Laboratory – 5

Waveforms and Signals

Objectives

The objectives of this laboratory are

- to become familiar with a full-wave rectifier made from a transformer and semiconductor diodes,
- to become familiar with the zener diode,
- to build a sawtooth generator,
- to investigate series resonance of an *RLC* circuit.

Full-wave rectifier

A full-wave rectifier is most often used to convert AC voltage to DC voltage. Consider the circuit below.

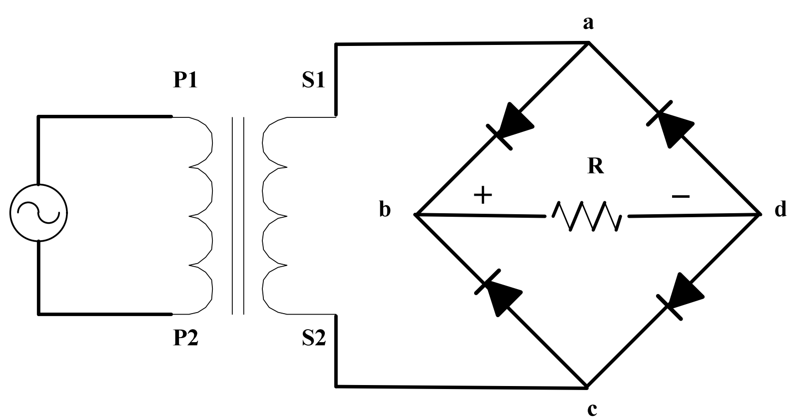


Figure 5.1 Full-wave rectifier circuit.

When the sine wave is positive at S1, current flows from a-b-d-c and back to S2. The voltage V_{bd} will appear as the positive half of a sine wave. When the sine wave is positive at S2, current flows from c-b-d-a and back to S1. The voltage V_{bd} will again be the positive part of the sine wave in shape. The voltage V_{bd} will therefore be as shown in Figure 5.2. We call this a full-wave rectified sine wave. In practice, the resistor *R* is replaced with an *RC* filter with a long time constant. This smoothes out the ripple of the sine wave and converts the signal to DC. This DC voltage is then used, typically, in transistor circuits. You will further study this circuit and the filter in the electronics lab during your junior year.

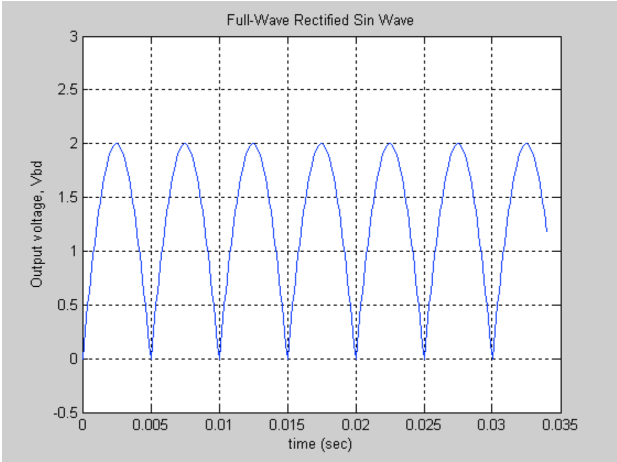


Figure 5.2: Full-wave rectified sine wave.

Zener Diode

The symbol for a zener diode is shown in Figure 5.3.

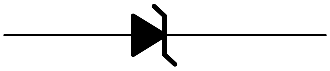
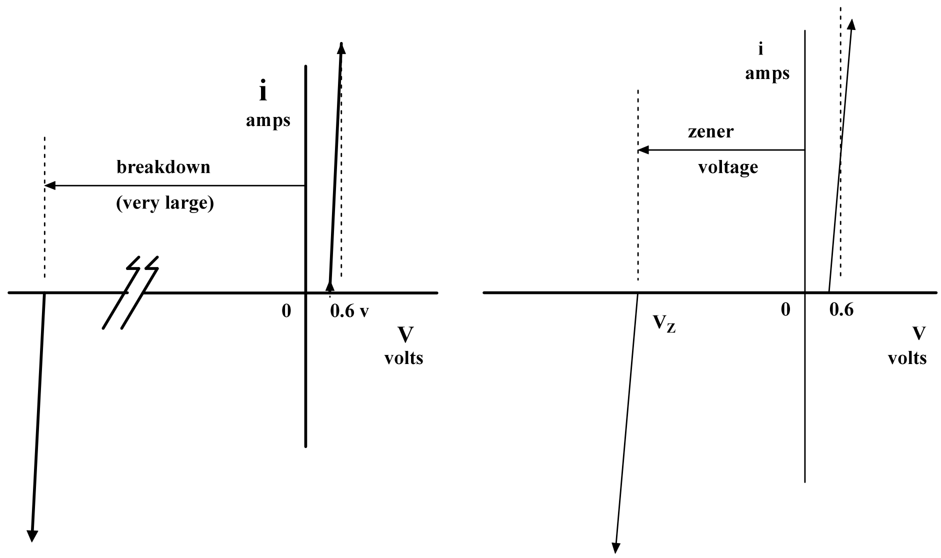


