Electricity and New Energy

AC Circuit Fundamentals

Courseware Sample

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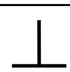
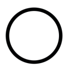
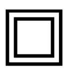
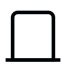
Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* sign , indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
	Direct current
	Alternating current
	Both direct and alternating current
	Three-phase alternating current
	Earth (ground) terminal

Safety and Common Symbols

Symbol	Description
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

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Preface

Electricity is used in all aspects of modern society, be it in residential, commercial, or industrial applications. It is used for lighting, heating, transport, communications, computations, and a host of other functions. While most power networks in the world operate in alternating current, direct current is also commonly used in applications that require low voltage or that use batteries as a power source.

Knowing the basic principles of both dc circuits and ac circuits is of the utmost importance when training electrical technicians or any technician that has to deal with electricity. The AC/DC Training System, Model 3351, is a portable training system that allows students to explore the fundamentals of electricity. Throughout the courses performed using the training system, students acquire the basic knowledge necessary to work with electricity, both in theory and in practice. Students are also introduced to the troubleshooting of electrical circuits to bolster their efficiency in the field.

The AC/DC Training System is divided in two courses, each dealing with a type of electrical current. The first course, *DC Circuit Fundamentals*, deals with the general concept of electricity, as well as with the fundamental concepts of direct current circuits. The second course, *AC Circuit Fundamentals*, deals with the fundamental concepts of alternating current circuits.

Although electricity has been known to Man since ancient times, it is only in modern times that it began to be commonly used as a power source (photo courtesy of Postdlf).

Preface

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

About This Manual

Manual objectives

When you have completed this manual, you will be familiar with the basic principles of alternating current, as well as with the voltage and current sine waves in ac circuits. You will be introduced to common components in ac circuits: capacitors, inductors, transformers, and relays, and be familiar with the operation of these components. You will know the most important concepts of electrical distribution, such as what a power network and a distribution network are. Finally, you will be introduced to the troubleshooting of electrical circuits, and learn two methods important for troubleshooting: the voltmeter method and the ohmmeter method.

Safety considerations

Safety symbols that may be used in this manual and on the equipment are listed in the Safety Symbols table at the beginning of the manual.

Safety procedures related to the tasks that you will be asked to perform are indicated in each exercise.

Make sure that you are wearing appropriate protective equipment when performing the tasks. You should never perform a task if you have any reason to think that a manipulation could be dangerous for you or your teammates.

Systems of units

Units are expressed using the International System of Units (SI) followed by the units expressed in the U.S. customary system of units (between parentheses).

To the Instructor

You will find in this Instructor Guide all the elements included in the Student Manual together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to you is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to another. For this reason, the results and answers given in this manual should be considered as a guide. Students who correctly performed the exercises should expect to demonstrate the principles involved and make observations and measurements similar to those given as answers.

Sample Exercise

Extracted from

the Student Manual

and the Instructor Guide

AC Circuits and AC Capacitors

EXERCISE OBJECTIVE

When you have completed this exercise, you will be familiar with the basic principles of alternating current. You will be introduced to ac voltage and current sine waves, as well as to related concepts such as frequency, period, peak value, and rms value. You will also be introduced to a component of the AC/DC Training System: the ac power source. You will know how to make circuit measurements in ac circuits. Finally, you will be familiar with the operation of ac capacitors.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Introduction to alternating current
- AC voltage and current sine waves
  Frequency and period of a sine wave. Peak value and RMS value of a sine wave.
- Training system component: the ac power source
- Circuit parameter measurements in ac circuits
  Measuring voltage. Measuring current. Measuring resistance and capacitance. Using a multimeter for ac measurement.
- Introduction to ac capacitors
  Operation of ac capacitors. Reactance of ac capacitors. Equivalent capacitance and capacitive reactance of series and parallel ac capacitors.

DISCUSSION

Introduction to alternating current

In the *DC Circuit Fundamentals* course, you saw that, in direct current (dc) circuits, electricity is supplied using a dc power source, as shown in Figure 1a. You also saw that, in dc circuits, current flows in a single direction. In the conventional representation, electrical current flows from the positive terminal of the dc power source to the negative terminal. In other words, it flows from the high-voltage terminal to the low-voltage terminal.

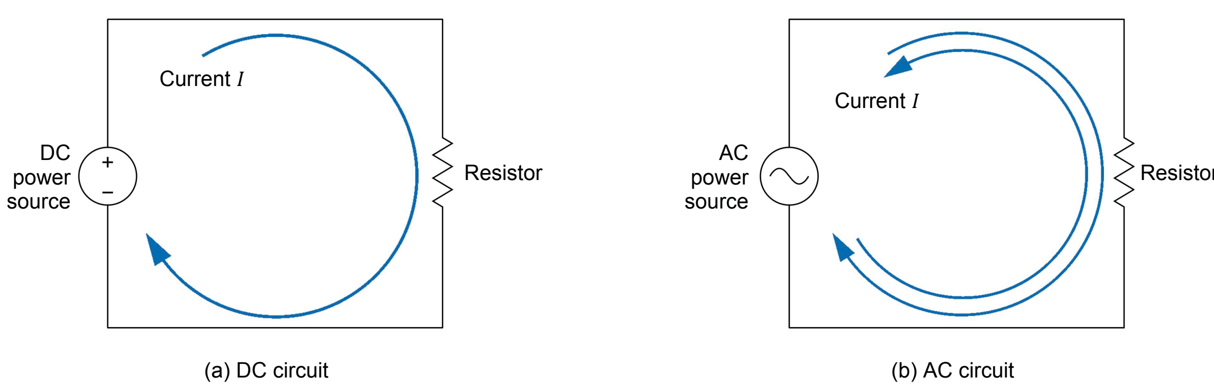


Figure 1. Current direction in a dc circuit and in an ac circuit.

In alternating current (ac) circuits, on the other hand, electricity is supplied using an ac power source, as shown in Figure 1b. In ac circuits, current continuously switches direction because the voltage at the ac power source terminals continuously changes polarity, alternating between positive and negative.

AC voltage and current sine waves

The voltage and current in an ac circuit are both represented using a **sine wave**, as shown in Figure 3. The following characteristics can be observed from the graph:

- The voltage or current periodically changes from one polarity to the other.
- The value of the voltage or current continuously changes with time. This value ranges from a positive maximum to a negative maximum.
- The portion of the wave during which the voltage or current is of positive (+) polarity is called the positive half-wave. The portion of the wave during which the voltage or current is of negative (–) polarity is called the negative half-wave.
- A complete sine wave **cycle** consists of a positive half-wave and a negative half-wave.

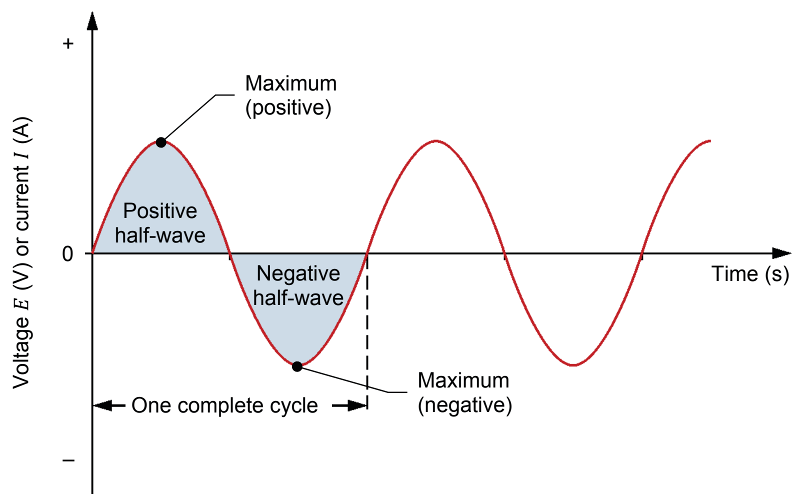


Figure 3. Typical sine wave of the voltage and current in an ac circuit as a function of time.

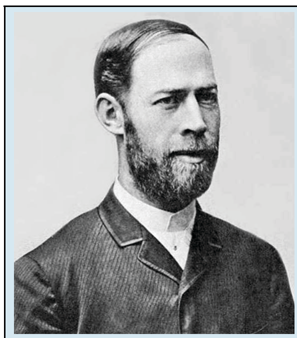


Figure 2. German physicist Heinrich Hertz.

