Lab 3

AC Voltages, Transformer, Generator

Introduction

In this lab you will explore more electric circuit concepts:

- You will use AC voltage signals, and build a simple transformer and an AC generator.
- You will learn how to use the oscilloscope and function generator.

Before we start this lab, we need to learn:

- The difference between DC and AC signals.
- Some of the people that discovered these electric circuit concepts.
- What electromagnetic induction is.

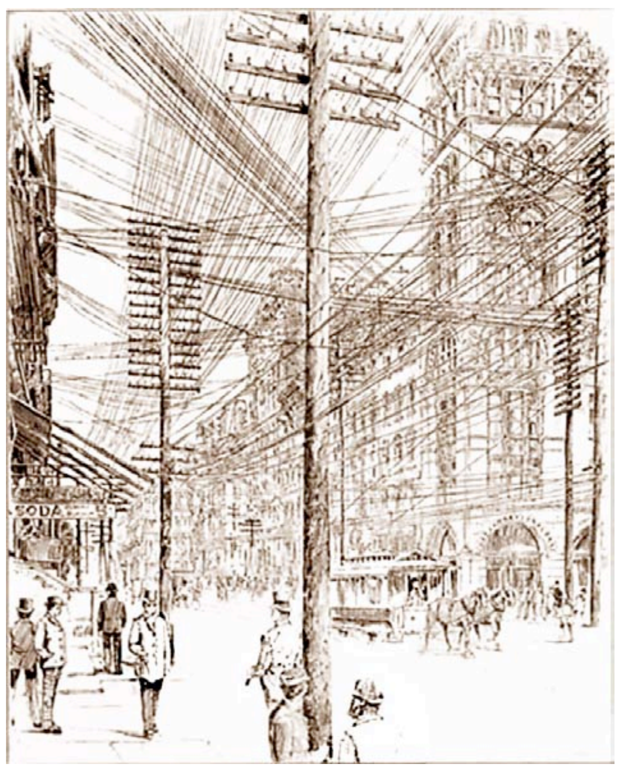
Delivery of Electric Power

Direct Current (DC) Electric Power

In the early years, electricity was delivered at a constant voltage. We call these "direct current" (DC) systems.

In the 1900's, DC voltage could not easily be converted to higher or lower voltage values.

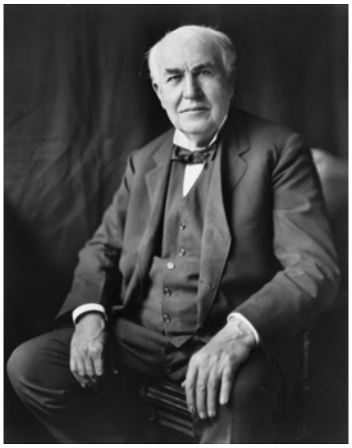
- And so cities had many sets of power stations and power lines, delivering electricity to customers at many different voltages.



A street in New York in 1890.

Picture from Wikipedia

DC Electric Power



Picture from Wikipedia

The American inventor Thomas Edison (1847 - 1931) was one of the pioneers of electrical technologies.

- In 1880, he established the Edison Illuminating Company, to provide DC electric power to customers, so that he could sell them his light bulbs.
- In 1890, he founded Edison General Electric, which is now called General Electric.

Edison established the first industrial research lab in the United States, and employed many scientists and engineers.

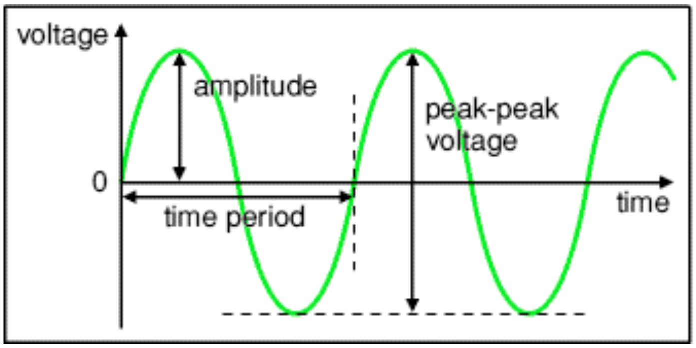
- One of them was Henry Ford (1863 - 1947), who became an engineer with the Edison Illuminating Company in 1891. He later founded the Ford Motor Company.

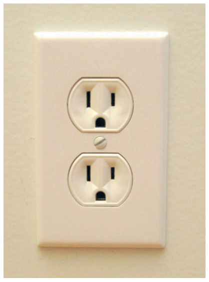
Picture from Wikipedia

Alternating Current (AC) Electric Power

Generally, we now use "alternating current" (AC) systems to deliver electric power to homes and industries. AC systems use a voltage that varies in time sinusoidally, and swings between a positive and a negative amplitude.

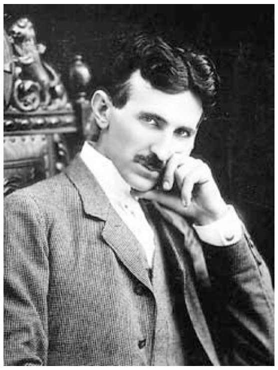
- Since the voltage reverses periodically, the current in the circuit also reverses periodically. Hence, the name "alternating current" (AC).





The voltage in your house is AC.

