Today

1. Radio Fundamentals
2. Electricity
3. Electrical Circuits and Components (as much as we have time for)
   1. Next Week we'll pick up next week where we left off

- 1pm: Amateur Radio Club Meeting
  - Everyone is welcome to join!
  - We'll be joined by our ARES Emergency Coordinator and Training Coordinator

Metric Prefixes – The Language of Radio (see Table 2.1)

- Metric system used because numbers cover large range of values
- Most common prefixes in radio …
  - Pico (p), 0.000000000001, 10^{-12}
  - Nano (n), 0.000000001, 10^{-9}
  - Milli (m), 0.001, 10^{-3}
  - Centi (c), 0.01, 10^{-2}
  - Kilo (k), 1000, 10^{3}
  - Mega (**M**), 1000000, 10^{6}
  - Giga (**G**), 1000000000, 10^{9}

*NOTE: **M**ega and **G**iga use capital letters in the abbreviation.*

Table 2.1: International System of Units (SI) — Metric Units

PREFIX	SYMBOL	MULTIPLICATION FACTOR
Tera	T	10^{12} = 1,000,000,000,000
Giga	G	10^{9} = 1,000,000,000
Mega	M	10^{6} = 1,000,000
Kilo	k	10^{3} = 1000
Hecto	h	10^{2} = 100
Deca	da	10^{1} = 10
Deci	d	10^{-1} = 0.1
Centi	c	10^{-2} = 0.01
Milli	m	10^{-3} = 0.001
Micro	µ	10^{-6} = 0.000001
Nano	n	10^{-9} = 0.000000001
Pico	p	10^{-12} = 0.000000000001

NOTE

$$10^{-1} = \frac{1}{10}$$

$$10^{-2} = \frac{1}{100}$$

$$10^{-3} = \frac{1}{1000}$$

PRACTICE QUESTIONS

We will cover some, but not all, of the practice questions – some study will be necessary!

How many milliamperes is 1.5 amperes?

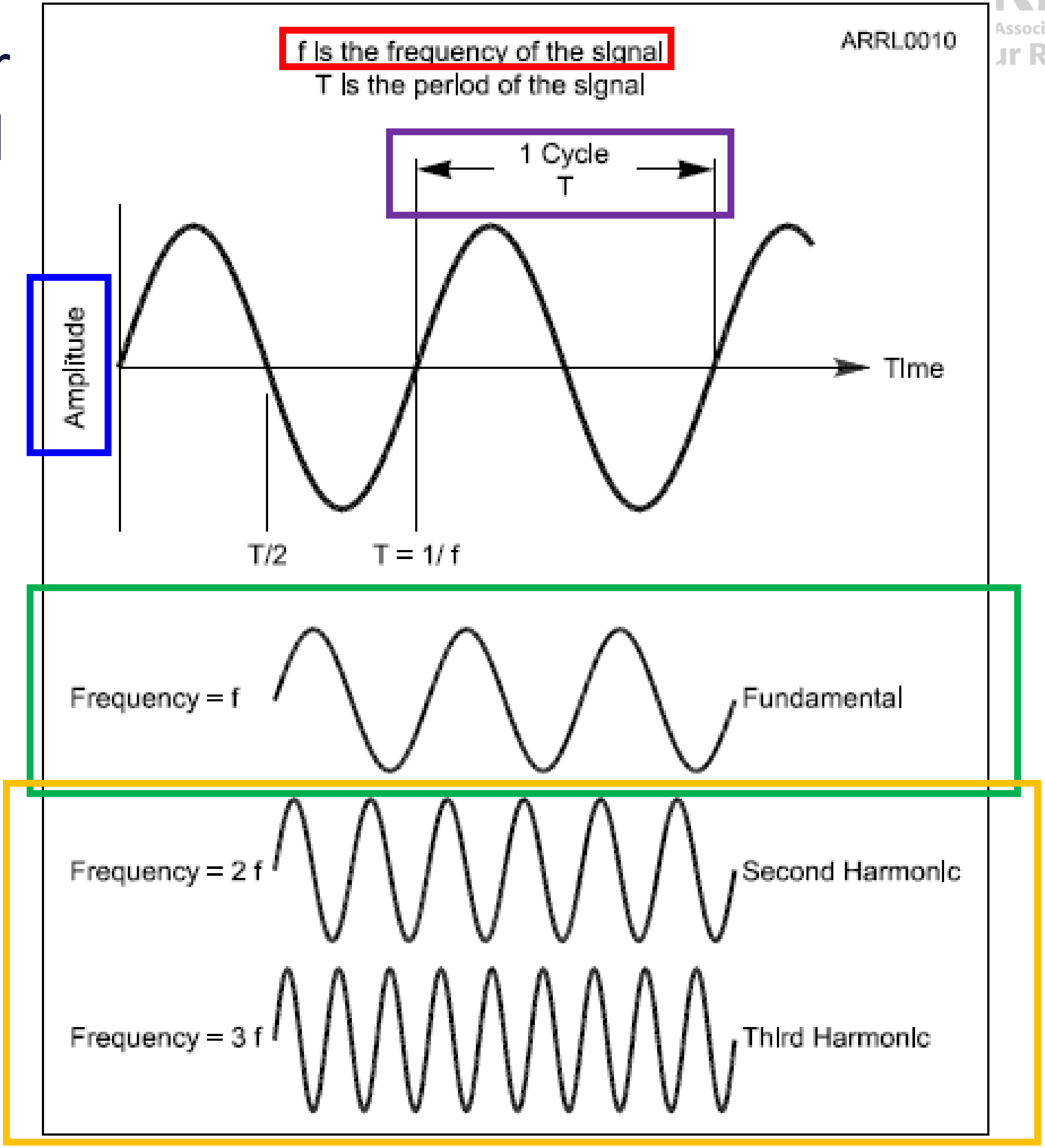
A. 15 milliamperes
B. 150 milliamperes
C. 1500 milliamperes
D. 15,000 milliamperes

T5B01 C 2-2 *(Format: **T5B01** = test pool question, **C** = correct answer, **2-2** = page number in manual)*

Electromagnetic Waves

- Electromagnetic waves are made up of *electric* and *magnetic* energy (fields)
  - Vary in the pattern of a sine wave
  - Travel at the speed of light
- How radios communicate with electromagnetic waves:
  - Transmitter signal makes electrons in the antenna move
  - Antenna radiates this energy as electromagnetic waves
  - Waves travel some distance
  - As the waves encounter an antenna, the electrons in the antenna move in sync with the wave, which is interpreted by the receiver

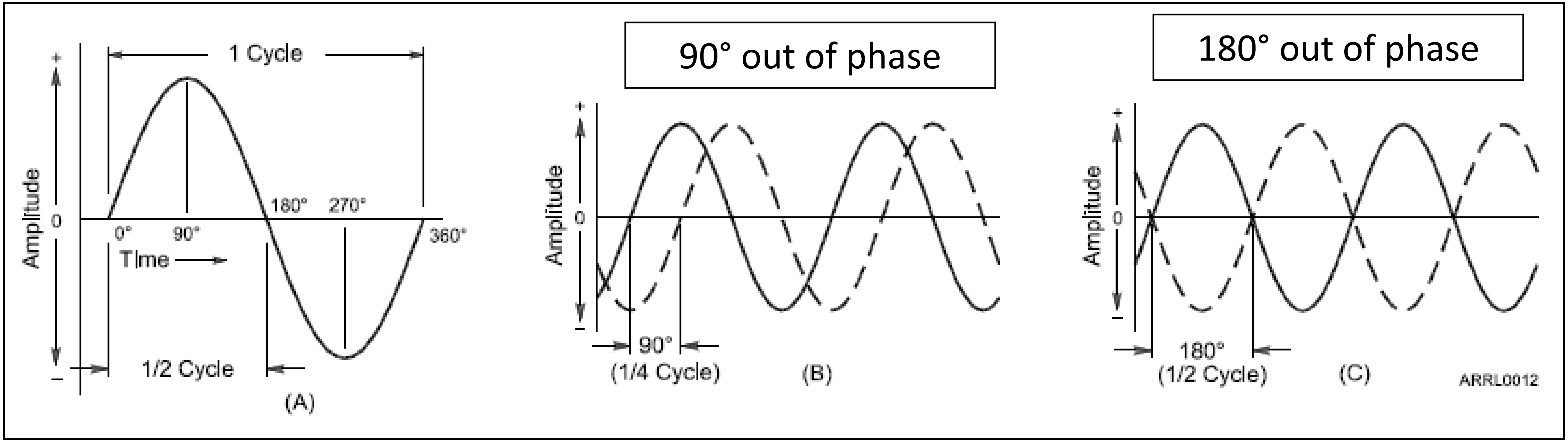
Figure 2.1: The frequency of a signal and its period are reciprocals. Higher frequency means shorter period and vice-versa.



WAVE VOCABULARY

- Oscillation
- Amplitude
- Frequency (hertz, Hz, cycles/sec)
- Period (T, seconds, s)
- Fundamental
- Harmonics

Phase



Position within a cycle is called ***phase***. Phase is used to compare how sine wave signals are aligned in time. Measured in degrees.

What is the unit of frequency?

A. Hertz
B. Henry
C. Farad
D. Tesla

T5A06 A 2-3

What describes the number of times per second that an alternating current makes a complete cycle?

A. Pulse rate
B. Speed
C. Wavelength
D. Frequency

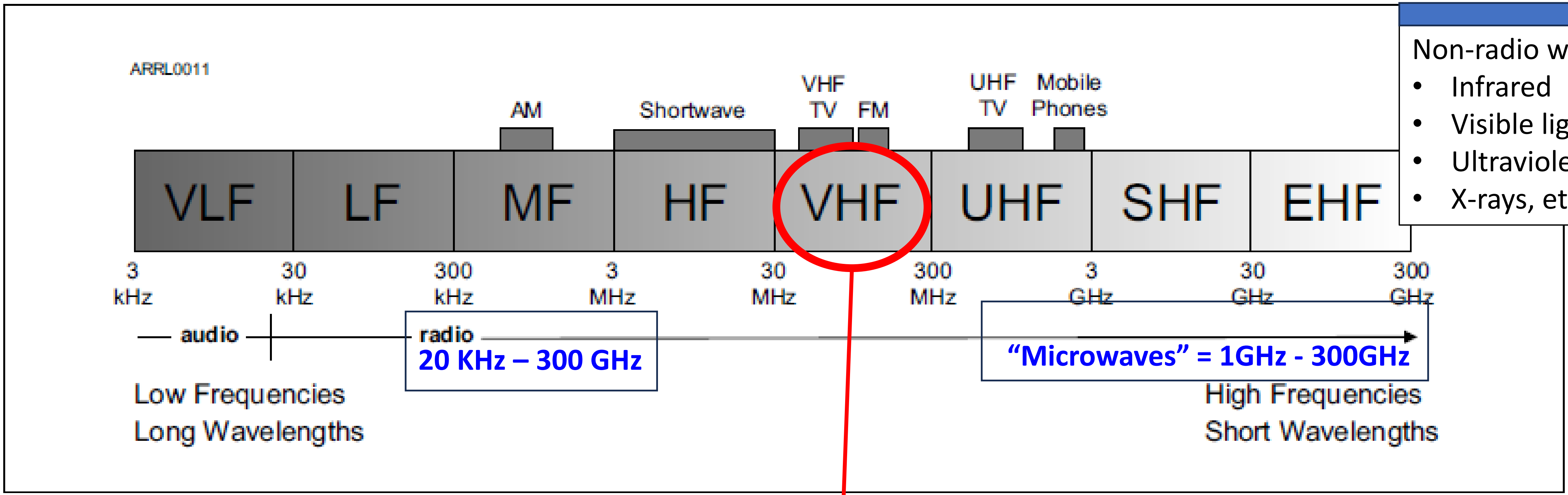
T5A12 D 2-3

What is the abbreviation for kilohertz?

A. KHZ
B. khz
C. khZ
D. kHz

T5C13 D 2-3

The Radio ("RF") Spectrum



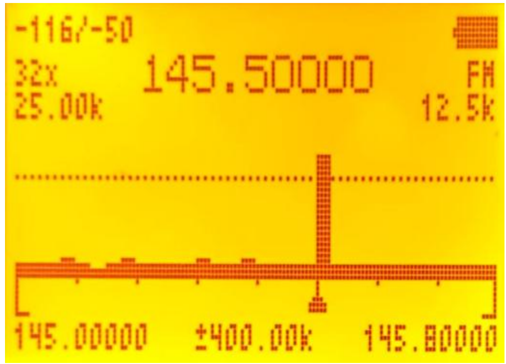
Non-radio waves:
- Infrared
- Visible light
- Ultraviolet
- X-rays, etc

"Band": range of frequencies with similar properties or common purpose
"Amateur Bands": bands used by hams (e.g., 144-148 MHz)

