The ARRL General Class License Course

All You Need to Pass Your General Class Exam

LEVEL 2: General

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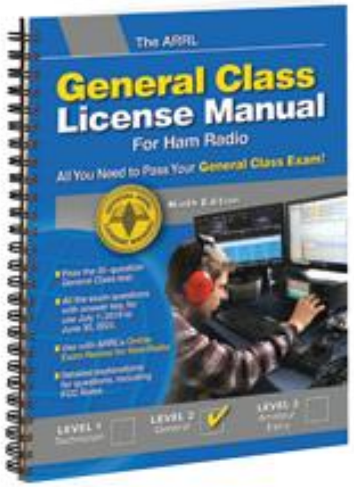

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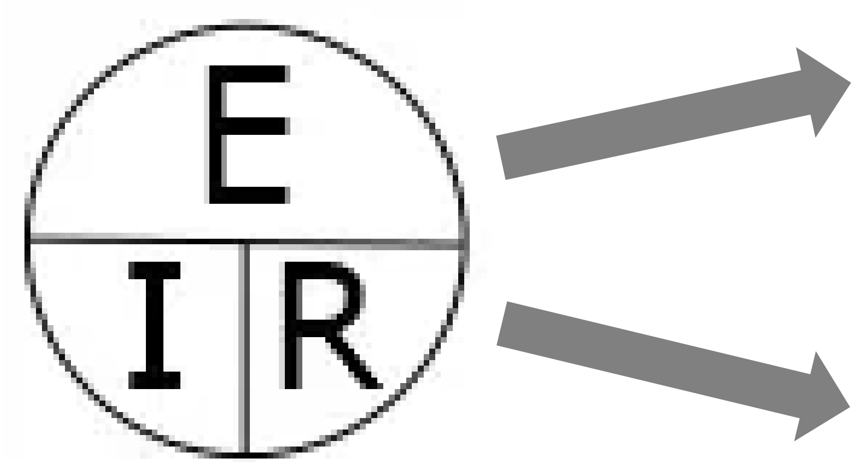
Module 4a

ARRL General Class
Chapter 4 – Components & Circuits
(4.1, 4.2, 4.3, 4.4)

Power & Decibels, AC Power, Basic Components, Reactance, Impedance & Resonance

Power and Decibels

Recall Ohm's Law from
your Technician training …



$$E = I \times R$$

$$I = \frac{E}{R}$$

Power and Decibels (cont.)

Similarly …

$$P = E \times I$$

$$E = \frac{P}{I}$$

Power and Decibels (cont.)

Substituting the Ohm's Law equivalents for voltage and current allows power to be calculated using resistance …

$$P = I^2 \times R$$

$$P = \frac{E^2}{R}$$

Power Calculation Examples

To find out how many watts of electrical power are used if 400 Vdc is supplied to an 800 Ω resistor …

$$P = \frac{E^2}{R} = \frac{400^2}{800} = \frac{400 \times 400}{800} = \frac{160000}{800} = 200 \text{ W}$$

Power Calculation Examples (cont.)

To find out how many watts are being dissipated when a current of 7.0 mA flows through a 1.25 kΩ resistor …

$$P = I^2 \times R = 0.007^2 \times 1250 =$$
$$0.007 \times 0.007 \times 1250 = 0.06125 \text{ W} =$$
$$61.25 \text{ mW}$$

Calculating a Power or Voltage Ratio from dB

$$\text{Power Ratio} = \log^{-1}\left[\frac{dB}{10}\right]$$

$$\text{Voltage Ratio} = \log^{-1}\left[\frac{dB}{20}\right]$$

Inverse log notes …

Written as … $\log_{10}^{-1}$

or … $\log^{-1}$

On scientific calculators …

- LOG^{-1}
- ALOG
- 10^X
- INV then LOG

Useful Power vs. dB Value to Remember

If you double the power (or cut it in half), there's a 3 dB change …

$$\text{dB} = 10\log_{10}\left[\frac{2}{1}\right] = 10\log_{10}(2) = 10 \times (0.3) = 3\ \text{dB}$$

Converting dB to Percentage & Vice Versa

$$dB = 10\log\left(\frac{Percentage\ Power}{100\%}\right)$$

$$Percentage\ Power = 100\% \times \log^{-1}\left(\frac{dB}{10}\right)$$

$$dB = 20\log\left(\frac{Percentage\ Voltage}{100\%}\right)$$

$$Percentage\ Voltage = 100\% \times \log^{-1}\left(\frac{dB}{20}\right)$$

Application example: Suppose you are using an antenna feed line that has a loss of 1dB. You can calculate the amount of transmitter power that's actually reaching your antenna and how much is lost in the feed line.

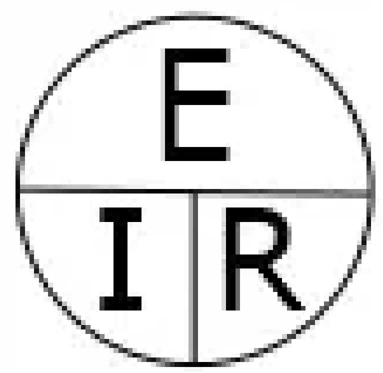
$$\text{Percentage Power} = 100\% \times \log^{-1}\left(\frac{-1}{10}\right) = 100\% \times \log^{-1}(-0.1) = 79.4\%$$

Current, Voltage, and Power Review

- *Current* (I) is the flow of electrons
  - Measured in *amperes* (A or amps) with an *ammeter*
- *Voltage* (E) is the force that makes electrons move
  - Measured in *volts* (V) with a *voltmeter*
  - Polarity of voltage refers to direction from positive to negative
- *Power* (P) is the product of voltage and current ($P = E \times I$)
  - Measured in *watts* (W)

Resistance and Ohm's Law Review

- Ohm's Law states …
  - R = E / I
  - I = E / R
  - E = I × R



- The voltage caused by current flowing through a resistance is called a *voltage drop*

Frequency Review

- A complete sequence of ac current (alternating current) flowing, stopping, reversing, and stopping again is a *cycle*
- The number of cycles per second is the current's *frequency* (f), measured in *hertz* (Hz)
- A *harmonic* is a frequency at some integer multiple (2, 3, 4, etc.) of a lowest or *fundamental* frequency
  - The harmonic at twice the frequency is the *second harmonic*, at three times is the *third harmonic* (there is no first harmonic)

Wavelength Review

- Speed of light in space (c) is 300 million (3×10^8) meters per second … somewhat slower in wires and cables
- Wavelength (λ) of radio wave is the distance it travels during one complete cycle
  - $\lambda = c / f$
  - $f = c / \lambda$
- A radio wave can be referred to by frequency *OR* wavelength because the speed of light is constant

PRACTICE QUESTIONS

What dB change represents a factor of two increase or decrease in power?

A. Approximately 2 dB
B. Approximately 3 dB
C. Approximately 6 dB
D. Approximately 12 dB

How many watts of electrical power are used if 400 VDC is supplied to an 800 ohm load?

A. 0.5 watts
B. 200 watts
C. 400 watts
D. 3200 watts

How many watts of electrical power are used by a 12 VDC light bulb that draws 0.2 amperes?

A. 2.4 watts
B. 24 watts
C. 6 watts
D. 60 watts

How many watts are dissipated when a current of 7.0 milliamperes flows through a 1250 ohm resistance?

A. Approximately 61 milliwatts
B. Approximately 61 watts
C. Approximately 11 milliwatts
D. Approximately 11 watts

What percentage of power loss would result from a transmission line loss of 1 dB?

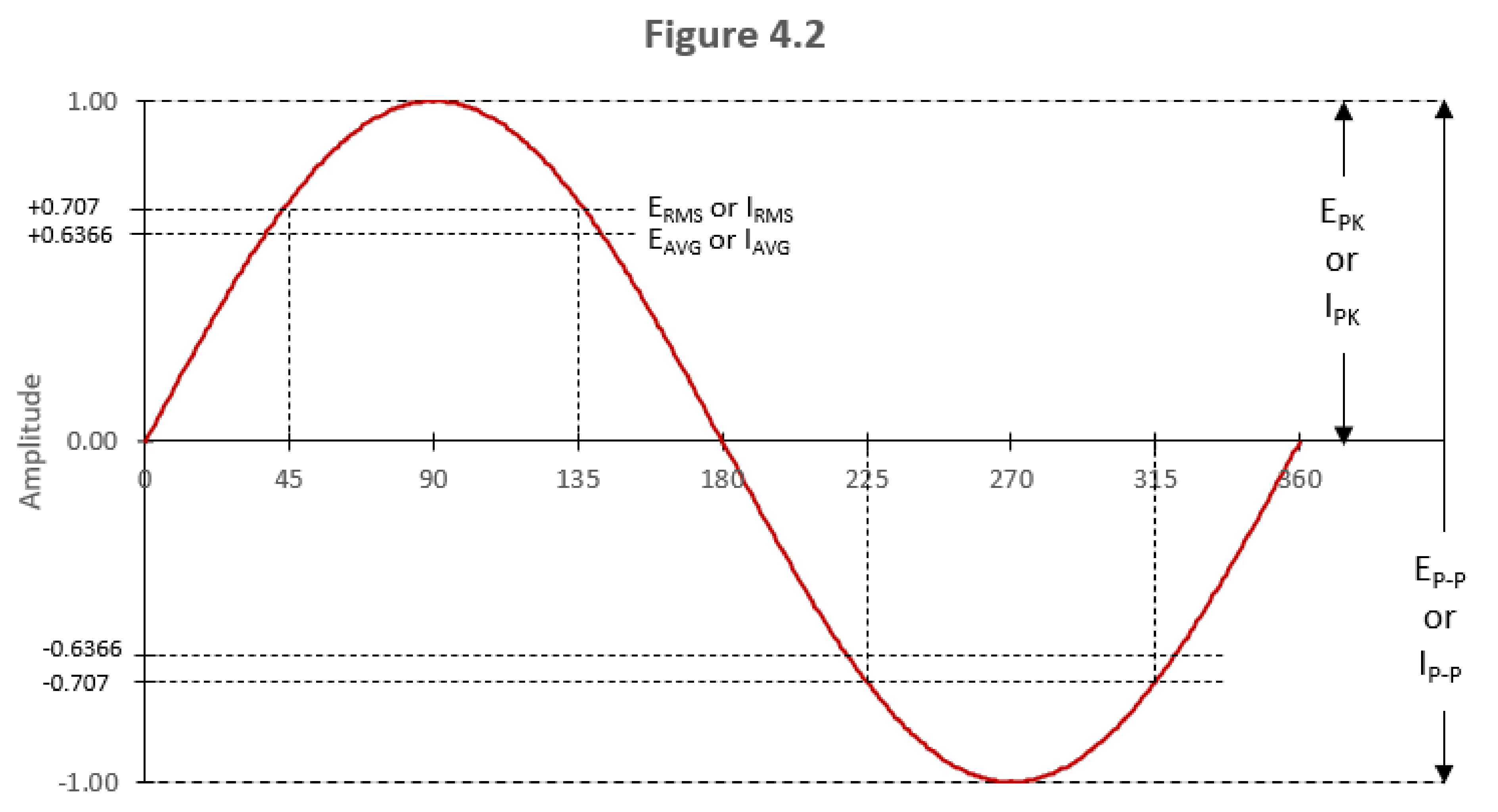
A. 10.9 percent
B. 12.2 percent
C. 20.6 percent
D. 25.9 percent

AC Power / RMS: Definition & Measurement

- The power equation is very clear for dc power …
  - $P = E^2 / R$
- However, what is the value of *E* for ac power?
  - Not peak, not average … it's *RMS* (*root mean square* or V_{RMS})
- The RMS for a sine wave is 0.707 times the sine wave's peak voltage

Figure 4.2

Relationships between RMA, average, peak, and peak-to-peak ac voltage and current



Waveform Formulas

(Note: Do not use these for non-sine waves!)

$$V_{RMS} = 0.707 \times V_{PK} = 0.707 \times \frac{V_{PP}}{2}$$

$$V_{PK} = 1.414 \times V_{RMS}$$

$$V_{PP} = 2 \times 1.414 \times V_{RMS} = 2.828 \times V_{RMS}$$

It is particularly important to know the relationship between RMS and peak voltages to choose components that have sufficient voltage ratings. Capacitors are often connected across the ac power line to perform RF filtering. The capacitor must be rated to withstand the ac peak voltage.

