Electricity and New Energy
AC/DC Training System

DC Circuit Fundamentals

Courseware Sample

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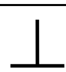
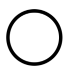
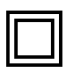
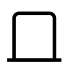
Safety and Common Symbols

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
3~	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 concepts of electricity. You will be able to define voltage, current, resistance, power, and capacitance, and know how to measure these parameters using their respective measuring instruments. You will know the difference between dc and ac circuits. You will be introduced to the most common components used in dc circuits: power sources, switches, resistors, capacitors, solenoids, relays, and motors. You will know what series and parallel circuits are, and be able to calculate the equivalent resistance and capacitance of series and parallel components. You will be familiar with Ohm's law, as well as Kirchhoff's voltage and current laws, and be able to apply these laws to electrical circuits. You will be introduced to the notions of magnetism and electromagnetism.

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

Exercise 2

Switches

EXERCISE OBJECTIVE

When you have completed this exercise, you will be familiar with the uses of switches in electrical circuits, as well as with the most common types of switches. You will know the possible configurations of switches in electrical circuits. You will be introduced to a component of the AC/DC Training System: the indicator light.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Introduction to switches
- Switch types
  Toggle switch. Knife switch. Normally open push-button switch. Normally closed push-button switch. Selector switch.
- Switch configurations
  Single-pole single-throw switch. Double-pole single-throw switch. Single-pole double-throw switch. Double-pole double-throw switch.
- Training system component: the indicator light

DISCUSSION

Introduction to switches

Switches are basic components of electrical circuits. The main use of switches is to either prevent or allow the flow of electrical current at a particular point of a circuit. When the switch is in its open state, it prevents the flow of electrical current. In other words, the circuit containing the switch is open. On the other hand, when the switch is in its closed state, it allows the flow of electrical current just as if no switch were present. In this case, the circuit containing the switch is closed. One of the most common electrical switches is a standard residential light switch. When this switch is set to its open state, the light is off. When it is set to its closed state, the light is on.

Some switches also allow, instead of simply preventing the flow of current, to divert it. This way, it is possible to use the switch in order to select which load of a circuit is powered on and which is not.

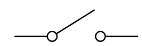
Switch types

There are many types of switches, classified according to their mechanism of operation. The most common switch types are described in the following subsections.

Toggle switch

The toggle switch is operated manually using a lever or a handle. A toggle switch generally allows selection between only two states, determined by the position of the lever. The most common example of a toggle switch is the light switch. Table 3 shows the circuit diagram symbol of a toggle switch.

Table 3. Toggle switch symbol.

Component	Symbol
Toggle switch	

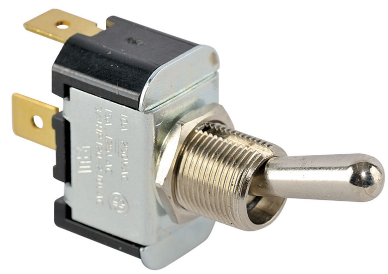


Figure 18. Example of a toggle switch. Notice the terminations of the switch, located on its back. These allow connection of the switch to the required terminals of the circuit.

Knife switch

The knife switch consists of a hinged metal lever that can be inserted in a slot, allowing contact, or removed from the slot, preventing contact. Table 4 shows the circuit diagram symbol of a knife switch.

Table 4. Knife switch symbol.

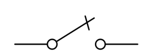
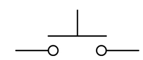
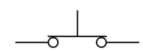
Component	Symbol
Knife switch	

Figure 19. Example of a knife switch. The metal lever is currently inserted into the slot. Therefore, the switch allows current flow between its terminals.

Normally open push-button switch

The **normally open** (NO) push-button switch is operated by a push button. The state of the push button determines the state of the switch. When the button is released, the switch is open (hence the name). When the button is pressed, the switch is closed. For example, a car horn is an NO push-button switch. When the horn is released, the circuit is open and no current flows in the horn. However, when it is pressed, the circuit closes, current flows in the circuit and a sound is produced. Table 5 shows the open and closed state circuit diagram symbols of an NO push-button switch.

Table 5. Open and closed state symbols of an NO push-button switch.

Component	Symbol
Open state of NO push-button switch	
Closed state of NO push-button switch	

Normally closed push-button switch

The **normally closed** (NC) push-button switch is operated by a push button. The state of the push button determines the state of the switch. When the button is released, the switch is closed (hence the name). When the button is pressed, the switch is open. For example, the light in a refrigerator is activated by an NC push-button switch. When the refrigerator door button is pressed (i.e., when the door is closed), the circuit is open and no current flows in the refrigerator light. However, when it is no longer pressed (i.e., when the door opens), the circuit closes and current flows in the refrigerator light. Table 6 shows the closed and open state circuit diagram symbols of an NC push-button switch.

Table 6. Closed and open state symbols of an NC push-button switch.

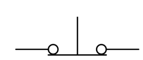
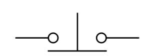
Component	Symbol
Closed state of NC push-button switch	
Open state of NC push-button switch	

Figure 20. Emergency buttons are examples of an NC push-button switch. When the push button is released, the circuit is closed and current flows normally. However, when the push button is pressed (i.e., in the case of an emergency), the circuit becomes open and current ceases to flow in it (© Siemens AG 2014, all rights reserved).

Selector switch

The selector switch is manually operated using a rotating knob. It allows selection between two or more positions, each position making contact at a different branch in the circuit. Table 7 shows the circuit diagram symbol for a selector switch with three positions. As the symbol indicates, from a single circuit branch, the selector switch allows connection to any of three different circuit branches.

Table 7. Selector switch symbol.

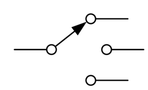
Component	Symbol
Selector switch	

Figure 21. Example of a selector switch. Notice the slots located at the back of the switch allowing connection to different branches in the circuit depending on the position of the rotating knob.

Switch configurations

In addition to the different working mechanisms described in the previous section, switches can also be classified according to their configuration. These configurations are differentiated by the number of poles and the number of throws of the switch.

The number of **poles** of a switch indicates the number of circuits (or circuit branches) that are controlled by the switch. For instance, a single-pole switch controls only one circuit, while a double-pole switch controls two circuits. Basically, a double-pole switch is equivalent to two single-pole switches that are controlled by the same switch mechanism (e.g., lever, push button, knob).

The number of **throws** of a switch indicates the number of contacts to which the switch can be connected. In other words, it represents the number of circuit branches that the switch can make contact with. For instance, a single-throw switch can make contact with only one circuit path, while a double-throw switch can make contact with two circuit paths.

Based on the above notions, the most common switch configurations are described in the following subsections. Note that any of these configurations can be used in conjunction with any of the switch types described in the previous section. In practice, however, some switch configurations are generally used with a particular switch type.

Single-pole single-throw switch

A single-pole single-throw (SPST) switch is the most simple switch configuration. Figure 22 shows an example of an SPST switch. As the figure shows, the switch controls only one circuit and can make contact with only one circuit path. An SPST switch is basically an on/off type of switch allowing the circuit to be either open or closed.

