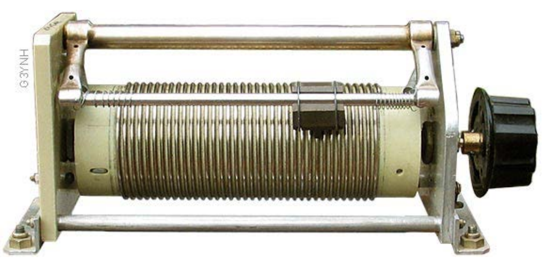
LARC BASIC AMATEUR RADIO COURSE - 2019

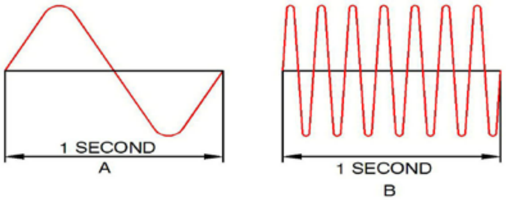
CAPACITANCE and INDUCTANCE (Chapter 4)

Mike Cook© VE3ZMC



Capacitance and Inductance are very important properties affecting AC currents.

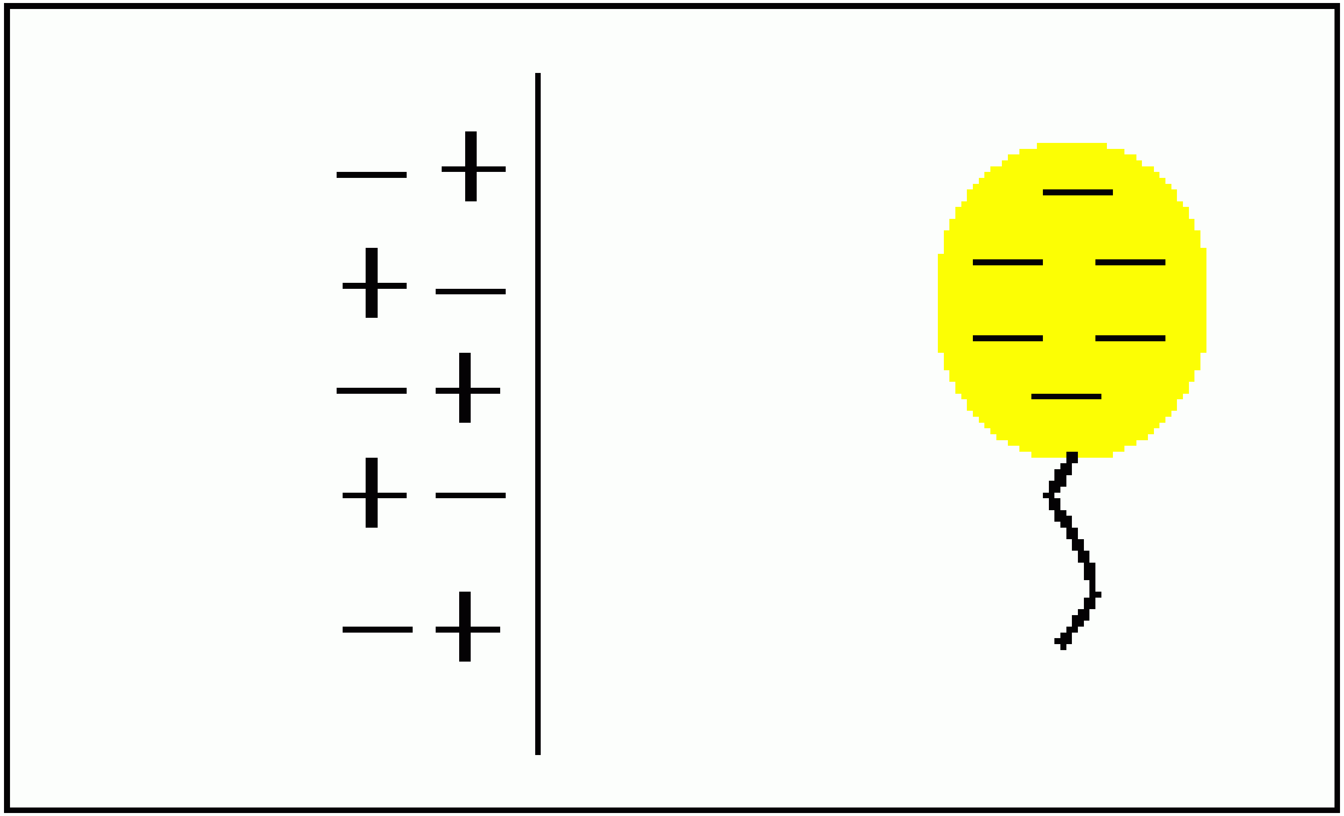
They are both frequency-dependent properties.

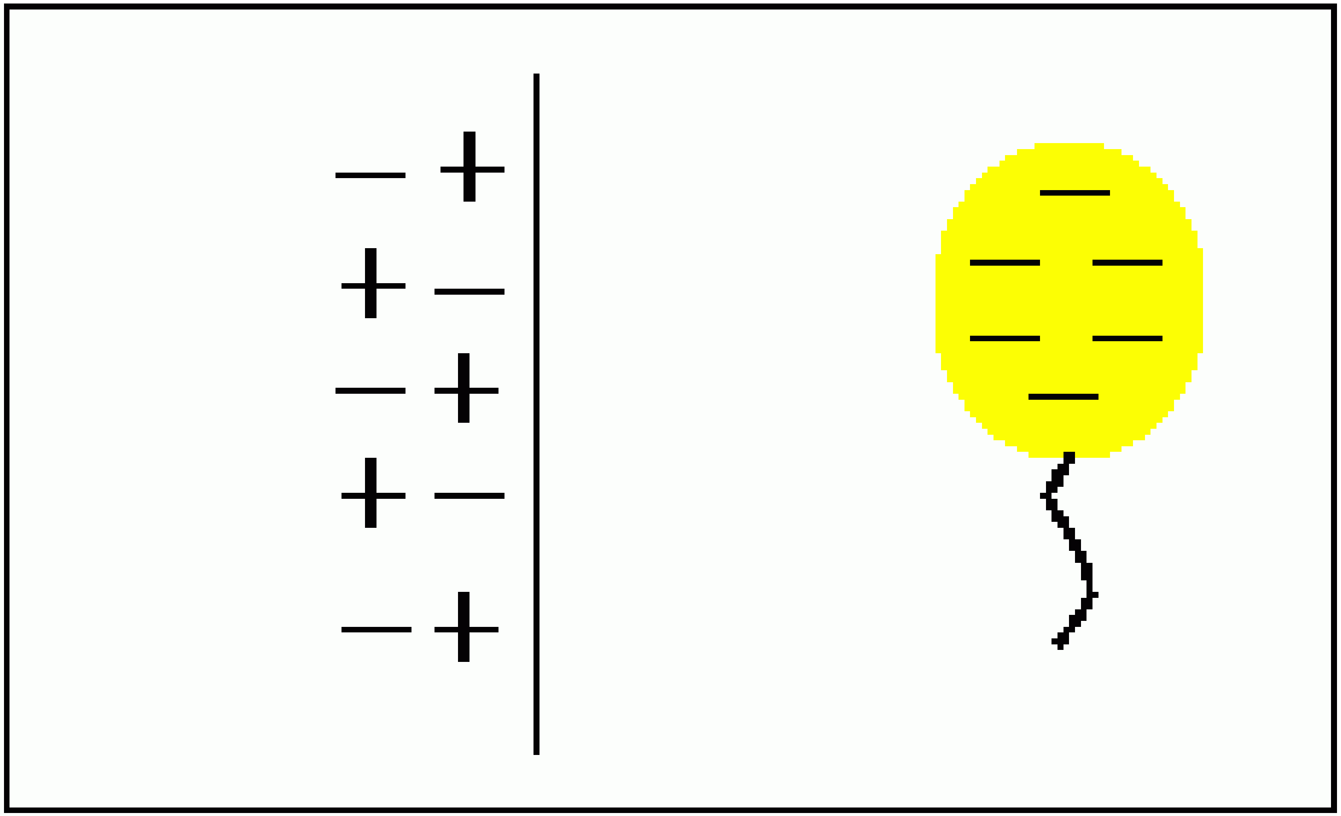


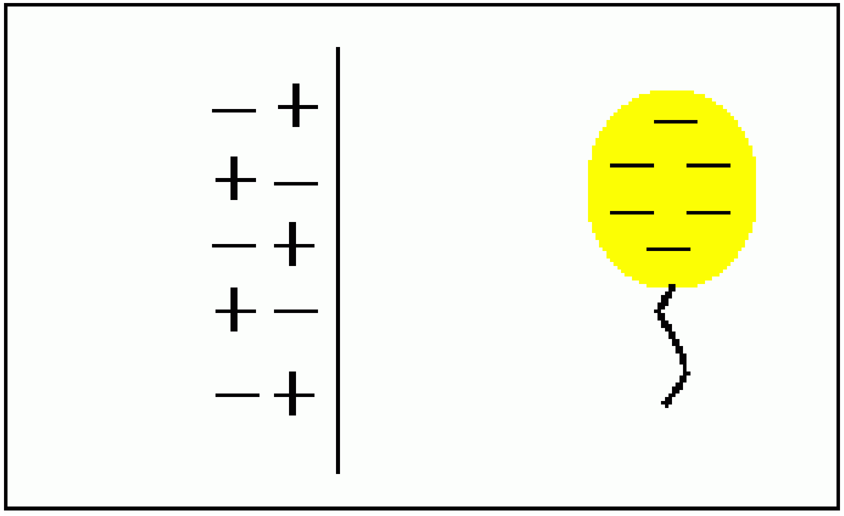
We will also look at the phenomenon of resonance which is very important for radio and involves both capacitance and inductance.

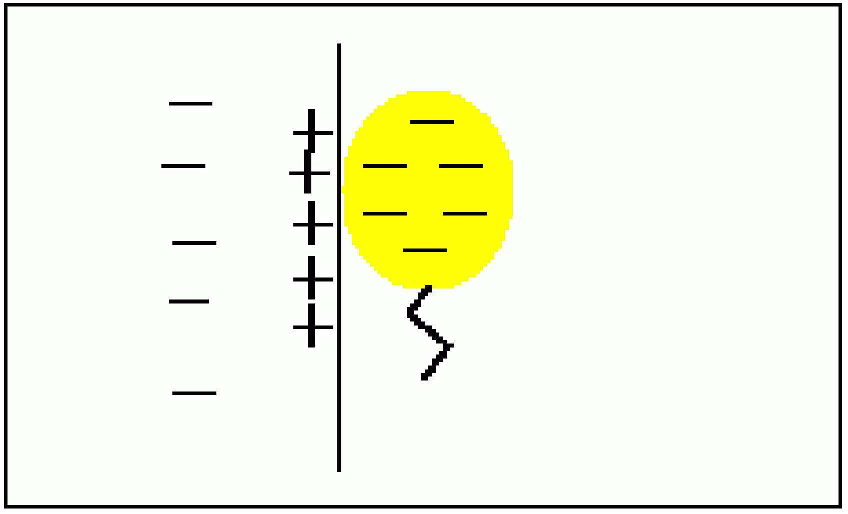
There are two kinds of induction, electrostatic and electromagnetic.

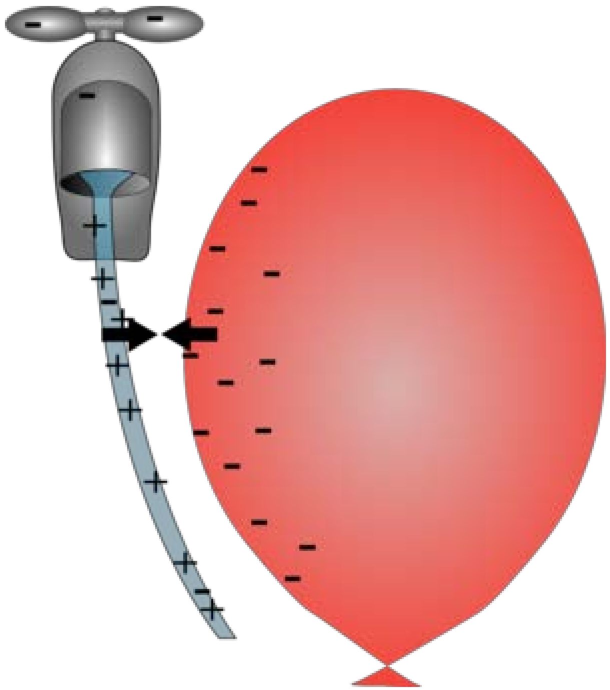
Electrostatic induction is involved in the way capacitors work so we will start with capacitance.

