Amateur Extra License Class

1

Amateur Extra Class

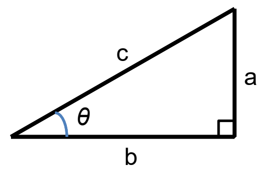
Chapter 4
Electrical Principles

2

Radio Mathematics

Basic Trigonometry

- Sine
  - sin(θ) = a/c
- Cosine
  - cos(θ) = b/c
- Tangent
  - tan(θ) = a/b
- ArcSin, ArcCos, ArcTan



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Radio Mathematics

Complex Numbers

- Ordinary numbers are called “real” numbers.
- Mathematicians have also identified a class of numbers called “complex” numbers.
  - Represented by

    X + jY where $j = \sqrt{-1}$
  - Also called “imaginary” numbers.
    - “X” is the “real” part.
    - “jY” is the “imaginary” part.

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Radio Mathematics

Complex Numbers

- Because $\sqrt{-1}$ is not a "real" number, it has some rather weird behavior when used in calculations.

Summary

$$j = \sqrt{-1}$$
$$j^2 = -1$$
$$j^3 = -j$$
$$j^4 = +1$$
$$\frac{1}{j} = -j$$

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Radio Mathematics

Rectangular and Polar Coordinates

- Mathematical tools used to plot numbers or a position on a graph.
- 2-dimensional & 3-dimensional coordinate systems are the most common.
  - Latitude & Longitude = 2-dimensional.
  - Latitude, Longitude, & Altitude = 3-dimensional.

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Radio Mathematics

Rectangular and Polar Coordinates

- Complex impedances consisting of combinations of resistors, capacitors, and inductors can be plotted using a 2-dimensional coordinate system.
- There are two types of coordinate systems commonly used for plotting impedances.
  - Rectangular.
  - Polar.

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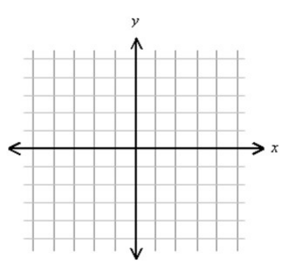
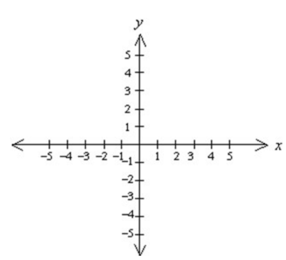
Radio Mathematics

Rectangular and Polar Coordinates

- Rectangular Coordinates
  - Also called Cartesian coordinates.





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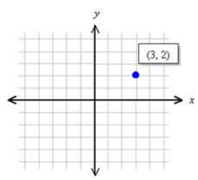
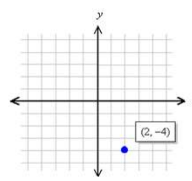
Radio Mathematics

Rectangular and Polar Coordinates

- A pair of numbers specifies a position on the graph.
  - 1st number (x) specifies position along horizontal axis.
  - 2nd number (y) specifies position along vertical axis.





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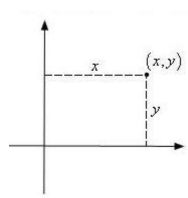
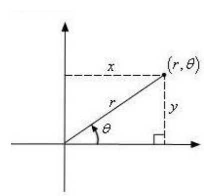
Radio Mathematics

Rectangular and Polar Coordinates

- Polar Coordinates
  - A pair of numbers specifies a position on the graph.
    - 1st number (r) specifies distance from the origin.
    - 2nd number (θ) specifies angle from horizontal axis.





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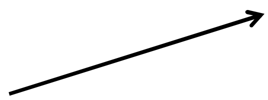
Radio Mathematics

Rectangular and Polar Coordinates

- Vectors
  - A vector is a line with both length and direction & is represented by a single-headed arrow.

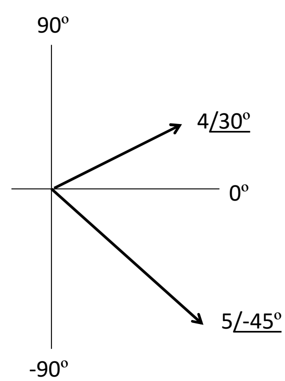


  - A phasor (phase vector) is often used to represent phase relationships between impedances.

Radio Mathematics

Rectangular and Polar Coordinates

- Polar Coordinates
  - Specify a phasor.
    - The length of the phasor is the impedance.
    - The angle of the phasor is the phase angle.
    - The angle is always between +90º & -90º.



Radio Mathematics

Rectangular and Polar Coordinates

- Rectangular Coordinates
  - When plotting impedances, both the X & Y axes are usually linear.
    - Each step represents an equal increase in value.
  - When plotting frequency response, the Y axis often uses a logarithmic scale.
    - Each step represents an ever-increasing, unequal increase in value.

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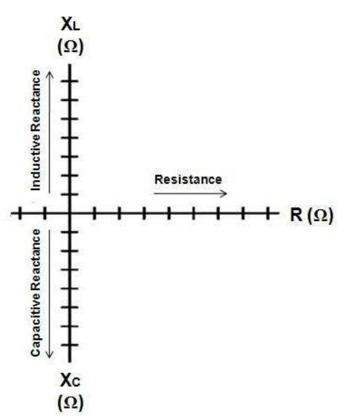
Radio Mathematics

Plotting Impedance

- Resistance along positive x-axis (right).
- Inductive reactance along positive y-axis (up).
- Capacitive reactance along negative y-axis (down).
- Negative x-axis (left) not used.



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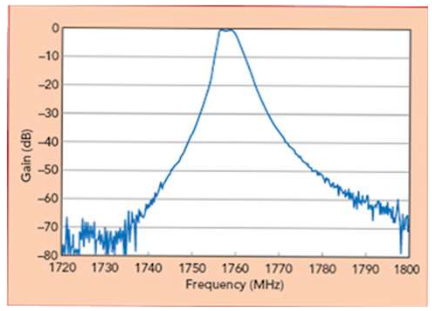
Radio Mathematics

Plotting Frequency Response

- Frequency along x-axis (left & right).
  - Usually a linear scale, but can be logarithmic.
- Signal level along y-axis (up & down).
  - Usually a logarithmic scale.



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Radio Mathematics

Working with Polar and Rectangular Coordinates

- Complex numbers can be expressed in either rectangular or polar coordinates.
- Adding/subtracting complex numbers more easily done using rectangular coordinates.
  - (a + jb) + (c + jd) = (a+c) + j(b+d)
  - (a + jb) - (c + jd) = (a-c) + j(b-d)

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Radio Mathematics

Working with Polar and Rectangular Coordinates

- Multiplying/dividing complex numbers is more easily done using polar coordinates.
  - $a\underline{/\theta_1} \times b\underline{/\theta_2} = a \times b\ \underline{/\theta_1 + \theta_2}$
  - $a\underline{/\theta_1}\ /\ b\underline{/\theta_2} = a / b\ \underline{/\theta_1 - \theta_2}$

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Radio Mathematics

Working with Polar and Rectangular Coordinates

- Converting from rectangular coordinates to polar coordinates.

$$r = \sqrt{x^2 + y^2}$$

$$\theta = \text{ArcTan}\ (y/x)$$

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Radio Mathematics

Working with Polar and Rectangular Coordinates

- Converting from polar coordinates to rectangular coordinates.

$$x = r \times \cos(\theta)$$

$$y = r \times \sin(\theta)$$

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Electrical Principles

Electrical and Magnetic Fields

- Energy
  - Unit of measurement is the Joule (J).
- Work
  - Transferring energy.
    - Raising a 1 lb object 10 feet does 10 foot-pounds of work & adds potential energy to the object.
    - Raising a 10 lb object 1 foot does 10 foot-pounds of work & adds potential energy to the object.
    - Moving the same object sideways does not do any work & does not add any potential energy to the object.

