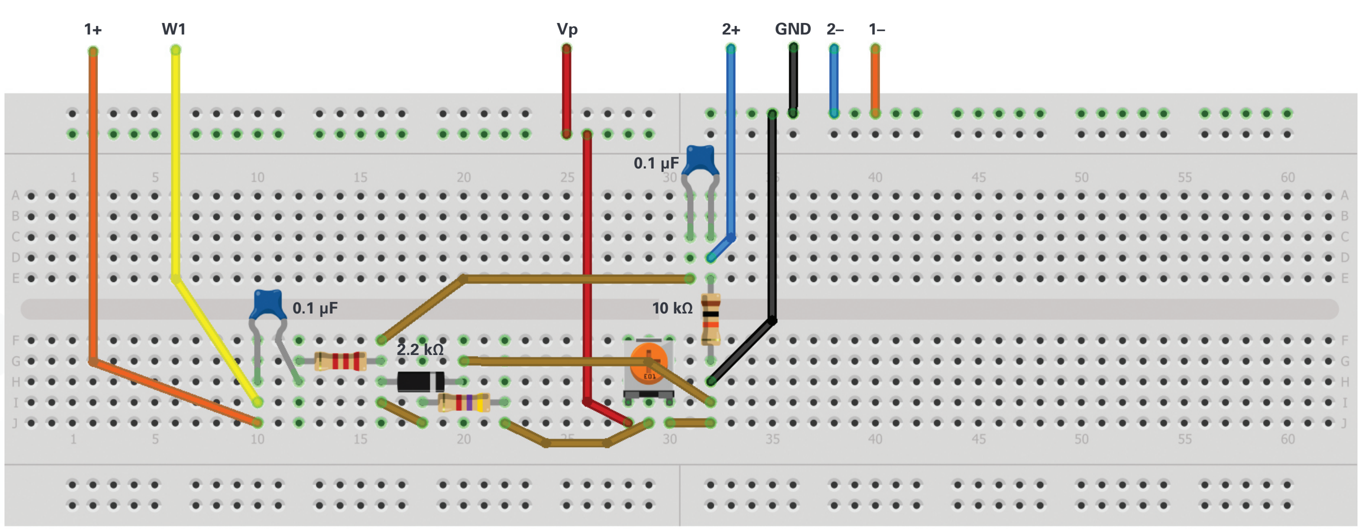


Figure 22. Variable attenuator breadboard circuit.

Hardware Setup

Waveform generator W1 should be configured for a 10 kHz sine wave with 200 mV amplitude (or less) and offset set to 0. Set Scope Channel 1+ at 100 mV per division and Scope Channel 2+ connected at R4 to 100 mV per division. Set the measurements tab to display Ch1 peak-to-peak and Ch2 peak-to-peak.

Procedure

Plot the two waveforms using the oscilloscope provided by the Scopy tool.

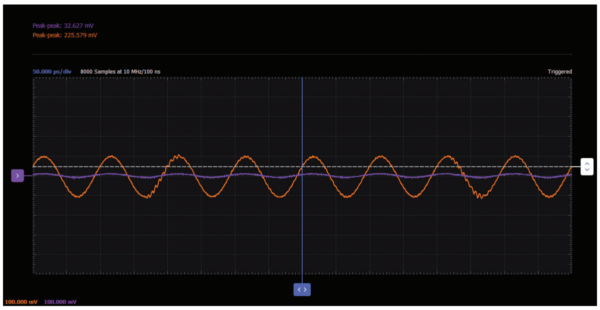


Figure 23. Variable attenuator waveforms.

The purpose of C1 (and C2) is to block dc from the input and output circuits so that the operating point of the diode is not affected. The attenuator uses the fact that that small signal resistance of the diode r_D is a function the dc flowing in the diode I_D. See Equation 1.

$$r_D = n\frac{V_T}{I_D}\,V_T = \frac{k_T}{q} \tag{1}$$

Where:

n is the diode area (size) scale factor

V_T is the thermal voltage

I_D is the diode current

k is Boltzmann's constant

q is the electron charge

T is the absolute temperature

In the circuit, a voltage divider is set up between R1 and the resistance of D1. The current in D1 is varied by changing the current in R2. When the current in D1 is small, r_D is large and the fraction of the input signal seen at the output is large. As the current in D1 increases, its resistance decreases, and the fraction of the input seen at the output decreases.

Questions

What is the maximum input signal level that you can use without distorting the output signal? What circuit parameter determines the upper limit of the input signal?

