SCARS

Technician / General

License Course

Week 3

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.

Fundamentals of Electricity

- Electrical charge can be positive or negative.
  - Opposite charges attract each other
- Electrical current is the flow of *electrons*.
  - –Electrons are negatively-charged atomic particles, usually surrounding an atom's positively-charged nucleus of protons (positive) and neutrons (neutral – no charge)
  - –Electrons move in response to an *electromotive force* and can move independently of atoms

Basic Electrical Concepts

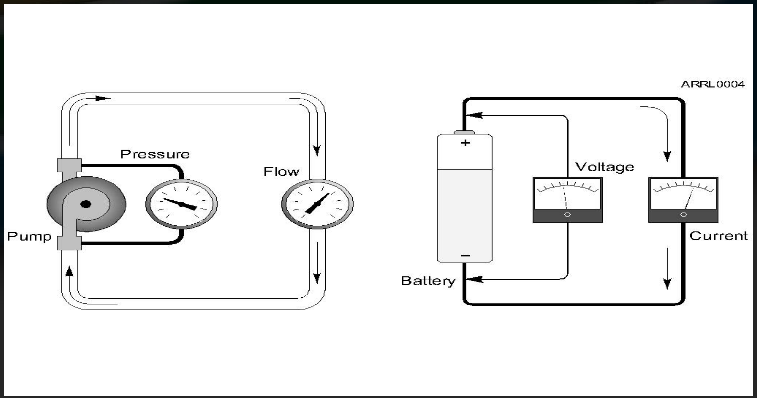
- Current: the movement of electrons, measured in *amperes* (A) by an *ammeter*, and represented by *I* in formulas
- Voltage: the amount of electromotive force (emf), also called *electrical potential*, measured in *volts* (V) by a *voltmeter*, represented by *E* or *V* in formulas

Basic Electrical Concepts

- Resistance: the opposition to the movement of electrons, measured in *ohms* (Ω) by an *ohmmeter* and represented by R in formulas.
- Resistance is like friction and turns electrical energy into heat when current flows.
- *Conductors* permit current flow (low resistance) and *insulators* block current flow (high resistance).

Basic Electrical Concepts

- The flow of water through a pipe is a good analogy to understand the three characteristics of electricity and how they are related.

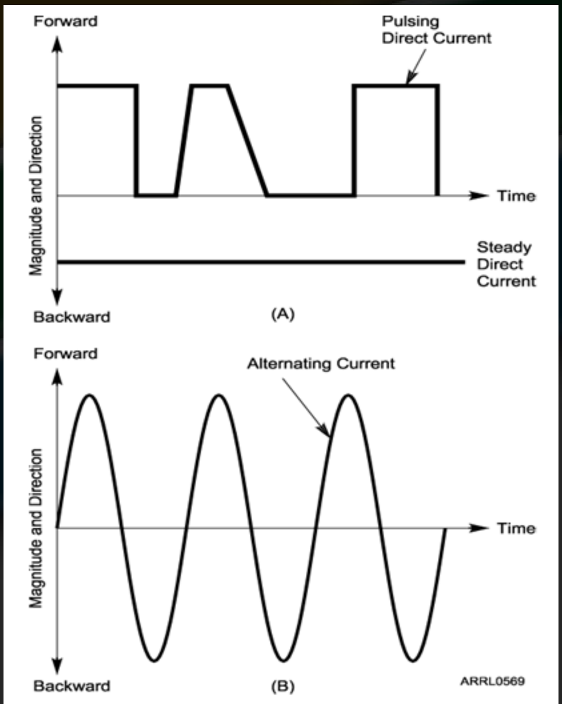


Basic Electrical Concepts

- Voltage from a *source* of electrical energy causes current to flow.
- Resistance is a material's opposition to the flow of current.
- Voltage, current and resistance affect each other. For example, higher voltage (bigger push) causes more current (more flow).

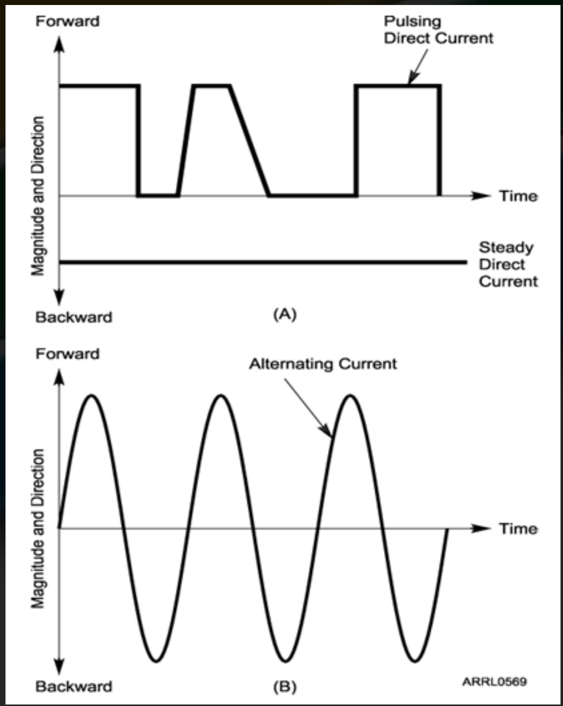
The Two Kinds of Current

- Current that flows in only one direction, is called direct current (dc).
  - –Batteries are a common source of dc.
- Current that flows in one direction then in the opposite direction is called alternating current (ac).
  - –Household current is ac



The Two Kinds of Current

- AC current reverses direction on a regular basis
  - Each process of reversing is a *cycle*.
  - The number of cycles per second is *frequency,* measured in hertz (Hz).
- 1 Hz = 1 cycle per second

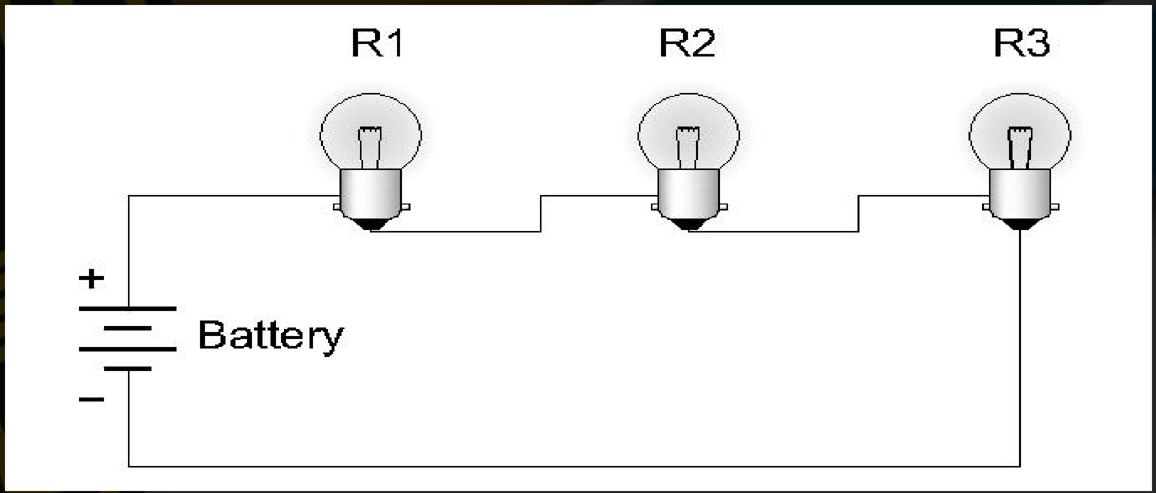


The Electric Circuit: An Electronic Roadmap

- For current to flow, there must be a path from one side of the energy source to the other side of the source – this path is called a *circuit*.
  - There must be a pipe (conductive path) through which the water (current) can flow.
- There are two types of electric circuits.
  - Series and parallel

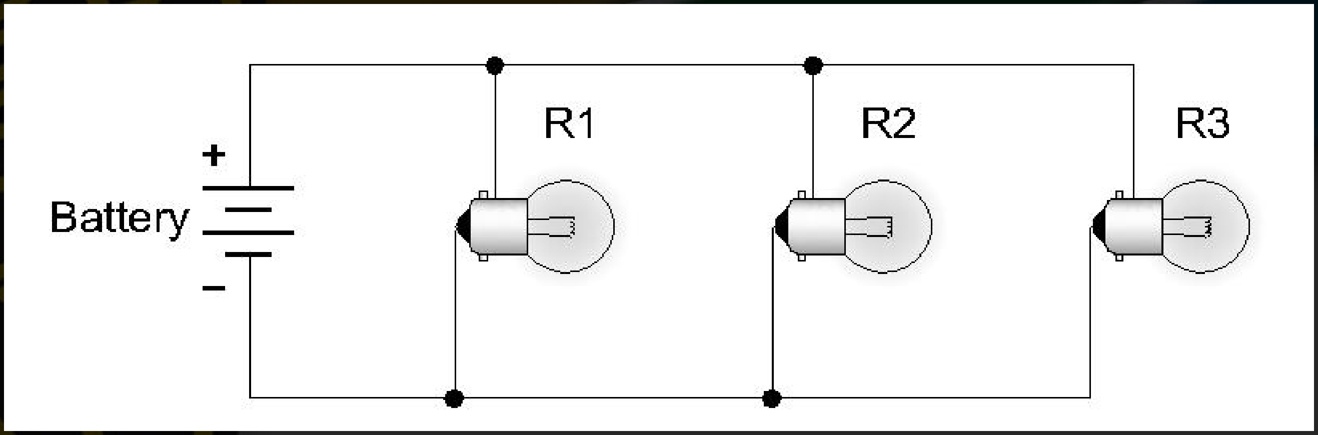
Series Circuits

- Series circuits provide one and only one path for current flow.

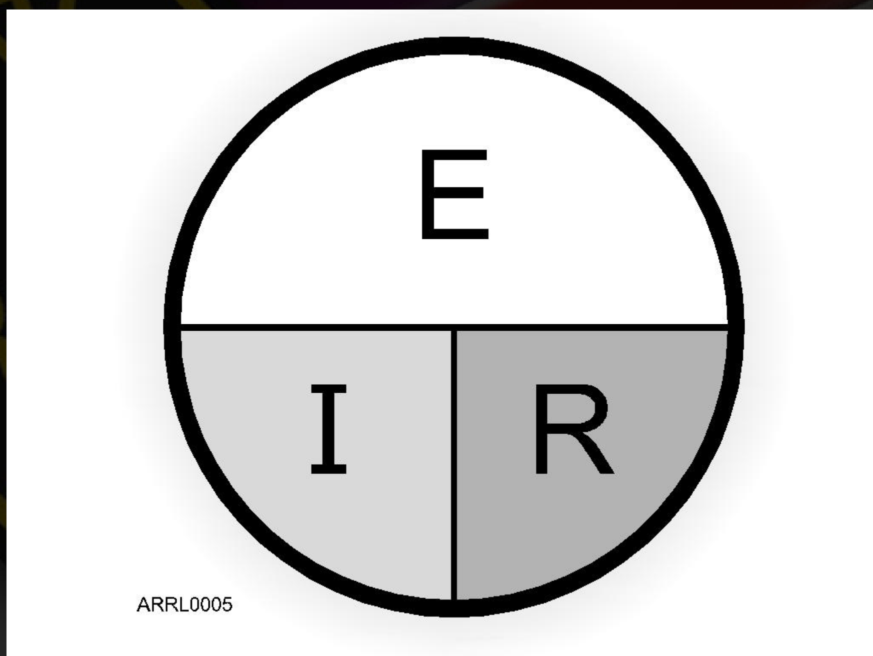


Parallel Circuits

- Parallel circuits provide multiple paths for current flow.



Ohm's Law



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

R = E / I

I = E / R

E = I x R

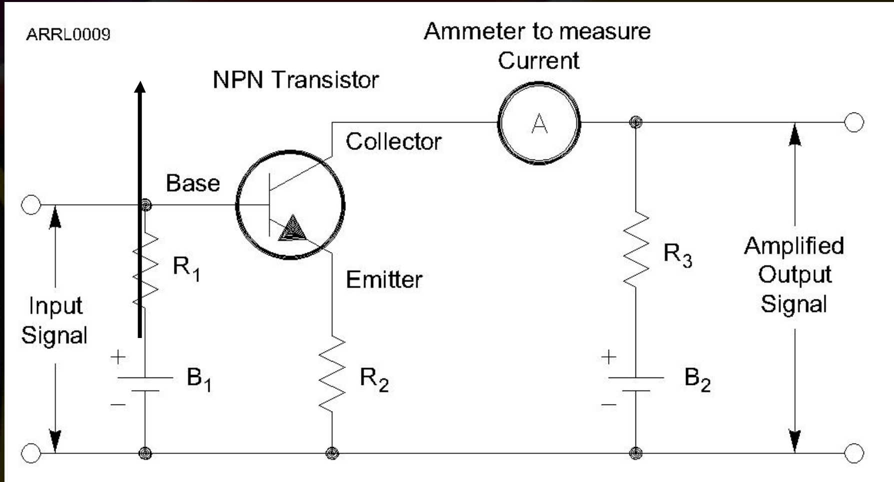
Electronics – Controlling the Flow of Current

- To make an electronic device (like a radio) do something useful (like a receiver), we need to control and manipulate the flow of current.
- There are a number of different electronic components that are used to do this

Schematic Diagrams

- We can draw pictures of electronic components forming circuits, such as for the parallel and series circuit examples. This is too cumbersome for most circuits.
- Schematic diagrams use symbols with different components, each having a different symbol.

Schematic Diagrams



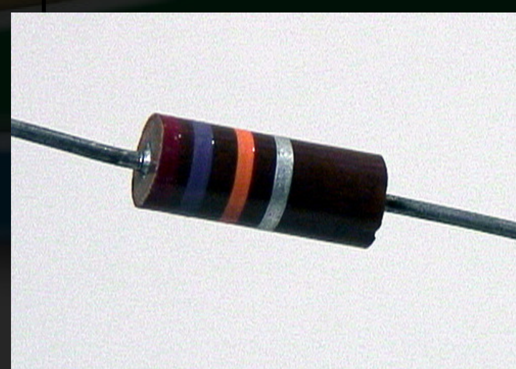
The lines and dots on schematics represent electrical connections between the components.