Refer to Figure 4.2

Waveform Calculation Examples

Example: A sine wave with a peak voltage of 17 V has what RMS value?

$$V_{RMS} = 0.707 \text{ X } V_{PK} = 0.707 \text{ X } 17 \text{ V} = \mathbf{12\ V}$$

Example: A sine wave with a peak-peak voltage of 100 V has what RMS value?

$$V_{RMS} = 0.707 \text{ X } \frac{V_{P\text{-}P}}{2} = 0.707 \text{ X } \frac{100}{2} = \mathbf{35.4\ V}$$

PEP: Definition and Measurement

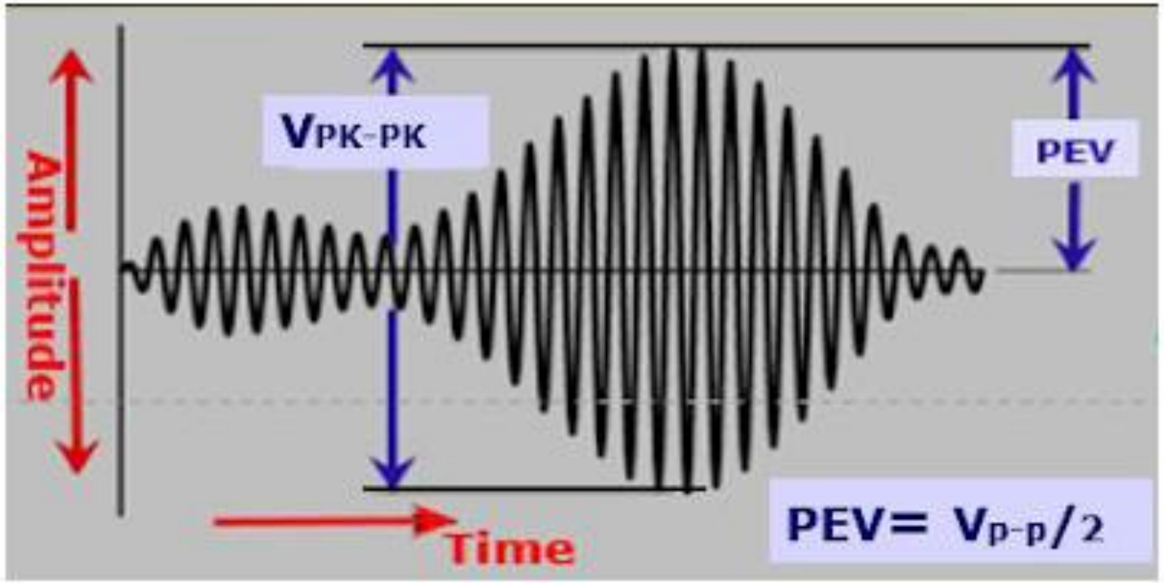
- PEP = *Peak envelope power*
- PEP is the *average power* of one complete RF cycle at the peak of the signal’s envelope … a convenient way of measuring the max power of amplitude-modulated signals
- However, this definition is confusing …
  - See (following slide) definition from www.mdarc.org

Clarification of Peak Envelope Power

RF signals such as AM and SSB have a constantly changing amplitude during transmission, like the image at the top of the page. For these signals, there will be points where the amplitude is at its greatest (see figure below). This is the "one RF cycle at the crest of the modulation envelope" in the definition.

Other signals, such as FM, PM (phase modulation) and CW, have a constant amplitude, so every RF cycle is its "peak" cycle.

Once that cycle is identified, we calculate the average power over its complete duration. That's the red area in figure on next slide.



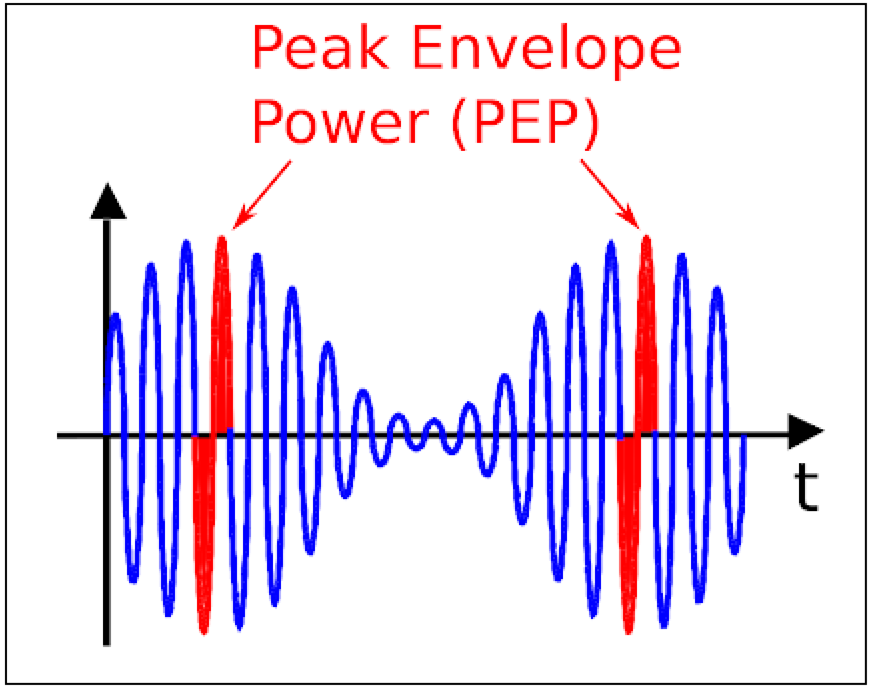
Clarification of Peak Envelope Power (cont.)

Once that cycle is identified, we calculate the average power over its complete duration. That's the red area in figure below.

Note that we calculate the power in both the positive voltage half-cycle and the negative voltage half-cycle. They don't cancel out because, as shown below, the PEV is squared, making both of them positive.

Start by measuring the amplitude of the peak, usually in volts. That is PEV in figure on previous slide

Then apply the following formula … (next slide) …



PEP Calculations

$$PEP = \frac{(PEV \times 0.707)^2}{R} = \frac{{V_{RMS}}^2}{R}$$

Example: If PEV is 50V across a 50Ω load, the PEP power is …

$$PEP = \frac{(50 \times 0.707)^2}{50} = \frac{35.35^2}{50} = \frac{1249.62}{50} = 25W$$

Example: If a 50Ω load is dissipating 1200W PEP, the RMS voltage is …

$$VRMS = \sqrt{PEP \times R} = \sqrt{1200 \times 50} = 245V$$

PEP Summary

- PEP equals the average power IF an amplitude-modulated signal is NOT modulated
  - An example of this is when modulation is removed from an AM signal (leaving only the steady carrier) or when a CW transmitter is keyed
- An FM signal is a constant-power signal, so *PEP is always equal to average power for FM signals*. In other words, if an average-reading wattmeter connected to your transmitter reads 1060W when you close the key on CW, your output power will be …

1060W

PRACTICE QUESTIONS

What is the output PEP from a transmitter if an oscilloscope measures 200 volts peak-to-peak across a 50 ohm dummy load connected to the transmitter output?

A. 1.4 watts
B. 100 watts
C. 353.5 watts
D. 400 watts

What value of an AC signal produces the same power dissipation in a resistor as a DC voltage of the same value?

A. The peak-to-peak value
B. The peak value
C. The RMS value
D. The reciprocal of the RMS value

What is the peak-to-peak voltage of a sine wave with an RMS voltage of 120.0 volts?

A. 84.8 volts
B. 169.7 volts
C. 240.0 volts
D. 339.4 volts

What is the RMS voltage of a sine wave with a value of 17 volts peak?

A. 8.5 volts
B. 12 volts
C. 24 volts
D. 34 volts

What is the ratio of peak envelope power to average power for an unmodulated carrier?

A. 0.707
B. 1.00
C. 1.414
D. 2.00

What would be the RMS voltage across a 50 ohm dummy load dissipating 1200 watts?

A. 173 volts
B. 245 volts
C. 346 volts
D. 692 volts

What is the output PEP of an unmodulated carrier if an average reading wattmeter connected to the transmitter output indicates 1060 watts?

A. 530 watts
B. 1060 watts
C. 1500 watts
D. 2120 watts

What is the output PEP from a transmitter if an oscilloscope measures 500 volts peak-to-peak across a 50 ohm resistive load connected to the transmitter output?

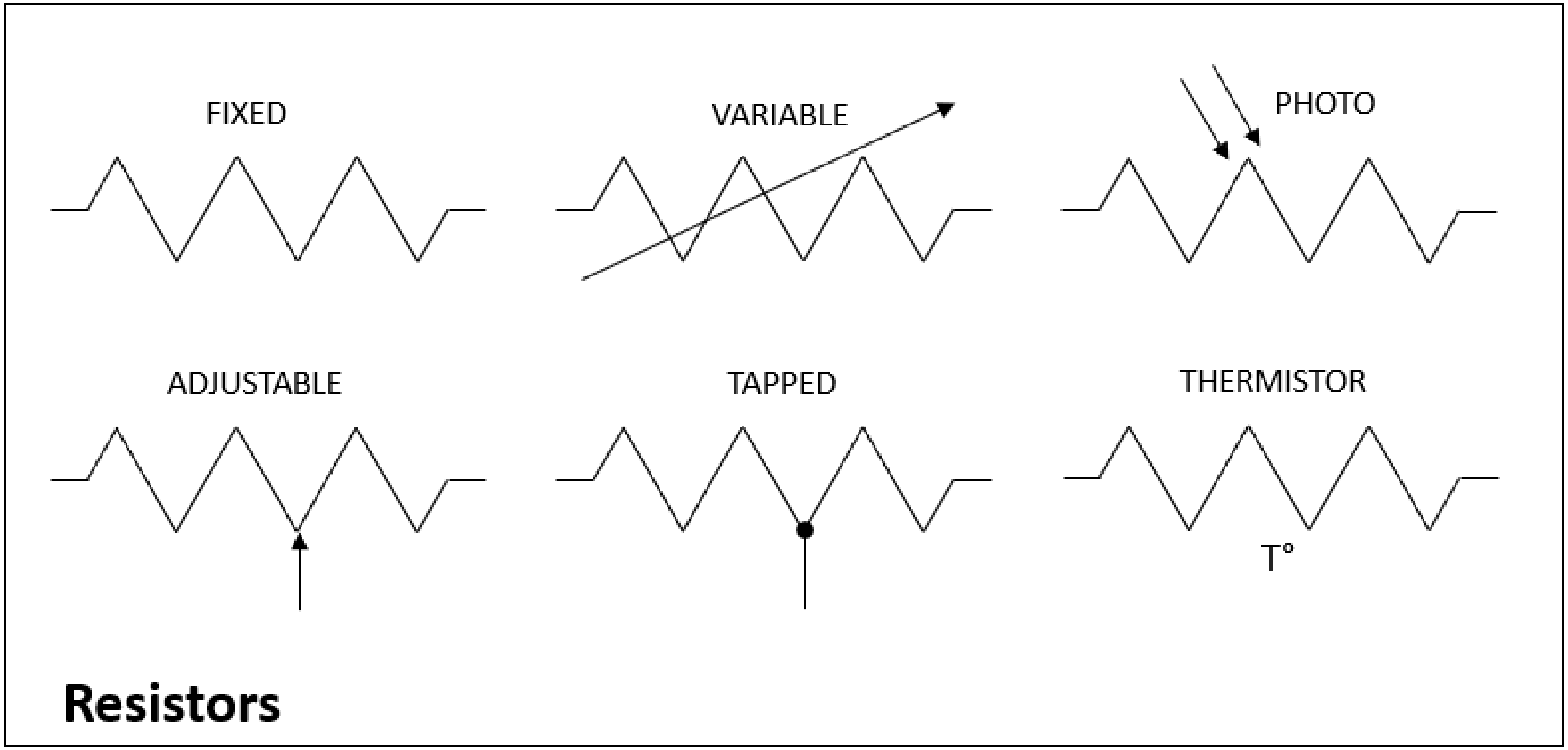
A. 8.75 watts
B. 625 watts
C. 2500 watts
D. 5000 watts

