Electronics and Electromagnetism

Lab 8: The War of Currents: Why Use Alternating Current (AC)
(Diodes & Transformers)

Purpose

In this Lab, we will start by re-visiting the concepts of current and resistivity by briefly describing three different classes of materials called: conductors, insulators and semiconductors. We will then move on to discuss the types of electric currents, namely DC and AC and discuss about the advantages of using the latter. we will see how AC-to-DC conversion is done using diode rectifiers and using signal generator to provide input voltage, as well as the capacitor to smooth the output voltage.

Electric Current and Resistivity

An electric current is a flow of electric charge. In electric circuits this charge is often carried by moving electrons in a wire. It can also be carried by ions in an electrolyte, or by both ions and electrons such as in an ionized gas (plasma). The SI unit for measuring an electric current is the **Ampere (A)**, which is the flow of electric charge across a surface at the rate of one coulombs per second **(Q/s).** Electric current is measured using a device called an Ammeter. Electric currents cause a phenomenon called Joule heating, which is the phenomenon that creates light in incandescent light bulbs. It is this very phenomenon that caused your "low-value" resistors to become hot as they allowed a huge current to flow through them. Electric currents also create magnetic fields, which are used in motors, inductors and generators.

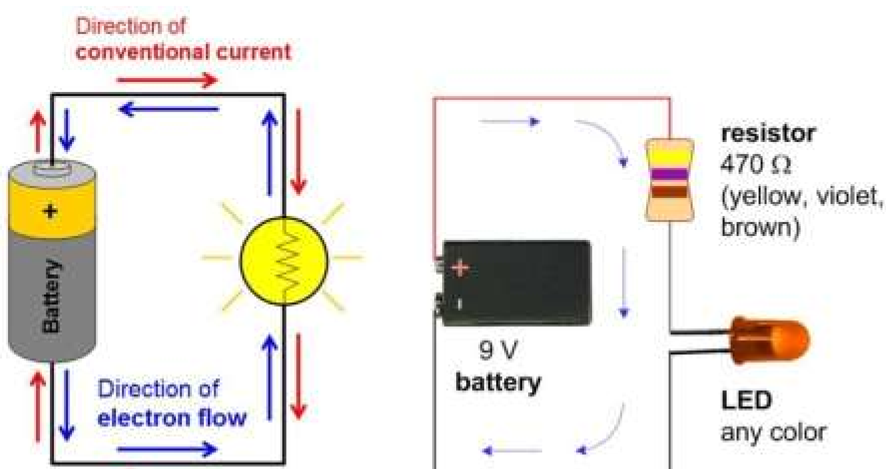


Figure 1: The direction of current and electron flow

The moving charged particles in an electric current are called charge carriers.

- In metals, valence electrons can move freely within the metal. The ease with which these charge carriers can move about in the materials is generally termed as resistivity.
- In a different class of materials called insulators, this availability of free electrons is minimal because they are tightly bound to the atoms and are therefore not "free" to move about. They therefore exhibit a large resistivity. In other words, they do not conduct much current. A few examples of insulators are rubber, cement, glass, plastic etc.
- There are yet another class of materials called semiconductors whose resistivity lies in between those of metals and insulators. More interestingly, the resistivity of such materials can be tuned from an insulating region to a conductive region. This excellent property of semiconductors is what led to the inventions of the diode and the field effect transistor (FET) and to the proliferation of the electronics industry as we know it today!

To fully appreciate and understand the intricate mechanisms responsible for the behavior of metals, insulators, and semiconductors, you must study quantum mechanics and the band theory of solids, which are advanced topics not within the scope of this course. But feel free to ignite your curiosity!