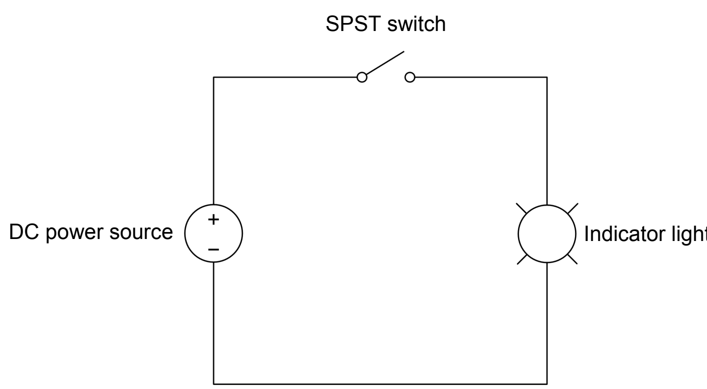


Figure 22. Circuit containing an SPST switch.

Double-pole single-throw switch

A double-pole single-throw (DPST) switch operates just as two SPST switches actuated using the same mechanism. Figure 23 shows an example of a DPST switch. Note the dotted line used to indicate that the two switch symbols are in fact a single DPST switch. As the figure shows, the same switch is used to control both indicator lights at the same time. Just as for the SPST switch, the DPST switch is basically an on/off switch, the difference being that it controls more than one circuit branch at the same time.

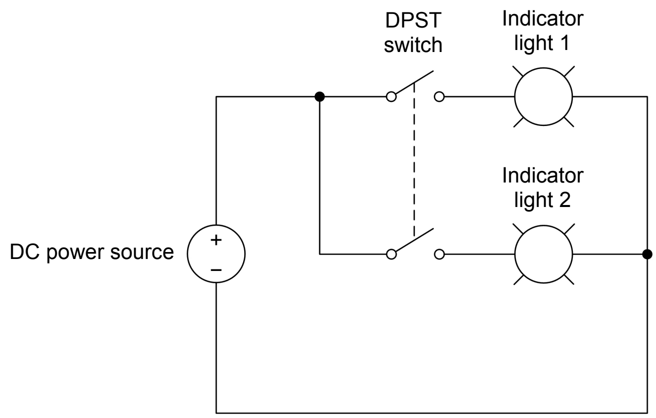


Figure 23. Circuit containing a DPST switch.

Single-pole double-throw switch

A single-pole double-throw (SPDT) switch allows selection between two different circuit branches. Figure 24 shows an example of an SPDT switch. As the figure shows, the SPDT switch can make contact with two circuit branches. This means that the SPDT switch can either make contact with the branch containing indicator light 1 or with the branch containing indicator light 2, but not with both at the same time. Note that, in this example, it is impossible to open the circuit using the switch, as current flows in one branch of the circuit at all times.

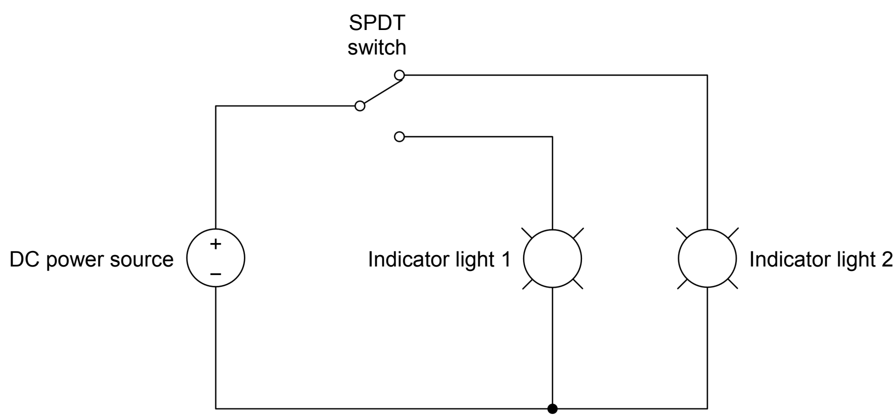


Figure 24. Circuit containing an SPDT switch.

Double-pole double-throw switch

A double-pole double-throw (DPDT) switch operates just as two SPDT switches actuated using the same mechanism. Figure 25 shows an example of a DPDT switch. As the figure shows, when the switch is in its upper position, current flows through indicator lights 1 and 3, while indicator lights 2 and 4 are off. On the other hand, when the switch is in its lower position, current flows through indicator lights 2 and 4, while indicator lights 1 and 3 are off. Therefore, just as in the circuit of Figure 24, it is impossible to open the circuit, as current flows in two branches of the circuit at all times.

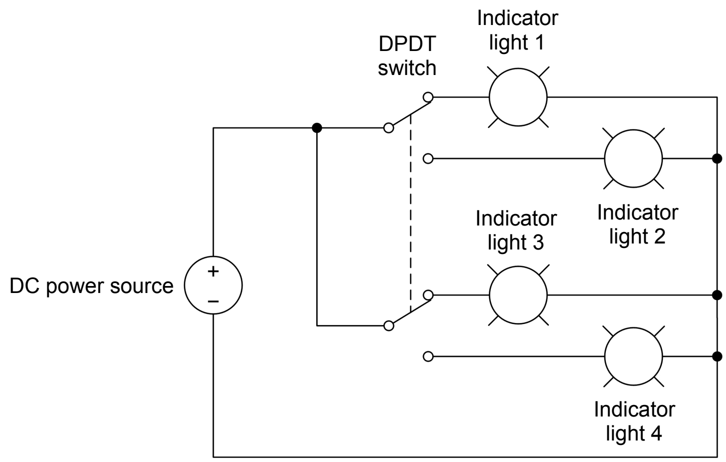
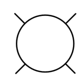


Figure 25. Circuit containing a DPDT switch.

Training system component: the indicator light

An indicator light is a basic type of component often found in electrical circuits. It basically consists of a lamp and is designed to produce light from electricity. The electrical diagram symbol for an indicator light is shown in Table 8.

Table 8. Indicator light symbol.

Component	Symbol
Indicator light	

There are different types of lamps, differentiated by the way each type produces light. The most common type is the incandescent lamp. In this type of lamp, light is produced by making current flow through the filament wire (usually a tungsten wire) in the lamp. As the wire heats due to the current flowing through it, it begins to glow. This phenomenon is called incandescence. Figure 26 shows a typical incandescent light bulb.

All three indicator lights in the AC/DC Training System are incandescent lamps. They have a nominal voltage of 24 V, which means that they are designed to operate with a voltage of 24 V applied to their terminals. Also, they have a power rating of 2 W, which means that they are best suited for applications requiring a 2 W light bulb.