Figure 5.3 Symbol of a zener diode.

The main difference between the diode and the zener diode is the reverse breakdown voltage. An ordinary diode will have a very large reverse bias breakdown voltage, usually greater than 400 volts. The zener diode is manufactured to have much lower reverse bias breakdown voltage. Most of the time, zeners are referred to by using their breakdown voltage: for example; a 3.9 V (1N5228B) zener. . . a 5.1 V (1N5313B) zener, …a 24 V (1N5252B) zener, etc. Figure 5.4 illustrates the diode and zener diode typical ideal characteristics.



>>>Better graphs

(a) regular diode characteristics (b) zener diode characteristics

Figure 5.4 Ideal characteristics of a diode and zener diode.

As a simple example of how a zener diode might be used, consider the circuit of Figure 5.5.

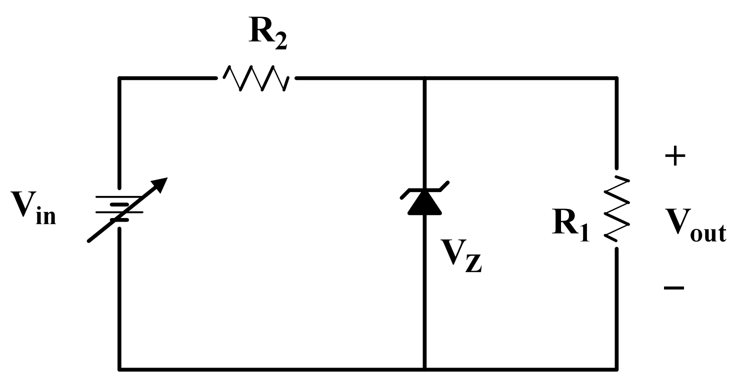


Figure 5.5 Illustrating use of a zener diode.

For this circuit

$$V_{out} = \frac{R_1}{R_1 + R_2} V_{in} \ \ , \text{ for } \frac{R_1}{R_1 + R_2} V_{in} < V_z$$

$$V_{out} = V_z \ \ , \text{ for } \frac{R_1}{R_1 + R_2} V_{in} > V_z$$

Zener diodes are often used in voltage regulator circuits.

Sawtooth Wave Generator

Consider the op-amp circuit shown in Figure 5.6.

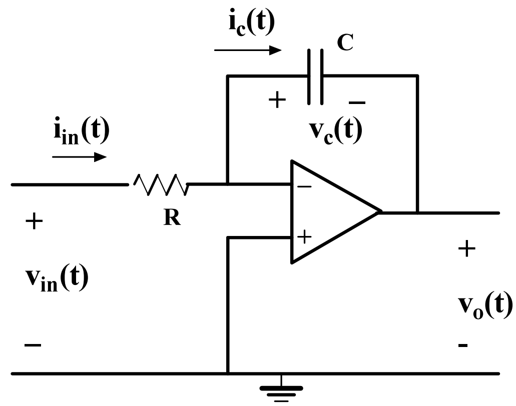


Figure 5.6 Op amp circuit that can be used to integrate the input signal

Assuming an ideal op amp, $v_o(t) = -v_C(t)$ and $v_C(t) = \frac{1}{C}\int_0^t i_C(\lambda)d\lambda + v_C(0)$. We also know that for an ideal op amp, $i_C(t) = i_{in}(t)$. The input current is related to the input voltage by $i_{in}(t) = \frac{v_{in}(t)}{R}$. Combining equations,

$$v_o(t) = -\frac{1}{RC}\int_0^t v_{in}(\lambda)d\lambda + v_c(0)$$

In particular, if $v_{in}(t)$ is a negative step input (a constant negative voltage), the output voltage will be a ramp as illustrated in Figure 5.7.