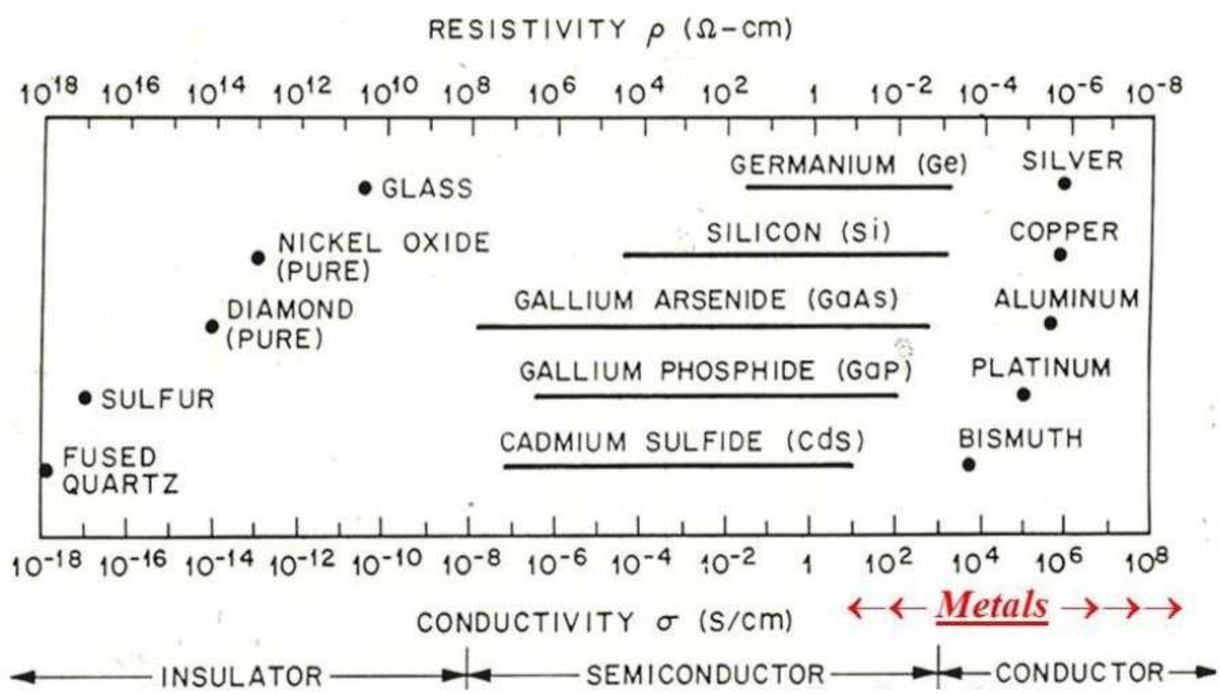


Figure 2 : Resistivity (Conductivity) chart for common metals, semiconductors, and insulators

Types of Electric Current

Electric current is mainly classified into two types, i.e., alternating current (AC) and direct current (DC). In alternating current (AC) systems, the movement of electric charge periodically reverses direction at the AC frequency, which is measured in the units of **Hertz (Hz)**. AC is the form of electric power most commonly delivered to businesses and residences. The usual waveform of an AC power circuit is a sine wave. Certain applications use different waveforms, such as triangular or square waves. Audio and radio signals carried on electrical wires are also examples of alternating current. In contrast, direct current (DC) is the unidirectional flow of electric charge, or a system in which the movement of electric charge is in one direction only. Direct current is produced by sources such as batteries, thermocouples, solar cells, and commutator-type electric machines of the dynamo type. Direct current may flow in a conductor such as a wire, but can also flow through semiconductors, insulators, or even through a vacuum as in electron or ion beams.

