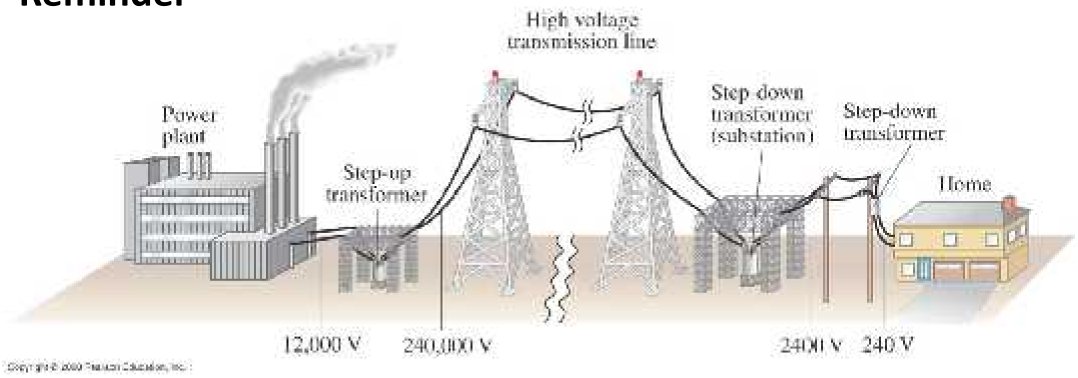
W01

Transformers and rectification

What is a transformer?

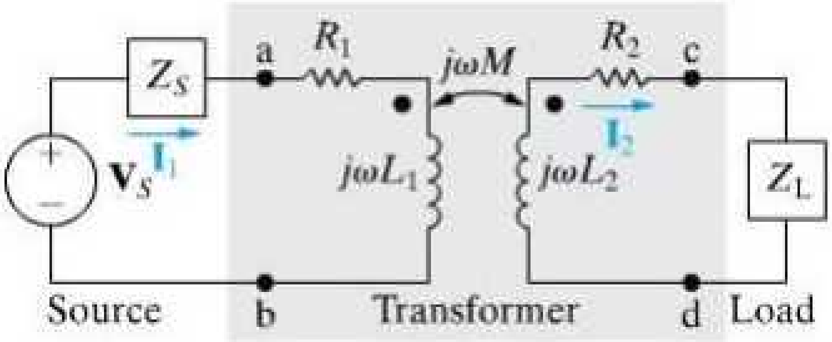
Reminder



A transformer is a device for increasing or decreasing AC voltage

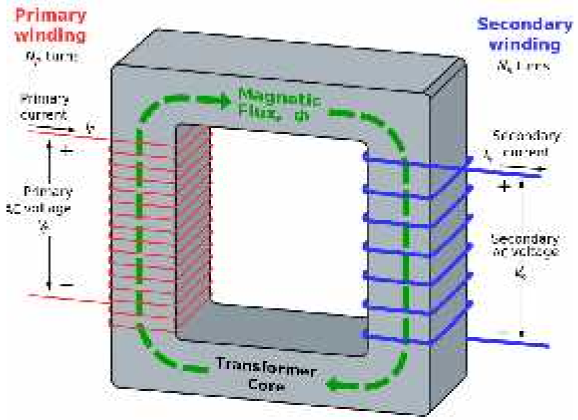
Definition

A transformer is a power converter that transfers electrical energy from one circuit to another through inductively coupled conductors—the transformer's coils <u>without changing its frequency</u>



Structure

A transformer consists of two independent coils wrapped around a common ferromagnetic core.



A simple transformer has a soft iron or silicon steel core and windings placed on it(iron core). Both the core and the windings are insulated from each other.

The winding connected to the main supply (<u>input winding</u>) is called the primary and the winding connected to the load circuit is called the secondary (<u>output winding</u>).

What is a transformer?

Operating Principle of a Transformer

The transformer operates in two steps:

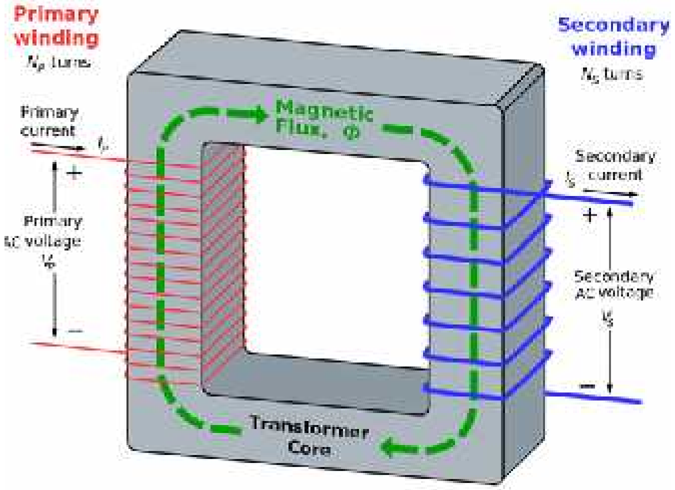
- first, that an electric current can produce a magnetic field (*electromagnetism*),
- second that a changing magnetic field within a coil of wire induces a voltage across the ends of the coil (*electromagnetic induction*).

Transformer is a static device (and doesn’t contain on rotating parts), <u>Therefore, it is in need of a time varrying electrical source (eg. AC source)</u> to generate a changing magnetic field on core

Changing the current in the primary coil changes the magnetic flux that is developed. The changing magnetic flux induces a voltage in the secondary coil.

When the primary winding is connected to ac mains supply, a current flows through it.

