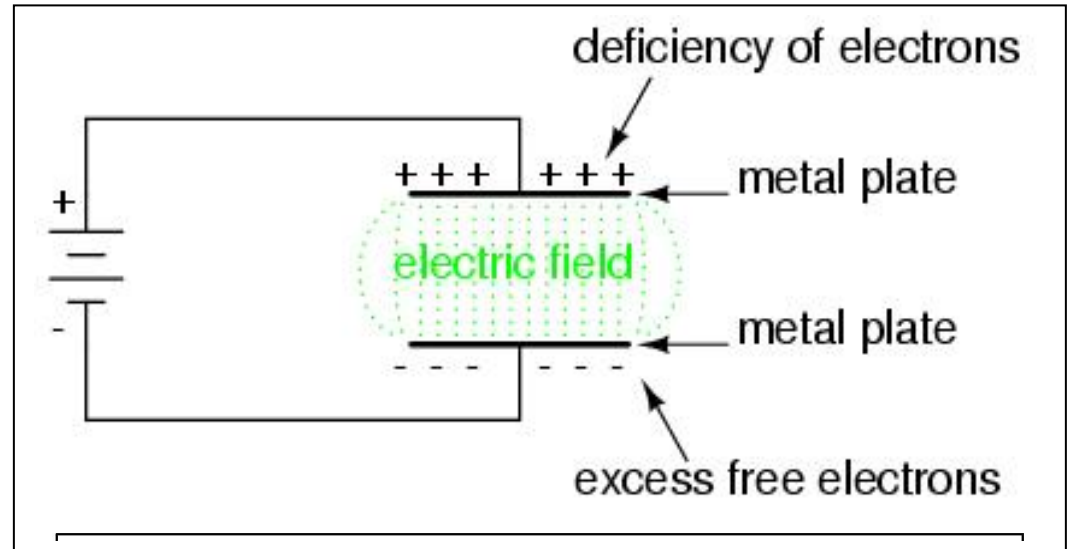


Lesson 04

Capacitors Inductors Antennas

Capacitors A capacitor is two conductors separated by an insulator. That's pretty generic, isn't it? For example, you are a salt water sack (conductor) separated from your lab partner by an insulator (air). Does that make you two a capacitor? You bet. How about your automobile (steel) separated from the earth (conductor) by rubber tires? Yup (anybody old enough to remember "grounding straps"?). How about the earth and the moon separated by space? You bet. Going to the other extreme, how about two copper atoms separated by the "nothingness" of a billionth of an inch inside the copper molecule? You got it.

