UNITED STATES MARINE CORPS
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Marine Corps Engineer School
Marine Corps Base
Camp Lejeune, North Carolina 28542-5040

U-08A03
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STUDENT HANDOUT

ALTERNATING CURRENT

1. **OVERVIEW:** The purpose of this period of instruction is to introduce you to the most widely used type of electrical current, alternating current and its characteristics.

2. **LEARNING OBJECTIVES:**

a. **Terminal Learning Objectives:** Provided a schematic, a faulty generator set electrical system, and applicable tools and test equipment, with the aid of references, repair the generator set electrical system so that it functions properly in accordance with the appropriate equipment technical manual. (1142.01.03)

b. **Enabling Learning Objectives:**

(1) Provided an illustration of a suspended, closed loop conductor within a pair of magnetic poles, and a illustration of an AC sine wave, without the aid of references, identify the location on the sine wave that corresponds with the position of the closed loop conductor within the magnetic field, in accordance with FM 11-61. (1142.01.03bg)

(2) Provided a list of components, identify the components that make up the rotor in a Marine Corps generator, in accordance with FM 11-61. (1142.01.03bh)

(3) Provided an illustration of three-phase sine waves, without the aid of references, identify the relative amplitude of one sine wave as it is compared to another at a given axis, in accordance with FM 11-61. (1141.01.03bi)

(4) Provided the output of a three-phase generator and a list of winding configurations, identify the configuration that would produce the output in accordance with FM 11-61. (1142.01.03bj)

(5) Provided a selection of definitions, without the aid of references, identify the correct definition for the term cycle, in accordance with FM 11-61. (1142.01.03bk)

(6) Provided a diagram of an AC sine wave showing several cycles, without the aid of references, identify the point on the sine wave that illustrates the completion of the first cycle, in accordance with FM 11-61. (1142.01.03bl)

(7) Provided a selection of definitions, without the aid of references, identify the correct definition for the term positive alternation, in accordance with FM 11-61. (1142.01.03bm)

(8) Provided a diagram of a AC sine wave showing one cycle, without the aid of references, identify the point on the sine wave that illustrates the completion of the positive alternation, in accordance with FM 11-61. (1142.01.03bn)

(9) Provided a selection of definitions, without the aid of references, identify the correct definition for the term negative alternation, in accordance with FM 11-61. (1142.01.03bo)

(10) Provided a diagram of a AC sine wave showing one cycle, without the aid of references, identify the point on the sine wave that illustrates the completion of the negative alternation, in accordance with FM 11-61. (1142.01.03bp)

(11) Provided a selection of definitions, without the aid of references, identify the correct definition for the term period, in accordance with FM 11-61. (1142.01.03bq)

(12) Provided a selection of definitions, without the aid of references, identify the correct definition for the term frequency, in accordance with FM 11-61. (1142.01.03br)

(13) Provided a selection of definitions, without the aid of references, identify the correct definition for the term peak value, in accordance with FM 11-61. (1142.01.03bs)

(14) Provided a selection of definitions, without the aid of references, identify the correct definition for the term peak-to-peak value, in accordance with FM 11-61. (1142.01.03bt)

(15) Provided the peak voltage of a circuit and the formula to calculate the peak-to-peak voltage, without the aid of references, calculate the peak-to-peak voltage for the circuit, in accordance with FM 11-61. (1142.01.03bu)

(16) Provided a selection of definitions, without the aid of references, identify the correct definition for the term effective value, in accordance with FM 11-61. (1142.01.03bv)

(17) Provided the effective voltage of a circuit and the formula for finding peak voltage, compute the peak voltage in accordance with FM 11-61. (1142.01.03bw)

(18) Provided a selection of definitions, without the aid of references, identify the correct definition for the term average value, in accordance with FM 11-61. (1142.01.03bx)

(19) Provided a diagram of an AC wave form containing an amplitude line, an axis line, and a plotted alternating-current sine wave, without the aid of references, identify the amplitude line, in accordance with FM 11-61. (1142.01.03by)

(20) Provided a diagram of an AC wave form containing an amplitude line, an axis line, and a plotted alternating-current sine wave, without the aid of references, identify the axis line, in accordance with FM 11-61. (1142.01.03bz)

(21) Without the aid of references, identify the effect inductance has on alternating current, in accordance with FM 11-61. (1141.01.03ca)

(22) Without the aid of references, identify the effect capacitance has on alternating current, in accordance with FM 11-61. (1141.01.03cb)

(23) Given the formula for computing phase angle, resistance, inductive reactance, and capacitive reactance of a series RLC circuit, compute the phase angle of the circuit, in accordance with FM 11-61. (1142.01.01cc)

(24) Given a list of resistance readings, select the reading that identifies a working capacitor, in accordance with Electricity Concepts Unit II. (1141.01.03cd)

(25) Given the total voltage and current of a circuit, the voltage and current at a resistor and possible power factors, identify the power factor, in accordance with FM 11-61. (1142.01.03ce)

(26) Given an AC circuit, a list of formulas, and possible changes in the power factor, identify how the power factor would change if the inductance was changed, in accordance with FM 11-61. (1142.01.03cf)

(27) Given an AC circuit, a list of formulas, and possible changes in the power factor, identify how the power

factor would change if the capacitance was changed, in accordance with FM 11-61. (1142.01.03cg)

(28) Given a list of operating characteristics, select the characteristics that describes the operation of a transformer, in accordance with FM 11-61. (1142.01.03ch)

(29) Given a list of symptoms and a list of transformer defects, match each symptom to the defect that would cause the symptom, in accordance with FM 11-61. (1142.01.03ci)

OUTLINE

1. **A.C. compared to D.C.**: Alternating current is current which constantly changes in amplitude and reverses direction at regular intervals. You learned previously that direct current flows only in one direction, and that the amplitude of current is determined by the number of electrons flowing past a point in a circuit in one second.

EXAMPLE: A coulomb of electrons moves past a point in a wire in one second and all of the electrons are moving in the same direction, the amplitude of direct current in the wire is one ampere. If a half coulomb of electrons moves in one direction past a point in the wire in half a second, then reverses direction and moves past the same point in the opposite direction during the next half-second, a total of one coulomb of electrons still passes the point in one second. So the amplitude of the alternating current remains one ampere.

a. Disadvantages of D.C. compared to A.C.:

(1) If a direct-current system is used, the voltage must be generated at the level (amplitude or value) required by the load.

EXAMPLE: To properly light a 240 volt lamp, the D.C. generator must deliver 240 volts. If a 120 volt lamp is to be supplied power from the 240 volt generator, a resistor or another 120 volt lamp must be placed in series with the 120 volt lamp to drop the 120 volts. When the resistor is used to reduce the voltage, an amount of power equal to that consumed by the lamp is wasted.

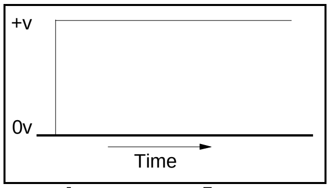
(2) Another disadvantage of the D.C. system becomes evident when the D.C. from the generating station must be transmitted a long distance over wires to the consumer. When this happens, a large amount of power is lost due to the resistance of the wire. The power loss is equal to I^2R.

b. Advantages of A.C. compared to D.C.:

(1) Unlike direct voltages, alternating voltages can be stepped up or down in amplitude by a device called a transformer.

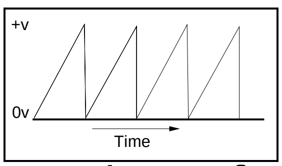
(2) Use of the transformer permits efficient transmission of electrical power over long-distance lines. At the electrical power station, the transformer output power is at high voltage and low current levels. At the consumer end of the transmission lines, the voltage is stepped down by a transformer to the value required by the load.

c. D.C. and A.C. Voltage Waveforms: A waveform is a graphical representation showing the variation of voltage over a period of time. If a graph is constructed showing the amplitude of a D.C. voltage across the terminals of a battery with respect to time, it will appear as in the figure below.

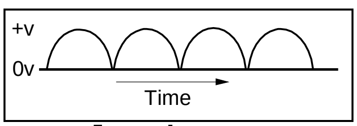


Direct Voltage

Some voltages go through periodic changes in amplitude. In the figures below are examples of these types of waveforms. Even though the voltages are changing in amplitude, the waveforms do not change directions; therefore, they are still considered D.C. waveforms.

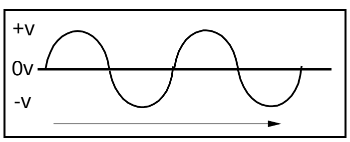


Sawtooth wave form



Pulsating D.C.

The alternating voltage waveform below periodically changes in amplitude, but also changes direction regularly.



Alternating Voltage

2. **Generation of the Sine Wave**:

a. The most common method of producing a sine wave is through the use of a generator. The basic rotating armature generator consists of:

(1) Magnetic poles (stationary).

(2) Closed loop conductor or armature.

(3) Slip rings (metallic).

(4) Brushes (carbon or graphite).

(5) Mechanical driving force or prime mover.

b. With the conductor in position "A" or parallel to the magnetic lines of force (zero degrees of rotation) no magnetic lines of force are cut and no voltage is induced (produced) in the conductor and as a result, no current flow.

c. As the conductor begins to rotate clockwise a voltage is induced in the conductor.

d. At position "B", or 90 degrees of rotation, maximum lines of force are being cut by the rotating conductor and maximum voltage is being induced into the conductor. At 90 degrees the conductor is in the middle or at the right angle to the lines of force.

e. At position "C", or 180 degrees of rotation, the conductor is again parallel to the magnetic lines of force. Since no magnetic lines of force are being cut, no voltage is induced in the conductor.

f. At position "D", or 270 degrees of rotation, maximum lines of force are being cut, by the rotating conductor and maximum voltage is again produced in the conductor.

g. At position "E", which is the same as position "A", or 360 degrees of rotation, the conductor is again parallel to the magnetic lines of force and zero volts are induced.

h. Whenever a rotating conductor is parallel to the magnetic lines of force, zero volts are induced in the conductor. When the conductor cuts the magnetic field at 90 or 270 degrees, maximum volts are produced.

i. What we have produced by rotating a conductor 360 degrees through a magnetic field is one single sine wave of alternating current or one single phase of A.C.

j. Since the closed loop conductor armature rotates through the magnetic field, this type of generator is called a rotating armature type generator.

3. **Three Phase Generators:** There are two types of three phase generators (or generators that produce sine waves), the rotating armature and the rotating magnetic field types.

a. Rotating Armature Type:

(1) Has three closed looped conductors placed 120 degrees apart.

(2) Has three sets of brushes and slip rings.

(3) Has three separate output voltages 120 degrees apart.

(4) The order of the phases reaching peak voltage will always be Phase A, Phase C, and then Phase B. When Phase A is at 90°, Phase B will be at 330° or 120° from positive peak voltage. Phase C will be at 210° or 60° from negative peak voltage. Remember, positive peak voltage and negative peak voltage are always equal. The only difference is that the polarity of the source changes and current flows in the opposite direction. This holds true with all three phase generators.

(5) The output is taken off the generator through the brushes which ride on the slip rings.

(6) This generator is only good for small power (kW) requirements due to the problem encountered with arcing at the brushes.

b. Rotating Magnetic Field Type:

(1) The three separate output conductors (coils) are stationary and are mounted in the stator.

(2) Has three separate output voltages 120 degrees apart.

(3) The three output conductors are connected to the generator load change over board.

(4) The rotating magnetic field is mounted on the generator rotor, which is directly coupled to the diesel engine.

(5) As the magnetic field rotates along with the rotor it cuts across the stationary conductors inducing a voltage in them.

(6) Since the output is taken directly from the stationary conductors there is no loss due to arcing.

(7) This generator is good for large power (kW) requirements.

c. Marine Corps Generators: Marine Corps Generators are a combination of both rotating armature and revolving field types.

(1) The rotating armature is mounted on the front of the rotor shaft.

(a) The stationary windings are mounted in the stator.

(b) The stationary windings receive direct current from the voltage regulator.

(c) The alternating current produced by the rotating armature generator is changed to direct current by the field diodes and supplied to the revolving field.

(2) The revolving magnetic field cuts across the stator windings producing alternating current voltage. This alternating voltage is then supplied to the voltage reconnection board.

d. Voltage Reconnection Board:

(1) Low Wye Configuration, 120/208 volts

(a) The stator windings are connected in parallel.

(b) The voltage in parallel is constant 120v.