Since the winding links with the core, current flowing through the winding will produce an alternating flux in the core.



EMF is induced in the secondary coil since the alternating flux links the two windings.

$$V_P = N_P \cdot \frac{d\phi_P}{dt} \text{ (Faraday' Law)}$$

$$V_S = N_S \cdot \frac{d\phi_P}{dt} \text{ (Faraday' Law)}$$

$$\therefore \frac{V_S}{V_P} = \frac{N_S}{N_P} \text{ or } V_S = V_P \cdot \frac{N_S}{N_P}$$

The frequency of the induced EMF is the same as that of the flux or the supplied voltage.

Transformer mathematics

Relationships

Voltage Ratio: Ratio of primary voltage to secondary voltage is equal to ratio of the number of turns

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} = \boxed{K}$$

Turns ratio (or the transformation ratio) is the fundamental parameter for relating electrical quantities on primary and secondary circuit

Current Ratio: Energy conservation requires that (neglecting core losses) that the primary power equals the secondary power.

$$V_P \cdot I_P = V_S \cdot I_S$$

$$\frac{I_S}{I_P} = \frac{N_P}{N_S} = \frac{1}{K}$$

If the secondary coil has more turns (loops) than the primary, it is called a step-up transformer

$$\frac{N_S}{N_P} = K > 1$$

If the secondary coil has less turns (loops) than the primary, it is called a step-down transformer

$$\frac{N_S}{N_P} = K < 1$$

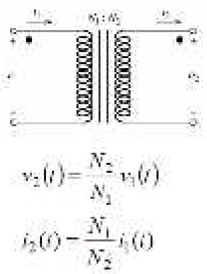
Impedance Ratio:

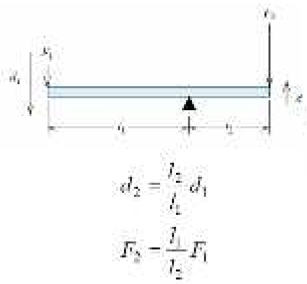
$$Z_L = \frac{V_L}{I_L} = \frac{V_S}{I_S}$$

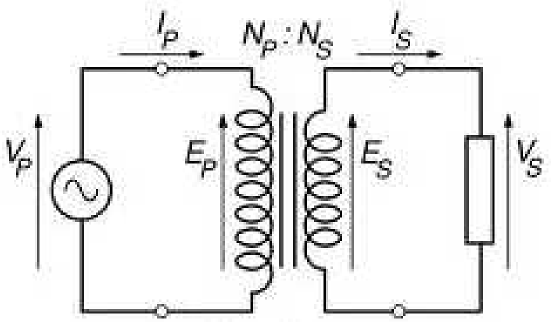
$$Z_L = \frac{V_S}{I_S} = \frac{KV_P}{I_P/K} = K^2 \frac{V_P}{I_P} = K^2\,{}^{P}Z_L$$

$$\frac{{}^{P}Z_L}{Z_L} = \frac{1}{K^2}$$

What if K=1?





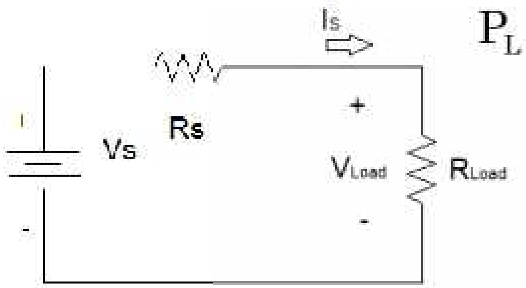


An application of transformer

Impedance Matching

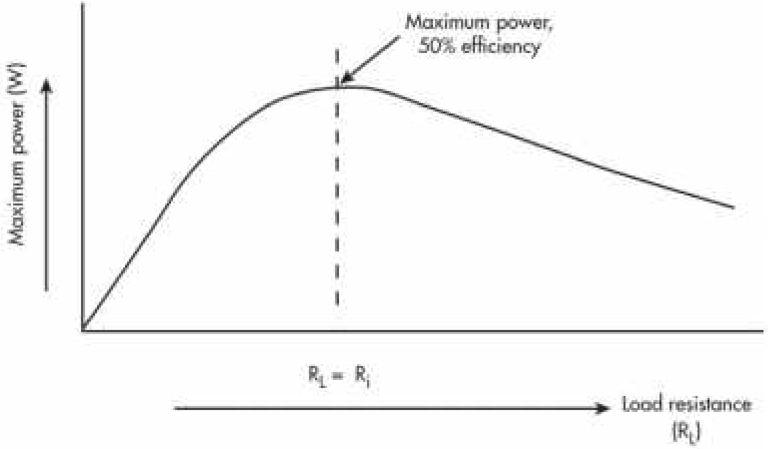
A transformer can be used to raise or lower apparent impedance of a load to match loads to amplifiers to achieve <u>*maximum power transfer*</u>

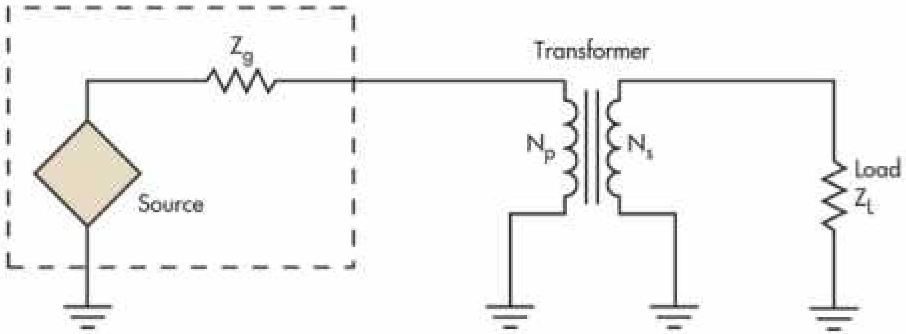
For any power source, the maximum power transferred from the power source to the load is when the resistance of the load R_L is equal to the equivalent or input resistance of the power source ($R_{in} = R_{Th}$ or R_N).
The process used to make $R_L = R_{in}$ is called impedance matching.