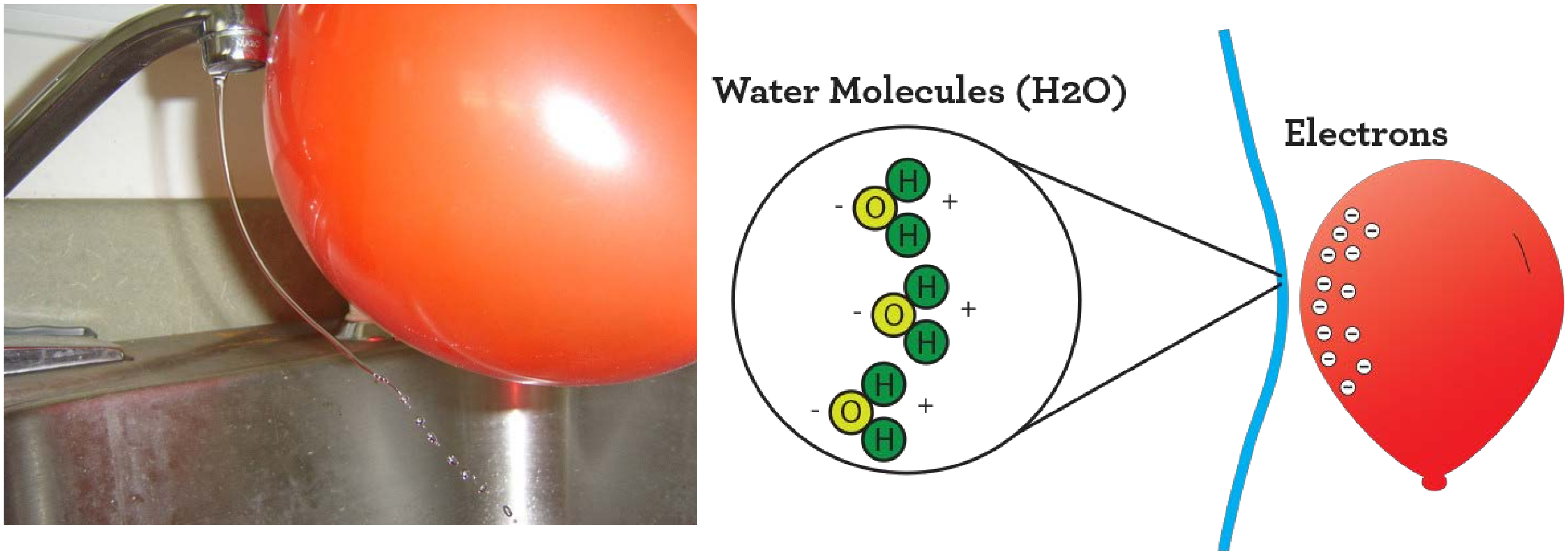







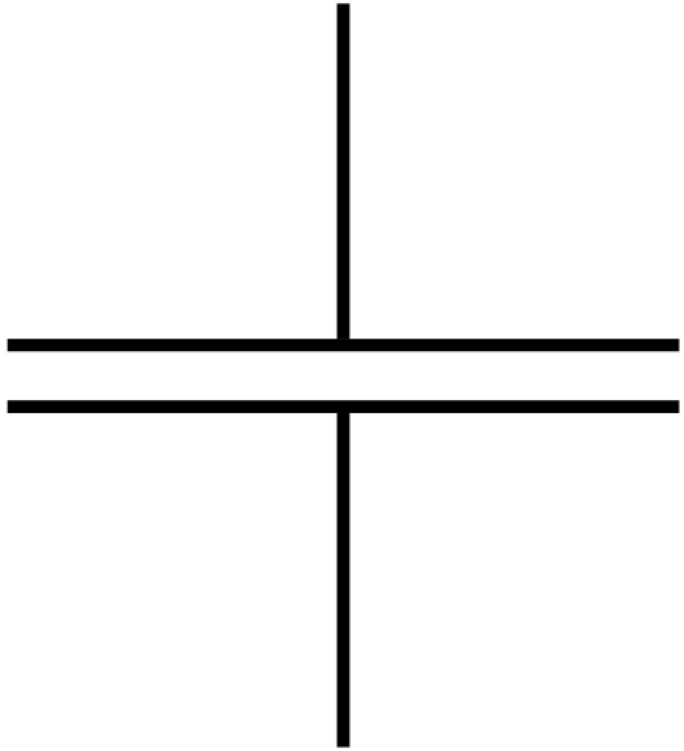


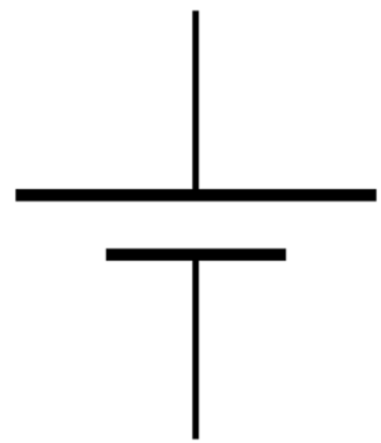




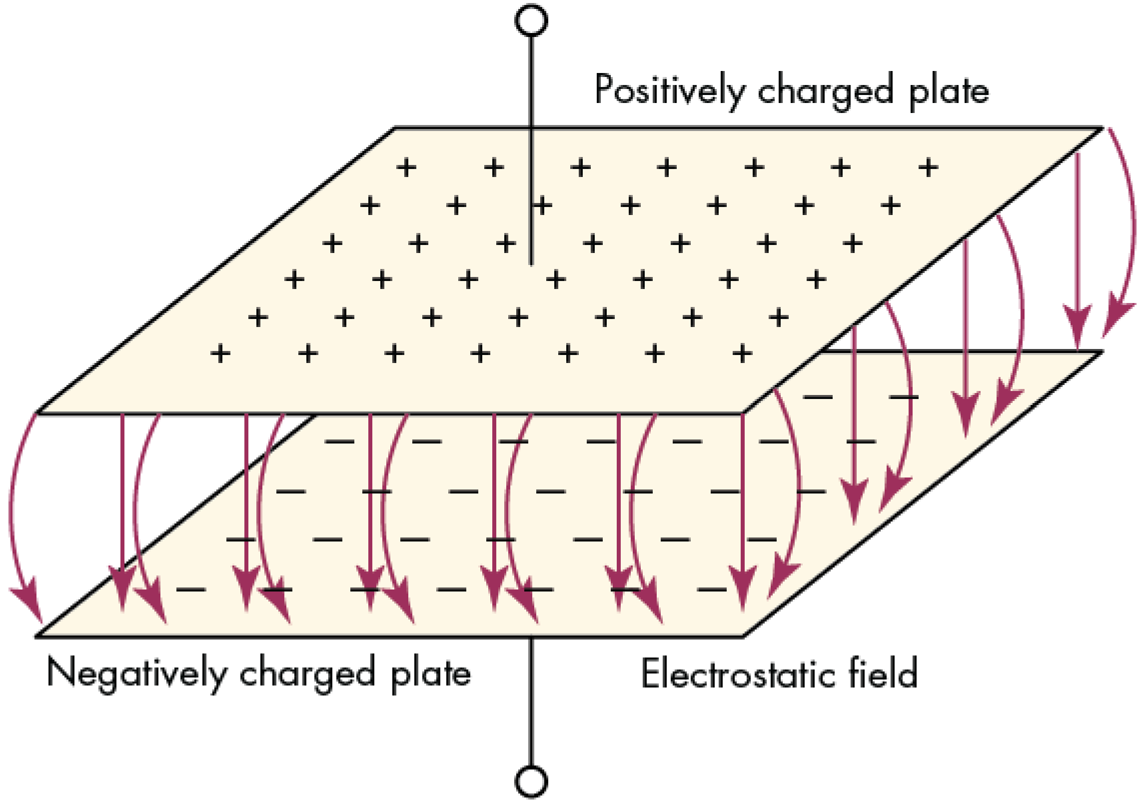
Electrostatic induction

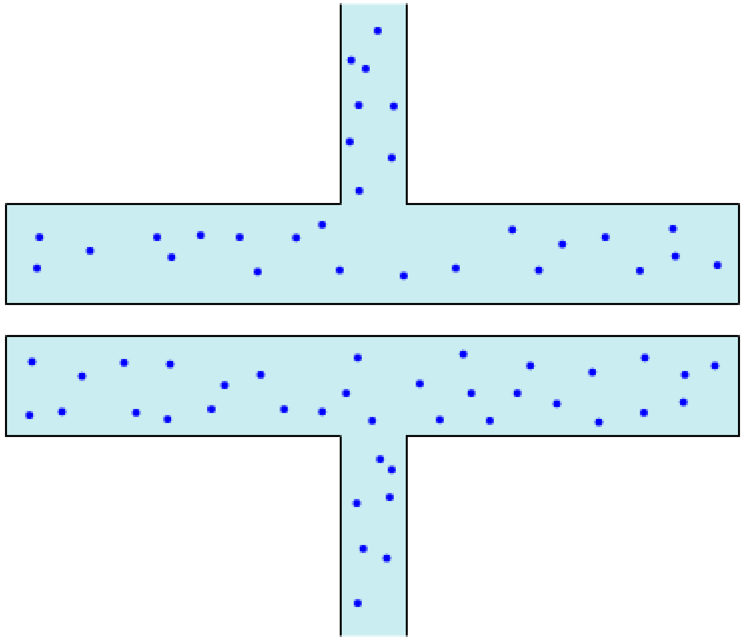
Capacitance



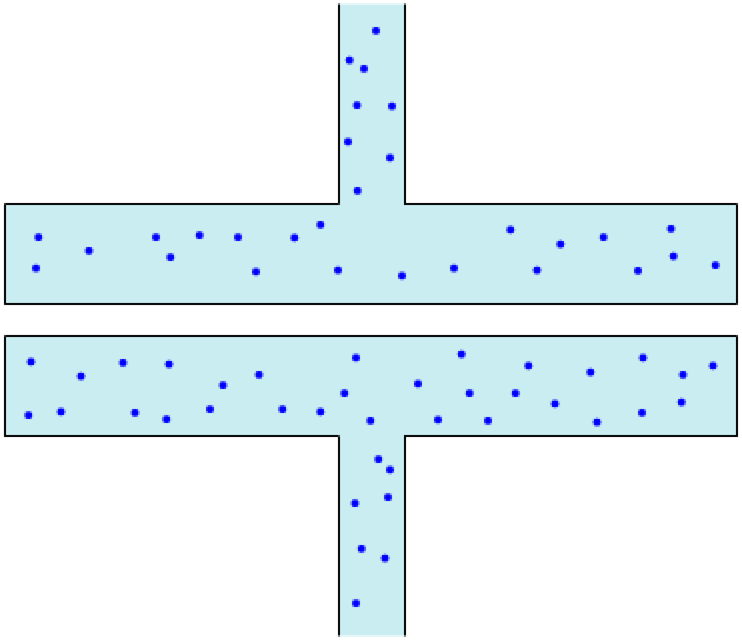


The symbol for capacitance is C and the units are Farads (F)

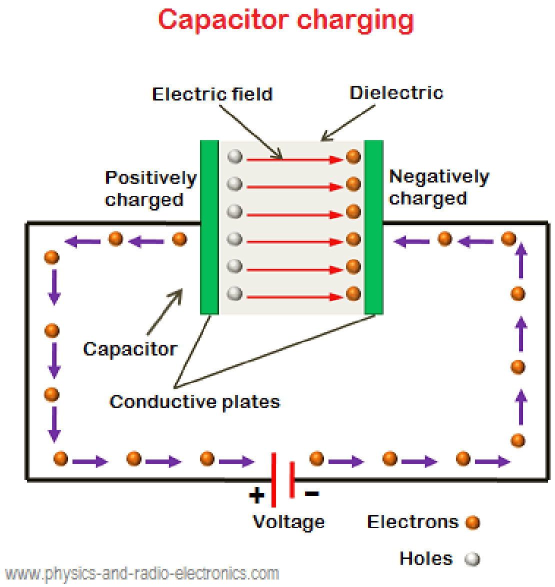

Positively charged plate
Negatively charged plate
Electrostatic field

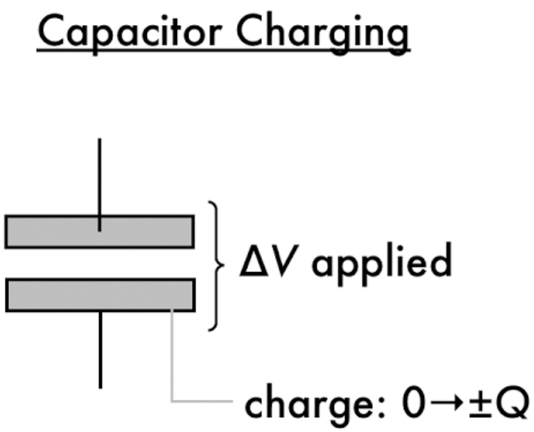


Charge



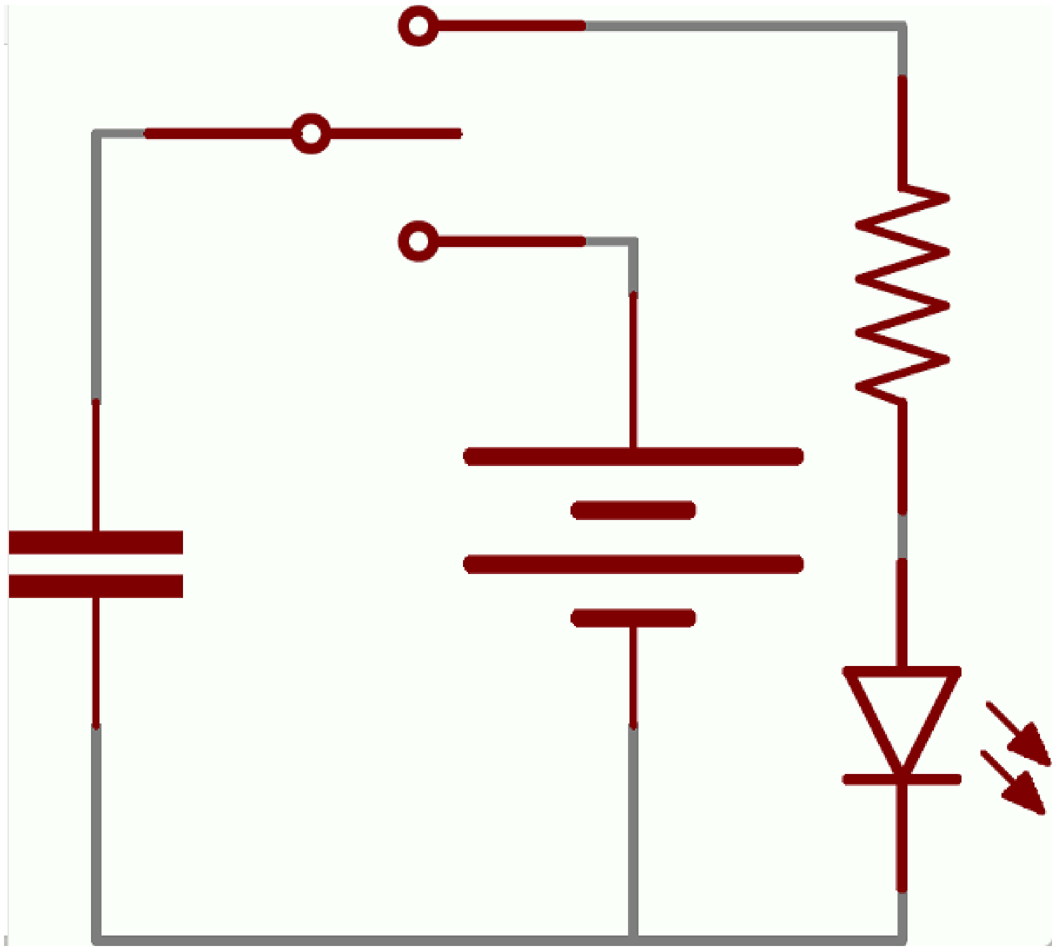
Charge

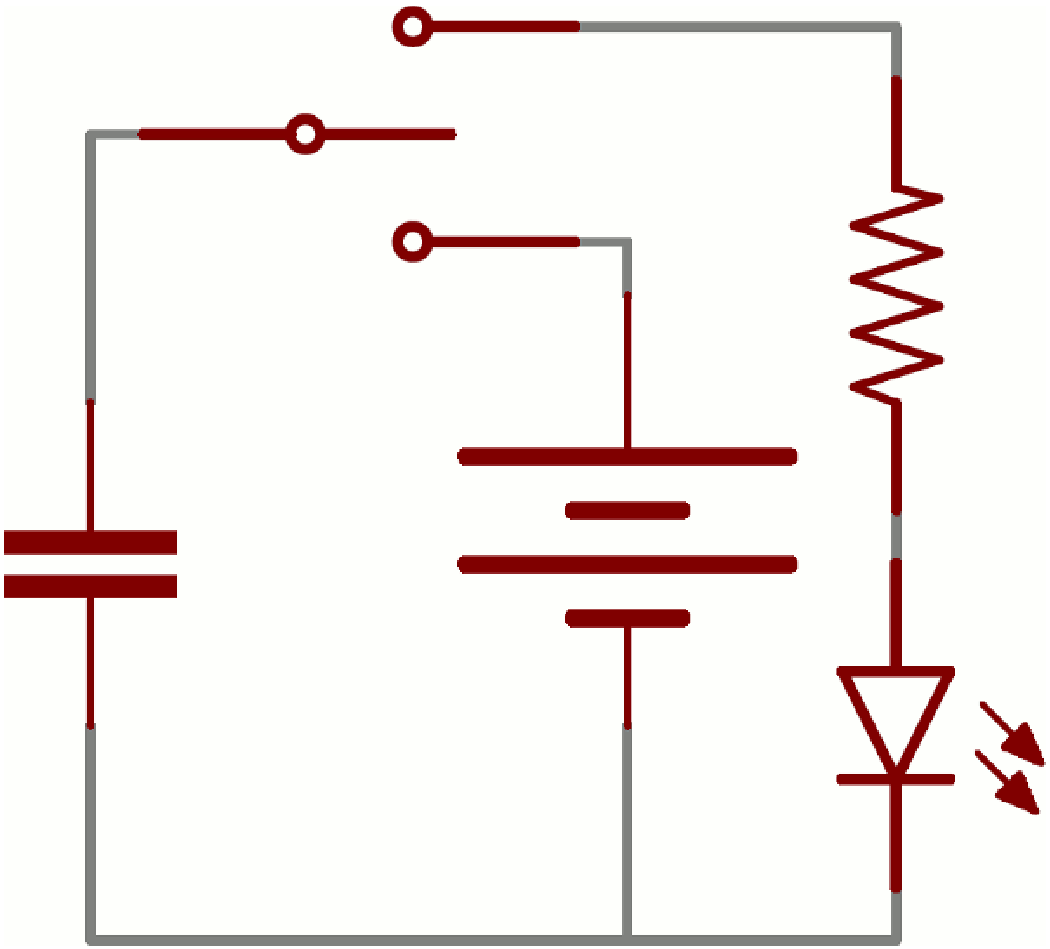


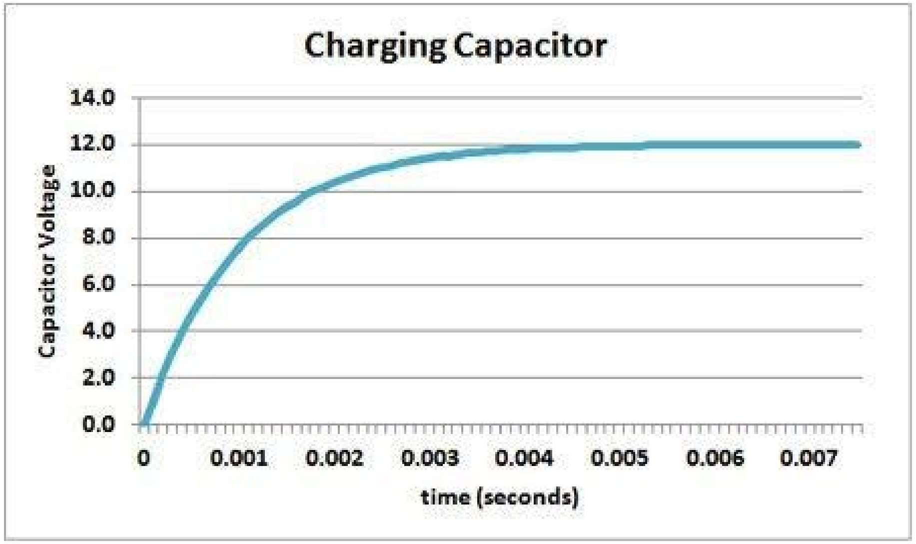


Using DC, the current only flows until the charge on the plate saturates

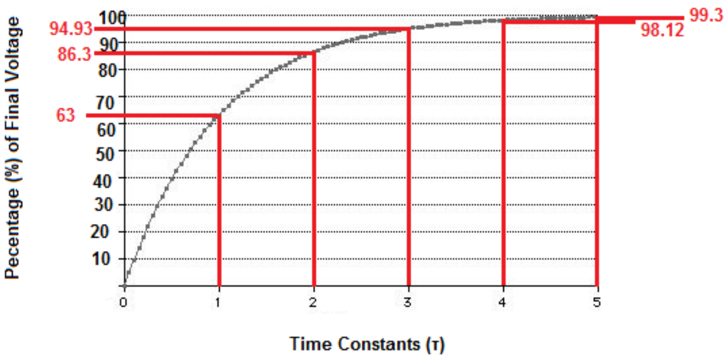
Removing the battery and connecting a load allows current to flow and discharge the capacitor

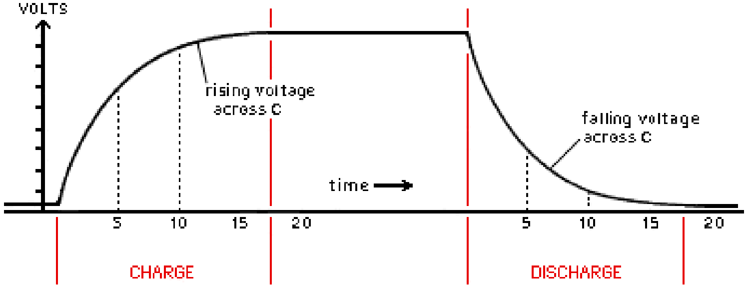


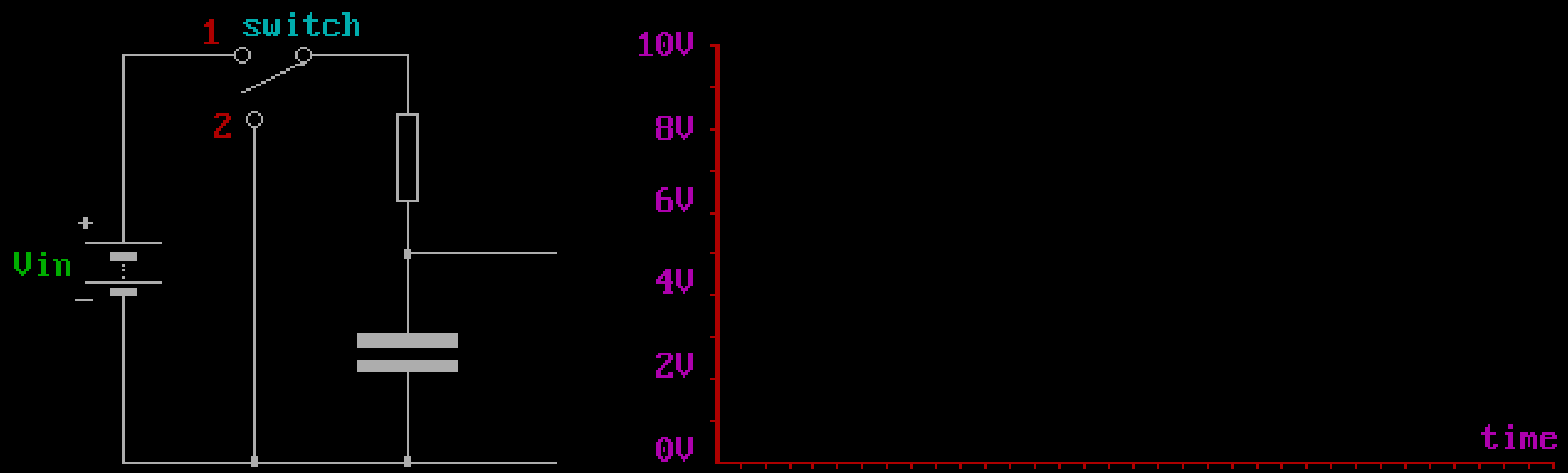




Time Constant (τ) = R x C



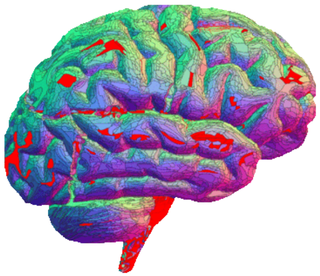


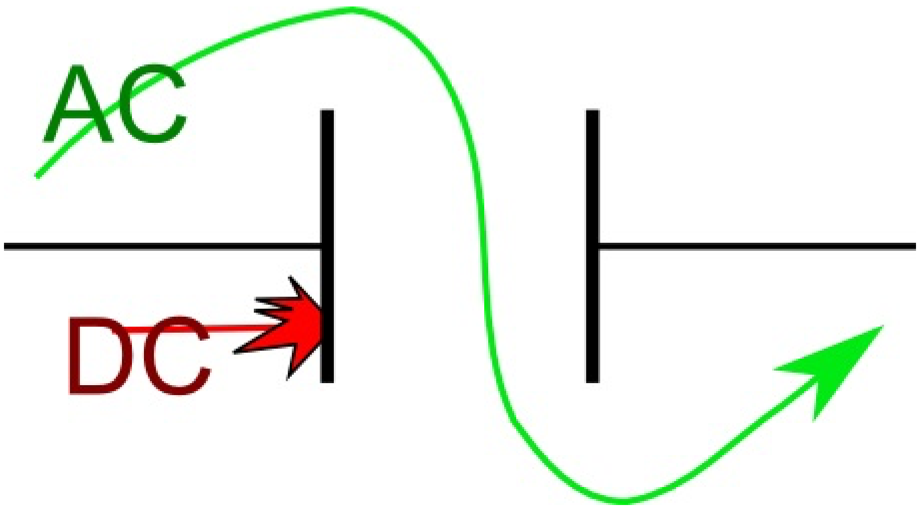

1
switch
2
+
Vin
−
10V
8V
6V
4V
2V
0V
time

A very brief flow of current occurs and then it stops.