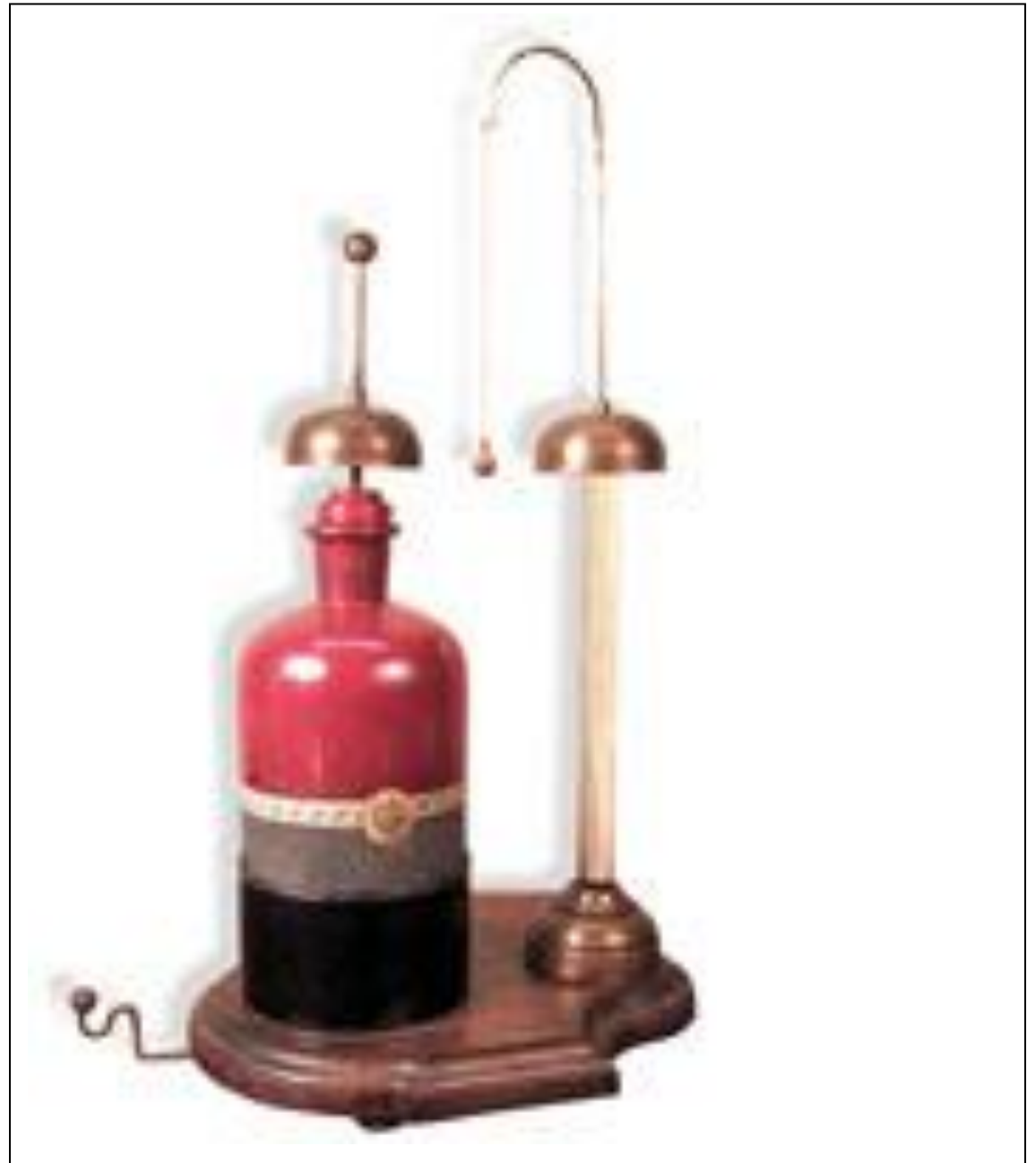


One of the first capacitors was the Leyden jar, so named because it was invented by Pieter van Musschenbroek of the University of Leyden, Netherlands in 1745. It consisted of an outer metal shell, a glass jar, and an inner metal plate. Two brass conductors separated by a glass insulator. Because at the time it was thought to "condense" the "vapors of electricity" into a jar, it was originally called a "condenser", a name that was used for this electrical device up until the 1950s when the modern word capacitor became the preferred nomenclature.



Benjamin Franklin (late, of Philadelphia) did some experimentation with atmospheric static electricity. Franklin used the static electricity to first attract the small pith ball to the Leyden jar's "bell", and then after it was charged, it was repelled to the "grounding" bell, then reattracted to the jar bell, and so on until the static charge was dissipated. In this manner, Franklin could just listen to find out when his kite was in an area of greater electrical activity.

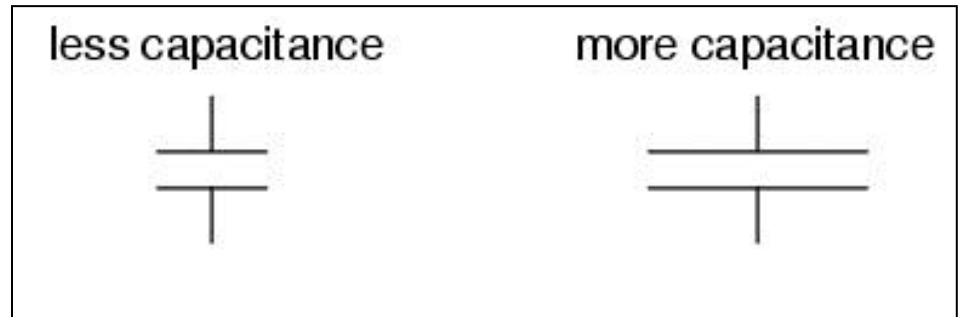
Again, as we said in the first lesson, Franklin was no fool. He did NOT fly his kite in a thunderstorm, but flew it when thunderstorms had passed through and charged the atmosphere.



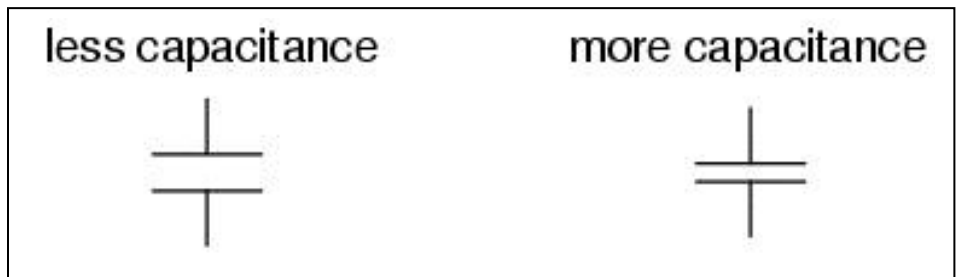
If you remember nothing else about capacitors, remember that they **store charge** and **pass AC but block DC**.

Let's talk about the various things that affect the value of the capacitor, which is measured in "farads" (after Michael Faraday). The farad is far too large of a value to use, since it is based on the coulomb which (as we saw in Lesson 1) is a LOT of electrons. We will use the microfarad (one millionth of a farad), the nanofarad (one billionth of a farad) and the picofarad (one trillionth of a farad) as common units of capacitance.

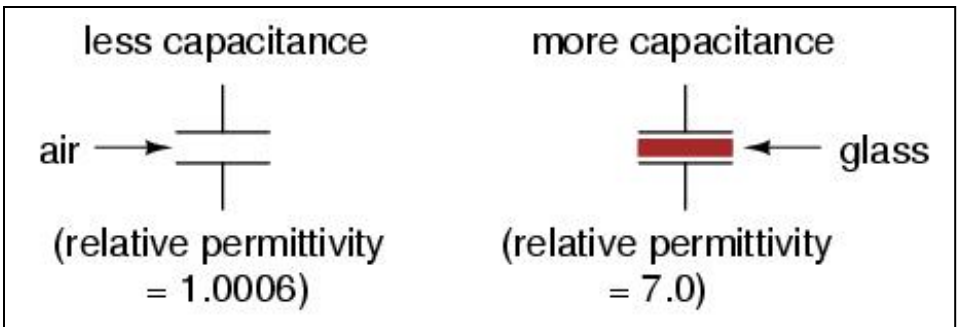
If we have a large plate area, we have "space" for a lot of electrons, and thus larger plates = more capacitance.



