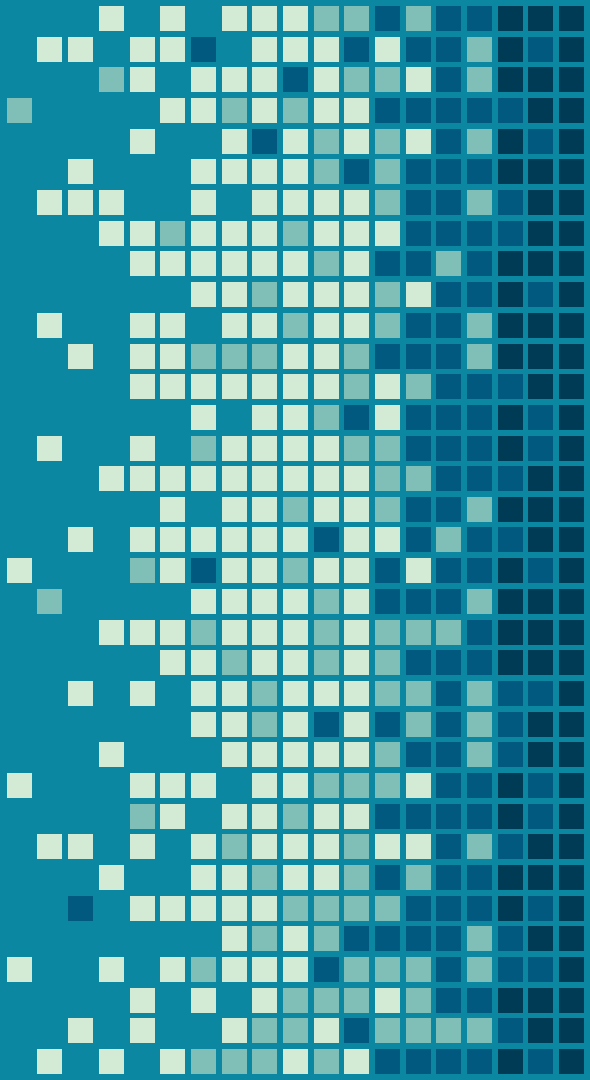
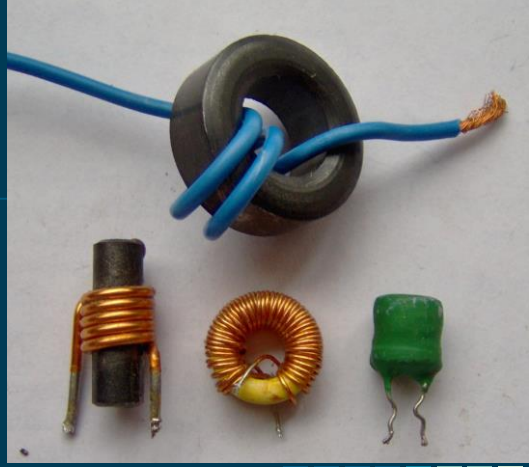
INDUCTORS

Michael D'Argenio – mjdargen@ncsu.edu
Electrical Engineering – SS 2019 – Duke TIP



Inductors



- A passive two-terminal component that stores energy in a magnetic field when electric current flows through it.
- Also known as coils or chokes.
- Consists of a conductor wrapped into a coil around a core.
  - The “core” can be iron, ferrite, or air (conductive materials increase the magnetic field and the inductance).
- Inductors are characterized by their inductance (L).

Inductance

- Inductance – the ratio of the voltage to the rate of change of the current. This is measured in henry (H).

$$L = \frac{V}{\Delta I}$$

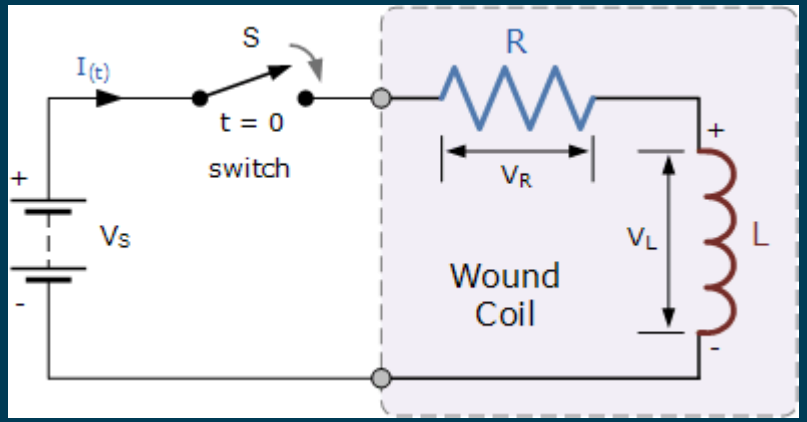
- An inductor opposes changes in current by developing a voltage across it proportional to the rate of change of the current.

