“Breadboarding” a Simple FM Transmitter

A Pre-study Guide

The New Jersey Antique Radio Club’s

Radio Technology Museum

At InfoAge

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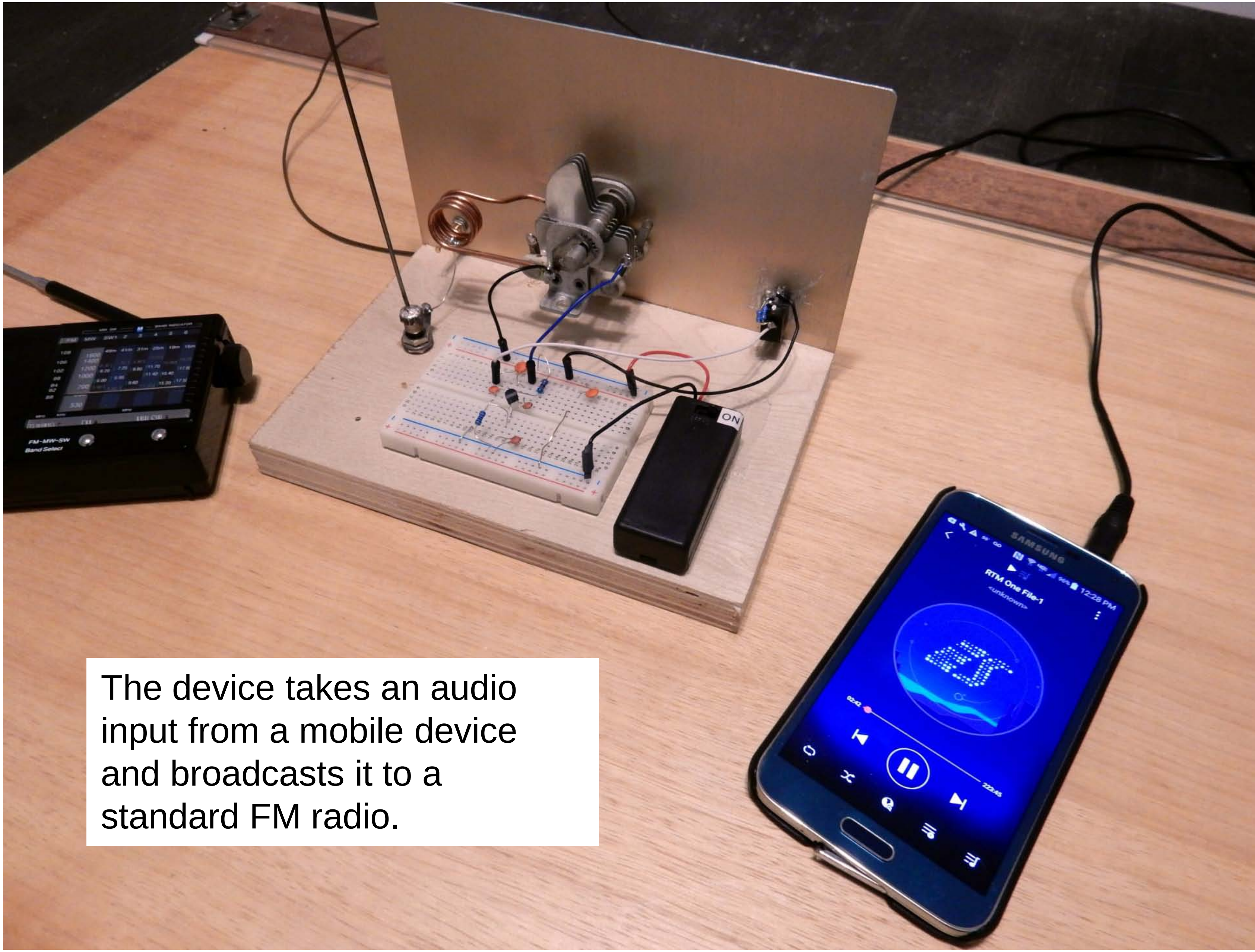
The Breadboard
From Paper to Reality

- An essential step before committing to a “hard” design.
- Allows easy circuit modification.

A 1920’s radio constructed Breadboard style.

The Project

- Assume the role of an electrical-engineering technician.
- Assemble a simple frequency-modulated (FM) transmitter.
- Use the solder-less breadboard technique
- Troubleshoot as needed
- Observe its operation



The device takes an audio input from a mobile device and broadcasts it to a standard FM radio.

Don't Panic!

- The following is background information.
- You are not expected to master it.
  - That could take years.
- Rather, peruse it and see what wisdom you can acquire.

Clarke's Third Law

Any sufficiently advanced technology is indistinguishable from magic.

Arthur C. Clarke, "Profiles of The Future", 1962

British science fiction writer, science writer and futurist (1917 - 2008)

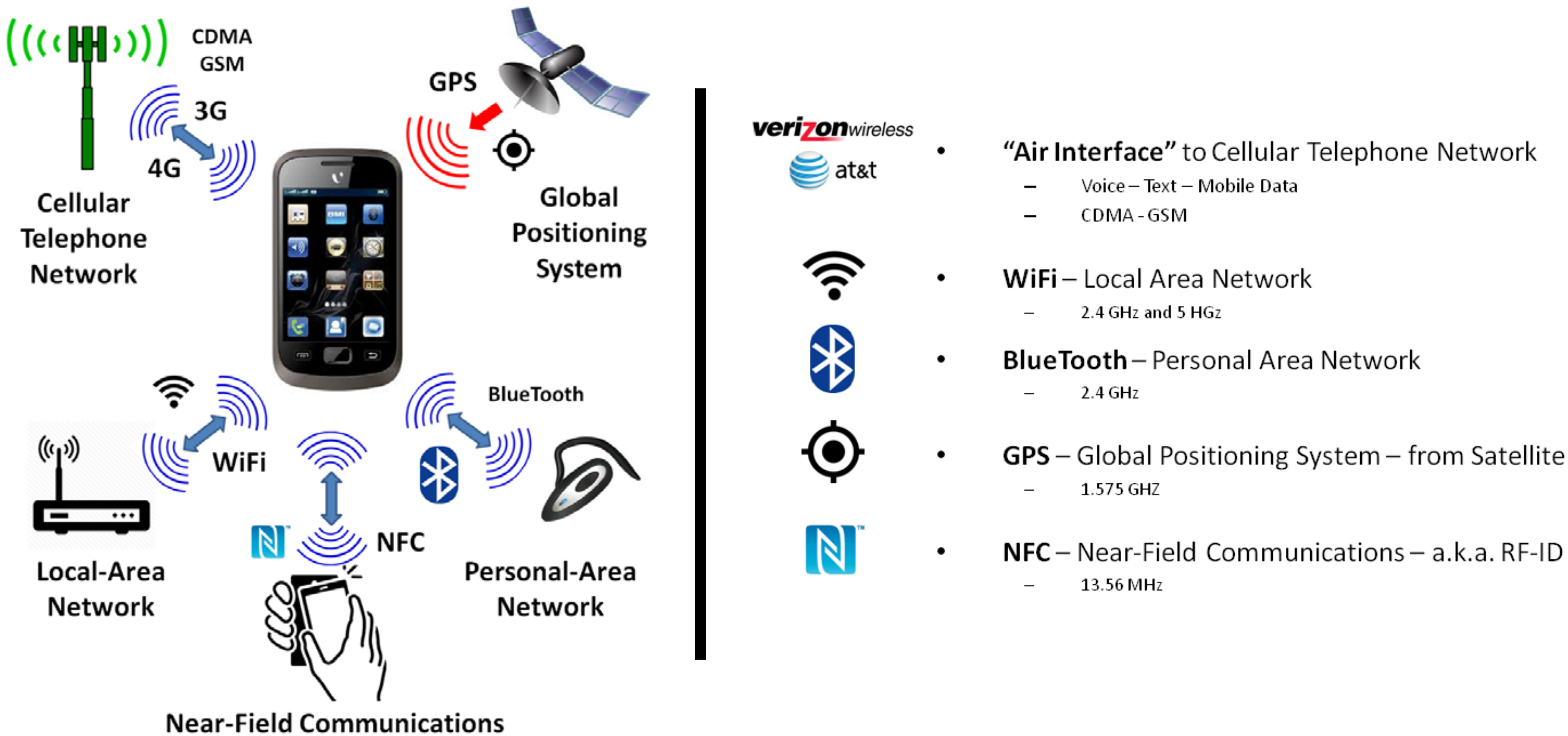
FM doesn't always stand for Frequency Modulation!