Frequency and period of a sine wave

The **frequency** of a sine wave defines the number of times that a sine wave cycle (such as the one in Figure 3) repeats per second. The higher the frequency, the more the cycle repeats per second, and the steeper the curve of the resulting sine wave. Frequency is measured in hertz (Hz) after German physicist Heinrich Hertz, who proved the existence of electromagnetic waves. Frequency is usually denoted using the letter f.

In North America, the frequency of the current supplied by public power distribution utilities is 60 Hz, which means that a complete sine wave cycle repeats 60 times per second. In Europe, Asia, Africa, Russia, the Middle-East, and Australia, power network frequency is usually 50 Hz. In South America and Japan, this frequency is either 50 Hz or 60 Hz.

The **period** of a sine wave defines the time length of a sine wave cycle (such as the one in Figure 3). Period is measured in seconds (s) and is usually denoted using the letter T. It can be calculated using the following equation:

$$T = \frac{1}{f} \tag{1}$$

where T is the period of the sine wave, expressed in seconds (s)
f is the frequency of the sine wave, expressed in hertz (Hz)

Frequency can be calculated using the reciprocal of the above equation:

$$f = \frac{1}{T} \tag{2}$$

Therefore, in a 60 Hz ac power network, the period of one cycle is equal to 1/60 Hz = 16.7 ms. In a 50 Hz ac power network, the period of one cycle is equal to 1/50 Hz = 20 ms.

Peak value and RMS value of a sine wave

When considering a dc voltage or current, the magnitude of that voltage or current is constant. Therefore, the magnitude of the voltage measured across a component or of the current flowing through it is a constant value. When measuring ac voltage or ac current, however, the magnitude of the voltage or current varies continuously with time. To solve this problem, voltage and current sine waves in ac circuits are usually defined using two constant values: the peak value and rms value of the sine wave.

The **peak value** of a sine wave corresponds to the maximal value of the sine wave (positive or negative), as shown in Figure 4.

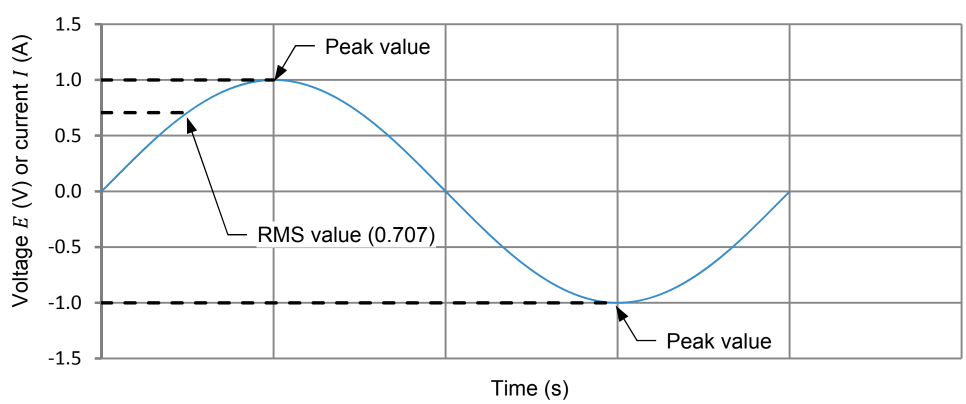


Figure 4. Peak value and rms value of a sine wave.

The **rms value** (for root-mean-square value) of a sine wave corresponds to the effective value of that sine wave, as shown in Figure 4. The rms value defines the magnitude that the sine wave would have if it were constant. The rms value of a voltage sine wave is calculated using the following equation:

$$E_{RMS} = \frac{E_{Peak}}{\sqrt{2}} = 0.707 \times E_{Peak} \tag{3}$$

where E_{RMS} is the rms value of the voltage sine wave, expressed in volts (V)
E_{Peak} is the peak value of the voltage sine wave, expressed in volts (V)

Similarly, the rms value of a current sine wave is calculated using the following equation:

$$I_{RMS} = \frac{I_{Peak}}{\sqrt{2}} = 0.707 \times I_{Peak} \tag{4}$$

where I_{RMS} is the rms value of the current sine wave, expressed in amperes (A)
I_{Peak} is the peak value of the current sine wave, expressed in amperes (A)

Consider for example the circuit of a 24 V dc power source connected to a resistor (see Figure 1a). When the dc power source is on, a certain amount of power is supplied to that resistor. Now, consider another circuit in which an ac power source is connected to an identical resistor (see Figure 1b). In order for the ac power source to supply the same amount of power to the resistor, it is necessary to adjust the voltage of the ac power source until its rms voltage is equal to the dc power source voltage. The resulting voltage curves as a function of time for both circuits are shown in the graph of Figure 5.

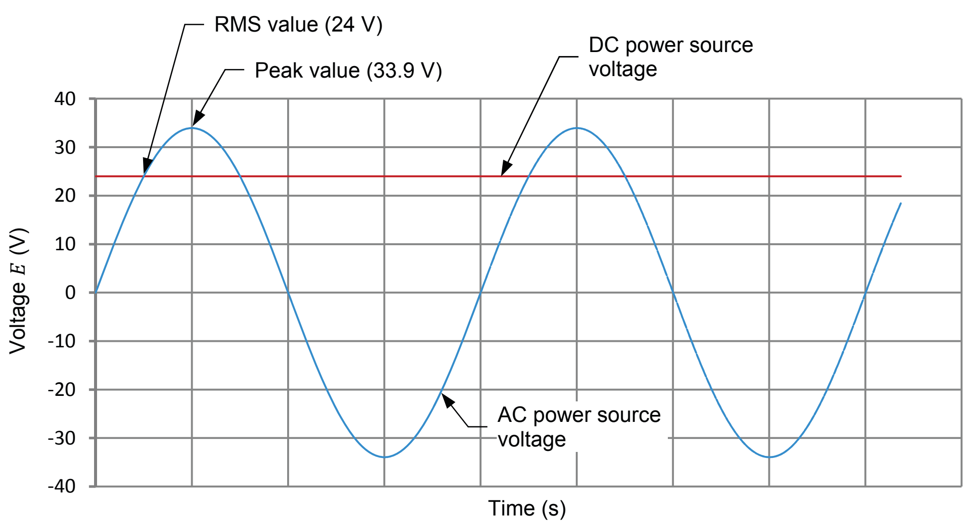


Figure 5. Voltage curves for a 24 V dc power source and an ac power source with an rms voltage of 24 V supplying the same amount of power to an identical resistor.

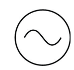
As Figure 5 shows, the dc power source voltage corresponds to the rms value of the ac power source. However, the peak value of the ac power source is in fact higher ($E_{RMS} \times \sqrt{2} = 33.9$ V) than the dc power source voltage. If the same graphs were made for the currents flowing in the dc and ac circuits, the same relationships would be found.

Training system component: the ac power source

The ac power source is one of the most important components in the AC/DC Training System. It is used in all procedures requiring ac power. To turn the ac power source on, set the Power Input switch of the training system to the I position. To turn the ac power source off, set the Power Input switch of the training system to the O position. Be sure never to turn the ac power source on unless it is stated to do so. Not respecting this instruction could damage the equipment or give you or a comrade a shock.

The ac power source in the training system has an rms voltage rating of 24 V and an rms current rating of 1 A. Note that it is common to indicate the voltage and current ratings of ac components as rms values. The circuit diagram symbol for an ac power source is shown in Table 1.

Table 1. AC power source symbol.

Component	Symbol
AC power source	

The ac power source is protected using a circuit breaker. Although this component is covered only in exercise 5 of this manual, it is important to know that it protects the power source from overcurrents. If the intensity of the current flowing from the ac power source ever reaches a value greater than its current rating (1 A) for a certain length of time, the circuit breaker will open the circuit, thus preventing damage to the power source and other equipment. The circuit breaker can be reset by pressing the button beside the ac power source. Before doing so, however, be sure to ascertain and correct the problem causing the overcurrent, otherwise the circuit breaker will trip again when you turn the ac power source back on.

Circuit parameter measurements in ac circuits

Circuit parameter measurement in ac circuits is achieved using the same measuring instruments as in dc circuits. The connections required are also very similar. This is explained in detail for each type of parameter in the following subsections.