AC Electric Power



Nikola Tesla (1856 - 1943) was a Serbian mechanical and electrical engineer, who later became an American citizen.

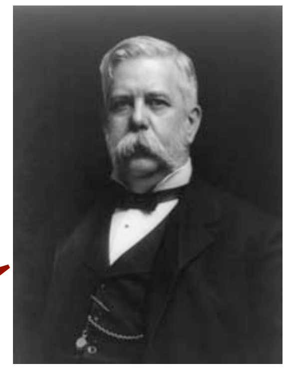
- Tesla's work on AC generation forms the basis of modern AC electric power systems.

His many inventions, eccentric personality, and research on things like death ray weapons led to him being regarded as a "mad scientist".

George Westinghouse Jr. (1846 - 1914) was an American engineer.

- In 1886, he founded the Westinghouse Electric Company, which delivered AC electric power.
- In 1888, Westinghouse partnered with Tesla.

In 1869, when he was 22 years old, he invented the railway air brake. Before this centralized system, brakemen had to run from car to car, manually applying brakes.



Picture from Wikipedia

The "War of Currents": AC vs. DC

Electric power can be delivered using DC or AC systems. Which is better?

- The answer depends on the distance and the technology used.

In the late 1800's, the answer was not so clear. The Edison and Westinghouse companies were adversaries in this battle.

- At first, when Tesla first arrived in the US in 1884, he briefly worked with Thomas Edison. But he soon quit after a dispute over how much he should be paid. Edison also did not appreciate Tesla's ideas on AC power transmission.
- Edison carried out a publicity campaign to discourage AC usage. Edison tried to demonstrate AC was dangerous by publicly killing animals using AC voltages.

Eventually, Tesla's efficient AC electric motor and power transmission ideas helped win the battle for AC.

War of Currents: Winner was AC

Voltages in an AC system can be easily increased or decreased using a transformer.

An adapter uses a transformer to reduce the 120 V in the wall socket to lower values.

A transformer is used to convert the high voltage of a power line, to 120 V before entering homes.

The ability to easily change AC voltages led to AC winning the War of Currents:

- Electric power could be delivered more efficiently using high voltages.
- At the customer, the voltage is reduced it to a lower value, which can be used more safely.

High Voltage Power Transmission

Why is the delivery of electric power more efficient when high voltages are used?

Two reasons are:

1. Power delivered is equal to: $P_{Delivered} = V \times I$.
   - And so if we want a high $P_{Delivered}$, we need a high voltage, or a high current, or both.
   - A high current needs a larger copper wire, which is expensive and heavier. Therefore, a solution is to use a higher voltage.

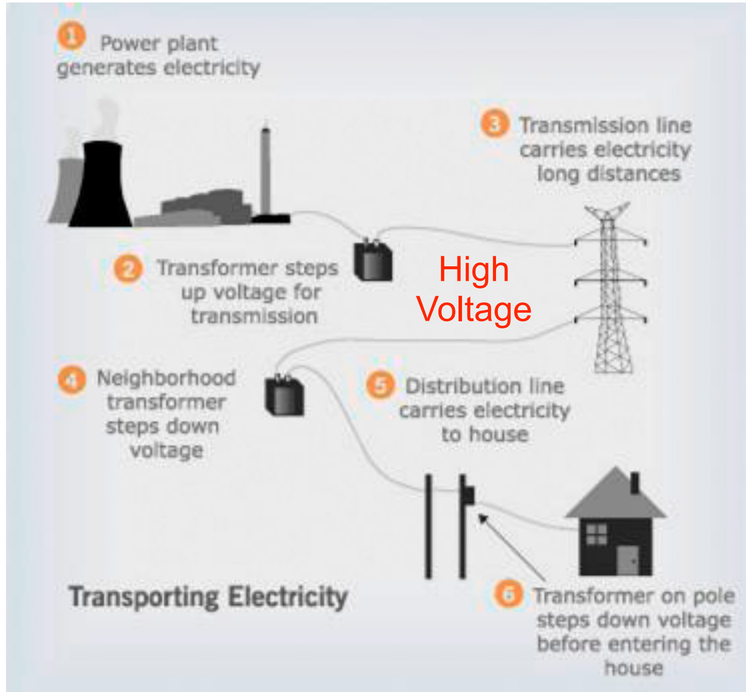
2. Power loss in a wire is equal to: $P_{Wire\ Loss} = I^2 \times R_{Wire}$. And so if we want low losses when delivering power:
   - We need short wires, which means having power plants close to users.
   - Or we should use lower current. If lower current is desired, then in order to maintain the same amount of power delivered, voltage must be higher.

Modern AC Power Transmission

Electric power is generated in AC form at the power station.

Electric power is converted to high voltage for transmission.

Voltages are reduced as needed at the customer.



Electric Power Generation in Manitoba

Nelson river power plant

Manitoba Hydro's Nelson River HVDC Transmission System: 4 GW over 950 km (approximately 70% of Manitoba's total installed generation)

Approximately 40% of Manitoba Hydro's revenues comes from exports. Manitoba's hydroelectric dams use their reservoirs to enable power cycling. Power is imported to Manitoba when prices are low and exported when prices are high (day/night).