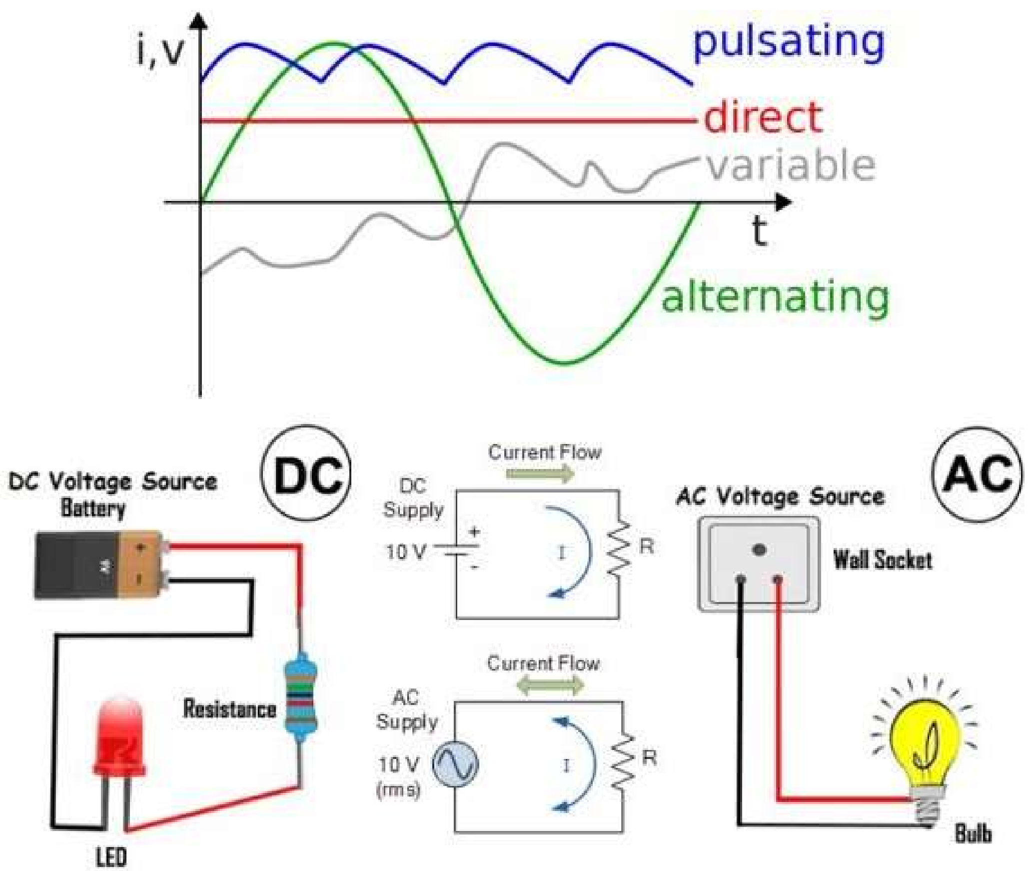


Figure 3: Top: Different type of currents. AC and DC are the more commonly used types. Bottom: Examples of AC and DC usage in applications.

The War of Currents: Why Alternating Current? Some History….

Thomas Edison, a prolific inventor in the 19th and 20th centuries, holds the record for the most U.S. patents by one person. When it came to technology, he was usually a winner. But there was one important area where Edison lost - and lost badly. It was called the 'War of Currents,' and it pitted Edison and his support for direct current (DC) electricity against engineers like George Westinghouse and Nikola Tesla, who supported alternating current (AC).

Figure 4: Nicola Tesla and Thomas Edison notorious for their War of Currents

In the 1880s, incandescent lighting was the main goal, and DC was just as good as AC. But a storm was brewing, and it centered on which type of power, AC or DC, would be best for power generation, electric motors, and power transmission.

The war came to a head in 1893, when the contract to provide electricity to the Chicago World's Fair was awarded to Westinghouse, whose proposal, using AC, came in over 30% cheaper than Edison's. In that same year, the Niagara Falls Power Company decided to go with AC power generation for the city of Buffalo and signed with Westinghouse and Tesla as well. These two major victories were part of the changes taking place rapidly in the 1890s that set us on a path toward AC power. Let's find out why AC had the edge over DC.

Advantages of AC over DC:

- **Power Transmission & Transformers**

The first advantage AC power has over DC is in power transmission. Early on, Tesla and Westinghouse realized that for electrical power to be practical, it had to be efficiently transmitted over great distances. Hydroelectric power was an early favorite, and suitable waterpower sources were sometimes hundreds of miles away from the destination. Both AC and DC have power loss in long lines because of the resistance in the wires. For a fixed power, higher voltage results in lower current through the power line, and lower current means lower power line losses.

The early engineers realized that very high voltage is needed for efficient power transmission. Today, long-haul power lines operate at voltages in excess of 300,000 volts to minimize power loss! Using transformers, it is easy to boost AC voltage to these high levels and then reverse the process at the consumer end. DC voltage does not work in a transformer. Because of transformers, AC won out as the favorite for power transmission.

Figure 5: High voltage transmission lines used to transport AC electricity

- **Power Generation**

AC's next advantage is in power generation. One of the most important inventions of the late 1800s was the AC generator, which was a simple design made practical by Westinghouse. Mechanical generation of DC is much more complicated, and most DC today is generated by batteries, solar cells, fuel cells, or by converting AC to DC.