If the plates are squeezed closer together, the more electrons are attracted to the opposite plate and thus the more capacitance. Think of it as the dance where the little boy electrons and the little girl electrons get closer and closer together ... oh, you get the idea.



If an insulator with a greater *dielectric constant* is inserted between the plates, then it "focuses" the electrons and thus increases the capacitance.



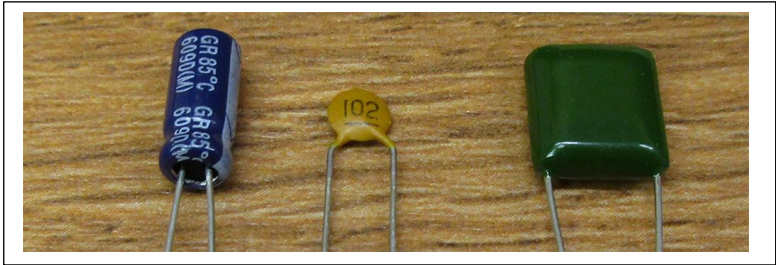
Here is a table of some common dielectrics and their constants (all measured relative to a vacuum with constant 1.0000):

Material	Relative permittivity (dielectric constant)
Vacuum -----	1.0000
Air -----	1.0006
Gasoline -----	1.94
Mylar -----	2.0
PTFE, FEP ("Teflon") -----	2.0
Polypropylene -----	2.20 to 2.28
ABS resin -----	2.4 to 3.2
Polystyrene -----	2.45 to 4.0
Waxed paper -----	2.5
Transformer oil -----	2.5 to 4
Hard Rubber -----	2.5 to 4.80
Wood (Oak) -----	3.3
Silicones -----	3.4 to 4.3
Bakelite -----	3.5 to 6.0
Quartz, fused -----	3.8
Wood (Maple) -----	4.4
Glass -----	4.9 to 7.5
Castor oil -----	5.0
Wood (Birch) -----	5.2
Mica -----	5.0 to 8.7
Porcelain -----	6.5
Alumina -----	8.0 to 10.0
Distilled water -----	80.0
Barium titanite ("ceramic") -----	7500

One trick that is widely used is to use aluminum foil for one plate of the capacitor and a liquid conducting electrolyte to form aluminum oxide on the plate. This hyper-thin layer of oxide acts as the dielectric in an ELECTROLYTIC capacitor. **Electrolytic capacitors are generally the most capacitance in the smallest size possible.**

Here is a picture of a few different kinds of capacitors:

Electrolytic, ceramic, and plastic (left to right)



So how do I calculate the value of a capacitor if I know all these values? Quite simply

$$C = (0.224 * \epsilon * (n-1) * A) / d$$

Where C is the value of the capacitor in picofarads, ϵ is the dielectric constant, n is the number of plates, A is the area of one plate in square inches, and d is the distance between the plates in inches.

For example, if I have two sheets of tinfoil a foot square separated by a mylar ("saran wrap") sheet 0.0005" thick, I will have

$$C = (0.224 * 2 * 1 * 144) / 0.0005 = 128,824 pf \text{ (or about 129nf)}$$

What are your odds of doing this right, the first time, using a hand calculator? Did I hear "nearly zero"? Exactly correct. What do we do when we have a nasty equation that give us fits? Did I hear "spreadsheet"? Correct again. Go to your engineering spreadsheet file and find the Excel spreadsheet makeL&C.xls, input the values for capacitor, and see if the sheet doesn't come out like this (don't worry about "frequency" or Xc yet):

Making Inductors and Capacitors		
Jim Weir		
02-Jan-01		
frequency	120.0E+6	Hertz
Number of plates	2	
Area of one plate	144	Square inches
Dielectric constant	2	k
Distance between plates	500.0E-6	inches
Capacitance	129.0E-9	farads
Xc	10.3E-3	ohms

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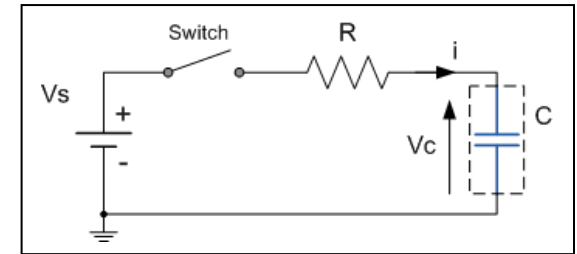
Well, now I know how to make capacitors and what their values will be, but so what? What is the use of a capacitor in an electronic circuit?

Quite simply, a capacitor attempts to keep the **VOLTAGE IN A CIRCUIT CONSTANT**. If the supply voltage goes UP, it accepts more electrons to try and keep that voltage down, and if the voltage goes DOWN it supplies electrons to keep the voltage up.

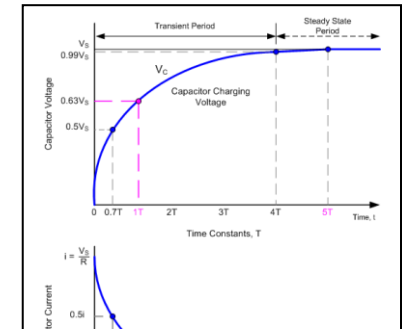
Thus, if a voltage is noisy, by means of a capacitor we can strip that noise from the voltage, making a nice quiet circuit.