The Resistor

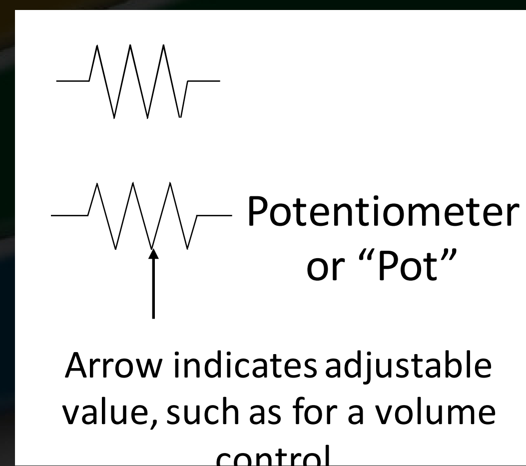
- The function of a resistor is to restrict the flow of current.
- Remember Ohm's Law:

  $I = E / R$

  $E = I \times R$



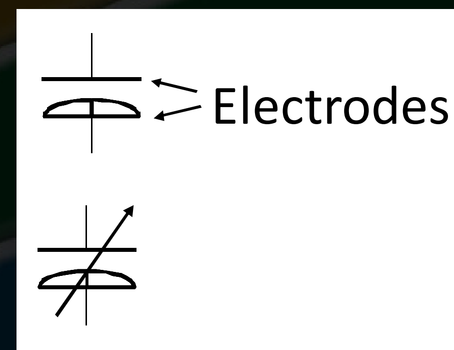
- Schematic symbol

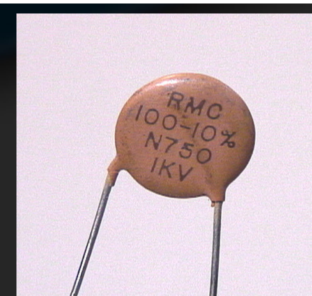


The Capacitor

- The function of a capacitor is to store electrical energy – called *capacitance.*
  - –Acts like a battery
  - –Stores energy in an electric field created by voltage between the electrodes with insulating *dielectric* material between them

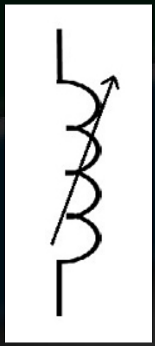
- Schematic symbol





The Inductor

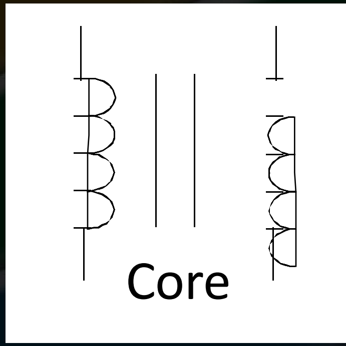
- The function of an inductor is to store magnetic energy – called *inductance.*
  - A coil of wire around a *core* of air or magnetic material like iron or ferrite
  - Stores energy in a magnetic field created by current in the wire
- Schematic symbol

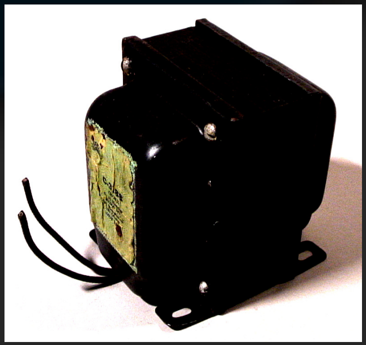


The Transformer

- A pair of inductors sharing a common core
  - Also share their magnetic field
  - Used to transfer energy from one circuit to another without a direct connection
  - Changes the ratio of voltage and current

- Schematic symbol





Electrical Units

- Each type of component has a value measured in specific units:
  - Resistors > resistance > ohms (Ω)
  - Capacitors > capacitance > farads (F)
  - Inductors > inductance > henrys (H)

Component Designators

- Each schematic symbol has a *designator* to denote which component it refers to. For example, the 10th resistor in a circuit is R10.
- Resistors (R), capacitors (C), inductors (L).

Indicators and Displays

- Indicators communicate status
  - ON/OFF, ready/stand-by, left/right
  - LEDs, light bulbs, symbols, audio tones
- Displays communicate values or text
  - Numeric values, warnings, messages
  - Digital and analog meters, LCD screens

Reactance

- Capacitors and inductors store energy, rather than dissipating it like resistors.
- 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

Impedance

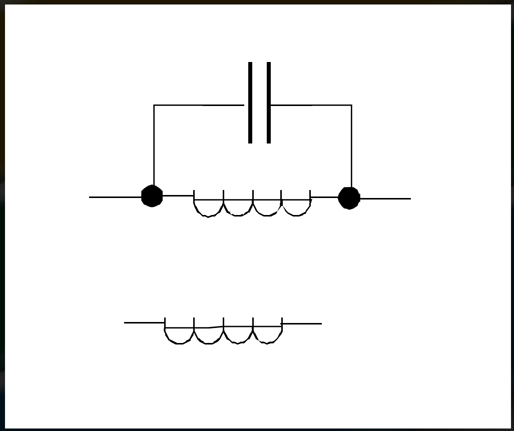
- The combination of resistance (*R*) and reactance (*X*) is called *impedance*, represented by the symbol *Z*.
- Impedance represents a circuit's opposition to both ac and dc currents.

Resonance

- A component's reactance depends on frequency: X_L increases with frequency while 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.

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.

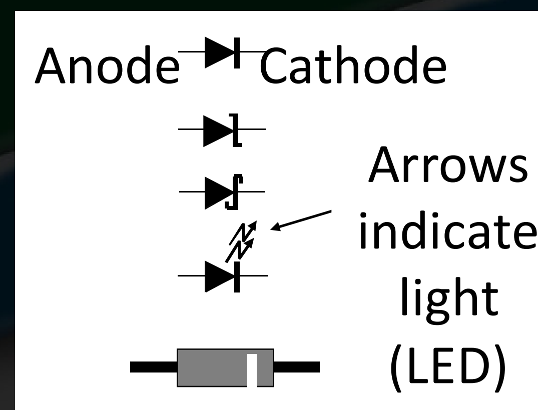


Semiconductor Components

- Made of material like silicon that are "OK" conductors but not as good as metals.
- Impurities added to semiconductors create material with more than usual electrons (*N-type)* and fewer than usual (*P-type*) electrons.
- Structures of N and P material can control current flow through the semiconductor.

The Diode

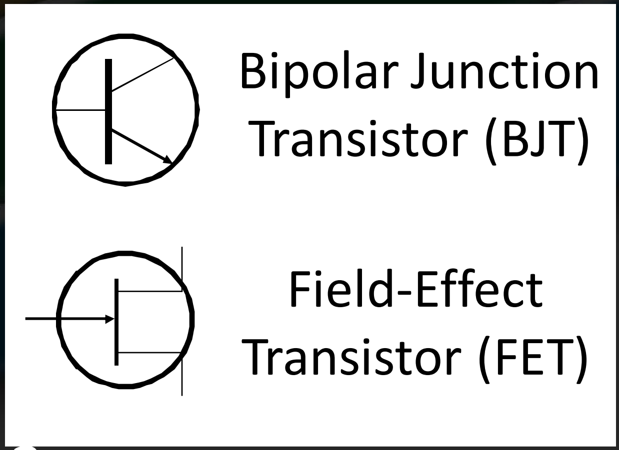
- Allows current to flow in only one direction.
  - Two electrodes: *anode* and *cathode*
  - AC current is changed to varying pulses of dc – called *rectification*
  - Diodes used to change ac power to dc power are called *rectifiers*
- Schematic symbol
- Designator (D or CR)



The Transistor

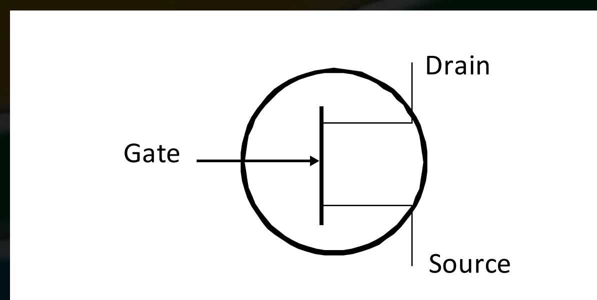
- The function of a transistor is to control large signals with small ones.
  - An “electronically controlled current valve”
  - When used as an amplifier a transistor produces *gain*
  - Transistors can also be used as a switch

- Schematic symbol
  - Designator (Q)



The Transistor

- The Field-Effect Transistor (FET) has a conducting path or channel of N and P material connected to the drain and source electrodes.

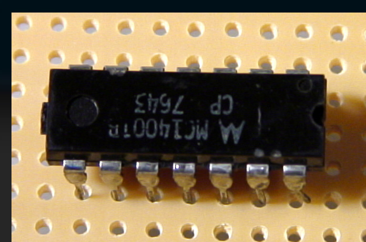


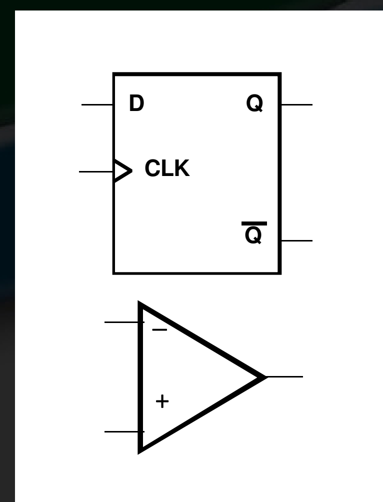
- Voltage applied to the gate electrode controls current through the channel.

The Integrated Circuit

- The integrated circuit is a collection of components contained in one device that accomplishes a specific task.

- Schematic symbol
- Designator (IC or U)

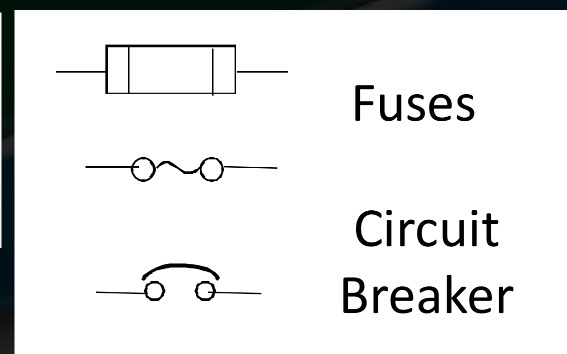




Protective Components

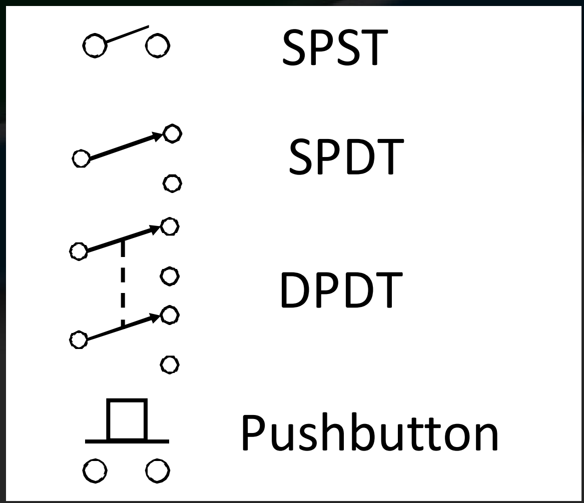
- Fuses and circuit breakers are designed to remove power in case of a circuit overload.
  - –Fuses blow – one time protection
  - –Circuit breakers trip – can be reset and reused
  - –Always use proper rating

- Schematic symbol
- Designator (F or CB)



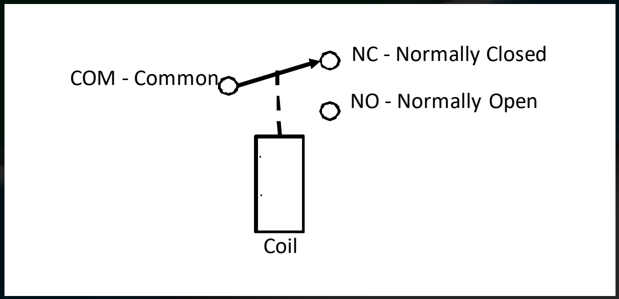
Switches

- Switches are used to interrupt or allow current to flow.
  - Each circuit controlled by the switch is a *pole*
  - Each position is called a *throw*
- Schematic symbol
- Designator (S or SW)

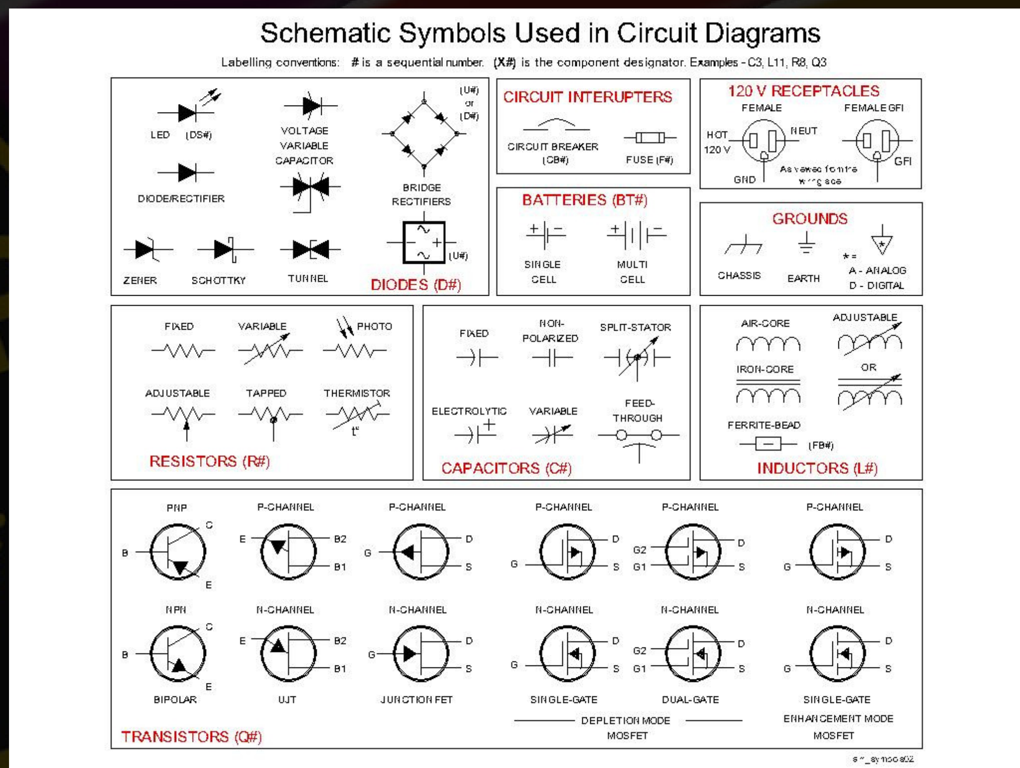


Relays

- Relays are switches activated by current in a coil (electromagnet)
  - Relays use the same pole/throw names as switches
  - The moving switch is called the *armature*
  - *Contacts* are named by when they are connected
- Schematic symbol
- Designator (K or RLY)



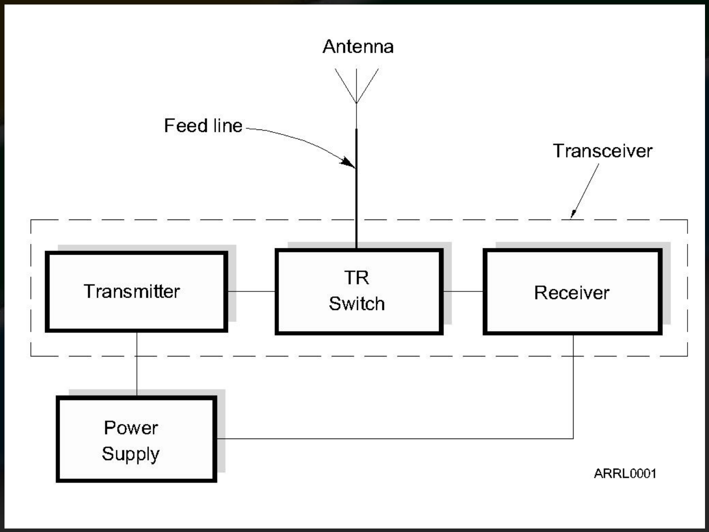
Other Circuit Symbols



The Basic Transceiver

- Combination of "transmitter" and "receiver"
  - Abbreviated "XCVR"

  (X = trans)
  - Antenna switched between transmitter and receiver by the TR switch

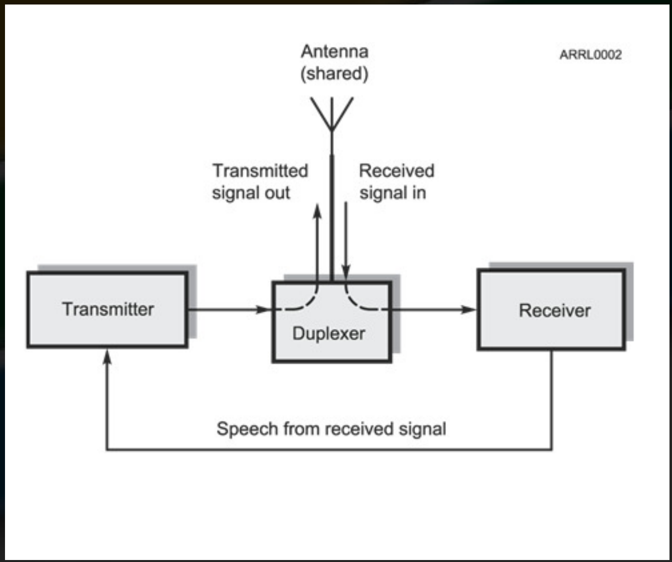


Transmit/Receive (TR) Switch

- TR switch allows a single antenna to be switched to the transmitter when sending and to the receiver when receiving.
  - In a transceiver, the TR switch is inside the unit and operates automatically.
  - Transceivers cannot transmit and receive at the same time like a repeater.