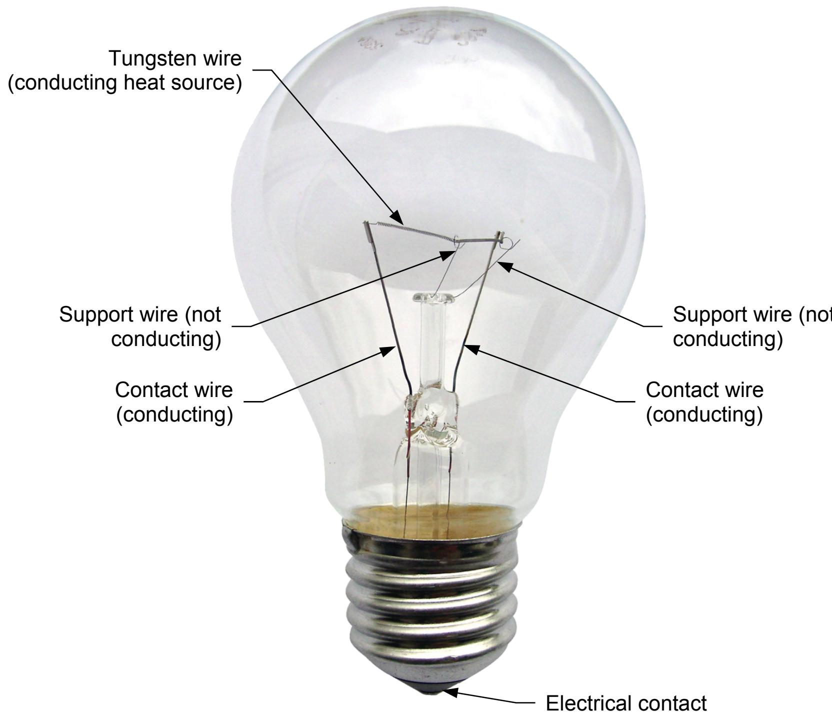


Figure 26. Typical incandescent light bulb (photo courtesy of KMJ).

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Set up
- Connection of dc power circuits containing different types of switches
  Knife switch. Normally open push-button switch. Normally closed push-button switch. Single-pole single-throw switch. Single-pole double-throw switch. Selector switch.
- NO push-button switch application: car horn circuit

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

Connection of dc power circuits containing different types of switches

In this section, you will connect different dc circuits, each containing a particular type of switch and a load. In each circuit, you will observe and record the operation of the load depending on the state of the switch.

Knife switch

4. Connect the equipment as shown in Figure 27. Figure 28 shows the corresponding wiring diagram. Make sure that the knife switch is in its open position, i.e., that the metal lever of the switch is not inserted in the slot.

In this exercise, the circuits that you need to connect are given as both a wiring diagram and a circuit diagram. This is done to allow familiarization with the use of circuit diagrams. Note, however, that in later exercises, only circuit diagrams are given.

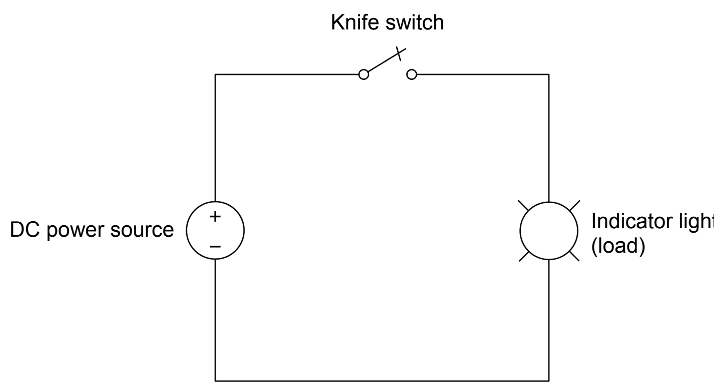


Figure 27. DC power source connected to an indicator light and a knife switch (circuit diagram).

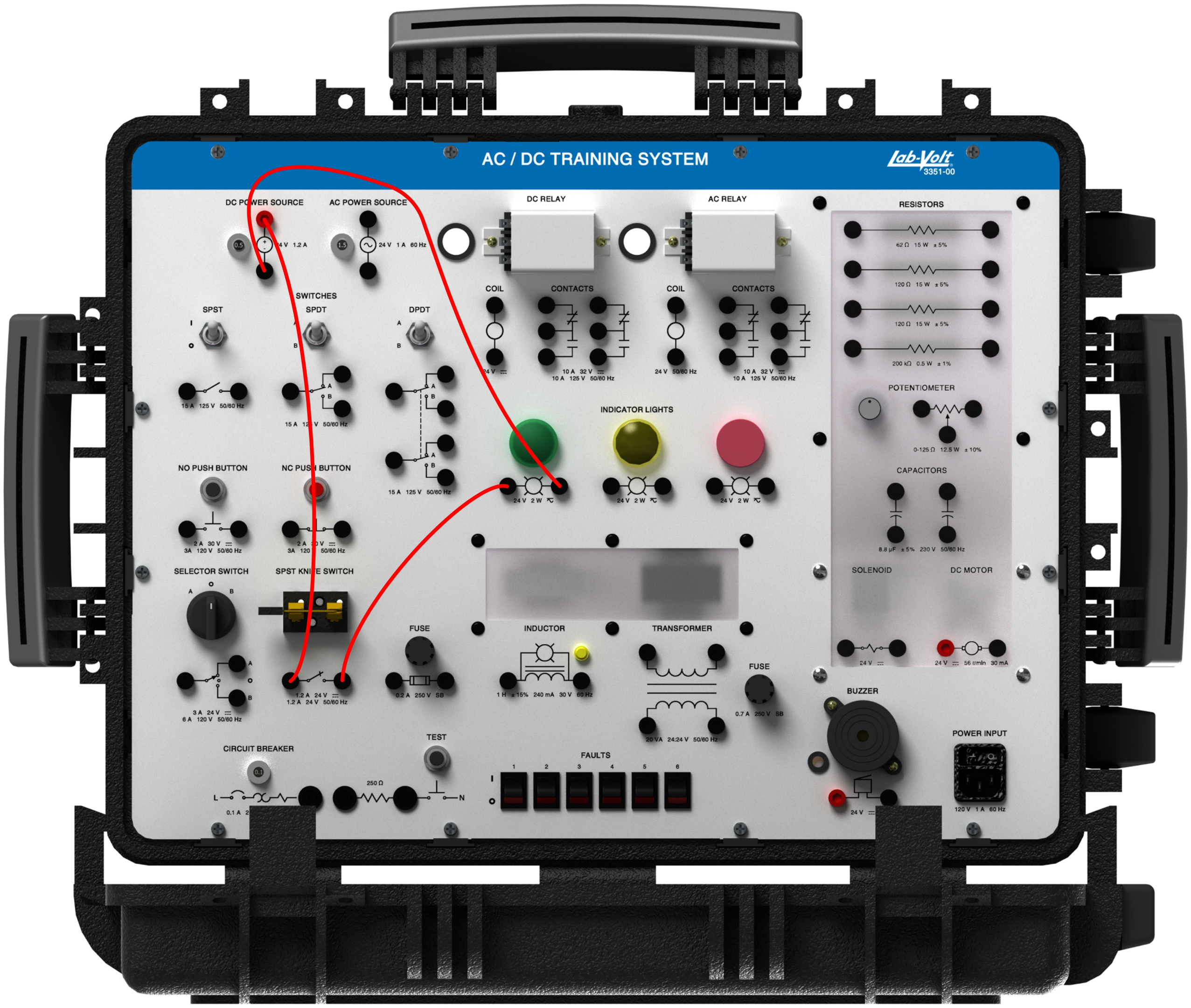


Figure 28. DC power source connected to an indicator light and a knife switch (wiring diagram).

5. Turn the dc power source on.

6. Set the knife switch to its closed state by inserting the metal lever of the switch in the slot, then set it back to its open state. Observe what happens as you do so. Repeat this step a few times.

7. Describe the indicator light operation depending on the state of the knife switch. Indicate for each state of the switch whether the resulting circuit is open or closed.

When the knife switch is in its open state (i.e., when the metal lever of the switch is not inserted in the slot), the indicator light is off. The resulting circuit is open. When the knife switch is in its closed state (i.e., when the metal lever of the switch is inserted in the slot), the indicator light is on. The resulting circuit is closed.