DC Voltages Are Still Used Too

We still use and need DC voltages. Some uses include:

Microprocessors, which are used in computers, televisions, etc., need DC voltage. AC voltage is converted to DC voltage in their power supply.

For very long distance transmission of electric power, DC voltage is used instead of AC voltage, since it is less expensive.

Power and High Voltage Engineers

One of the expertise areas in electrical and computer engineering is in Power and Energy Systems. Some of the jobs of these engineers include:

Design and build power generation and transmission equipment.

Control power networks and ensure their stability.

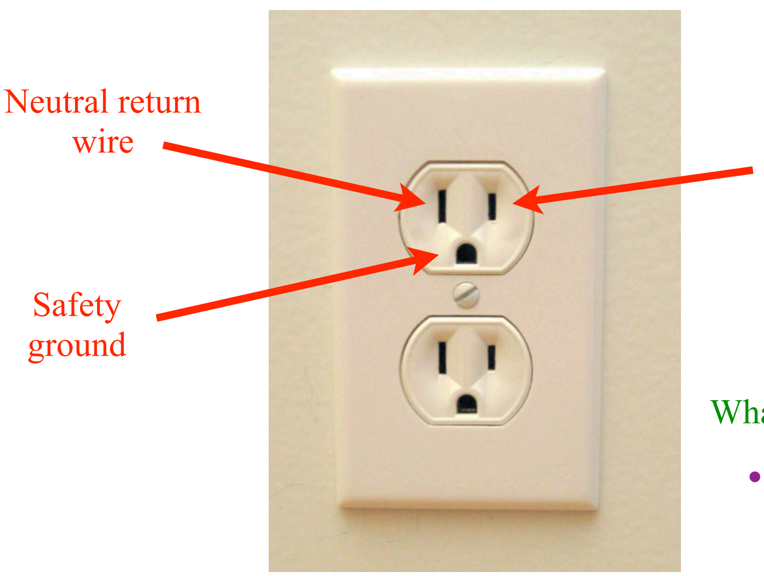
Develop "power electronics" technologies, such as those used in hybrid vehicles.

AC Power in Your Home

The Socket In The Wall

In a modern home in North America, the electrical socket looks like this.

- If it is wired correctly, the electrical connections should be as shown.



What is the AC voltage in the socket?

- No, it is not 120 volts.

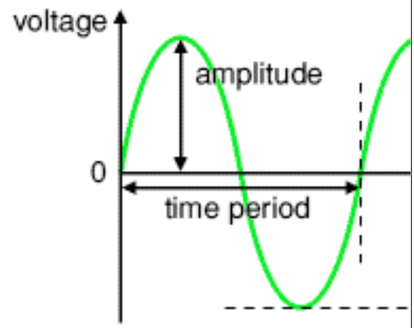
RMS Voltage

In your home the voltage is not actually 120 V. Rather it swings sinusoidally between ± 170 volts. The 120 V number is the RMS voltage.

- The RMS voltage is the "root mean square" voltage.

In an AC circuit, since the voltage is always changing, the power being delivered is constantly changing.

- If the voltage is always changing, how do we then use P = V x I to calculate power ?!??!?!



To make life easier on people, it is common to state the voltage to be not the peak amplitude, but rather a lower number which delivers the time averaged power.

- For a sinusoidal AC voltage, this value is calculated to be 0.707 of the amplitude.

$$V_{rms} = \frac{V_{amplitude}}{\sqrt{2}} = 0.707 \times V_{amplitude}$$

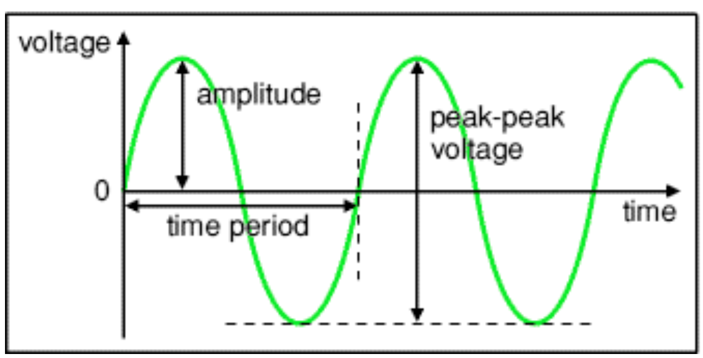
Frequency of an AC Signal

A sinusoidal AC signal repeats continuously. The number of times it repeats per second, its frequency, is measured in Hertz (or Hz).

- Hertz is defined as the number of complete cycles per second.
- The AC voltage in your house is 60 Hz. In Europe, 50 Hz is used.

$$\text{Frequency} = \frac{1}{\text{Time Period}}$$

1 Hz = 1 cycle per second



Example: If the frequency is 50 Hz, the time period is: $\text{Time period} = \frac{1}{50} = 0.02 \text{ s}$

Voltage, Current &

Electrical Safety

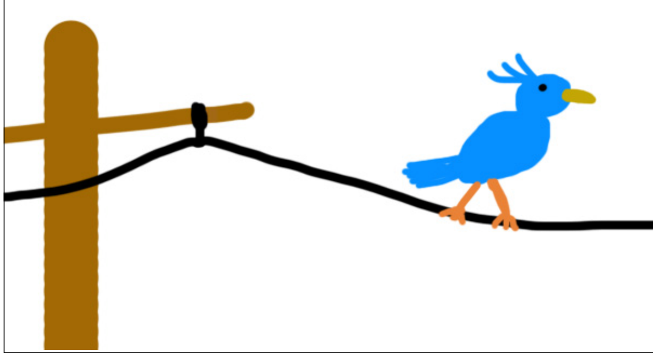
Dangers of Electric Current

Voltage is the potential to cause electric current to flow.