The Basic Repeater

- Relays signals from low-power stations over a wide area
  - Simultaneously re-transmits received signal on the same band
  - TR switch replaced with duplexer which allows antenna to be shared without switching



What Happens During Radio Communication? (Review)

- Transmitting (sending a signal):
  - Information (voice, data, video, commands, etc.) is converted to electronic form.
  - The information in electronic form is added to a radio wave.
  - The radio wave carrying the information is sent from the station antenna into space.

What Happens During Radio Communication? (Review)

- Receiving:
  - The radio wave carrying the information is intercepted by the receiving station's antenna.
  - The receiver extracts the information from the received wave.
  - The information is then presented to the user in a format that can be understood (sound, picture, words on a computer screen, response to a command,

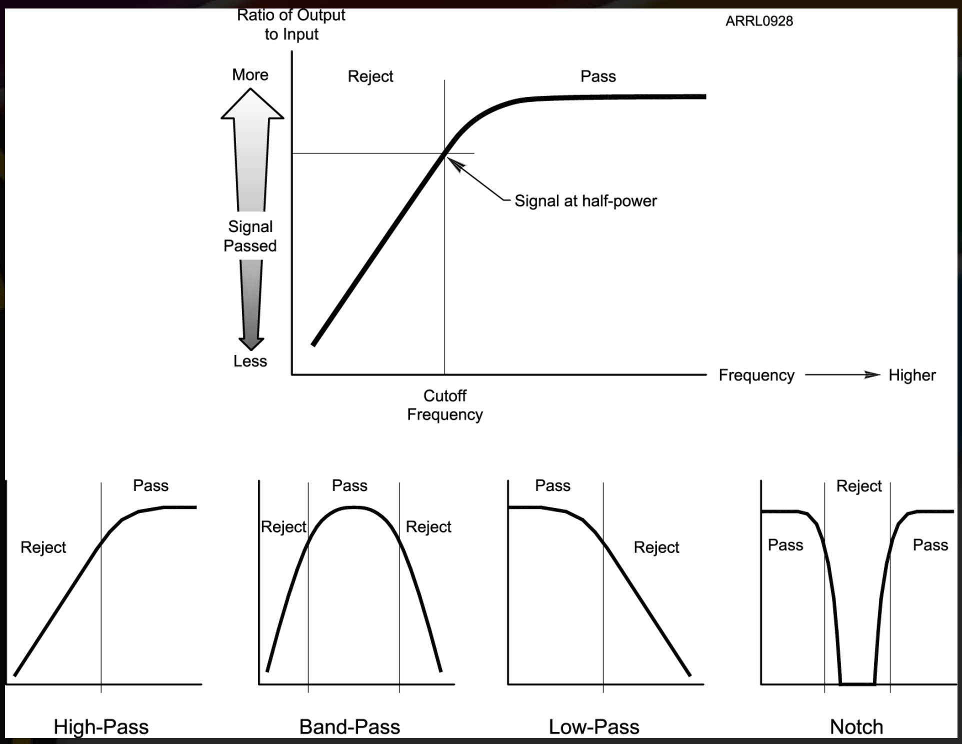
What Happens During Radio Communication? (Review)

- Adding and extracting the information can be simple or complex.
- This makes ham radio fun…learning all about how radios work.
- Don’t be intimidated. You will be required to only know the basics, but you can learn as much about the “art and science” of radio as you want.

Filters

- Circuits that act on signals differently according their frequency.
- Filters can reject, enhance, or modify signals.

Types of Filters



Adding Information - Modulation

- When we add some information to the radio wave (the *carrier*), we *modulate* the wave.
  - Morse code (CW), speech, data
- Different modulation techniques vary different properties of the wave to add the information:
  - Amplitude, frequency, or phase

Adding Information - Modulation

- Modulator and demodulator circuits
  - Modulators add information to an RF signal, demodulators recover the information

Changing Frequency - Mixers

- Signal frequencies can be changed by combining with another signal, called *mixing*
  - Also referred to as *heterodyning*
- Two signals are combined in a *mixer*
  - Generates *mixing product* signals
  - Sum and difference of the input signals
  - Shifts frequency by adding or subtracting
- Different than a *multiplier* which multiplies a signal's frequency by some integer, usually 2 or 3

Sensitivity and Selectivity

- Two essential tasks for a receiver:
  - Hear a signal and hear only one signal
- *Sensitivity* is a measure of how well the receiver can detect weak signals
- *Selectivity* is a measure of the receiver's ability to discriminate between signals
- *Preamplifiers* make a receiver more sensitive
  - Preamplifiers added between antenna and receiver

Transverter

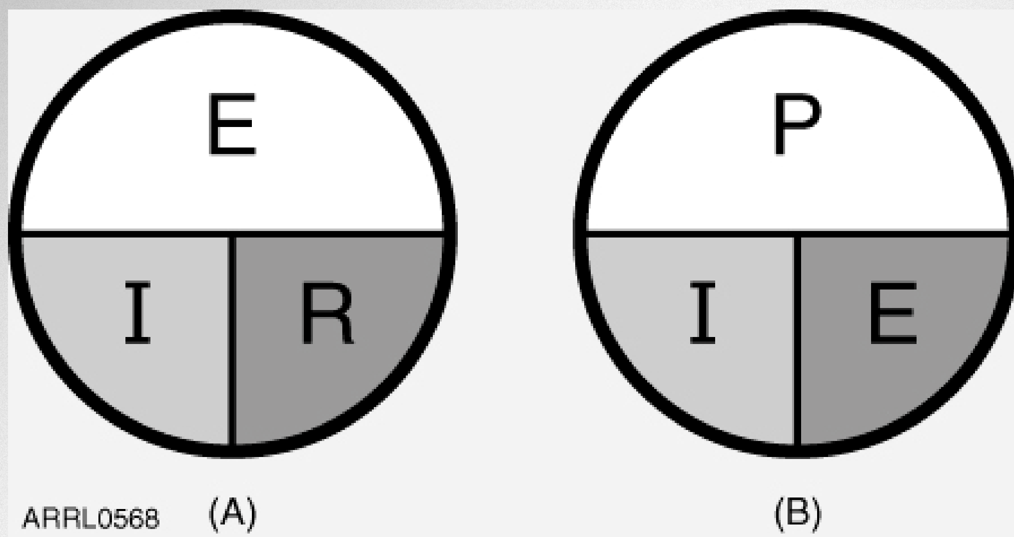
- Short for “transceiving converter” (XVTR)
- Converts a transceiver to operate on another band
  - Usually to a higher frequency
  - External mixers shift frequency
- Typical examples
  - HF SSB/CW at 28 MHz converted to/from 222 MHz
  - VHF SSB/CW at 144 MHz converted to/from 10 GHz

Current Voltage and Power

- *Current* = I, the flow of electrons, measured in Amperes (A or Amps) with an ammeter
- *Voltage* = E, force that makes electrons move, measured in volts (V) with a voltmeter
- *Power* (P) is measured in watts (W) with a wattmeter, P = E x I

Resistance & Ohms Law

- Resistance (R) is the opposition to current flow measured in Ohms (Ω) with an ohmmeter.



$R=E/I$, $I=E/R$, $E=I \times R$, $P=I \times E$, $P=I^2 \times R$, $P=E^2 / R$

Doing the Math

- G5B03 – How many watts of electrical power are used if 400 V dc is supplied to an 800 ohm resister?

$$P=E^2/R$$

P= (400 x 400) / 800 = 160,000 / 800

1600,000 / 800 = **200 watts**

Doing the Math

- G5B04 – How many watts of electrical power are used by a 12 V dc light bulb that draws 0.2 A?

$$P = E \times I$$

P = 12V x 0.2A = **2.4 watts**

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Doing the Math

- G5B05 – How many watts are being dissipated when a current of 7.0 mA flows through a 1.25 k (omega) resistor?

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

$$P = (.007 \times .007) / 1250 = 0.06125 \text{ W}$$

0.06125 = <u>**61.25 mW**</u>

Doing the Math - Decibels

- The formula for calculating decibels (dB)
  - dB = 10 $\log_{10}$ (power ratio) = 20 $\log_{10}$ (voltage ratio)
  - dB = 10 $\log_{10}$ (P_M / P_{Ref}) = 20 $\log_{10}$ (V_M /V_{Ref})
- What is the gain of an amplifier that turns a 5 watt signal into a 25 watt signal?
  - dB = 10 $\log_{10}$ (25 / 5) = 10 $\log_{10}$ (5) = 10 x (0.7) = **7 dB** Calculator key strokes: 5, log, x, 10, = 6.9897 *(round up to 7)*

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Doing the Math - Decibels

- Calculating a Power or Voltage Ratio from dB
- Power ratio = $\log^{-1}$ (dB/10)
- Example 1: A power ratio of 9 dB = ?
  - $\log^{-1}$ (9/10), $\log^{-1}$ (.9) = **8**
  - Keystrokes: 9 / 10 = .9 [2nd function] log = 7.94328 (round up)
  - Voltage ration = $\log^{-1}$ (dB/20)
- Example 2: A voltage ratio of 32 dB = ?
  - $\log^{-1}$ (32/20) = $\log^{-1}$ (1.6) = **40**
  - Keystrokes: 32/20=1.6 [2nd function] log = 39.8107
  - Round the answer up to 40

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Doing the Math Decibels

- Converting dB to percentage and vice versa:
  - dB = 10 log (Percentage Power / 100%)
  - dB = 20 log (Percentage Voltage / 100%)
  - Percentage Power = 100% x $\log^{-1}$ (dB/10)
  - Percentage Voltage = 100% x $\log^{-1}$ (dB/20)

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Doing the Math Decibels

- G5B10 - What percentage of power loss would result from a transmission line loss of 1 dB?
  - Percentage Power = 100% x $\log^{-1}$ (dB/10)
  - 100% x $\log^{-1}$ (-1/10) = 100% x $\log^{-1}$ (-.1) = **79.4%**
  - Keystrokes: 1 [+/-] /10= [2nd function] log x 100 = 79.4328
  - (round the answer to 79.4%)

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3 dB Rule

- G5B01 – Remember that to double or reduce in half is a 3dB change
- A 2 times increase in power is ___ dB?
  - $dB = 10 \log_{10} (P_M / P_{Ref})$
  - $dB = 10 \log_{10} (2 / 1) = 3dB$
  - Keystrokes: 2 / 1 = 2 [log] x 10 = 3.010299
  - (round answer to 3dB)

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AC Power

- Definition and Measurement
- Root Mean Square (V_{RMS})
  - The RMS value for an ac voltage is equivalent to the value of a dc voltage that results in the same power dissipation in a resistor

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Definition & Measurement

- RMS value is 0.707 times the ac waveform's peak voltage (V_{PK})
  - $V_{RMS} = 0.707 \times V_{PK} = 0.707 \times (V_{P-P} / 2)$
  - $V_{PK} = 1.414 \times V_{RMS}$
  - $V_{P-P} = 2 \times 1.414 \times V_{RMS} = 2.828 \times V_{RMS}$

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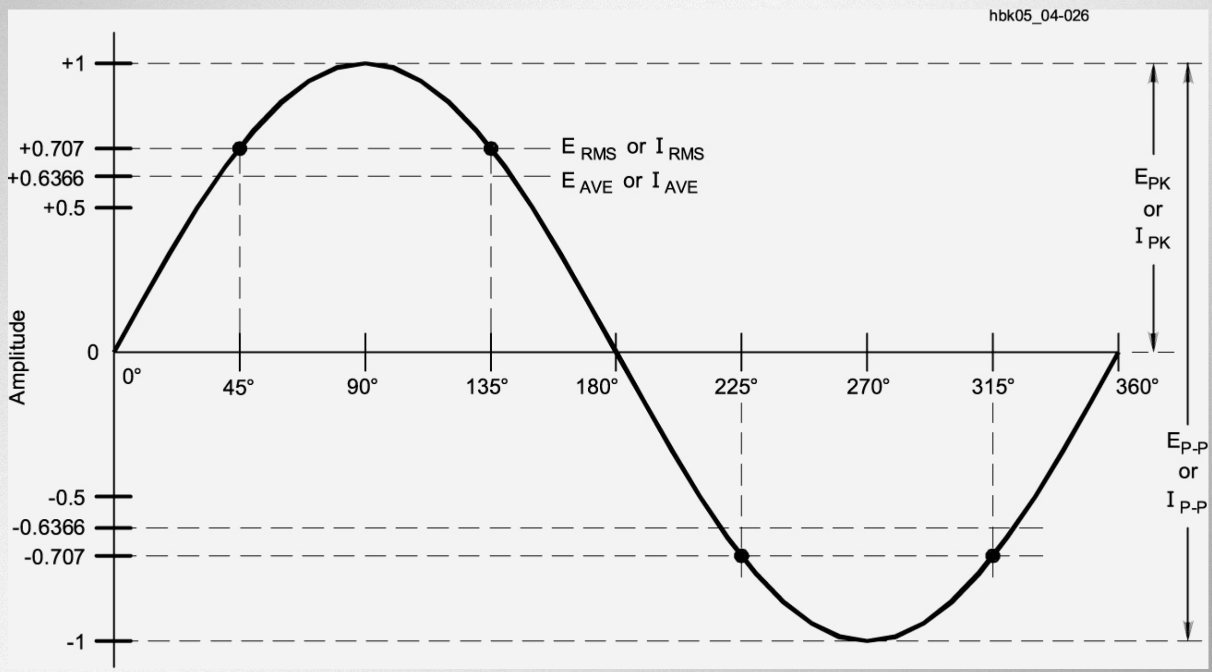
Measurements

- Relationships between RMS, average, peak-to-peak values



Doing the RMS Math

A sine wave with a peak voltage of 17 V has an RMS value of?

- V_{RMS} = 0.707 x 17 V = **12 V**

A sine wave with a peak-to-peak voltage of 100 V has an RMS value of?

•V_{RMS} = 0.707 x (100 / 2) = **35.4 V**

A sine wave with an RMS voltage of 120 V has a peak-to-peak voltage of?