8. Turn the dc power source off.

Normally open push-button switch

9. In the circuit of Figure 27, replace the knife switch by a normally open (NO) push-button switch. This results in the following circuit. Figure 30 shows the corresponding wiring diagram.

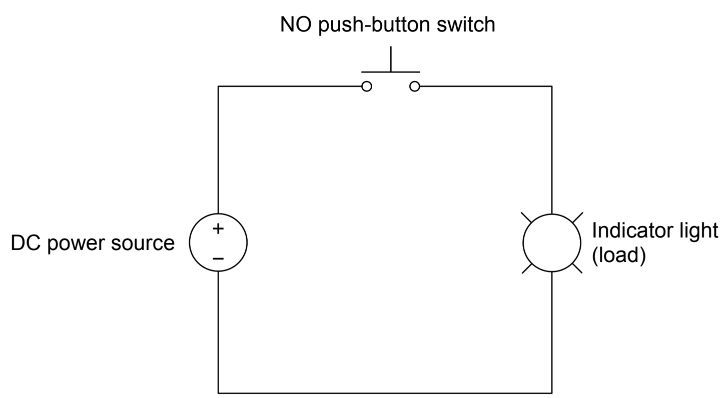


Figure 29. DC power source connected to an indicator light and an NO push-button switch (circuit diagram).

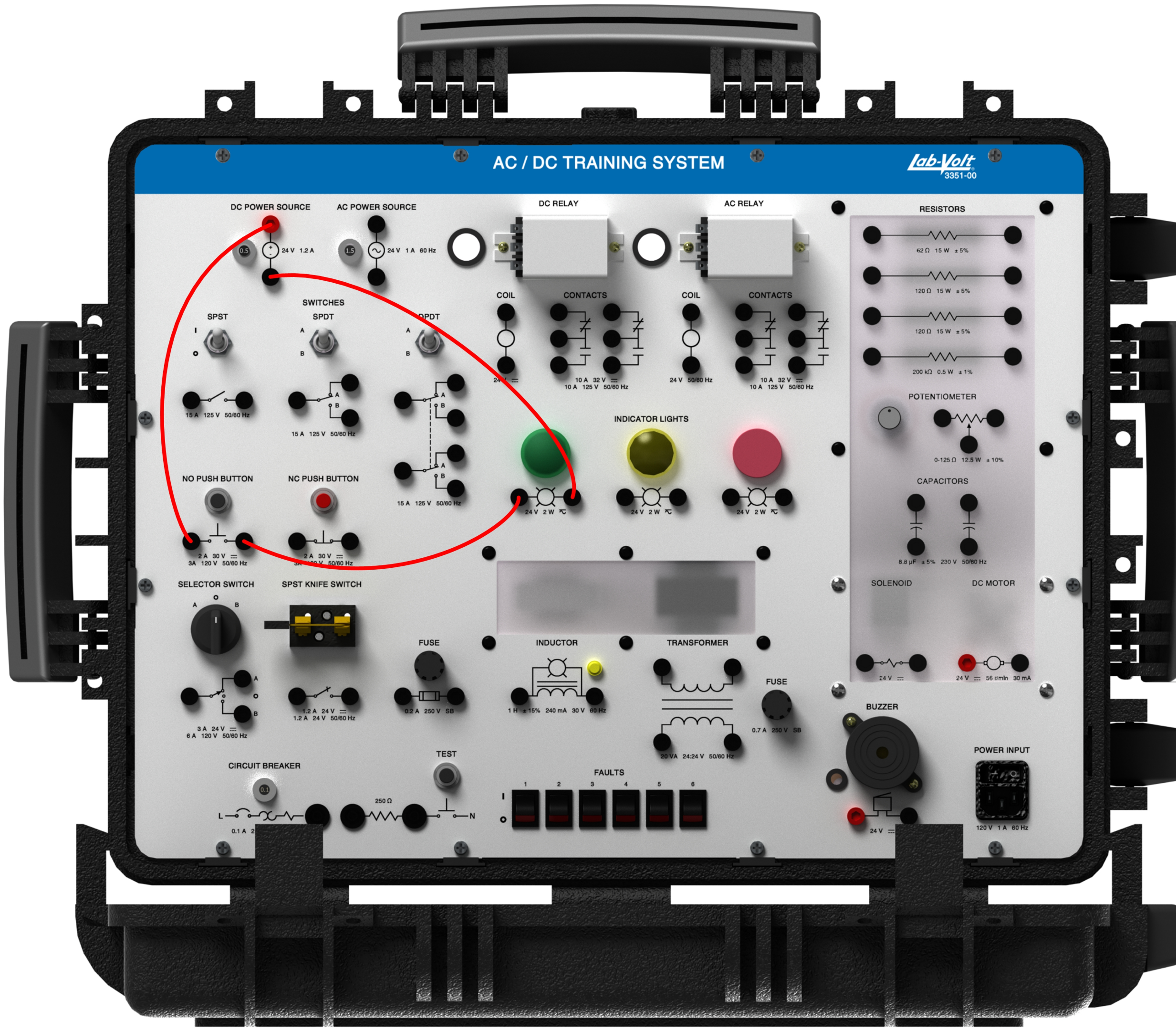


Figure 30. DC power source connected to an indicator light and an NO push-button switch (wiring diagram).

10. Turn the dc power source on.

11. Press on the push button for about five seconds, then release it. Observe what happens as you do so. Repeat this step a few times.

12. Describe the indicator light operation depending on the state of the NO push-button switch. Indicate for each state of the switch whether the resulting circuit is open or closed.

When the NO push-button switch is released, the indicator light is off. The resulting circuit is open. When the NO push-button switch is pressed, the indicator light is on. The resulting circuit is closed.

13. Turn the dc power source off.

Normally closed push-button switch

14. In the circuit of Figure 29, replace the NO push-button switch by a normally closed (NC) push-button switch. This results in the following circuit. Figure 32 shows the corresponding wiring diagram.

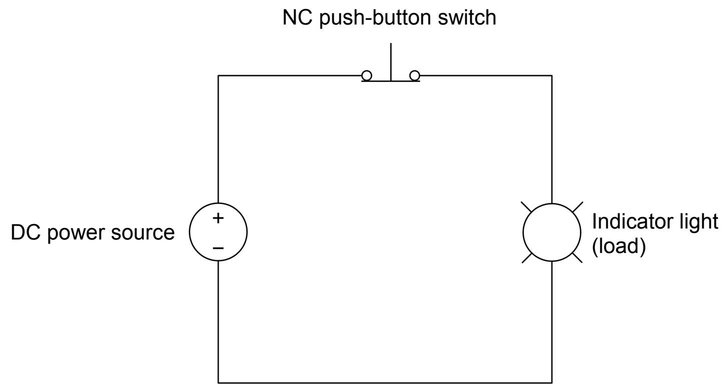


Figure 31. DC power source connected to an indicator light and an NC push-button switch (circuit diagram).