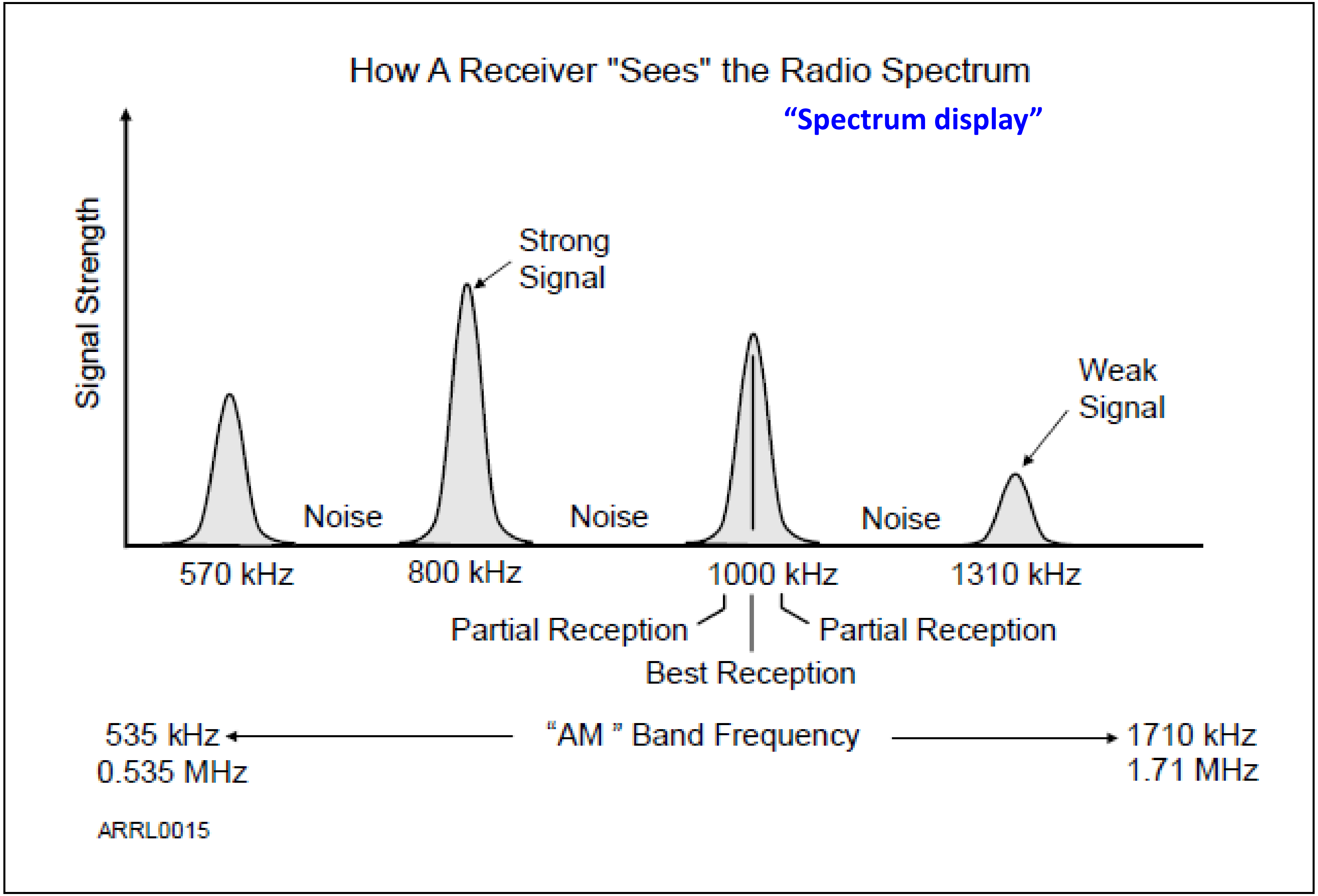
Table 2.2: RF Spectrum Ranges

Range Name	Abbreviation	Frequency Range
Very Low Frequency	VLF	3 kHz – 30 kHz
Low Frequency	LF	30 kHz – 300 kHz
Medium Frequency	MF	300 kHz – 3 MHz
High Frequency	HF	3 MHz – 30 MHz
Very High Frequency	VHF	30 MHz – 300 MHz
Ultra High Frequency	UHF	300 MHz – 3 GHz
Super High Frequency	SHF	3 GHz – 30 GHz
Extremely High Frequency	EHF	30 GHz – 300 GHz

Figure 2.4



-116/-50
32x
25.00k
145.50000
FM
12.5k
145.00000
±400.00k
145.80000



How A Receiver "Sees" the Radio Spectrum
"Spectrum display"
Signal Strength
Strong Signal
Weak Signal
Noise
Noise
Noise
570 kHz
800 kHz
1000 kHz
1310 kHz
Partial Reception
Partial Reception
Best Reception
535 kHz
0.535 MHz
"AM" Band Frequency
1710 kHz
1.71 MHz
ARRL0015

What frequency range is referred to as VHF?

A. 30 kHz to 300 kHz
B. 30 MHz to 300 MHz
C. 300 kHz to 3000 kHz
D. 300 MHz to 3000 MHz

T3B08 B 2-4

What does the abbreviation “RF” mean?

A. Radio frequency signals of all types
B. The resonant frequency of a tuned circuit
C. The real frequency transmitted as opposed to the apparent frequency
D. Reflective force in antenna transmission lines

T5C06 A 2-4

Wavelength (λ)

$$\lambda = \frac{c}{f}$$

← Speed of light

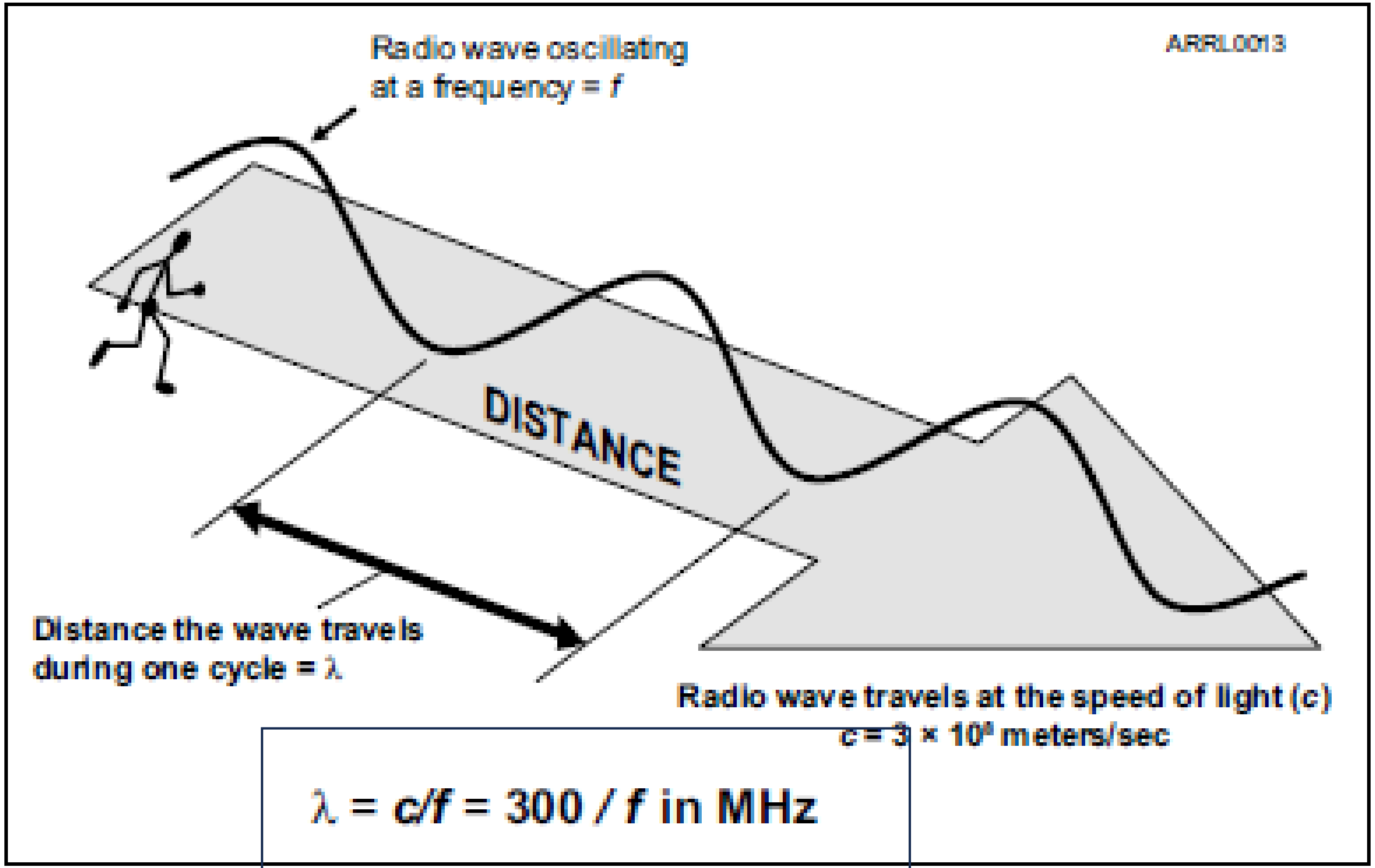
← Frequency (Hz)

Wavelength = meters per cycle

Ham bands can be referred to by:

- Frequency (144MHz)
- Wavelength (2m)

If you know c or f, you know the other!
(frequency, wavelength)



$\lambda = c/f = 300 / f$ in MHz

(after converting units for MHz)

What is the velocity of a radio wave traveling through free space?

A. Speed of light
B. Speed of sound
C. Speed inversely proportional to its wavelength
D. Speed that increases as the frequency increases

T3B04 A 2-5

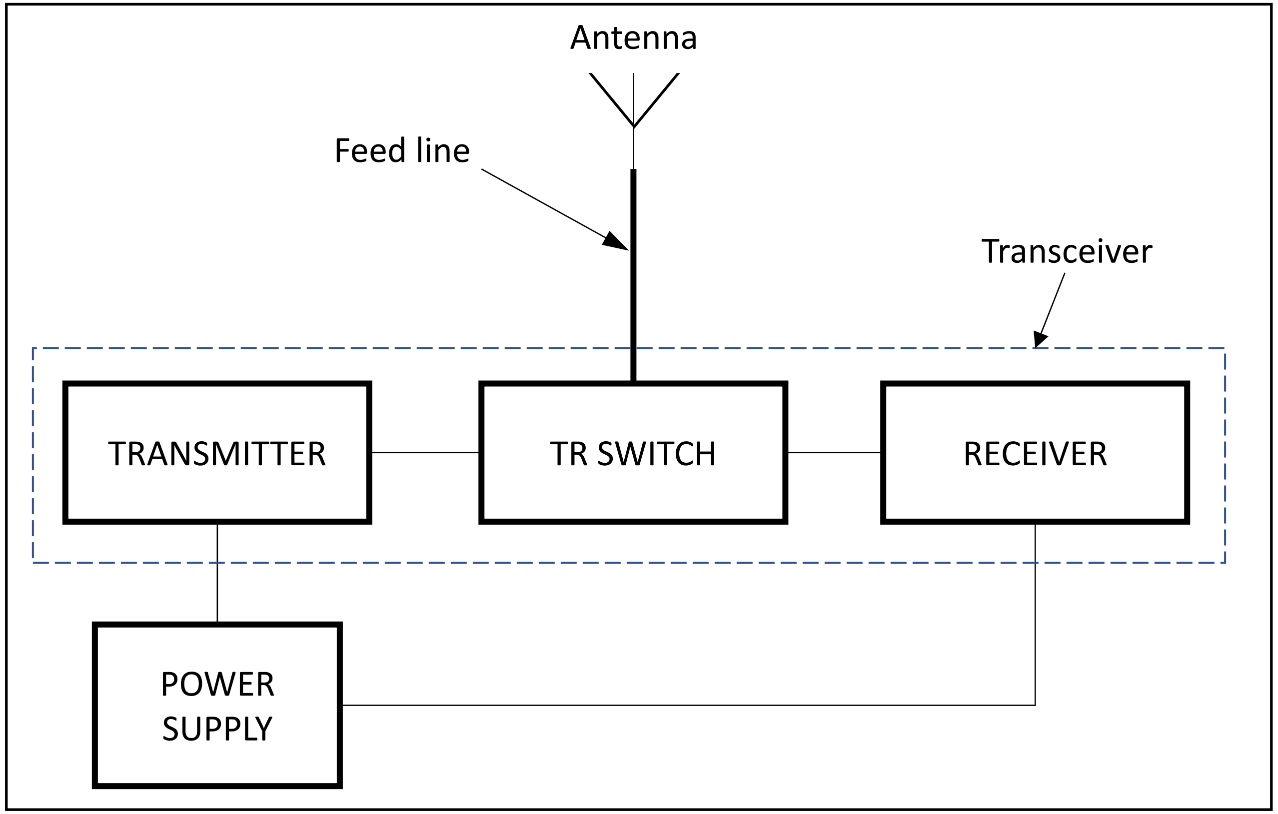
What is the formula for converting frequency to approximate wavelength in meters?

A. Wavelength in meters equals frequency in hertz multiplied by 300
B. Wavelength in meters equals frequency in hertz divided by 300
C. Wavelength in meters equals frequency in megahertz divided by 300
D. Wavelength in meters equals 300 divided by frequency in megahertz

T3B06 D 2-5

Radio Station Basics – 3 Elements

- **Transmitter ("XMTR")**
  - Generates a signal from speech/CW/data
- **Receiver ("RCVR")**
  - Recovers the speech/CW/data from the signal
- **Antenna**
  - Converts signals from the transmitter into radio waves
  - Captures radio waves, turns them into signals for the receiver
- **Feed line / Transmission line**
  - Connects the antenna to the transmitter/receiver

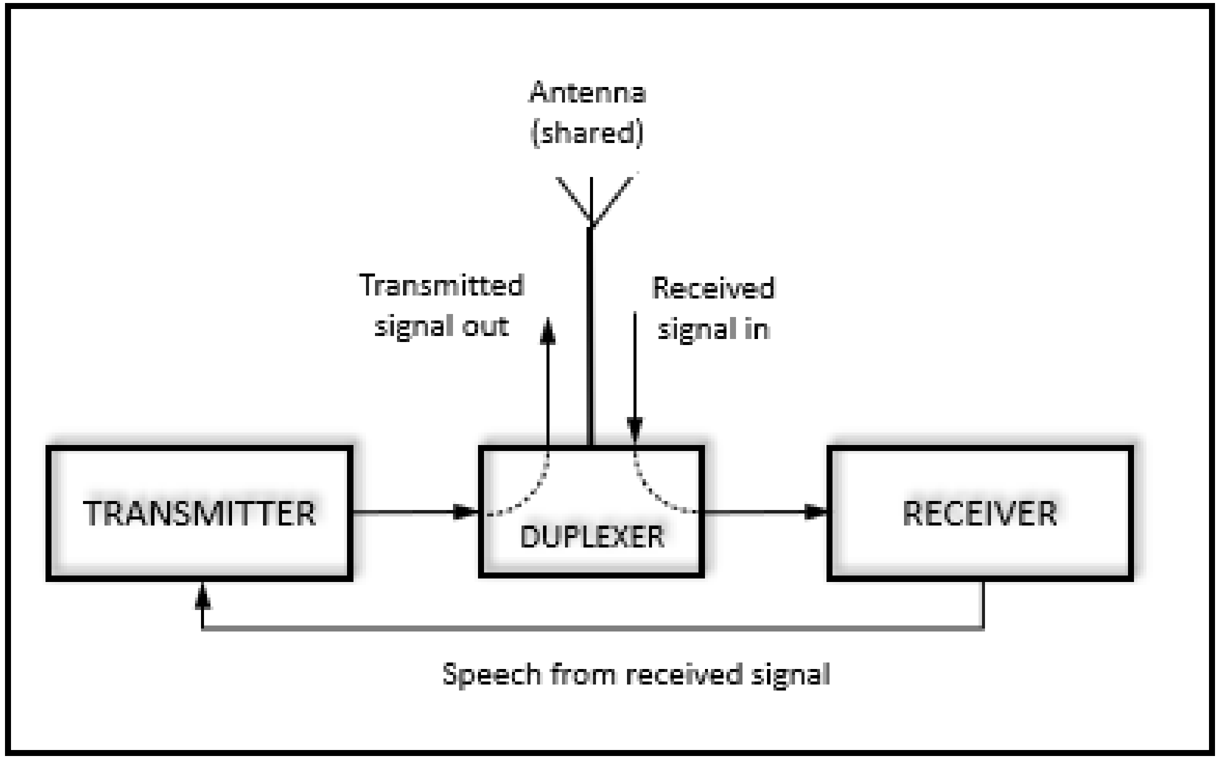


Most amateur radios are **Transceivers ("XCVR"),** which combine a transmitter with a receiver

CW = "continuous wave", frequently conveying Morse Code

Repeaters

- A radio that simultaneously re-transmits received signals on a *different* frequency
  - **"Duplex communication"**
- Purpose: allow low-power portable stations to communicate over a larger area
  - Usually at high points (mountains, buildings)
  - Critical resource in emergencies
- More about repeaters coming in a later chapter



What is a transceiver?

