Capacitors

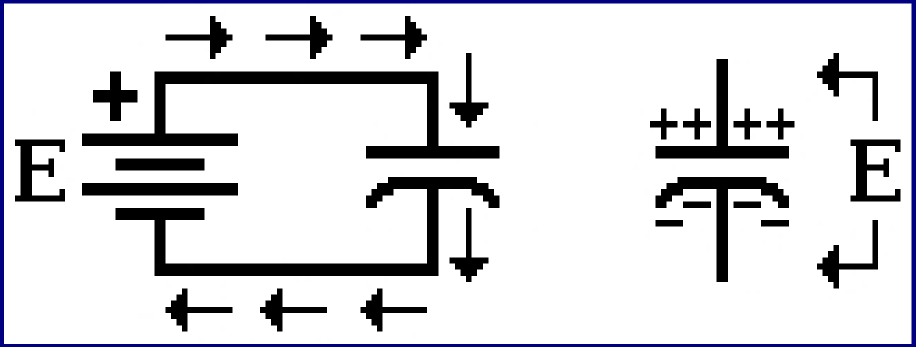
The Opposite of Inductors

In So Many Ways

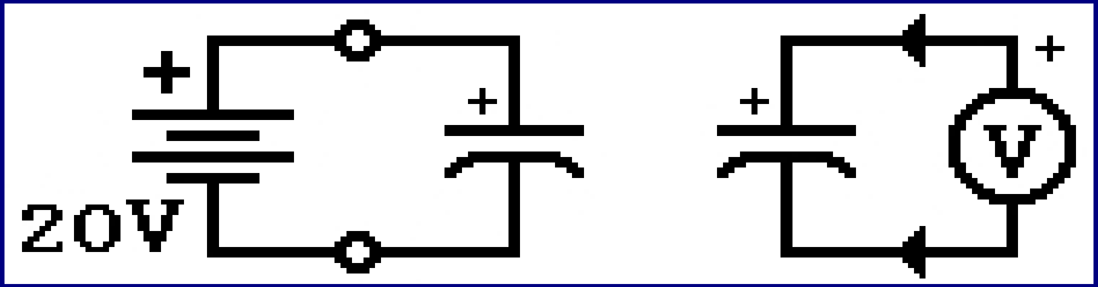
Capacitors store Charge, Block DC current, Pass AC Current in a frequency dependant way, Filter the power bus, Resonate a tuned circuit, and come in a multitude of shapes, sizes, types, and ratings. Best to know these little wonders.

A Capacitor is two metal Plates or Foils seperated by an insulator.

When a voltage difference is applied across the plates a current occurs as electrons leave the plate connected to the positive terminal, and an equal current flows out of the plate connected to the negative terminal.



When the Voltage source is disconnected from the capacitor the charge remains, or is stored.



Connecting a volt meter or a resistive load will provide a current path and the capacitor will discharge at a rate determined by the size of the capacitor, and the resistance of the load.

The product of Capacitance and Resistance is called the Time Constant.

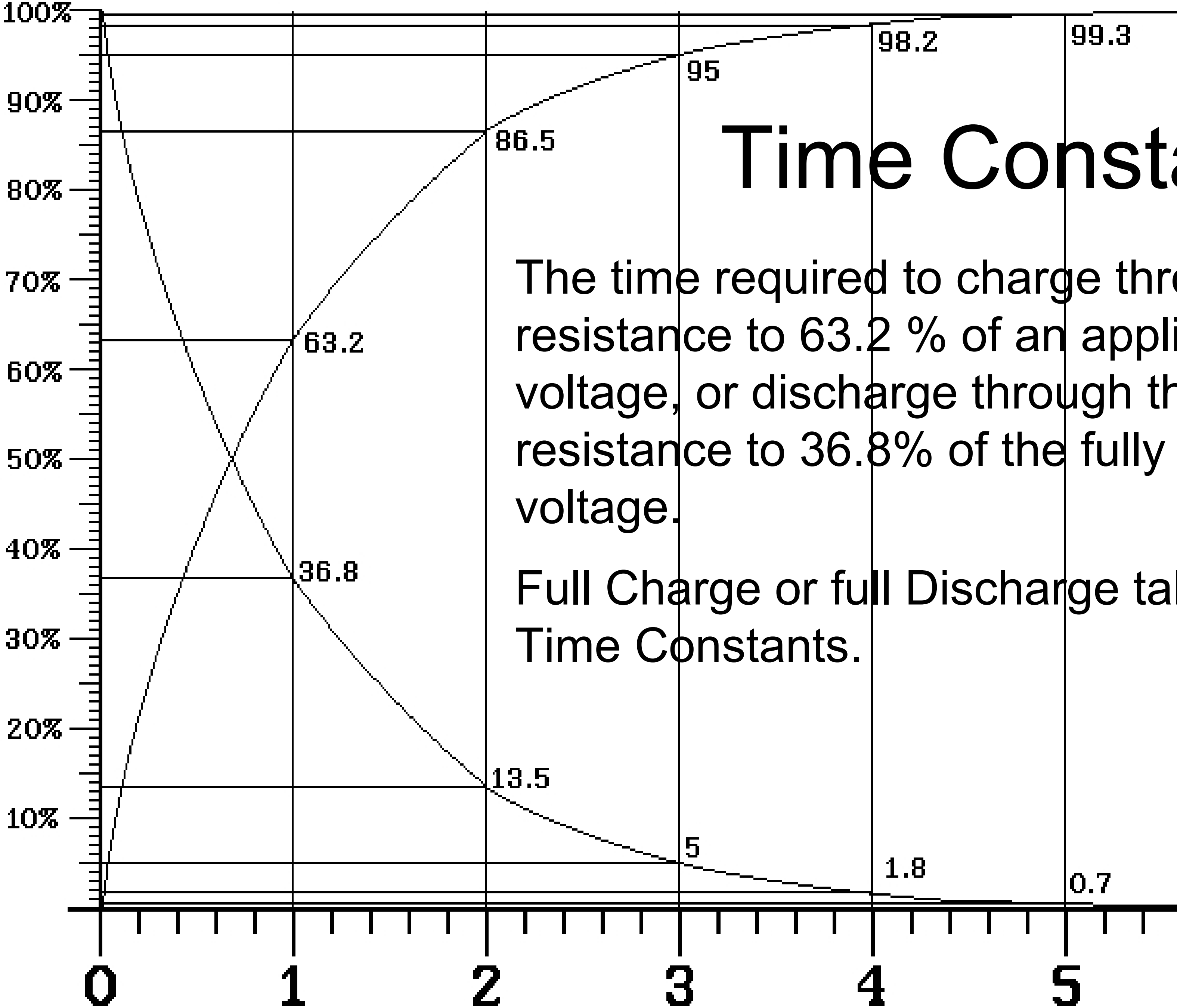
$$TC = R \times C$$

Where TC is in seconds, R in Ohms, and C is in Farads.

Time Constant

The time required to charge through a resistance to 63.2 % of an applied voltage, or discharge through that resistance to 36.8% of the fully charged voltage.