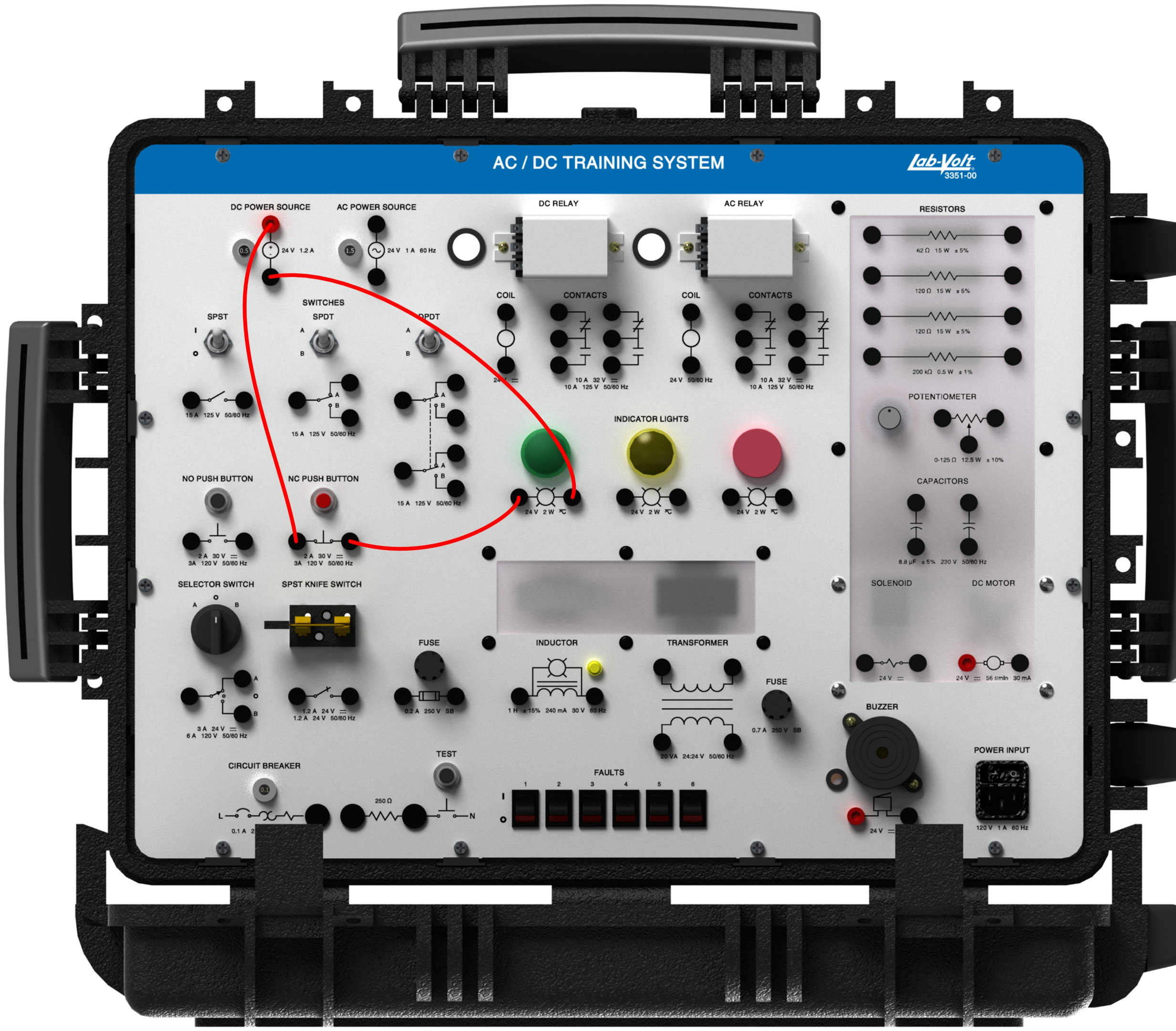


Figure 32. DC power source connected to an indicator light and an NC push-button switch (wiring diagram).

15. Turn the dc power source on.

16. Press on the push button for about five seconds, then release it. Observe what happens as you do so. Repeat this step a few times.

17. Describe the indicator light operation depending on the state of the NC push-button switch. Indicate for each state of the switch whether the resulting circuit is open or closed.

When the NC push-button switch is released, the indicator light is on. The resulting circuit is closed. When the NC push-button switch is pressed, the indicator light is off. The resulting circuit is open.

18. Explain briefly how the circuit in Figure 31 operates just as the circuit for the light in a refrigerator.

Just as in the circuit of Figure 31, when the door of a refrigerator is open, the NC push-button switch for the door is released. The resulting circuit is closed and therefore the refrigerator light is on. Conversely, when the door of the refrigerator is closed, the NC push-button switch for the door is pressed. The resulting circuit is open and therefore the refrigerator light is off.

19. Turn the dc power source off.

Single-pole single-throw switch

20. In the circuit of Figure 33, replace the NC push-button switch by a single-pole single-throw (SPST) switch. When you connect the SPST switch, make sure that it is in its open state. This results in the following circuit. Figure 34 shows the corresponding wiring diagram.

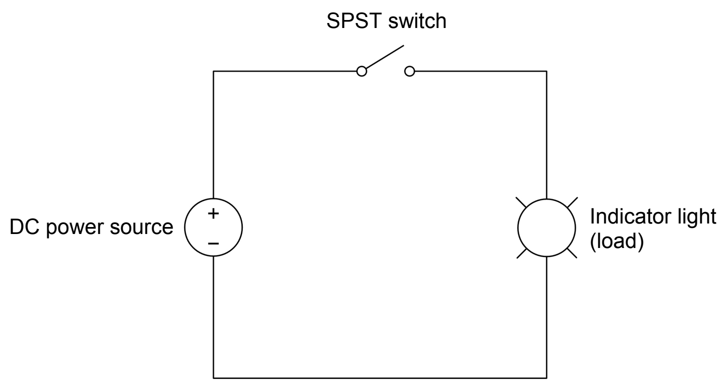


Figure 33. DC power source connected to an indicator light and an SPST switch (circuit diagram).