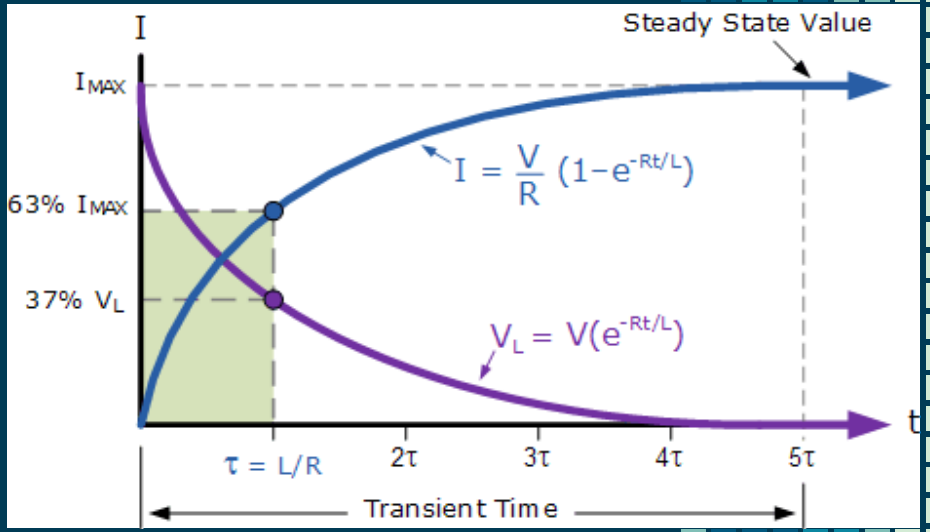
Capacitors vs. Inductors

- Capacitors
  - Resist changes in voltage
  - Quick voltage changes produce large currents
  - Store energy in electric fields

- Inductors
  - Resist changes in current
  - Quick current changes produce large voltages
  - Store energy in magnetic fields

Inductor I/V Characteristics



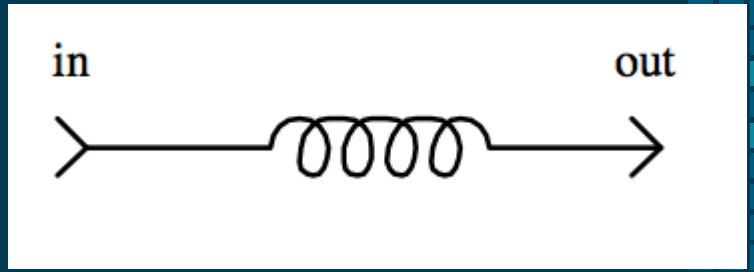


How Inductors Work

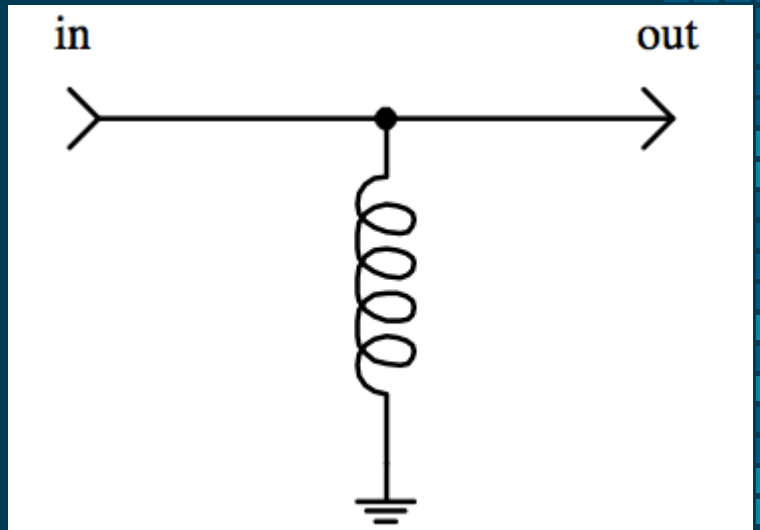
- Change in current creates a directly proportional change in the magnetic field strength.
- Increasing the magnetic field requires energy, so the resistance of the inductor increases and there is a voltage drop across it.
- Once the inductor has built up the magnetic field, the resistance returns to zero and there is no voltage drop.
- If the current decreases, the magnetic field must also decrease. The energy returns to the circuit causing a voltage rise.

Inductors can also be used as filters!

- In a series configuration, the inductor blocks AC, while allowing DC to pass.