Full Charge or full Discharge takes 5 Time Constants.



Capacitance

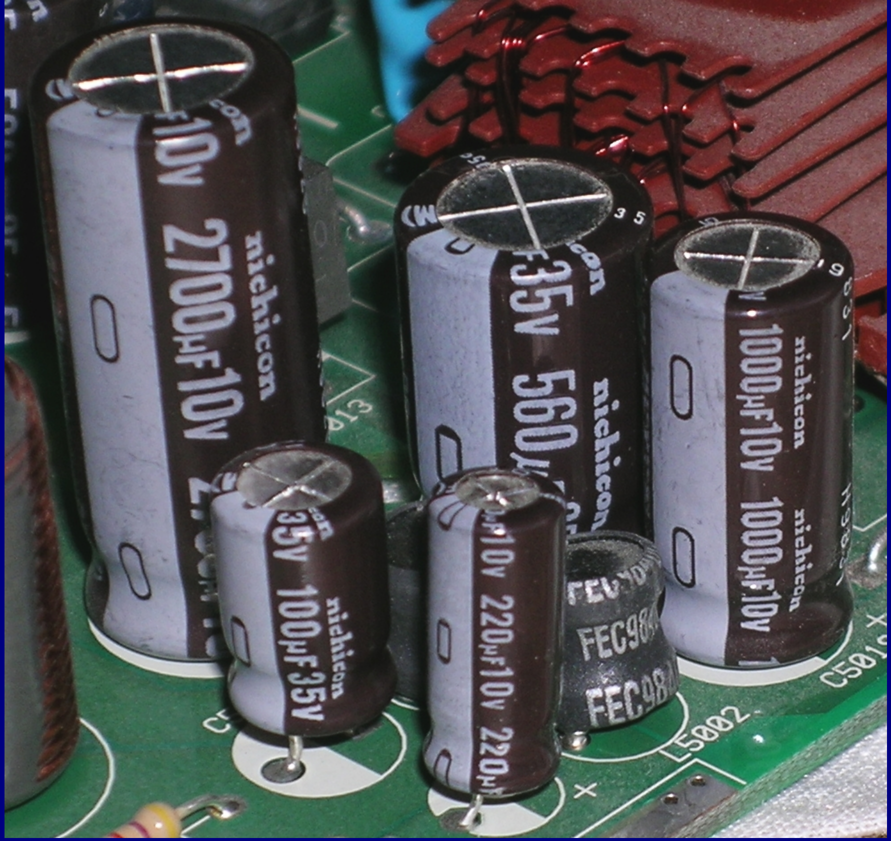
Capacity is measured in Farads, in honour of Michael Faraday.

A 1 Farad Capacitor will store 1 Coulomb at a Potential of 1 volt.

While Super and Ultra Capacitors in Farad sizes are now common, smaller sizes are practical for audio and radio circuits. You will see:

microfarad	μF,	1/1,000,000F	1^{-6}
nanofarad	nF,	1/1,000,000,000	1^{-9}
picofarad	pF,	1/1,000,000,000,000	1^{-12}

The micro-microfarad (mmf) of old is now the picofarad, not the nanofarad!



This forest of electrolytic capacitors is in the power supply section, and includes:

2700µF 10V, 560µF 35V

100µF 35V, 1000µF 10V

220µF 10V,

Note that electrolytic capacitors are polarized, with a positive and a negative lead. The negative lead is always marked.

Capacitor Factors

Area: *A*

The area of the plates of a capacitor directly effect the amount of capacity.

Separation: *d*

The distance between the plates inversely effects the amount of capacity.

Dielectric Constant: Є

The electrostatic density of the material between the plates directly effects the capacity.

$$C = \epsilon \frac{A}{d}$$

Dielectric Constant

Different insulating materials have a different impact upon the amount of capacitance that an area and separation will create.

Vacuum = 1 Air = 1.0006 Teflon = 2.1

Paper (dry) = 2.2 - 3.5 Polystyrene = 2.6

Mylar = 3 Polycarbonate = 3 Transil Oil = 4

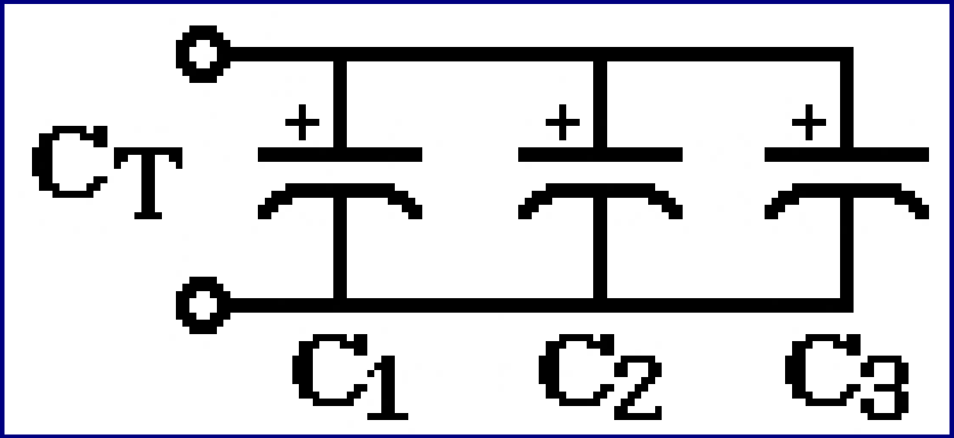
Pyrex = 4.7 Mica = 5.5 - 9.3 Porcelain = 5.5

Steatite = 5.8 Barium Titanate = 1250

Perovskite Ceramic CaCu3Ti4O12 = 10 000

Capacitors in Parallel

Connecting Capacitors in Parallel simply Adds their Areas.



Add Capacitor Values.

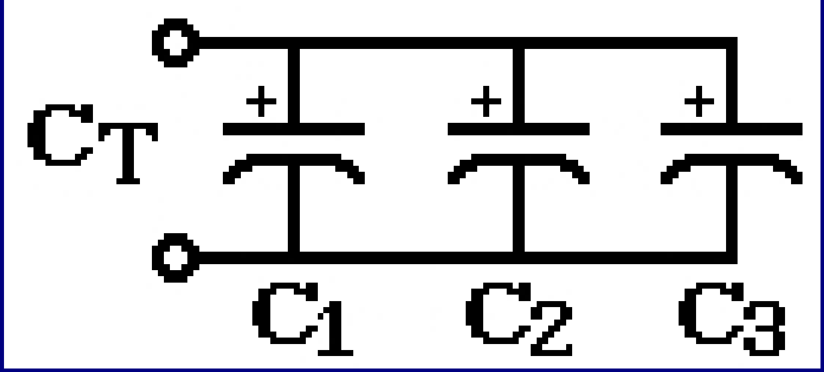
eg: 100μF + 50μF = 150μF

and: 12nF + 220pF = 12.22nF

and 1.5μF + 0.47μF = 1.97μF

and 3.3nF + 680pF + 820pF = 4.8nF

Voltage Ratings of Parallel Caps



Parallel Circuits share a common voltage.