Another use of capacitors in a circuit is to set some sort of TIMING. Circuits that oscillate (generate some sort of signal or frequency waveform) almost all use a capacitor as their timing mechanism in some manner. How does this come about? Because of the famous "RC time constant".

Here we see a battery (V_s) connected to a switch and then to a resistor and capacitor in series. The question becomes, what happens at the moment the switch is thrown to connect the battery to the resistor?



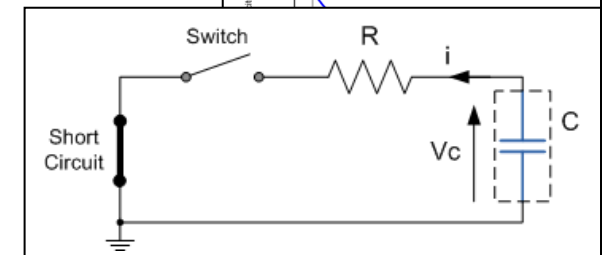
The answer is that the capacitor will start to charge and will get to 63% of the battery voltage in one "time constant". What is a time constant? It is simply the product of R and C ($\tau = R \cdot C$). It will get to 85% of the battery voltage in two time constants. It will, for all practical purposes, become equal to the battery voltage in five time constants.



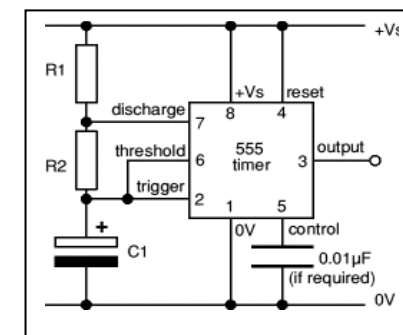
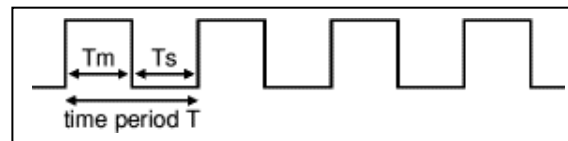
If you would like to see a practical example of how to use capacitors, go to www.rstengineering.com/kitplanes/ and look at the June, July, and August 2000 issues for details on how to build a fuel gauge using capacitors.

How does that work going the other way? That is, if the capacitor is fully charged, and if I replace the battery with a short circuit, what will the voltage across the capacitor look like after the switch is thrown?

Pretty much the inverse of the charging equations. Now the capacitor will come to 37% of the battery voltage within one time constant, 15% of the battery voltage in two time constants, and for all intents and purposes be at zero volts within 5 time constants.



Now if we replace the "switch" with something that does the "switching" automatically (the classic is a case in point) we have a capacitor that sets the frequency of oscillation.

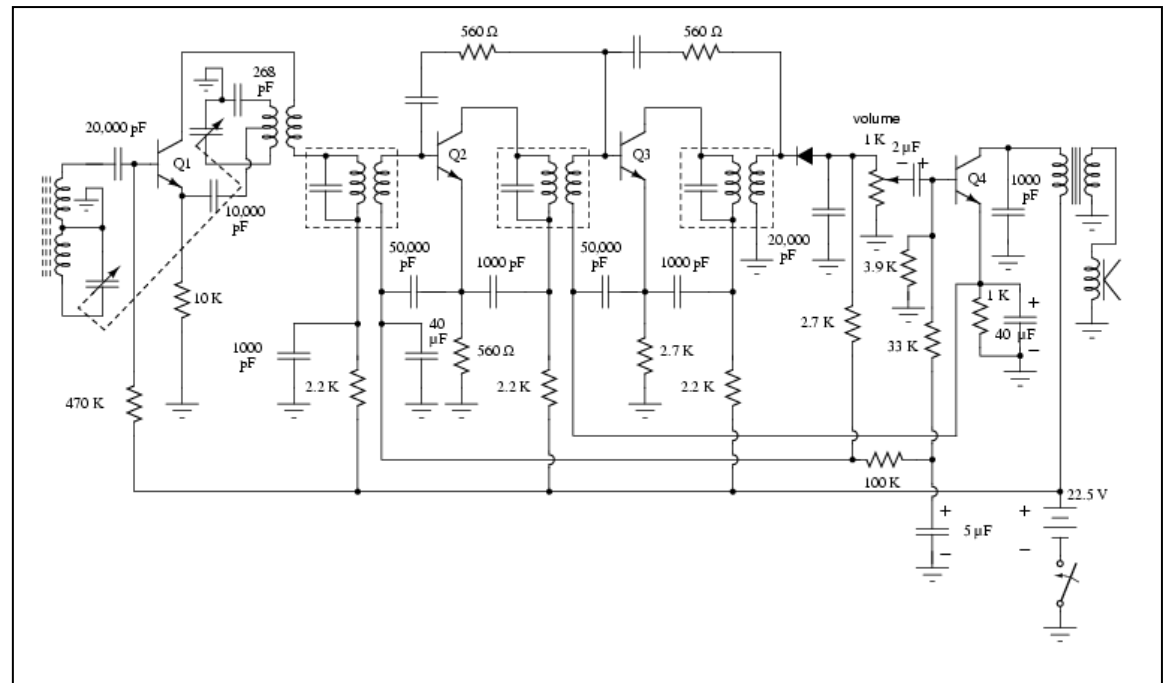
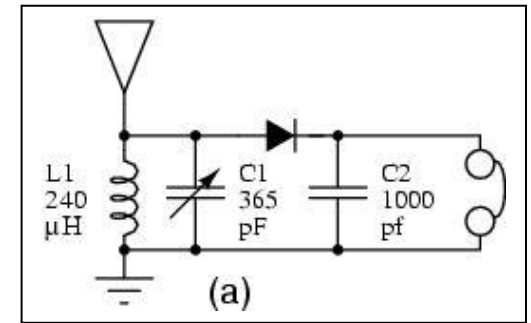