•V_{P-P} = 2 x 1.414 x 120 = 2.828 x 120 = **339.4 V**

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PEP Definition & Measurement

- 1500 W PEP (peak envelope power) is full amateur power limit
- PEP is the average power of one complete RF cycle at the peak of the signal's envelope
- PEP is an easy way to measure or specify the maximum power of an amplitude modulated signal
- PEV (peak envelope voltage) is the voltage at the peak of the signal envelope

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PEP Doing the Math

- Example 10:

Example 10: If PEV is 50 V across a 50-Ω load, the PEP power is

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

- Keystrokes:
  - 50 x 0.707 = 35.35 [x^2] = 1249.6225 / 50 = 24.99245 W
  - Round the answer to <u>25 W</u>

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PEP Doing the Math

Example 11:

Example 11: If a 50-Ω load is dissipating 1200 W PEP, the RMS voltage is

$$V_{RMS} = \sqrt{PEP \times R} = \sqrt{1200 \times 50} = 245\ V \quad [G5B12]$$

- Keystrokes:
  - 1200 x 50 = 60,000 [square root symbol] = 244.9489
  - Round answer to 245 V

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PEP Doing the Math

- Example 13:

Example 13: If an oscilloscope measures 200 V_{P-P} across a 50-Ω load, the PEP power is

$$PEP = \frac{\left[\frac{0.707 \times 200}{2}\right]^2}{50} = \frac{4999}{50} = 100 \text{ W} \quad [G5B06]$$

- Keystrokes:
  - 0.707 x 200 = 141.4 / 2 = 70.7 [x^2] / 50 = 99.968
  - Round answer to <u>100 W</u>

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PEP Doing the Math

- What is the output PEP from a transmitter if an oscilloscope measures 500 volts peak-to-peak across a 50 Ω resistor connected to the transmitter output?
- Keystrokes:
  - 0.707 x 500 = 353.5 / 2 = 176.75 [x^2] / 50 = 624.81125
  - Round answer to <u>625 W</u>

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PEP & Average Readings

- PEP is equal to average power if an amplitude modulated signal is not modulated
  - An unmodulated AM signal, a key down CW signal, and a FM signal are all constant power modes for which PEP = Average Power.
  - *Single sideband PEP is not equal to average power*
- If your CW transmitter generates 1060 W average output power, the PEP is also 1060 W

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Resistors & Resistance

- Resistors may have the same nominal value but vary in other characteristics

Table 4.1
Characteristics of Resistor Types

Resistor Type	*Power Ratings*	*Applications*
Carbon composition	⅛ – 2 W	General use, wire leads
Carbon film	⅒ – ½ W	General use, wire leads and SMT package
Metal film	⅒ – ½ W	Low-noise, wire leads and SMT package
Wirewound	1 W – 100 W or more	Power circuits
Metal oxide	½ – 10 W	Noninductive for RF applications

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Resistors & Resistance

- Resistance nominal values
  - 1 Ω to more than 1 MΩ (value or color bands printed on them)
- Resistor Tolerance (accuracy)
  - Precision (1% or less), general purpose (5 or 10%)
- Temperature Coefficients (tempco) are change characteristics (positive or negative)
  - Positive increases in value as temperature goes up
  - Negative decreases in value as temperature goes down

Resistors & Resistance

- Parasitic Inductance:
  - Parasitic – unwanted characteristic resulting from the component's physical construction (wire-wound resistor on a ceramic form)
  - Placing a wire-wound resistor in an RF circuit can disrupt operation or tuning
  - RF circuits normally use carbon composition, carbon film, or metal oxide resistors which have very low inductance

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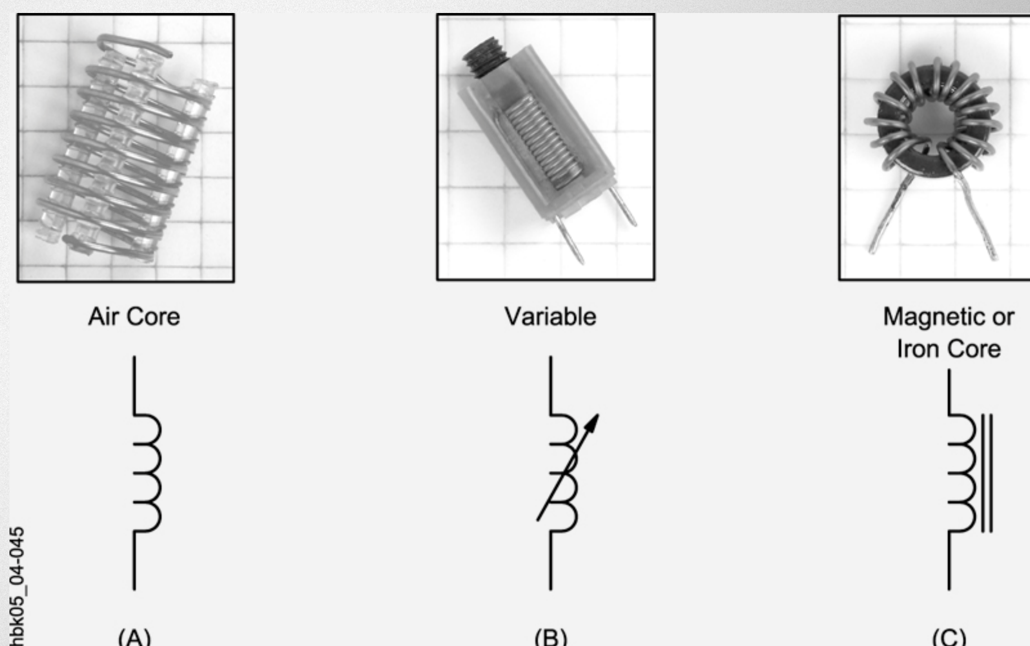
Inductors & Inductance

- Laminated iron core – dc and ac power and filtering
- Powdered iron solenoid – power supplies, RF chokes, audio and low-frequency circuits
- Powdered iron & ferrite toroids – audio and radio circuits
- Air core – RF transmitting



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Inductors & Inductance

- *Variable inductors* – used in low-power receiving and transmitting applications
  - *Low-power* - adjusted by moving a magnetic core in and out of the inductor
  - *High-Power* - adjusted by moving a sliding contact along the inductor, like a roller inductor in an antenna matching network

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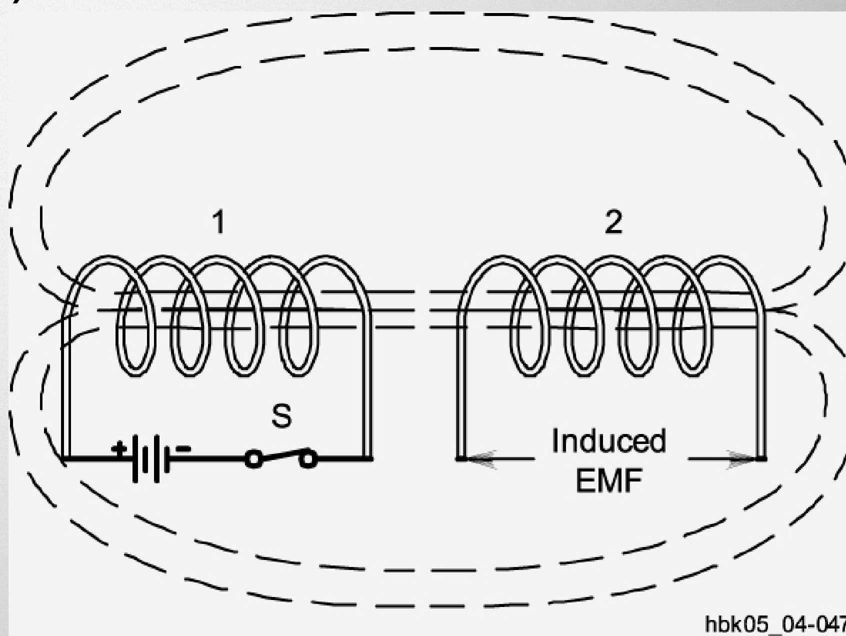
Inductors & Inductance

- Inductance is the ability to store magnetic energy (measured in henries, H)
- Increasing the core permeability will increase the ability to store magnetic energy and thus the inductance
- The core material is selected based on its suitability for a range of frequencies

Inductors & Inductance

- When inductors are placed close together with their axes aligned, the magnetic energy from one inductor passes through the other inductor, sharing some of its energy (coupling or mutual inductance)



Inductors & Inductance

- Two solenoid inductors should be oriented at right angles to each other to minimize their mutual inductance
- Coupling allows signals to be shared between circuits without a direct connection.
  - Coupling can be undesirable
- Toroid inductors with a magnetic core keep nearly all of the magnetic energy in the core so that coupling is minimized.

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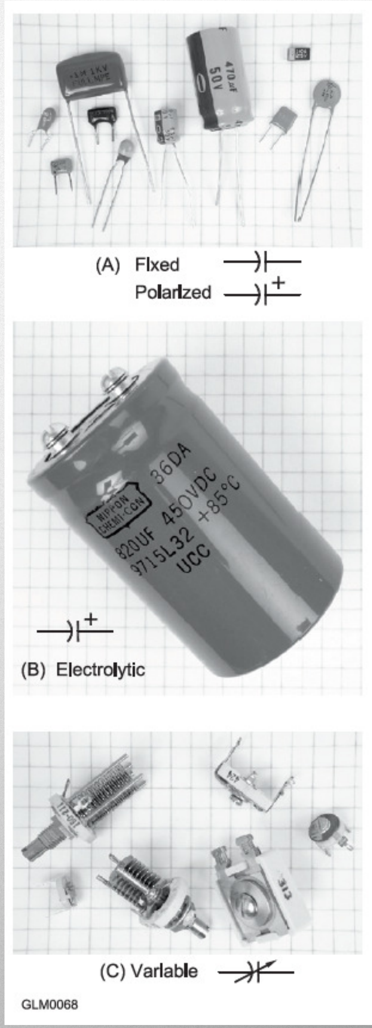
Capacitors & Capacitance

- 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



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Capacitors & Capacitance

- The simplest capacitor is a pair of metal plates separated by air
- Capacitor types:
  - Ceramic – RF filtering, bypassing at high frequencies, low cost
  - Plastic film – audio circuits & lower radio frequencies
  - Silvered-mica – highly stable, low loss, use in RF circuits
  - Electrolytic and tantalum – power supply filter circuits
  - Air and vacuum dielectric – transmitting and RF circuits

Capacitors & Capacitance

- Aluminum and tantalum electrolytic capacitors
  - Dielectric is a thin film
  - Voltage must be applied with the correct polarity
  - Benefit – Create large capacitances in comparatively small volumes

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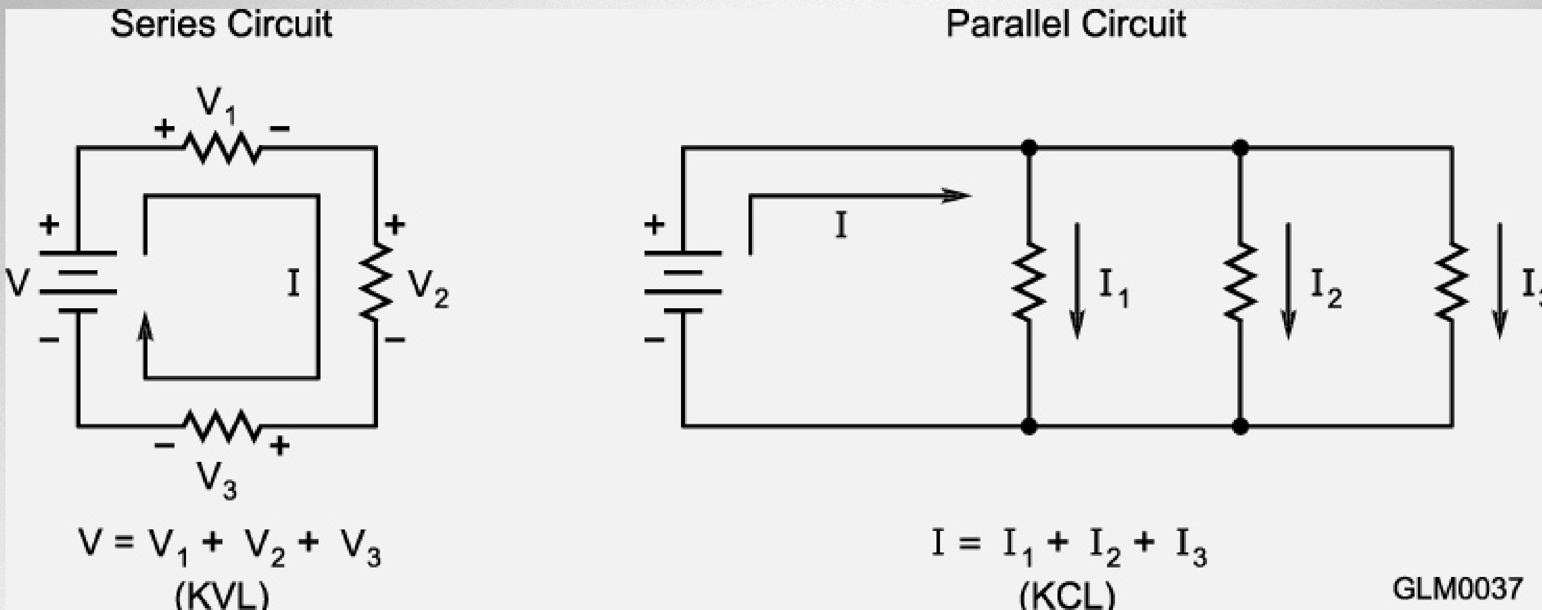
Components in Series & Parallel Circuits

- Kirchhoff's Voltage Law
- Kirchhoff's Current Law



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Adding Components in Series and Parallel

Table 4.3

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

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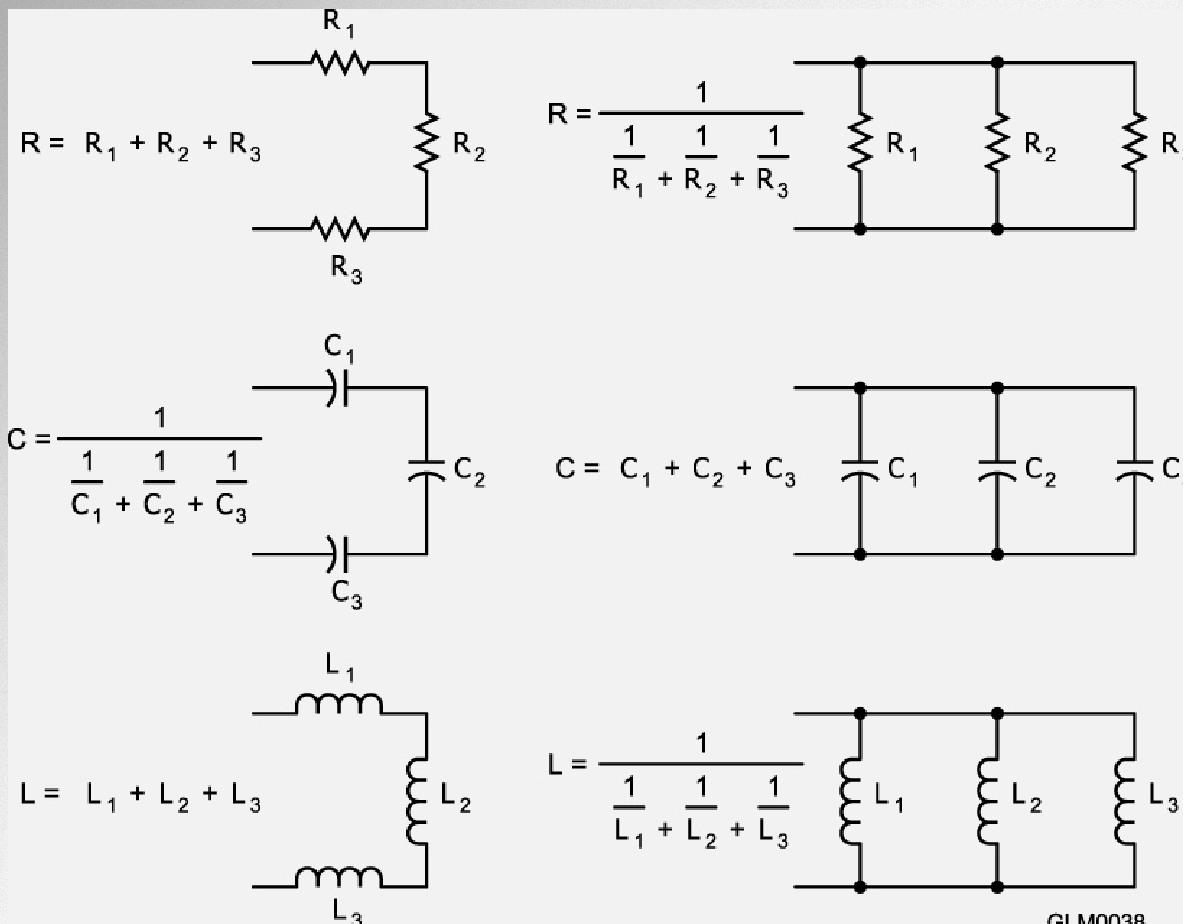
Doing the Math



