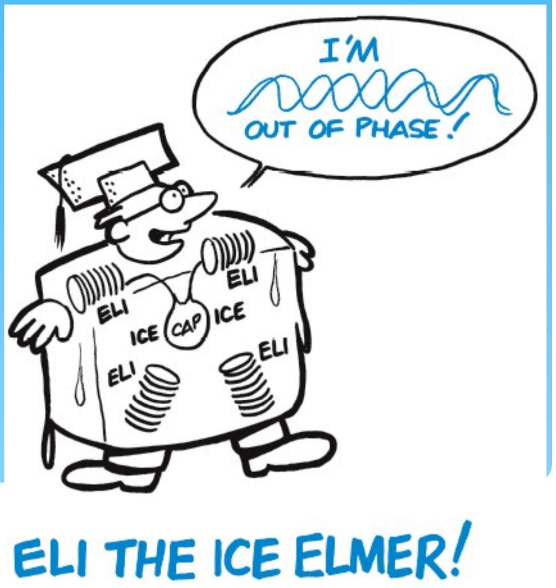
Amateur Extra License Class

Electrical Principles

Valid July 1, 2024
Through
June 30, 2028

Santa Fe Trail
Amateur Radio Club
2026

Larry Hall KD0RIU



Amateur Extra License Class

- Goal – Extra Class License
- You are 2/3 of the way already. You passed Technician and General Class tests.
- Take your time on the test. Keep track of the question number and answer sheet number.
- Magic test score number is 37/50 (74%)or higher.
- Learning is an ongoing process that will continue long after you have passed the Extra Class test.

Amateur Radio Extra Class
Chapter 4 – Electrical Principles

Math can be easy

- Powers of $10^{??}$ – how do they work?
- Ohm’s Law -> E = I * R
- Power equation -> P = E * I
- Reactance chart – how to visualize this
  - Resistance
  - Capacitive Reactance
  - Inductive Reactance
- AmateurLogic.tv – additional resource for learning

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Chapter 4 – Electrical Principles

Math can be easy

- Powers of 10 – how does it work?
  - 1 x 10^{0} = 1, power of 10^{0} = 1, so it does not change the number.
  - The *"exponent"* moves the decimal point left/right by the value in exponent
  - 1 x 10^{12} = 1,000,000,000,000. example -> THz, tera (trillion)
  - 1 x 10^{9} = 1,000,000,000. GHz, giga (billion)
  - 1 x 10^{6} = 1,000,000. MΩ, MHz (million)
  - 1 x 10^{3} = 1 x (10 x 10 x 10) = 1,000. KΩ, kHz (thousand)
  - *1 x 10^{0} = 1.0* inches, feet, miles
  - 1 x 10^{-3} = 1 / (10 x 10 x 10) = 0.001 mH, millisecond (milli)
  - 1 x 10^{-6} = 0.000 001 uH, microfarad (micro)
  - 1 x 10^{-9} = 0.000 000 001 nH, nanosecond (nano)
  - 1 x 10^{-12} = 0.000 000 000 001 pF, picosecond (pico)

Positive exponents move the decimal point to the right (->) making bigger numbers.
Negative exponents move the decimal point to the left (<-) making smaller numbers.

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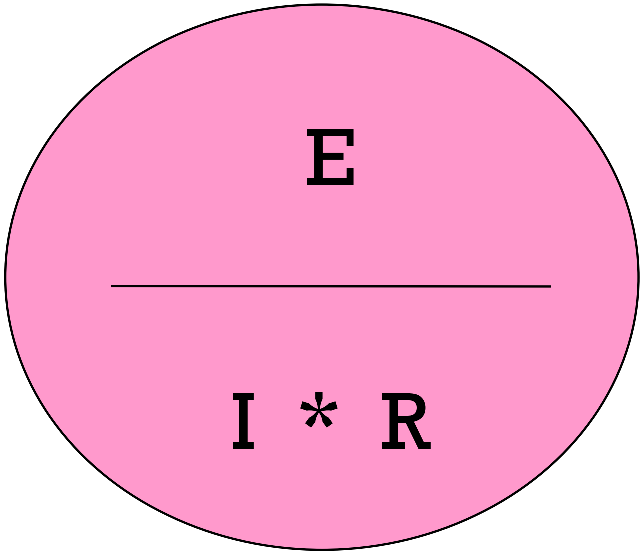
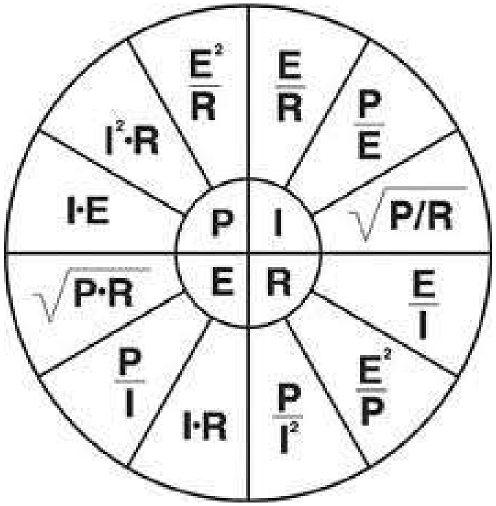
Chapter 4 – Electrical Principles

Math can be easy

- Ohm's Law -> E(voltage) = I(current) * R(resistance)

  Both sides of the equation are equal. This allows us to use the substitution process to find a value. If we know any two of the variables, then we can calculate the third variable.





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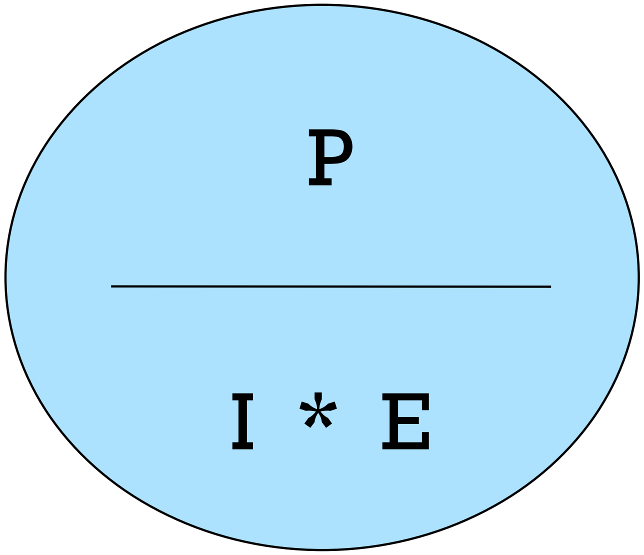
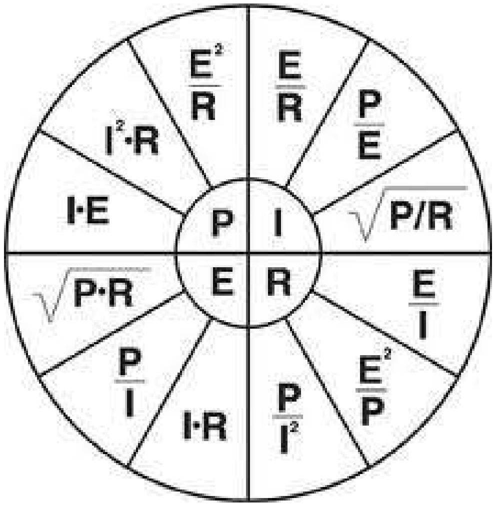
Chapter 4 – Electrical Principles

Math can be easy

- Power equation -> P(power) = I(current) * E(voltage)

  Both sides of the equation are equal. This allows us to use substitution to find a value. Once again, if we know any two of the variables then we can calculate the third variable.





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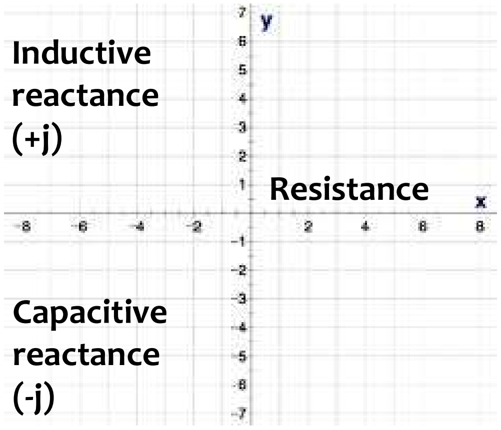
Chapter 4 – Electrical Principles

Math can be easy

- Reactance chart – how to visualize this [ohms +/-j]
  - Resistance (ohms)
  - Capacitive Reactance (-j)
  - Inductive Reactance (+j)
  - j = √-1 and 1/j = -1, these are defined constants used in electronics
- Rectangular and Polar Coordinates

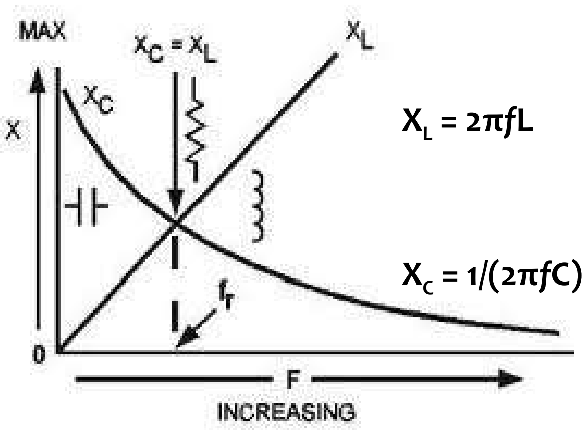
Rectangular coordinates



Inductive reactance (+j)

Resistance

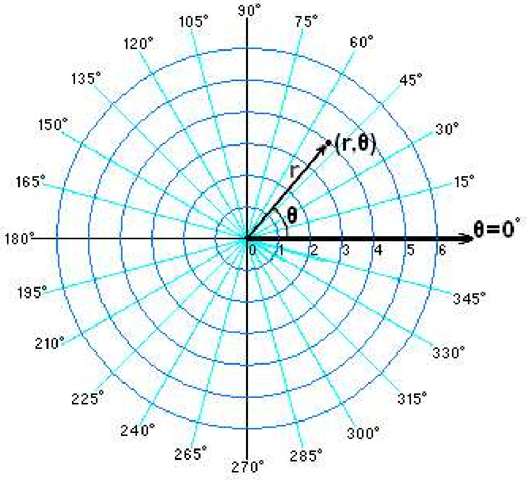
Capacitive reactance (-j)



$X_L = 2\pi f L$

$X_C = 1/(2\pi f C)$

Polar coordinates



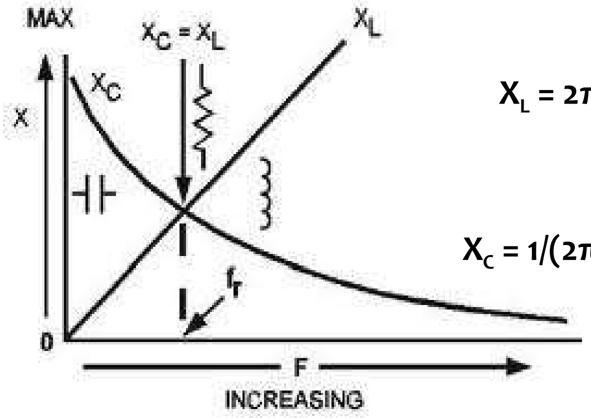
Math can be easy

- Reactance chart – how to visualize this
  - Resistance
  - Capacitive Reactance
  - Inductive Reactance

This is the basis for all AC circuits.

The crossover point where $X_L = X_C$ is the f_r resonant frequency. This is what every antenna designer is trying to accomplish.

If the f_r is at the desired frequency and the impedance is 50 ohms then you will have a SWR of 1.0, a "perfect" match. If the SWR is higher and the reactance is not zero, the antenna has more reactance (inductive or capacitive) depending on where f_r is located.



Inductive reactance

$X_L = 2\pi f L$

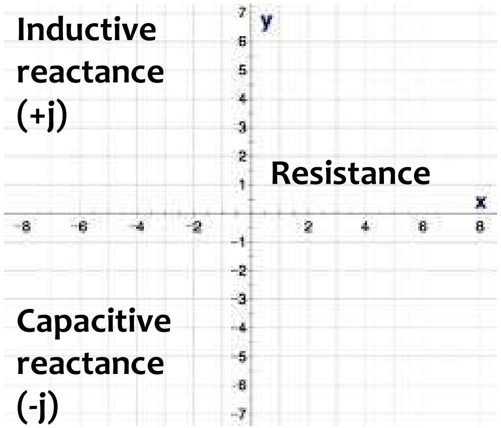
$X_C = 1/(2\pi f C)$

Capacitive reactance

Math can be easy

- Rectangular and Polar Coordinates

Rectangular coordinates



This chart will be used in several examples.

The horizontal axis is called the ***X axis*** and is where the ***Resistance*** values are located.

The vertical axis is called the **Y axis** and is where the ***Reactance*** values are located. This is j axis.

Positive Y axis is for **Inductors** and negative Y axis is for **Capacitors**.

We will write equations like 300 + j400 which is a point in the upper right quadrant of the chart.

