General Class Theory I

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General Class Theory I

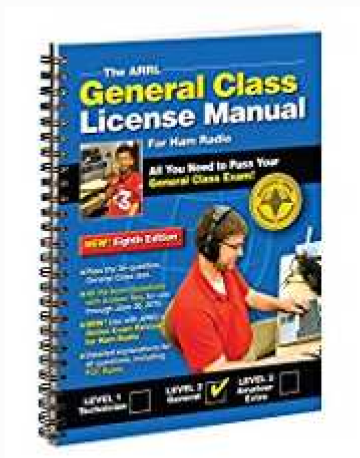
This material is intended to prepare a Technician License holder with the background and information necessary to pass the General Class test Subelements G5 Electrical Principles and G6 Electrical Components.

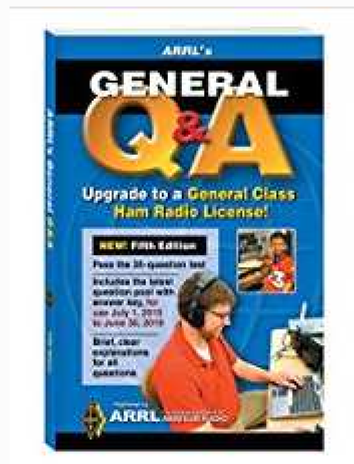
Course goals:

- Provide a understanding of the basic electrical concepts of passive and active components.
- Review most of the questions in the pool (in red)
- Try to indicate what is best memorized

ARRL Books

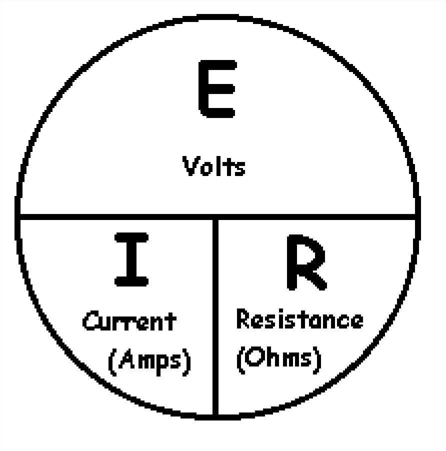
- It is recommended that the student use the ARRL General Class License Manual or the Q&A Book





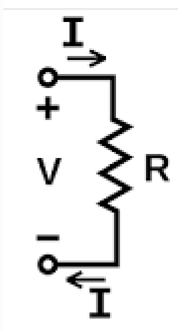
Ohms Law

- V or E: Voltage – force that moves electrons measured in volts
- I: Current - flow of electrons measured in amperes
- R: Resistance – opposition to the flow of electrons measured in ohms

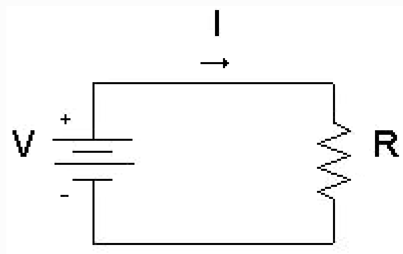


Ohm's Law:

$E = IR$



Ohms Law Example



If V = 10V and R = 1000 Ω (1KΩ), what is the current?

E = IR

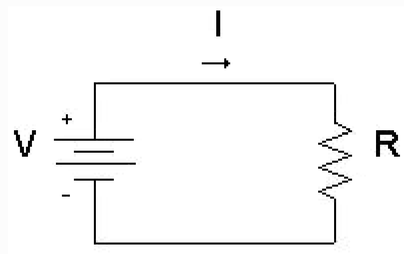
I = E/R = 10V/1000Ω

= .01 amperes = 10 ma

Power

Power is the rate of energy doing work in a circuit (often as generating heat).

$P = I \times E$
measured in watts



Use Ohm's law to calculate power P when resistance and voltage or resistance and current are known:

$E = IR \rightarrow P = I^2R$ (know current and resistance)

$I = E/R \rightarrow P = V^2/R$ (know voltage and resistance)

Power Example

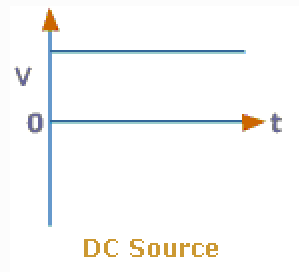
How many watts of electrical power are used if 400VDC is supplied to an 800Ω load? (G5B03)

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

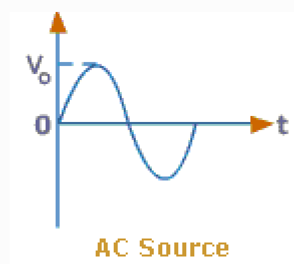
$$= \frac{(400)^2}{800} = 200\text{watts}$$

AC vs. DC

DC – Direct Current: constant voltage (think battery)

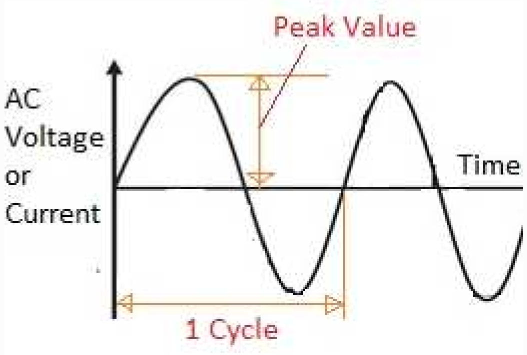


AC – Alternating Current: voltage changes with respect to time (think 117V at home or radio waves)



Frequency and Wavelength

- The **Frequency** of an AC waveform is measured in cycles per second or Hertz (Hz).
- The **Wavelength** (λ) of a AC waveform is the distance it travels in one cycle.



Radio waves travel at the speed of light in free space or 300×10^6 meters/sec – "**c**"

$$F \times \lambda = c$$

Frequency x wavelength = speed of light

Radio Wave wavelength example

What is the approximate frequency of the 40M band?

