DOCUMENT RESUME

ED 190 888 CE 026 573

TITLE Military Curricula for Vocational & Technical Education. Basic Electricity and Electronics Individualized Learning System. CANTRAC A-100-0010. Module Eleven: Capacitance. Study Booklet.

INSTITUTION Chief of Naval Education and Training Support, Pensacola, Fla.: Ohio State Univ., Columbus. National Center for Research in Vocational Education.

REPORT NO NAVEDTRA-34258-11

PUB DATE Mar 77

NOTE 199p.: For related documents see CE 026 560-593.

EDRS PRICE MF01/PC08 Plus Postage.

DESCRIPTORS *Electricity: *Electronics: Individualized Instruction: Learning Activities: Learning Modules: Postsecondary Education: Programed Instruction: *Technical Education

IDENTIFIERS *Capacitors: Military Curriculum Project

ABSTRACT

This individualized learning module on capacitance is one in a series of modules for a course in basic electricity and electronics. The course is one of a number of military-developed curriculum packages selected for adaptation to vocational instructional and curriculum development in a civilian setting. Seven lessons are included in the module: (1) The Capacitor, (2) Theory of Capacitance, (3) Total Capacitance, (4) Resistive Capacitance Time Constant, (5) Capacitive Reactance, (6) Phase and Power Relationships, and (7) Capacity Design Considerations. Each lesson follows a typical format including a lesson overview, a list of study resources, the lesson content, a programmed instruction section, and a lesson summary. (Progress checks are provided for each lesson in a separate document, CE 026 562.) (LRA)

NAVEDTRA 34258-11

CHIEF OF NAVAL EDUCATION AND TRAINING

MARCH 1977

Military Curricula for Vocational & Technical Education

BASIC ELECTRICITY AND ELECTRONICS INDIVIDUALIZED LEARNING SYSTEM.

MODULE ELEVEN. CAPACITANCE.

STUDY BOOKLET.

THE NATIONAL CENTER FOR RESEARCH IN VOCATIONAL EDUCATION
THE OHIO STATE UNIVERSITY

MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

Agriculture	Food Service
Aviation	Health
Building & Construction Trades	Heating & Air Conditioning
Clerical Occupations	Machine Shop
Communications	Management & Supervision
Drafting	Meteorology & Navigation
Electronics	Photography
Engine Mechanics	Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

EAST CENTRAL
Rebecca S. Douglass
Director
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Springfield, IL 62777
217/782-0759

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Airdustrial Park
Olympia, WA 98504
206/753-0879

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The National Center Mission Statement

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

- Generating knowledge through research
- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Installing educational programs and products
- Operating information systems and services
- Conducting leadership development and training programs

FOR FURTHER INFORMATION ABOUT
Military Curriculum Materials
WRITE OR CALL
Program Information Office
The National Center for Research in Vocational Education
The Ohio State University
1960 Kenny Road, Columbus, Ohio 43210
Telephone: 614/486-3655 or Toll Free 800/848-4815 within the continental U.S. (except Ohio)

THE NATIONAL CENTER
FOR RESEARCH IN VOCATIONAL EDUCATION

Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

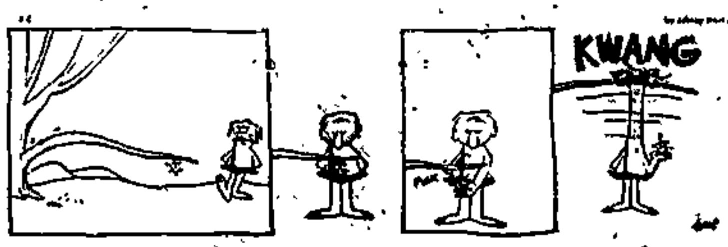
OVERVIEW

MODULE ELEVEN
CAPACITANCE

In this module you will learn about another circuit quantity, capacitance, and discover the effects of this component upon circuit current, voltage, and power. You will learn about the circuit component which makes use of this quantity and how it functions.

For you to more easily learn the above, this module has been divided into the following seven lessons:

TURN TO THE FOLLOWING PAGE AND BEGIN LESSON I.



If you don't know what it does don't fool with it!

BASIC ELECTRICITY AND ELECTRONICS

INDIVIDUALIZED LEARNING SYSTEM

MODULE ELEVEN

LESSON I

The Capacitor

Study Booklet

OVERVIEW
LESSON 1

The Capacitor

In this lesson you will study and learn about the following:

- -electrostatic field
- -what a capacitor is
- -what a capacitor does

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES

LESSON I

The Capacitor

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the fol

STUDY BOOKLET:

Lesson Narrative

Programmed Instruction

Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1b "Basic Electricity, Alternating Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D. C.: U.S. Government Printing Office, 1965.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON 1

The Capacitor

The Capacitor

By now you are familiar with every component in your power supply and the role each plays in the circuit except for the two capacitors.

An important concept in the understanding of capacitance is the electrostatic force field and its representation by electrostatic lines of force.

The Electrostatic Field

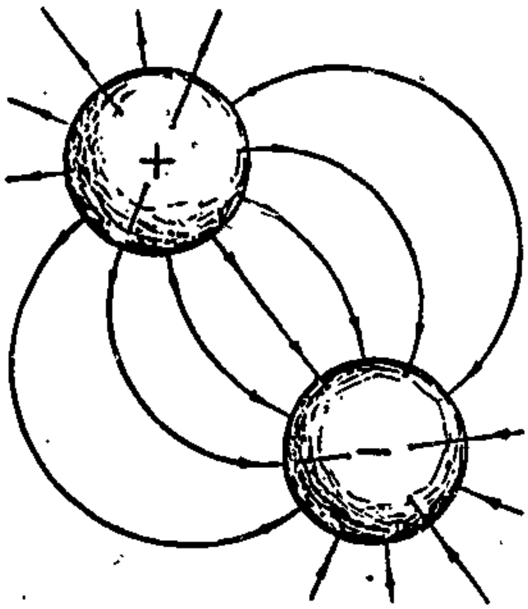
You already know that bodies having like charges repel each other and that bodies having unlike charges attract each other. A body that is deficient in electrons is designated as having a positive charge, while a body that has an excess of electrons is designated as having a negative charge.

The phenomenon of charge attraction or repulsion leads to the supposition that each charged body has around it an electrostatic field made up of invisible lines of force similar to lines of magnetic flux.

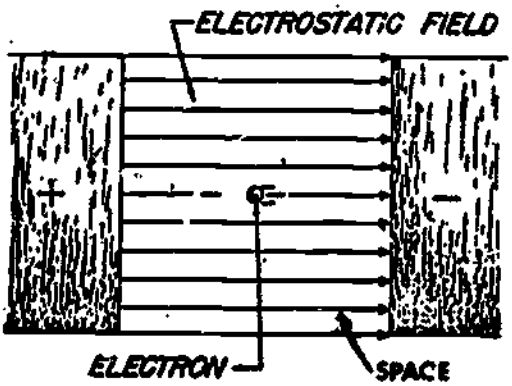
Electrostatic lines of force differ from magnetic lines of flux in two respects:

1. Electrostatic lines do <u>not</u> form closed loops (observe the illustration on the next page), whereas lines of magnetic flux do form closed loops.

2. Electrostatic lines are polarized from positive to negative, whereas magnetic flux lines are directed from the <u>N</u> to the <u>S</u> pole outside of the magnet.



The closer the charged bodies are to each other, the stronger is the force between them. The farther apart they move, the weaker the force becomes.

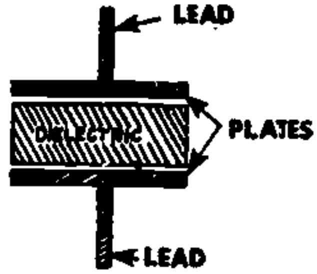


This illustration shows two charged metal plates, one negative, the other positive, and the electrostatic field between them polarized in the direction of the arrows.

If a free electron were placed in the center of the electrostatic field, because like charges repel, it would tend to be repelled by the negative plate. On the other hand, because unlike charges attract, it would be attracted to the positive plate; therefore, it would move in a direction opposite to the electrostatic field. (The direction of the field was defined more than a century ago when it was thought that positive charges were the current carriers.)

What a Capacitor Is

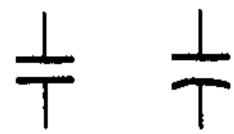
A capacitor consists of two conducting surfaces called plates which are separated by a nonconductor called the dielectric.



The dielectric between the two plates may be vacuum, air, waxed paper, ceramic, glass or any other nonconducting material through which electrons will not easily pass.

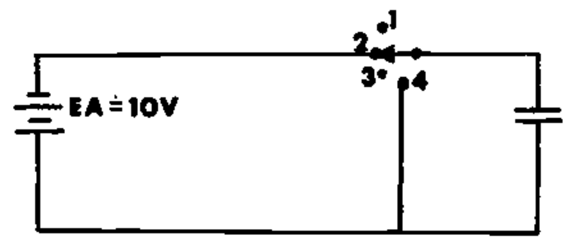
Schematic Symbol

The schematic symbol for a capacitor represents the leads connected to the two plates and separated by space.



What a Capacitor Does

A capacitor stores energy between its plates when the plates are charged. To show how this energy is stored, let's examine the action in this circuit:



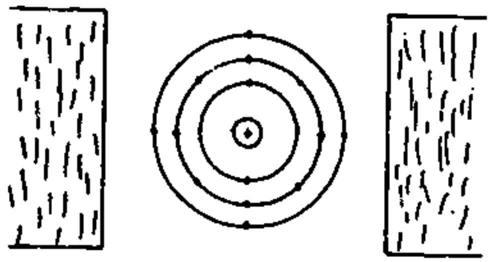
When the switch is first moved to position 2, the source will move electrons around the circuit from the capacitor's lower plate to the upper plate. Current cannot flow through the dielectric so the electrons pile up on the top plate and a difference of potential builds up between the two plates. This voltage on the capacitor will rise to equal the source voltage, and current flow will then stop. An electrostatic (force) field is established between the plates by the difference of potential and energy is stored in this field.

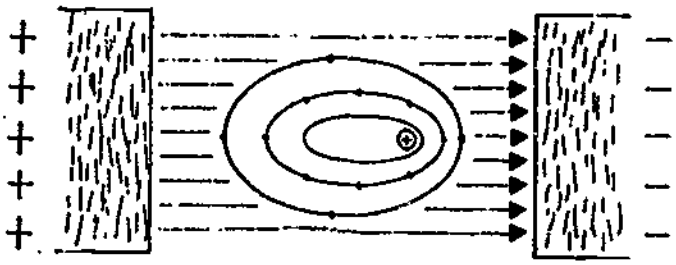
Moving the switch to position 3 after the capacitor is charged will cause no change in the circuit conditions for the excess electrons on the top plate of the capacitor still have no place they can go. The capacitor will still have 10 volts difference of potential between its plates.

If the switch is now placed in position 4, a path is created for the electrons to travel from the top plate to the bottom, and the force of attraction and repulsion (electrostatic field) will make them move until the force drops to 0. At this point, all the stored energy has been returned to the circuit.

You saw earlier how a free electron placed in an electrostatic field is attracted to the positively charged plate. Now let's see what happens to the atoms of a dielectric material in a capacitor.

This illustration shows one atom of the non-conducting dielectric between the plates of an uncharged capacitor. Remember that the electrons of an insulator are not free to leave the atom, they are tightly bound electrons.





The illustration shows what happens to an atom in the dielectric when the capacitor is charged. Because the electrons tend to be attracted to the positive plate and repelled by the negative plate, but are not free to leave the atom, the orbital shells are stretched toward the attracting plate, thus elongating their orbits and distorting the shape of the atom. In this way some dielectric materials increase the capacitor's ability to store a charge. The energy required to distort the electron orbits is transferred from the source to the electrons. Because energy can never be created nor destroyed, as long as there is a charge on the plates the electron orbits remain distorted.

You can think of the displaced electrons as being like a spring which is stretched. As long as a spring is held in a state of tension. it stores energy. Similarly, when the charges of the plates neutralize in the capacitor, the electrons spring back to their normal position; the energy which was stored returns to the circuit.

A capacitor, then, is an electrical device consisting of two conducting plates separated by a nonconducting material; it is a device that stores electrical energy in its electrostatic field.

A capacitor's ability to store energy makes it dangerous to the repairman, for the charge may be retained even after the circuit is de-energized. The only way you can be certain a capacitor does not have a charge is to discharge it, preferably not through your body! Review the safety precautions in Module Zero before you put your hands in any circuit containing capacitors.

Electrons do not flow through the nonconducting dielectric in a capacitor. However, electrons can be forced to move through a non-conductor if enough force is applied. It is conceivable, then, that if you apply a great enough voltage, you can force the bound electrons of the dielectric to break loose and move through a capacitor. If the voltage rating of a capacitor is exceeded, it destroys the capacitor's ability to store energy, thus destroying its purpose.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON I

The Capacitor

TEST FRAMES ARE 8 AND 27. AS BEFORE, GO FIRST TO TEST FRAME 8 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

---

1. Recall that like charges ____________ (repel/attract) and unlike charges ____________ (repel/attract).

- -

(repel; attract)

---

2. This principle is put to use by the components in your power supply called capacitors. These components are cylindrical in shape, and larger than the resistors.

   The capacitors are located between what terminals in your power supply?

   ____ a. T1 - T2
   ____ b. T2 - T7
   ____ c. T2 - T3
   ____ d. T3 - T7

- -

(b. T2 - T7; d. T3 - T7)

---

3. An electrical charge at rest is known as static electricity. From this you might infer that a capacitor works on the principle of:

   ____ a. electromagnetic lines of force.
   ____ b. electrostatic lines of force.

- -

(b. electrostatic lines of force)

---

4. The forces of attraction and repulsion are caused by electrostatic lines of force that surround every charged body.

Which of the following bodies has an electrostatic field?

____ a. (+-)

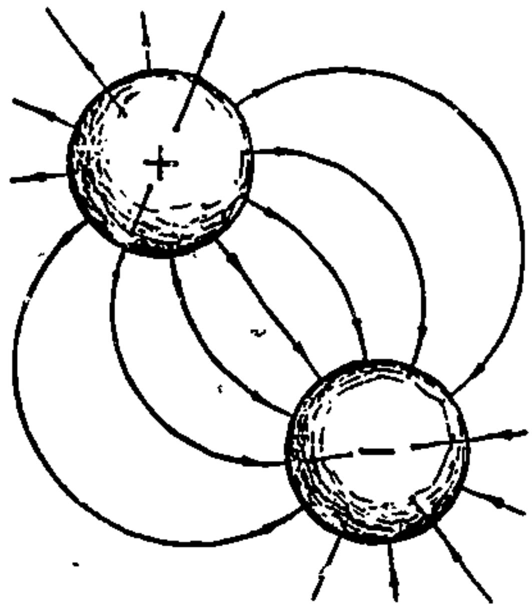
____ b. (++)

____ c. (--)

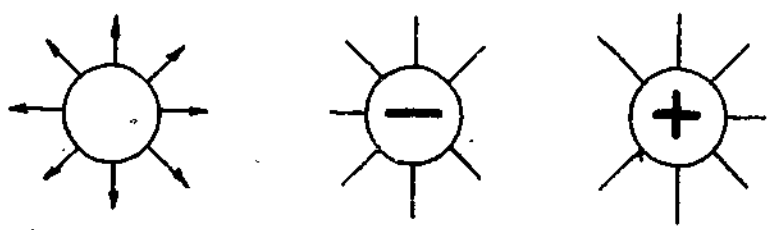
- -

(b; c)

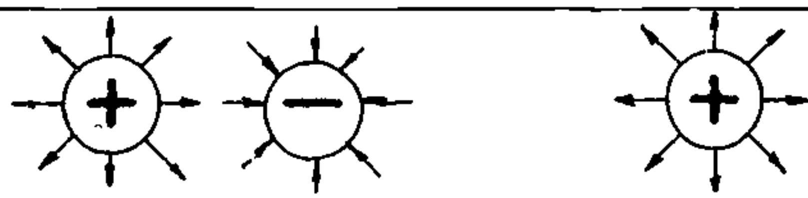
5. For simplicity, and by agreement, the electrostatic field is represented schematically by lines which are said to leave a positive charge and enter a negative charge.



Complete each item below by showing the sign of each charge or the direction of the field.



A. B. C.



A. B. C.

6. Electrostatic lines of force differ from magnetic lines of flux in that they do not form closed loops.

Check the correct statement(s).

____ a. Electrostatic lines are continuous loops between negative and positive.
____ b. Electrostatic lines do not leave the negative body and enter the positive body.
____ c. Electrostatic lines of force travel from negative to positive by charged bodies in an infinite direction.

(b) Electrostatic lines do not leave the negative body and enter the positive body.

7. Electrostatic lines of force are basically different from magnetic lines of flux in another respect in that they do not have north and south poles.

Electrostatic lines of force:

____ a. can be considered north and south.
____ b. leave a north pole and enter a south pole.
____ c. leave a south pole and enter a north pole.
____ d. are not considered north and south.

(d) are not considered north and south.

8. Electrostatic lines of force:

____ a. are invisible.
____ b. form closed loops.
____ c. are directed from negative to positive.
____ d. move from N to S.
____ e. are directed from positive to negative.

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

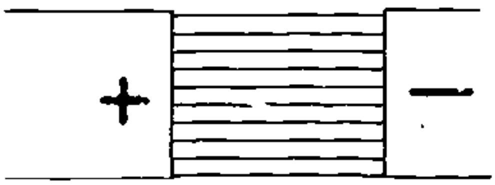
ANSWERS - TEST FRAME 8

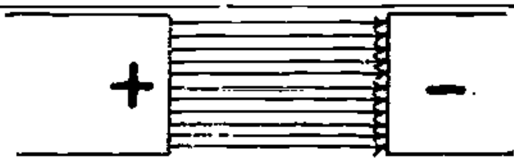
a. are invisible.

e. are directed from positive to negative.

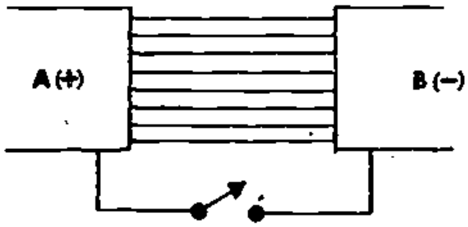
IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO TO TEST FRAME 27. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 8 AGAIN.

9. An electrostatic field can be formed between two pieces of conducting material separated by a nonconductor. Show with arrows the direction of the electrostatic lines in this sketch.





10. Energy may be stored in an electrostatic field like that of frame 9, for the excess electrons on the right-hand piece of metal (plate) will try to move to the left-hand plate because of the attraction between positive and negative. If a conducting path is placed between the plates, the energy will be returned to the circuit.



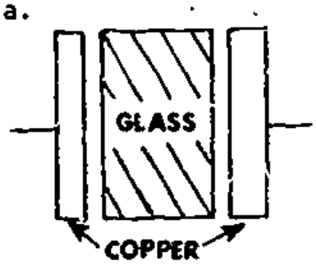
Electrons will move from ____________ when the switch is closed.
A to B/B to A

(B to A)

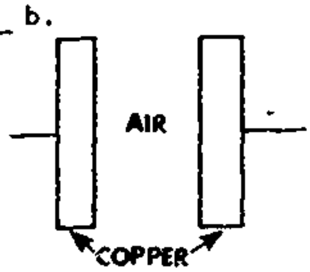
11. The ability of this device to store energy may be increased by placing a nonconducting solid between the plates in place of air or a vacuum. You will see why this is so in the following frames.

Which of these units will be able to store more energy in the electrostatic field?

____ a.



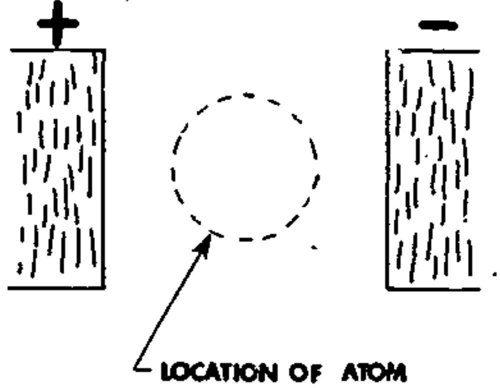
____ b.



(a)

23

12. If an atom of a nonconducting material is placed in the center of an electrostatic field, its electrons will not leave the atom as readily as those of an atom of a conducting material; however, they will be affected by the force of the field.



With the two bodies charged as shown in the preceding illustration, the orbital electrons are:

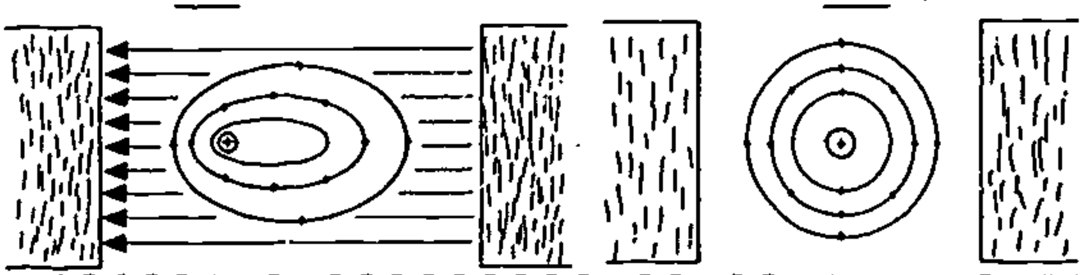
____ a. attracted toward the positive body.
____ b. not affected at all.
____ c. attracted toward the negative body.

(a) attracted toward the positive body

13. When a nonconducting solid is placed between two bodies with opposite charges, the electrostatic field stretches the orbits of its bound electrons, but normally does not dislodge the electrons from their orbits.

Which of the following illustrations shows an atom of a nonconducting material between two charged bodies?

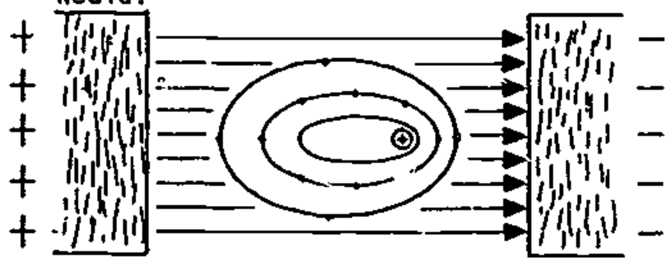
____ a. ____ b.



(a)

14. We can relate this concept to the stretching of a spring. As long as you exert a force, the spring remains stretched; as soon as you let go, the spring snaps back.

If we were to neutralize the charges in the diagram, the electrons would:



____ a. dislodge from the atom.
____ b. stay where they are.
____ c. go back to circular orbits.

- -

(c) go back to circular orbits

15. The device used to store energy by virtue of an electrostatic field is called a <u>capacitor</u>.

A capacitor stores electrical energy in a/an:

____ a. magnetic field.
____ b. electrostatic field.
____ c. static field.

- -

(b) electrostatic field

16. A capacitor consists of two conducting surfaces called <u>plates</u> that have wires connected to them. The plates are separated by a nonconductor called the <u>dielectric</u>.

A capacitor physically consists of:

____ a. plates, leads, conductors.
____ b. leads, plates, iron.
____ c. dielectric, plates, conductors.
____ d. conductors, leads, dielectric.

- -

(c) dielectric, plates, conductors.

17. The dielectric between the two plates may be vacuum, air, paper, glass, or any other nonconducting material through which electrons do not easily pass.

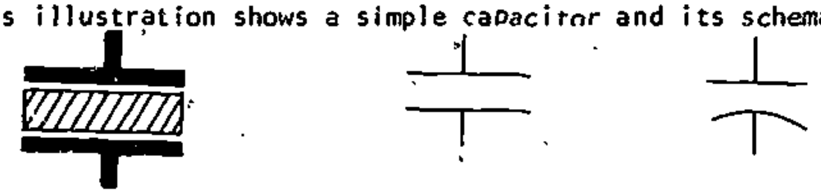
The best dielectric material is:

____ a. iron.
____ b. ceramic.
____ c. copper.
____ d. silver.

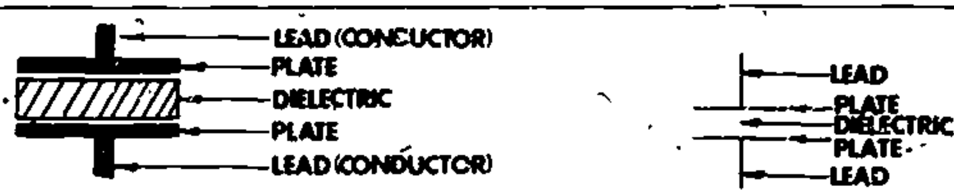
(b) ceramic

---

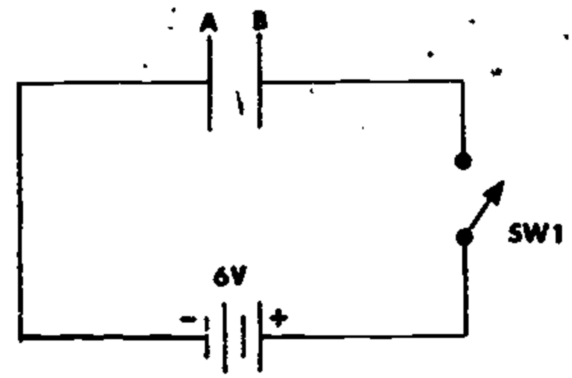
18. This illustration shows a simple capacitor and its schematic symbol



Label the diagrams below.



19.



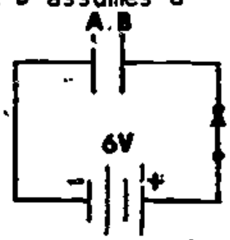
If the two plates of the capacitor have no charge on them and SW1 is closed, electrons are:

_____ a. pulled off Plate A.
_____ b. pulled off Plate B.
_____ c. forced onto Plate A.
_____ d. forced onto Plate B.

- -

(b. pulled off Plate B; c. forced onto Plate A.)

20. Plate A now assumes a negative charge and Plate B assumes a positive charge.



Check the correct statement(s).

_____ a. A difference of potential exists between the two plates.
_____ b. Electrostatic lines of force are directed from Plate A to Plate B.
_____ c. Electrostatic lines of force are directed from Plate B to Plate A.

- -

(a. A difference of potential exists between the two plates; c. Electrostatic lines of force are directed from Plate B to Plate A.)

21. Recall that the dielectric material of a capacitor is a nonconductor.

Check the correct statement(s).

____ a. There is normal current flow through a capacitor.
____ b. The bound electrons in the dielectric stretch their orbits like a spring when the capacitor is charged.
____ c. No current is supposed to flow through a capacitor.

(b. the bound electrons in the dielectric stretch their orbits like a spring when the capacitor is charged; c. No current is supposed to flow through a capacitor.)

22. Because energy cannot be destroyed, a capacitor stores the energy required of the charge in its electrostatic field.

As long as there is a difference in potential between the plates of a capacitor, it keeps the energy in its:

____ a. dielectric.
____ b. plates.
____ c. electrostatic field.
____ d. leads.

(c) electrostatic field

23. A capacitor is capable of storing and retaining an electrical charge, because of this it represents a potential danger even after the circuit is de-energized.