(c) The current in parallel is added. In our example, the current in each winding is 52 amperes giving us a total of 104 amperes.

(d) The voltage between phases is 208 volts. The reason for this is that no two voltages will be at 100% at the same time but will average out to 173%. Converting to a decimal, this gives us the three-phase multiplier of 1.73.

(e) The single-phase voltage is 120 volts and when multiplied by the three phase multiplier (1.73), the result is 208 volts, three phase.

(2) High Wye Configuration, 240/416 volts

(a) The stator windings are connected in series.

(b) The voltage in series is added giving us a voltage of 240 volts.

(c) The resistance in series is added, thus doubling our resistance and reducing our current to 52 amperes.

(d) The voltage between phases is 416 volts. The reason for this is the voltage averages out to be 173% of the single-phase voltage. Converting to a decimal, this gives us the three-phase multiplier of 1.73.

(e) The single-phase voltage is 240 volts and when multiplied by the three phase multiplier (1.73), the result is 416 volts, three phase.

e. Magnitude of the Induced Voltages: The magnitude of the induced EMF (voltage) depends on four factors.

(1) The number of turns of the coil is the same as increasing conductor length; thus more electrons are available for displacement.

(2) The speed of relative motion, more lines of force can be cut per unit of time.

(3) The sine of the angle of rotation relates to the trigonometric function, which will be discussed later.

(4) Strength of the magnetic field. Of these factors the strength of the magnetic field is the easiest for us to control since the number of turns of the coil and the speed of motion or rpm's is determined by the manufacturer.

(a) If the field is stronger, there will be more magnetic lines of force to be cut; producing the movement of a large amount of electrons.

(b) If the field is weak, there will be less magnetic lines of force to be cut; producing the movement of a smaller amount of electrons.

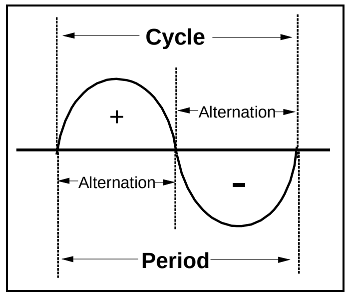
(c) The strength of the exciter magnetic field is controlled from an external source called a voltage regulator.

1 The stationary windings of the exciter receives a sample of the output voltage from the voltage regulator and induces a voltage in the rotating armature.

2 The voltage produced in the rotating armature is alternating current voltage which is converted to direct current voltage by the field diodes.

3 This direct current voltage produces direct current which is sent to the rotating magnetic field.

4. **Alternating Current Sine Wave Characteristics**:



a. The Cycle:

(1) When the rotating coil of a basic two pole generator completes one revolution, it is said to have completed one cycle.

(2) A cycle is a complete set of positive and negative values.

(3) Positive will be from 0° to maximum, (above the time or axis line) and back to 180°.

(4) Negative will be from 180° to maximum, (below the time or axis line) and back to 360° or 0°.

b. Alternation:

(1) Alternation is defined as a complete set of positive or negative values and is often referred to as one half of a cycle.

(2) Above the horizontal time line is called the positive alternation or positive half cycle.

(3) Below the horizontal time line is called the negative alternation or negative half cycle.

(4) The terms positive and negative refer to the polarity of the induced voltage and the direction of the current flow relative to the time or axis line.

c. Period:

(1) The period of A.C. voltage or current is the time required to complete one cycle.

(2) The period of one cycle is equal to the reciprocal of the frequency.

$$T=1/F$$

(3) Frequency is the number of cycles per second and is expressed in hertz (Hz). An example is 60 Hz, the standard frequency used in the United States.

(4) Mathematically expressed by the formula:

$$F=1/T$$

EXAMPLE: At a frequency of 60 Hertz, how much time does it take to complete one cycle?

Because of the relationship between time and frequency, we can use the formula T=1/F and show the time to be 0.0167 sec/cycle.

d. Frequency Spectrum:

(1) The ranges of the frequencies of A.C. voltages encountered in electronic applications are called the frequency spectrum.

(2) Power for lights, motors, and home appliances is obtained from power frequencies. The basic power frequency in the United States is 60 Hz, while many foreign countries use 50 Hz.

(3) Marine Corps generators operate at power frequencies of 50/60 and 400 Hz.

(a) The 50/60 Hz generators power lights and motors.

(b) The 400 Hz generators power communications and radar equipment.

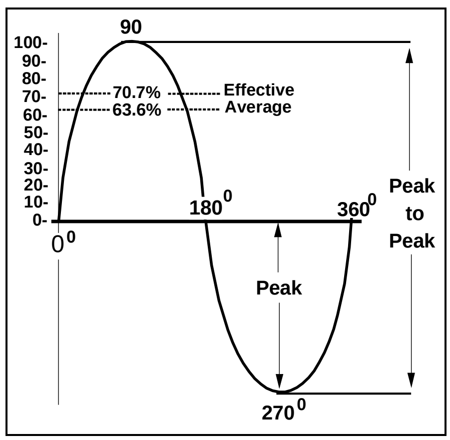
(c) The three main categories of frequencies are power, audio, and radio.

5. **Alternating Current Values**: Direct current and voltage rise almost instantaneously to a circuit's maximum value and remain at that value. However, alternating current and voltage are constantly increasing and decreasing in value and periodically changing direction. As a result of this behavior, it is necessary to express the current and voltage in terms of maximum

or peak values, peak-to-peak values, effective or RMS (root-mean-squared) values, average values, and instantaneous values.

a. The Instantaneous Value of voltage or current is the value of voltage or current at any particular instant in time along the waveform. The value may be zero if the particular instant is the time in the cycle at which the polarity of the voltage is changing. It may also be the same as the peak value, if the selected instant is the time in the cycle at which the voltage or current stops increasing and starts decreasing. There are actually an infinite number of instantaneous values between zero and peak value. Mathematically expressed by the formula:

$$e = \sin \supset \times E_{max}$$



b. The Peak Value of voltage and current is defined as the maximum instantaneous value of voltage or current.

(1) Occurs at 90° and 270°.

(2) May be either the positive or negative peak.

(3) The positive peak is always equal to the negative peak.

(4) Peak voltage is identified as E_p and maximum voltage is identified as E_{max}.

(5) Both E_p and E_{max} have the same numerical value.

c. The peak-to-peak value is twice the peak value.

(1) Is measured from the maximum positive peak to the maximum negative peak.

(2) The peak-to-peak value is identified as E_{pp}.

(3) Mathematically expressed:

$$E_{pp}=2\times E_p$$

d. Effective (RMS) Value - The A.C. voltage and current that produces heat at exactly the same rate as direct current.

(1) The heating effect is a measure of how much heat a circuit component dissipates or converts to electrical power (watts).

(2) The effective value of A.C. voltage and current is determined by taking the instantaneous values of voltage and current for one alternation squaring them, finding the average of the squared values, and finding the square root of the average value. By doing this, a figure is obtained which is equal to the value of direct current which would produce the same heating effect.

(3) Because it is the square root of the squared instantaneous values, the effective value is also known as the root-mean-squared (RMS) value.

(4) Mathematically expressed by the formula:

$$E_{eff}=.707\times E_p$$

EXAMPLE: E_{max} or E_p = 100 volts. What is the effective value? 70.7V_{eff}.

Using this same formula, if the effective voltage, (70.7V) is known and we want to find the peak value, then we simply divide both sides by .707:

$$E_p=E_{eff}/.707$$

Since E_{pp} is twice E_p, E_{pp} is 200V.

e. Average value is the average value of the instantaneous values of voltage and current for one alternation.

(1) Either alternation may be used since in a pure sine wave, they are both equal.

(2) Mathematically expressed by the formula:

$$E_{avg} = E_p \times .636$$

EXAMPLE: E_p = 100 volts. What is the average value? 63.6V

Using this same formula, if the average voltage, (63.6V) is known and we want to know the peak value, then we simply divide both sides by .636:

$$E_p = E_{avg} / .636$$

Since E_{pp} is twice E_p, E_{pp} is 200V.

6. **The Oscilloscope**:

a. The oscilloscope displays a graphic picture of the variations of voltage or frequency over a period of time.

b. The oscilloscope, often called the “O-Scope”, can be used to measure voltage and frequency. By measuring the voltage and knowing the resistance, the current can also be determined.

c. The oscilloscope consists of the cathode ray tube (CRT) and its associated circuits.

d. The four main parts to the cathode ray tube are; the container, electron gun, deflecting system, and the screen.

(1) The container is a vacuum tube. All air is removed so that the filament will not burn out and electrons will move freely through the tube.

(2) The electron gun is an arrangement of tube elements used to introduce electrons into the tube, accelerate them, and form them into a narrow beam. The electron gun consists of the cathode, filament, control grid, first anode or focusing anode, and the second anode or acceleration anode.

(3) The deflection system is a control system, which moves electrons in the desired direction up or down, left and right. The system consists of the vertical and horizontal deflection plates.

(4) The screen is covered with a luminescent phosphor (.002 inches thick) which when bombarded with electrons, will emit light.

e. Controls and Connectors:

(1) Power Supply and CRT: The oscilloscope can be operated from either a 100-volt, 120-volt, 220-volt, or 240-volt

nominal voltage source. The line voltage selector assembly on the rear panel converts the instrument from one operating range to the other.

(2) Power Switch: The power is set on at the pushed-in position, and set off at the released position.

(3) Power Lamp: This lamp illuminates red when the power supply is in the on state.

(4) Trace Rotation Control: Used to align the trace of CRT with the horizontal graticule.

(5) Intensity Control: This knob works the brightness adjust variable resistor. Brightness is increased by rotating the intensity knob clockwise.

(6) Focus Control: After obtaining an appropriate brightness by operating the intensity knob, adjust focus until the bright line is clear.

(7) Illum Control: Controls graticule illumination. Useful to illuminate the graticule when viewing in a dark area.

(8) CAL 0.5V: Output terminal of calibration square wave of about 1khz and 0.5v. It is used to calibrate the probe combination. We will not be utilizing this control.

(9) Time/Division Select Switch: Selects the sweep rate in steps from 0.2 microseconds per division to 0.2 seconds per division.

(10) Sweep Uncal Lamp: Light is on when SWP VAR is out of CAL detent position.

(11) SWP Variable Control: This control works as CAL and the sweep time is calibrated to the value indicated by TIME/DIV knob.

(12) Position Pull X10 Mag Control: This knob is used to move the bright line in horizontal directions.

(a) The bright line is moved toward the right when the knob is rotated clockwise and toward the left when the knob is rotated counterclockwise.

(b) Sweep is magnified 10 times by pulling the position knob out.

(13) CH1 ALT MAG Switch: CH1 input signal is displayed alternately by each single sweep of x1 (NORM) and X10 (MAG).

(14) Mode Select Switch:

(a) Auto position: This position automatically triggers sweep, and a sweep is always conducted.

(b) Norm position: Use this mode when effecting synchronization to a very low frequency signal (25hz or less).

(c) TV (V) position: This setting is used when observing the entire vertical picture of a television signal.

(d) TV (H) position: This setting is used when observing the entire horizontal picture of a television signal.

(15) Level Control: This knob is used to decide at which portion of the waveform should the sweep be started.

(16) Trig Input Connector: An input terminal used for an external triggering signal.

(17) Source Select Switch: This switch is used to select the triggering source sweep.

(a) INT position: This setting is used when the input signal applied to CH1 or CH2 becomes the triggering signal.

(b) LINE position: This setting is used when observing a signal triggering with power supply line frequency.

(c) EXT position: This setting is used when an external triggering signal is applied to the TRIG INPUT connector.

(18) Volts/Division Select Switch: Selects the vertical deflection in steps from volts to millivolts. The small red knob must be in the calibration position, which is rotated fully clockwise.

(19) Position Pull DC Offset Control: This knob is used to adjust the position of the vertical axis. The image rises with the clockwise rotation of this knob and falls with the counterclockwise rotation. This also operates as a pull type switch to magnify the sensitivity.

(20) CH1 Input Connector: BNC connector for vertical axis input.

(21) AC/GND/DC Switch:

(a) AC position: Place switch at this setting for alternating current measurements.

(b) GND position: Must be set on GND to start, then switched to the correct setting when you're ready to use the unit.

(c) DC position: Place switch at this setting for direct current measurements.

(22) DC Offset Volt Out Connector: This is the output connector to readout the voltage measurement with a digital multimeter.

(23) DC Balance Adjustment Control: Used to calibrate the axis.