2g. Absolute Value Circuits

Objective

The purpose of this activity is to investigate absolute value circuits. Rectifiers, or absolute value circuits, are often used as detectors to convert the amplitudes of ac signals to dc values to be more easily measured. For this type of circuit, the ac signal is first high-pass filtered to remove any dc term, then rectified and perhaps low-pass filtered. As we have seen in the simple rectifier circuits constructed with diodes, the circuit does not respond well to signals with a magnitude less than a diode drop (0.6 V for silicon diodes). This limits their use in designs where small amplitudes are to be measured. For designs in which a high degree of precision is needed, op amps can be used in conjunction with diodes to build precision rectifiers.

Materials

- One dual op amp (such as ADTL082 or similar)
- Five 10 kΩ resistors
- Two small signal diodes (1N914 or similar)
- Two 4.7 µF decoupling capacitors

Directions

The inverting op amp circuit can be converted into an ideal (linear precision) half-wave rectifier by adding two diodes, as shown in Figure 24. For the negative half of the input diode, D1 is reverse biased and diode D2 is forward biased and the circuit operates as a conventional inverter with a gain of –1. For the positive half of the input, diode D1 is forward biased, closing the feedback around the amplifier. Diode D2 is reverse biased disconnecting the output from the amplifier. The output will be at the virtual ground potential (–input terminal) through the 10 kΩ resistor.

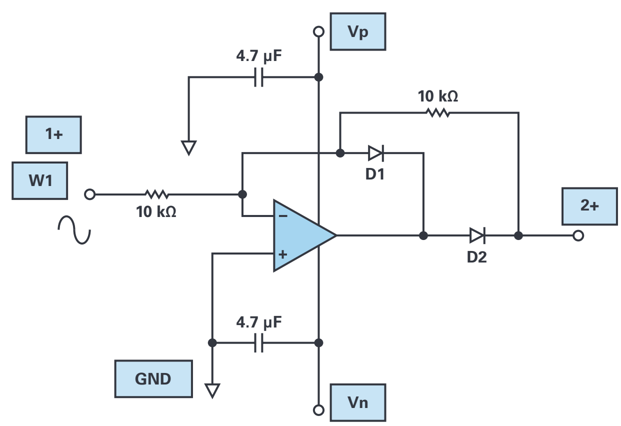


Figure 24. Connection diagram for a precision half-wave rectifier.

Procedure

The peak of the rectified output, as seen in Figure 26, is now equal to the peak value of the input. There is also a sharp transition as the input crosses zero. The experimenter should investigate the waveforms at different points in the circuit to explain why this circuit works better than the simple diode half-wave rectifier.

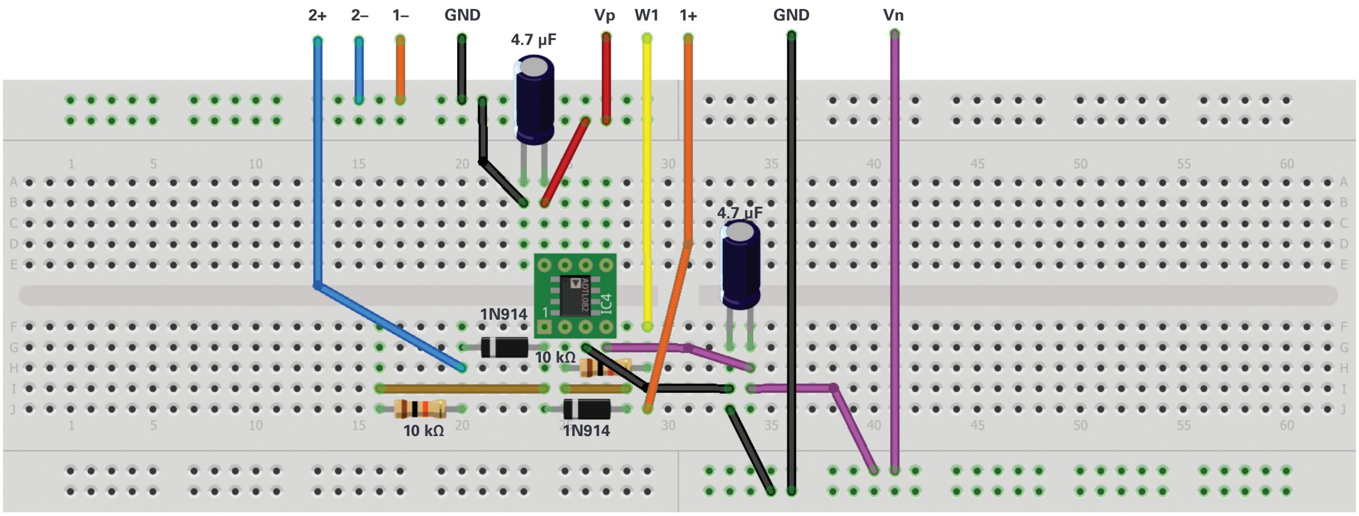


Figure 25. Precision half-wave rectifier breadboard circuit.