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Electrical Principles

Electrical and Magnetic Fields

- Field.
  - A region of space where energy is stored and through which a force acts.
    - Energy stored in a field is called potential energy.
  - Fields cannot be detected by any of the 5 human senses.
  - You can only observe the effects of a field.
    - Example: Gravity.

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Electrical Principles

Electrical and Magnetic Fields

- Electronics deals with 2 types of fields:
  - Electric field.
  - Magnetic field.

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Electrical Principles

Electrical and Magnetic Fields

- Electric Field
  - Detected by a voltage difference between 2 points.
  - Every electric charge has an electric field.
  - Electric energy is stored by moving electric charges apart so that there is a voltage difference (or potential) between them.
    - Voltage potential = potential energy.
  - An electrostatic field is an electric field that does not change over time.

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Electrical Principles

Electrical and Magnetic Fields

- Magnetic Field
  - Detected by effect on moving electrical charges (current).
  - Magnetic energy is stored by moving electric charges to create an electric current.
  - A magnetostatic field is a magnetic field that does not change over time.
    - Stationary permanent magnet.
    - Earth's magnetic field (almost).

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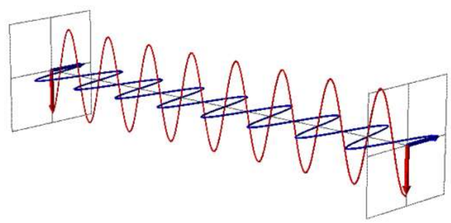
Electrical Principles

Electromagnetic Fields & Waves

- Electromagnetic wave.
  - If the electric or magnetic fields are changing, they produce an electromagnetic wave which travels through space



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E5C04 -- What type of Y-axis scale is most often used for graphs of circuit frequency response?

A. Linear

B. Scatter

C. Random

D. Logarithmic

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Principles of Circuits

RC and RL Time Constants

- Electrical energy storage.
  - Both capacitors and inductors can be used to store electrical energy.
  - Both capacitors and inductors resist changes in the amount of energy stored.
    - The same as a flywheel resisting a change to its speed of rotation.

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Principles of Circuits

RC and RL Time Constants

- Electrical energy storage.
  - Capacitors store electrical energy in an electric field.
    - Energy is stored by applying a voltage across the capacitor's terminals.
    - Strength of field (amount of energy stored) is determined by the voltage across the capacitor.
      - Higher voltage → more energy stored.
  - Capacitors oppose changes in voltage.
    - Generate a current flow to counteract the voltage change.

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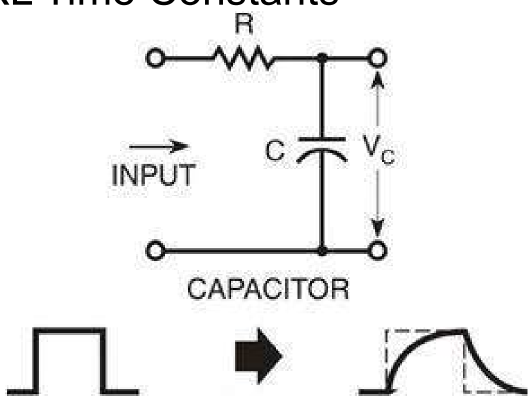
Principles of Circuits

RC and RL Time Constants



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Principles of Circuits

RC and RL Time Constants

- Magnetic energy storage.
  - Inductors store electrical energy in a magnetic field.
    - Energy is stored by passing a current through the inductor.
    - Strength of field (amount of energy stored) is determined by the amount of current through the inductor.
      - More current → more energy stored.
  - Inductors oppose changes in current.
    - Generates a voltage (induced voltage) to counter the voltage causing the change in current.

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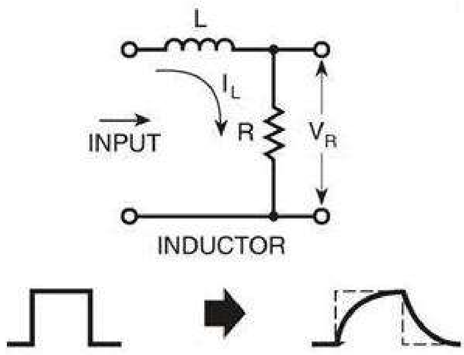
Principles of Circuits

RC and RL Time Constants



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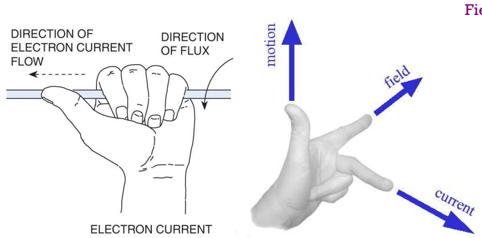
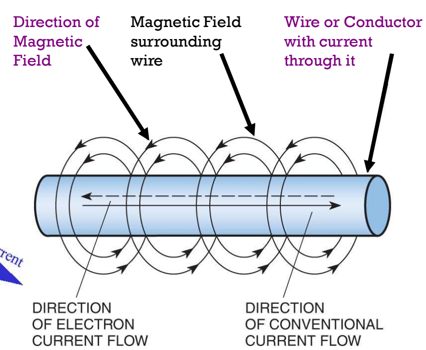
Principles of Circuits

Magnetic Field Direction

- Left-Hand Rule



Left-Hand Rule



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Principles of Circuits

RL and RC Time Constants

- Time Constant.
  - When a DC voltage is first applied to a capacitor, the current through the capacitor will initially be high but will fall to zero.
  - When a DC current is first applied to an inductor, the voltage across the inductor will initially be high but will fall to zero.
  - "Time constant" is a measure of how fast this transition occurs.

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Principles of Circuits

RL and RC Time Constants

- Time Constant.
  - In an R-C circuit, one time constant is defined as the time it takes the voltage across an uncharged capacitor to reach 63.2% of its final value.
  - In an R-C circuit, the time constant (Ƭ) is calculated by multiplying the resistance (R) in Ohms by the capacitance (C) in Farads.

$$Ƭ = R \times C$$

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Principles of Circuits

RL and RC Time Constants

- Time Constant.
  - In an R-L circuit, one time constant is defined as the time it takes the current through an inductor to reach 63.2% of its final value.
  - In an R-L circuit, the time constant (Ƭ) is calculated by dividing the inductance (L) in Henrys by the resistance (R) in Ohms.

Ƭ = L / R

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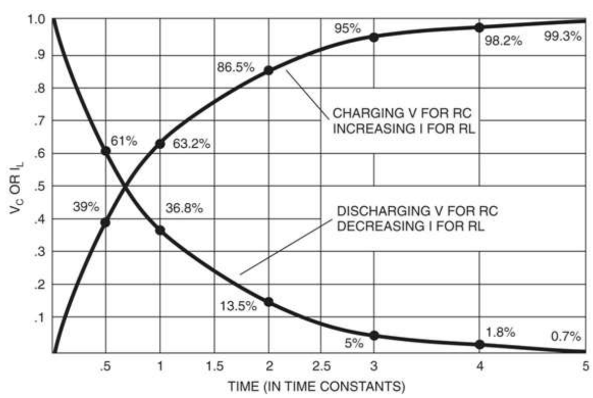
Principles of Circuits

RL and RC Time Constants



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Principles of Circuits

RL and RC Time Constants

	Charging	Discharging
Time Constants	Percentage of Applied Voltage	Percentage of Starting Voltage
1	63.20%	36.80%
2	86.50%	13.50%
3	95.00%	5.00%
4	98.20%	1.80%
5	99.30%	0.70%

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Principles of Circuits

RL and RC Time Constants

- Time Constant.
  - After a period of 5 time constants, the voltage or current can be assumed to have reached its final value.
    - "Close enough for all practical purposes."

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E5B01 -- What is the term for the time required for the capacitor in an RC circuit to be charged to 63.2% of the applied voltage or to discharge to 36.8% of its initial voltage?