After a capacitive circuit has been de-energized there may still be an excess of electrons on the __________ plate and a deficiency of electrons on the __________ plate of the capacitor.

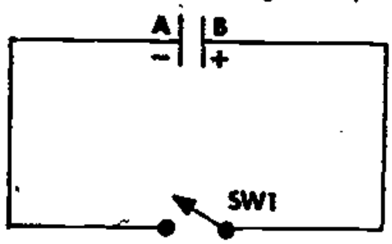
(negative, positive)

24. Before attempting any repairs or measurements in a de-energized capacitive circuit all residual charge should be removed from the capacitor. To do this a conducting path is placed across the plates of the capacitor allowing movement of electrons between the plates and thus neutralizing any remaining charge.

(Go to next frame.)

25. If the charge across the plates is allowed to neutralize, the energy which was stored is released and returned to the circuit.

If SW1 was closed across this charged capacitor:



____ a. the excess electrons on Plate A would move to Plate B through the capacitor.
____ b. the excess electrons on Plate B would move to Plate A through the capacitor.
____ c. the excess electrons on Plate A would move to Plate B through the external circuit.
____ d. the excess electrons on Plate B would move to Plate A through the external circuit.

(c) the excess electrons on Plate A would move to Plate B through the external circuit.

26. If enough force is applied to a capacitor, you can force the bound electrons of the dielectric to break loose and move through a capacitor.

If too high a voltage is applied to a capacitor, it:

____ a. allows current flow through it.
____ b. is not able to store a charge.
____ c. stores a greater charge.

(a. allows current flow through it; b. is not able to store a charge)

27. Check the statement(s) about a charged capacitor that is (are) true.

____ a. forces electrons through the dielectric from its negative plate to its positive plate.

____ b. has a difference of potential across its plates.

____ c. stores energy on the plates.

____ d. stores energy in electrostatic field.

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 27

b. Has a difference of potential across its plates.

d. Stores energy in electrostatic field.

IF ANY OF YOUR ANSWERS IS INCORRECT, GO BACK TO FRAME 9 AND TAKE THE PROGRAMMED SEQUENCE.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

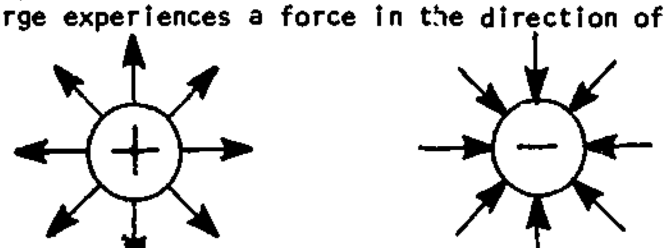
SUMMARY
LESSON I

The Capacitor

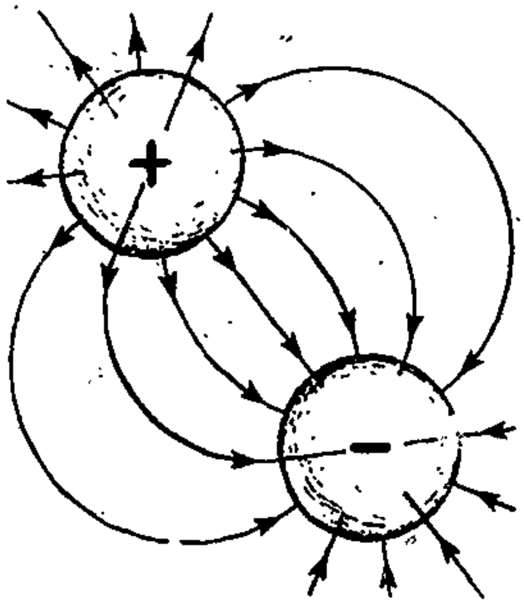
Basically, capacitors store electrical energy. Imagine that you have a body with an excess of positive charges and you gradually move a negatively charged body toward it. At some distance separating the two bodies, you will notice an attractive force between the two unlike charges and that this attraction increases as you bring them closer together. On the other hand, if you were to bring a second positively charged body near the first positive charge, at some distance separating the two like charges, you would notice a repelling force that increases as the separation decreases.

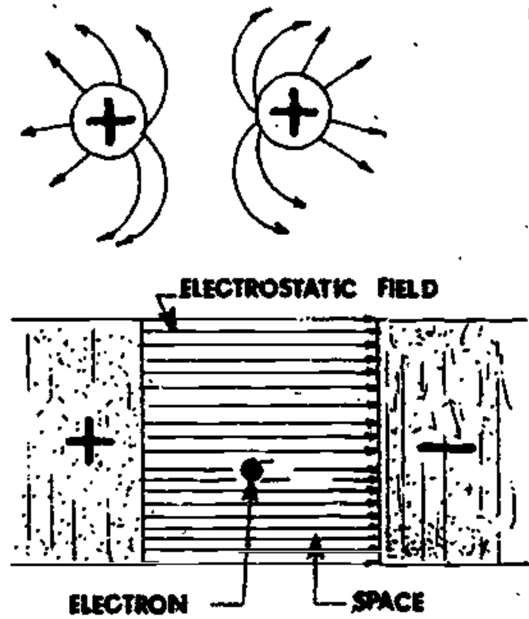
An isolated charged body, such as the fixed positive charge in the example, has surrounding it a force field which interacts with any other charge brought within its field. The strength of this force field at any point depends on the magnitude of the body's charge and the distance from the body. This field can be represented by invisible lines of force and is called the electrostatic field of a charged body. By definition, neutral bodies have no electrostatic fields.

The direction of the field, and therefore, the direction of the lines of force, is defined as leaving a positive charge and entering a negative charge as indicated in the illustration on the next page. The direction of the field was defined more than a century ago when it was thought that positive charges were the current carriers. Hence a positive charge experiences a force in the direction of the lines of force.



A free electron placed in the field of a charged body, therefore, moves in a direction against the electrostatic field. When two or more charged bodies are placed sufficiently close to one another that their electrostatic fields overlap, the direction and magnitude of the resulting lines of force are changed. The following examples illustrate like- and unlike-charged spheres and opposite-charged parallel plates.



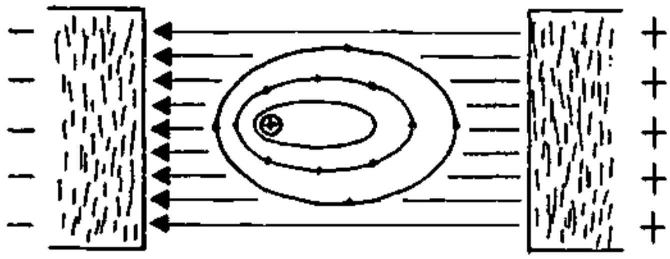


An illustrative exercise is to imagine you have a free electron and you "drop" it at different locations in each of the three fields illustrated. Remembering that electrons move against lines of force, find the place that the electron would come to rest.

A capacitor consists of two conducting plates separated by an insulator called the dielectric. Air is a common dielectric since dry air is a non-conductor. Mica, ceramic, and glass are other common dielectric materials.

A capacitor stores electrical energy in the electrostatic field resulting from opposite charges on its plates. A capacitor placed in a circuit with a voltage source has charges of opposite polarities on its two plates as a result of electron flow. When the magnitude of the charge on the capacitor equals the voltage source, current flow ceases. The charged capacitor, and resulting electrostatic field, is storing the electrical energy developed by the voltage source. Capacitors in a circuit must be treated carefully, for you can never be sure a capacitor is not charged unless you short its plates together. Review safety precautions in Module Zero before working on any circuit containing capacitors. By shorting the capacitor plates with a conductor, current flows, the plate charge goes to zero, and the electric field goes to zero. Hence, the stored electrical energy is released and returned to the circuit.

Since the insulating dielectric is matter composed of atoms and molecules, the tightly-bound charged particles in an atom, namely electrons and protons, are displaced from their equilibrium positions. Therefore, you have a distortion of the atomic configuration under the influence of the electrostatic force field:



In case of material dielectrics, additional energy is stored by distorting the atomic orbits from normal.

The positively charged nucleus is attracted to the negative plate, while the orbital electrons are attracted toward the positive plate.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.


ACCIDENTS
don't just happen—
THEY ARE CAUSED!

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE ELEVEN

LESSON II

Theory of Capacitance

Study Booklet

OVERVIEW
LESSON II

Theory of Capacitance

In this lesson you will study and learn about the following:

- -definition of capacitance
- -measuring capacitance
- -charging the capacitor
- -discharging the capacitor
- -factors affecting capacitance

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON II

Theory of Capacitance

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

- Lesson Narrative
- Programmed Instruction
- Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1a "Basic Electricity, Direct Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

NAVPERS 93400A-1b "Basic Electricity, Alternating Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

AUDIO-VISUAL:

Slide/Sound Presentation - "Factors Affecting Capacitance."

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON II

Theory of Capacitance

Definition of Capacitance

Capacitance is usually defined as the measure of the ability of two conducting surfaces separated by some form of nonconductor to store an electric charge. In other words, if we measure the ability of a capacitor to store electrical energy, we speak of the capacitance (C) of the component.

Measuring Capacitance

Capacitance is measured in units called farads, named after Faraday (of Faraday's Law fame). A farad is abbreviated as f.

Capacitance is equal to 1 farad when a voltage changing at the rate of 1 volt per second causes a charging current of 1 amp to flow.

Like resistance and inductance, capacitance is a physical property and cannot be changed by voltage, current, or frequency.

The basic definition of the farad is as follows: A capacitor has a capacitance of 1 f if it stores 1 coulomb (Q) of charge when connected across a potential of 1 volt, or

$$C = \frac{Q}{E}$$

If we increase the voltage, what happens to capacitance?

____

Nothing! Remember, capacitance is a physical property and cannot be changed by changing voltage. When voltage is changed, the number of electrons (charge or Q) on the plates of a capacitor must change.

What is the C of a capacitor if .001 Q of charge is stored when a potential of 200 v is applied to C? ____________

$$C = \frac{Q}{E}$$

$$C = \frac{0.001}{200\ v}$$

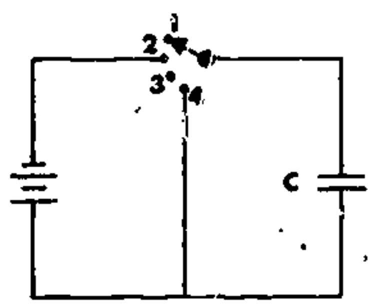
$$C = 5\ \mu f$$

Normally, capacitance is measured in microfarads (µf) or picofarads (pf). Pico is equivalent to 10^{-12}.

If a capacitor is rated at 3200 pf, what is its rating in microfarads? ____________

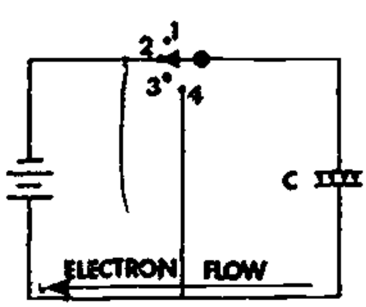
3200 pf is the same as 0.0032µf.

Charging the Capacitor



UNCHARGED

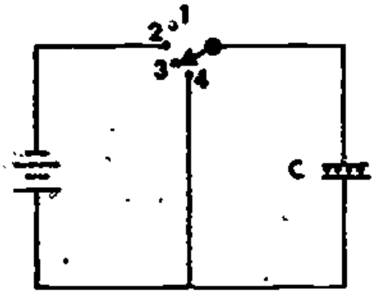
We will again use an idealized situation, a purely capacitive circuit, to explain capacitor action. In this de-energized circuit, the plates of the capacitor are not charged, no electrostatic field has been created, and no energy is stored in the capacitor.



CHARGING

Now, if we move the switch to position 2, there is a surge of electron flow. This causes:

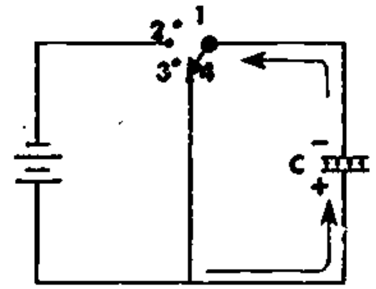
1. electrons to pile up on the top plate.
2. the top plate to become negative.
3. electrons to be pulled off the bottom plate.
4. the bottom plate to become positive.
5. an electrostatic field between the plates.
6. a difference of potential to exist between the plates.
7. energy to be stored in the electrostatic field.



As soon as the difference of potential across the capacitor (E_c) is equal to the applied voltage (10 volts in this purely capacitive circuit), the two voltages in the circuit balance and the flow of electrons stops. The capacitor is now charged.

Moving the switch to position 3 after the capacitor is charged leaves the electrons on the plates with no path to return to a neutral condition, and in theory, the capacitor can hold this charge forever. In actuality, a good capacitor can hold a charge for weeks at a time, and a capacitor can shock you severely if you touch both terminals of a charged one. Again, be sure to follow safety precautions when you work on a circuit containing capacitors.

Discharging the Capacitor



Now, if we move the switch to position 4, we provide a conducting path between the two plates of the capacitor. There is an excess of electrons on the negative plate which can now flow to the positive plate which lacks electrons. With the capacitor acting as the source, current flows briefly and the capacitor releases its charge. As the capacitor discharges, it becomes neutralized, and the stored energy is returned to the circuit.

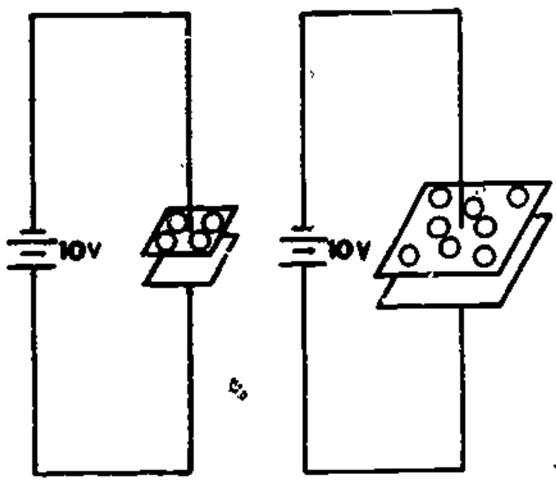
It is important to understand that a capacitor does not consume power. The energy that the capacitor draws from the source is recovered when the capacitor discharges.

Remember that at no time does electron current flow through the capacitor. The current that appears to flow in a capacitive circuit is called <u>displacement current</u>. As one electron returns to the positive plate, a different electron leaves the negative plate; no electrons actually flow through the dielectric.

Factors Affecting Capacitance

Three factors affect capacitance - the area of the plate surface, the amount of space between plates, and the dielectric constant.

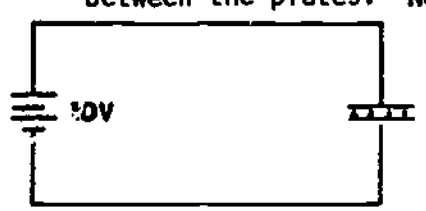
Plate Area - The greater the surface area of the plates, the greater the capacitance.



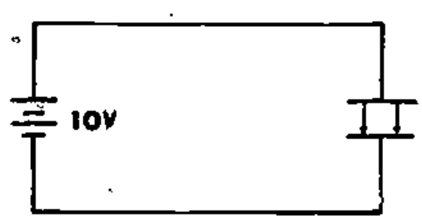
Observe the difference in the area of the plates in figures A and B. Notice also that fewer electrons pile up on the plates of the smaller capacitor (A). On the smaller plate, electrons are closer together and repel each other more. Due to the repelling effect, the source cannot force as many electrons onto the smaller plate as on the larger one. Because electrons spread out more on a larger plate, the repelling effect is less for a given number of electrons.

Capacitance is directly proportional to plate area. Therefore, if we double the plate area, we double the capacitance.

Plate Spacing - Capacitance is also determined by the distance between the plates. Notice in the illustration that the plates in figures A and B are identical except for the spacing between them.



A



B

By Coulomb's Law we know that the closer together the plates are, the stronger the electrostatic field and a stronger field means a greater capacitance.

Therefore, we can say that capacitance is inversely proportional to plate spacing. The greater the distance between the plates, the smaller the capacitance.

Dielectric Constant - The amount of capacitance of a pair of plates is affected to a great degree by the type of dielectric material used between the plates.

Experimentation has proved that, when the area between the plates is a vacuum, the capacitor has a minimum capacitance. To compare the ability of dielectric materials to increase capacitance, numbers designated as dielectric constants have been assigned to each dielectric material.

The dielectric constant for vacuum is 1 and air is very nearly the same, so it is usually considered to be 1. Some other common dielectric constants are:

Waxed paper	3.5
Glass	5-10
Wood	2.5-8
Pure Water	81

The dielectric constant tells how many times the material increases the capacitance when used instead of a vacuum for the dielectric. If the vacuum dielectric of a capacitor is replaced with pure water, the capacitance will be 81 times greater.

We can say that capacitance is directly proportional to the dielectric constant and the plate area, and inversely proportional to the distance between the plates.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON II

Theory of Capacitance

TEST FRAMES ARE 10, 18, AND 27. AS BEFORE, FIRST GO TO TEST FRAME 10 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

---

1. Recall that inductance is associated with the ability of an inductor or circuit to oppose a change in:

   ____ a. inductive reactance.
   ____ b. henrys.
   ____ c. current.
   ____ d. CEMF.

- -

(c) current

---

2. In contrast, capacitance is associated with the ability of a capacitor or circuit to oppose a change in voltage.

   Two plates separated by a dielectric and connected in a circuit:

   ____ a. have inductive reactance.
   ____ b. oppose any variation of the circuit potential difference.
   ____ c. have the ability to pass a current.

- -

(b) oppose any variation of the circuit potential difference

---

3. Capacitance may be defined as the ability of two conducting surfaces separated by a nonconductor to store electrical energy.

   A capacitor is a component which may:

   ____ a. store electrical energy.
   ____ b. oppose a change in voltage.
   ____ c. normally pass current.
   ____ d. store current via its associated magnetic field.

- -

(a. store electrical energy; b. oppose a change in voltage)

4. The symbol used to designate a capacitor is C.

The letter that is used to indicate a device that stores electrical energy and opposes a change in voltage is:

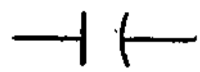
____ a. R.
____ b. L.
____ c. C.
____ d. V.

- -

(c) C

5. Capacitance is measured in units called farads, abbreviated f.

The capacitor shown has a capacitance of ________.



.04f

- -

(40,000 μfd)

6. Capacitors with capacitance values in the farad range may be as large as the building you are in. More practical units of measurement are the microfarad (10^{-6} farad) abbreviated μf and the picofarad (10^{-12} farad) abbreviated pf.

Which value of capacitance is the greatest?

____ a. 10 μf
____ b. 5 μf
____ c. 15 pf

- -

(a) 10 μf

7. Sometimes it will be necessary for you to convert from µf to pf and vice versa.

Example: 3200 pf is the same as 0.0032 µf.

We can arrive at the equivalent for the prefix by first substituting the power of ten; 3200 pf = 3200 x 10^{-12} f. Then all we have to do is move our decimal point six places to the left to change to microfarad (10^{-6} f). So we can say that 0.0032 µf is equal to 3200 pf.

Now let's work a few problems.

a. 5 µf equals ____________ pf
b. 0.025 µf equals ____________ pf
c. 500 pf equals ____________ µf
d. 0.0085 f equals ____________ µf

(a. 5,000,000; b. 25,000; c. 0.0005; d. 8500)

8. Like resistance and inductance, capacitance is determined by the component design and does not vary with changes in voltage, current, or frequency.

The C of a capacitor:

____ a. goes up when I, E, or frequency is increased.
____ b. goes down when I, E, or frequency is decreased.
____ c. is strictly a physical property.
____ d. does not increase or decrease with changes in I, E, or frequency.

(c. is strictly a physical property; d. does not increase or decrease with changes in I, E, or frequency)

9. A capacitor is said to have a capacitance of 1 farad if it stores 1 coulomb (Q) of charge when connected across a potential of 1 volt. Stated as an equation, $C = \frac{Q}{E}$.

Example: What is the C of a capacitor if 0.001 Q of charge is stored when a potential of 200 v is applied across it?

$$C = \frac{Q}{E}$$

$$C = \frac{0.001\ Q}{200v}$$

$$C = 5\ \mu f$$

What is the value of a capacitor that stores 0.015 coulombs of charge when a potential difference of 300 volts is connected across its plates?

____ a. 5 µf
____ b. 50 µf
____ c. 0.5 pf
____ d. 5 pf

(b) 50 µf

---

10. Match the correct term to each description.

____ 1. ability of a circuit to oppose a change in voltage.
____ 2. ability of a circuit to oppose a change in current.
____ 3. ability of two conducting surfaces separated by a nonconductor to store an electric charge.

a. inductance

b. capacitance

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 10

1 - b

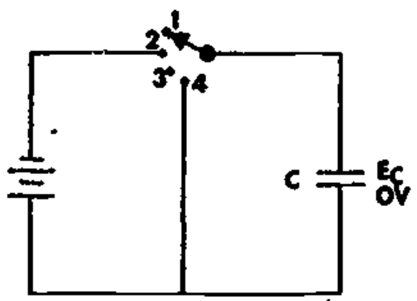
2 - a

3 - b

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO TO TEST FRAME 18. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 10 AGAIN.

---

11. We will now analyze a purely capacitive circuit and see what happens when we charge the capacitor.

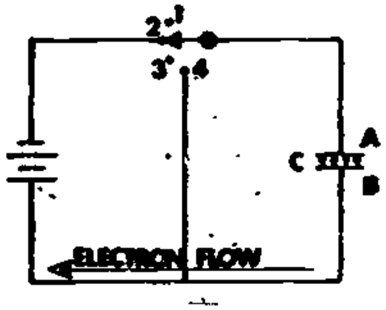


In the circuit shown:

____ a. an electrostatic field exists between the capacitor's plates.
____ b. no potential difference exists across the capacitor.
____ c. current flow is maximum.
____ d. energy is being stored in the capacitor's electrostatic field.

(b) no potential difference exists across the capacitor

12. If ~ now move the switch to position 2, electrons move in the direction indicated by the arrow.



In the circuit above:

____ a. plate A is becoming negative.
____ b. electrons are moving through every part of the circuit.
____ c. plate B is becoming positive.
____ d. a capacitor voltage is developing.
____ e. the plates are storing energy via inductance.
____ f. an electrostatic field is developing.

(a. plate A is becoming negative; c. plate B is becoming positive; d. a capacitor voltage is developing; f. an electrostatic field is developing)

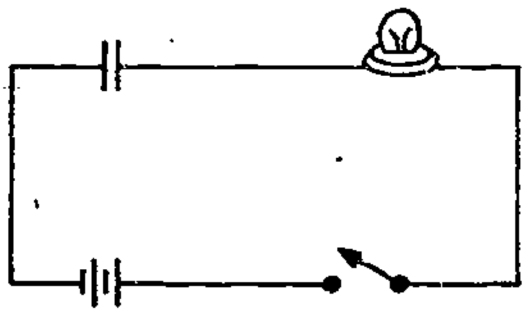
13. As the capacitor is being charged, electrons are flowing through every part of the circuit except the dielectric of the capacitor.

The current that seems to flow in a capacitive circuit is a result of the displacement of electrons; it can be called:

____ a. circuit current.
____ b. capacitor current.
____ c. displacement current.

(c) displacement current

14.



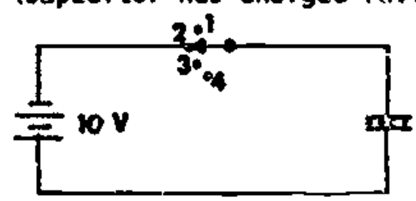
When you close the switch in this circuit, displacement current appears to flow through the capacitor.

While the capacitor is charging, the lamp ____________ light.
will/will not

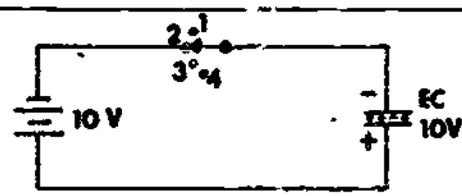
(will)

15. After a brief period of time, the capacitor is charged and the capacitor voltage (E_C) equals the source voltage and opposes more current flow in the circuit.

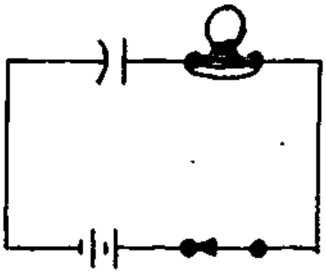
Label the polarity of the capacitor voltage and write in its value. (Capacitor has charged fully.)



E_C = ______



16.



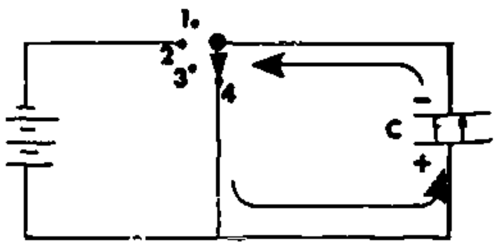
When the capacitor voltage equals the source voltage you really have two sources connected together that oppose one another.

After the capacitor is fully charged, the displacement current ____________ stop and the lamp ____________ light.
will/will not will/will not

(will; will not)

17. If the switch is moved to position 4, there is a current path between the two plates of the capacitor and the charge can neutralize.

As the capacitor discharges:



____ a. E_C increases.
____ b. E_C decreases.
____ c. displacement current flows.
____ d. stored energy is returned to the circuit.
____ e. electron current flows through the capacitor.

(b. E_C decreases; c. displacement current flows; d. stored energy is returned to the circuit)

18. Match the correct term to each description.

____ 1. exists only when capacitor charges and discharges.	
____ 2. polarity opposes E_a	a. displacement current
____ 3. developed as capacitor charges.	
____ 4. decreases as capacitor charges.	b. capacitor voltage

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 18

1 - a

2 - b

3 - b

4 - a

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO TO TEST FRAME 27. OTHERWISE, GO BACK TO FRAME 11 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 18 AGAIN.

19. Now we learn about the factors which affect the capacitance of a capacitor. First is the plate area. Capacitance is directly proportional to the plate area.

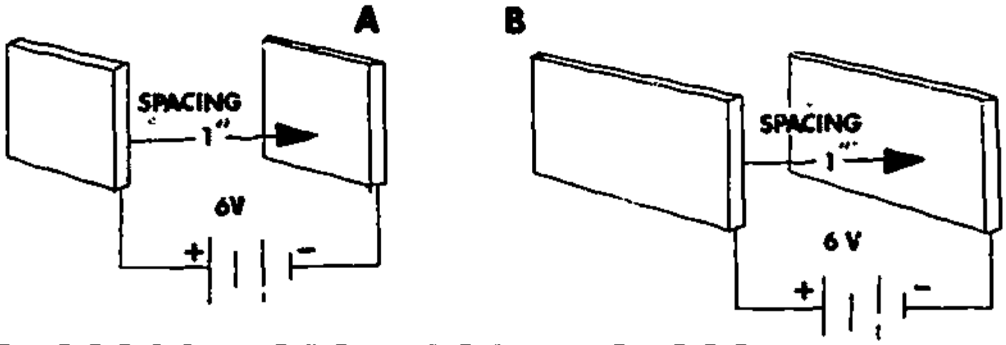
To decrease the capacitance of a capacitor you can

____ a. increase plate area.
____ b. increase applied voltage.
____ c. decrease the plate area.

(c) decrease the plate area

20. A capacitor with large plates can store more charge with the same amount of voltage applied than one with smaller plates.