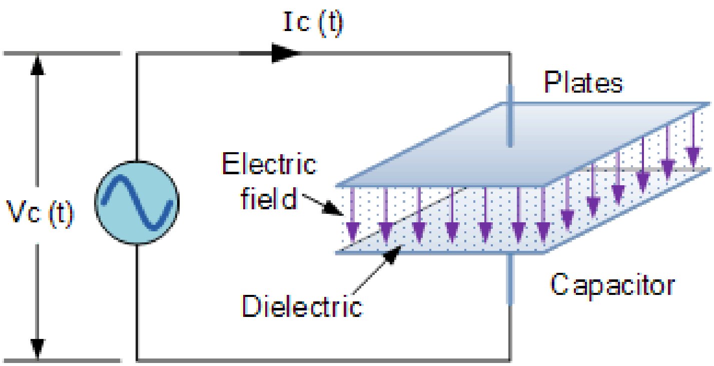
The charge is stored. *So capacitors block DC current*

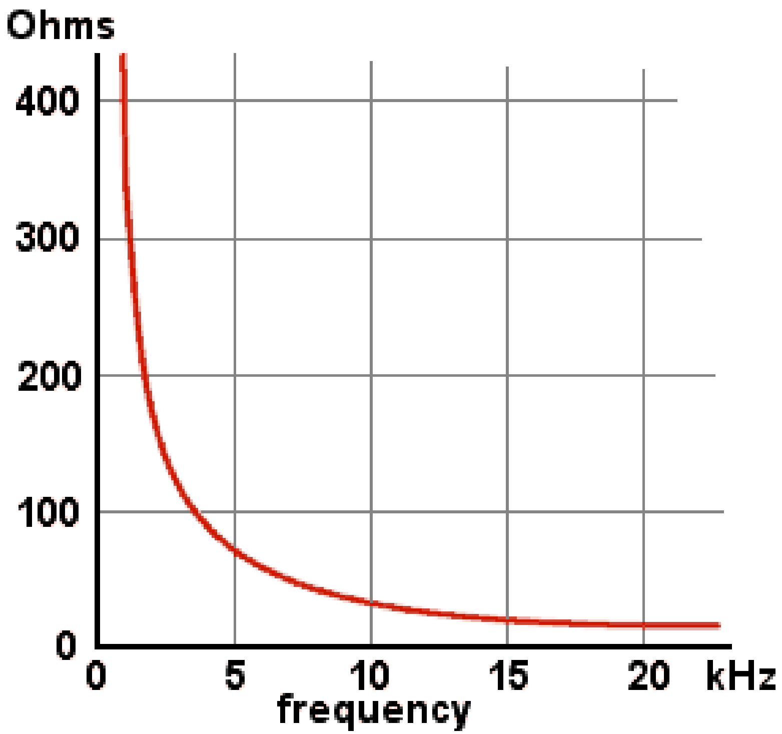
But what happens if AC current is used?



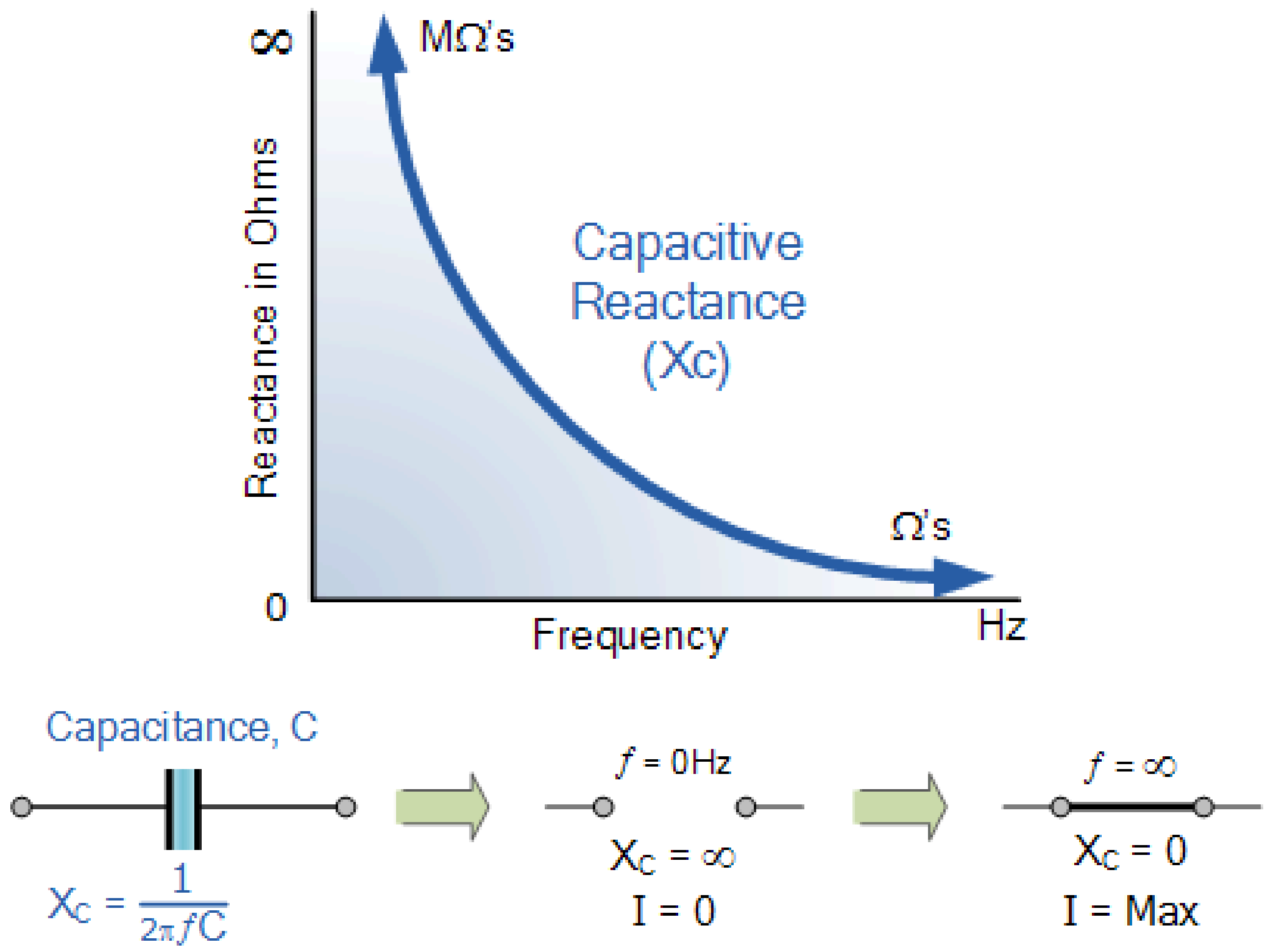


AC can pass depending on frequency (*f*) (or wavelength (λ))



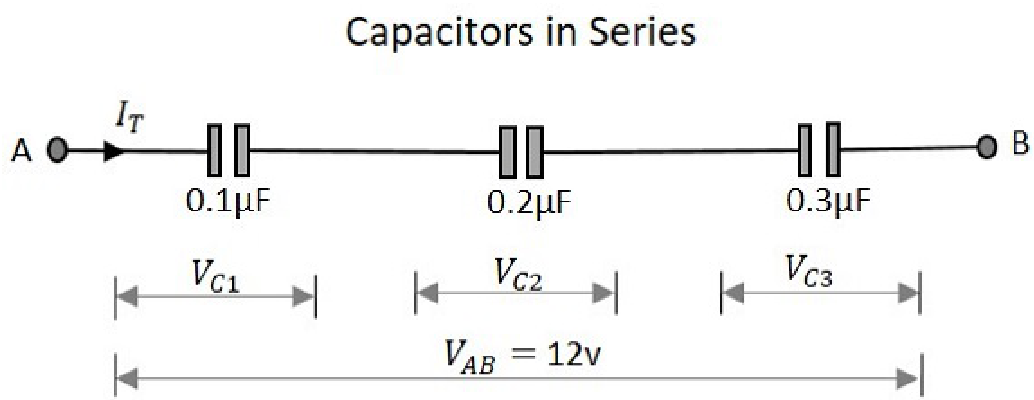


For "resistance" to AC current we use the term "reactance" symbol X and units Ω



∞
MΩ's
Reactance in Ohms
Capacitive
Reactance
(Xc)
Ω's
0
Frequency
Hz
Capacitance, C
$X_C = \frac{1}{2\pi f C}$
f = 0Hz
$X_C = \infty$
I = 0
$f = \infty$
$X_C = 0$
I = Max

Series and Parallel calculations

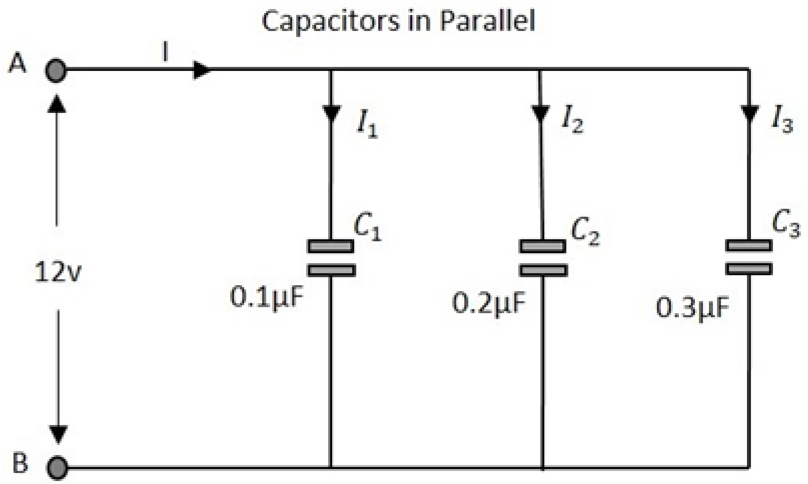


$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

$$V_T = V_{C1} + V_{C2} + V_{C3}$$

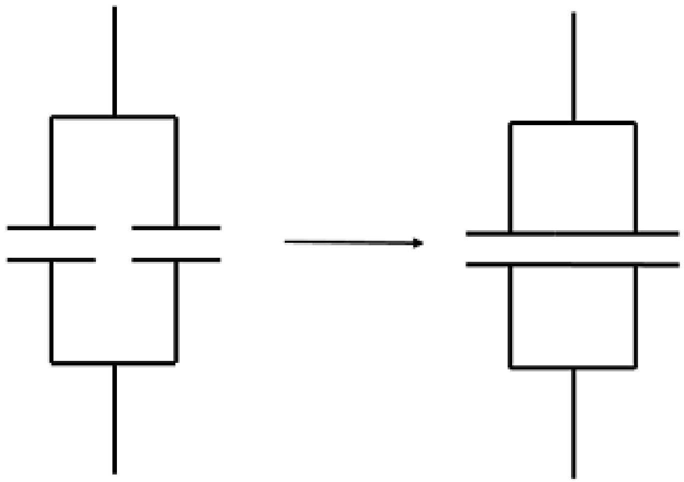
$$I = I_1 = I_2 = I_3$$



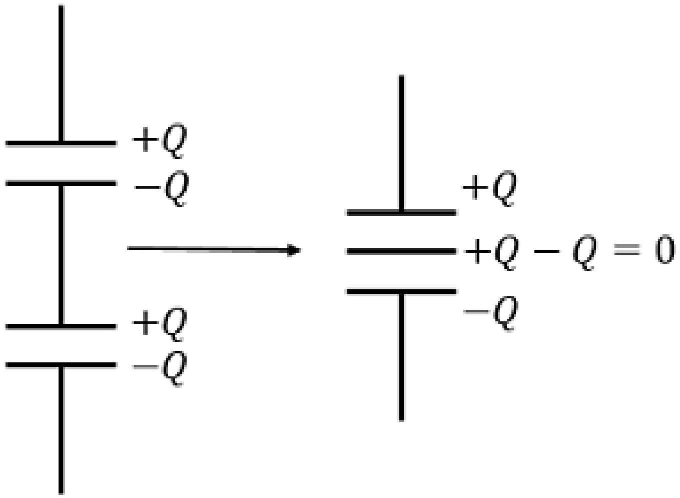
$$C_T = C_1 + C_2 + C_3$$

$$V_T = V_1 = V_2 = V_3$$

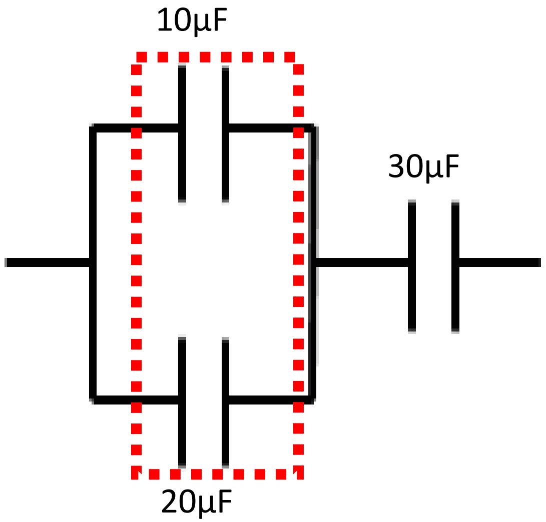
$$I_T = I_1 + I_2 + I_3$$



$C_{total} = C_1 + C_2$



$1/C_{total} = 1/C_1 + 1/C_2$



Parallel first:

$C_1 = 10\mu F + 20\mu F = 30\mu F$

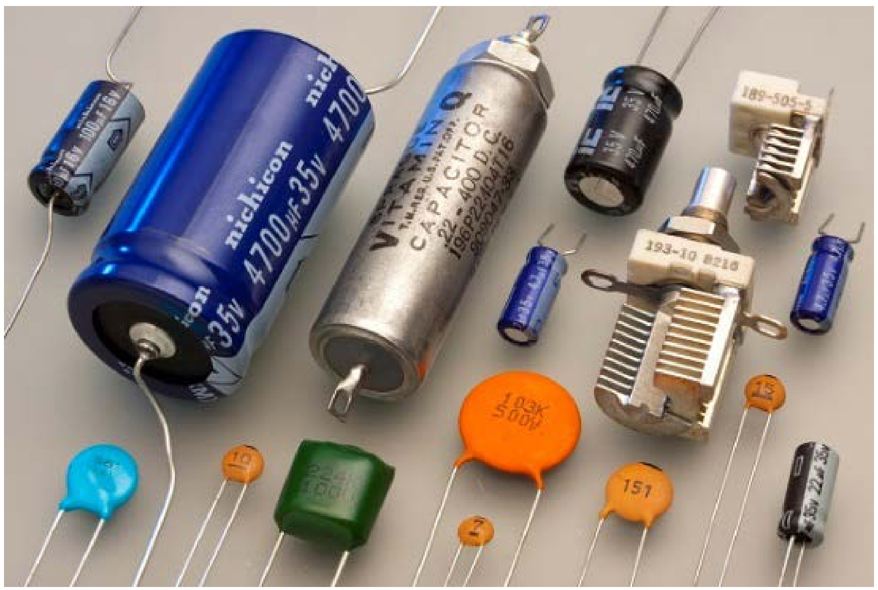
Then series:

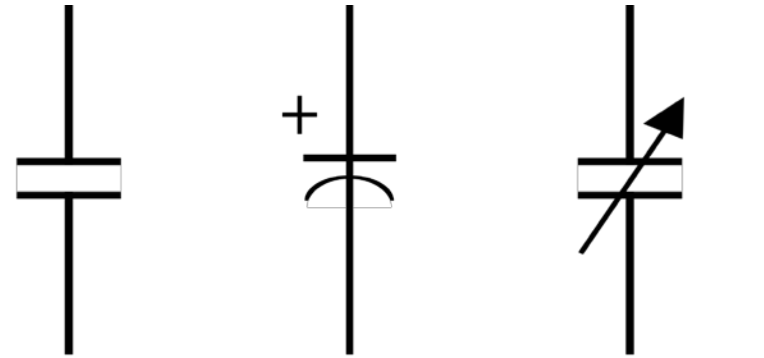
$1/C_{total} = 1/C_1 + 1/C_2 = 1/30\mu F + 1/30\mu F = 2/30\mu F$

$C_{total} = 30\mu F/2 = 15\mu F$

Or 30x30/30+30 = 900/60 = 15

There are many types of capacitors



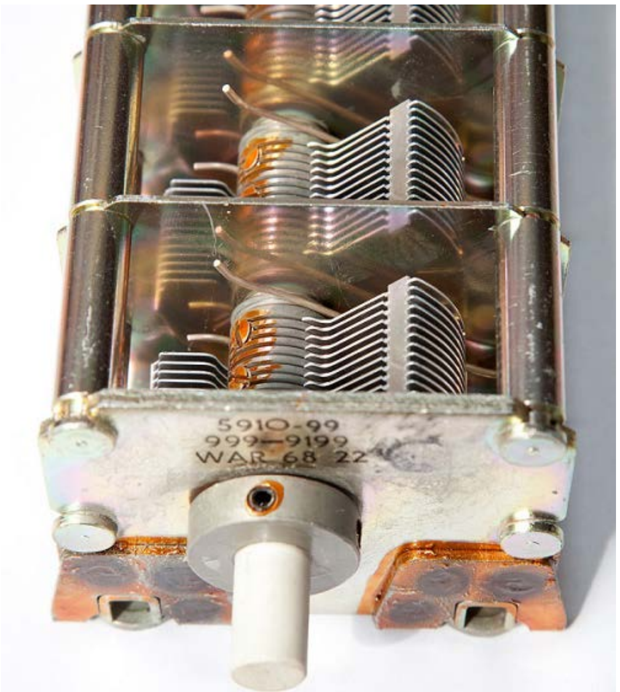


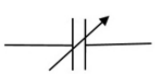
Fixed Capacitor Polarized Capacitor Variable Capacitor

Images of Glass Capacitors

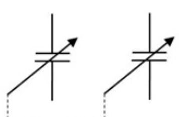

CSI Capacitors
a division of
CSI Technologies, Inc.
(619) 747-4000
PART NO. 4F5971NP
DATE CODE 9027
CAPACITANCE 4 uF
VOLTAGE 4 KVDC
CAUTION
DISCHARGE
BEFORE HANDLING