"555" timer

Finally, we can use our capacitor to tune a radio to a particular station. If we make the plates of the capacitor so that one stays in position while the other one is rotated in or out of the fixed plates, we can vary the capacitance and (as we will see in a bit) vary the RESONANT frequency of the coil (L1) and capacitor (C1). Note that C1 has an ARROW going through it. This denotes a VARIABLE capacitor.



The world's first "transistor radio" was made by Regency and called the TR-1. It cost \$50 in 1954 dollars, or about \$450 in today's money.



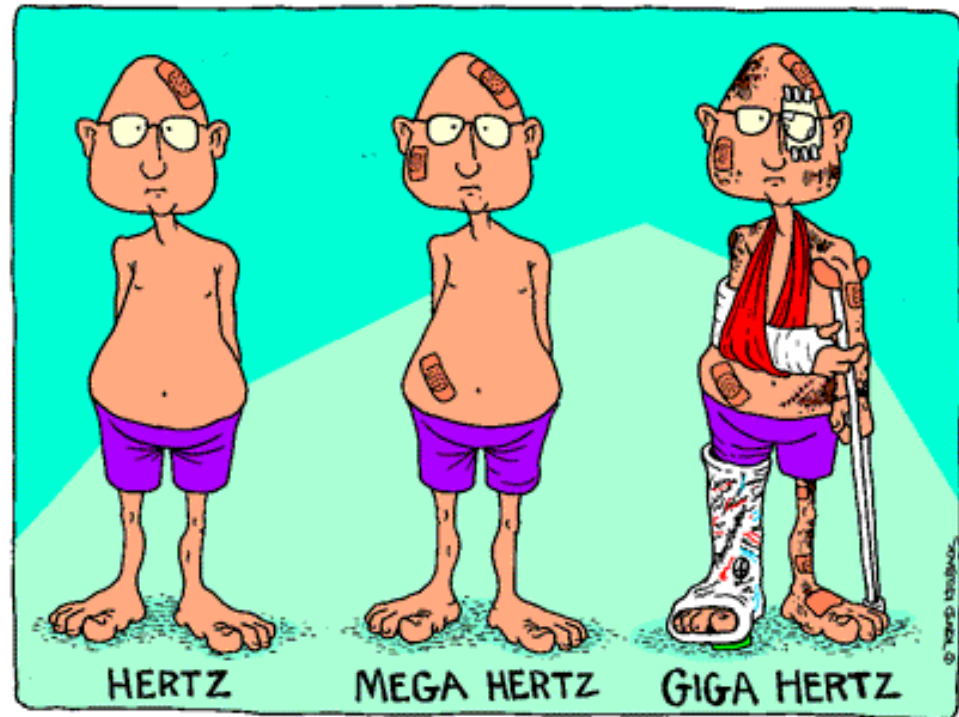
Rather than beat this horse to death, you may wish to visit this site for some interesting insights into capacitors:

<http://micro.magnet.fsu.edu/electromag/electricity/capacitance.html/>

While we are at it, since capacitors can store voltages and in some cases store lethal quantities of voltage and current, here are some simple rules to remember when the voltage starts getting quite high (say, above 30 volts or so):

The Commonsense Rules (for voltages above 30 volts).

- a. Work thee with a partner that he may pluck thy mangled body from the innards of the equipment.
- b. Causeth thee to tag the switch that supplieth large doses of juice so that thy days in this vale of tears be long.
- c. Carrieth thee not ironmongery near the wires of death, lest thy body continuously glow and thy spouse thus have no use for thee save thy wages.
- d. Stoweth one hand within thy breeches when probing a contraption with much voltage.
- e. Enjoy thy water recreation and thy voltage sources, but lead them not into proximity.
- f. Trust thy belief in the Angel of Death by assuming that she lurketh within all equipment until proven otherwise.
- g. Disdaineth gum wrappers and pennies when making emergency fuses.
- h. The fuse doth not contain within itself the Magic Genie. It bloweth for a reason, which thou shalt ascertain before wasting copious quantities of replacement fuses.
- i. Believe that the Spirit of Whappo lives within the charged capacitor even though thee hath pulled the plug. Use thy grounding rod and thy shorting wire judiciously.
- j. Removeth thy baubles and bangles lest the spirit of Ampere be allowed to roam free within thy body.



Inductors are nothing more than coils of wire and the **INDUCTANCE** of the coil is measured in **HENRIES** (after Joseph Henry, the electromagnet guru). While I could go into a long song and dance about inductors, this site:

<http://micro.magnet.fsu.edu/electromag/electricity/inductance.html/>

says it far better than I ever could.

Note that the spreadsheet also contains a section on "inductance" whereby you can calculate the value of inductance for your little coil if you don't want to use the formula:

$$L = (a^2 * n^2 * \mu) / (9a + 10b)$$

Where L is the inductance (in microhenries), a is the coil radius (in inches), b is the coil length (in inches), n is the number of turns, and μ is the permeability of the material inside the coil.