The capacitor storing the most charge is capacitor ____.
(A) (B)



(B)

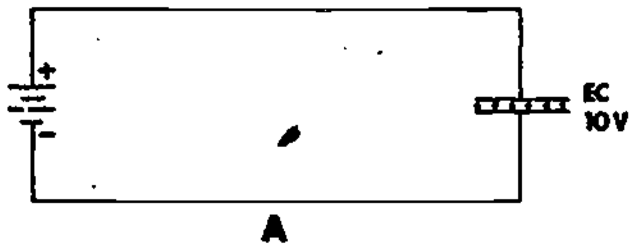
21. Capacitance varies inversely with the distance between the plates.

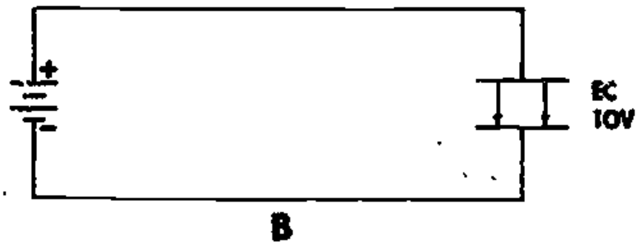
Capacitance increases if you:

____ a. move the plates closer together.
____ b. move the plates farther apart.
____ c. increase plate area.
____ d. decrease plate area.

(a. move the plates closer together; c. increase plate area)

22. The electrostatic field intensity also varies inversely with the distance between the plates.





The capacitor in circuit ______ has the strongest electrostatic field. (A) (B)

(A)

23. As the strength of the electrostatic field increases, a greater charge is stored.

As the electrostatic field gets stronger:

____ a. electrons leave the dielectric.
____ b. more energy is stored in the electrostatic field.
____ c. more electrons are stored in the dielectric.

(b) more energy is stored in the electrostatic field

24. The dielectric constant is a number that compares the capacitance of a capacitor with this dielectric material to the same capacitor with a vacuum dielectric. A vacuum is given the dielectric constant of one (1).

Here are some examples of dielectric constants:

Material	Dielectric Constant
waxed paper	3.5
glass	5-10
wood	2.5-8
pure water	81

Pure water will __________ capacitance 81 times compared to a vacuum. raise/lower

---

(raise)

25. The capacitance can be raised if a better nonconducting material is used between the plates.

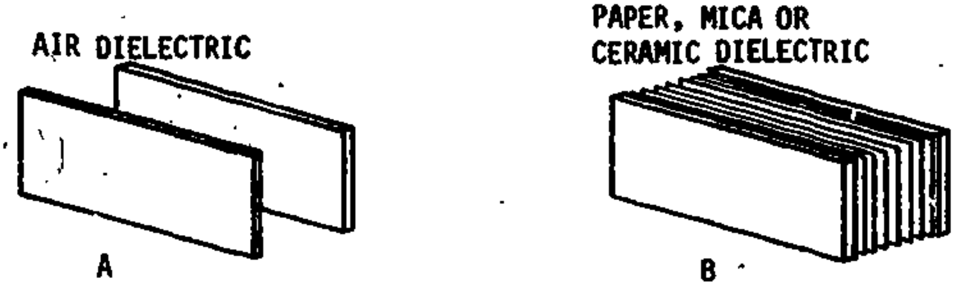
Of the materials listed, the capacitance of a capacitor is greatest if we use a ______________ dielectric.

____ a. silver
____ b. copper
____ c. mica
____ d. gold

(c) mica

26. Experimentation has proved that when the dielectric between the plates is vacuum or air the capacitor's ability to store a charge is at a minimum.

Assume the plate spacing and plate area are the same in each of the capacitors illustrated. Capacitor ______ has the greatest capacitance.
(A) (B)



(B)

---

27. Check the items that increase capacitance.

____ a. increasing frequency.
____ b. increasing voltage.
____ c. larger plates.
____ d. using mica as a dielectric instead of air.
____ e. using vacuum as dielectric instead of waxed paper.
____ f. moving plates closer together.
____ g. increasing current.

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 27

c. larger plates.

d. using mica as a dielectric instead of air.

f. moving plates closer together.

IF ANY OF YOUR ANSWERS IS INCORRECT, GO BACK TO FRAME 19 AND TAKE THE PROGRAMMED SEQUENCE.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON II

Theory of Capacitance

Definition of Capacitance

Capacitance is usually defined as the ability of a circuit to store electrical energy. Therefore, the capacitance (C) of a capacitor in an electrical circuit is a measure of this ability to store electrical energy.

Capacitance is measured in units called farads. A 1-farad capacitor will store 1 coulomb of charge when a potential of 1 volt is applied across the terminals.

$$C \text{ (farads)} = \frac{Q \text{ (coulombs)}}{E \text{ (volts)}}$$

Normally capacitance is measured in microfarads (μf) or picofarads (pf). One farad is equal to:

$$10^6 \text{ μf} = 10^{12} \text{ pf}$$

Capacitance is a physical property of the component and does not depend on the circuit parameters of voltage, current, and resistance. A capacitor will have the same value of capacitance (farads) in one circuit as in any other circuit in which it is placed.

Factors Affecting Capacitance

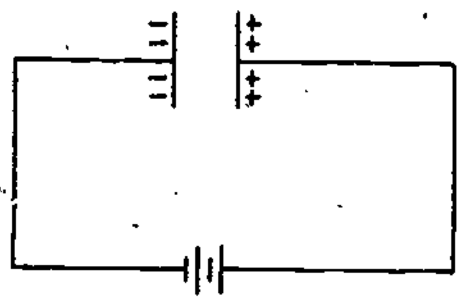
The physical properties of a capacitor that affect its value of capacitance include: (1) area of the plate surfaces; (2) spacing between the plates; (3) dielectric constant of the insulator.

Plate Area - The greater the surface area of the plates, the greater the capacitance. Remember capacitance is the ability to store charge; so a greater plate area means more storage area for charges. Capacitance is directly proportional to plate area. Therefore, if we double the plate area, we double the capacitance.

Plate Separation - The capacitance is inversely proportional to the separation between the plates. That is, if we double the separation between two plates, keeping all other factors the same, the capacitance is one-half its original value. Since capacitance is the ability to store energy in the electrostatic field, increasing the separation between plates decreases the field strength, thus decreasing the capacitance.

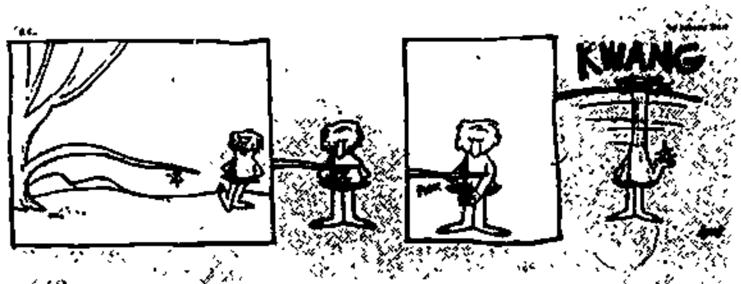
<u>Dielectric Constant</u> - The dielectric constant is a measure of the ability of a nonconductor to store electrical energy in the distortion of its atomic configuration. Hence, a material with a large dielectric constant can store more energy in the distortion of its atomic orbits than material with a low constant. Dielectric constants are relative numbers based on 1.0 for a vacuum. Dielectric constants for other common materials are:

Vacuum	1.0
Waxed Paper	3.5
Glass	5-10
Pure Water	81



<u>Displacement Current</u> - Remember that at no time does current flow through the capacitor. The current that appears to flow in a capacitive circuit is a <u>displacement current</u>. When one electron arrives at the positive plate of the voltage source, another electron leaves the negative plate, giving the appearance of a continuous current.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.



If you don't know what it does don't fool with it!

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE ELEVEN

LESSON III

Total Capacitance

Study Booklet

OVERVIEW
LESSON III

Total Capacitance

In this lesson you will study and learn about the following:

- -series capacitors
- -parallel capacitors
- -series-parallel capacitors

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON III

Total Capacitance

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative

Programmed Instruction

Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1b "Basic Electricity, Alternating Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

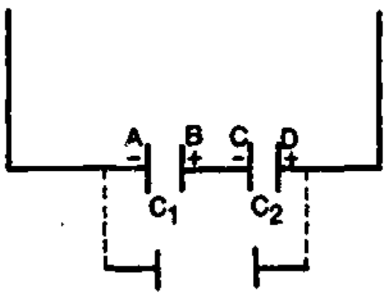
NARRATIVE
LESSON III

Total Capacitance

Capacitors can be placed in circuits either in series or parallel, just as inductors and other components can. Then, to determine the total capacitance in a circuit, we must be familiar with the rules for calculating capacitance in the various configurations of circuits.

Series

If we wire two capacitors in series as shown, in effect, we increase the distance between two plates, A and D. You know that increasing the space between plates decreases capacitance. Therefore, when capacitors are wired in series, total capacitance decreases. Total capacitance (C_T) then is less than the amount of the smallest capacitor.



Recall that inductance and resistance in series are additive; capacitance is not. To find C_T in series we apply the rules for determining resistances in parallel. For example, we can find total capacitance by using the sum of the reciprocals method,

$$C_T = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}}, \text{ for series combinations,}$$

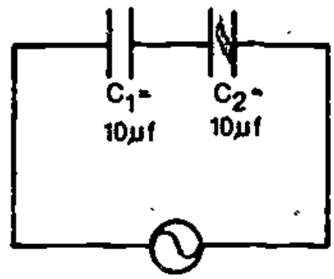
or the product over the sum method if only two capacitors are in series,

$$C_T = \frac{C1 \times C2}{C1 + C2}.$$

Observe that these are methods for solving for total resistance in parallel, but now we have substituted C for R to solve for C_T in series.

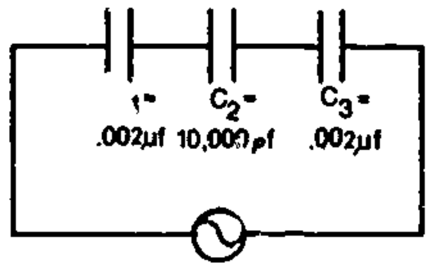
Find C_T in both circuits.

(1)



C_T = ____

(2)

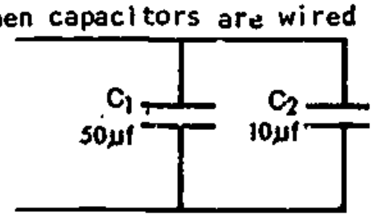


C_T = ____

Total capacitance in problem (1) is 5 µf, and in problem (2) is 909pf or, rounded off, 910pf. Problem (1) could have been solved simply by dividing the equal value of the two capacitors (10µf) by the number of capacitors. 10 ÷ 2 = 5µf. Problem (2) can be solved by the sum of the reciprocals method.

Parallel

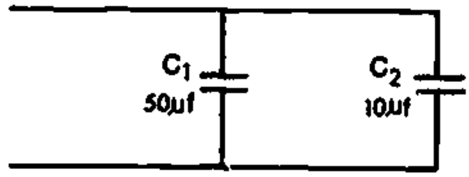
When capacitors are wired in parallel as shown, you can assume that, in effect, the cross-sectional area of the plates has been increased. As the plate area increases, capacitance increases; therefore, in parallel connections, the values of individual capacitors can be added to determine total capacitance.



$$C_T = C1 + C2 + C3 + \dots + Cn$$

Capacitance in parallel is figured in the same way that resistance is computed in series.

Find C_T. ____________



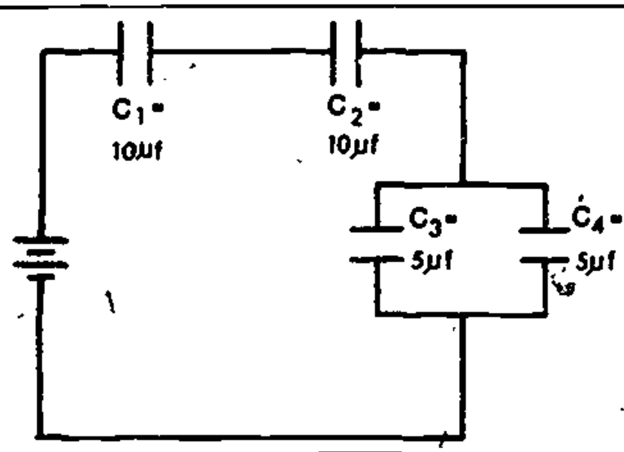
C_T in this parallel circuit is 60 µf.

Series-Parallel

Now that you know the rules for finding total capacitance in both series and parallel circuits, you can combine these rules to solve for C_T in series-parallel circuits.

Recall that when solving resistive circuits the first step was to determine the equivalent resistance of the parallel network.

See if you can find C_T in this circuit; remember that the rules are exactly opposite to those you used for R_T.



C_T = ______

By parallel rules, C3 and C4 in the parallel network can be added for a total of 10 µf. Then, in effect, we have a circuit with three 10μf capacitors in series. If we divide 10μf by 3, we arrive at a figure of 3.3μf which is C_T in this series-parallel circuit.

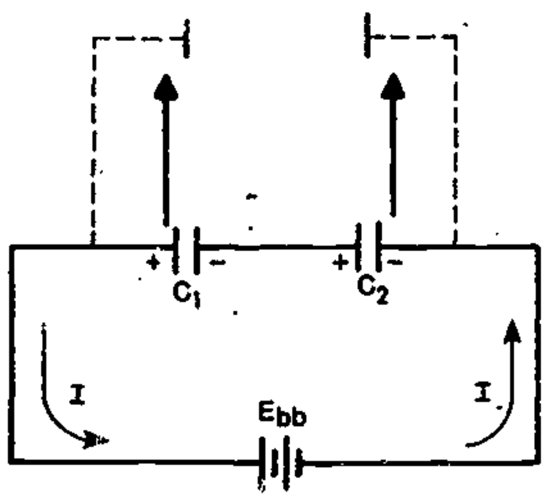
AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON III

Total Capacitance

TEST FRAMES ARE 4, 8 AND 13. AS BEFORE FIRST GO TO TEST FRAME 4 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

1.



Notice that when we connect capacitors in series we have in effect increased the distance between the plates.

From this we can conclude that when capacitors are wired in series, total capacitance (C_T).

_____ a. increases.
_____ b. decreases.
_____ c. stays the same.

(b) decreases (NOTE: Capacitance is inversely proportional to distance between the plates.)

2. To find total capacitance (C_T) when capacitors are connected in series, use the same formula you would use to find total resistance or total inductance when they are connected in parallel.

Which formula(s) can be used to determine C_T of series connected capacitors?

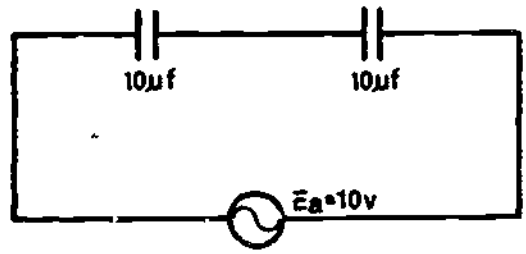
____ a. $C_T = C1 + C2 + \ldots + Cn$

____ b. $C_T = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}}$

____ c. $C_T = \frac{C1 \times C2}{C1 + C2}$

(b.) $C_T = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}}$; (c.) $C_T = \frac{C1 \times C2}{C1 + C2}$

3. Example: Find the total capacitance of this circuit.



Solution: $C_T = \frac{C1 \times C2}{C1 + C2}$ or $C_T = \frac{1}{\frac{1}{C1} + \frac{1}{C2}}$

$C_T = \frac{10\mu f \times 10\mu f}{10\mu f + 10\mu f}$ $C_T = \frac{1}{\frac{1}{10\mu f} \quad \frac{1}{10\mu f}}$

$C_T = \frac{100 \times 10^{-12}}{20 \times 10^{-6}}$ $C_T = \frac{1}{\frac{2}{10\mu f}}$

$C_T =$ $C_T = 5\mu f$

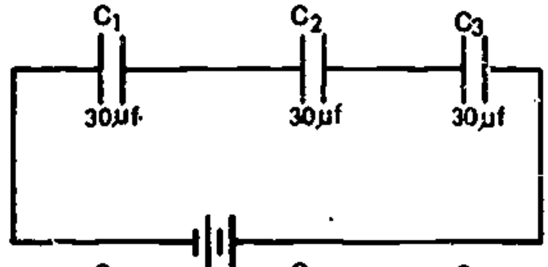
In this particular circuit, what other method might have been used? ____________

- -

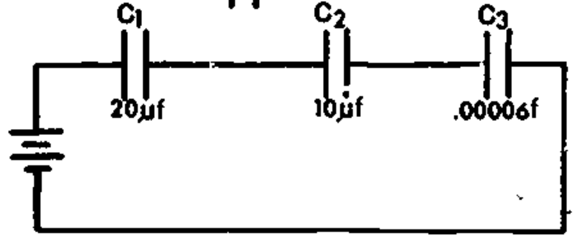
(equal value method: $C_T = \frac{C}{n}$)

4. Find the total capacitance of these circuits (state all answers in µf).

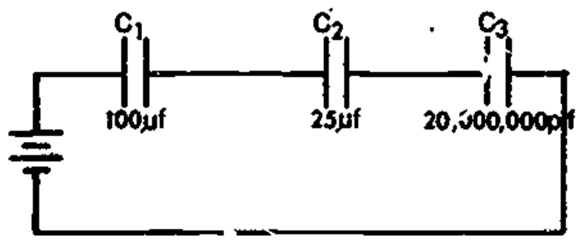
____ a.



____ b.



____ c.



- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 4

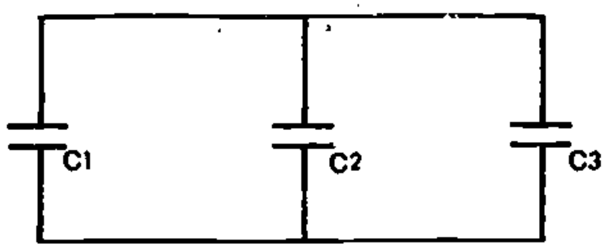
a. 10μf

b. 6μf

c. 10μf

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, GO TO TEST FRAME 8. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 4 AGAIN.

5.



Notice that when we connect capacitors in parallel, we effectively increase the plate area.

From this we can conclude that when capacitors are connected in parallel C_T:

____ a. increases.
____ b. decreases.
____ c. stays the same.

(a) increases

6. To find C_T when capacitors are connected in parallel, use the same formula you would use to find total resistance or total inductance in series.

Which formula can be used to determine C_T of parallel connected capacitors?

___ a. $C_T = \frac{C1 \times C2}{C1 + C2}$

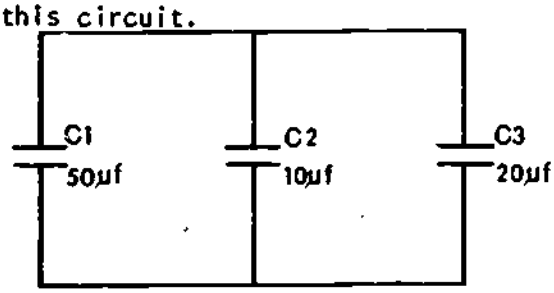
___ b. $C_T = C1 + C2 + C3 + \ldots + Cn$

___ c. $C_T = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3} + \ldots + \frac{1}{Cn}}$

(b. $C_T = C1 + C2 + C3 + \ldots + Cn$)

---

7. Find C_T of this circuit.



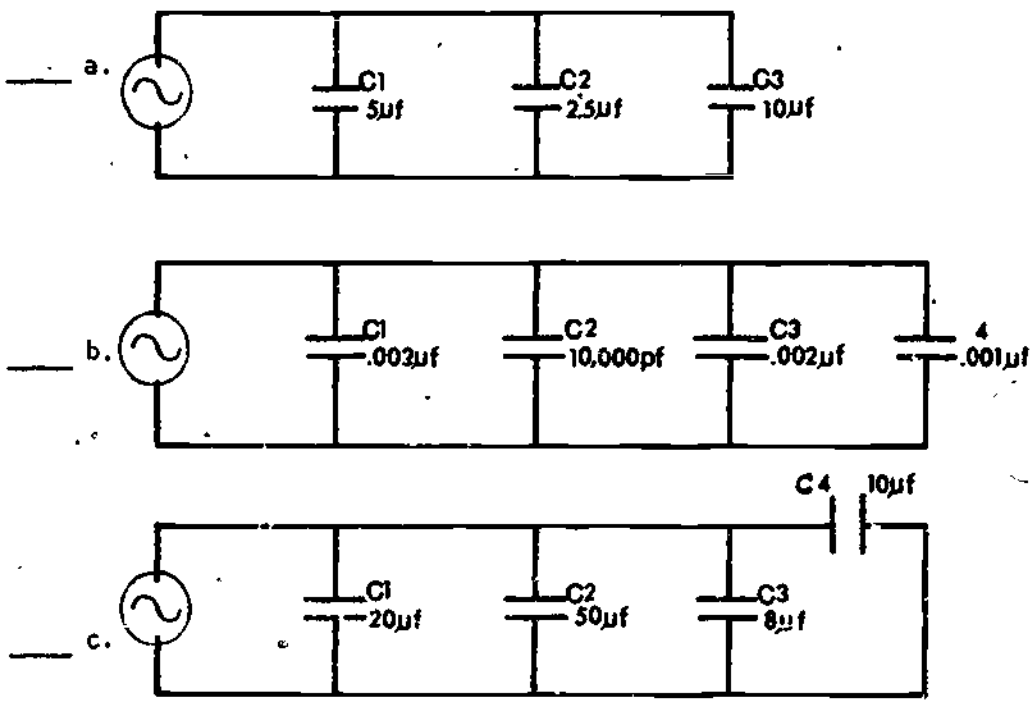
C_T = ______

($C_T = C1 + C2 + C3$

$C_T = 50\mu f + 10\mu f + 20\mu f$

$C_T = 80\mu f$)

8. Find the total capacitance of these circuits.



(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 8

a. 17.5μf

b. 15,000pf or 0.015μf

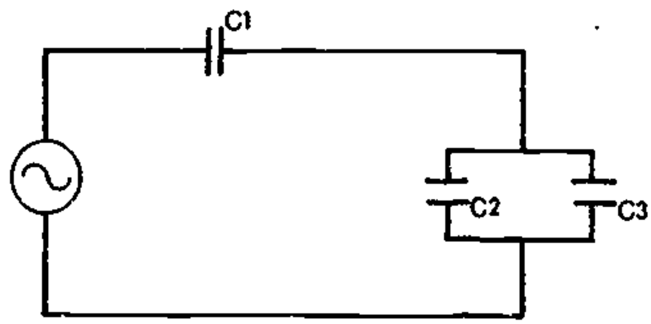
c. 88μfd

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, GO TO TEST FRAME 13. OTHERWISE, GO BACK TO FRAME 5 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 8 AGAIN.

9. Capacitance in series is computed the same way as resistance in ______ (series/parallel). Capacitance in parallel is computed the same way as resistance in ______ (series/parallel).

(parallel; series)

10.



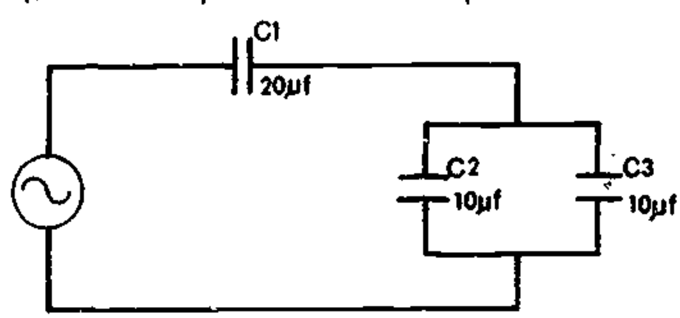
To find the C_T for the series-parallel network shown, we can:

____ a. add C1, C2, and C3 directly.
____ b. use the reciprocal method to find C_{eq} of C2 and C3 and add this sum directly to C1.
____ c. add C2 and C3 directly and use the reciprocal method to find the equivalent capacitance of this sum and C1.

(c) add C2 and C3 directly and use the reciprocal method to find the equivalent capacitance of this sum and C1.)

11. To solve the below series-parallel capacitive circuit for C_T, the first step is to determine the equivalent capacitance (C_{eq}) of the parallel network.

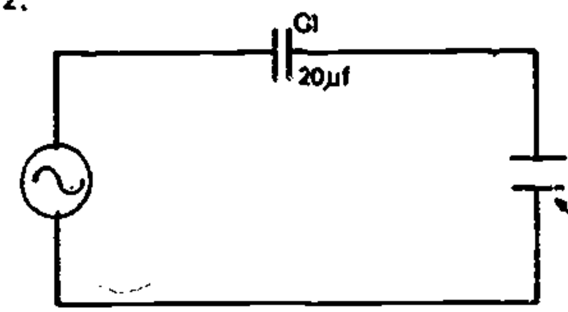
Find the equivalent capacitance of the parallel network.



____ a. 5µf
____ b. 20µf
____ c. 10µf

(b) 20µf

12.



Our next step is to combine the equivalent capacitance (C_{eq}) with C1.

C_T for this circuit is:

____ a. 20µf
____ b. 25µf
____ c. 10µf
____ d. 40µf

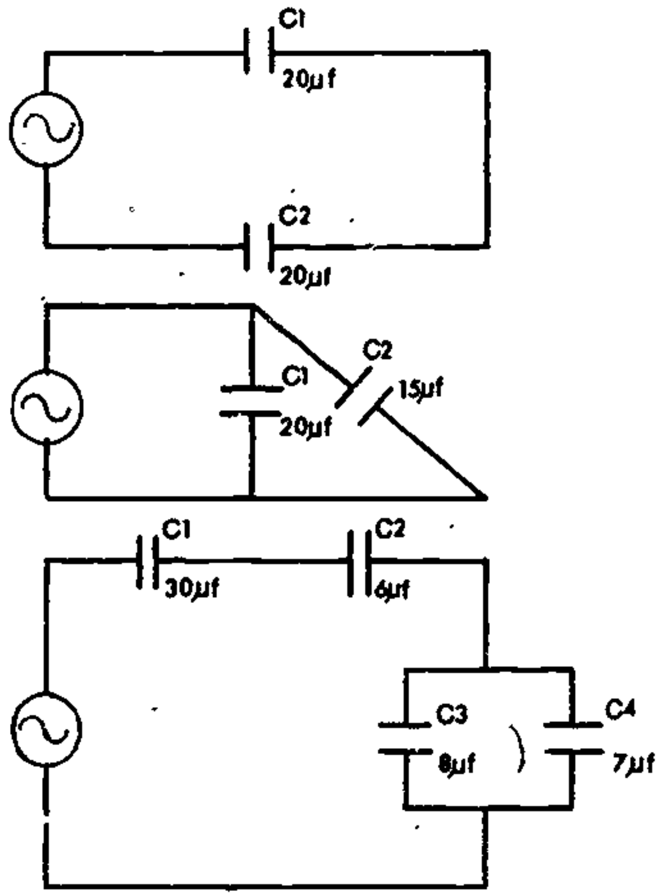
(c) 10µf

13. Solve each circuit for C_T.

____ a.

____ b.

____ c.



(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 13

a. 10μf

b. 35μf

c. 3.75μf

- -

IF ANY OF YOUR ANSWERS IS <u>INCORRECT</u>, GO BACK TO FRAME 9 AND TAKE THE PROGRAMMED SEQUENCE.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

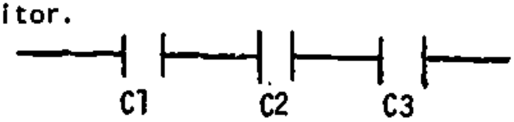
SUMMARY
LESSON III

Total Capacitance

In many complex circuits, capacitors occur in several configurations of series, parallel, and series-parallel connections. To determine the total capacitance of a circuit, we must be familiar with the rules for calculating capacitance for the three common circuit configurations.