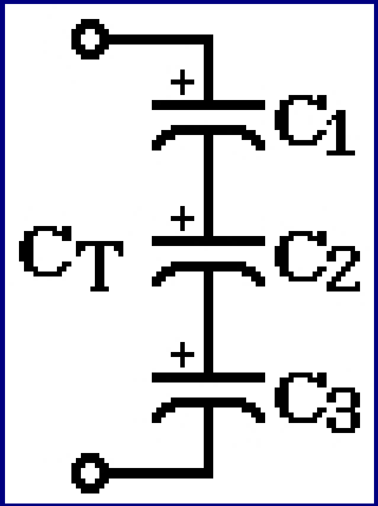
All capacitors must have a voltage rating higher than the applied voltage.

This rating may be the same for all capacitors, or they may be different, so long as the lowest rating is higher than the applied voltage.

eg: 10μF63V + 22μF36V + 100μF25V might be connected to an 18 volt circuit.

Capacitors in Series

Capacitors connected in Series Add the spacing between Plates. This reduces the total amount of capacitance.



If the capacitors are of equal value, the voltage across each capacitor is equal.

Total capacitance is always smaller than the value of the smallest capacitor.

For Two: For Three or More:

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

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

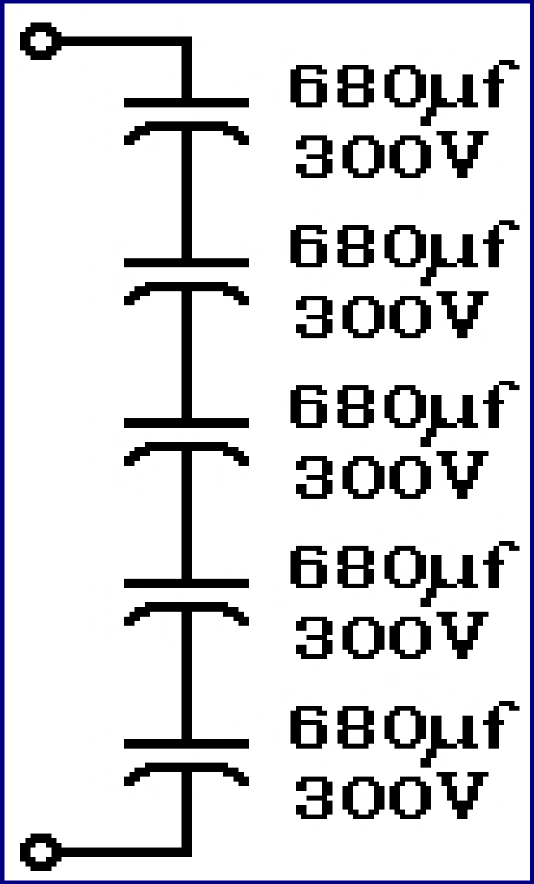
Equal Capacitors In Series

Equal capacitors in series reduce capacitance by the number of capacitors.

Five 680μF capacitors create a 680 / 5 = 136μF capacitor.

Their Separations Add, and so do their equal voltage ratings.

Five 300 Volt capacitors can be charged to 300 x 5 = 1500 Volts



Unequal Capacitors in Series

Must Use the Series Capacitor Equation.

$$\frac{1}{C_T}=\frac{1}{47\,nF}+\frac{1}{68\,nF}+\frac{1}{27\,nF}+\frac{1}{56\,nF}+\frac{1}{33\,nF}$$

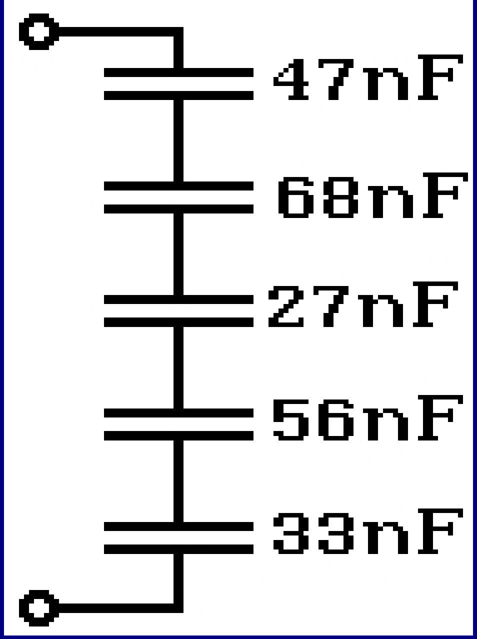
1/47nF = 21,276,595

1/68nF = 14,705,882

1/27nF = 37,037,037

1/56nF = 17,857,143

1/33nF = 30,303,030

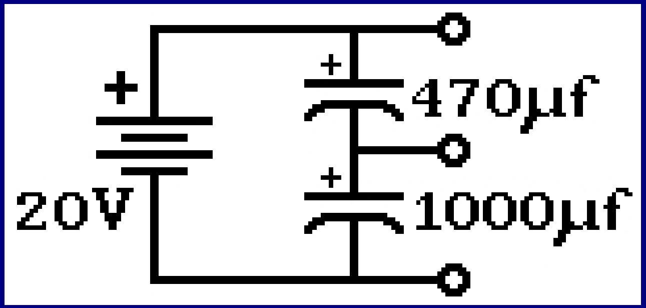


$1/C_T$ = 121,179,687 so C = 8.25nF

Voltage Division of UnequalCapacitors

The flow of charge in a series capacitor circuit is equal everywhere.

$$V = \frac{Q}{C}$$



Capacitor Voltage is inversely proportional to its Capacitance.

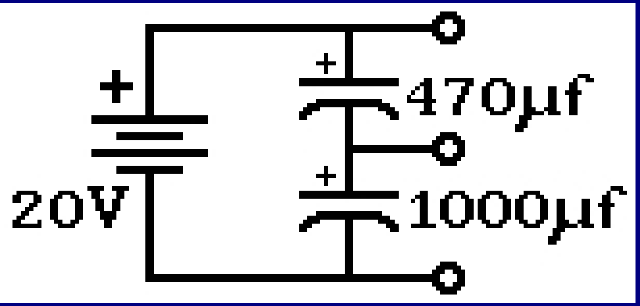
$$V_X = \frac{C_T}{C_X} \times V_T$$

Small capacitors will have high voltage.

$$V_1 = \frac{C_2}{C_1} \times V_2$$

Large capacitors will have low voltage.

Voltage Division of Unequal Capacitors



$$V_X = \frac{C_T}{C_X} \times V_T$$

$$C_T = \frac{1000\,\mu F \times 470\,\mu F}{1470\,\mu F} = 319.7\,\mu F$$

$$V_{1000} = \frac{319.7\,\mu F}{1000\,\mu F} \times 20\,V = 6.4\,V$$

$$V_{470} = \frac{319.7\,\mu F}{470\,\mu F} \times 20\,V = 13.6\,V$$

Variable Capacitance

A variable capacitor has a fixed set of Stator plates insulated from the frame, and a rotating set of plates mounted on the tuning shaft.

Changing the position of the rotor plates changes the overlap between plates, which changes the capacitance.