- High voltages can be dangerous because they can cause large amounts of current to flow through your body.

Recall Ohm's Law: $I = \frac{V}{R_{Body}}$

The international safety symbol showing danger of electric shock.



However, it is the current that passes through your body that harms you.

- Why can this bird safely sit on this power line?

Working At High Voltages

If you are safely isolated from the ground, you can work with high voltages without any danger of electric current passing through your body.

This movies shows linesman working on live power lines.

They get on and off using a helicopter so that they don't complete an electric circuit between them and the ground.

Notice how they carefully equalize their "electric potential" before they climb on or off the power line.

The Van de Graaff Generator

In 1929, the American physicist Robert Van de Graaff (1901 - 1967) invented the Van de Graaff generator. This device can generate very large electric voltages, even millions of volts.

- A non-conducting belt transfers charge generated at a lower electrode to an upper collection electrode. This charge can build up to very high voltages.

Even though the voltage is very high, the electric current from a typical Van de Graaff generator is small, and so you can ***"safely"*** touch it.

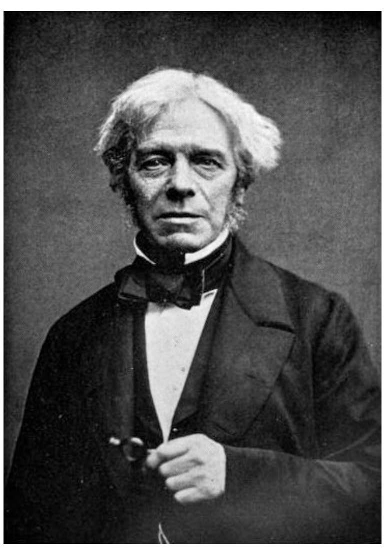
Picture from Wikipedia

How Do We Make AC Voltage?

&

How Does A Transformer Work?

Michael Faraday (1791 - 1867)



Picture from Wikipedia

Michael Faraday was an English chemist and physicist, and some say one of the most influential scientists in history.

- In 1831, he discovered electromagnetic induction, showing that a changing magnetic flux produces a voltage across the terminals of a nearby wire loop.

$$emf = -\frac{d\Phi}{dt}$$

- This means that when a wire loop moves near a magnet (or when a magnet moves near a wire loop), an electric current is observed in the wire.

This relationship forms the foundation of electric motor and generator technology.

Faraday is famous for his many electromagnetic and chemical discoveries. In 1834, Michael Faraday invented the rubber balloon, making children everywhere very happy.

Joseph Henry (1797 - 1878)

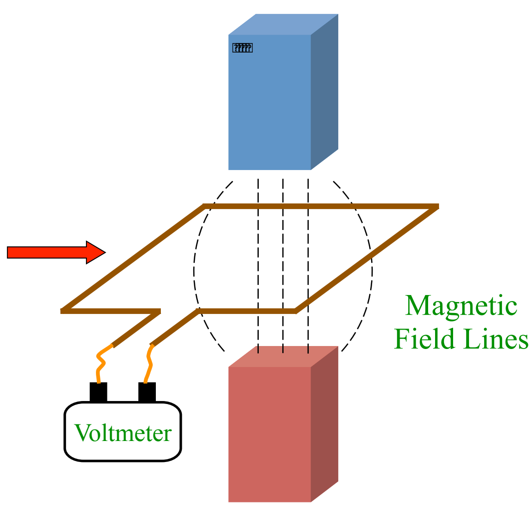
In 1830, the American scientist Joseph Henry independently discovered electromagnetic induction, but Faraday published his results first.

- Henry invented the doorbell in 1831, and relay in 1835.
- Henry's later work on the electromagnetic relay, and improvements to the electromagnet, helped make the electric telegraph possible.

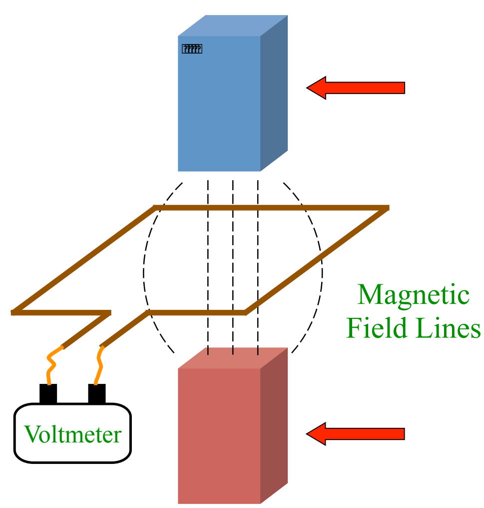
Henry's first love was the theatre, and he almost became a professional actor. His interest in science started at age 16 when he read a book of lectures on scientific topics.