Series

For two or more capacitors wired in series as shown, the total capacitance is smaller than any of the individual capacitances. The total capacitance of the circuit below can be thought of as one capacitor with an increased plate separation equivalent to the plate separations of each individual capacitor.

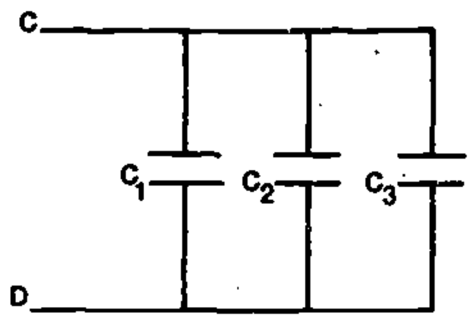


The total capacitance can be calculated with the formula for series configurations.

$$C_T = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}}$$

Parallel

For capacitors wired in parallel, total capacitance for the circuit below increases since the effective cross-sectional area of the plates has been increased.



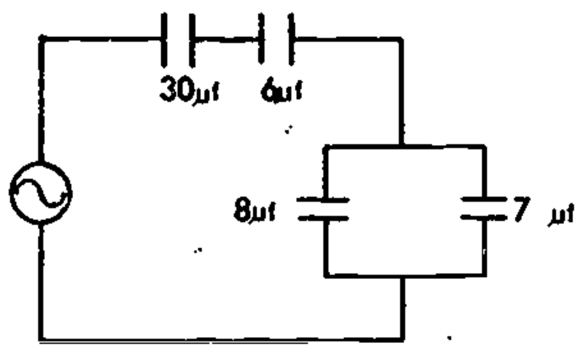
The total capacitance for the parallel configuration can be calculated with the formula,

$$C_T = C1 + C2 + C3$$

Series-Parallel

In complex circuits, total capacitance can be calculated by reducing the series-parallel network to a simple series or parallel circuit and then solving the resulting equivalent circuit. This is the same procedure that was used in solving complex resistive circuits.

Perform the following exercise by solving the circuit for total capacitance.



C_T = ______

$C_T = 3.75\ \mu f$

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.


POOR SHOT—
POOR
HOUSEKEEPING

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE ELEVEN

LESSON IV

RC Time Constant

Study Booklet

OVERIVEW
LESSON IV

RC Time Constant

In this lesson you will study and learn about the following:

- -analyzing an RC circuit on charge
- -analyzing an RC circuit on discharge
- -computing RC time constants
- -Universal Time Constant Chart
- -effect of variation of time constant

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES

LESSON IV

RC Time Constant

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

- Lesson Narrative
- Programmed Instruction
- Experiment
- Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1b "Basic Electricity, Alternating Current."

Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

AUDIO-VISUAL:

Sound/Slide Presentation - "Capacitance: Time constants."

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

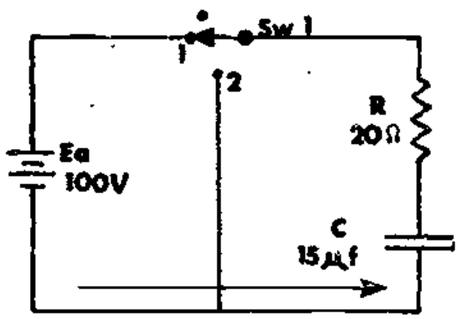
NARRATIVE
LESSON IV

RC Time Constant

You know that, theoretically, in a purely capacitive circuit the capacitor charges instantly when the circuit is energized, as there is nothing in the circuit to limit current flow to the capacitor.

You know that there cannot be a practical, purely capacitive circuit because every circuit contains conductor resistance and internal resistance in the source. There is always some resistance in a circuit; therefore, it is necessary to analyze what happens in a resistive-capacitive circuit (RC circuit) as the capacitor charges.

Analyzing an RC Circuit on Charge



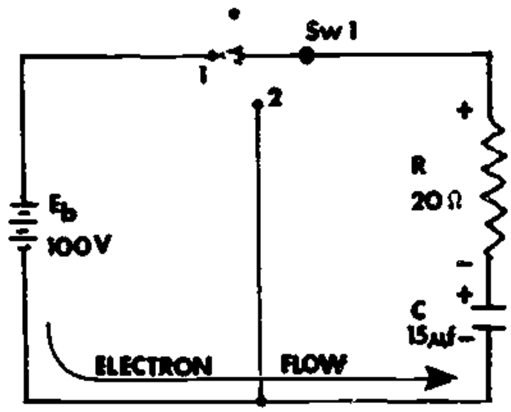
In the circuit illustrated, the 20-ohm resistor represents all circuit resistance lumped into one value.

Before SW1 was closed to position 1, the circuit was open, and there was no current flow, no voltage drop across R1, nor any capacitor voltage.

The instant SW1 is closed to position 1, current flow is maximum in the circuit. By Ohm's Law, if E_a is 100 volts and R is 20 ohms, maximum current is 5 amps. Therefore, at the instant the circuit is energized, there is 5 amps of current in the circuit.

Recall that in an LR circuit, at the instant the circuit is energized current is minimum. Again, in comparing, we see that inductance and capacitance act in opposite manners.

Now at time zero when the circuit is energized, current is maximum, and the voltage drop across the resistance is maximum at 100 volts. Voltage across the capacitor (E_C) is zero.



As the capacitor charges, it starts to build up a difference of potential, E_C, which is in direct opposition to the applied voltage. Therefore, current decreases, the voltage drop across the resistor decreases, and EC increases.

$I \downarrow$

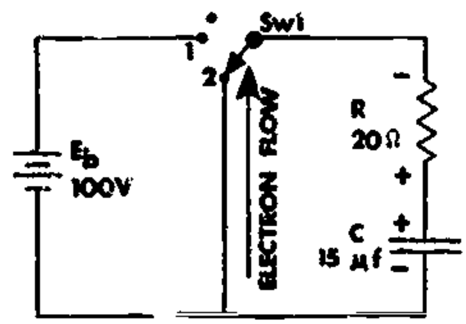
$E_R \downarrow$

$E_C \uparrow$

This trend continues until current is zero, E_R is zero, and E_C is maximum at 100 volts. Notice that the sum of the voltage drops across the resistor and the capacitor equals the applied voltage.

Notice also that the presence of resistance in the circuit limits the charging current, and the capacitor always takes some period of time to reach its fully charged state. Then the circuit becomes static ($I = 0$; $E_R = 0$; E_C = max.) until something is done to change it.

Discharge



Now, if SW1 is moved to position 2, we provide a path for the piled up electrons at the negative plate to flow to the positive plate. E_C of 100 volts becomes a source. The energy stored by the capacitor is discharged.

Therefore, upon beginning discharge, current is again maximum at 5 amps. The capacitor voltage has become the source voltage, and therefore, the voltage drop across the resistance equals the capacitor voltage. When E_C is 100 volts, then E_R is 100 volts. As the capacitor voltage begins to decrease, E_R decreases proportionately.

When E_C is 70 volts, E_R is 70 volts. As voltage decreases, current decreases. This trend continues until the capacitor is fully discharged. Then: E_C is zero
E_R is zero
I is zero

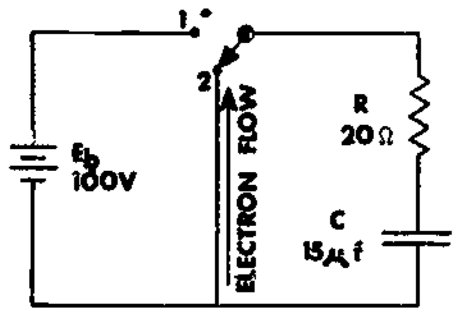
Computing RC Time Constants

The length of time that a capacitor takes to reach 63.2% of its maximum voltage or to decrease to 36.8% of its maximum voltage is called one TC. It takes five time constants to fully charge the capacitor through a resistance, and five time constants to fully discharge the capacitor through the resistance.

The formula for determining one TC in an RC circuit is:

TC (in seconds) = R (in ohms) x C (in farads)

In this circuit, what is the TC? ____________



$TC = R \times C$

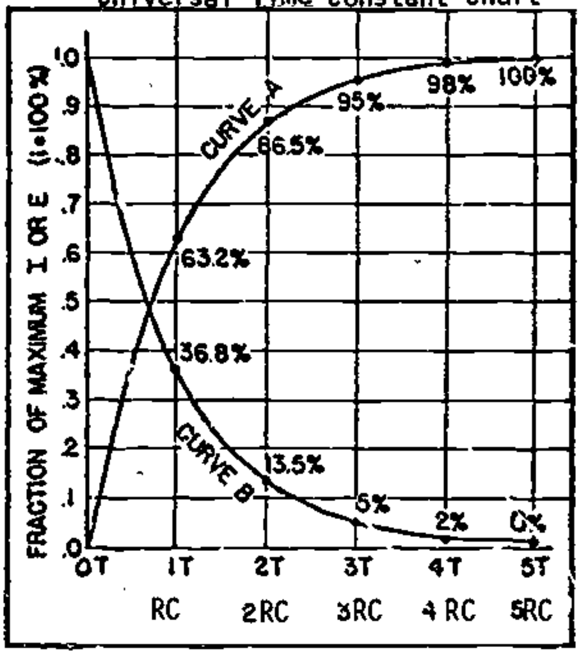
$TC = (20 \text{ ohms}) \times (15 \times 10^{-6} \text{ f})$

$TC = 300 \times 10^{-6}$ seconds or 300 microseconds or

0.3 milliseconds

Therefore, in this circuit it takes 0.3 milliseconds for E_C to increase to 63.2% of its maximum (100 v), or 63.2 volts; or it takes 0.3 milliseconds for the E_R to decrease to 36.8% from full charge (36.8 volts).

Universal Time Constant Chart



Let's look again at our old friend, the Universal Time Constant Chart, which never changes.

The percentages that are valid for inductance are also valid for capacitance.

From analysis of the RC circuit, can you determine what quantities are plotted on Curve A?

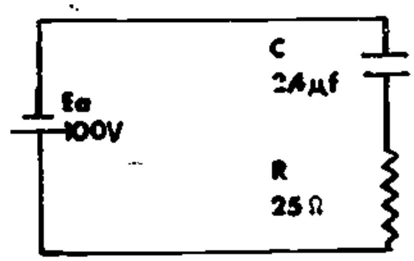
____

What is plotted on Curve B? ______

____

In a capacitive-resistive circuit, I and E_R are maximum at Time 0, and capacitor voltage is on the rise; therefore, Curve A indicates E_C on the rise, or on charge. Curve B represents I on charge and E_R on charge, as they decrease. It also represents all quantities on discharge, E_C, I, and E_R.

Recall that you can solve for quantities at particular time constants by using the percentages on the chart and multiplying maximums by the percentage for a given time constant.



By using the values in the above circuit and the percentages of the Universal TC Chart, which you have memorized, find:

I max. = ____________
TC = ____________
E_R @ T3 = ____________
E_C @ T2 = ____________
E_C @ 240 microseconds = ________

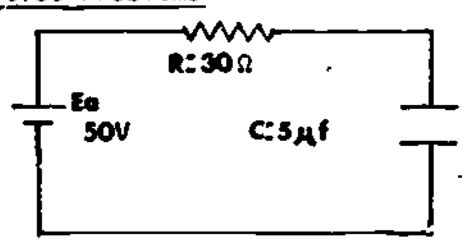
By Ohm's Law, you determine that I = 4 amps. The time constant formula TC = R x C tells us that TC = 60 microseconds.

E_R @ Time 3 = 5% x 100 volts or 5 volts
E_C @ Time 2 = 86.5% x 100 volts or 86.5 volts
E_C @ 240 microseconds - E_c at time 4 = 98% x 100 volts = 98 volts

---

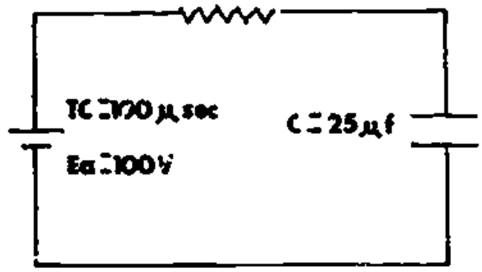
Practice Problems

1.



FIND: TC = ______
E_C @ T2 = ______
E_R @ T2 = ______
I @ 450 μsec = ______

2.



FIND: E_R @ 1 TC = ___
I @ 200 μsec = ___

3. In problem 2, if the value of R is increased after 5 TC have passed, what will happen to E_C? ___

Answers

1. TC = 150 μsec

   E_C @ T2 = 43.25 v

   E_R @ T2 = 6.75 v

   I @ 450 μsec ≈ 83.5 ma

2. E_R @ 1 TC = 36.8 v

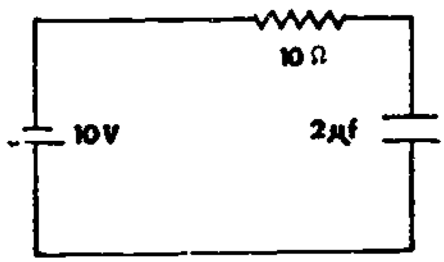
   I @ 200 μsec = 3.375 amps

3. Nothing

Effects of Variations in TC

The time constant of a given circuit is equal to R x C. Therefore, if resistance or capacitance is increased, the TC increases. If either R or C is decreased, the TC decreases.

The only way TC can be changed is to vary R or C. The only other independent variable in the circuit is the applied voltage. Let's see what happens in this circuit if the E_a is changed from 10 volts to 20 volts. The time constant does not change; it still takes 20 microseconds for the capacitor voltage to reach 63.2% of its maximum. However, the maximum will have doubled from 10 volts to 20 volts; therefore, the



capacitor must charge to twice the voltage in the same amount of time.

Therefore, if E_a increases, the rate of charge also increases. The capacitor has to charge faster. If E_a decreases, the rate of charge decreases.

AT THIS POINT, YOU MAY PERFORM THE EXPERIMENT WHICH STARTS ON PAGE 110 PRIOR TO TAKING THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE RESOURCES LISTED. IF YOU DO THE EXPERIMENT, TAKE THE PROGRESS CHECK, AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMEO INSTRUCTION
LESSON IV

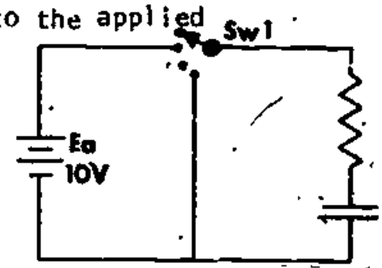
RC Time Constant

TEST FRAMES ARE 12, 17, 33 ANO 37. AS BEFORE, GO FIRST TO TEST FRAME 12 ANO SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE OIRECTIONS GIVEN AFTER THE TEST FRAME.

---

1. A capacitor charges to the source potential instantly if there is no resistance in the circuit.

   In the circuit shown, the capacitor charges to the applied voltage:



   ____ a. the moment switch is closed.

   ____ b. in a definite amount of time.

- -

(b) in a definite amount of time

---

2. The amount of time required to charge a capacitor to 63.2% (or decrease to 36.8%) of the applied voltage in a OC resistive-capacitive (RC) circuit is known as the time constant (TC).

   A time constant is:

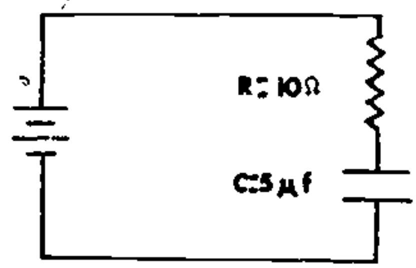
   ____ a. the time required to fully charge the capacitor.
   ____ b. the time required for the source voltage to decrease to 36.8% of E_a.
   ____ c. the time required for E_C to be 63.2% of E_a.

- -

(c) the time required for E_C to be 63.2% of E_a.

3. To determine the TC of a DC series RC circuit we use the formula TC (in seconds) = R (in ohms) x C (in farads).

Determine the time it takes for E_C in this circuit to reach 63.2% of E_a.



____ a. 50 msec

____ b. 2 μsec

____ c. 50 μsec

(c) 50 μsec

---

4. The formula TC = R x C says that the time it takes the capacitor to charge to 63.2% of applied voltage is directly proportional to the product of R and C.

If the value of R or C is increased in an RC circuit, the time to charge the capacitor:

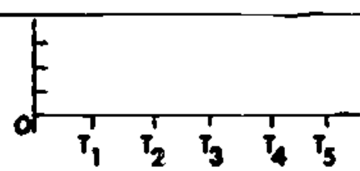
____ a. increases.
____ b. decreases.
____ c. stays the same.

(a) increases

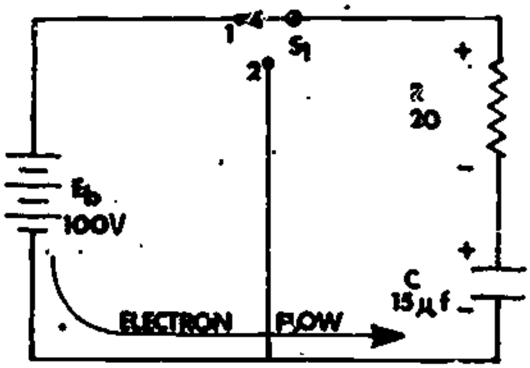
---

5. Recall from DC LR circuits that it takes about 5 time constants to reach steady values.

Label the time constants below.



6.



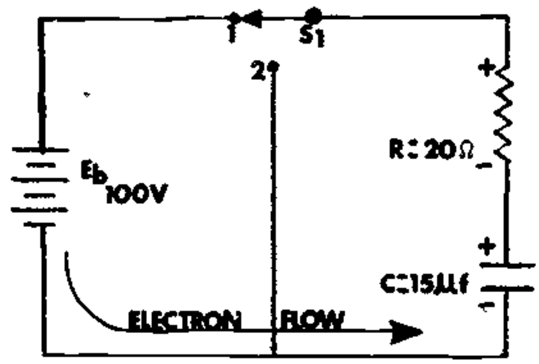
We will now analyze a DC RC circuit while charging the capacitor. At the instant the switch is closed displacement current is at its greatest Ohm's Law value because the capacitor has not built up an opposing voltage.

At the instant the switch is closed:

____ a. E_C is minimum.
____ b. E_C is maximum.
____ c. I is maximum.
____ d. I is minimum.

(a. E_C is minimum; c. I is maximum)

7.



Ohm's Law can be used to determine the amount of current flow in the circuit which, for the first instant, is controlled only by the resistance.

The moment the switch is closed, the maximum current is:

____ a. 6.6 a.
____ b. 5 a.
____ c. 0.2a.
____ d. 6.6μa.

(b) 5a.

8. Because current flow through the resistor is maximum the instant the switch is closed, E_R is also maximum.

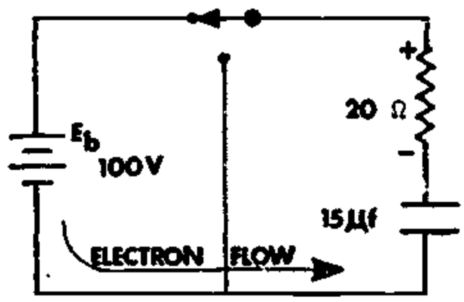
In the schematic below, when the circuit is first energized, the voltage drop across the resistor is:

____ a. 5 v.

____ b. 100 v.

____ c. 6.6 v.

____ d. equal to E_a.



(b. 100 v; d. equal to E_a)

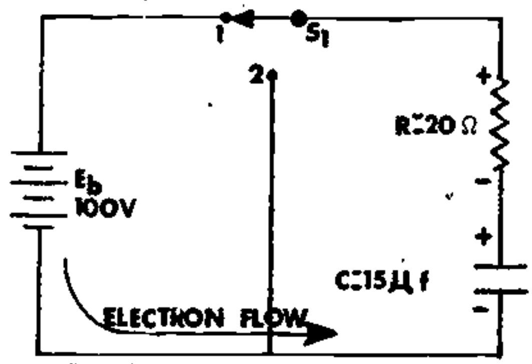
9. As the capacitor continues to charge, the circuit current starts to decrease because E_C is opposing E_a.

As the potential difference across the capacitor increases:

____ a. current flow increases.

____ b. current flow decreases.

____ c. E_a decreases.



(b) current flow decreases

10. As the current flow in the circuit is decreasing, the voltage drop across the resistor must also be decreasing.

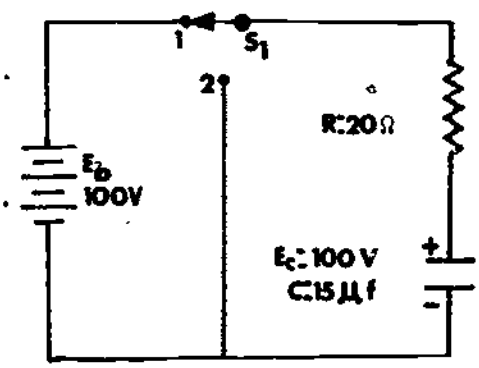
Which of the below statement(s) is true concerning a DC series RC circuit?

____ a. E_R varies inversely with charge time.

____ b. E_R varies directly with charge time.

____ c. E_C varies inversely with charge time.

____ d. E_C varies directly with charge time.



(a. E_R varies inversely with charge time; d. E_C varies directly with charge time.)

11. When E_C is equal to E_a all electron flow stops.

Refer to the diagram in frame 10. When E_C is equal to 100 volts the current in the circuit is ________ (maximum/zero) and E_R is ________ (maximum/zero).

- -

(zero; zero)

12. Check the correct statements concerning a DC RC circuit when the capacitor is fully charged.

____ a. E_C maximum

____ b. E_C zero

____ c. I maximum

____ d. I zero

____ e. E_R maximum

____ f. E_R zero

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 12

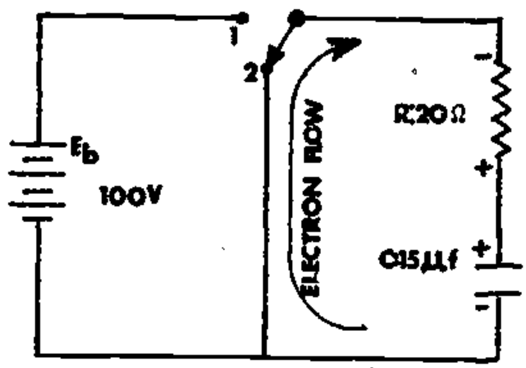
a. E_C maximum

d. I zero

f. E_R zero

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 17. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 12 AGAIN.

13.



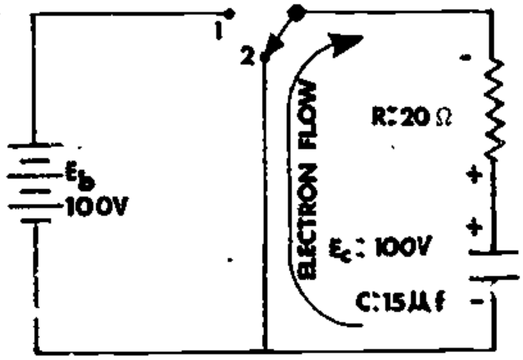
Now if the switch is moved to position 2, the capacitor discharges.

During discharge, the capacitor acts as a:

____ a. load.
____ b. source.
____ c. resistance.

(b) source

14.



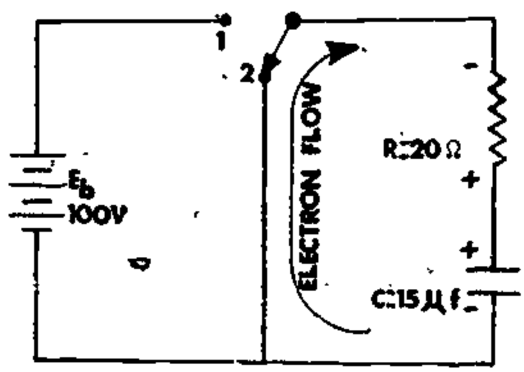
The instant that the switch is moved to position 2 electron flow in the circuit is at its maximum Ohm's Law value again.

The instant the switch in the above circuit is thrown to position 2, current flow is _______________ amps.

---

(5)

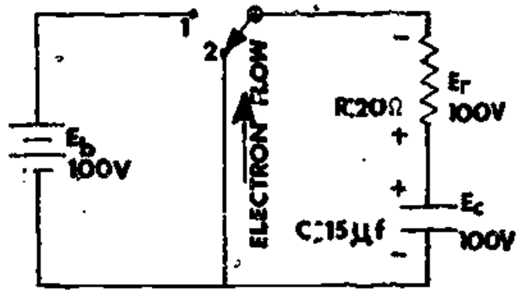
15.



As the capacitor continues to discharge, its potential decreases, and current flow in the circuit _______________.
increases/decreases

(decreases)

16.



Recall that in any circuit the voltage rise is equal to the voltage drop.

As the capacitor discharges:

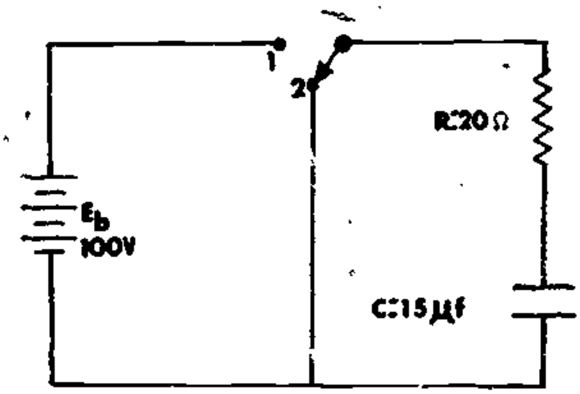
____ a. E_R and E_C decrease together.

____ b. E_R increases.

____ c. as E_C decreases, E_R increases.

(a) E_R and E_C decrease together

17.



Check the conditions that exist in the above circuit when the capacitor is fully discharged.

____ a. E_R maximum.
____ b. E_R zero.
____ c. I maximum.
____ d. I zero.
____ e. E_C maximum.
____ f. E_C zero.

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 17

b. E_R zero.