Measuring voltage

Voltage measurement in ac circuits is achieved by connecting a voltmeter across (i.e., in parallel with) the two points where voltage is to be measured, as shown in Figure 6. The polarity of the voltmeter is not indicated in the circuit. This is because an ac power source has no positive or negative terminal (voltage continuously alternates between positive and negative). Therefore, the polarity of the voltmeter probes does not need to be respected when measuring ac voltage. Note that, unless stated otherwise, the voltage value indicated by a voltmeter is an rms value.

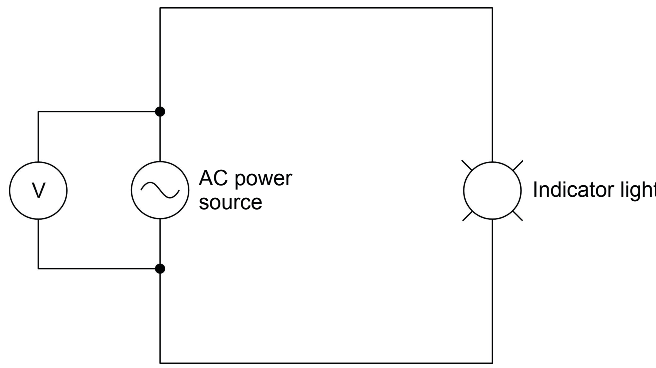


Figure 6. Using a voltmeter to measure the voltage across an ac power source.

Measuring current

Current measurement in ac circuits is achieved by connecting an ammeter in series with the point where current is to be measured, as shown in Figure 7. The polarity of the ammeter is not indicated in the circuit. This is because current in an ac circuit is neither positive nor negative, but continuously alternates between positive and negative. Therefore, the polarity of the ammeter probes does not need to be respected when measuring ac current. Note that, unless stated otherwise, the current value indicated by an ammeter is an rms value.

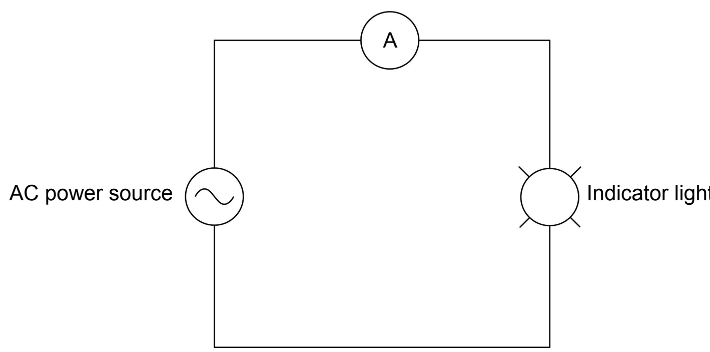


Figure 7. Using an ammeter to measure the current flowing in a circuit.

Ammeters are just as susceptible to overcurrents in ac circuits as they are in dc circuits. Because of this, when connecting an ammeter, whether in dc or ac circuits, it is important to make especially sure to observe the required connections.

Measuring resistance and capacitance

Resistance and capacitance measurement in ac circuits is achieved in exactly the same way as it is in dc circuits. This is because, to measure these two parameters, it is necessary to remove the power source from the circuit. Therefore, the type of current produced by the power source (dc or ac) has no impact on resistance or capacitance measurement.

Resistance is measured by connecting an ohmmeter across (i.e., in parallel with) the two points where resistance is to be measured, as shown in Figure 8.

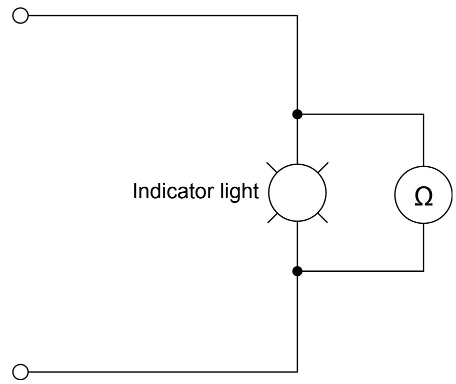


Figure 8. Using an ohmmeter to measure the resistance of an indicator light.

Capacitance is measured by connecting a capacitance meter across (i.e., in parallel with) the two points where capacitance is to be measured, as shown in Figure 9.

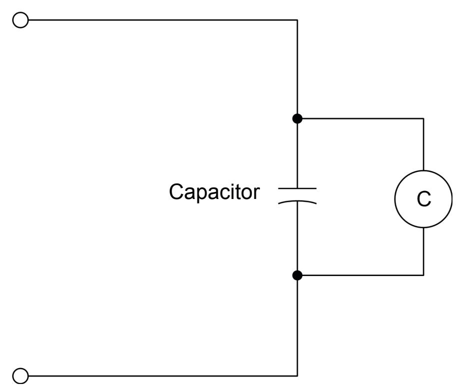


Figure 9. Using a capacitance meter to measure the capacitance of a capacitor.

Using a multimeter for ac measurement

In the *DC Circuit Fundamentals* course, you saw that multimeters combine multiple measuring instruments in one device. You learned how to perform measurements in dc circuits. Most multimeters also allow measurement in ac circuits. To perform measurements in ac circuits, simply select the appropriate function on the multimeter. Figure 10 shows a typical multimeter with its functions indicated on the picture. The multimeter function indicated in red is not covered and need not be studied.

Note that, on a multimeter, dc and ac measurements can be differentiated one from the other by the symbol indicated beside the letter A or V. Table 2 shows the symbols for dc and ac measurements.

Table 2. DC and ac measurement symbols.

Component	Symbol
DC measurement	⎓
AC measurement	∿

Figure 10. Typical multimeter.

Introduction to ac capacitors

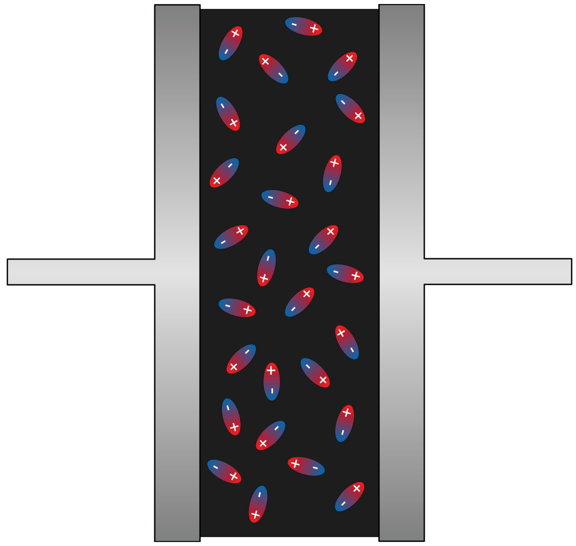
In the *DC Circuit Fundamentals* course, you saw that dc capacitors are electrical components that oppose voltage changes in a circuit and store electrical energy. You also saw that most capacitors consist of two conducting materials (usually a metal) separated by an insulating material, called a dielectric (e.g., glass, air, paper), with a pair of terminals on the capacitor providing access to the metal plates. Capacitors are rated using their capacitance, expressed in farads (F).

AC capacitors are basically the same as dc capacitors: they also consist of two conducting materials separated by an insulating material. The main rating of ac capacitors is also capacitance. Their operation, however, is slightly different due to the unique properties of ac circuits in comparison to dc circuits.

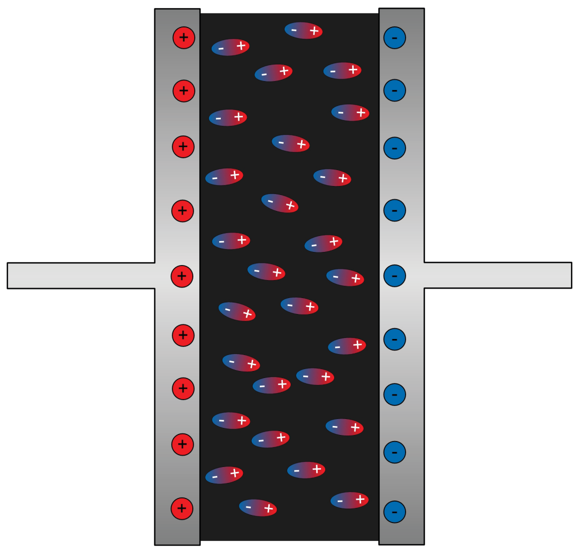
Figure 11. Banks of capacitors are often used in power transmission substations. Capacitors such as these have a very high capacitance value.