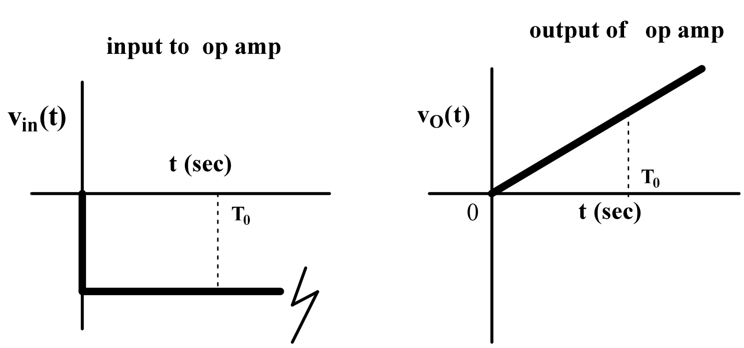


Figure 5.7 Integration of a negative step input applied to an op amp.

Suppose there is some way to momentarily discharge the capacitor. That is, suppose the capacitor can be shorted for, say, 1 nano second and then the short removed. Furthermore, let the short appear every T_o, $2T_o$, $3T_o$ ……… nT_o. The output of the op amp will then be as shown in Figure 5.8.

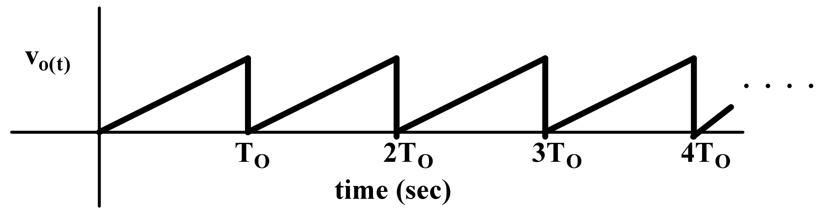


Figure 5.8 A sawtooth waveform.

A device that can be used to momentarily short the capacitor is a *solid-state reed relay*. The device is contained inside a DIP chip, same size as a logic circuit chip. The internal circuit schematic is shown in Figure 5.9

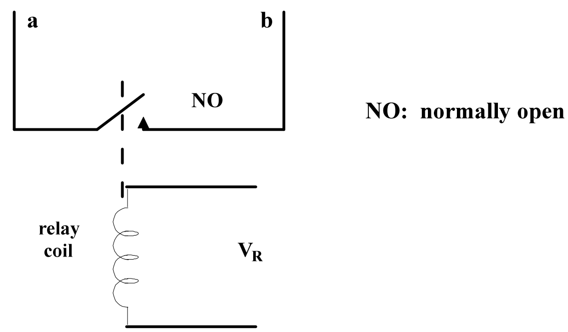


Figure 5.9 Schematic of a solid-state relay.

When $V_R \geq V_{\text{operate}}$, the relay contacts close. We can use the relay with the op amp integrator to produce a sawtooth waveform. The circuit for doing this is shown in Figure 5.10.

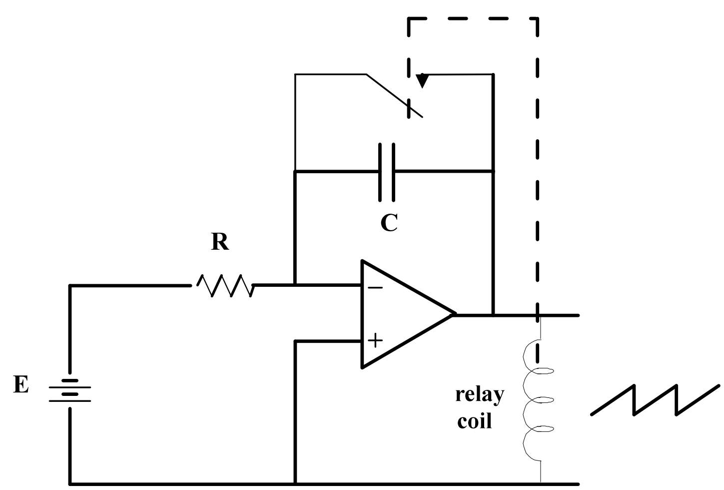


Figure 5.10 Circuit for producing a sawtooth waveform.