A. A device that combines a receiver and transmitter
B. A device for matching feed line impedance to 50 ohms
C. A device for automatically sending and decoding Morse code
D. A device for converting receiver and transmitter frequencies to another band

T7A02 A 2-7

What type of amateur station simultaneously retransmits the signal of another amateur station on a different channel or channels?

A. Beacon station
B. Earth station
C. Repeater station
D. Message forwarding station

T1F09 C 97.3(a)(40) 2-8

Fundamentals of Electricity

- Radios are powered by electricity and radio signals are a form of electrical energy
- A basic understanding of how we control electricity allows you to better install and operate your radio
- Electrical charge can be positive or negative
  - Opposite charges attract each other (like charges repel)
- Electrical current is the flow of ***electrons***
  - ***Electron:*** negatively-charged atomic particle
    - Electrons surround the atom's nucleus of protons (+) and neutrons (neutral – no charge)
    - Electrons move in response to ***electromotive force*** and are not tied to a single atom

Basic Electrical Concepts

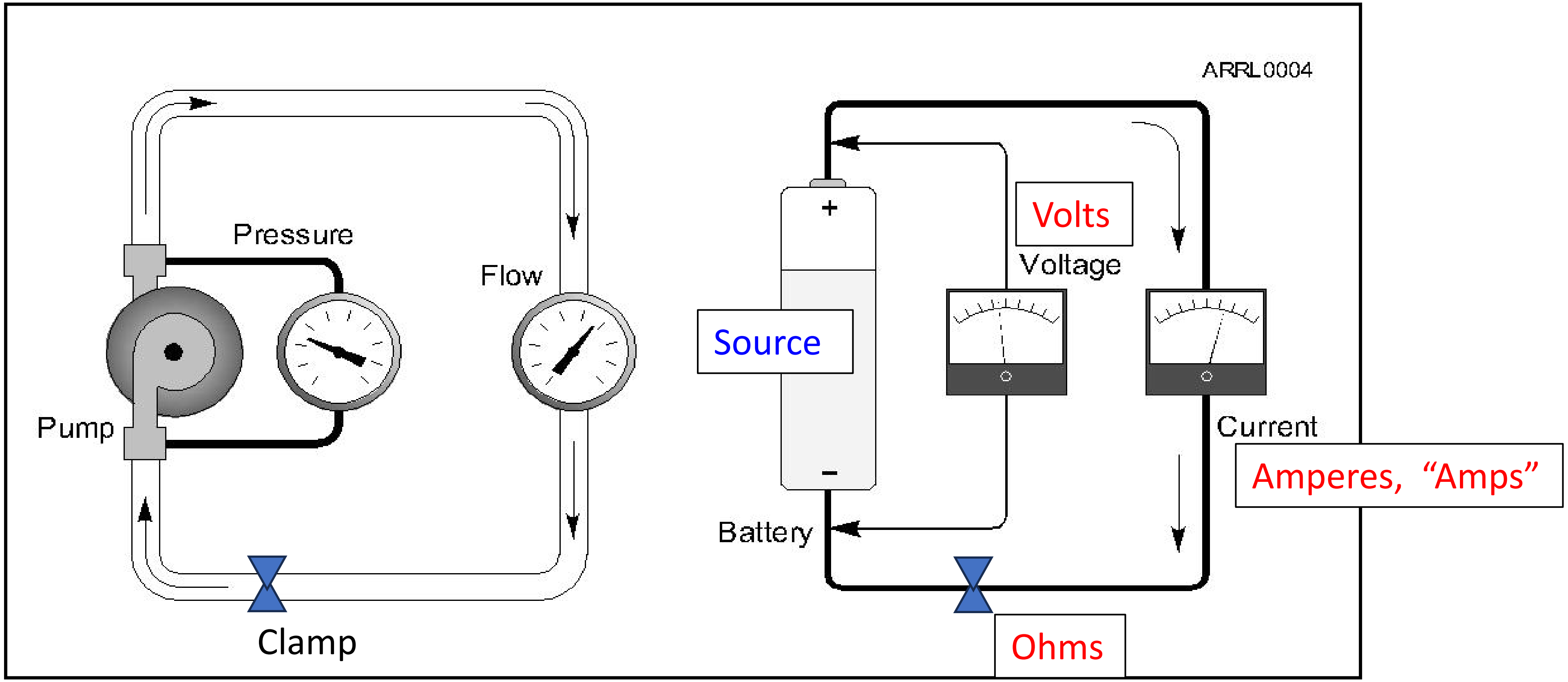
- **Voltage**: electromotive force "electric potential"
  - **Units**: volts (***V***) *(may be represented by **E** or **V** in formulas)*
  - Measured by a *voltmeter*
- **Current:** movement of electrons
  - **Units:** amperes ("amps", ***A***) *(represented by **I** in formulas)*
  - Measured by an *ammeter*
- **Resistance:** opposition to current
  - **Units:** ohms (***Ω***) *(represented by **R** in formulas)*
  - Measured by an *ohmmeter*

Voltage, Current and Resistance all affect each other in a circuit

- **Conductors** permit current flow (low resistance)
- **Insulators** block current flow (high resistance)
- **Polarity** indicates whether voltages are **+** or **-**

Basic Electrical Concepts (cont.)

- Analogy: water flowing through a pipe

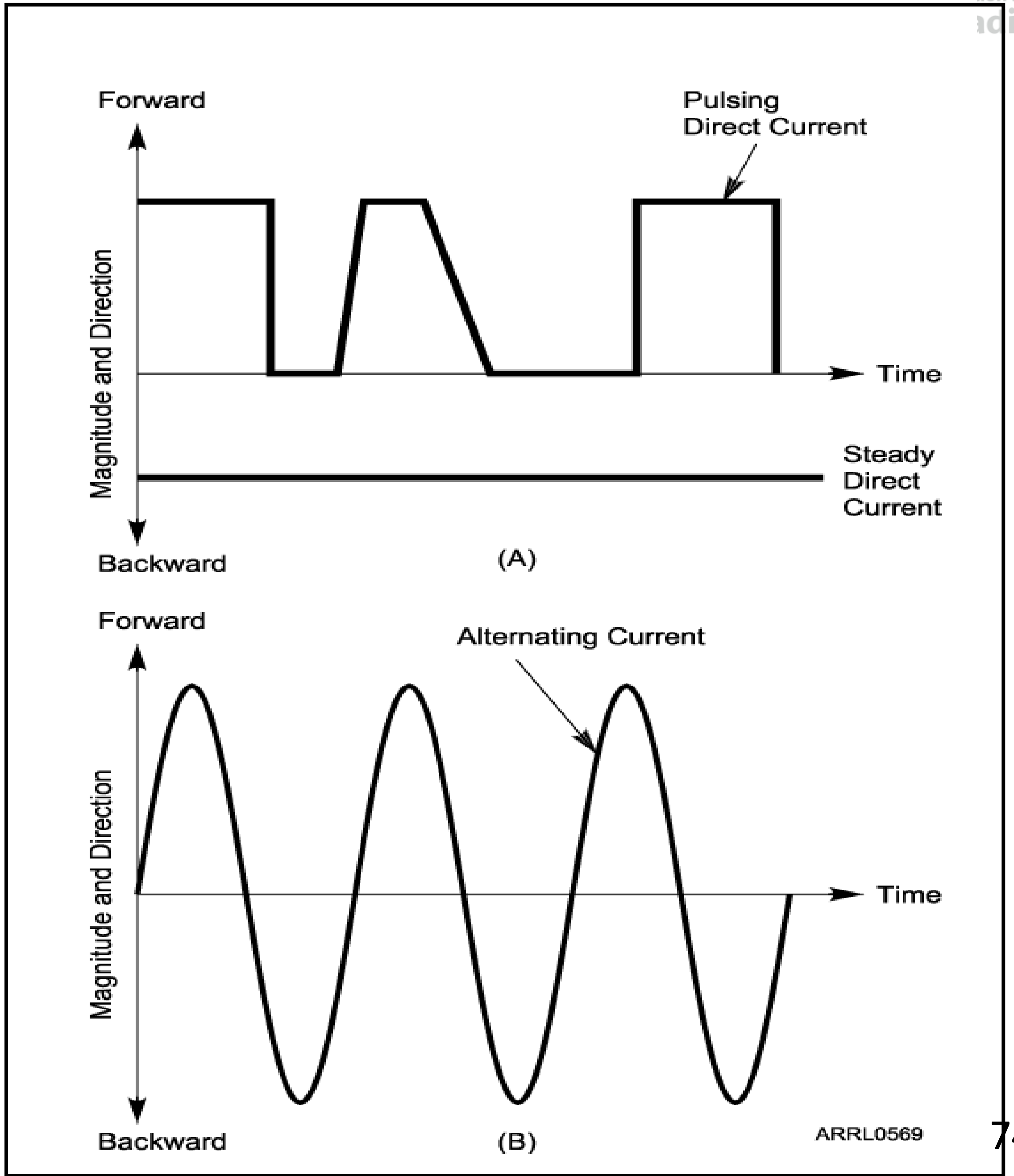


Multimeters

- 3 basic test meters: voltmeters, ammeters, and ohmmeters
- *Multimeters* combine all 3 into a single tool
  - Short for "multifunction meter"
  - Measures all three electrical values: voltage, current, and resistance
  - Other names: *VOM* (volt-ohm meter) or *DVM* (digital volt meter)
- Ways meters are damaged:
  - Measuring voltage of an energized circuit when the meter is set to measure resistance
  - Exceeding meter's voltage rating … voltmeter and leads not rated for use at the voltages to be measured

The Two Kinds of Current

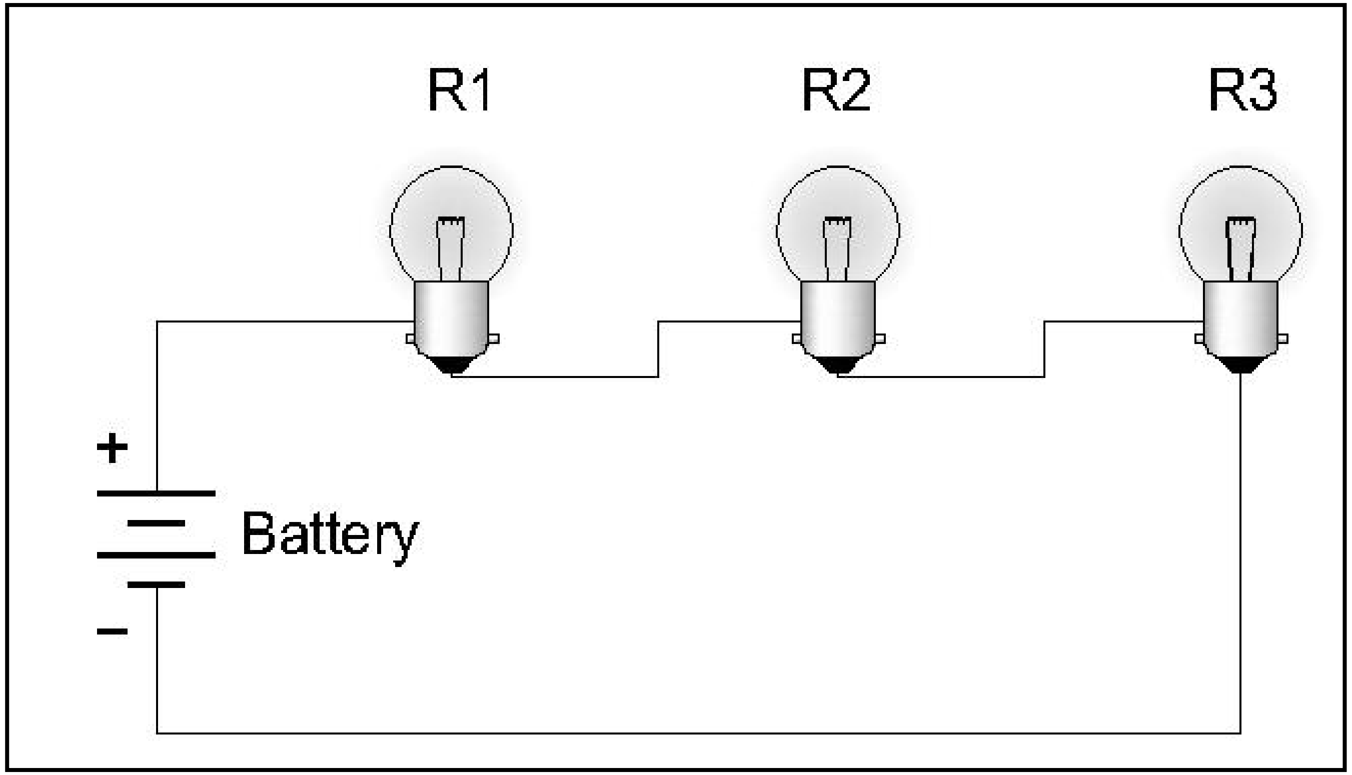
- ***Direct Current (DC)***
  - Current flows in one direction
  - Common source: batteries
- ***Alternating Current (AC)***
  - Current flow alternates directions periodically
    - Each complete reversal is a ***cycle***
    - ***Frequency***: number of cycles per second (units: hertz "Hz")
  - Common example: household current



