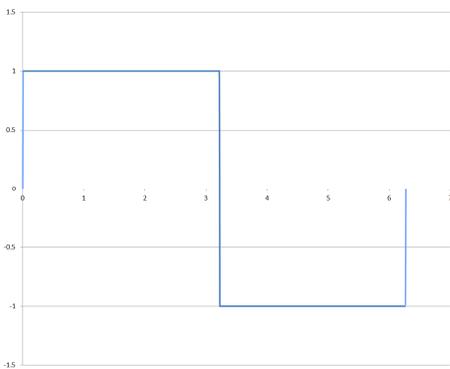


## How do we use an oscilloscope?

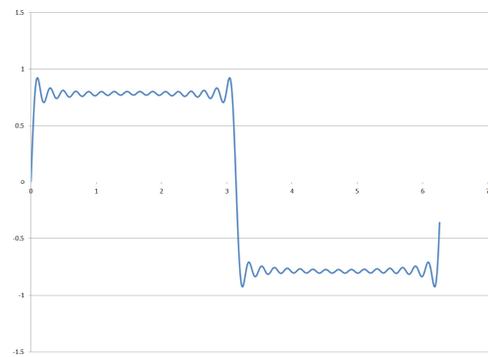
- Measure signals with unknown wave shapes and frequency other than 60 Hz sine waves and dc.
- To get a picture of the waveform.
  - Distortion?
  - Phase duration?
  - Magnitude

Any wave shape can be reproduced by the sum of sine waves of the appropriate magnitude and frequency.

60 cycle/second square wave



Sum of the fundamental and the 3<sup>rd</sup> to the 31<sup>st</sup> harmonic.

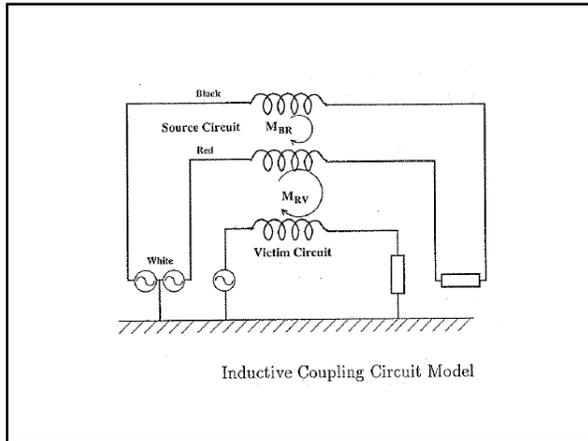


## Impedance

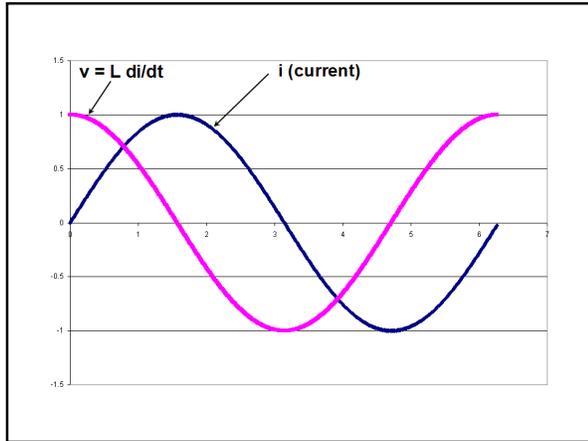
- Resistance,  $V=IR$
- Inductance
- Capacitance

## Inductance

- Oersted – Current carrying conductor creates a magnetic field.
- Ampere – Magnetic field linearly related to the magnitude of the current creating it.
- Faraday & Henry – Changing magnetic field could induce voltage in neighboring circuits, proportional to the rate of change of the current producing the field.



$$V = L \, di/dt$$



The faster you try to change the current through an inductor, the more it will resist and the more it looks like an open circuit. Thus, the higher the frequency the more an inductor looks like an open and the more it will try to block the high frequency current from passing through it.