Basic Components

- Refer to the following 5 slides … selected basic component samples from Figure 4.4 (page 4-8)
- Three most basic components …
  - Resistors: Designated with an *R*, resist flow of electricity, measured in ohms (*Ω*)
  - Capacitors: Designated *C*, store electric energy, measured in farads (*F*)
  - Inductors: Designated *L*, store magnetic energy, measured in henries (*H*)

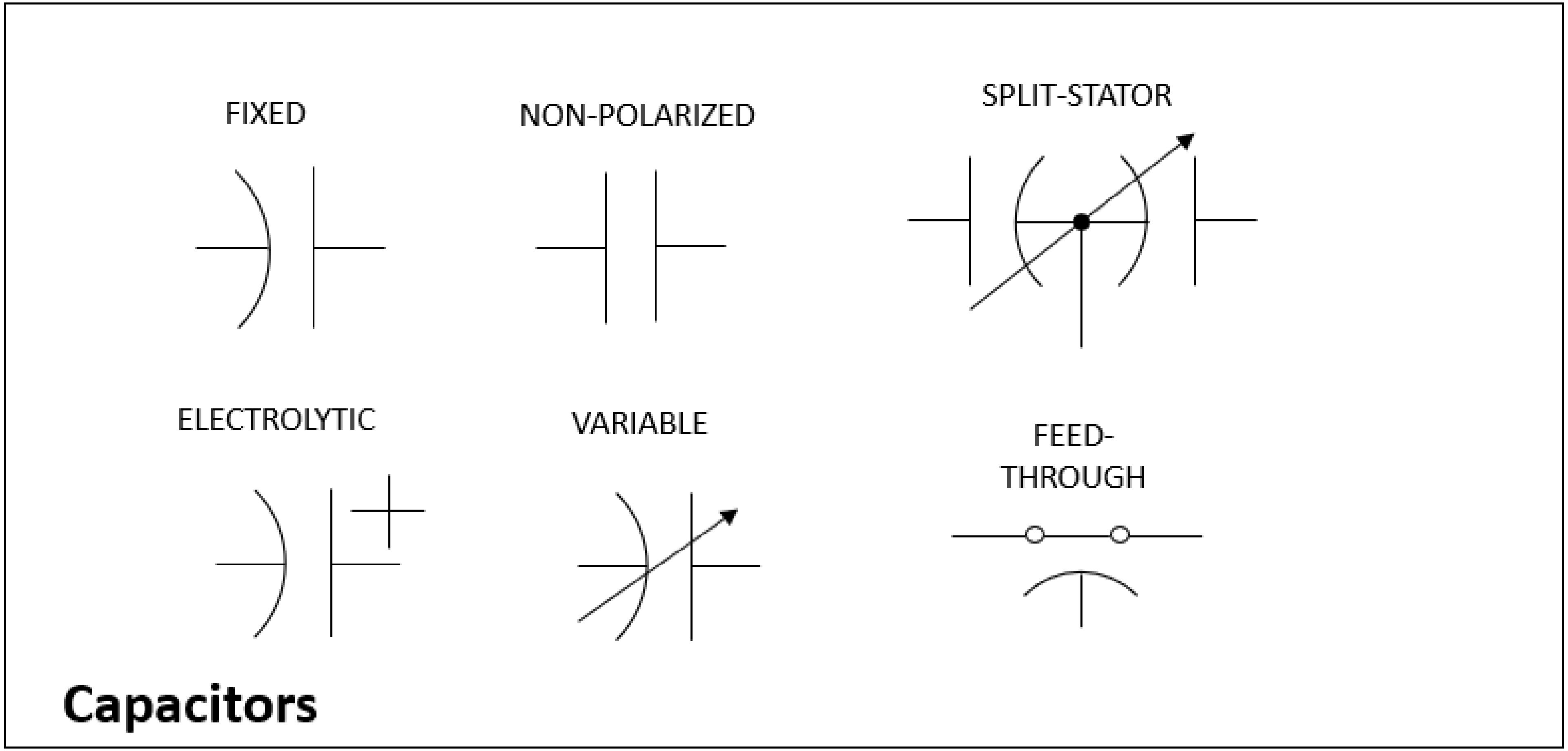
Common Schematic Symbols: Resistors

Fig. 4.4



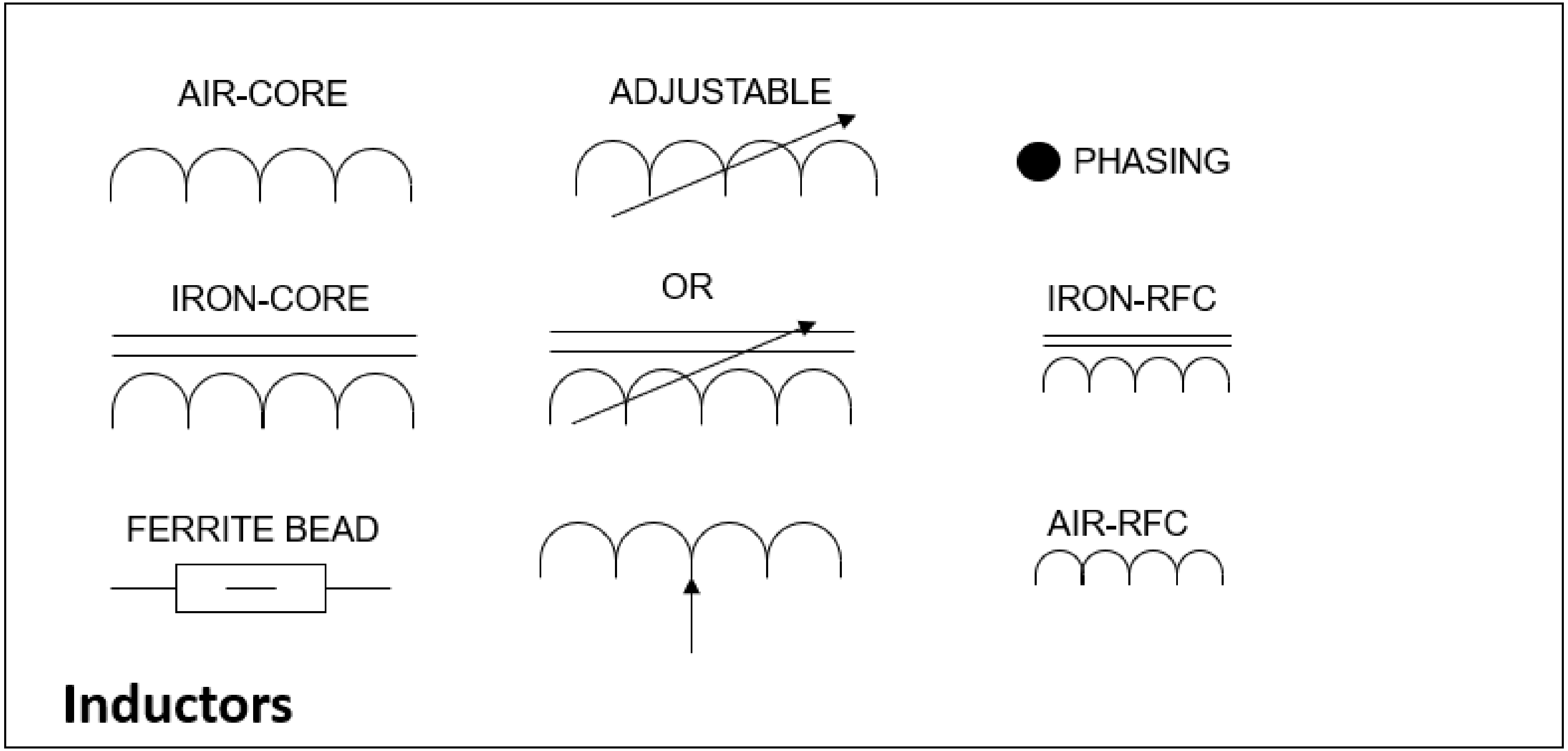
Common Schematic Symbols: Capacitors

Fig. 4.4



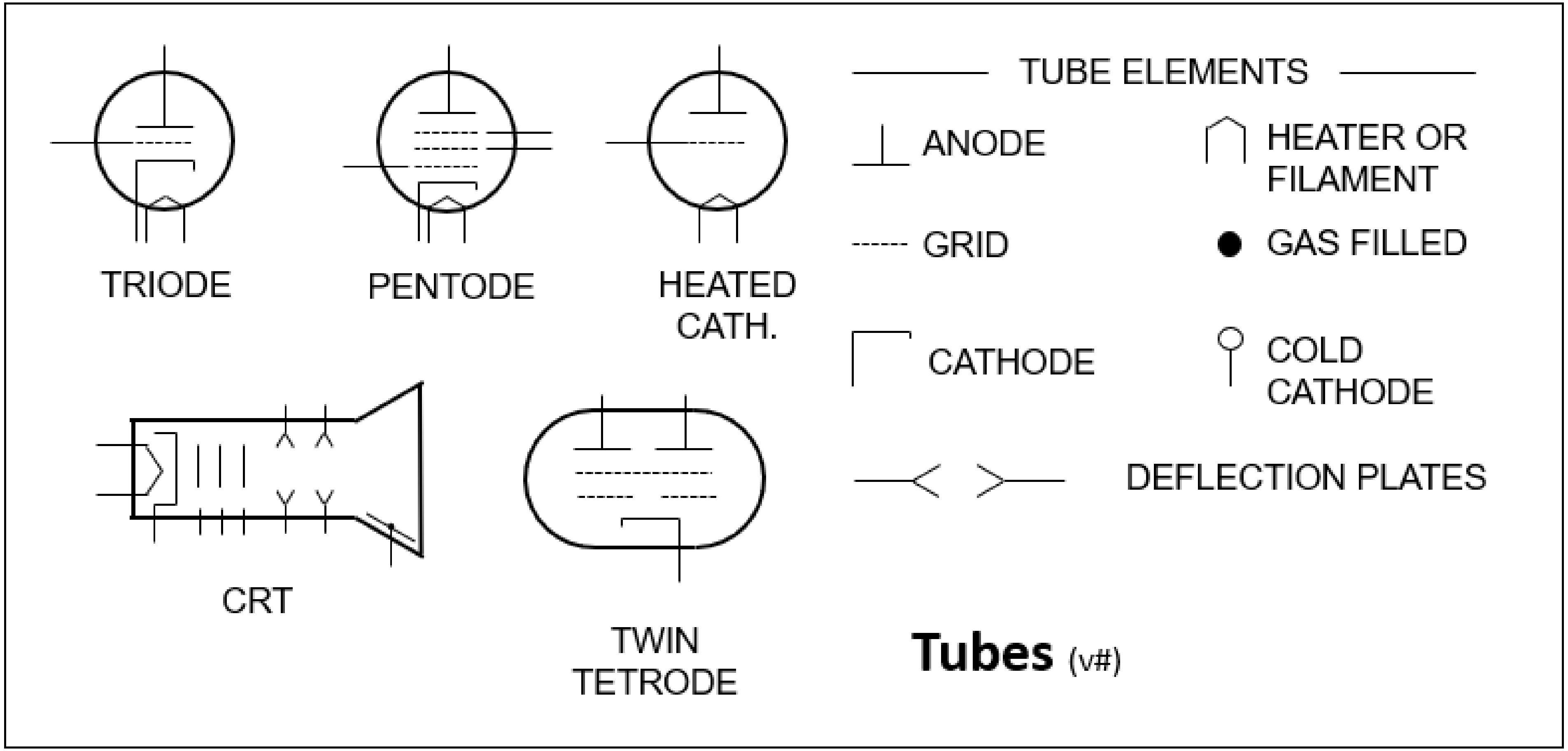
Common Schematic Symbols: Inductors

Fig. 4.4



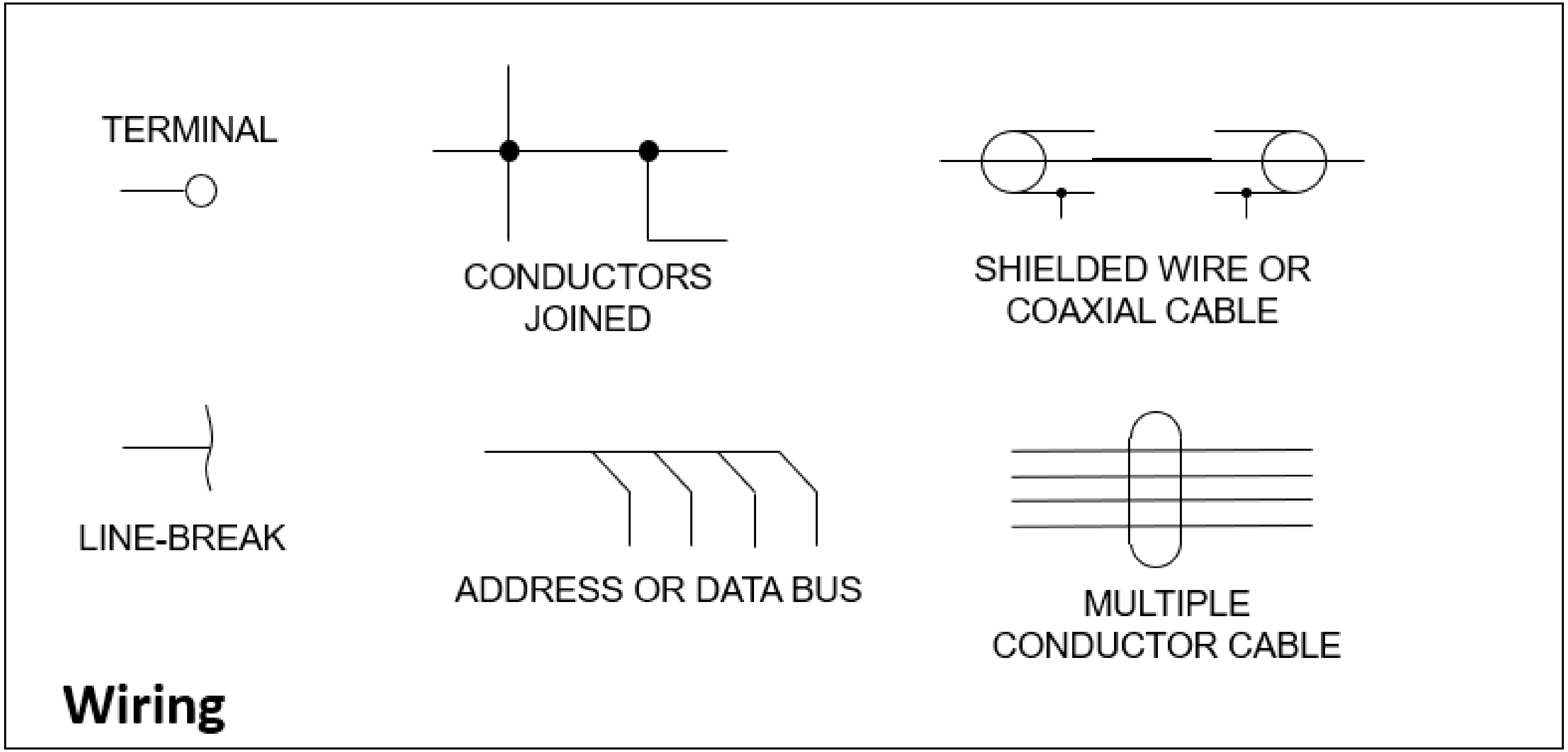
Common Schematic Symbols: Tubes

Fig. 4.4



Common Schematic Symbols: Wiring

Fig. 4.4



Resistors and Resistance

- Several common types
- Available with nominal values from 1Ω or less to more than 1MΩ
  - Nominal value printed with text or colored bands
  - Most common units are ohms (Ω), kilo ohms (kΩ), and megohms (MΩ)
- Precision tolerances range from 1% or less to 10%

Converting Between Units