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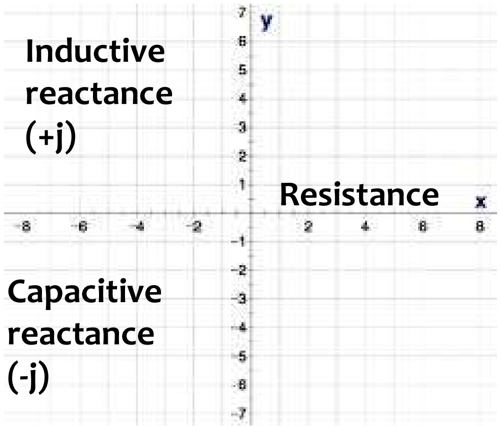
Chapter 4 – Electrical Principles

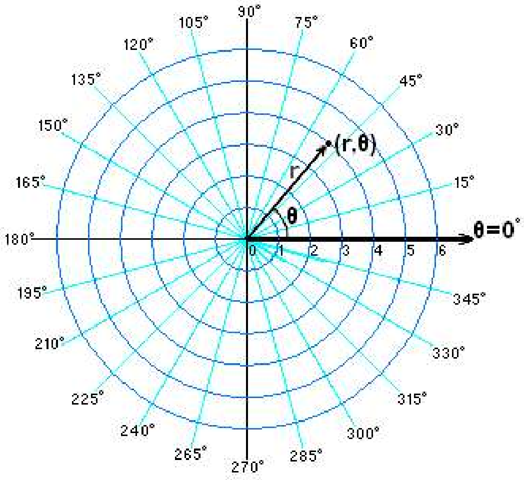
Math can be easy

- Rectangular and Polar Coordinates
  - There are 2 ways to write and impedance.
  - It can be 300 + j400 or 500 @ 53.13 degrees.
  - Some math functions are easier with one of these formats so we will convert between them.

Rectangular coordinates



Polar coordinates



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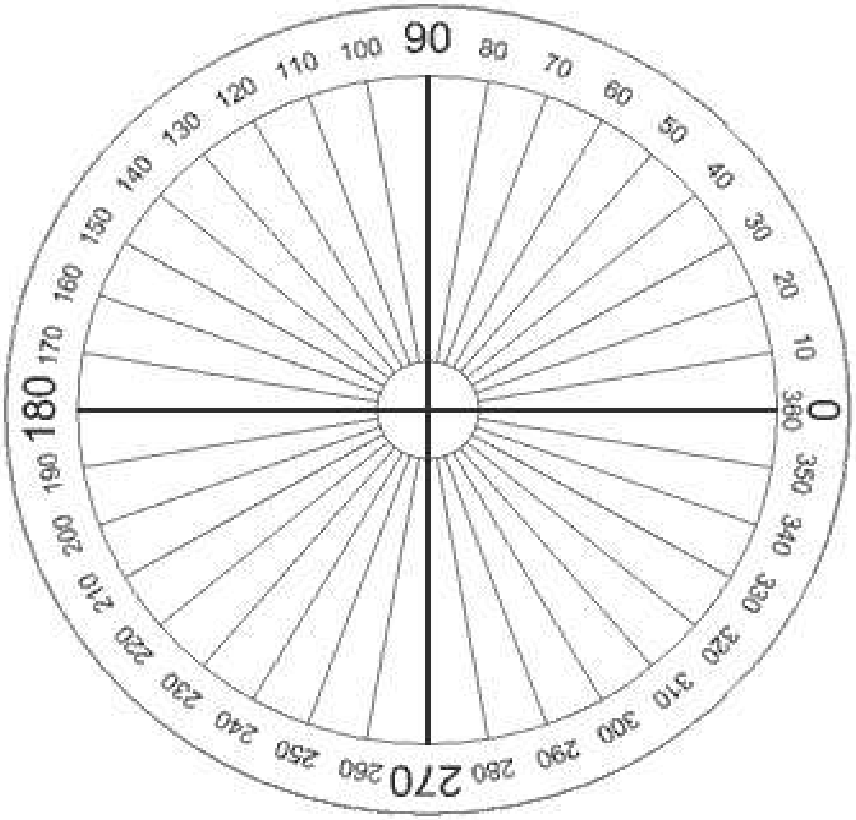
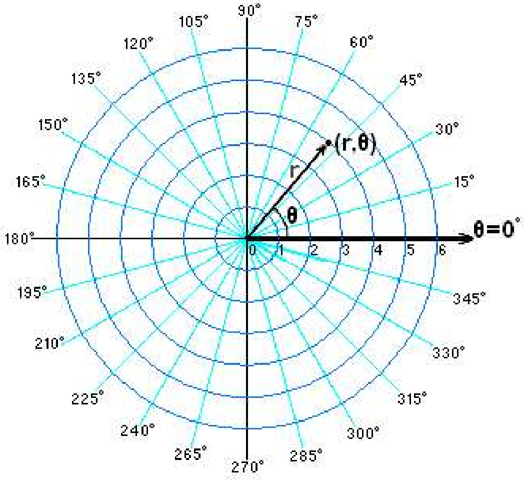
Math can be easy

- Polar Coordinates – around the circle (360 degrees).
  - -90 degrees is the same as +270 degrees.



Polar coordinates



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Chapter 4 – Electrical Principles

- **Chapter 4 sections**
  - 4.1 - Radio Mathematics
    - Rectangular and Polar Coordinates
    - Complex Coordinates
  - 4.2 – Electrical Principles
    - Electromagnetic Fields and Waves
  - 4.3 Principles of Circuits
    - RC and RL Time Constants
    - Phase Angle
    - Complex Impedance
    - Reactive Power and Power Factor
    - Resonant Circuits
    - Q of Components and Circuits
    - Components at RF and Microwave Frequencies
    - Magnetic Cores

Amateur Radio Extra Class
Chapter 4 – Electrical Principles

4.1 – Radio Mathematics

The "imaginary unit" or "unit imaginary number" is denoted as *j*. It is a mathematical concept which extends the real number system (1,2,3…) into the complex number system (300 + *j*400). The imaginary unit's core property is that $j^2 = -1$ so $j = \sqrt{-1}$. The term imaginary is used because there is no real number that has a negative square root.

E5C11…(p4-2) What do the two numbers represent that are used to define a point on a graph using rectangular coordinates?

A. The magnitude and phase of the point
B. B. The sine and cosine values
C. The coordinate values along the horizontal and vertical axes
D. The tangent and cotangent values

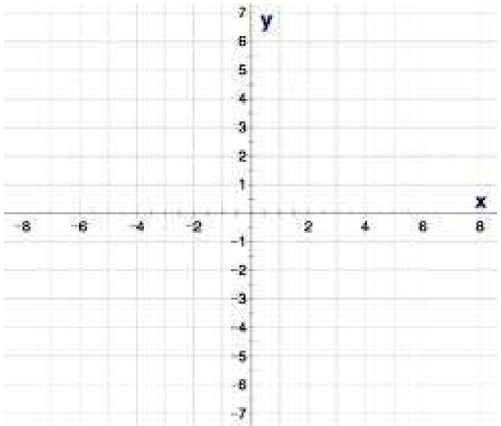
Examples:

Point 1 = (300, -400) or 300 – j400 ohms

Point 2 = (400, 300) or 400 + j300 ohms

Point 6 = (400, 0) or 400 + j0 or just 400 ohms

Rectangular coordinates



Working with Polar and Rectangular Coordinates

- Adding $(a + jb) + (c + jd) = (a + c) + j(b + d)$
- Multiplying $a \angle \text{Ø}_1 * b \angle \text{Ø}_2 = (a * b)(\text{Ø}_1 + \text{Ø}_2)$
- Dividing $a \angle \text{Ø}_1 / b \angle \text{Ø}_2 = (\frac{a}{b}) \angle (\text{Ø}_1 - \text{Ø}_2)$
- Rectangular to Polar form
  - $R = \surd(a^2 + b^2)$ -> this is the hypotenuse of the triangle
  - $\text{Ø} = \tan^{-1}(\frac{b}{a})$ -> this is the angle
- Polar to Rectangular form
  - $A = r \cos \text{Ø}$ -> this is the resistive part
  - $B = r \sin \text{Ø}$ -> this is the reactive part
- Complex Coordinates (p4-2)
  - $j = \surd{-1}$ and $1/j = -1$, these are defined constants used in electronics
- Good news – only a few questions on the test use Polar Coordinates.

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Chapter 4 – Electrical Principles

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4.2 – Electrical and Magnetic Fields (p4-4)

Electrostatic and Electromagnetic Energy fields are invisible just like Gravity.
But you see their effects all the time. Here are some examples;

Northern Lights is a common name for the Aurora Borealis (*Polar Aurorae*) in the Northern Hemisphere. Similar in the Southern Hemisphere (*Aurora Australis*).
Motor spins.
Resistor or Heater gets hot when power is turned on.
Static sparks.
Hair is frizzy.
Compass points North.
Magnets attract or repel depending on the N-S alignment of their poles.

We all know about the field of Gravity.
Your body has mass, and it interacts with the Earth's gravitational field so that it attracts you. The more mass you have, the more you weigh on the scales. ☺

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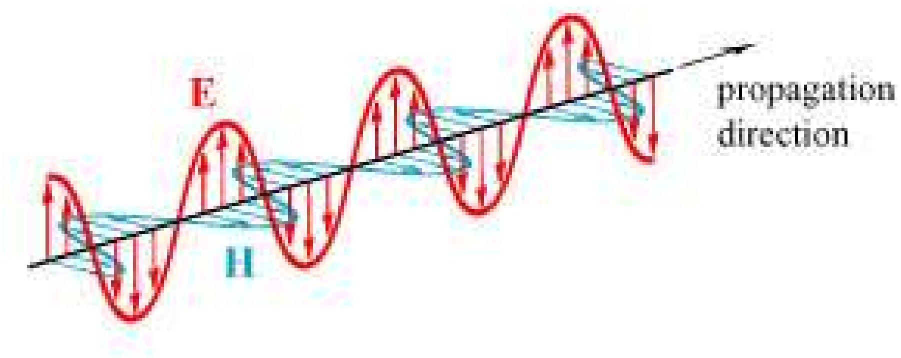
- The *E-Plane* (electric) and *H-Plane* (magnetic) components make up the electromagnetic wave and are created as a single entity.
- The E-Plane determines the *antenna polarization* (vertical or horizontal)
- The H-Plane contains the magnetic field. They are 90 degrees apart.
- The *E and H fields vary with time in a sinusoidal pattern*. The potential energy is shared between the electric and magnetic fields, just as energy is stored in electrostatic and magnetostatic fields.



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Chapter 4 – Electrical Principles

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Chapter 4 – Electrical Principles

4.3 – Principles of Circuits (p4-6)

This section of the book covers the fundamentals of how electrical circuits work.

Understanding these basic ideas will lead you to resonance, tuned circuits, Q and all sorts of great radio know-how.

How *capacitors* store energy.

How *inductors* store energy.

***Time constants* for circuits.**

We will look at inductors and capacitors with AC voltages.

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Chapter 4 – Electrical Principles

4.3 – Principles of Circuits – RC and RL Time Constants (p4-6)

This section of the book covers the fundamentals of how electrical circuits work.

Capacitors store electrons. These electrons are added to the capacitor when we put a voltage across its terminals. The capacitor builds up voltage as it accumulates electrons on one side of the cap and loses electrons on the other.

Inductors store energy in the magnetic field around the inductor as the current rises. When the current is reduced or turned off, the inductor's magnetic field will collapse and they to keep the current flowing – this is called Back *Electromagnetic Force* (EMF).

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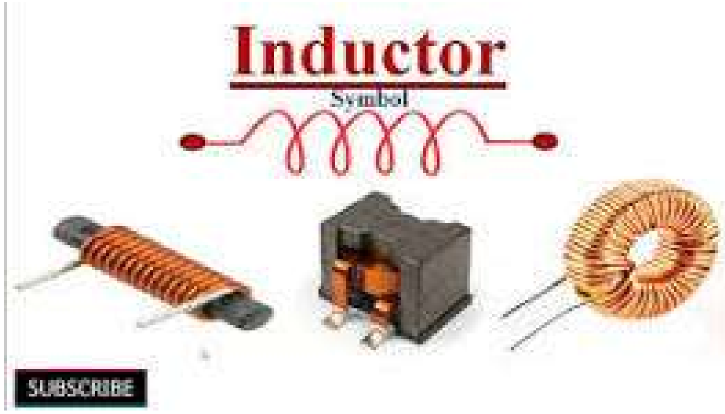
- **An *inductor* is made up of piece of wire wound around a form that can be a tube or toroid. If wound on a ferrite type material, then the magnetic properties will be enhanced. When a current is run through the inductor, *energy is stored in the magnetic field* developed around the coil of wire. Think of a balloon and its expansion with air added.**

- **A *capacitor* is made up of parallel plates separated by a dielectric (non-conductor). When a voltage is placed across a capacitor, *energy is stored in the electrostatic field* developed between the capacitor plates. Think of a water tank being filled higher and higher.**



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Chapter 4 – Electrical Principles

In DC circuits, when we apply a voltage across a capacitor, we expect to measure the same voltage as the attached supply. Right?

But have we thought about how long it takes for the capacitor voltage to get to the same value as the supply voltage? The amount of time that it takes for this to happen is called a *Time Constant*.

If you are very careful around high voltage supplies, then you already know about Time Constants and that the capacitors in a high voltage power supply can stay charged after power is turned off.

Ask an OM about the days when they tinkered inside a TV or HF power amplifier that was filled with glowing tubes. They will tell you *"to use only <u>one</u> hand and don't lean on a grounded workbench"* and "NO ring" on your finger. Discharge the power supply capacitors before putting your hand in the case!