A. An exponential rate of one
B. One time constant
C. One exponential period
D. A time factor of one

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E5B04 -- What is the time constant of a circuit having two 220-microfarad capacitors and two 1-megohm resistors, all in parallel?

A. 55 seconds
B. 110 seconds
C. 440 seconds
D. 220 seconds

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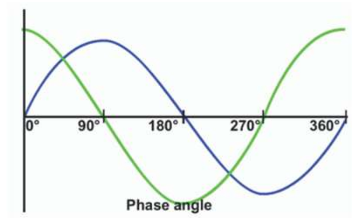
Principles of Circuits

Phase Angle

- The difference in time between 2 different signals at the same frequency is called the phase angle.
- The phase angle is measured in degrees.



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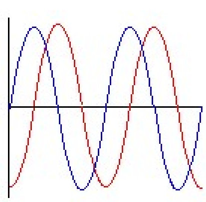
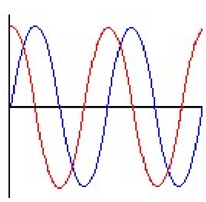
Principles of Circuits

Phase Angle

- Leading signal is ahead of 2nd signal.
- Lagging signal is behind 2nd signal.


Blue signal leads red signal.


Blue signal lags red signal.

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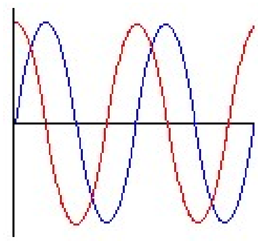
Principles of Circuits

Phase Angle

- AC Voltage-Current Relationship in Capacitors.
  - In a capacitor, the current leads the voltage by 90°.



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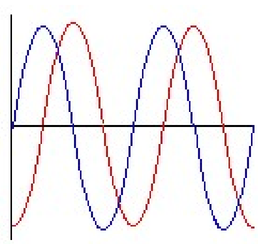
Electrical Principles

Phase Angle

- AC Voltage-Current Relationship in Inductors
  - In an inductor, the current lags the voltage by 90°.



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Principles of Circuits

Phase Angle

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Principles of Circuits

Phase Angle

- Combining reactance with resistance.
  - In a resistor, the voltage and the current are always in phase.
  - In a circuit with both resistance and capacitance, the current will lead the voltage by less than 90°.
  - In a circuit with both resistance and inductance, the current will lag the voltage by less than 90°.
  - The size of the phase angle depends on the relative sizes of the resistance to the inductance or capacitance.

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Principles of Circuits

Combining Reactance and Resistance

- Inductive Reactance.

$$X_L = 2\pi fL \quad \underline{/90^\circ}$$

- Inductive reactance increases with increasing frequency.
- Inductor looks like a short circuit at 0 Hz (DC).
- Inductor looks like an open circuit at very high frequencies.

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Principles of Circuits

Combining Reactance and Resistance

- Capacitive Reactance.

$$X_C = 1/2\pi fC \quad \underline{/-90^\circ}$$

- Capacitive reactance decreases with increasing frequency.
- Capacitor looks like an open circuit at 0 Hz (DC).
- Capacitor looks like a short circuit at very high frequencies.

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Principles of Circuits

Combining Reactance and Resistance

- When resistance is combined with reactance the result is called impedance.

$$X = X_L - X_C$$

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

$$\theta = \text{ArcTan}\,(X/R)$$

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E5B09 -- What is the relationship between the AC current through a capacitor and the voltage across a capacitor?

A. Voltage and current are in phase
B. Voltage and current are 180 degrees out of phase
C. Voltage leads current by 90 degrees
D. Current leads voltage by 90 degrees

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E5B10 -- What is the relationship between the AC current through an inductor and the voltage across an inductor?

A. Voltage leads current by 90 degrees
B. Current leads voltage by 90 degrees
C. Voltage and current are 180 degrees out of phase
D. Voltage and current are in phase

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Principles of Circuits

Complex Impedance

- Complex impedances are normally written using rectangular coordinate values:

$$Z = R + jX$$

  - Z = Impedance.
  - R = Resistance.
  - X = Reactance.
    - Inductive reactance is positive.
    - Capacitive reactance is negative.

Principles of Circuits

Complex Impedance

- Complex impedances can be written using polar coordinate values:

$$Z = M\ \underline{/\theta}$$

  - Z = Impedance.
  - M = Magnitude.
  - θ = Phase angle.
    - Inductive reactances have a positive phase angle.
    - Capacitive reactances have a negative phase angle.

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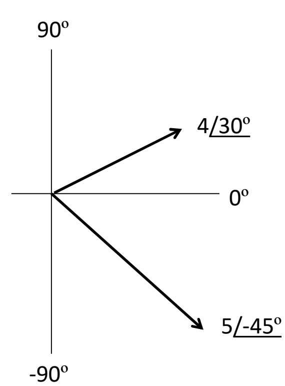
Radio Mathematics

Complex Impedance

- A complex impedance plotted in polar coordinates is also called a phasor.
  - The length of the phasor is the impedance.
  - The angle of the phasor is the phase angle.
  - The angle is always between +90º & -90º.



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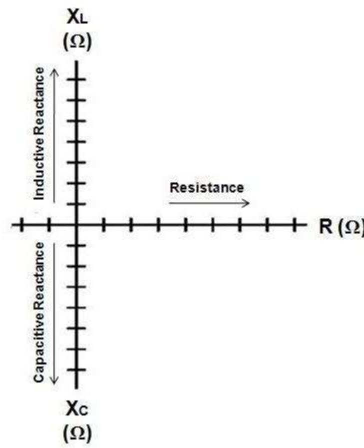
Principles of Circuits

Complex Impedance

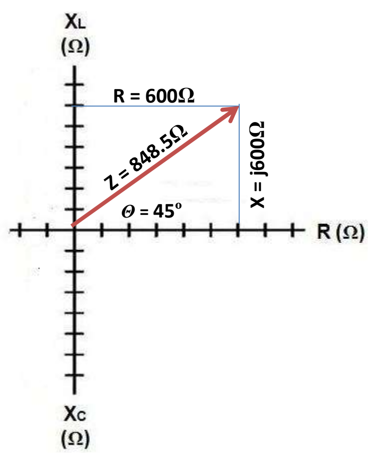
- Resistance along positive x-axis (right).
- Inductive reactance along positive y-axis (up).
- Capacitive reactance along negative y-axis (down).
- Negative x-axis (left) not used.



Principles of Circuits

Complex Impedance

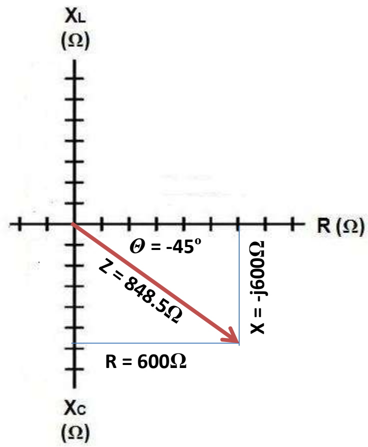
- R = 600 Ω
- X_L = j600 Ω
- Z = 848.5 Ω <u>/45°</u>



Principles of Circuits

Complex Impedance

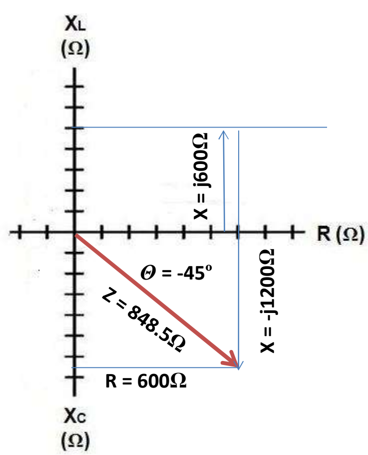
- R = 600 Ω
- X_C = -j600 Ω
- Z = 848.5 Ω <u>/-45º</u>



Principles of Circuits

Complex Impedance

- R = 600 Ω
- X_L = j600 Ω
- X_C = -j1200 Ω
- X = -j600 Ω
- Z = 848.5 Ω <u>/-45º</u>



E5C01 -- Which of the following represents pure capacitive reactance of 100 ohms in rectangular notation?