CONVERT FROM	CONVERT TO (a)	CONVERT TO (b)
Ohms	Kiloohms: Divide by 1000	Megohms: Divide by 1,000,000
Kiloohms	Ohms: Multiply by 1000	Megohms: Divide by 1000
Megohms	Ohms: Multiply by 1,000,000	Kiloohms: Multiply by 1000

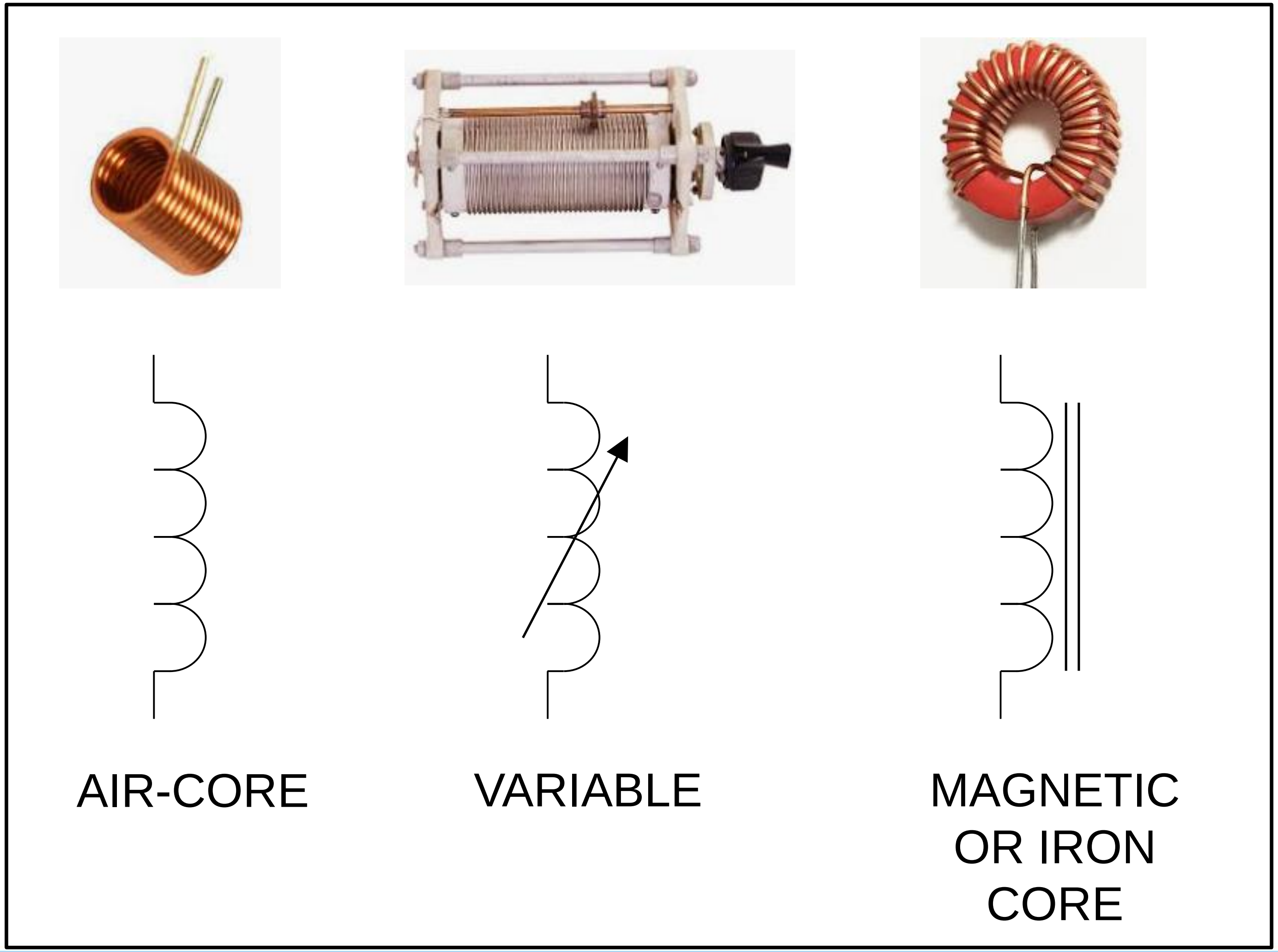
EXAMPLE: 150 Ω = 150 / 1000 = 0.15 KΩ and 150 Ω = 150 / 1,000,000 = 0.00015 MΩ

EXAMPLE: 4.7 kΩ = 4.7 X 1000 = 4700 kΩ and 4.7 kΩ = 4.7 / 1000 = .0047 MΩ

EXAMPLE: 2.2 MΩ = 2.2 X 1,000,000 = 2,200,000 Ω and 2.2 MΩ = 2.2 X 1000 = 2200 kΩ

Inductors and Inductance

- Like resistors, several common types
- Double lines indicate a solid magnetic core
- Variable inductors often have solid cores. Use of double lines on schematics is optional
- Miniature inductors (not shown) look similar to resistors



Inductor Design

- Inductance (ability to store magnetic energy) is directly proportional to the square of the number of turns and area enclosed by each turn
  - Making an inductor LONGER without changing number of turns or diameter REDUCES inductance
- Increasing the ability to store magnetic energy (called *permeability*) increases the inductance

Inductor Design (cont.)