INDUCTANCE

Inductive Reactance (ohms) =  $X_L = 2\pi fL$

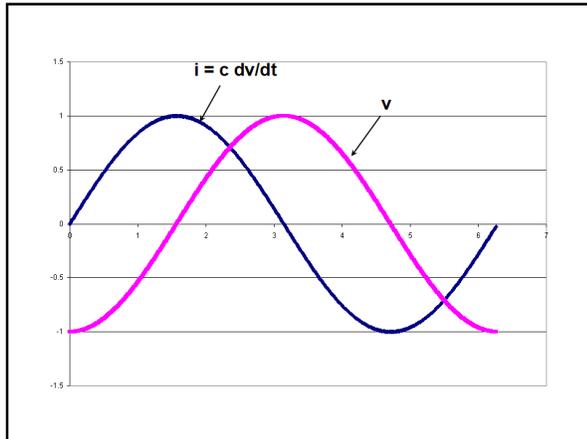
F = frequency in hertz (Hz)  
L = inductance in millihenrys (mh)

Example: (L = 13 mh)

@ 60 Hz	→	$X_L = 5$ ohms
@ 1000 Hz	→	$X_L = 81$ ohms
@ 10000 Hz	→	$X_L = 817$ ohms
@ 100000 Hz	→	$X_L = 8170$ ohms

Capacitance

$$i = C \, dv/dt$$



The current leads the voltage on a capacitor. In other words, the charge has to build up on the plates first (current first) before the voltage across the plates builds up.

- The current through (or into) a capacitor is zero if the voltage across it is not changing with time. A capacitor is thus an open circuit to dc.
- A finite amount of energy can be stored in a capacitor even if the current through the capacitor is zero. (Voltage is constant)
- It is impossible to change the voltage across a capacitor by a finite amount in zero time, for this would require an infinite current.
- **The higher the frequency, the more the capacitor looks like a short circuit.**

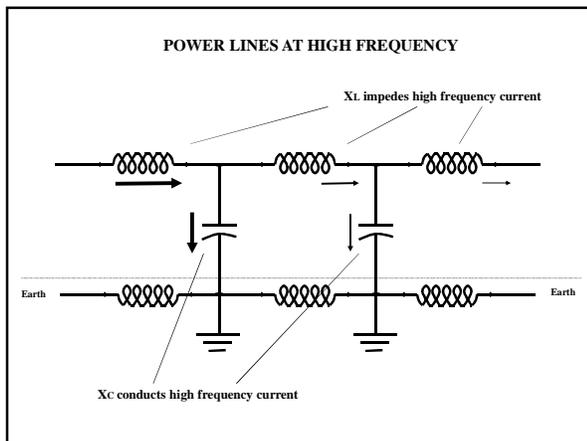
CAPACITANCE

Capacitive Reactance (ohms) =  $X_c = 1 / 2\pi fC$

F = frequency in hertz (Hz)  
C = capacitance in  $\mu$ farads ( $\mu$ f)

**Example: (C = 1  $\mu$ f)**

@ 60 Hz	→	$X_c = 2650$ ohms
@ 1000 Hz	→	$X_c = 159$ ohms
@ 10000 Hz	→	$X_c = 15.9$ ohms
@ 100000 Hz	→	$X_c = 1.59$ ohms



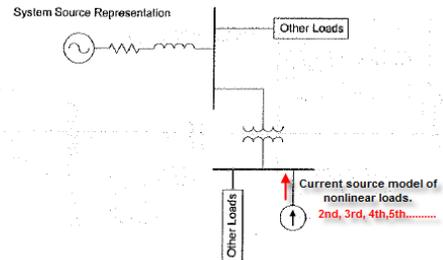
**Kirchhoff's Laws**

The laws still apply, regardless of the frequency. The current always returns to the source. (regardless of whether it is a power frequency current, a fencer pulse, a switching transient, a harmonic current,...)

