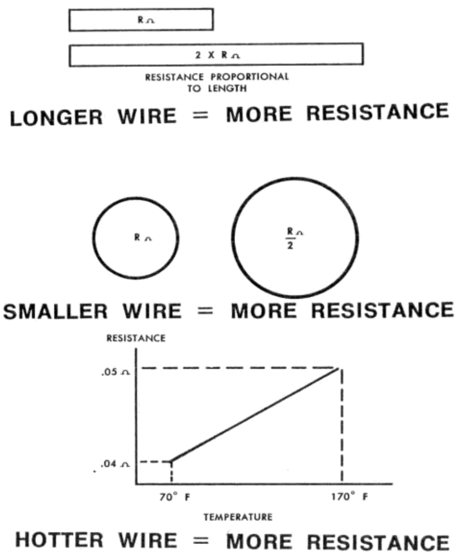
UNIT I

1. Define R-L-C parameters.

Resistance

- One ohm, or R is the amount of electrical resistance overcome by one volt to cause one amp of current to flow.
- Electrical current follows the path of least resistance.
- Electricity can encounter resistance by the type of conductor, the size of
- Conductor and even corrosion on the connections.
- Resistance is proportional to the length and the diameter of the wire being used in the circuit.
- Thick wires (having larger diameter) have less resistance than thin wires (smaller diameter).
- Longer wires have more resistance than short wires. If the.length of wire is doubled, the resistance is doubled.
- If the size or cross-sectional area of the wire is reduced to half, the resistance is doubled.
- Wire Gage (AWG): **As wire gage ↑ wire size ;diameter ↓**
- Temperature also affects resistance.
- In a controlled setting such as electric heat or a cooking stove, electrical resistance is beneficial.
- Too much friction or resistance in a wire can result in the insulation melting and increased potential for a fire hazard.
- As a conductor gets hotter, the amount of resistance increases.
- Opposition to flow in electrical circuits is called resistance (or impedance).
- Measured in Ohms by using an ohmmeter.

Resistance in a Conductor



$$R = \rho L / A$$

ere

R = Resistance (Ω)

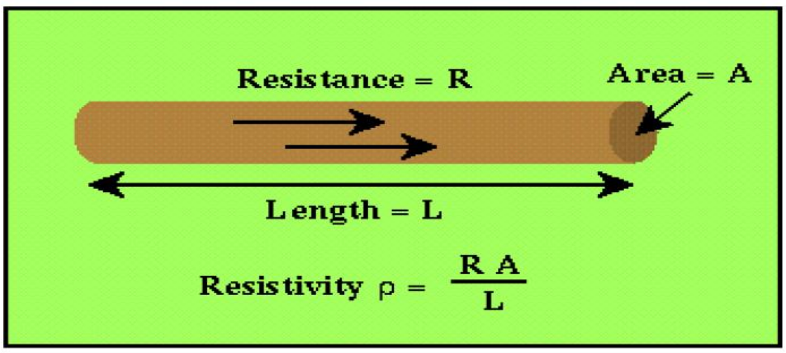
ρ = Resistivity of wire – a function of Temperature

L= Length of wire

A= Cross-sectional area of wire

As wire gage ↑ wire size (diameter) ↓

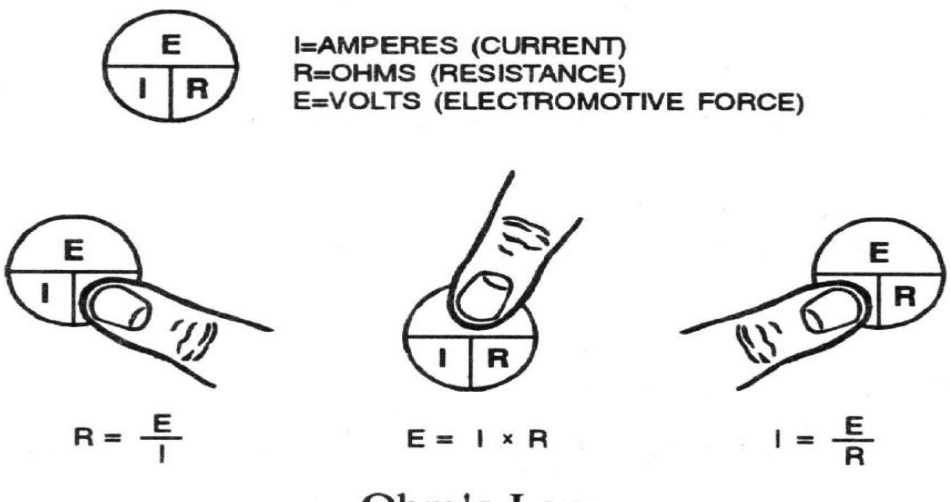
Resistivity (ρ)



When selecting wire it is critical to consider: the length of the run, the gauge of the voltage of the circuit, the amp draw and the temperature.

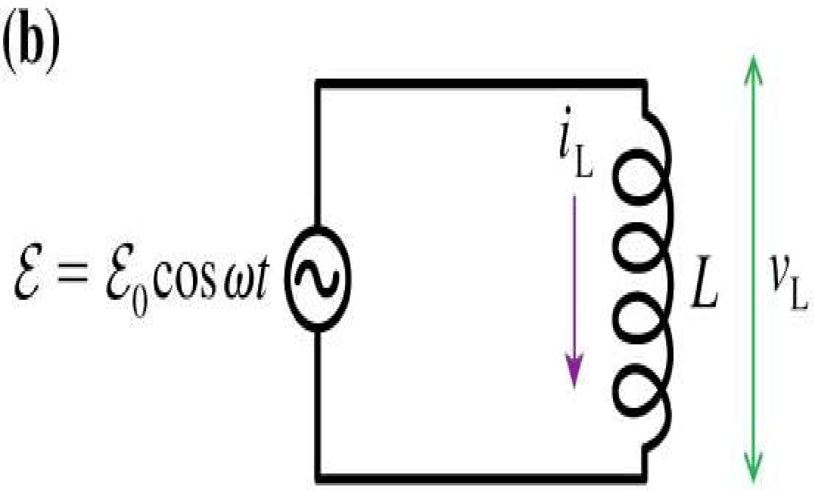
Ohm's Law:

- Identifies the relationship between voltage, amperage (current) and resistance.
- States that the current (amperage) in a circuit is directly proportional to the applied voltage and inversely proportional to the resistance in a circuit.
- The greater the voltage, the greater the current.
- If the resistance is doubled, the current will be half.



Ohm's Law

Inductors



$$v_L = V_L \cos \omega t$$

$$i_L = \frac{V_L}{L}\int \cos\omega t\,dt = \frac{V_L}{\omega L}\sin\omega t = \frac{V_L}{\omega L}\cos\left(\omega t - \frac{\pi}{2}\right)$$

$$= I_L \cos\left(\omega t - \frac{\pi}{2}\right)$$

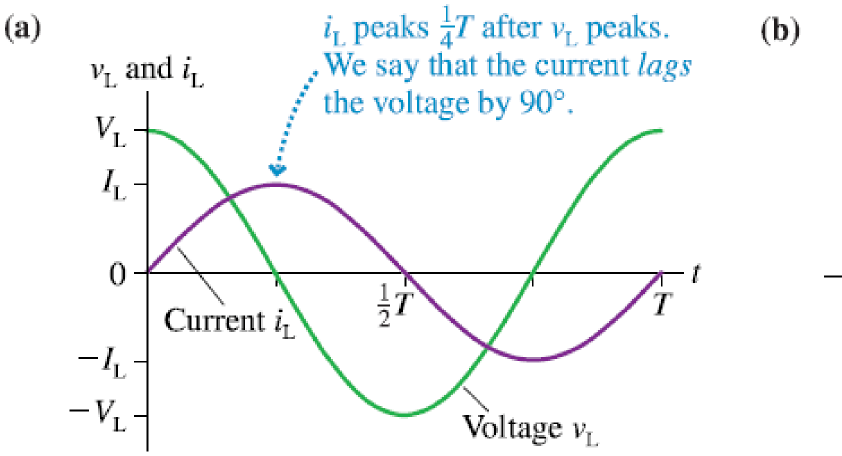
The AC current through an inductor lags the inductor voltage by υ/2 rad, or 90°.