- The type of core and winding affects inductance and vary according to the use/purpose of the inductor
- Variable inductors are often used in low-power receiving and transmitting applications
  - Adjusted by moving a magnetic core in and out of the inductor (threaded cores move when turned)
  - For high-power inductors, adjustment is made by moving a sliding contact along the inductor

Converting Between Units

CONVERT FROM	CONVERT TO (a)	CONVERT TO (b)
Nanohenries	Microhenries: Divide by 1000	Millihenries: Divide by 1,000,000
Microhenries	Nanohenries: Multiply by 1000	Millihenries: Divide by 1000
Millihenries	Nanohenries: Multiply by 1,000,000	Microhenries: Multiply by 1000

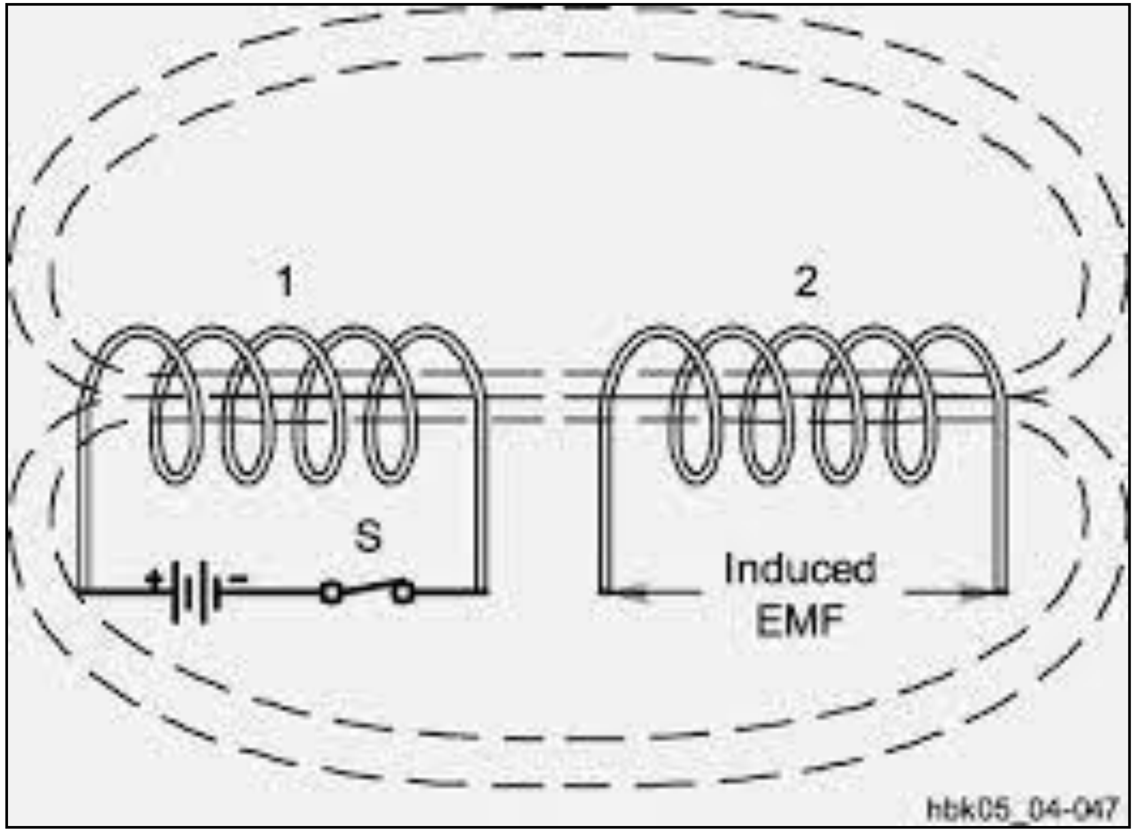
EXAMPLE: 330 nH = 330 / 1000 = 0.33 µH and 330 nH = 330 / 1,000,000 = 0.00033 mH

EXAMPLE: 6.8 µH = 6.8 X 1000 = 6800 nH and 6.8 µH = 6.8 / 1000 = .0068 mH

EXAMPLE: 88 mH = 88 X 1,000,000 = 88,000,000 nH and 88 mH = 88 X 1000 = 8800 µH

Inductor Coupling

- Place 2 inductors close together with axes aligned
- Magnetic field from one inductor can also pass through the second one, sharing some of its energy
- This is called *coupling*
- The ability of inductors to share or transfer magnetic energy is called *mutual inductance*



Inductor Design (cont.)

- In toroidal winding the core contains nearly all the inductor's magnetic field
- Since little of the field extends outside the core, toroids can be placed next to each other (in almost any orientation) with minimal mutual inductance
- This property makes them useful in RF circuits
- Composition of the core varies (ferrite, powdered iron, even exotic "rare earth" metals), making it possible to obtain wide range of inductance values in a relatively small package
- The combination of materials ("mix") in the core is selected so the inductor performs best over a specific range of frequencies

PRACTICE QUESTIONS

What is an advantage of using a ferrite core toroidal inductor?

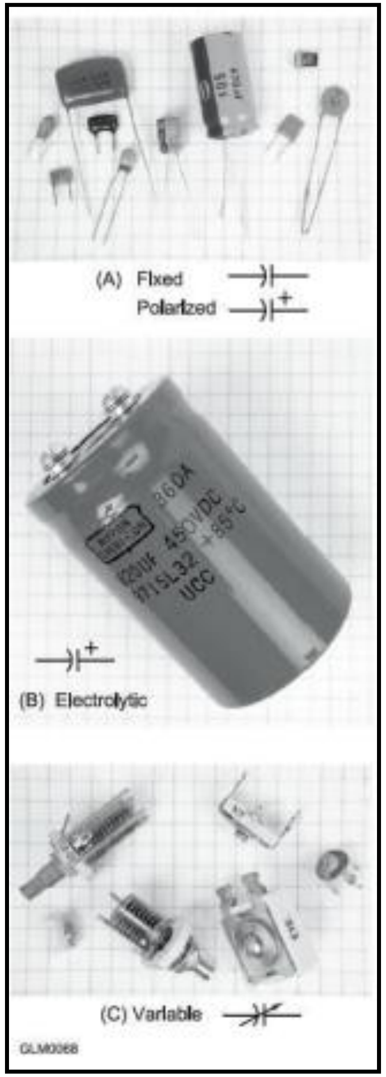
A. Large values of inductance may be obtained
B. The magnetic properties of the core may be optimized for a specific range of frequencies
C. Most of the magnetic field is contained in the core
D. All these choices are correct

What determines the performance of a ferrite core at different frequencies?

A. Its conductivity
B. Its thickness
C. The composition, or “mix,” of materials used
D. The ratio of outer diameter to inner diameter

Capacitors and Capacitance

- Capacitors have two conducting surfaces (*electrodes*) separated by a *dielectric*
- Capacitance is the ability to store electric energy, measured in *farads* (F)
- Blocks dc current flow
- The simplest capacitor is a pair of metal plates separated by air



Capacitors and Capacitance (cont.)

- Tantalum and electrolytic capacitors are *polarized*, meaning the dc voltage may only be applied on one direction without damaging the electrolyte (check polarity markings for correct installation)
- Capacitors have *voltage ratings*. Exceeding this rating can result in arcing between conducting surfaces (usually destroys all but air-dielectric capacitors)

Capacitors and Capacitance (cont.)

- Capacitor types:
  - Ceramic – RF filtering, bypassing at high frequencies, low cost
  - Plastic film – audio circuits & lower radio frequencies
  - Silvered-mica – highly stable, low loss, used in RF circuits
  - Electrolytic and tantalum – power supply filter circuits
  - Air and vacuum dielectric – transmitting and RF circuits

Capacitors and Capacitance (cont.)

- Capacitor uses:
  - Blocking – pass ac signals while blocking dc signals
  - Bypass – provide low impedance path for ac signals around higher-impedance circuit
  - Filter – smooth out voltage pulses of rectified ac to an even dc voltage
  - Suppressor – absorb energy of voltage transients or spikes
  - Tuning – vary frequency of resonant circuits or adjust impedance matching circuits

Aluminum and Tantalum Electrolytic Capacitors

- Designed to optimize their energy storage capabilities
- Voltage must be applied with the correct polarity
- Creates large capacitances in comparatively small volumes
- Aluminum: Uses metal foil for conducting surfaces and dielectric is an insulating layer on the foil created by a wet paste or gel
- Tantalum: Similar to aluminum in that a porous mass of tantalum is immersed in an electrolyte

PRACTICE QUESTIONS

What is the value in nanofarads (nF) of a 22,000 picofarad (pF) capacitor?

A. 0.22
B. 2.2
C. 22
D. 220

What is the value in microfarads of a 4700 nanofarad (nF) capacitor?

A. 47
B. 0.47
C. 47,000
D. 4.7

Which of the following is an advantage of an electrolytic capacitor?

A. Tight tolerance
B. Much less leakage than any other type
C. High capacitance for a given volume
D. Inexpensive RF capacitor

Which of the following is an advantage of ceramic capacitors as compared to other types of capacitors?

A. Tight tolerance
B. High stability
C. High capacitance for given volume
D. Comparatively low cost

Transformers

- Transformers transfer ac power between 2 or more inductors (called *windings*) sharing a common core
- The winding **TO** which power is applied is the *primary*
- The winding **FROM** which power is supplied is the *secondary*
- When voltage is applied to primary, mutual inductance causes voltage to appear across secondary
- Transformers work in “both directions”

Transformers (cont.)

- Transformers change power from one combination of ac voltage and current to another by using windings with different numbers of turns
  - The transformation occurs because all windings share the same magnetic field (wound on the same core)
- A significant change between secondary & primary usually requires a change in wire size between windings
  - In step-up transformers, the primary carries higher current and is wound with larger diameter wire than the secondary

Transformer "Math"

- The ratio of number turns in the primary winding (N_P) to the number of turns in the secondary (N_S) determines how current and voltage are changed
- Since most circuits are concerned with voltage, most transformer equations relate transformer input (primary) voltage (E_P) to output (secondary) voltage (E_S)

$$\frac{E_S}{E_P} = \frac{N_S}{N_P} \quad \text{OR} \quad E_S = E_P \times \frac{N_S}{N_P}$$

Transformer “Math” Examples

What is the voltage across a 500-turn secondary winding if 120V ac is applied across the 2250-turn primary winding?

$$E_S = E_P \times \frac{N_S}{N_P} = 120\,V \times \frac{500}{2250} = 120\,V \times 0.222 = 26.7\,V$$

Transformer "Math" Examples (cont.)

What would be the secondary-to-primary turns ratio to change 115V ac to 500V ac?

$$\frac{E_S}{E_P} = \frac{N_S}{N_P} \quad \text{... is the same as ...} \quad \frac{N_S}{N_P} = \frac{E_S}{E_P}$$

$$\frac{N_S}{N_P} = \frac{E_S}{E_P} = \frac{500}{115} = 4.35$$

PRACTICE QUESTIONS

What causes a voltage to appear across the secondary winding of a transformer when an AC voltage source is connected across its primary winding?

A. Capacitive coupling
B. Displacement current coupling
C. Mutual inductance
D. Mutual capacitance

What happens if a signal is applied to the secondary winding of a 4:1 voltage step-down transformer instead of the primary winding?