How Current Flows

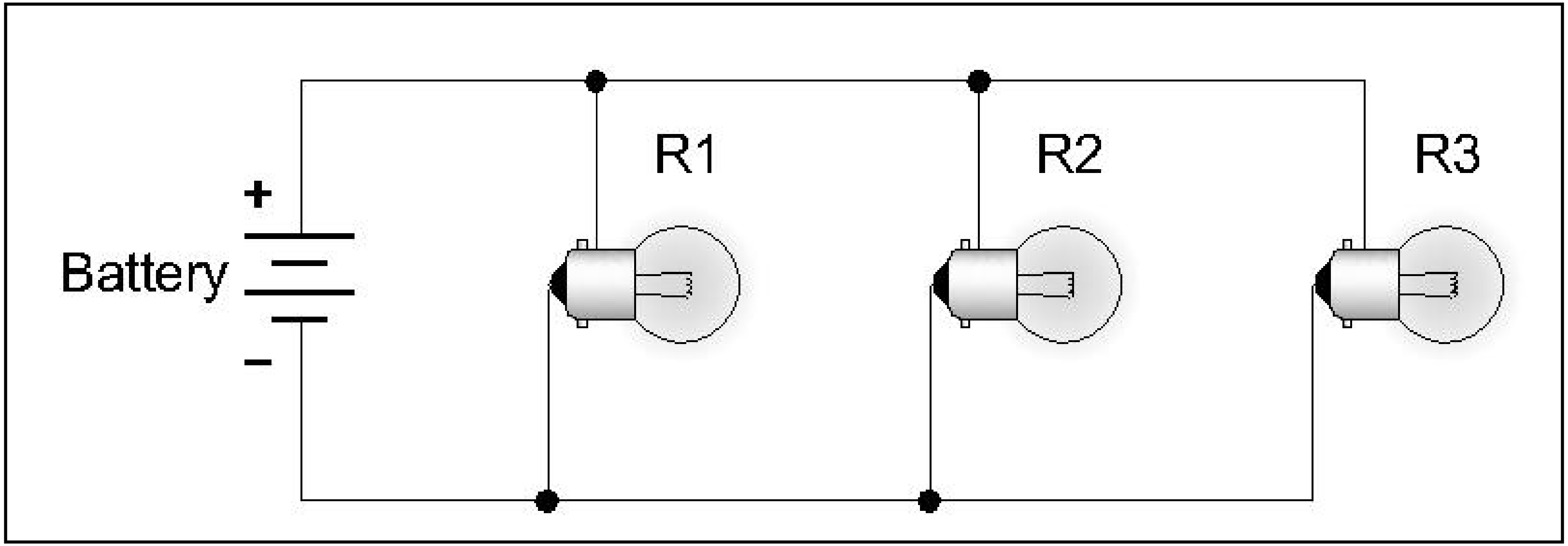
- ***Circuit:*** any path through which current can flow
  - Electrical circuits compose from ***components*** and their connections
- Kinds of circuits
  - ***Series***: when the same current must flow through all components
  - ***Parallel:*** when different current (but same voltage) flows through components
  - ***Short circuit***: a direct connection between two points in a circuit
  - ***Open circuit***: an unconnected circuit – made by breaking a current path

Series Circuit



*Same **CURRENT** at all points in the circuit. Series circuits provide one and only one path for current flow.*

Parallel Circuit



*Same **VOLTAGE** at all parts of the circuit. Parallel circuits provide multiple paths for current flow.*

Ohm's Law: E=IR

- E: voltage
  - Units – volts (V)
- I: current
  - Units – amperes (A)
- R: resistance
  - Units – ohms (Ω)

R = E / I
I = E / R
E = I x R

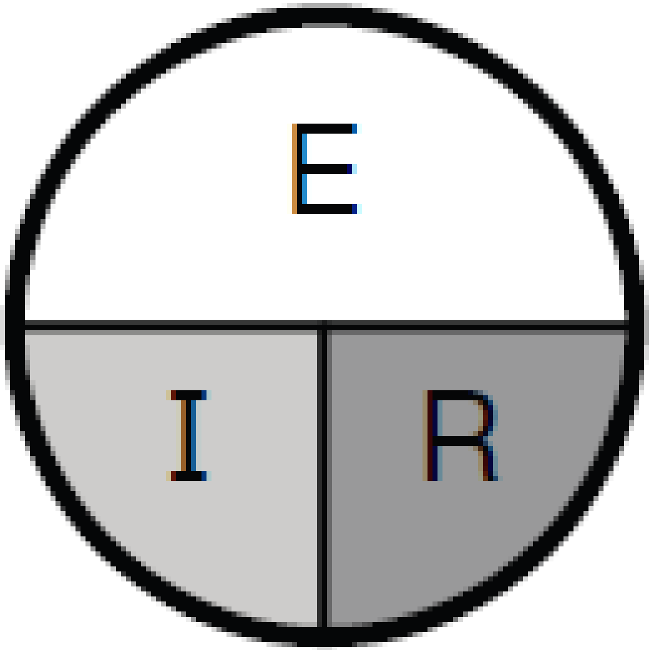
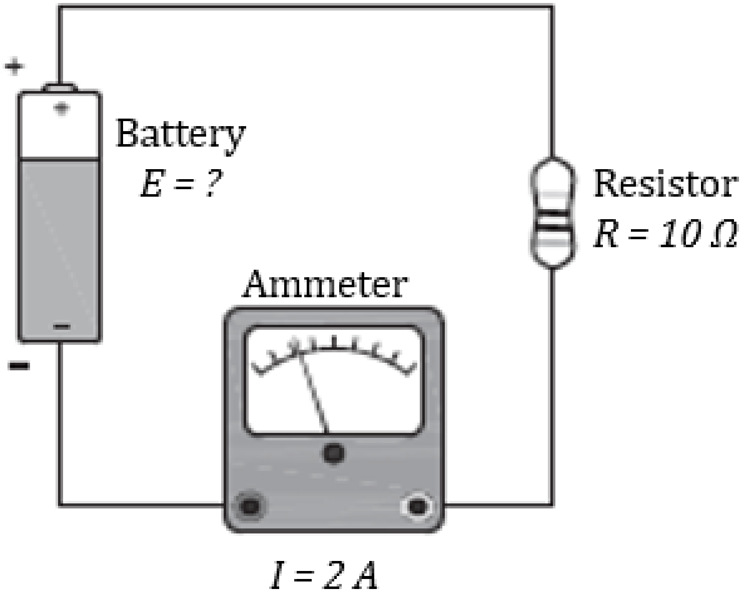


Figure 3.5A —If you know any two of the quantities, the equation to find the third — just cover up the unknown quantity. The positions of the remaining two symbols show if you have to multiply (side-by-side) or divide (one above the other).

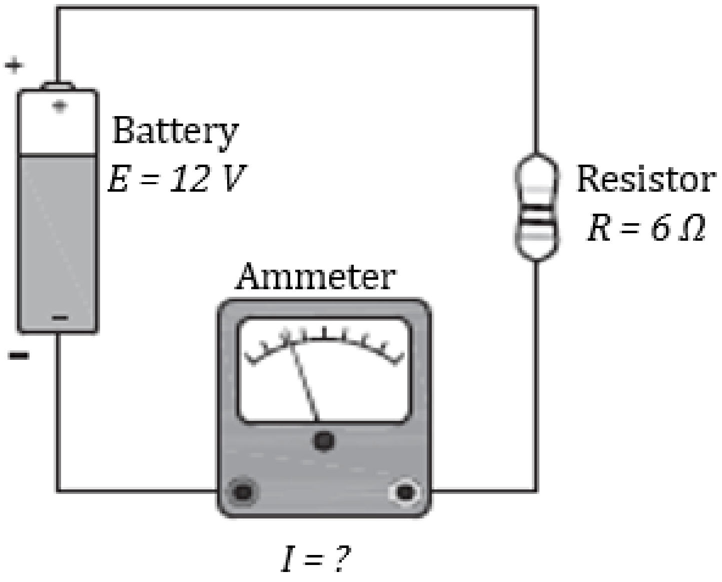
Examples of how to use Ohm's Law



Given I = 2 Amperes
R = 10 Ohms

Find: E (voltage)

E = I × R = 2 × 10 = 20 Volts
Voltage Equals 20 Volts



Given E = 12 Volts
R = 6 Ohms

Find: I (current)

I = E / R = 12 6 = 2 Amps

Current Equals 2 Amperes

More Ohm's Law Examples

What is the resistance of a circuit in which a current of 3 amperes flows when connected to 90 volts?

$$R = E / I = 90\ V / 3\ A = 30\ \Omega$$

What is the current in a circuit with an applied voltage of 120 volts and a resistance of 80 ohms?

$$I = E / R = 120\ V / 80\ \Omega = 1.5\ A$$

What is the voltage across a 2-ohm resistor if a current of 0.5 amperes flows through it?

$$E = I \times R = 0.5\ A \times 2\ \Omega = 1\ V$$

Power

- *Power*, represented by the symbol P, is the rate at which electrical energy is used
  - Measured in *watts* (W)
- A device that consumes or dissipates power is referred to as a *load*

$$P = I \times E$$
$$E = P \,/\, I$$
$$I = P \,/\, E$$

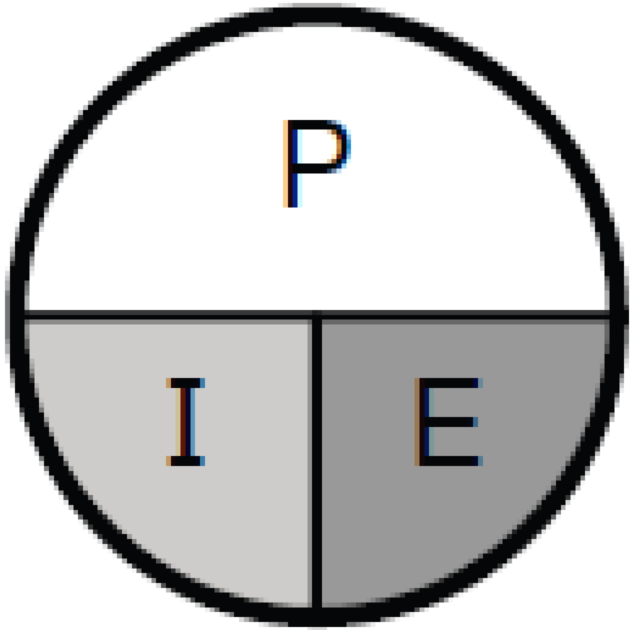


Figure 3.5B — Simple diagram to help remember the Ohm's Law. If you know any two of the quantities, the equation to find the third — just cover up the unknown quantity. The positions of the remaining two symbols show if you have to multiply (side-by-side) or divide (one above the other).

Example Power Calculations

How much power is delivered by a voltage of 13.8 volts DC and a current of 10 amperes?

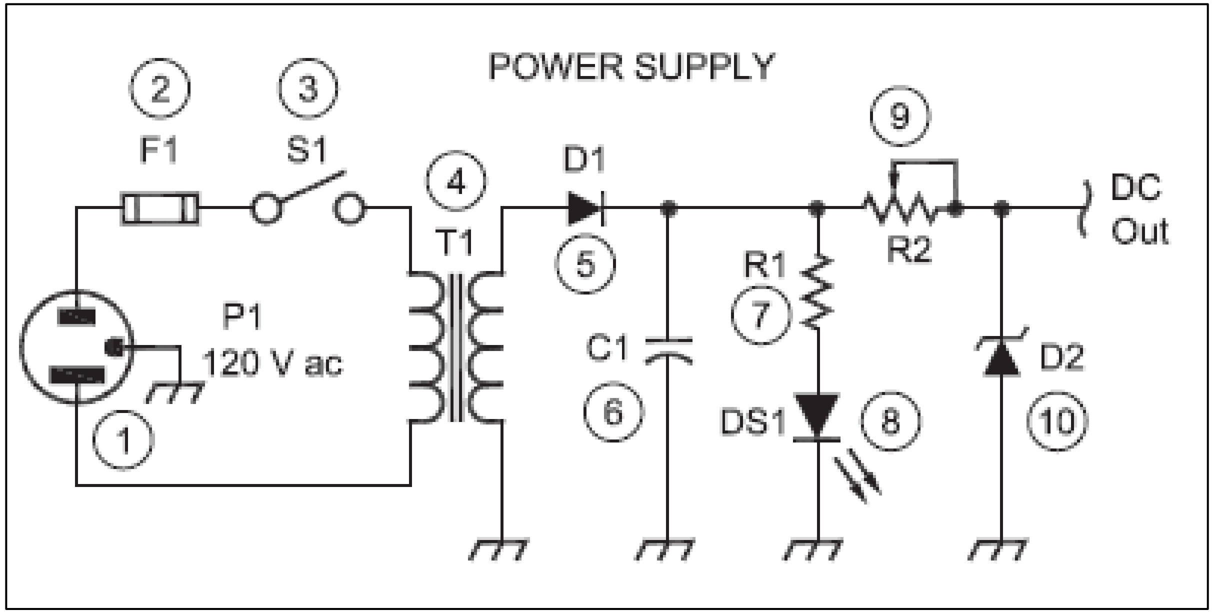
$$P = E \times I = 13.8\ \text{V} \times 10\ \text{A} = 138\ \text{W}$$

How much current is required to deliver 120 watts at a voltage of 12 volts DC?

$$I = P / E = 120\ \text{W} / 12\ \text{V} = 10\ \text{A}$$

Components and Units

- Components in electrical circuits performs functions such as storing or using energy, routing current, or amplifying signals
- The three most basic types of electronic components are ***resistors***, ***capacitors*** and ***inductors***
- ***Schematic diagrams*** are a convenient shorthand for complex circuits