Magnetic Induction

Moving Wire



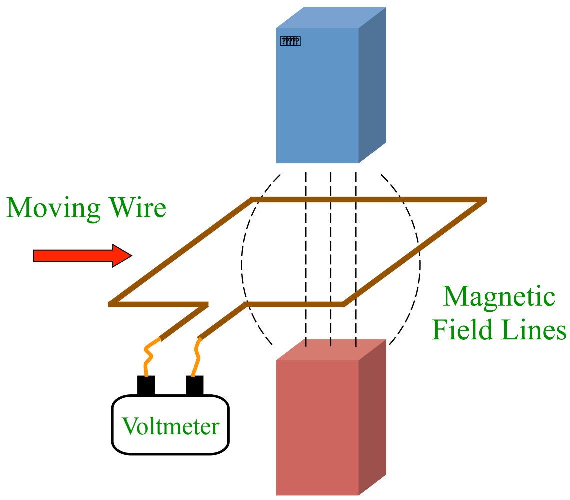
Moving Magnet



Whether we move the wire loop or the magnet, a voltage is induced at the ends of the wire loop, as the wire cuts through the magnetic field lines.

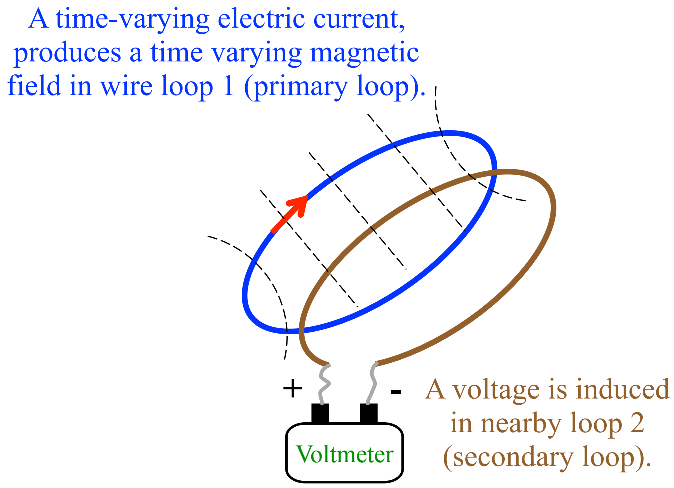
Magnetic Induction

Generator Mode



A voltage can be induced in a wire by moving the wire in a fixed magnetic field.

Transformer Mode



A voltage can be induced in a loop by placing it in a magnetic field that varies with time.

Generating AC Voltages

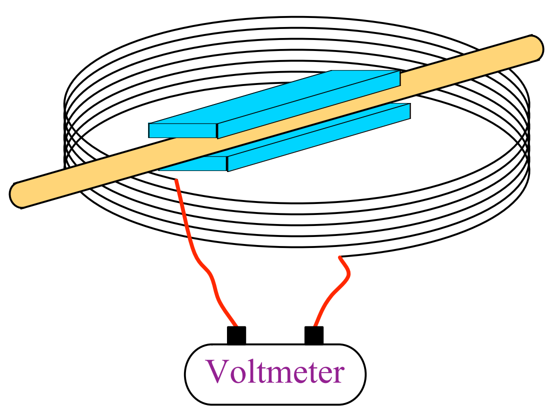
$$emf = -\frac{d\Phi}{dt}$$

Electromagnetic induction tells us that a changing magnetic field creates a current in a wire coil.

- Therefore, we should be able to make an AC generator by moving, or rotating, a magnet near a wire coil.

A simple AC generator can be made by attaching, one or more magnets to a shaft, and rotating it near or inside a wire coil.

- When the magnets rotate, the magnetic flux passing through the coil changes, creating an AC voltage.



You will build a simple AC generator in today's lab using this design.

Generating AC Voltages

$$emf = -\frac{d\Phi}{dt}$$

Looking at this equation more closely, we see that the voltage should increase if:

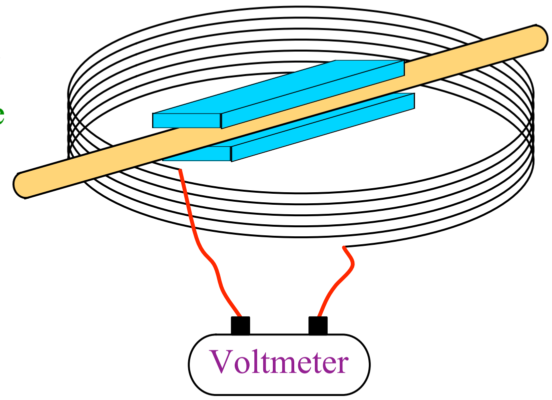
- The magnets rotate faster.
- The magnets are more powerful.

The number of turns in the coil is also important.

- The voltage generated is proportional to the number of coil windings.

Therefore, for a coil with N turns:

$$emf = -N\frac{d\Phi}{dt}$$

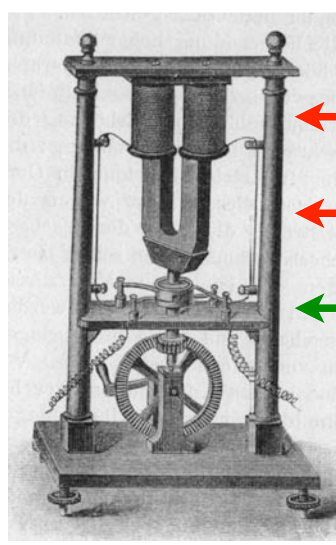


An Early AC Generator

In 1832, only 1 year after Faraday's discovery, the French instrument maker Hippolyte Pixii (1808 - 1835) built an early form of an alternating current generator.