A. 0 - j100
B. 0 + j100
C. 100 - j0
D. 100 + j0

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E5C02 -- How are impedances described in polar coordinates?

A. By X and R values
B. By real and imaginary parts
C. By phase angle and amplitude
D. By Y and G values

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E5C03 -- Which of the following represents an inductive reactance in polar coordinates?

A. A positive 45 degree phase angle
B. A negative 45 degree phase angle
C. A positive 90 degree phase angle
D. A negative 90 degree phase angle

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E5C05 -- What kind of diagram is used to show the phase relationship between impedances at a given frequency?

A. Venn diagram
B. Near field diagram
C. Phasor diagram
D. Far field diagram

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E5C06 -- What does the impedance 50 – j25 represent?

A. 50 ohms resistance in series with 25 ohms inductive reactance

B. 50 ohms resistance in series with 25 ohms capacitive reactance

C. 25 ohms resistance in series with 50 ohms inductive reactance

D. 25 ohms resistance in series with 50 ohms capacitive reactance

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E5C07 -- Where is the impedance of a pure resistance plotted on rectangular coordinates?

A. On the vertical axis

B. On a line through the origin, slanted at 45 degrees

C. On a horizontal line, offset vertically above the horizontal axis

D. On the horizontal axis

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E5C08 -- What coordinate system is often used to display the phase angle of a circuit containing resistance, inductive and/or capacitive reactance?

A. Maidenhead grid
B. Faraday grid
C. Elliptical coordinates
➡ D. Polar coordinates

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E5C09 -- When using rectangular coordinates to graph the impedance of a circuit, what do the axes represent?

➡ A. The X axis represents the resistive component and the Y axis represents the reactive component
B. The X axis represents the reactive component and the Y axis represents the resistive component
C. The X axis represents the phase angle and the Y axis represents the magnitude
D. The X axis represents the magnitude and the Y axis represents the phase angle

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Principles of Circuits

Admittance and Susceptance

- Conductance (G) = 1 / Resistance (R)
- Admittance (Y) = 1 / Impedance (Z)
- Susceptance (B) = 1 / Reactance (X)

- Unit of measurement = siemens (S)
  - Formerly “mho”.

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Principles of Circuits

Admittance and Susceptance

- Like impedance, admittance can also be plotted in either rectangular or polar coordinates.

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Principles of Circuits

Admittance and Susceptance

- In polar coordinates, taking the reciprocal of an angle reverses the sign of the angle.
  - For example: 1/45° = -45°
  - If the reactance is positive (inductive), then the susceptance is negative.
  - If the reactance is negative (capacitive), then the susceptance is positive.

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Principles of Circuits

Admittance and Susceptance

- To convert from impedance to admittance or from admittance to impedance:
  - Express the impedance or admittance in polar coordinates.
  - Take the reciprocal of the magnitude.
  - Change the sign of the angle.

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Principles of Circuits

Admittance and Susceptance

Remember -- Taking the reciprocal of an angle reverses the sign of the angle.

Example:

An impedance of 141Ω @ $\angle 45°$

is equivalent to

7.09 mS (millisiemens) @ $\angle -45°$

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Principles of Circuits

Admittance and Susceptance

- Calculating Impedances & Phase Angles
  - Basic principles:
    - If $X_L > X_c$, then reactance is inductive (+).
    - If $X_L = X_c$, then reactance is 0 (pure resistance).
    - If $X_L < X_c$, then reactance is capacitive(-).

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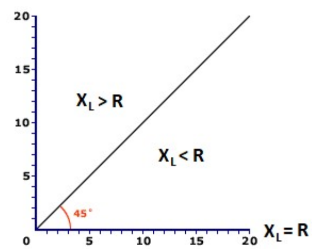
Principles of Circuits

Admittance and Susceptance

- Calculating Impedances & Phase Angles
  - For inductive reactance:
    - If X < R, then θ is between 0° and +45°.
    - If X = R, then θ = +45°.
    - If X > R, then θ is between +45° and +90°.



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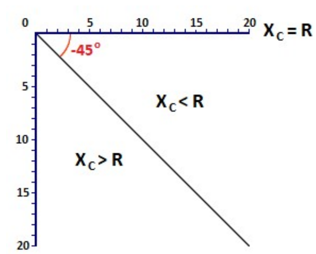
Principles of Circuits

Admittance and Susceptance

- Calculating Impedances & Phase Angles
  - For capacitive reactance:
    - If X < R, then θ is between 0° and -45°.
    - If X = R, then θ = -45°.
    - If X > R, then θ is between -45° and -90°.



74

E5B02 -- What letter is commonly used to represent susceptance?

A. G
B. X
C. Y
D. B

75

E5B03 -- How is impedance in polar form converted to an equivalent admittance?

A. Take the reciprocal of the angle and change the sign of the magnitude
B. Take the reciprocal of the magnitude and change the sign of the angle
C. Take the square root of the magnitude and add 180 degrees to the angle
D. Square the magnitude and subtract 90 degrees from the angle

76

E5B05 -- What is the effect on the magnitude of pure reactance when it is converted to susceptance?

A. It is unchanged
B. The sign is reversed
C. It is shifted by 90 degrees
➡ D. It becomes the reciprocal

77

E5B06 -- What is susceptance?

A. The magnetic impedance of a circuit
B. The ratio of magnetic field to electric field
➡ C. The imaginary part of admittance
D. A measure of the efficiency of a transformer

78

E5B07 -- What is the phase angle between the voltage across and the current through a series RLC circuit if XC is 500 ohms, R is 1 kilohm, and XL is 250 ohms?

A. 68.2 degrees with the voltage leading the current

B. 14.0 degrees with the voltage leading the current

➡ C. 14.0 degrees with the voltage lagging the current

D. 68.2 degrees with the voltage lagging the current

79

E5B08 -- What is the phase angle between the voltage across and the current through a series RLC circuit if XC is 300 ohms, R is 100 ohms, and XL is 100 ohms?

➡ A. 63 degrees with the voltage lagging the current

B. 63 degrees with the voltage leading the current

C. 27 degrees with the voltage leading the current

D. 27 degrees with the voltage lagging the current

80

E5B11 -- What is the phase angle between the voltage across and the current through a series RLC circuit if XC is 25 ohms, R is 100 ohms, and XL is 75 ohms?

A. 27 degrees with the voltage lagging the current
B. 27 degrees with the voltage leading the current
C. 63 degrees with the voltage lagging the current
D. 63 degrees with the voltage leading the current

81

E5B12 -- What is admittance?

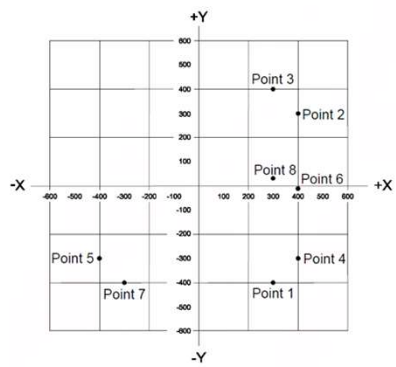
A. The inverse of impedance
B. The term for the gain of a field effect transistor
C. The inverse of reactance
D. The term for the on-impedance of a field effect transistor

82

E5C10 -- Which point on Figure E5-1 best represents the impedance of a series circuit consisting of a 400-ohm resistor and a 38-picofarad capacitor at 14 MHz?

A. Point 2
B. Point 4
C. Point 5
D. Point 6

Figure E5-1

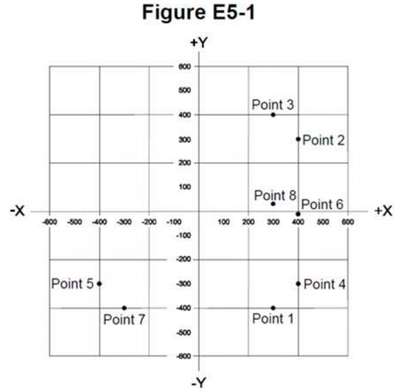


83

E5C11 -- Which point in Figure E5-1 best represents the impedance of a series circuit consisting of a 300-ohm resistor and an 18-microhenry inductor at 3.505 MHz?