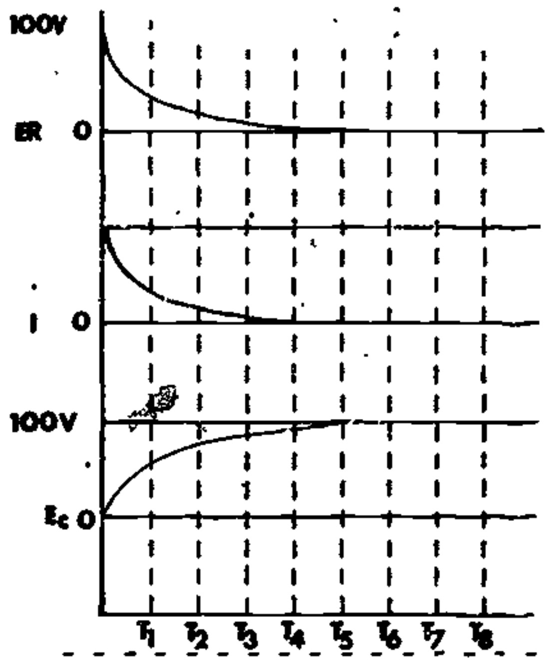
d. I zero.

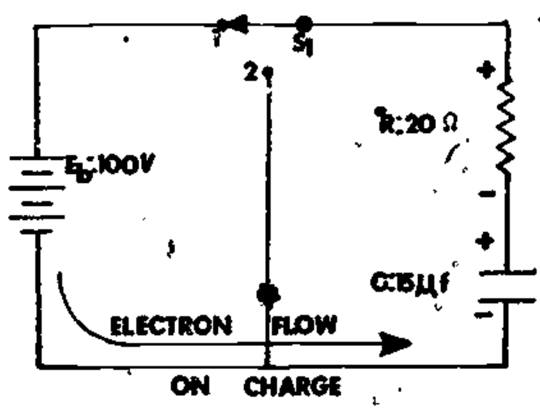
f. E_C zero.

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 33. OTHERWISE, GO BACK TO FRAME 13 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 17 AGAIN.

18. Use the graphs below to answer frames 19 to 22. These graphs show capacitor voltage, circuit current, and the voltage drop across the resistor in the series RC circuit during growth.

(Circuit is energized at time zero.)





(Go to next frame.)

19. At T0, E_C is at its ______________ value.
maximum/minimum

(minimum)

20. Circuit current at T0 is at its ______________ value.
maximum/minimum

(maximum)

21. The curve for E_R and circuit current are similar because they both reach their __________ and __________ values at the same time.

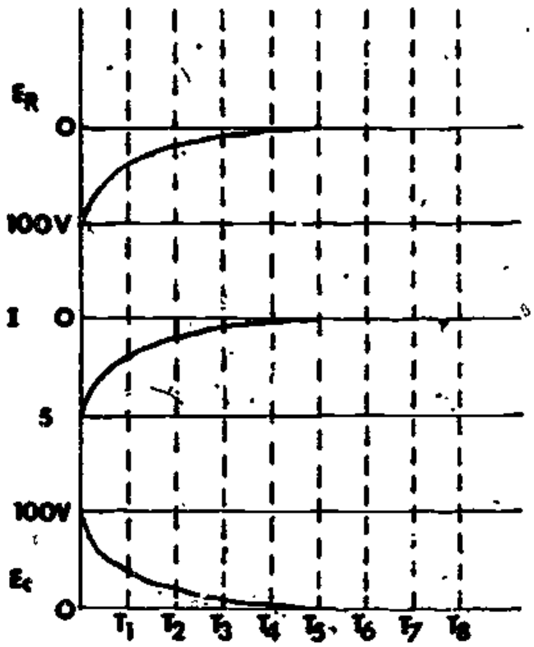
(minimum; maximum) (either order)

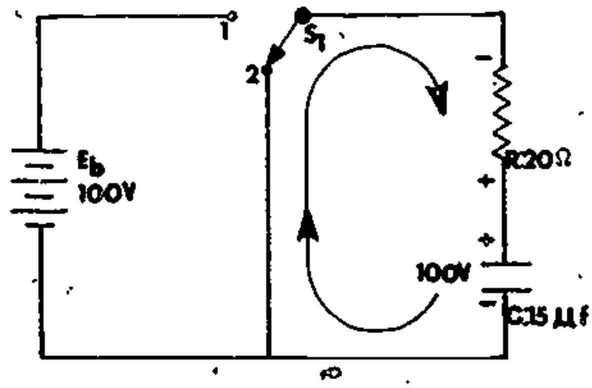
22. The greatest rate of change in current occurs between:

_____ a. T1 - T2.
_____ b. T2 - T3.
_____ c. T4 - T5.
_____ d. T0 - T1.

(d) T0 - T1

23. Use the graphs below to answer frames 24 to 27. These graphs show E_C, circuit current, and E_R during discharge of the capacitor in the RC circuit shown below. (Circuit is de-energized at time zero.)





DECAY CURVES

(Go to next frame)

24. The greatest voltage drop across the resistor is at time:

____ a. T0.
____ b. T1.
____ c. T3.
____ d. T5.

(a) T0

25. The capacitor is completely discharged at:

____ a. T1.
____ b. T4.
____ c. T6.
____ d. T2.

- -

(c) T6

26. The greatest rate of change in current is between:

____ a. T1 - T2.
____ b. T2 - T3.
____ c. T4 - T5.
____ d. T0 - T1.

- -

(d) T0 - T1

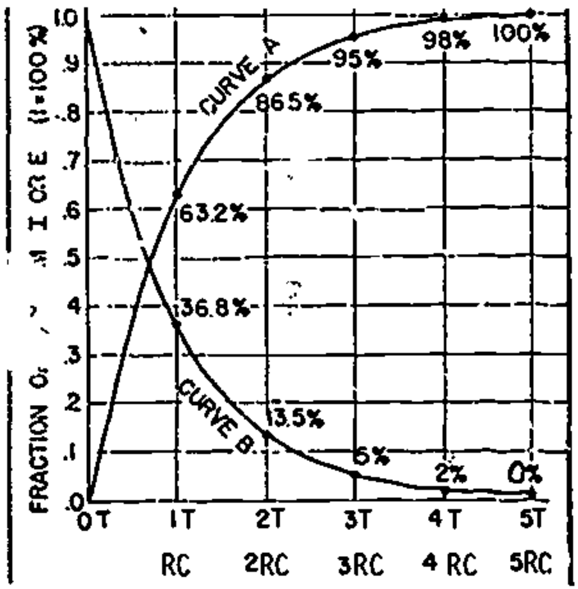
27. When the electrostatic field of the capacitor is depleted what are the values of:

Current? ________
E_C? ________
E_R? ________

- -

(all zero)

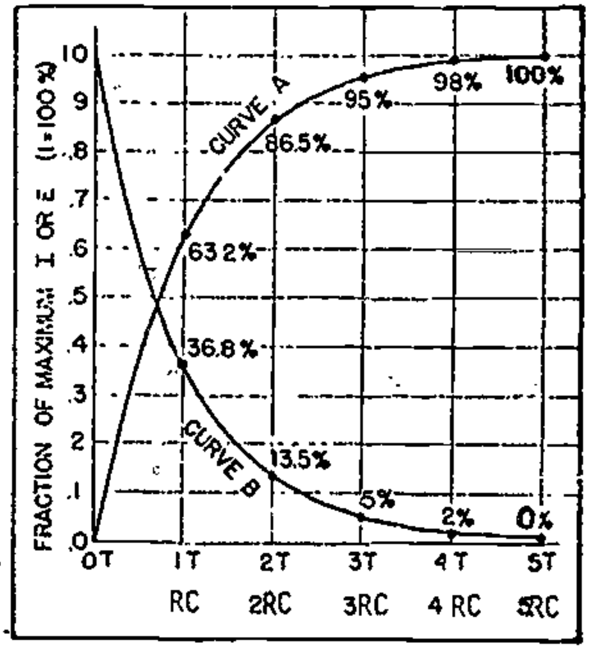
28. Let's look again at our old friend the Universal Time Constant Chart which <u>never</u> changes.

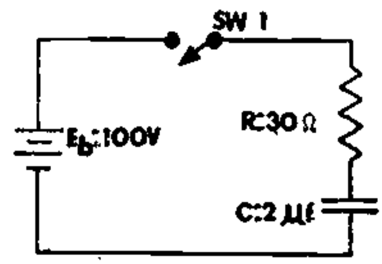


From this chart, you can determine the values of E_C, E_R and I during the __________ and __________ of an RC circuit.

(growth or charge; decay or discharge)

29. Recall that you can solve for quantities at particular time constants by using the percentages on the chart and multiplying maximum values by the percentage for the time constants.





Example:

In the circuit shown, find:

1. the time constant. ______
2. E_R (2 TC after switch is closed). ______
3. E_C (180 μsec after switch is closed.) ______
4. I (5 TC after switch is closed.) ______

(Answers on next page.)

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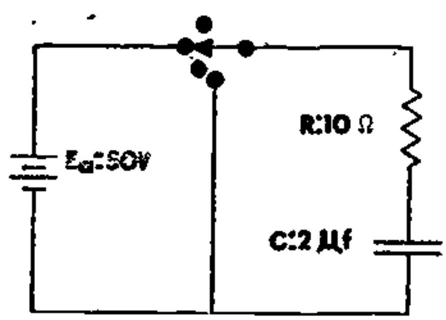
1. TC = R x C
   TC = (30Ω) (2 μf)
   TC = 60 μsec

2. E_R after 2 TC:
   100 v x 0.135
   E_R = 13.5 v

3. After 180 μsec, we are at the
   3rd time constant
   100 v x 0.95
   E_C = 95 v

4. Capacitor is fully charged
   Current flow stops
   I = 0 a

30.



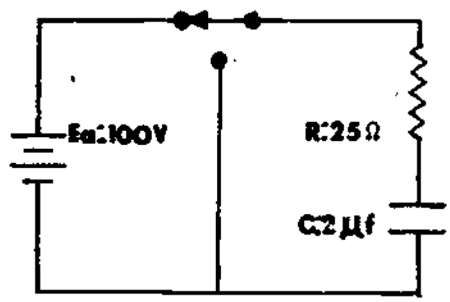
Assume the capacitor in the above circuit is being charged.
What is the voltage drop across the capacitor after 60 μsec?

____ a. 47.5 v
____ b. 2.5 v
____ c. 50 v

(a) 47.5 v

110

31.

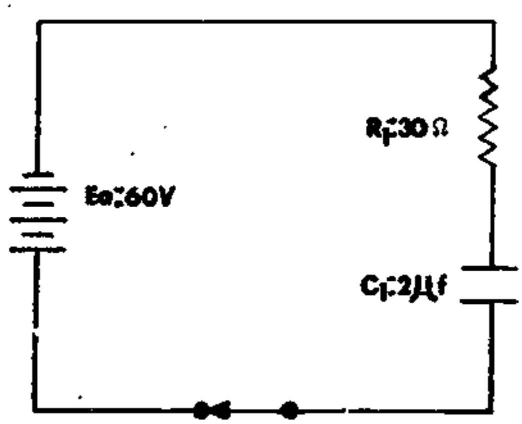


Assume the capacitor in the above circuit is being discharged. What is I at T1?

____ a. 4 a
____ b. 2.52 a
____ c. 1.47 a

(c) 1.47a

32.

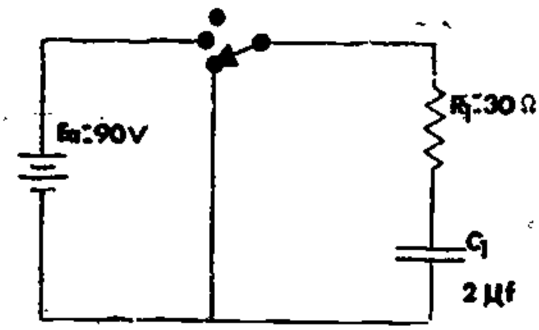


Assume the capacitor is being charged. Solve for the quantities indicated.

a. I maximum ____________
b. TC ____________
c. E_R at T2 ____________
d. E_C at T3 ____________
e. I at T4 ____________

(a. 2a; b. 60 μsec; c. 8.1v; d. 57v; e. 0.04a)

33.



The capacitor started discharging at T0. Solve for:

a. I at T1 ____________
b. E_R at T1 ____________
c. E_R at T3 ____________
d. I at T5 ____________
e. E_C at T5 ____________

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 33

a. 1.10 amps

b. 33.12 v

c. 4.5 v

d. 0 amps

e. 0 volts

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 37. OTHERWISE, GO BACK TO FRAME 18 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 33 AGAIN.

34. Recall that the time constant is directly proportional to the product of R and C.

If R or C is decreased in a DC RC circuit, it takes:

____ a. less time to charge the capacitor.
____ b. more time to charge the capacitor.
____ c. the same time to charge the capacitor.

(a) less time to charge the capacitor

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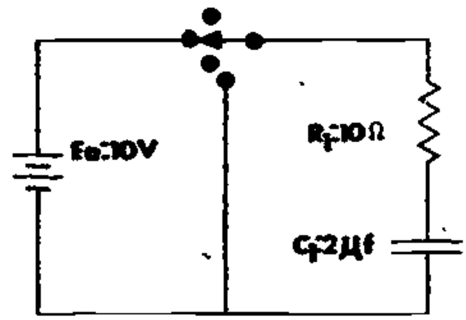
35.



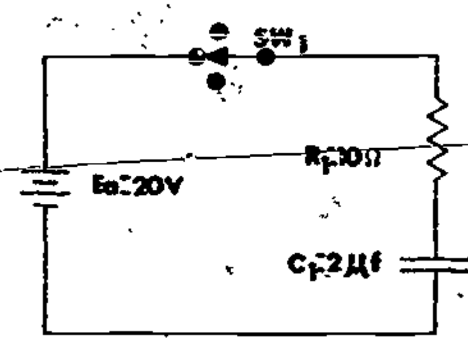
In a DC RC circuit, if E_a is increased or decreased, the time constant will not change.

If the applied voltage in the above circuit is varied, the capacitor charges to 63.2% of E_a in ________.

____ a. 5μsec.
____ b. 10μsec.
____ c. 20μsec.

(c) 20 μsec

36.



Notice that in the above circuit we have increased E_a but left the values of R and C the same. Now the capacitor must charge to a higher voltage in the same period of time.

In a DC RC circuit, if E_a is increased then the rate of charge is:

____ a. increased.
____ b. decreased.
____ c. stays the same.

(a) increased

37. In a DC RC circuit, if:

____ 1. R is increased.	a. rate of charge increases
____ 2. E_a is decreased.	b. rate of charge decreases
____ 3. C is decreased.	c. TC decreases
____ 4. E_a is increased.	

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 37

1. b.

2. b.

3. a and c.

4. a.

IF ANY OF YOUR ANSWERS IS <u>INCORRECT</u>, GO BACK TO FRAME 34 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 37 AGAIN.

NOW TAKE THE EXPERIMENT WHICH BEGINS ON THE NEXT PAGE, IF YOU HAVE NOT ALREADY DONE SO.

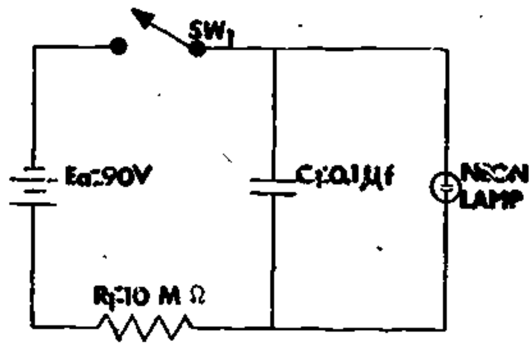
EXPERIMENT

RC Time Constant

This experiment illustrates one possible application of RC circuits making use of RC time constants.

1. Draw Practice Board #11-4, a 90-volt battery, a 10 MΩ resistor, a 1 MΩ resistor, and an oscilloscope from the resource center.

2. This is the circuit you will be working with.



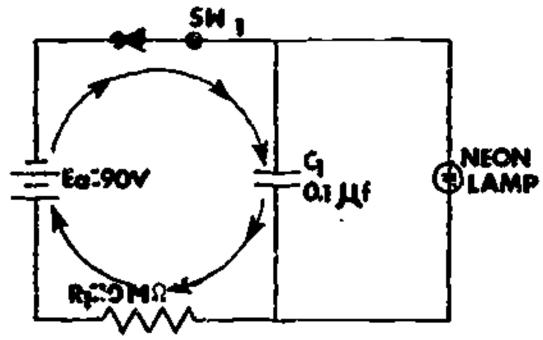
First an explanation of a new device, the neon lamp. This type of lamp is designed to fire (light) at a particular voltage (65-70 v for this lamp). Until this voltage is impressed across it, the lamp acts as an open circuit and no current flows through it. When the proper voltage is applied, the lamp fires and acts as a short circuit, conducting current until the voltage drops below its extinguishing voltage (approx 35-40 v for this lamp).

At the instant the switch is closed will the lamp light?

______ Yes/No

ANSWERS ARE LOCATED ON PAGE 114.

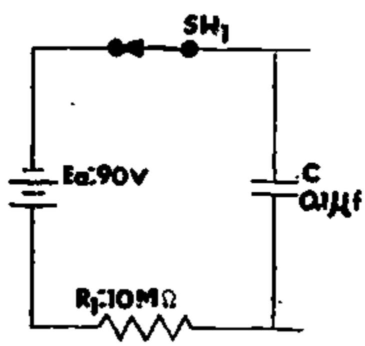
3.



At the instant the switch is closed, current flows as shown, charging the capacitor through the 10 MΩ resistor. No current flows through the neon lamp because the firing voltage has not yet been reached.

Disregarding the neon lamp, how long does it take to charge the capacitor to source voltage? ____________

4. Because no current is flowing through the lamp, the circuit at this time appears as a 10 MΩ resistor in series with a 0.1 μfd capacitor as shown:



$TC = R \times C$

$(10 \times 10^6) \cdot (.1 \times 10^{-6})$

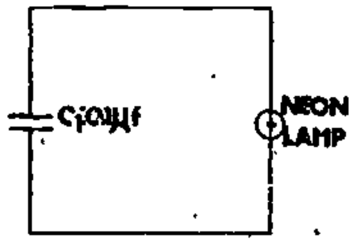
<u>TC = 1 sec</u>

Charge time = 5 TC

5(s) = <u>5 sec</u>.

The neon lamp is in parallel with the capacitor. Will the capacitor ever charge to 90 v? ________
Yes/No

5. Since voltage is common across a parallel network, the voltage developed across the capacitor as it charges is impressed across the neon lamp. Once the capacitor has charged to a value equal to the lamp's firing voltage (65-70 v), the lamp fires, conducting current and discharging the capacitor.

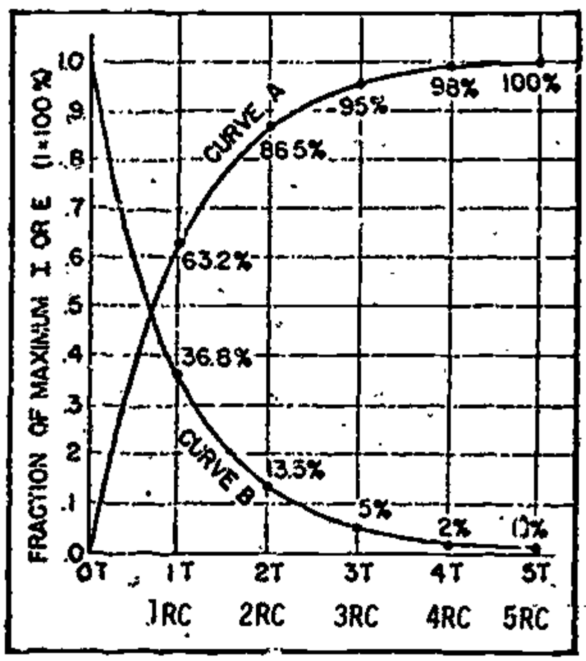


The neon lamp has a cut-off voltage of 35-40 volts. Will the capacitor discharge completely when the lamp fires? ______ Yes/No

6. To determine the time required for the capacitor to charge enoug to fire the lamp the first time, two values must be considered, the firing voltage (65-70 v) and the time constant (1 sec).

Source voltage is 90 v; so after 1 sec the capacitor charges to ________ volts, after 2 sec it could charge to ________ volts.

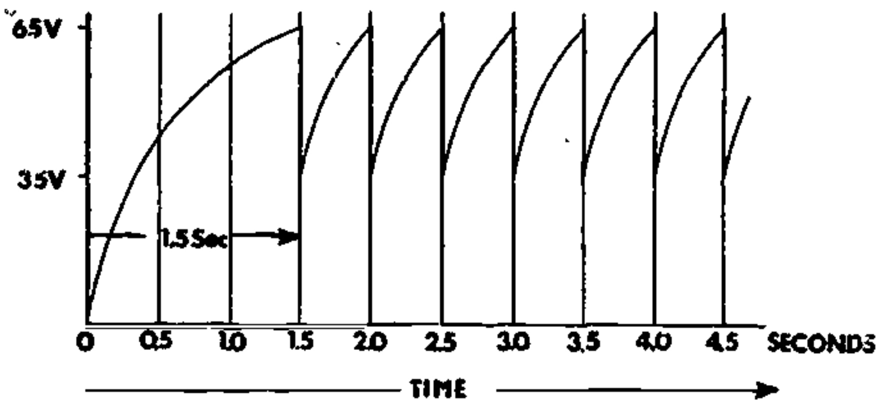
7. The firing voltage for the lamp lies between these two values. So the initial flash time must be somewhere between 1 and 2 sec. By using the Universal Time Constant Chart, the time can be pin-pointed with a little more accuracy as _____ to _____ seconds.



8. Connect the 90 v battery between terminals T1 and T8. Now measure the time it takes for the lamp to flash for the first time. Close the switch and time the first flash. De-energize the circuit and short the capacitor. Repeat this procedure several times to find an average time. REMEMBER THE CAPACITOR MUST BE SHORTED EACH TIME THE CIRCUIT IS DE-ENERGIZED.

Time ____________________

9. If you left the circuit energized after the initial flash, you may have noticed that the subsequent flashes occurred in less time (about 0.5 sec apart). The increased firing rate occurs, because the lamp does not conduct long enough to completely discharge the capacitor. This graph shows the voltage variations in the circuit after the switch is closed (Time 0).



Notice that on the initial charge, the capacitor must charge from 0 to approximately 65 volts while on each succeeding charge it only has to go from 35 to 65 volts.

10. The flash rate may be varied by changing the value of resistance in series with the capacitor.. To prove this, replace the 10 MΩ resistor with the 1 MΩ resistor. This decrease in resistance causes the flash rate to ________________. To prove your
increase/decrease
answer energize the circuit and observe the flash rate. De-energize the circuit and short the capacitor.

11. The charge and discharge cycle of the capacitor may be viewed by placing an oscilloscope across the capacitor.

    a. Set the oscilloscope up according to the instructions given in "The Oscilloscope Job Program 9-6-1."

b. Connect the ground lead to the negative side of the capacitor.

c. Connect the probe to the positive side.

d. Energize the circuit and adjust the scope to obtain a clear trace.

e. Sketch the trace:

f. De-energize the circuit and short the capacitor.

g. Turn off and disconnect the scope.

h. Replace the 1 MΩ resistor with the 10 MΩ resistor.

i. Return materials to the resource center.

Answers:

2. No

3. 5 sec

4. No

5. No

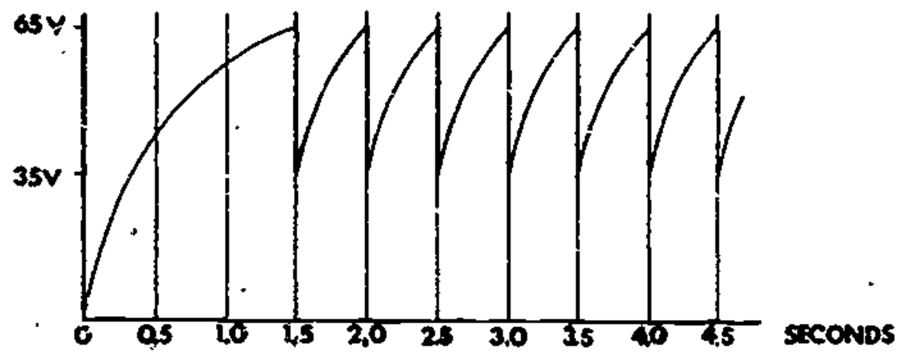
6. 56.89 v; 77.8 v

7. approximately 1.25 - 1.5 sec

8. between 1.2 and 1.5 sec

10. Increase

11. e. The sketch should be similar to:



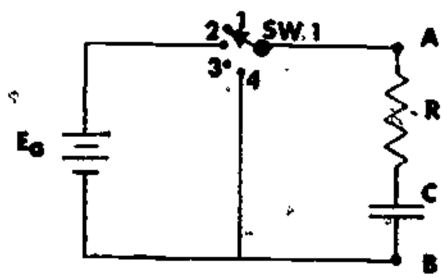
YOU MAY NOW TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON IV

RC Time Constant

In a purely capacitive circuit, the capacitor charges instantly when the voltage is applied, and similarly, discharges instantly when shorted. Practically, every circuit has conductor resistance (wire), internal resistance (source) and other resistive components. The resistance in the below illustration represents all circuit resistance lumped into one valve. In this lesson we will discuss the phenomenon of resistive-capacitive circuits in the transition state. That is, we want to describe voltage and current characteristics of an RC circuit during the time of charging or discharging the capacitive elements.

A typical resistive-capacitive circuit is illustrated below. It contains a voltage source, resistive and capacitive components, and a switch which can be positioned for: (1 and 3) open circuit; (2) capacitor charging; and (4) capacitor discharging.



In position 1, there is no current flow, no voltage drop across R, and no charge on the capacitor.

At the instant the switch is closed to position 2, the full voltage, E_a, appears across points A to B and current flows.

By Ohm's Law, the instantaneous maximum current flow is $I = \frac{E_a}{R}$.

At this initial time (Time 0), current is maximum, voltage drop across R is equal to E_a, and the voltage and charge across C is zero. As the capacitor charges, a voltage develops across C opposing E_a and, hence, decreases current flow. When the charge of the capacitor reaches maximum, the voltage drop across C is equal and opposite to E_a preventing any more current flow. Therefore, the larger R is, the longer the time required to reach equilibrium.

When the switch is moved to position 4, the capacitor-resistor elements are shorted, and the voltage across C produces a current, $I = \frac{E_C}{R}$, moving in the opposite direction to the charging current.

It is important to note that:

$$E_a \text{ (max)} = E_C \text{ (max)}$$

and

$$I \text{ charging (max)} = I \text{ discharging (max)}$$

since R is constant. As discharge current flows, I and E_C approach zero.