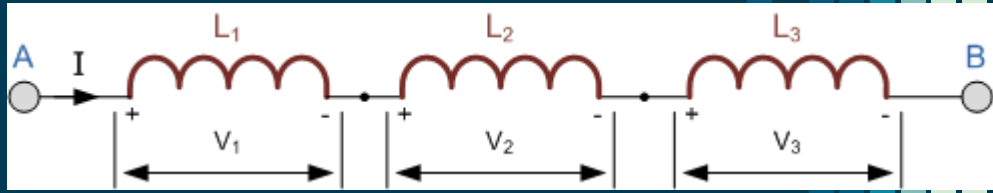
- In a parallel configuration, the inductor blocks DC, while allowing AC to pass.



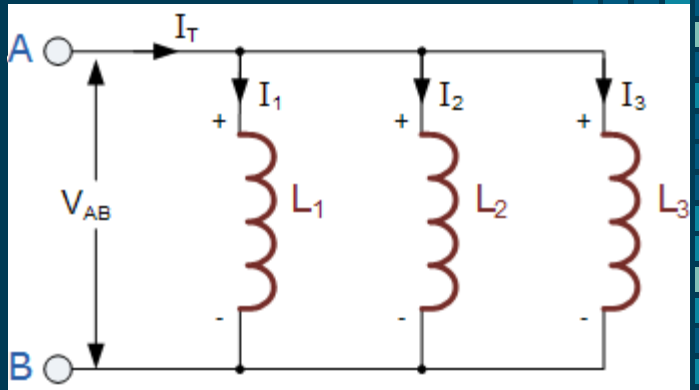
*Opposite of capacitors

Series/Parallel Inductors

- Series Inductors
  - Same as series resistors
  - $L_{eq} = L_1 + L_2 + L_3$



- Parallel Inductors
  - Same as parallel resistors
  - $L_{eq} = \frac{1}{\frac{1}{L_1}+\frac{1}{L_2}+\frac{1}{L_3}}$

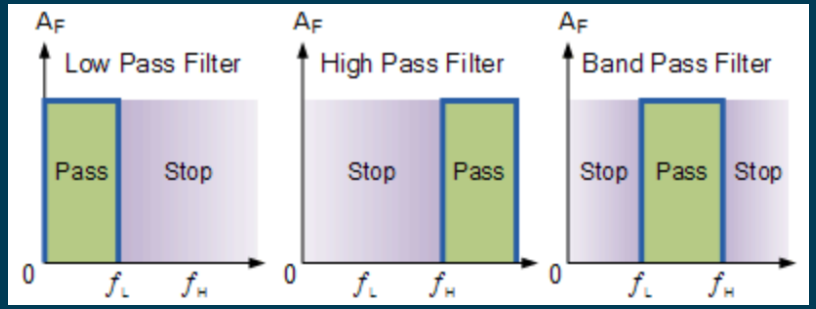


Uses

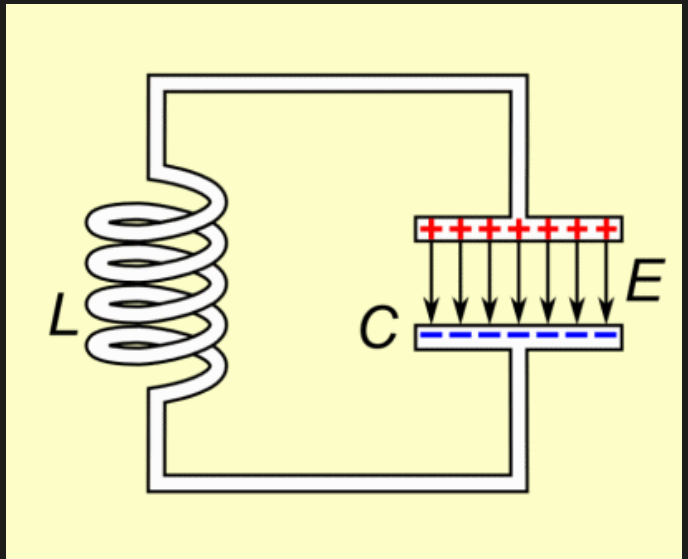
- Removes spikes from a power supply
- Can block AC and allow DC to pass
- Used with capacitors to make tuned circuits (LC)
- Coils in relays
- Solenoids
- Transformers
- Much more

LC Circuits

- Also known as resonant or tuned circuits.
- LC circuits are used either for generating signals at a particular frequency or picking out a signal at a particular frequency from a more complex signal.
- This function is called a bandpass filter.



Animated diagram showing the operation of a tuned circuit. The capacitor C stores energy in its electric field E and the inductor L stores energy in its magnetic field B (green). The animation shows the circuit at progressive points in the oscillation. The oscillations are slowed down; in an actual tuned circuit the charge may oscillate back and forth thousands to billions of times per second.