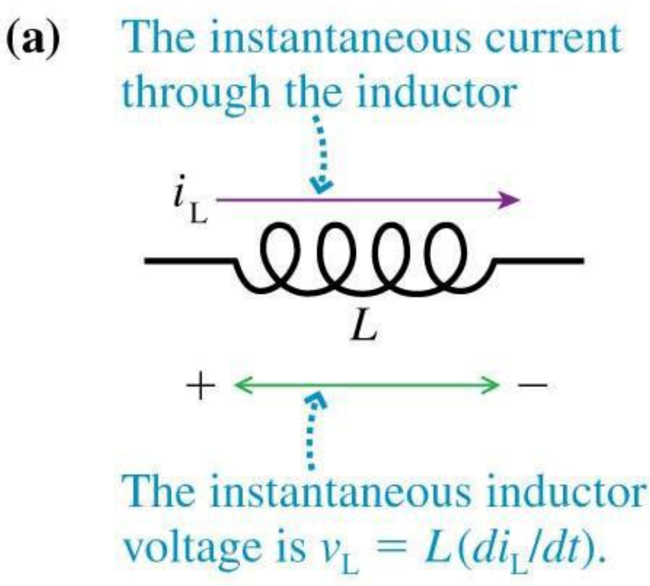
The inductive reactance X_L is defined as $X_L \equiv \omega L$

Reactance relates the peak voltage V_L and current I_L:

$$I_L = \frac{V_L}{X_L} \quad \text{or} \quad V_L = I_L X_L$$

NOTE: Reactance differs from resistance in that it does *not* relate the instantaneous inductor voltage and current because they are out of phase. That is, $v_L \neq i_L X_L$.





Capitors

The AC current to and from a capacitor *leads* the capacitor voltage by υ/2 rad, or 90°.

The capacitive reactance X_C is defined as

$$X_C \equiv \frac{1}{\omega C}$$

The units of reactance, like those of resistance, are ohms.

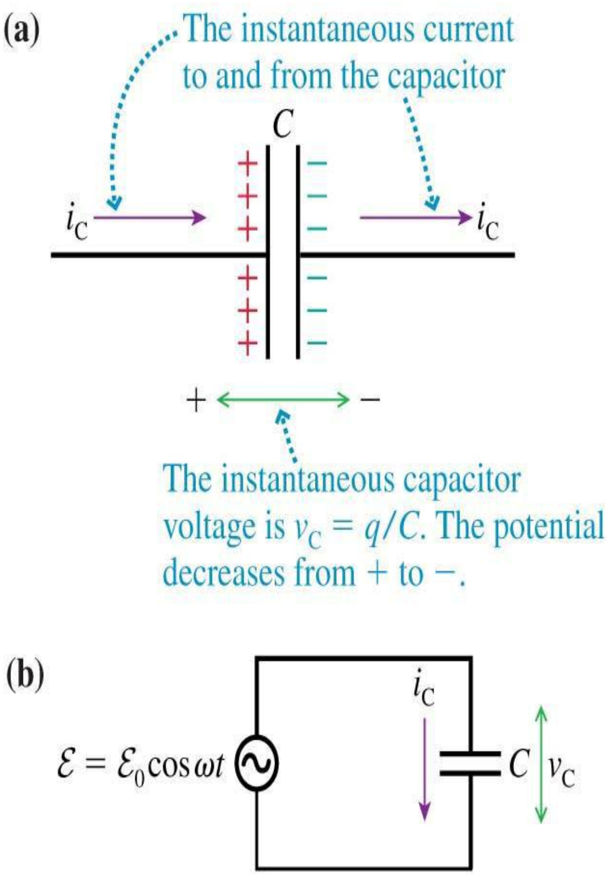
Reactance relates the peak voltage V_C

and current I_C:

$$\boxed{I_C = \frac{C}{X_C} \quad \text{or} \quad V_C = I_C X_C}$$

V

FIGURE 36.7 An AC capacitor circuit.

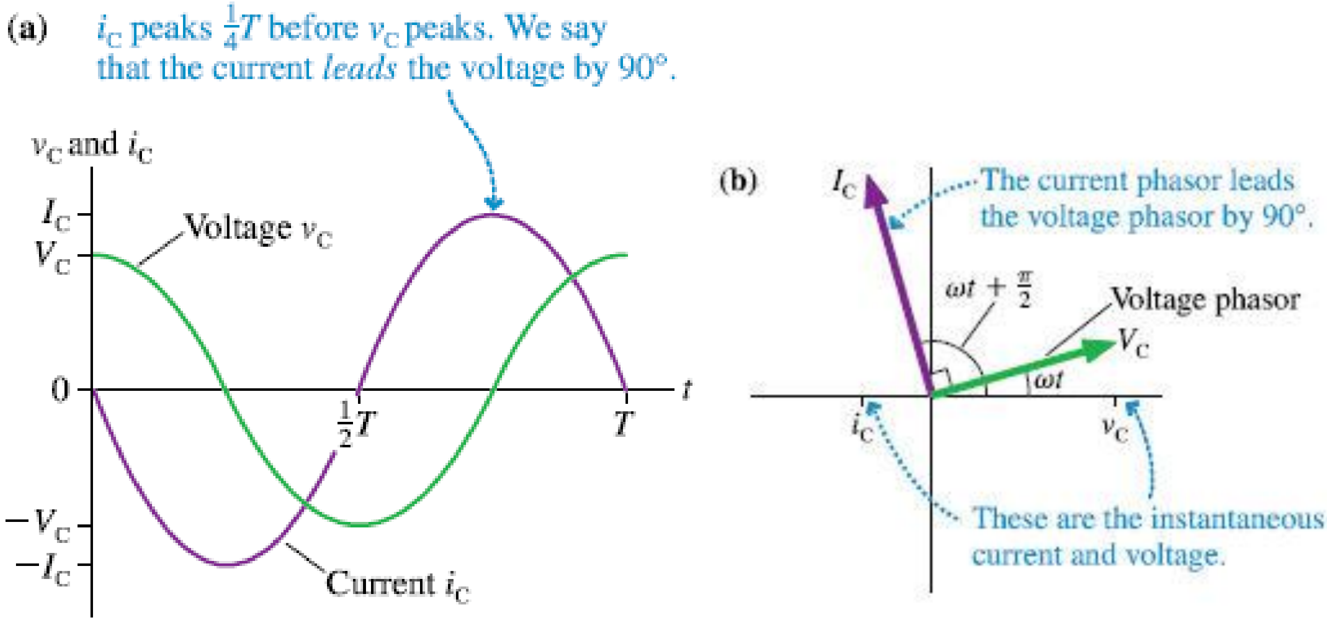


NOTE: Reactance differs from resistance

in that it does *not*

relate the instantaneous capacitor

voltage and current because they are out of phase. That is, $v_C \neq i_C X_C$.