The steps of the engineering design process are to:

- **Define the Problem**
- **Do Background Research**
- **Specify Requirements**
- **Brainstorm Solutions**
- **Choose the Best Solution**
- **Do Development Work**
- **Build a Prototype**
- **Test**
- **Redesign**

This Project

How does all that stuff get into your mobile device?



- 4 or 5 Radio subsystems make your device "Wireless."
- This is made possible by advances in semiconductor technology
- See: https://en.wikipedia.org/wiki/Moore%27s_law

The Prediction of the Existence of Radio Waves

Maxwell's Equations

Circa 1861

$$\nabla \cdot \mathbf{E} = \frac{\rho_v}{\varepsilon} \qquad \text{(Gauss' Law)}$$

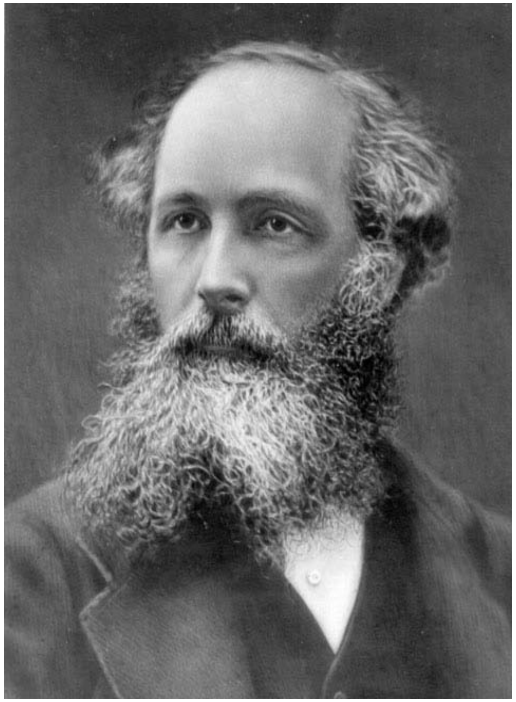
$$\nabla \cdot \mathbf{H} = 0 \qquad \text{(Gauss' Law for Magnetism)}$$

$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t} \qquad \text{(Faraday's Law)}$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \varepsilon \frac{\partial \mathbf{E}}{\partial t} \qquad \text{(Ampere's Law)}$$

Maxwell's equations explain how electromagnetic waves can physically propagate through space.

- The changing magnetic field creates a changing electric field through Faraday's law.
- In turn, that electric field creates a changing magnetic field through Maxwell's addition to Ampère's law.
- This perpetual cycle allows these waves, now known as electromagnetic radiation, to move through space at the velocity of light, c. (= 300,000,000 meters per second or 186,272 miles per second).

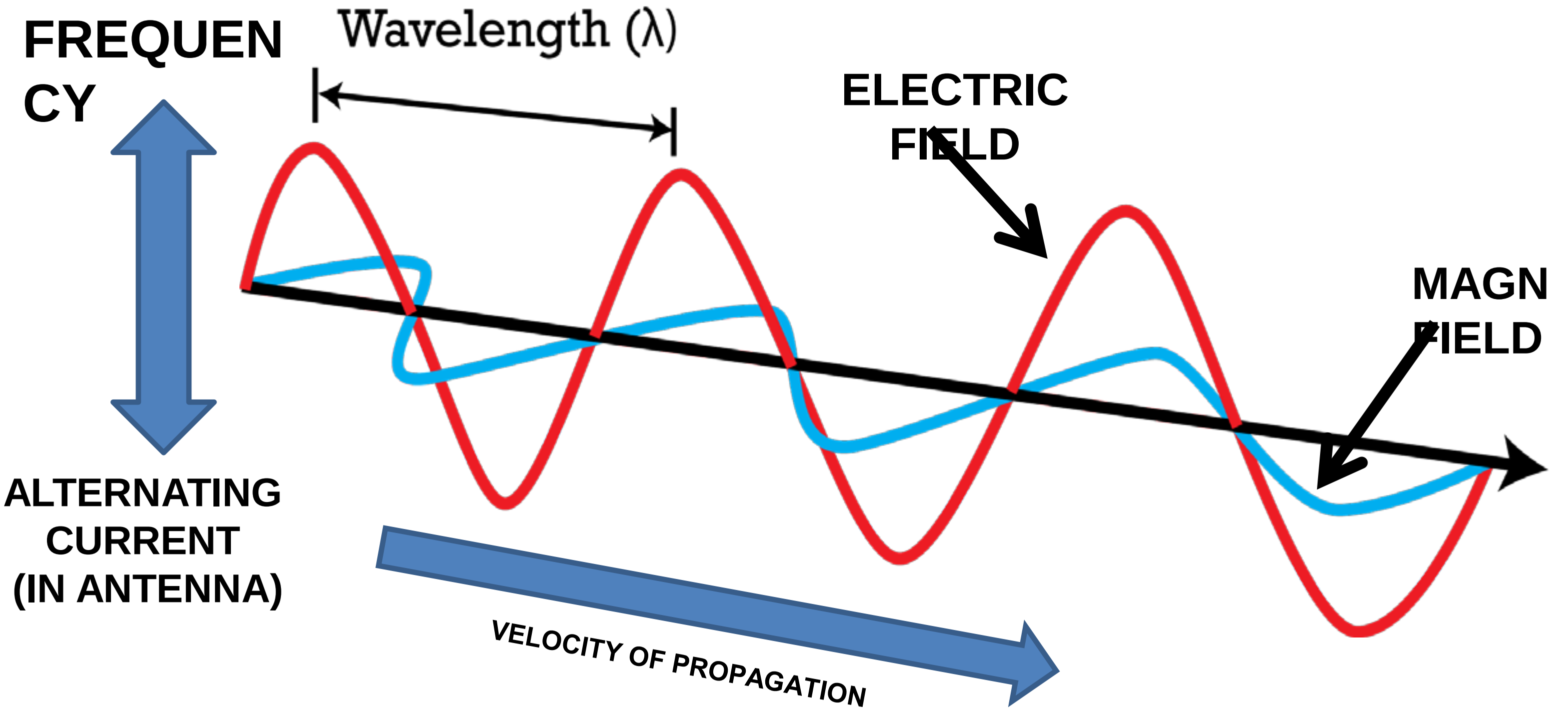


James Clerk Maxwell (1831–1879)
Scottish Physicist

I.e., Maxwell discovered the invisible world of electro-magnetic radiation with a pencil!