(24) Mode Select Switch: Selects the type of input.

(a) CH1 position: Only the signal that has been applied to CH1 appears on the screen.

(b) CH2 position: Only the signal that has been applied to CH2 appears on the screen.

(c) ALT position: Signals applied respectively to CH1 and CH2 appear on the screen alternatively at each sweep.

(d) CHOP position: At this setting, the input signals applied to CH1 and CH2 respectively are switched at about 250kHz independent of the sweep and at the same time it appears on the screen. This setting is used when the sweep time is long in 2-channel observation.

(e) ADD position: The algebraic sum of the input signals applied respectively to CH1 and CH2 appears on the screen.

(25) INT TRIG Select Switch: This switch is used to select the internal triggering signal source sweep.

(a) CH1 position: The input signal applied to CH1 becomes the triggering signal.

(b) CH2 position: The input signal applied to CH2 becomes the triggering signal.

(c) VERT Mode position: For observing two waveforms.

f. Theory of Operation:

(1) The Cathode: The filament inside the cathode is heated. When electrons within the filament have absorbed enough energy, they will be emitted into the space between the cathode and the control grid.

(2) Control Grid: By applying a negative potential to the control grid and since electrons are leaving the cathode, electrons that are emitted by the cathode are forced toward the center.

(3) First Anode: The electrons that are moving toward the center come under the influence of the positive first anode and move to the right forming into a beam.

(4) Second Anode: The beam that has been formed is traveling at a slow rate until it comes under the influence of the second anode which is more positive than the first anode. At this time, the beam of electrons is moving in a straight line towards the screen. It now becomes necessary to find a means of moving or deflecting the beam across the screen.

(5) Vertical deflection plates receive their input from the vertical oscillator. The vertical oscillator causes an alternating difference in potential to be felt across the vertical plates.

(a) On the positive half cycle, plate (1) is positive and plate (2) is negative. The electron beam is repelled by plate (2) and attracted by plate (1). This causes the electron beam to move in a vertical direction on the screen from A to B.

(b) On the negative half cycle, plate (1) is negative and plate (2) is positive. The electron beam is repelled by plate (1) and attracted by plate (2). This causes the electron beam to move in a vertical direction on the screen from B to A.

(c) As a result of the alternating difference in potential across the vertical deflection plates, a vertical line appears on the screen.

(6) Horizontal deflection plates receive their input from the horizontal oscillator. The horizontal oscillator causes an alternating difference in potential to be felt across the horizontal plates.

(a) On the positive half cycle, plate (1) is positive and plate (2) is negative. The electron beam is repelled by plate (2) and attracted by plate (1). This causes the electron beam to move in a horizontal direction on the screen from A to B.

(b) On the negative half cycle, plate (1) is negative and plate (2) is positive. The electron beam is repelled by plate (1) and attracted by plate (2). This causes the electron beam to move in a horizontal direction on the screen from B to A.

(c) As a result of the alternating difference in potential across the horizontal deflection plates, a horizontal line appears across the screen.

(d) In order to form a picture of a waveform on the screen, both the vertical and horizontal inputs are synchronized by the sweep circuit generator.

g. Initial Setup:

(1) Before turning the power switch on, ensure the power supply voltage is within the range of 108-132v for AC 120v set.

(2) Insert the plug of the power cord on the rear panel into the power supply wall socket and set the controls as follows:

(a) Power Switch – Off

(b) Intensity Control - Rotate counterclockwise fully.

(c) Focus Control - Midrange

(d) AC/GND/DC Switch - GND

(e) Position Pull DC Offset Knob - Midrange

(f) Vertical Mode Switch - CH1

(g) Mode Select Switch - AUTO

(h) Source Select Switch - INT

(i) INT TRIG Select Switch - CH1

(j) Time/Div Knob - 0.5ms/div

(k) Position Pull x10 Mag Control - Midrange

(3) After placing the controls on the settings listed above, turn on the power, wait 15 second’s, and then rotate the intensity knob clockwise until a bright line appears.

(a) Once the bright line appears, set the focus control at the point where the bright line is the sharpest.

(b) Align the bright line with the horizontal scale line at the center of the screen by operating the CH1 position controls.

7. **Measuring With the Oscilloscope:** The screen contains 10 horizontal and 8 vertical squares. Each square is called a division. In the middle of the screen both horizontally (time or axis line) and vertically (amplitude line) is a graduated line with 4 sub division marks per square. This divides each division into 5 equal parts. In order to measure voltage, a signal voltage must be inputted to CH1 or CH2 by using a signal generator or the oscilloscope probe. The volts/division knob determines how many volts there are in each division. The oscilloscope will display peak voltage for DC and peak to peak voltage for AC.

a. Voltage Measurement (A.C.):

(1) After completing the initial set up procedures, bring the brightness and focus to optimum positions for easy read out.

(2) Adjust the base line so that it is aligned with the center horizontal line and centered on the screen.

(3) Turn the AC/GND/DC switch to AC.

(4) Adjust the sine wave so that you have the biggest complete sign wave on your screen, (within the division boxes), that is possible.

(5) Position the sine wave so that the negative peak is on a division line and the positive peak is centered on the amplitude line.

(6) Count the number of divisions and then the number of sub divisions.

(7) Get the voltage off of the VOLTS/DIV knob and divide it by 5, this will give you the value of the sub divisions.

(8) Multiply the number of divisions by your voltage from your VOLTS/DIV knob and also multiply the number of sub divisions by the value of each sub division and add them together to get your peak to peak value.

(9) Once we have determined the peak to peak voltage using the oscilloscope, we can determine the peak, average, and effective voltage by using the formulas we learned earlier in this lesson.

b. Voltage Measurement (D.C.):

(1) All of the set up procedures are the same as they were for measuring A.C. except the following steps:

(2) Turn the AC/GND/DC switch to DC.

(3) Your D.C. waveform will continue to be shown as a straight horizontal line. However, it will rise above the time or axis line.

(4) Count the number of divisions and sub divisions the line rose. Calculate the quantity of each sub division by dividing your VOLTS/DIV by 5. Multiply the number of divisions by the value on the VOLTS/DIV knob and add the number of sub divisions multiplied by the value of the sub division to get the total peak voltage.

c. Frequency Measurements:

(1) In order to measure the frequency of a sine wave; we must first determine the time it takes to complete one cycle or the period.

(2) In order to measure the period of the wave form, we must place the wave form on the screen so that the positive and negative peaks are an equal distance above and below the horizontal scale.

(3) Once the waveform is centered on the time or axis line, we count the number of divisions and sub-divisions along the time/axis line.

(4) After determining the number of divisions, this number is multiplied by the setting on the time/division. Calculate the value for the sub-divisions in the some way you did for voltage calculation. The result will be the period of the waveform.

(5) Once the period is determined, it can be divided into one in order to determine the frequency.

d. Computing Current: Ohm's Law states that the voltage drop across a resistor is proportional to the current flowing through it. To compute the current using the oscilloscope, you must measure the voltage across a resistor of a known value and then compute the current using Ohm’ Law.

8. **Signal Generator**:

a. The signal generator is used to inject known signals into an electronic circuit. Once the known signal is injected into the circuit, test equipment like the oscilloscope can be used to troubleshoot the circuit.

b. There are two types of signal generators, the audio frequency generator (AF) and the radio frequency generator (RF).

c. The audio frequency range is from 20 Hz to 20,000 Hz and can be detected by the human ear.

d. The RF generator goes to frequencies beyond hearing and can be considered small radio transmitters.

e. The RF generator in the electricity trainers has a range of 200 kHz to 6MHz.

f. The signal generator produces two types of waveforms, sine wave, and square wave.

g. The signal generator is a combination AF and RF signal generator and consists of

(1) Power switch with pilot light.

(2) Multiplier range buttons.

(3) Sine and square wave output connections.

(4) AF and RF band dials.

9. **Preparing for Operation**:

a. To operate the oscilloscope in conjunction with the signal generator, place both the oscilloscope and signal generator in the desired location, close enough where you can operate both items of equipment.

b. Signal generator

(1) Place the AF band on 6.

(2) Push in the x10 multiplier range button.

(3) Connect the output cable provided to the sine wave output and connect it to the channel 1 input on the oscilloscope.

(4) Plug in the A.C. power cable to a 120-volt 50/60 Hz A.C. source.

(5) **DO NOT** energize the signal generator at this time.

c. Now prepare the oscilloscope for operation in the same manner as taught previously in this lesson.

d. Once the oscilloscope has been set up and allowed to warm up, a horizontal line should appear on the screen. Flip the AC/GND/DC switch from GND to AC.

e. Adjust the Volt/Div and/or the Time/Div knob until the waveform is the desired size. You are now ready to measure the waveform.

10. **Inductance**:

a. Inductance is the property of an electrical circuit that opposes a change in current.

(1) The symbol for inductance is L.

(2) The basic unit of measure for inductance is the henry (H).

(3) One henry is equal to the inductance required to induce one volt in an inductor by a change in current of one ampere per second.

(4) Mathematically expressed by the formula: $E_{ind}=L(i \div t)$

E_{ind} = Voltage induced

L = Inductance in henrys

i = Small change in current

t = Small change in time

EXAMPLE: A circuit has a change in current of 1 ampere per second and an inductance of 1 henry, thus the induced voltage is:

$$E_{ind} = L(i \div t)$$

$$E_{ind} = 1h(1\ amp \div 1\ sec)$$

$$E_{ind} = 1\ volt$$

(5) Inductance has the same effect on current that inertia has on the movement of a mechanical object. (Analogy) If you have ever pushed a heavy load like a car, you know that it takes more work to start the load moving than it does to keep it moving. Once the load is moving, it is easier to keep it moving than to stop it again. This is because the load possesses the property of inertia. Inertia is the property of a mass, which opposes a change in velocity.

b. Self inductance is the property of a conductor to induce (produce) a voltage within itself.

(1) There are three requirements necessary in order to produce a voltage through magnetism, a conductor, a magnetic field, and relative motion between the two.

(a) Surrounding any current carrying conductor there is a magnetic field.

(b) As the current changes (increases) from 0 to 2 amps, the magnetic field increases. The magnetic field starts at the center of the conductor and expands outward cutting across the conductor. This process continues until the current reaches its maximum value. Once the current reaches maximum value the magnetic field is no longer expanding across the conductor but reaches its maximum size and remains stationary.

(c) During the time when the magnetic field has been changing as a result of the changing current, it has been cutting across the conductor satisfying the three requirements needed to produce a voltage or emf.

(2) This voltage is called self-induced voltage because the voltage is induced in the conductor carrying the current.

(3) This voltage/emf is also referred to as counter electromotive force.

(a) The polarity of the counter electromotive force (cemf) is in the opposite direction to the applied voltage.

(b) The overall effect will be to oppose a change in current.

(c) This effect is summarized by Len's Law which states that the induced emf in any circuit is always in a direction to oppose the emf that produced it.

(d) If the emf of self-inductance were not a cemf, when the current increased, the induced emf would increase aiding the applied voltage. This would cause the applied voltage to increase thus causing an increase in current flow. This process would continue until current reached an infinite amount, a condition not possible in the physical universe.

c. Inductance and Coils: To increase the property of inductance, the conductor can be formed into a loop or coil. A coil is also called an inductor.

(1) When a conductor is formed into a loop and current flows through the conductor, the magnetic field around the

conductor becomes stronger. As this magnetic field cuts across the looped conductor, the resulting cemf becomes stronger.

(2) When current is building up it produces a growing magnetic field. This field produces an emf in an opposite direction to the actual flow of current and opposes the growth of current. The whole reaction, or opposition, is caused by the creation or collapse of the magnetic field, which expands and contracts cutting across the conductors, producing a counter electromotive force.

d. Factors Affecting Coil Inductance: There are five basic factors that affect coil inductance: the number of turns of the coil, diameter or cross sectional area, length of the coil, core material, and the number of layers of windings in the coil.

(1) Number of Turns of the Coil - Conductors become much more inductive when they are wound into coils. This is true because there is maximum linkage of the magnetic field between the coil turns. The more turns we have, the stronger the magnetic field cutting the wire, producing more cemf. A field cutting twice the number of turns will produce four times the voltage.

(2) Diameter or cross-sectional Area - Physically, it takes more wire to construct a coil of large diameter compared to a coil of small diameter with an equal number of turns. Therefore, more lines of force exist to induce a counter emf in the coil with the larger diameter. The inductance of a coil increases directly as the cross-sectional area of the core increases.

