SCHOOL OF ELECTRICAL AND ELECTRONIC ENGINEERING

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1. AC SIGNALS

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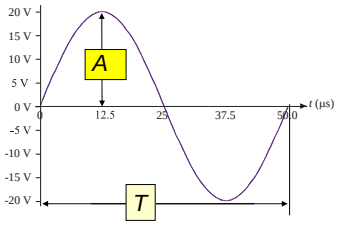
Sine waves

Sine waves are characterized by the amplitude and period. The **amplitude** is the maximum value of a voltage or current; the **period** is the time interval for one complete cycle.

Example

The amplitude (*A*) of this sine wave is 20 V

The period is 50.0 μs



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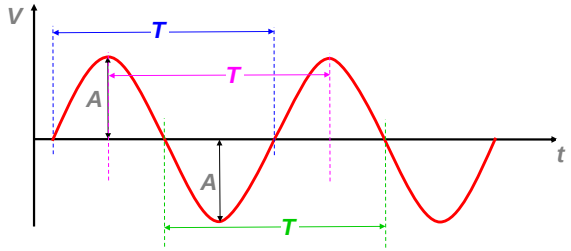
Sine waves

The period of a sine wave can be measured between any two corresponding points on the waveform.



By contrast, the amplitude of a sine wave is only measured from the center to the maximum point.

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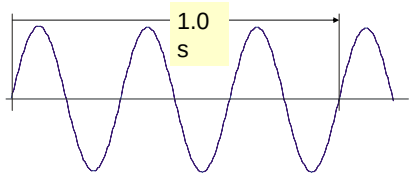
Frequency

Frequency (*f*) is the number of cycles that a sine wave completes in one second.

Frequency is measured in **hertz** (Hz).

Example

If 3 cycles of a wave occur in one second, the frequency is 3.0 Hz



Period and frequency

The period and frequency are reciprocals of each other.

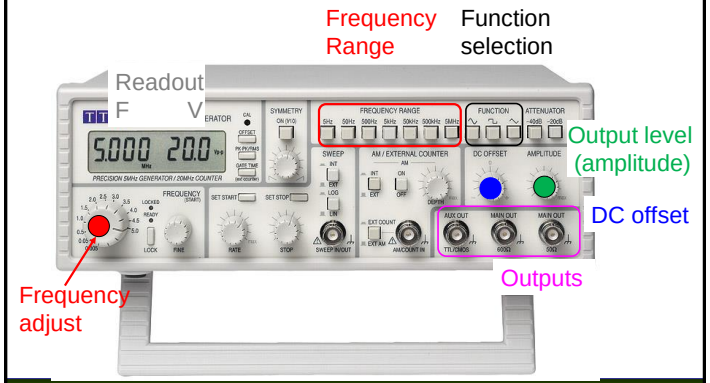
$f = \frac{1}{T}$ and $T = \frac{1}{f}$

Thus, if you know one, you can easily find the other.

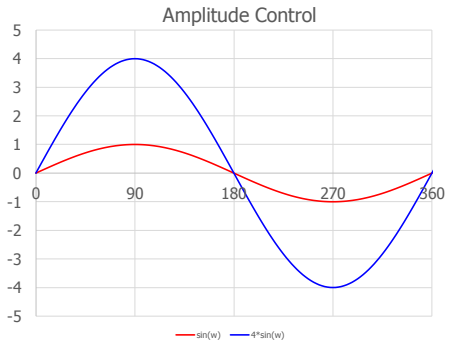
Example

If the period is 50 μs, the frequency is 0.02 MHz = 20 kHz.

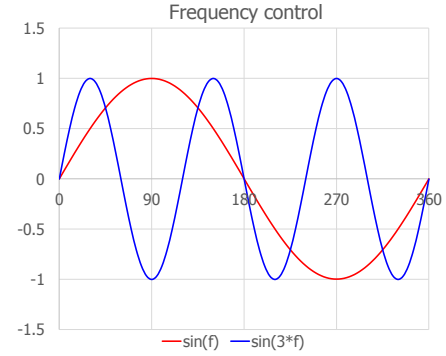
Function Generator



Amplitude control



Frequency control



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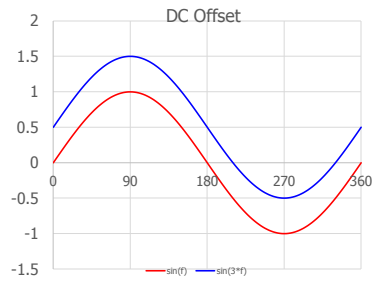
DC offset control