Since only DC voltages were used at this time, a commutator was later added, after a suggestion by Andre Ampère.

- It is a rotary switch that reverses the current at the moment the AC voltage changes to negative, keeping the voltage always positive.



Picture from Wikipedia

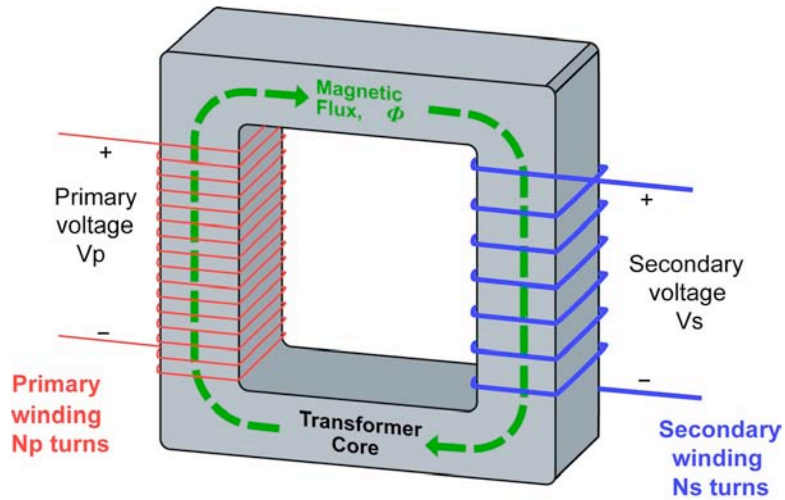
Transformer Operation

Transformers are used to convert **AC voltages** between high and low values. They can simply be made by wrapping two wire coils around a magnetic material.

- The AC current in the primary side coil creates a magnetic flux.
- This flux then induces an AC current on the secondary side coil.

The voltage ratio between the two sides of the transformer, is equal to the turns ratio between the wire coils.

$$\frac{Vs}{Vp} = \frac{Ns}{Np}$$



Important Things To

Remember

Important Points

Electric power is delivered more efficiently at higher voltages, since the current is lower, resulting in lower resistive losses in the transmission wires.

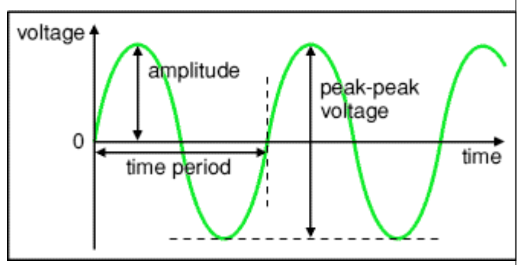
Faraday's law tells us that a changing magnetic flux produces a voltage across the terminals of a nearby wire coil, that is proportional to the rate of change of the magnetic flux and the number of turns in the wire coil.

$$emf = -N\frac{d\Phi}{dt}$$

For a transformer: $$\frac{Vs}{Vp} = \frac{Ns}{Np}$$

For a sinusoidal AC signal, you should understand this figure, and that the RMS voltage is defined as:

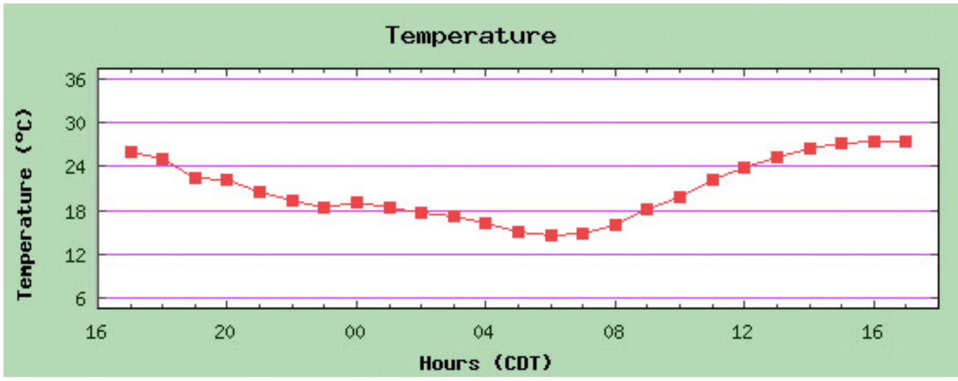
$$V_{rms} = \frac{V_{amplitude}}{\sqrt{2}} = 0.707 \times V_{amplitude}$$



Equipment Used in Today's Lab

Time-Varying Parameters

There are many parameters that vary with time, such as the outdoor temperature over a 24 hour period.