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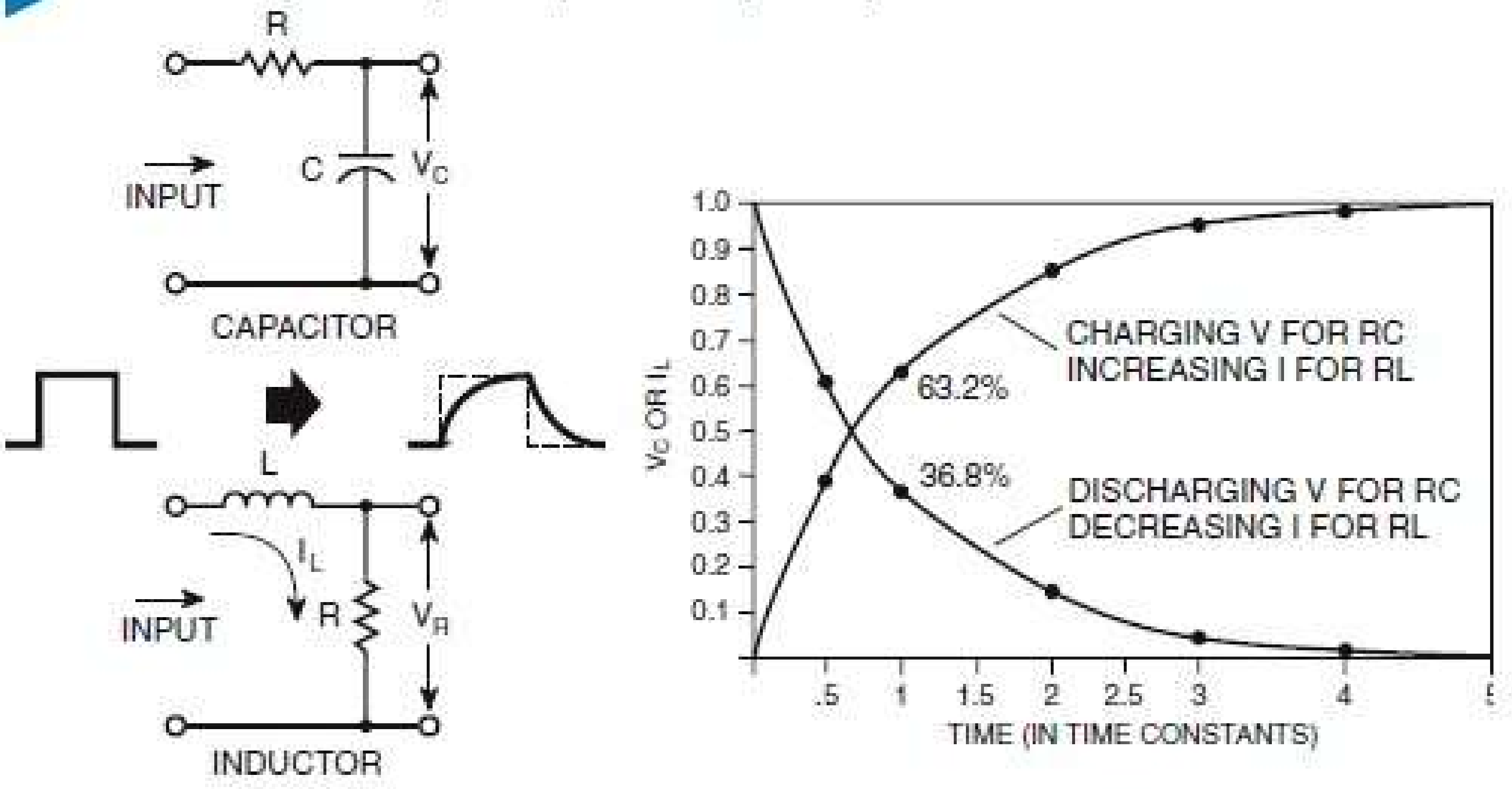

RC (R × C) and RL (L ÷ R) Time Constant

a. Schematics

b. Curves

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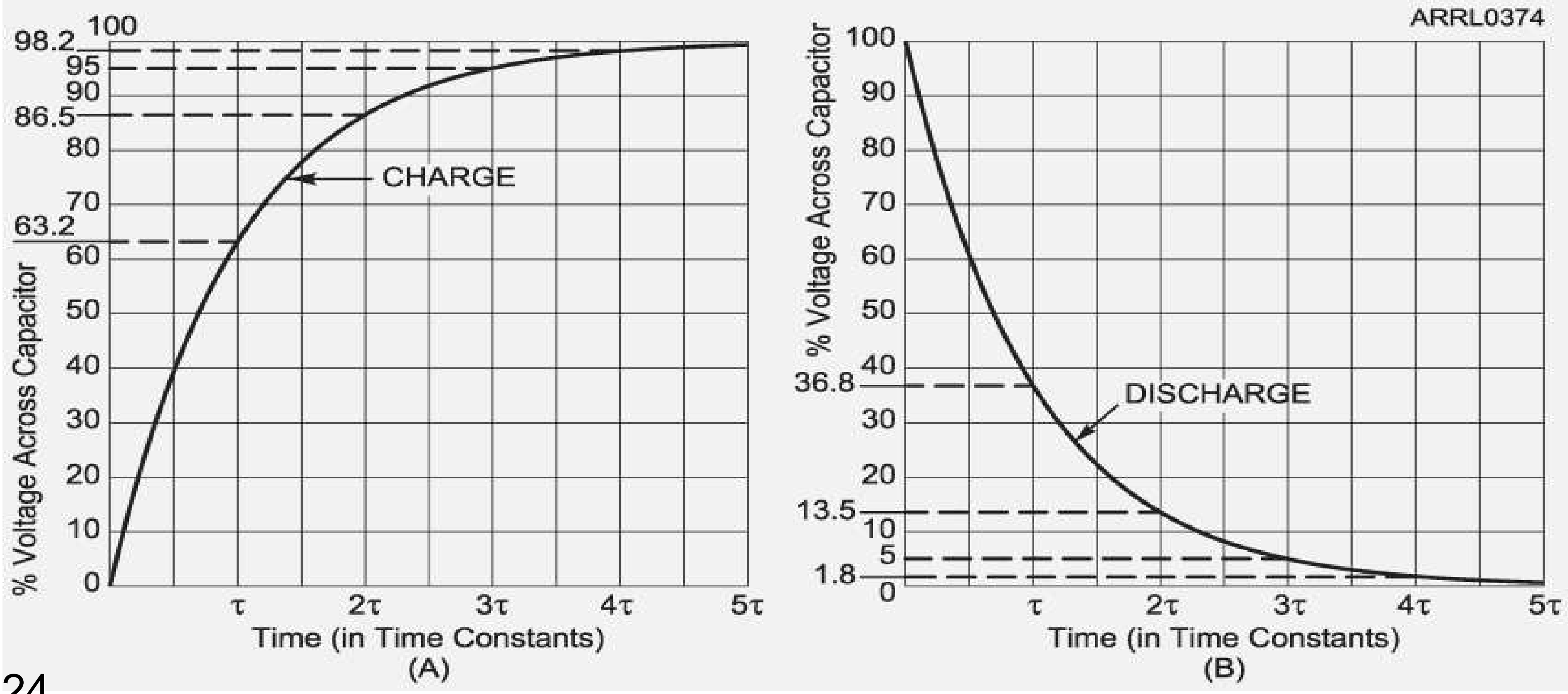
- **‘Time Constant’ Graphs for Charge and Discharge of Voltage or Current.**



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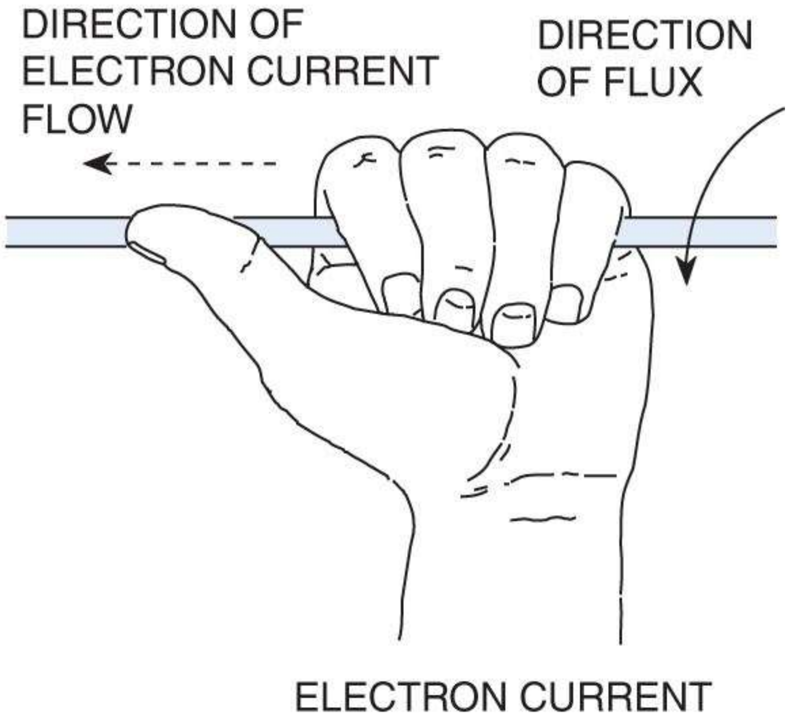
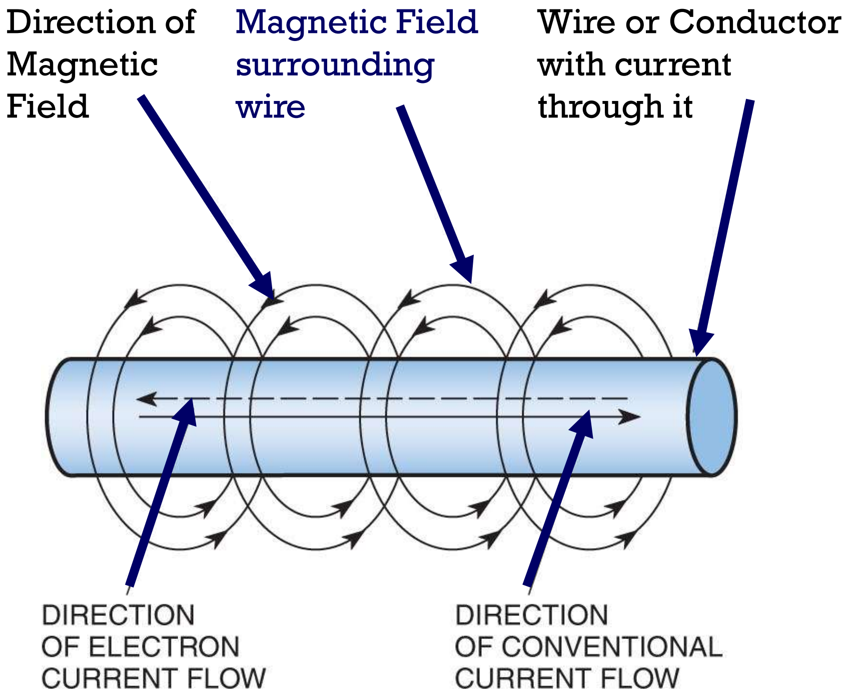
Conventional vs. Electron Current Flow





Left-Hand Rule **– applies to** ***Electron current flow (- to +)***

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Chapter 4 – Electrical Principles

- **E5B01…(p4-6) 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

- The ***term*** is ***Time Constant***. It is a calculation ($\tau = R*C$) of the capacitor value (Farads) and the resistor in series (Ohms) and the answer is in Seconds.
- Each ***time constant*** will change the voltage value up or down by 63.2% from the current value to the new value.
- See Figure 4.10 on page 4-8.

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Chapter 4 – Electrical Principles

- E5B04…(p4-6) **What is the time constant of a circuit having two 220 microfarad capacitors and two 1 Meg ohm resistors, all in parallel?**

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

- R = (R1 * R2) / (R1 + R2)
- R = (1 MΩ * 1MΩ) / (1MΩ + 1MΩ) = 500 KΩ
- C = C1 + C2
- C = 220 uF + 220 uF = 440 uF
- Ƭ=R*C = 500 KΩ * 440 uF = 220 seconds
- Ω is the symbol for Ohms

RC Time Constant Calculations (p4-9)

$V(t) = E(1 - e^{-t/T})$ for *charging* capacitors

where:

V(t) is the voltage across the capacitor at time ***t.***
E is the applied voltage to the circuit.
t is the time in seconds since the capacitor began charging/discharging.
e is the base for natural logarithms, 2.718.
T is the time constant for the circuit in seconds. ***(pronounced tau)***

T = R * C

T is the Greek letter tau, used to represent the time constant.
R is the total circuit resistance in Ohms. (KΩ, MΩ - need power of 10 adjustment)
C is the capacitance in Farads. (uF, nF, pF - need power of 10 adjustment)

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- **RC Time Constant Calculations (p4-9)**

$V(t) = E(e^{-t/T})$ for *discharging* capacitors

where:

V(t) is the voltage across the capacitor at time ***t***.
E is the applied voltage to the circuit.
t is the time in seconds since the capacitor began charging/discharging.
e is the base for natural logarithms, 2.718.
T is the time constant for the circuit in seconds.

$T = R * C$

T is the Greek letter tau, used to represent the time constant.
R is the total circuit resistance in Ohms. (KΩ, MΩ - need power of 10 adjustment)
C is the capacitance in Farads. (uF, nF, pF - need power of 10 adjustment)

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Chapter 4 – Electrical Principles

- E5B01…(p4-6) **What is the term for the time required for the capacitor in an RC circuit to be charged to 63.2% of the supply voltage?**

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

- In an RC circuit, assuming there is no initial charge on the capacitor, *it takes* ***one time constant to charge a capacitor to 63.2 percent of its final supply voltage*** value.

Time Constants	Charge % of applied voltage	Discharge % 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%

RL Time Constant Calculations (p4-12)

$I(t) = E/R * (1 - e^{-t/T})$ for *current* in inductors

where:

$I(t)$ is the current in amperes at time t.
E is the applied voltage to the circuit.
R is the circuit resistance in ohms.
t is the time in seconds since the capacitor began charging/discharging.
e is the base for natural logarithms, 2.718.
T is the time constant for the circuit in seconds.

$T = L / R$

T is the Greek letter tau, used to represent the time constant.
R is the total circuit resistance in Ohms. (KΩ, MΩ - need power of 10 adjustment)
L is the inductance in Henrys. (mH, uH, nH - need power of 10 adjustment)

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Chapter 4 – Electrical Principles

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Phase Angle – what is happening to the energy? (p4-12~15)

The voltage is constantly changing in an AC waveform. The voltage and current will not change instantaneously in an inductor or capacitor, so there will be a difference in the voltage and current with respect to time.