A. The output voltage is multiplied by 4
B. The output voltage is divided by 4
C. Additional resistance must be added in series with the primary to prevent overload
D. Additional resistance must be added in parallel with the secondary to prevent overload

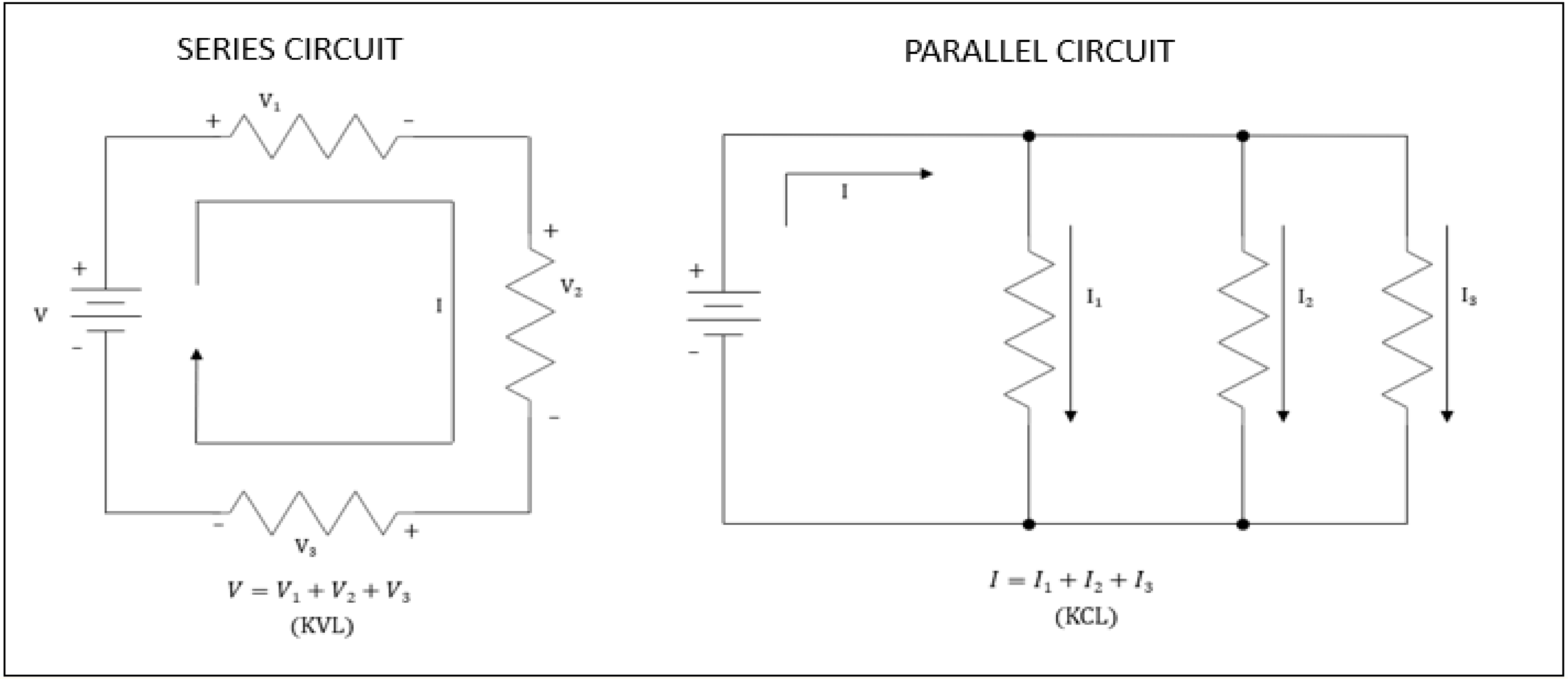
What is the RMS voltage across a 500-turn secondary winding in a transformer if the 2250-turn primary is connected to 120 VAC?

A. 2370 volts
B. 540 volts
C. 26.7 volts
D. 5.9 volts

Why is the conductor of the primary winding of many voltage step-up transformers larger in diameter than the conductor of the secondary winding?

A. To improve the coupling between the primary and secondary
B. To accommodate the higher current of the primary
C. To prevent parasitic oscillations due to resistive losses in the primary
D. To ensure that the volume of the primary winding is equal to the volume of the secondary winding

Components in Series and Parallel Circuits



Components in Series and Parallel Circuits

- In series circuits, the current is the same in all components and voltages are summed (*Kirchoff's Voltage Law*).
  - Voltages add in a series circuit
- In parallel circuits, voltage across all components is the same and the sum of currents into and out of circuit junctions must be equal (*Kirchoff's Current Law*).
  - Currents add in a parallel circuit
- Components connected in series or parallel can be replaced with a single equivalent component

Calculating Series & Parallel Equivalent Values

COMPONENT	IN SERIES
RESISTOR	ADD VALUES, R1 + R2 + R3 + …
INDUCTOR	ADD VALUES, L1 + L2 + L3 + …
CAPACITOR	RECIPROCAL OF RECIPROCALS, 1/(1/C1 + 1/C2 + 1/C3 + …)

COMPONENT	IN PARALLEL
RESISTOR	RECIPROCAL OF RECIPROCALS, 1/(1/R1 + 1/R2 + 1/R3 + …)
INDUCTOR	RECIPROCAL OF RECIPROCALS, 1/(1/L1 + 1/L2 + 1/L3 + …)
CAPACITOR	ADD VALUES, C1 + C2 + C3 + …

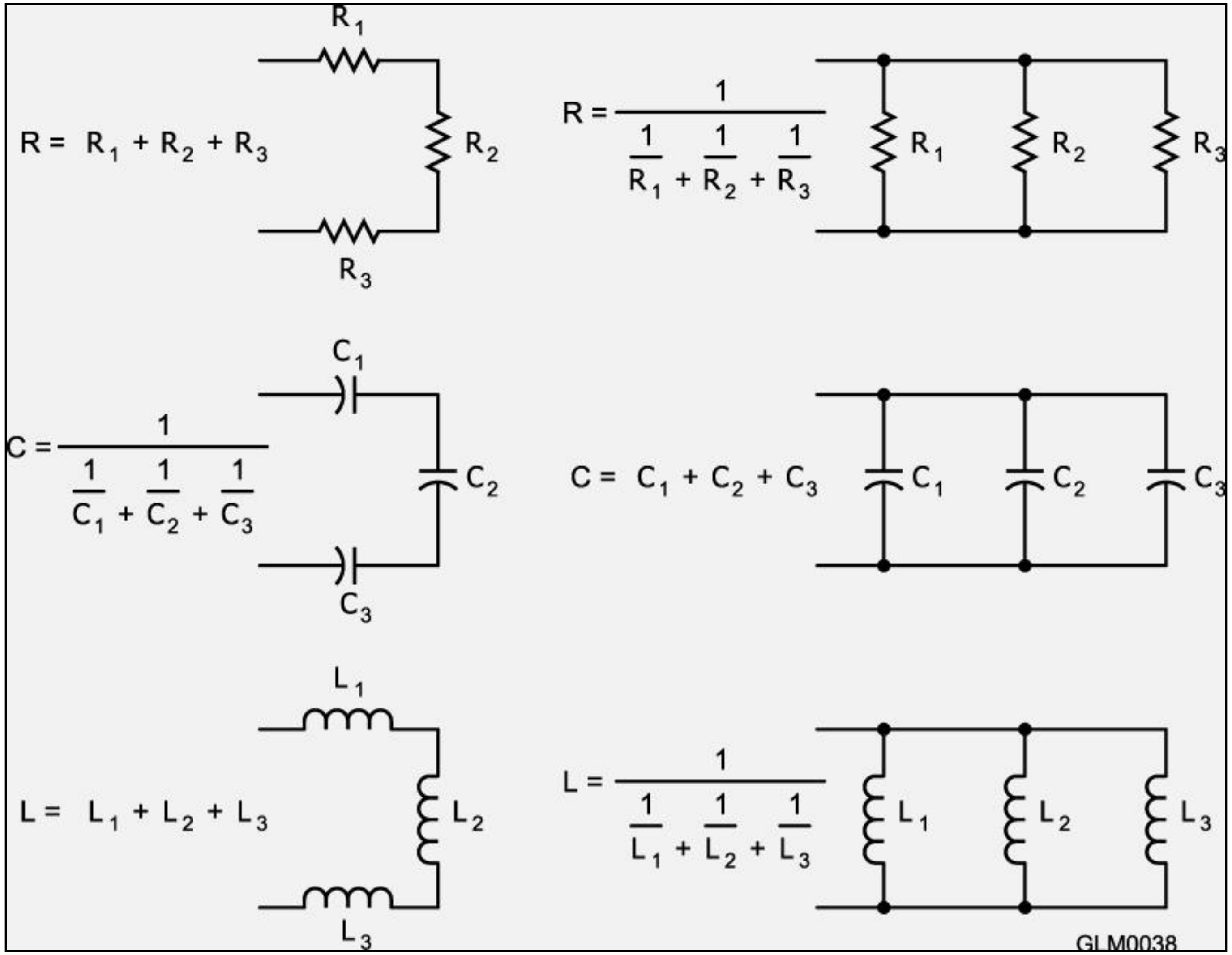
Refer to Figure 4.10

Effect on Total Value of Adding Components in Series and Parallel

COMPONENT	ADDING IN SERIES	ADDING IN PARALLEL
RESISTOR	INCREASE	DECREASE
INDUCTOR	INCREASE	DECREASE
CAPACITOR	DECREASE	INCREASE

Refer to Figure 4.10

Figure 4.10: This drawing illustrates how components in series and parallel can be combined into a single equivalent component value.



Examples: Calculating Series & Parallel Equivalent Values

Three 100 Ω resistors …

In Series … $R_{EOU} = 100 + 100 + 100 = 300\ \Omega$

In Parallel … $R_{EQU} = \dfrac{1}{\frac{1}{100} + \frac{1}{100} + \frac{1}{100}} = \dfrac{1}{\frac{3}{100}} = \dfrac{100}{3} = 33.3\ \Omega$

Three 100 µF capacitors …

In Series … $C_{EQU} = \dfrac{1}{\frac{1}{100} + \frac{1}{100} + \frac{1}{100}} = \dfrac{1}{\frac{3}{100}} = \dfrac{100}{3} = 33.3\ \mu\text{F}$

In Parallel … $C_{EOU} = 100 + 100 + 100 = 300\ \mu\text{F}$

Calculating Series & Parallel Equivalent Values (cont.)

With only two components, the *reciprocal of reciprocals* calculation is greatly simplified …

$$R_{EQU} = \frac{R1 \times R2}{R1 + R2}$$

Inductance of a 20 mH and 50 mH inductor …

In series … $L_{EOU} = 20 + 50 = 70\ mH$

In parallel … $L_{EQU} = \frac{L1 \times L2}{L1 + L2} = \frac{20 \times 50}{20 + 50} = 14.29\ mH$

PRACTICE QUESTIONS

How does the total current relate to the individual currents in each branch of a purely resistive parallel circuit?

A. It equals the average of each branch current
B. It decreases as more parallel branches are added to the circuit
C. It equals the sum of the currents through each branch
D. It is the sum of the reciprocal of each individual voltage drop

Which of the following components increases the total resistance of a resistor?

A. A parallel resistor
B. A series resistor
C. A series capacitor
D. A parallel capacitor

What is the total resistance of three 100 ohm resistors in parallel?

A. 0.30 ohms
B. 0.33 ohms
C. 33.3 ohms
D. 300 ohms

If three equal value resistors in series produce 450 ohms, what is the value of each resistor?

A. 1500 ohms
B. 90 ohms
C. 150 ohms
D. 175 ohms

What is the equivalent capacitance of two 5.0 nanofarad capacitors and one 750 picofarad capacitor connected in parallel?

A. 576.9 nanofarads
B. 1733 picofarads
C. 3583 picofarads
D. 10.750 nanofarads

What is the capacitance of three 100 microfarad capacitors connected in series?

A. 0.30 microfarads
B. 0.33 microfarads
C. 33.3 microfarads
D. 300 microfarads

What is the inductance of three 10 millihenry inductors connected in parallel?