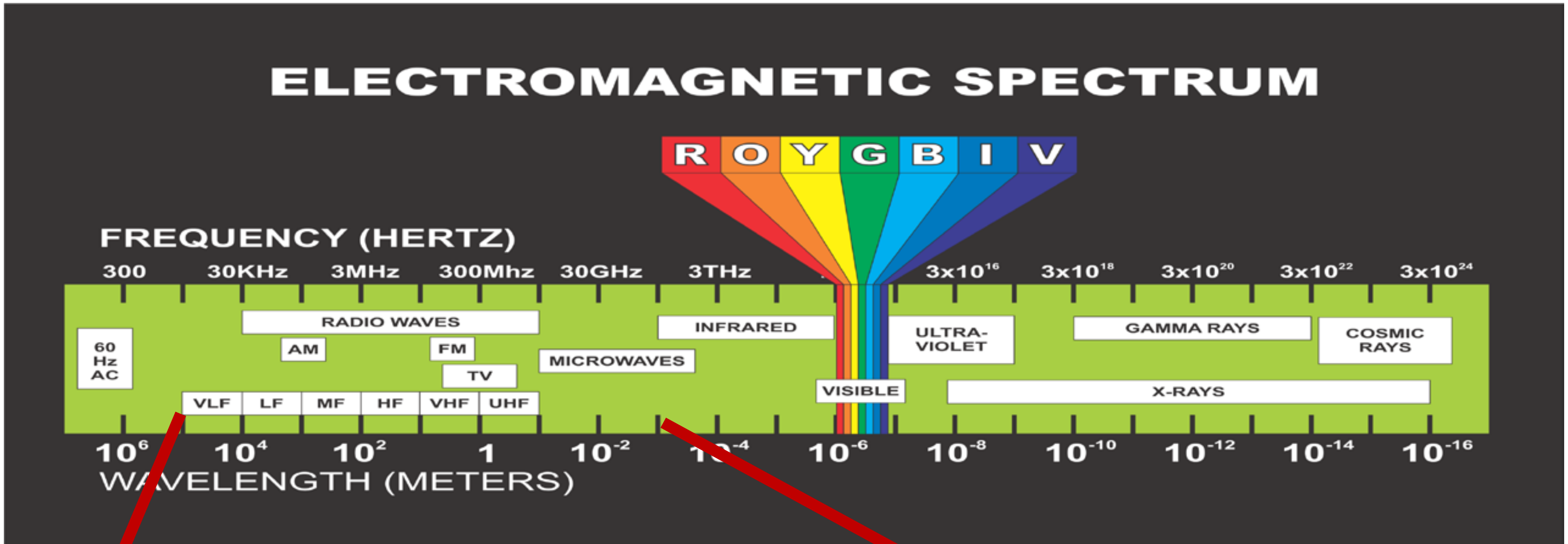
Electromagnetic Waves
Carry Energy through Space

Frequency and Wavelength

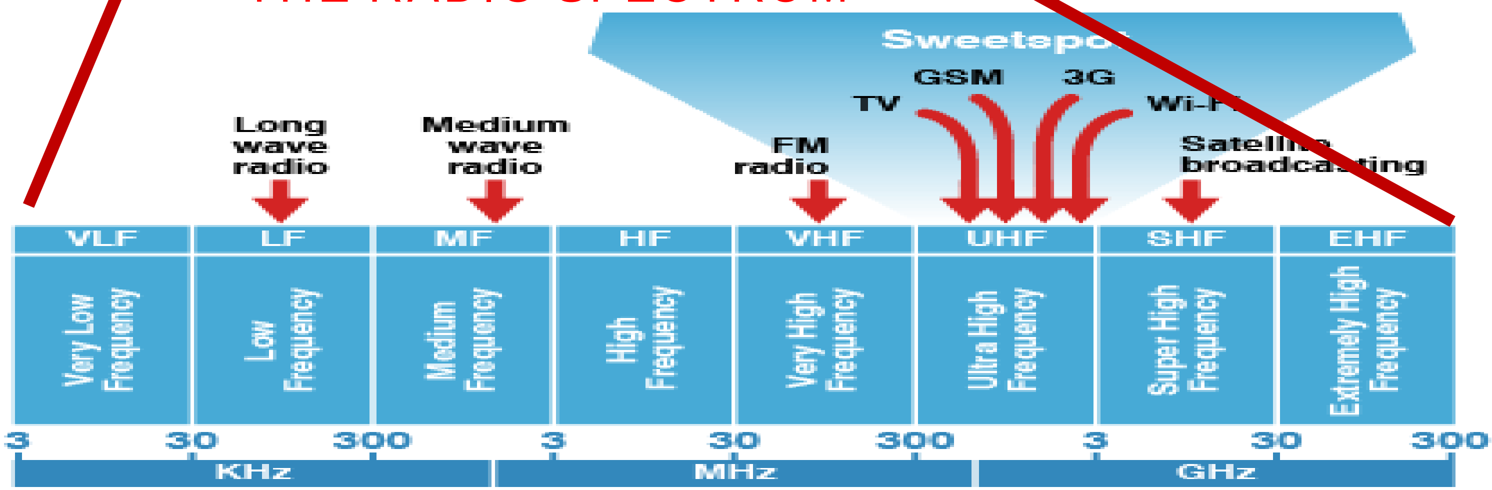


How far does the wave travel for one cycle of the field?

$$\lambda = \frac{C}{f} = \frac{\text{SPEED OF LIGHT}}{\text{FREQUENCY}} = \frac{\text{300,000,000 meters/second}}{\text{cycles / second (Hertz)}}$$