$F \times \lambda = c \rightarrow F = c / \lambda$

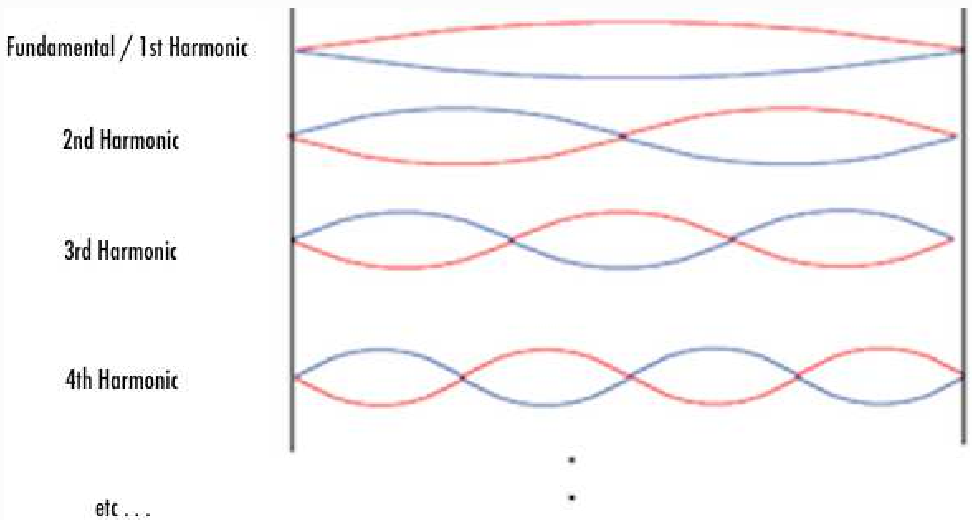
$F = (3 \times 10^8 \text{ meters/sec}) / 40 \text{ meters}$

$= 7.5 \times 10^6$ Hz or 7.5 MHz

(Actual band is 7.0 to 7.3Mhz)

Harmonics

Harmonics are waveforms whose frequencies related by integer multipliers.



Note that many of the ham bands are harmonically related:
80M, 40M, 20M, 10M.

Scientific units

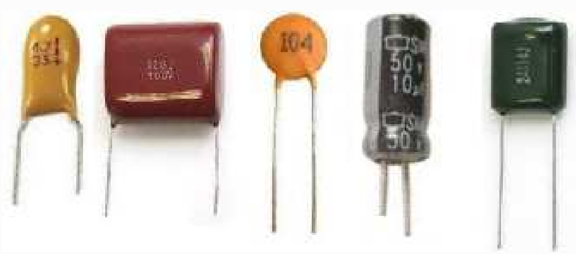
G	Giga	10^9
M	Mega	10^6
K	Kilo	10^3
m	milla	10^{-3}
μ	micro	10^{-6}
n	nano	10^{-9}
p	pico	10^{-12}

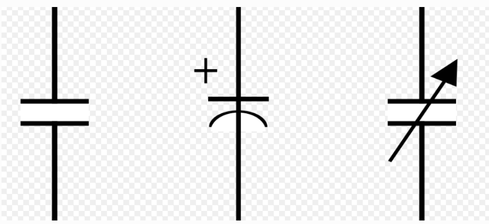
Example: What is the value in nanofarads (nF) of a 22,000 pF capacitor?

$22000 \times 10^{-12} / 1000 = 22 \times 10^{-12}/10^{3} = 22 \times 10^{-9} = 22nF$

Capacitors

- Capacitors physically are parallel conducting plates
- When a DC voltage is applied to a capacitor, current flows into the capacitor until the capacitor is “charged”, ie the voltage across the plates reaches a voltage equal to the applied voltage
- When a capacitor is charged an electric field is created between the plates in which energy is stored
- A **dielectric** is a the material separating the plates that influences the amount of charge stored (and hence the capacity)





Capacitance

- The value of capacitors is measured in **farads**
- Capacitors block DC current
- AC current will flow through a capacitor (plates continually charging and discharging) with some opposition to the current.
- This opposition to current is called **capacitive reactance**.
- Reactance (X_c) is measured in ohms and is

$$X_C = \frac{1}{2\pi FC}$$

where F = frequency and C is capacitor value in farads

Reactance

Unlike resistance, to understand the impact of reactance we need to also know the frequency of the waveform applied to the component.

Let's assume 100pF capacitor at 7Mhz. The reactance is

$$X = \frac{1}{2\pi FC} = \frac{1}{2 \times \pi \times 7 \times 10^{6} \times 100 \times 10^{-12}} = 227\Omega$$

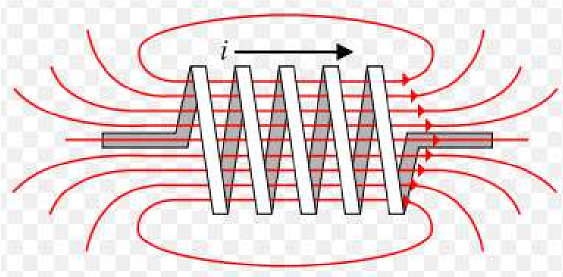
At 28Mhz the reactance of this capacitor is

$$X_{C} = \frac{1}{2 \times \pi \times 28 \times 10^{6} \times 100 \times 10^{-12}} = 56.8\Omega$$

As F↑ → Xc ↓ and as F ↓ → Xc ↑

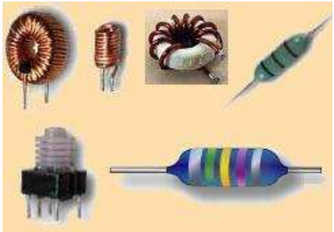
Inductors

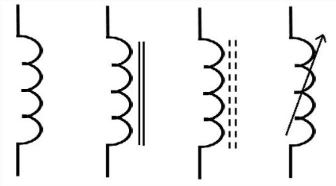
- Inductors are often coils of wire
- A magnetic field is created when a current flows through the coil
- Energy is stored in this magnetic field



•The amount of energy stored in an inductor is increased by the square of the number of turns

• **Core material** inserted in the inductor can also increase the inductance





Inductance

- Inductors oppose changes in current flow
- DC current flows through an inductor with very small resistive loss
- AC currents flow through an inductor with opposition to current.
- The opposition to current is called **inductive reactance**.
- Reactance (X_L) is measured in ohms and is

$$X_L = 2\pi FL$$

where F is frequency and L is inductance measured in **henrys**

As F↑ → X_L↑ and as F↓ → X_L ↓

Impedance

Impedance is the general term for the opposition to current in a circuit.