Operation of ac capacitors

In the *DC Circuit Fundamentals* course, you saw that charges accumulate in dc capacitors as long as the capacitor is not fully charged. As soon as the capacitor is fully charged (when the capacitor voltage is equal to the dc power source voltage), current stops flowing in the circuit. Figure 12a shows the charges in the conducting plates and dielectric of a capacitor when it is fully discharged, while Figure 12b shows the same components when the capacitor is fully charged.



(a) Fully discharged capacitor



(b) Fully charged capacitor

Figure 12. Conducting plates and dielectric of a capacitor when it is fully discharged and fully charged.

Now, consider the circuit in Figure 13 showing an ac power source connected to a capacitor.

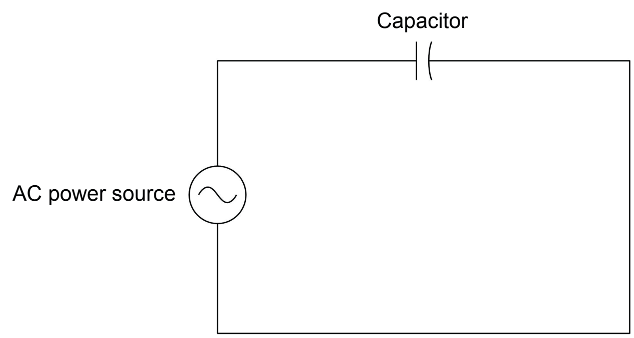
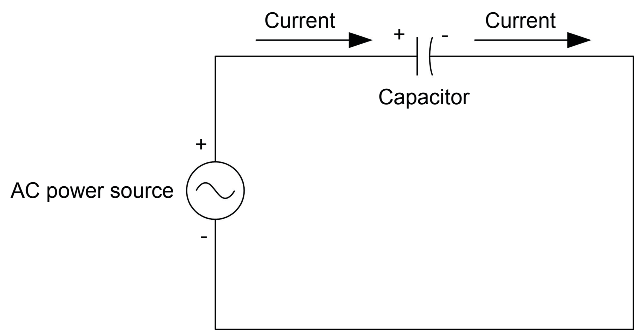
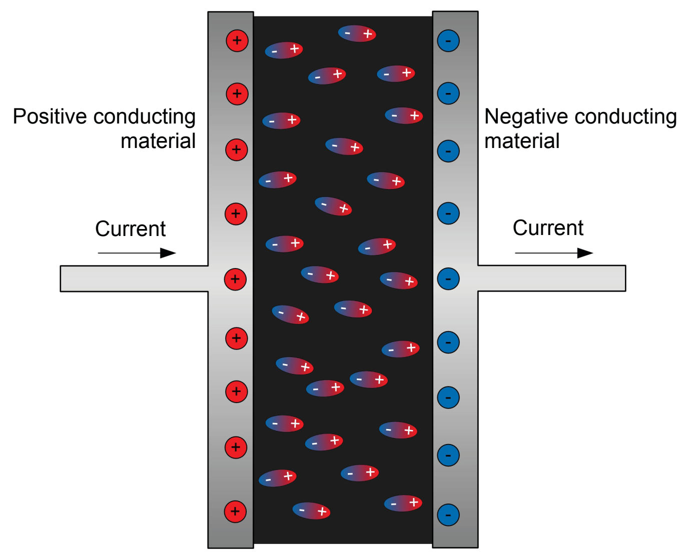


Figure 13. AC power source connected to a capacitor.

When the ac power source is turned on, a voltage is applied to the capacitor. During the positive half-wave of the voltage sine wave, one of the terminals of the power source is positive. Therefore, current flows from this terminal to the capacitor, then back to the negative terminal of the power source, as shown in Figure 14a. The voltage applied to the capacitor causes positive charges to accumulate on the conducting plate of the capacitor connected to the positive terminal of the power source, and negative charges to accumulate on the conducting plate of the capacitor connected to the negative terminal of the power source. This is shown in Figure 14b.



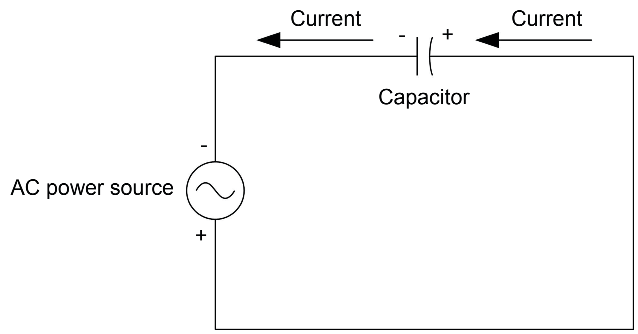
(a) Circuit in Figure 13 during the positive half-wave of the voltage sine wave



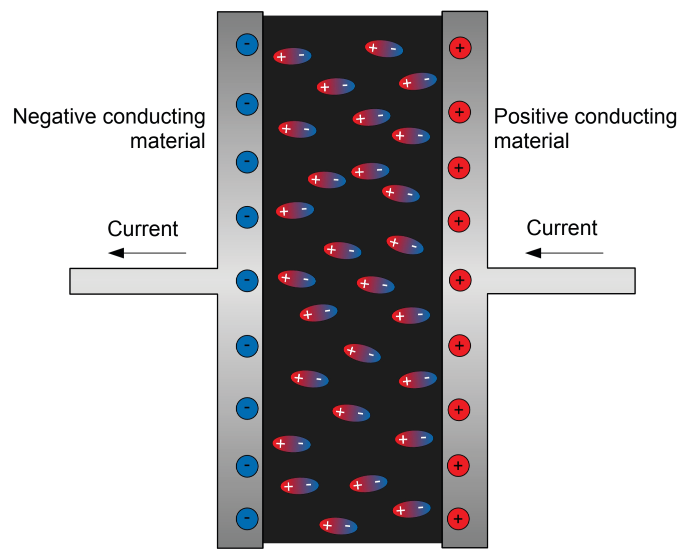
(b) Capacitor in detail showing the accumulated charges

Figure 14. Circuit in Figure 13 and capacitor charges during the positive half-wave of the voltage sine wave.

When the voltage sine wave becomes negative, the polarity of both terminals of the ac power source is inverted. This reverses the direction of current flow and inverts the polarity of the charges accumulated at each conducting plate of the capacitor, as shown in Figure 15a and b.



(a) Circuit in Figure 13 during the negative half-wave of the voltage sine wave



(b) Capacitor in detail showing the accumulated charges

Figure 15. Circuit in Figure 13 and capacitor charges during the negative half-wave of the voltage sine wave.

The process shown in Figure 14 and Figure 15 repeats at every cycle of the voltage sine wave produced by the ac power source. As you can see, even though the capacitor can become fully charged during a half cycle, it immediately discharges and recharges with an inverted polarity in the next half cycle. Because of this, current never stops flowing in such a circuit.

Reactance of ac capacitors

As stated in the previous subsection, ac capacitors do not prevent current flow as they never stay fully charged for long due to the nature of alternating current. However, capacitors in ac circuits oppose current flow in the circuit, exactly like resistors. The opposition to current flow of an ac capacitor is referred to as its capacitive reactance and depends on its capacitance, as well as on the frequency of the ac power source. The capacitive reactance of an ac capacitor is calculated using the following equation:

$$X_C = \frac{1}{2\pi f C} \tag{5}$$

where X_C is the capacitive reactance of the capacitor, expressed in ohms (Ω)
f is the frequency of the ac power source, expressed in hertz (Hz)
C is the capacitance of the capacitor, expressed in farads (F)

As you can see from Equation (5), the capacitive reactance X_C of an ac capacitor is expressed in ohms (Ω), just like the resistance of a resistor. Because of this, in ac circuits containing a capacitor, the capacitive reactance X_C of the capacitor replaces the resistance R when using Ohm's law to calculate the voltages and currents in the circuit. Ohm's law thus becomes:

$$I = \frac{E}{X_C} \tag{6}$$

where I is the current flowing in the capacitor, expressed in amperes (A)
E is the voltage applied across the capacitor, expressed in volts (V)
X_C is the capacitive reactance of the capacitor, expressed in ohms (Ω)

Consider for example the ac circuit in Figure 16 containing a capacitor. The ac power source has a voltage of 120 V and operates at a frequency of 60 Hz, while the capacitance of the capacitor is equal to 16 μF.