The period of the sawtooth wave can be adjusted using either E, C or R. The amplitude is fixed at the value of the relay pick-up voltage, V_{operate}. One can obtain a larger amplitude for the sawtooth by amplification. An application of the sawtooth waveform is in driving (moving) the horizontal trace of an oscilloscope.

***RLC* Series Resonance**

Consider the series *RLC* circuit shown in Figure 5.11

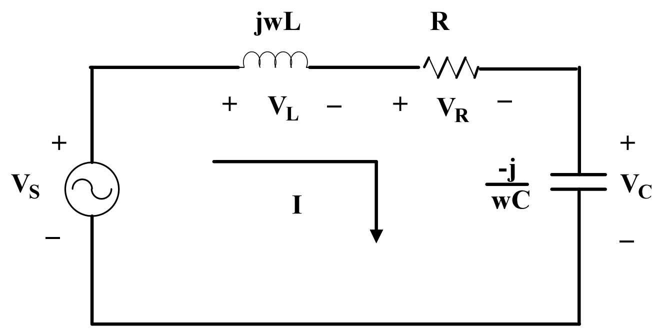


Figure 5.11 Series *RLC* circuit.

The input impedance is given by $Z = R + j\omega L + 1/j\omega C$. If $\omega L = 1/\omega C$, the impedance becomes entirely real. Under this condition the circuit is said to be in resonance. The frequency of resonance is $\omega_0 = \frac{1}{\sqrt{LC}}$. Several things happen when the circuit is in resonance.

- the input impedance is real
- the input voltage V_s and the current I are in phase
- the impedance is minimum (for series resonance)

Also, at resonance the inductor voltage and the capacitor voltage can be much higher than V_s. The *quality factor* of the resonance Q is defined by

$$Q = \frac{\omega_0 L}{R} = \frac{1}{\omega_0 RC} = \frac{1}{R}\sqrt{\frac{L}{C}}.$$

Another way of expressing Q is $Q = 2\pi \frac{\text{maximum energy stored}}{\text{total energy lost per period}}$. Quality factor is a measure of how close the resonance is to a lossless resonance. If $R = 0$, the circuit has no elements that dissipate energy and is therefore lossless and $Q \to \infty$. In the lossless case, no energy is lost per period. For more information on series and parallel resonance, and the definition of Q as given above, see the references given at the end of this lab.

The concept of Q also applies to other resonant systems, particularly mechanical systems.

It can be shown that the voltage across the resistor has a maximum value at resonance. If $Q \geq 5$, the frequency at which the capacitor and inductor voltages are at a maximum magnitude is very close to ω_0.

We will be limited in what can be measured and observed in the laboratory because the coil has an internal resistance of approximately 90 ohms. It is an inherent part of the inductor. Therefore, we cannot measure the resistor voltage as such, nor can we measure the voltage across *L*. We can measure the voltage across the capacitor. It can be shown that at resonance $|V_C| = |V_L| = |V_s| Q$.

Most basic circuit texts give an expanded presentation of parallel and series resonance. The presentation includes development of equations for low frequency and high frequency cutoff of the circuit and the circuit bandwidth as related to the quality factor *Q*. The bandwidth pertains to the resistor voltage and since we cannot measure this voltage (given our inductor) we will not be examining bandwidth in the laboratory. However, you will be given the opportunity to see that the voltage across the capacitor peaks and that this voltage can be several time larger than the applied voltage.

PreLab

Complete the following exercises prior to coming to the lab. As usual, turn-in your prelab work to the lab instructor before starting the Laboratory Exercises.

Part 1PE

From the analysis of the circuit in Figure 5.10 we know that $\mathrm{v}_o(t) = -\frac{1}{RC}\int_0^t \mathrm{v}_{in}(\lambda)d\lambda + \mathrm{v}_c(0)$. We also know that the output goes to zero when $\mathrm{v}_o(t)$ reaches the operating voltage of the relay. Hence to get the time period of one cycle we can rewrite the above equation as $\frac{V_{\text{operate}}RC}{E} = T_0$ where *E* is the supplied voltage on the input. Assume the operating voltage of the relay is 2.2V and that *C* is 1μF and *E* = 8 V, calculate the value of *R* that is needed to obtain a period of 0.1sec.