2. Define Voltage and Current.

Electrical Voltage

- An electrical generator (or battery) forces electrons to move from atom to atom.
- This push or force is like the pressure created by a pump in a water system.
- In an electrical circuit this pressure (electromotive force) is called voltage.
- The volt (V) is the unit by which electrical pressure is measured.

Electrical Current (Amperage)

- While voltage refers to the electrical pressure of a circuit, current or amperage refers to the electrical flow of a circuit.
- Current or amperage is the amount of electric charges (or electrons) flowing past a point in a circuit every second.
- One ampere (amp or A) is equal to 6.28 billion billion (or 6.28 x 10^{18}) electrons per second.

3. Explain concept of Dependent Sources.

An *independent source* (voltage or current) may be DC (constant) or time-varying, but does not depend on other voltages or currents in the circuit

The *dependent source* magnitude is a function of another voltage or current in the circuit.

Voltage-Controlled Current Source (VCCS)

Current-Controlled Current Source (CCCS)

Voltage-Controlled Voltage Source (VCVS)

Current-Controlled Voltage Source (CCVS)

4. Explain –active elements

-passive elements.

Active circuit components

- Conservation of energy: active components must get their power from *somewhere*!
- From non-electrical sources
  - – Batteries (chemical)
  - – Dynamos (mechanical)
  - – Transducers in general (light, sound, etc.)

- From other electrical sources
  - – Power supplies
  - – Power transformers
  - – Amplifiers

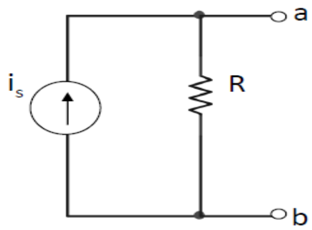
Passive lumped constants

- Classical LTI
  - – Resistors are AC/DC components.
  - – Inductors are AC components (DC short circuit).
  - – Capacitors are AC components (DC open circuit).
- Other components
  - – Rectifier diodes.
  - – Three or more terminal devices, e.g. transistors.
  - – Transformers.

5. What is Source Transformation?

Source transformation is a circuit simplifying technique

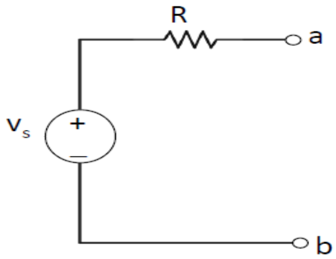
It is the process of replacing **a voltage source v_S in series with a resistor R** by a **current source i_S in parallel with a resistor R,** or vice versa



Terminal a-b sees:

Open circuit voltage: i_sR

Short circuit current: i_s



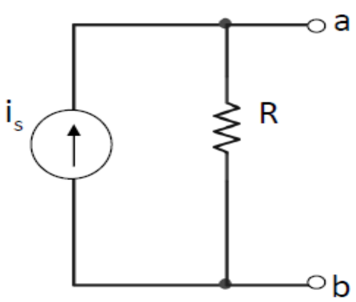
Terminal a-b sees:

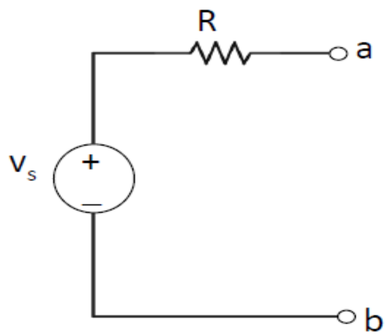
Open circuit voltage: v_s

Short circuit current: v_s/R

Another circuit simplifying technique

It is the process of replacing **a voltage source vS in series with a resistor R** by a **current source iS in parallel with a resistor R,** or vice versa



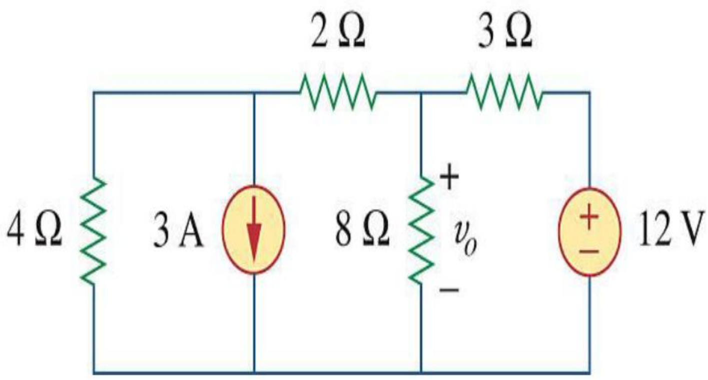


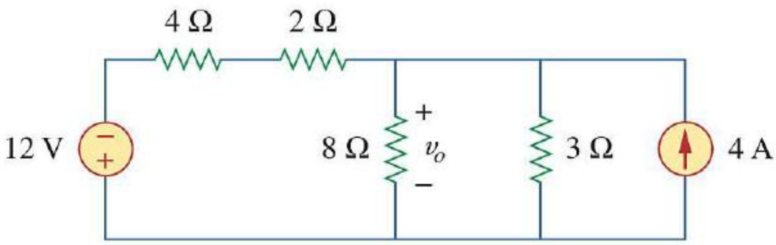
For both to be **equivalent,**

$$\boxed{i_sR = v_s \quad \text{or} \quad i_s = v_s/R}$$

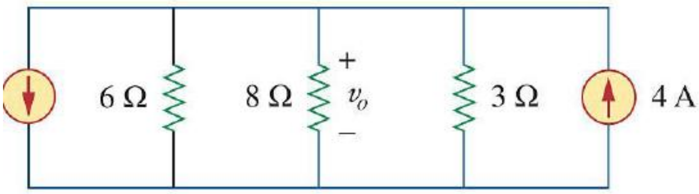
Example 1

Find v_o in the circuit shown below using source transformation





(a)



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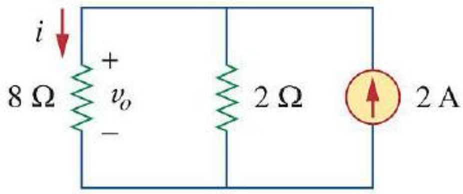


(c)

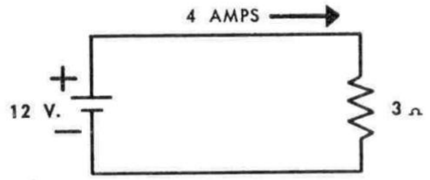
6. Explain Series ; Parallel ; Series-Parallel networks.

Series Circuits

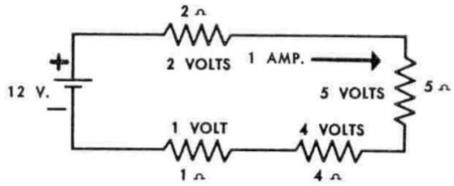
– Designed so that the current or electricity must flow through each device or resistor (light bulb for example) in the circuit.

– If one of the devices such as a lamp for example burns out, the flow of electricity is stopped.