$$P_L = V_L^{\,2}/R_L$$

$$P_L = \frac{\left[\dfrac{R_L}{R_L + R_{Th}} V_{Th}\right]^2}{R_L}$$





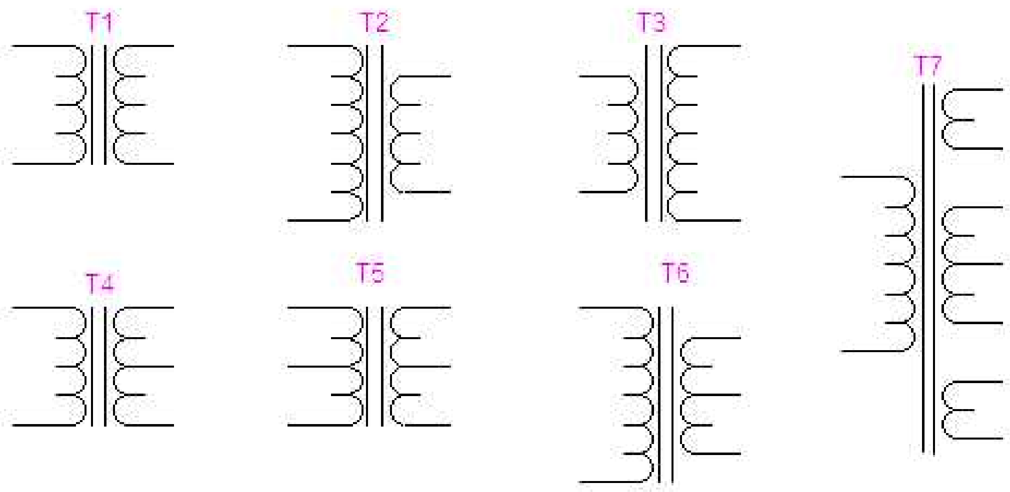
What is a transformer?

Basic Types of Transformers

T1: a one-to-one isolation transformer. The voltage in is the same as the voltage out. These are used to isolate the "hot" side of the power line from the user on the secondary side

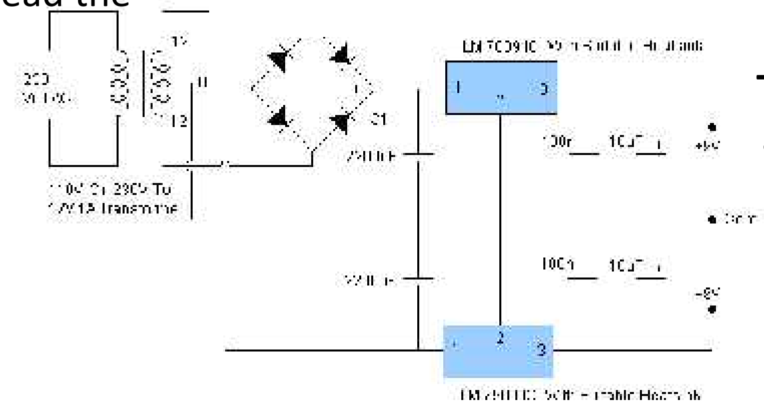
T2: basic step down transformer

T3: basic step up transformer



T7: transformer with multiple secondaries. The individual windings can be any combination of step up or step down

T4: transformer with center-tapped secondary. The voltage measured from the center tap connection to either end should read the same.



T5: transformer with center tapped primary and secondary.

T6: *step down transformer with center-tapped secondary.*

Rectification

Introduction

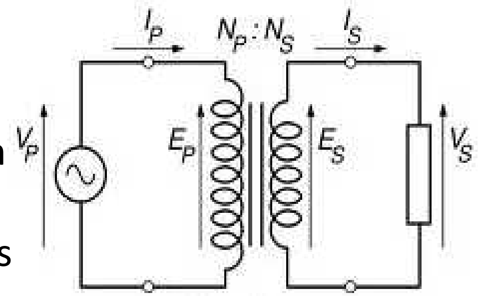
Electricity is transferred from power plants to houses or business as alternate current because of decreasing losses during transfer. On the other hand, semi conductors use direct current. Thus, it is needed to be transformed into the direct current.

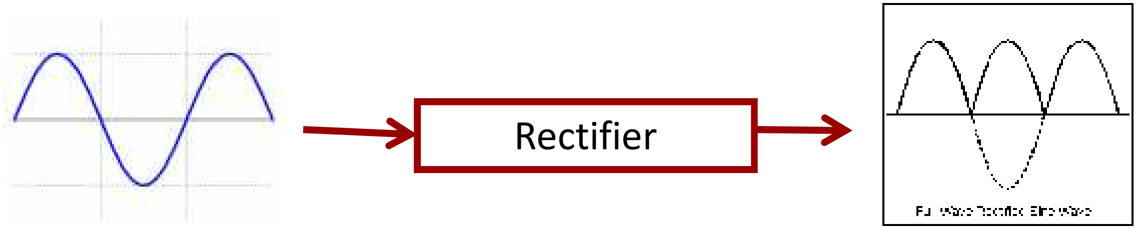
A rectifier is a circuit which converts the Alternating Current (AC) input power into a Direct Current (DC) output power.