(3) Length of the Coil - Two coils with the same number of turns. In coil (A), the turns are widely spaced generating a small amount of magnetic linkage. In coil (B), the coil has more closely spaced turns. This close spacing increases the magnetic linkage, increasing the inductance of the coil. Increasing the length of the coil while keeping the same number of turns increases the distance between turns which decreases inductance.

(4) Core Material - There are two basic types of core materials, soft iron and air. The soft iron core has high permeability and low reluctance and provides a better path for magnetic lines of flux. This increases the number of lines of flux that are cutting each loop of the coil thus increasing the inductance of the coil. When using an air core coil, there is no low reluctance path provided for the magnetic flux so it tends to spread out producing a weaker magnetic field and less inductance.

(5) Number of Layers of Windings in the Coil – By increasing the number of layers of windings, this increases the

number of coil turns and the cross-sectional area of the coil which causes the inductance to increase.

e. Effects of Inductance on Direct Current: Electrical inductance is like mechanical inertia and causes electric current to rise and fall at a slower rate.

(1) In a purely resistive circuit the current rises almost instantaneously.

(a) If switch, S-1, is closed, the current in the circuit begins to rise. After one second, the current changes from 0 to 2 amperes. During the time that the current is changing, the magnetic field, which results from the current flow, cuts across the conductor producing a counter electromotive force (cemf). The cemf of self-inductance causes a delay in the rise of the current.

(b) As the current continues to increase and the magnetic field continues to expand across the conductor, the cemf continues to oppose the rise of current. As a result, there is some time lag in the rise in circuit current.

(c) Once the current has reached its maximum value and there is no longer a changing current, the magnetic field becomes stationary and there is no longer any cemf. As a result, the current flows.

(d) If switch, S-1, is now open, the current begins to fall towards zero. As the magnetic field collapses, the cemf tends to hold the current up causing a delay in the fall of the current.

(2) In a purely inductive circuit, the current rises at a much slower rate than in a purely resistive circuit due to the increased CEMF of self-inductance. When we form the conductor into a coil, the magnetic field becomes stronger, thus the cemf will be greater and the rise of circuit current slower.

f. Growth and Decay of Current in a LR Series Circuit: The time required for the current to rise to maximum value is a function of the resistance and inductance of a coil.

(1) The time required for current to rise in a coil (inductor) is equal to:

$$T = \frac{L}{R}$$

and is called the LR time constant.

(2) One LR time constant is the time required for the current in an inductor to increase to 63.2% of the maximum current.

(3) Each time constant is equal to the time required for the current to increase by 63.2% of the difference in value between the current flowing in the inductor and the maximum current.

(4) It takes five LR time constants before maximum current will flow.

(5) If we have a LR circuit with an inductance of 2 henrys and a resistance of 10 ohms, we can determine the LR time.

$T = L \div R \qquad T = 2 \div 10$

$T = .2$ seconds

(a) Each LR time constant is .2 seconds and it takes five LR times for the current to rise to maximum value.

(b) During the first LR time, the current increases to 63.2% of 10 amperes which is the total circuit current.

```
   10 amperes
 x.632
  6.32 amperes
```

During time one the current increased from zero to 6.32 amps. This leaves 3.68 amps of current.

```
  10.00 amps
 - 6.32
   3.68 amps
```

(c) During LR time two, the current increases 63.2% of the remaining current, 3.68 amps.

```
  3.68 amps     6.32 amps       10.00 amps
 x.632        + 2.33           - 8.65
  2.33 amps     8.65 amps        1.35 amps
```

During time two, the current increased from 6.32 amps to 8.65 amps. This leaves 1.35 amps of current.

(d) During LR time three, the current increases 63.2% of the remaining 1.35 amps.

```
  1.35 amps    8.6500 amps     10.0000 amps
```

```
 x .632         + .8532          - 9.5032
  .8532 amps    9.5032 amps         .4968 amps
```

During time three, the current increased from 8.65 amps to 9.5032 amps. This leaves .4968 amps of current.

(e) During LR time four, the current increases 63.2% of the remaining .4968 amps.

```
  .4968 amps     9.5032 amps      10.0000 amps
 x .632         + .3139          - 9.8171
  .3139 amps     9.8171 amps        .1829 amps
```

During time four, the current increased from 9.5032 to 9.8171 amps.

(f) During LR time five, the current increases 63.2% of the remaining .1829 amps.

```
  .1829 amps    9.8171 amps
 x .632        + .1156
  .1156 amps    9.9327 amps
```

During time five, the current increased from 9.8171 to 9.9327 amps.

(g) Thus, the current at the end of the fifth time constant is almost equal to 10 amperes.

(h) Once the current reaches 10 amperes, the magnetic field becomes stationary, there is no longer an affect from the cemf and the circuit current flows freely.

(i) When the LR circuit is de-energized, the circuit current decreases to zero in five time constants at the same rate that it previously increased.

(j) From LR time constant, we can see that we can control the time required for circuit current to rise and fall. This LR time becomes very important in electronic power supplies where we must filter or smooth out current.

(k) The time required for current to rise or fall will be directly proportional to the circuit inductance and inversely proportional to the circuit resistance.

(6) The only times that inductance will have an effect on DC is when the current is rising to maximum current when the circuit is first energized and when the current is falling to zero when the circuit is de-energized.

11. **Inductance and Alternating Current**: In a direct current circuit inductance only has an affect on the current when it is rising or falling. This occurs only when the circuit switch is closed or open. In an alternating current circuit, the current is always changing, increasing and decreasing in size and periodically changing direction. Thus, we constantly have the effect of inductance (electrical inertia) in an A.C. circuit.

a. Inductive Reactance: The opposing force which an inductor presents to the flow of alternating current cannot be called resistance, since it is not a result of friction within a conductor.

(1) This force is called inductive reactance because a coil reacts to changes in alternating current.

(2) Inductive reactance is measured in ohms.

(3) The symbol for inductive reactance is X_L.

X = reactance

L = inductance

(4) In an A.C. circuit, the rate of change of current depends on the angular velocity (speed of the conductor through a magnetic field or the magnetic field across a conductor).

(5) Angular velocity is the rate of change of the angle of conductor rotation and is measured in radians per second.

(6) Each cycle of A.C. consists of 2π radians. A radian is equal to 57.296^o

(7) The angular velocity is $W = 2\pi F$.

(8) Inductive reactance is directly proportional to the angular velocity and inductance and can be shown by the formula

$$X_L = 2\pi FL$$

X_L = inductive reactance

2π= Number of radians in a circle and is mathematically expressed as 6.28.

F = frequency of the A.C.

L = inductance in henrys

(9) From this formula, we can see that inductive reactance is directly proportional to frequency and inductance.

(a) If the frequency increases the inductive reactance increases.

(b) If the inductance increases the inductive reactance increases.

EXAMPLE: If F = 60 Hz and L = 2h X_L = ?

$$X_L = 2\pi FL$$
$$X_L = 6.28 \times 60 \times 2$$
$$X_L = 753.6\ \Omega$$

b. SERIES RESISTIVE/INDUCTIVE (RL) CIRCUITS:

(1) Ohm's Law applies to all circuits.

(2) In a series circuit, the current is constant.

$$I_T = I_R = I_L$$

(3) In a series circuit, the voltage is added, but because of inductive reactance, we cannot simply take the arithmetic sum of the voltages. We must find the vectored or algebraic sum of the voltages.

$$E_T = \sqrt{E_R^2 + E_L^2}$$

(4) In a series circuit, the opposition is added, but again because of inductive reactance, we cannot simply take the arithmetic sum of the oppositions. We must find the vectored or algebraic sum of the circuit oppositions. Since an A.C. series RL circuit contains resistance and inductive reactance, total opposition is called impedance and its symbol is Z.

$$Z = \sqrt{R^2 + X_L^2}$$

(5) Looking at our circuit, let's first look at the voltage and current relationships at the resistor and the coil or inductor.

(a) In any purely resistive circuit, the voltage and current go through their maximum and minimum values together. That is, they rise and fall together or are in step or in phase with each other. Phase is the angular relationship between voltage and current and at the resistor there is no angle generated between E and I so they are in phase.

(b) At the inductor, because of the inductive reactance constantly opposing the current, a phase shift takes place and there will be a phase difference between E and I of 90° with the voltage leading the current by 90°.

1 This phase difference, measured in degrees, is called the phase angle.

2 It is because of this angular difference between E and I that we must find the vectored or algebraic sum of the voltage and impedance.

(c) Since the circuit current is constant, we can use Ohm's Law and determine the voltage drops at R and L.

$$E_R = I_R \times R$$
$$E_R = 2a \times 10\Omega$$
$$E_R = 20V$$

$$E_L = I_L \times X_L$$
$$E_L = 2a \times 10\Omega$$
$$E_L = 20V$$

(d) The total voltage can be found by using our voltage formula.

$$E_T = \sqrt{E_R^2 + E_L^2}$$
$$E_T = \sqrt{20^2 + 20^2}$$
$$E_T = \sqrt{400 + 400}$$
$$E_T = \sqrt{800}$$
$$E_T = 28.28V$$

(e) We can illustrate how we would find this voltage (E_T) by using a vector diagram.

1 In any A.C. circuit, all values of R are always plotted on the horizontal line, in this case E_R (V1) is 20V. This is done because at the resistor E and I are in phase and there is no angle generated between them.

<u>2</u> At the inductor, E and I are out of phase by 90^o with E leading I. As a result, E_L (V2) must be plotted on the vertical line 90^o ahead of E_R.

<u>3</u> To add the two voltages using vectors, we use the head and tail method. The tail of V1 is placed on the head of V2. The tail of V3 is placed on the head of V2 and then to the head of VI forming a right triangle.

<u>4</u> E_T will be the hypotenuse of the right triangle.

(5) The phase angle is the number of electrical degrees of lead or lag between the voltage and current waveforms in an A.C. circuit.

(a) In order to find the phase angle, ⊃⬢, we use the tangent trigonometric function, $\frac{O}{A}$, the opposite over the adjacent or $\frac{E_L}{E_R}$

⊃⬢ $= \frac{E_L}{E_R}\ TAN^{-1}$ or INV. TAN

⊃⬢ $= \frac{20}{20} TAN^{-1}$

⊃⬢ $= 1\ \ TAN^{-1}$

An inverse tangent of one (1), will give us a phase angle of 45^o.

(b) From this problem, we can see that if the altitude and base of the right triangle are the same regardless of numerical values, the phase angle will always be 45^o.

(c) We can also conclude that the hypotenuse (total voltage in this case) is greater than either side of the triangle, but less than the sum of the two sides.

(d) We also know if the altitude (E_L) increases, the phase angle will be greater and the total voltage will increase. The reverse effect takes place if the altitude decreases.

(7) We can find the impedance of this circuit in two ways.

(a)Since we already know the circuit voltage and current, we can use Ohm's law for total circuit values.

$$Z = \frac{E_T}{I_T}$$
$$Z = \frac{28.28V}{2A}$$
$$Z = 14.14\Omega$$

(b) We can also use our impedance formula:

$$Z = \sqrt{R^2 + X_L^2}$$
$$Z = \sqrt{10^2 + 10^2}$$
$$Z = \sqrt{100 + 100}$$
$$Z = \sqrt{200}$$
$$Z = 14.14\Omega$$

(8) Power in Series RL Circuits: Power in a purely resistive A.C. circuit is the same as power in a D.C. circuit ($P=E \cdot I$), since the voltage and current are in phase. But in an RL circuit, the voltage will lead the current somewhere between 0 and 90 degrees (the phase angle) and the voltage and current will be out of phase.

(a) The total power delivered to the circuit is called apparent power and is measured in volt amps (VA). The apparent power is the product of the total circuit current and the total circuit voltage.

$$A_P = E_T \times I_T$$
$$A_P = 28.28V \times 2A$$
$$A_P = 56.56VA$$

(b) The true power is the product of the voltage and current at the resistive load and is measured in watts. At the resistive load, power is consumed and none is returned to the source.

$$P_T = E_R \times I_R$$
$$P_T = 20V \times 2A$$
$$P_T = 40W$$

(c) The reactive power is the product of the voltage and current at the inductor and is measured in volt amps reactive (VAR'S). However, the power at the inductor is not consumed, it is stored and returned to the source in the expanding and contracting magnetic field. Since this power is not consumed it is called reactive power.

$$P_R = E_L \times I_L$$
$$P_R = 20V \times 2A$$
$$P_R = 40VAR'S$$

(d) The power factor is a number that represents the portion of the apparent power dissipated in the circuit. The power factor is equal to the ratio of the true power to the apparent power or the cosine of the phase angle. The power factor is measured in percent.

$$P_F = \frac{P_T}{A_P}$$
$$P_F = \frac{40W}{56.56VA}$$
$$P_F = .707$$
$$P_F = 70.7\%$$

or the cosine of the phase angle which was 45°

$$P_F = COS \supset Ø$$
$$P_F = COS\ 45^{O}$$
$$P_F = .707$$
$$P_F = 70.7\%$$

(e) The apparent power of an A.C. circuit can be represented by a power triangle using a vector diagram.

$$A_P = \sqrt{P_T^2 + P_R^2}$$

1 In any A.C. circuit, all values of R1 are always plotted on the horizontal line, in this case, P_T = 40 watts. This is done because at the resistor, E and I are in phase.