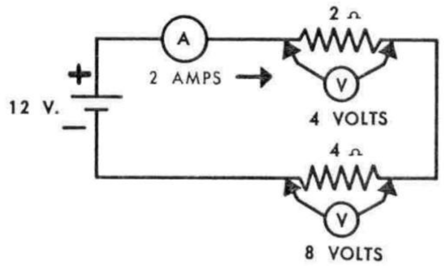
– This system would not work well for lighting or most applications. The series principle is used in fuses and circuit breakers, where it is necessary to stop the flow of current for safety purposes.



BASIC SERIES CIRCUIT



SERIES CIRCUIT WITH FOUR RESISTORS

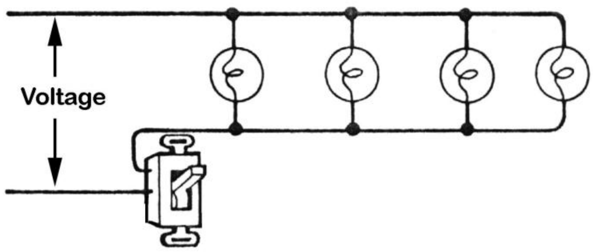


SERIES CIRCUIT WITH TWO RESISTORS

Parallel Circuits

– Each device (light bulb for example) has an independent path for the flow of electricity.

PARALLEL CIRCUIT

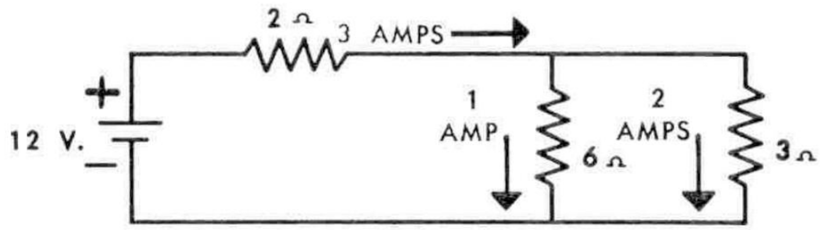


- Resistors connected in parallel have the same voltage across them.

$$1/R_p = 1/R_1 + 1/R_2 + 1/R_3 + \ldots.$$

- Resistors connected in parallel have different current flows through them (unless they have the same resistance); in other words, the current flow through the resistor depends on the resistance of the resistor.

Example of a Series – Parallel circuit:



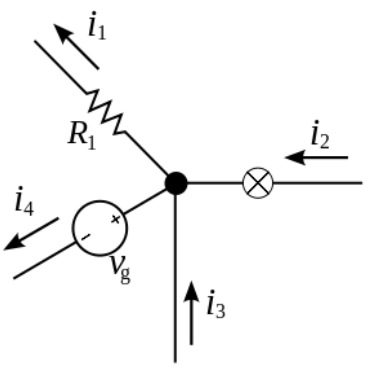
7. Define Kirchoff's Laws.

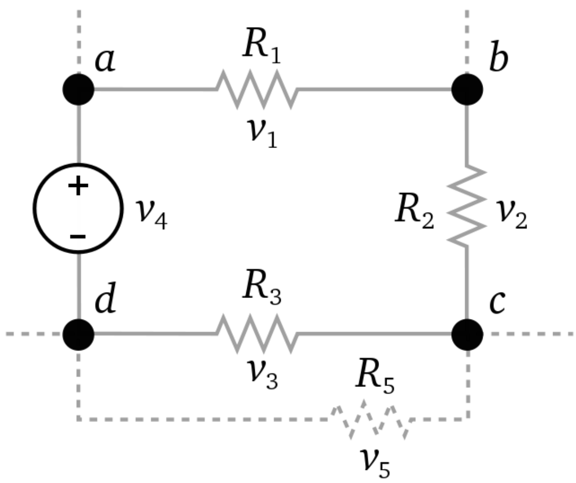
Kirchhoff's Voltage Law **(KVL)**:

The sum of all of the voltage drops in a series circuit equals the total applied voltage.

Kirchhoff's Current Law **(KCL)**:

The total current in a parallel circuit equals the sum of the individual branch currents.

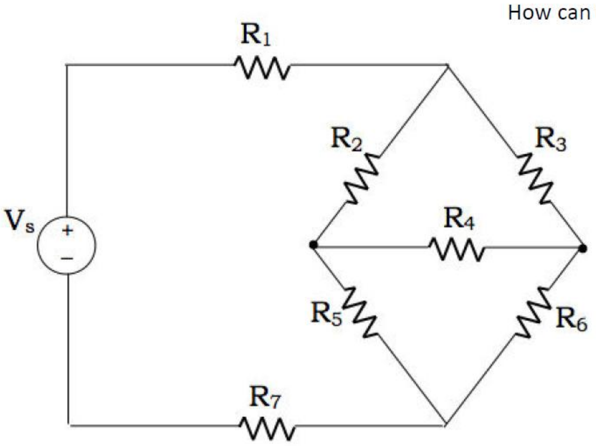


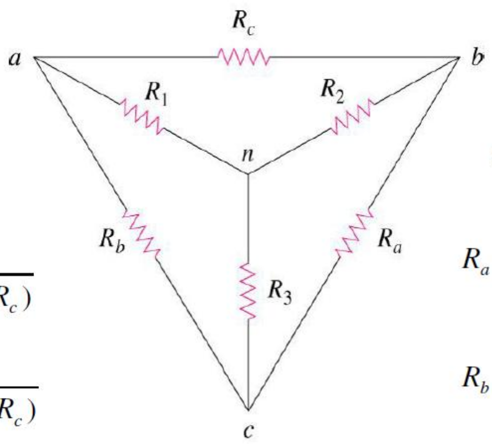


8. Explain the concept of Star to Delta transformation.

Star ⇔ delta transformation

How can we combine R_1 to R_7 ?





Delta -> Star

$$R_1 = \frac{R_b R_c}{(R_a + R_b + R_c)}$$

$$R_2 = \frac{R_c R_a}{(R_a + R_b + R_c)}$$

$$R_3 = \frac{R_a R_b}{(R_a + R_b + R_c)}$$

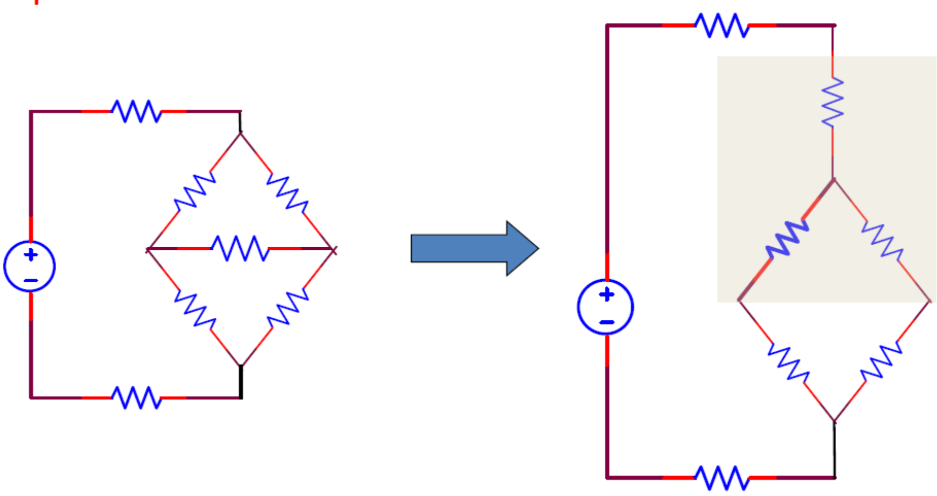
Star -> Delta

$$R_a = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_1}$$

$$R_b = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_2}$$

$$R_c = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_3}$$

Star ⇔ delta transformation
example



9. Compare Mesh and Nodal analysis concepts.

Primary Formal Circuit Analysis Methods

NODAL ANALYSIS

("Node-Voltage Method")

0) Choose a reference node

1) Define unknown node voltages

2) Apply KCL to each unknown node, expressing current in terms of the node voltages

=> N equations for N unknown node voltages

3) Solve for node voltages

=> determine branch currents

MESH ANALYSIS

("Mesh-Current Method")

1) Select M independent mesh currents such that at least one mesh current passes through each branch*

M = #branches - #nodes + 1

2) Apply KVL to each mesh, expressing voltages in terms of mesh currents

=> M equations for M unknown mesh currents

3) Solve for mesh currents

=> determine node voltages

*Simple method for *planar* circuits

A mesh current is not necessarily identified with a branch current.