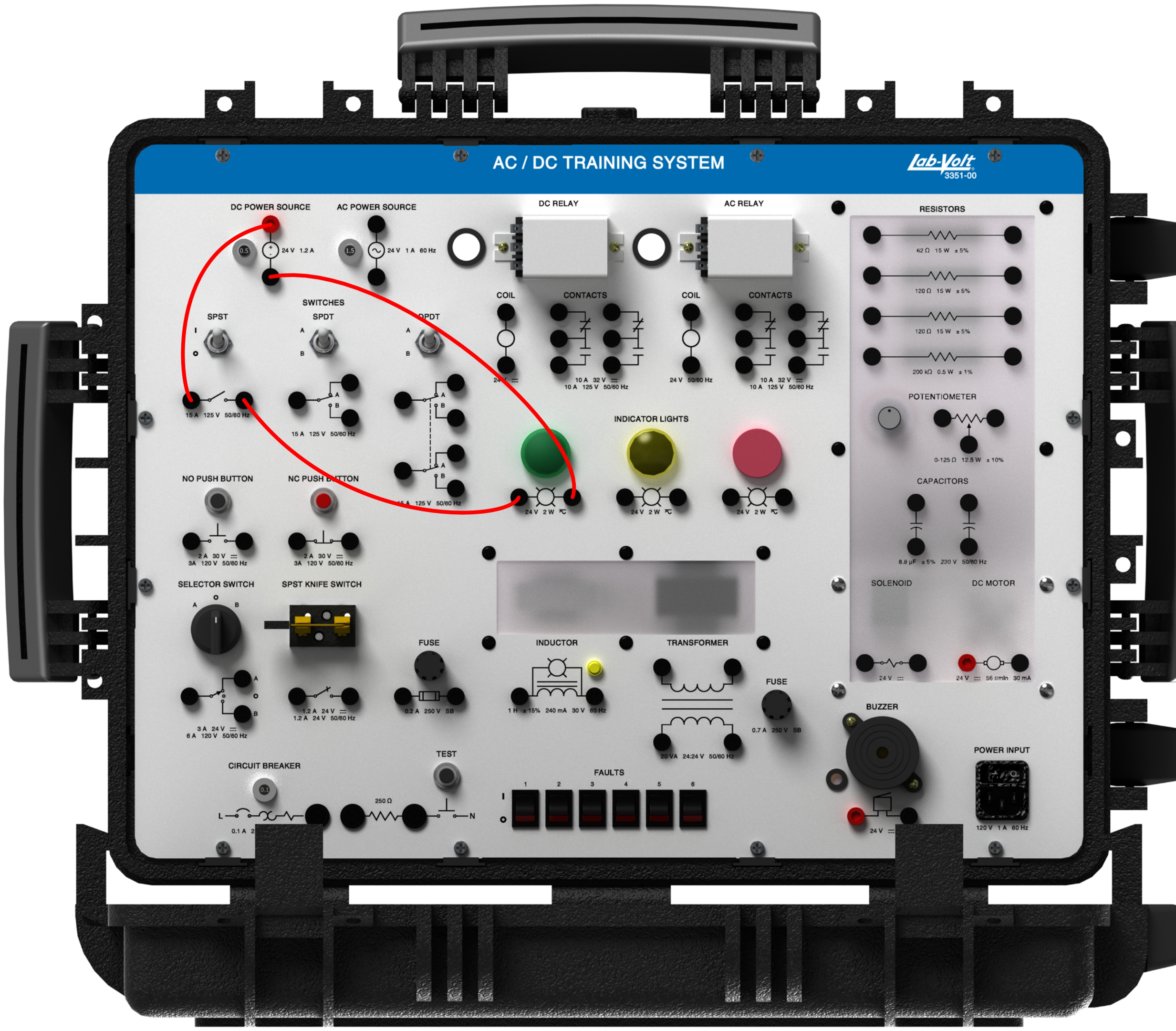


Figure 34. DC power source connected to an indicator light and an SPST switch (wiring diagram).

21. Turn the dc power source on.

22. Toggle the SPST switch between its open state and its closed state, waiting a few seconds before each switching. Observe what happens as you do so. Repeat this step a few times.

23. Describe the indicator light operation depending on the state of the SPST switch. Indicate for each state of the switch whether the resulting circuit is open or closed.

When the SPST switch is in its open state, the indicator light is off. The resulting circuit is open. When the SPST switch is in its closed state, the indicator light is on. The resulting circuit is closed.

24. Turn the dc power source off.

Single-pole double-throw switch

25. Connect the circuit shown in Figure 35. In this circuit, the SPST switch is replaced by a single-pole double-throw switch (SPDT) and a second branch (also containing an indicator light) is added. When you connect the SPDT switch, make sure that it is in position A. Figure 36 shows the corresponding wiring diagram.

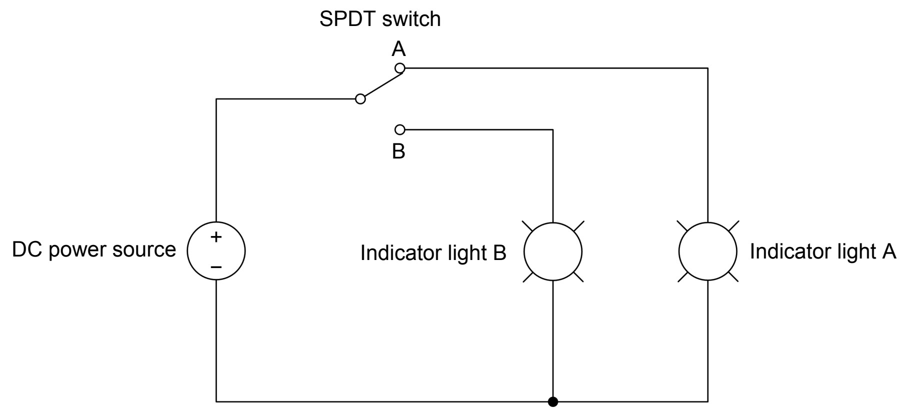


Figure 35. DC power source connected to two indicator lights and an SPDT switch (circuit diagram).

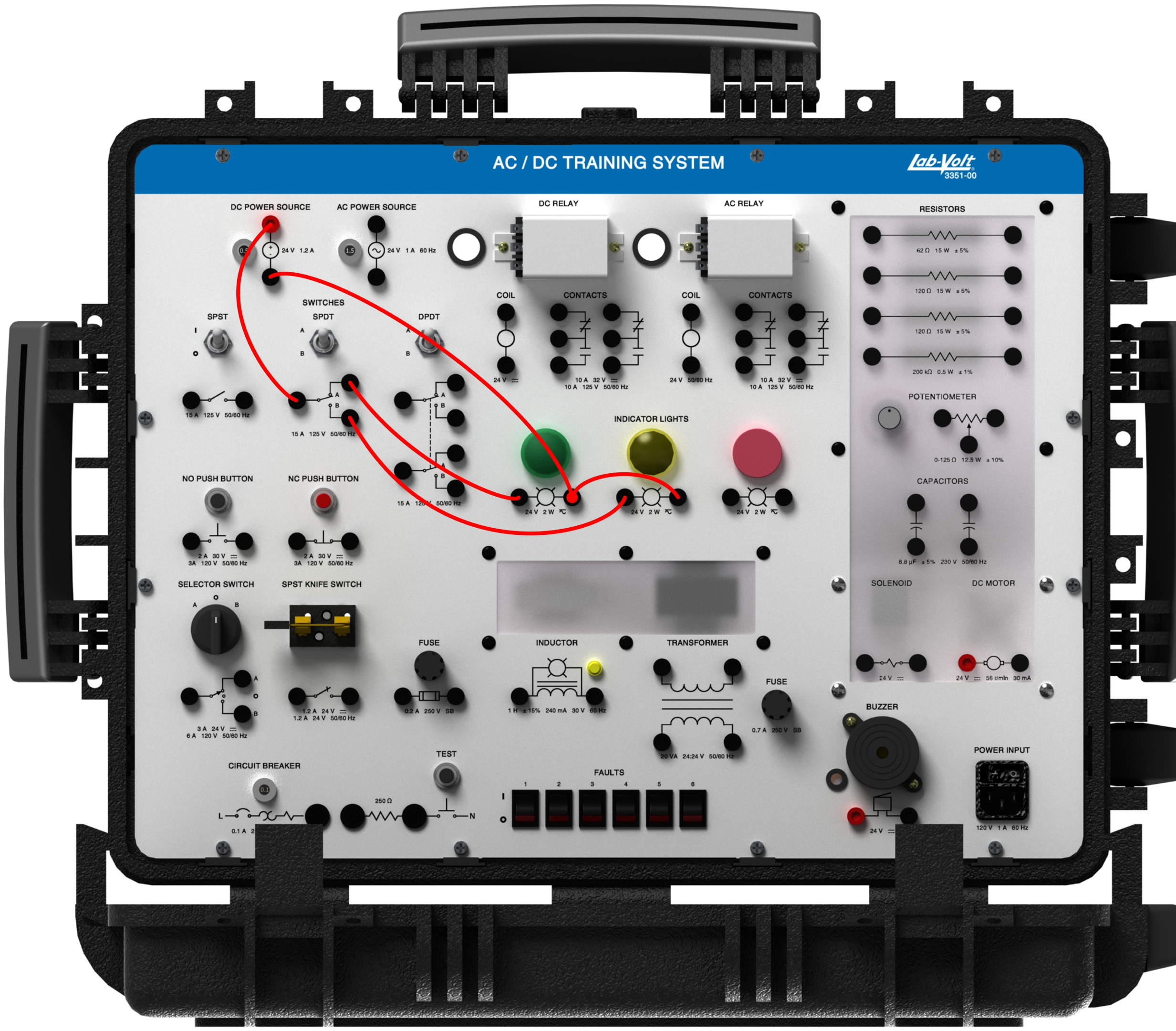


Figure 36. DC power source connected to two indicator lights and an SPDT switch (wiring diagram).