A. 0.30 henries
B. 3.3 henries
C. 3.3 millihenries
D. 30 millihenries

What is the inductance of a 20 millihenry inductor connected in series with a 50 millihenry inductor?

A. 0.07 millihenries
B. 14.3 millihenries
C. 70 millihenries
D. 1000 millihenries

What is the capacitance of a 20 microfarad capacitor connected in series with a 50 microfarad capacitor?

A. 0.07 millihenries
B. 14.3 millihenries
C. 70 millihenries
D. 1000 millihenries

Which of the following components should be added to a capacitor to increase the capacitance?

A. An inductor in series
B. A resistor in series
C. A capacitor in parallel
D. A capacitor in series

Which of the following components should be added to an inductor to increase the inductance?

A. A capacitor in series
B. A resistor in parallel
C. An inductor in parallel
D. An inductor in series

What is the total resistance of a 10 ohm, a 20 ohm, and a 50 ohm resistor connected in parallel?

A. 5.9 ohms
B. 0.17 ohms
C. 10000 ohms
D. 80 ohms

Reactance

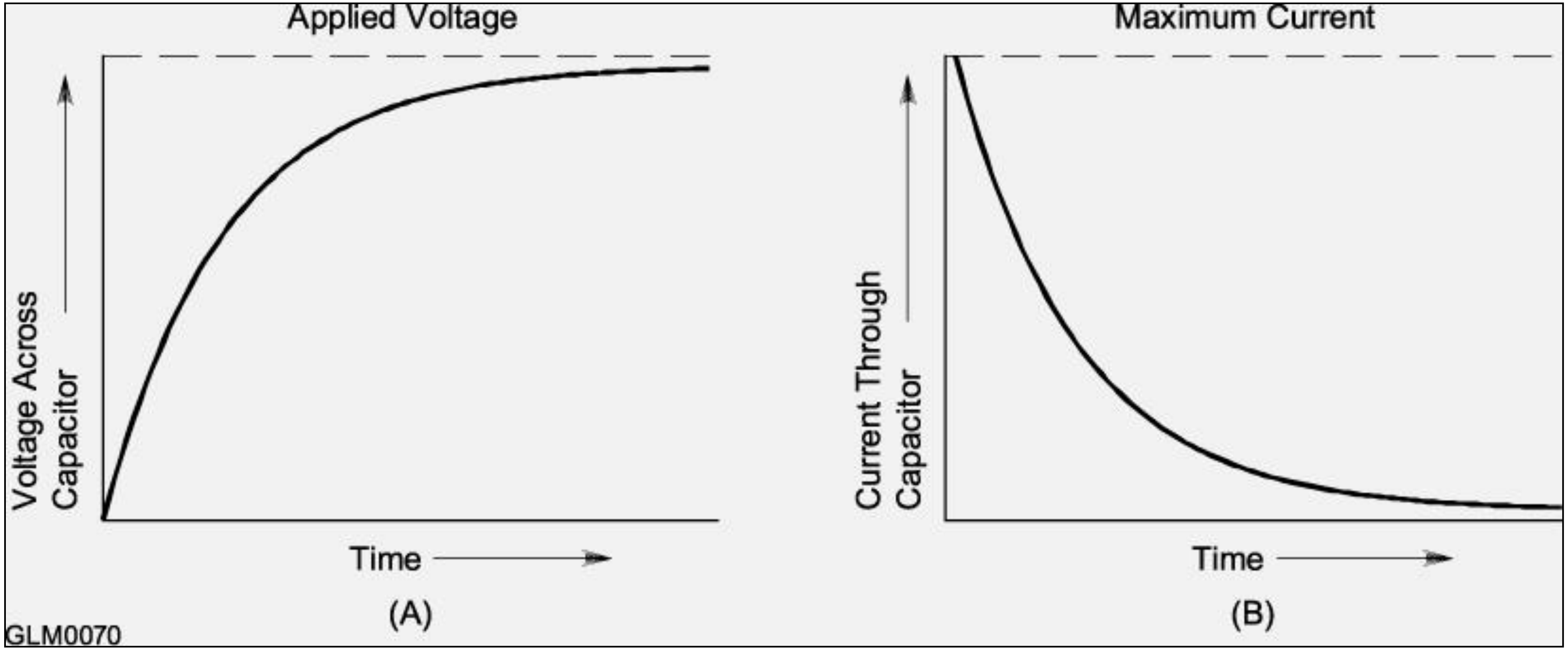
- Reactance: Resistance to the flow of ac current caused by capacitance or inductance. Denoted by *X*. Measured in ohms (*Ω*), like resistance.
- Capacitive reactance: Opposition to ac current flow from the stored energy in a capacitor. Denoted by X_C.
- Capacitors behave differently with ac and dc current. With dc, when voltage is initially applied, capacitor looks like a short circuit. After charging, it looks like an open circuit. This is how it blocks dc signals. AC behavior depends upon voltage frequency.

Capacitive Reactance

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

$f = frequency\,(Hz)$
$C = capacitance\,(farads)$

As the frequency of the applied signal increases, X_C decreases, and vice versa



Reactance (cont.)

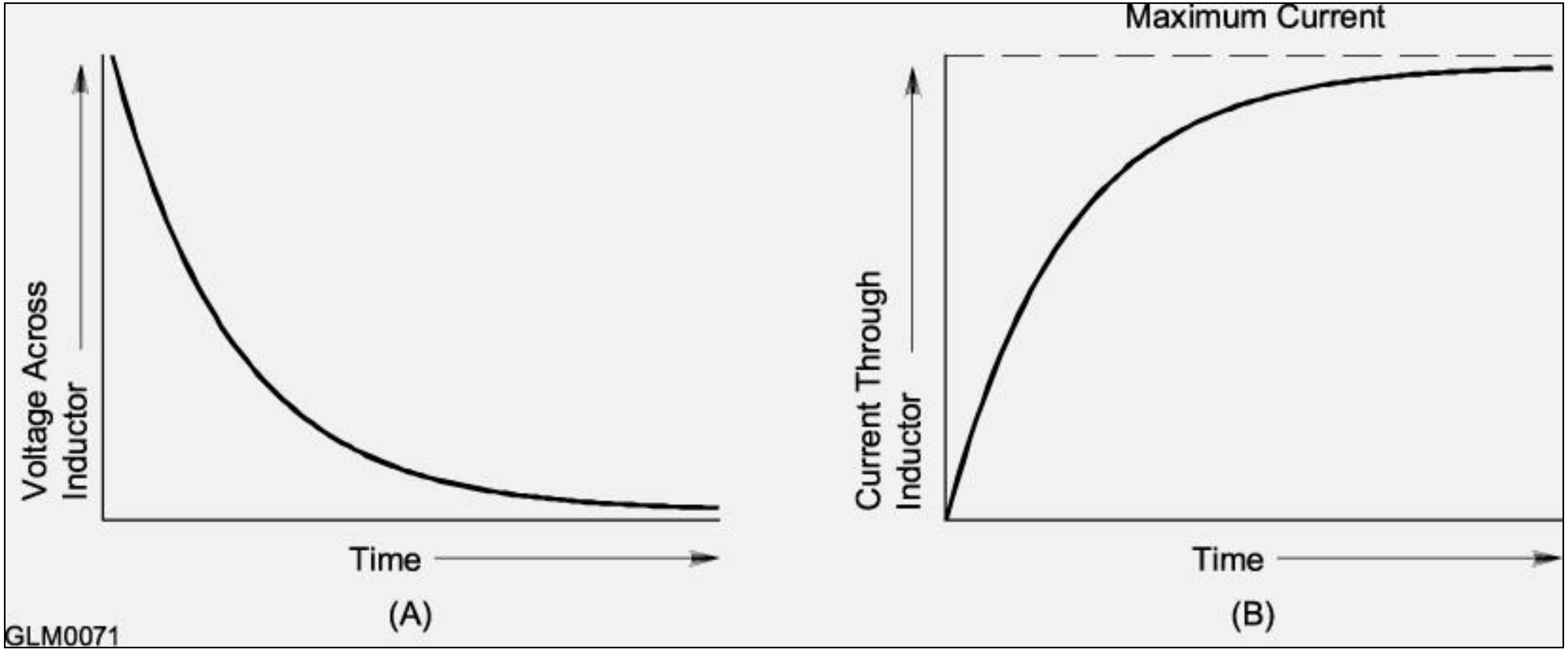
- Inductive reactance is the opposition to ac current flow from the stored energy in a inductor and is denoted by X_L
- Behavior with frequency is described by:

$$X_L = 2\pi f L$$

f = frequency (Hz)
L = inductance (henrys)

Inductive Reactance

As the frequency of the applied signal increases, X_L increases, and vice versa



Parasitic Inductance

- Parasitic: an unwanted characteristic resulting from the component's physical construction. Examples:
  - The coils in wire-wound resistors (coils create parasitic inductance)
  - Wire leads of components
  - In inductors, each pair of turns creates parasitic capacitance in series with the inductance
- Often significant enough to disrupt circuit's operation or affect tuning in radios

PRACTICE QUESTIONS

What is reactance?

A. Opposition to the flow of direct current caused by resistance
B. Opposition to the flow of alternating current caused by capacitance or inductance
C. A property of ideal resistors in AC circuits
D. A large spark produced at switch contacts when an inductor is de-energized

Which of the following causes opposition to the flow of alternating current in an inductor?

A. Conductance
B. Reluctance
C. Admittance
D. Reactance

Which of the following causes opposition to the flow of alternating current in a capacitor?

A. Conductance
B. Reluctance
C. Admittance
D. Reactance

How does an inductor react to AC?

A. As the frequency of the applied AC increases, the reactance decreases
B. As the amplitude of the applied AC increases, the reactance increases
C. As the amplitude of the applied AC increases, the reactance decreases
D. As the frequency of the applied AC increases, the reactance increases

How does a capacitor react to AC?

A. As the frequency of the applied AC increases, the reactance decreases
B. As the frequency of the applied AC increases, the reactance increases
C. As the amplitude of the applied AC increases, the reactance increases
D. As the amplitude of the applied AC increases, the reactance decreases

What unit is used to measure reactance?

A. Farad
B. Ohm
C. Ampere
D. Siemens

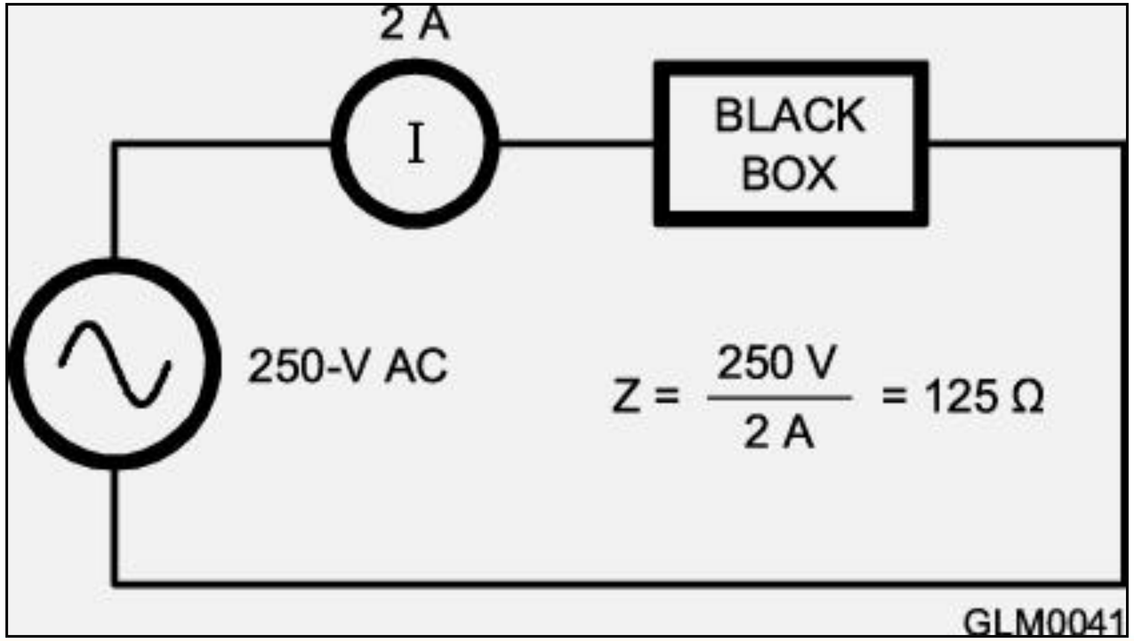
Which of the following is a reason not to use wire-wound resistors in an RF circuit?