其利电子
QILE ELECTRONIC
QLPC
2500V-1000uF
Cn=1000uF ± 5%
Un=2500VDC
-40℃～+85℃
铜陵其利电子材料有限公司
Qili Electronic Material CO., LTD





Symbol of a variable capacitor



Symbol of a variable ganged capacitor

Image of a Trimmer Capacitor

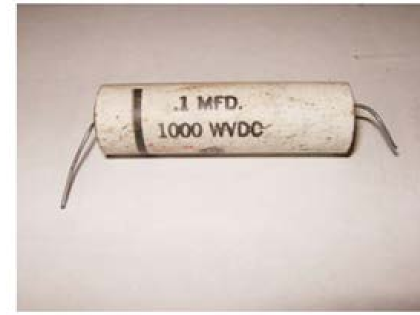
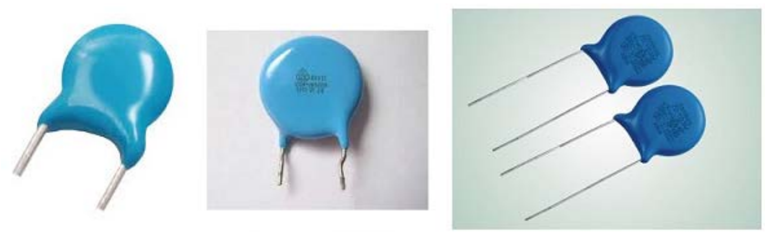
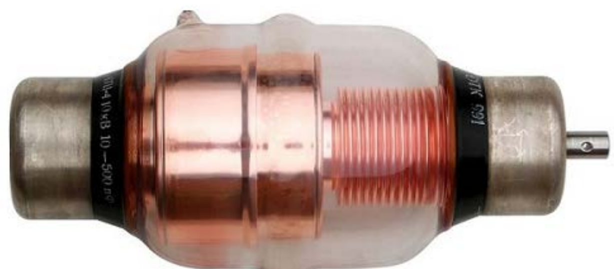


Image of a Paper Capacitor

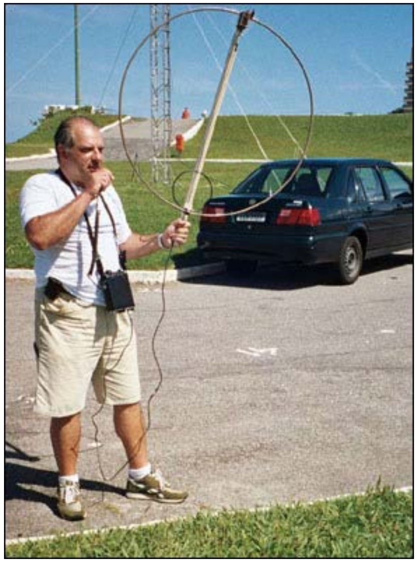


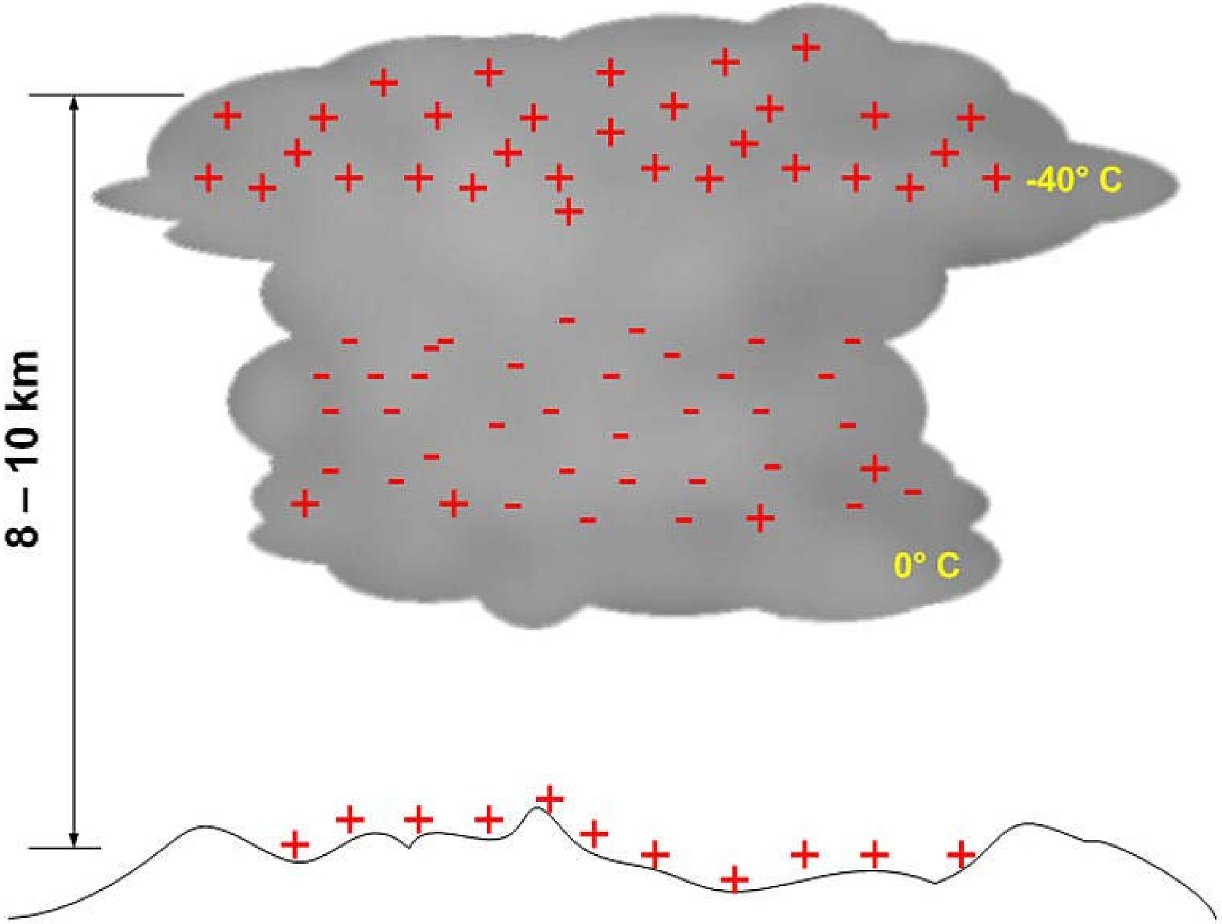
Images of different Ceramic Capacitors



Capacitance depends on the area of the plates, the distance between the plates, and the dielectric in between them. The dielectric can include air, glass, polyethylene, mica, Teflon® etc.

Vacuum capacitors (fixed or variable) are designed to overcome high voltage breakdown. You will see them used in loop antennas.




8 – 10 km
-40° C
0° C


QKm

Can you see the positive upstroke?

Luminosity is very low because the current is very low

Photographs like this are very rare


How many volts?

B-005-9-6 What determines the capacitance of a capacitor?

1. The material between the plates, the area of one side of one plate, the number of plates and the spacing between the plates

2. The material between the plates, the number of plates and the size of the wires connected to the plates

3. The number of plates, the spacing between the plates and whether the dielectric material is N type or P type

4. The material between the plates, the area of one plate, the number of plates and the material used for the protective coating

B-005-9-3 If two equal-value capacitors are connected in series, what is their total capacitance?

1. Twice the value of one capacitor

2. The same as the value of either capacitor

3. The value of one capacitor times the value of the other

4. Half the value of either capacitor

B-005-9-9 Three 15 microfarad capacitors are wired in series. The total capacitance of this arrangement is:

1. 45 microfarads
2. 12 microfarads
3. 5 microfarads
4. 18 microfarads

B-005-9-7 If two equal-value capacitors are connected in parallel, what is their capacitance?

1. The same value of either capacitor

2. The value of one capacitor times the value of the other

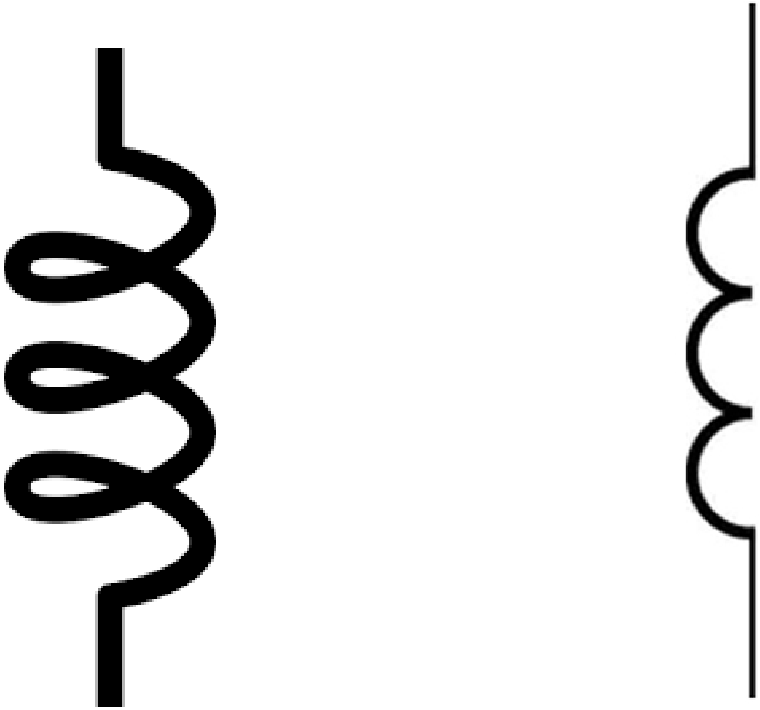
3. Half the value of either capacitor

4. Twice the value of either capacitor

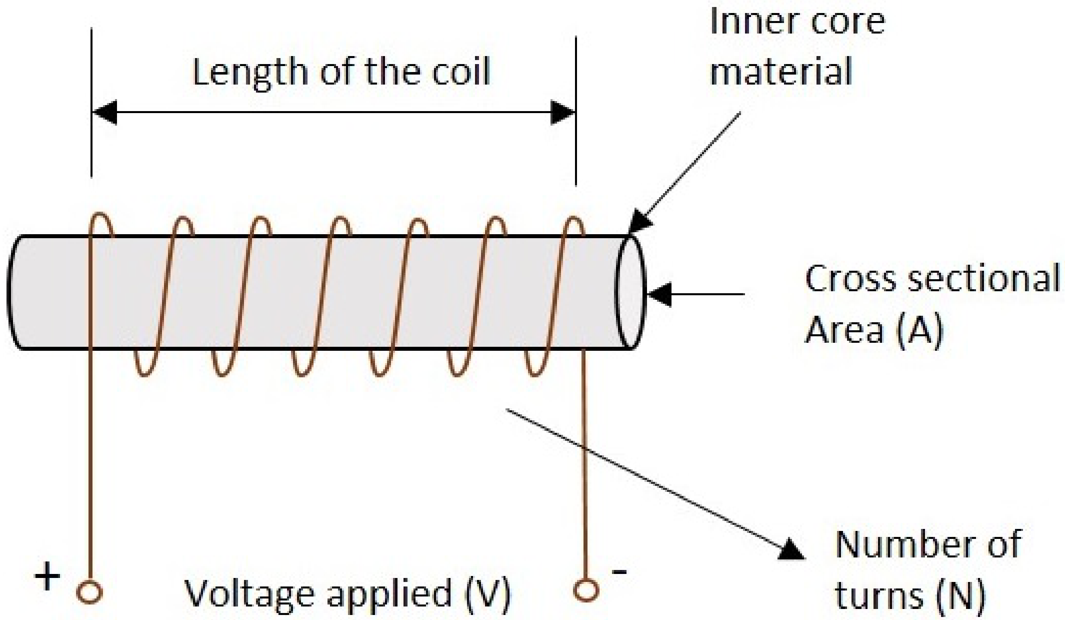
B-005-10-2 How does a capacitor react to AC?

1. **As the frequency of the applied AC increases, the reactance decreases**
2. **As the frequency of the applied AC increases, the reactance increases**
3. **As the amplitude of the applied AC increases, the reactance increases**
4. **As the amplitude of the applied AC increases, the reactance decreases**

Inductance

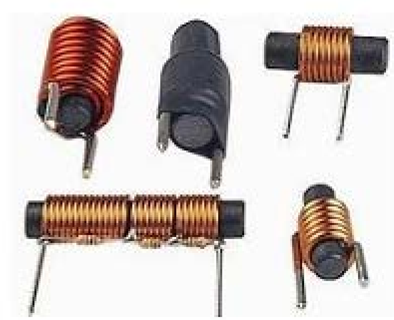


The symbol for inductance is L and the units are Henrys (H)

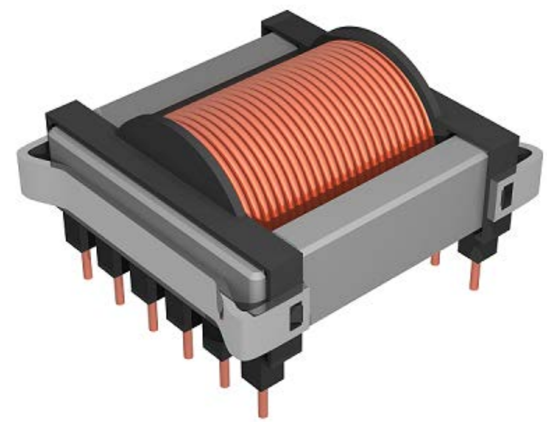

Length of the coil
Inner core
material
Cross sectional
Area (A)
Number of
turns (N)
+
Voltage applied (V)
-

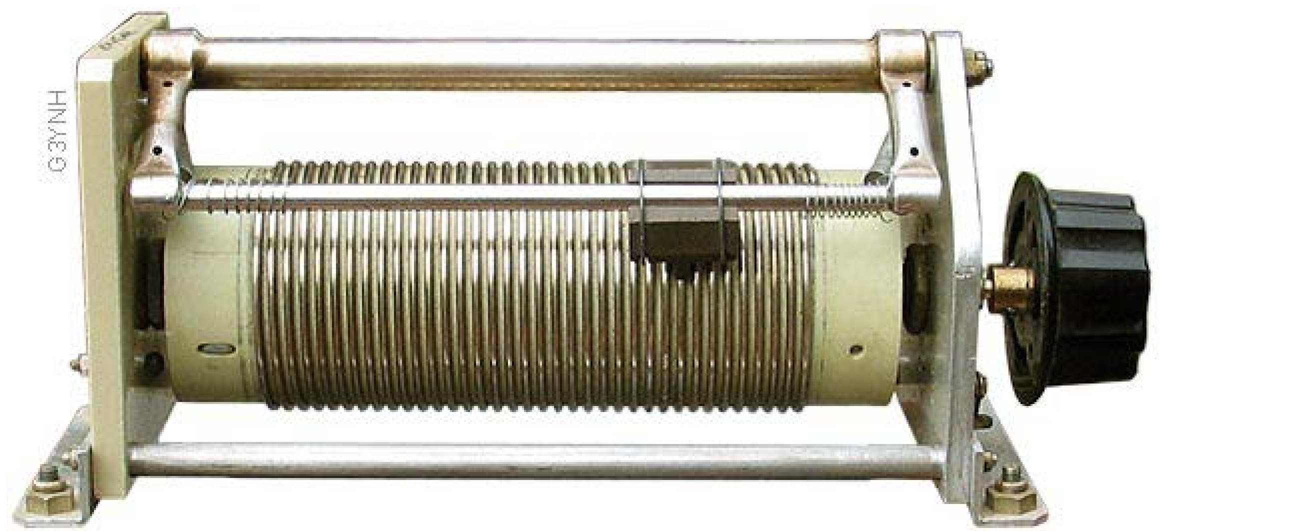
Core

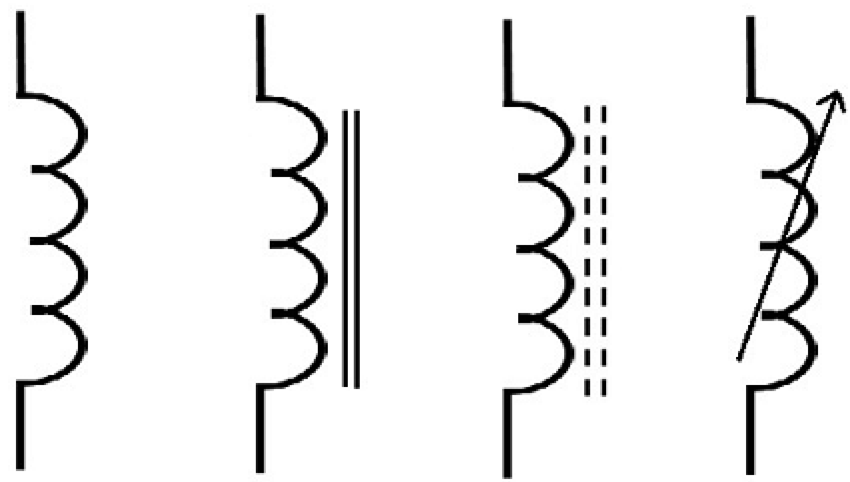
Core wounded with wire



Inductors having different types of core




G3YNH



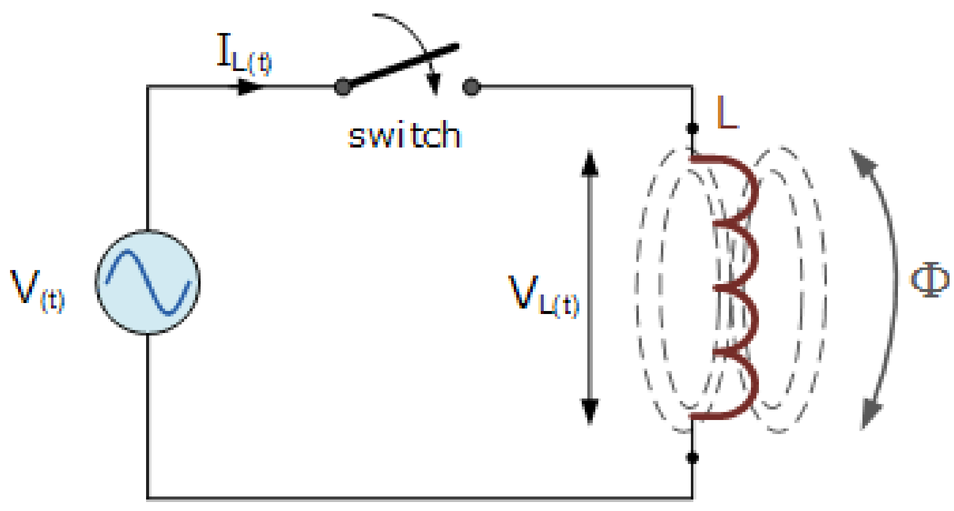
Air Core Inductor

Iron Core Inductor

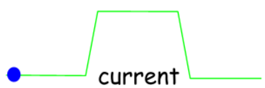
Ferrite Core Inductor

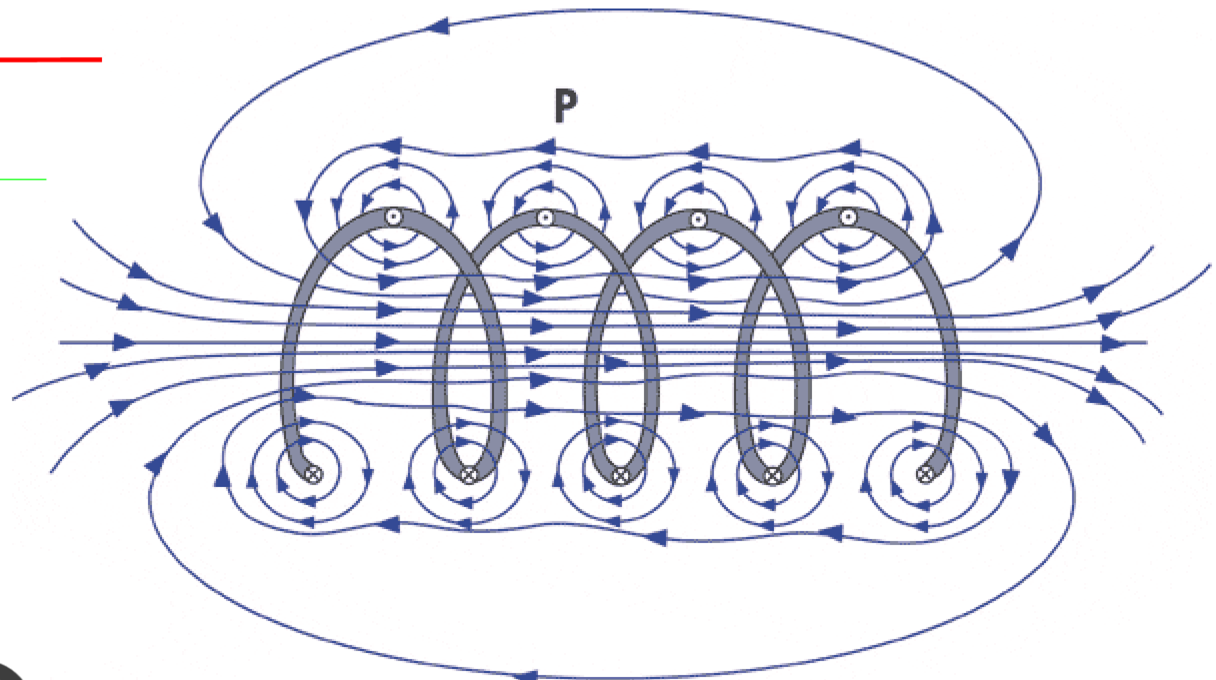
Variable Core Inductor

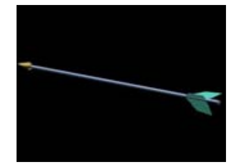
The inductor is the other frequency-dependent device which we need to learn about.