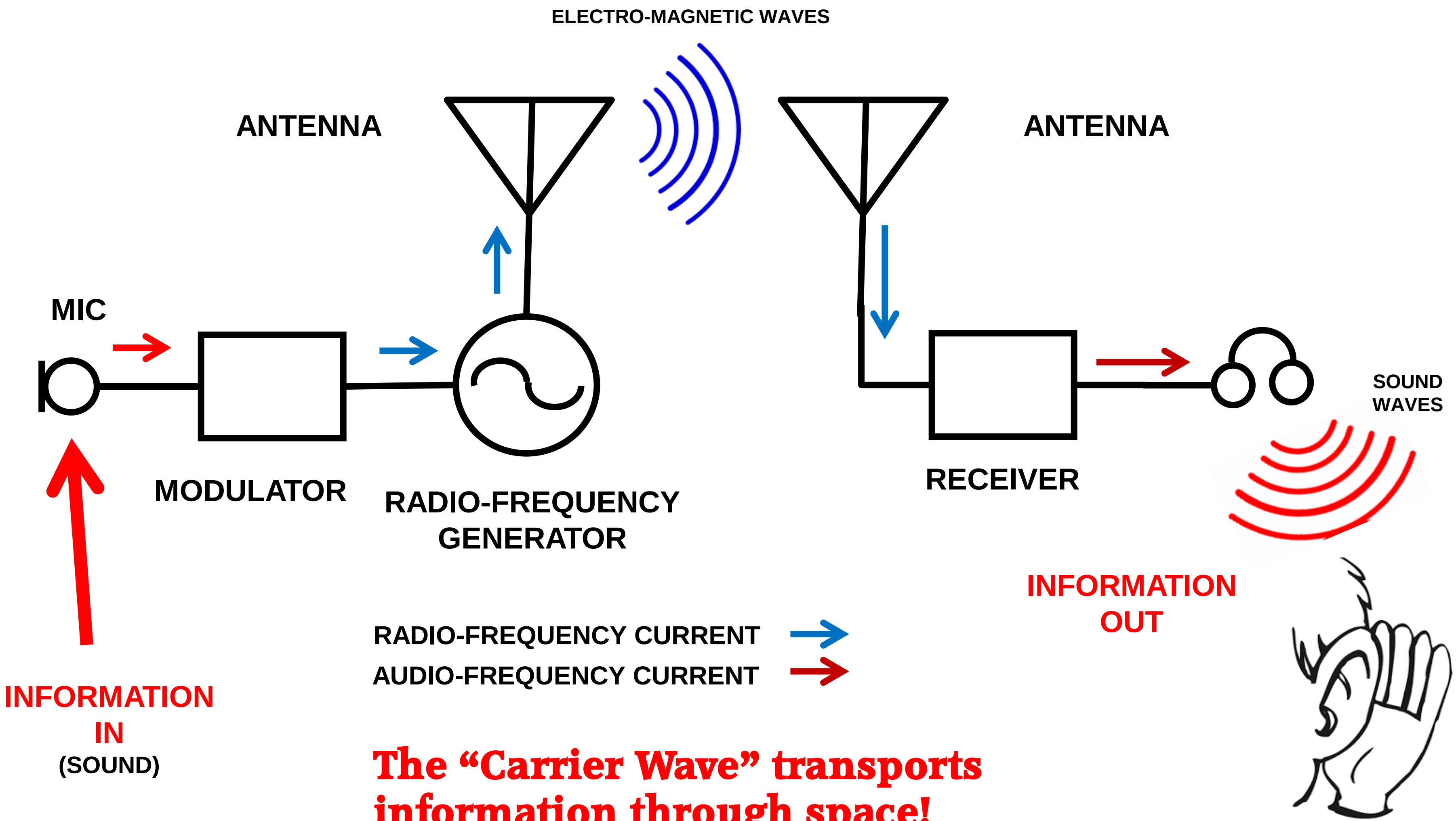
THE RADIO SPECTRUM



3E3 3E4 3E5 3E6 3E7 3E8 3E9 3E10 3E11

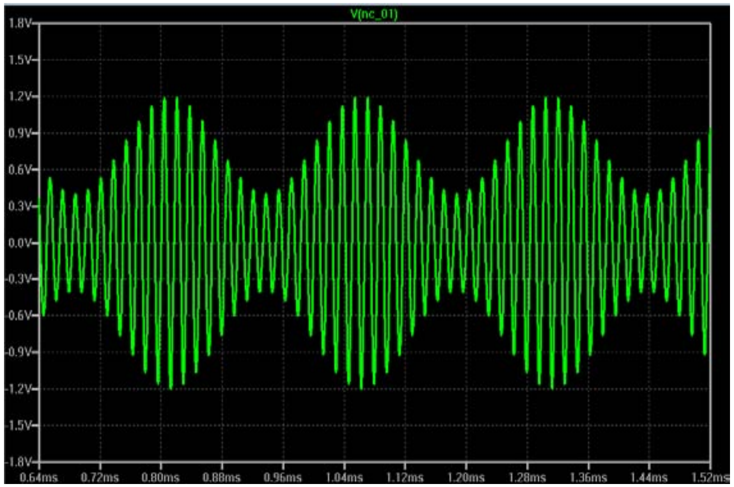
Each higher-frequency band can carry ten times more information than the one to its left!

A SIMPLE RADIO SYSTEM

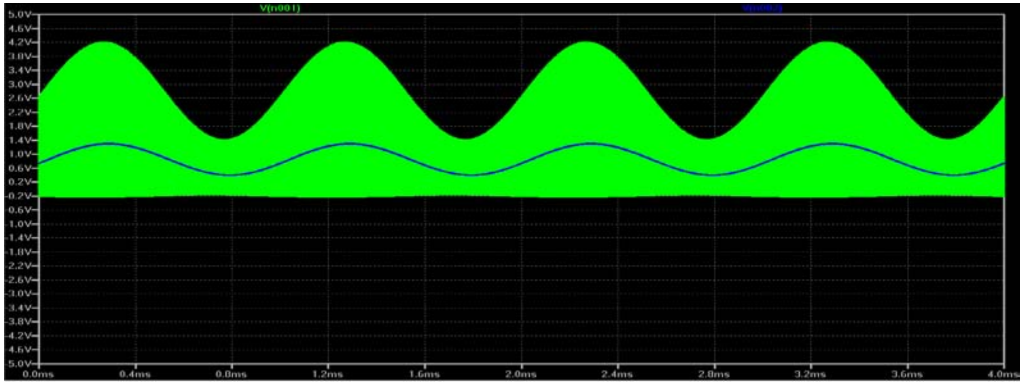


The "Carrier Wave" transports information through space!

Amplitude Modulation (AM)
(The Obvious Way)



Time Domain ->
60KHz modulated by 4KHz

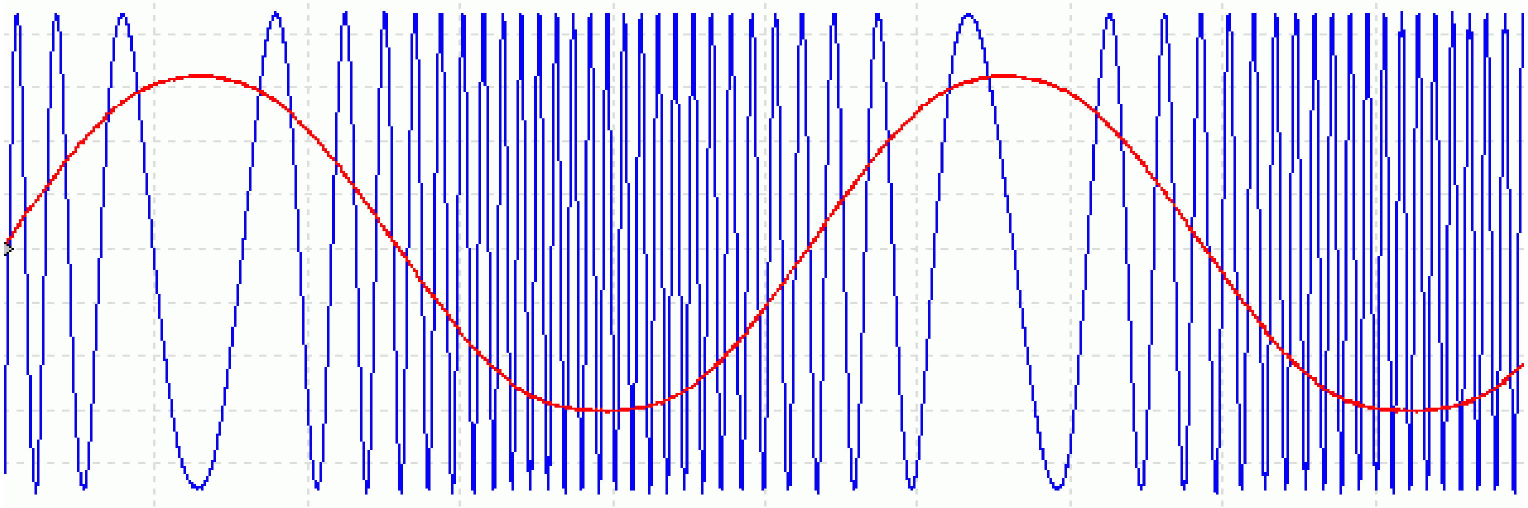


Detection:

- **Bottom half of the waveform has been clipped off by a diode rectifier.**
- **Recovered audio, after audio filtering, shown in blue.**

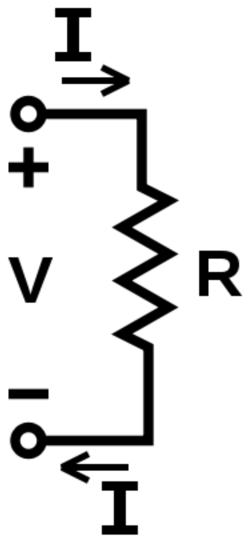
- The original modulation scheme for radio telephone
- Susceptible to noise interference.
- (NOTE: “K” represents 1000)

Frequency Modulation (FM)
(The Subtle Way)



- Frequency of the carrier wave is shifted proportional to the amplitude of the information.
- Resistant to noise. (a.k.a. Static)
- Overrides weaker signals
- Hi-Fidelity is easy