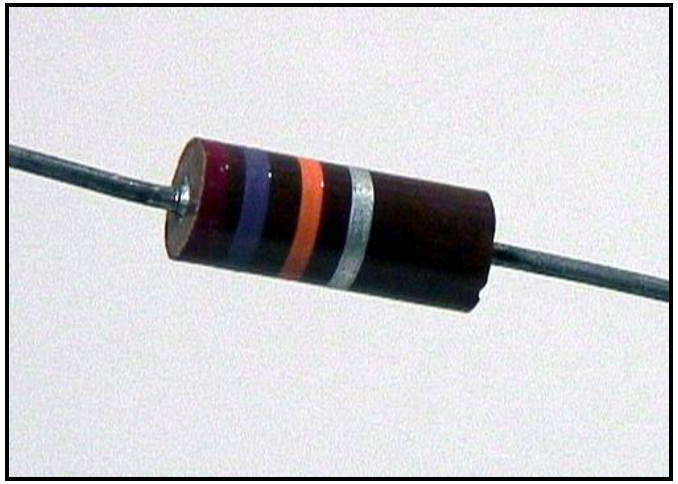


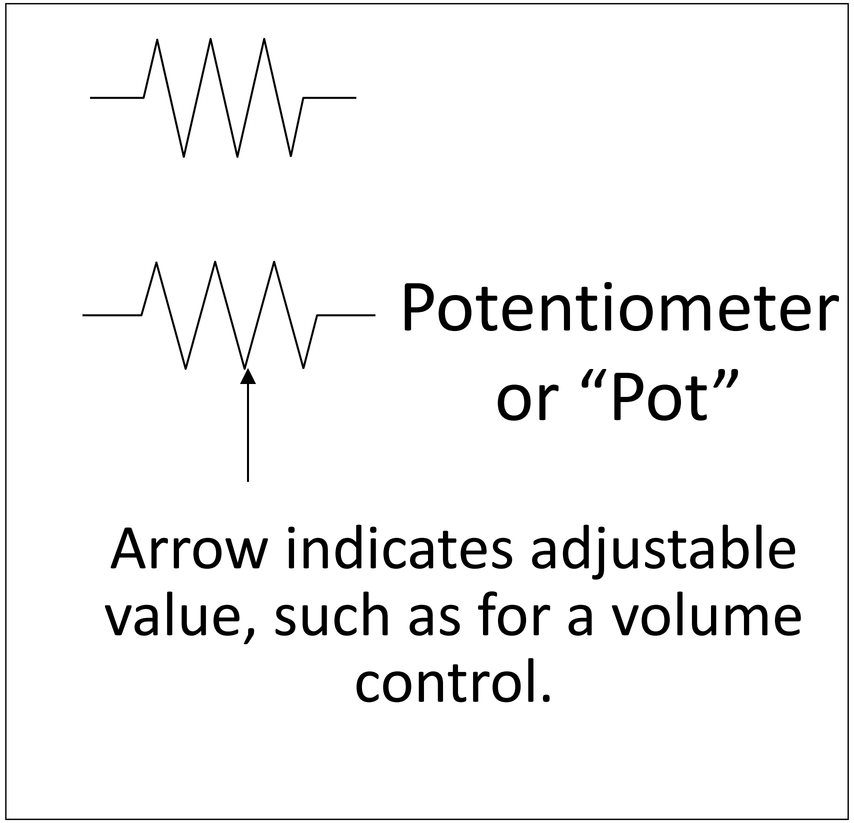
More on schematics later …

Resistors

- Function: To restrict the flow of current, like a valve in a water pipe
- Resistance measured in ohms (**Ω**)
- Remember Ohm's Law (R = resistance)

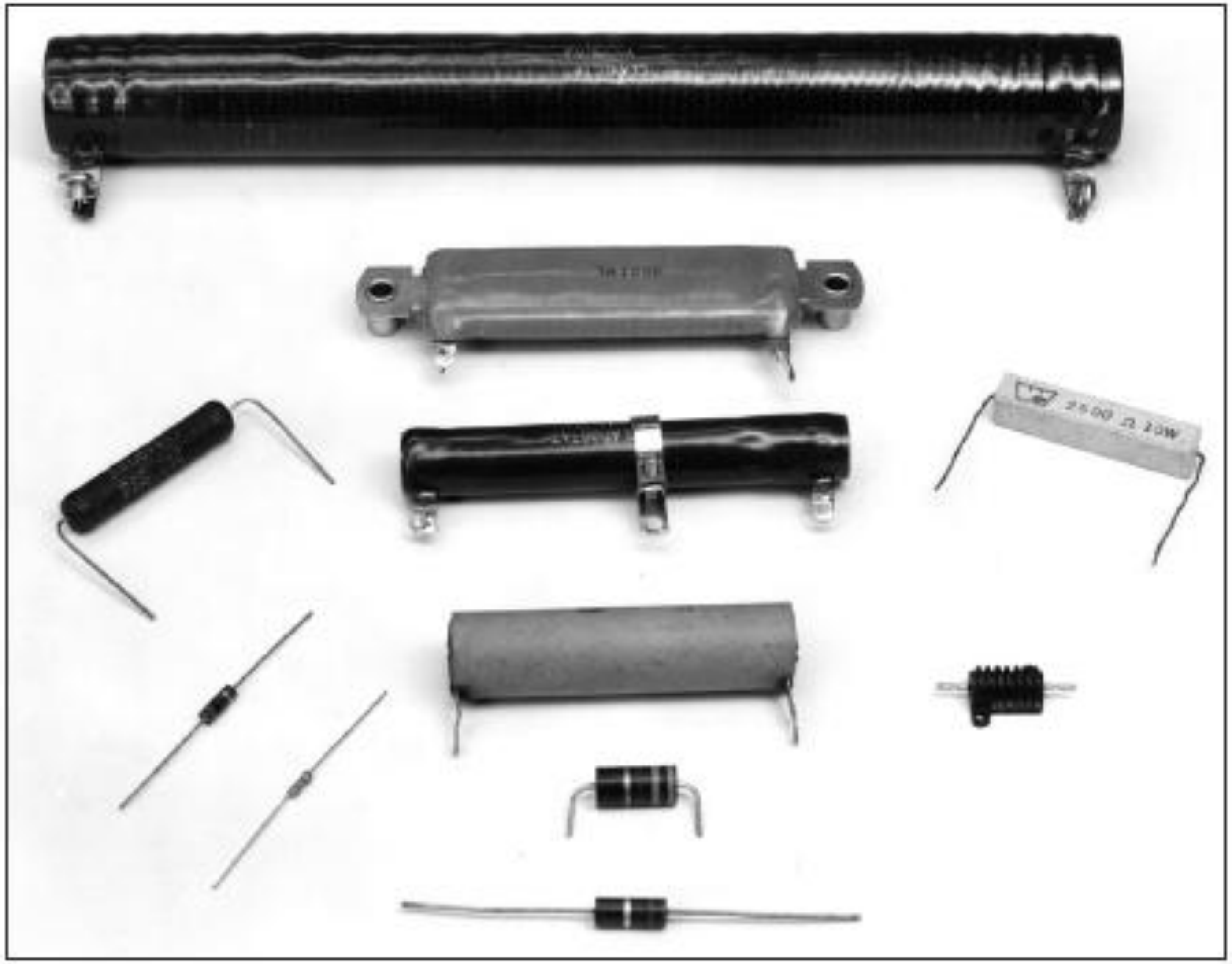
$$I = E / R$$
$$E = I \times R$$
$$R = E / I$$





Resistor Schematic

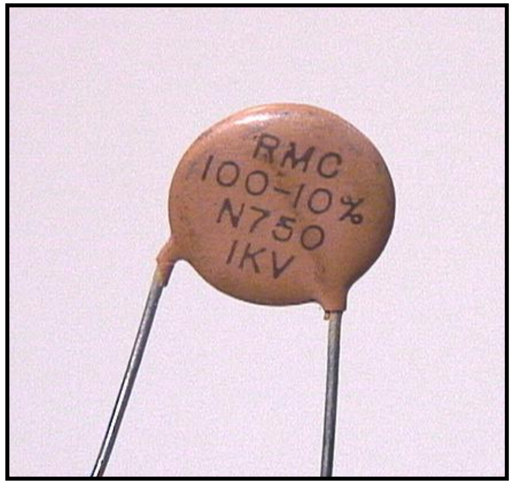
Large Variety of Resistors!

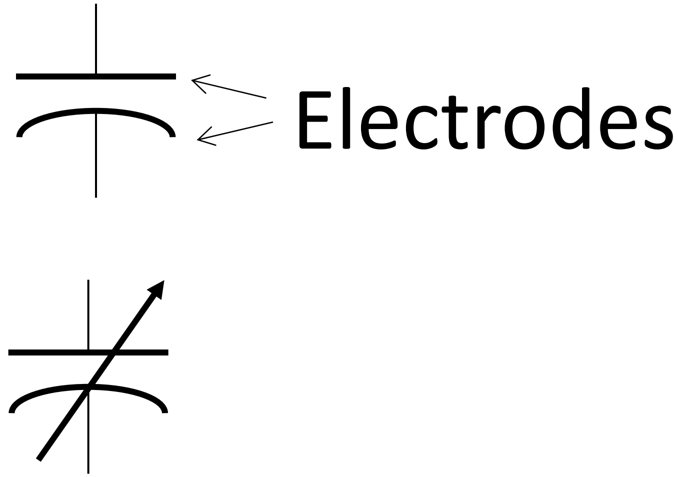


Capacitors

- The function of a capacitor is to store electrical energy – called *capacitance*
  - Capacitance measured in *farads (F)*
- Acts like a short-term battery

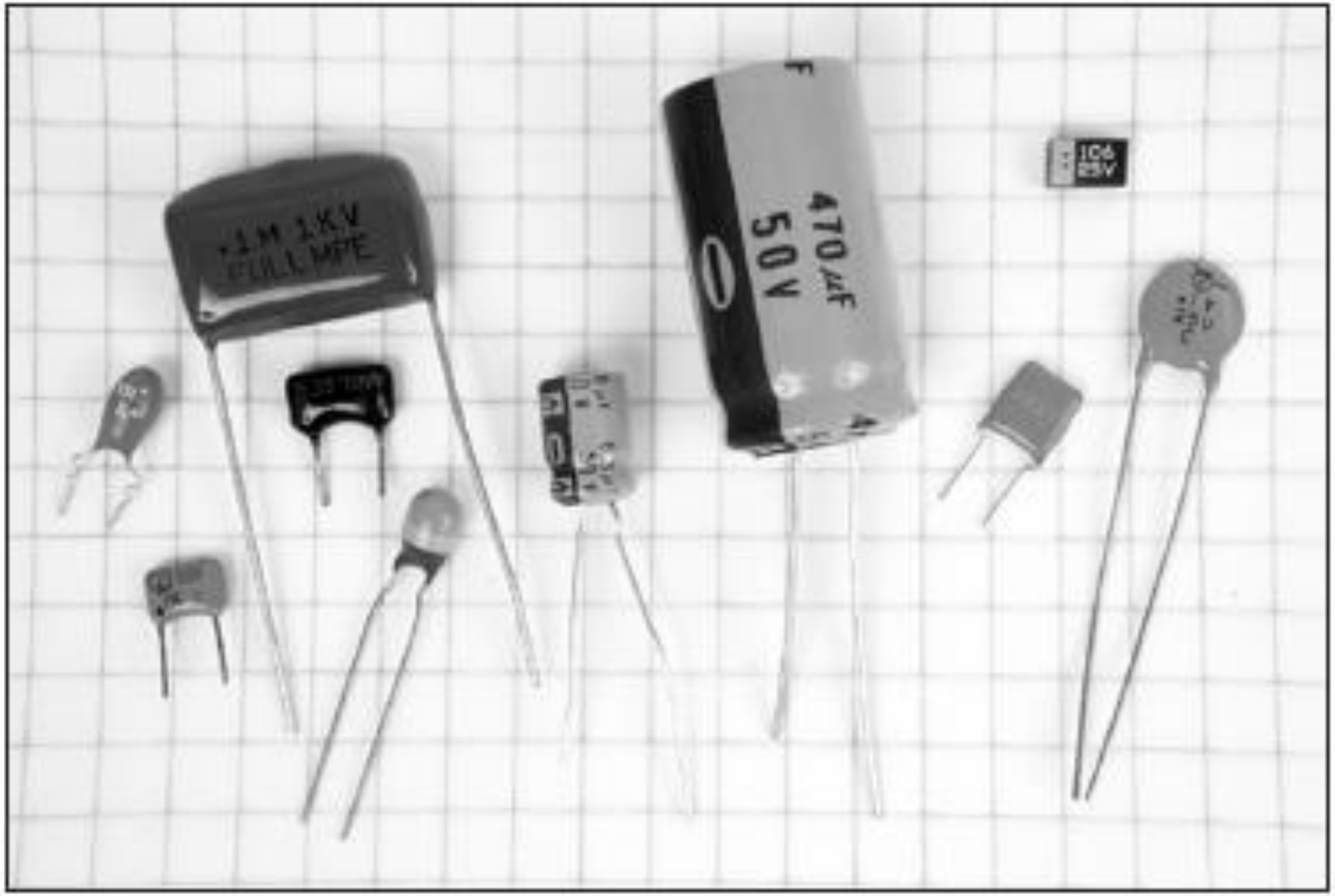
Stores energy in an electric field created by voltage between the electrodes with insulating dielectric material between them





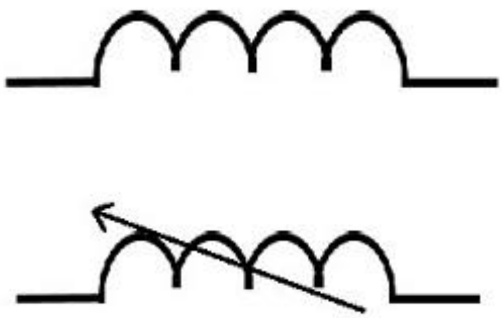
Schematic

Large Variety of Capacitors!