420pF “Broadcast Band” Variable

Variable Transmitting Capacitors designed for High Voltage and High Current in a Power Amplifier or Tuner.

Top is a 65-850pF 3KV Air Variable.

Bottom is a 10-1000pF 5KV Ceramic Vacuum Variable.

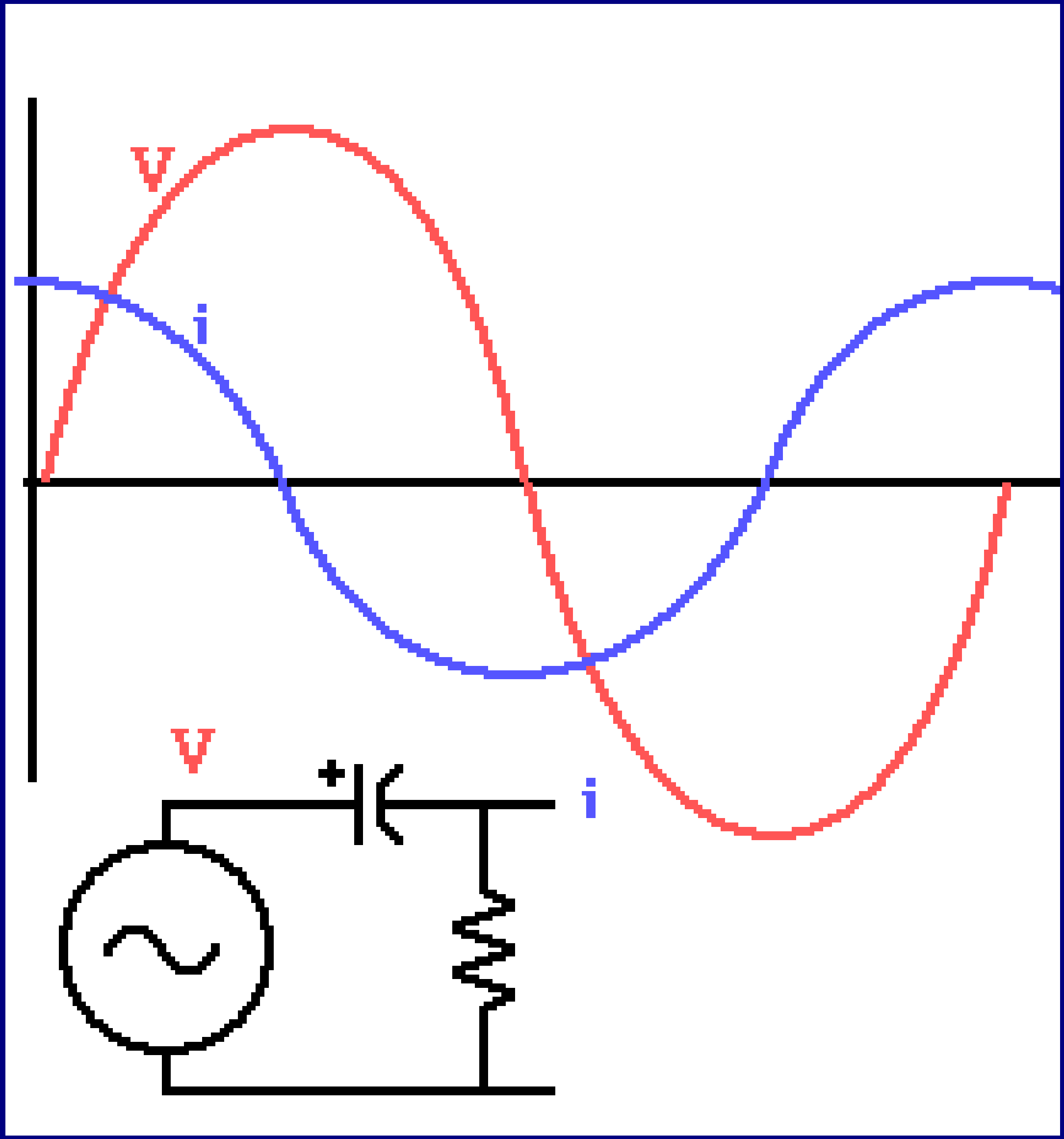
IMPEDANCE

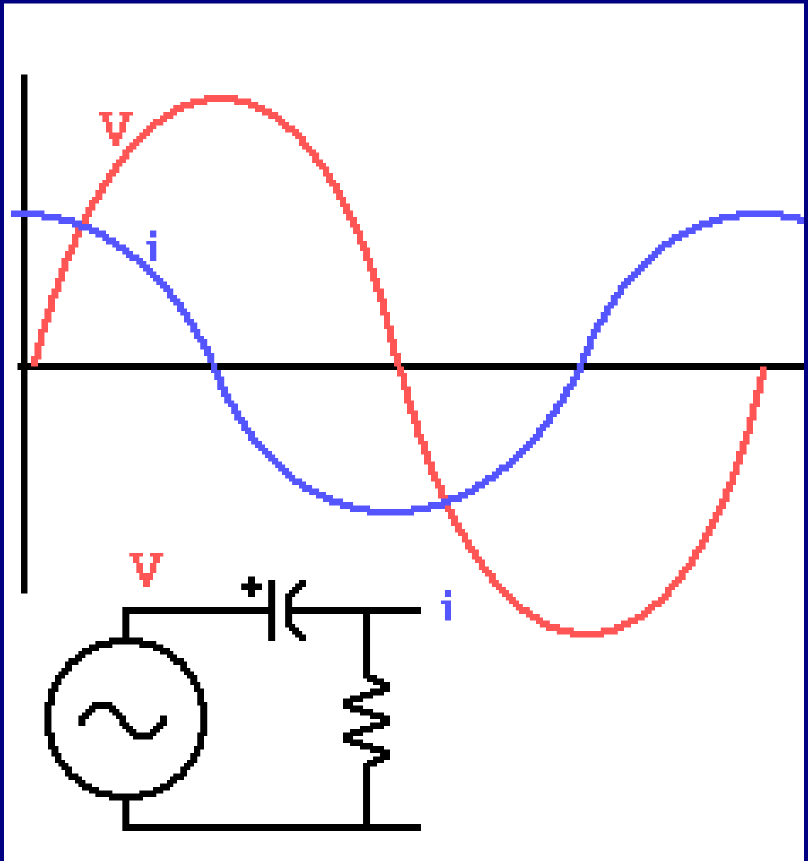