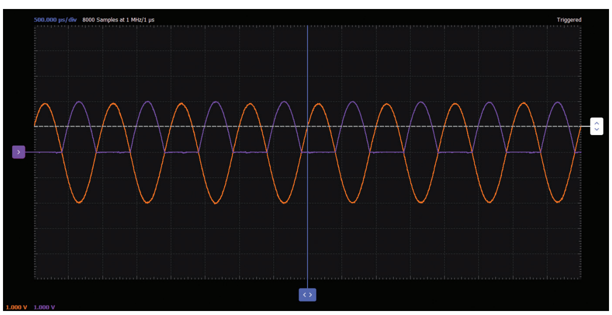


Figure 26. Precision half-wave rectifier waveforms.

Directions

The circuit shown in Figure 27 is an absolute value circuit, often called a precision full-wave rectifier. It should operate like a full-wave rectifier circuit constructed with ideal diodes (the voltage across the diode, in forward conduction, equals 0 V). The actual diodes used in the circuit will have a forward voltage of around 0.6 V.

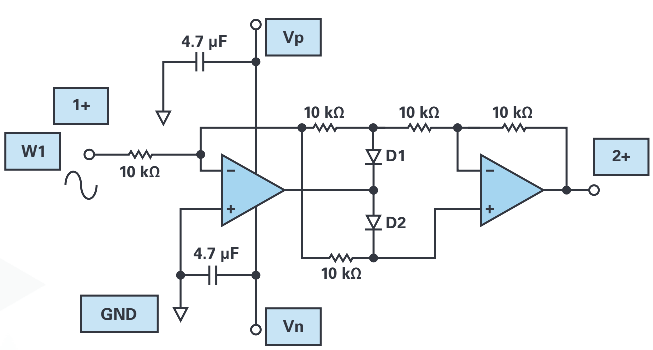


Figure 27. Connection diagram for absolute value circuit.

Procedure

For this laboratory exercise you should:

- a. Study the circuit and determine how it works. There is very fundamental concept that should help in understanding how this circuit operates. Given an op amp configured with negative feedback, the inverting and noninverting input terminals will try to reach the same voltage level, often referred to as a virtual short.
- b. Plan some tests to see if this circuit indeed is an absolute value circuit. Perform these tests, fully documenting all tests and results.
- c. Make the input voltage a 6 V amplitude sinusoid at 1 kHz. Carefully measure and record voltages at all nodes in the circuit.

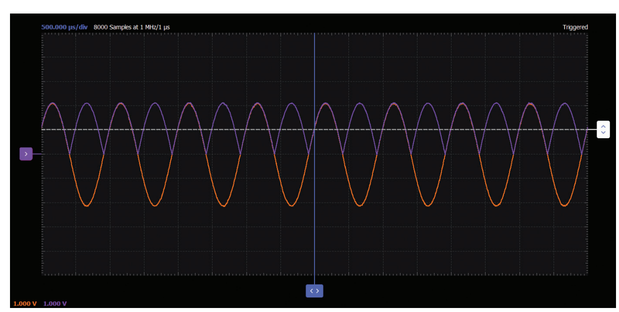


Figure 29. Absolute value waveforms.

Questions

Report on your experiments by fully documenting all tests and results.

2h. A Voltage Doubler Circuit

Voltage doublers are very useful in situations where the load current is relatively light, and the required dc voltage is higher than what is available from the system power supply.