The ***inductor*** stores energy in the ***electromagnetic field*** so it wants to keep the current flow constant. This external field is where the inductor stores energy. When circuit current decreases, the electromagnetic field collapses because it is wants to keep a <u>constant current flow </u>in the circuit. *Think of a balloon, it gets physically bigger when you blow air into it and smaller when you let it go.*

The ***capacitor*** stores energy in the ***electrostatic field*** so it wants to keep the voltage constant. It builds up electrons on the internal plates/layers of the capacitor to store energy. The <u>capacitor gives back those electrons </u>when the circuit voltage decreases relative to the capacitor voltage. *Think of that water tank, the level of the water changes if you stop filling the tank and then the output will stop flowing a little while later. The output flow didn't stop flowing immediately after you shut off the water.*

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Chapter 4 – Electrical Principles
Additional Information

Phase Angle – who is leading and following? (p4-14~18)

There is a phase relationship between voltage and current in an AC circuit. One is leading the other by 90° when you have an inductor or capacitor. Look at the parts of the waveform that have the same slope (up or down).

“*ELI*” the “*ICE*” Man can tell you which one leads the other.

“*ELI*” for Inductors means, Voltage (E) leads Current (I)
“*ICE*” for Capacitors means Current (I) leads Voltage (E)

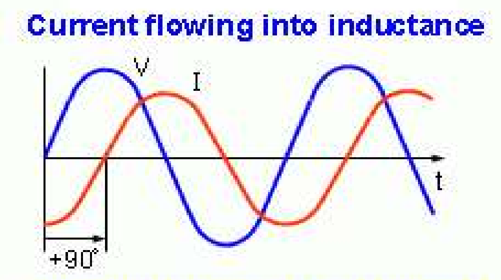

Figure 4-17 (p4-14)
Electromagnetic field – external to the inductor.
(E – L – I)

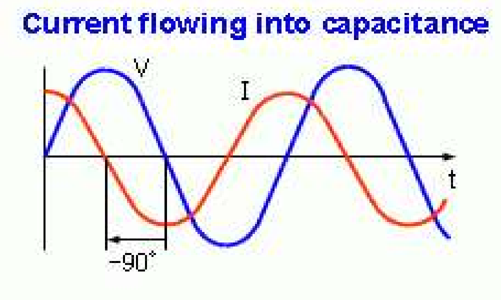

Figure 4-14 (p4-13)
Electrostatic field – inside the capacitor.
(I – C – E)

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- **E5B09…(p4-12) What is the relationship between the current through a capacitor and the voltage across a capacitor?**
- A ***capacitor is an "ICE" circuit where current (I) leads the voltage (E)***, as you see in "ICE" where the letter "I" is leading the letter "E."
- **E5B10…(p4-15) What is the relationship between the current through an inductor and the voltage across an inductor?**
- This is an ***"ELI" condition where voltage (E) leads the current (I)*** as we see in "ELI" where the letter "E" is ahead of the letter "I."

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Phase Angle – Combining Reactance and Resistance (p4-12~15)

Reactance is defined as the opposition to AC current flow through an inductance or capacitance.

Inductive reactance (X_L) increases with frequency

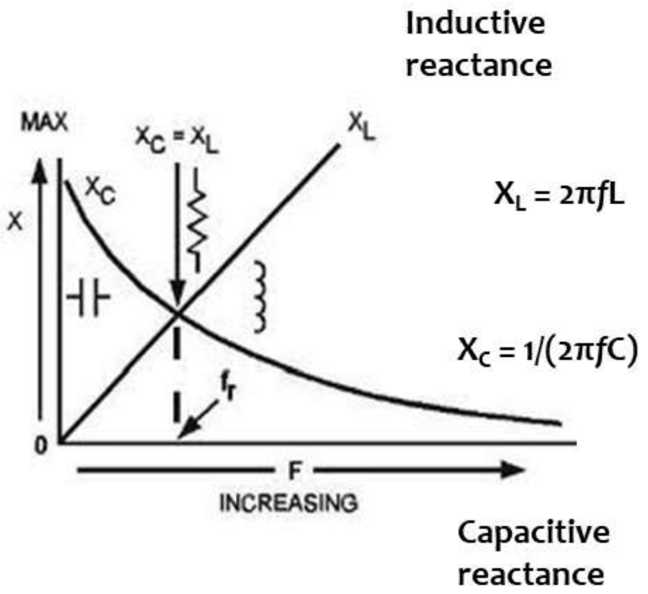
$$X_L = 2\pi f L$$

X_L is the reactance in ohms
π is pi = 3.14159 (or pi on your calculator)
f is the frequency in hertz
L is the inductance in henrys

Capacitive reactance (X_C) decreases with frequency

$$X_C = 1 / (2\pi f C)$$

X_C is the reactance in ohms
π is pi = 3.14159 (or pi on your calculator)
f is the frequency in hertz
C is the capacitance in farads



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- 4.3 Principles of Circuits
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Amateur Radio Extra Class
Chapter 4 – Electrical Principles

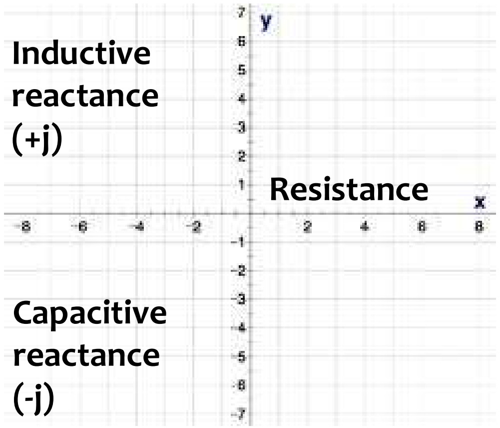
4.3 – Principles of Circuits– Complex Impedance (p4-16~18)

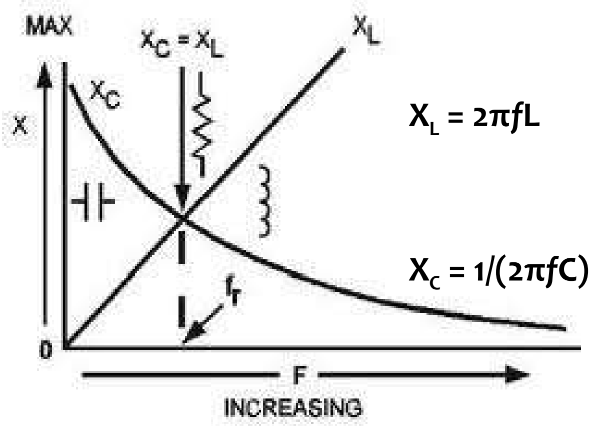
Impedance values can be written in rectangular form as Z = R + *j*X. The value for jX will be positive for inductance and negative for capacitance. For example, 50 – j25 consists of 50 ohms of resistance and 25 ohms of capacitive reactance.

The same impedance can be written in polar form as |Z|∠θ, where Z is the magnitude of the impedance and θ is its phase angle. 55.9∠-26.56 degrees.

Note – Complex Impedance is frequency dependent, ***f is part of the X reactance.***

Rectangular coordinates

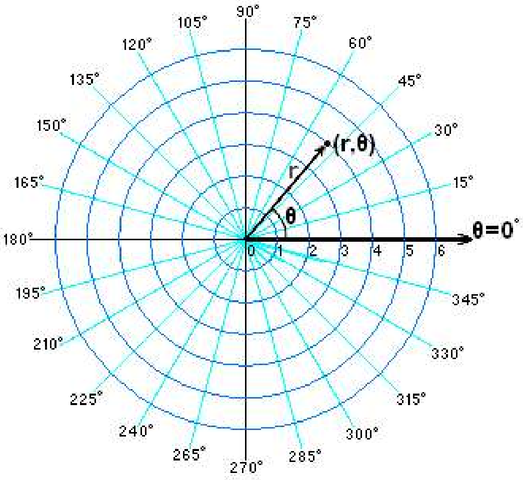




$X_L = 2\pi fL$

$X_C = 1/(2\pi fC)$

Polar coordinates



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Chapter 4 – Electrical Principles

Complex Impedance – Admittance and Susceptance (p4-19)

Impedance values can be written in rectangular form as $Z = R + jX$.

The reciprocal of impedance (Z) is ***Admittance (Y). Y = 1 / Z***

Admittance in rectangular form is Y = G + jB

- Y represents Admittance – inverse of Impedance (resistance and reactance)
- G represents Conductance – inverse of Resistance
- B represents Susceptance – inverse of Reactance

Conductance (G) is the real part and ***Susceptance (B)*** is the imaginary part.

Like impedance, admittance can be written in either rectangular or polar form.
$Y = G + jB$ or $|Y|\angle\theta$.

The reciprocal of the polar form changes the sign of the angle +/-.

When combining parallel elements, the math is easier in this form ($Y = G + jB$) vs Impedance ($Z = R + jX$).

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Chapter 4 – Electrical Principles

Complex Impedance – Calculating Impedance and Phase Angles (p4-20)

Rule 1: Impedances, resistances and reactances in series add together.
Rule 2: Admittance is the reciprocal of impedance. (Y = 1/Z) and (Z = 1/Y)
Rule 3: Admittances, conductances and suscepatances in parallel add together.
Rule 4: Inductive and capacitive reactance in series cancel. So $j5 + -j5 = 0$.
Rule 5: $1/j = -j$

There are number of examples in this section of the ARRL book. FYI, this is high level math. You may not find many times that you need to compute these kinds of values. There are not many questions on the exam from this section, so don’t lose your mind about whether you completely understand these equations. ☺

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Chapter 4 – Electrical Principles

- E5C01…(p4-16) **Which of the following represents a capacitive reactance of 100 ohms in rectangular notation?**

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

- The reactive phase angle for a capacitor will be ***negative*** so the correct answer is ***A***.

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Chapter 4 – Electrical Principles

- **E5B12…(p4-19) 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

- So, this is ***Admittance = 1 / Impedance or Y = 1 / Z.***

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Chapter 4 – Electrical Principles

- **E5B06…(p4-19) 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

- So, this is ***Susceptance = 1 / Reactance or B = 1 / X***.

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Chapter 4 – Electrical Principles

- E5C06…(p4-16) **What does the impedance 50 - j25 represent?**
  A. 50 ohms in series with 25 ohms inductive reactance
  B. 50 ohms 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

- Key point is **"-j"** which means that it must be ***capacitive reactance***. We know right off the bat that the ***answer is going to be either B or D because a capacitive*** reactance will have a negative rectangular coordinate. ***"50"*** tells us that it is 50 ohms of real resistance, so the answer must be ***B*****.**

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Chapter 4 – Electrical Principles

- **E5C03…(p4-16) 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

- Remember inductors have a positive reactance and capacitors have a negative reactance value. So, it must be a ***positive phase*** angle.

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Chapter 4 – Electrical Principles

- **E5B05…(p4-19) What is the effect on the magnitude of pure reactance when it is converted to a susceptance?**
  A. It is unchanged
  B. The sign is reversed
  C. It is shifted by 90 degrees
  D. It is replaced by its reciprocal

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Chapter 4 – Electrical Principles

- **E5C8…(p4-16) What coordinate system is often used to display the phase angle of a circuit containing resistive, inductive, and/or capacitive reactance components of an impedance?**
- The ***polar coordinate system*** can be plotted using ***rectangular coordinates***. The polar coordinate system is the hypotenuse of the triangle with the angle. Example, right triangle with the sides equal to 1. For this triangle, the angle is 45 degrees, and the hypotenuse is the square root of 2.
- **E5C09…(p4-16) When using rectangular coordinates to graph the impedance of a circuit, what does the horizontal axis represent?**
- The X (horizontal) axis represents the resistive component of the impedance. The Y (vertical) axis represents the reactive component. The ***resistance is plotted on the horizontal axis***.

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Chapter 4 – Electrical Principles

- E5C08…(p4-16) **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

- To display the impedance of a circuit with its phase angle, you would use a polar coordinate system. ***Polar coordinates provides a visual representation of the value of the impedance and its phase angle*.**

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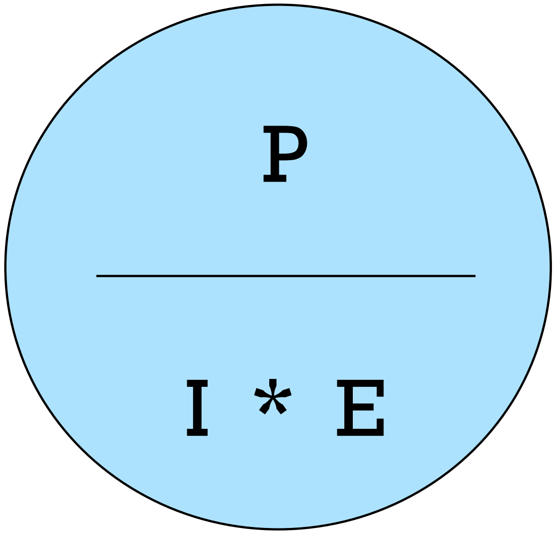
Chapter 4 – Electrical Principles

4.3 – Principles of Circuits – Reactive Power and Power Factor (p4-24)

Power is rate of doing work or using energy per unit of time.

In this section we will find out what Reactive Power is and how it does NO work for us.

We will also learn about Power Factor, how to calculate it and how to improve it in our systems.



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Chapter 4 – Electrical Principles

Reactive power does NO work. Motors have resistance and inductance.