Resistors and Ohm's Law

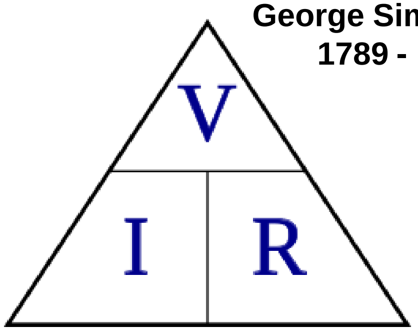


$$I = \frac{V}{R}$$

$$V = I \cdot R \qquad R = \frac{V}{I}$$

I = Current in Amps
V = Voltage in Volts
R = Resistance in Ohms

George Simon Ohm
1789 - 1865

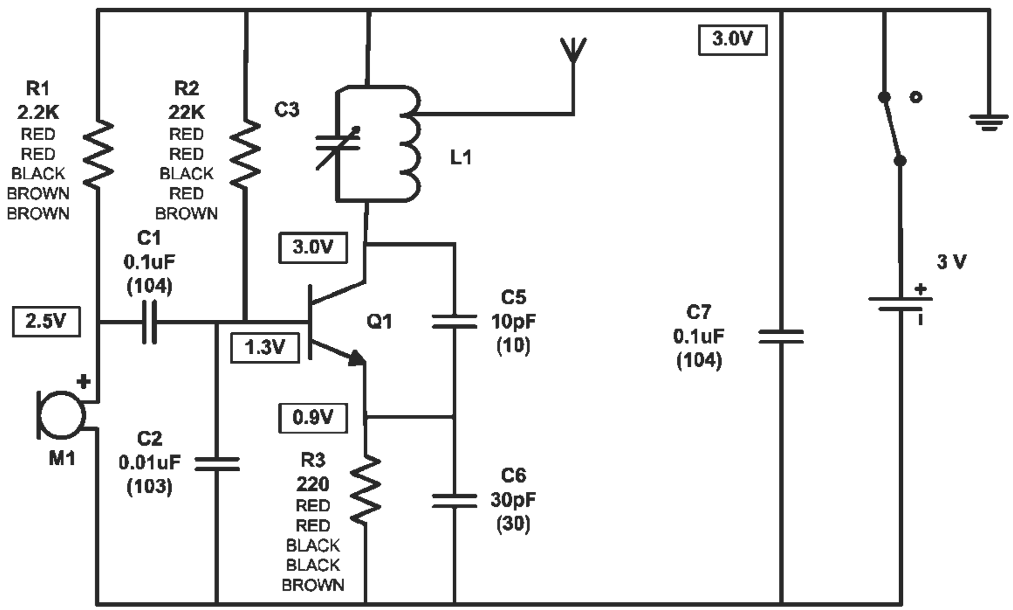


The technicians way, cover the value to be calculated with your thumb. What remains is the proper math problem.

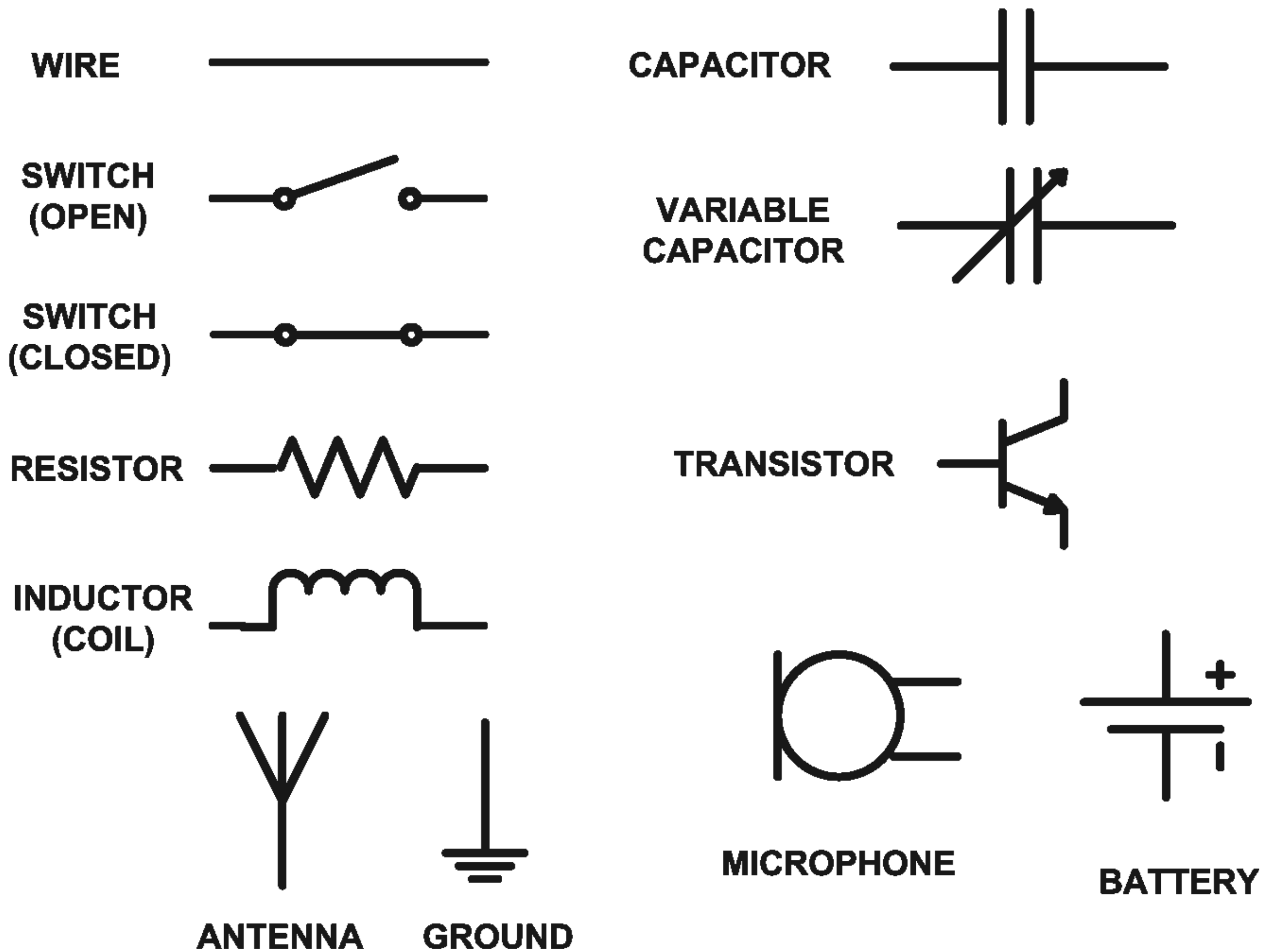
- Resistors limit the flow of current in keeping with Ohm's Law.
- Resistance is constant with changing frequency.
- (NOTE: V is often represented as "E" – Electromotive Force)

The Schematic Diagram

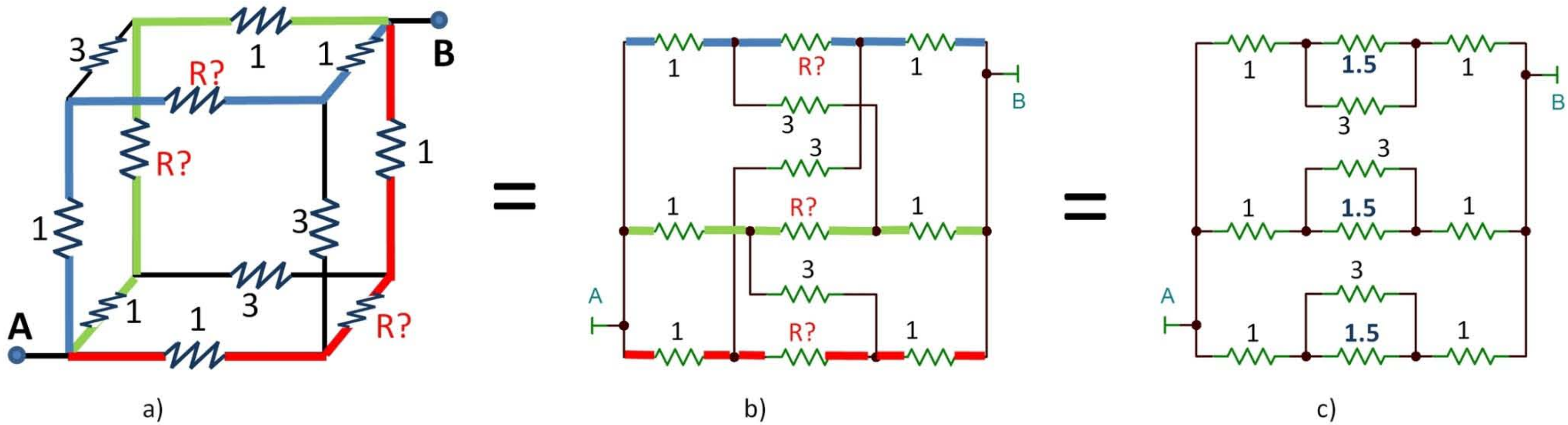
- An electrical road map
- Generally reads from:
  - – Left to Right
  - – Top to Bottom