The AC Resistance

Capacitive Reactance

Inductive Reactance

Capacitive Reactance





$$X_C = \frac{1}{2\pi f C}$$

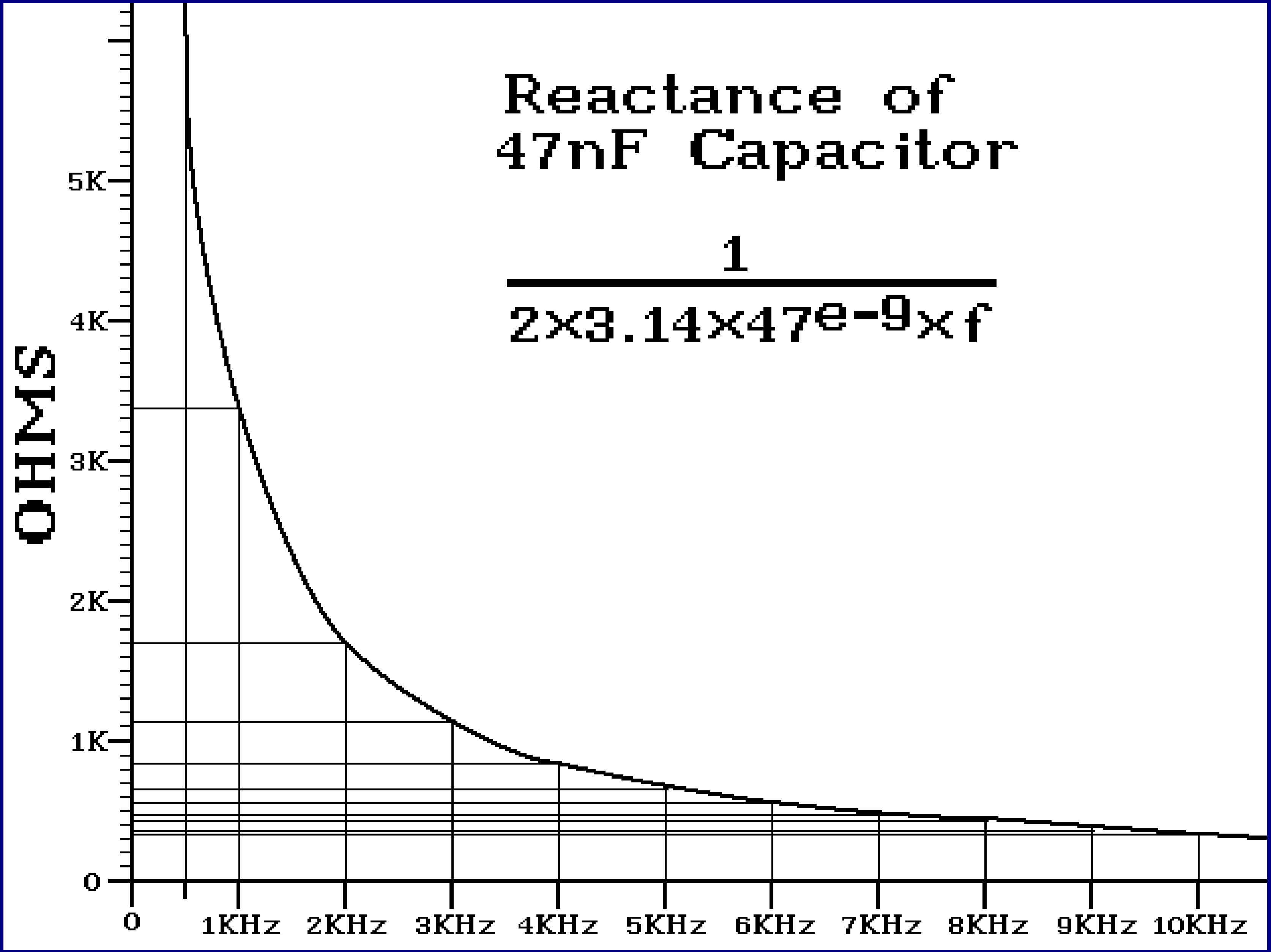
Current Leads Voltage in a capacitor by 90 degrees.

Or…

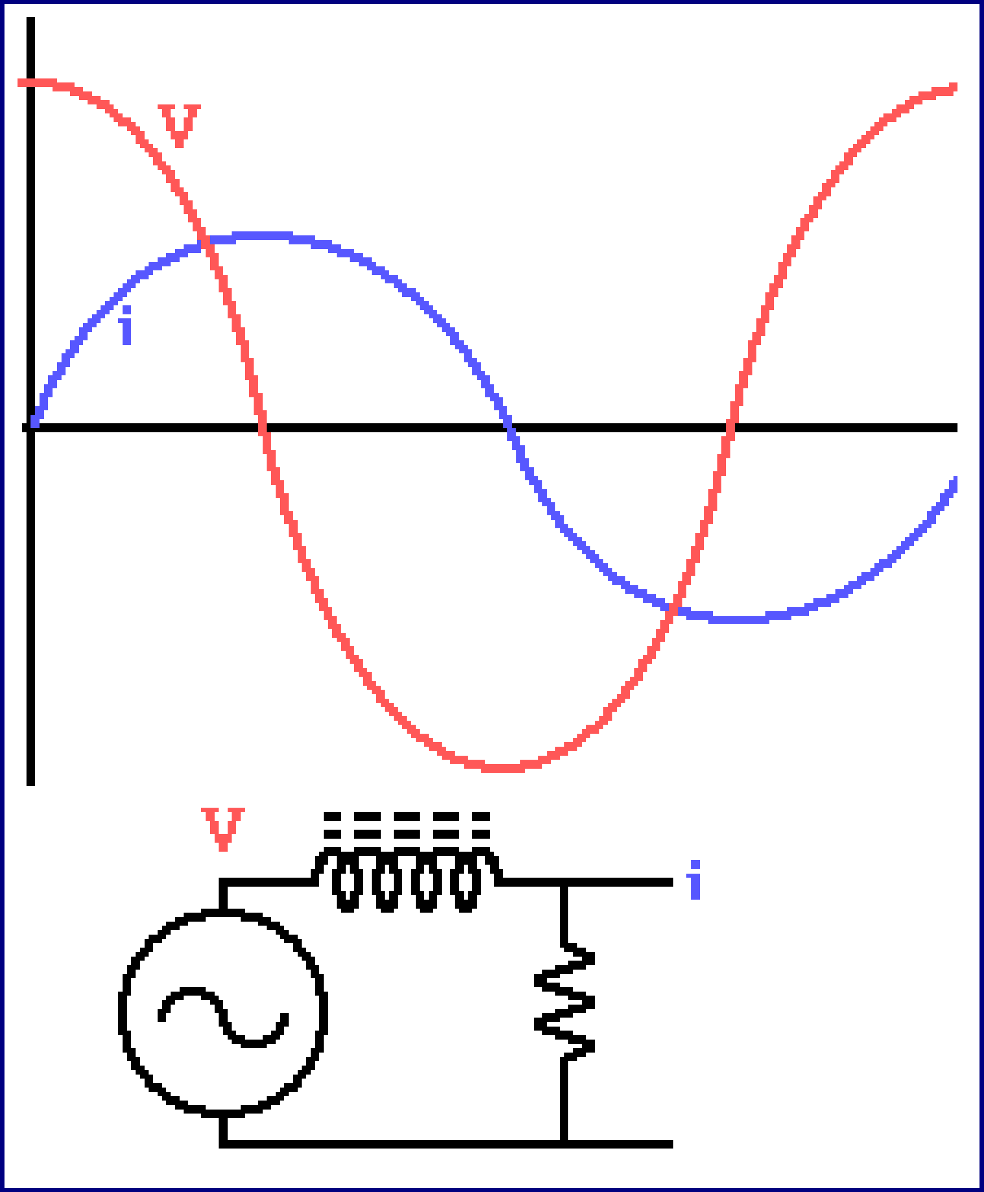
Voltage Lags Current by 90 degrees.