Reactive Power indicates ***non-productive power*** produced in circuits containing inductors and capacitors. Since out-of-phase power in inductors will tend to cancel out-of-phase power in capacitors, reactive power is ***wattless***. It is not converted to heat or dissipated. It is energy being stored temporarily in a field and then returned to the circuit. ***It circulates back and forth in a coil's magnetic field and/or a capacitor's electrostatic field.***

No real circuit can be only reactive, there is always some resistance. But reactance in a circuit will reduce that amount of ***work done*** versus the amount of ***power input*** to the circuit. ***Power Factor*** is the ratio of ***true power / apparent power.***

Amateur Radio Extra Class
Chapter 4 – Electrical Principles

Complex Impedance – Reactive Power and Power Factor (p4-24~27)

Power is rate of doing work or using energy per unit of time. Only the resistive part of the circuit consumes and dissipates power as heat.

Apparent power expressed in units of volt-amperes (VA) rather than watts. Apparent power in an inductor or capacitor is called reactive power or nonproductive, wattless power. The difference between ***apparent power*** and ***real power*** is called the ***power factor***. The power factor for a resistor is very close to 1.

$PF = P_{REAL} / P_{APPARENT}$

Motors are the reason that the power factor for power company lines are less than 1. Large capacitor banks are switched onto the power lines to make the power factor closer to 1, which makes the power lines more efficient.

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Chapter 4 – Electrical Principles

- **E5D09…(p4-24) What happens to reactive power in ideal inductors and ideal 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

- In a circuit that has both capacitors and inductors, the ***reactive power*** oscillates back and forth between magnetic and electric fields and ***does not get dissipated***.

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Chapter 4 – Electrical Principles

- **E5D12…(p4-25) What is reactive power?**

  A. Power consumed in the circuit
  B. Power consumed by the inductor’s wire resistance
  C. Power consumed in inductors and capacitors
  D. Wattless, nonproductive power

- The letters AC are found in the word ***reactive*** (meaning out-of-phase). It indicates ***non-productive power*** produced in circuits containing inductors and capacitors. Since out-of-phase power in inductors will tend to cancel out-of-phase power in capacitors, reactive power is ***wattless***. It is not converted to heat and dissipated. It is energy being stored temporarily in a field and then returned to the circuit. It circulates back and forth in a coil’s magnetic field and/or a capacitor’s electrostatic field.

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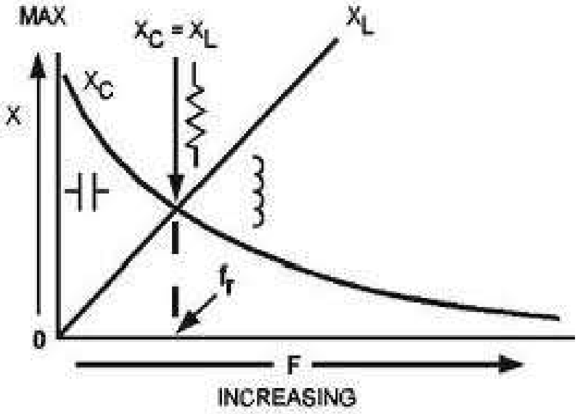
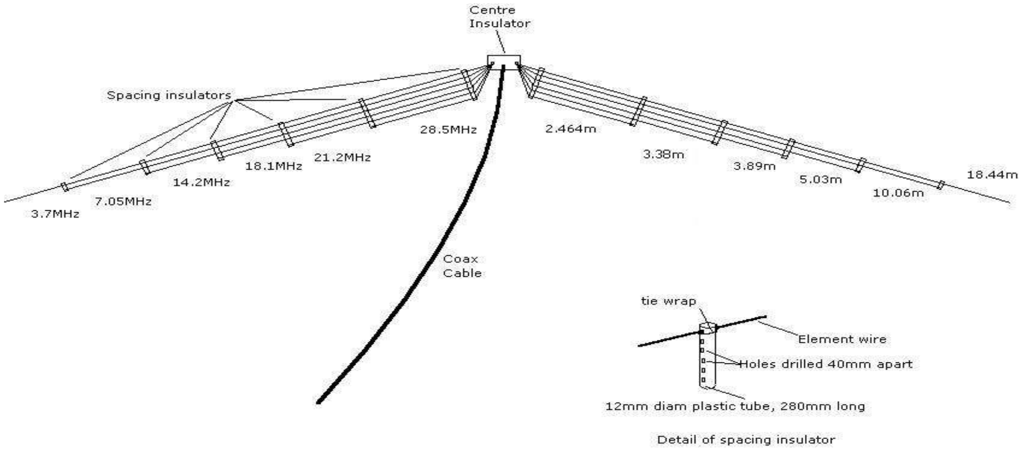
4.3 – Principles of Circuits – Resonant Circuits (p4-27)

Resonant circuits are used in a lot of places in radio.

Resonance happens when the inductive and capacitive reactances are equal. See Figure 4-24.

One example is your antenna. If you have a dipole antenna, then you will cut the length of the wire for a specific frequency. If your wire is too long, then it will be resonant at a lower frequency than desired. It would also show inductive reactance at the desired higher frequency.





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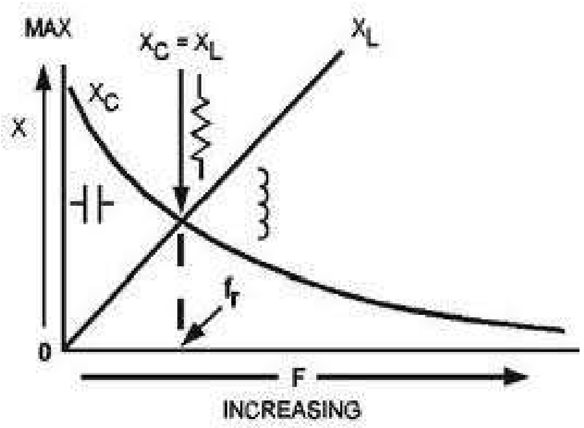
Chapter 4 – Electrical Principles

E5A03…(p4-27) What is the resonance 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



$X_L = 2\pi fL$ and $X_C = 1 / (2\pi fC)$

So $f_r = 1 / (2\pi\sqrt{LC})$
$f_r = 1 / [6.28 * \sqrt{(50\ \text{uH} * 40\ \text{pf})}\ ]$

L in Henries –> $50 * 10^{-6}$
C in Farads → $40 * 10^{-12}$
$\sqrt{(50\ \text{uH} * 40\ \text{pf})} = \sqrt{2000 * 10^{-18}} = 44.72 * 10^{-9}$

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Figure 4-25 (p4-29) Shows a ***series resonant circuit***.

Notice that the ***current is at a maximum*** at resonance for a series RLC circuit. The Signal Generator produces an AC voltage with varying frequency.

The circuit resistance will be close to the value of R only because the ***inductor and capacitor impedances cancel out***. Remember the Rectangular Coordinate chart (+j and –j) and we plotted the addition of the reactances, so ***at resonance we only have the resistance*** remaining and it is on the horizontal X axis.

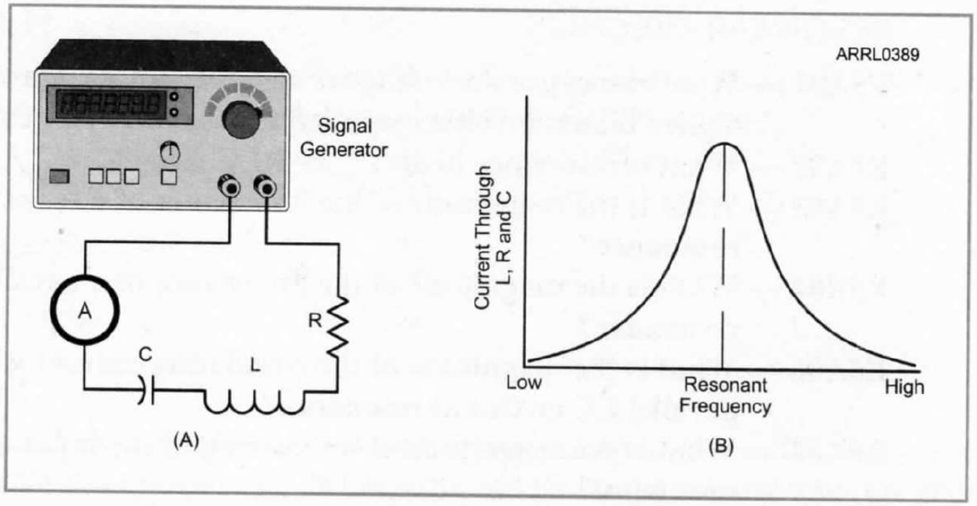

Figure 4.25 — A series-connected LC or RLC circuit presents a minimum value of resistance at the resonant frequency. Therefore, at resonance, the current passing through the circuits reaches a maximum.

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Chapter 4 – Electrical Principles

Figure 4-26 (p4-31) Shows a *parallel resonant circuit* or sometimes know as a *"tank circuit"*.

Notice that the ***current is at a minimum*** at resonance in a parallel resonant circuit.

The circuit resistance will be close to the value of R only because the ***inductor and capacitor impedances are at a maximum absolute value*** (large +j and large –j) so ***they act as if they are not a part of the circuit*** when compared to the resistance value in the resistor.

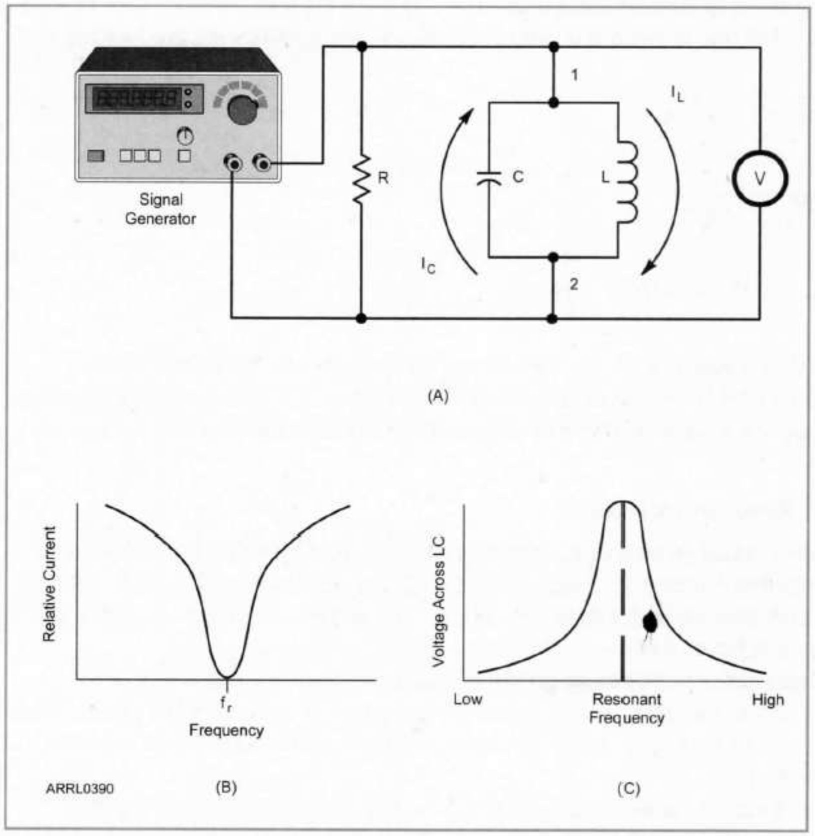

Figure 4.26 — A parallel-connected LC or RLC circuit presents a very high resistance at the resonant frequency. Therefore, at resonance, the voltage across the circuit reaches a maximum.

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Chapter 4 – Electrical Principles

- E5A10…(p4-29) **What is the resonant frequency of an RLC circuit if R is 33 ohms, L is 50 microhenrys and C is 10 picofarads?**

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

- **$f_r = 1 / (2\pi\sqrt{LC})$**
- First multiply microhenrys and picofarads, take their square root, multiply by 6.28, and then divide your answer into 1,000,000,000. Easy! Here are the keystrokes: Clear, 50 x 10 = √ X 6.28 = 140.4. Remember 140.4. Clear, ***1,000,000,000 ÷ 140.4 = 7,122,507 Hz which is 7.12 MHz***.

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Chapter 4 – Electrical Principles

- E5A01…(p4-30) **What can cause the voltage across reactances in 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

Coils (having inductance) and capacitors (having capacitance) will be at resonance when the capacitive reactance equals the inductive reactance.

At resonance, large voltages greater than the applied voltage can be present across these components in the circuit. You can see this with a mobile whip antenna – if something were to touch the whip in transmit, you might see quite a spark!

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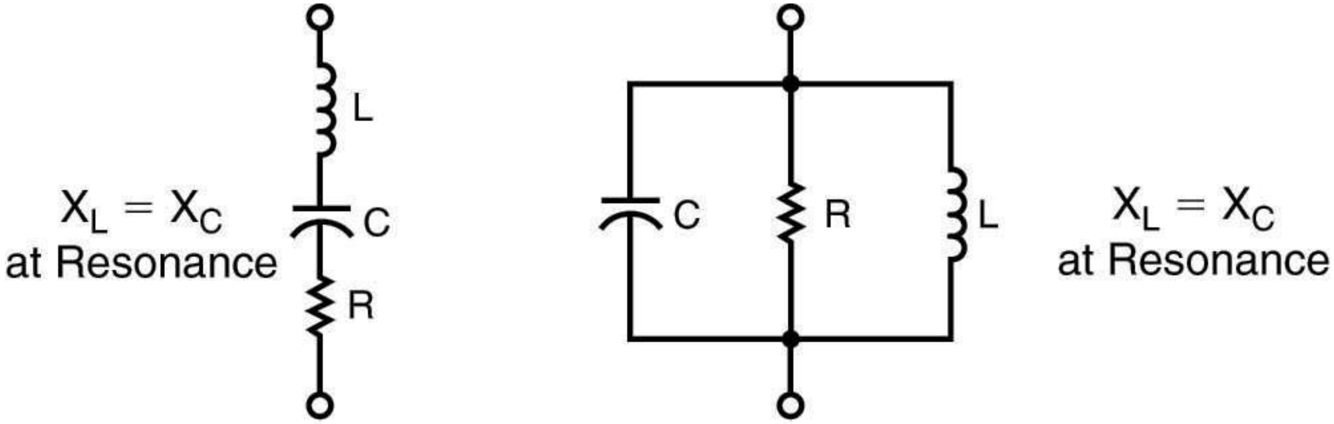
- **E5A03…(p4-30) What is the magnitude of the impedance of a series RLC circuit at resonance?**

  A. High, as compared to the circuit resistance
  B. Approximately equal to capacitive reactance
  C. Approximately equal to inductive reactance
  D. Approximately equal to circuit resistance

- ***At resonance, the magnitude of the impedance is equal to the circuit resistance***. Did you ever wonder why the serious mobile ham always uses a gigantic loading coil for his series resonant antenna? The bigger the loading coil, the less resistance.