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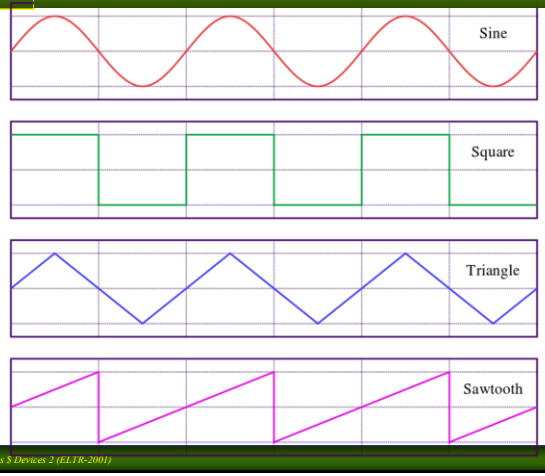
Waveform (Function) control



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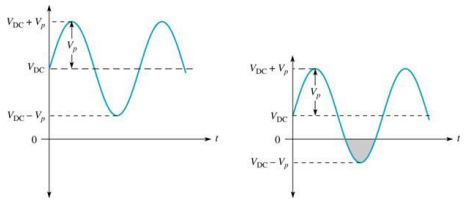
Superimposed dc and ac voltages

Frequently dc and ac voltages are together in a waveform.

They can be added algebraically, to produce a composite waveform of an ac voltage “riding” on a dc level.



(a) $V_{DC} > V_p$. The sine wave never goes negative.

(b) $V_{DC} < V_p$. The sine wave reverses polarity during a portion of its cycle, as indicated by the gray area.

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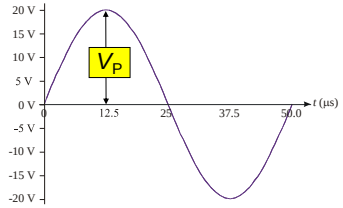
Sine wave voltage and current values

There are several ways to specify the voltage of a sinusoidal voltage waveform. The amplitude of a sine wave is also called the peak value, abbreviated as V_P for a voltage waveform.

Example

The peak voltage of this waveform is 20 V.



Sine wave voltage and current values

The voltage of a sine wave can also be specified as either the peak-to-peak or the rms value.

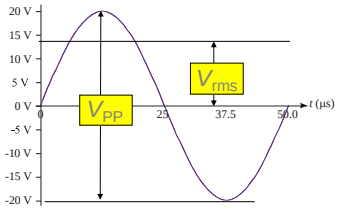
The peak-to-peak is twice the peak value.

The rms value is 0.707 times the peak value.

Example

The peak-to-peak voltage is 40 V.

The rms voltage is 14.1 V.



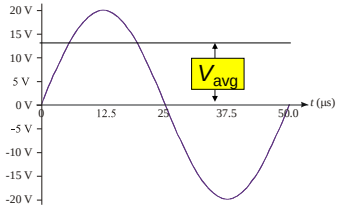
Sine wave voltage and current values

For some purposes, the average value (actually the half-wave average) is used to specify the voltage or current.

By definition, the average value is as 0.637 times the peak value.

Example

The average value for the sinusoidal voltage is 12.7 V.

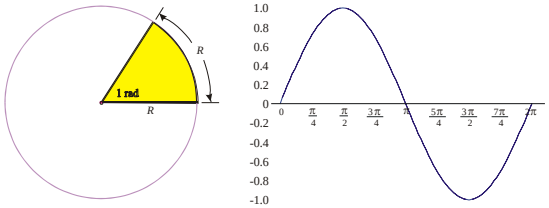


Angular measurement

Angular measurements can be made in degrees (°) or radians.

The radian (rad) is the angle that is formed when the arc is equal to the radius of a circle.

There are 360° or 2π radians in one complete revolution.



Angular measurement

There are 2π radians in one complete revolution and 360° in one revolution. To find the number of radians, given the number of degrees:

$$\text{rad} = \frac{2\pi \text{ rad}}{360°} \times \text{degrees}$$

This can be simplified to:

$$\text{rad} = \frac{\pi \text{ rad}}{180°} \times \text{degrees}$$

To find the number of degrees, given the number of radians:

$$\text{deg} = \frac{180°}{\pi \text{ rad}} \times \text{rad}$$

Angular measurement

Example How many radians are in 45°?