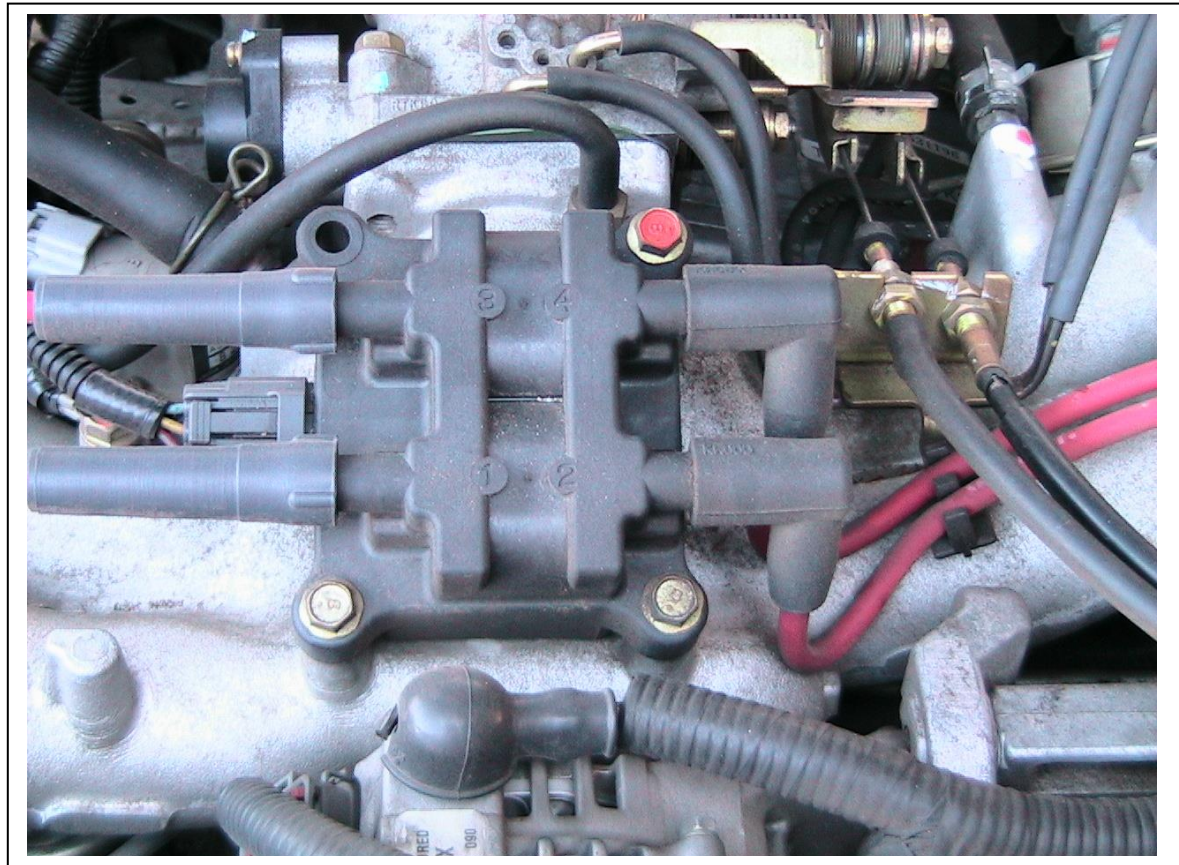
Permeability is the property of a material (usually iron or ferrite) that concentrates the force lines within the coil to increase the inductance. Permeabilities can range from 1 (air or vacuum) to upwards of 1,000,000 for some nickel-iron mixtures such as mumetal (77% nickel, 5% copper, 2% chromium, and 16% iron).

Diameter of coil	250.0E-3 inches
Length of coil	350.0E-3 inches
Number of turns	9 n
Permeability	1 u
Inductance	273.6E-9 henries
XI	206.3E+0

An inductor stores energy in a **MAGNETIC FIELD** and has the property of trying to keep **CURRENT CONSTANT** in a circuit. It does this by varying the voltage across the inductor in an attempt to keep the current constant. There are several uses for this sort of behavior; one of the most common is shown here:

This is a common **SPARK COIL** on an internal combustion automobile engine. When it comes time for a spark plug to ignite the gasoline vapor inside the cylinder, a current is supplied to the coil and then the circuit is abruptly broken with a switch controlled by the engine. The coil attempts to keep the current constant by the use of the magnetic field to generate a huge voltage at the end of the coil, which is then allowed to jump across a small gap in the plug, igniting the gasoline vapor.

The inductor has a TIME CONSTANT similar to a capacitor. While the magnetic field takes a fairly short time to build up, it is not instantaneous, but builds up (and is discharged) as a function of the circuit resistance and the inductance of the coil.