A. Point 1
B. Point 3
C. Point 7
D. Point 8

Figure E5-1

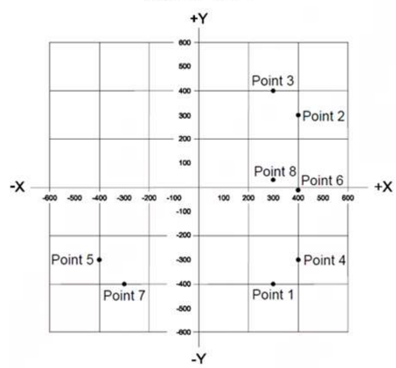


84

E5C12 -- Which point on Figure E5-1 best represents the impedance of a series circuit consisting of a 300-ohm resistor and a 19-picofarad capacitor at 21.200 MHz?

A. Point 1
B. Point 3
C. Point 7
D. Point 8

Figure E5-1



Principles of Circuits

Reactive Power and Power Factor

- Power
  - Rate of doing work (using energy) over time.
    - 1 watt = 1 joule/second

Principles of Circuits

Reactive Power and Power Factor

- Definition of Reactive Power.
  - A pure resistance consumes energy.
    - Voltage & current are in phase (θ = 0°).
    - Work is done.
    - Power is used.

87

Principles of Circuits

Reactive Power and Power Factor

- Definition of Reactive Power.
  - Capacitance & inductance only store & return energy, they do not consume it.
    - Voltage & current are 90° out of phase (θ = ±90°).
    - No work is done.
    - No power is used.

88

Principles of Circuits

Reactive Power and Power Factor

- Definition of Reactive Power.
  - P = I x E only works when voltage & current are in phase.
  - True formula is P = I x E x cos(θ)
    - cos(0°) = 1
    - cos(90°) = 0
  - P = I x E gives *apparent* power.
    - Expressed as Volt-Amperes (V-A) rather than Watts.

89

Principles of Circuits

Reactive Power and Power Factor

- Definition and Calculation of Power Factor.
  - P = I x E → Apparent Power (P_A)
  - P = I x E x cos(θ) → Real Power (P_R)
  - Power Factor (PF) = P_R / P_A
  - PF = cos(θ)
  - P_R = P x PF

90

E5D03 -- What is the phase relationship between current and voltage for reactive power?

A. They are out of phase
B. They are in phase
C. They are 90 degrees out of phase
D. They are 45 degrees out of phase

91

E5D09 -- What happens to reactive power in ideal inductors and capacitors?

A. It is dissipated as heat in the circuit
B. Energy is stored in magnetic or electric fields, but power is not dissipated
C. It is canceled by Coulomb forces in the capacitor and inductor
D. It is dissipated in the formation of inductive and capacitive fields

92

E5D11 -- How much real power is consumed in a circuit consisting of a 100-ohm resistor in series with a 100-ohm inductive reactance drawing 1 ampere?

A. 70.7 watts

B. 100 watts

C. 141.4 watts

D. 200 watts

93

E5D12 -- What is reactive power?

A. Power consumed in circuit Q

B. Power consumed by an inductor s wire resistance

C. The power consumed in inductors and capacitors

D. Wattless, nonproductive power

94

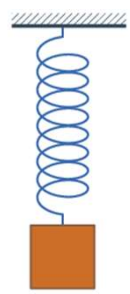
Break

95

Principles of Circuits

Resonant Circuits

- Mechanical systems have a natural frequency where they want to vibrate when stimulated.
  - Violin or guitar string.
- This is called resonance.
- Electrical circuits containing both capacitors and inductors behave in a similar manner.



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Principles of Circuits

Resonant Circuits

- As frequency increases, inductive reactance increases.
- As frequency increases, capacitive reactance decreases.
- At some frequency, inductive reactance & capacitive reactance will be equal.
- This is called the resonant frequency.

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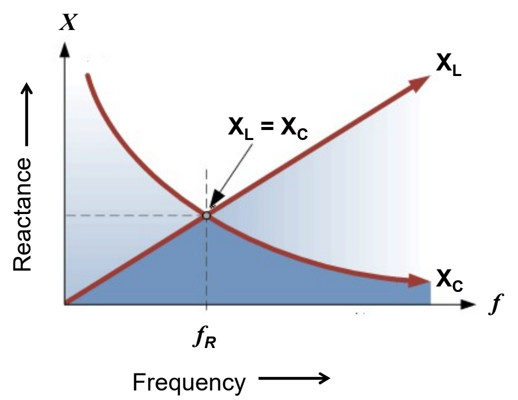
Principles of Circuits

Resonant Circuits



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Principles of Circuits

Resonant Circuits

- At the resonant frequency:
  - Inductive & capacitive reactances cancel each other out.
  - Circuit impedance is purely resistive.
  - Voltage & current are in phase.

99

Principles of Circuits

Resonant Circuits

Calculation of Resonant Frequency.

- Inductive reactance is

$$X_L = 2\pi f L$$

- Capacitive reactance is:

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

100

Principles of Circuits

Resonant Circuits

Calculation of Resonant Frequency.

- At resonance $X_L = X_C$

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

- The resonant frequency is:

$$f_R = \frac{1}{2\pi\sqrt{LC}}$$

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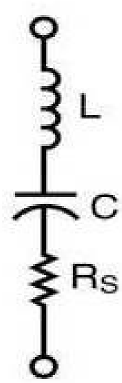
Principles of Circuits

Resonant Circuits



- Stored Energy in Resonant Circuits.
  - Series Resonant Circuit.
    - The impedance is at the minimum.
      - $Z = R_S$
    - The voltage across the resistor is equal to the applied voltage.
    - The voltages across the inductance & the capacitance are 180° out of phase.
    - The sum of the individual voltages is greater than the applied voltage.

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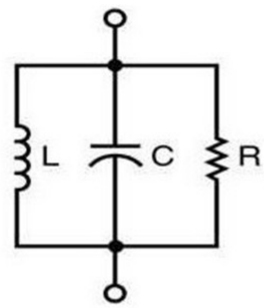
Principles of Circuits

Resonant Circuits

- Stored Energy in Resonant Circuits.
  - Parallel Resonant Circuit.
    - Impedance is at the maximum.
      - $Z = R_P$
    - Current through resistor equals current through circuit.
    - Currents through inductance & capacitance are 180° out of phase.
    - Sum of currents through all components greater than current through circuit.



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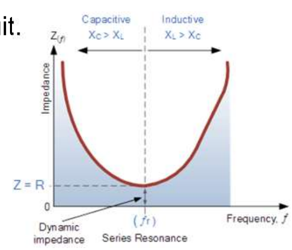
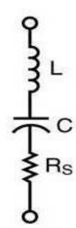
Principles of Circuits

Resonant Circuits

- Stored Energy in Resonant Circuits
  - Impedance of Resonant Circuits Versus Frequency.
    - Series Resonant Circuit.





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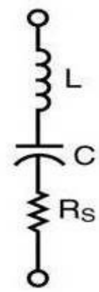
Principles of Circuits

Resonant Circuits

- Impedance of Resonant Circuits Versus Frequency.
  - Series Resonant Circuit
    - Capacitive below resonance.
    - Resistive at resonance.
    - Inductive above resonance.



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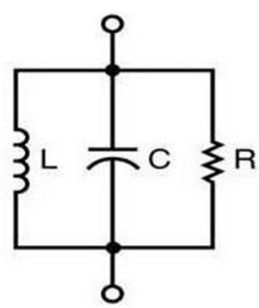
Principles of Circuits

Resonant Circuits

- Impedance of Resonant Circuits Versus Frequency.
  - Parallel Resonant Circuit.
    - Inductive below resonance.
    - Resistive at resonance.
    - Capacitive above resonance.



