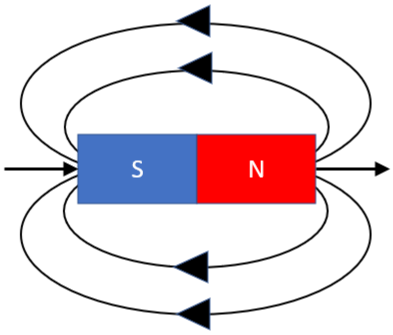
Lesson 5

Magnets

A magnet is an object with an invisible field that can attract ferromagnetic materials. The strength of the magnet's field is called the "flux density". A magnet has two poles, North and South, and the field flows from North to South.

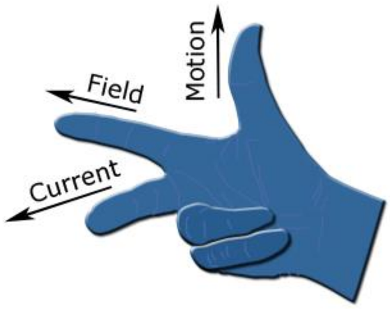
Magnets have a North and a South field. Opposite poles attract and like poles repel.



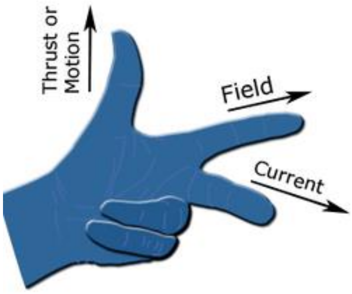
Induced Current

Electricity is generated by passing a conductor through a magnetic field. As the conductor passes through a magnetic field, electrons will move along the conductor in one direction. Reverse the field and current flows in the opposite direction. See Figure 1 below.

Fleming's right-hand rule (for generators) shows the direction of induced current when a conductor attached to a circuit moves in a magnetic field. (Right to generate)



Fleming's left-hand rule (for electric motors) is a simple way of indicating the direction of motion of a conductor in a magnetic field. (Left to motor)



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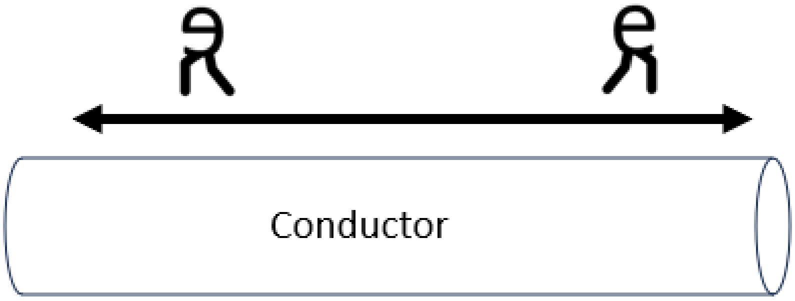
Alternating Current

Alternating current is where the directional flow of electrons, in a conductor, switches back and forth at regular intervals or cycles. This flow over time is shown as a sinusoidal wave. The number of cycles back and forth is termed the frequency (f) and is measured in Hertz (Hz).



Sinusoidal (Sine) Wave

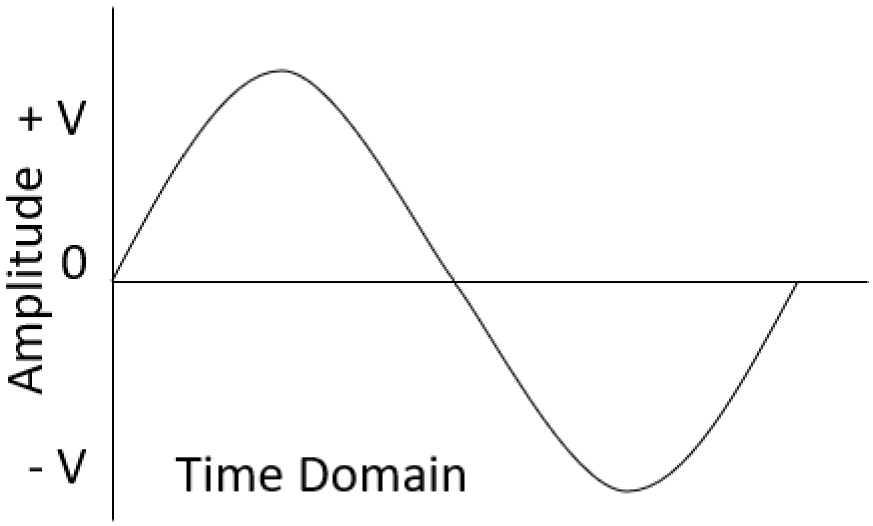


Figure 1

Voltages

The **peak value** is the highest voltage value reached in either direction.