Part 2PE

(a) For the circuit of Figure 5.11 calculate the resonant frequency. Use *L* = 100mH , *R* = 90 Ω and *C* = 0.22 μ F

(b) Calculate the *Q* for the circuit.

(c) Calculate the magnitude of the voltage across the capacitor at the resonant frequency.

(d) Show that the magnitude of the voltage across the capacitor is equal to *Q* times the magnitude of source voltage at the resonant frequency.

Laboratory Work

Part 1LE

(a) Connect the circuit of Figure 5.12. Use a sine wave of frequency 100Hz and 2V peak to peak as an input. This is the AC waveform that is to be full-wave rectified as shown in Figure 5.12. Let the load resistor *R* be 470 ohms.

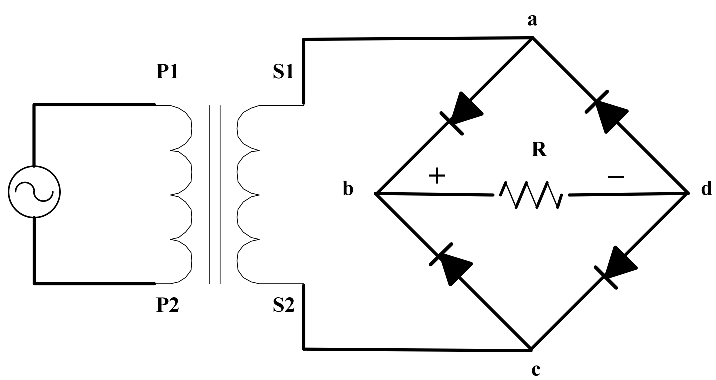


Figure 5.12 Full-wave rectifier circuit.

(b) Use one channel of the oscilloscope to display the input sine wave being supplied to P1-P2 of the transformer and the other channel to display the rectified output across the 470 ohm resistor.

(c) Obtain a print out of the oscilloscope screen with both the sinusoidal input wave and the full-wave rectified signal being displayed simultaneously.

Part 2LE

(a) Connect the circuit of Figure 5.13. Use $R_1 = 100\text{k}\Omega$, $R_2 = 10\text{k}\Omega$ and a 3.9 V (1N5228B) zener diode.

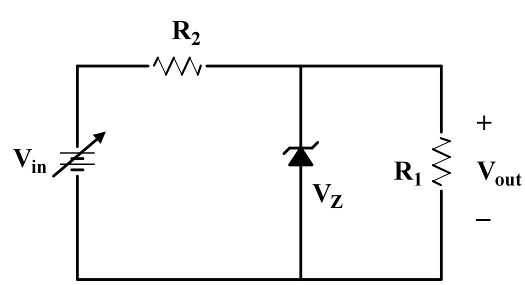


Figure 5.13 Circuit to be constructed for Part 2 LE.

(b) Measure and record the voltage across resistor R_1. Since this voltage will stop increasing at the zener voltage of around 3.9 volts, you will need to refine the voltage step size in the region close to 3 volts. In other words, you should be able to define where the zener voltage across R_1 stops increasing to within 0.1 volts. Record the values of the source voltage and the voltage across R_1.

. **Part 3LE**

(a) Connect the circuit of Figure 5.14. Use the values mentioned in part 1PE and the value of the resistor that you calculated.

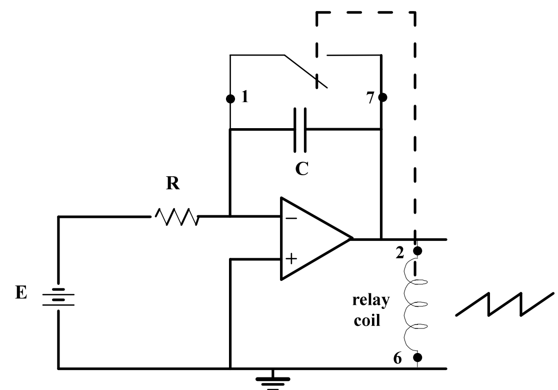


Figure 5.14 Circuit to be constructed for Part 3LE.

(b) With the circuit operational, display the output sawtooth waveform on the oscilloscope and measure the time period. Also obtain a print out of the oscilloscope screen.