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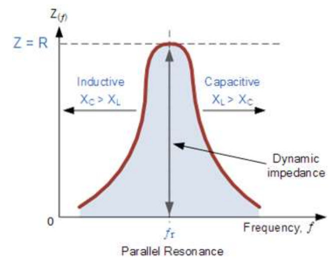
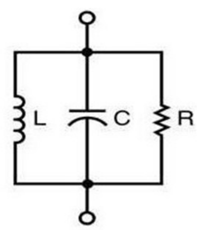
Principles of Circuits

Resonant Circuits

- Impedance of Resonant Circuits Versus Frequency.
  - Parallel Resonant Circuit.





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E5A01 -- What can cause the voltage across reactances in a series RLC circuit to be higher than the voltage applied to the entire circuit?

A. Resonance
B. Capacitance
C. Low quality factor (Q)
D. Resistance

108

E5A02 -- What is the resonant frequency of an RLC circuit if R is 22 ohms, L is 50 microhenries, and C is 40 picofarads

A. 44.72 MHz

B. 22.36 MHz

➡ C. 3.56 MHz

D. 1.78 MHz

109

E5A03 -- What is the magnitude of the impedance of a series RLC circuit at resonance?

A. High, compared to the circuit resistance

B. Approximately equal to capacitive reactance

C. Approximately equal to inductive reactance

➡ D. Approximately equal to circuit resistance

110

E5A04 -- What is the magnitude of the impedance of a parallel RLC circuit at resonance?

A. Approximately equal to circuit resistance
B. Approximately equal to inductive reactance
C. Low compared to the circuit resistance
D. High compared to the circuit resistance

111

E5A06 -- What is the magnitude of the circulating current within the components of a parallel LC circuit at resonance?

A. It is at a minimum
B. It is at a maximum
C. It equals 1 divided by the quantity 2 times pi, times the square root of (inductance L multiplied by capacitance C)
D. It equals 2 times pi, times the square root of (inductance L multiplied by capacitance C)

112

E5A07 -- What is the magnitude of the current at the input of a parallel RLC circuit at resonance?

A. Minimum
B. Maximum
C. R/L
D. L/R

113

E5A08 -- What is the phase relationship between the current through and the voltage across a series resonant circuit at resonance?

A. The voltage leads the current by 90 degrees
B. The current leads the voltage by 90 degrees
C. The voltage and current are in phase
D. The voltage and current are 180 degrees out of phase

114

E5A10 -- What is the resonant frequency of an RLC circuit if R is 33 ohms, L is 50 microhenries and C is 10 picofarads?

A. 7.12 MHz
B. 23.5 kHz
C. 7.12 kHz
D. 23.5 MHz

115

Principles of Circuits

Q of Components and Circuits

- So far we have been dealing with ideal components.
  - Pure resistance.
  - Pure capacitance.
  - Pure inductance.

116

Principles of Circuits

Q of Components and Circuits

- **ALL** physical components are non-ideal.
  - Physical resistors exhibit some inductance & capacitance.
  - Physical capacitors exhibit some resistance & inductance.
  - Physical inductors exhibit some resistance & capacitance.

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Principles of Circuits

Q of Components and Circuits

- A physical inductor can be thought of as a resistor in series with an ideal inductor.

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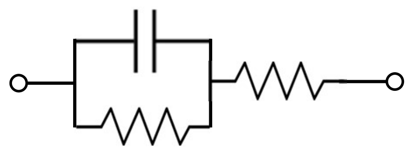
Principles of Circuits

Q of Components and Circuits

- A physical capacitor can be though of as a resistor in parallel with and a resistor is series with an ideal capacitor.



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Principles of Circuits

Q of Components and Circuits

NOTE: The book only refers to a resistor in series with the capacitor. However, capacitor leakage (represented by a resistor in parallel with the capacitor), is often more significant than the series resistance when determining circuit behavior.

The series resistance is extremely small compared to the leakage (parallel) resistance.

When calculating circuit Q, the leakage resistance can usually be ignored.

120

Principles of Circuits

Q of Components and Circuits

- In an ideal capacitor or inductor, all energy is stored.
- In a non-ideal capacitor or inductor, some energy is dissipated in the resistance.
- The ratio between the stored and the dissipated energy is called the quality factor or "Q".

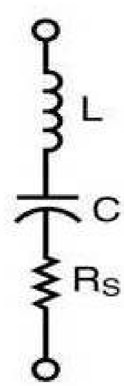
Q = X / R

121

Principles of Circuits

Q of Components and Circuits

- Quality factor (Q).
  - Ratio of power stored (P_S) in circuit to power dissipated (P_D) in circuit.
  - $Q = P_S / P_D$
    - $P_S = I^2 \times X$
    - $P_D = I^2 \times R$
  - $Q = X / R$



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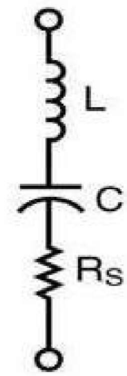
Principles of Circuits

Q of Components and Circuits

- Quality factor (Q).
  - Q always goes down when resistance is added in series with or in parallel with a component.
    - The internal series resistance of an inductor is almost always greater than the internal series resistance of a capacitor.
    - The resistance of the inductor is primarily responsible for the Q of circuit.



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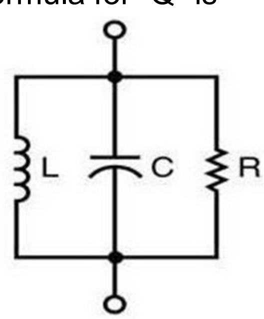
Principles of Circuits

Q of Components and Circuits

- Quality factor (Q).
  - In parallel resonant circuits, the formula for "Q" is slightly different:

Q = R / X



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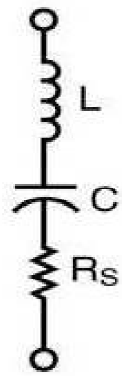
Principles of Circuits

Q of Components and Circuits

- Quality factor (Q).
  - Q affects bandwidth & efficiency of circuit.
    - Higher Q → Higher efficiency (lower losses).
    - Higher Q → Narrower bandwidth.



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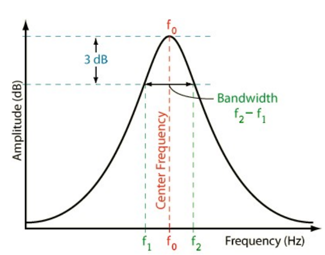
Principles of Circuits

Q and Resonant-Circuit Bandwidth

- Half-power bandwidth (BW).
  - The difference in frequency between the points on the response curve where the power is reduced by one half (-3dB).

$$BW = f_2 - f_1$$



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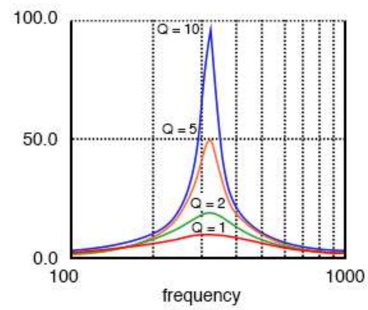
Principles of Circuits

Q and Resonant-Circuit Bandwidth

- The bandwidth is dependent upon the Q of the circuit.
  - BW = f_R / Q



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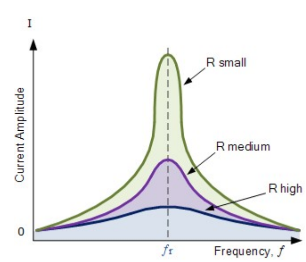
Principles of Circuits

"Q" and Bandwidth of Resonant Circuits

- Lower resistance yields:
  - Narrower bandwidth.
  - Lower losses.
- Higher resistance yields:
  - Wider bandwidth.
  - Higher losses.