Inductors

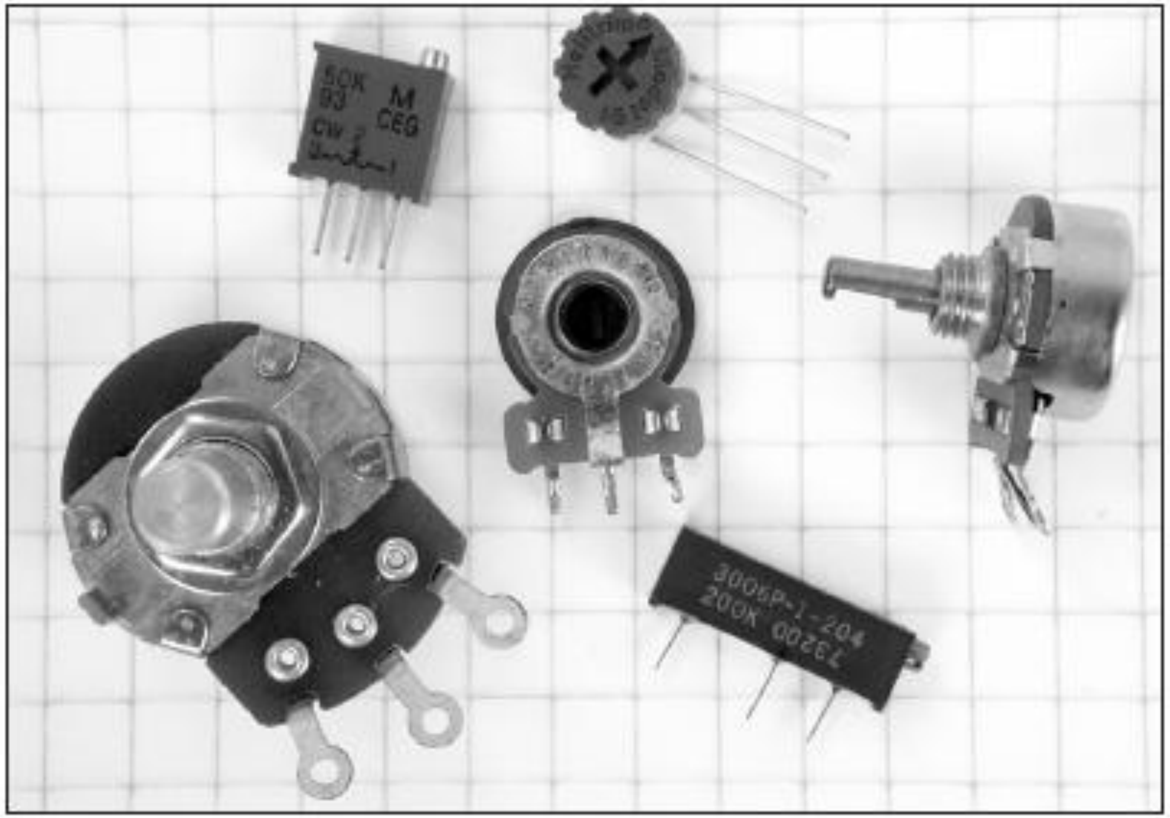
- Function: To store energy in the magnetic field created by current flowing in a wire
  - Called *inductance*, measured in *henrys* (H)
- Made from wire wound in a coil, sometimes around a core of magnetic material that concentrates the magnetic energy



Schematic

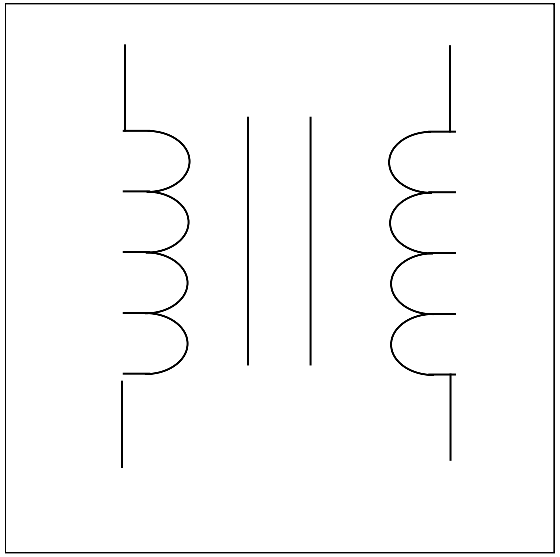
Variable Components

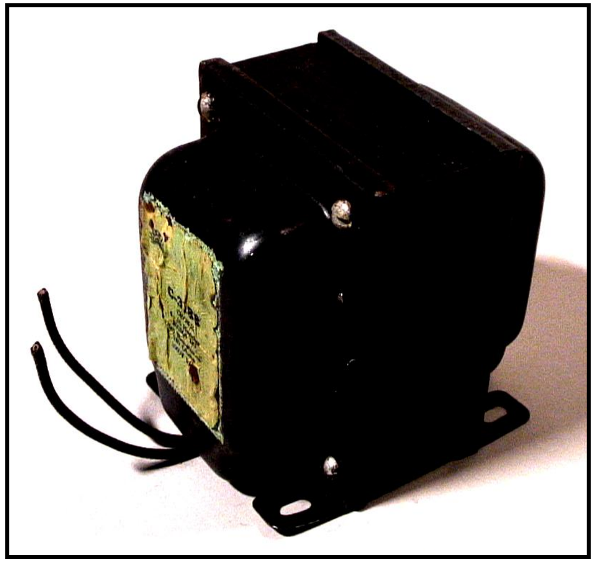
- All three types of basic components are also available as adjustable or variable models
- A variable resistor is also called a *potentiometer*, frequently used to adjust voltage or potential, such as for a volume control



Transformers

- Made from two or more inductors that share their stored energy
  - Transfer energy from one inductor to another, but change voltage and current
- Example: laptop charging brick
  - Transfer energy from 120V AC to a lower voltage and current





Reactance and Impedance

- In a resistor, AC voltages and currents are exactly in step, or *in phase*
- In capacitors and inductors, voltage and current have a *phase difference*
  - Capacitors and inductors store energy, resistors dissipate energy
- Energy storage creates an effect called *reactance* (symbol X) that acts like a resistance in opposing the flow of AC current
  - Capacitors create ***capacitive reactance*** (X_C)
  - Inductors create ***inductive reactance*** (X_L)
  - The effects of each are complementary

Reactance and Impedance (cont.)

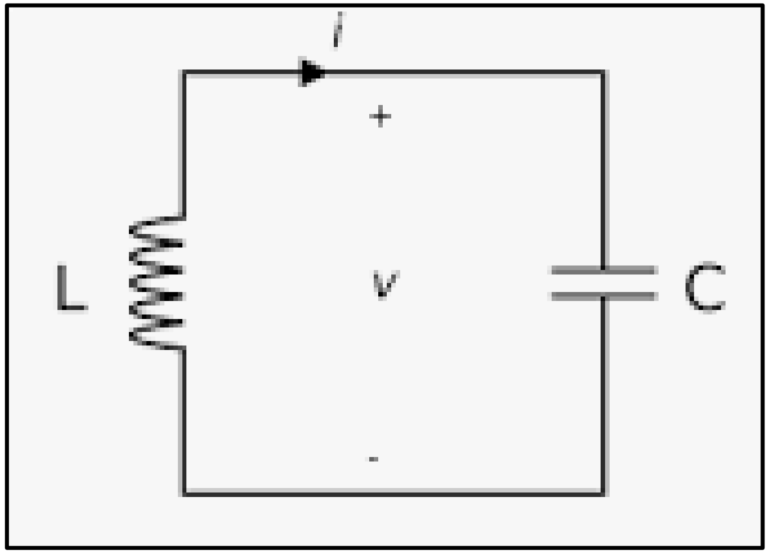
- The combination of *resistance* (R) and *reactance* (X) is called *impedance*, represented by the symbol Z (units: ohms)
  - Impedance represents a circuit's *opposition* to ***both*** AC and DC currents
- Radio circuits almost always have both resistance and reactance, so impedance is often used as a general term to mean the circuit's opposition to AC current flow

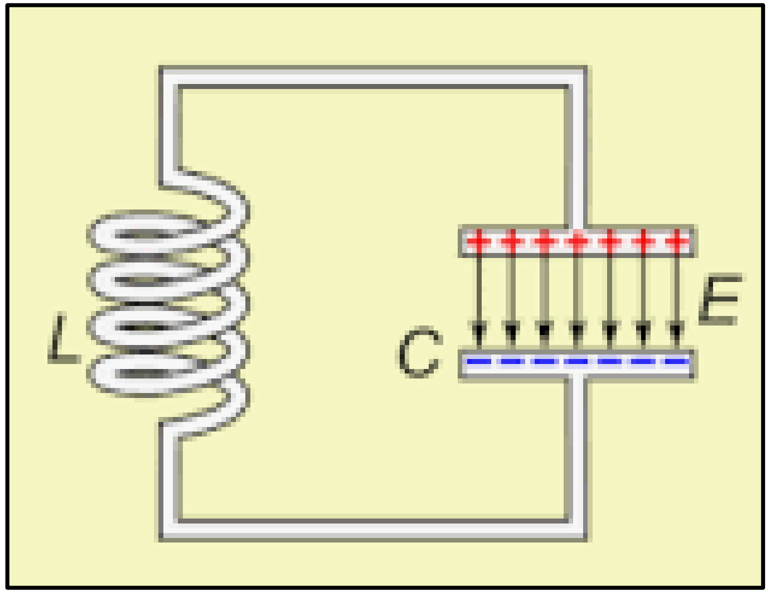
Resonance

- Circuits that contain both a capacitor and an inductor are called *resonant* circuits or *tuned* circuits
- A component's reactance depends on frequency
  - Inductive reactance (X_L) increases with frequency, capacitive reactance (X_C) decreases
- At the frequency for which a circuit's X_L and X_C are *equal*, their effects cancel
  - This is the circuit's *resonant frequency*
- At *resonance*, a circuit has *only resistance*, which affects AC and DC current equally
- A tuned circuit acts as a *filter*
  - A filter passes or rejects signals at its resonant frequency
  - Useful for radios to filter out unwanted signals!

Resonant or Tuned Circuit

- *Capacitors* and *inductors* connected together create a tuned circuit
- When X_L and X_C are equal, the circuit is resonant
- If C or L are adjustable, the resonant frequency can be varied or *tuned*



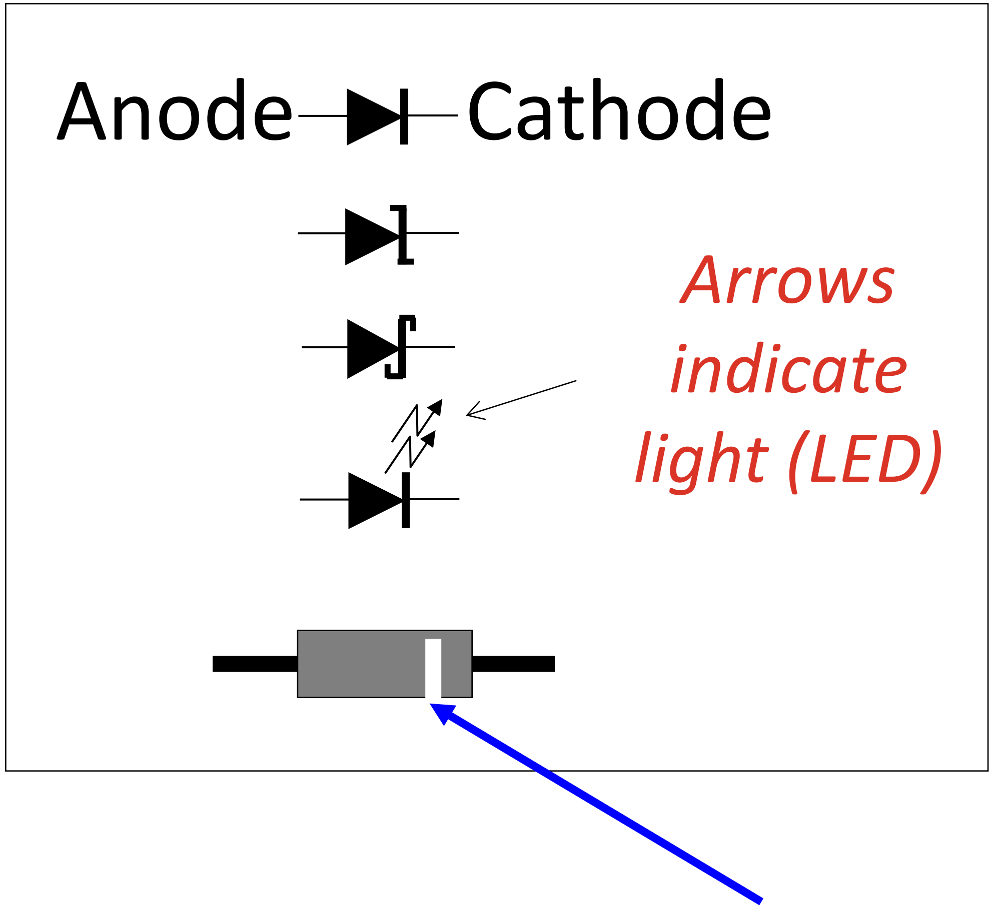


Diodes, Transistors and Integrated Circuits *(Semiconductors)*

- Components made of “OK” conductors (not metals)
  - ***N-Type semiconductors:*** made from materials with more electrons
  - ***P-Type semiconductors***: made from materials with fewer electrons
- Structures of N and P material can control current flow
- When N- and P-type material are placed in contact with each other, the result is a *PN junction* that conducts better in one direction than the other

Diodes

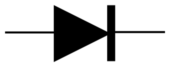
- One-way Current
  - Two electrodes (Anode, Cathode)
  - AC current is changed to varying pulses of DC (called *rectification*)
  - Diodes used to change AC power to DC power are called *rectifiers* (heavy-duty diodes)
- Designator (D or CR)
- If AC voltage is applied to a diode, the result is a pulsing DC current
  - Current is blocked when the voltage tries to push electrons in the wrong direction



Stripe on diode indicates CATHODE

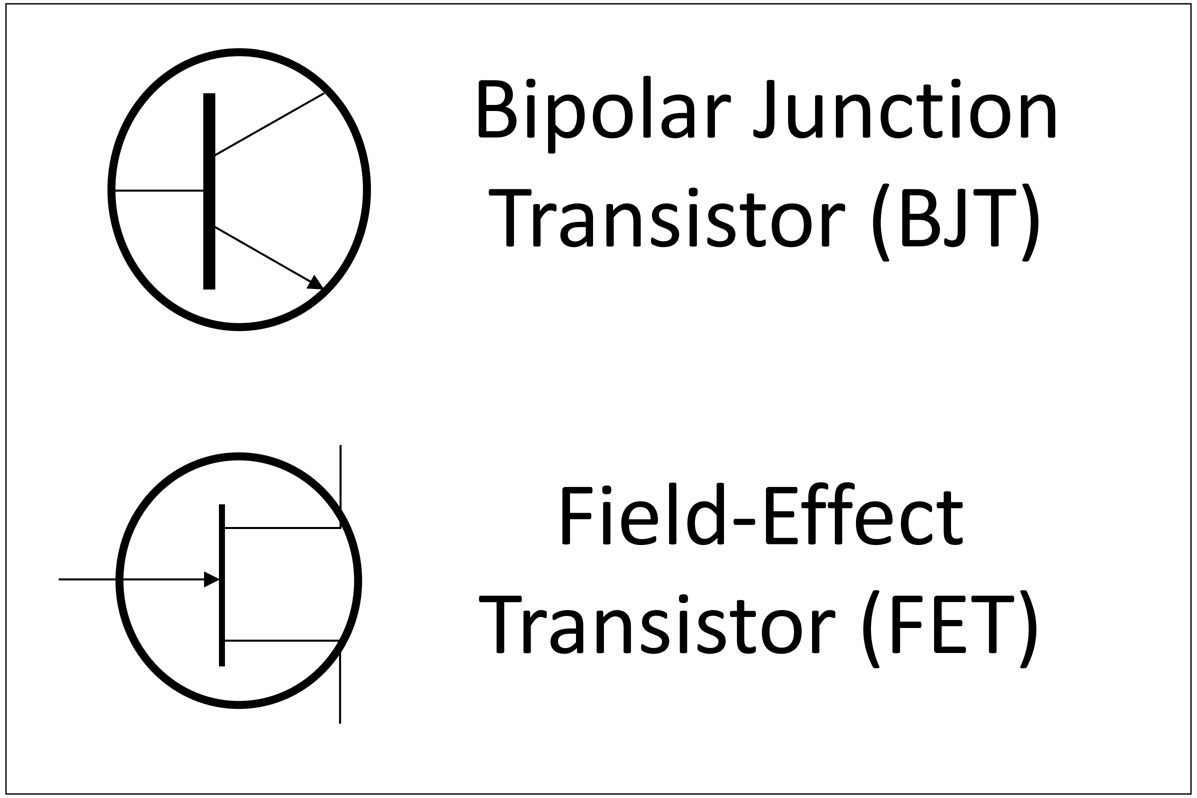
Diodes (cont.)