Impedance is measured in ohms.

Impedance includes the effects of both resistance and reactance and applies to AC and DC currents.

In electrical equations, impedance is shown as “Z”

Parasitic Components

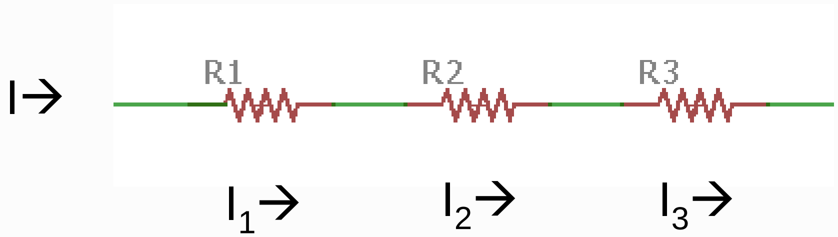
Components have unwanted characteristics called **parasitics** that can effect circuit performance.

For example:

- Leads in all components have inductance
- There is capacity between windings of inductors
- Wire wound resistors are inductive.

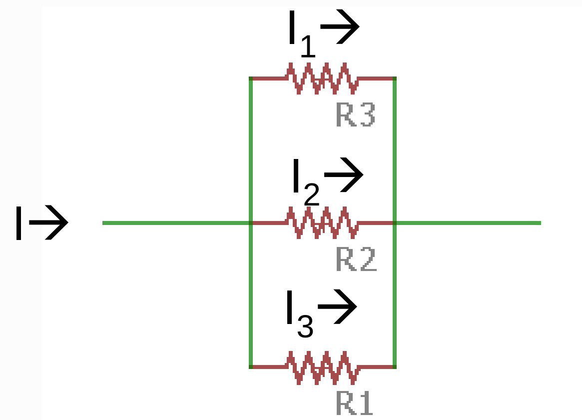
Series and Parallel Circuits

Series Circuit



$I = I_1 = I_2 = I_3$

Parallel Circuit



I = I1 + I2 + I3

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

Answer: It equals the sum of the currents through each branch.

Series and Parallel Circuits

Serial Circuit Equations

$$R = R_1 + R_2 + R_3$$

Parallel Circuit Equations

$$R = \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)}$$

For two resistors:

$$R = \frac{R_1 \times R_2}{R_1 + R_2}$$

Series and Parallel Circuits

Serial Circuit Equations

$$R = R_1 + R_2 + R_3$$

$$L = L_1 + L_2 + L_3$$

$$C = \frac{1}{\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)}$$

Parallel Circuit Equations

$$R = \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)}$$

$$L = \frac{1}{\left(\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}\right)}$$

$$C = C_1 + C_2 + C_3$$

To increase impedance:

For R's and L's add in R or L in series.

For C's add C's in parallel

Series and Parallel Examples

1. What is the total resistance of three 100Ω resistors in parallel?

$$R = \frac{1}{(\frac{1}{100} + \frac{1}{100} + \frac{1}{100})} = \frac{100}{3} = 33.3\Omega$$

2. What is the equivalent capacity of two 5nf and one 750pf capacitors in parallel?

$$C = 5\,x\,10^{-9} + 5\,x\,10^{-9} + 750\,x\,10^{-12} =$$

$$5\,x\,10^{-9} + 5\,x\,10^{-9} + .750\,x\,10^{-9} = 10.750\,\text{nf}$$

3. What is the capacity of 3 100uf capacitors in series?

33.3 uf See #1 above

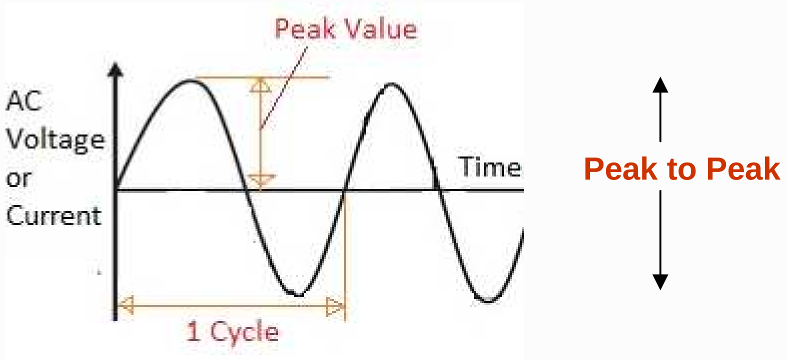
RMS Voltage

The power in a DC circuit is V^2/R; how we find power in an AC circuit?

The value of an AC signal that produces the same power dissipation as a DC voltage is the RMS Value. (Root Mean Square).

For a sine wave (only):

$V_{RMS} = .707 \times V_{PK}$



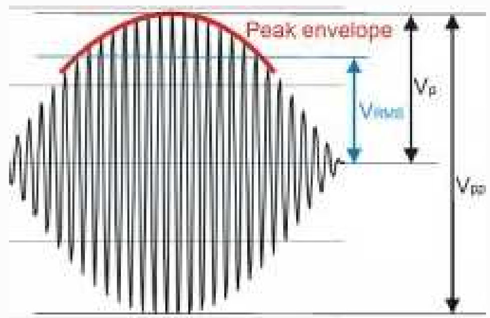
Example: What is the RMS voltage of a sine wave with 17V peak?