COMMON SCHEMATIC SYMBOLS



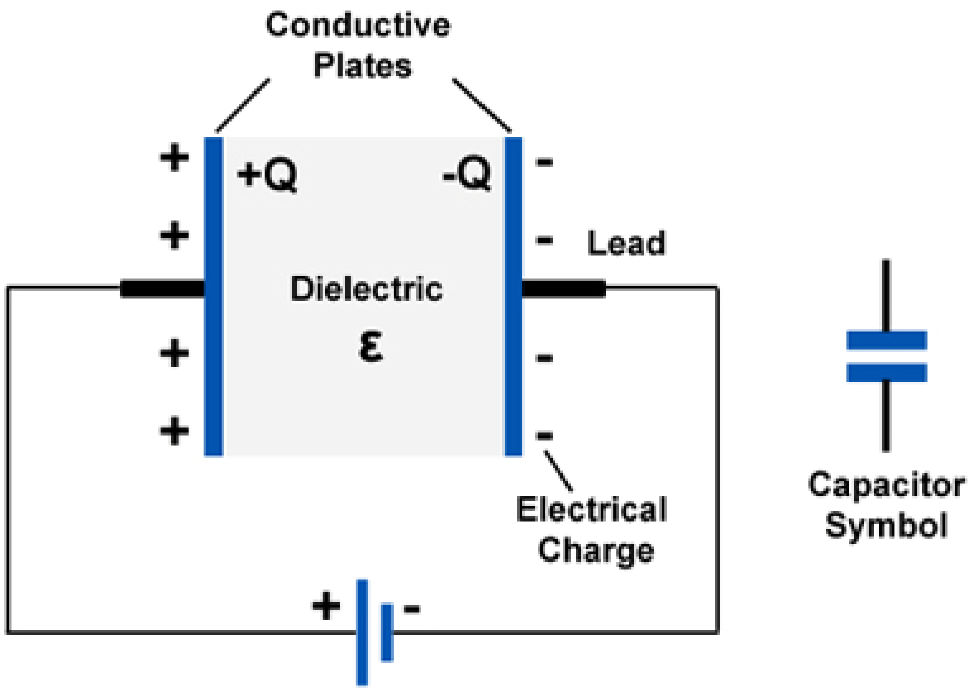
The dreaded Resistor Cube puzzle



a) b) c)

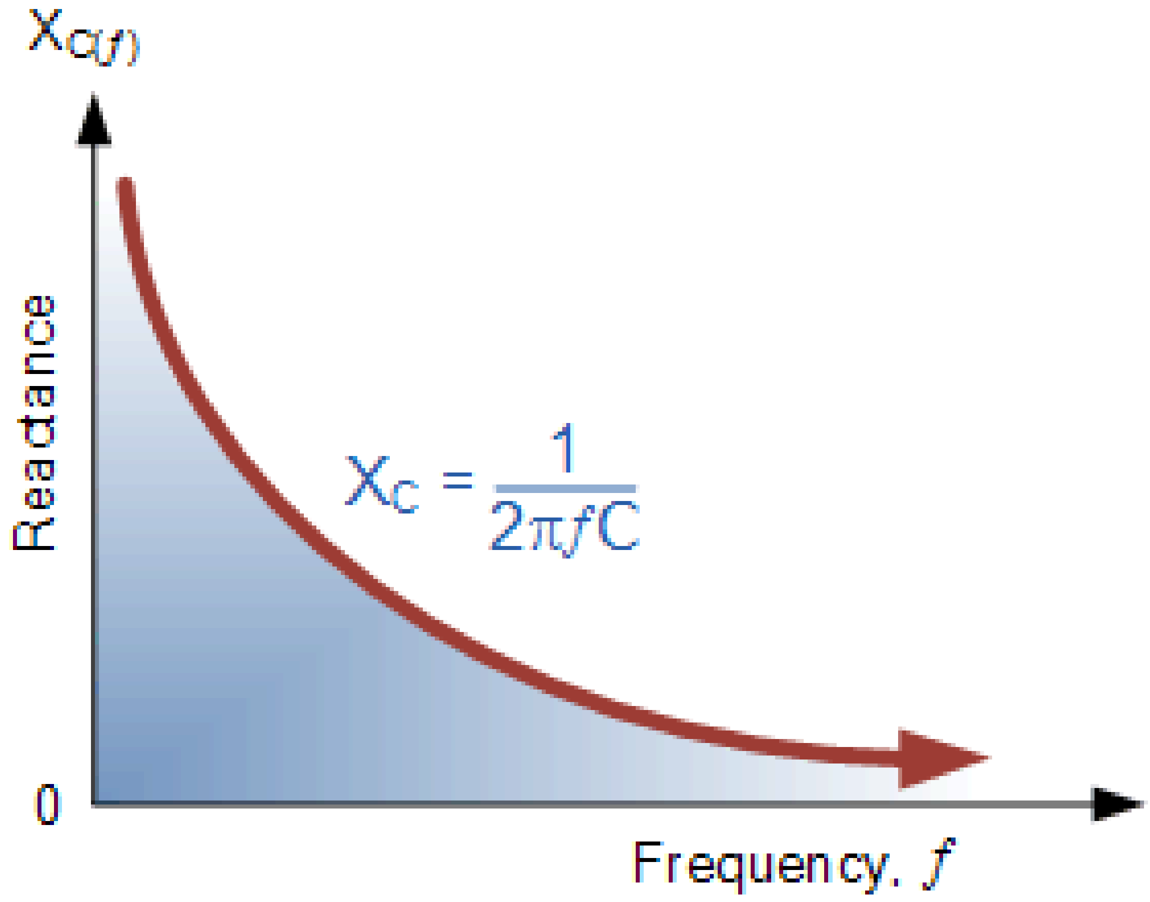
- Redrawing the schematic to reveal the series and parallel circuits so total resistance can be calculated.
- Answer 5/6 Ohm.
- See: http://www.rfcafe.com/miscellany/factoids/kirts-cogitations-256.htm

Capacitors



- Conductive plates separated by an insulator.
- Stores energy electrostatically
- Blocks DC
- Passes AC
- Displays Capacitive Reactance (AC Resistance)

Capacitive Reactance



- In a capacitor reactance decreases with rising frequency.

The Function of Resistors and Capacitors in a Circuit

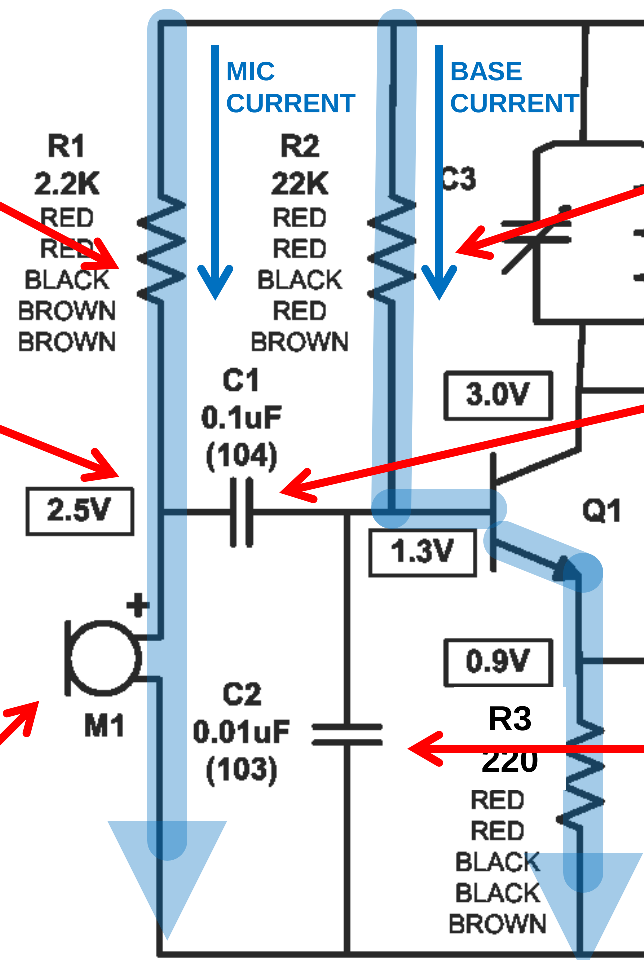
+3 Volts

R1 supplies and limits current to the microphone

R2 supplies and limits current to the base circuit of Q1, a transistor, establishing its correct operating conditions.

DC voltage here moves up and down at an audio-frequency rate because of the action of the microphone.

C1 blocks direct-current (DC) flow between the mic circuit and the base circuit, but passes audio frequency (AF) currents.