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Doing the Math

- Make your calculator do the hard work
- Some calculators require a 2nd function key to get to a 2nd set of commands, like using the shift key on your computer's keyboard
- Example 14: Three 100 Ω resistors in parallel?
  - Keystrokes: 100 [2nd function 1/x] + 100 [2nd function 1/x] + 100 [2nd function 1/x] = 33.33333 Ω

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Doing the Math

- Ex. 15: Three 100 μF capacitors in series?
  - Keystrokes: 100 [2^{nd} function 1/x] + 100 [2^{nd} function 1/x] + 100 [2^{nd} function 1/x] = 33.33333 μF
- Ex. 16: Three 10 mH inductors in parallel?
  - Keystrokes: 10 [2^{nd} function 1/x] + 10 [2^{nd} function 1/x] + 10 [2^{nd} function 1/x] = 3.33333 mH
- Ex. 17: A 20 mH and 50 mH inductor in series?
  - Keystrokes: 20 + 50 = 70 mH (simple addition)

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Doing the Math

- Ex. 18: A 20 μF and 50 μF capacitor in series?
  - Keystrokes: 20 [2nd function 1/x] + 50 [2nd function 1/x] + = 14.2857 μF (round to 14.29 μF)
- Ex. 19: A 10 Ω, 20 Ω, and 50 Ω resistor in parallel?
  - Keystrokes: 10 [2nd function 1/x] + 20 [2nd function 1/x] + 50 [2nd function 1/x] = 5.88235 Ω (round to 5.9 Ω)

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Doing the Math

- Ex. 20: Total capacitance of two 5 nF and one 750 pF in parallel?
  - (*First convert 5nF to pF = 5 x 1000 = 5000 pF*)

Keystrokes: 5000 + 5000 + 750 = 10750 pF/1000 = 10.75 nF

- Ex. 21: What three equal value resistors can be combined in parallel to equal 50 Ω?

  Problem restated R/3 = 50 Ω, multiply both sides by 3 to put the R by itself. R = 3 x 50 = 150 Ω

  Proof: 150 [2nd function 1/x] + 150 [2nd function 1/x] + 150 [2nd function 1/x] = 50 Ω

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Transformers

- Primary Winding – power is applied
- Secondary winding – power is extracted
- When voltage is applied to the primary winding (E_P), mutual inductance causes voltage (E_S) to appear across the secondary winding (works in both directions)
- The *turns ratio* of the secondary (N_S) to the primary (N_P) windings determines how the current and voltage are changed
  - $E_S = E_P \times (N_S / N_P)$ and $I_S = I_P \times (N_P / N_S)$

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Transformers

- A significant change between primary and secondary voltage usually requires a change in the size of wire between windings
- In a step-up transformer, the primary winding carries higher current and is wound with larger-diameter wire than the secondary

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Doing the Transformer Math

- Example 22 – Voltage across a 500 turn secondary when 120 V is applied to a 2250 turn primary?
  - E_S = (applied voltage) x (N_S/N_P)
  - Keystrokes:
    - E_S = 500/2250 = 0.22222222 x 120 = 26.66666666 V
    - Answer is rounded to 26.7 V

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Reactance

- Definition: The resistance to the flow of ac current caused by capacitance or inductance is called reactance and is denoted by X. It is measured in ohms, like resistance.

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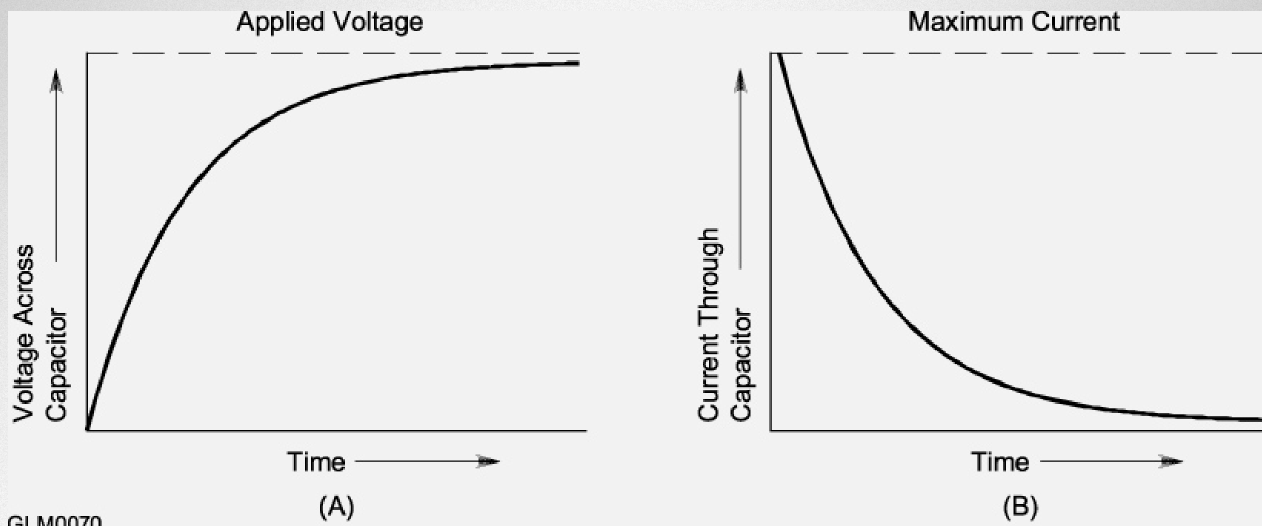
Reactance

- Capacitive reactance: The opposition to ac current flow from the stored energy in a capacitor is called capacitive reactance (X_C)
- As the frequency of the applied signal increases, X_C decreases. and vice versa



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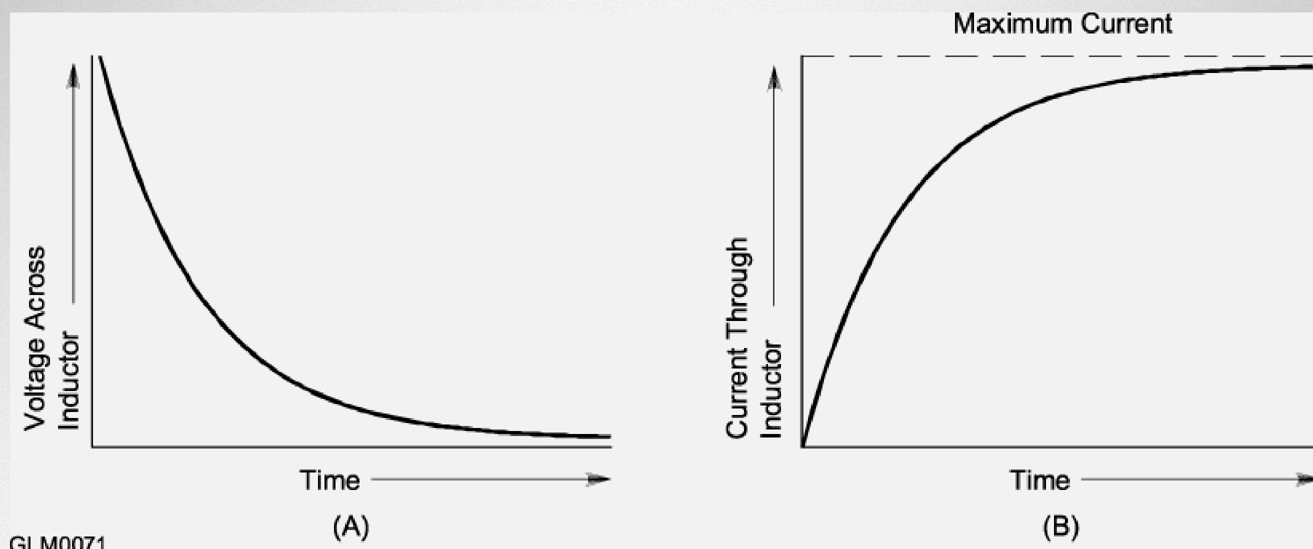
Reactance

- Inductive reactance is the opposition to ac current flow from the stored energy in a inductor and is denoted by X_L
- As the frequency of the applied signal increases, X_L increases and visa versa



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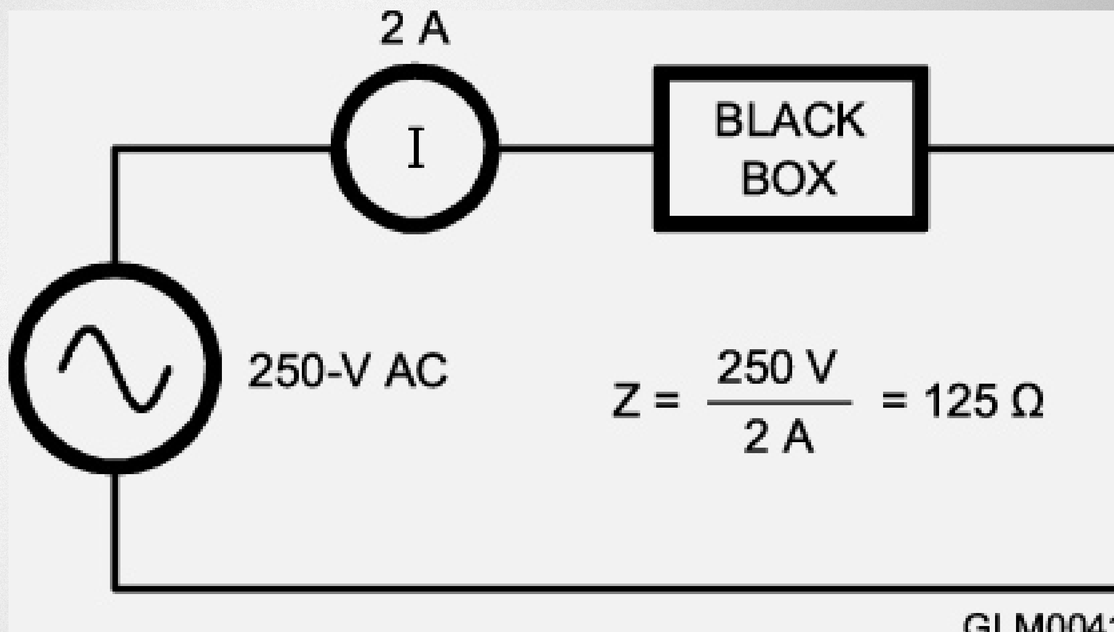
Impedance

- Impedance - opposition to current flow in an ac circuit
  - Denoted by “Z” and is measured in ohms (Ω)
  - The ratio of voltage to current



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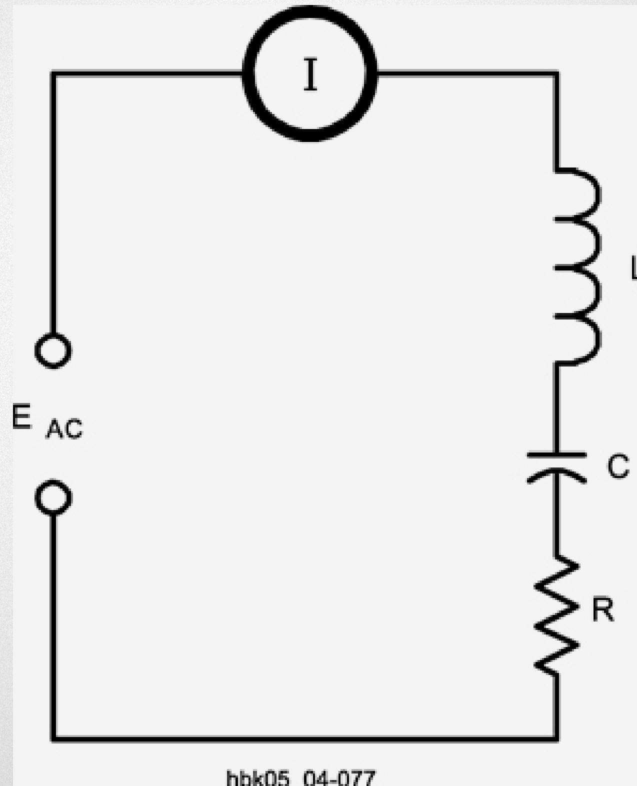
Resonance

- Resonance in a circuit or antenna occurs when capacitive and inductive reactance are equal
- In a resonant series circuit the reactances of the L and C cancel, forming a short circuit, leaving only the resistance, R, as the circuit's impedance
- Resonance is used in filters or tuned circuits to pass or reject specific frequencies



Impedance Transformation

- A transformer changes the ratio of voltage and current between the primary and secondary circuits and so changes the impedance
- $Z_p = Z_s (N_p / N_s)^2$ and $\sqrt{(Z_p / Z_s)} = N_p / N_s$
- Example 27: What turns ratio is required to change a 600 Ω impedance to a 4 Ω impedance?