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E4B08 -- Which of the following can be used to measure the Q of a series-tuned circuit?

A. The inductance to capacitance ratio

B. The frequency shift

➡ C. The bandwidth of the circuit's frequency response

D. The resonant frequency of the circuit

129

E5A05 -- What is the result of increasing the Q of an impedance-matching circuit?

➡ A. Matching bandwidth is decreased

B. Matching bandwidth is increased

C. Losses increase

D. Harmonics increase

130

E5A09 -- How is the Q of an RLC parallel resonant circuit calculated?

A. Reactance of either the inductance or capacitance divided by the resistance
B. Reactance of either the inductance or capacitance multiplied by the resistance
➡ C. Resistance divided by the reactance of either the inductance or capacitance
D. Reactance of the inductance multiplied by the reactance of the capacitance

E5A11 -- What is the half-power bandwidth of a resonant circuit that has a resonant frequency of 7.1 MHz and a Q of 150?

A. 157.8 Hz
B. 315.6 Hz
➡ C. 47.3 kHz
D. 23.67 kHz

E5A12 -- What is the half-power bandwidth of a parallel resonant circuit that has a resonant frequency of 3.7 MHz and a Q of 118?

A. 436.6 kHz
B. 218.3 kHz
C. 31.4 kHz
D. 15.7 kHz

133

E5A13 -- What is an effect of increasing Q in a series resonant circuit?

A. Fewer components are needed for the same performance
B. Parasitic effects are minimized
C. Internal voltages increase
D. Phase shift can become uncontrolled

134

Principles of Circuits

Components at RF and Microwave Frequencies

- Skin effect and Q.
  - A DC current is evenly distributed across the cross-sectional area of a conductor.
  - As frequency is increased, current flow is concentrated towards the outer surface of a conductor.
    - The effective cross-sectional area is reduced.
    - The effective resistance is increased.

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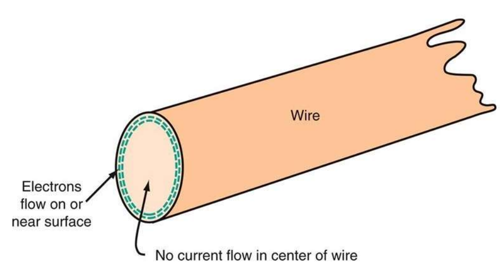
Principles of Circuits

Components at RF and Microwave Frequencies

- Skin effect and Q.



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Principles of Circuits

Components at RF and Microwave Frequencies

- Skin effect and Q.
  - As frequency is increased, the Q of an inductor increases until the skin effect takes over & the Q is reduced.
    - $Q = X_L / R$
    - X_L increases linearly with frequency.
    - R increases exponentially with frequency.
    - As the frequency increases, the skin effect becomes more significant, raising the resistance & lowering the Q.

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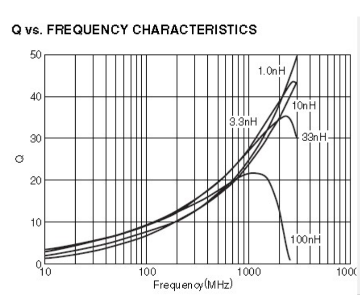
Principles of Circuits

Components at RF and Microwave Frequencies

- Skin effect and Q.



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Principles of Circuits

Components at RF and Microwave Frequencies

- Self Resonance.
  - When talking about "Q", we were concerned with parasitic resistance.
  - When talking about self resonance, we are concerned with parasitic reactance.

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Principles of Circuits

Components at RF and Microwave Frequencies

- Self Resonance.
  - All physical capacitors have some parasitic inductance.
    - Lead inductance.
    - Above the self-resonant frequency, a capacitor will look like an inductor.

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Principles of Circuits

Components at RF and Microwave Frequencies

- Self Resonance.
  - All physical inductors have some parasitic capacitance.
    - Inter-turn capacitance.
    - Above the self-resonant frequency, an inductor will look like a capacitor.

141

Principles of Circuits

Components at RF and Microwave Frequencies

- Effects of Component Packaging at RF.
  - Self resonance is of particular concern at VHF frequencies & above.
    - Commonly-used components may have self-resonant frequencies at or below the frequency of operation.
    - Need specially-constructed components for use at VHF & above and also use special construction techniques.
      - Striplines.
      - Waveguides.

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Principles of Circuits

Components at RF and Microwave Frequencies

- Effects of Component Packaging at RF.
  - Different components packaging styles have different amounts of lead inductance.
  - Through hole components have more lead inductance than surface-mount (SMT) components.
    - 1” of lead ≈ 20 μH

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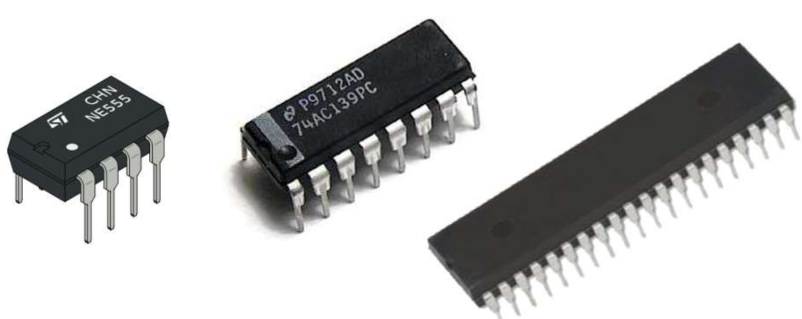
Principles of Circuits

Dual-Inline-Package (DIP)

- Commonly used for integrated circuits.
  - Through-hole leads add inductance.



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Principles of Circuits

Surface-Mount Components (SMT)

- Replacing DIP & other through-hole components.
  - No leads ➔ No lead inductance.
  - Better for VHF & UHF circuits.
  - Better for automated PCB assembly.

145

E5D01 -- What is the result of conductor skin effect?

A. Resistance increases as frequency increases because RF current flows closer to the surface

B. Resistance decreases as frequency increases because electron mobility increases

C. Resistance increases as temperature increases because of the change in thermal coefficient

D. Resistance decreases as temperature increases because of the change in thermal coefficient

146

E5D02 -- Why is it important to keep lead lengths short for components used in circuits for VHF and above?

A. To increase the thermal time constant

➡ B. To minimize inductive reactance

C. To maintain component lifetime

D. All these choices are correct

147

E5D04 -- Why are short connections used at microwave frequencies?

A. To increase neutralizing resistance

➡ B. To reduce phase shift along the connection

C. To increase compensating capacitance

D. To reduce noise figure

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E5D05 -- What parasitic characteristic causes electrolytic capacitors to be unsuitable for use at RF?

A. Skin effect
B. Shunt capacitance
➡ C. Inductance
D. Dielectric leakage

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E5D06 -- What parasitic characteristic creates an inductor's self-resonance?

A. Skin effect
B. Dielectric loss
C. Coupling
➡ D. Inter-turn capacitance

150

E5D07 -- What combines to create the self-resonance of a component?

A. The component's resistance and reactance
B. The component's nominal and parasitic reactance
C. The component's inductance and capacitance
D. The component's electrical length and impedance

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E5D08 -- What is the primary cause of loss in film capacitors at RF?

A. Inductance
B. Dielectric loss
C. Self-discharge
D. Skin effect

152

E6E02 -- Which of the following device packages is a through-hole type?

A. DIP
B. PLCC
C. BGA
D. SOT

153

E6E09 -- Which of the following component package types have the least parasitic effects at frequencies above the HF range?

A. TO-220
B. Axial lead
C. Radial lead
D. Surface mount

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E6E10 -- What advantage does surface-mount technology offer at RF compared to using through-hole components?

A. Smaller circuit area
B. Shorter circuit-board traces
C. Components have less parasitic inductance and capacitance
➡ D. All these choices are correct

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E6E11 -- What is a characteristic of DIP packaging used for integrated circuits?