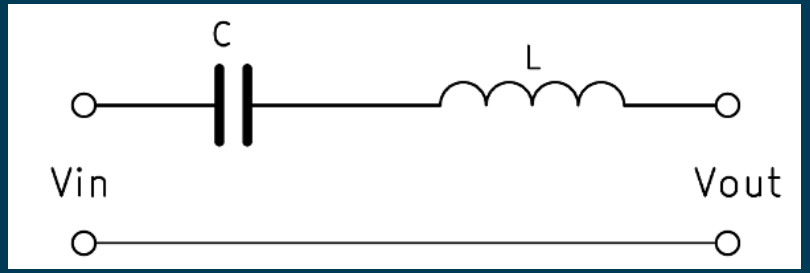


LC Circuit Uses

- Radio receivers
- Amplifiers
- Oscillators
- Filters
- Tuners
- Mixers
- Contactless cards (RFID, NFC)

LC Circuit – 1st Order

- $f_0 = \frac{1}{2\pi\sqrt{LC}}$
- $Z = \sqrt{\frac{L}{C}}$
- $C = \frac{1}{2\pi Z f_L}$
- $L = \frac{Z}{2\pi f_H}$

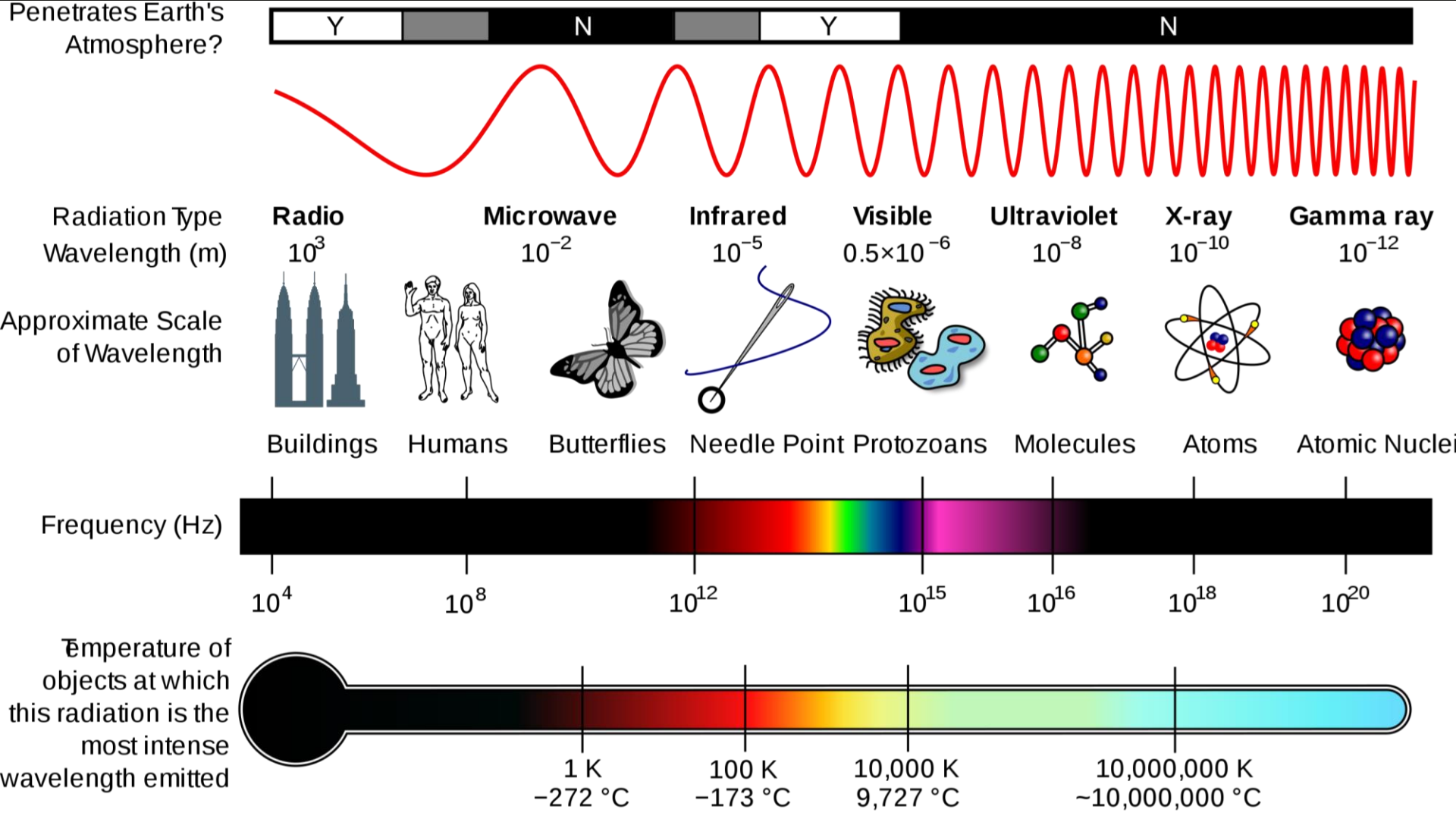


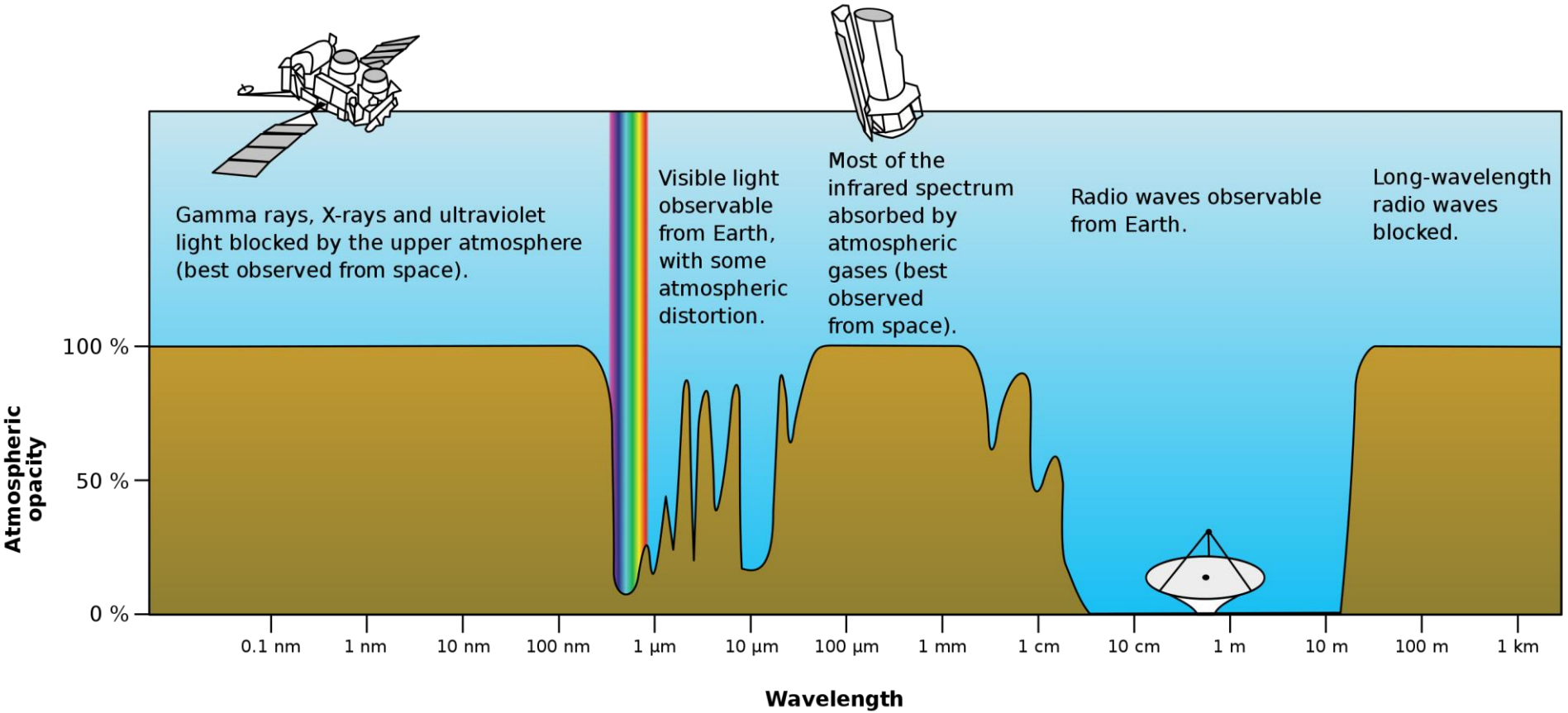
LC Circuit Simulation

- Ltspice Simulation
- C = 1uF, L = 2mH
- f_L = 3535 Hz, f_H = 3580 Hz, f_0 = 3559 Hz