$VRMS = 17\ V_{PK} \times .707 = 12\ V_{RMS}$

Peak Envelope Power (PEP)

Peak Envelope Power is the average power of one complete RF cycle at the peak of the signal's envelope.

$$PEP = \frac{(V_{RMS})^2}{R} = \frac{[.707\, x V_{PK}]^2}{R}$$



V_{PK} is also written as PEV or $\frac{V_{PP}}{2}$

The above relation is true only for a sine wave.

The FCC uses PEV to set power standards for maximum transmission power

PEP Examples

What is the output PEP from a transmitter if an oscilloscope measures 500 volts peak to peak across a 50Ω dummy load connected to the Transmitter output?

$$V_{RMS} = .707 x V_{PK} = .707 x \frac{V_{P-P}}{2}$$

$$PEP = \frac{{V_{RMS}}^2}{R} = \frac{(.707 x \frac{500}{2})^2}{50} = 624.8 \text{watts}$$

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

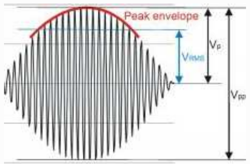
$$ {V_{RMS}}^2 = PEP \times R$$

$$V_{RMS} = \sqrt{PEP \times R}$$

$$V_{RMS} = \sqrt{1200 \times 50} = 244.9 \text{volts}$$

PEP and modulation

PEP is equal to the average power of an RF signal it *if is not modulated*, i.e. it is only a sine wave is being transmitted as in CW operation. (Also FM is always a constant constant-power signal.)



Questions:

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

Answer: 1.00

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

Answer: 1060 watts

The Decibel

The decibel (dB) is a powerful way to refer to voltage or power **ratios**.

Power ratio:

$$dB = 10\log_{10}\left(\frac{P_M}{P_{Ref}}\right)$$

Voltage ratio:

$$dB = 20\log_{10}\left(\frac{V_M}{V_{Ref}}\right)$$

If the ratio of the power or voltage is > 0, then the dB value is positive.

If the ratio of the power or voltage is < 0, then the dB value is negative.

The Decibel

10 dB power gain → power ↑ 10x

or 100 watts is 10dB greater than 10 watts

3 dB power loss → power ↓ ½ x

Example: if an amplifier provides 25 watts output for 5 watts input, how much power gain does it have measured in dB?

5 watts to 50 watts is +10dB; 50 watts to 25 watts is -3dB

so, 5 watts to 25 watts is 10dB - 3dB = 7dB.

Decibel example

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

$$-1\text{dB} = 10\log_{10}\left(\frac{P}{100}\right)$$

$$-\frac{1}{10} = \log_{10}\left(\frac{P}{100\text{watts}}\right)$$

$$10^{\left(\frac{-1}{10}\right)} = \frac{P}{100\text{watts}} = .794$$

$$P = 79.4\text{watts}$$

So 100-79.4 = 20.5 watts loss or 20.5/100 or 20.5% loss

dB Facts

dBV means dB is calculated with respect to 1V (V_{REF} = 1V)

dBm means dB is calculated with respect to 1mW (P_{REF} = 1mW)

One S unit is 6db

S9 = -73 dBm (50.2 uV into 50 V)

1500 watts referenced to 100 watts is
10log (1500/100) = 11.7dB or about 2 S units

Components

Active and passive components used in ham radio electronics

- Resistors
- Capacitors
- Inductors
- Transformers (and impedance matching)
- Connectors
- Batteries
- Diodes -- Ge and Si
- Transistors – bipolar and FET
- Integrated circuits – analog and digital

Resistors

- Values – 1Ω to 10M Ω +
- Tolerance – how close is the actual value to the nominal value:
  - 1% -- “precision”
  - 5-10% -- general purpose
- **Temperature Coefficient** (Tempco or TC) – change of the value of the resistance with temperature.
- Types:
  - Carbon: general use
  - metal: general use, low noise
  - wire-wound: power, high inductance and not suitable for RF
  - metal oxide: RF (non-inductive)

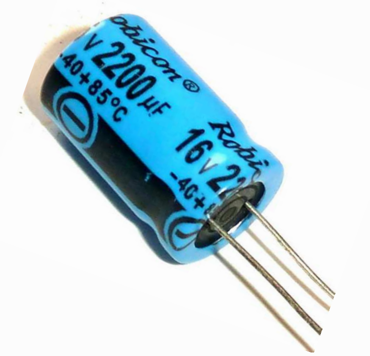


Capacitors

- Values a few pf to tenths of a farad depending on geometry and dielectric

- Types:
  - Ceramic: RF, bypass, inexpensive
  - Plastic Film: audio, low frequency RF
  - Silver Mica: RF, stable
  - Air and vacuum: transmitting and RF
  - Electrolytic and tantalum: power supply filters, high capacitance for a given volume.

- Polarized capacitors (for example electrolytic have a "+" and "-" connection.) Reversing a polarized capacitor can short-circuit the device, destroy the dielectric layer, and potentially cause the device to overhead and explode.



- Once know as "condensers"

Inductors

- "Coils"
- Values generally in mH and uH range and a function of the geometry of the coils, parameters of the core and the number of turns.
- Inductance ↑ with the square of the number of turns.
- Core types:
  - Laminated iron core: AC and DC power filtering
  - Powered iron solenoids: power supply, RF, chokes, radio circuits
  - Powered iron and ferrite toroids: radio and audio circuits
  - Air core: transmitting.

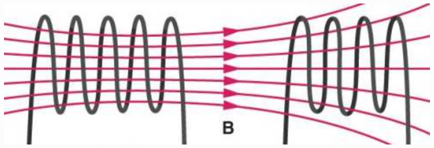
Inductors

- **Ferrite core inductors** are very useful for RF work.

- Ferrite core inductors have several advantages:

    Most of the magnetic field is in the core
    Magnetic properties of the core may be optimized for a specific range of frequencies
    Large values of inductance may be obtained.

- Energy can be shared between inductors by means of **mutual inductance** through a common electronic field.