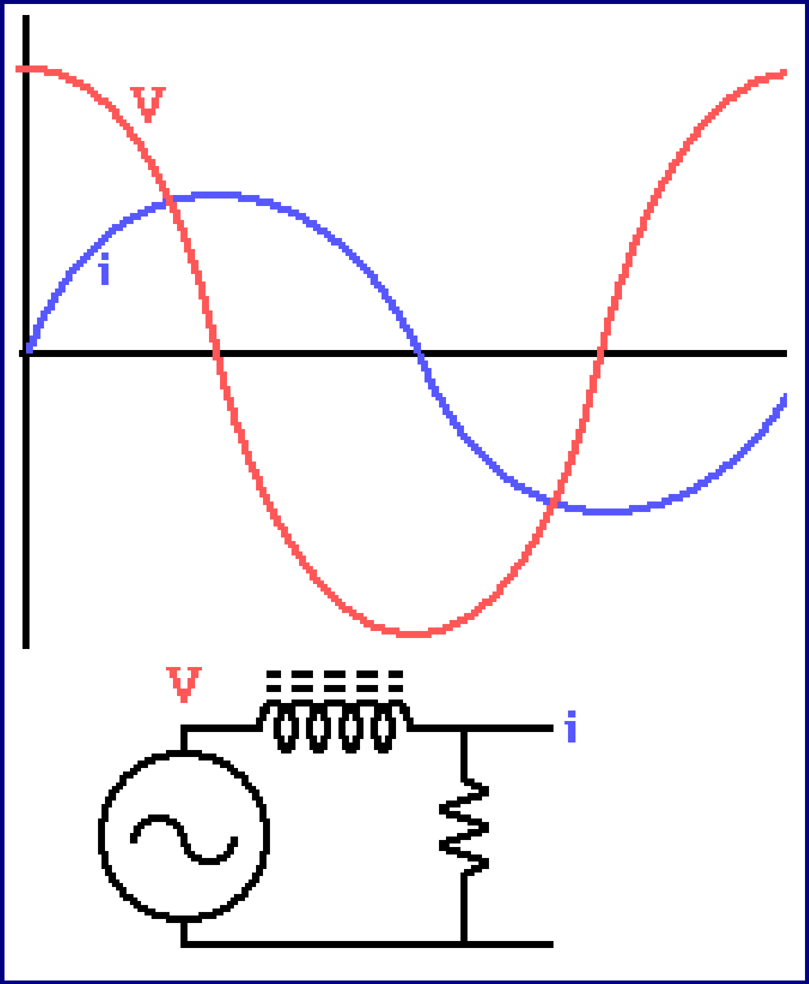
Capacitive Reactance decreases with increasing frequency.

Reactance is Frequency Dependant



Inductive Reactance





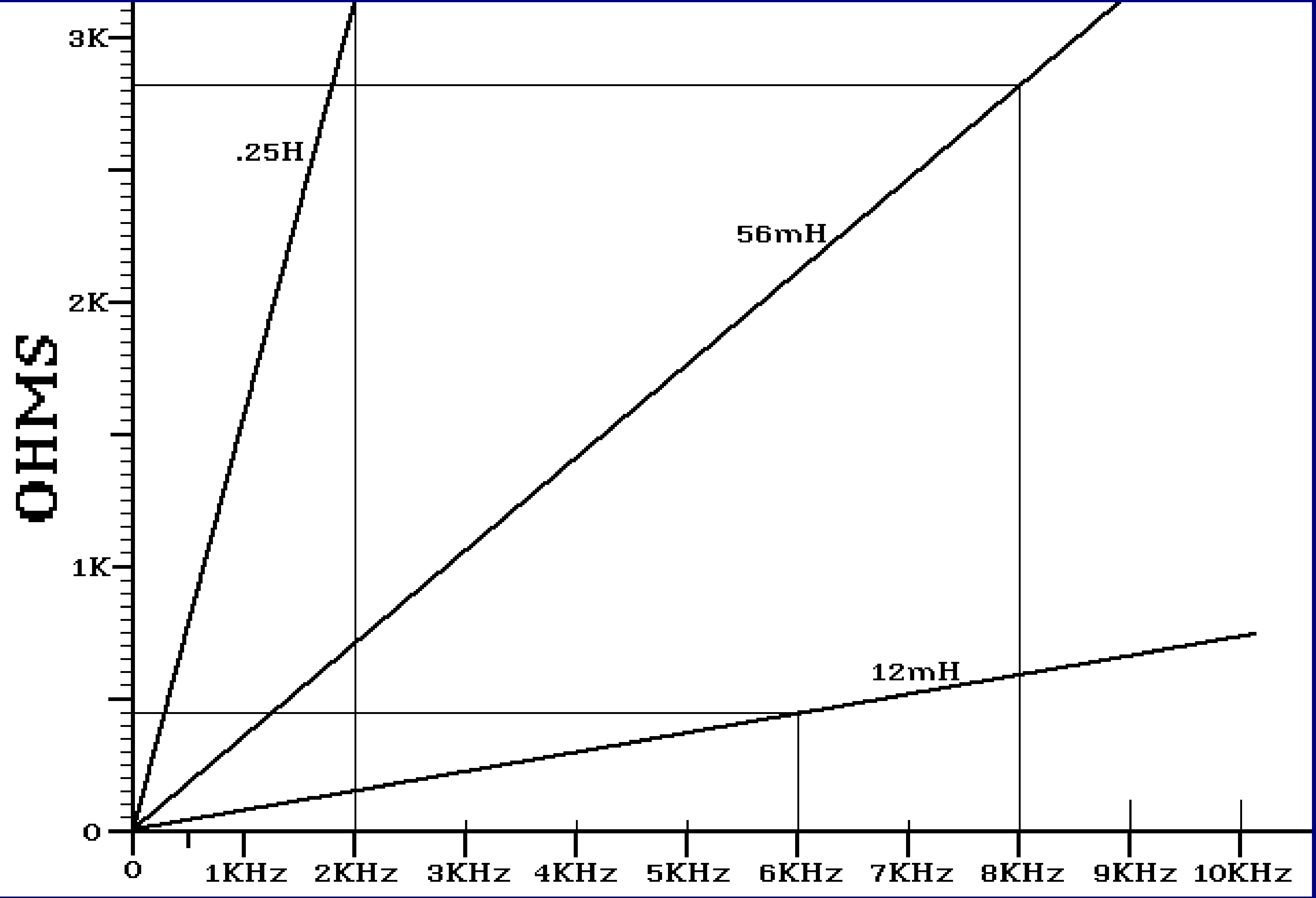
Current Lags Voltage in an Inductor by 90 degrees,

Or:
Voltage Leads Current by 90 degrees.