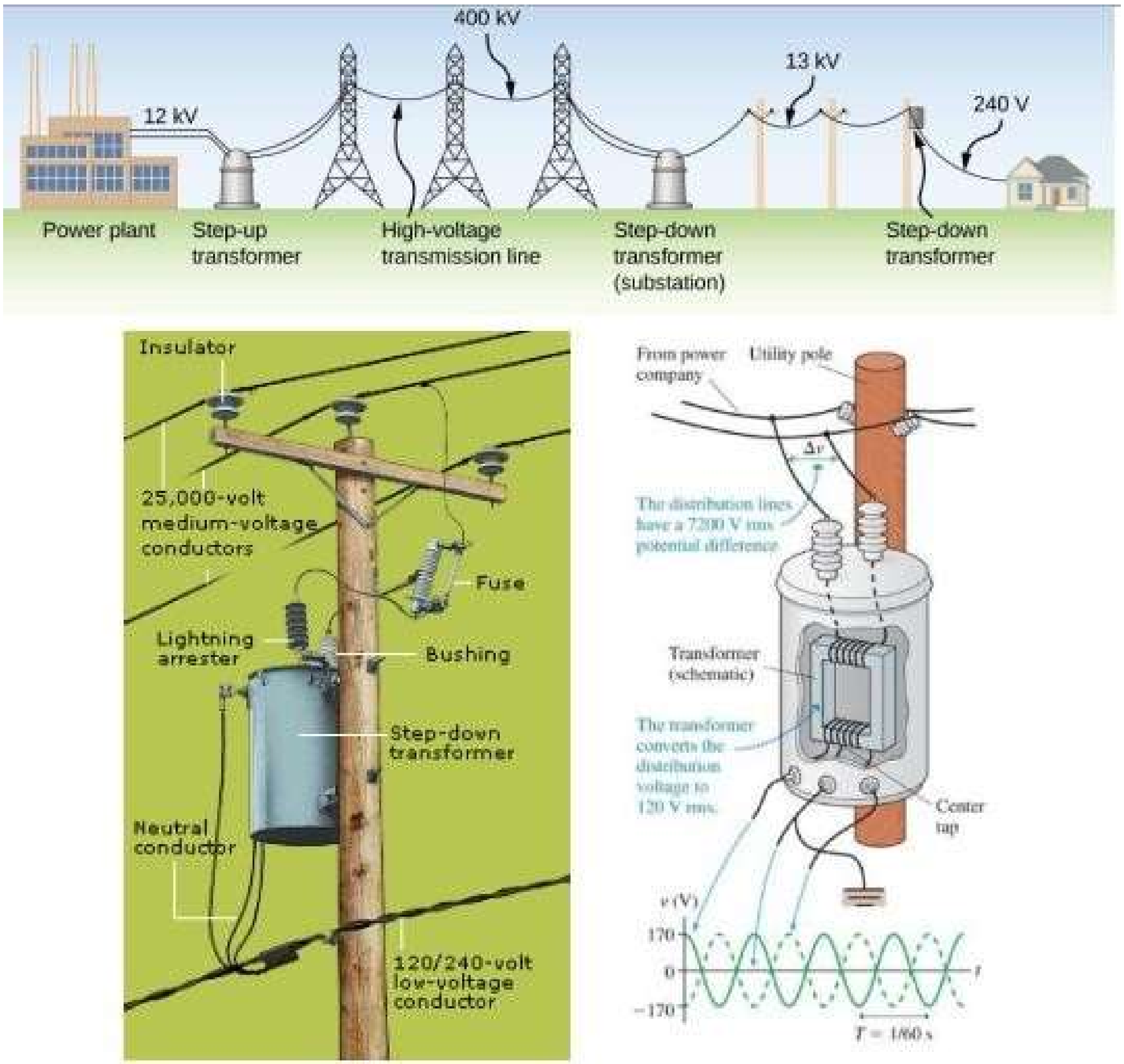


Figure 6: Top: The entire process by which electricity reaches out homes from the power plant. Bottom: A Transformer that steps down the voltage to a 240V used in your homes

- **Power Consumption**

AC also has an advantage when it comes to power consumption. DC machines required brushes and commutators to operate, thus increasing complexity and maintenance. Tesla patented the first practical AC induction motor, and General Electric put an industrial version into production in the 1890s, the perfect companion to the AC power already being generated. Very soon, these motors were installed across the U.S. in factories, mines, and shops. Today, we use AC induction motors in our houses for things like electric fans, air conditioning compressors, garbage disposers, etc. The simplicity of AC motors, along with the ability to use AC power readily, makes them a better choice than DC.