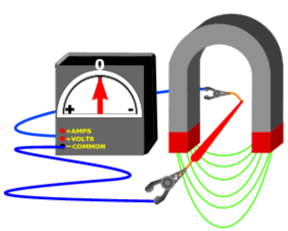


Coiled inductors work by electromagnetic induction



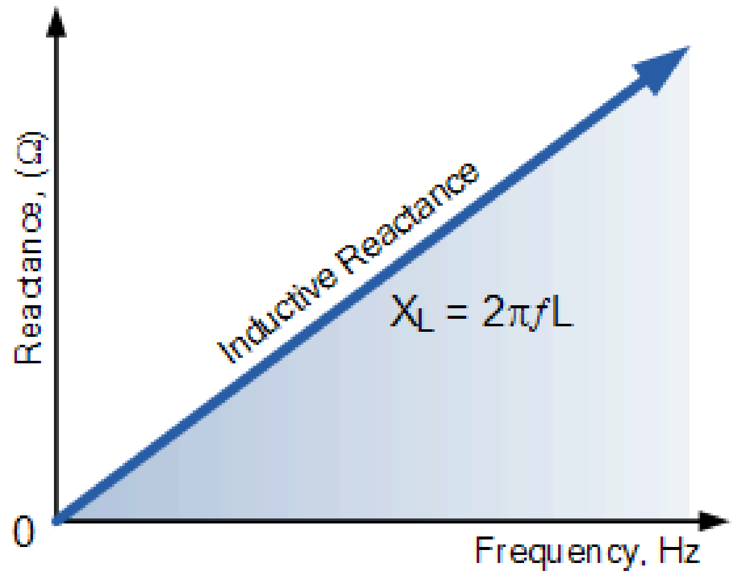


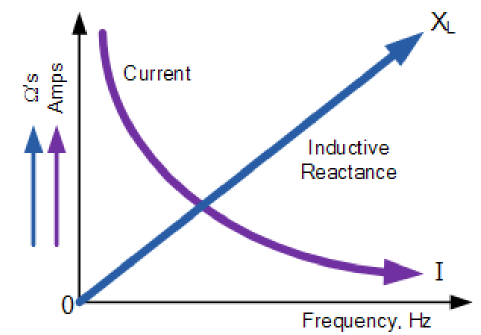


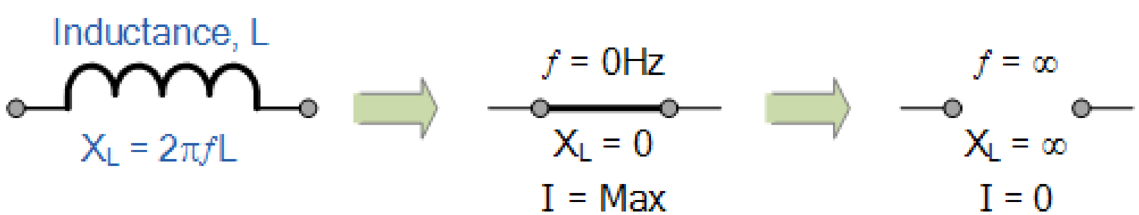


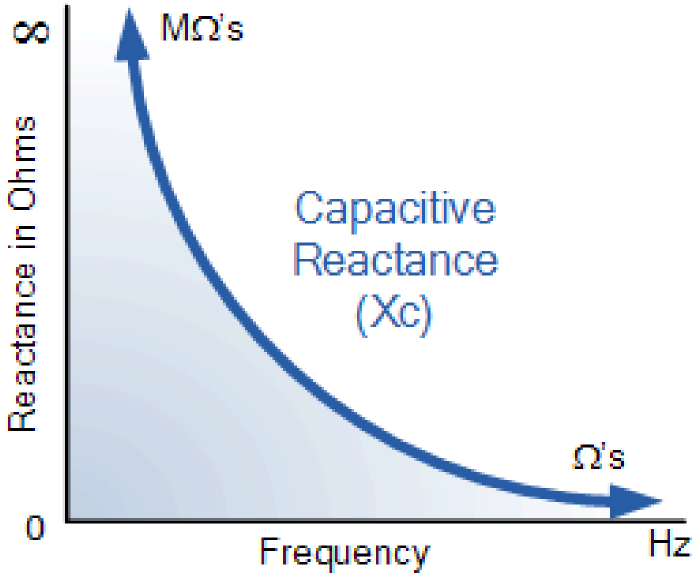
The changing magnetic field causes (induces) a current which is in the opposite direction. It therefore opposes current flow.

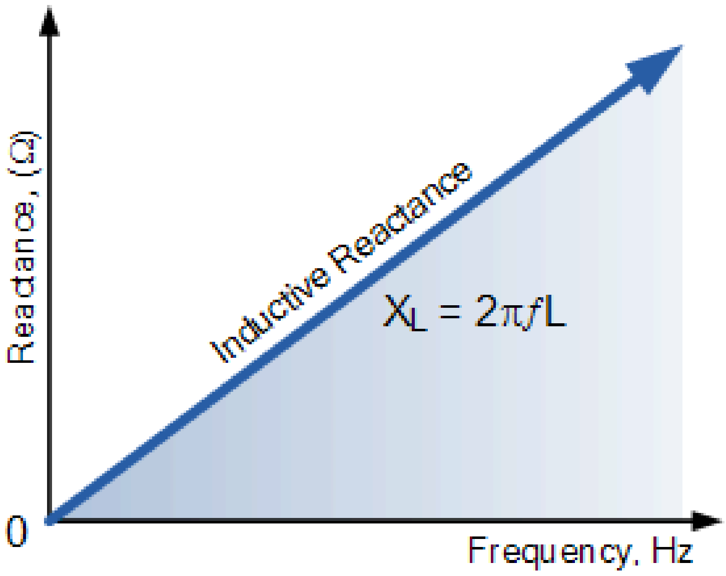
It is called the self-inductance (or just inductance) of a coil.


Reactance, (Ω)
Inductive Reactance
$X_L = 2\pi f L$
0
Frequency, Hz


Ω's
Amps
Current
X_L
Inductive Reactance
I
0
Frequency, Hz

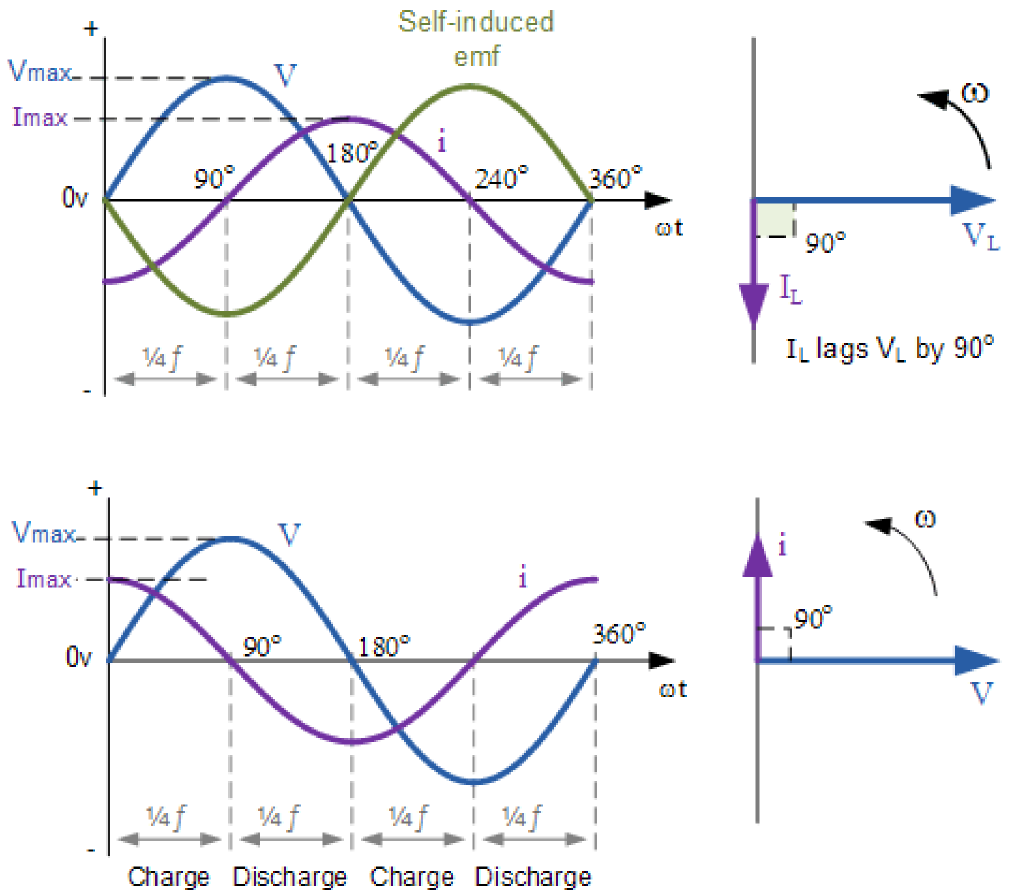

Inductance, L
$X_L = 2\pi f L$
f = 0Hz
$X_L = 0$
I = Max
$f = \infty$
$X_L = \infty$
I = 0





Inductors "block" AC and pass DC. Capacitors "block" DC and pass AC

A better word is impede



ELI

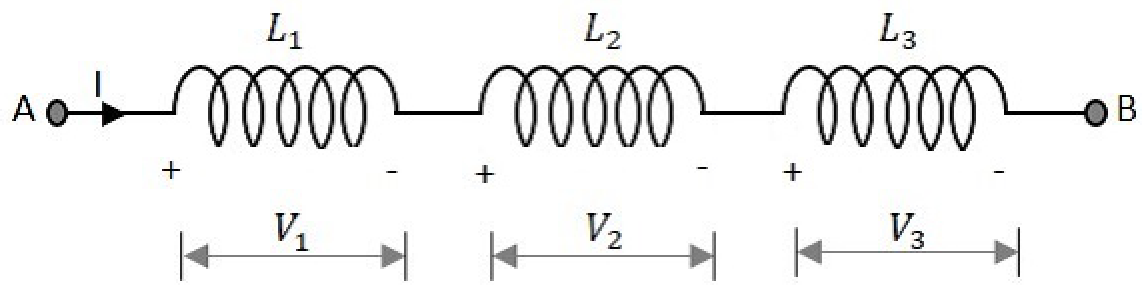
the

ICE

man

Series and Parallel calculations *similar to resistance*

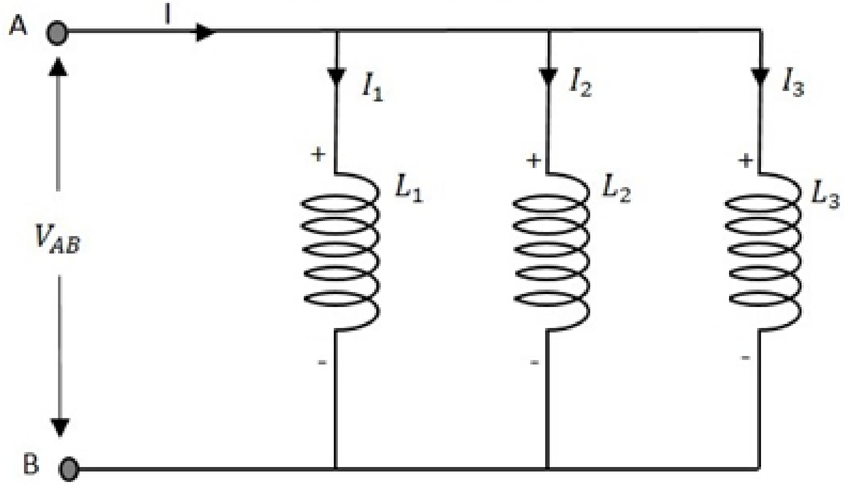
Inductors in Series



$$L_T = L_1 + L_2 + L_3$$

$$V = V_1 + V_2 + V_3 \qquad I = I_1 = I_2 = I_3$$

Inductors in Parallel



$$L_T = \frac{L_1 \times L_2}{L_1 + L_2}$$

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}$$

$$V = V_1 = V_2 = V_3$$

$$I = I_1 + I_2 + I_3$$

B-005-9-1 If two equal-value inductors are connected in series, what is their total inductance?

1. Half the value of one inductor

2. The same as the value of either inductor

3. The value of one inductor times the value of the other

4. Twice the value of one inductor

B-005-9-5 What determines the inductance of a coil?

1. The core material, the number of turns used to wind the core and the frequency of the current through the coil

2. The core diameter, the number of turns of wire used to wind the coil and the type of metal used for the wire

3. The core material, the core diameter, the length of the coil and the number of turns of wire used to wind the coil

4. The core material, the core diameter, the length of the coil and whether the coil is mounted horizontally or vertically

B-005-10-10 What is the approximate inductive reactance of a 1.0 Henry choke coil used in a 60 hertz circuit?