Inductive Reactance (X_L) increases with increasing frequency.

$$X_L = 2\pi f L$$

Reactance Varies with Frequency



IMPEDANCE

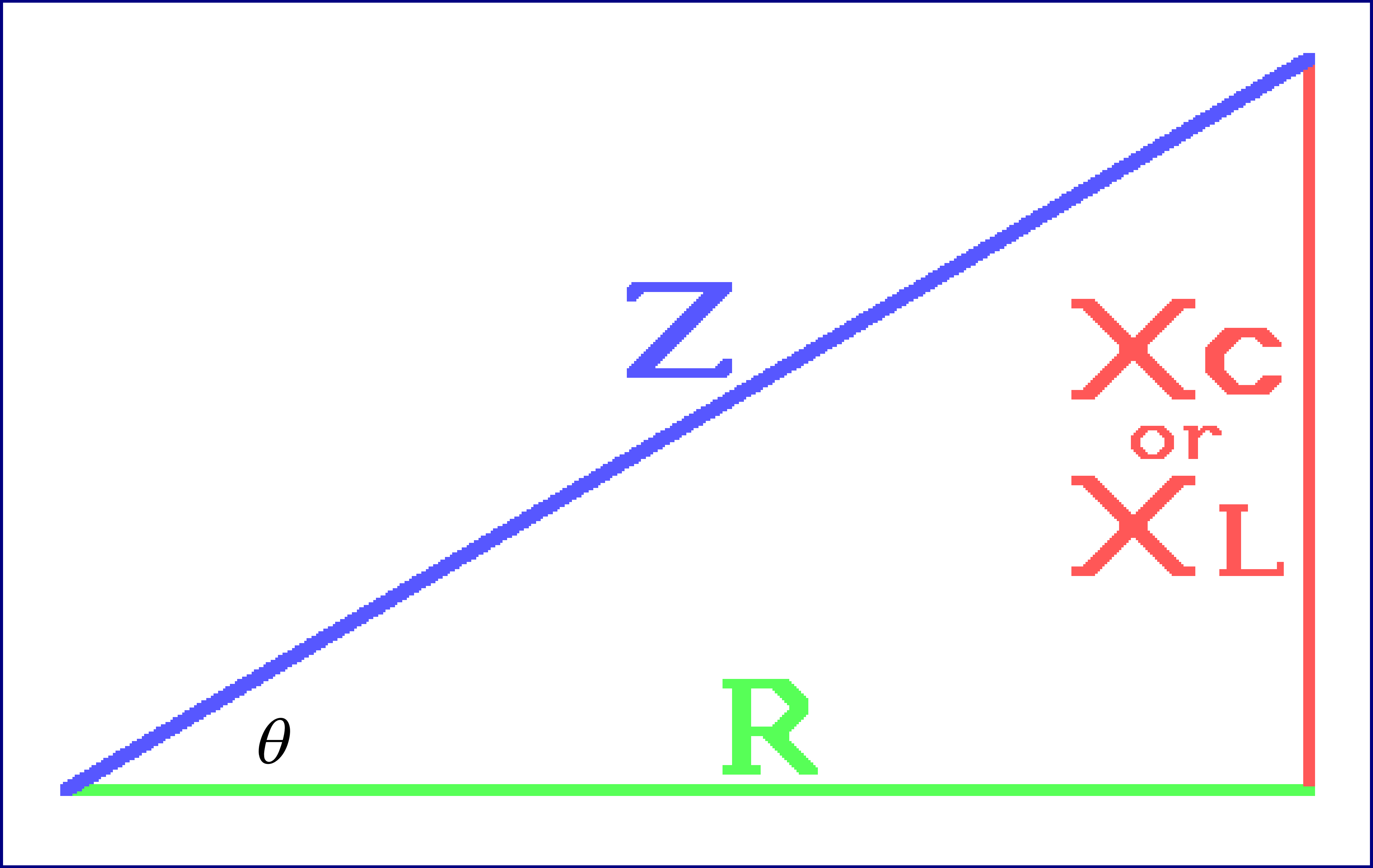
Real circuits contain both Resistance & Reactance.

Current in a resistor is in phase with the applied voltage.

Current in a Reactance (a capacitor or coil) is either leading or lagging.

Combining Resistance and Reactance creates an Impedance in which the current leads or lags voltage by less than 90 degrees.

Impedance



Complex Numbers

Impedance is made up of two parts:

The Real Resistance, in Ohms.

The "Imaginary" Reactance, in Ohms.

The rectangular form usually used is:

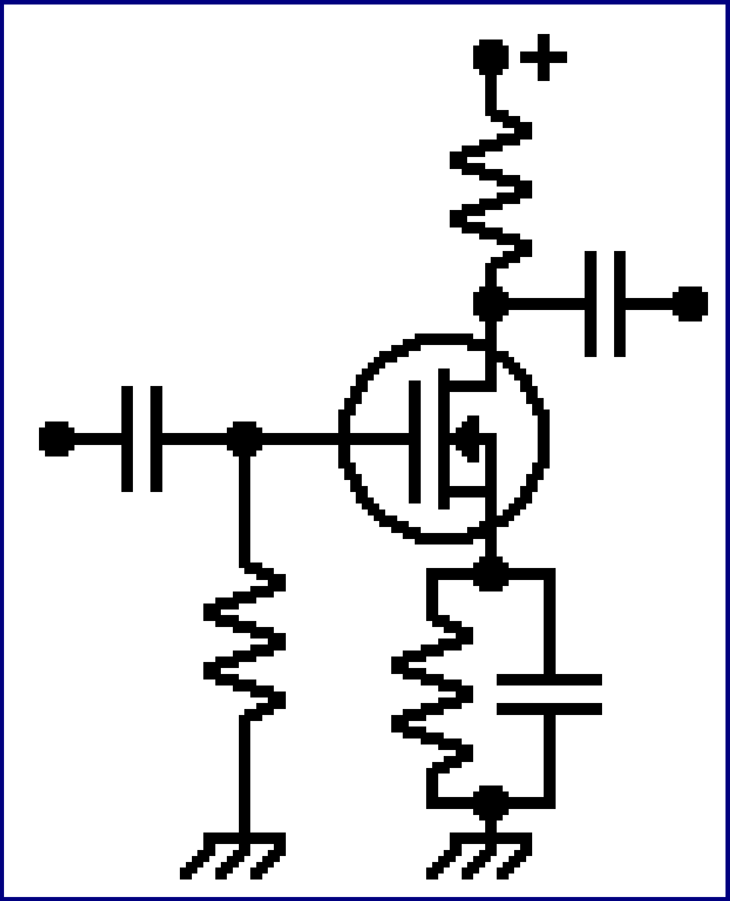
Resistance plus or minus Reactance

$$Z = R+X_L \quad \text{or} \quad R-X_C$$

Impedance can also be shown as a magnitude and phase angle:

$$Z \angle \theta$$

Applications: Coupling and Bypass

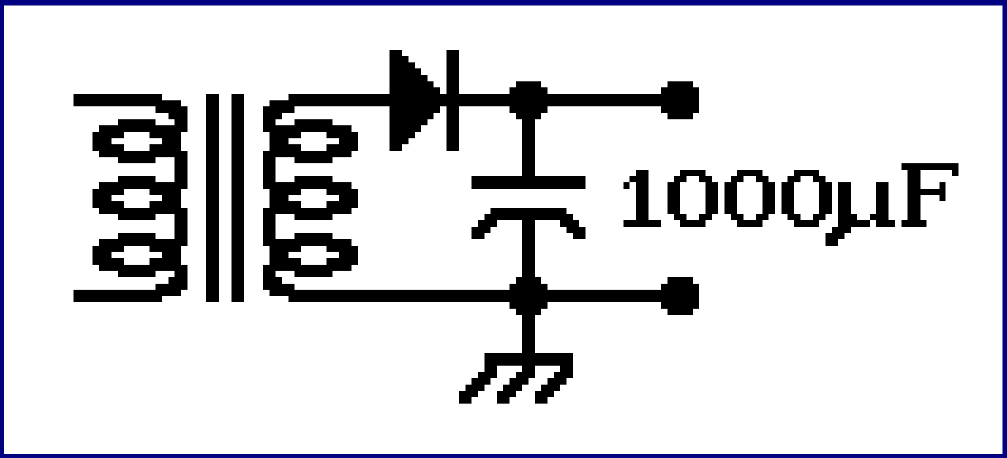


Capacitors used for coupling signals into and out of amplifiers must be big enough to have low X_C.

Capacitors that bypass resistors must have a X_C lower than the resistance.

$$C = \frac{1}{2\pi f X_C}$$

Applications: Filtering



A large capacitor is used to store charge in a power supply.

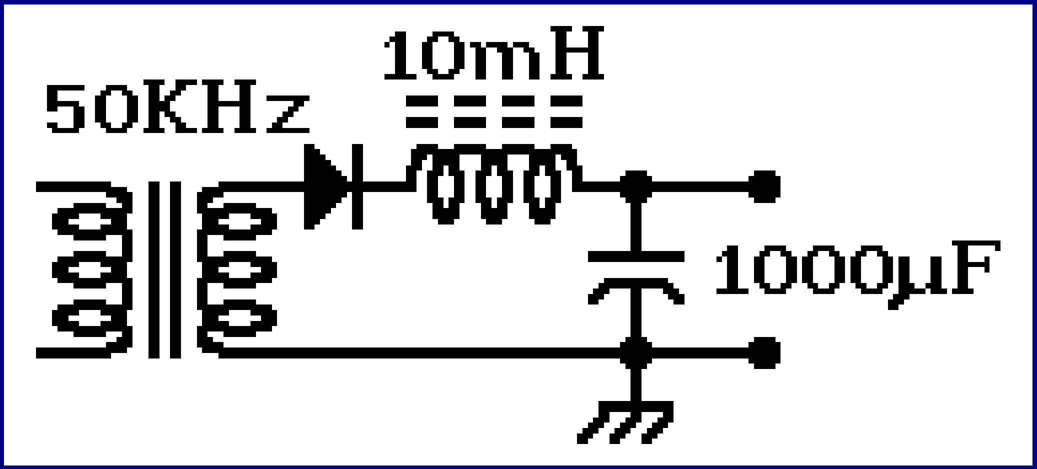
The rectified power is at 60Hz, line frequency.

What is the X_C of the filter capacitor?

$$X_C = \frac{1}{2\pi f C}$$

$$X_C = \frac{1}{2\pi 60 \times 1^{-3}} = \frac{1}{377 \times 1^{-3}} = 2.65\,\Omega$$

Applications: Filtering



In a switch mode power supply the frequency is 50KHz.

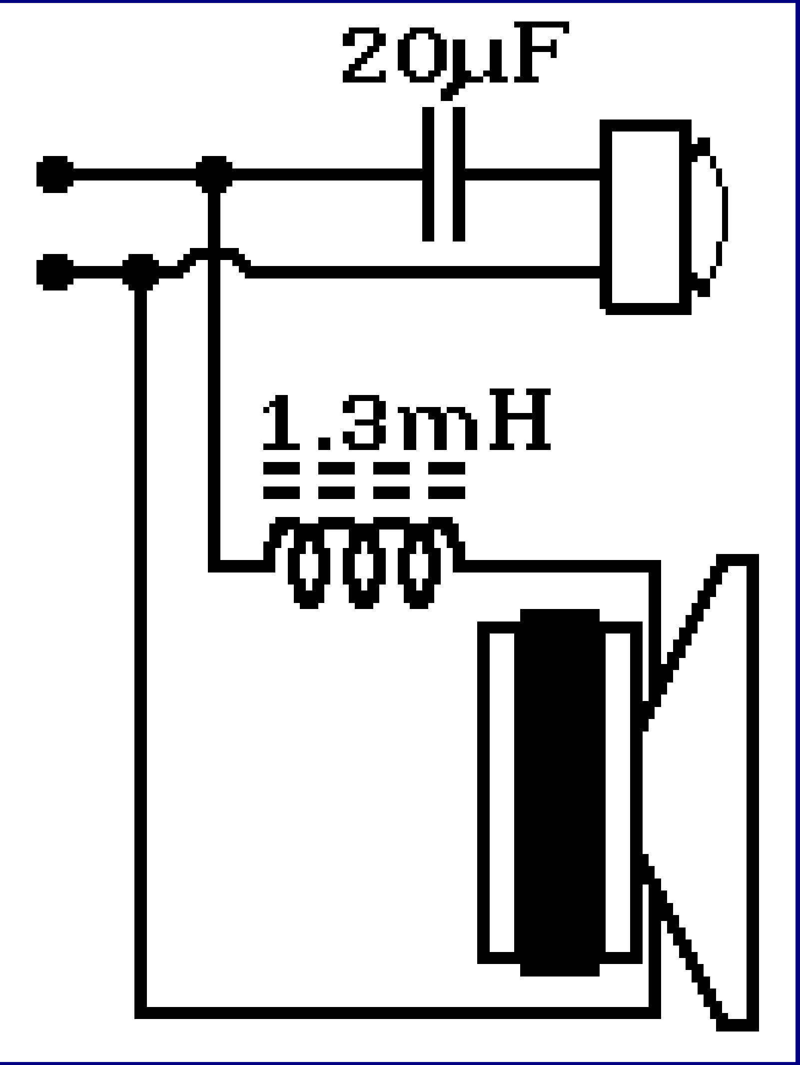
What is the X_L of the choke coil?

What is the X_C of the filter capacitor?

$$X_L = 2\pi f L = 2\pi 50000\, L$$
$$314159 \times 0.01$$
$$3141.6\,\Omega$$

$$X_C = \frac{1}{2\pi 50^3 \times 1^{-3}} = \frac{1}{314159 \times 1^{-3}} = 3.2\, m\Omega$$

Applications: Separating Frequencies



A Woofer can’t handle frequencies over 1KHz.

A Tweeter can’t handle frequencies under 1KHz.

A Cross Over Network blocks high frequencies from the woofer and low frequencies from the tweeter.