Amateur Radio Extra Class Chapter 4 – Electrical Principles

- A mobile whip antenna will have ***maximum current*** in a series RLC circuit ***at resonance***.
- You may be able to feel that a mobile whip antenna is warm to the touch after transmitting for a period of time. The heat is generated by the current through the coil while transmitting on the radio. Make sure no one trasmits while you are touching the coil!



Series and Parallel Resonant Circuits.

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- **Parallel resonant circuits have several current paths.**

- At resonance, the ***parallel RLC*** components present a high resistance to the circuit and the ***current is at a minimum*** which is mostly going through the resistor. Figure 4-26(p4-31)

- At resonance, the ***series RLC*** comFigures 4-25(p4-29) and 4-26(p4-31)ponents preset a low resistance to the circuit and the ***current is at a maximum***. Figure 4-25(p4-29)

- Whether the system is parallel or series RLC resonant, the ***impedance will always be equal to the circuit resistance***.

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Chapter 4 – Electrical Principles

- E5A06…(p4-31) **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, multiplied by the square root of inductance L multiplied by capacitance C
  D. It equals 2 multiplied by Pi, multiplied by frequency "F", multiplied by inductance "L"

- A ***parallel circuit at resonance*** is like a tuned trap in a multi-band trap antenna. At resonance, the trap keeps power from going any further to the longer antenna elements. But be assured there is ***maximum circulating current*** within the parallel RLC circuit. Now don't get confused with this question – a parallel circuit has maximum current within it, and minimum current going on to the next stage. That's why they are called parallel resonant circuits "traps."

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- E5A08…(p4-31) **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

- When a circuit is ***at resonance, voltage and current are in phase***.
- If you remember "ELI the ICE man" it will help you visualize the relationship of voltage and current when they are NOT in resonance:

  ELI = voltage (E) leads current (I) in an inductive (L) circuit.

  ICE = current (I) leads voltage (E) in a capacitive (C) circuit.

  At ***Resonance:*** XL = XC = voltage and current in phase (neither is leading the other).

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4.3 – Principles of Circuits – Q of Components and Circuits (p4-32)

- Q (Quality Factor) is the ratio of Reactance to Resistance.

- $Q_{series} = X/R$
- $Q_{parallel} = R/X$

- There is no way to raise the Q of an inductor or capacitor except by building a component with less internal resistance
- The internal resistance of a capacitor is usually much less than an inductor, so the limiting factor on Q of resonant circuit is the inductor resistance
- Fig 4-27 shows that there is resistance in both a capacitor and inductor along with reactance

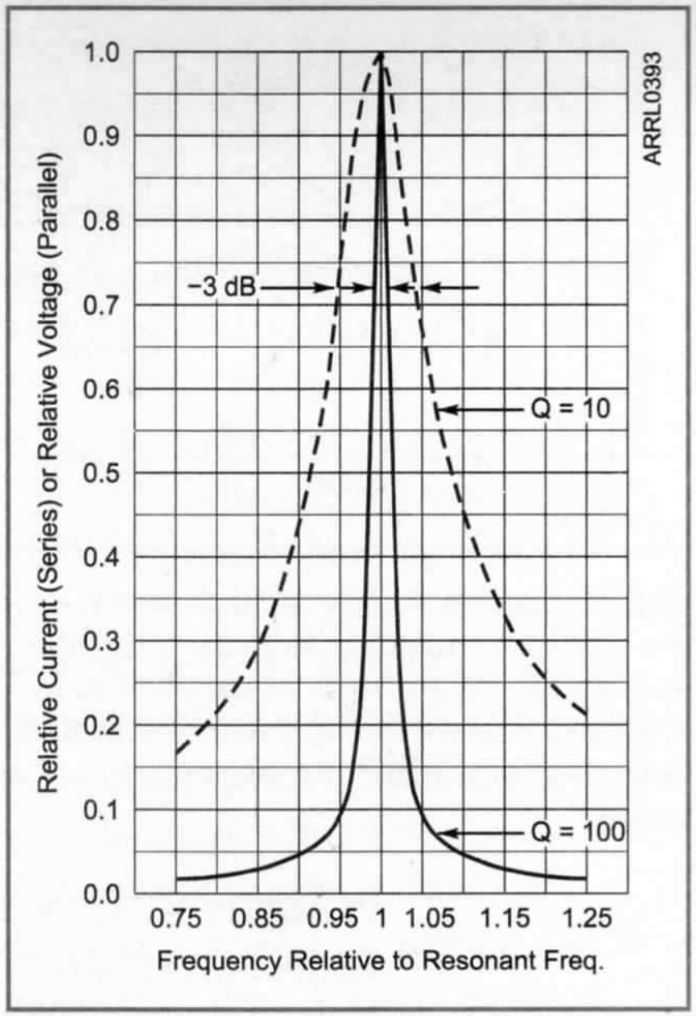

Figure 4.29 — The –3 dB bandwidth

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Chapter 4 – Electrical Principles

- E5A09…(p4-32) **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

- With a little math and knowing that the ***reactance of the inductor and capacitor are the same equal (but opposite sign)***, Q can be computed by knowing just the reactance value for one of them.

- Antennas are parallel resonant circuits, so lower conductor resistance will increase bandwidth.

- ***Q parallel = R/X***

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Chapter 4 – Electrical Principles

4.3 – Principles of Circuits – Q of Components and Circuits (p4-32~34)

- Resonant circuit bandwidth is the -3db points below the peak. Fig. 4-29, page 4-33
- The half-power points (-3db) are called f_1 and f_2.
- Higher Q means a more selective frequency response or more narrow bandwidth in both parallel and series resonant circuits.
- Bandwidth equals the resonant frequency divided by Q.
- $BW = f_r / Q$
- The frequencies for $f_1 = f_r - (0.5*BW)$; $f_2 = f_r + (0.5*BW)$

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- E5A13…(p4-32) **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

- Figure 4-29 illustrates the affect of Q. ***Higher Q means smaller Bandwidth***, but also this is more selective.

- Series Resonant circuits will have higher currents at resonance.

- Parallel Resonant circuits will have higher voltages at resonance.

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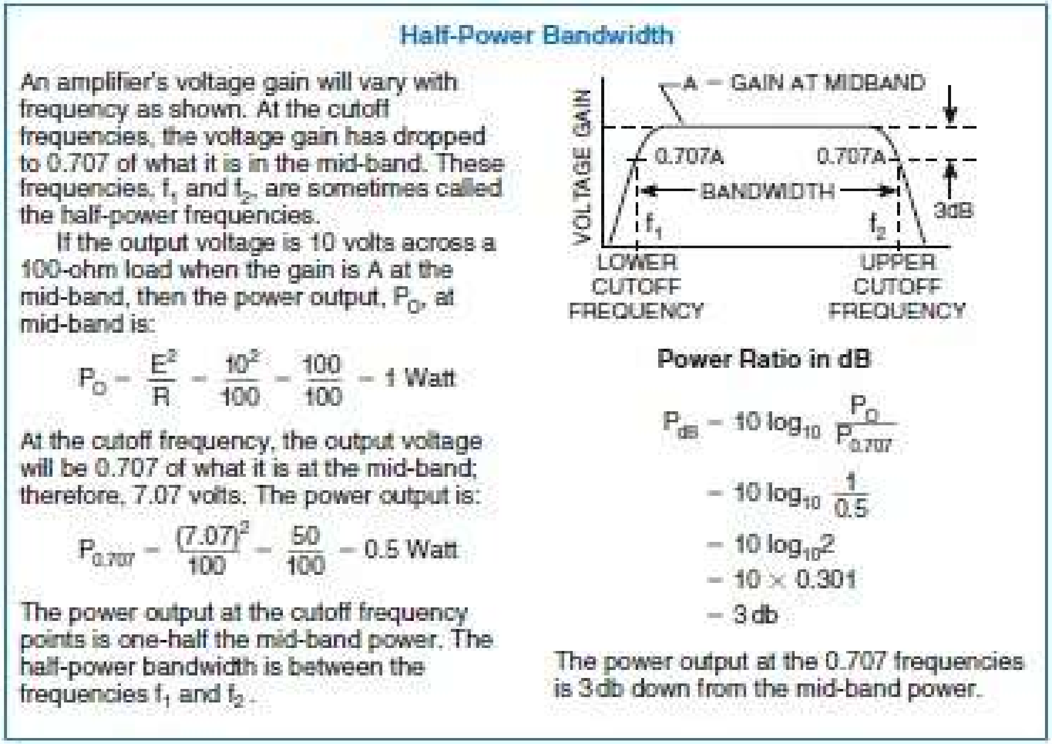
- **E5A11…(p4-34) What is the half-power bandwidth of a resonant circuit that has a resonant frequency of 7.1 MHz and a Q of 150?**

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



Half-Power Bandwidth

An amplifier's voltage gain will vary with frequency as shown. At the cutoff frequencies, the voltage gain has dropped to 0.707 of what it is in the mid-band. These frequencies, f_1 and f_2, are sometimes called the half-power frequencies.

If the output voltage is 10 volts across a 100-ohm load when the gain is A at the mid-band, then the power output, P_O, at mid-band is:

$$P_O = \frac{E^2}{R} = \frac{10^2}{100} = \frac{100}{100} = 1 \text{ Watt}$$

At the cutoff frequency, the output voltage will be 0.707 of what it is at the mid-band; therefore, 7.07 volts. The power output is:

$$P_{0.707} = \frac{(7.07)^2}{100} = \frac{50}{100} = 0.5 \text{ Watt}$$

The power output at the cutoff frequency points is one-half the mid-band power. The half-power bandwidth is between the frequencies f_1 and f_2.

Power Ratio in dB

$$\begin{aligned} P_{dB} &= 10 \log_{10} \frac{P_O}{P_{0.707}} \\ &= 10 \log_{10} \frac{1}{0.5} \\ &= 10 \log_{10} 2 \\ &= 10 \times 0.301 \\ &= 3 \text{ db} \end{aligned}$$

The power output at the 0.707 frequencies is 3 db down from the mid-band power.

- 7.1 MHz divided by 150. Remember for kHz from MHz, move three decimal places right. Clear, ***7100 ÷ 150 = 47.33 kHz***

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- **E5A12…(p4-33) What is the half-power bandwidth of a 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

- With this many half-power bandwidth questions in the pool, you can count on at least one being on your upcoming Extra Class Element 4 exam. With this question, go from MHz to kHz, and then divide it by the Q. Clear, enter ***3700 ÷ 118 = 31.36 kHz***. Round the answer to 31.4.

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Chapter 4 – Electrical Principles

- **Figure 4.31** **Stray capaciatance is present in all inductors.**

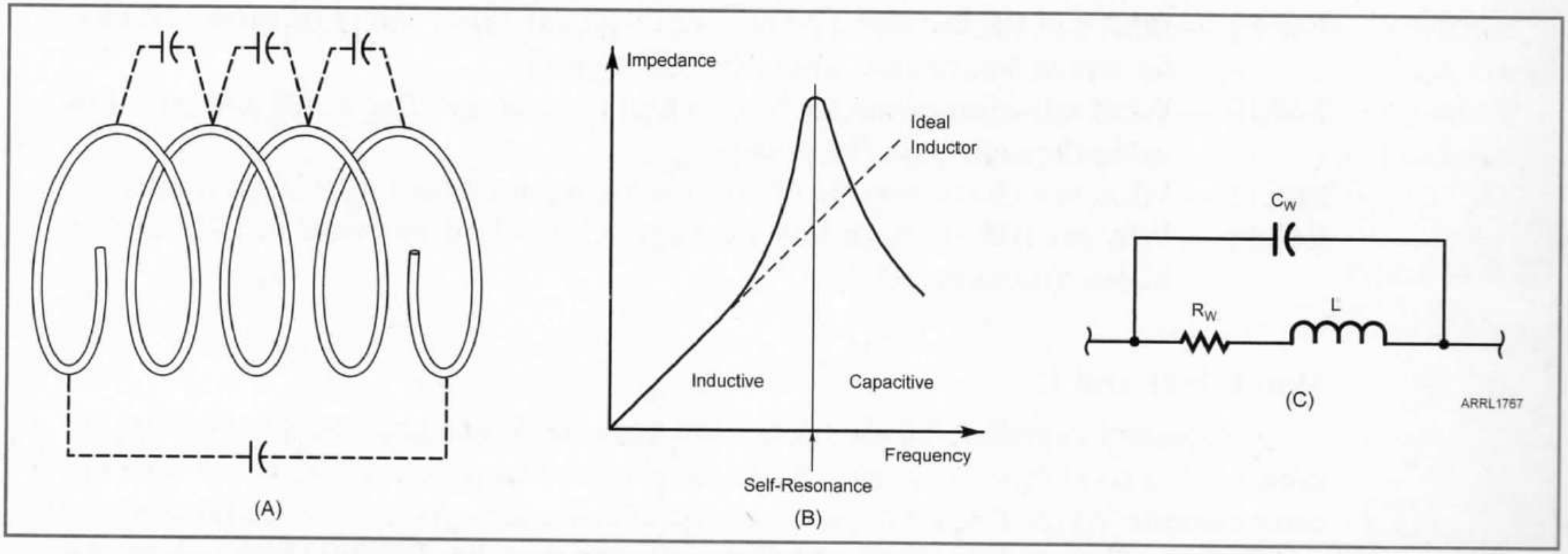

Figure 4.31 — Inductors have capacitance between their turns that acts as a capacitance in parallel with the inductance. The graph at B shows how distributed capacitance resonates with the inductance. The equivalent circuit of the inductor, including wire resistance, R_W, is shown at C.