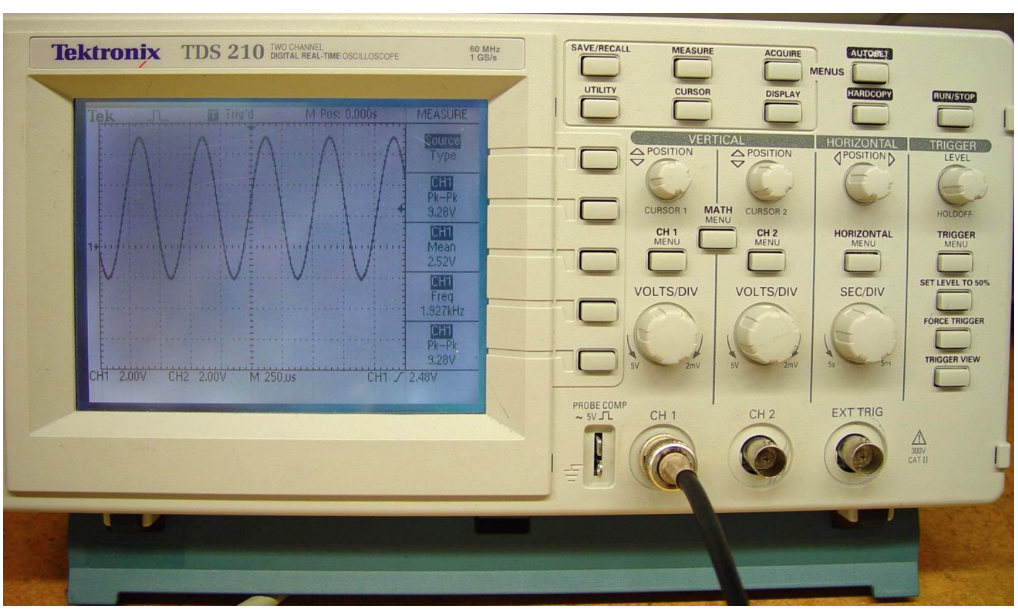
If the parameter of interest varies slowly with time, we can make a plot of the parameter manually.

However, for a fast-varying voltage we need a special device ...

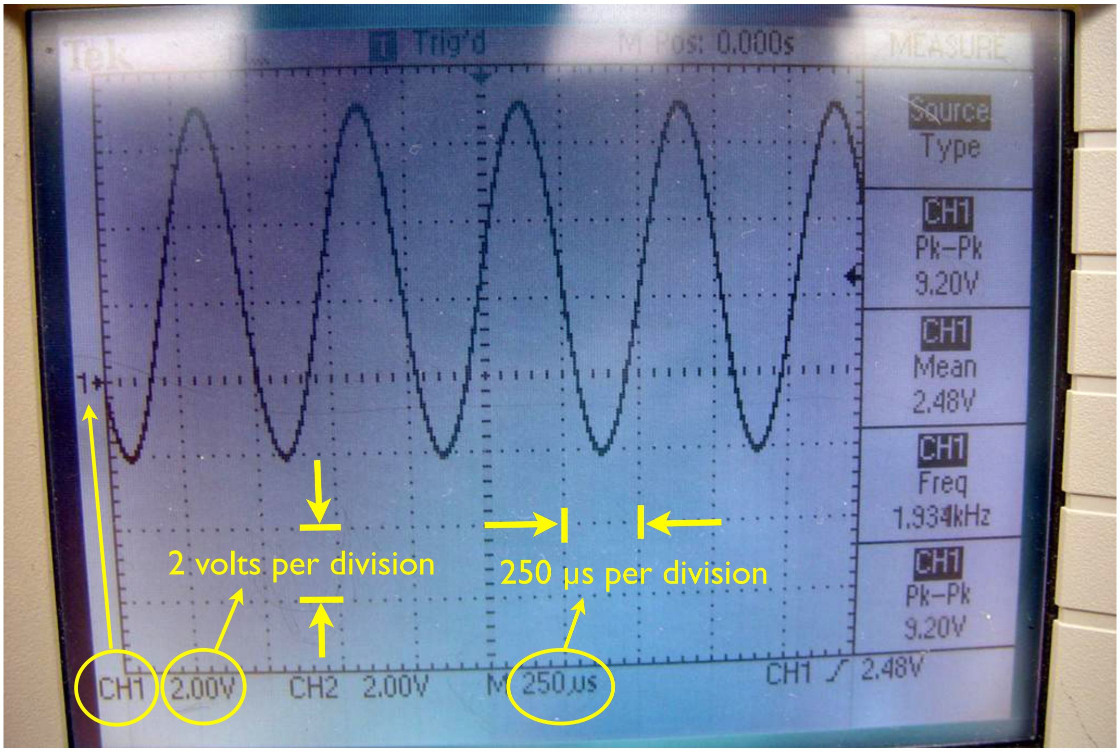
What is an Oscilloscope?

An oscilloscope is piece of equipment that shows the variation of a voltage with time.

- Basically it is a voltmeter that not only shows the value of the voltage, but also shows how it varies with time.