2 At the inductor, E and I are out of phase by 90° with E leading I, as a result, the reactive power is plotted on the vertical line 90° ahead of the true power.

3 To add the two powers, reactive is added to the true power and the apparent power will appear as the hypotenuse of the right triangle formed.

c. Series Inductor Combinations: In solving A.C. series circuits, more than one inductor can be connected in series in order to obtain different inductance values.

(1) Inductance in series is calculated the same way as resistance is series. Resistance in series is additive, so total inductance is series will be additive.

$$L_T = L_1 + L_2 + L_3 \cdots\cdots$$

(2) Inductive reactance in series is also added.

$$X_{LT} = X_{L1} + X_{L2} + X_{L3} \cdots\cdots\cdots$$

(3) When solving circuit problems when given the circuit inductance of several coils, the inductance values are added to find the total inductance. Once the total inductance is calculated, the total inductive reactance can be found by placing the total inductance into the formula for inductive reactance

$$X_{LT} = 2\pi\ FL_T$$

d. Parallel Resistive/Inductive (RL) Circuits:

(1) Ohm’s Law applies to all circuits.

(2) In a parallel circuit the voltage is constant.

$$E_T = E_R = E_L$$

(3) In a parallel circuit, the current is added, but because of the angular difference between E and I, we cannot

simply take the arithmetic sum of the branch currents. We must find the vectored or algebraic sum of the currents.

$$I_T = \sqrt{I_R^2 + I_L^2}$$

(4) In order to find the impedance of a parallel RL circuit, we can use Ohm's Law for total circuit values or the vectored sum parallel impedance formula.

(a) Ohm's Law $$Z = \frac{E_T}{I_T}$$

(b) Vectored sum $$Z = \frac{R \times X_L}{\sqrt{R^2 + X_L^2}}$$

(5) Looking at the circuit, since the voltage is constant, we can use Ohm's Law to determine the circuit current through each parallel branch.

(a) $$I_R = \frac{E_R}{R}$$

(b) $$I_L = \frac{E_L}{X_L}$$

(6) The total current can be found by using the parallel current formula:

$$I_T = \sqrt{I_R^2 + I_L^2}$$
$$I_T = \sqrt{10^2 + 10^2}$$
$$I_T = \sqrt{100 + 100}$$
$$I_T = \sqrt{200}$$
$$I_T = 14.14a$$

(7) We can illustrate how we would find the total current (I_T) by using a vector diagram.

(a) All values of R are always plotted on the horizontal line, in this case I_R is 10 amps. This is done because E and I are in phase at the resistor.

(b) At the inductor, E and I are out of phase by 90° with E leading I. As a result, I_L must be plotted on the vertical line 90° ahead of I_R.

(c) To add the two currents using vectors, I_L must be added to I_R forming a right triangle. The total current (I_T) will appear as the hypotenuse of the right triangle.

(8) The phase angle is the number of electrical degrees of lead or lag between the voltage and current waveforms in an A.C. circuit. In order to find the phase angle, ⊃⬢, we use the tangent trigonometric function, $\frac{O}{A}$, the opposite over the adjacent or $\frac{I_L}{I_R}$

$$\supset⬢ = \frac{I_L}{I_R} \; TAN^{-1}$$ or **INV. TAN**

(9) The apparent power, true power, reactive power, and power factor formulas for parallel RL circuits are the same as the power formulas in series RL circuits.

(a) $A_P = E_T \times I_T \quad or \quad A_P = \sqrt{P_T^2 + P_R^2}$

(b) $P_T = E_R \times I_R$

(c) $P_R = E_L \times I_L$

e. Parallel Inductor Combinations: In solving A.C. parallel circuits, more than one inductor can be connected in parallel to obtain different inductance values.

(1) Inductance and inductive reactance in parallel are calculated the same as resistors in parallel.

$$L_T = \frac{L}{N}$$

(a) $$L_T = \frac{L_1 \times L_2}{L_1 + L_2}$$

$$L_T = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}}$$

$$X_{LT} = \frac{X_L}{N}$$

(b) $$X_{LT} = \frac{X_{L1} \times X_{L2}}{X_{L1} + X_{L2}}$$

$$X_{LT} = \frac{1}{\frac{1}{X_{L1}} + \frac{1}{X_{L2}} + \frac{1}{X_{L3}}}$$

(2) Once the value of inductive reactance has been determined, it can be placed in the parallel impedance formula.

f. Frequency Changes in Series and Parallel RL Circuits:

(1) Series RL Circuits:

(a) If the frequency increases, the inductive reactance will increase since it is directly proportional to frequency.

(b) Since inductive reactance is measured in Ohm's, the total circuit opposition or impedance will also increase.

(c) If the total circuit opposition increases, then the circuit current decreases.

(d) The voltage drop across the inductor will increase and the voltage drop across the resistor decreases.

(e) The total voltage will remain constant.

(f) The phase angle will increase as the circuit is becoming more inductive.

(g) Since the phase angle increases, the power factor will decrease.

(h) The same effects will take place with an increase in inductance.

(i) With the reactance of the coil increasing, it tends to block the circuit current. The higher the frequency the greater the blocking effect.

(j) The reverse effects will take place with a decrease in frequency. The lower we drop the frequency, the less reactance from the coil and more current flow. The inductor will pass more current and is said to act as a low pass filter.

(2) Parallel RL circuits.

(a) If the frequency increases, the inductive reactance will increase.

(b) Since inductive reactance is measured in Ohm's, the total circuit opposition or impedance will also increase.

(c) Since the impedance increases, the total current will decrease.

(d) The voltage drop across the resistor remains the some so the current through the resistor will remain the same.

(e) The voltage drop across the inductor will remain the same, but since the inductive reactance increased, the current through the inductor will decrease.

(f) The phase angle will decrease as the circuit is becoming less inductive.

(g) Since the phase angle decreases, the power factor will increase.

(h) As the frequency increases, the inductor will block current through the inductive branch and pass current through the resistive branch and is said to act as a high pass filter.

(i) The reverse effects will take place with a decrease in frequency.

12. **Capacitance**:

a. Is the property of an electrical circuit or component that opposes a change in voltage across it.

(1) The capacitor is a device that has the ability to store an electrical charge.

(a) There are two main classes of capacitors, fixed and variable.

1 Fixed

a Capacitance fixed during manufacturing process.

b There are two types, polarized and non-polarized.

2 Variable

a Capacitance can be varied.

b Largely used in transmitters and receivers.

(b) There are many different types of capacitors

1 Paper Capacitors

a General rating 300 pico Farads (pF) to 4 micro Farads (μF).

b General working voltage 500V.

c Tubular or encapsulated in shape.

d Made of two rolls of tinfoil with a tissue paper dielectric.

2 Ceramic Capacitors

a Extremely small in size.

b General rating 1 pF to .01 μF.

c General working voltage 500V.

d Can be made with a working voltage up to 30,000 volts for television or communications equipment.

e Disk or tubular in shape.

3 Mica Capacitors

a General rating 50 pF to .02 μF.

b General working voltage 500V.

c Encapsulated in shape.

d Made of molded Bakelite.

4 Electrolytic or Polarized

a Normally used in direct current circuits where large amounts of capacitance are required.

b General rating 5 to 1,000 μF.

c General voltage rating 25, 50, and 150 volts.

d 6 and 10 volt capacitors are often used in transistor circuits.

5 Variable Capacitors

a Capacitance is varied by rotating the rotor shaft.

b Rotor plates (moving part) mesh with the stator plates (stationary part).

c Full mesh is maximum capacitance.

d Out of mesh is minimum capacitance.

(2) The ability of holding or storing a charge is called capacitance or capacity.

(3) The basic unit of measure of capacitance is the Farad.

(4) A capacitor consists of two conducting plates separated by an insulating material called a dielectric. The name of the capacitor is generally the material that makes up the dielectric.

(5) A one-Farad capacitor stores one coulomb of charge when one volt of electrical pressure is applied to its plates.

$$C = \frac{Q}{E} \qquad 1\ Farad = \frac{1\ Coulomb}{1\ Volt}$$

C = Capacitance in Farads

Q = Quantity of charge in coulombs

E = Voltage

(6) The Farad is a large unit of charge and most capacitors are rated in smaller units called micro Farads (μF-10^{-6}) or pico Farads (pF-10^{-12}).

(7) The amount of charge that a capacitor requires is determined by the capacitance and the voltage.

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

$$Q = C \times E$$

1 coulomb = 1 Farad × 1 volt

(8) The value of capacitance is fixed by the physical size of the capacitor.

(9) The maximum amount of voltage applied to a capacitor depends on the strength of the dielectric material.

b. Factors affecting the capacitance (capacity) of a capacitor:

(1) There are three factors that affect the capacitance of a capacitor, the plate surface area, the distance between the plates, and the dielectric material.

(a) The plate surface area. A capacitor with a large plate area can store more charge than a capacitor with a small plate area. Simply stated, the larger the plate area the larger the capacitance.

(b) Distance between the plates. The capacitance of a capacitor is indirectly proportional to the distance between the plates. If the charges are further apart they lose strength just as the electron (- charge) in the outer orbit of an atom is not tightly held to the positive charge in the nucleus. Mathematically expressed by the formula:

$$F = \frac{Q_1 \times Q_2}{D^2}$$

From this formula, we can see that the Force (F) is directly proportional to the quantity of charge ($Q_1 \times Q_2$) and inversely proportional to the distance squared, D^2.

(c) The dielectric material. The capacitance of a capacitor is directly proportional to the dielectric constant of the insulating material.

1 The dielectric constant is the ability of the material to withstand electrostatic lines of force.

2 A dielectric material with a high dielectric constant (K) is a better insulator than a material with a low dielectric constant.

3 All dielectric materials are assigned a dielectric constant or K factor.

4 All dielectric constants are compared to air in a vacuum which is used as the reference for all dielectric constants.

5 The formula used to compute the value of capacitance is:

$$C = 0.2249 \frac{KA}{d}$$

C = capacitance in micro Farads

A = Area of one plate in square inches

d = distance between the plates in inches

K = dielectric constant of the insulating material

0.2249 = a constant for conversion from metric to British units

EXAMPLE: K = 3.5 dielectric constant of paper

d = .05 inch

A = 12 square inches

$$C = 0.2249 \frac{KA}{d}$$

$$C = 0.2249 \left(\frac{3.5 \times 12}{0.05}\right)$$

C = 189 micro Farads

6 From this formula, we can see that if the dielectric constant increases the capacitance will increase.

c. Voltage Rating of Capacitors:

(1) The voltage rating is referred to as the working voltage.

(a) The working voltage is the maximum voltage that can be applied to the capacitor without damage to the dielectric.

(b) The working voltage depends on the dielectric material and the thickness of the dielectric.

(c) If we exceed the working voltage of a capacitor the dielectric could break down and a short circuit will occur.

(d) A capacitor that may be charged to 500 volts D.C. cannot be safely charged to 500 volts rms A.C. since 500 volts rms A.C. will have a peak voltage of 707 volts.

1 A capacitor requiring 500 volts rms A.C. would need a working voltage of 750V peak.

2 In practice, a capacitor should be selected with a working voltage 50% greater than the effective voltage applied to it.

d. Charging and Discharging a Capacitor:

(1) Charging:

(a) With the switch in position one, the circuit is de-energized.

(b) At the instant the switch is placed in position two, a displacement of electrons (displacement current) takes place in all parts of the circuit.

(c) This electron displacement is directed away from the negative terminal and toward the positive terminal. A brief surge of current will flow as the capacitor charges.