Transformer

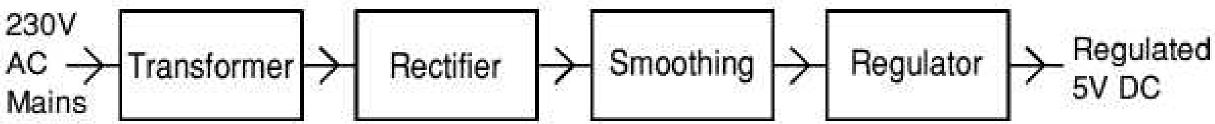
It is used to arrrange voltage level of DC output.

Transformers convert AC electricity from one voltage to another with little loss of power.
The ratio of the number of turns on each coil, called the **turns ratio**, determines the ratio of the voltages

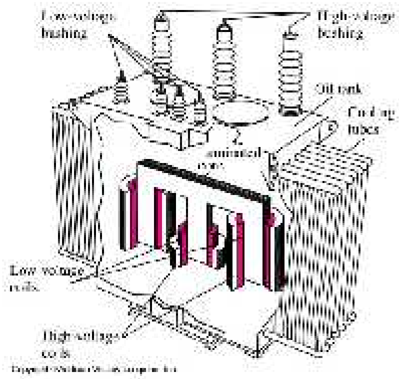




$$\frac{V_S}{V_P} = \frac{N_S}{N_P} = K$$



Block Diagram of a Regulated Power Supply System



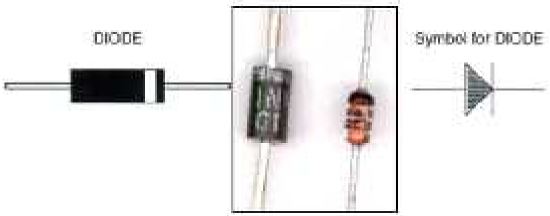
$$V_P \cdot I_P = V_S \cdot I_S$$

$$\frac{I_S}{I_P} = \frac{N_P}{N_S} = \frac{1}{K}$$

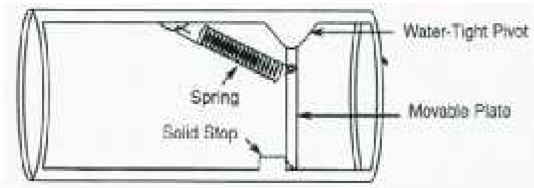
Rectification

Diodes

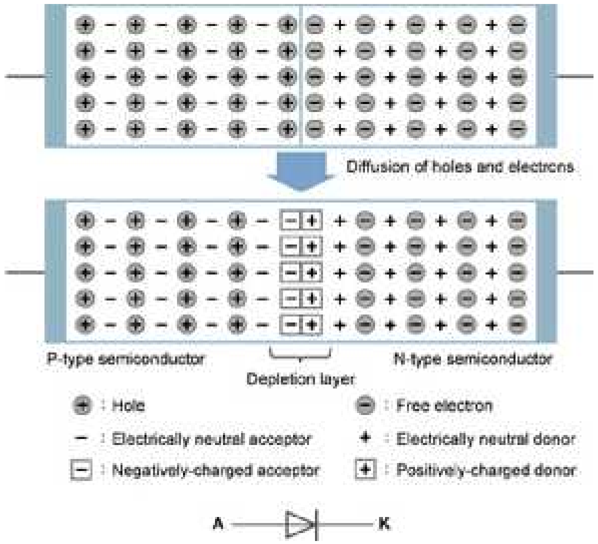
Diodes are basic unidirectional semiconductor devices that will only allow current to flow through them in one direction only, acting more like a one way electrical valve.



A diode is an semiconductor component that, in general, will pass current in only one direction

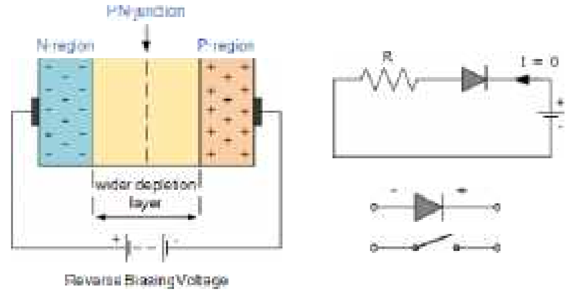


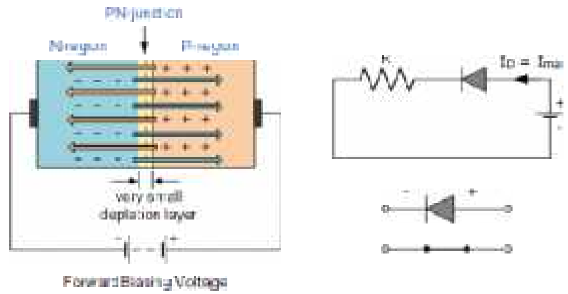
Diodes are made from a single piece of **Semiconductor** material which has a positive "P-region" at one end and a negative "N-region" at the other.



PN Junction Diode Operation

When a diode is connected in a **Reverse Bias** condition, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material.