Peak to peak value is the difference between the positive peak and the negative peak.

The RMS (Root Mean Squared) value is equal to the value of the constant direct current that would produce the same power dissipation in a resistive load. Angle 45 degrees.

Note: AC voltages and currents are normally quoted in RMS values unless stated otherwise. Using a multimeter to read the mains voltage, the reading the meter gives is the RMS value.

RMS = 0.707 x Peak value.

Example: The peak voltage is 339 V AC. What is the RMS value?

RMS = 0.707 x 339

RMS = 240 V

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Average valve

The average value of sine wave over one complete cycle is zero as the two halves cancel each other. The average value is taken over half a cycle and is 0.637 times the peak value.

Angle 39.56847907 degrees.

Average value = 0.637 x Peak value.

Example: 10V peak sine wave. What is the average value?

10 x 0.637 = 6.37 V

Instantaneous value

The voltage or Instantaneous value at any point along the wave, regarding the angle, can be calculated by the formula below.

$$E_{int} = E_{Peak}\ x\ Sine\ (\theta)$$

Example: What is the voltage at 30^0 in the. E int = 339 x Sine (30) = 339 x 0.5 = 168 V

Waveform

A **cycle** is measured from the point where the wave crosses the zero line, goes positive then goes negative and back to the zero line.

Period (P) is the time taken for one cycle.

Frequency (f) is measurement of cycles per second and is measured in Hertz. (Hz)

$$f = \frac{1}{P}$$

Example : P = 0.02 seconds f = 1 / 0.02 = 50 Hz

Wavelength

Waves travel at the speed of light unless constrained. The distance a wave, of a given frequency, would travel in one cycle, is called the wavelength. The wavelength is measured in metres and has the symbol lambda (λ)

$$\lambda = c/f$$

$\lambda = Wavelengh$
C = constant 300 x 10^6 metres per second
f = frequency in Hz

Example: f = 144 MHz Wavelength = 0.003 /144,000,000 = 2 metres

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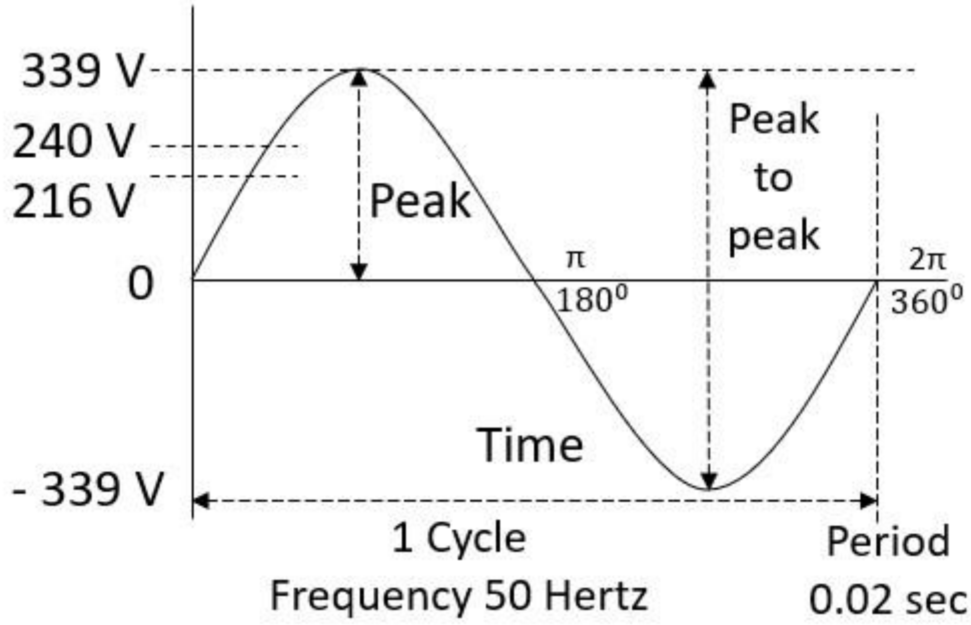

Figure 2, this is a sinewave depiction of the Australian mains power.