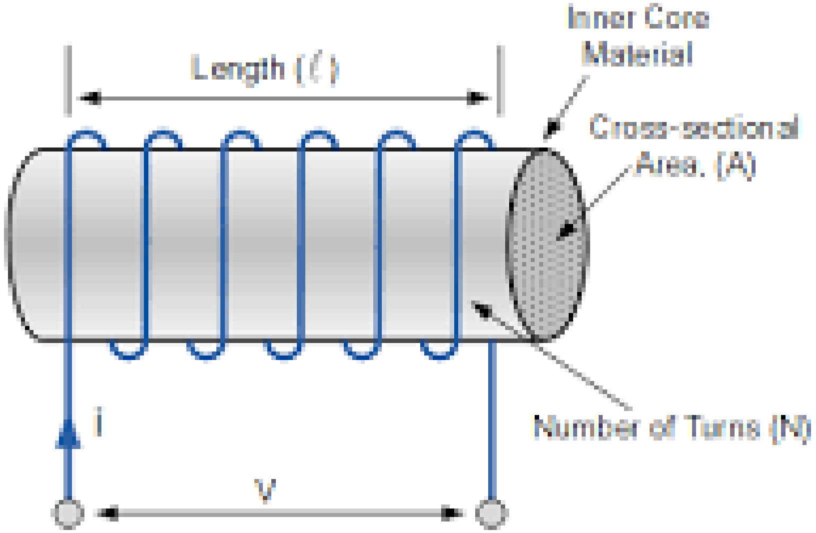


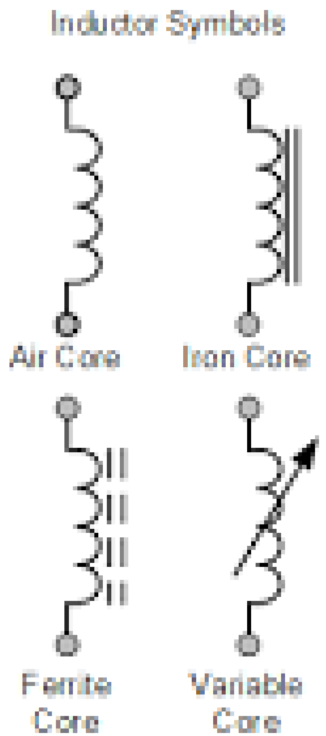
C2 shorts the base circuit of Q1 to ground for radio frequencies (RF), but not for audio frequencies (AF) (remember – capacitive reactance!)..

Resistance of the microphone Changes in response sound pressure at its diaphragm.

GROUND

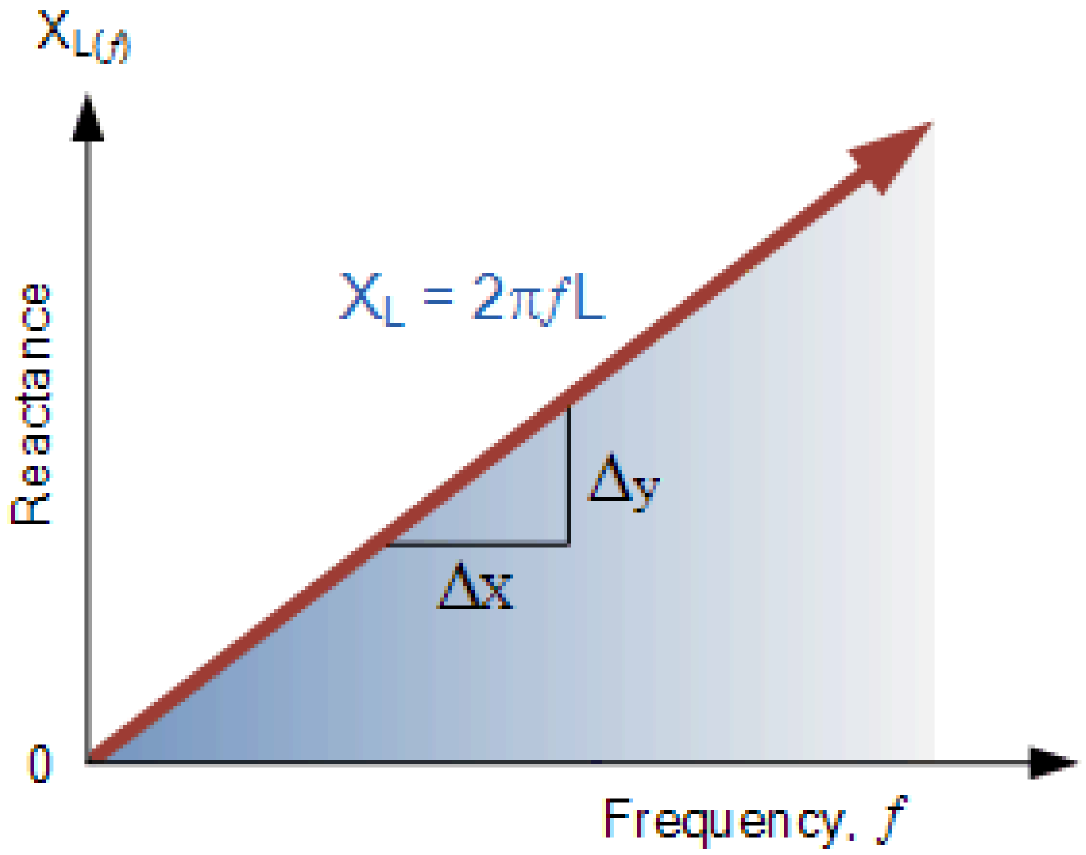
Inductors





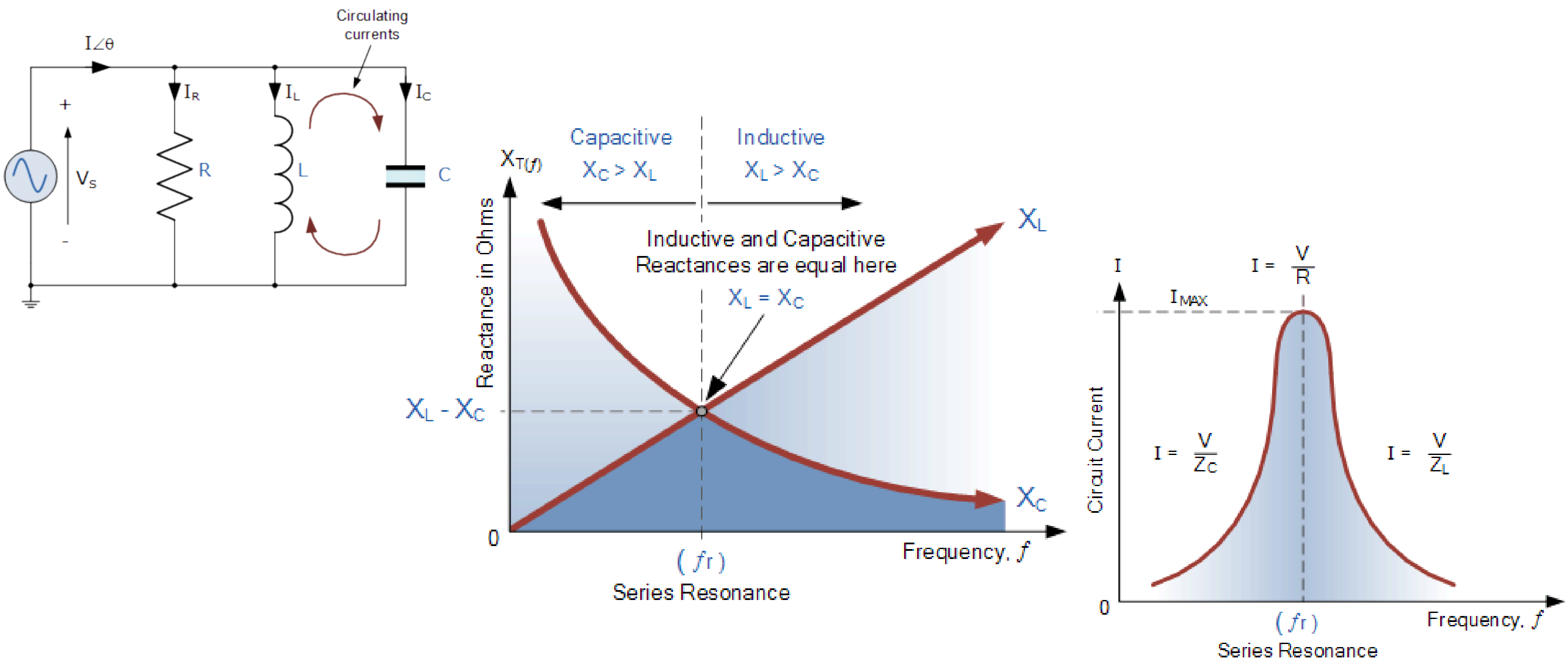
- Coiled insulated conductor
- Sores energy magnetically
- Passes DC
- Resists AC
- Displays "Inductive Reactance" (AC Resistance)

Inductive Reactance



- In an inductor reactance increases with rising frequency.