- When current flows through a diode, a small positive voltage develops from the anode to the cathode
  - Called *forward voltage drop*, usually less than 1 V
  - Voltage depends on the type of diode and the materials it’s made from
- Light-emitting diode or *LED* gives off light when current flows through it in the forward direction from anode to cathode
  - Used as visual indicators (use less power than incandescent bulbs/lamps)
  - Material from which the LED is made determines the color of light

Anode  Cathode

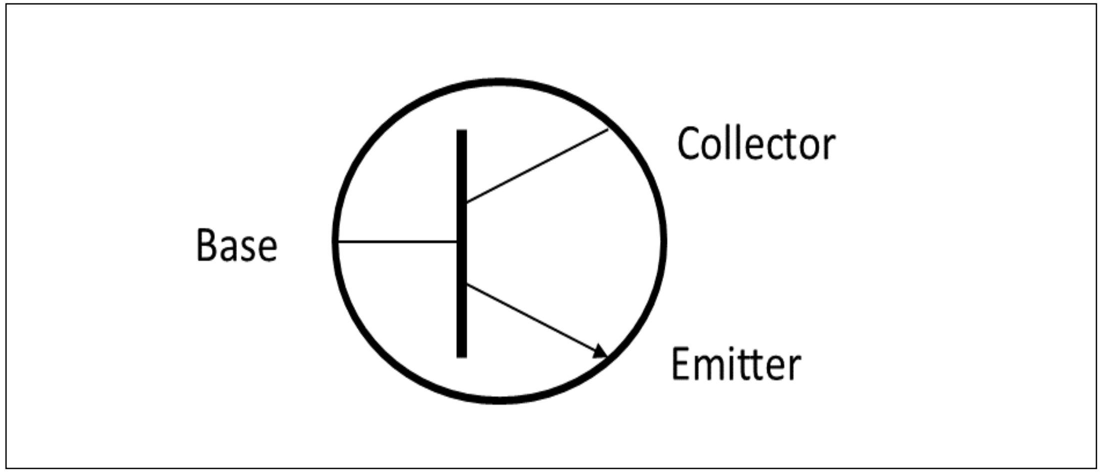
Transistors

- The function of a transistor is to *control* large signals with small ones
  - An “electronically controlled current valve”
  - When used as an amplifier, a transistor produces *gain*
  - Transistors can also be used as a *switch*
- Designator (Q)



Transistors (cont.)

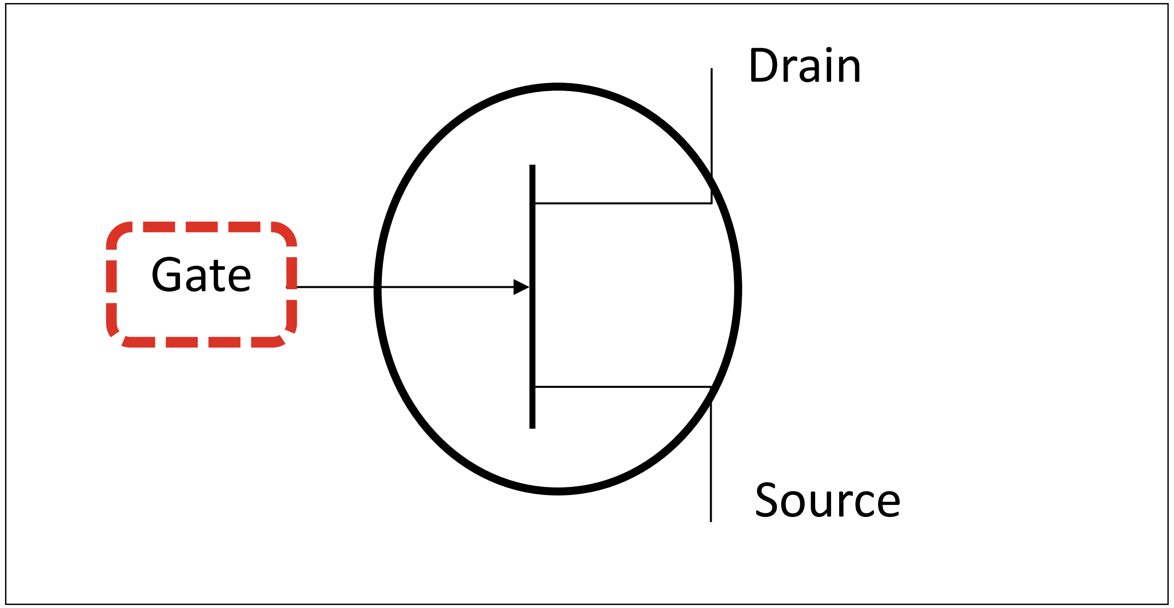
- Two common types of transistors: *bipolar junction transistors* (BJT) and *field effect transistors* (FET)
- The Bipolar Junction Transistor (BJT) has three layers of N or P material connected to electrodes
- Depending on the arrangement of layers, a BJT is either an NPN or PNP transistor
- The three electrodes of an FET are the *gate*, *drain*, and *source*
- RF power transistors are used as the primary gain-producing component in RF power amplifiers



Bipolar Junction Transistor Schematic (showing the 3 electrodes)

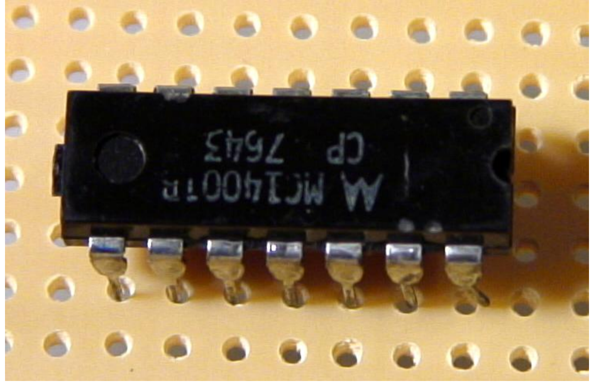
Transistors (cont.)

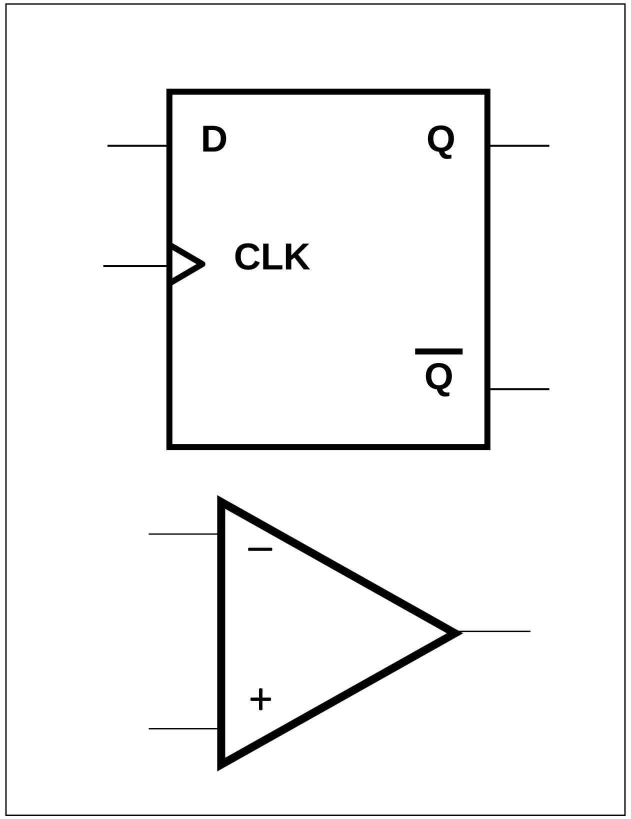
- The Field-Effect Transistor (FET) has a conducting path or channel of N and P material connected to the drain and source electrodes
- Voltage applied to the gate electrode controls current through the channel



Integrated Circuits

- An integrated circuit (IC or chip) is made of many components connected together as a useful circuit and packaged as a single component
- Designator (IC or U)

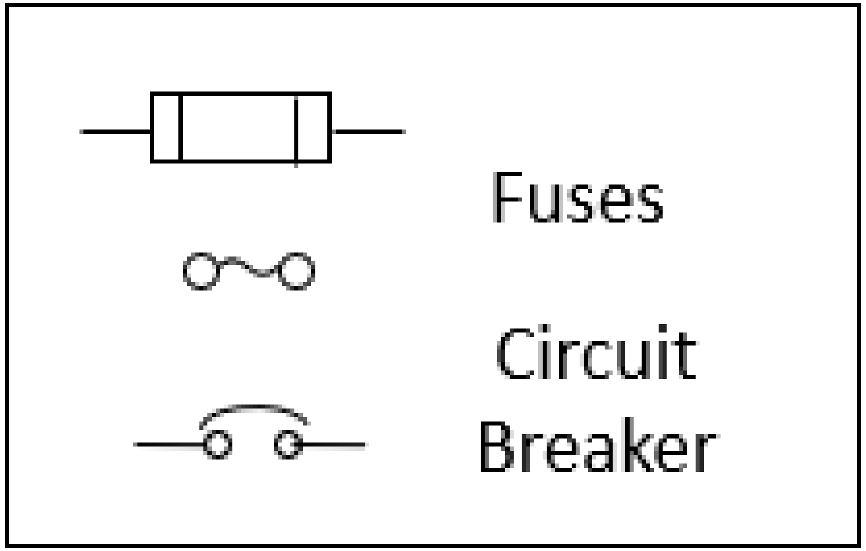




Protective Components

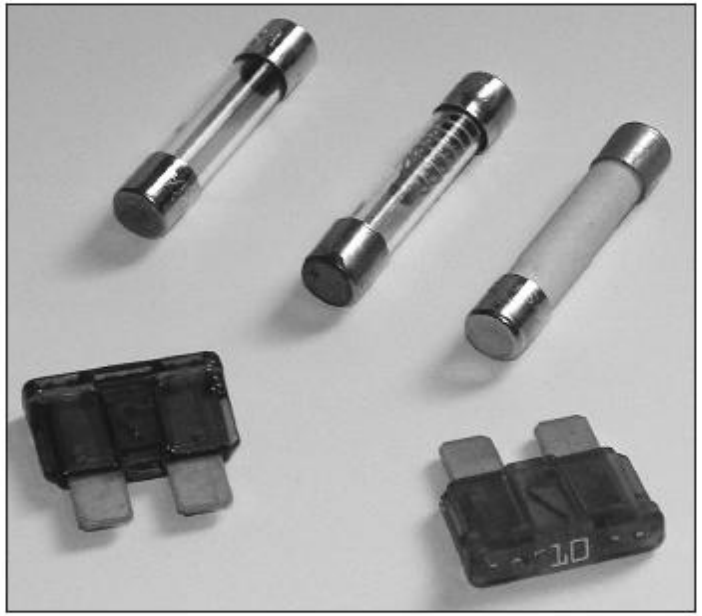
- Protective components (such as *fuses* and *circuit breakers*) are used to prevent equipment damage or safety hazards such as fire or electrical shock

- Designed to remove power in case of a circuit *overload*
  - Fuses blow – one time protection
    - Short length of metal is melted when circuit overloaded, which breaks the circuit
  - Circuit breakers trip – can be reset and reused
- Important: ***use the correct current rating!***
  - Replacing with a higher current rating could damage equipment or start a fire

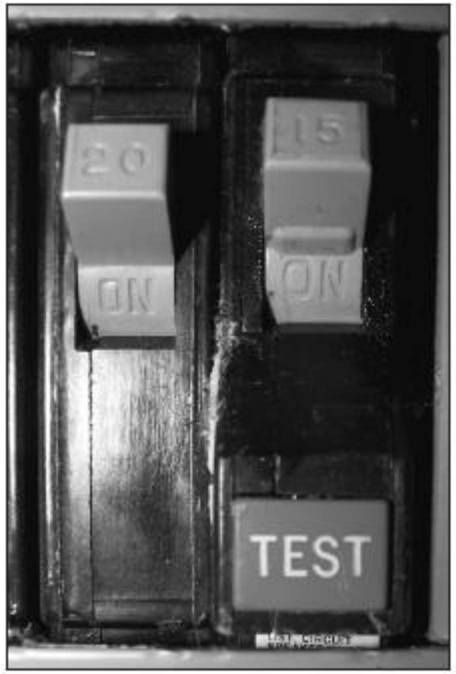


Schematics

Circuit Breaker



Fuses



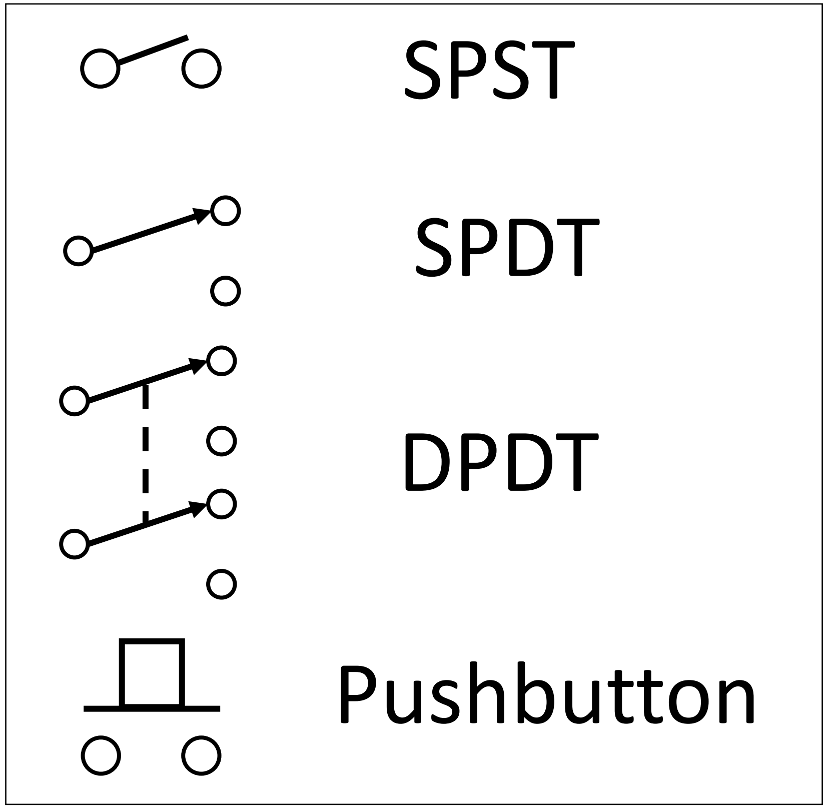
Ground Fault Circuit Interrupter (GFCI) circuit breaker