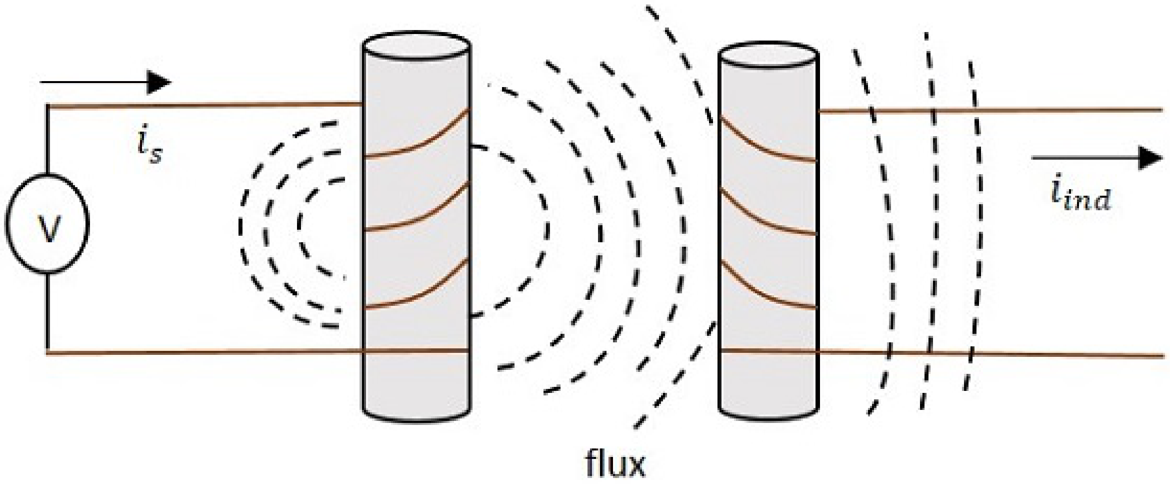
1. 376 ohms

2. 3760 ohms

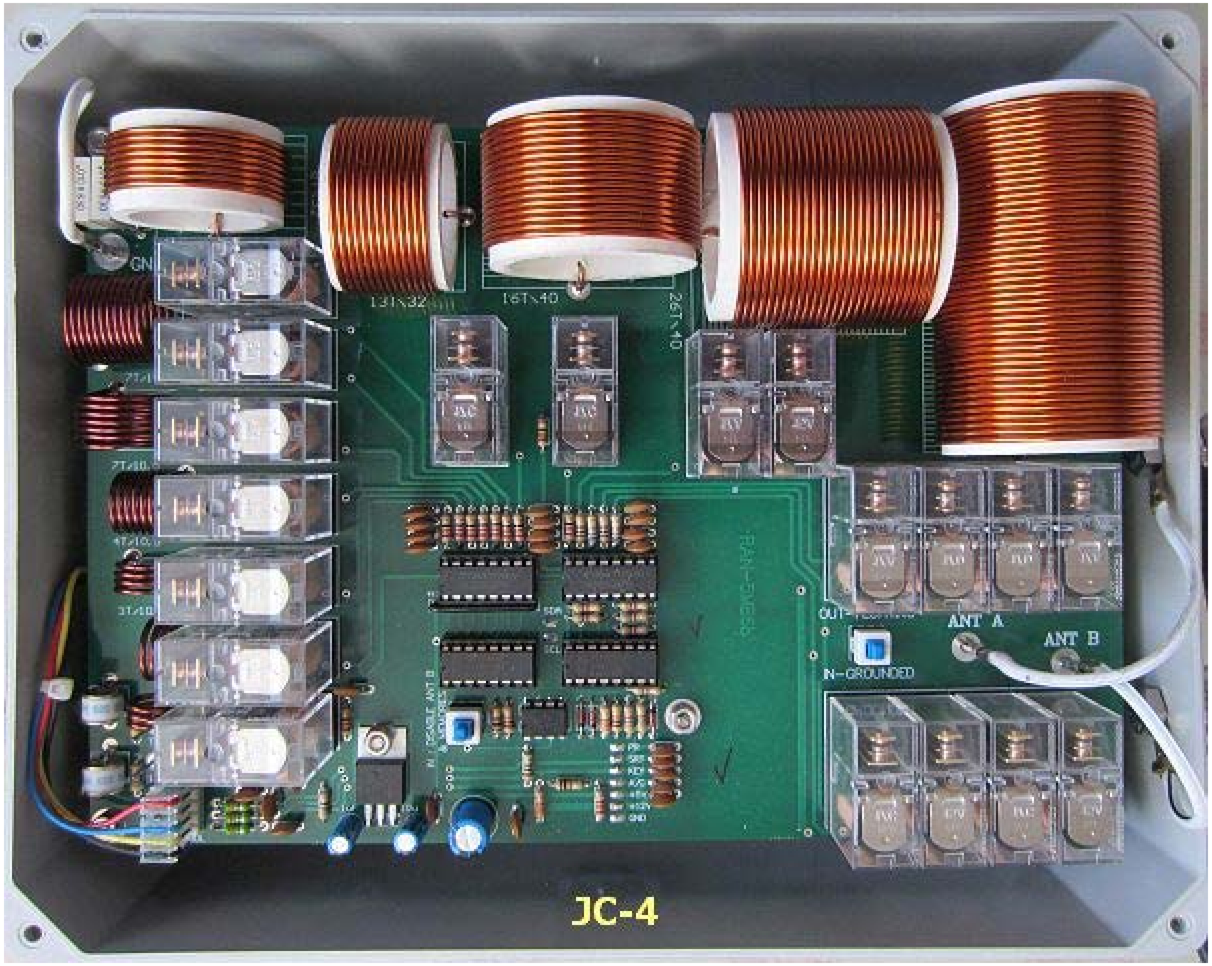
3. 188 ohms

4. 1888 ohms

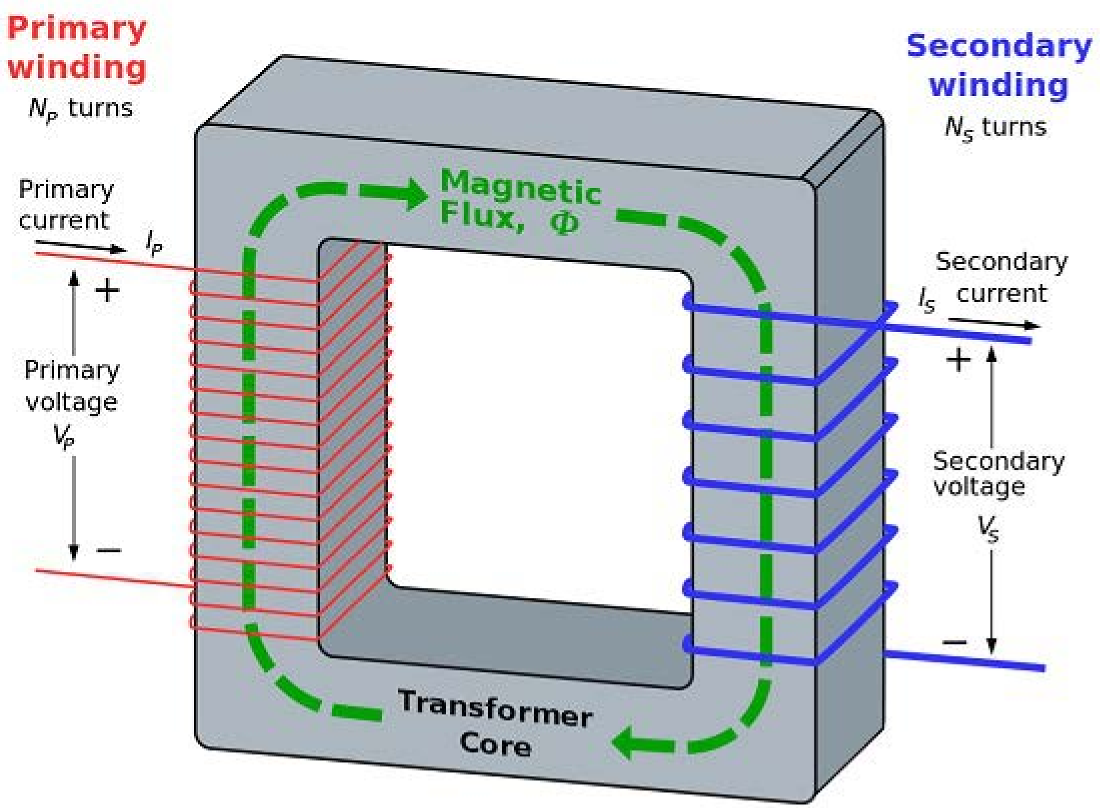
Mutual Inductance



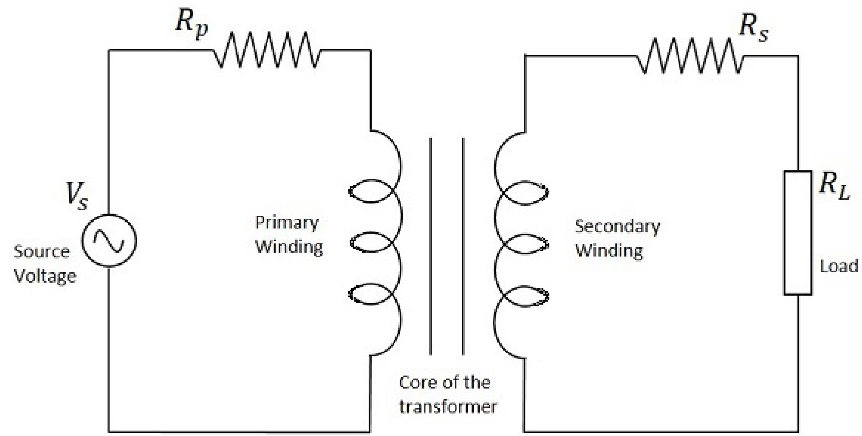
This is magnetic coupling

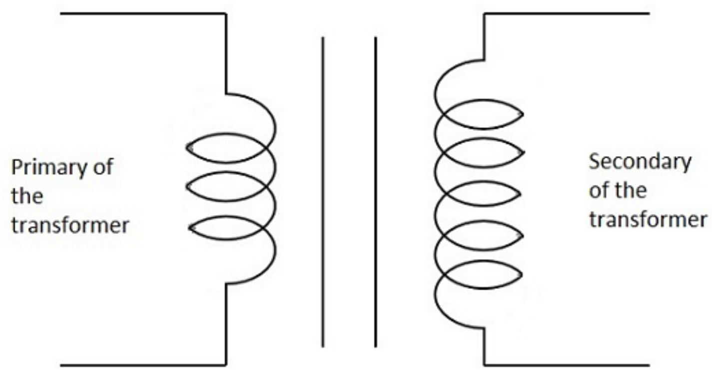


JC-4

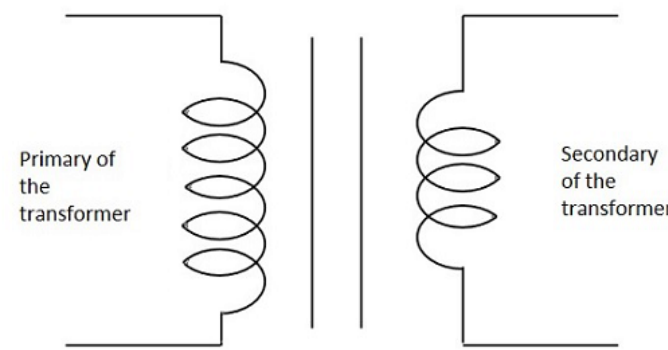


Current is induced in the secondary coil





Step-up transformer



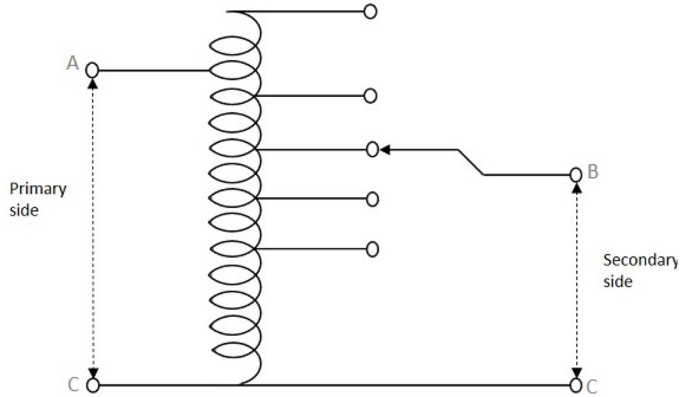
Step-down transformer

$$\frac{E_S}{E_P} = \frac{N_S}{N_P} \qquad Eqn\,4-3$$

$$E_P = 150 \text{ VAC}$$
$$N_P = 120 \text{ turns}$$
$$\frac{N_S}{N_P} = 5:2$$

$$N_S = \frac{5 \times 120}{2} = 300 \text{ turns}$$

$$E_S = \frac{300 \times 150}{120} = 375 \text{ V}$$



Symbol of Auto-transformer

Auto-transformers do not isolate


PAUWELS
CANADA


50
4.8 / 16

B-005-11-4 In a mains power transformer, the primary winding has 250 turns, and the secondary has 500. If the input voltage is 110 volts, the likely secondary voltage is:

1. 440 V

2. 220 V

3. 560 V

4. 24 V

B-005-11-2 A transformer operates a 6.3 volt 2 ampere light bulb from its secondary winding. The power consumed by the primary winding is approximately:

1. 13 watts

2. 6 watts

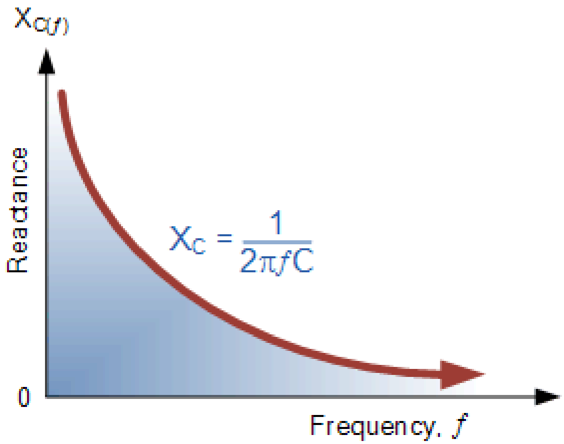
3. 8 watts

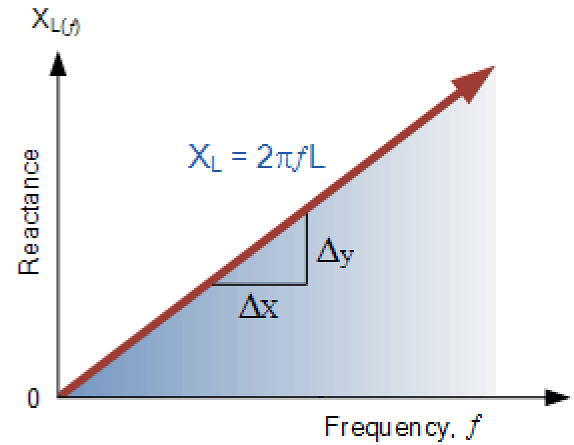
4. 3 watts

B-005-10-1 How does a coil react to AC?
1. As the amplitude of the applied AC increases, the reactance decreases
2. As the amplitude of the applied AC increases, the reactance increases
3. As the frequency of the applied AC increases, the reactance increases
4. As the frequency of the applied AC increases, the reactance decreases

Impedance

We know about reactance now. Circuits can have reactance <u>and</u> resistance



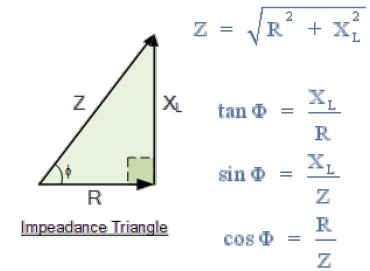


$$X_C = \frac{1}{2\pi fC} \qquad \text{Eqn 4-7}$$

$$X_L = 2\pi fL \qquad Eqn\ 4-6$$

Impedance Z (*measured in* Ω) is the sum of reactance and resistance

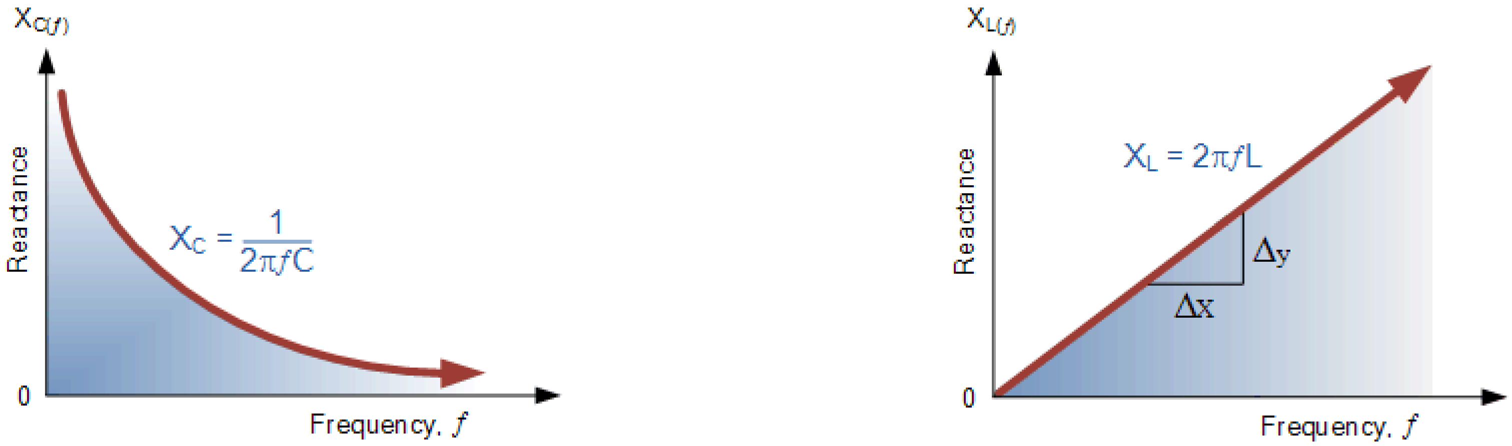
$$Z = \sqrt{R^2 + X^2} \qquad \text{Eqn 4-8}$$



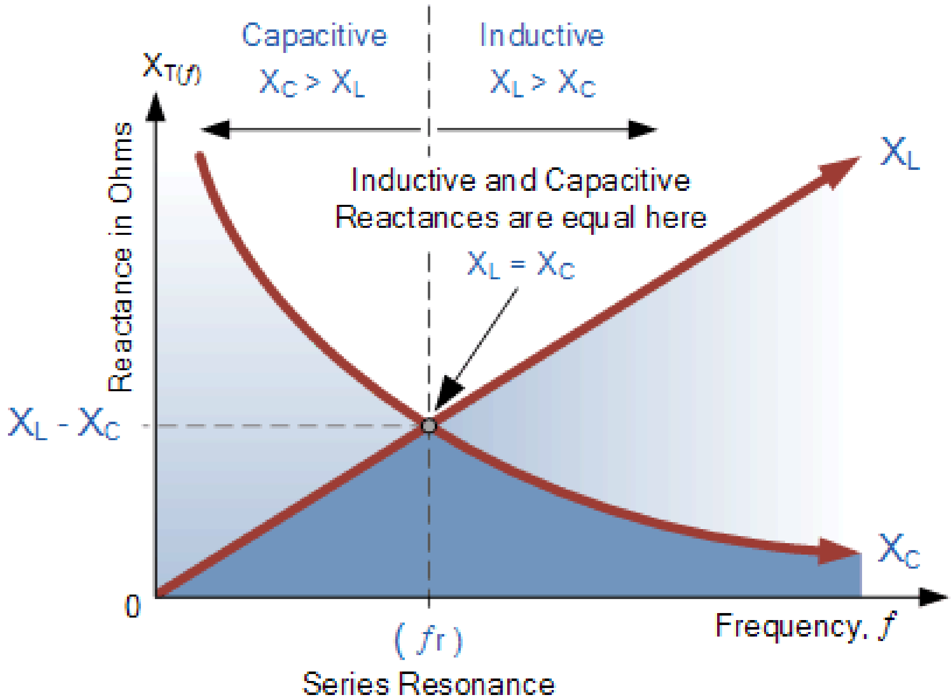
Matching impedances is an important concept in radio. The output of a transmitter should have the same impedance as the feed line and antenna it is connected to.

Hams spend a lot of time adjusting the impedance of their antennas so that the maximum power transfer from the transmitter can happen.