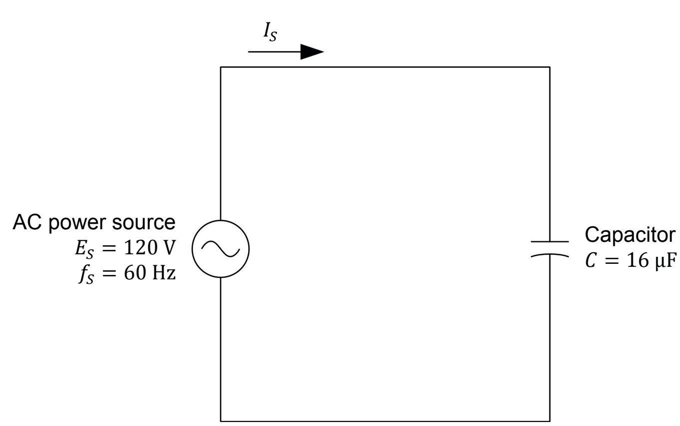


Figure 16. AC circuit containing a capacitor.

To calculate the current I_S flowing in the circuit, it is necessary to first calculate the capacitive reactance X_C of the capacitor:

Remember that
1 μF = 0.000001 F
or 1 × 10-6 F.

$$X_C = \frac{1}{2\pi f_S C} = \frac{1}{2\pi \times 60\ \text{Hz} \times (16 \times 10^{-6}\ \text{F})} = 165.79\ \Omega$$

Using the capacitive reactance X_C of the capacitor, it is then possible to calculate the current I_S flowing in the circuit:

$$I_S = \frac{E_S}{X_C} = \frac{120\ \text{V}}{165.79\ \Omega} = 0.72\ \text{A}$$

Equivalent capacitance and capacitive reactance of series and parallel ac capacitors

The equivalent capacitance of series and parallel ac capacitors is calculated in exactly the same way as for dc capacitors. This means that the equivalent capacitance of series capacitors is calculated using the following equation:

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n} \tag{7}$$

where C_{eq} is the equivalent capacitance of all capacitors in the series circuit, expressed in farads (F)
C_n is the capacitance of each capacitor in the circuit, expressed in farads (F)

The equivalent capacitance of parallel capacitors is calculated using the following equation:

$$C_{eq} = C_1 + C_2 + \cdots + C_n \tag{8}$$

where C_{eq} is the equivalent capacitance of all capacitors in the parallel circuit, expressed in farads (F)
C_n is the capacitance of each capacitor in the circuit, expressed in farads (F)

It is then possible to convert the calculated equivalent capacitance of the circuit into an equivalent capacitive reactance value for the series or parallel circuit.

Alternately, it is possible to obtain the equivalent capacitive reactance of a series or parallel circuit using the individual capacitive reactance of each capacitor in the circuit. In this case, the equivalent capacitive reactance of series capacitors is calculated using the following equation:

$$X_{eq} = X_{C_1} + X_{C_2} + \cdots + X_{C_n} \tag{9}$$

where X_{eq} is the equivalent capacitive reactance of all capacitors in the series circuit, expressed in ohms (Ω)
X_{C_n} is the capacitive reactance of each capacitor in the circuit, expressed in ohms (Ω)

The equivalent capacitive reactance of parallel capacitors is calculated using the following equation:

$$\frac{1}{X_{eq}} = \frac{1}{X_{C_1}} + \frac{1}{X_{C_2}} + \cdots + \frac{1}{X_{C_n}} \tag{10}$$

where X_{eq} is the equivalent capacitive reactance of all capacitors in the parallel circuit, expressed in ohms (Ω)

X_{C_n} is the capacitive reactance of each capacitor in the circuit, expressed in ohms (Ω)

As you can see, the equivalent capacitive reactance of series and parallel capacitors is calculated in exactly the same way as when calculating the equivalent resistance of series and parallel resistors.

Consider for example the series ac circuit in Figure 17 containing three capacitors. The ac power source has a voltage of 220 V and operates at a frequency of 50 Hz, while the capacitance of the capacitors is equal to 20 μF, 40 μF, and 32 μF.

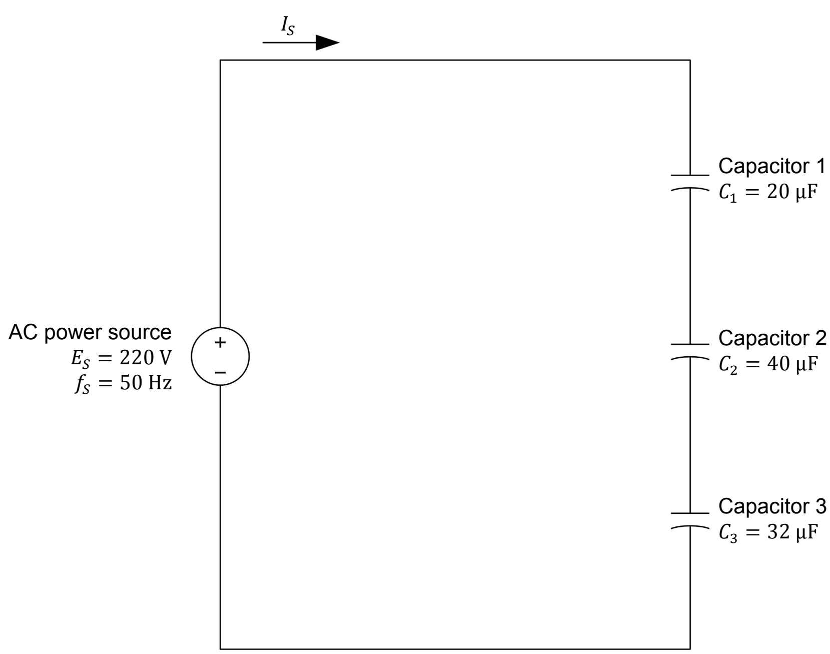


Figure 17. Series ac circuit containing three capacitors.

Calculating the equivalent capacitive reactance $X_{eq\,(X_{C_1},X_{C_2},X_{C_3})}$ of the capacitors in the circuit can be done in either of the two following ways:

Using the equivalent capacitance C_{eq}:

$$\frac{1}{C_{eq\,(C_1,C_2,C_3)}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{20\ \mu\text{F}} + \frac{1}{40\ \mu\text{F}} + \frac{1}{32\ \mu\text{F}}$$

$$C_{eq\,(C_1,C_2,C_3)} = 9.412\ \mu\text{F}$$

$$X_{eq\,(X_{C_1},X_{C_2},X_{C_3})} = \frac{1}{2\pi f_S C_{eq\,(C_1,C_2,C_3)}} = \frac{1}{2\pi \times 50\ \text{Hz} \times (9.412 \times 10^{-6}\ \text{F})} = 338.20\ \Omega$$

Using the capacitive reactance of each capacitor:

$$X_{C_1} = \frac{1}{2\pi f_S C_1} = \frac{1}{2\pi \times 50\ \text{Hz} \times (20 \times 10^{-6}\ \text{F})} = 159.15\ \Omega$$

$$X_{C_2} = \frac{1}{2\pi f_S C_2} = \frac{1}{2\pi \times 50\ \text{Hz} \times (40 \times 10^{-6}\ \text{F})} = 79.58\ \Omega$$

$$X_{C_3} = \frac{1}{2\pi f_S C_3} = \frac{1}{2\pi \times 50\ \text{Hz} \times (32 \times 10^{-6}\ \text{F})} = 99.47\ \Omega$$

$$X_{eq\,(X_{C_1},X_{C_2},X_{C_3})} = X_{C_1} + X_{C_2} + X_{C_3} = 159.15\ \Omega + 79.58\ \Omega + 99.47\ \Omega = 338.20\ \Omega$$

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Set up
- Comparison between a dc circuit and an ac circuit
- Determining the capacitance and capacitive reactance of ac capacitors
- Connecting a circuit containing a capacitor
- Calculating the reactance of series capacitors
- Calculating the reactance of parallel capacitors

PROCEDURE

Set up

In this section, you will set up the AC/DC Training System.

1. Install the AC/DC Training System on a stable surface, then open the training system.

2. Make sure that the main power switch on the AC/DC Training System is set to the O (off) position, then connect its Power Input to an ac power outlet.

3. Make sure that all fault switches are set to the O position, indicating that no fault is inserted in the operation of the AC/DC Training System.