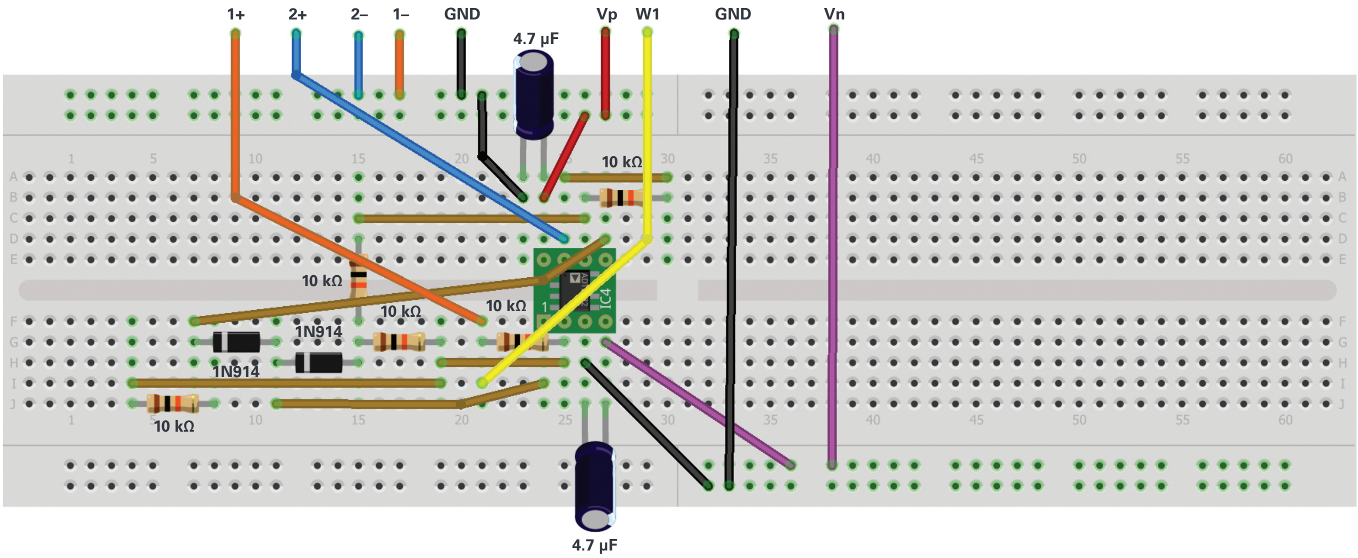


Figure 28. Absolute value breadboard circuit.

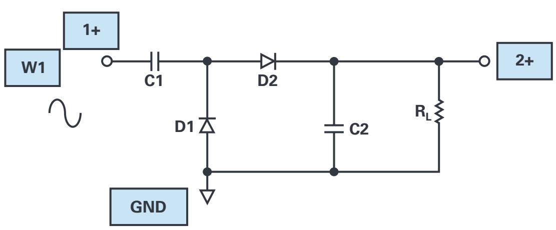


Figure 30. Connection diagram for voltage doubler circuit.

How this circuit operates is not as straightforward as the diode rectifier circuits we examined earlier. To understand this circuit, we need to look at it during successive half-cycles of the ac input from W1. We will start by assuming ideal components and that C1 = C2.

- 1. During the first negative half-cycle, D1 will be forward biased and will hold the right end of C1 at one diode drop below ground. Therefore, C1 will charge to a voltage nearly equal to the peak voltage (v_{PEAK}) of the ac input, with its left end being negative with respect to ground.
- 2. During the following positive half cycle, D1 will be reverse biased and will not conduct current. The voltage on C1 will add to the ac input voltage, so a voltage of approximately 2 V_{PEAK} will appear at the left end of D2. Since C2 is not yet charged at all, this will forward bias D2 and allow the voltage at the right end of C1 to be applied to the top of C2. C2 will charge as C1 discharges, until the two capacitors can no longer forward bias D2. For the first positive half-cycle, the voltage on C2 will be equal to V_{PEAK}, and C1 will be completely discharged, so that all the voltage at the left end of D2 comes from the ac input.
- 3. On the next negative half-cycle, C1 charges again to V_{PEAK}, through D1. If there is no load to discharge C2, its output will remain at +V_{PEAK}.
- 4. On the second positive half-cycle, C2 is still charged to +V_{PEAK}, while the voltage at the left end of D2 is again +2 V_{PEAK}. Again, C1 transfers part of its charge to C2, but this time they stop when C2 is charged to a voltage of +1.5 V_{PEAK}.
- 5. This action continues, cycle by cycle, with C1 being fully recharged to V_{PEAK} on each negative half cycle, and then charging C2 to a voltage halfway between its starting voltage and +2 V_{PEAK}. C2 will never quite charge to +2 V_{PEAK}, but it will come very close.

With nonideal components there is a small (0.6) voltage drop across each diode when it is forward biased. This will reduce the maximum no load output voltage of the doubler. Any load on this circuit, such as R_L, will always draw current from C2, thus discharging this capacitor to some extent. On each positive half-cycle, C1 will recharge C2 from the voltage it had at the start of the half-cycle halfway up to +2 V_{PEAK}. The ripple on the output will be larger and the average dc value will be lower.