A. The resistor’s tolerance value would not be adequate for such a circuit
B. The resistor’s inductance could make circuit performance unpredictable
C. The resistor could overheat
D. The resistor’s internal capacitance would detune the circuit

Impedance

- Impedance is the opposition to current flow in an ac circuit caused by resistance, reactance, or any combination of the two. Denoted by *Z*. Measured in ohms.
- Like resistance, it's the ratio of voltage to current (Fig. 4.13).

Figure 4.13

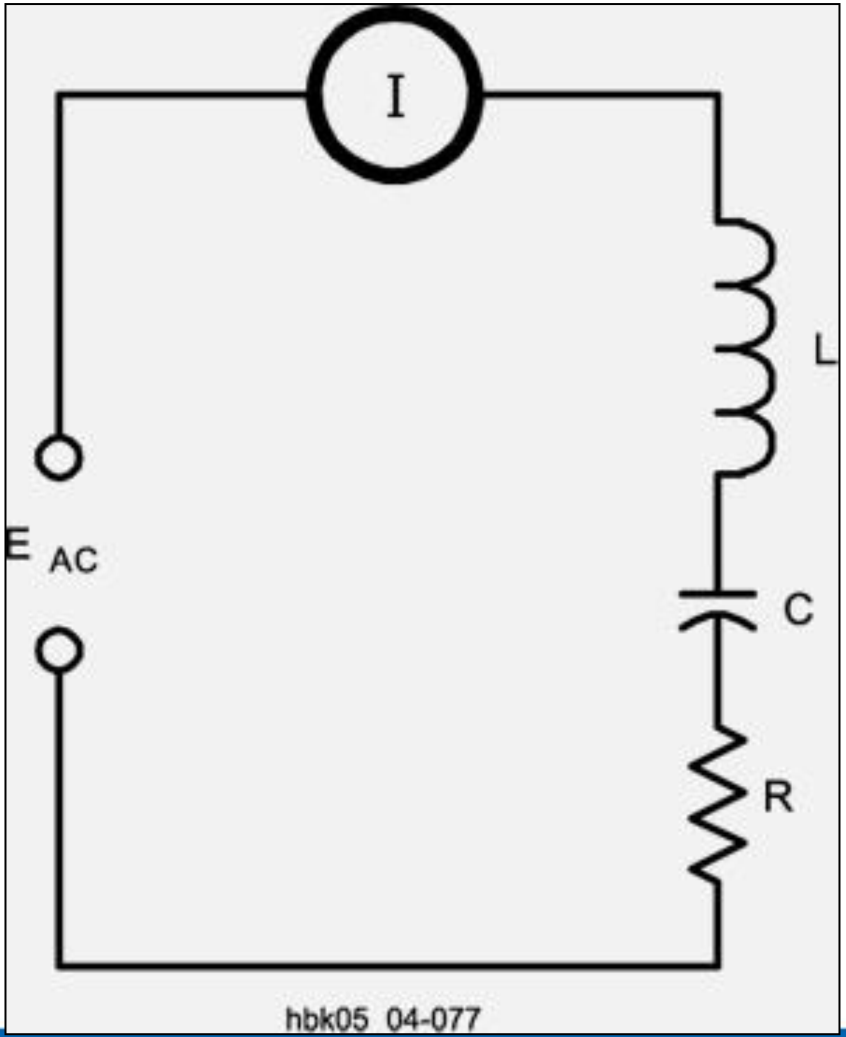


Resonance

- Resonance is the condition in which there is a match between the frequency at which a circuit or antenna naturally responds to the frequency of an applied signal
- Occurs when capacitive and inductive reactance are equal
- In a resonant series circuit, reactance of L and C cancel, making a short circuit, leaving only the resistance (R) as the circuit's impedance
- Used in filters & tuned circuits to pass or reject specific frequencies

Resonant Series Circuit

In a resonant series circuit, the reactance of L and the reactance of C cancel, making a short circuit. This leaves only the resistance (R) as the circuit's impedance.



Self-Resonance

- Resonance can occur when a component's expected reactance equals the reactance of it's parasitic reactance (called *self-resonance*
- Results in a component that appears to be a short or open circuit at the self-resonant frequency
- Above this frequency, the component's reactance switches type, making an inductor capacitive and a capacitor inductive!

Impedance Transformation

- A transformer can change the combination of voltage and current while transferring energy
- The transformer also changes impedance between the primary and secondary circuits (by changing the ratio of voltage and current between the primary and secondary circuits)
- The turns ratio controls the transformation in the same way as the ratio of gear teeth in a mechanical transmission

Impedance Transformation Examples

$$Z_P = Z_S\left[\frac{N_P}{N_S}\right] \quad \text{or} \quad \sqrt{\frac{Z_P}{Z_S}} = \frac{N_P}{N_S}$$

What is the primary impedance if a 200 Ω load is connected to the secondary of a transformer with a 5:1 secondary-to-primary turns ratio?

$$Z_P = Z_S\left[\frac{N_P}{N_S}\right] = 200\left[\frac{1}{5}\right]^2 = 8\ \Omega$$

Impedance Transformation Examples (cont.)

What turns ratio is required to change a 600 Ω impedance to a 4 Ω impedance?

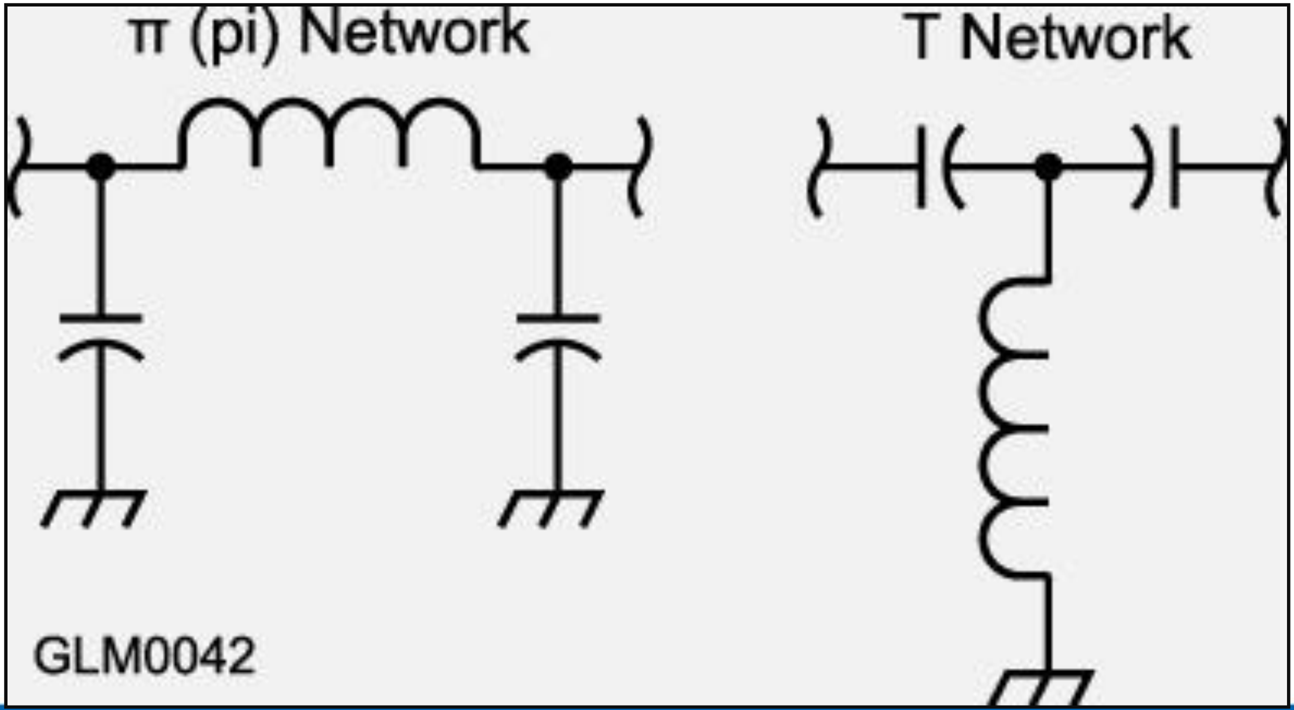
$$Turns\ ratio = \frac{N_P}{N_S} = \sqrt{\frac{Z_P}{Z_S}} = \sqrt{\frac{600}{4}} = \sqrt{150} = 12.25$$

Impedance Matching

- An energy source's ability to deliver power to a load is limited by its *internal impedance*
- Amateur transmitting equipment is designed so that the internal impedance of its output circuits is 50 Ω
- If the difference between the antenna system impedance and transmitter's out impedance is great enough, the transmitter may reduce output power to avoid damage (solution is an *impedance-matching circuit*)

Impedance Matching (cont.)

- Most impedance-matching circuits are *LC* circuits (inductors and capacitors) … see figure below:



Impedance matching can also be performed by special lengths and connections of transmission lines.

PRACTICE QUESTIONS

What is impedance?

A. The electric charge stored by a capacitor
B. The inverse of resistance
C. The opposition to the flow of current in an AC circuit
D. The force of repulsion between two similar electric fields

What happens when the impedance of an electrical load is equal to the output impedance of a power source, assuming both impedances are resistive?

A. The source delivers minimum power to the load
B. The electrical load is shorted
C. No current can flow through the circuit
D. The source can deliver maximum power to the load

What is one reason to use an impedance matching transformer?

A. To minimize transmitter power output
B. To maximize the transfer of power
C. To reduce power supply ripple
D. To minimize radiation resistance

Which of the following devices can be used for impedance matching at radio frequencies?

A. A transformer
B. A Pi-network
C. A length of transmission line
D. All these choices are correct

Which of the following describes one method of impedance matching between two AC circuits?

A. Insert an LC network between the two circuits
B. Reduce the power output of the first circuit
C. Increase the power output of the first circuit
D. Insert a circulator between the two circuits

What is the turns ratio of a transformer used to match an audio amplifier having 600 ohm output impedance to a speaker having 4 ohm impedance?

A. 12.2 to 1
B. 24.4 to 1
C. 150 to 1
D. 300 to 1

What happens when an inductor is operated above its self-resonant frequency?

A. Its reactance increases
B. Harmonics are generated
C. It becomes capacitive
D. Catastrophic failure is likely

END OF MODULE 4a

Slides created by …

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Feel free to contact me if you find errors or have suggestions for improvement.