- **Modern Lighting**

Modern lighting also works better with AC power. Incandescent lights (the type that Edison made practical) can operate on AC or DC, but Fluorescent lighting is a different story. Fluorescent lights use a gas, such as argon or mercury vapor, that is excited by the presence of a high voltage. This excitation of the gas creates light in the visible or ultraviolet spectrum. For a number of practical reasons, AC is a better choice for the design and operation of fluorescent lights than DC.

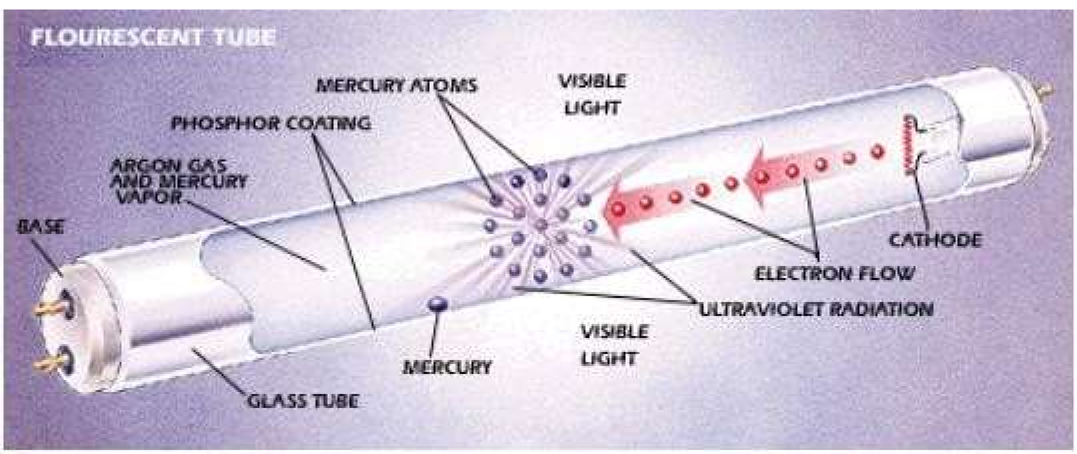


Figure 7: The inner construction of a Fluorescent tube

How Do Incandescent Light Bulbs Actually Glow?

The constant glow that you see from a light bulb is actually deceiving. The light bulb actually goes ON and OFF (crosses the zero-current point) once after every half cycle, which means it goes ON an OFF at approximately 120 times in 60 cycles (or 1 sec).

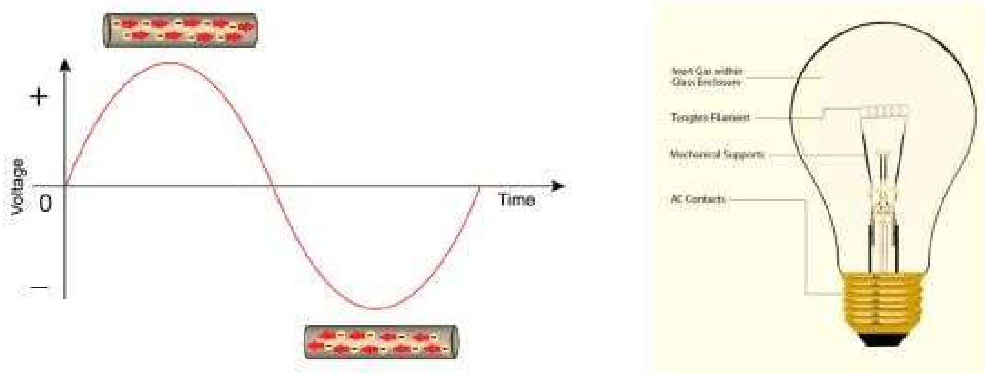


Figure 8: Left: In the case of an alternating current, the direction of flow of electrons reverses every half cycle. Right: The working parts of an incandescent light bulb