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Chapter 4 – Electrical Principles

Chapter 4 sections

- 4.1 - Radio Mathematics
  - Rectangular and Polar Coordinates
  - Complex Coordinates
- 4.2 – Electrical Principles
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- 4.3 Principles of Circuits
  - RC and RL Time Constants
  - Phase Angle
  - Complex Impedance
  - Admittance and Susceptance
  - Reactive Power and Power Factor
  - Resonant Circuits
  - Q of Components and Circuits
  - Components at RF and Microwave Frequencies
  - Magnetic Cores

Amateur Radio Extra Class
Chapter 4 – Electrical Principles

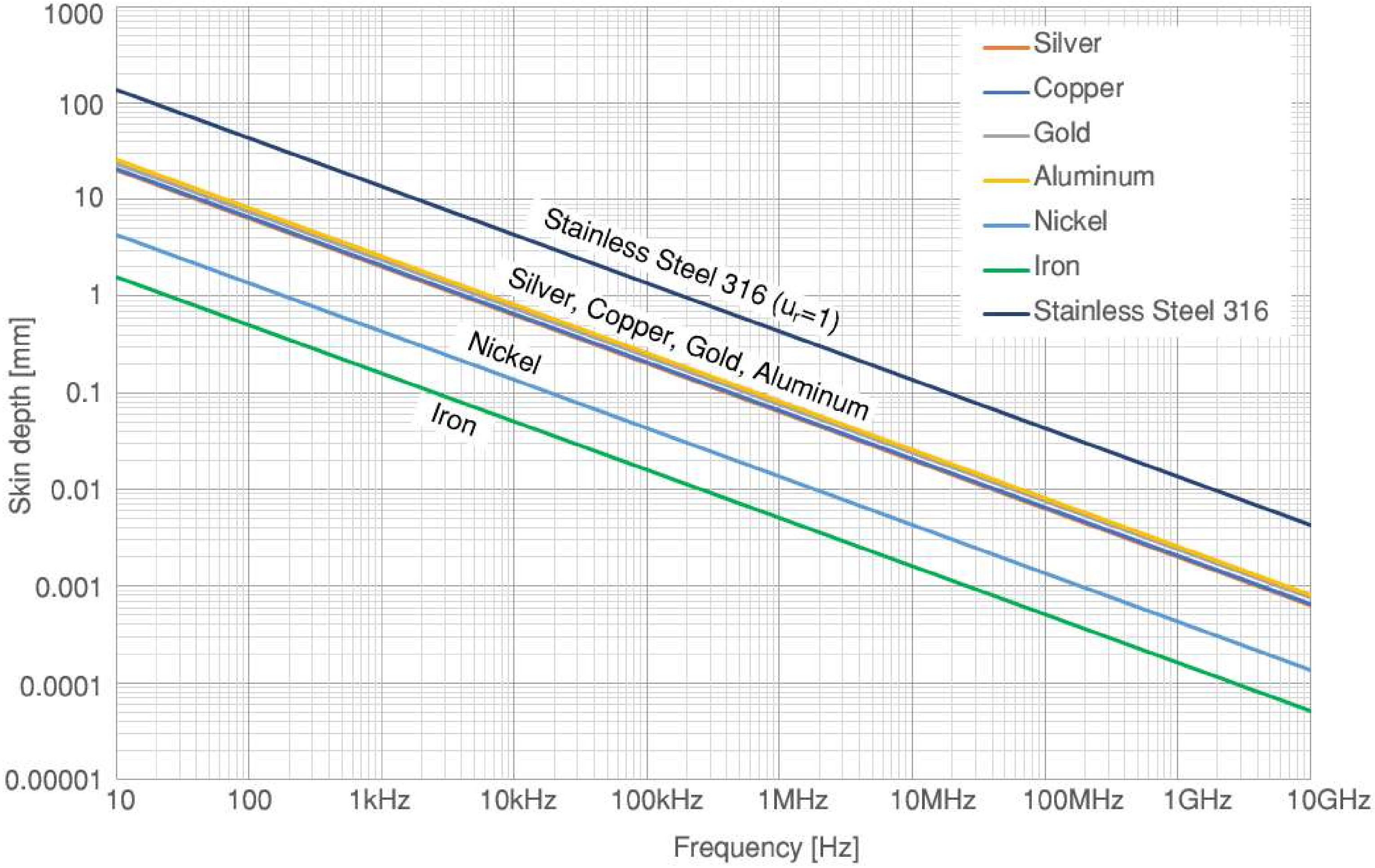
4.3 – Principles of Circuits – Components at RF and Microwave Frequencies (p4-34)

- Skin Effect and Q
- Skin Effect – as the frequency of the RF signal increases, the electric and magnetic fields of signals do not penetrate as deeply into the conductor.
- At DC, the entire cross-section of the wire is carrying current.

Amateur Radio Extra Class
Chapter 4 – Electrical Principles

4.3 – Principles of Circuits – Components at RF and Microwave Frequencies

Academy of EMC. (mm ~= 0.039”)



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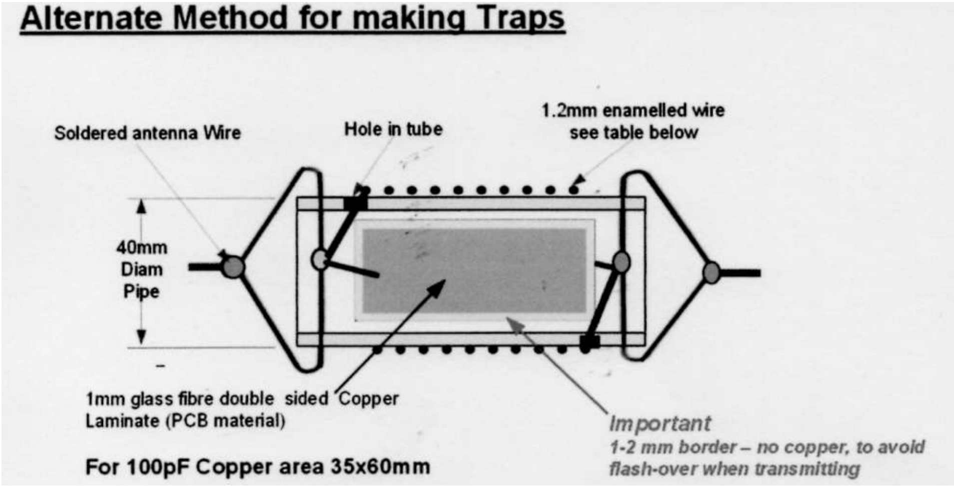
Chapter 4 – Electrical Principles

- **E56D06…(p4-34)** **What is the primary cause of inductor self-resonance?**
- Because of the ***parasitic inter-turn capacitance*** – very small capacitance between each turn of and inductor there is a self resonance frequency for the component.
- Figure 4.31B shows how the inductor reactance changes over frequency.
- Notice the ***peak reactance at self-resonance*** and the decrease in reactance above that frequency.
- Trap antennas use the inductor capacitance effect to set the resonant frequency of the trap. The number of turns on the inductor is the variable. Wire spacing will change the parasitic inter-turn capacitance.



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Chapter 4 – Electrical Principles

4.3 – Principles of Circuits – Components at RF and Microwave Frequencies (p4-34)

- Self-Resonance and Effects of Component Packaging at RF

- For inductors and capacitors, above a particular frequency that is dependent on the component design, the Q of the component will not match the expected values from the reactance equation.
- The skin effect will cause the Q to decrease as frequency increases. See Figure 4.30
- Inductors can become a self-resonant circuit. This is not a desired operation of the part. VHF and UHF frequencies are where these effects can happen.

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Chapter 4 – Electrical Principles

4.3 – Principles of Circuits – Effects of Component Packaging at RF (p4-36)

- Parasitic Inductance happens due to the leads of a component.
- The windings in an inductor will have a small amount of capacitance between each winding. As the frequency increase this capacitance will change the impedance of the part in a non-linear fashion. See Figure 4.31B
- Some IC packages use thin wires to bond a connection between the silicon and the lead frame of the package. These wire-bonds will have a small amount of inductance and at high frequencies this will affect the operation of the part in the circuit.
- IC manufacturers have moved away from DIP packages for most components except very high-power devices and connectors. Today, most of the ICs used in circuits with be in surface mount style packages.

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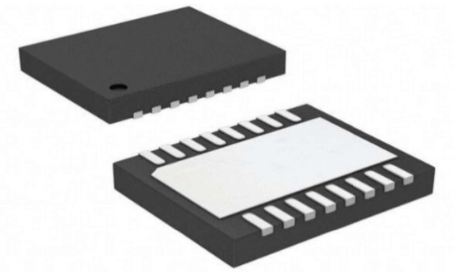
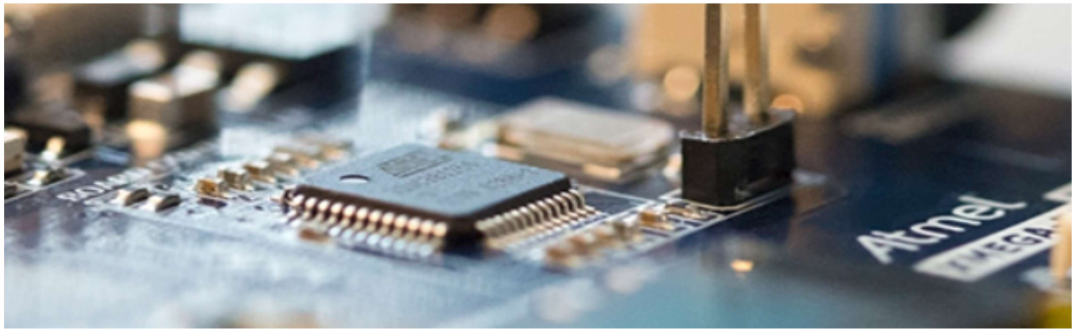
Chapter 4 – Electrical Principles

- E6E10…(p4-36) **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

- As device complexity and operating frequency increased, even the leads of the DIP packages became too long (added inductance). The solution was surface mount components that have ***very small or no leads*** at the side of the package. Surface mounts parts are placed on the PCB and soldered with paste to the copper traces.





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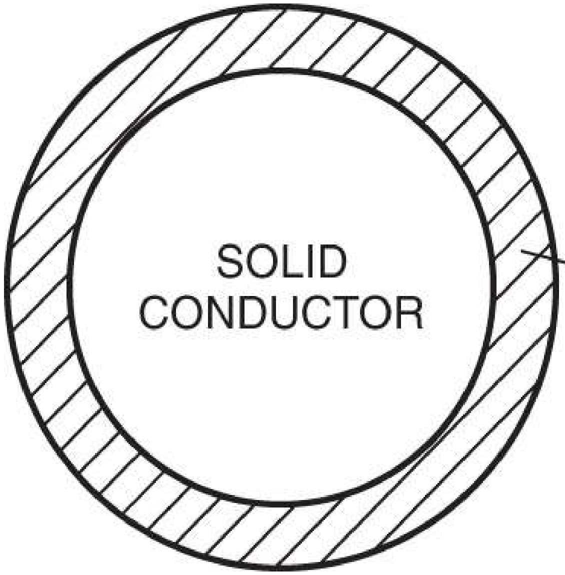
Chapter 4 – Electrical Principles

- **E5D01…(p4-34) What is the result of skin effect?**
- If you ever had a chance to inspect an old wireless station, you would have seen that the antenna "plumbing" leading out of the transmitter was usually constructed of hollow copper tubing. ***Radio frequency current always travels along the thin outside layer of a conductor***, and as frequency increases, there is almost no current in the center of the conductor. The higher the frequency, the greater the ***skin effect***. Therefore, we use wide copper ground foil to minimize the resistance to AC current that we need to pass to ground.



SKIN EFFECT – The higher the frequency, the thinner the layer used by the AC signal current.

Amateur Radio Extra Class
Chapter 4 – Electrical Principles

- E5D02…(p4-36) **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 avoid unwanted inductive reactance
  C. To maintain component lifetime
  D. All of these are correct

- All wire leads have some inductance. For example, ***#24 AWG*** wire typically used for leads in discrete components has an ***inductance of about 24 nH per inch***. At VHF and higher frequencies and high-speed digital circuits this inductive reactance can be a concern. Shorter connections help reduce the inductance. Flat metal straps instead of wires can also be used in RF ground connection.