Radio Frequency Spectrum

Abbreviation	Classification	Range from	Range to
VLF	Very low Frequency	3 kHz	30 kHz
LF	Low frequency	30 kHz	300 kHz
MF	Medium Frequency	300 kHz	3 MHz
HF	High Frequency	3 MHz	30 MHz
VHF	Very High Frequency	30 MHz	300 MHZ
UHF	Ultra-High Frequency	300 MHz	3 GHz
SHF	Super High Frequency	3 GHz	30 GHz
EHF	Extremely High Frequency	30 GHz	300 GHz

Phase

Although the horizontal axis on Figure 1 is the time domain measured in seconds, treating the sine wave as a 360^0 circle is better for referencing. Starting at 0^0 and moving right. The cycle has a positive peak at $90^{0,}$ passes through 0 again at 180^0 , a negative peak at 270^0 and returns to 0 at 360^0.

Now the phase difference between two sine waves can be measured. See Figure 3.

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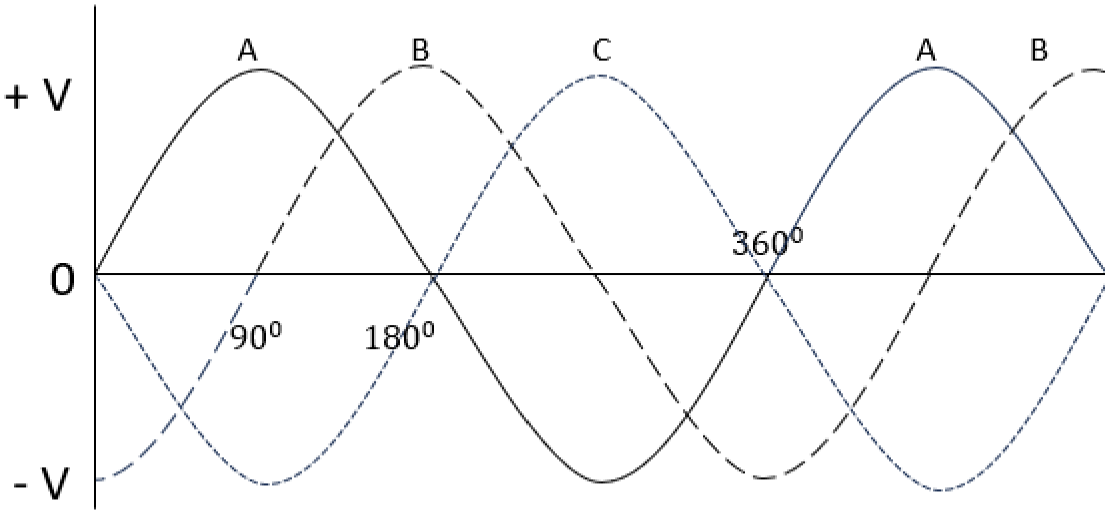

Figure 3

Wave B is 90^0 out of phase with wave A. B and C are 90^0 out of phase. A and C are 180^0 out of phase. Wave A and C will cancel each other out as A is going positive, B is going negative.

A practical example is three phase power. This is a common power supply for heavy load electric machines. Each wave is 120^0 apart and they are the same amplitude and frequency. See Figure 4 from Wikipedia.

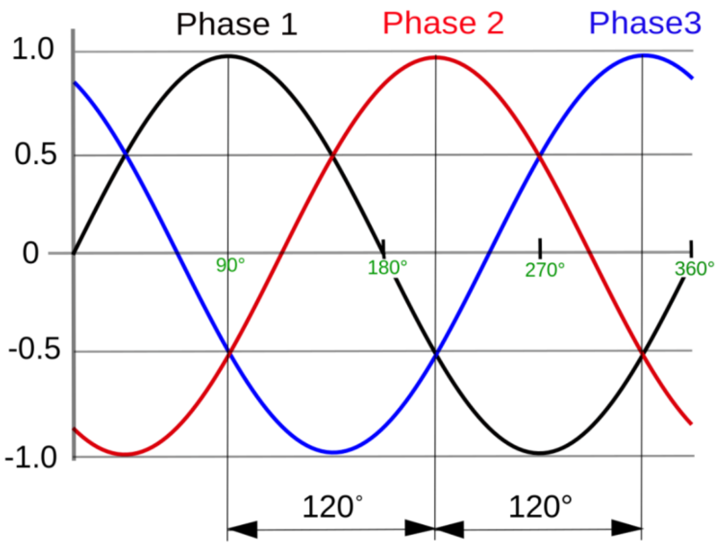

Figure 4

Harmonics

A harmonic is a frequency that is a multiple of the fundamental frequency. The fundamental frequency is also called the 1st harmonic and multiples of this frequency are called higher harmonics.