Comparison between a dc circuit and an ac circuit

In this section, you will connect a dc circuit containing a resistor. You will measure the resistor voltage and the current flowing in the circuit. You will then replace the dc power source by an ac power source, and again measure the resistor voltage and the current flowing in the circuit. You will compare the parameters measured in the dc circuit to the parameters measured in the ac circuit.

4. Connect the circuit shown in Figure 18. Use the 62 Ω resistor to implement the resistor. Connect the voltmeter and ammeter as shown in the circuit.

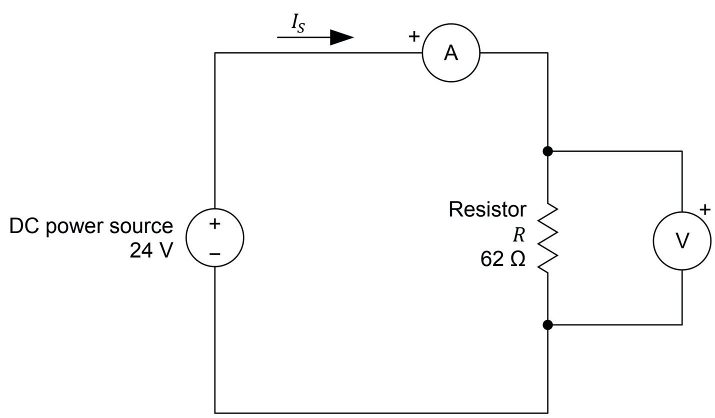


Figure 18. DC circuit containing a resistor.

5. Turn the dc power source on.

6. Measure the voltage E_R across the resistor. Record the value below.

Resistor voltage E_R = _______ V

Resistor voltage E_R = 24.0 V

7. Measure the current I_S flowing in the circuit. Record the value below.

Current I_S = _______ A

Current I_S = 0.388 A

8. Turn the dc power source off.

9. Connect the circuit shown in Figure 19. The only modification in the circuit is that the dc power source has been replaced by an ac power source. The rest of the circuit is identical to the circuit in Figure 18.

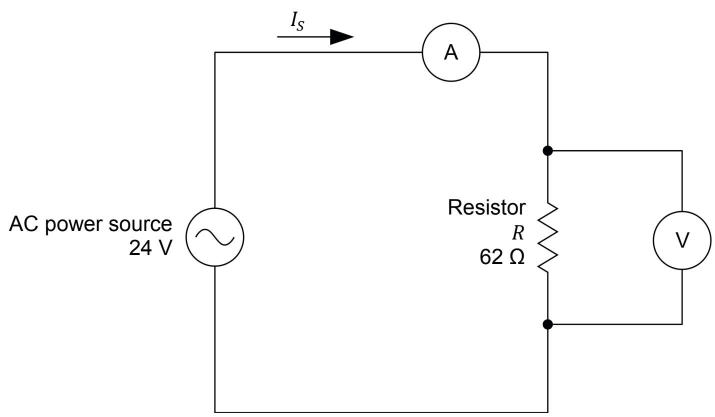


Figure 19. AC circuit containing a resistor.

10. Turn the ac power source on.

11. Measure the rms value of the voltage E_R across the resistor. Record the value below.

Resistor voltage $E_R =$ _______ V

Resistor voltage $E_R = 25.43$ V

12. Measure the rms value of the current I_S flowing in the circuit. Record the value below.

Current $I_S =$ _______ A

Current $I_S = 0.411$ A

13. Compare the resistor voltage E_R and the current I_S recorded in the ac circuit to those you recorded in the dc circuit. What can you conclude?

The rms value of the resistor voltage E_R and the current I_S in the ac circuit are close to the resistor voltage E_R and the current I_S in the dc circuit. This indicates that an rms value measured in an ac circuit is equal to the same value measured in an equivalent dc circuit.

14. Turn the ac power source off.

Determining the capacitance and capacitive reactance of ac capacitors

In this section, you will measure the capacitance of both capacitors in the AC/DC Training System, and compare the measured values to the rated value indicated on the front panel of the system. You will then calculate the capacitive reactance of the capacitors using their measured capacitance values.

15. Connect the circuit shown in Figure 20. Use the first of the 8.8 μF capacitors to implement the capacitor.

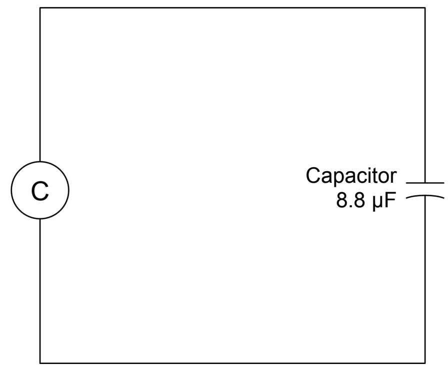


Figure 20. Circuit for measuring the capacitance of each capacitor in the AC/DC Training System.

16. Measure the capacitance C_1 of the first capacitor. Record the value below.

Capacitance C_1 = _______ μF

Capacitance $C_1 = 8.92$ μF

17. In the circuit of Figure 20, replace the first capacitor of the AC/DC Training System by the second capacitor.

18. Measure the capacitance C_2 of the second capacitor. Record the value below.

Capacitance C_2 = _______ μF

Capacitance $C_2 = 8.86$ μF

19. Compare the capacitance C_1 and C_2 of the capacitors you just recorded to the capacitance of the capacitors indicated on the front panel of the AC/DC Training System. Are both capacitance values within the limit of the tolerance (also indicated on the front panel) of the rated capacitance of the capacitors?

❑ Yes ❑ No

Yes

20. Calculate the capacitive reactances X_{C_1} and X_{C_2} of the capacitors using the capacitances C_1 and C_2 you recorded in this section.

The capacitive reactance of a capacitor is calculated using the following equation:

$$X_C = \frac{1}{2\pi f C}$$

Capacitive reactance X_{C_1} = _______ Ω

Capacitive reactance X_{C_2} = _______ Ω

The capacitive reactances X_{C_1} and X_{C_2} of the capacitors are calculated below:

$$X_{C_1} = \frac{1}{2\pi f_S C_1} = \frac{1}{2\pi \times 60\ \text{Hz} \times 8.92\ \mu\text{F}} = 297.37\ \Omega$$

$$X_{C_2} = \frac{1}{2\pi f_S C_2} = \frac{1}{2\pi \times 60\ \text{Hz} \times 8.86\ \mu\text{F}} = 299.39\ \Omega$$

Connecting a circuit containing a capacitor

In this section you will connect an ac circuit containing a capacitor. You will observe the current flowing in the circuit after you turn the ac power source on. You will measure the capacitor voltage and the current flowing in the circuit, and use these values to calculate the reactance of the capacitor. You will compare this reactance value obtained from circuit measurements to the reactance of the capacitors you calculated in the previous section.

21. Connect the circuit shown in Figure 21. Use the first 8.8 μF capacitor to implement the capacitor.

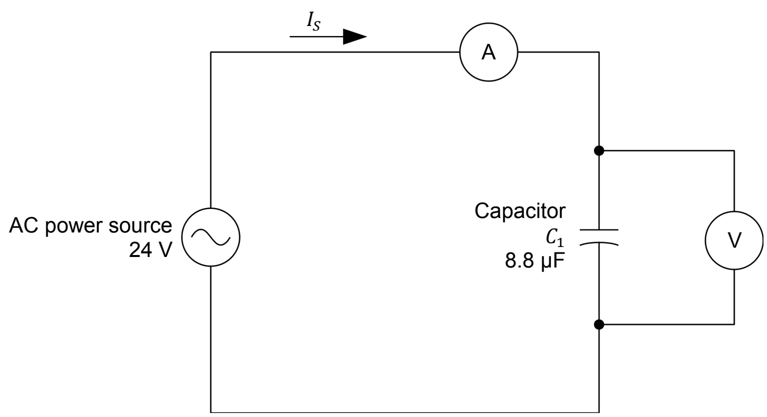


Figure 21. AC power source connected to a capacitor.

22. Turn the ac power source on.

23. Observe the current I_S flowing in the circuit after you turn the ac power source on. What happens to current I_S? Explain briefly, considering what you know about the operation of capacitors in dc and ac circuits.