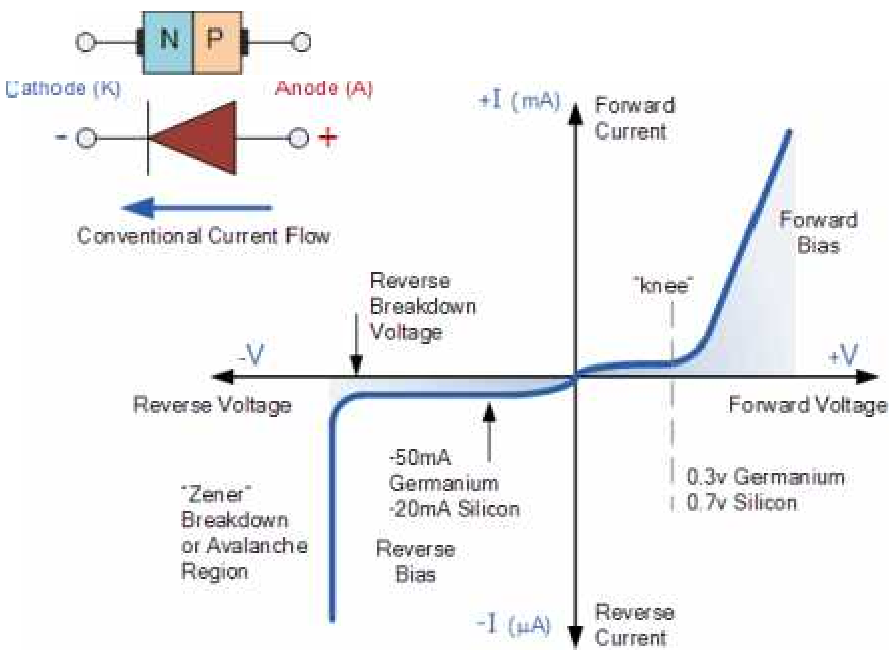


When a diode is connected in a **Forward Bias** condition, a negative voltage is applied to the N-type material and a positive voltage is applied to the P-type material.

Rectification

Diode Characteristics Curve

However, unlike a resistor, a diode does not behave linearly with respect to the applied voltage as the diode has an exponential I-V relationship



Rectifier Diodes

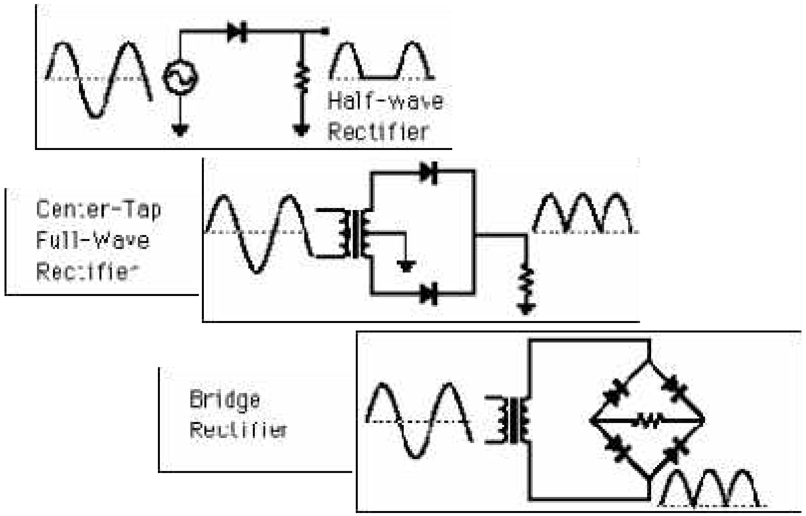
Rectifier diodes are used in power supplies to convert alternating current (AC) to direct current (DC). They are also used elsewhere in circuits where a large current must pass through the diode. All rectifier diodes are made from silicon and therefore have a forward voltage drop of 0.7V.

Diode	Maximum Current	Maximum Reverse Voltage
1N4001	1A	50V
1N4002	1A	100V
1N4007	1A	1000V
1N5401	3A	100V
1N5408	3A	1000V

Rectification

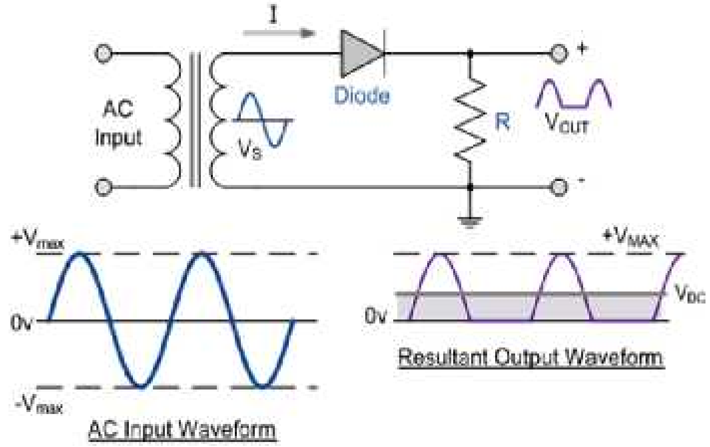
Types of Rectification

Power (rectifiers) diodes can be used individually as above or connected together to produce a variety of rectifier circuits such as "Half-Wave", "Full-Wave" or as "Bridge Rectifiers".