Also, the term incandescent refers to the emission of light as a result of being heated. To explain this phenomenon on a microscopic scale, one can imagine that the Joule heat (generated from the current), imparts this energy to the electrons of the atoms of the filament (usually tungsten, W). The electrons absorb this energy and get excited to a higher energy level. However, this higher energy level is unstable and hence the election has a natural tendency to come back to its ground state (lower energy level) over time. When it does, it releases the excess energy in the form of radiation (or light). This is the light that that we see. However, it must be noted, that incandescent bulbs are not very efficient. A lot of heat generated is being lost to the environment. This is the reason why light bulbs are generally very hot to the touch.

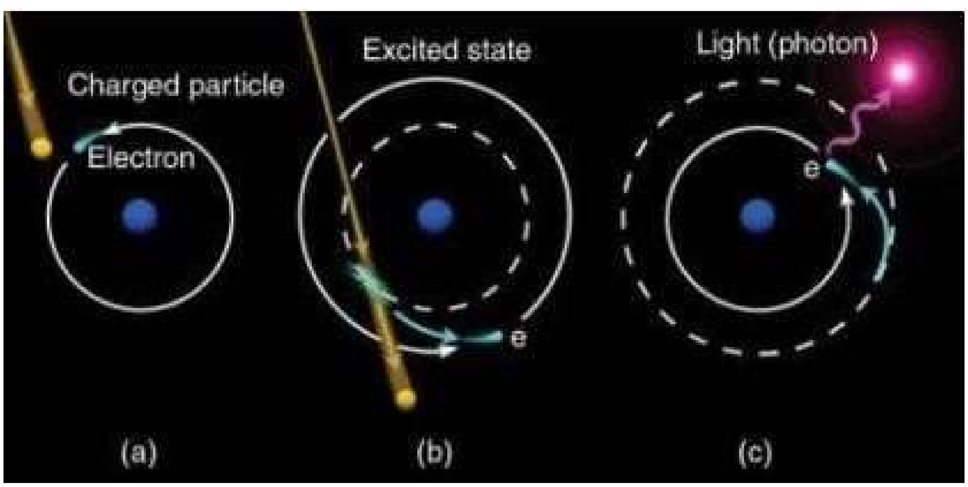


Figure 9: The microscopic process by which light is emitted from atoms

Full Wave Rectifiers

The basic form of a full-wave bridge rectifier is shown in the figures below. The circuit consists of 4 diodes that are connected in a "bridge-like" fashion. It can be seen by following the color arrows that during both the positive and the negative half cycle of the AC voltage, a current is made to flow in the same direction in a load resistor. When we tap this as an output, we get a unidirectional current, which we call a rectified output.

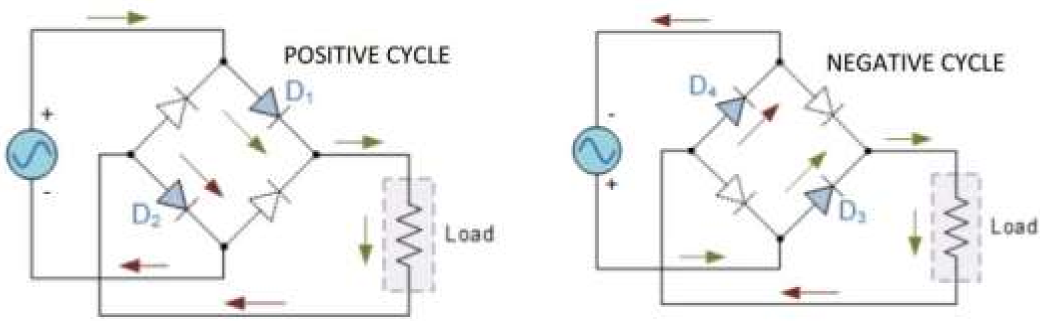


Figure 10: A full-wave rectifier circuit without smoothing capacitor.