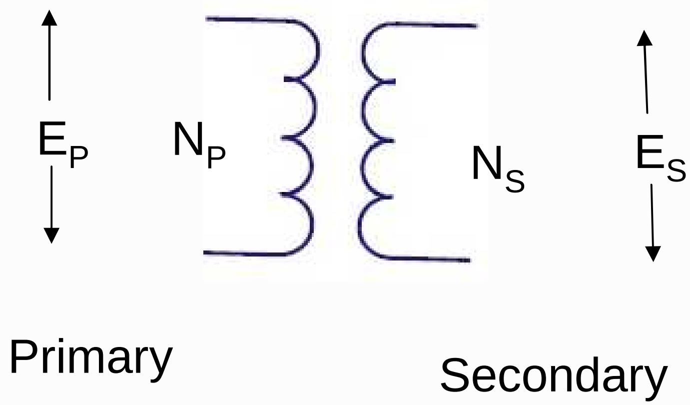


- Mutual inductance is the basis of transformers.

- However, to minimize mutual inductance of 2 solenoid inductors, place them at right angles to minimize interaction of fields

Transformers

Transformer: two or more inductors wound on a common coil for the purpose of transferring energy between them. The voltage appearing across the secondary winding of a transformer when an AC voltage is applied to the primary is caused by mutual inductance.



N – number of turns in winding

Transformer voltage transformation

$$\frac{E_S}{E_P} = \frac{N_S}{N_P}$$

$$E_S = \frac{N_S}{N_P} \times E_P$$

Transformer Voltage Transformation Example

What is the voltage across a 500 turn secondary winding if 120VAC is applied to the 2250 turn primary?

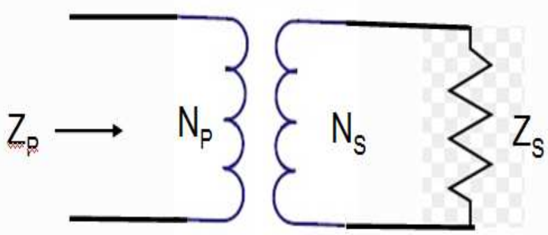
$$\frac{E_S}{E_P} = \frac{N_S}{N_P}$$

$$E_S = \frac{N_S}{N_P} \times E_P$$

$$E_S = \frac{500}{2250} \times 120V = 26.7V$$

If you reverse the primary and secondary of a 4:1 step down transformer, the secondary becomes 4 times the primary voltage.

Transformer Impedance Transformation



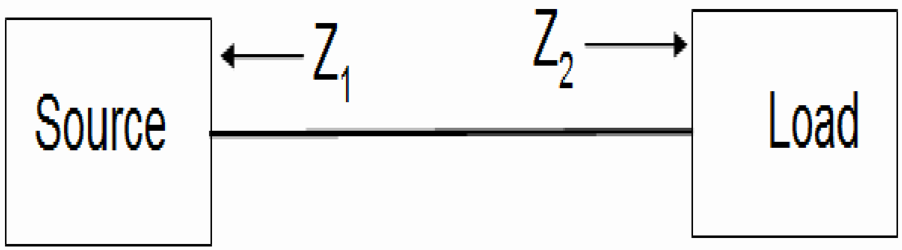
$$Z_P = Z_S \times [\frac{N_P}{N_S}]^2$$

$$\frac{N_P}{N_S} = \sqrt{\frac{Z_P}{Z_S}}$$

Example: What is the turn ratio required to change 600Ω impedance to 4Ω impedance?

$$\frac{N_P}{N_S} = \sqrt{\frac{600}{4}} = \sqrt{150} = 12.25$$

Impedance Matching



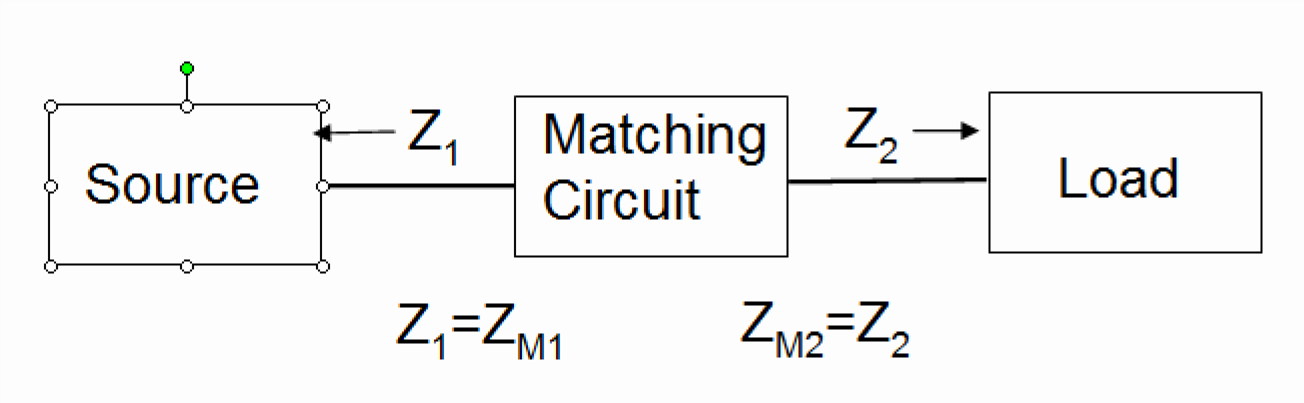
Maximum Power Transfer Theorem: Maximum power is transferred when $Z_1 = Z_2$ and are purely resistive.

This important so that the source can deliver maximum power to the load.

Most transceivers are designed for 50Ω output impedance. Coax is often 50Ω, but antenna systems probably are generally not 50Ω over the entire band.

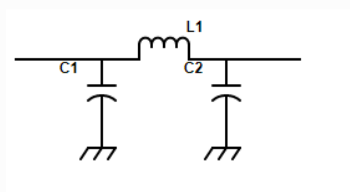
Impedance Matching

Impedance matching circuits “transform” impedance to match the load.



Matching circuits can be made of LC circuits.