The second harmonic is twice the fundamental frequency. The third harmonic is three times the fundamental frequency.

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If the fundamental frequency is 2 MHz the harmonics will be a multiple of this fundamental frequency.

Fundamental	2nd Harmonic	3rd Harmonic	4th Harmonic
2 MHz	4 MHz	6 MHz	8 MHz

Example: What is the 3rd harmonic of 14 MHz.

14 x 3 = 42 MHz

Transformers

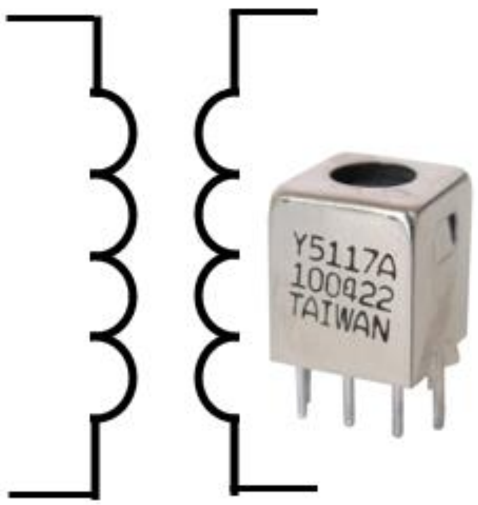
A transformer two coils positioned so the magnetic field of one coil, the primary coil, induces a current in the other coil, the secondary coil.

Transformer Types

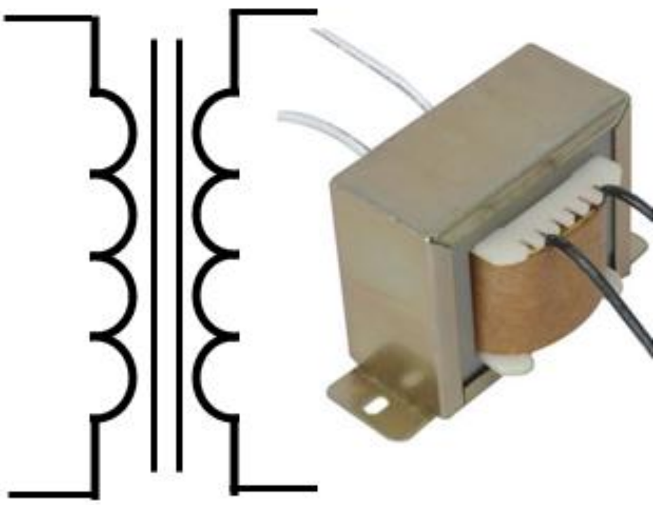
- Step-up transformer. Output voltage greater than input.
- Step-down transformer. Output voltage less than input.
- Isolation transformer. A ratio of 1:1 provides no change in voltage but only provides electrical isolation.
- Centre-tapped transformer. A centre tap on the secondary winding allows a single transformer to generate two output voltages that have half of the amplitude that appears across the entire secondary winding.

Cores

Low frequency transformers are usually wound on iron cores.
High frequency transformers are usually air cored.



Air core transformer



Iron core transformer

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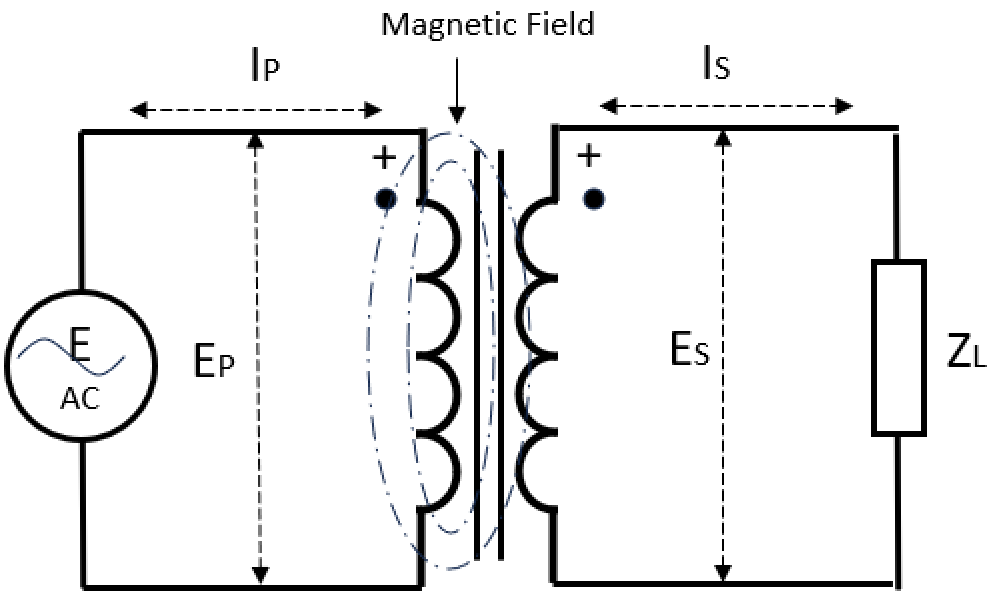
Figure 5