Halfwave Rectifier

During each "positive" half cycle of the AC sine wave, the diode is *forward biased* as the anode is positive with respect to the cathode resulting in current flowing through the diode. Since the DC load is resistive, voltage across the load resistor will therefore be the same as the supply voltage.



$$V_{out} = 0.318\ V_{max} = 0.45\ V_{rms}$$

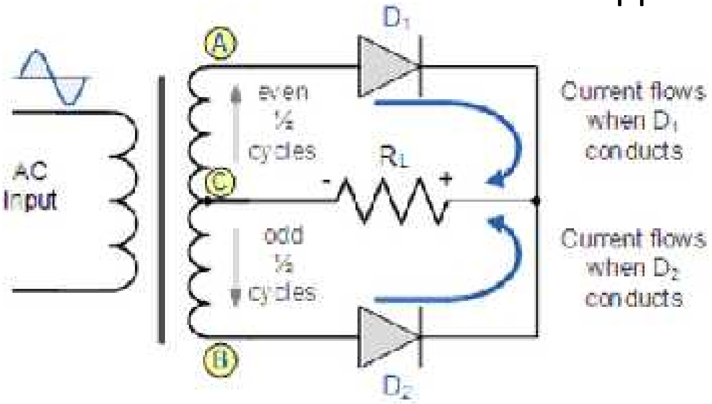
During each "negative" half cycle of the AC sine wave, the diode is *reverse biased* as the anode is negative with respect to the cathode therefore, No current flows through the diode or circuit and no voltage appears across it.

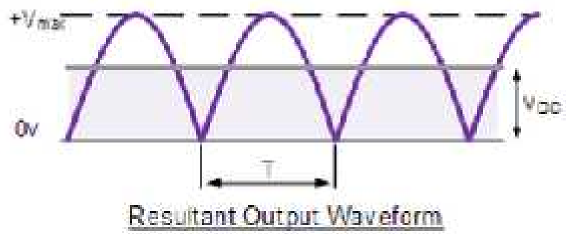
This type of circuit is called a "half-wave" rectifier because it passes only half of the incoming AC power supply

Rectification

Full Wave Rectifier

In a Full Wave Rectifier circuit, two diodes are used, one for each half of the cycle. A transformer is used whose secondary winding is split equally into two halves with a common centre tapped connection, (C).





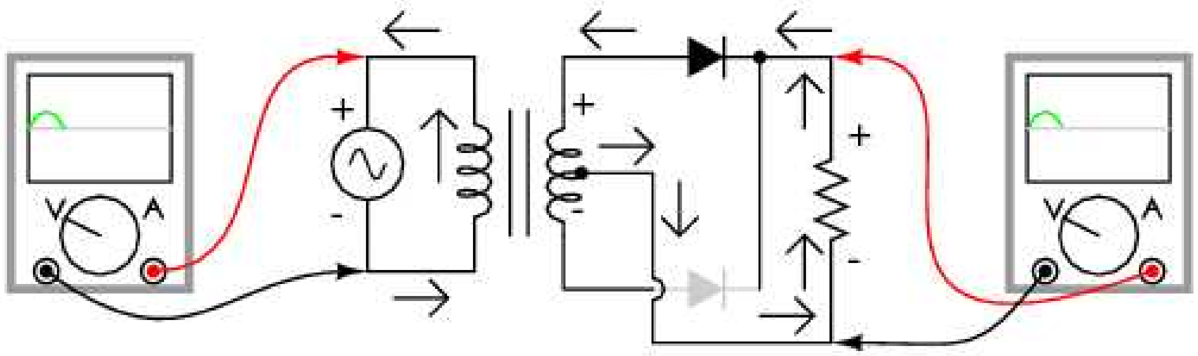
$$V_{out} = 0.637V_{max} = 0.9V_{rms}$$

This configuration results in each diode conducting in turn when its anode terminal is positive with respect to the transformer centre point C producing an output during both half-cycles, twice that for the half wave rectifier.

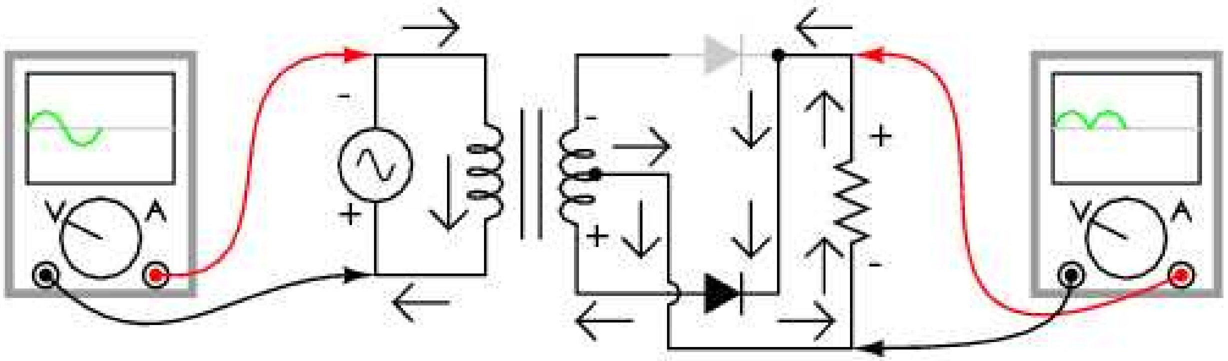
Rectification

Full Wave Rectifier

Consider the first half-cycle, when the source voltage polarity is positive (+) on top and negative (-) on bottom.
At this time, only the top diode is conducting; the bottom diode is blocking current, and the load “sees” the first half of the sine wave, positive on top and negative on bottom.
Only the top half of the transformer's secondary winding carries current during this half-cycle



During the next half-cycle, the AC polarity reverses.
Now, the other diode and the other half of the transformer's secondary winding carry current while the portions of the circuit formerly carrying current during the last half-cycle sit idle.
The load still “sees” half of a sine wave, of the same polarity as before
One disadvantage of this full-wave rectifier design is the necessity of a transformer with a center-tapped secondary winding.