Circuit Gatekeepers … Switches & Relays

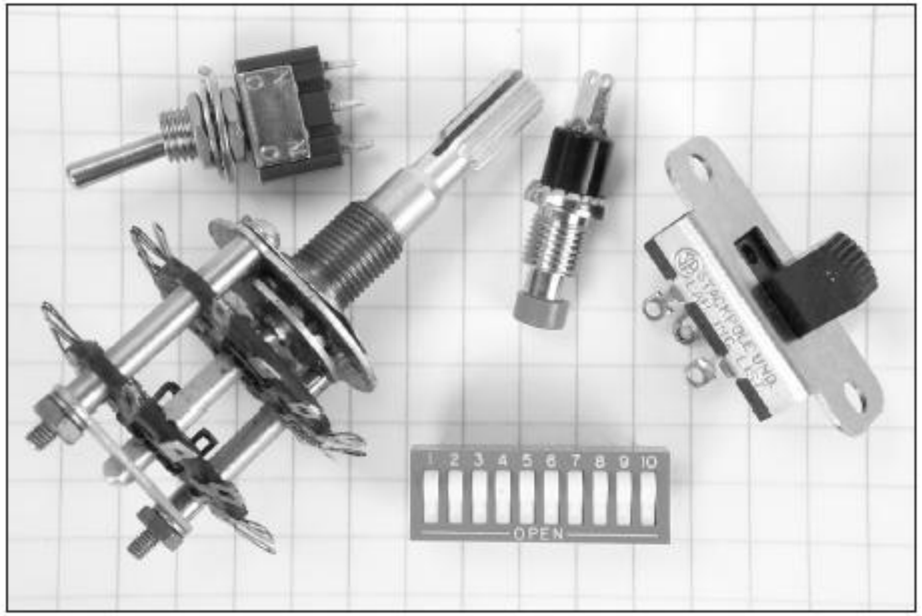
- *Switches* and *relays* control current through a circuit by connecting and disconnecting paths for current to follow
- Switches and relays are described by # poles, # throws
  - The combination of poles and throws describes the switch
  - Each circuit controlled by the switch is a *pole*
  - Each position is called a *throw*

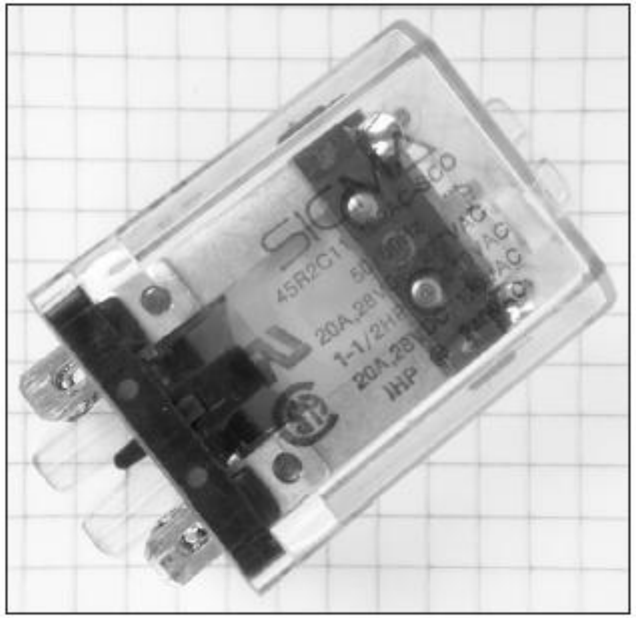
- Switches are operated manually
- Relays are controlled electronically by electromagnet

Switch Configurations



Switches





Relay

Indicator, Meters and Displays

- Indicators and displays are important components for radio equipment
  - An *indicator* is either ON or OFF
- A *meter* provides information as a numeric value
- A *display* combines indicators, numbers, and labels
  - A *liquid crystal display* or **LCD** is used on the front panel of many radios and test instruments

Fig 3.15 – Schematic Symbols (see text)

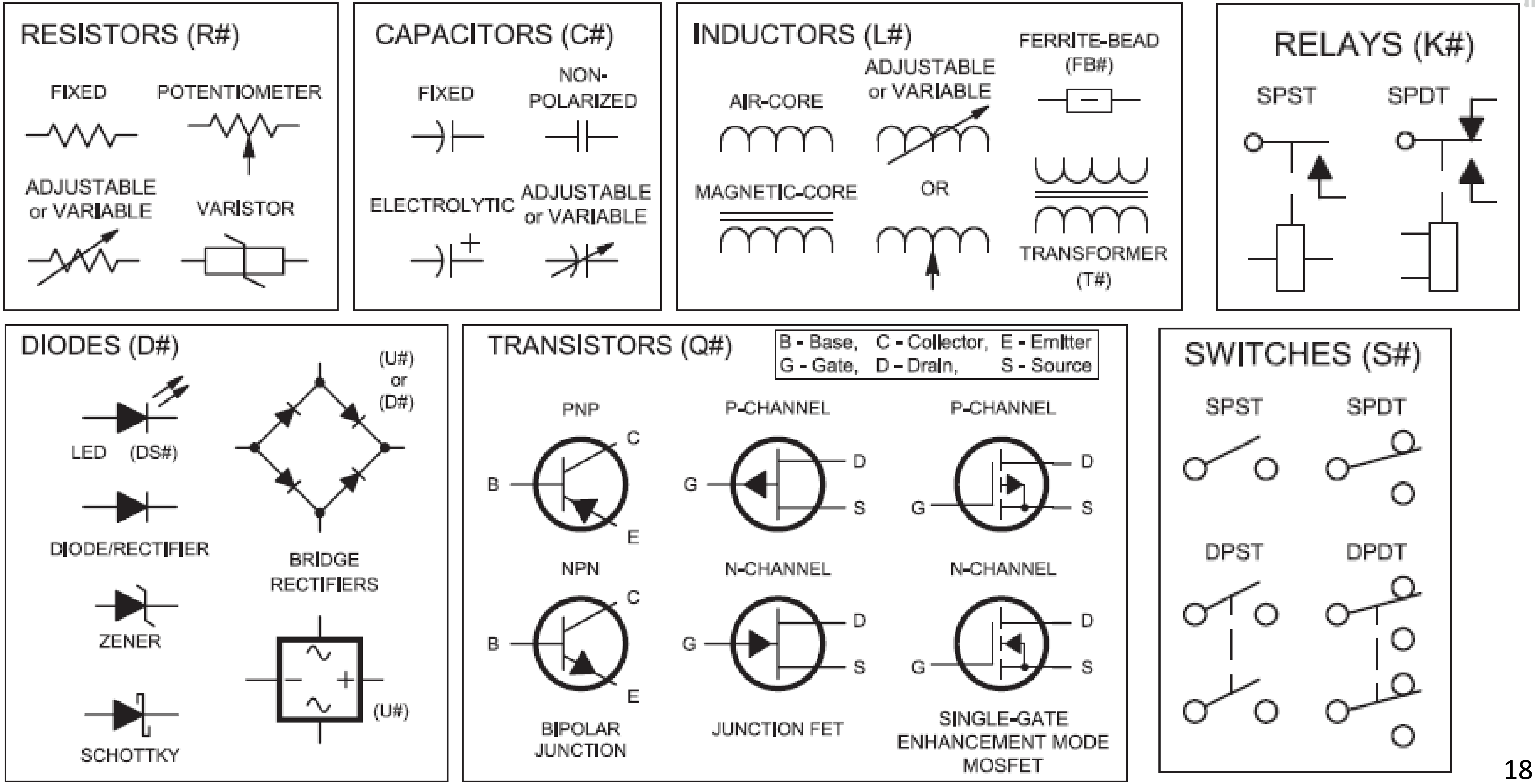
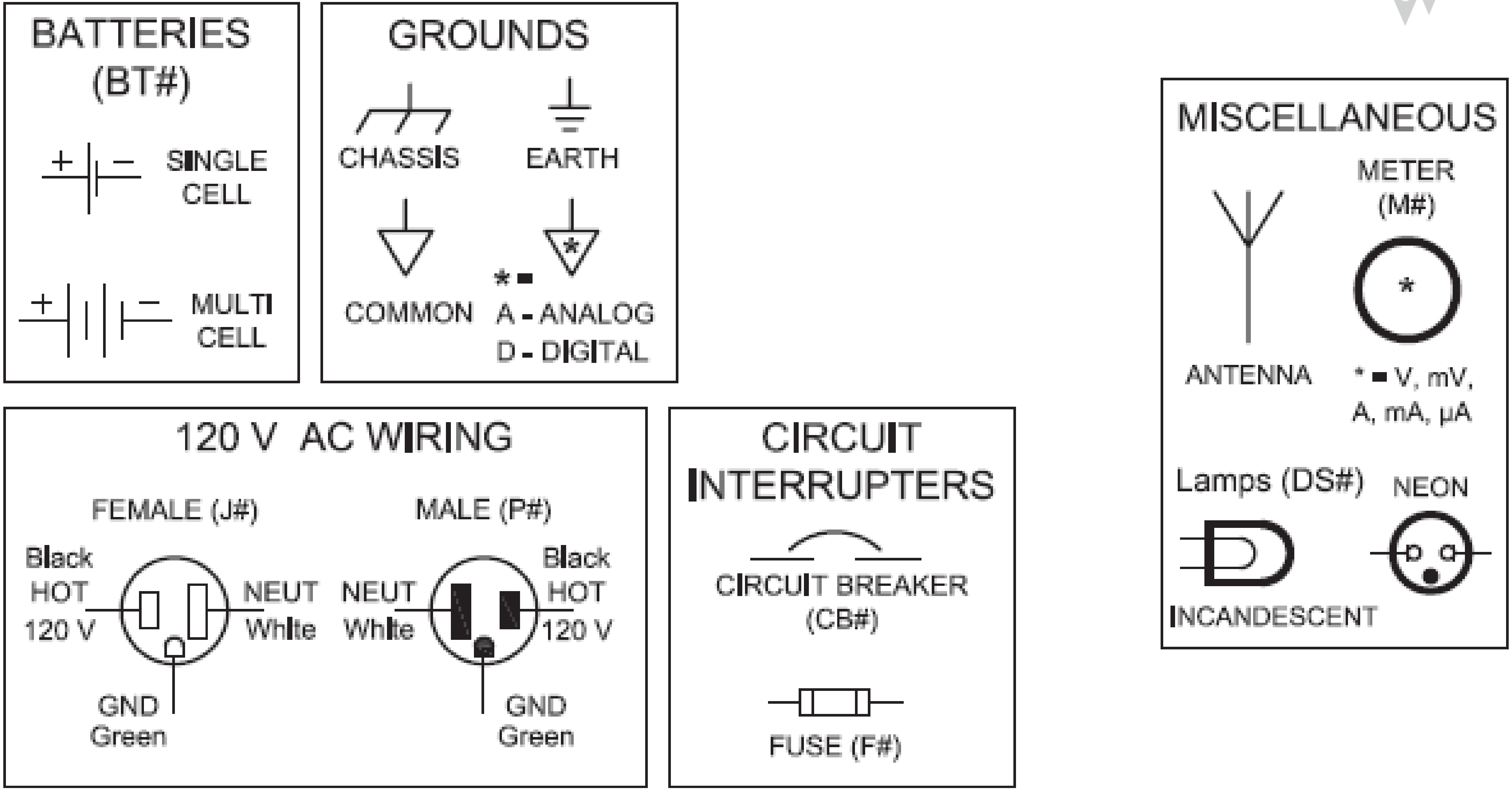


Fig 3.15 – Schematic Symbols (cont., see text)



Schematic Diagrams and Symbols

- *Symbols* are used when drawing a circuit because there are so many types of components
- *Schematic diagrams* are a visual description of a circuit and its components that uses standardized drawings called *circuit symbols*
  - Shows how the components are connected electrically

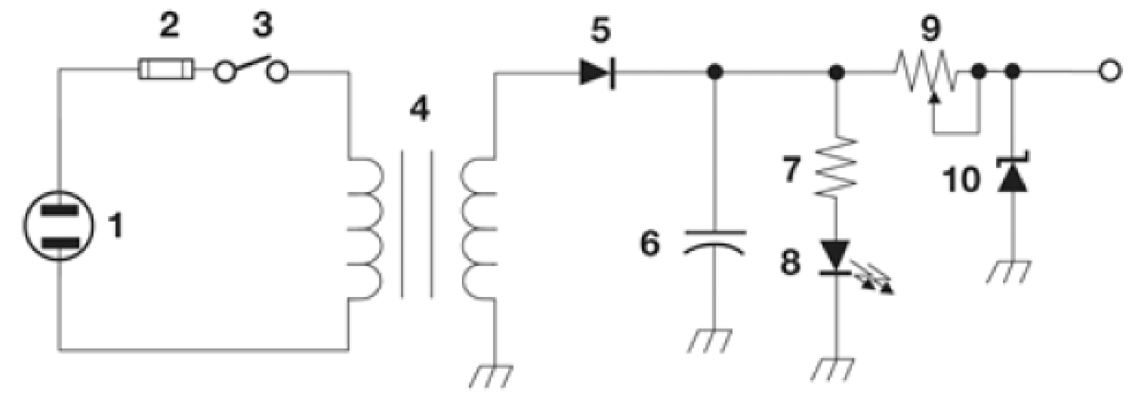


Figure T-2

Radio Circuits – Big Picture

- An *oscillator* produces a steady signal at one frequency
  - Used in both receivers and transmitters to determine the operating frequency
- The process of combining data or voice signals with an RF signal is *modulation*
- Modulators add the data or voice signal to an RF signal or carrier
  - A *demodulator* circuit extracts the information from a modulated signal
- *Mixers* combine two RF signals and shift one of them to a third frequency (closely related to a modulator)

Next Week

- Please read:
  - Chapters in the ARRL Book
    - **Ch 4**: Propagation, Antennas and Feed Lines
    - **Ch 5**: Amateur Radio Equipment

- Also start reviewing question pool:
  - Subelements from today:
    - **T5 –** Electrical Principles
    - **T6 –** Electronic and Electrical Components
  - Question pool is in the back of the book, and on ARRL website
    - https://arrl.org/question-pools (look for the Technician Class Question Pool)