(d) At the instant the switch is thrown the positive terminal of the battery draws electrons from the conductor and plate one. Since electrons are drawn off plate one it becomes positively charged. The negative terminal of the battery repels electrons toward plate two and it becomes negatively charged.

(e) In every part of the circuit, a clockwise displacement of electrons occurs.

(f) As electrons accumulate on the top plate and others depart the bottom plate, a difference in potential or voltage builds up across the capacitor plates.

(g) The polarity of the voltage which builds up across the capacitor opposes the source voltage.

1 The source voltage (emf) forces current around the circuit in a clockwise direction.

2 The emf developed across the capacitor, however, has a tendency to force current in a counterclockwise direction, opposing the source emf.

(h) As the capacitor continues to charge, the voltage across the capacitor rises until it equals the source voltage.

(i) Once the capacitor voltage equals the source voltage, the two voltages balance one another and current ceases to flow in the circuit.

(j) While the capacitor is charging, no current flows through the capacitor. The insulating material (dielectric) prevents current flow by preventing the current from having a complete path to flow through.

(k) The current that appears to flow through the circuit is called displacement current.

(l) While the capacitor is charging, the displacement current starts at a high value. As the charge on the capacitor plates builds up (opposing the source voltage), the current drops until the capacitor is fully charged and there will be no current flow.

(m) When the capacitor is fully charged, the electrostatic field between the plates is maximum and the energy stored in the dielectric is maximum.

(n) If the charged capacitor is disconnected from the source, the charge will be retained for some period of time. The length of time the charge is retained depends on the amount of leakage current present. Since electrical energy is stored in the capacitor, a charged capacitor can act as a source emf.

(2) Discharging:

(a) To discharge a capacitor, the charges on both plates must be neutralized. This is accomplished by placing a conducting path between the plates or placing the switch in position three.

(b) With the switch in position three, the excess electrons on the negative plate can flow to the positive plate and neutralize its charge.

(c) When the capacitor discharges, the stored energy is returned to the circuit.

(d) The capacitor does not consume power. The energy the capacitor draws from the source is recovered when the capacitor discharges.

e. Growth and Decay of Voltage in a RC Series Circuit: The time required for the voltage to rise to its maximum value is a function of the resistance and capacitance of a circuit.

(1) The time required for voltage to rise in a RC circuit is equal to R%C (T = RC) and is called the RC time constant.

(2) One RC time constant is the time required for the voltage to increase to 63.2% of the maximum voltage.

(3) Each time constant is equal to the time required for the voltage across the capacitor to increase to 63.2% of the applied voltage.

(4) It takes five RC time constants before the maximum voltage will appear across the capacitor.

(5) If we have an RC circuit with a capacitance of .02 Farads and a resistance of 10⦸, we can determine the RC time.

$T = R \cdot C$ or $T = 10 \cdot .02F$
$T = .2$ seconds

(a) Each RC time constant is .2 seconds and it takes five RC times for the current to rise to a maximum value.

(b) During RC time one, the voltage increases to 63.2% of 10 volts which is the applied voltage.

$$\begin{array}{r} 10 \text{ volts} \\ \times\ \underline{.632} \\ 6.32 \text{ volts} \end{array}$$

During time one, the voltage increased from zero to 6.32 volts. This leaves 3.68 volts remaining which is felt across the resistor.

(c) During RC time two, the voltage across the capacitor increases 63.2% of the remaining voltage, 3.68 volts.

$$\begin{array}{r} 3.68 \text{ volts} \\ \times\ \underline{.632} \\ 2.33 \text{ volts} \end{array}$$

During time two, the voltage increased from 6.32 volts to 8.65 volts. This leaves 1.35 volts remaining which is felt across the resistor.

(d) During RC time three, the voltage across the capacitor increases 63.2% of the remaining voltage, 1.35 volts.

$$\begin{array}{r} 1.35 \text{ volts} \\ \times\ \underline{.632} \\ .8532 \text{ volts} \end{array}$$

During time three, the voltage increased from 8.65 volts to 9.5032 volts. This leaves .4968 volts remaining which is felt across the resistor.

(e) During RC time four, the voltage across the capacitor increases 63.2% of the remaining voltage, .4968 volts.

$$\begin{array}{r} .4968 \text{ volts} \\ \times\ \underline{.632} \\ .3139 \text{ volts} \end{array}$$

During time four, the voltage increased from 9.5032 to 9.8171 volts. This leaves .1829 volts remaining which is felt across the resistor.

(f) During RC time five, the voltage across the capacitor increases 63.2% of the remaining voltage, .1829 volts.

$$\begin{array}{r} .1829 \text{ volts} \\ \times\ \underline{.632} \\ .1156 \text{ volts} \end{array}$$

During time five, the voltage increased from 9.8171 to 9.9327 volts. This leaves .1156 volts remaining which is felt across the resistor.

(g) Thus, the voltage across the capacitor is almost equal to the source voltage, 10 volts and the voltage across the resistor is almost zero.

(h) Once the voltage across the capacitor reaches 10 volts, there is no current flow in the circuit and the capacitor is said to have blocked the current.

(i) When the RC circuit is de-energized, the circuit voltage decreases to zero in five time constants at the same rate that it previously increased.

(j) From the RC time constant, we can see that we can control the time required for a capacitor to charge and discharge. This RC time becomes very important in electronic power supplies where we must filter or smooth out the voltage.

(k) The time required to charge and discharge a capacitor is directly proportional to circuit resistance and capacitance.

f. Testing Capacitors: The most common failure of a capacitor occurs when there is a short in the capacitor. When a capacitor is shorted, there is an internal breakdown in the dielectric. The break in the dielectric permits the two plates to touch each other or it carbonizes so that there is a low resistance between the plates.

(1) A shorted or leaky capacitor can be tested through the use of an ohmmeter. This test is referred to as the Capacitor Kick Test.

(2) When testing for a shorted capacitor in a circuit, it is usually desirable to disconnect one lead of the capacitor from the circuit. By disconnecting the capacitor from the circuit, it is possible to test only the capacitor and not other parts of the circuit.

(3) Place the ohmmeter leads across the capacitor.

(4) If the capacitor is shorted, the resistance will be very low and the ohmmeter will read a low or zero resistance.

(5) If the capacitor is good, when the ohmmeter leads are first placed across the capacitor, the ohmmeter will show a very low or zero resistance. As the ohmmeter battery charges the capacitor, the ohmmeter display will move quickly to open or infinite resistance.

(6) With the digital ohmmeter, the Kick Test happens quite rapidly, so you must pay close attention to the digital display. If using an analog meter, the needle moves more slowly. The result will be the same no matter which ohmmeter is used.

(7) The higher resistance ranges offer increased sensitivity for checking smaller capacitors.

13. **Capacitance and Alternating Current:** In a direct current circuit, a capacitor, once it is charged, will block current flow. In an alternating current circuit, the capacitor will charge and discharge when the applied voltage changes. While the capacitor is charging and discharging, there is a charge and discharge current. Though the capacitor does not actually pass current through it, the current oscillates back and forth along with the frequency of the circuit and it appears that current flows. Thus, it is said that a capacitor will pass A.C.

a. Capacitive Reactance: The opposing force which a capacitor presents to the flow of alternating current is called capacitive reactance.

(1) This force is called capacitive reactance because of two factors.

(a) For a given voltage and frequency, the number of electrons which go back and forth from plate to plate is limited by the storage ability or capacitance of the capacitor. As the capacitance is increased, a greater number of electrons change plates every cycle and since current is a measure of the number of electrons passing a given point in a given amount of time, the current is increased. The reverse affect takes place with a decrease in capacitance.

(b) Increasing the frequency will cause the number of electrons to change plates more often (faster). As a result more electrons will pass a given point in a given time, thus we have more current flow. The reverse affect takes place with a decrease in frequency.

(2) Capacitive reactance is measured in ohms.

(3) The symbol for capacitive reactance is: X_C

X = reactance
C = capacitance

(4) Capacitive reactance is indirectly proportional to frequency and capacitance and can be shown by the formula:

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

X_C = capacitive reactance

2π = 6.28, a constant

F = frequency

C = capacitance in Farads

From the formula, we can see that if the frequency or capacitance increases, the capacitive reactance will decrease. If the frequency or capacitance decrease, the reverse affect will take place.

EXAMPLE: If F = 60 Hz and C = 5 μf Find X_C = ?

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

$$X_C = \frac{1}{6.28 \times 60 \times .000005}$$

$$X_C = \frac{1}{.001884}$$

$$X_C = 531\Omega$$

b. SERIES RESISTIVE/CAPACITIVE (RC) CIRCUITS:

(1) Ohm's Law applies to all circuits.

(2) In a series circuit, the current is constant.

$$I_T = I_R = I_C$$

(3) In a series circuit, the voltage is added, but because of capacitive reactance, we cannot simply take the arithmetic sum of the voltages. We must find the vectored or algebraic sum of the voltages.

$$E_T = \sqrt{E_R^2 + E_C^2}$$

(4) In a series circuit, the opposition is added, but again, because of capacitive reactance, we must find the vectored or algebraic sum of circuit oppositions.

$$Z = \sqrt{R^2 + X_C^2}$$

(5) Looking at the circuit, let's first look at the phase relationships between voltage and current at the circuit components.

(a) At the resistor, the voltage and current are in phase and there is no angle generated between them.

(b) At the capacitor, because the capacitor opposes any change in voltage, a phase shift takes place causing a phase difference between E and I of 90° with the current leading the voltage.

1 This phase difference is called the phase angle.

2 It is because of this angular difference between E and I that we must find the vectored or algebraic sum of the voltage and impedance.

(c) Since the circuit current is constant, we can use Ohm's Law and determine the voltage drops at R and C.

1

$$E_R = I_R \times R$$
$$E_R = 4a \times 20\Omega$$
$$E_R = 80V$$

2

$$E_C = I_C \times X_C$$
$$E_C = 4a \times 20\Omega$$
$$E_C = 80V$$

3 The total voltage can be found by using the voltage formula:

$$E_T = \sqrt{E_R^2 + E_C^2}$$
$$E_T = \sqrt{80^2 + 80^2}$$
$$E_T = \sqrt{6400 + 6400}$$
$$E_T = \sqrt{12{,}800}$$
$$E_T = 113.13V$$

(d) We can illustrate how we would find this voltage (E_T) by using vectors.

1 All values of R are always plotted on the horizontal line in this case E_R 80V.

2 At the capacitor, E and I are 90° out of phase with I leading E. As a result E_C, must be plotted 90° behind E_R.

3 To add the two voltages E_C is added to E_R forming a right triangle. The total voltage (E_T) will appear as the hypotenuse of the right triangle

(e) The phase angle is found the same way as with series RL circuits substituting C for L.

$$\angle 2 = \frac{E_C}{E_R} TAN^{-1}$$

$$\angle 2 = \frac{80}{80} TAN^{-1}$$

$$\angle 2 = 1\ TAN^{-1}$$

$$\angle 2 = 45^o$$

(f) We can find the impedance of this circuit the same way as with series RL circuits substituting X_C for X_L.

1 $$Z = \frac{E_T}{I_T}$$

$$Z = \frac{113.13V}{4a}$$

$$Z = 28.28\Omega$$

2 $$Z = \sqrt{R^2 + X_C^2}$$

$$Z = \sqrt{20^2 + 20^2}$$

$$Z = \sqrt{400 + 400}$$

$$Z = \sqrt{800}$$
$$Z = 28.28\ \Omega$$

(6) Power is calculated the same as series RL circuits, again substituting C for L.

(a) The apparent power is the product of the total circuit current and voltage or the vectored sum of the true power and the reactive power.

1 $$A_P = E_T \times I_T$$
$$A_P = 113.13V \times 4a$$
$$A_P = 452.52\ volt\ amps\ (VA)$$

2 $$A_P = \sqrt{P_T^2 + P_R^2}$$
$$A_P = \sqrt{320^2 + 320^2}$$
$$A_P = \sqrt{102400 + 102400}$$
$$A_P = \sqrt{204800}$$
$$A_P = 452.54\ VA$$

(b) The true power is the product of the voltage and current at the resistive load.

$$P_T = E_R \times I_R$$
$$P_T = 80v \times 4a$$
$$P_T = 320w$$

(c) The reactive power is the product of the voltage and current at the capacitor. The power at the capacitor is not consumed, but is stored and returned to the circuit by the electrostatic field around the capacitor.

$$P_R = E_C \times I_C$$
$$P_R = 80v \times 4a$$
$$P_R = 320\ VAR'S$$

(d) The power factor is equal to the ratio of the true power to the apparent power or the cosine of the phase angle.