10. Define R.M.S. and Average values, Form Factor.

The effective or **RMS value** of an alternating current is measured in terms of the direct current value that produces the same heating effect in the same value resistance. The RMS value for any AC waveform can be found from the following modified average value formula.

$$V_{RMS} = \sqrt{\frac{V_1^2 + V_2^2 + V_3^2 + V_4^2 + \ldots + V_n^2}{n}}$$

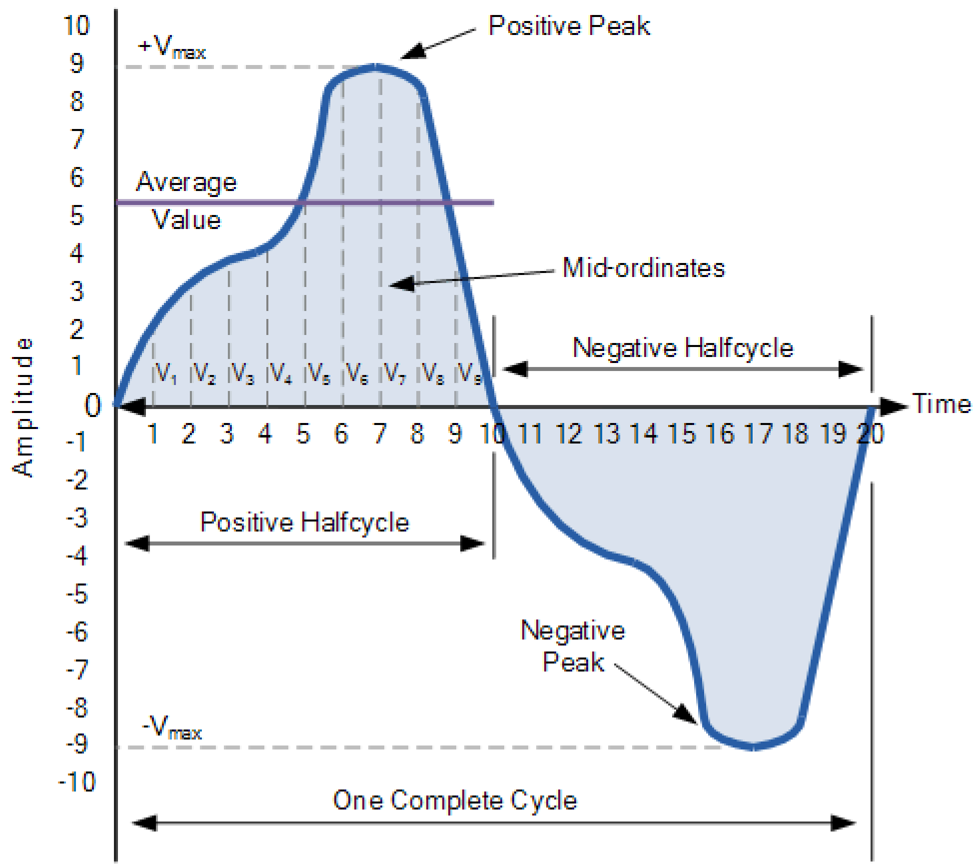
Where: n equals the number of mid-ordinates.

For a pure sinusoidal waveform this effective or R.M.S. value will always be equal to $1/\sqrt{2} \times V_{max}$which is equal to $0.707 \times V_{max}$ and this relationship holds true for RMS values of current. The RMS value for a sinusoidal waveform is always greater than the average value except for a rectangular waveform. In this case the heating effect remains constant so the average and the RMS values will be the same.

One final comment about R.M.S. values. Most multimeters, either digital or analogue unless otherwise stated only measure the R.M.S. values of voltage and current and not the average. Therefore when using a multimeter on a direct current system the reading will be equal to I = V/Rand for an alternating current system the reading will be equal to Irms = Vrms/R.

The **average or mean value** of an AC waveform is calculated or measured over a half cycle only and this is shown below.

Average Value of a Non-sinusoidal Waveform



To find the average value of the waveform we need to calculate the area underneath the waveform using the mid-ordinate rule, trapezoidal rule or Simpson's rule found in mathematics. The approximate area under any irregular waveform can easily be found by simply using the mid-ordinate rule. The zero axis base line is divided up into any number of equal parts and in our simple example above this value was nine, (V_1 to V_9). The more ordinate lines that are drawn the more accurate will be the final average or mean value. The average value will be the addition of all the instantaneous values added together and then divided by the total number. This is given as.

$$V_{average} = \frac{V_1 + V_2 + V_3 + V_4 + \ldots + V_n}{n}$$

Where: n equals the actual number of mid-ordinates used.

For a pure sinusoidal waveform this average or mean value will always be equal to 0.637 x V_{max} and this relationship also holds true for average values of current.

Form Factor and Crest Factor

Although little used these days, both **Form Factor** and **Crest Factor** can be used to give information about the actual shape of the AC waveform. Form Factor is the ratio between the average value and the RMS value and is given as.

$$\text{Form Factor} = \frac{\text{R.M.S value}}{\text{Average value}} = \frac{0.707 \times \text{Vmax}}{0.637 \times \text{Vmax}}$$

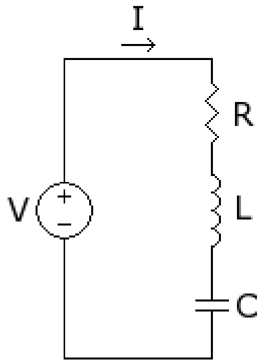
For a pure sinusoidal waveform the Form Factor will always be equal to 1.11.

Crest Factor is the ratio between the R.M.S. value and the Peak value of the waveform and is given as.

$$\text{Crest Factor} = \frac{\text{Peak value}}{\text{R.M.S. value}} = \frac{\text{Vmax}}{0.707 \times \text{Vmax}}$$

For a pure sinusoidal waveform the Crest Factor will always be equal to 1.414.