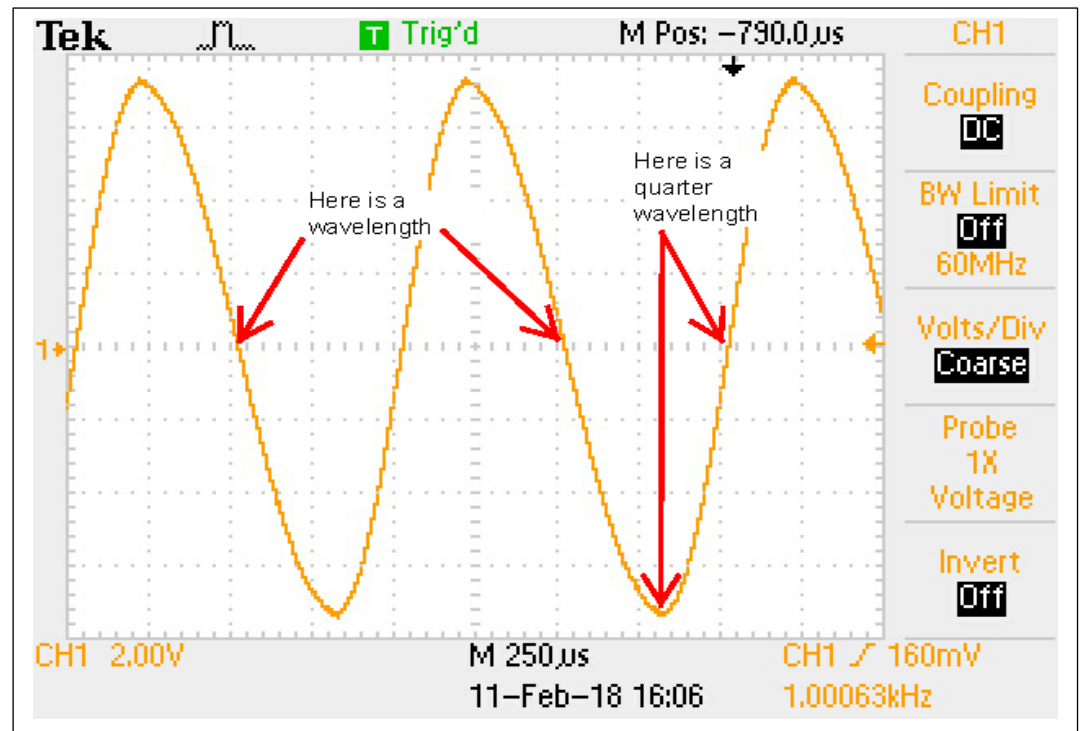
ANTENNAS is a subject that books ... nay entire SERIES of books have been written about. We will investigate some rather simple antennas in our lab today. The one thing that you want to remember about antennas is that almost all of them are built on the QUARTER-WAVELENGTH principle.



Son of student in 2008 built an aviation band antenna over the Winter break. Flying copilot for the airlines today.

What's a quarter-wavelength? For that matter, what's a WAVE???

As we saw from our study of capacitors, a WAVE is a repetitive signal that goes through a zero, a maximum, a zero, a minimum, and back to a zero on a regular basis. Here is a wave and a quarter-wave:



If we go back and think about it, we can see that if the wave travels at the speed of light (186,000 miles per hour or 3×10^8 meters per second, both of them are equivalent) then if a wave has a frequency of so many cycles per second, then it will travel some distance in that time. In particular, it will travel a distance equal to $\frac{\text{speed of light in distance per second}}{\text{frequency of the wave in cycles per second}}$.

If light travels 186,000 miles per second, then it travels $(186,000 * 5280 \text{ feet per second} * 12 \text{ inches per foot})$ or 11.8×10^9 inches per second. If you want to do metric, then if it does $3 * 10^8$ meters per second then it does $3 \text{ E}8 * 39.37$ or 11.8×10^9 inches per second. Same number, any way you want to look at it.

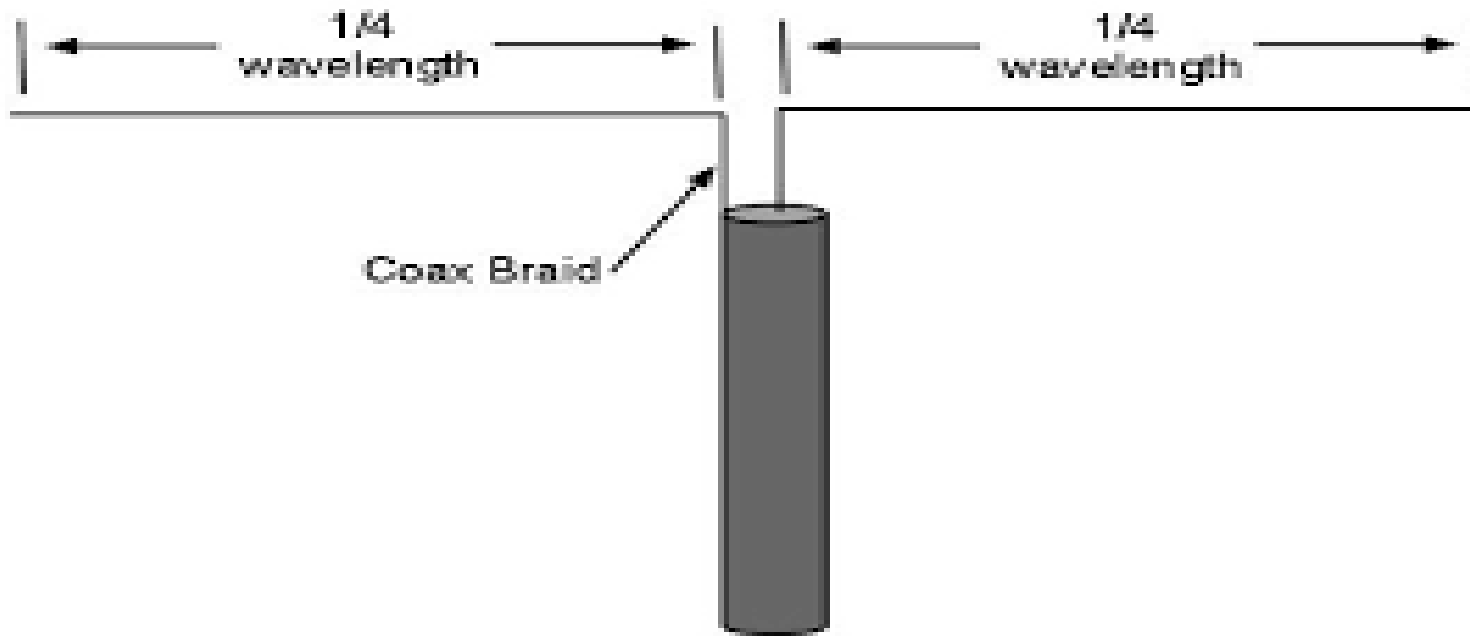
So, since we are committed in this class to inches, then we can say that we will work with 11.8×10^9 inches per second as the speed of light.