1

$$P_F = \frac{P_T}{A_P}$$

$$P_F = \frac{320\ w}{452.52\ VA}$$

$$P_F = .707$$

$$P_F = 70.7^{\%}$$

2

$$P_F = COS\ \angle 2$$

$$P_F = COS\ 45^{o}$$

$$P_F = .707$$

$$P_F = 70.7^{\%}$$

(7) Series Capacitor Combinations: In solving A.C. series circuits, more than one capacitor can be connected in series in order to obtain different capacitance values.

(a) Capacitance in series acts like resistance in parallel since capacitors in series has the effect of increasing the distance between the plates or increasing the strength of the dielectric.

$$C_T = \frac{C}{N}$$

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

(b) Capacitive reactance in series is like resistance in series since in series if the circuit capacitance decreases, the capacitive reactance increases.

$$X_{CT} = X_{C1} + X_{C2} + X_{C3}........$$

(c) When solving circuit problems when given the circuit capacitance of several capacitors, the total circuit capacitance may be found first. Once the total capacitance is calculated, the total capacitive reactance can be found by placing the total capacitance into the formula for capacitive reactance.

$$X_{CT} = \frac{1}{2\pi FC_T}$$

c. Parallel Resitive/Capacitive (RC) Circuits:

(1) Ohm’s Law applies to all circuits.

(2) In a parallel circuit, the voltage is constant.

$$E_T = E_R = E_C$$

(3) The current is added, but we must find the vectored or algebraic sum of the currents.

$$I_T = \sqrt{I_R^2 + I_C^2}$$

(4) In order to find impedance, we can use Ohm's Law for total circuit values or the parallel impedance formula.

(a) $Z = \frac{E_T}{I_T}$

(b) $Z = \frac{R \times X_C}{\sqrt{R^2 + X_C^2}}$

(5) Since the voltage is constant, we can use Ohm's Law to determine the current through each parallel branch.

(a) $I_R = \frac{E_R}{R}$

(b) $I_C = \frac{E_C}{X_C}$

(c) The total current can be found by using our parallel current formula.

$$I_T = \sqrt{I_R^2 + I_C^2}$$
$$I_T = \sqrt{10^2 + 10^2}$$
$$I_T = \sqrt{100 + 100}$$
$$I_T = \sqrt{200}$$
$$I_T = 14.14\ a$$

(6) We can illustrate how we would find the total current (I_T) by using a vector diagram.

(a) I_R, 10 amps, is plotted on the horizontal line since E and I are in phase at the resistor.

(b) At the capacitor, E and I are 90° out of phase and, as a result, I_C must be plotted on the vertical line 90° behind I_R.

(c) To add the two currents using vectors, I_C must be added to I_R forming a right triangle. The total current (I_T) will appear as the hypotenuse of the right triangle.

(7) The phase angle is found the same way as with parallel RL circuits by substituting C for L.

$$\supset\Leftrightarrow = \frac{I_C}{I_R} TAN^{-1}$$

$$\supset\Leftrightarrow = \frac{10}{10} TAN^{-1}$$

$$\supset\Leftrightarrow = 1\ TAN^{-1}$$

$$\supset\Leftrightarrow = 45^o$$

A tangent of one will give us a phase angle of 45°

(8) To find the circuit powers, we use the same formulas that we used for power in series.

(a) There are two formulas for calculating the apparent power.

1 $A_P = E_T \times I_T$
$A_P = 200V \times 14.14a$
$A_P = 2828VA$

2 $A_P = \sqrt{P_T^2 + P_R^2}$
$A_P = \sqrt{2000^2 + 2000^2}$
$A_P = \sqrt{4000000 + 4000000}$
$A_P = \sqrt{8000000}$
$A_P = 2828\,VA$

(b) True power

$$P_T = E_R \times I_R$$
$$P_T = 200V \times 10a$$
$$P_T = 2000W$$

(c) Power reactive

$$P_R = E_C \times I_C$$
$$P_R = 200V \times 10a$$
$$P_R = 2000\,VAR'S$$

(d) The power factor is equal to the cosine of the phase angle or the true power divided by the apparent power.

1 Cosine of 45° = .7071
Expressed as a percent 70.7%

2 $P_F = \dfrac{P_T}{A_P}$

(9) Parallel Capacitor Combinations: In solving A.C. parallel circuits, more than one capacitor can be connected in parallel to obtain different capacitive values.

(a) Capacitance in parallel is like resistance in series since putting capacitors in parallel has the affect of increasing the plate surface area.

$$C_T = C_1 + C_2 + C_3 \cdots$$

(b) Capacitive reactance in parallel is like resistance in parallel since capacitance in parallel is increased the capacitive reactance decreases.

$$X_{CT} = \frac{X_C}{N}$$

$$X_{CT} = \frac{X_{C1} \times X_{C2}}{X_{C1} + X_{C2}}$$

$$X_{CT} = \frac{1}{\frac{1}{X_{C1}} + \frac{1}{X_{C2}} + \frac{1}{X_{C3}}}$$

d. Frequency Changes in Series and Parallel RC Circuits:

(1) Series RC Circuits

(a) If the frequency increases, the capacitive reactance will decrease since it is indirectly proportional to the frequency.

(b) Since capacitive reactance is measured in ohms, the circuit impedance will decrease.

(c) If the impedance decreases, the total circuit current will increase.

(d) The voltage drop across the capacitor will decrease and increase across the resistor.

(e) The total circuit voltage will remain constant.

(f) The phase angle will decrease as the circuit is becoming more resistive.

(g) The same affects will take place with an increase in capacitance.

(h) With the reactance of the capacitor decreasing, it tends to pass the circuit current. The higher the frequency the higher the current passed. The capacitor is said to act as a high pass filter.

(i) The reverse affects will take place with a decrease in frequency.

(2) Parallel RC Circuits

(a) If the frequency increases, the capacitive reactance decreases.

(b) The total impedance decreases.

(c) The total circuit current will increase.

(d) The phase angle will increase.

(e) The current through the resistor will remain the same.

(f) The current through the capacitor will increase.

(g) As the frequency increases, the capacitor will pass more current through the capacitive branch and will block current through the resistive branch.

(h) The reverse affects will take place with a decrease in frequency.

14. **Series and Parallel RLC Circuits**:

a. Series RLC Circuits

(1) Ohm's Law applies to all circuits.

(2) In a series circuit, the current is constant.

$$I_T = I_R = I_L = I_C$$

(3) In a series circuit, the voltage is added, but we must find the vectored or algebraic sum of the voltages.

$$E_T = \sqrt{E_R^2 + (E_L - E_C)^2}$$
$$or \quad (E_C - E_L)^2$$

(4) In a series circuit, the oppositions are added, but we must find the vectored or algebraic sum of the oppositions.

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$or\ (X_C - X_L)^2$$

(5) Looking at the circuit, let's start with the voltage.

(a) Since the circuit current is constant, we can use Ohm's Law and determine the voltage drops at R, L, and C.

<u>1</u>
$$E_R = I_R \times R$$
$$E_R = 4a \times 10\Omega$$
$$E_R = 40v$$

<u>2</u>
$$E_L = I_L \times X_L$$
$$E_L = 4a \times 20\Omega$$
$$E_L = 80v$$

<u>3</u>
$$E_C = I_C \times X_C$$
$$E_C = 4a \times 10\Omega$$
$$E_C = 40v$$

(b) The total voltage can be found by using the voltage formula.

$$E_T = \sqrt{E_R^2 + (E_L - E_C)^2}$$
$$E_T = \sqrt{40^2 + (80 - 40)^2}$$
$$E_T = \sqrt{40^2 + 40^2}$$
$$E_T = \sqrt{1600 + 1600}$$
$$E_T = \sqrt{3200}$$
$$E_T = 56.56v$$

(c) We can illustrate how to find this voltage (E_T) by using vectors.

<u>1</u> E_R is plotted on the horizontal line, in this case 40 volts.

2 E_C is plotted 90° behind E_R since at the capacitor, the voltage lags the current by 90°.

3 E_L is plotted 90° ahead of E_R since at the inductor, the voltage leads the current by 90°.

4 To add the three voltages, since E_L is larger than E_C, E_C is subtracted from E_L and the difference is added to ER forming a right triangle. The total voltage (E_T) will appear as the hypotenuse of the triangle.

(d) The phase angle is found the same way as with series RL or RC circuits, except you must find the difference between E_L and E_C first.

$$E_L - E_C \quad or$$

$$\supset\Leftrightarrow = \frac{E_C - E_L}{E_R} TAN^{-1}$$

(e) We can find the impedance of this circuit by using Ohm's Law or the impedance formula.

1 $$Z = \frac{E_T}{I_T}$$

$$Z = \frac{56.56\ v}{4\ a}$$

$$Z = 14.14\ \Omega$$

2 $$Z = \sqrt{R^2 + (X_L - X_C)^2 or\ (X_C - X_L)^2}$$

$$Z = \sqrt{10^2 + (20-10)^2}$$

$$Z = \sqrt{10^2 + 10^2}$$

$$Z = \sqrt{100+100}$$

$$Z = \sqrt{200}$$

$$Z = 14.14\ \Omega$$

(6) Power is calculated the same way as with series RL and RC circuits.

(a) The apparent power is the product of the total voltage and total current or the vectored sum of the true power and the reactive power.

1 $$A_P = E_T \times I_T$$
$$A_P = 56.56v \times 4a$$
$$A_P = 226.24\,VA$$

2 $$A_P = \sqrt{P_T^2 + P_R^2}$$
$$A_P = \sqrt{160^2 + 160^2}$$
$$A_P = \sqrt{25{,}600 + 25{,}600}$$
$$A_P = \sqrt{51{,}200}$$
$$A_P = 226.24VA$$

(b) The true power is the product of the voltage and current at the resistive load.

$$P_T = E_R \times I_R$$
$$P_T = 40v \times 4a$$
$$P_T = 160w$$

(c) The reactive power is the difference in the power at the inductor and capacitor.

$$P_R = (P_L - P_C) \text{ or } (P_C - P_L)$$

1 $$P_L = E_L \times I_L$$
$$P_L = 80v \times 4a$$
$$P_L = 320\,VAR'S$$

2 $$P_C = E_C \times I_C$$
$$P_C = 40v \times 4a$$
$$P_C = 160\,VAR'S$$

3 $P_R = 320 - 160$
$P_R = 160\ VAR'S$

(d) The Power factor is the cosine of the phase angle or the true power divided by the apparent power.

1 $P_F = COS\ \supset\Leftrightarrow$

2 $P_F = \frac{P_T}{A_P}$

c. Parallel RLC Circuits:

(1) Ohm’s Law applies to all circuits.

(2) In a parallel circuit, the voltage is constant.

$$E_T = E_R = E_L = E_C$$

(4) The current is added, but we must find the vectored or algebraic sum of the currents.

$$I_T = \sqrt{I_R^2 + (I_L - I_C)^2 \quad or\ (I_C - I_L)^2}$$

(5) In order to find the impedance we can use Ohm’s Law for total values or the product over the sum.

(a) $Z = \frac{E_T}{I_T}$

(b) In order to use the product over the sum, we must first find the circuit reactance or X.

1 If X_L is larger than X_C

$$X = \frac{X_L \times X_C}{X_L - X_C}$$

2 If X_C is larger than X_L

$$X = \frac{X_C \times X_L}{X_C - X_L}$$

3 Once we have found X, we substitute it for X_L or X_C in our parallel impedance formula.

$$Z = \frac{R \times X}{\sqrt{R^2 + X^2}}$$

(5) Looking at the circuit, since the voltage is constant, we can use Ohm's Law to determine the current through each parallel branch.

(a) $$I_R = \frac{E_R}{R}$$

$$I_R = \frac{120v}{5\Omega}$$

$$I_R = 24a$$

(b) $$I_L = \frac{E_L}{X_L}$$

$$I_L = \frac{120v}{10\Omega}$$

$$I_L = 12a$$

(c) $$I_C = \frac{E_C}{X_C}$$

$$I_C = \frac{120v}{20\Omega}$$

$$I_C = 6a$$

(d) The total current can be found by using the parallel current formula.

$$I_T = \sqrt{I_R^2 + (I_L - I_C)^2}$$
$$I_T = \sqrt{24^2 + (12 - 6)^2}$$
$$I_T = \sqrt{24^2 + 6^2}$$
$$I_T = \sqrt{576 + 36}$$
$$I_T = \sqrt{612}$$
$$I_T = 24.74a$$

(e) We can illustrate how we would find the total current (I_T) by using vectors.