(c) If the time period of the sawtooth wave is not 0.1 msec, this may be because the operating point of the relay ($V_{operate}$) is not 2.2 V. Determine the operating point of your relay and recalculate *R* accordingly. To do this, set-up the circuit shown in Figure 6.15.

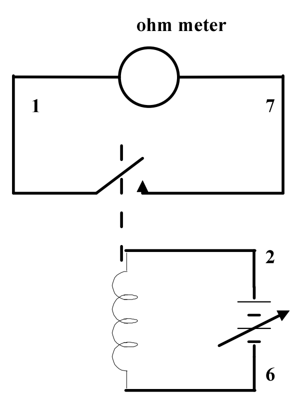


Figure 5.15: Circuit for determining $V_{operate}$ for the reed relay.

Start varying the input DC voltage gradually from 0 V until the ohm-meter suddenly reads 0 ohms. This is the operating point of the relay. Note that initially the ohm-meter will be reading infinite impedance.

(d) Using the new value of $V_{operate}$, determine the new R for a T_0 of 0.1 seconds. Insert the new R in your circuit. Record the amplitude and period of the sawtooth on the oscilloscope. Obtain a printout of the waveform.

Part 4LE

Connect the circuit of Figure 5.16. Use the same values of components as in the pre-lab. Note that the inductor has a resistance of 90Ω. No other resistor should be added to the circuit.

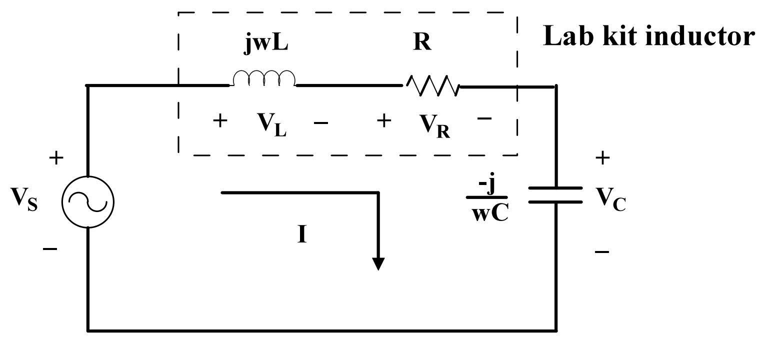


Figure 5.16 Circuit to be constructed for Part 4LE.

(a) Supply a sine wave of 2 V peak to peak and the frequency set to the resonance frequency Calculated in pre-lab, Part 2PE. To determine the resonance frequency practically, set the oscilloscope to read the voltage across the capacitor and vary the frequency of the input sine wave on either side of the calculated resonant frequency until you find the frequency at which the voltage across the capacitor is a maximum.

(b) Record the maximum voltage across the capacitor and the resonant frequency determined practically.

Questions and Discussions

(a) Based on Part 2LE:
From your readings draw a graph with the input voltage on the X-axis and the output voltage on the Y-axis.

(b) Based on Part 3LE:
What is that time period of the sawtooth wave that was observed with your prelab value of R? What is the new value R? Show all your calculations.

(c) Based on 4LE:
What is the observed resonant frequency and the voltage across the capacitor at resonant frequency? Calculate Q.

Before Leaving the Laboratory

Be sure the following is completed before you leave the laboratory.

(a) Check to be sure that you have all the required measured values.

(b) Have the laboratory instructor check your laboratory readings.

(c) Restore your laboratory station (equipment and chairs) to the condition they were in when you arrived. Remove any debris from the work area and floor.

Thank you for your cooperation.

Laboratory Report

The following should be included in your laboratory report. If you have any questions be sure to contact the lab instructor.

(a) Give a short (100 words) summary of what is to be accomplished in the lab exercise.

(b) Tabulate all the readings you obtained in the lab exercise.

(c) Present all oscilloscope printouts neatly labeled.

(d) Answer the questions listed above.

(e) Write a brief conclusion (approximately 200 words)

(f) Attach the graded prelab at the end of your report.

References

Engineering Circuit Analysis; pp 550, Hayt, W. H.; Kemmerly, J. E.; Durbin, S. M.; 8th Edition; McGraw-Hill Book Company, 2012

Fundamentals of Electric Circuits, pp 633, Alexander, C. K.; Sadiku, M.N.O.; 2nd Edition, McGraw-Hill Book Company, 2003.