Computing RC Time Constants

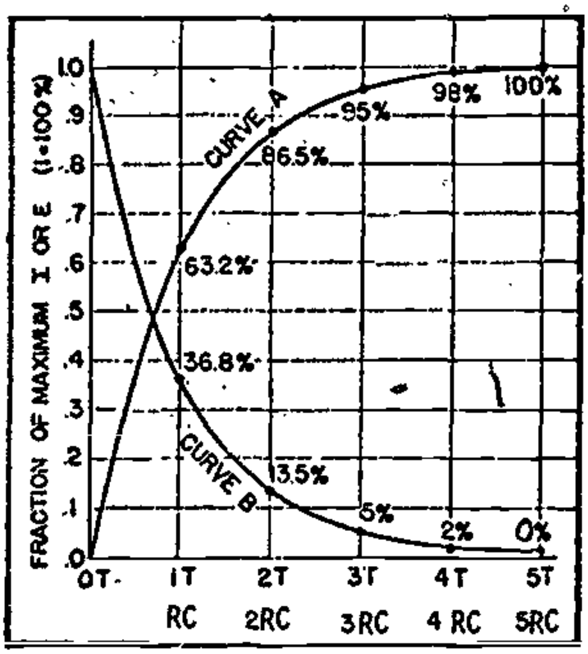
By definition, the time it takes a capacitor to charge and reach 63.2% of its maximum voltage, E_a, is one time constant, TC.

$$TC = R \times C$$

Likewise, the time constant for discharging a capacitive-resistive circuit from maximum is that time E_C takes to fall to 36.8% of its maximum value. This is the same TC calculated from the formula for the same RC circuit.

Universal Time Constant Chart

The Universal Time Constant graph that was valid for inductance also applies to capacitive phenomenon in the transition state.



With the switch at position 2 at Time 0, I and E_a are maximum. Capacitor voltage, E_C, is zero. As current flows and charging of C occurs, Curve A represents the increasing capacitor voltage. Curve B represents the decreasing current and voltage drop across R.

You can calculate maximum values of E_R and I at Time 0 from Ohm's Law. The RC time constant of the circuit is calculated from TC = R x C. From the graph, you can then calculate E_C, E_R, and I at any time by multiplying the maximum values by the percentage for that time.

The time constant of any RC circuit depends only on the values of R and C and does not depend on E_a.

AT THIS POINT, YOU MAY PERFORM THE EXPERIMENT WHICH STARTS ON PAGE 110 PRIOR TO TAKING THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU DO THE EXPERIMENT, TAKE THE PROGRESS CHECK, AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE ELEVEN
LESSON V

Capacitive Reactance

Study Booklet

OVERVIEW
LESSON V

Capacitive Reactance

In this lesson you will study and learn about the following:

- how a capacitor works
- comparing inductors and capacitors
- capacitance in AC circuits
- how frequency affects X_C
- how capacitance affects X_C
- mathematical formula for X_C
- how X_C affects current

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON V

Capacitive Reactance

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative

Programmed Instruction

Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1b "Basic Electricity, Alternating Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

AUDIO-VISUAL:

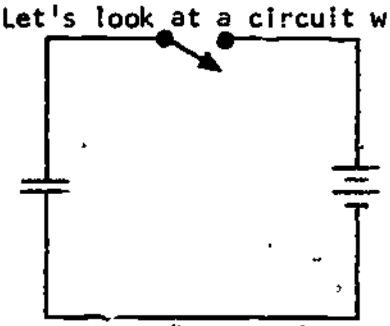
Super 8 - "Capacitive Reactance"

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON V

Capacitive Reactance

How a Capacitor Works



Let's look at a circuit with a capacitor in it. At the instant that the switch is closed, there is no voltage developed across the capacitor, so the source sees no opposition in the circuit. Circuit current is maximum at this first instant and electrons will pile up on one plate of the capacitor and pull away from the other plate until a difference of potential equal to source voltage builds up across the capacitor. At that time, E_a and E_C are equal and opposite, and the displacement current ceases.

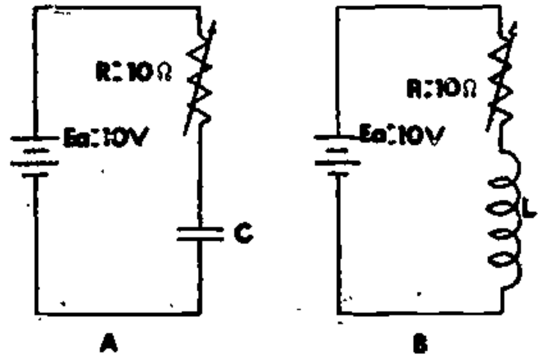
Now, with the capacitor in a fully-charged state, if the source were changed from 10 volts to 20 volts, the capacitor would again react to a voltage change by charging until a capacitor voltage of 20 volts was reached.

You recall that capacitance is associated with the ability of a circuit to oppose a change in voltage. Therefore, any change in the applied voltage -- not only an increase, but also a decrease -- causes the capacitor to react. For example, if the applied voltage to our capacitive circuit were decreased now from 20 volts to 10 volts, the capacitor would discharge until E_C was again equal to E_a.

The capacitor opposes changes in the source voltage through the charge and discharge currents. The delay in the change of capacitor voltage in an RC circuit (RC time constants) is a good illustration of this.

Comparing Inductors and Capacitors

To point out that a capacitor reacts to the rate of change in voltage, not to the rate of change in current, it may help to analyze the two circuits at the top of the next page:



NOTE: Assume both circuits have been on for more than five time constants.

How would the inductor and the capacitor react in the circuits above if the variable resistor were changed from 10Ω to 5Ω? ______________________________

____

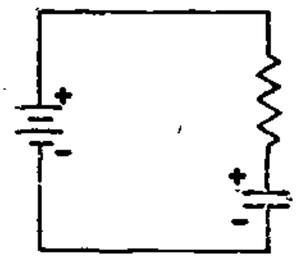
Note that in circuit B, if resistance were decreased, current would increase, and the inductor would react to the change in current by producing more CEMF to choke the increase in current flow.

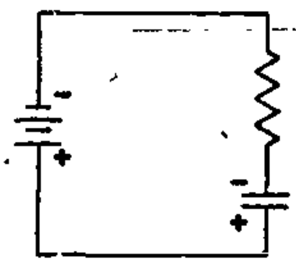
However, in circuit A, as the capacitor is fully charged, displacement current becomes zero, and changing the resistance does not affect a change in current, nor does the capacitor react. A capacitor only reacts to oppose a change in the voltage across it.

Capacitance in AC Circuits

Up to this time, we have observed capacitors in only DC circuits. Now, you can see that if we were to take the battery out of the circuit and quickly reconnect it with the terminals reversed, the electron flow would be opposite to the original direction through the circuit. If we continued to repeat this process very quickly (changing the battery connections back and forth from one polarity to another), we would have the same effect as if we had an AC source, which constantly changes polarity.

To react to the changing voltage, the polarity across the plates of the capacitor must change constantly.





If the capacitor has time (a short enough time constant) to charge to this maximum value, at the moment the voltage reverses, the capacitor reacts by discharging to again equalize the capacitor voltage and the applied voltage. Remember, the amount of resistance and capacitance determines how much time is required to fully charge the capacitor; so it is possible (in fact probable) that the capacitor does not charge to its maximum value when the applied voltage reverses; therefore, the capacitor is continuously charging or discharging.

Capacitive Reactance (X_C)

We noted above that with an AC voltage, it is possible that the capacitor might never have a chance to fully develop the voltage across its plates. We said this depends upon the amount of resistance and capacitance. The higher the frequency, the less time it takes the applied voltage to go from zero to maximum, and consequently, the less time the capacitor has to charge. One other factor affecting this process, then, is the frequency of the applied voltage. The higher the frequency, the less time the capacitor has to react. The less time the capacitor has to react, the higher the current or the less capacitive reactance there is. Increased $f \uparrow$ decreased $X_C \downarrow$. Therefore, we can say that X_C is inversely proportional to f.

Capacitance Affects X_C

Similarly, if you increase the capacitance, X_C decreases. For example, by increasing capacitance we increase the amount of charge required to develop a given potential difference across the capacitor. ($C = \frac{Q}{E}$; therefore, $E = \frac{Q}{C}$.)

If capacitance is increased, it takes the capacitor longer to charge to the applied voltage, and a greater current will flow during the charging process. Thus capacitive reactance is less.

Increased C ↑ decreases X_C↓. Just as X_C is inversely proportional to frequency, it is also inversely proportional to capacitance.

X_C Formula

The formula for finding X_C reflects the inverse relationship of f and C:

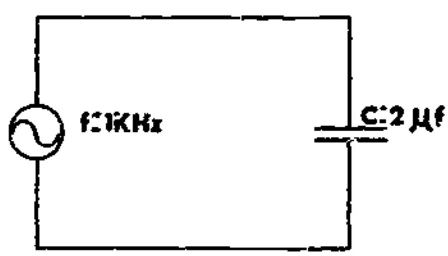
$$X_C = \frac{1}{2\pi fC}$$

Note that although resistance affects the amount of time required to charge or discharge the capacitor, it does not affect the amount of opposition the capacitor offers to the AC current. X_C is independent of circuit resistance.

Here, as in the formula for X_L, the 2π is a constant (6.28). One divided by 2π is equal to 0.159; therefore, you may simplify the X_C formula to:

$$X_C = \frac{0.159}{fC}$$

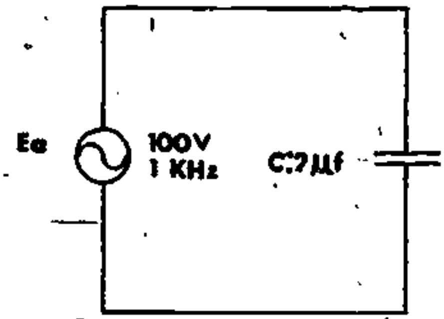
Find X_C in this circuit.



X_C = ________

Answer: 79.5 ohms.

Effects of X_C on Current



Let's see what happens to other circuit quantities when X_C is changed in a purely capacitive circuit.

What happens to total current if we increase frequency? You know that if you increase f: f ↑

X_C ↓

and if opposition decreases: I_T ↑

What happens to total current if you decrease capacitance?

C ↓

X_C ↑

I_T ↓

Substituting X_C in Ohm's Law Formula

As X_C is opposition, it can be substituted for R in the Ohm's Law formulas.

Find I_T in a circuit where E_a = 100v and X_C = 50Ω.

I_T = ____________

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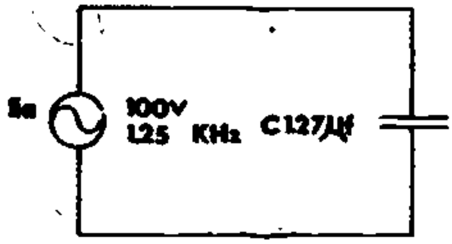
Total current is 2 amps.

$$I_T = \frac{E_a}{X_C}$$

$$I_T = \frac{100\ v}{50\Omega}$$

$$I_T = 2\ a$$

In this circuit find:



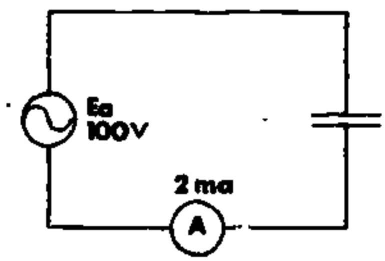
X_C: ______

I_T: ______

Answers: $X_C = 100\ \Omega$

$I_T = 1\ a$

Find X_C. ______________



Answer: $X_C = \frac{E_a}{I_T}$

$$X_C = \frac{100\ v}{2ma}$$

$$X_C = 50\ k\Omega$$

In Lesson III you learned that parallel capacitance is additive and that series capa itance must be computed by the product over the sum or reciprocal method. This is true only for capacitance. Capacitive reactance is an opposition to current and is measured in ohms. Because of this, total capacitive reactance (X_{CT}) is computed in the same manner as total resistance.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON V

Capacitive Reactance

TEST FRAMES ARE 16, 29 AND 31. AS BEFORE, GO FIRST TO TEST FRAME 16 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

---

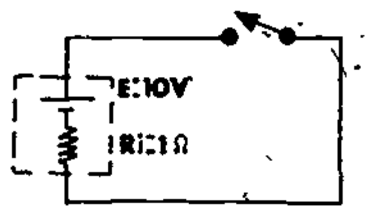
1. Recall that one of the characteristics of capacitance is the ability to oppose a change in circuit ____________.
   voltage/current

- -

(voltage)

---

2. We can most easily observe how this happens by recalling our knowledge of internal resistance.



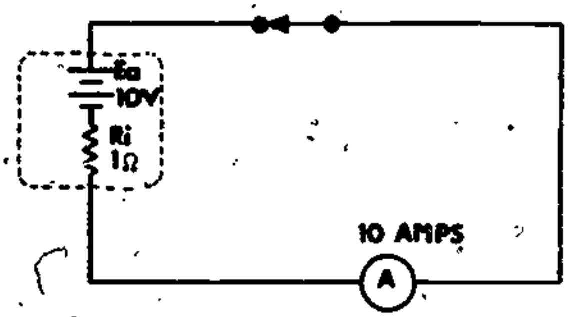
When the switch is closed, current flow is:

_____ a. 1 amp.
_____ b. 10 amps.
_____ c. 0.1 amps.

- -

(b) 10 amps

3.

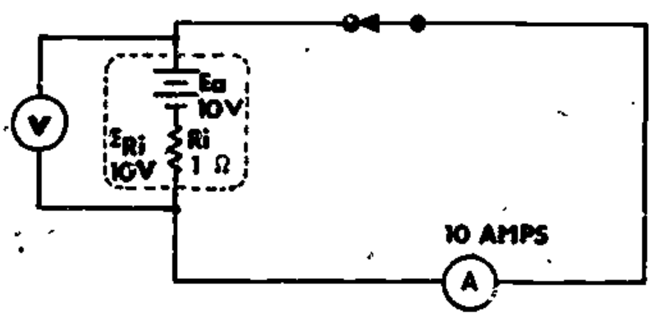


How much voltage is dropped across the internal resistance?

_____ a. 5 volts
_____ b. 1 volt
_____ c. 10 volts

(c) 10 volts

4.



Theoretically, the entire amount of applied voltage would be dropped across the internal resistance.

Internal resistance:

_____ a. decreases the terminal voltage of the source.
_____ b. increases the terminal voltage of the source.
_____ c. has no effect on the terminal voltage of the source.

(a) decreases the terminal voltage of the source

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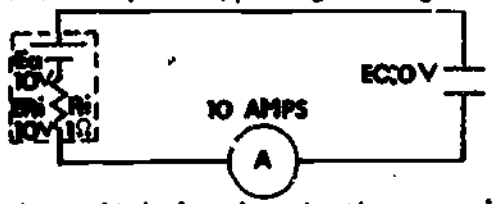
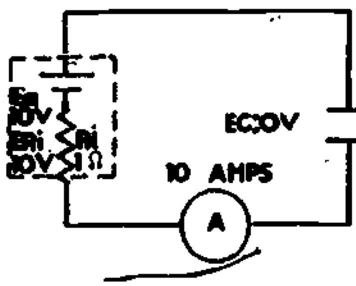
5. Let's look at this same circuit with a capacitor in it. At the instant the switch is closed, the capacitor has not had a chance to charge and develop an opposing voltage.



The instant the switch is closed, the capacitor in the above circuit acts like a/an __________ circuit.
open/short

(short)

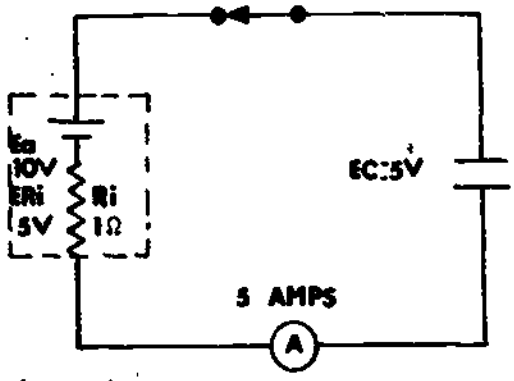
6.



The instant the switch is closed in the above circuit, only the ______________________ is limiting current flow.
capacitor/internal resistance

(internal resistance)

7.

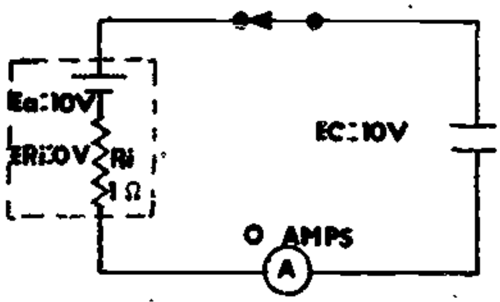


As the capacitor charges:

____ a. E_{R1} decreases.
____ b. terminal voltage decreases.
____ c. terminal voltage increases.
____ d. E_{R1} increases.

(a. E_{R1} decreases; c. terminal voltage increas s.)

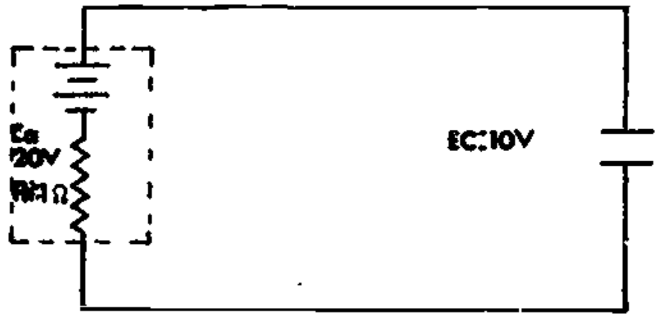
8.



The terminal voltage of the source in the above circuit does not reach its full value until the capacitor is fully ____________.

(charged)

9.



If we now suddenly change E_a to 20 v, the capacitor has to react to this change by ______________.
charging/discharging

- -

(charging)

10. Any change in the applied voltage causes the capacitor to react to that change.

If E_a in a capacitive circuit decreases, the capacitor has to ______________.
charge/discharge

- -

(discharge)

11. Due to the property of capacitance, any change in E_a causes the capacitor to react so as to limit the change in capacitor voltage until the capacitor is fully charged or discharged.

Check the correct statement(s).

____ a. While the capacitor is charging or discharging, a voltage is developed across Rl.

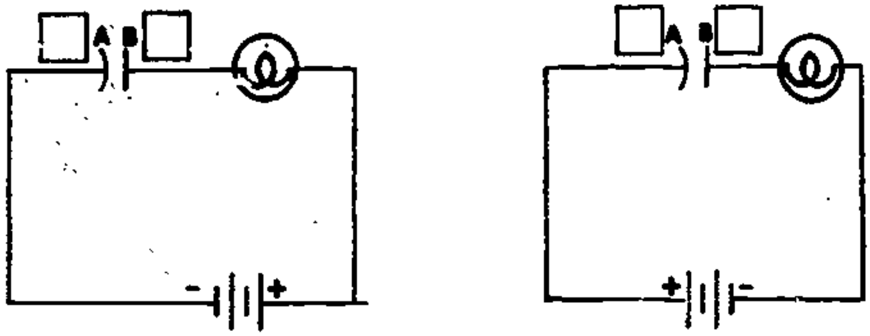
____ b. While the capacitor is charging or discharging, the capacitor voltage does not equal E_a.

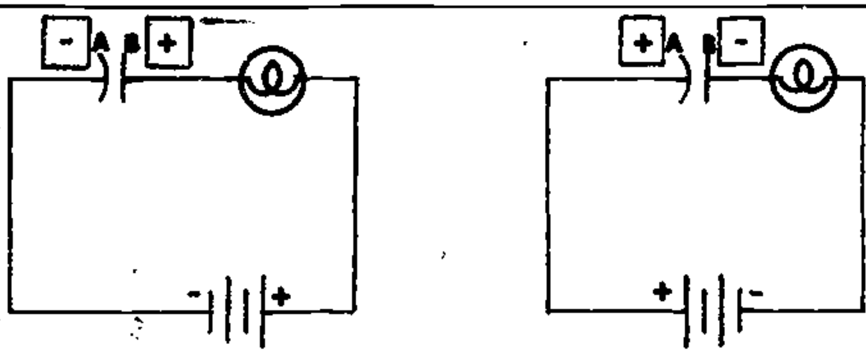
____ c. While the capacitor is charging or discharging, the terminal voltage does not change.

(a. While the capacitor is charging or discharging, a voltage is developed across Rl; b. While the capacitor is charging or discharging, the capacitor voltage does not equal E_a.

12. Let's see what happens when we use an alternating source voltage in a capacitive circuit.

You can reverse the charge across a capacitor by reversing the battery as shown below. In each circuit, draw the polarity signs in the boxes next to plates A and B.

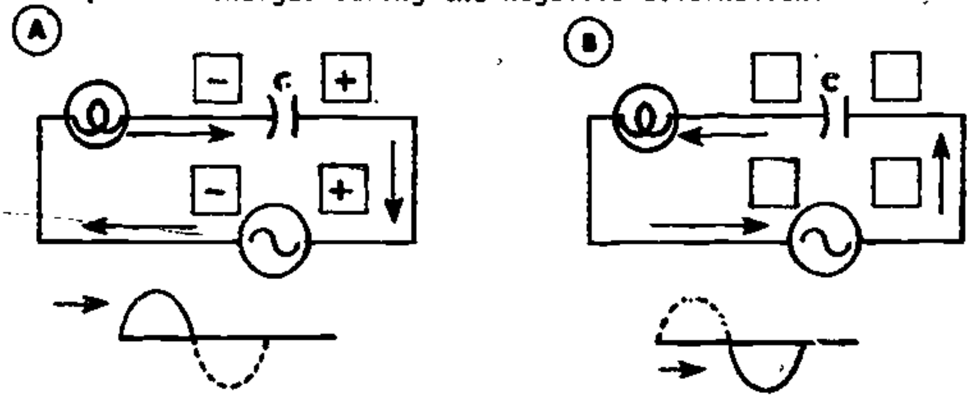


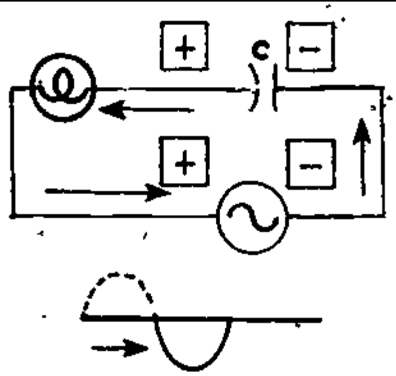


13. An AC generator alternately reverses polarity; therefore, if we connect an alternator across the circuit, the capacitor reverses its charge with each ________ of AC voltage.

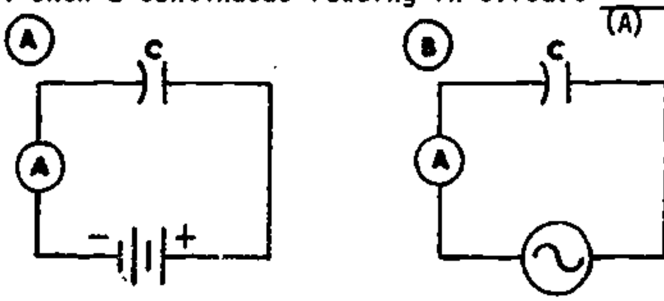
(alternation)

14. In figure A, the positive alternation charges the capacitor as shown. Draw the polarity signs in figure B to show how the capacitor charges during the negative alternation.





15. If you connect ammeters into the circuits below, the ammeter will show a continuous reading in circuit ______.
(A) (B)



(B)

16. A capacitor:

____ a. blocks AC.

____ b. blocks a steady flow of DC.

____ c. acts as an open in a DC circuit when it is fully charged.

____ d. acts as a short in a DC circuit when fully charged.

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 16

b. blocks a steady flow of DC.

c. acts as an open in a DC circuit when it is fully charged.

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO TO TEST FRAME 29. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 16 AGAIN.

---

17. When there is an AC source, the capacitor is constantly reacting to the change and developing a voltage that opposes any change in E_a.

The effect of these two opposing voltages ____________ current.

(limit)

---

18. The opposition which a capacitor offers to alternating current is called capacitive reactance and is designated X_C.

Capacitive reactance:

____ a. limits current flow in a capacitive AC circuit.
____ b. is an ability to oppose a change in voltage.
____ c. is an ability to oppose a change in AC current.

(a) limits current flow in a capacitive AC circuit

19. The opposition a capacitor offers to AC is measured in the same units as the opposition an inductor or resistor offers.

X_C is measured in:

_____ a. henrys.
_____ b. farads.
_____ c. ohms.

- -

(c) ohms

20. When the source is constantly changing polarity, as in AC, it is possible that the capacitor might never have the time to develop an opposing voltage equal to the source voltage.

The faster an AC voltage changes, the ________ the capacitor will react. (more/less)

- -

(less)

21. We can say then that capacitive reactance is inversely proportional to frequency.

If frequency is decreased:

_____ a. X_C goes up.
_____ b. X_C goes down.
_____ c. X_C stays the same.
_____ d. C goes up.

- -

(a) X_C goes up

22. Since a greater amount of capacitance must accumulate more charge to reach a given voltage, you can see that if C is increased, it takes longer for the capacitor to charge and it reacts less quickly.

If capacitance is increased:

____ a. X_C goes up.
____ b. X_C goes down.
____ c. X_C stays the same.

(b) X_C goes down

23. We can say that X_C is ________ proportional to f and C.

(inversely)

24. The formula for finding X_C reflects the inverse relationships of f and C.

$X_C = \frac{1}{2\pi fC}$ Where: X_C = capacitive reactance in ohms

2π = a constant (6.28)

f = frequency in Hertz

C = capacitance in farads

Example: What is the X_C of the circuit illustrated below?

Solution: $X_C = \frac{1}{2\pi fC}$

$$X_C = \frac{1}{(6.28)(4 \times 10^3)(25 \times 10^{-6})}$$

Note: Any time you have $\frac{1}{6.28}$ you can simplify the equation and substitute 0.159 for the numeral 1 above the line. ($X_C = \frac{0.159}{fC}$)

So: $X_C = \frac{0.159}{(4 \times 10^3)\ (25 \times 10^{-6})}$

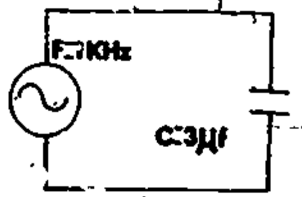
$$X_C = \frac{0.159}{100 \times 10^{-3}}$$

$$X_C = 1.59\ \Omega$$

- -

(Go to next frame)

25. What is the capacitive reactance of the circuit illustrated below?



____ a. 53 MΩ
____ b. 8 MΩ
____ c. 53 Ω
____ d. 1 kΩ

(c) 53 Ω

26. X_C cannot be measured with an ohmmeter, but the value of E_a and I can be determined and Ohm's Law applied.

The Ohm's Law formula to find X_C can be written as:

____ a. $X_C = \frac{I}{E}$.

____ b. $X_C = E \times I$

____ c. $X_C = \frac{E}{I}$.

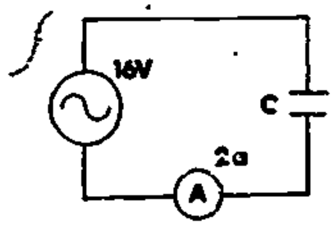
(c. $X_C = \frac{E}{I}$

27. What would your ohmmeter reading be if you attempted to measure X_C across a capacitor?

____ a. 0 ohms
____ b. infinity
____ c. depends on the resistance of the capacitor

(b) infinity (It will read infinity because the capacitor will simply charge to the value of the internal batteries of the ohmmeter, and then all current will stop.)