π Network



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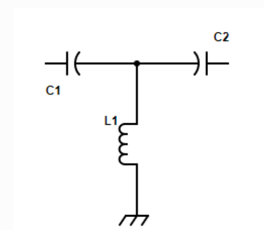


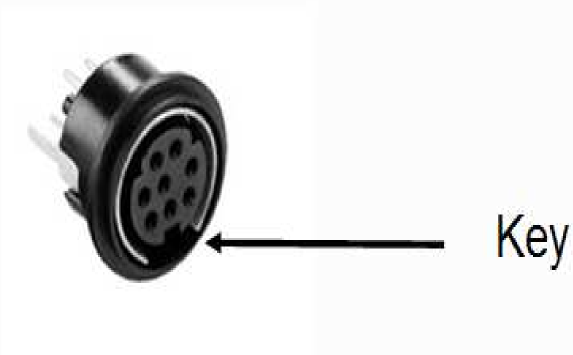
Matching circuits can also be transformers or tuned lengths of coax

Connectors

A wide range of connectors are used in ham radio for interconnect.

- DIN – a family of connectors suitable for audio and control signals 
- DE-9 -- serial port connectors for RS-232 
- PL 259/SO 239 – standard RF connector for up to 150Mhz 
- Type N Connector – up to 10Ghz, moisture resistant 
- SMA Connector – small threaded connector, use up to several GHz 
- RCA Phono – used for audio connections 
- BNC – quick connect/disconnect connector used up to 2Ghz 

Connector keying



Keyed connectors assure that connectors can go together only in one way and avoid damage from incorrect mating.

Batteries

Battery characteristics:

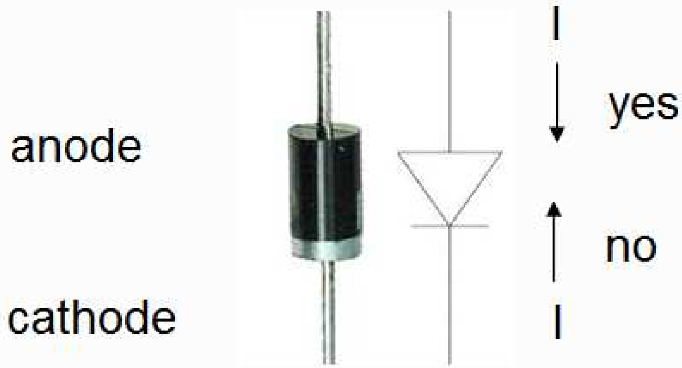
- Chemistry: Alkaline, NiCD, Li, Carbon-Zinc
- Disposable or rechargeable
- Full battery charge: 1.5V to 9V
- Energy rating: 25mAH to 14000mAH

What is the minimum allowable discharge for a maximum life of a standard 12V lead acid battery? 10.5V

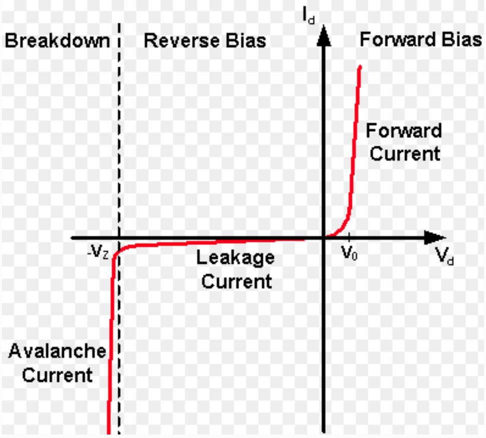
What is an advantage of low internal resistance of nickel cadmium batteries? High discharge current

When is it acceptable to recharge a carbon-zinc primary cell? That would be never.

Diodes



Ideal diodes allow current to flow in only one direction



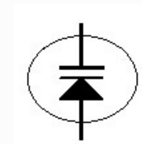
Real diodes have a **forward threshold voltage** (V0 or VF), reverse leakage current, and a reverse breakdown voltage.

Diodes

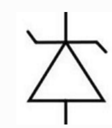
Diode types:

- Silicon (Si) – general purpose, widely used, V_F = .7V
- Germanium (Ge) – general purpose, not used widely, V_F = .3V
- Schottky – low junction capacity allows operation at high frequency and fast switching circuits

- PIN -- low forward voltage drop, used for RF switching
- Varactor – reverse biased junction can be as small variable capacitor



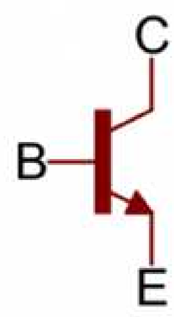
- Zener – operates in reverse mode at given voltage, used as voltage regulator.



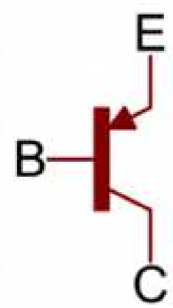
Bipolar Transistors

Bipolar transistors are a semiconductor devices which can provide power gain and act as a switch.