Resonant Circuits

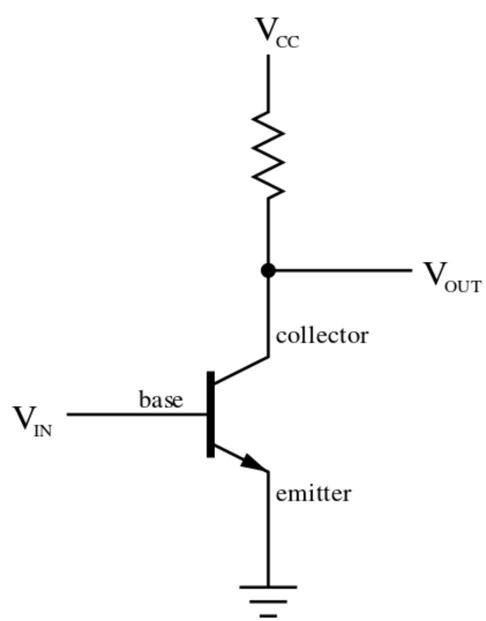


- A parallel circuit containing capacitance and inductance will be resonant at the frequency where the capacitive and inductive reactances are equal
- .Such a circuit can be used as a frequency-selective filter.

Electron Devices

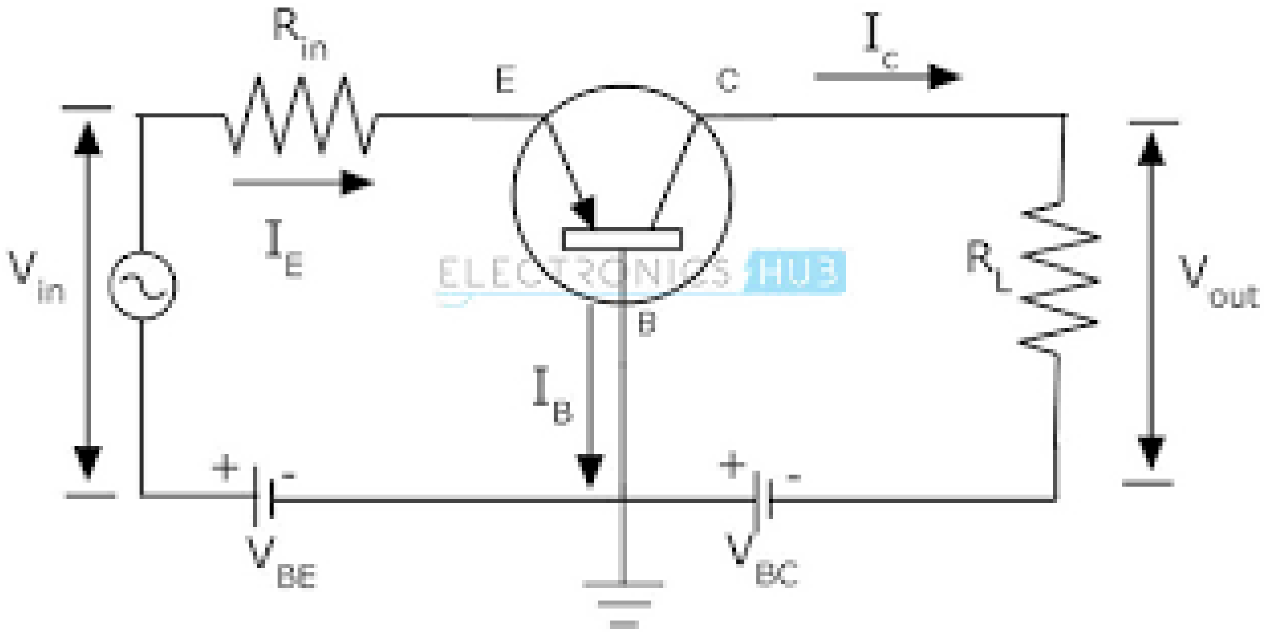
The Bipolar Junction Transistor

- A small current in the base-emitter circuit controls a larger current in the collector-emitter circuit.
- A transistor can serves as an amplifier or switch.

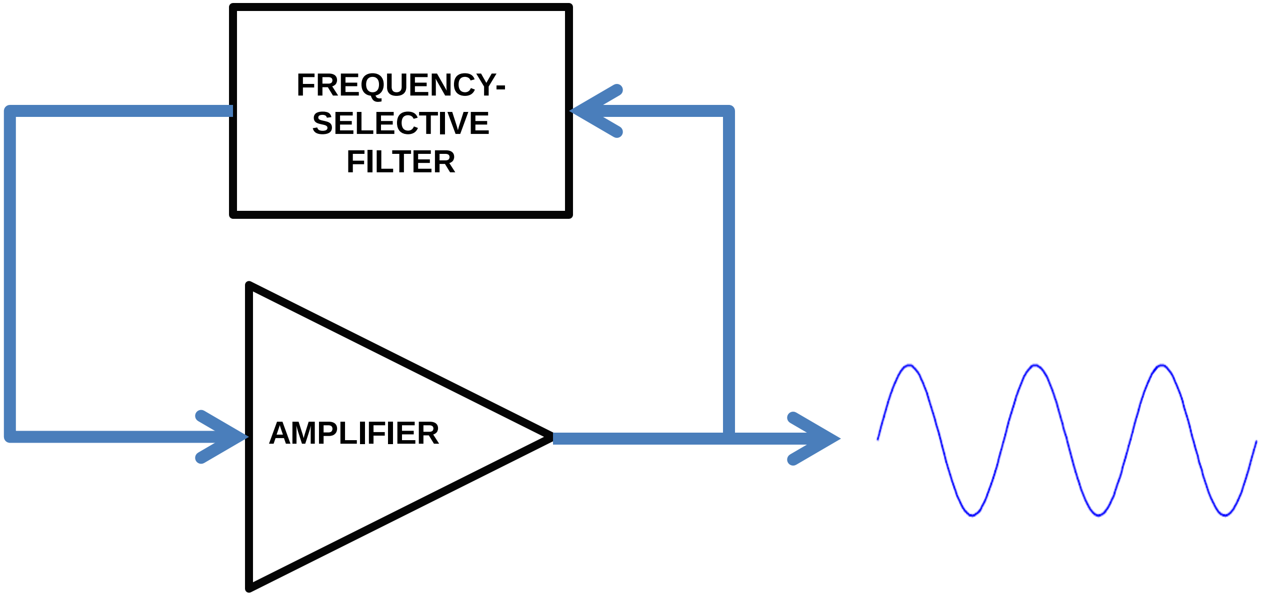


The Amplifier in our Circuit

- We will be using an NPN transistor in the so-called “common-base” circuit topology.
- (The circuit in his drawing uses a PNP transistor, so the battery polarities and direction of current flow are reversed.)
- Current in the emitter-base circuit, I_B, is multiplied in the emitter-collector circuit, I_C, effecting amplification.



Oscillators



- The circuit oscillates due to positive feedback from the amplifier output to its input.
- The frequency of oscillation is determined by the filter.

Our Circuit

Frequency-Modulated Common-Base Colpitts Oscillator