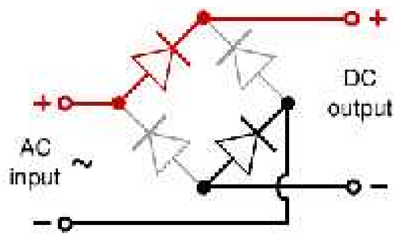


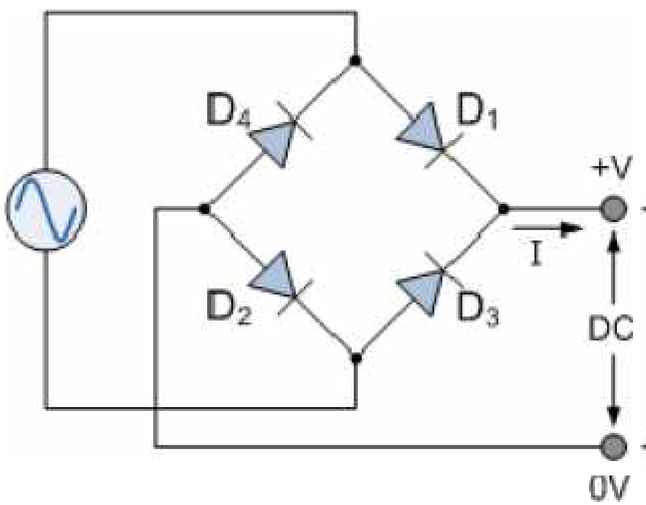
Rectification

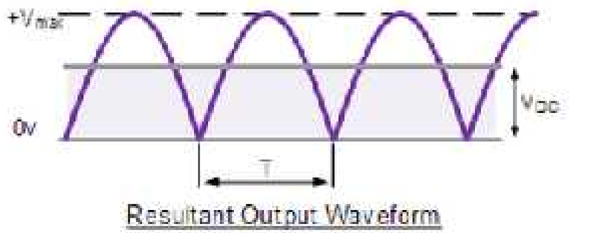
Bridge Rectifier

Another type of circuit that produces the same output waveform as the full wave rectifier circuit is that of the Full Wave Bridge Rectifier. This type of single phase rectifier uses four individual rectifying diodes connected in a closed loop "bridge" configuration to produce the desired output.

The main advantage of this bridge circuit is that it does not require a special centre tapped transformer. The single secondary winding is connected to one side of the diode bridge network and the load to the other side







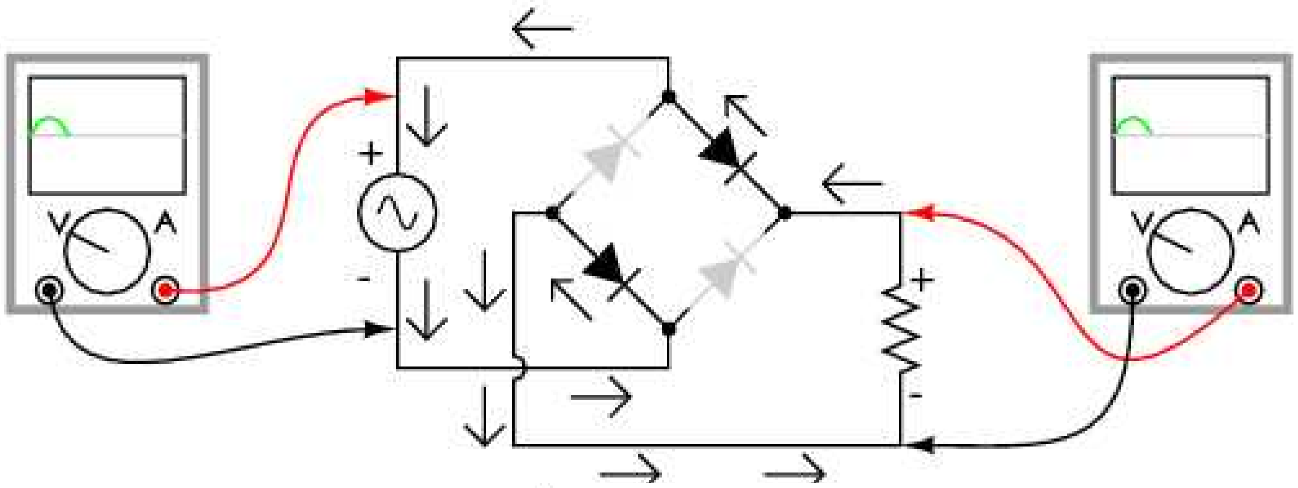
$$V_{out} = 0.637 V_{max} = 0.9 V_{rms}$$

However in reality, during each half cycle the current flows through two diodes instead of just one so the amplitude of the output voltage is two voltage drops (2 x 0.7 = 1.4V) less than the input V_{MAX} amplitude