Resonance



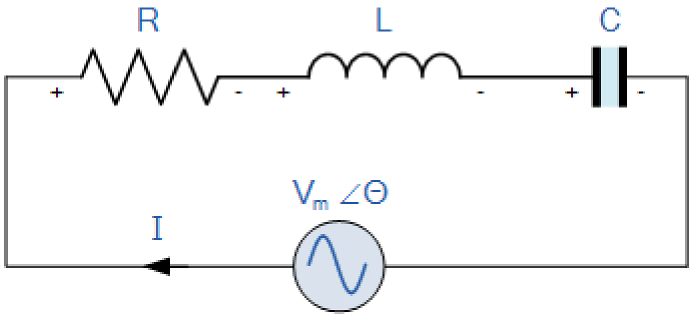
At some frequency X_C will equal X_L



When $X_c = X_L$ the reactances cancel leaving only resistance

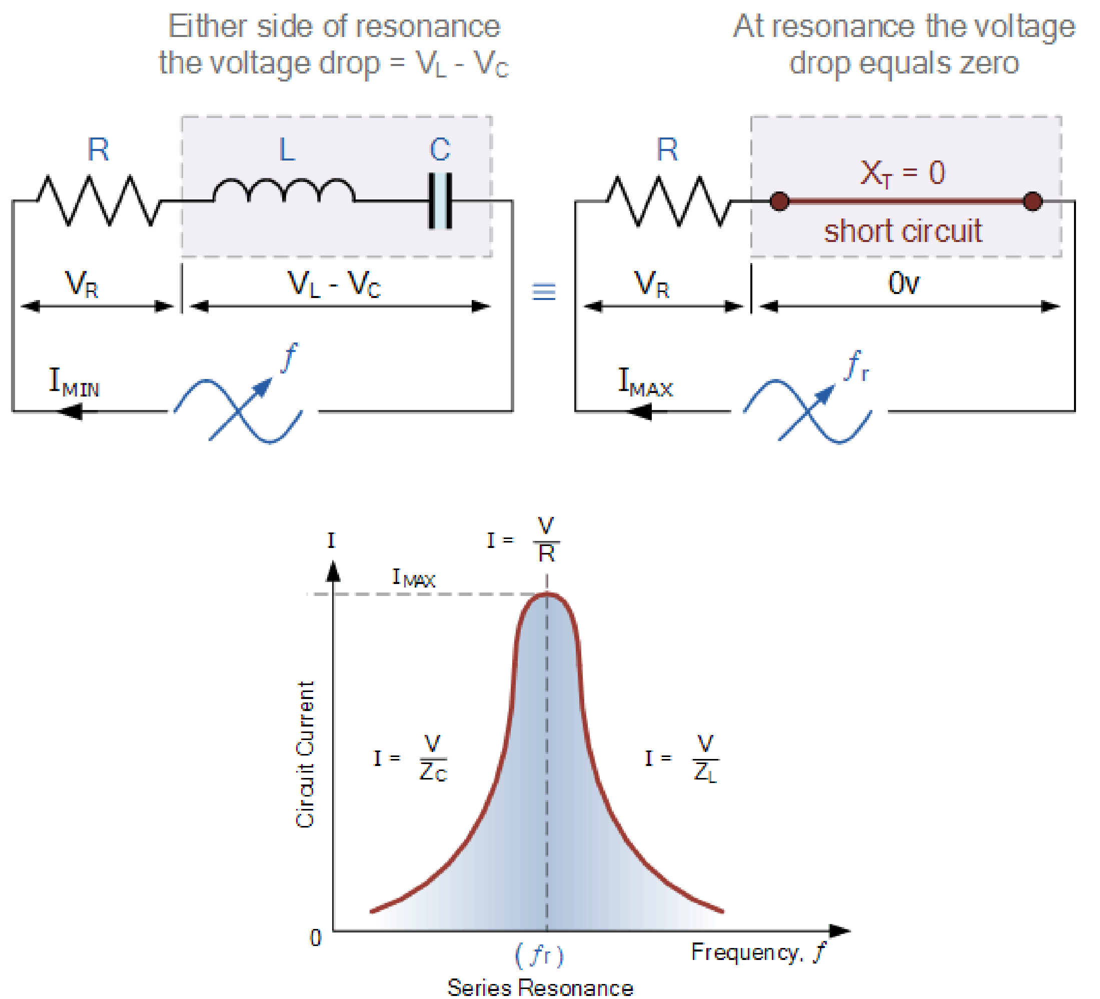
This is an example of a series resonant circuit ***aka a tuned circuit***

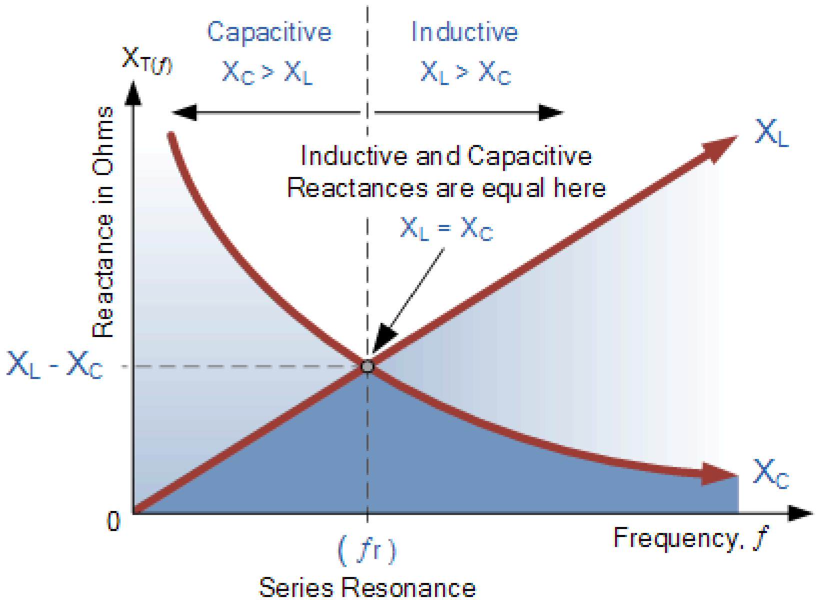
Acceptor circuit



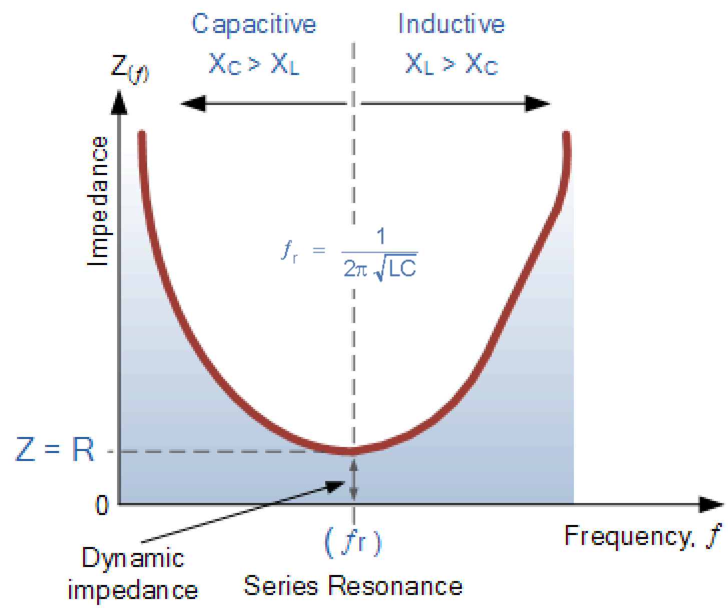
Frequency selection
Band pass filter

$$f_r = \frac{1}{2\pi\sqrt{LC}} \qquad Eqn\ 4-11$$


Either side of resonance
the voltage drop = VL - VC
At resonance the voltage
drop equals zero
R
L
C
R
XT = 0
short circuit
VR
VL - VC
VR
0v
IMIN
f
IMAX
fr
I
I = V/R
IMAX
Circuit Current
I = V/ZC
I = V/ZL
0
(fr)
Series Resonance
Frequency, f



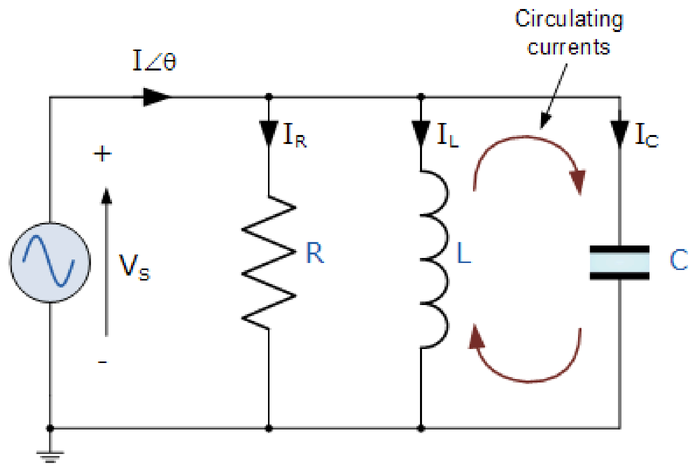
Capacitive
XC > XL
Inductive
XL > XC
XT(f)
Reactance in Ohms
XL
Inductive and Capacitive
Reactances are equal here
XL = XC
XL - XC
XC
0
(fr)
Series Resonance
Frequency, f



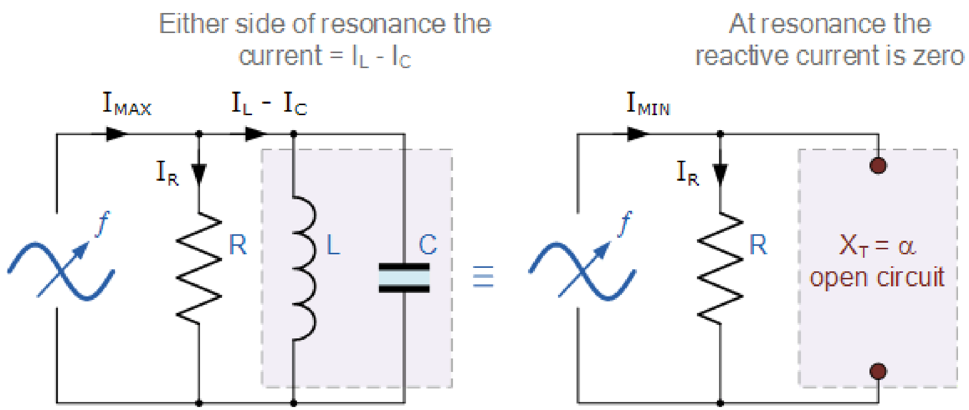
Capacitive
XC > XL
Inductive
XL > XC
Z(f)
Impedance
fr = 1 / 2π √LC
Z = R
0
(fr)
Dynamic
impedance
Series Resonance
Frequency, f

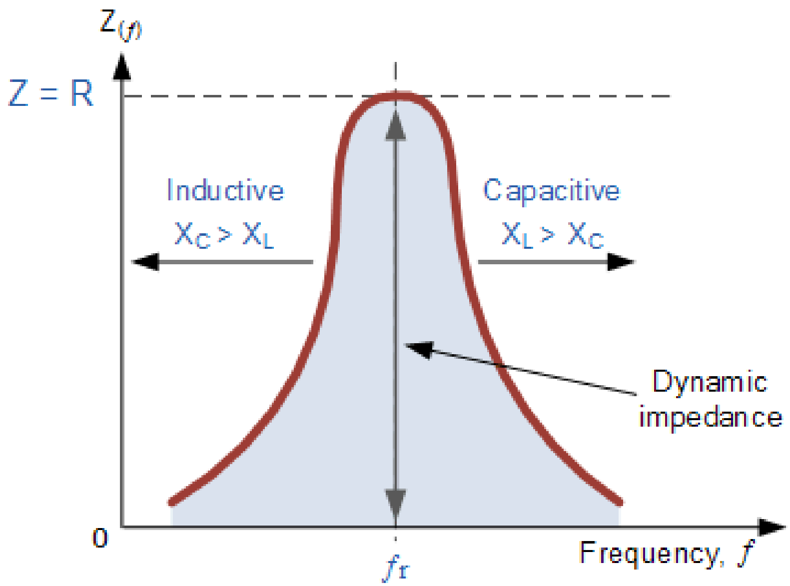
This is an example of a parallel resonant circuit ***also a tuned circuit***