26. Turn the dc power source on.

27. Switch the SPDT switch back and forth between position A and position B, waiting a few seconds before each switching. Observe what happens as you do so.

28. Describe the operation of indicator lights A and B depending on the position of the SPDT switch.

When the SPDT switch is set to position A, indicator light A is on, while indicator light B is off. When the SPDT switch is set to position B, indicator light B is on, while indicator light A is off.

29. Turn the dc power source off.

Selector switch

30. Connect the circuit shown in Figure 37. In this circuit, the SPDT switch is replaced by a selector switch. When you connect the selector switch, make sure that it is in the O position. Figure 38 shows the corresponding wiring diagram.

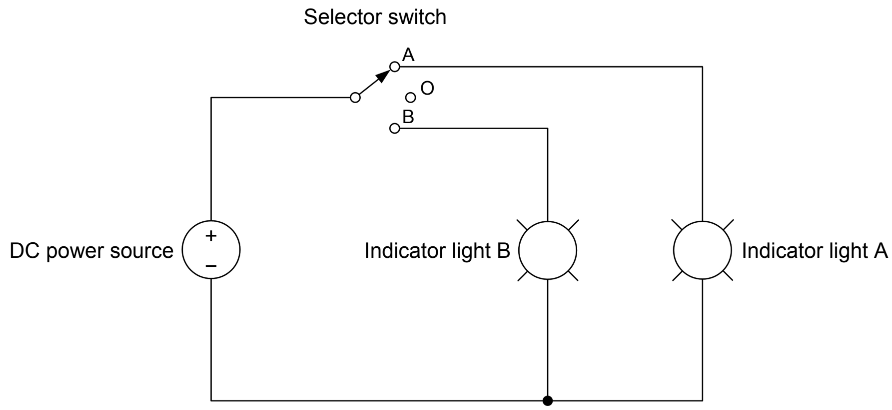


Figure 37. DC power source connected to two indicator lights and a selector switch (circuit diagram).

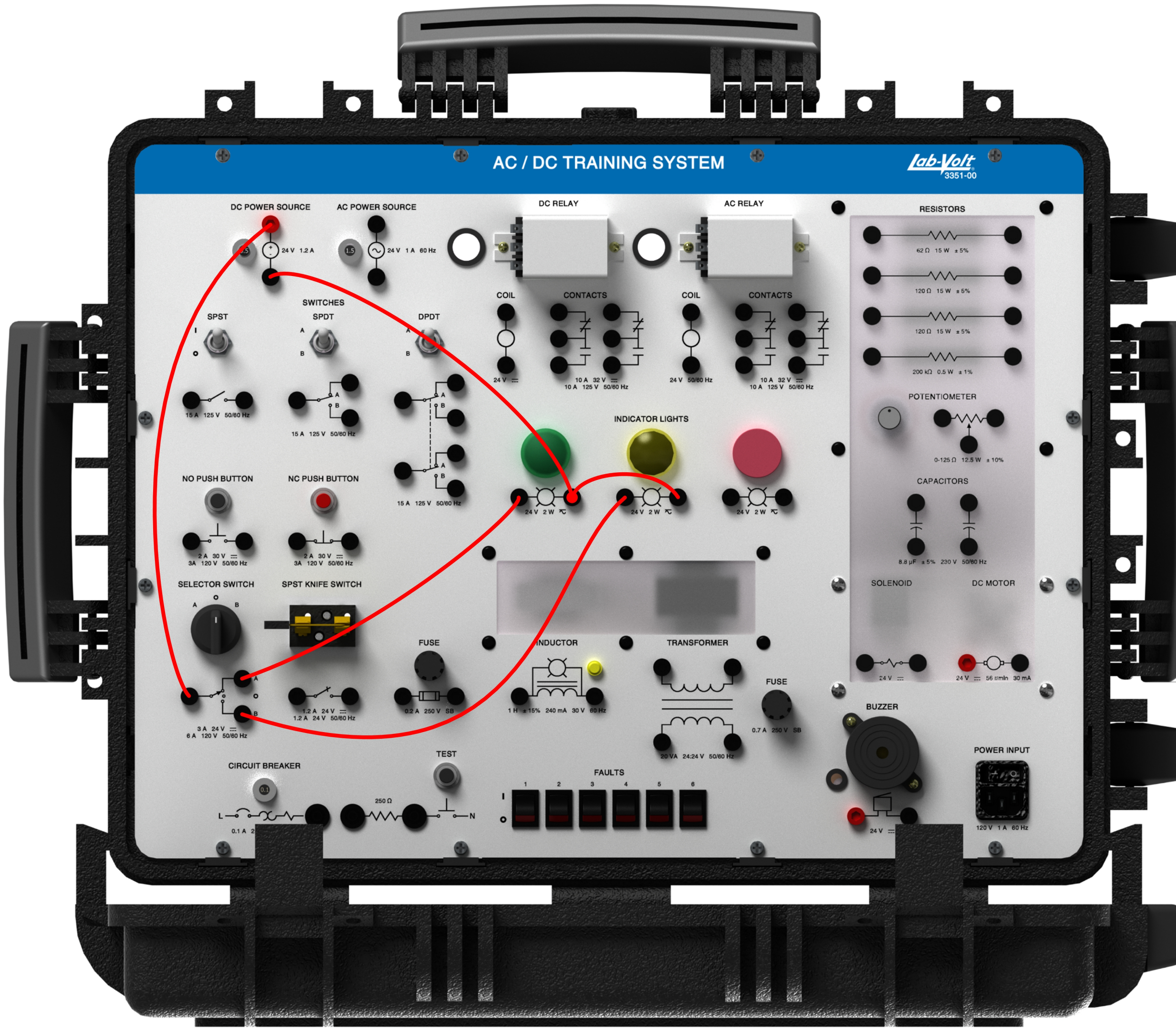


Figure 38. DC power source connected to two indicator lights and a selector switch (wiring diagram).

31. Turn the dc power source on.

32. Switch the selector switch back and forth between the A, B, and O positions, waiting a few seconds between each switching. Observe what happens as you do so.

33. Describe the operation of indicator lights A and B depending on the position of the selector switch.

When the selector switch is set to position A, indicator light A is on, while indicator light B is off. When the selector switch is set to position B, indicator light B is on, while indicator light A is off. Finally, when the selector switch is set to the O position, both indicator lights are off.