Amateur Radio Extra Class
Chapter 4 – Electrical Principles

- E5D04…(p4-36) **Why are short connections necessary at microwave frequencies?**

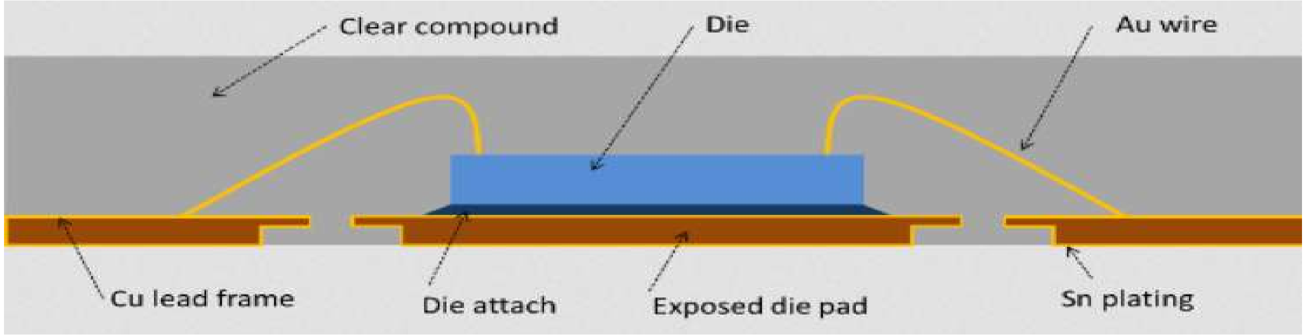
A. To increase neutralizing resistance

B. To reduce phase shift along the connection

C. Because of ground reflections

D. To reduce noise figure

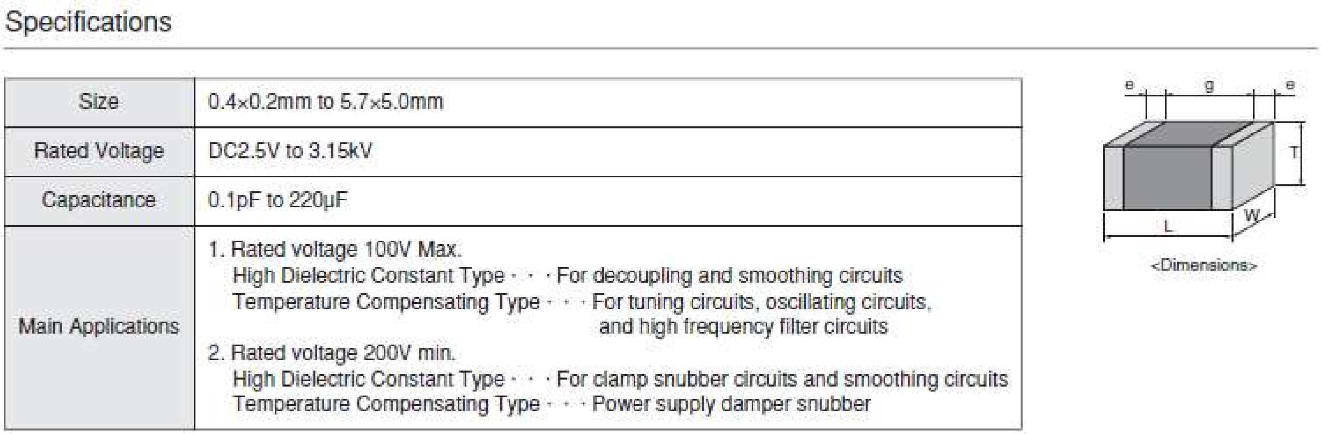
- As wavelengths get shorter (higher frequency), the ***electrical length of component leads*** (inside + outside length) cause phase shifts in the signal traveling in the lead. The phase shift can be difficult to control and might lead to oscillation or uneven frequency response.



Amateur Radio Extra Class
Chapter 4 – Electrical Principles

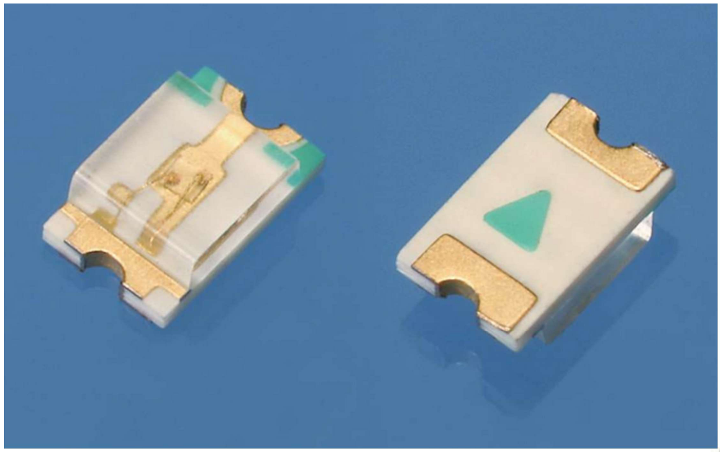
- **E6E09…(p4-36) Which of the following component package types would be most suitable for use at frequencies above the HF range?**

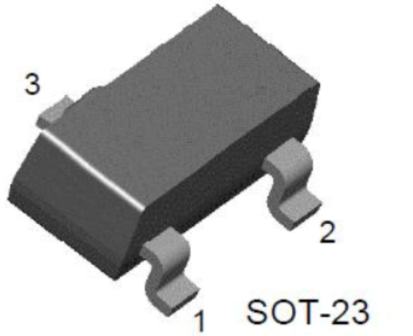
A. TO-220
B. Axial lead
C. Radial lead
D. Surface mount



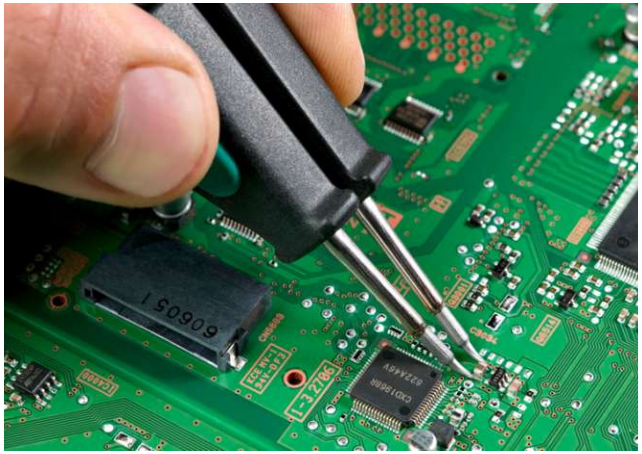
Specifications

Size	0.4×0.2mm to 5.7×5.0mm
Rated Voltage	DC2.5V to 3.15kV
Capacitance	0.1pF to 220μF
Main Applications	1. Rated voltage 100V Max. High Dielectric Constant Type・・・For decoupling and smoothing circuits Temperature Compensating Type・・・For tuning circuits, oscillating circuits, and high frequency filter circuits 2. Rated voltage 200V min. High Dielectric Constant Type・・・For clamp snubber circuits and smoothing circuits Temperature Compensating Type・・・Power supply damper snubber





1. Base 2. Emitter 3. Collector



Amateur Radio Extra Class
Chapter 4 – Electrical Principles

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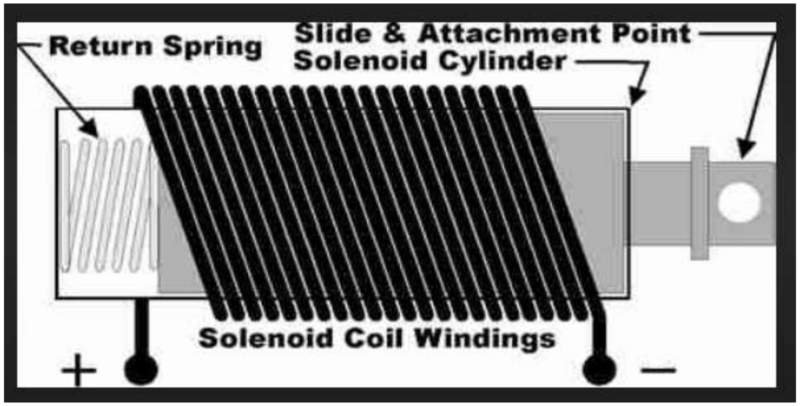
Amateur Radio Extra Class
Chapter 4 – Electrical Principles

4.3 – Principles of Circuits – Magnetic Cores (p4-36)

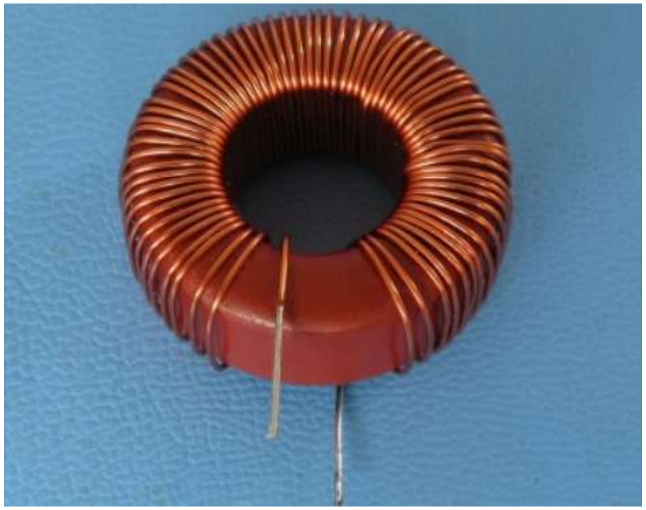
- **Inductors store magnetic energy and have reactance.**
- The shape of an inductor’s core affects how the magnetic field is contained.
- Doughnut shaped toroid cores reduce coupling to other conductors. Toroids hold most of the field in the toroid core. Type-31, -43 or -52 mix ferrite is commonly used for HF applications.

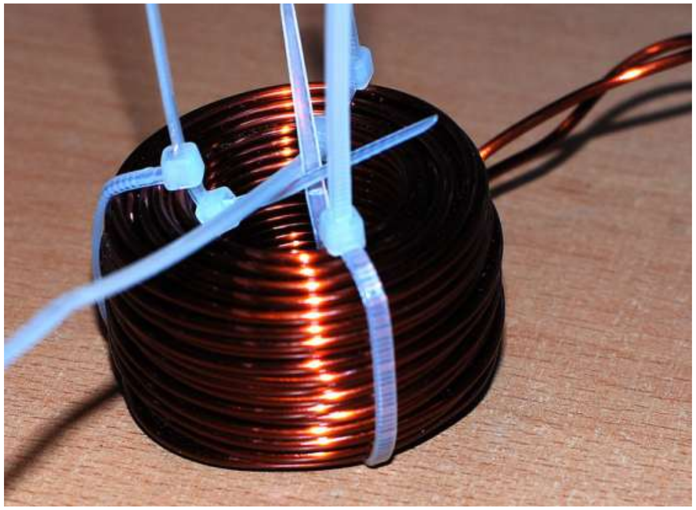


Amateur Radio Extra Class
Chapter 4 – Electrical Principles

4.3 – Principles of Circuits – Core Shape – Toroids and Beads (p4-38)

- Doughnut shaped toroid cores reduce coupling to other conductors.
- Toroid style inductors are used in RF and power supply circuits.
- One pass through the core is 1 turn. A loop around the toroid inductor is counted as 2 turns. Fig-4.33 has pictures.
- Ferrite beads are small cores that have a wire placed through them for a 1 turn inductor.





Amateur Radio Extra Class
Chapter 4 – Electrical Principles

- E6D06…(p4-36) **What core material property determines the inductance of a toroidal inductor?**

A. Thermal impedance
B. Resistance
C. Reactivity
D. Permeability

- ***Permeability*** refers to the strength of the magnetic field in the core as compared to the strength of the field with a core of air.
- Cores with higher permeability have more inductance for the same number of turns.
- Curie temperature is another important specification for toroids used in RF applications. This is the temperature that the core loses permeability. #31 and #43 are >130C. #52 is >250C.

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Chapter 4 – Electrical Principles

- **E6D08…(p4-37) Which of the following materials has the highest temperature stability of its magnetic characteristics?**

A. Brass

B. Powdered-iron

C. Ferrite

D. Aluminum

- When designing high current circuits, such as those in linear amplifiers, ***powdered iron toroids offer the greatest high current capabilities*** while maintaining a stable inductance. Powdered-iron toroids also offer good temperature stability.

Amateur Radio Extra Class
Chapter 4 – Electrical Principles

- **E6D05…(p4-36) How do ferrite and powdered iron compare for use in and 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 toroids are easier to use with surface mount technology

- ***Ferrite material comes in several chemical combinations*** for various applications so you should consult the ferrite manufacturer for the correct material for the application.
- Fair-Rite, Coilcraft, Coiltronics, Cooper Bussmann and Wurth are few manufacturers of cores.

Amateur Radio Extra Class
Chapter 4 – Electrical Principles

- E6D04…(p4-38) **Why are cores of inductors and transformers sometimes constructed in 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

- A transformer's core will contain some magnetic energy from the magnetizing current in the primary winding even if no load is connected on the secondary. The thin layers of material will help reduce the power lost as compared to other core types.

Amateur Radio Extra Class
Chapter 4 – Electrical Principles

- E6D12…(p4-38) **What causes inductor saturation?**

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

- Magnetic cores are used for transformers that couple power from a primary to a secondary winding through the core. When using a transformer of any kind, it is important to ***avoid exceeding the core's ability to store magnetic energy***, an effect called ***saturation***.
- For power transformers, we look at the voltage and current ratings for the component to size it appropriately.
- When saturation occurs, the output waveform becomrs distorted generating harmonics and other distortion products.

Amateur Radio Extra Class
Chapter 4 – Electrical Principles

- E6D07…(p4-38) **What is the current that flows in the primary winding of a transformer when there is no load is attached to the secondary winding?**
-

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

Amateur Radio Extra Class
Chapter 4 – Electrical Principles

- E6D10…(p4-37) **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

- The ***toroidal inductor concentrates the magnetic field within the core material***, protecting other nearby components from stray magnetic fields from that inductor.

Amateur Radio Extra Class
Chapter 4 – Electrical Principles

- E6D09…(p4-39) **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

- If you look in the modern ***VHF/UHF*** single-band or dual-band ***amplifier***, you'll see many leads dressed on a small ***ferrite bead*** to minimize parasitics coming down voltage or control lines.

Amateur Radio Extra Class
Chapter 4 – Electrical Principles

- **Thank you for your attention.**
- **Questions?**