28. Calculate X_C in the circuit illustrated below.



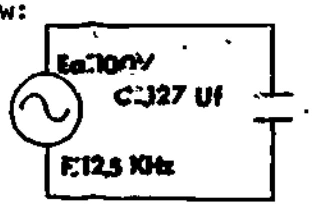
___ a. 8 Ω
___ b. 32 Ω
___ c. 1.25 Ω

- -

(a) 8 Ω

29. Solve for the quantities listed in the circuits illustrated below:

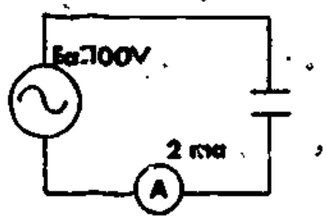
A.



X_C = ______

I_T = ______

B.



X_C = ______

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 29

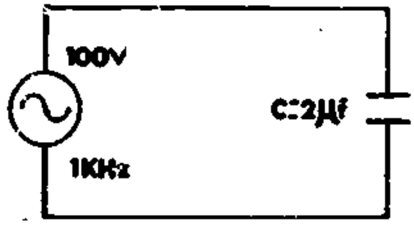
A. 100 Ω, 1 amp

B. 50,000 Ω

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO TO TEST FRAME 31. OTHERWISE, GO BACK TO FRAME 17 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 29 AGAIN.

30. Since X_C depends on the frequency of the applied voltage and the amount of capacitance, let's see what happens to other quantities when these values are changed in a purely capacitive circuit.

Example:



If frequency is increased in the above circuit, then X_C decreases; if X_C decreases, then I_T must increase.

f ↑

X_C ↓

I_T ↑

If C is decreased in the above circuit, then:

____ a. X_C decreases.

____ b. X_C increases.

____ c. I_T decreases.

____ d. I_T increases.

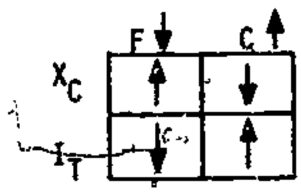
(b. X_C increases; c. I_T decreases)

31. Indicate by arrows what will happen to X_C and I_T in an AC capacitive circuit if f is decreased; if C is increased.

	F ↓	C ↑
X_C		
I_T		

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

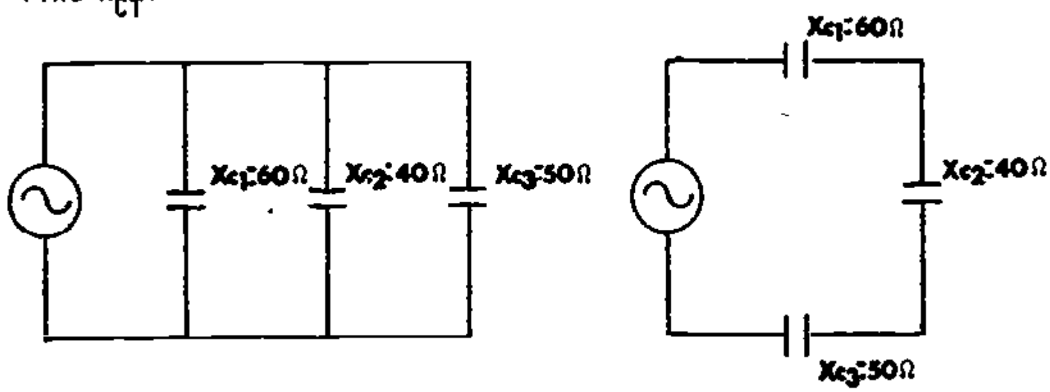
ANSWERS - TEST FRAME 31



IF ANY OF YOUR ANSWERS IS INCORRECT, GO BACK TO FRAME 30 AND TAKE THE PROGRAMMED SEQUENCE.

32. Total capacitive reactance (X_{CT}) is computed in the same way as total resistance, product over sum or reciprocal method for parallel circuits, addition for series circuits.

Find X_{CT}.



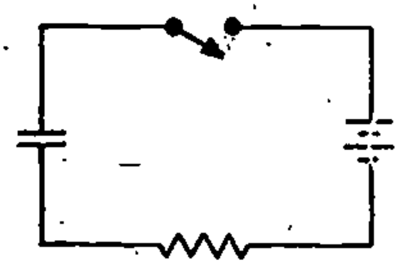
(a. 16.2Ω; b. 150Ω)

YOU MAY NOW TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON V

Capacitive Reactance

You will recall that a capacitor reacts to the rate of change of voltage applied to it. At the instant the switch is closed in the circuit shown, maximum current flows and a difference of potential starts to build up between the capacitor plates. This difference in potential opposes the source voltage and reduces the voltage across the resistor, thereby reducing circuit current. When the capacitor voltage equals the applied voltage, current flow stops. If we then decrease E_a, the capacitor voltage becomes greater than E_a, and current flows in the opposite direction. This reverse current continues until the capacitor voltage again equals E_a.



If we replace the DC source with an AC source, the capacitor voltage continuously varies as it tries to stay equal and opposite to the applied voltage. Because the capacitor voltage opposes applied voltage, it limits current from the source. This opposition to alternating current flow is called <u>capacitive reactance</u>. Its symbol is X_C and it is measured in ohms.

Factors Affecting X_C

<u>Frequency</u> of the AC source voltage affects the magnitude of X_C. With an AC source, the voltage is constantly changing polarity and it is possible that the capacitor may never have a chance to fully charge (develop full potential) before the applied voltage changes polarity. The higher the frequency of changing polarity, the less time the capacitor has to react. The resulting capacitor voltage, opposing the source voltage, never reaches maximum by the time the reverse charging-discharging part of the cycle begins. Therefore, the higher the frequency, the less time the capacitor has to react, the lower the capacitive voltage opposing the source voltage, and the less capacitive reactance. An increase in <u>f</u> produces a decrease in X_C. X_C is inversely proportional to frequency.

<u>Capacitance</u> affects the magnitude of X_C. From the formula for the time constant of an RC circuit, $TC = R \times C$, the time constant increases when capacitance increases. If capacitance increases, it takes longer for the capacitor to charge. The capacitor's reaction takes more current and X_C decreases. X_C is also inversely proportional to <u>C</u>.

The formula for calculating X_C is:

$$X_C = \frac{1}{2\pi fC}$$

where 2π is a constant equal to 6.28.

Since X_C is a measure of opposition to alternating current flow calculated in ohms, increasing X_C by decreasing f or C produces a decrease in I. Similarly, decreasing X_C by increasing f or C produces a corresponding increase in I.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.


DON'T
GET
TURNED
ON
PLAY IT
COOL WITH
ELECTRICITY

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE ELEVEN
LESSON VI

Phase and Power Relationships

Study Booklet

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OVERVIEW
LESSON VI

Phase and Power Relationships

In this lesson you will study and learn about the following:

- -phase relations in a purely capacitive circuit
- -vector representations of phase relationships
- -angle theta, θ
- -power factor

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON VI

Phase and Power Relationships

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative
Programmed Instruction
Experiment
Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1b "Basic Electricity, Alternating Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

AUDIO-VISUAL:

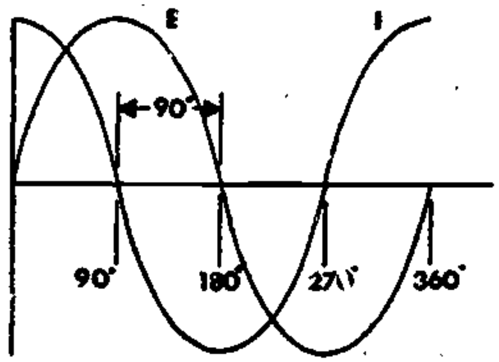
Slide/Sound Presentation - "Capacitance: Phase Relations."

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON VI

Phase and Power Relationships

Phase Relations in a Purely Capacitive Circuit



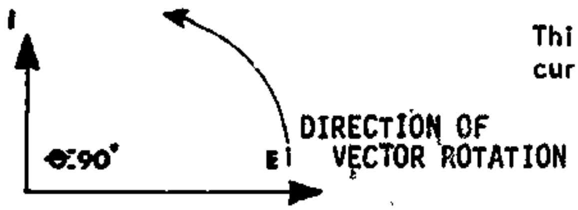
The chart on the left represents the waveforms of both current and voltage in a purely capacitive, idealized circuit. Notice that current and voltage are 90° apart or out of phase.

At 0 degrees on the graph, the rate of change of applied voltage is greatest, and maximum current flows to charge the capacitor to the source voltage value.

As the rate of change of applied voltage decreases (0° to 90° on the graph), the charging current gradually decreases until, at 90°, the capacitor voltage and the applied voltage are not changing and current is 0. An instant later, the applied voltage starts decreasing and a discharge current flows to reduce the capacitor voltage. This discharge current is opposite in direction to the initial charging current, so it is shown on the graph as negative.

At 180°, the rate of change of the capacitor voltage and applied voltage are again maximum, and peak current must flow to keep the two voltages equal. From 180° to 270°, the applied and capacitor voltages increase to their peak negative value while the charging current gradually decreases to 0 at 270°. After 270°, the circuit voltage decreases and the capacitor commences to discharge causing current to flow in the positive direction again. Conditions at 360° are the same as those at 0°, and the cycle repeats as long as the AC voltage is applied to the circuit.

Vector Representation of Phase Relationships



This vector representation shows current leading voltage by 90°.

You can remember the phase relationships in either an inductive or a capacitive circuit by the phrase:

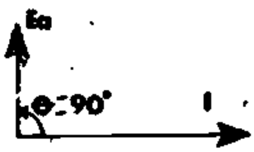
E L I	the	I C E m a n
Voltage leads Current in an inductive circuit		Current leads Voltage in a capacitive circuit

Study the vectors representing the phase relationships that we have learned for the three idealized circuits we have studied.

Purely Resistive

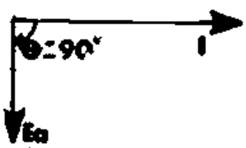
Voltage and current are in phase; therefore, the phase angle is 0°.

Purely Inductive



Voltage leads current by 90°.

Purely Capacitive



Current leads voltage by 90°.

Angle Theta

In the angles of the vectors on the preceding page, this symbol appears: θ. This is the Greek letter theta. Angle theta will be under consideration in our future studies. It is always the phase angle between current and voltage.

Power Factor

In a purely resistive circuit, you know that all the apparent power is dissipated by the load in the form of heat. If P_a in a purely resistive circuit is 100 va, then the P_t is 100 w. When all the power that the source supplies to the circuit is used by the load, the circuit is said to have unity power factor.

Power companies strive to achieve this ideal power factor for reasons of economics. You can easily understand that the company loses money if the plant supplies considerably more current to the circuits than they are paid for. For this reason, power companies pay considerable attention to the power factor in their circuits.

When all the power in a circuit is used, as in a purely resistive circuit, the power factor is unity or one. Unity is the highest power factor possible. In all circuits other than a purely resistive or a purely reactive circuit, the power factor or PF will be between 0 and 1.

Power factor can be computed by dividing true power by apparent power:

$$PF = \frac{P_t}{P_a}$$

Power Factor in Reactive Circuits

In a purely inductive circuit, if P_a equals 100 va, what is P_x? P_x = ________________

Reactive power in a purely inductive circuit equals the apparent power; therefore, P_x = 100 vars.

By the formula for finding the power factor, you can determine the power factor for this purely inductive circuit.

$$PF = \frac{P_t}{P_a}$$

$$PF = \frac{0}{100\ va} = 0$$

In a purely inductive circuit, none of the power is actually being consumed - it is merely being stored and sent back to the source, so the PF is 0.

Similarly, in a purely capacitive circuit, no power is being dissipated. All power is being stored in the electrostatic field and then is returned to the source. Therefore, there is no true power, and the power factor is 0.

Any time you have a purely reactive circuit, the power factor is 0. Any time you have a purely resistive circuit, the power factor is 1. Circuits having both resistance and reactance have a power factor of somewhere between zero and one, depending on the values of both resistive and reactive components.

When you have a purely reactive circuit, what are the values of:

PF? __________

θ? __________

You know the power factor in a purely reactive circuit with no true power is 0. The phase angle is 90°.

In a purely resistive circuit, what is:

PF? __________

θ? __________

The power factor is 1 and phase angle is 0.

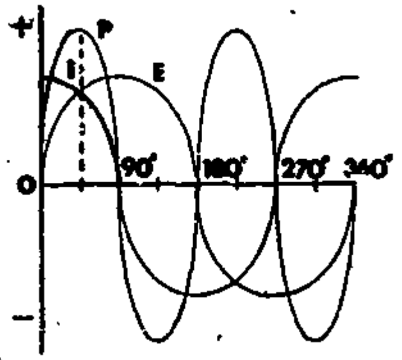
If you know that the PF is 0, what kind of a circuit is represented? __________

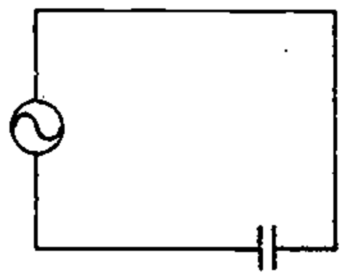
This is a purely reactive circuit, either inductive or capacitive.

If the phase angle is 0°, and PF is 1, what kind of a circuit is represented? __________

This must be a purely resistive circuit.

Let's see what a graphic representation of the current, voltage and power relationships looks like for a purely capacitive AC circuits.





The power curve is drawn by plotting the product of instantaneous voltage and instantaneous current through their variations. The positive alternations of the power graph represent power transfer from the source to the capacitor. The negative alternations represent power returning to the source.

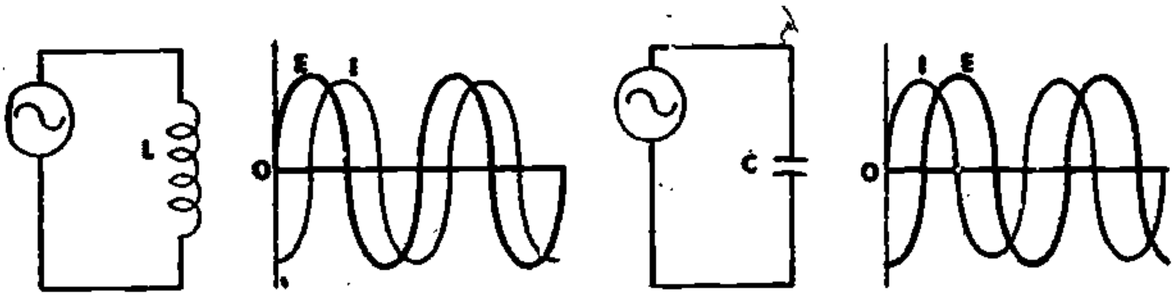
AT THIS POINT, YOU MAY PERFORM THE EXPERIMENT WHICH STARTS ON PAGE 167 PRIOR TO TAKING THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU DO THE EXPERIMENT, TAKE THE PROGRESS CHECK, AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON VI

Phase and Power Relationships

TEST FRAMES ARE 5 AND 17. AS BEFORE, GO FIRST TO TEST FRAME 5 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

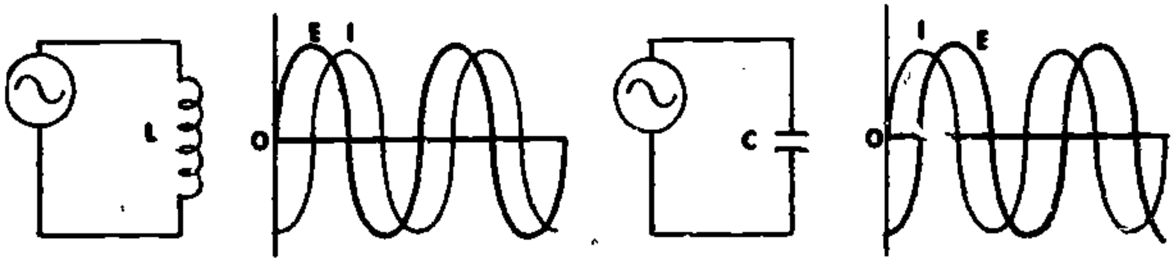
1. Notice that in inductive circuit A, current rises to maximum after voltage. But in capacitive circuit B, current rises to maximum ____________ voltage.
before/after



Circuit A Circuit B

(before)

2. In an inductive circuit, we say that voltage (E) leads current (I). But in a capacitive circuit we say that:



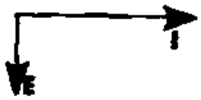
____ a. I and E are in phase.
____ b. E and I.
____ c. I lags E.
____ d. I leads E.

(d) I leads E

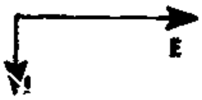
3. In a purely capacitive circuit, the current leads the applied voltage by 90°.

Which of the below vector diagrams represents the phase relation between E and I in a purely capacitive circuit?

____ a. 

____ c. 

____ b. 

____ d. 

(a, c)

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4. To remember the phase relationships of current and voltage in purely inductive and purely capacitive circuits, you can use this memory aid: ELI the ICE man.

ELI means that voltage (E) in a purely inductive circuit (L) ________ current (I).
leads/lags

ICE means that current (I) in a purely capacitive circuit (C) ________ voltage (E).
leads/lags

(leads; leads)

5. In a purely capacitive circuit:

____ a. E leads I by 180°.

____ b. I leads E by 180°.

____ c. I leads E by 90°.

____ d. E leads I by 90°.

(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.)

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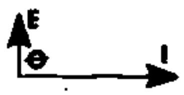
ANSWER - TEST FRAME 5

c. I leads E by 90°.

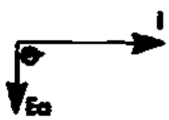
IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO TO TEST FRAME 17. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 5 AGAIN.

6. Let's have a quick review of the three vectors we have used so far in our study of E and I phase relationships.

Match the correct term to each vector.

____ 1. 

____ 2. 

____ 3. 

a. purely resistive

b. purely inductive

c. purely capacitive

(1. b; 2. a; 3. c)

7. Recall that in a purely inductive circuit the power delivered by the source is stored in the inductor's:

____ a. electrostatic field.
____ b. electromagnetic field.
____ c. static field.

(b) electromagnetic field

8. All power that is delivered by the source in a purely capacitive circuit is stored in the capacitor's electrostatic field.

Check the correct statement.

____ a. All power is consumed in a purely capacitive circuit.
____ b. No power is consumed in a purely capacitive circuit.
____ c. The electrostatic field of a capacitor consumes energy.

(b) No power is consumed in a purely capacitive circuit

9. Recall that the power that the source delivers and the circuit apparently uses is called:

____ a. resistive power.
____ b. potential power.
____ c. apparent power.

(c) apparent power

10. Recall that apparent power (P_a) is a product of E_a and I_T and its unit of measure is the:

____ a. watt (w).
____ b. volt amp (va).

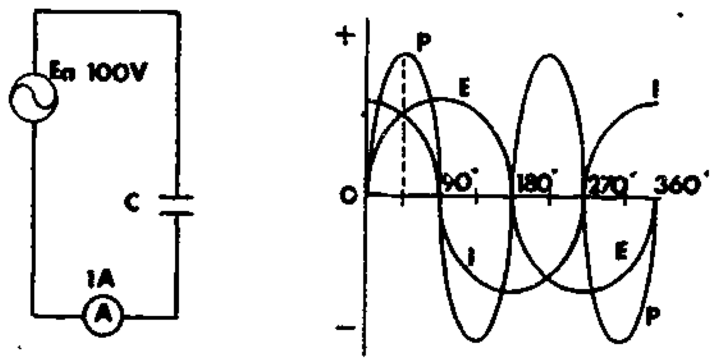
(b) volt amp (va)

11. Also recall that reactive power (P_X) is power that is stored by the reactive component, whether it be an inductor or a capacitor, and its unit of measure is the:

____ a. watt (w).
____ b. volt amp reactive (var).
____ c. volt amp (va).

(b) volt amp reactive (var)

12. Use the illustretion below to answer frames 13 to 17. This chart shows the relationship of power, voltage, and current in a purely capacitive AC circuit. The power waveform indicates that during the charging of the capacitor power is being delivered by the source, and during the discharge of the capacitor power is being returned to the circuit.



(Go to next frame.)

13. The source in the purely capacitive AC circuit shown in frame 12 is furnishing ________ to the circuit.

____ a. 100 w.
____ b. 100 va.
____ c. 100 vars.

(b) 100 va

14. Because the circuit is not consuming any power, the capacitor is storing:

____ a. 100 w.
____ b. 100 va.
____ c. 100 var.

(c) 100 var

15. In a purely capacitive circuit:

____ a. watts equal volt amps.
____ b. volt amps equal volt-amps reactive.

- -

(b) volt amps equal volt-amps reactive

16. The capacitor will charge during what part or parts of the alternator's cycle?

____ a. 90° to 180° and 270° to 360°.
____ b. 0° to 90° and 180° to 270°.
____ c. 0° to 180° only.
____ d. 180° to 360° only.

- -

(b) 0° to 90° and 180° to 270°

17. The energy that is stored by the capacitor, as indicated by the positive alternation of the power waveform, is ______________ on the negative alternation.

____ a. consumed
____ b. returned to circuit

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWER - TEST FRAME 17

b. returned to circuit

IF YOUR ANSWER IS INCORRECT, GO BACK TO FRAME 6 AND TAKE THE PROGRAMMED SEQUENCE.

IF YOUR ANSWER IS CORRECT, DO THE EXPERIMENT WHICH STARTS ON THE NEXT PAGE.

EXPERIMENT

WITH SERIES RC CIRCUIT

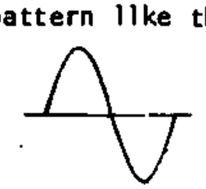
USING THE OSCILLOSCOPE AND A SIGNAL GENERATOR

Now that you have completed the lessons on series RC circuits, set up your test equipment and circuit board and see the phase relationship of E_C and E_R in a series RC network. Draw an O scope and a signal generator from the material center.

If needed, refer to the operating instructions on the scope and signal generator in Module Nine. Otherwise, simply study the scope controls and the signal generator controls. As before, the oscilloscope is a RCA Model WO33A. The signal generator is an EICO, Model 377.

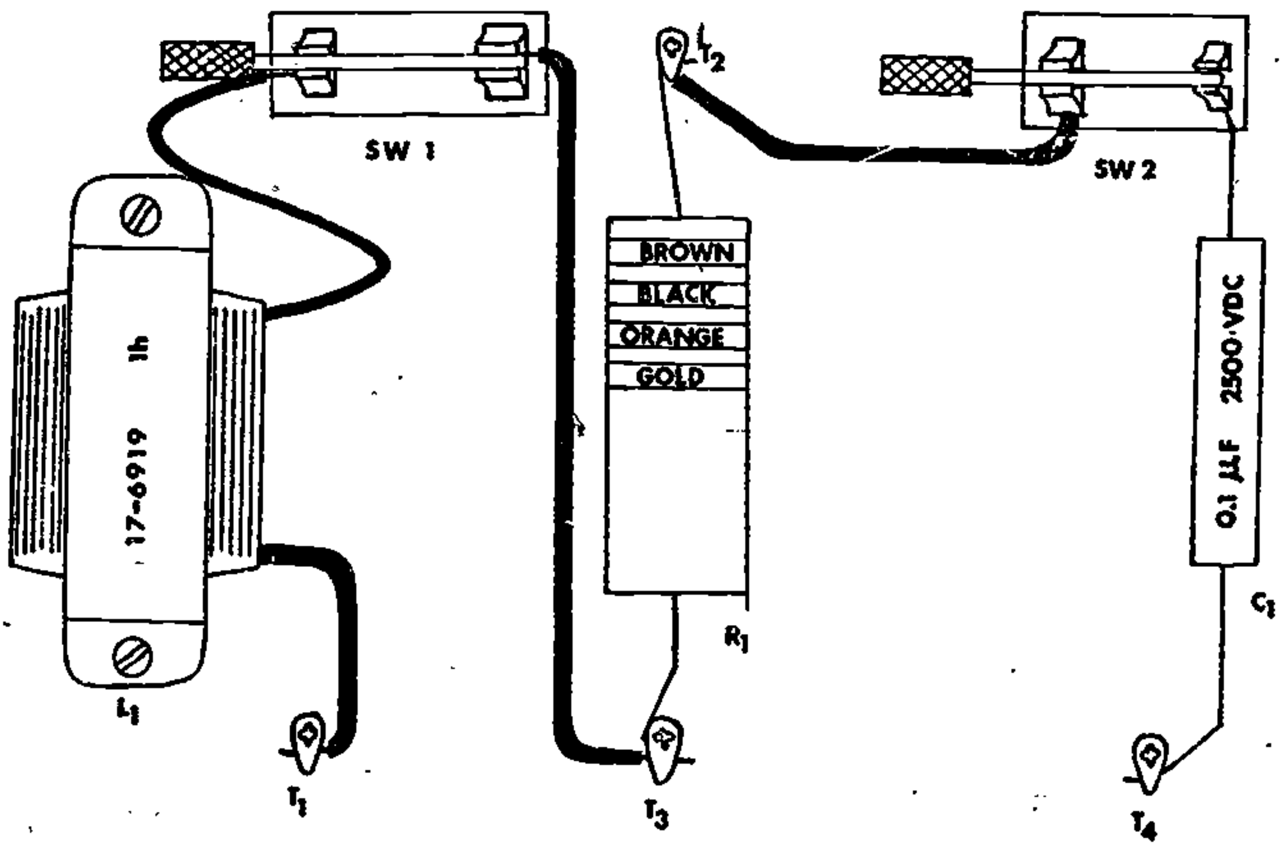
Using the series connected RLC vector board (PB 9-6/11-6), the oscilloscope and the signal generator, do the following:

1. Ensure that scope and signal generator are off.
2. Turn signal generator AMPL (Amplitude) control to 0.
3. Plug scope and signal generator in power source, turn equipment on to warm up.
4. On the vector board, open SW1, close SW2. This sets up a series RC network from T3 to T4.
5. Connect upper output terminal of the signal generator to terminal T4, the lower output terminal to T3.
6. Connect black jumper from upper signal generator output terminal to the EXT SYNC/H input on scope.
7. Connect screw-on test lead to the V input on scope. This test lead has three separate clips on its head, one blue, one black, and one yellow.
8. From scope test lead connect the short black clip to terminal T2 on the vector board.
9. Connect a red test lead to the blue clip; this test lead will be used to pick up our signal at different points in the circuit.
10. On scope, set SYNC switch to EXT position.
11. On scope, set V range to 60.
12. On scope, set H/SWEEP selector to 1500.
13. Adjust intensity for clear distinct trace.
14. On signal generator, set BAND selector to Range B.
15. Set sine/square wave selector switch to SINE position.
16. Set AMPL (amplitude) control to its maximum (100).
17. Using red test lead (from step 9) hold it to terminal T3, adjust signal generator frequency selector to about 1500 cycles on scale B.
18. Using scope control's SYNC/PHASE and SWEEP VERNIER control adjust for a scope pattern like this:



SERIES RLC CIRCUIT

PB 9-6/11-6



19. Move red test lead from terminal T3 to T4; do not change any scope signal generator control settings. You should have a pattern like this  , indicating a phase shift of something less than 90 degrees.