Rejector circuit

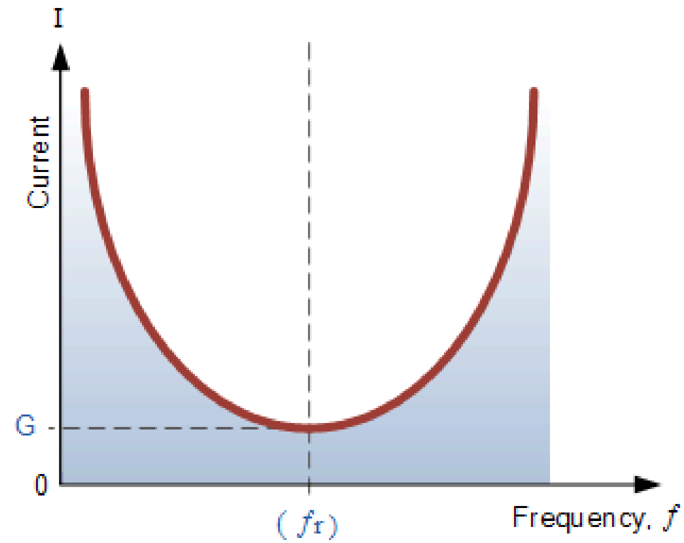


Band stop filter
IF trap
“Tank” circuit in an oscillator



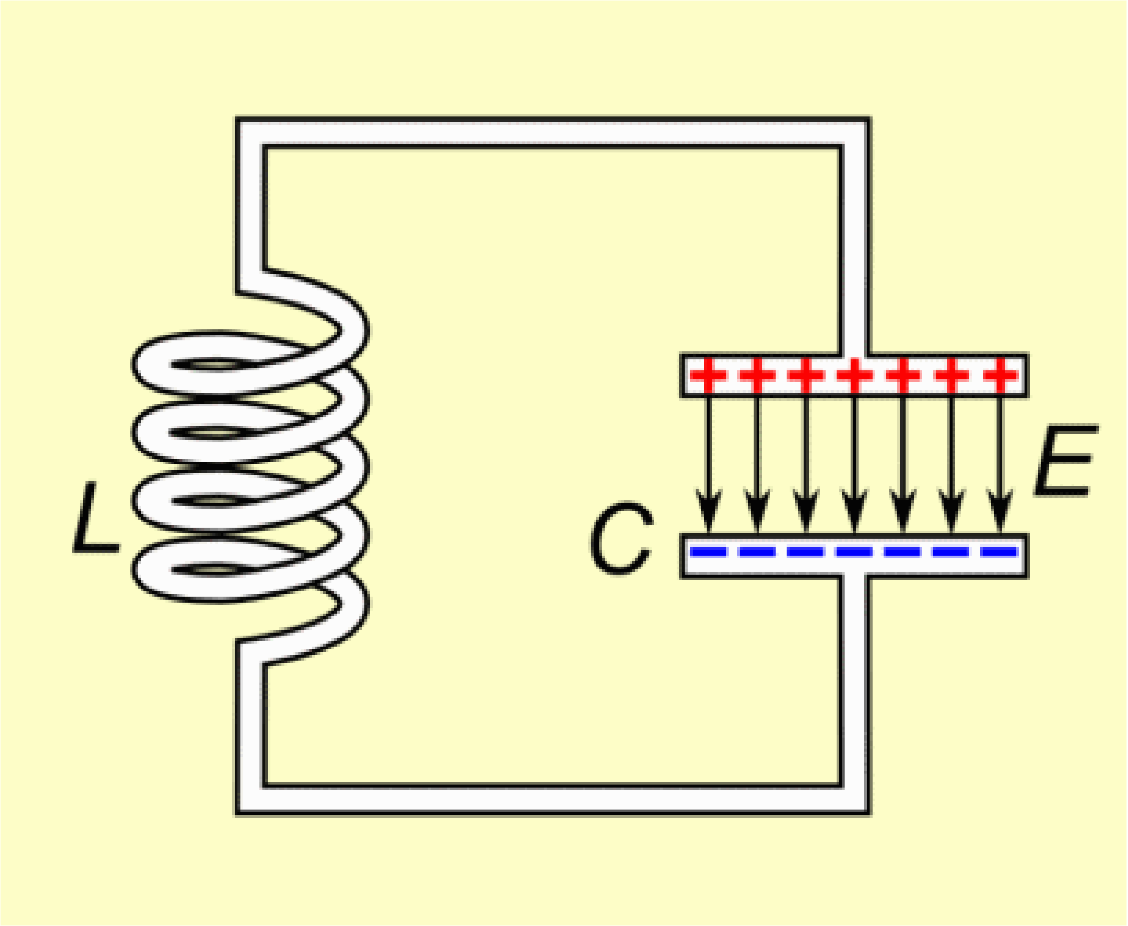


Parallel Resonance

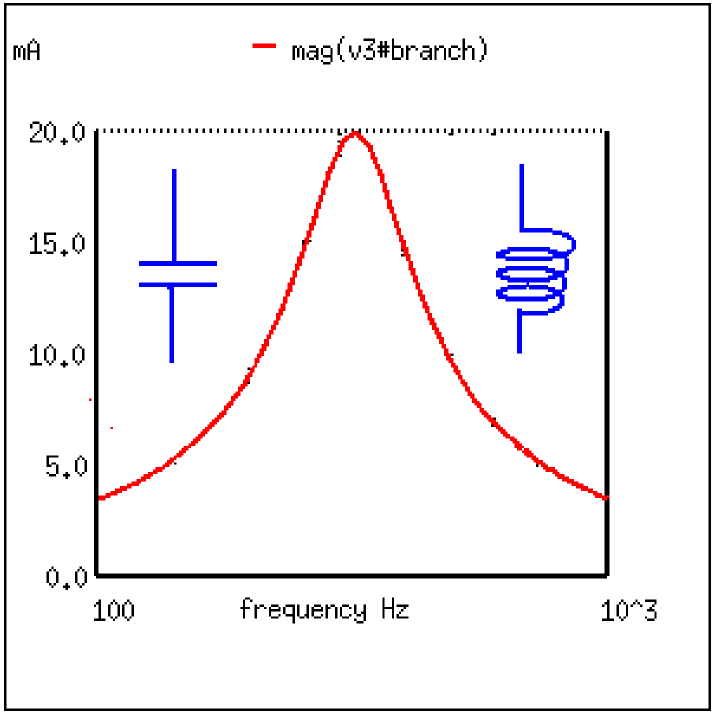


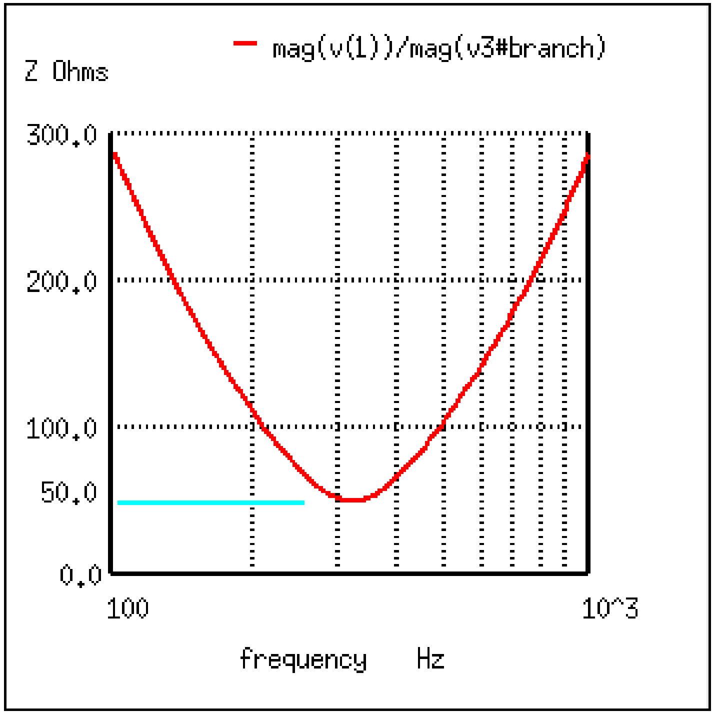
Parallel Resonance

$$f_r = \frac{1}{2\pi\sqrt{LC}} \qquad Eqn\ 4-11$$

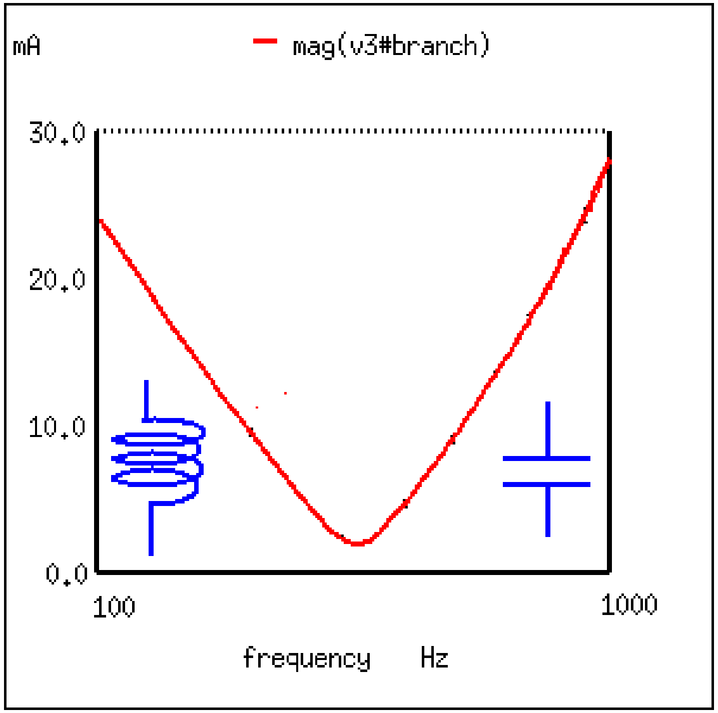


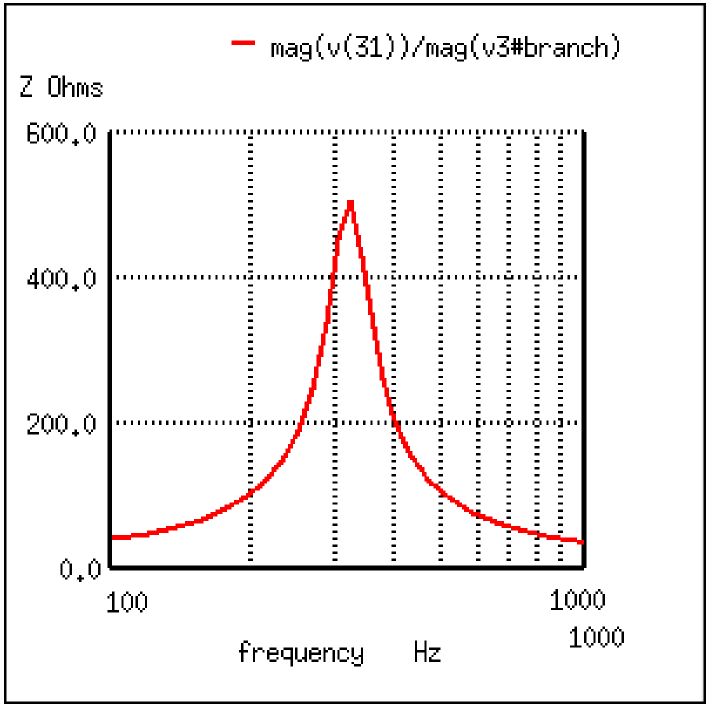
Tank circuit



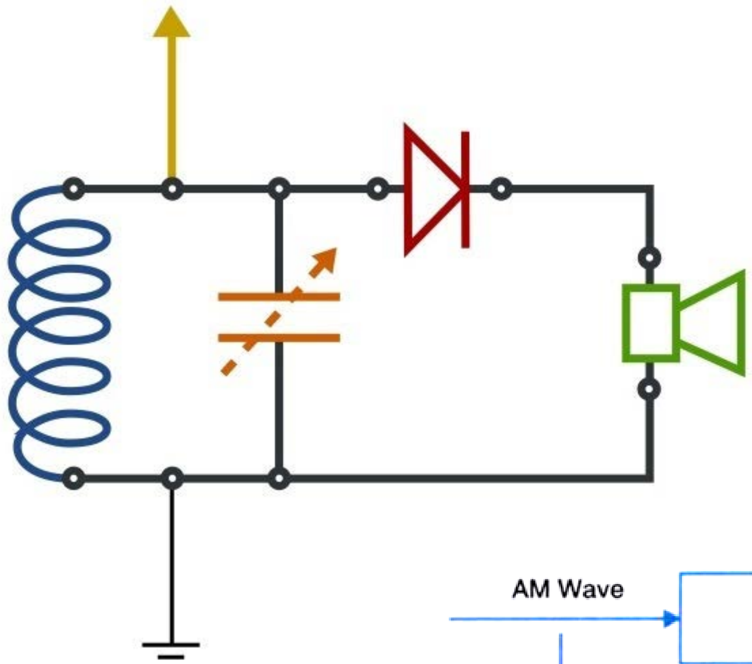


Series resonance

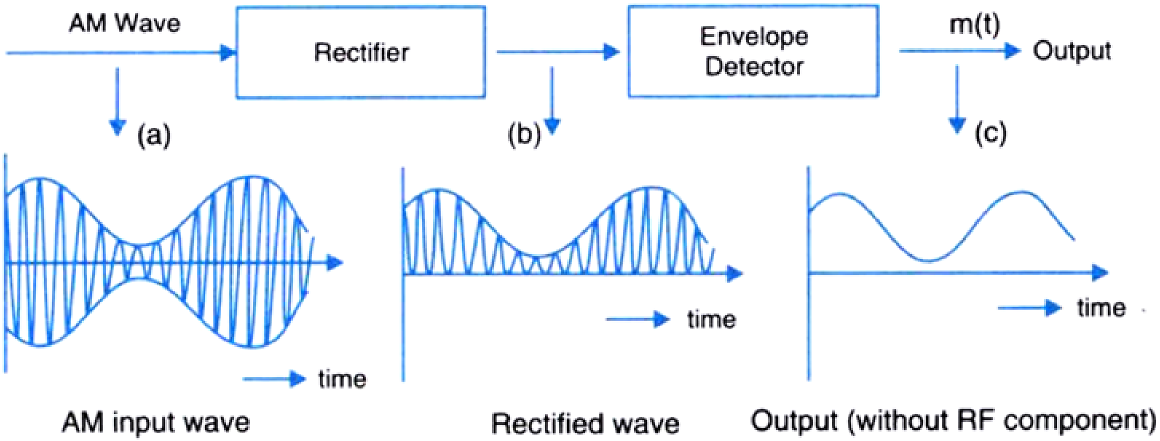


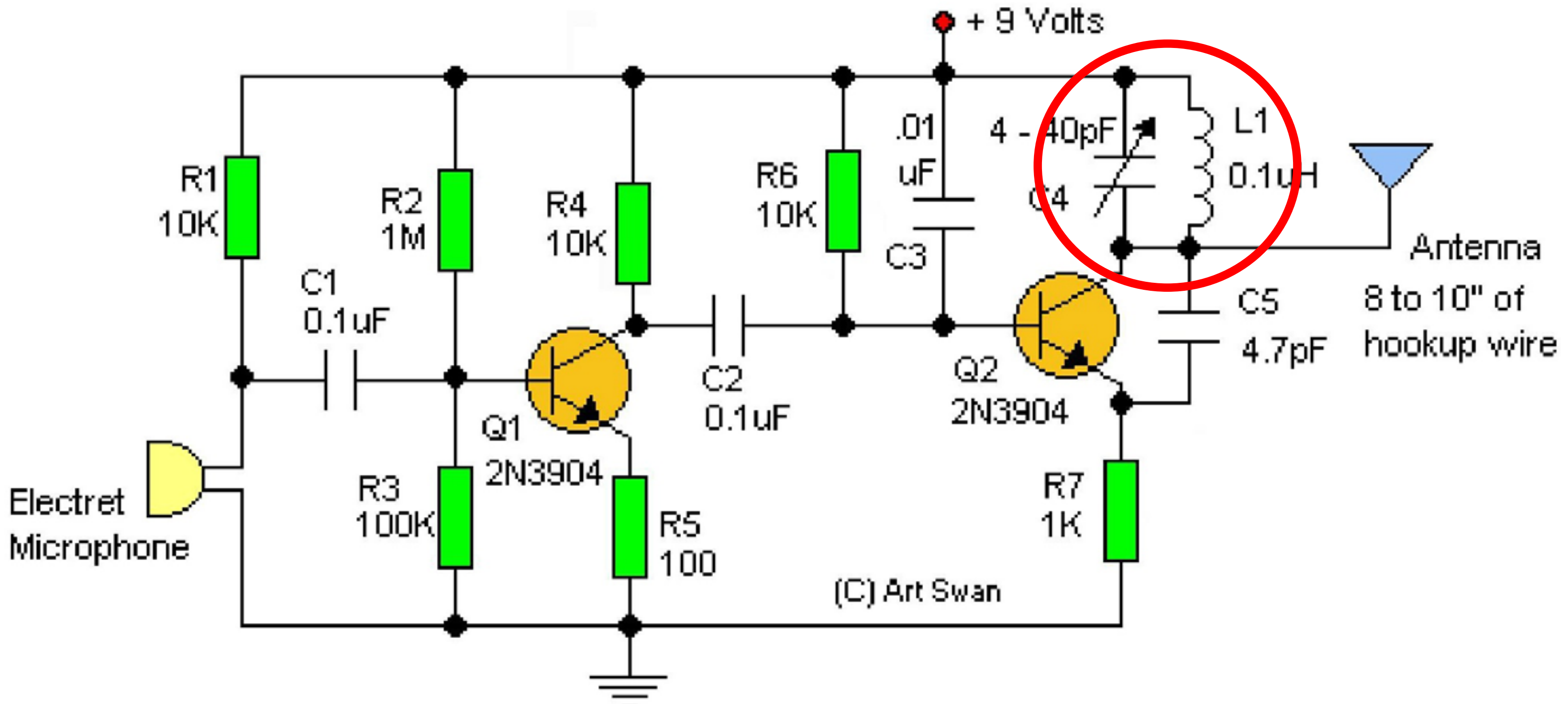


Parallel resonance

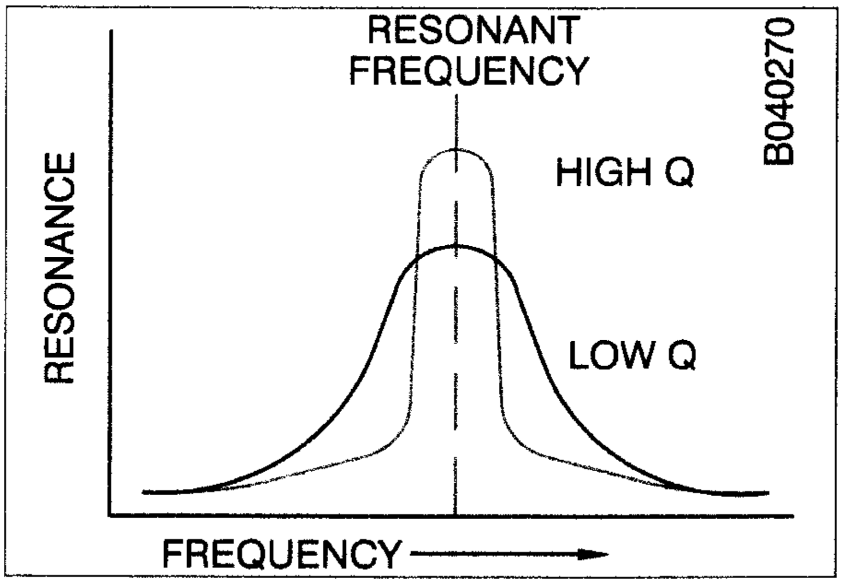


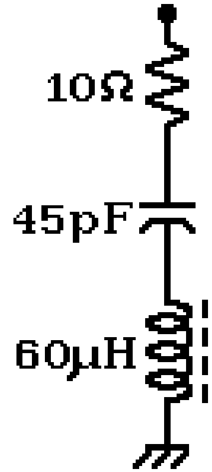
This is a crystal radio



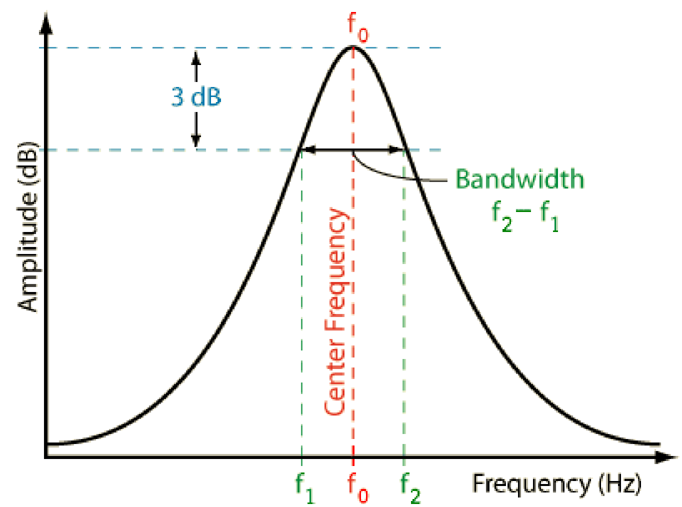

+ 9 Volts
R1
10K
R2
1M
R4
10K
R6
10K
.01
uF
C3
4 - 40pF
C4
L1
0.1uH
Antenna
8 to 10" of
hookup wire
C1
0.1uF
C2
0.1uF
C5
4.7pF
Q1
2N3904
Q2
2N3904
Electret
Microphone
R3
100K
R5
100
R7
1K
(C) Art Swan

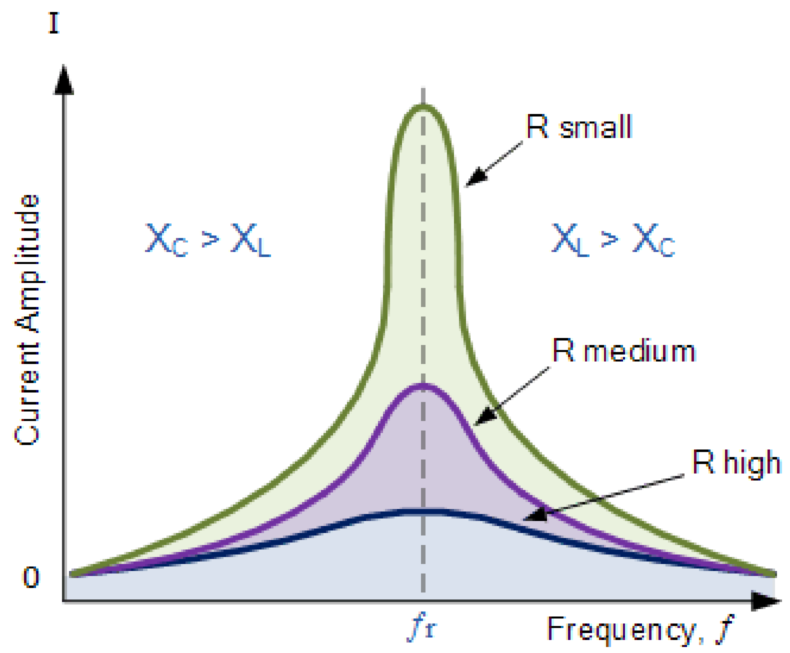
Q

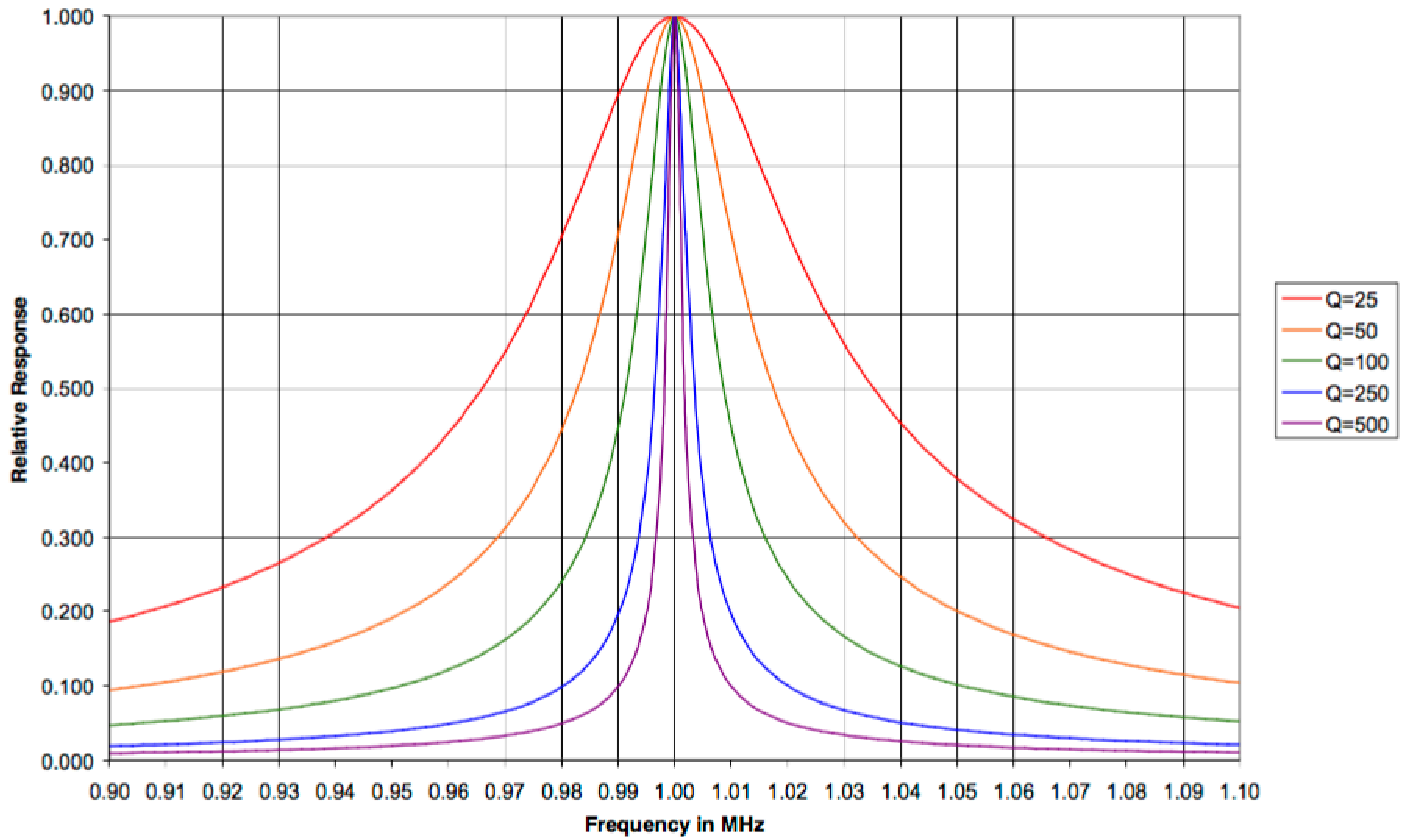




$$Bw = \frac{F_R}{Q} = \frac{3.06^6\ Hz}{115.5} = 26.52KHz$$




I
Current Amplitude
0
$X_C > X_L$
$X_L > X_C$
R small
R medium
R high
f_r
Frequency, f


1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
Relative Response
0.90 0.91 0.92 0.93 0.94 0.95 0.96 0.97 0.98 0.99 1.00 1.01 1.02 1.03 1.04 1.05 1.06 1.07 1.08 1.09 1.10
Frequency in MHz
Q=25
Q=50
Q=100
Q=250
Q=500

B-005-12-1 Resonance is the condition that exists when:

1. inductive reactance and capacitive reactance are equal

2. inductive reactance is the only opposition in the circuit

3. the circuit contains no resistance

4. resistance is equal to the reactance

B-005-12-7 In a series resonant circuit at resonance, the circuit has:

1. low impedance

2. high impedance

3. low mutual inductance

4. high mutual inductance

B-006-6-5 What happens when the impedance of an electrical load is equal to the internal impedance of the power source?

1. The electrical load is shorted

2. The source delivers maximum power to the load

3. No current can flow through the circuit

4. The source delivers minimum power to the load

Next time: Waves and Propagation