11. Explain steady state analysis of Series RLC with Sinusoidal excitation.



In this circuit, the three components are all in series with the voltage source. The governing differential equation can be found by substituting into Kirchhoff's voltage law (KVL) the constitutive for each of the three elements. From KVL, $v_R + v_L + v_C = v(t)$

where v_R, v_L, v_C are the voltages across R, L and C respectively and $v(t)$ is the time varying voltage from the source. Substituting in the constitutive equations,

$$Ri(t) + L\frac{di}{dt} + \frac{1}{C}\int_{-\infty}^{\tau=t} i(\tau)\,d\tau = v(t)$$

For the case where the source is an unchanging voltage, differentiating and dividing by L leads to the second order differential equation:

$$\frac{d^2 i(t)}{dt^2} + \frac{R}{L}\frac{di(t)}{dt} + \frac{1}{LC}i(t) = 0$$

This can usefully be expressed in a more generally applicable form:

$$\frac{d^2 i(t)}{dt^2} + 2\alpha\frac{di(t)}{dt} + {\omega_0}^2 i(t) = 0$$

α and ω_0 are both in units of angular frequency. α is called the *neper frequency*, or *attenuation*, and is a measure of how fast the transient of the circuit will die away after the stimulus has been removed. Neper occurs in the name because the units can also be considered to be nepers per second, neper being a unit of attenuation. ω_0 is the angular resonance frequency.

For the case of the series RLC circuit these two parameters are given by: $\alpha = \frac{R}{2L}$ and $\omega_0 = \frac{1}{\sqrt{LC}}$

A useful parameter is the *damping factor*, ζ which is defined as the ratio of these two, $\zeta = \frac{\alpha}{\omega_0}$

In the case of the series RLC circuit, the damping factor is given by,

$\zeta = \frac{R}{2}\sqrt{\frac{C}{L}}$ The value of the damping factor determines the type of transient that the circuit will exhibit. Some authors do not use ζ and call α the damping factor.

Laplace domain

The series RLC can be analyzed for both transient and steady AC state behavior using the Laplace transform. If the voltage source above produces a waveform with Laplace-transformed *V*(*s*) (where *s* is the complex frequency $s = \sigma + i\omega$), KVL can be applied in the Laplace domain:

$$V(s) = I(s)\left(R + Ls + \frac{1}{Cs}\right)$$

where *I*(*s*) is the Laplace-transformed current through all components. Solving for *I*(*s*):

$$I(s) = \frac{1}{R + Ls + \frac{1}{Cs}}V(s)$$

And rearranging, we have that

$$I(s) = \frac{s}{L\left(s^2 + \frac{R}{L}s + \frac{1}{LC}\right)}V(s)$$

Sinusoidal steady state

Sinusoidal steady state is represented by letting $s = i\omega$

Taking the magnitude of the above equation with this substitution:

$$|Y(s = i\omega)| = \frac{1}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}.$$

and the current as a function of ω can be found from

$$|I(i\omega)| = |Y(i\omega)||V(i\omega)|.$$

There is a peak value of $|I(i\omega)|$. The value of ω at this peak is, in this particular case, equal to the undamped natural resonance frequency.

$$\omega_0 = \frac{1}{\sqrt{LC}}.$$

12. Explain concept of Reactance, Impedance, Susceptance and Admittance

Admittance is a measure of how easily a circuit or device will allow a current to flow. It is defined as the inverse of impedance. The SI unit of admittance is the siemens (symbol S). Oliver Heaviside coined the term *admittance* in December 1887.[1]

$$Y \equiv \frac{1}{Z}$$

where

Y is the admittance, measured in siemens

Z is the impedance, measured in ohms

The synonymous unit mho, and the symbol ℧ (an upside-down uppercase omega Ω), are also in common use.

Resistance is a measure of the opposition of a circuit to the flow of a steady current, while impedance takes into account not only the resistance but also dynamic effects (known as reactance). Likewise, admittance is not only a measure of the ease with which a steady current can flow, but also the dynamic effects of the material's susceptance to polarization:

$$Y = G + jB$$

where

- Y is the admittance, measured in siemens.
- G is the conductance, measured in siemens.
- B is the susceptance, measured in siemens.
- $j^2 = -1$

Conversion from impedance to admittance

The impedance, Z, is composed of real and imaginary parts,

$$Z = R + jX$$

where

- *R* is the resistance, measured in ohms
- *X* is the reactance, measured in ohms

$$Y = Z^{-1} = \frac{1}{R + jX} = \left(\frac{1}{R^2 + X^2}\right)(R - jX)$$

Admittance, just like impedance, is a complex number, made up of a real part (the conductance, *G*), and an imaginary part (the susceptance, *B*), thus:

$$Y = G + jB$$

where *G* (conductance) and *B* (susceptance) are given by:

$$G = \Re(Y) = \frac{R}{R^2 + X^2}$$

$$B = \Im(Y) = -\frac{X}{R^2 + X^2}$$

The magnitude and phase of the admittance are given by:

$$|Y| = \sqrt{G^2 + B^2} = \frac{1}{\sqrt{R^2 + X^2}}$$

$$\angle Y = \arctan\left(\frac{B}{G}\right) = \arctan\left(-\frac{X}{R}\right)$$

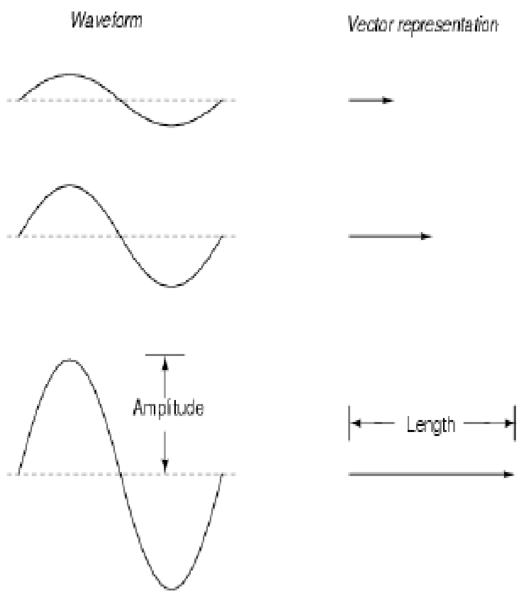
where

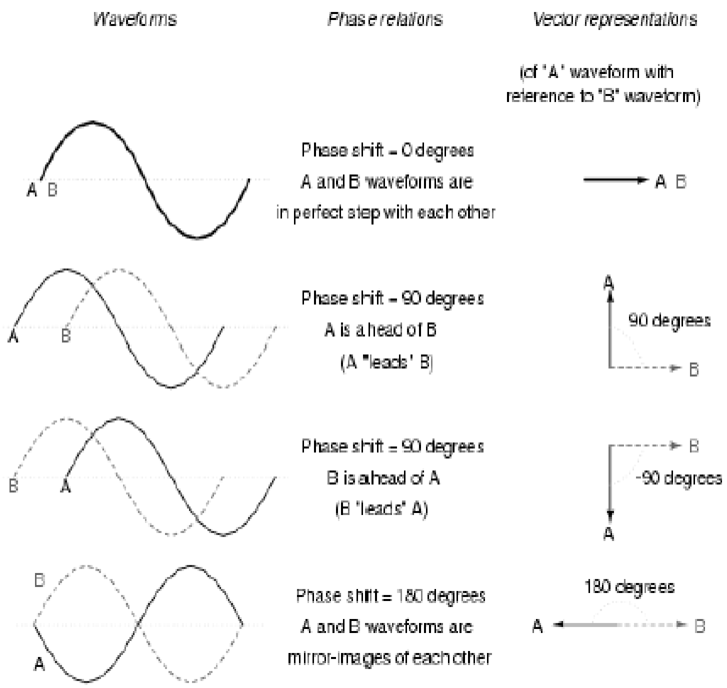
- *G* is the conductance, measured in siemens
- *B* is the susceptance, also measured in siemens

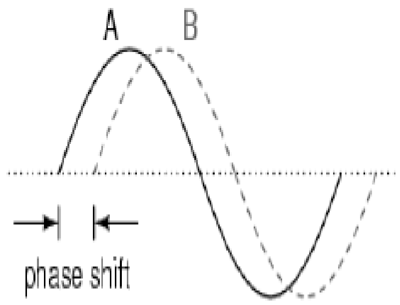
Note that (as shown above) the signs of reactances become reversed in the admittance domain; i.e. capacitive susceptance is positive and inductive suceptance is negative.