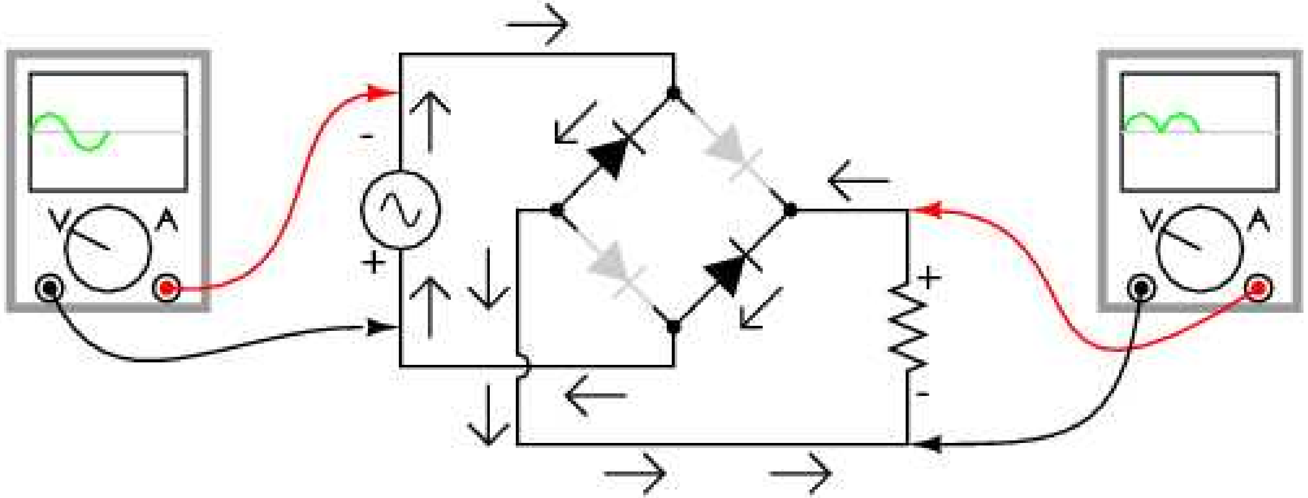
Rectification

Bridge Rectifier

During the positive half cycle of the supply,
diodes D1 and D2 conduct in series while diodes D3 and D4 are reverse biased and the current flows through the load as shown below.



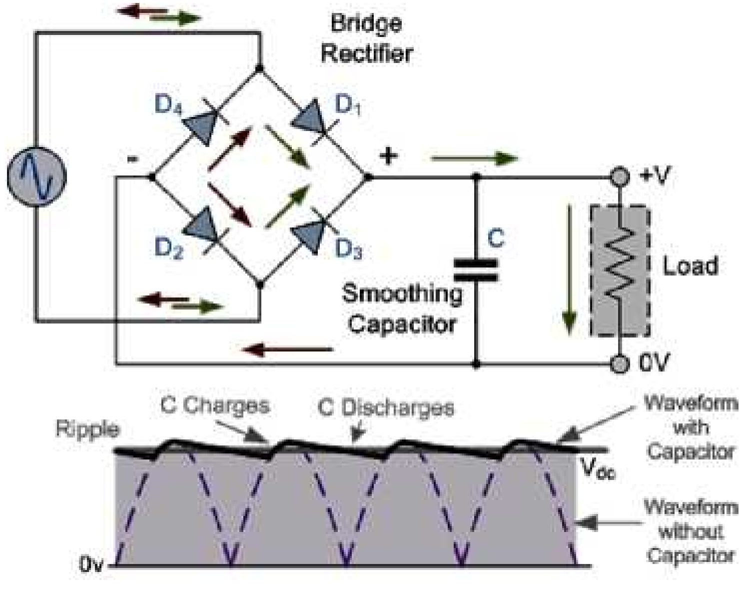
During the negative half cycle of the supply,
diodes D_3 and D_4 conduct in series, but diodes D_1 and D_2 switch "OFF" as they are now reverse biased. The current flowing through the load is the same direction as before.



Rectification

Bridge Rectifier

The smoothing capacitor converts the full-wave rippled output of the rectifier into a smooth DC output voltage.

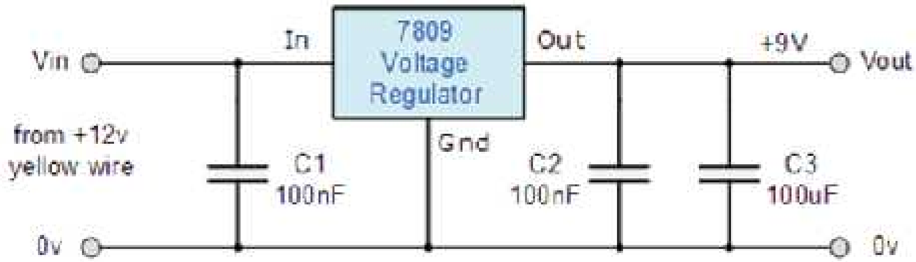


Resultant Output Waveform

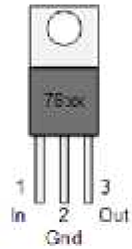
Generally for DC power supply circuits the smoothing capacitor is an Aluminium Electrolytic type that has a capacitance value of 100uF or more with repeated DC voltage pulses from the rectifier charging up the capacitor to peak voltage.

Voltage Regulators

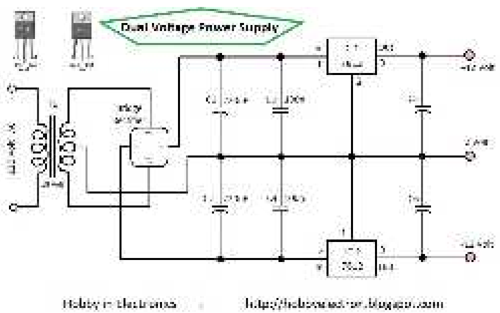
Voltage regulators dimnishes the oscilations in rectifier circuits. In fact they are more generally used for to obtain stable voltage in wide variety of electronic circuits.



Voltage Regulator



Type	Min Input Voltage	Output Voltage
7805	7V	+5V
7806	8V	+6V
7808	10V	+8V
7809	11V	+9V
7812	15V	+12V
7815	18V	+15V
7818	22V	+18V
7824	30V	+24V



Rectification

Bridge Rectifier