Note that the output current capacity of this circuit is only half the current capacity of a normal rectifier circuit. Any additional load current taken from the voltage doubler will simply cause C2 to discharge faster, thus reducing the output voltage. It is never possible to get more power out of the voltage doubler than goes into it.

The charging and recharging of C2 can be made faster if C1 is made larger than C2. For example, if C1 = 10 µF and C2 = 1 µF, C1 can transfer much more charge to C2 on each positive half-cycle, and the voltage on C2 will increase much faster than the voltage on C1 will decrease. Of course, this also means that the output current capacity is even more limited, since C2 will discharge rapidly as well as charge rapidly.

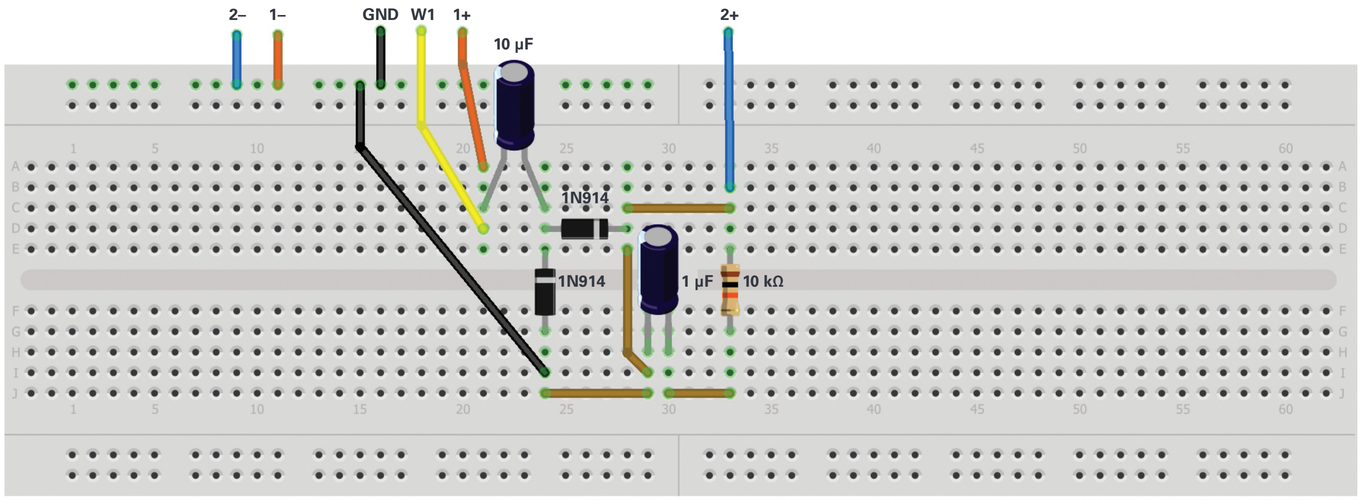


Figure 31. Voltage doubler breadboard circuit.

Procedure

Plot the two waveforms using the oscilloscope provided by the Scopy tool.

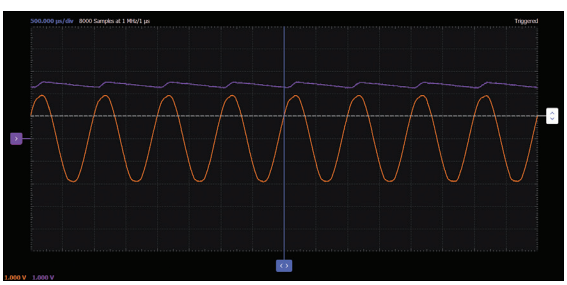
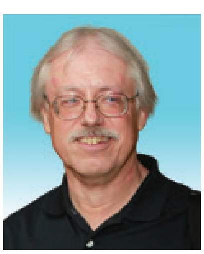


Figure 32. Voltage doubler waveforms.

Questions

The circuit in Figure 30 produces a positive dc output voltage. How can it be reconfigured to make a negative output voltage? Construct the voltage inverter and repeat the experiment/simulation.

You can find the answer at the StudentZone blog.



About the Author

Doug Mercer received his B.S.E.E. degree from Rensselaer Polytechnic Institute (RPI) in 1977. Since joining Analog Devices in 1977, he has contributed directly or indirectly to more than 30 data converter products and he holds 13 patents. He was appointed to the position of ADI Fellow in 1995. In 2009, he transitioned from full-time work and has continued consulting at ADI as a Fellow Emeritus contributing to the Active Learning Program. In 2016 he was named Engineer in Residence within the ECSE department at RPI. He can be reached at *doug.mercer@analog.com*.

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