$$\frac{V_P}{V_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S} = \sqrt{\frac{Z_P}{Z_S}}$$

Figure 6

The transformer shown in Figure 6, represents an ideal transformer.

1. A primary voltage, E_{AC}, pushes an alternating current, I_P, through the primary coil.
2. The primary coil in the transformer produces a magnetic field, which changes as the current changes.
3. The iron core adds to the strength of the magnetic field.
4. The magnetic field passes through (or cuts) the secondary coil.
5. The changing magnetic field induces a changing voltage, E_S, in the secondary coil.
6. The induced potential difference produces an alternating current, I_S, in the external circuit.

Dots

The dots represent matching polarities. As the dot side on the primary goes positive, the dot side on the secondary also goes positive. Correspondingly, as the dot on primary goes negative, the dot on the secondary also goes negative.

Losses

In this lesson, all transformers are considered 100% efficient. In reality, this is not normal.

Some of the losses are listed below.

- Hysteresis losses due to nonlinear magnetic effects in the transformer core.
- Eddy current losses due to joule heating in the core.
- Resistive and inductive loss in the transformer windings.

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- Leakage flux that escapes from the core and passes through one winding only resulting in primary and secondary reactive impedance.

Voltage Ratio

The ratio of turns in the primary and secondary coils determines the voltages in the primary and secondary.

$$\frac{V_p}{V_S} = \frac{N_p}{N_S}$$

The ratio of the voltage in the primary (V_P) over the voltage in the secondary (V_S) = the ratio of turns in the primary (N_P) over the number of turns in the secondary (N_S).

Example: Primary voltage is 240 V. The secondary is to be 12 V. What is the turns ratio between the primary and secondary coils?

240 / 12 = 20 /1

The primary has twenty times more windings than the secondary.

Power

The power in the primary = power in the secondary applies to each side of the ideal transformer.

Applying the formulae, Power = V x I

Voltage in the primary x Current in the primary = V in the secondary x current in the secondary

$$V_P \times I_P = V_S \times I_S$$

Example: VP = 240V IP = 1 A What is the power in the primary and secondary?

240 W

Current Ratio

The current ratio is opposite to the voltage ratio. If a transformer drops voltage from primary to secondary, the current capacity in the secondary will increase. This is shown from the power equations.

In the example above, 240 V and 1 A in the primary gives 240 W. If the secondary is wound to provide 12 V, and has the same power rating of 240 W, what is the current. Using the power formula 240 x 1 = 12 x ? . This provides 20 A.

This is better shown in the formula.

$$\frac{I_s}{I_p} = \frac{N_p}{N_S}$$

Example: Turns ratio of 20:1 primary to secondary and I_P is 1 A what is I_S?

20 A

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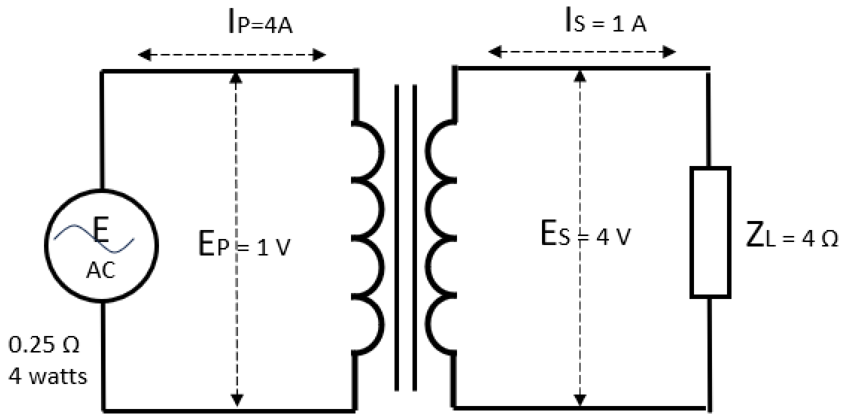
Impedance Ratio

Transformers are also used to match impedances such as a Balun and an amplifier output matching transformer in amateur radio.