NPN



PNP

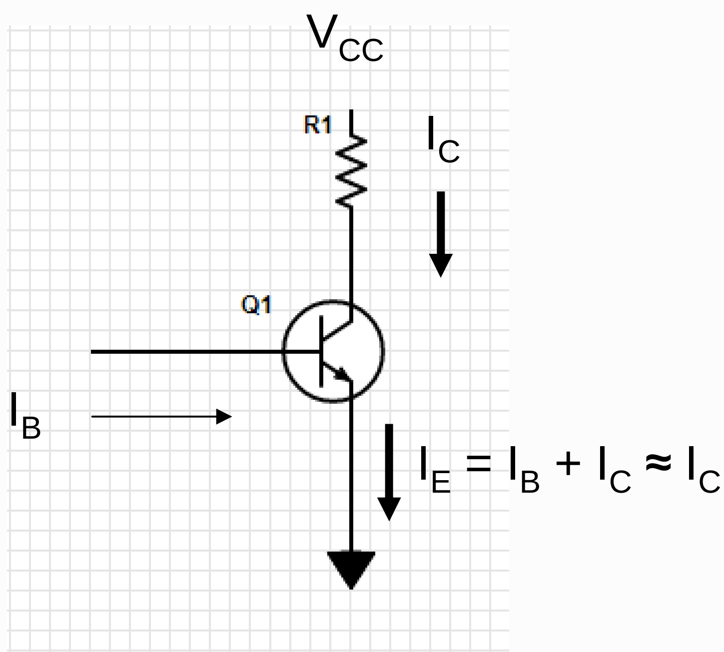


B – base
C – collector
E – emitter

N and P are types of semiconductor material

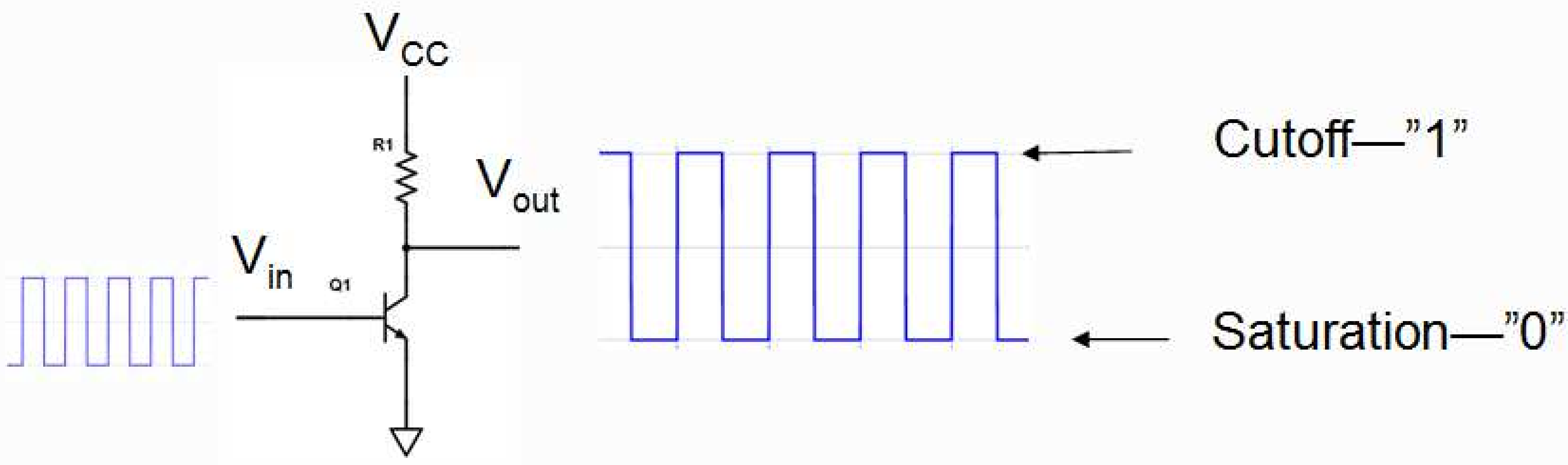
When properly biased, a small current flowing into the base of transistor can cause a much larger current to flow through the collector. The ratio of these currents is **β** for DC currents and $\mathbf{h_{fe}}$ for AC currents.

NPN Transistor operation



- A small base current generates a large collector current
- The emitter current is about equal to the collector current
- If no current is flowing, the collector terminal will be at the supply voltage V_{CC} → "**Cutoff**"
- If the transistor is completely turned on, the collector terminal will be very close to ground → "**Saturation**"
- A transistor operating between saturation and cutoff is in the "**active region**"
- A PNP transistor operates the same way except that current flows out of the base.

Bipolar Transistor Switches



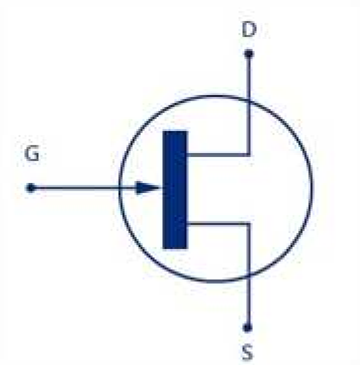
What are the stable operating points for a bipolar transistor used as a switch in a logic circuit?

It's saturation and cutoff regions.

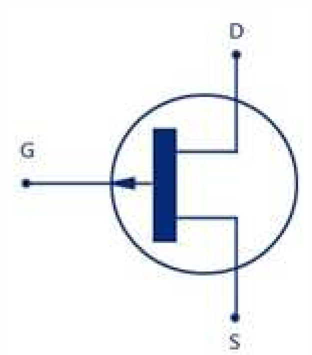
FET Transistors

Field effect transistors are a semiconductor devices which can provide power gain and act as a switch. Gate voltage controls current flowing source to drain.

N and P channel Junction FET's have a direct gate connection to the channel.



N channel FET

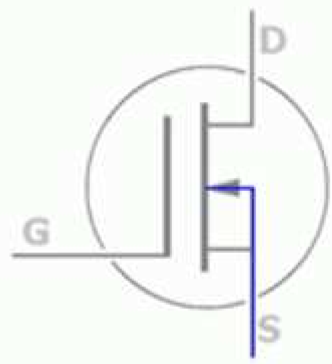


P channel FET

G – gate
D – drain
S – Source
Drain to source
is the "channel"

MOSFET transistor

MOS FET—Metal Oxide Gate FET—have an thin insulated layer of oxide between the gate and the channel. This allows very little current to flow and hence they can be very low power. MOS FET's are the transistors used in most microprocessors.



N channel MOSFET

Transistor packages

Transistors come in various packages. "TO"– Transistor Outline

TO-92 general purpose, small signal, low power

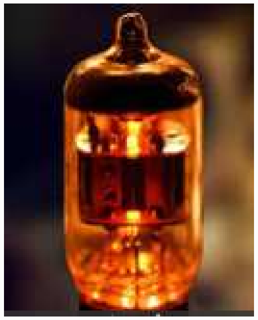
TO-3 used for power applications

TO-220 used for power applications

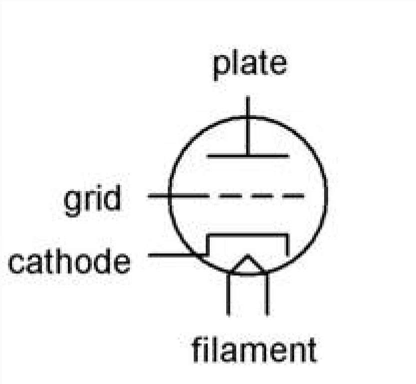
The cases of some large power transistors must be insulated from ground to avoid shorting the collector or drain voltage to ground.