13. Discuss Phase and Phase Difference, Concept of Power Factor, j-notation, complex and Polar forms of representation.

Vectors and AC waveforms

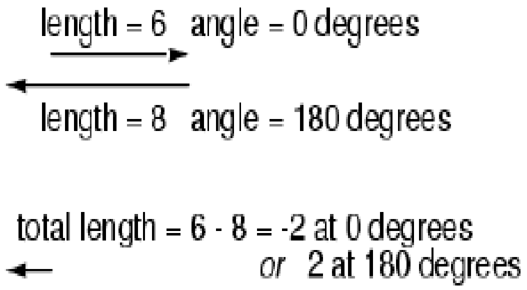


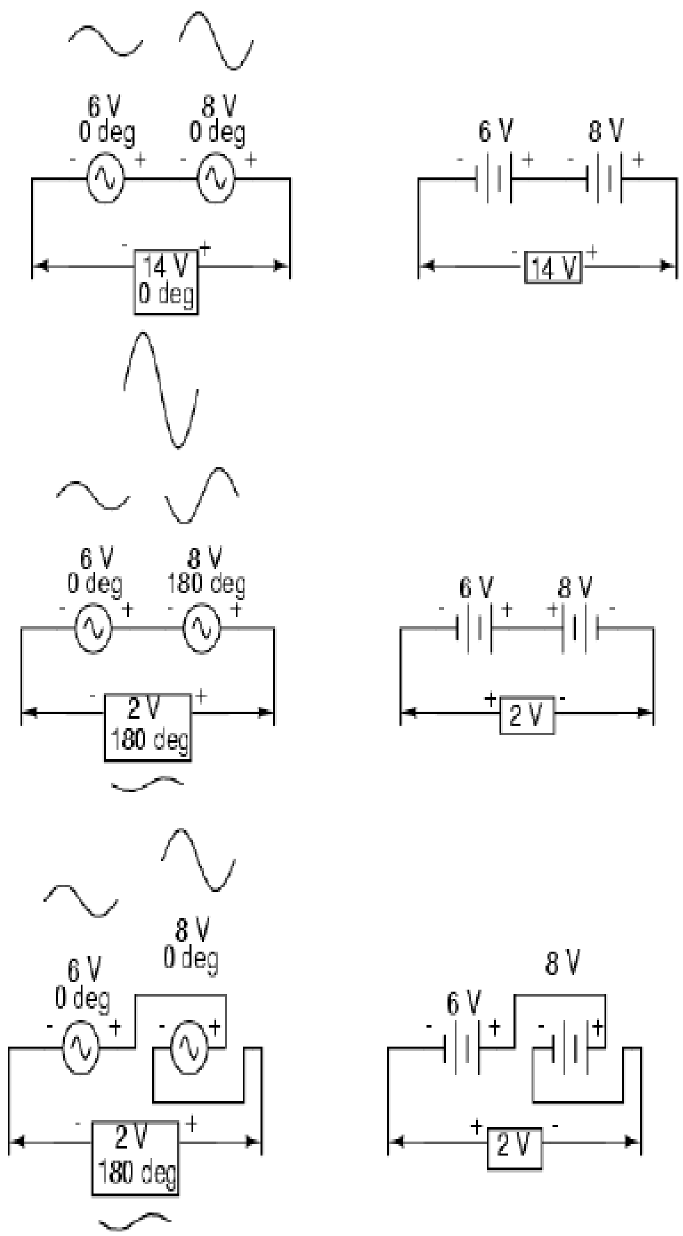


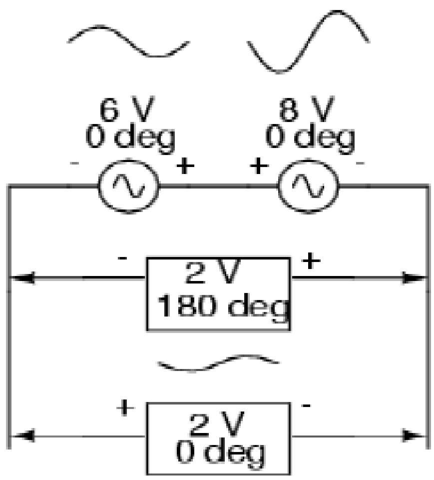


When used to describe an AC quantity, the length of a vector represents the amplitude of the wave while the angle of a vector represents the phase angle of the wave relative to some other (reference) waveform.

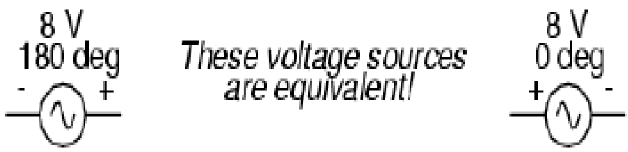
Simple vector addition







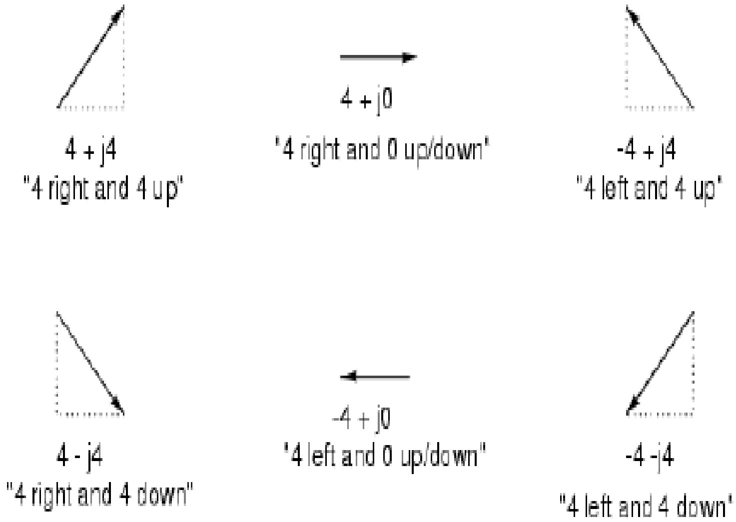
Just as there are two ways to express the phase of the sources, there are two ways to express their resultant sum.



Polar and rectangular notation

In "rectangular" form, a vector's length and direction are denoted in terms of its horizontal and vertical span, the first number representing the horizontal ("real") and the second number (with the "j" prefix) representing the vertical ("imaginary") dimensions.