Keystrokes: 600 / 4 = 150 [sq root] =12.24744871, rounded to 12.25 :1

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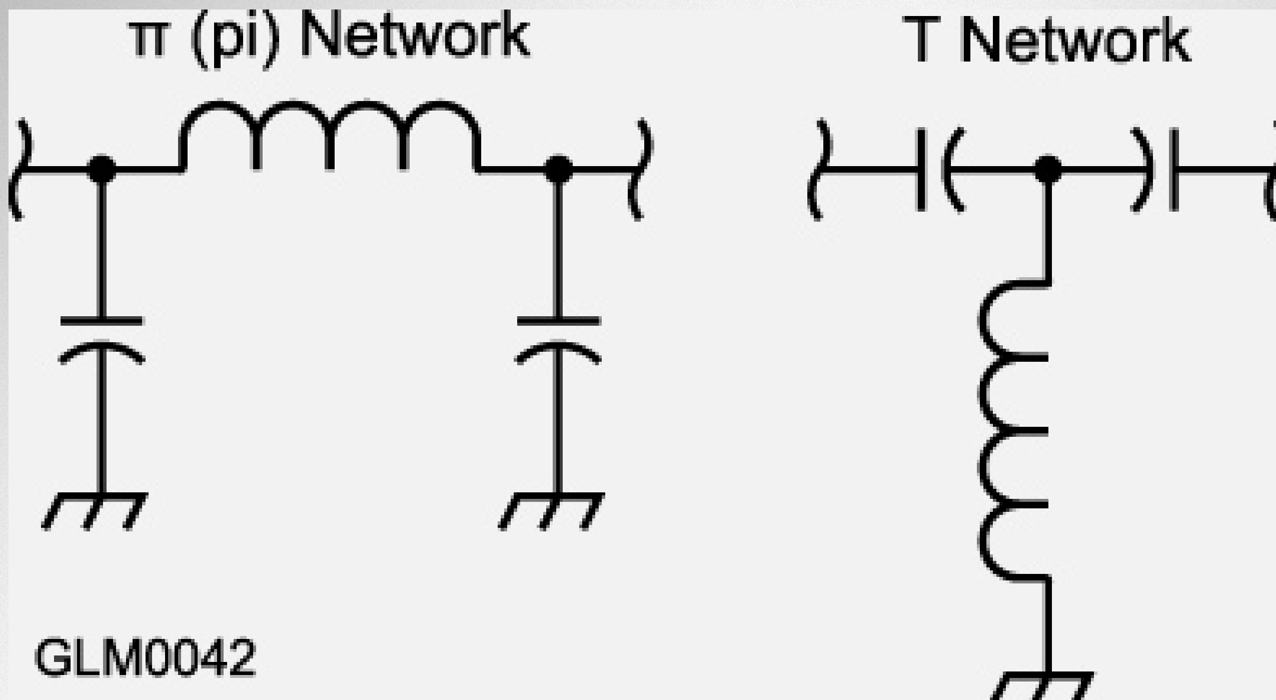
Impedance Matching

- Maximum power transfer occurs when the source and load impedances are equal
- Amateur transmitting equipment is designed to have a 50 Ω output
- Most antennas are designed to have a feed point impedance of 50 Ω but rarely present that impedance over the whole band
- An impedance-matching circuit changes the variable impedance into the desired value

Impedance Matching

Most impedance matching circuits are LC circuits made up of inductors and capacitors



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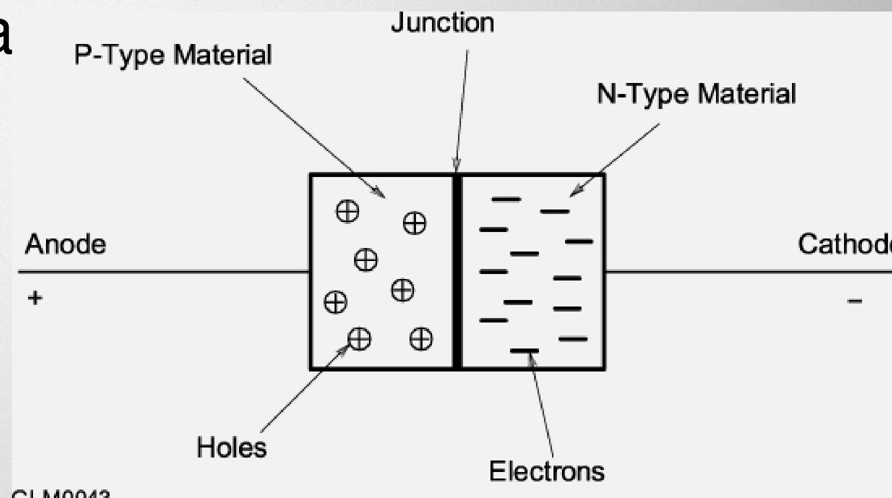
Impedance Matching

- Special RF impedance-matching transformers are often used to equalize impedances of the source and load to maximize the transfer of power to the load
- Special lengths of coax can be used to match impedances

Semiconductor Components

- Diodes & Rectifiers
  - Junction diode uses PN junction to block flow of current in one direction
  - Current flows when a positive voltage is applied from the P-type to the N-type material (forward bias)
  - Diode forward volta silicon 0.7 V, germanium 0.3 V



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Semiconductor Components

- Diode Ratings:
  - *Peak inverse voltage (PIV)* – maximum reverse voltage before breakdown occurs.
  - *Average forward current (I_F)* – Exceeding the diode's rating will destroy the diode's internal structure due to heat.
  - *Junction capacitance* (C_J) – when reverse biased, layers of P- and N-type material act like plates of a small capacitor. The larger the C_J the longer it takes to switch to conducting.

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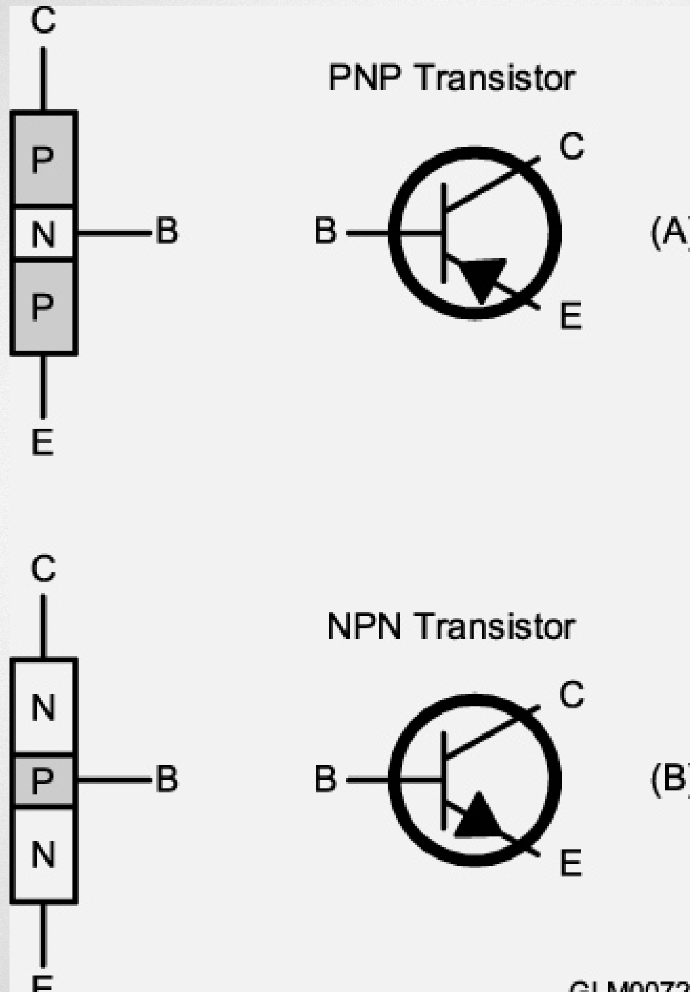
Diode Types

- *PIN diode* – low forward voltage drop, used for RF switching
- *Schottky diode* – low junction capacitance allows high-frequency operation
- *Varactor* – reverse biased acts like a variable capacitor
- *Zener diode* – used as a voltage regulator

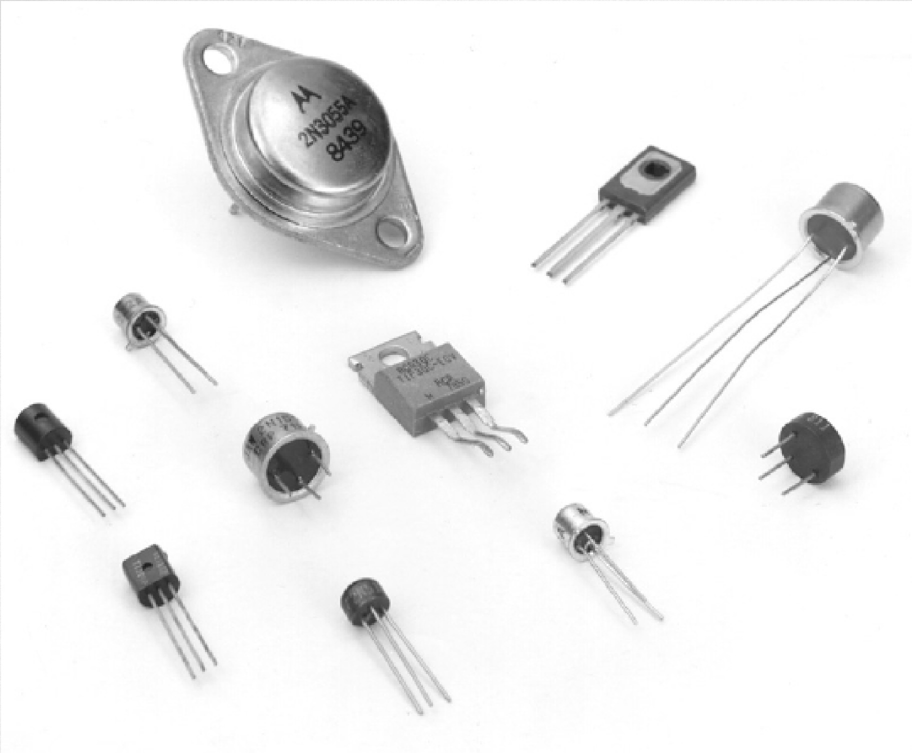
Bipolar Transistors

- Bipolar junction transistors have 3 electrodes:
  - Collector (C)
  - Base (B)
  - Emitter (E)
- Controlled by current flow between base and emitter



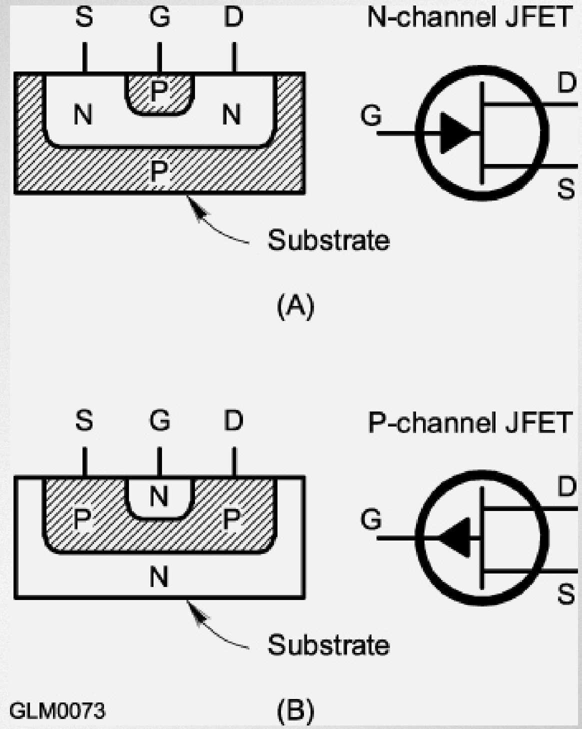
Bipolar Transistors

- Very little base-emitter current is required for the collector-emitter current to flow
- Control of a larger current by a smaller current is *current gain* or *beta (β)*



Field Effect Transistor (FET)

- The FET has 3 electrodes
  - Drain (D)
  - Source (S)
  - Gate (G)
- Controlled by voltage between gate and source.
- Metal-oxide-semiconductors (MOSFETs) insulate the gate with a thin layer of oxide

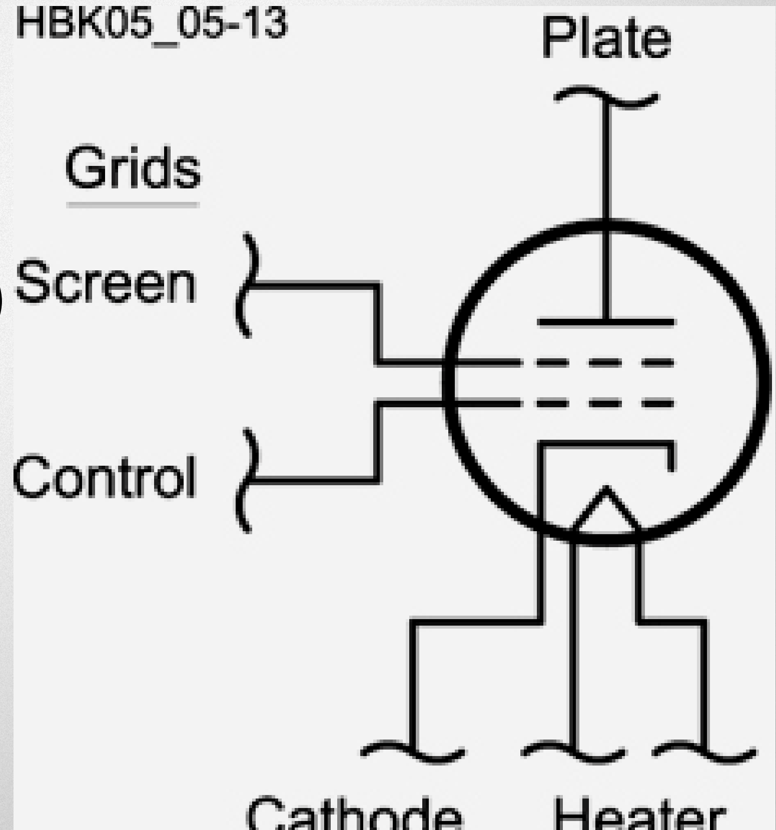


Transistors

- Transistors' high amplification makes them useful as *switches* for voltage and current
- *Saturation* – when further increases in input result in no output change
- *Cutoff* – when the input signal reduces output current to zero
- Saturation & cutoff states represent a *digital ON/OFF switch*
- A transistor's metal case can be connected to the chassis or heat sink by an insulator

Vacuum Tubes

- All amplifying tubes have at least 3 electrodes
- Compared to transistors, the tube is most like the field effect transistor (FET)
- Vacuum tubes typically operate at *hazardous voltages* as high as 2000 to 3000 volts (use **CAUTION!**)



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Vacuum Tubes

Tube terminology:

- *Filament or heater* – heats the cathode to make it emit electrons
- *Cathode* – source of electrons
- *Control grid* – regulates electron travel between the cathode and plate
- *Screen grid* – reduces grid-to-plate capacitance
- *Suppressor grid* – prevents electrons from traveling from the plate to the control or screen grid
- *Plate* – collects electrons

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Analog Integrated Circuits (ICs)

- Analog ICs or “chips”:
  - Used for amplification, filtering, measurement, and power control
  - A linear voltage regulator is used to maintain a power supply output at a constant voltage over a wide range of currents
  - Operational amps (op amp) are used for dc and audio circuits

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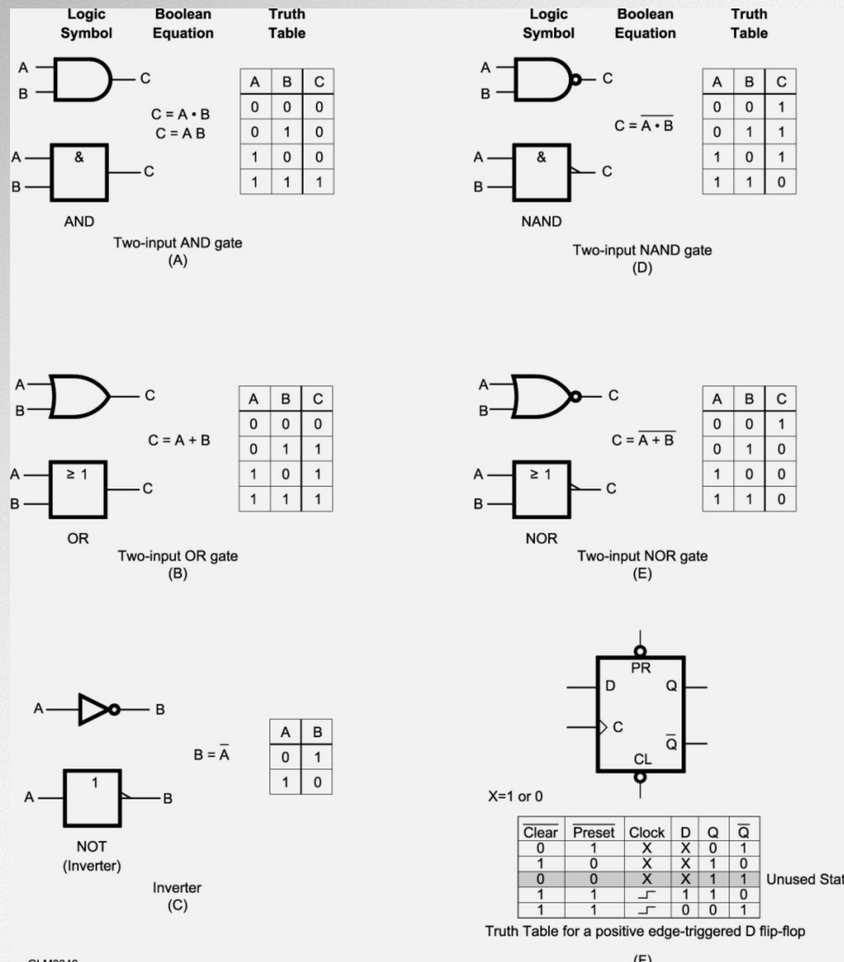
Digital Integrated Circuits (ICs)