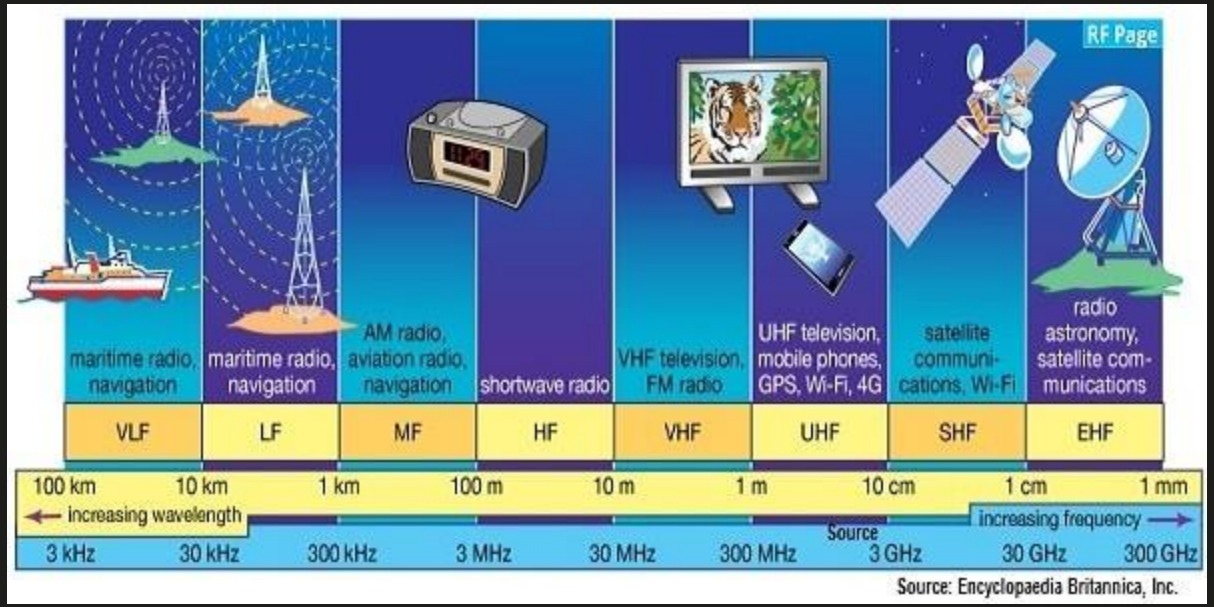
Electromagnetic Spectrum

- The range of frequencies (the spectrum) of electromagnetic radiation and their respective wavelengths and photon energies.


Penetrates Earth's Atmosphere?
Y
N
Y
N
Radiation Type
Wavelength (m)
Approximate Scale of Wavelength
Radio
10^{3}
Microwave
10^{-2}
Infrared
10^{-5}
Visible
0.5×10^{-6}
Ultraviolet
10^{-8}
X-ray
10^{-10}
Gamma ray
10^{-12}
Buildings
Humans
Butterflies
Needle Point
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^{4}
10^{8}
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}
Temperature of objects at which this radiation is the most intense wavelength emitted
1 K
−272 °C
100 K
−173 °C
10,000 K
9,727 °C
10,000,000 K
~10,000,000 °C


Gamma rays, X-rays and ultraviolet light blocked by the upper atmosphere (best observed from space).
Visible light observable from Earth, with some atmospheric distortion.
Most of the infrared spectrum absorbed by atmospheric gases (best observed from space).
Radio waves observable from Earth.
Long-wavelength radio waves blocked.
100 %
50 %
0 %
Atmospheric opacity
0.1 nm
1 nm
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength

RF Frequency Spectrum



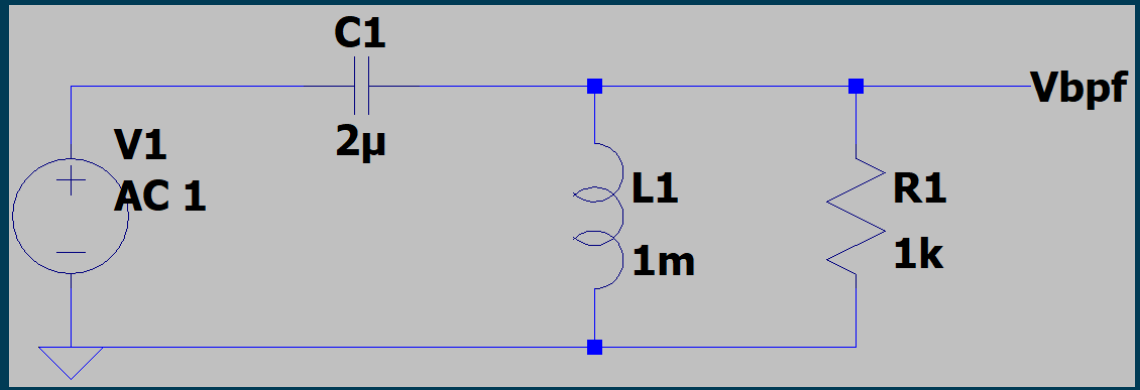
United States RF Spectrum

- Enforced by the FCC (Federal Communications Commission).