The current I_S flowing in the circuit is constant after the ac power source is turned on. This is because, in ac circuits, the current flowing in a capacitor does not decrease in time then stops when the capacitor is fully charged. Rather, the current flowing in an ac capacitor is constant. However, the capacitor has the effect of limiting the intensity of the current.

24. Measure the voltage E_{C_1} across the capacitor and the current I_S flowing in the circuit. Record the values below.

Capacitor voltage E_{C_1} = _______ V

Current I_S = _______ A

Capacitor voltage $E_{C_1} = 27.15$ V

Current $I_S = 0.089$ A

25. Using the voltage E_{C_1} across the capacitor and the current I_S flowing in the circuit you recorded in the previous step, calculate the capacitive reactance X_{C_1} of the capacitor.

The capacitive reactance of the capacitor can be calculated using the following variation of Ohm's law:

$$X_C = \frac{E}{I}$$

Capacitive reactance X_{C_1} = _______ Ω

The capacitive reactance X_{C_1} of the capacitor is calculated below:

$$X_{C_1} = \frac{E_{C_1}}{I_S} = \frac{27.15\ \text{V}}{0.089\ \text{A}} = 305.07\ \Omega$$

26. Is the capacitive reactance X_{C_1} of the capacitor you calculated from measured circuit parameters in the previous step close to the capacitive reactance of the first capacitor you calculated in step 20?

❑ Yes ❑ No

Yes

27. Turn the ac power source off.

Calculating the reactance of series capacitors

In this section, you will connect the two capacitors of the AC/DC Training System in series, and measure their equivalent capacitance. From this value, you will calculate their equivalent reactance. You will then connect an ac circuit containing the same two series capacitors. You will measure the voltage across the series capacitors and the current flowing in the circuit, and use these values to calculate the equivalent reactance of the capacitors. You will compare this equivalent reactance value obtained from circuit measurements to the equivalent reactance you calculated using the equivalent capacitance.

28. Connect the circuit shown in Figure 22. Use both 8.8 μF capacitors to implement the series capacitors.

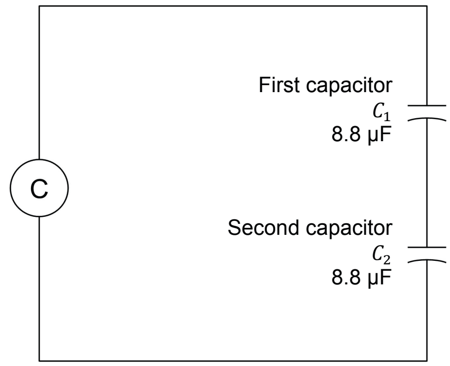


Figure 22. Circuit for measuring the capacitance of series capacitors.

29. Measure the equivalent capacitance $C_{eq\,(C_1,C_2)}$ of the series capacitors. Record the value below.

Equivalent capacitance $C_{eq\,(C_1,C_2)}$ = _______ μF

Equivalent capacitance $C_{eq\,(C_1,C_2)}$ = 4.45 μF

30. Using the equivalent capacitance $C_{eq\,(C_1,C_2)}$ you measured in the previous step, calculate the equivalent reactance $X_{eq\,(X_{C_1},X_{C_2})}$ of the series capacitors.

Equivalent reactance $X_{eq\,(X_{C_1},X_{C_2})}$ = _______ Ω

The equivalent reactance $X_{eq\,(X_{C_1},X_{C_2})}$ of the series capacitors is calculated below:

$$X_{eq\,(X_{C_1},X_{C_2})} = \frac{1}{2\pi f_S C_{eq\,(C_1,C_2)}} = \frac{1}{2\pi \times 60\ \text{Hz} \times 4.45\ \mu\text{F}} = 596.06\ \Omega$$

31. Connect the circuit shown in Figure 23. Use both 8.8 μF capacitors to implement the series capacitors.

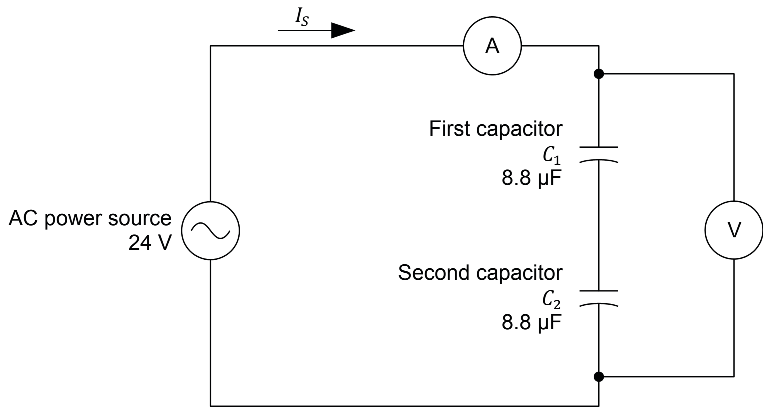


Figure 23. AC power source connected to two series capacitors.

32. Turn the ac power source on.

33. Measure the voltage E_C across the series capacitors and the current I_S flowing in the circuit. Record the values below.

Capacitors voltage E_{C_1,C_2} = _______ V

Current I_S = _______ A

Capacitors voltage $E_{C_1,C_2} = 27.15$ V

Current $I_S = 0.045$ A

34. Using the voltage E_{C_1,C_2} across the series capacitors and the current I_S flowing in the circuit you recorded in the previous step, calculate the equivalent reactance $X_{eq\,(X_{C_1},X_{C_2})}$ of the series capacitors.

The equivalent capacitive reactance of the series capacitors can be calculated using the following variation of Ohm's law:

$$X_C = \frac{E}{I}$$

Equivalent reactance $X_{eq\,(X_{C_1},X_{C_2})}$ = _______ Ω

The equivalent reactance $X_{eq\,(X_{C_1},X_{C_2})}$ of the series capacitors is calculated below:

$$X_{eq\,(X_{C_1},X_{C_2})} = \frac{E_{C_1,C_2}}{I_S} = \frac{27.15\ \text{V}}{0.045\ \text{A}} = 603.33\ \Omega$$

35. Is the equivalent capacitive reactance $X_{eq\,(X_{C_1},X_{C_2})}$ of the series capacitors you calculated from measured circuit parameters in the previous step close to the equivalent capacitive reactance of the series capacitors you calculated in step 30?

❑ Yes ❑ No

Yes

36. Turn the ac power source off.

Calculating the reactance of parallel capacitors

In this section, you will connect the two capacitors of the AC/DC Training System in parallel, and measure their equivalent capacitance. From this value, you will calculate their equivalent reactance. You will then connect an ac circuit containing the same two parallel capacitors. You will measure the voltage across the parallel capacitors and the current flowing in the circuit, and use these values to calculate the equivalent reactance of the capacitors. You will compare this equivalent reactance value obtained from circuit measurements to the equivalent reactance you calculated using the equivalent capacitance.

37. Connect the circuit shown in Figure 24. Use both 8.8 μF capacitors to implement the parallel capacitors.

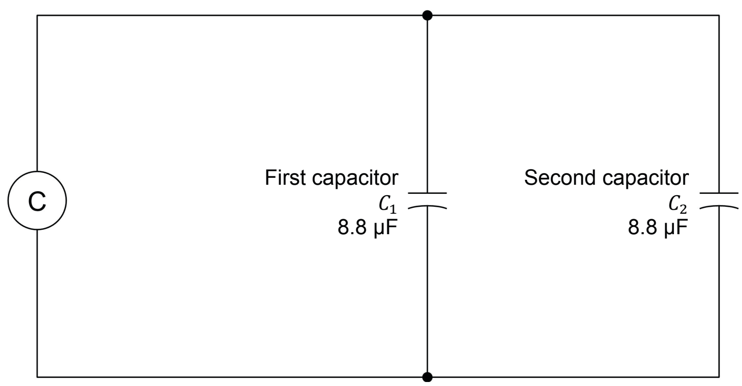


Figure 24. Circuit for measuring the capacitance of parallel capacitors.

38. Measure the equivalent capacitance $C_{eq\,(C_1,C_2)}$ of the parallel capacitors. Record the value below.

Equivalent capacitance $C_{eq\,(C_1,C_2)}$ = _______ μF

Equivalent capacitance $C_{eq\,(C_1,C_2)}$ = 17.78 μF

39. Using the equivalent capacitance $C_{eq\,(C_1,C_2)}$ you measured in the previous step, calculate the equivalent reactance $X_{eq\,(X_{C_1},X_{C_2})}$ of the parallel capacitors.