## Harmonics Rules of Thumb

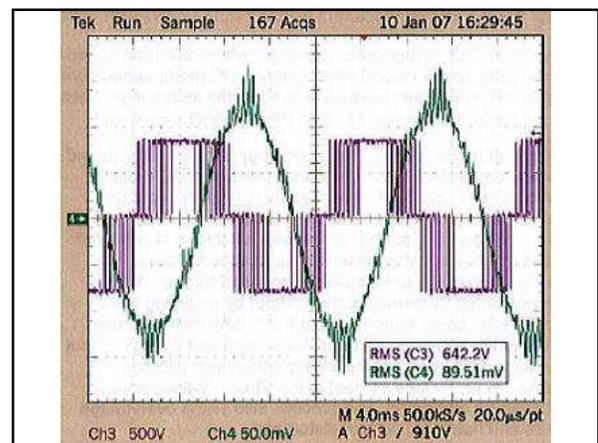
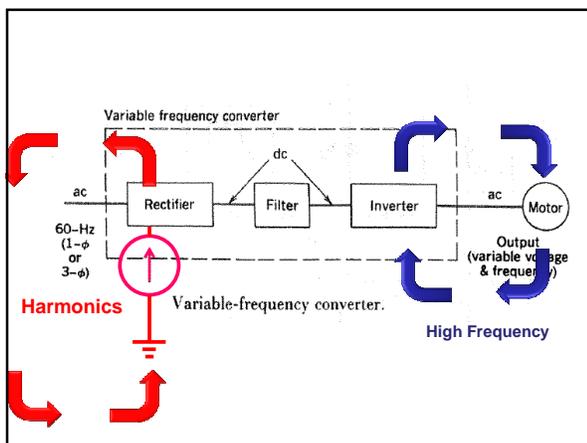
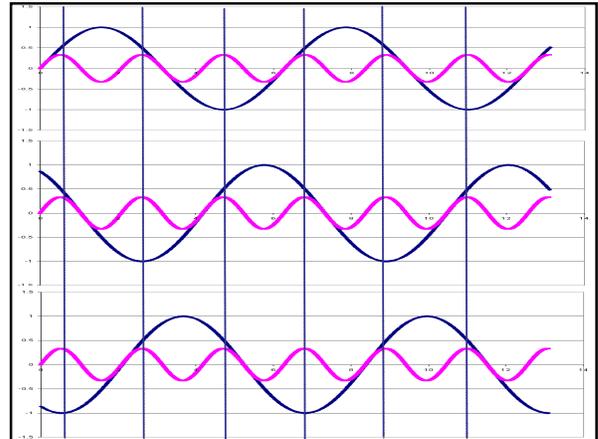
- If the waveform is repetitive at a specific frequency, the harmonics are multiples of that frequency.
- If the waveform is symmetrical about 0, all of the even harmonics drop out and only the odd harmonics are present.
- Triplen harmonics add in the neutral of three phase systems.
- Triplen harmonics (those that are multiples of 3) are blocked by any three phase delta winding.

- In general, a nonlinear load can be represented as a source of harmonic currents:



## HARMONICS

- The utility provides the voltage at 60 Hz.
- Harmonic currents are created by the customer load.
- Harmonic currents flow out from the source (harmonic load) into the power system (and back to the source) (Kirchhoff's Law).
- The utility system can not deliver real power at any frequency other than 60 Hz.



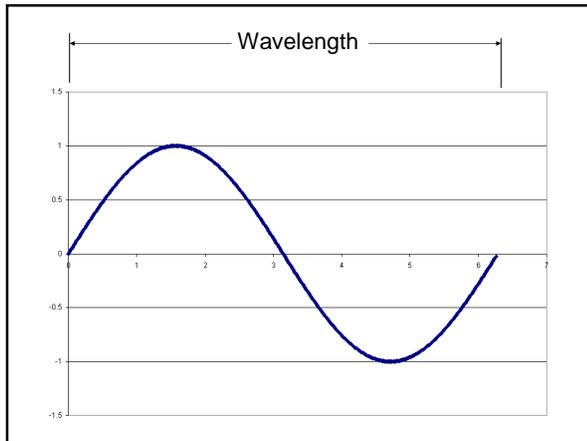
### Transient Propagation

- Obeys circuit laws
- Current flows in circuit
- Capacitance may complete circuit



### Impact of Electromagnetic Radiation and Measurements

- Frequency is measured in cycles/second. (Hertz)
- The speed of light is approximately 186,000 miles per second, or  $10^9$  ft/sec.
- $10^9 \text{ ft/sec} \div \text{cycles/sec (frequency)} = \text{ft/cycle (wave length of any signal)}$ .



### Frequency vs. Wavelength

Frequency	Wavelength
1 Megahertz	1000 feet
10 Megahertz	100 feet
50 Megahertz	20 feet

- Long leads connected to an oscilloscope may act like an antenna to high frequency signals.
- Rule of thumb: limit the end to end length of the leads used to make high frequency measurements to 10% of the wave length.
- In the presence of 10 MHz signals, the lead length should be limited to 10 feet.

### Summary

- Complex signals are made up of a sum of sine waves of various frequencies.
- Circuit impedance to a signal will vary with frequency, and thus the response to each frequency will look different.
- The distribution system will look like a low-pass filter, and thus will not pass high frequency signals.
- Current always returns to its source.
- Keep oscilloscope lead lengths short, to avoid interference.