You will notice that the output waveform obtained at the load will be quite bumpy since this is nothing but repeating positive half cycles of the sine wave. For AC-DC conversion applications, this is undesirable because the output is nowhere close to a steady DC signal. In order to remedy this problem, RC circuits are uses as filters to remove the waviness. The resulting waveform looks almost like a steady DC signal but has some ripples that cannot be fully eliminated. By choosing the right value of the capacitor, these ripples can be reduced to very low levels. Such a circuit, where this filtering is carried out is shown in the below figure. In this figure you will also notice a step-down transformer which is used to convert the AC voltage from the mains socket to a much smaller voltage level that can then be safely fed into the diode circuit.

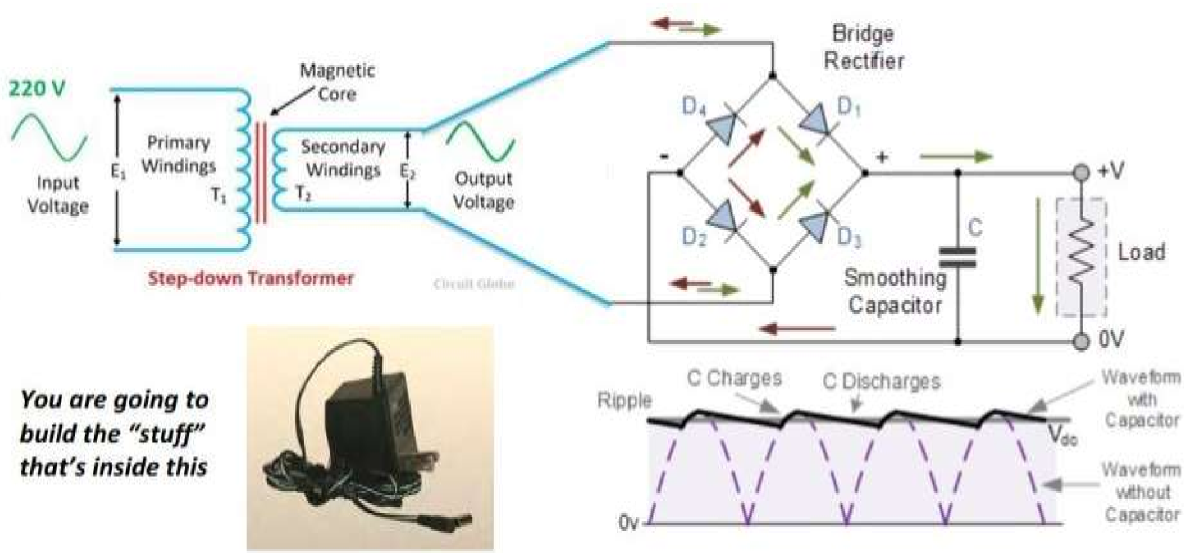
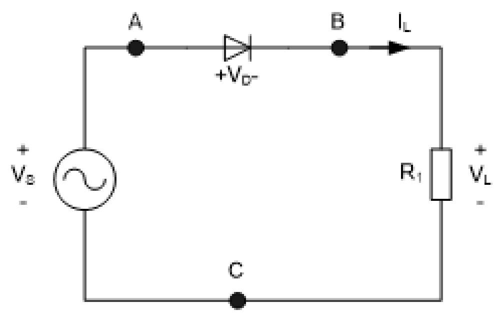


Figure 11: A full-wave rectifier circuit with smoothing capacitor

Experiment 1: Half Wave Rectifier

Apparatus

- Diode
- function Generator
- Oscilloscope
- 10K Resistor
- Bread Board
- 10µf Capacitor and 470µf



Setup the circuit in TinkerCad.

1) Construct the Circuit as shown in the figure.

2) Set up the function generator to sine wave of **50Hz** and **V_{pp} = 6V (DC offset is 0)**

3) Connect the function generator positive and negative terminals to **node A**(red) and **C(common - black) respectively.**

4) Use one Oscilloscope and Connect to node **A (+ve terminal), node C (-ve terminal)** to observe the input voltage form, determine Time/DIV for the oscilloscope y yourself (at least 1 full wave should be visible at the oscilloscope).

5) Use another Oscilloscope, observe the waveform at **B** with respect to common at **C**. make sure to use the same Time/DIV(scale of the signal) as the input wave form.