- Digital ICs operate with discrete values of voltage and current representing the binary numbers system values 0 and 1
- Digital electronic circuits operate with only two stable states of operation, ON or OFF
- Digital circuits can perform computations or control functions
- CMOS (complementary metal-oxide semiconductors) technology is popular because of its high speed and low power consumption

Digital Logic Basics



Digital Logic Basics

- The basic building blocks of digital circuits are called *gates*
  - *Inversion* (changing a 1 to a 0 and vice versa)
  - OR and AND functions
  - Inverted NOR and NAND
  - Truth tables explain the Boolean functions implemented by the gates

Digital Logic Basics

- Flip-flop – has 2 stable states
- Sequential logic – built on flip-flops feeding other flip-flops (used in counters)
- Example: a 3-bit counter (one with 3 flip-flops) can count $2^3 = 8$ different states
- Example: a 4-bit counter (one with 4 flip-flops) can count $2^4 = 16$ different states
- Shift register – a clocked array of circuits that passes data in steps along the array

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RF Integrated Circuits

- RF ICs are designed for functions commonly used for radio frequencies
  - Low-level high-gain amplifiers
  - Mixers
  - Modulators and demodulators
  - Filters
  - MMIC (monolithic microwave integrated circuit) works through microwave frequencies

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Microprocessors & Components

- A microprocessor is a computer on a single Integrated Circuit
- Capable of performing billions of instructions per second using combinations of digital logic gates
- Has parallel and serial input-output ports, counters and timers
- Nearly all built from CMOS logic

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Microprocessor Components

- Memory:
  - Volatile memory loses the data stored when power is removed
  - Nonvolatile memory retains data permanently even when power is off
  - Random-access memory (RAM) can be read or written to in any order
  - Read-only memory (ROM) stores data permanently and can't be changed

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Microprocessor Components

- Interfaces:
  - Serial interface transfers one bit of data in each transfer
  - Parallel interface transfers multiple bits of data in each operation
  - RS-232 serial interface is rapidly being replaced by USB (universal serial bus) serial interface
  - Modern computers don't have RS-232 ports, so use the USB port and RS-232 converter to interface them to your transceiver

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Microprocessor Components

- Visual Interfaces:
  - *Indicator* – device that presents ON/OFF information (LED)
  - *Display* – device capable of presenting text or graphics in visual form
  - An LED is a special diode that produces light when it is forward biased
  - LEDs are available in several different colors, including white
  - LEDs have replaced *incandescent* light bulbs because they last longer and react faster

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Microprocessor Components

- *Liquid crystal display* (LCD) – created by sandwiching liquid crystal material between transparent glass panels
  - When voltage is applied to the electrodes on the front panel, the liquid crystals twist and block the light
  - LCDs require ambient or back lighting since the liquid crystal layer does not generate light

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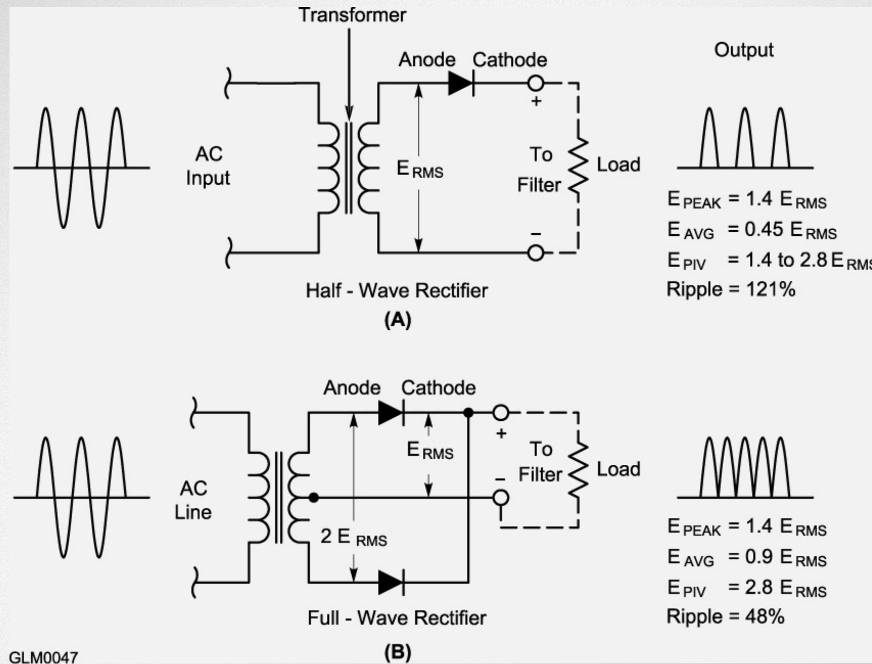
Rectifiers

- Half-wave rectifier allows current to flow in one-half of the input ac waveform (180˚) from the transformer, as shown in "A"



- Full-wave center-trapped rectifier two half-wave rectifiers operating on alternating half cycles, as shown in "B", using the transformer center tap for the current's return path

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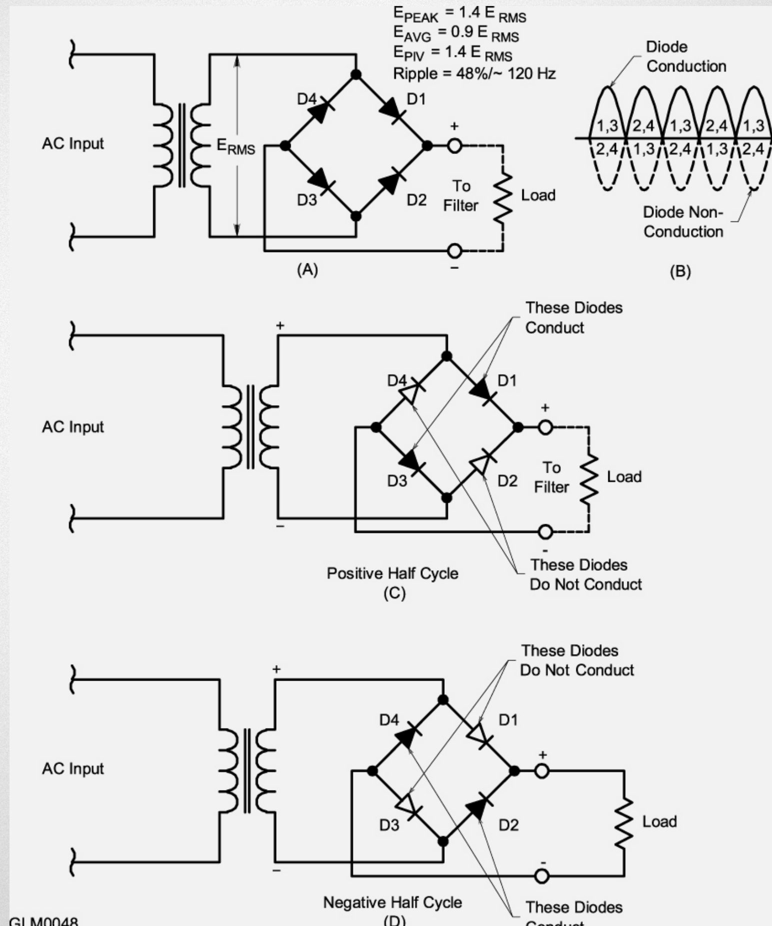
Rectifiers

- Full Wave Rectifier Circuits
  - Advantage – output is produced during entire 360° of the ac cycle
  - Output is a series of pulses at twice the frequency of the input voltage
  - Full-wave bridge rectifier – uses a pair of diodes on alternating ac cycle halves



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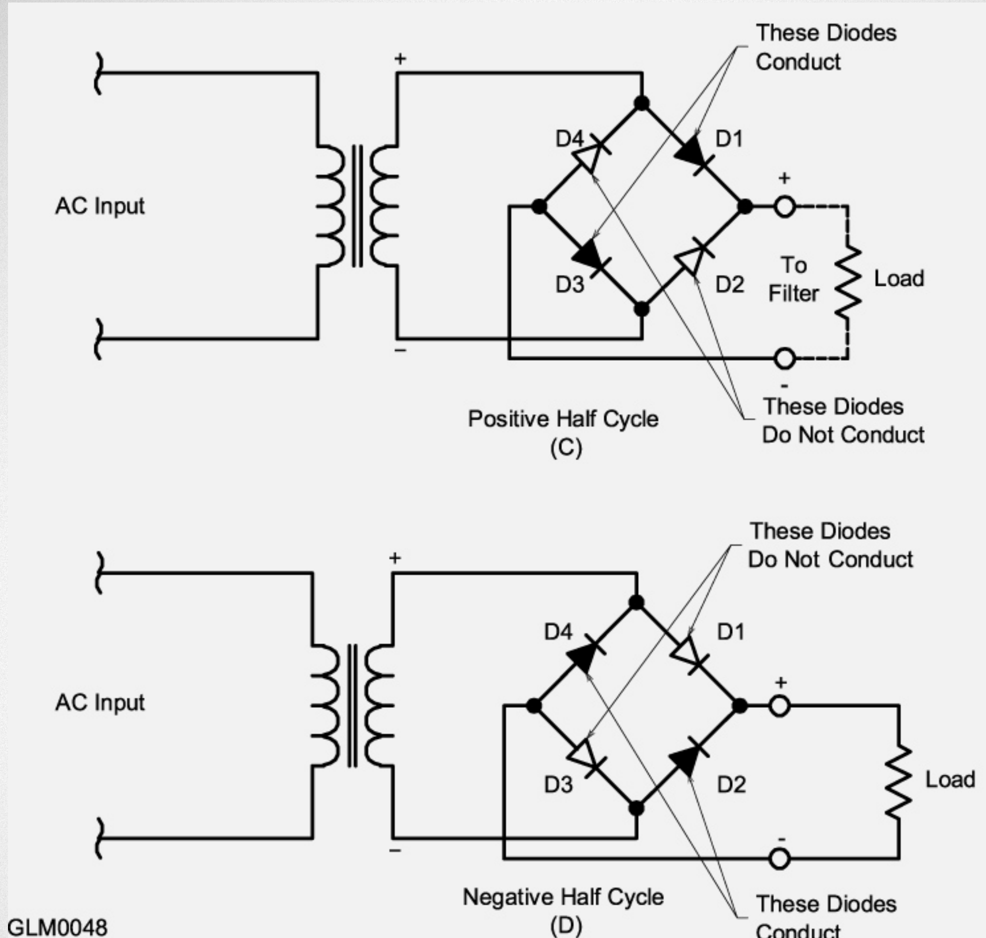
Rectifiers

- Full-wave bridge rectifier
- Diodes only have to withstand the full supply output voltage
- Each diode carries the full load current.



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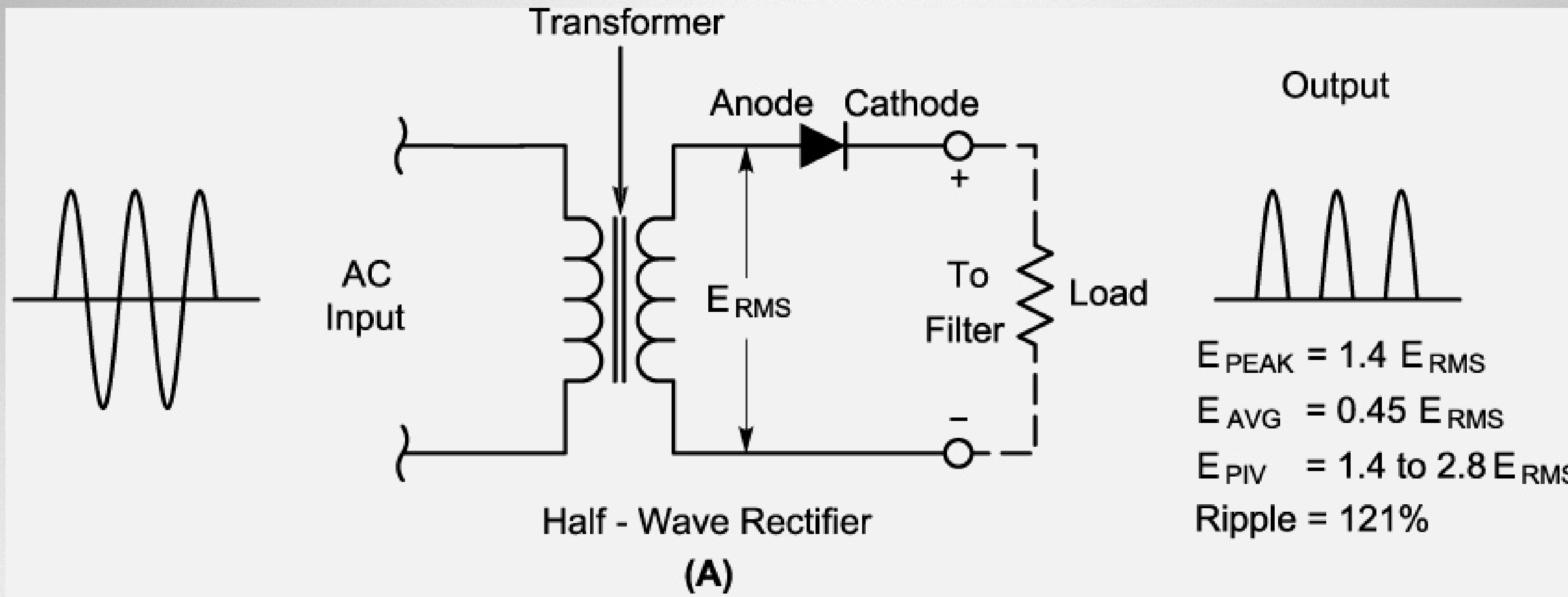
Rectifiers

- Peak inverse voltage in a half-wave rectifier is twice the supply output voltage
- Half-wave rectifier – the entire load current goes through one diode



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Filter Circuits

- Rectifier's *pulsed output* is unusable as dc
- *Filter networks* – made up of capacitors and inductors, smooth out the ripple
- Common method to smooth the ripple in a linear supply is a large *electrolytic capacitor*
- *Regulation* – the percent variation in output voltage between no load and full load
- *Inductor-input* or *choke-input* – uses an inductor to smooth current pulses with a capacitor so smooth voltage.