<u>1</u> I_R (24a) is plotted on the horizontal line since E and I are in phase at R.

<u>2</u> I_C (6a) is plotted 90° ahead of I_R since at the capacitor I leads E by 90°.

<u>3</u> I_L (12a) is plotted 90° behind I_R since at the inductor I lags E by 90°.

<u>4</u> To add the three voltages since I_L is larger than I_C it is subtracted from I_L and then added to I_R forming a right triangle. The total current (I_T) will appear as the hypotenuse of the triangle.

(6) The phase angle is found the same way as with parallel RL or RC circuits, except that you have to find the difference between I_L and I_C first.

$$\supset\Leftrightarrow = \frac{I_L - I_C \text{ or } I_C - I_L}{I_R} TAN^{-1}$$
$$\supset\Leftrightarrow = \frac{12 - 6}{24} TAN^{-1}$$
$$\supset\Leftrightarrow = \frac{6}{24} TAN^{-1}$$
$$\supset\Leftrightarrow = .25\, TAN^{-1}$$
$$\supset\Leftrightarrow = 14.04^o$$

A tangent of (0.25) will give us a phase angle of 14.04^{o}.

(7) To find the impedance, we can use Ohm's Law for total circuit values or the parallel impedance formula.

(a) $Z = \frac{E_T}{I_T}$

$$Z = \frac{120v}{24.74a}$$

$$Z = 4.85\Omega$$

(b) $X = \frac{X_C \times X_L}{X_C - X_L}$

$$X = \frac{20 \times 10}{20 - 10}$$

$$X = \frac{200}{10}$$

$$X = 20\Omega$$

(c) $Z = \frac{R \times X}{\sqrt{R^2 + X^2}}$

$$Z = \frac{5 \times 20}{\sqrt{5^2 + 20^2}}$$

$$Z = \frac{100}{\sqrt{25 + 400}}$$

$$Z = \frac{100}{\sqrt{425}}$$

$$Z = \frac{100}{20.62}$$

$$Z = 4.85\Omega$$

.

(8) To find the circuit power, we use the same formulas that we used for power in series.

(a) Apparent power

1
$$A_P = E_T \times I_T$$
$$A_P = 120v \times 24.74a$$
$$A_P = 2968.8\ VA$$

2
$$A_P = \sqrt{P_T^2 + P_R^2}$$
$$A_P = \sqrt{2880^2 + 720^2}$$
$$A_P = \sqrt{8{,}294{,}400 + 518{,}400}$$
$$A_P = \sqrt{8{,}812{,}800}$$
$$A_P = 2968.8\ VA$$

(b) True power

$$P_T = E_R \times I_R$$
$$P_T = 120v \times 24a$$
$$P_T = 2880w$$

(c) Power reactive

1
$$P_L = E_L \times I_L$$
$$P_L = 120v \times 12a$$
$$P_L = 1440\ VAR'S$$

2
$$P_C = E_C \times I_C$$
$$P_C = 120v \times 6a$$
$$P_C = 720\ VAR'S$$

3
$$P_R = P_L - P_C$$
$$P_R = 1440 - 720$$
$$P_R = 720\ VAR'S$$

(d) The power factor is equal to the cosine of the phase angle or the true power divided by the apparent power.

1 Cosine of 14.04^{o} = 0.970
Expressed as a percent 97%

2 $$P_F = \frac{P_T}{A_P}$$

$$P_F = \frac{2880}{2968.8}$$

$$P_F = .97$$

$$P_F = 97^{\%}$$

c. Frequency Changes in Series and Parallel RLC Circuits:

(1) Series RLC Circuits:

(a) The inductive reactance and capacitive reactance will vary with the frequency.

(b) If the frequency increases, X_L will increase and X_C will decrease.

(c) If the frequency decreases, X_L will decrease and X_C will increase.

(d) At some point by varying the frequency, X_L and X_C will be equal. This condition is called resonance.

(e) The frequency, when X_L and X_C are equal, is called the resonant frequency.

(f) At the resonant frequency, X_L and X_C, being opposites, will cancel each other out and the only circuit opposition will be the resistance.

(g) The circuit impedance will be at a minimum and current will be maximum.

(h) The phase angle will be zero and E and I will be in phase.

(i) Above and below resonance, the current is low because of the high impedance.

(j) At resonance, there is a maximum transfer of power.

(2) Parallel RLC Circuits

(a) X_L and X_C will vary with the frequency.

(b) At the resonant frequency, X_L and X_C will be equal.

(c) To understand further affects, we must look at a tank circuit.

1 The tank circuit operates on the interchange of energy between L and C.

2 If a momentary voltage is applied to the circuit and then removed, capacitor C1 will charge up when the voltage is applied. When the voltage is removed, C1 will discharge through L1 causing a magnetic field to build up around L1. When the capacitor has completely discharged, the magnetic field around L1 will collapse causing current to flow in the same direction and charging the capacitor in the opposite direction. When the magnetic field has completely collapsed, C1 will discharge in the opposite direction causing the magnetic field around L1 to build up and the process is repeated.

(3) This process generates a number of sine waves or oscillations (back and forth motions).

(a) This oscillation action is called the flywheel effect and is the basic principle of operation of oscillator circuits used in electronic equipment.

(b) To sustain oscillations, additional energy must be applied to the circuit on a regular basis.

(4) When A.C. is applied continuously at the resonant frequency, the following conditions exist.

(a) The currents through L and C are equal because XL and XC are equal.

(b) The line current is minimum.

(c) The circulating current is maximum indicating the opposition within the tank is minimum.

(d) The impedance of the circuit is minimum.

(e) The phase angle will be zero and E and I will be in phase.

(f) At frequencies below the resonant frequency, X_L is less than X_C and the current lags the voltage.

(g) At frequencies above the resonant frequency, X_C is less than X_L and the current leads the voltage.

15. **Transformers:** A transformer is an electrical device used to change voltage and current of one energy level to voltage and current of another energy level through electromagnetic induction. This transfer of energy is accomplished without any appreciable power loss.

a. The three main parts of a transformer are the primary winding, secondary winding, and the core.

(1) The primary winding is always connected to the A.C. source and receives energy from the source.

(2) The secondary winding is always connected to the load and receives energy from the primary winding.

(3) The core provides a low reluctance path for magnetic lines of force to insure high mutual inductance and a maximum transfer of energy. The core is also used to support the windings or coils.

(4) The enclosure protects the above components from dirt, moisture, and mechanical damage.

b. Transformer Core Characteristics:

(1) Commonly used core materials are air, soft iron, and silicon steel.

(a) Air core transformers are used in high frequency applications. (Above 20K Hz)

(b) Soft iron or silicon steel transformers are used in low frequency applications. (Below 20K Hz)

1 Provides better power transfer than the air core transformer.

2 Is constructed of laminated sheets of soft iron in order to dissipate heat.

3 The laminated sheets are insulated with a non-conducting material such as varnish and then formed into a core.

4 It takes 50 laminations to make a core one inch thick.

5 The purpose of the laminations is to reduce heat loss.

(2) There are two basic types of transformer cores, the Hallow core or core type and the Shell core or shell type.

(a) Hallow core

1 Core is in the shape of a rectangle.

2 Coils are placed on the outer legs of the core.

(b) Shell core

1 Core is in the shape of a rectangle with a central leg.

2 Coils are placed on the central leg.

c. How a Transformer Works:

(1) The ability of a transformer to transfer energy from its primary winding to its secondary winding is accomplished through mutual induction, which takes place when the changing magnetic field produced in the primary expands and cuts across the secondary winding.

(2) Effect of a load. When a load is connected across the secondary winding of a transformer, current will flow through the secondary and the load.

(a) The total magnetic flux, which results from primary and secondary current, is common to primary and secondary windings.

(b) The magnetic flux is the means by which energy is transferred from the primary to the secondary winding.

(c) Since the flux links both windings, it is called mutual flux.

1 The amount of flux linkage between the two coils is called the coefficient of coupling.

2 When all the flux produced links both coils, the coefficient of coupling is said to be 1.

3 Nothing is perfect and there will always be a few flux lines that fail to link the opposite winding and are in effect lost.

a This loss of flux is called flux leakage and prevents the coefficient of coupling from being one or unity.

b It is possible to achieve 98% coupling between coils of a well designed transformer.

d. Voltage, Current and the Turns Ratio: This characteristic of transformers is the main reason that transformers are used.

(1) Voltage and the turns ratio:

(a) The magnitude (size) of the voltage in the primary is directly proportional to the number of turns of the winding.

$E_p = N_p$

E_p = voltage in the primary

N_p = number of turns of the primary

(b) The magnitude of the voltage in the secondary is directly proportional to the number of turns of the winding.

$E_s = N_s$

E_s = voltage in the secondary

N_s = number of turns of the primary

If the voltage in the primary is 100 volts, the number of turns of the primary is 10 turns, and the number of turns of the secondary is 5 turns what is the voltage in the secondary.

Step 1. Write voltage and turns ratio

$$\frac{E_p}{E_s} = \frac{N_p}{N_s}$$

Step 2. Substitute the known values

$$\frac{E_p}{E_s} = \frac{100}{?}\text{ volts} = \frac{10}{5}\text{ turns } \frac{N_p}{N_S}$$

Step 3. Since voltage is directly proportional to the number of turns we cross multiply

$$\frac{100}{X} = \frac{10}{5}$$

$$E_p \cdot N_S = E_S \cdot N_p$$

$100 \cdot 5 = 10 \cdot X$

$500 = 10 \cdot x$

$50 = X$

ES = 50 volts

(c) Since the voltage in the secondary is less than the voltage in the primary, this is a step down transformer.

(d) If the voltage ratio, $\frac{100}{50}$, is reduced to its lowest terms, it will yield the turns ratio.

$$\frac{E_p}{E_s} \quad \frac{100}{50} = \frac{2}{1}$$

(2) Current and the turns ratio:

(a) The magnitude of the current in the primary and secondary windings is indirectly proportional to the number of turns. If the number of turns is increased, the inductive reactance will increase and the current flow will decrease. If the number of turns is decreased, the inductive reactance will also decrease and the current flow will increase.

(b) Write current and turns ratio as a proportion:

$$\frac{I_p}{I_s} = \frac{N_p}{N_s}$$

(c) Since current is indirectly proportional to the number of turns, you invert the turns ratio. Giving you the current to turns ratio:

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

e. Transformer Defects:

(1) A short in the primary windings causes:

(a) No voltage across the primary windings.

(b) Over current in the primary because of zero resistance.

(c) Insignificant induced voltage and current in the secondary windings.

(d) This problem can be found by de-energizing the primary windings and isolating the windings from the source. Measuring the resistance of the windings with an ohmmeter, a zero resistance reading would indicate a short in the windings.

(2) A short in the secondary windings causes:

(a) Zero resistance in secondary windings.

(b) Insignificant induced voltage and current in secondary windings.

(c) No current flow through external circuit.

(d) This problem can be found by de-energizing the transformer and isolating the secondary windings from the load. Measuring the resistance across the secondary windings with an ohmmeter should indicate a reading of zero ohms.

(3) An open in the primary windings causes:

(a) Resistance in primary windings is infinite.

(b) No current flow in primary windings.

(c) No induced voltage or current in secondary windings.

(d) This problem can be found by de-energizing the primary windings and isolating the windings from the source. Measuring the resistance across the primary windings with an ohmmeter would indicate an infinite reading.

(4) An open in the secondary windings causes:

(a) Resistance in secondary windings is infinite.

(b) No current flow in external circuit.

(c) This problem can be found by de-energizing the transformer and isolating the secondary windings from the external circuit. A resistance measurement across the secondary windings with an ohmmeter would indicate an infinite resistance.

(5) A turn-to-turn short in the primary windings causes:

(a) Less than normal resistance in the primary windings.

(b) Higher than normal current in the primary windings.

(c) This problem can be found by de-energizing the primary windings and isolating the windings from the source. A resistance measurement with an ohmmeter would indicate lower than normal resistance across the primary windings.

(6) A turn-to-turn short in the secondary windings causes:

(a) Less than normal resistance in the secondary windings.

(b) Higher than normal current flow in the secondary windings.

(c) This problem can be found by de-energizing the transformer and isolating the secondary windings from the load. A resistance measurement with an ohmmeter would indicate lower than normal resistance across the secondary windings.