Now just for a practical example, we want to cut a QUARTER WAVE for the middle of the FM radio broadcast band at 98 MHz. That's 98×10^6 cycles per second (98 Megahertz). Dividing the speed of light by the frequency, we come up with a WAVELENGTH of 120 inches.

But antennas are made on QUARTER wave lengths, so our antenna is going to be 30 inches long.

But wait a minute. That's a quarter of a wave for each ELEMENT, and in general, there are TWO elements to a di (greek word for two) pole, or dipole antenna. So now we know our FM antenna is going to be 60 inches (5 feet) long. Which is just about correct.

- A simple dipole antenna is TWO quarter waves (or a half-wave) elements end to end and fed in the middle with coaxial cable. Thus, a true dipole antenna measures half a wavelength from tip to tip. When you adjusted the length of the "rabbit ears" on your TV set (back in the days when we had analog TV) what you were really doing is trying to make the antenna into a half-wave dipole with each of the ears being a quarter wave long and fed in the middle with TV antenna wire.

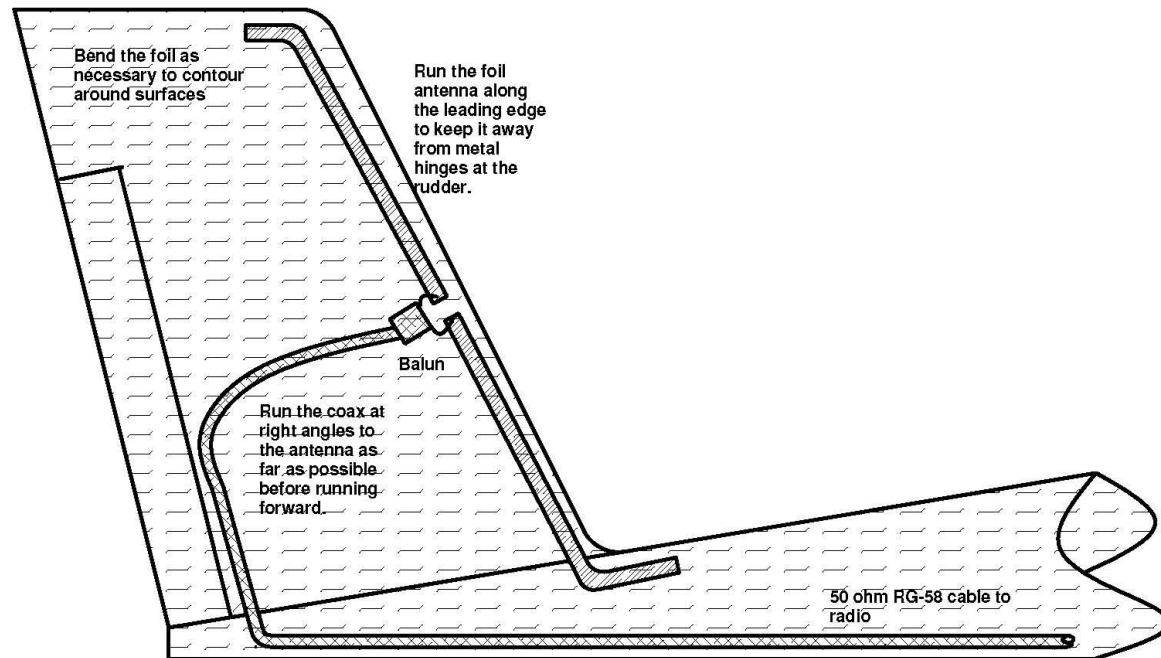


Now let's start talking real world. In 1984, a young test pilot came to me and asked if I could put half a dozen antennas on an airplane that had the wingspan of a 737. I allowed as to how I could, and the question was how light could I make them, because this airplane was going around the world on a single tank of gas.

The airplane is Voyager



And the antennas went inside of the fiberglass structure



Ferrite-Foil Antenna In Vertical Fin		
Scale: NTS	Approved by: <i>Jim Weir</i>	Drawn by: OWJ
Date: 4 Jun 96		Rev: A
RST Engineering 13249 Grass Valley Ave Grass Valley CA 95945 916/272-2203 (voice & fax) rst-engr@oro.net		Drawing # 802-8907

Route of Voyager