How to Read the Oscilloscope Display



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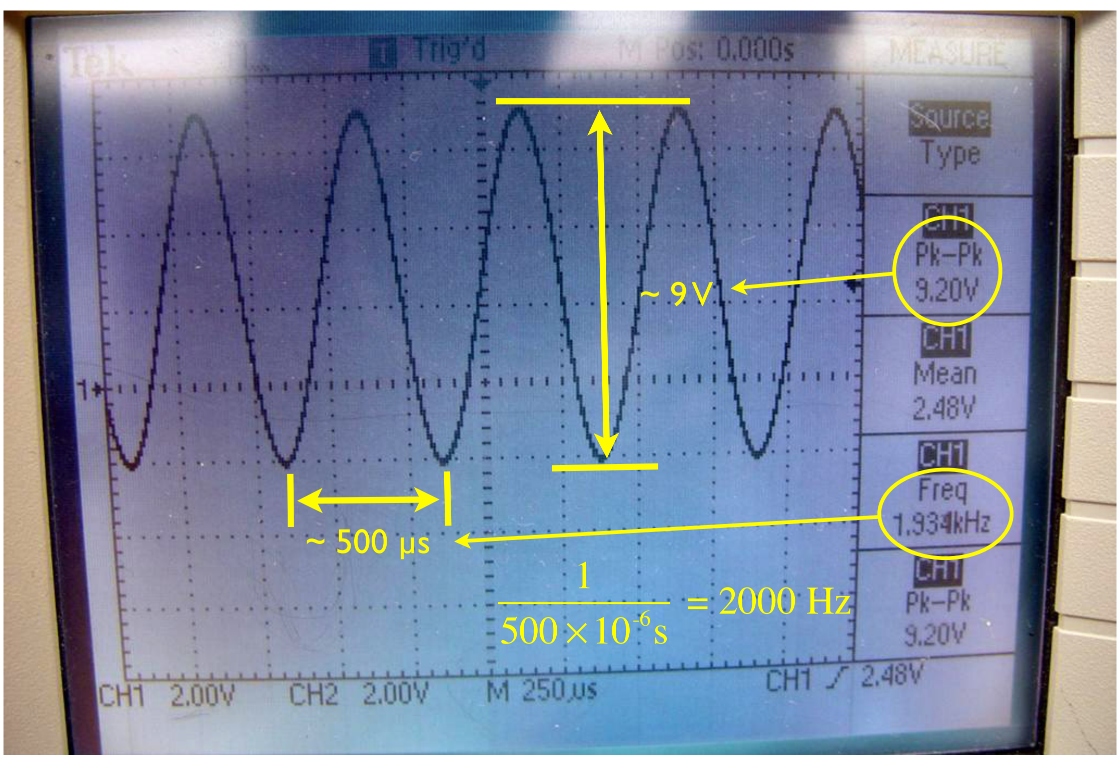
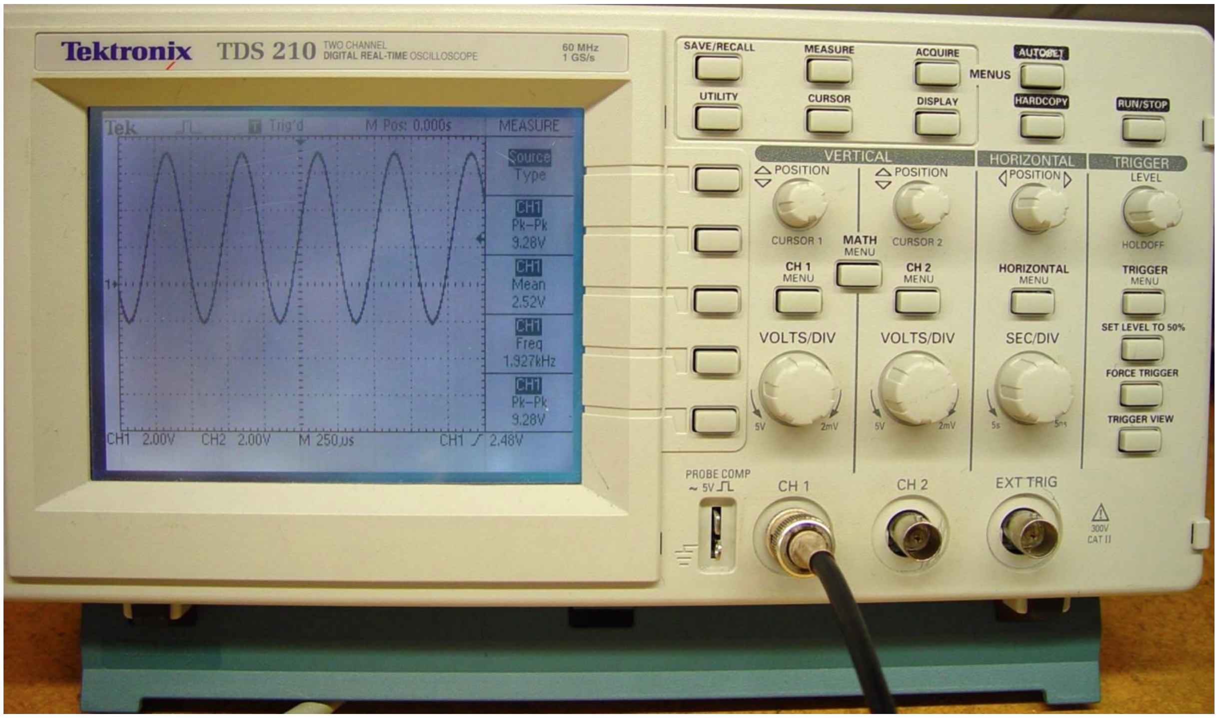


Oscilloscope Buttons



What is a Signal Generator?

A signal generator is a piece of equipment that we use to generate time-varying voltages, with various waveforms, amplitudes, and frequencies.