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Power Supplies

- Power supply safety:
  - Fuses in the primary are used to protect against short circuits or excessive current
  - *Bleeder resistors* discharge stored energy when the supply is turned off
  - Working on power supplies – wait for the bleeder resistor to discharge energy, even if it is unplugged

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Power Supplies

- Switching or Switchmode supplies:
  - Transistors switch current pulses at a high frequency (20 kHz or more) through a transformer and/or inductor then a capacitor filters the voltage
  - The high frequency allows lightweight inductors and transformers to be used
  - Linear supplies are very heavy due to their large, iron-core power transformer

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Batteries

- Large marine or RV storage batteries are often used as emergency backup power supplies
- Liquid-electrolyte or gel-electrolyte batteries are rated at 12 V but should be maintained at 13.8 V
- Lead-acid batteries are useful until their output drops to 10.5 V
- Discharging batteries past their minimum voltage will reduce the life of the battery

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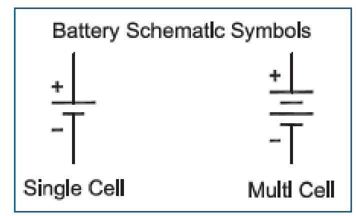
Batteries

Table 4-8
Battery Types and Characteristics

Battery Style	*Chemistry*	*Type*	*Full-Charge Voltage (V)*	*Energy Rating (average, mAh)*
AAA	Alkaline	Disposable	1.5	1100
AA	Alkaline	Disposable	1.5	2600 – 3200
AA	Carbon-Zinc	Disposable	1.5	600
AA	Nickel-Cadmium (NiCd)	Rechargeable	1.2	700
AA	Nickel-Metal Hydride (NiMH)	Rechargeable	1.2	1500 – 2200
AA	Lithium	Disposable	1.7	2100 – 2400
C	Alkaline	Disposable	1.5	7500
D	Alkaline	Disposable	1.5	14,000
9 V	Alkaline	Disposable	9	580
9 V	Nickel-Cadmium (NiCd)	Rechargeable	9	110
9 V	Nickel-Metal Hydride (NiMH)	Rechargeable	9	150
Coin Cells	Lithium	Disposable	3 – 3.3	25 – 1000



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Batteries

- NiCds (or Nicads) – designed to have low internal resistance to supply high discharge currents for tools and transmitters
- Battery self-discharge gradually reduces stored energy over time
  - Slow by storage in a cool and dry place
  - Freezing will damage batteries with liquid or gel electrolytes

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Charging Batteries

- Different types of batteries require different charging methods
- Use the *proper type of charger* to maximize the life and usefulness of the battery
- *Never* attempt to recharge a carbon-zinc, alkaline, or silver-nickel type battery (chemical reaction can not be reversed)

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Alternative Power

- *Solar Power* – photovoltaic conversion of sunlight directly to electricity
- Solar cells are a special type of diode
  - The forward voltage created as the electrons cross the junction is approximately 0.5 V dc (open circuit voltage)
  - Individual solar cells can be connected in series to create higher voltages (24 cells to create 12 V)
- *Wind generators* use dc generators connected to propellers that spin them

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Energy Storage

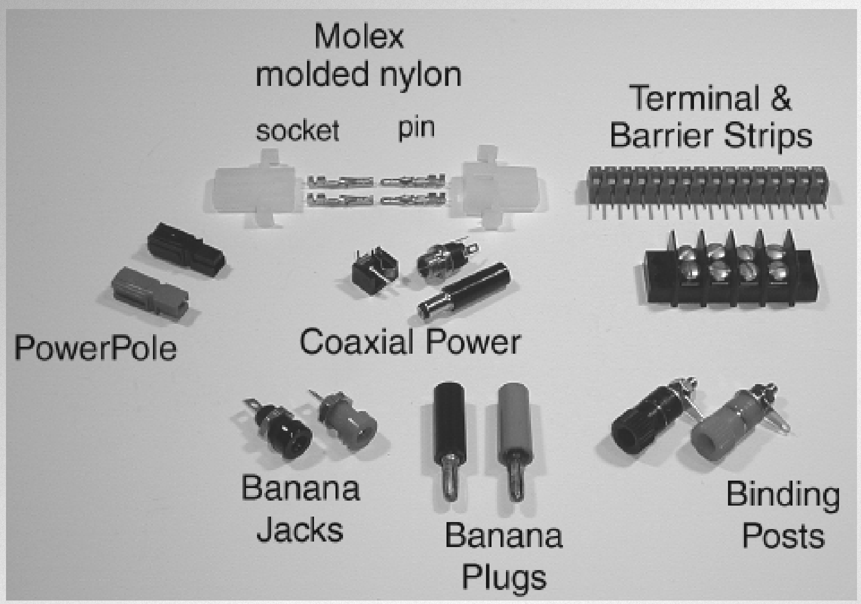
- Wind and solar power require a substantial energy storage system
  - No wind or sun means no power
  - Excess power needs to be stored during peak periods of generation (batteries are the most common method)
  - Diodes prevent the batteries from discharging back through the solar panels

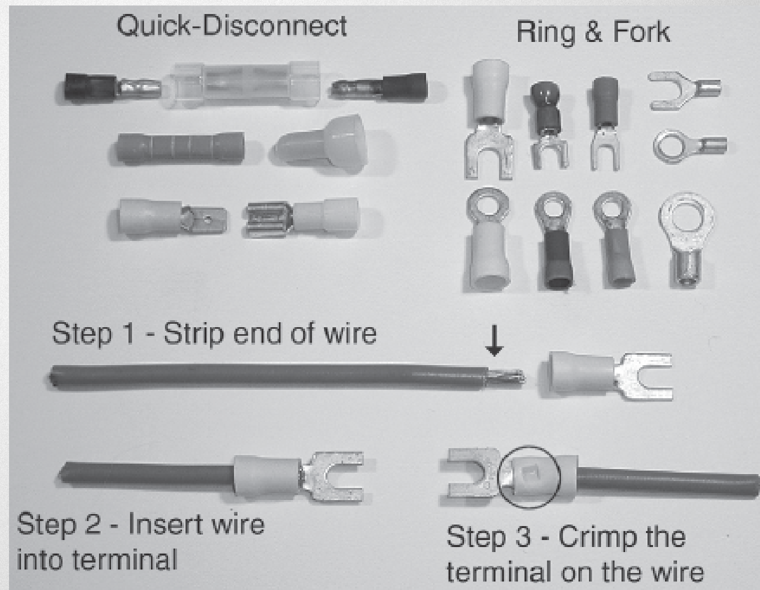
Connectors

- *Keyed connectors* only mate one way, reducing the possibility of damage
- *Plugs* are installed on cables
- *Jacks* are installed on equipment
- *Adaptors* make connections between different style connectors
- *Splitters* divide a signal between two connectors

Power Connectors

Anderson Powerpole® connectors have become the standard for radio equipment used by ARES





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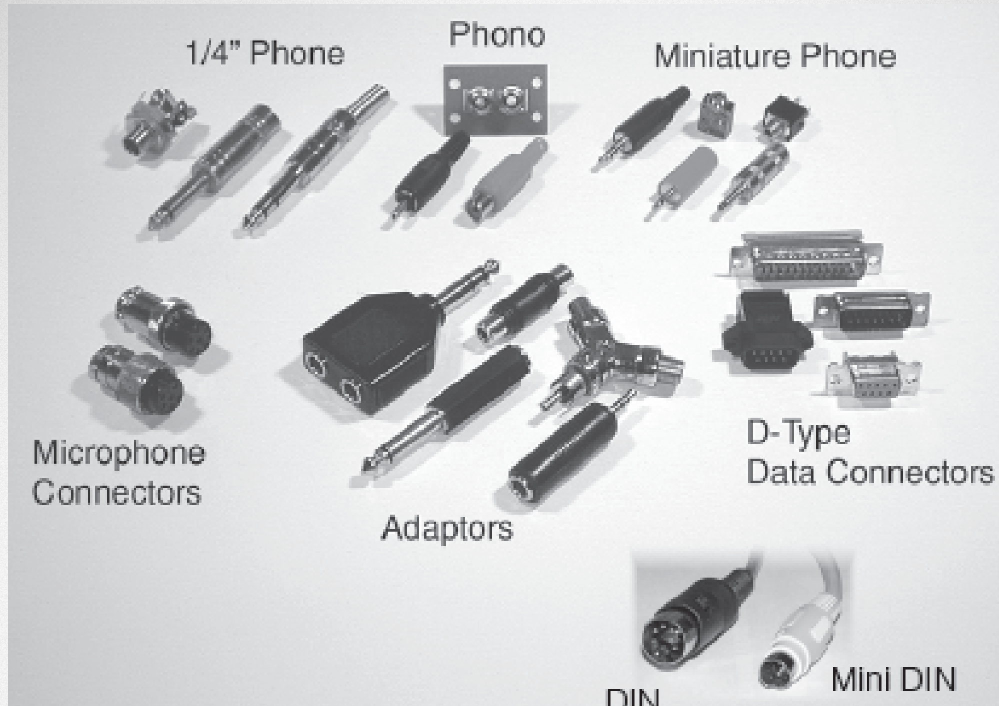
Audio Connectors

- Consumer electronics and Amateur Radio share many of the same connectors



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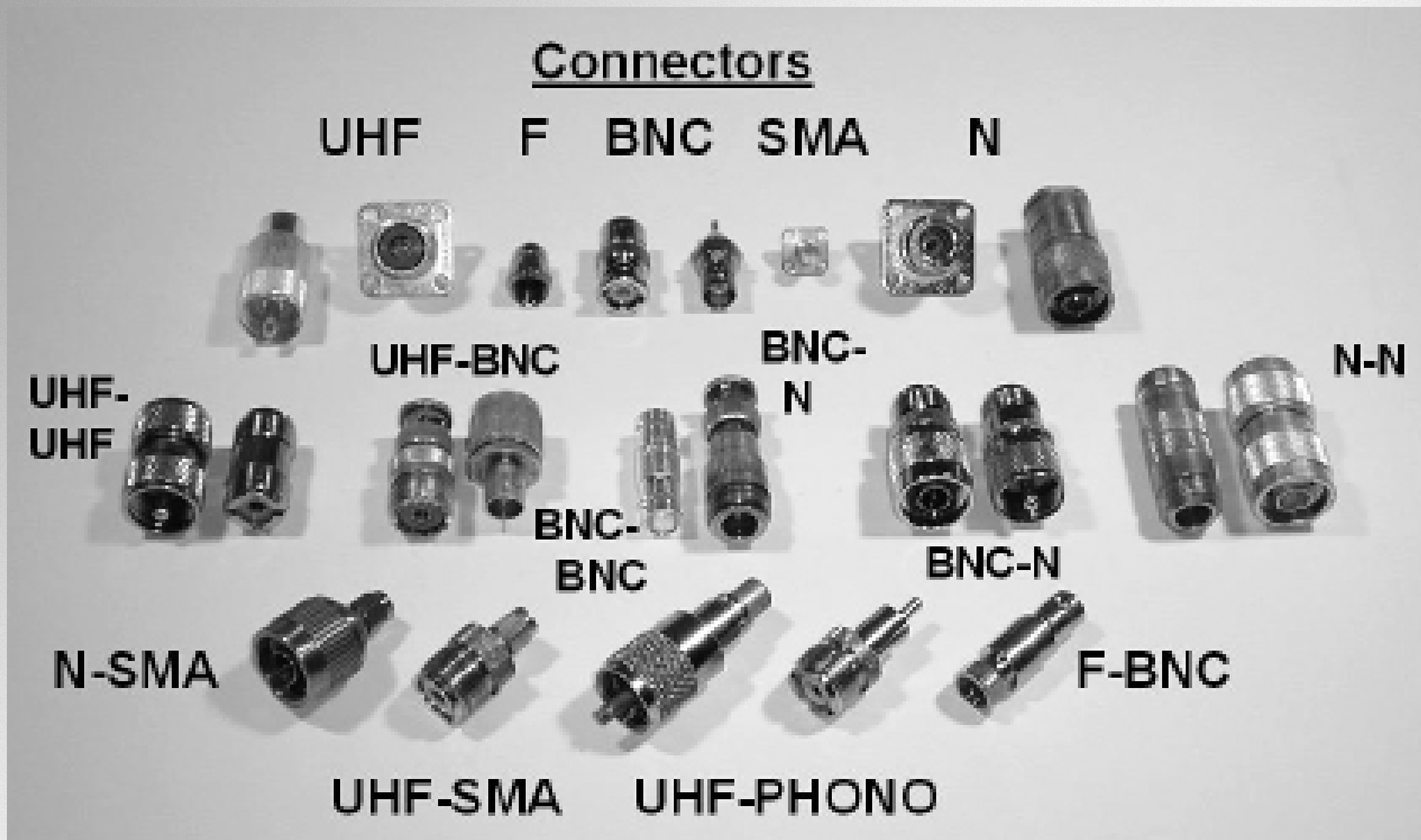
Audio Connectors

- Contact *tip* is the end of the plug
- The *sleeve* is the base of the plug
- The *ring* is a third contact between the tip and sleeve
- *Phono plugs* are often called RCA connectors (commonly used for audio signals)
- *DIN or mini-DIN* connectors are keyed and have up to 9 pins and are used to control multiple circuits on radio equipment

RF Connectors



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RF Connectors

- Special RF feed line connectors:
  - *UHF* connectors (SO-239 & PL-259) can be used up to 150 MHz
  - "*N*" connectors are moisture resistant and used up to 10 GHz
  - *SMA* connectors are small threaded connectors designed for miniature coaxial cable and are rated up to 18 GHz
    - Used on many hand-held radios

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Data Connectors

- Digital data is exchanged between the computers and amateur radios:
- *D-type* connectors are used for RS-232 (COM ports) and parallel ports
  - D-type 9-pin connector is referred to as DB-9 or DE-9 (commonly used for serial ports)
  - 25-pin D-type connector for parallel ports
- *USB* ports are standard for current computers

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Analog & Digital Meters

- Volt-ohm meter (VOM) is the simplest piece of test equipment
  - Measures – volts, current, resistance
  - Tests – continuity, diodes, transistors
- Two types of VOM – Analog and Digital
  - Analog meters have a moving needle and calibrated scales on the meter face
  - Analog meters are useful for finding a peak or minimum reading, such as when adjusting a tuned circuit

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Analog & Digital Meters

- Digital meters (DDMs) offer significantly greater precision than analog meters
- Digital meters have useful features:
  - *auto-ranging* to automatically select the proper display range
  - *peak hold* to capture maximum values
- When measuring voltage, the meter should have a high input impedance to place the minimum load on the circuit being measured

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Oscilloscope

- The oscilloscope (or “scope”) provides a visual display of voltage against time
  - Updated rapidly enough to give a real-time picture of the signal
  - Fast-changing complex waveforms can be measured
  - External signals are connected to horizontal and vertical channel inputs to control the display
  - Variable gain and update rates are available to display many types of signals.

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Monitoring Oscilloscope

- The transmitter’s attenuated output connects to the vertical channel of the oscilloscope to monitor the signal
  - Monitoring helps adjust keying waveforms, mic gain, and speech processing
  - The scope shows the effects of any adjustments that might cause distortion
  - A scope provides information that numeric meters can’t measure.

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Impedance & Resonance Measurement

- *An antenna analyzer* contains a CW signal generator, frequency counter, SWR bridge, and impedance meter
  - Connects to the antenna feed line to measure SWR using very small signals for measurements
  - Impedance measurements show resonance
  - Measures feed line velocity factor, electrical length, and characteristic impedance
  - Can be affected by strong nearby signals

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Field Strength & Power Meters

- Field strength meters measure the electrical field of transmitted signals
- Field strength meters can be used during antenna and transmitter adjustments
- Field strength meters can be used to measure antenna radiation patterns
- Standing wave ratio (SWR) can be measured from forward and reflected power measurements made with a *directional wattmeter*

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