The Vacuum Tube

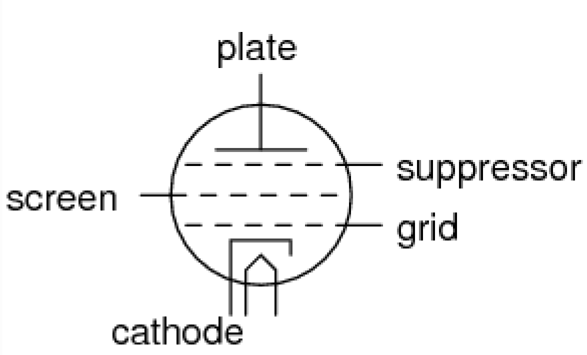
The vacuum tube discovery started the electronics industry. Although largely replaced by transistors, vacuum tubes still have a role in ham radio for power amplifiers. They can be viewed as "old FET's" because their operation is similar: a voltage on the grid controls current flow between cathode and plate.



Triode



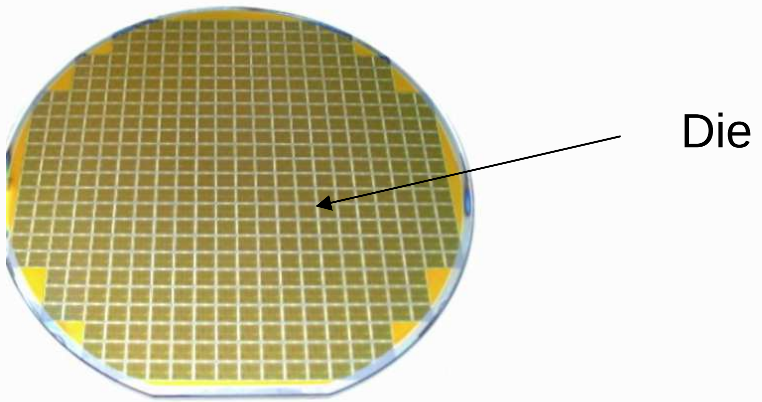
Pentode



More advanced vacuum tubes such as pentodes have screen elements that can reduce grid to plate capacity.

Integrated Circuits

Integrated Circuits (IC's or chips) incorporate multiple transistors and other passive components connected together on a single die. The A10 Iphone has 3.3 billion transistors.



Digital IC's incorporate multiple transistors as switches in two states to represent the "1's" and "0's" of binary logic.

Digital IC's

- TTL – Transistor-transistor logic. Early bipolar logic family still very useful for ham projects
- CMOS – MOSFET logic devices, lower power consumption vs. TTL
- ROM – Read only Memory
- RAM – Random access memory
  - Volatile – contents of memory go away when power is removed
  - Non-volatile – Memory contents don't go away when power removed
- Microprocessors – computers on a single integrated circuit (chip)
- DSP's – Digital Signal Processors specially designed microprocessor-- very important in software defined radios.

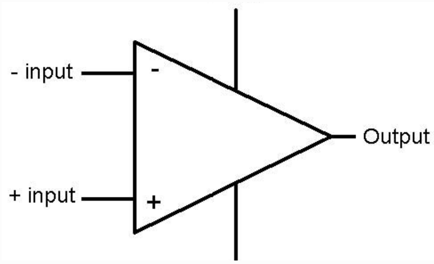
Analog IC's

Analog IC's work over a continuous range of voltages for applications such as amplification, power control, filtering and measurement.

Types of analog IC's include:

- Operation amplifier
- Linear voltage regulator
- MMIC – monolithic microwave integrated circuit

Example of an operation amplifier very useful in amplifiers and filter design:



Typical gain = 100,000
Input Z = 1MΩ
Output Z = very low

Mixed Signal and Interface IC's

Mixed Signal: both analog and digital on the same chip:

- ADC – analog to digital converter
- DAC – digital to analog converter
- Switching voltage regulator

Interface IC's: provide a means of communicating between computers or uprocessors and peripherals (e.g. printers) and other devices (e.g. radios):

•Parallel controllers (centronics) – old printer interface

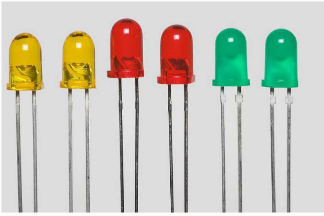
•Serial controllers:

  •RS 232 – connect radio to computer

  •USB – connect radio to computer

•Wireless: WIFI and Bluetooth

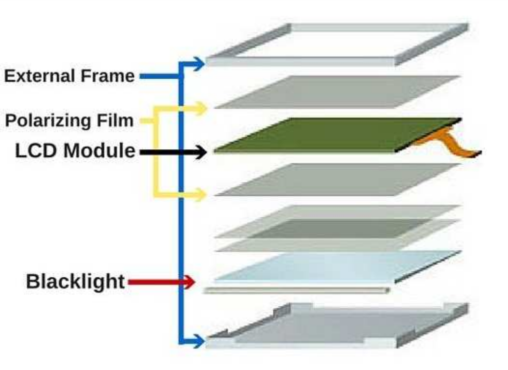
Visual I/O Devices



LED – Light Emitting Diode.

- Based on forward biased diodes
- Provides lower power consumption, faster response, and longer life than incandescent indicator lamps.

LCD's -- Liquid Crystal Display



Crystal material sandwiched between glass. Depending on polarization of the material, light will either pass or not

Requires ambient or backlighting to read the display.

Thank you

You should now be prepared for The General Class License Exam Subsections G5 and G6