The formula for the transformer. The number of turns in the primary over the turns in the secondary, the turns ratio, equals the square root of the impedance in the primary over the impedance in the secondary.

$$\frac{N_p}{N_S} = \sqrt{\frac{Z_P}{Z_S}}$$

Example: Need to match the amplifier output impedance of 0.25 Ω to a 4 Ω speaker,



What is the turns ratio for the transformer above?

$$NP / NS = \sqrt{0.25/4}$$

$$= 0.5 / 2$$

$$= 1/4$$

$$NP = 1 \quad NS = 4$$

The secondary winding has four times as many windings as the primary.

Centre Tapped Transformer

A Centre Tapped transformer has its secondary winding divided into two parts. This allows two individual voltages to be produced across the two ends. See below.

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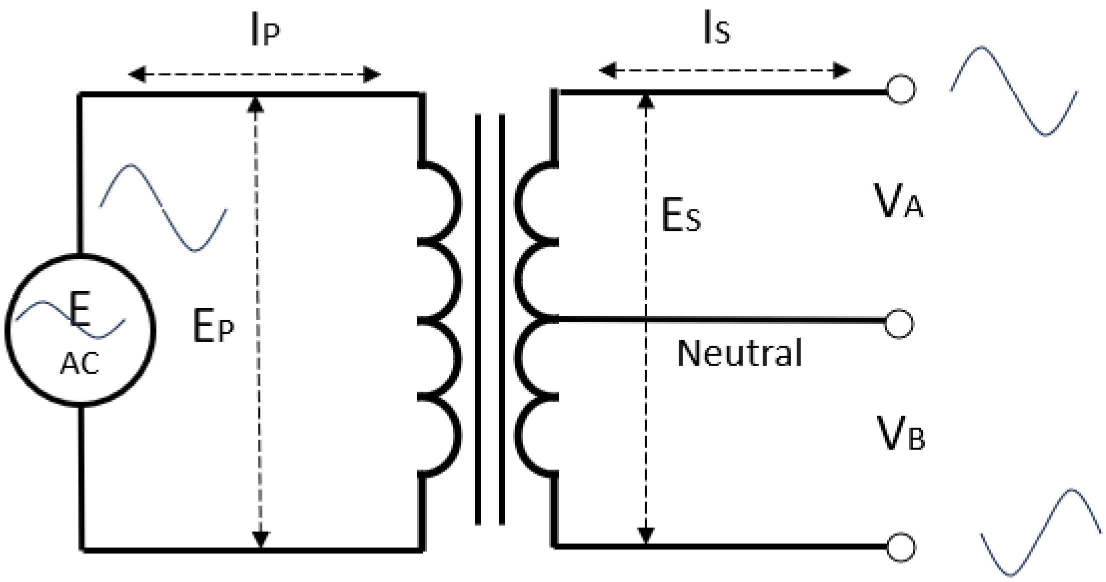
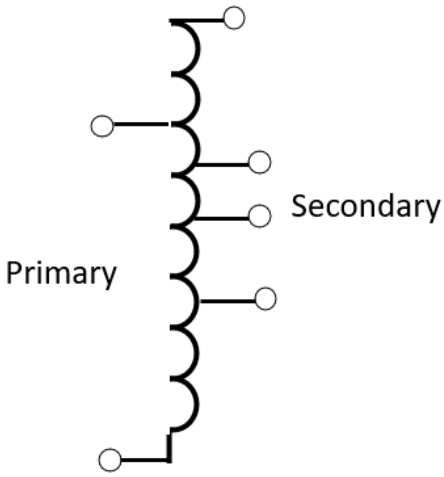


The outputs VA and VB are equal in magnitude but opposite in direction or they are 180 degrees out of phase.

Autotransformer

An autotransformer has only one winding where portions of the same winding act as both the primary winding and secondary winding sides of the transformer.

An example of an autotransformer is a traveler's voltage converter that allows 230-volt devices to be used on 120-volt supply circuits, or the reverse.



Autotransformer

Go to Lesson 5 questions.

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Have fun and stay safe

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