Equivalent reactance $X_{eq\,(X_{C_1},X_{C_2})}$ = _______ Ω

The equivalent reactance $X_{eq\,(X_{C_1},X_{C_2})}$ of the parallel capacitors is calculated below:

$$X_{eq\,(X_{C_1},X_{C_2})} = \frac{1}{2\pi f_S C_{eq\,(C_1,C_2)}} = \frac{1}{2\pi \times 60\ \text{Hz} \times 17.78\ \mu\text{F}} = 149.19\ \Omega$$

40. Connect the circuit shown in Figure 25. Use both 8.8 μF capacitors to implement the parallel capacitors.

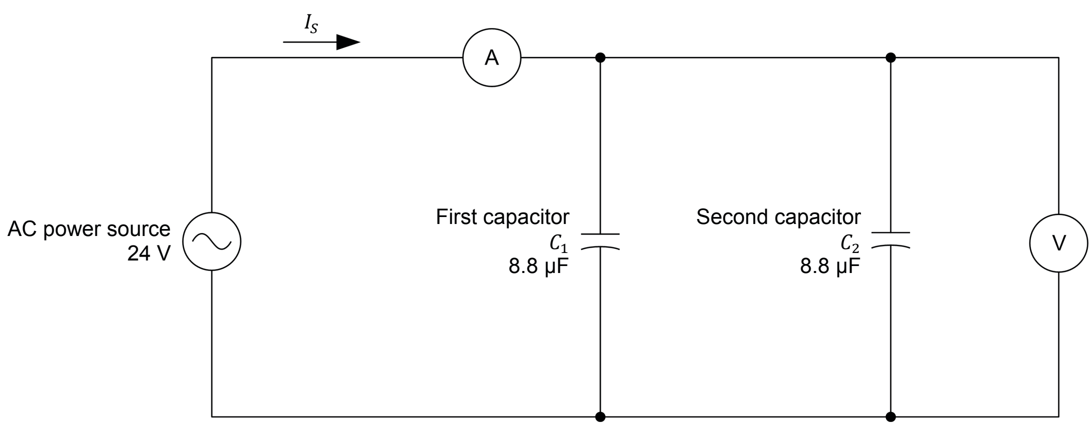


Figure 25. AC power source connected to two parallel capacitors.

41. Turn the ac power source on.

42. Measure the voltage E_{C_1,C_2} across the parallel capacitors and the current I_S flowing in the circuit. Record the values below.

Capacitors voltage E_{C_1,C_2} = _______ V

Current I_S = _______ A

Capacitors voltage E_{C_1,C_2} = 27.49 V

Current I_S = 0.178 A

43. Using the voltage E_{C_1,C_2} across the parallel capacitors and the current I_S flowing in the circuit you recorded in the previous step, calculate the equivalent reactance $X_{eq\,(X_{C_1},X_{C_2})}$ of the parallel capacitors.

Equivalent reactance $X_{eq\,(X_{C_1},X_{C_2})}$ = _______ Ω

The equivalent reactance $X_{eq\,(X_{C_1},X_{C_2})}$ of the parallel capacitors is calculated below:

$$X_{eq\,(X_{C_1},X_{C_2})} = \frac{E_{C_1,C_2}}{I_S} = \frac{27.49\text{ V}}{0.178\text{ A}} = 154.44\ \Omega$$

44. Is the equivalent reactance $X_{eq\,(X_{C_1},X_{C_2})}$ of the parallel capacitors you calculated in the previous step from measured circuit parameters close to the equivalent reactance of the parallel capacitors you calculated in step 30?

❑ Yes ❑ No

Yes

45. Turn the ac power source off.

46. Disconnect all leads from the training system, turn off the multimeter(s), and return all the equipment you used in this exercise to its storage location.

CONCLUSION

In this exercise, you became familiar with the basic principles of alternating current. You were introduced to ac voltage and current sine waves, as well as to related concepts such as frequency, period, peak value, and rms value. You were also introduced to a component of the AC/DC Training System: the ac power source. You learned how to make circuit measurements in ac circuits. Finally, you became familiar with the operation of ac capacitors.

REVIEW QUESTIONS

1. What is the main difference between direct current and alternating current?

Direct current flows in a single direction, from the positive terminal of a dc power source to the negative terminal. In alternating current, on the other hand, the direction of current flow continuously alternates between one direction and the other.

2. Briefly define what the frequency and period of a sine wave are.

The frequency of a sine wave defines the number of times that a sine wave cycle repeats per second. The period of a sine wave defines the time length of a sine wave cycle.

3. Briefly define what the peak value and rms value of a sine wave are.

The peak value of a sine wave corresponds to the maximal value of the sine wave. The rms value (for root-mean-square value) of a sine wave corresponds to the effective value of that sine wave. It defines the magnitude that the sine wave would have if it were constant.

4. What does the capacitive reactance of a capacitor represent and in which unit is it expressed? Explain briefly.

The capacitive reactance of a capacitor represents its opposition to current flow. The higher the capacitive reactance of a capacitor, the more it prevents the flow of electrons and consequently the more difficult it is to make electrons flow through it. Capacitive reactance is expressed in ohms (Ω), just like resistance.

5. Consider the circuit shown in Figure 26. Calculate the current I_S flowing in the circuit from the indicated parameters.

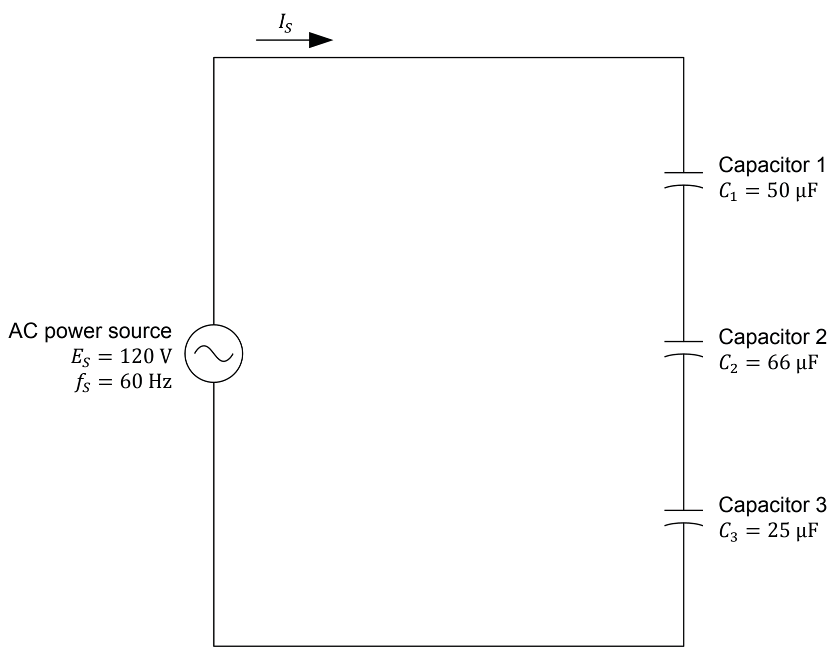


Figure 26. Circuit for review question 5.

It is first necessary to calculate the equivalent capacitance $C_{eq\ (C_1,C_2,C_3)}$ of the capacitors:

$$\frac{1}{C_{eq\ (C_1,C_2,C_3)}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{50\ \mu\text{F}} + \frac{1}{66\ \mu\text{F}} + \frac{1}{25\ \mu\text{F}}$$

$$C_{eq\ (C_1,C_2,C_3)} = 13.306\ \mu\text{F}$$

The equivalent capacitive reactance $X_{eq\,(X_{C_1},X_{C_2},X_{C_3})}$ can then be calculated:

$$X_{eq\,(X_{C_1},X_{C_2},X_{C_3})} = \frac{1}{2\pi f_S C_{eq\,(C_1,C_2,C_3)}} = \frac{1}{2\pi \times 60\ \text{Hz} \times (13.306 \times 10^{-6}\ \text{F})} = 199.35\ \Omega$$

The current I_S flowing in the circuit can then be calculated:

$$I_S = \frac{E_S}{X_{eq\,(X_{C_1},X_{C_2},X_{C_3})}} = \frac{120\ \text{V}}{199.35\ \Omega} = 0.602\ \text{A}$$

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