Solution:

$$\text{rad} = \frac{\pi \text{ rad}}{180^\circ} \times \text{degrees}$$

$$= \frac{\pi \text{ rad}}{180^\circ} \times 45^\circ = 0.785 \text{ rad}$$

Example How many degrees are in 1.2 radians?

Solution:

$$\text{deg} = \frac{180^\circ}{\pi \text{ rad}} \times \text{rad}$$

$$= \frac{180^\circ}{\pi \text{ rad}} \times 1.2 \text{ rad} = 69^\circ$$

Sine wave equation

Instantaneous values of a wave are shown as v or i.

The equation for the instantaneous voltage (v) of a sine wave is

$$v = V_p \sin\theta$$

where

V_p = Peak voltage

θ = Angle in rad or degrees

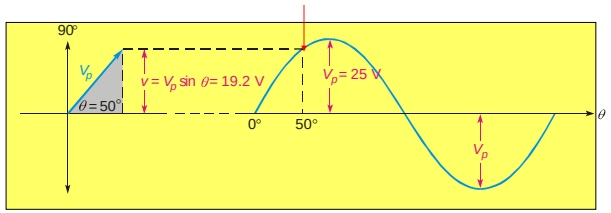
Example

If the peak voltage is 25 V, the instantaneous voltage at 50 degrees is 19.2 V

Sine wave equation

A plot of the example in the previous slide (peak at 25 V) is shown.

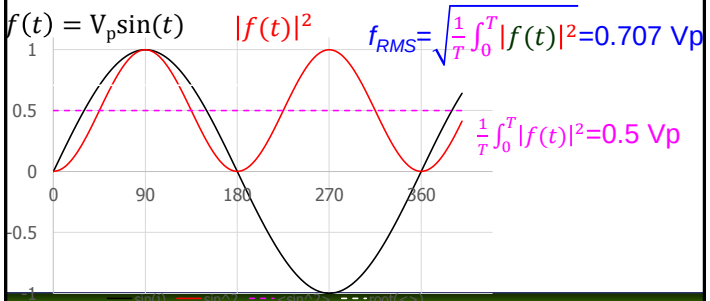
The instantaneous voltage at 50° is 19.2 V as previously calculated.



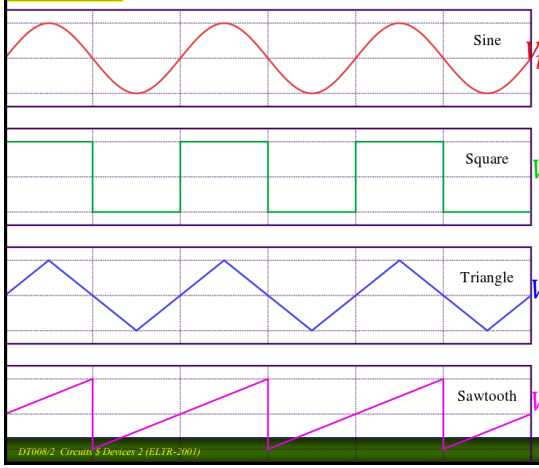
RMS Value

The RMS value of continuous-time waveform is the square root of the arithmetic mean of the square of the function that defines the continuous waveform.

In physics, the RMS current is the "value of the direct current that dissipates power in a resistor.



RMS Value for different waveforms



$V_p = \sqrt{2} \cdot V_{RMS}$

$V_p = V_{RMS}$

$V_p = \sqrt{3} \cdot V_{RMS}$

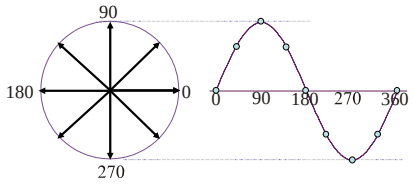
$V_p = \sqrt{3} \cdot V_{RMS}$

Phasors

The sine wave can be represented as the projection of a vector rotating at a constant rate.

This rotating vector is called a **phasor**.

Phasors are useful for showing the phase relationships in ac circuits.



Phase shift

The phase of a sine wave is an angular measurement that specifies the position of a sine wave relative to a reference.

To show that a sine wave is shifted to the left or right of this reference, a term is added to the equation given previously.