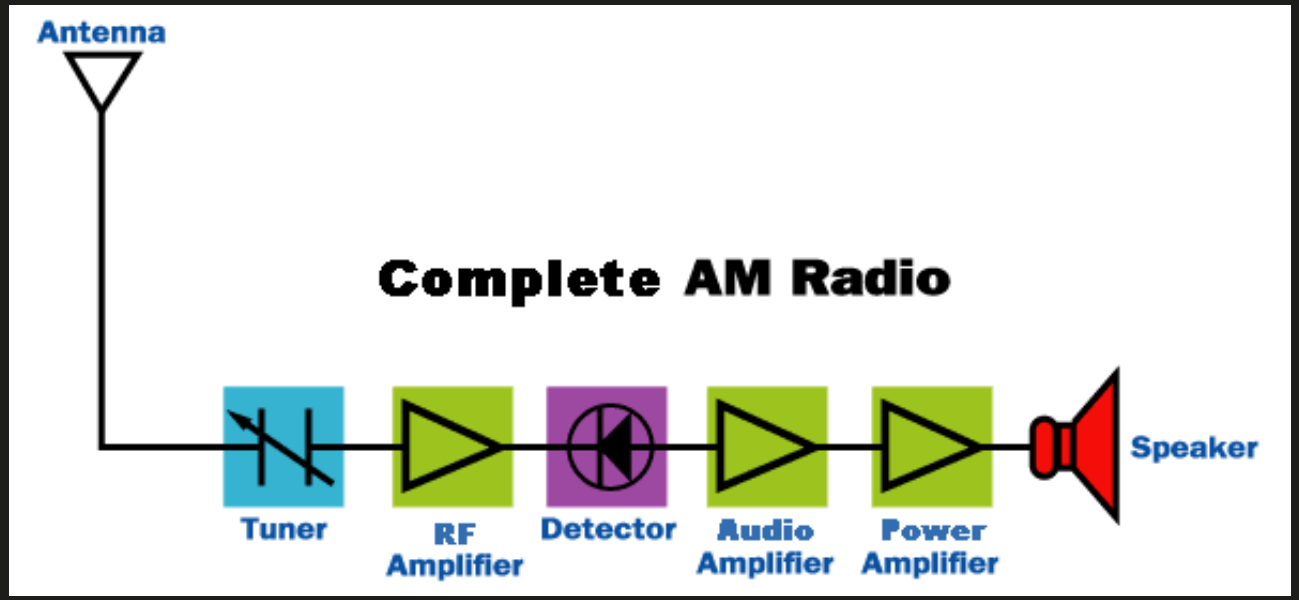
- https://en.wikipedia.org/wiki/File:United_States_Frequency_Allocations_Chart_2016_-_The_Radio_Spectrum.pdf

Activity: Build LC Tuning Circuit

- Can you design a first order LC tuning circuit to pick up AM radio station 1200?
- Calculate the f_0, build the circuit, and test.
- Sadly, we won't be able to pick up the radio. Requires a lot of circuitry.
- $f_0 = \frac{1}{2\pi\sqrt{LC}}$



AM Radio Design

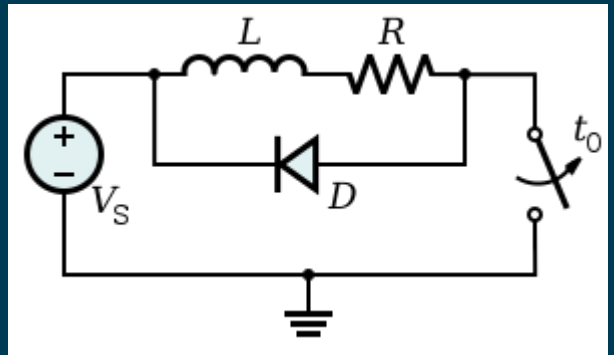


Why do we see a large voltage spike across the inductor when the current is stopped?