A. Extremely low stray capacitance (dielectrically isolated package)
B. Extremely high resistance between pins (doubly insulated package)
C. Two chips in each package (dual in package)
➡ D. Two rows of connecting pins on opposite sides of package (dual in-line package)

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E6E12 -- Why are DIP through-hole package ICs not typically used at UHF and higher frequencies?

A. Excessive dielectric loss

B. Epoxy coating is conductive above 300 MHz

C. Excessive lead length

D. Unsuitable for combining analog and digital signals

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Principles of Circuits

Magnetic Cores

- The core is whatever the wire is wound around.
- The coil can be wound on:
  - A non-ferrous material.
    - Air.
    - Plastic.
    - Cardboard.
  - Iron.
  - Powdered Iron.
  - Ferrite.

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Principles of Circuits

Magnetic Cores

- Adding a core of magnetic material concentrates magnetic field in the core.
  - Higher inductance.
  - More efficient (higher inductance with same resistance).

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Principles of Circuits

Magnetic Cores

- Permeability (μ)
  - Measurement of amount of concentration.

    $\mu = H_C / H_A$ (H = magnetic field strength)
  - Permeability of air = 1.

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Principles of Circuits

Magnetic Cores

- Core Materials
  - Air
    - Lowest inductance.
  - Iron
    - Low frequency (power supplies, AF).
    - Higher losses.

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Principles of Circuits

Magnetic Cores

- Core Materials
  - Powdered Iron.
    - Fine iron powder mixed with non-magnetic binding material.
    - Lower losses.
    - Better temperature stability.
  - Ferrite
    - Nickel-zinc or magnesium-zinc added to powdered iron.
    - Higher permeability.

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Principles of Circuits

Magnetic Cores

- Core Materials
  - Choice of proper core material allows inductor to perform well over the desired frequency range.
    - AF to UHF.

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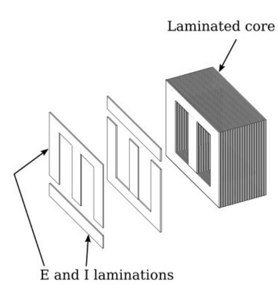
Principles of Circuits

Magnetic Cores

- Transformers
  - When the core material of a transformer or large inductor is iron, usually the core is constructed of several thin layers of iron.
  - This reduces losses caused by eddies in the magnetic field in the core.



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Principles of Circuits

Magnetic Cores

- Transformers
  - Saturation -- Above a certain current, the core material can no longer store the magnetic energy.
    - Saturation results in:
      - Distortion.
      - Overheating.
  - Magnetizing Current – The current flowing in the primary if no load is connected to the secondary.

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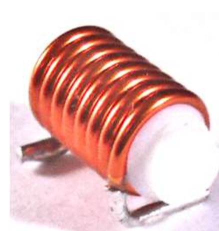
Principles of Circuits

Magnetic Cores



- Core shapes.
  - Solenoid Coil.
    - Inductance determined by:
      - Number of turns.
      - Diameter of turns.
      - Distance between turns (turn spacing).
      - Permeability (μ) of core material.
    - Not most efficient way to store magnetic energy.

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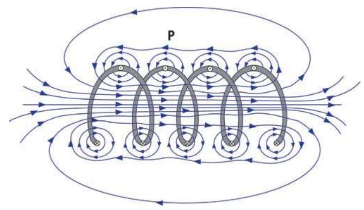
Principles of Circuits

Magnetic Cores

- Core shapes.
  - Solenoid Coil.
    - Magnetic field not confined within coil.
    - Permits mutual Inductance & coupling.



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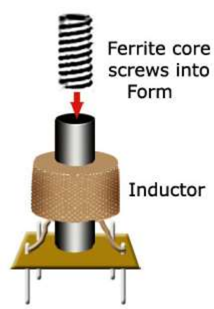
Principles of Circuits

Magnetic Cores

- Adjustable inductors.
  - Inserting a magnetic core (or slug) into a solenoidal coil will increase the inductance.
  - Changing the position of the slug will change the inductance.
  - Ferrite & brass are commonly used slug materials.
    - The low permeability of brass causes it to lower the inductance.



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Principles of Circuits

Magnetic Cores

- Toroidal Coil
  - Magnetic field almost completely confined within coil.
  - No stray coupling.
  - <20 Hz to about 300 MHz with proper material choice.

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Principles of Circuits

Calculating Inductance

- Inductance Index (A_L)
  - Value provided by manufacturer of core.
  - Accounts for permeability of core.
- Powdered Iron Cores
  - $L = A_L \times N^2 / 10{,}000$
    - L = Inductance in uH
    - A_L = Inductance Index in uH/(100 turns^2).
    - N = Number of Turns

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Principles of Circuits

Calculating Inductance

- Powdered Iron Cores
  - $L = A_L \times N^2 / 10{,}000$
  - $N = 100 \times \sqrt{L / A_L}$
    - L = Inductance in uH
    - A_L = Inductance Index in uH/(100 turns^2).
    - N = Number of Turns

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Principles of Circuits

Calculating Inductance

- Ferrite Cores
  - $L = A_L \times N^2 / 1{,}000{,}000$
  - $N = 1000 \times \sqrt{L / A_L}$
    - L = Inductance in mH
    - A_L = Inductance Index in mH/(1000 turns^2).
    - N = Number of Turns

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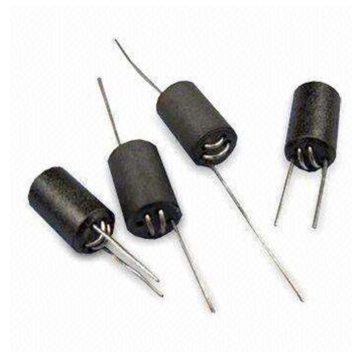
Principles of Circuits

Ferrite Beads

- RF suppression at VHF & UHF.



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E6D04 -- Why are cores of inductors and transformers sometimes constructed of thin layers?

A. To simplify assembly during manufacturing

B. To reduce power loss from eddy currents in the core

C. To increase the cutoff frequency by reducing capacitance

D. To save cost by reducing the amount of magnetic material

174

E6D05 -- How do ferrite and powdered iron compare for use in an inductor core?

A. Ferrite cores generally have lower initial permeability

B. Ferrite cores generally have better temperature stability

➡ C. Ferrite cores generally require fewer turns to produce a given inductance value

D. Ferrite cores are easier to use with surface-mount technology

175

E6D06 -- What core material property determines the inductance of an inductor?

A. Permittivity

B. Resistance

C. Reactivity

➡ D. Permeability

176

E6D07 -- What is the current that flows in the primary winding of a transformer when there is no load on the secondary winding?

A. Stabilizing current
B. Direct current
C. Excitation current
→ D. Magnetizing current

177

E6D08 -- Which of the following materials has the highest temperature stability of its magnetic characteristics?

A. Brass
→ B. Powdered iron
C. Ferrite
D. Aluminum

178

E6D09 -- What devices are commonly used as VHF and UHF parasitic suppressors at the input and output terminals of a transistor HF amplifier?

A. Electrolytic capacitors
B. Butterworth filters
➡ C. Ferrite beads
D. Steel-core toroids

179

E6D10 -- What is a primary advantage of using a toroidal core instead of a solenoidal core in an inductor?

➡ A. Toroidal cores confine most of the magnetic field within the core material
B. Toroidal cores make it easier to couple the magnetic energy into other components
C. Toroidal cores exhibit greater hysteresis
D. Toroidal cores have lower Q characteristics

180

E6D11 -- Which type of core material decreases inductance when inserted into a coil?

A. Ceramic
B. Brass
C. Ferrite
D. Aluminum

181

E6D12 -- What causes inductor saturation?

A. Operation at too high a frequency
B. Selecting a core with low permeability
C. Operation at excessive magnetic flux
D. Selecting a core with excessive permittivity

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Questions?

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Amateur Extra Class

Next Week

Chapter 5

Components and Building Blocks

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