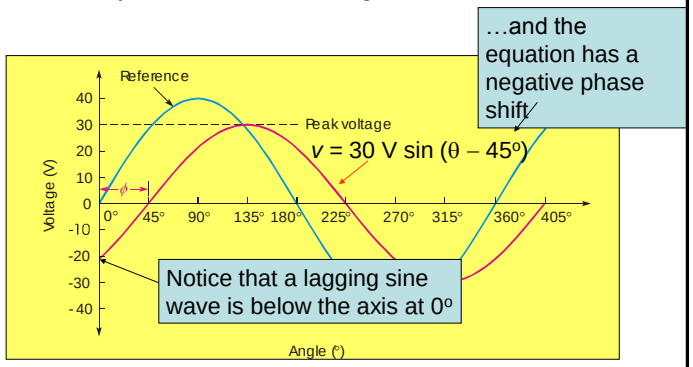
$$v = V_P \sin(\theta \pm \phi)$$

where

ϕ = Phase shift

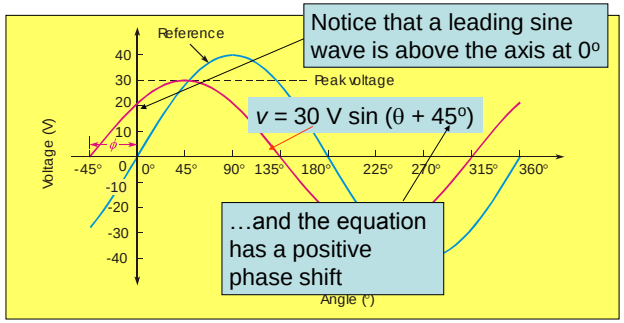
Phase shift

Example of a wave that lags the reference



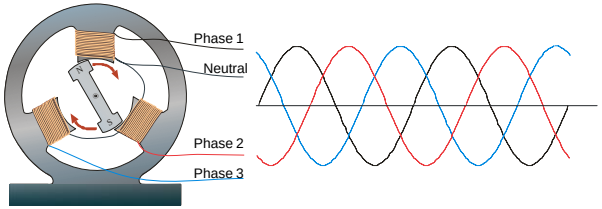
Phase shift

Example of a wave that leads the reference



Alternators

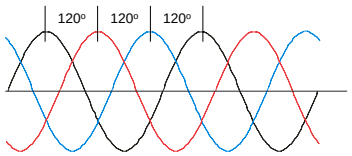
Alternators are ac generators. Utility companies use 3-phase alternators and deliver all three phases to industrial customers.
A simplified 3-phase alternator is illustrated.



Phase shift

An important application of phase-shifted sine waves is in electrical power systems.
Electrical utilities generate ac with three phases that are separated by 120° as illustrated.

Normally, 3-phase power is delivered to the user with three hot lines plus neutral. The voltage of each phase, with respect to neutral is 220 V.



Power in resistive AC circuits

The power relationships developed for dc circuits apply to ac circuits except you must use rms values in ac circuits when calculating power.

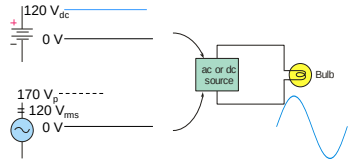
The power formulas are:

$$P = V_{rms} I_{rms}$$

$$P = \frac{V_{rms}^2}{R}$$

$$P = I_{rms}^2 R$$

For example, the dc and the ac sources produce the same power to the bulb:



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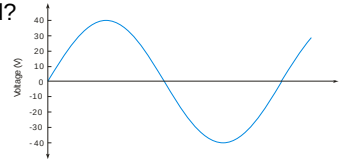
Power in resistive AC circuits

Example Assume a sine wave with a peak value of 40 V is applied to a 100 Ω resistive load. What power is dissipated?



Solution $V_{rms} = 0.707 \times V_p = 0.707 \times 40\ V = 28.3\ V$

$$P = \frac{V_{rms}^2}{R} = \frac{28.3\ V^2}{100\ \Omega} = 8\ W$$

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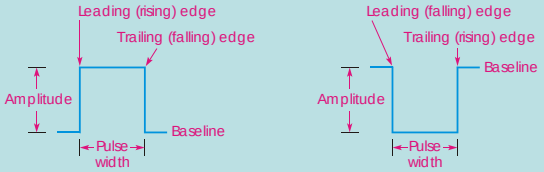
Pulse definitions

Ideal pulses



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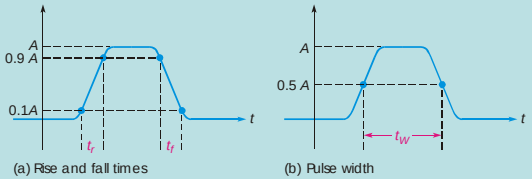
Pulse definitions

Non-ideal pulses



Notice that rise and fall times are measured between the 10% and 90% levels whereas pulse width is measured at the 50% level.

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Optional