34. Turn the dc power source off.

NO push-button switch application: car horn circuit

In this section, you will connect a circuit representing the circuit in a car horn using an NO push-button switch and a buzzer. You will press and release the NO push button a few times and observe what happens. You will confirm that the circuit operates just as the circuit in a car horn.

35. Connect the circuit shown in Figure 39. This circuit represents the circuit in a car horn. Figure 40 shows the corresponding wiring diagram.

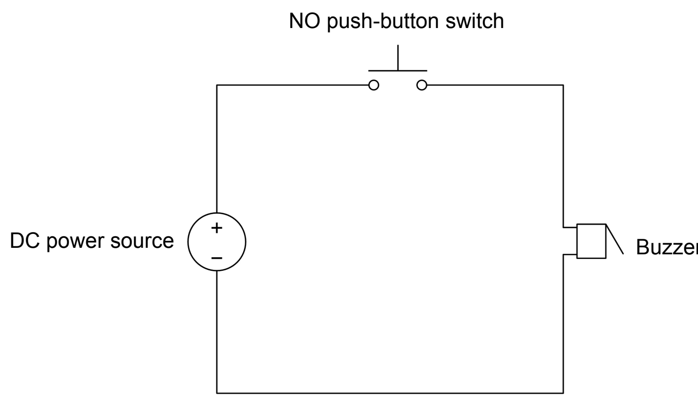


Figure 39. Car horn circuit (circuit diagram).

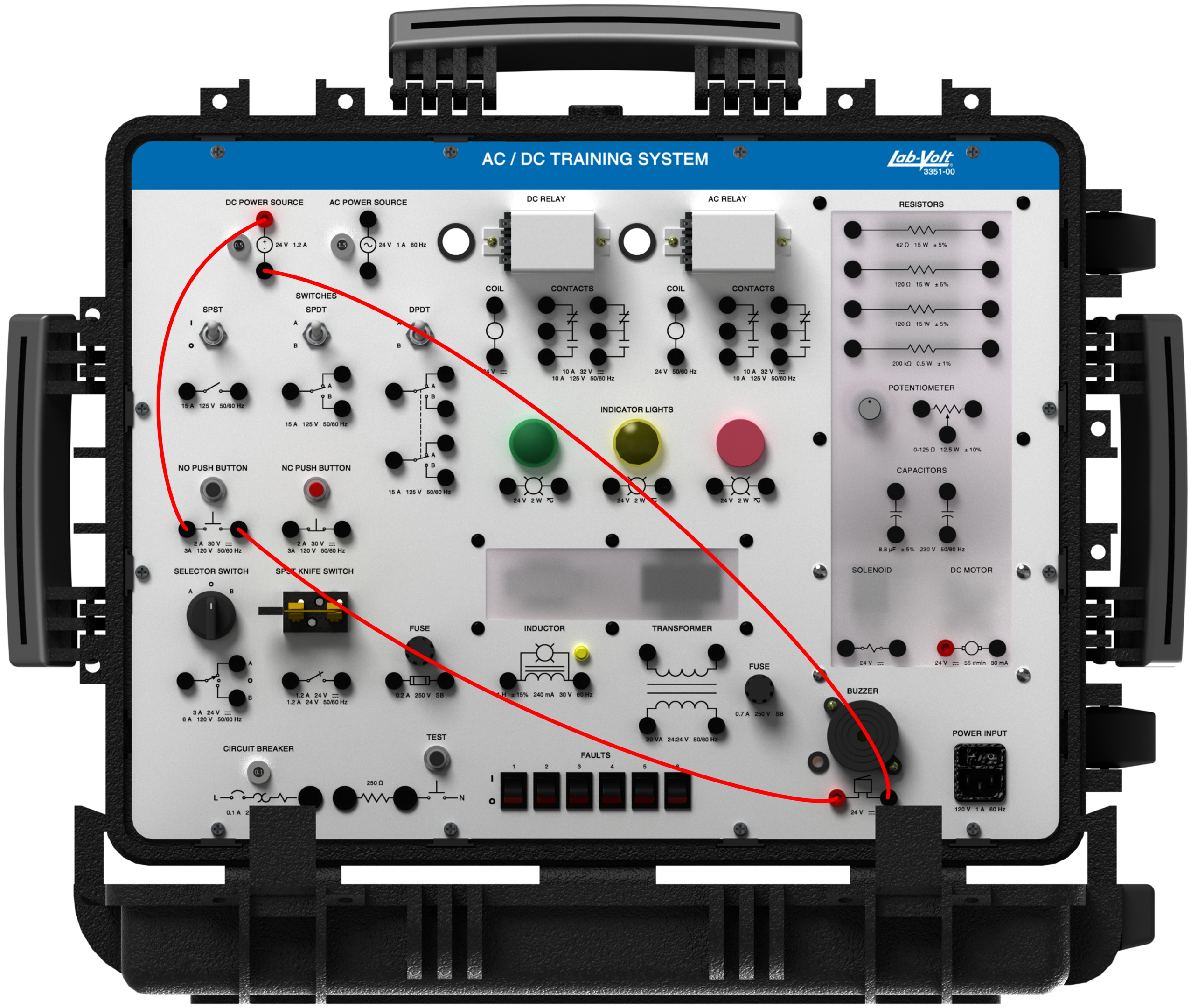


Figure 40. Car horn circuit (wiring diagram).

36. Turn the dc power source on.

37. Press on the push button for about five seconds, then release it. Observe what happens as you do so. Repeat this step a few times.

38. Describe the buzzer operation depending on the state of the NO push-button switch. Indicate for each state of the switch whether the resulting circuit is open or closed.

When the NO push-button switch is released, the buzzer is silent. The resulting circuit is open. When the NO push-button switch is pressed, the buzzer buzzes. The resulting circuit is closed.

Based on your observations, can you conclude that the circuit in Figure 39 operates just as the circuit in a car horn?

❑ Yes ❑ No

Yes

39. Turn the dc power source off.

40. 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 uses of switches in electrical circuits, as well as with the most common types of switches. You learned the possible configurations of switches in electrical circuits. You were introduced to a component of the AC/DC Training System: the indicator light.

REVIEW QUESTIONS

1. What is the main use of switches in electrical circuits?

   In electrical circuits, the main use of switches is to either prevent or allow the flow of current at a particular point of the circuit.

2. Name one example of a common toggle switch. What happens when this toggle switch is in its open state or its closed state?

   An example of a common toggle switch is the light switch. When a light switch is in its open state, the light is off. When it is in its closed state, the light is on.

3. Explain the operation of a normally open (NO) push-button switch. When is it open and when is it closed?

   A normally open (NO) push-button switch operates by pressing the push button. When the push button is released, the switch is open. When the push button is pressed, the switch is closed.

4. Explain the operation of a single-pole double throw (SPDT) switch.

   A single-pole double throw (SPDT) switch has two possible states and thus allows selection between two different circuit branches. When the switch is in one of its states, it allows connection to one branch of a circuit. When the switch is in its other state, it allows connection to another branch of the circuit.

5. Of what type are the indicator lights included in the AC/DC Training System? How does this type of lamp operate? Explain briefly.

The indicator lights included in the AC/DC Training System are incandescent lamps. In this type of lamp, light is produced by making current flow through the filament wire (usually a tungsten wire) in the lamp. As the wire heats due to the current flowing through it, it begins to glow.

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