6) Show **V_{BC}** in your results, note down the parameters **(V_{pp}, T, V_{max})** and scope settings(Time/div).

7) Answer the following questions (In result section)

I. What kind of input voltage wave form you can observe? Sine or repetitive signal?

II. What is the Amplitude of the Voltage (**V_{BC}**)? Do you agree with the amplitude.

III. Calculate the **V_{PP}** and **V_{rms}** voltages from your function generator input setting.

IV. Now write down the V_{pp} of the rectified Wave form.

V. You have heard the term RMS before in the previous lab, explain the use of RMS in AC-DC conversion?

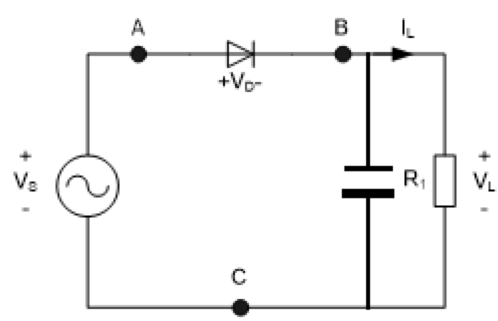
VI. What do you mean by a period T of a signal?

VII. What is the period T of input and output signals? Is there any difference if then explain why?

VIII. Now explain why this is called half wave rectification by referring to voltage waveform at **V_{BC}**.

IX. Thinking about the DC current and the DC wave form write down what are the disadvantages of the half wave rectifier.

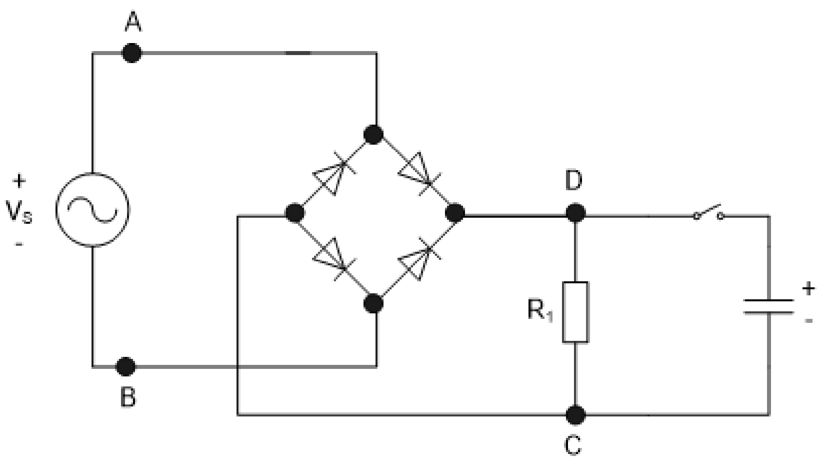
8) Now Connect the Capacitor parallel to the 10k Resistance. What happened to the wave form? Write down your observations. Explain why the shape of wave form changed?



Experiment 2: Full wave Bridge Rectifier

Apparatus

- 4 Diodes
- function Generator
- Oscilloscope
- 10K Resistor -1
- Bread Board
- 100μf & 470μf (Or any higher than 100μf) Capacitor 1



1) Construct the Circuit as shown in the above circuit.
2) For this circuit, set up V_S by using the function generator so that it produces a sine wave from, with a frequency of **50Hz**, and a peak-to-peak voltage of **12V**.
3) Connect one Oscilloscope to the node **A & B** in order to observe the input voltage and show the wave form in results.
4) What is the amplitude of the input Voltage?
5) Observe the Voltages across nodes D, C and the nodes B,C using two other oscilloscopes. show both wave forms in results.
6) What kind of wave forms can you observe? (Check the theory part of the lab to find out the type of wave forms).
7) Now connect another Oscilloscope to measure the V_{AD}.

8) What kind of Wave form can you observe, $\mathbf{V_{AD}}$? compare the difference between the wave forms of V_{AD} and V_{BC}.

9) Write down the advantages of full wave rectifier over the half wave rectifier.

10) Draw the current path of the full wave bridge rectifier (Direction of currents in the schematic diagram). Explain & what will happens if one diode gets short circuited or removed from the bridge.