By adjusting the SYNC/PHASE control you can adjust for a trace pattern that is 180° from the pattern found at T3. We do not have a 180° phase shift; however, this is why it's important not to change any control settings once the equipment is set up.

As in the Experiment in Module Nine, feel free to vary the signal generator frequency, take notice of the phase relations between E_R and E_C at whatever settings your equipment is set at.

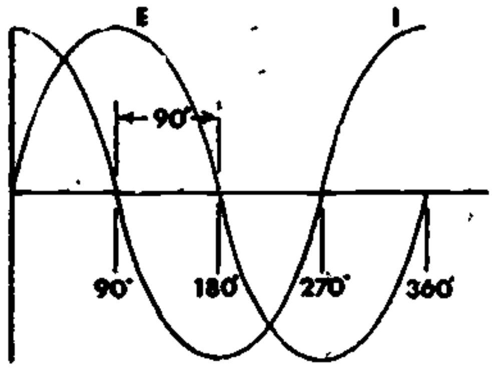
When you have completed your experiment, secure the equipment, make up the leads and turn the equipment back into the material center.

YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON VI

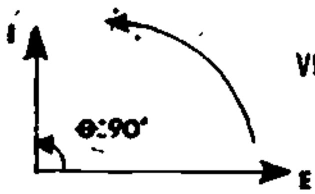
Phase and Power Relationships

A capacitor in an AC circuit causes a phase difference between voltage and current.



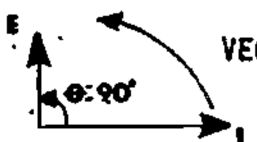
The chart on the left represents the AC waveform of both current and voltage in a purely capacitive, idealized circuit. Notice that current and voltage are 90° apart or out of phase. When current is maximum, both the applied voltage and the capacitor voltage are minimum. When current goes to zero, then voltages are maximum.

The vector representation of the voltage-current phase relationship in a purely capacitive circuit is shown below.



VECTOR ROTATION (CAPACITIVE)

Recall the voltage-current phase relationships for the idealized resistive and inductive circuits shown below.



VECTOR ROTATION INDUCTIVE

VECTOR ROTATION RESISTIVE

To remember voltage-current phase relationships in purely inductive and purely capacitive circuits, you can use the memory aid:

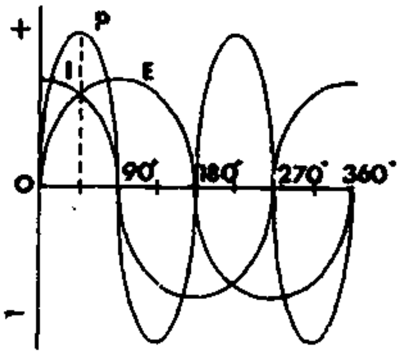
ELI the ICE man

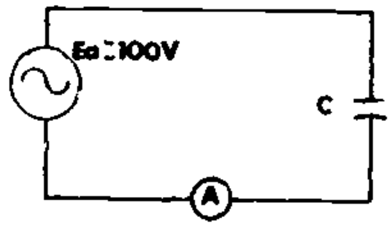
ELI refers to inductive circuits (L) where voltage (E) leads the current (I) by 90°. Similarly ICE refers to capacitive circuits (C) where current (I) leads voltage (E) by 90°.

In a purely resistive circuit, all apparent power is dissipated in the load. When all power the source supplies to a circuit is used by the load, the power factor is unity (1 or 100%).

In purely inductive and purely capacitive circuits, all power is being stored in the inductive or capacitive components and returned to the source through the circuit. Therefore PF = 0 for all purely reactive circuits. In complex circuits with combinations of resistive and reactive elements, the power factor (PF) is somewhere between 0 and 1, depending on the number and magnitude of components.

As a review, the following illustration shows the relationship of power, voltage, and current in a purely capacitive AC circuit.





AT THIS POINT, YOU MAY PERFORM THE EXPERIMENT WHICH STARTS ON PAGE 167 PRIOR TO TAKING THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU DO THE EXPERIMENT, TAKE THE PROGRESS CHECK, AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.


switches before making repairs

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE ELEVEN

LESSON VII

Capacitor Design Considerations

Study Booklet

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OVERVIEW
LESSON VII

Capacitor Design Considerations

In this lesson you will study an learn about the following:

- -variable capacitors
- -fixed capacitors
- -working voltage
- -WV rating and AC
- -capacitor color codes

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON VII

Capacitor Design Considerations

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

- Lesson Narrative
- Programmed Instruction
- Lesson Summary

ENRICHMENT MATERIAL:

- NAVPERS 93400A-1b "Basic Electricity, Alternating Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.
- NAVSHIPS 0967-000-0140 "Reference Data." Electronics Installation and Maintenance Book. Department of the Navy. Naval Ship Engineering Center. Washington, D.C.: U.S. Government Printing Office, 1967.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

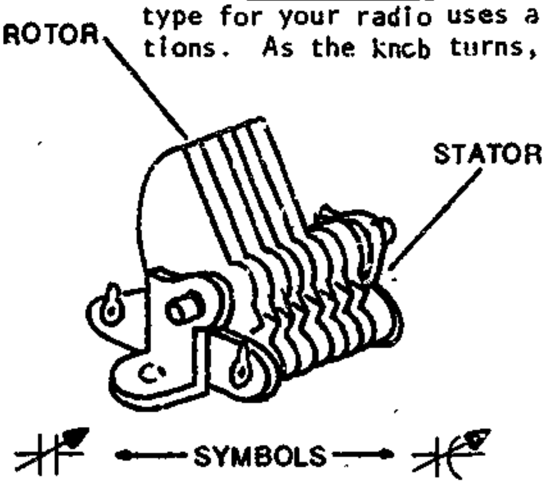
NARRATIVE
LESSON VII

Capacitor Design Considerations

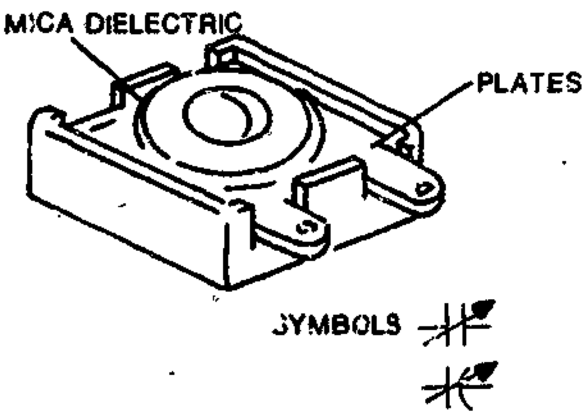
There are two general classifications of capacitors -- (1) variable and (2) fixed.

Variable Capacitors

We are concerned with two kinds of variable capacitors. The first is the rotor-stator capacitor. You are probably familiar with this type for your radio uses a rotor-stator capacitor to tune in stations. As the knob turns, it causes the plates to mesh, varying the effective plate area and consequently the amount of capacitance. The rotor-stator normally has air for its dielectric. You will learn more about what these variable capacitors do when you study resonance, which we will study in future lessons.



A second kind of variable capacitor is the compression capacitor. This type of capacitor, shown in the illustration, consists of two plates with a mica dielectric. The capacitance is varied by changing the distance between the plates simply by tightening or loosening the center screw. The compression capacitor is also found in radios. It serves to make fine tuning adjustments; however, it is not easily accessible and requires shop adjustment.



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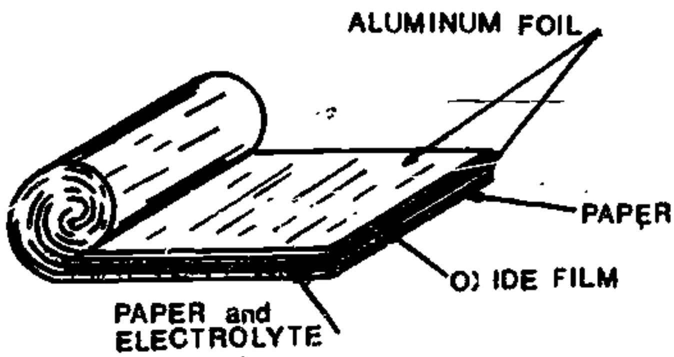
Fixed Capacitors

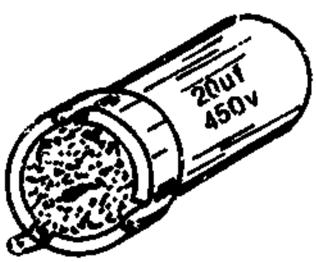
Fixed capacitors have a fixed value of capacitance. They are generally categorized by the kind of dielectric each uses. Common kinds of fixed capacitors use electrolytic, oil, mica, ceramic, and paper dielectrics.

Electrolytic

Your power supply has two electrolytic capacitors. The dielectric is a liquid or paste, generally paste. Electrolytic capacitors are used when a high amount of capacitance is required.

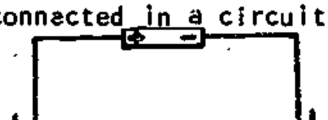


The inside of an electrolytic capacitor looks something like the illustration (upper left).



An electrolytic capacitor has two disadvantages.

1) It is polarized and must be connected in a circuit according to polarity.



If connected in reverse, the capacitor may be destroyed. Because it is polarized, it charges in only one direction.

2) The second disadvantage of an electrolytic capacitor is that it has low leakage resistance. That is, it cannot store energy over long periods of time.

Oil Capacitor

The other fixed capacitor that deserves special mention is the oil capacitor, which tends to be self-healing. That is, if the voltage applied to the capacitor exceeds its voltage rating, the dielectric may break down and permit an arc between the plates. Capacitors with most types of dielectric would be permanently damaged, but in the oil type, the gap caused by the arc closes when the excessive voltage is removed, and the capacitor is useful again. DO NOT ASSUME THAT ANY AMOUNT OF VOLTAGE MAY BE APPLIED TO AN OIL CAPACITOR WITHOUT PERMANENT DAMAGE.

Working Voltage

The maximum safe voltage that can be applied to a capacitor is called the working voltage, abbreviated WV. The WV is usually stamped on the body of the capacitor.

Recall that if a great enough voltage is applied to a capacitor, it can cause an arc through the dielectric between the plates, thus damaging the component.

If you increase the thickness of the dielectric, it can take a greater voltage. However, to increase the thickness of the dielectric, the space between plates must be increased, thus decreasing the capacitance. Therefore, if you increase the thickness of dielectric (assuming you are not changing the type of dielectric), you must also increase the plate area to keep the same value of capacitance.

WV Rating and AC

In earlier lessons we learned that AC voltage is not normally measured peak to peak. Instead, a voltmeter reads the effective value, which is less than the sine-wave peak.

Now consider what would happen to a capacitor with a 100 WV rating if 100 v of AC is applied to it. As the AC peaks, it exceeds 100 v and goodby capacitor! The voltage rating of a capacitor is usually given in working volts DC (WVDC). Consider a 115 v AC circuit in which you are called upon to replace a defective capacitor. If you were to put in a capacitor that is rated at 115 WVDC, chances are you would damage it because the actual voltage would exceed the working voltage. Remember, you must take into consideration that the AC will reach its peak value twice in each cycle. Always choose a capacitor whose WVDC rating is at least 50 percent above the effective value of AC that is present in the circuit. (Remember your meter reads effective values of AC.)

Perhaps you have observed that the capacitors in your power supply are rated for 50 WVDC. However, the AC source to the circuit is about 115 v which exceeds the capacitor rating. Will the capacitors in your power supply blow up? Why or why not? ______________________

Let's hope you remember that the transformer stepped down the source voltage in your power supply to about 24 volts. Now you can see the capacitors have a higher rating than the voltage applied.

Capacitor Color Codes

The value may be stamped on the body of the component, but sometimes values are indicated by color codes. Because there are so many shapes and sizes of capacitors, no one standard system has been adopted. There are, however, two major systems that we can mention:

1) Joint Army-Navy System (JAN)
2) Radio Manufacturers Association (R.M.A.)

A complete breakdown of these two systems and other systems can be found in the Electronics Installation and Maintenance Book (E.I.M.B.), "Reference Data" section. This book is available to you in this school and will be found on board most operating ships in the fleet.

Take a look at some representative values in the E.I.M.B. Become familiar with it as a reference.

Usually, when you find ou need to replace a capacitor in a specific piece of equip , your best reference will be the manufacturer's manual.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, YOU HAVE MASTERED THE MATERIAL AND ARE READY FOR THE MODULE TEST. SEE YOUR LEARNING SUPERVISOR.

IF YOU DECIDE NOT TO TAKE THE PROGRESS CHECK AT THIS TIME, OR IF YOU MISSED ONE OR MORE QUESTIONS, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU HAVE ANSWERED ALL THE PROGRESS CHECK QUESTIONS CORRECTLY. THEN SEE YOUR LEARNING SUPERVISOR FOR THE MODULE TEST.

PROGRAMMED INSTRUCTION
LESSON VII

Capacitor Design Considerations

TEST FRAMES ARE 12 AND 20. AS BEFORE, FIRST GO TO TEST FRAME 12 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

---

1. There are two general classifications of capacitors: the class in which the value of capacitance can be varied, and the class in which the value of capacitance is fixed.

   The two classifications of capacitors are:

   ____ a. general and constant.
   ____ b. fixed and variable.
   ____ c. changing and varied.

(b) fixed and variable

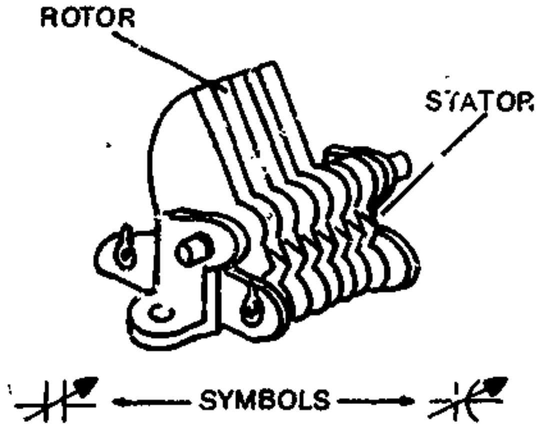
2. There are two main types of variable capacitors. The rotor-stator capacitor is a variable capacitor that usually uses air as its dielectric.

   A rotor-stator capacitor usually uses a/an __________ dielectric.

   ____ a. mica
   ____ b. ceramic
   ____ c. air

(c) air

3.



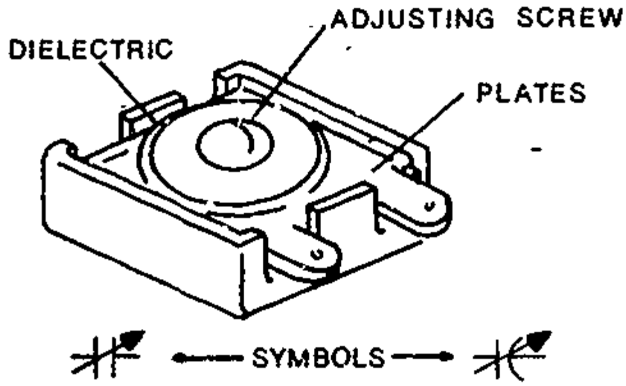
When the rotor is turned in a rotor-stator capacitor, the movement of the rotor plates increases or decreases the meshed area of the plates.

Capacitance is varied in a rotor-stator capacitor by:

____ a. moving the stator.
____ b. changing the plate area.
____ c. changing the dielectric.

(b) changing the plate area

4. A second type of variable capacitor is the compression capacitor. Its capacitance is changed by turning the adjusting screw which changes the plate separation.



The capacitance of a compression capacitor is varied by:

____ a. changing plate area.
____ b. increasing or decreasing distance between plates.
____ c. increasing or decreasing the E_a.

(b) increasing or decreasing distance between plates.

5. Capacitors that have a constant value are categorized by the type of insulating material used between the plates.

Fixed capacitors are named according to their:

____ a. dielectric.
____ b. plates.
____ c. capacitance.

(a) dielectric

6. Common kinds of fixed capacitors are paper, mica, oil, ceramic, and electrolytic (paste or liquid).

Electrolytic capacitors use chemicals in the form of a fluid or spongy dielectric material and are used when a large quantity of charge must be stored.

Electrolytic capacitors:

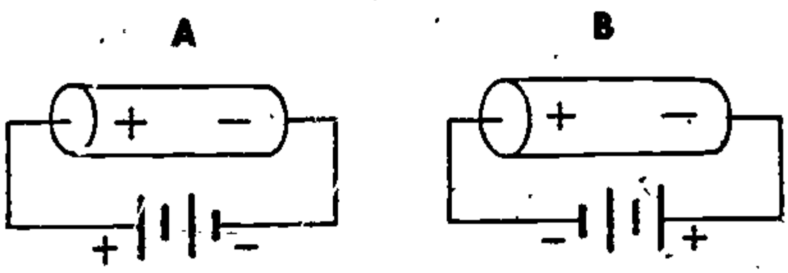
____ a. use a solid dielectric and have low capacitance.
____ b. use a paste or liquid dielectric and have a low capacitance.
____ c. use a paste or liquid dielectric and have a high capacitance.

- -

(c) use a paste or liquid dielectric and have a high capacitance

7. In electrolytic capacitors, the chemicals permit the capacitor to charge in only one direction.

In circuit ______ the capacitor is being charged correctly.
(A)/(B)

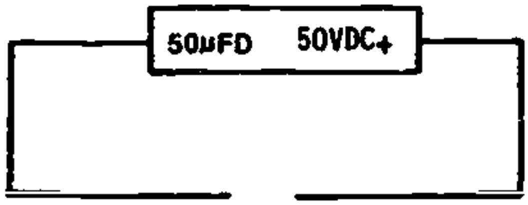


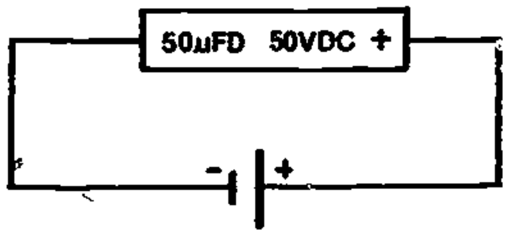
- -

(A)

8. In most cases the polarity of an electrolytic capacitor will be marked on the body. If electrolytic capacitors are charged in the wrong direction, they may explode.

Show how to charge the capacitor by drawing a battery across it and labeling the terminals.





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9. Another type of fixed capacitor that deserves mention is the oil capacitor.

An oil capacitor uses a/an ____________ dielectric.

(oil)

10. The oil capacitor tends to be self-healing in that, if too high an applied voltage causes a breakdown of the dielectric and an arc between the plates, the oil is capable of sealing the gap and restoring the capacitor to a useable condition when the voltage is removed. A breakdown of the dielectrics in most capacitors permanently damages the component.

Oil capacitors:

____ a. are permanently damaged by arcing.
____ b. can repair themselves.

(b) can repair themselves

11. The type and category of capacitor used in your power supply is:

____ a. variable oil.
____ b. fixed mica.
____ c. fixed electrolytic.
____ d. variable electrolytic.

(c) fixed electrolytic

12. Match the characteristics in Column B to the type of capacitor in Column A.

	A		B
____	1. rotor-stator capacitor	a.	plate area changes
____	2. oil capacitor	b.	plate spacing changes
____	3. electrolytic capacitor	c.	self-healing
____	4. compression capacitor	d.	usually polarized

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 12

1. a

2. c

3. d

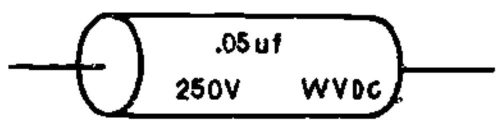
4. b

- -

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, GO TO TEST FRAME 20. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 12 AGAIN.

13. The maximum safe voltage that can be applied to a capacitor without damage is called its working voltage. Working voltage is abbreviated WV.

On the capacitor below, the letters following the voltage are WVDC. It means that in a DC circuit the capacitor has a ________ ________ of ________ volts.



- -

(working voltage; 250)

14. Recall that when we read AC voltage with our Simpson meter, we are reading the:

____ a. peak value.
____ b. peak-to-peak value.
____ c. effective value.

- -

(c) effective value

15. The effective value of AC is not the peak or maximum E or I generated for a particular alternation of a sine wave.

The peak value of an alternation is ___________ than the effective value. (greater/less)

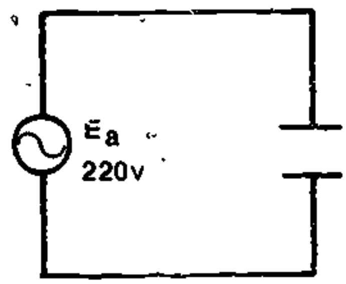
(greater)

16. The effective value of the circuit shown below is equal to what value of DC?

____ a. 310 v DC

____ b. 115 v DC

____ c. 220 v DC



(c) 220 v DC

17. Because of the peak voltage, a capacitor rated at 220 WVDC ___________ be used in a 220 v AC circuit. (can/cannot)

(cannot)

18. If the capacitor is rated in WVDC and it is to be used in an AC application, you must allow at least 50 percent more voltage rating than the effective value of the AC voltage.

A capacitor that is rated at 115 WVDC can be used in a:

____ a. 50 v AC circuit.
____ b. 100 v AC circuit.
____ c. 115 v AC circuit.

(a) 50 v AC circuit

19. The type and thickness of the dielectric in a capacitor are prime factors in determining how much voltage it can withstand.

The working voltage of a capacitor is primarily determined by the:

____ a. type and thickness of the dielectric.
____ b. capacitance.
____ c. area of the dielectric.

(a) type and thickness of the dielectric

20. Select the capacitor whose voltage rating is the lowest that can be safely used in a circuit with a 115v AC source.

____ a. 

____ b. 

____ c. 

(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWER - TEST FRAME 20

b

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, GO TO FRAME 21 AND COMPLETE THE PROGRAM. OTHERWISE, GO BACK TO FRAME 11 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 20 AGAIN.

---

21. Although the values of voltage and capacitance may be stamped on a capacitor's body, values are sometimes given in much the same way as resistor values.

    Some capacitors are ________________ ____________________.

(color coded)

---

22. Because there are so many shapes and sizes of capacitors, one standard system of color coding has not been developed.

    There are, however, two major systems that we can mention. These are the Joint Army-Navy system (JAN) and the Radio Manufacturers Association (R.M.A.).

    A complete breakdown of these two systems and other systems can be found in the Electronics Installation and Maintenance Book (E.I.M.B.), "Reference Data" section. This book is available to you in this school and will be found on board most operating ships in the fleet.

IF YOUR ANSWERS ARE CORRECT, YOU MAY NOW TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, YOU HAVE MASTERED THE MATERIAL AND ARE READY TO TAKE THE MODULE TEST. SEE YOUR LEARNING SUPERVISOR.

IF YOU DECIDE NOT TO TAKE THE PROGRESS CHECK AT THIS TIME, OR IF YOU MISSED ONE OR MORE QUESTIONS, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU HAVE ANSWERED ALL THE PROGRESS CHECK QUESTIONS CORRECTLY. THEN SEE YOUR LEARNING SUPERVISOR AND ASK TO TAKE THE MODULE TEST.

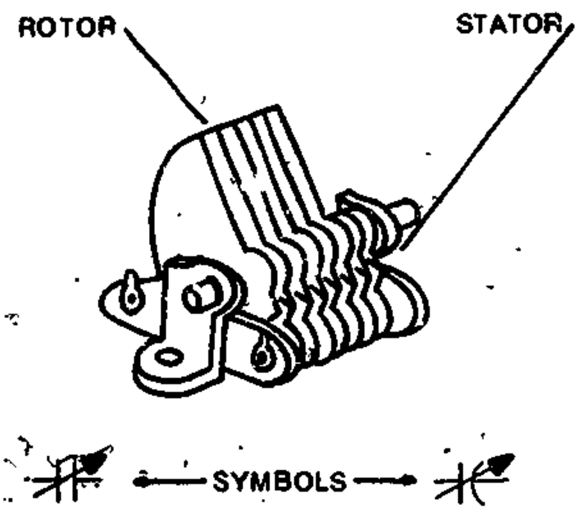
SUMMARY
LESSON VII

Capacitor Design Considerations

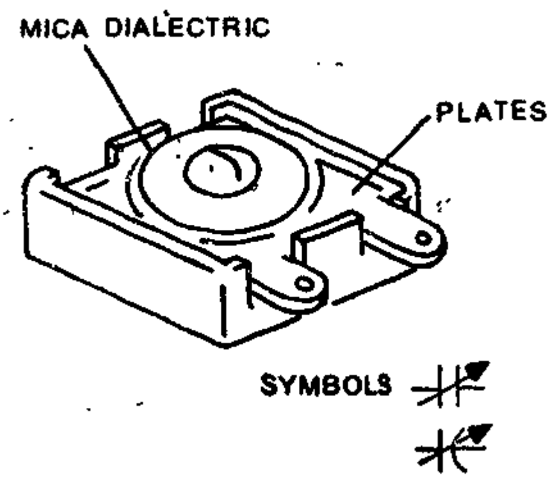
There are two general classifications of capacitors -- (1) variable and (2) fixed.

Variable Capacitors

Variable capacitors are constructed in such a way that their capacitance values can be changed by mechanically varying either the plate area or the plate separation.



The rotor-stator capacitor shown in the diagram varies C by changing the plate area. This is determined by the degree of meshing of rotor and stator plates. This type is an example of a capacitor which normally uses air as a dielectric.



The compression capacitor consists of two plates with a mica dielectric. The capacitance is varied by changing the plate separation.

Fixed Capacitors

Fixed capacitors have constant capacitance values and are generally classified by the kind of dielectric used. Common dielectrics for fixed capacitors are: paper, oil, mica, ceramic, and electrolytic.

The choice of the type of capacitor for a circuit configuration depends on many variables, such as capacitance, working voltage, leakage resistance, and size.

Working Voltage

The maximum safe voltage that can be applied across a given capacitor is called the working voltage, WV. Capacitors with large working voltages usually have relatively thick dielectrics which require considerable plate spacing, thus limiting the capacitance.

In choosing capacitor working voltages for AC circuits, remember that AC peak voltage is higher than the effective voltage. Since the working voltage of a capacitor is usually expressed in DC, choose WV values at least 50 percent higher than the AC voltage requirements.

Capacitor Color Codes

A single standard coding system for indicating capacitor values does not exist. There are, however, two major systems that are commonly used:

1.) Joint Army-Navy System (JAN)
2.) Radio Manufacturers Association (R.M.A.)

Consult the Electronics Installation and Maintenance Book (E.I.M.B.) for a complete breakdown of these two systems and others.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, YOU HAVE MASTERED THE MATERIAL AND ARE READY FOR THE MODULE TEST. SEE YOUR LEARNING SUPERVISOR.

IF YOU DECIDE NOT TO TAKE THE MODULE TEST AT THIS TIME, OR IF YOU MISSED ONE OR MORE QUESTIONS, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU HAVE ANSWERED ALL THE PROGRESS CHECK QUESTIONS CORRECTLY. THEN SEE YOUR LEARNING SUPERVISOR TO ASK FOR THE MODULE TEST.