Flyback Diode

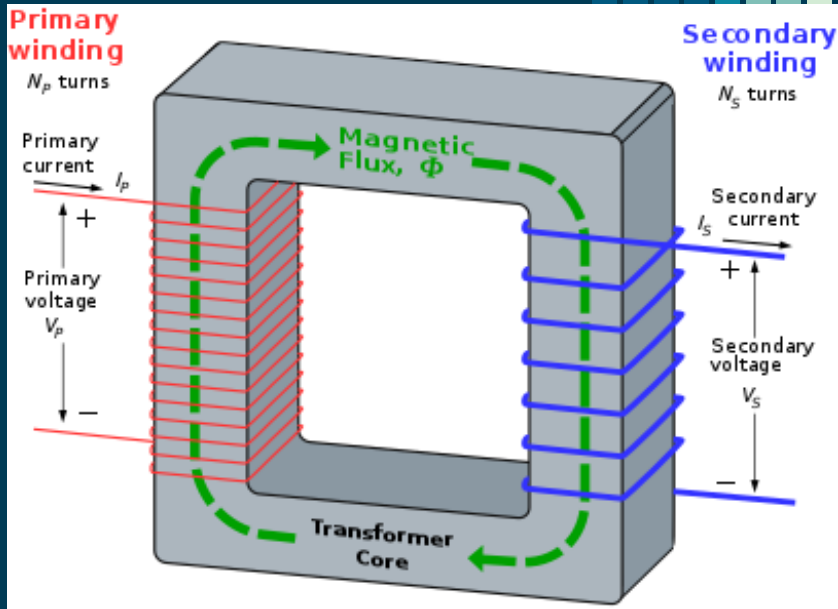
- When the current through an inductor is reduced or removed, there can be a large spike of voltage across the inductor.
- All of the energy stored in the magnetic field reenters the circuit and has nowhere to go.
- With the voltage now reversed across the inductor, the current can now flow through the diode and the voltage across the inductor is limited to the forward voltage of the diode.

Useful for relays, solenoids, and other similar inductor applications.



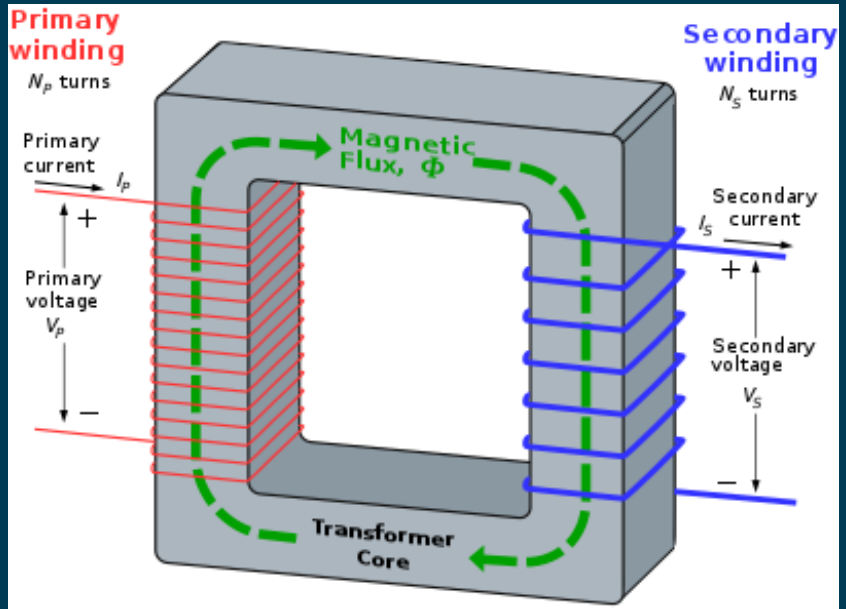
Transformer

- A static electrical device that transfers electrical energy between two or more circuits.
- Multiple coils that share 1 core.
- Used to either step up (higher voltage) or step down (lower Voltage).
- We don't create power, we just transform it!
- Power in = Power out



Transforming power

- Turns – number of rotations coil males around core.
- $Turns\ Ratio = \frac{N_p}{N_s} = \frac{\#\ of\ turns\ on\ primary\ coil}{\#\ of\ turns\ on\ secondary\ coil}$
- $\frac{V_p}{V_s} = \frac{N_p}{N_s}$
- Same ratios!
- $V_p \times I_p = V_s \times I_s$



Why don’t transformers work on DC?

Why don’t transformers work on DC?

- Need a changing current to produce a changing magnetic field.
- This changing magnetic field is what induces a voltage on the secondary side proportional to the turns ratio.
- With a constant current supply, no voltage will be induced on the secondary side.

Transformer Example

- Our transformer has a 10:3 (pri:sec) ratio.
- This means 10 turns on the primary side and 3 turns on the secondary side. This means it is a step-down.
- If we have 120 V on the primary, how many volts will we have on the secondary?

Design a Transformer

- We need 240 V and 3 A.
- We have 120 V available from the wall.
- Will this be a step-up or step-down transformer?
- What will the turns ratio be?
- How much current will we draw on the primary side?

Inductors will be back!

- We will talk about inductors/coils more when we discuss generators.