Note: *the proper notation for designating a vector's angle is this symbol: ∠*

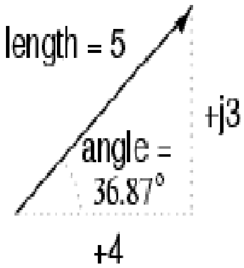


$5 \angle 36.87^\circ$ **(polar form)**

$(5)(\cos 36.87^\circ) = 4$ (real component)

$(5)(\sin 36.87^\circ) = 3$ (imaginary component)

$4 + j3$ **(rectangular form)**



$4 + j3$ **(rectangular form)**

$c = \sqrt{a^2 + b^2}$ (pythagorean theorem)

polar magnitude = $\sqrt{4^2 + 3^2}$

polar magnitude = 5

polar angle = $\arctan \frac{3}{4}$

polar angle = 36.87°

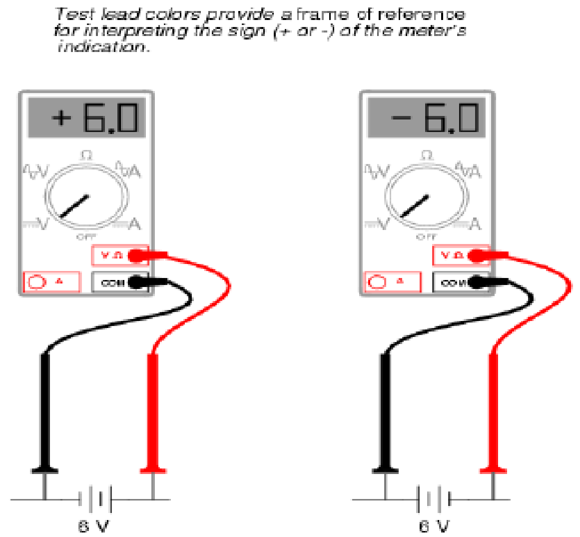
$5 \angle 36.87^\circ$ **(polar form)**

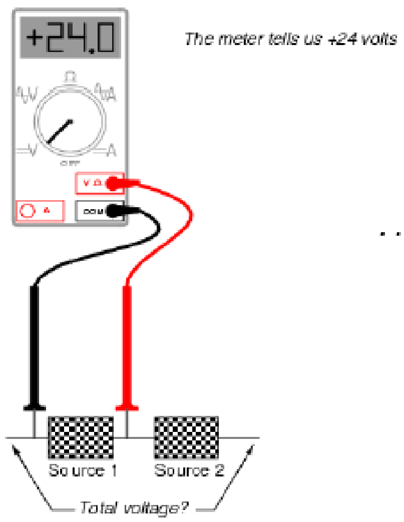
•*Polar* notation denotes a complex number in terms of its vector's length and angular direction from the starting point. Example: fly 45 miles ∠ 203° (West by Southwest).

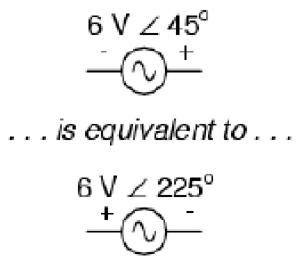
•*Rectangular* notation denotes a complex number in terms of its horizontal and vertical dimensions. Example: drive 41 miles West, then turn and drive 18 miles South.

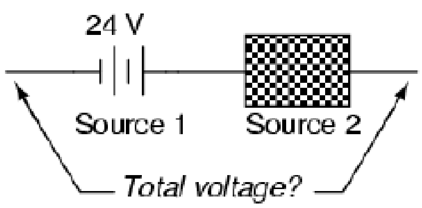
•In rectangular notation, the first quantity is the "real" component (horizontal dimension of vector) and the second quantity is the "imaginary" component (vertical dimension of vector). The imaginary component is preceded by a lower-case "j," sometimes called the *j operator*.

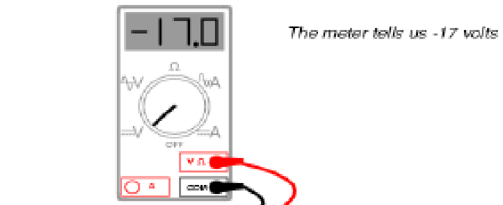
• Both polar and rectangular forms of notation for a complex number can be related graphically in the form of a right triangle, with the hypotenuse representing the vector itself (polar form: hypotenuse length = magnitude; angle with respect to horizontal side = angle), the horizontal side representing the rectangular "real" component, and the vertical side representing the rectangular "imaginary" component.





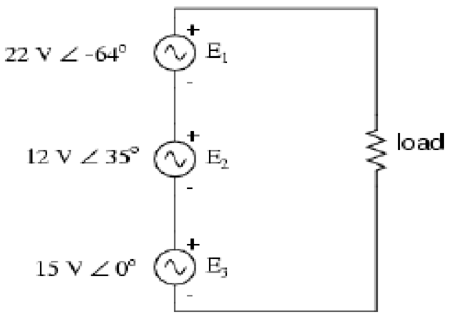


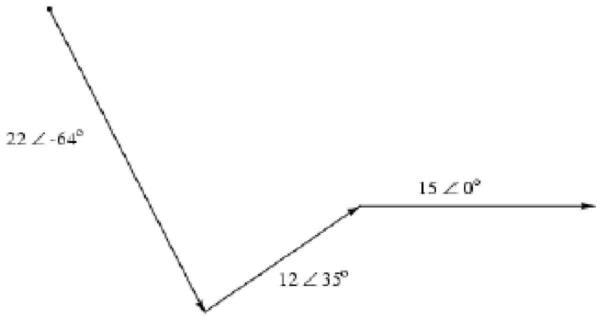




•Polarity markings are sometimes given to AC voltages in circuit schematics in order to provide a frame of reference for their phase angles.

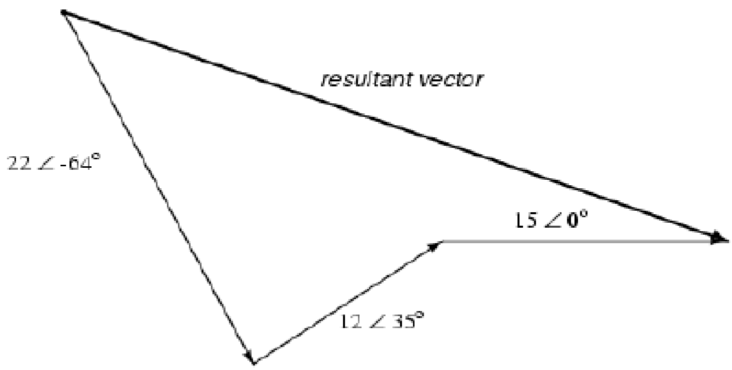
Some examples with AC circuits





$$E_{total} = E_1 + E_2 + E_3$$

$$E_{total} = (22\ V \angle -64^\circ) + (12\ V \angle 35^\circ) + (15\ V \angle 0^\circ)$$



$$15\ V \angle 0^\circ = 15 + j0\ V$$

$$12\ V \angle 35^\circ = 9.8298 + j6.8829\ V$$

$$22\ V \angle -64^\circ = 9.6442 - j19.7735\ V$$

$$\begin{array}{rll} & 15 & + j0 \quad V \\ & 9.8298 & + j6.8829\ V \\ + & 9.6442 & - j19.7735\ V \\ \hline & \mathbf{34.4740} & \mathbf{- j12.8906\ V} \end{array}$$

- All the laws and rules of DC circuits apply to AC circuits, with the exception of power calculations (Joule's Law), so long as all values are expressed and manipulated in complex form, and all voltages and currents are at the same frequency.

- When reversing the direction of a vector (equivalent to reversing the polarity of an AC voltage source in relation to other voltage sources), it can be expressed in either of two different ways: adding 180° to the angle, or reversing the sign of the magnitude.

- Meter measurements in an AC circuit correspond to the *polar magnitudes* of calculated values. Rectangular expressions of complex quantities in an AC circuit have no direct, empirical equivalent, although they are convenient for performing addition and subtraction, as Kirchhoff's Voltage and Current Laws require.