Module

1

What is AC?

AC Waves

What you'll learn in Module 1.

Section 1.1 AC Waves

Recognise common uses for AC

Recognise a sine wave

Section 1.2 Measuring the Sine Wave

Know measurements associated with sine waves

a. Peak to peak value.

b. Amplitude.

c. Peak value.

d. Periodic time.

e. Average value.

f. RMS value.

Section 1.3 AC Waves Quiz

Recall information on AC waves.

Module 1 – Introduction to AC Waves.

What is AC?

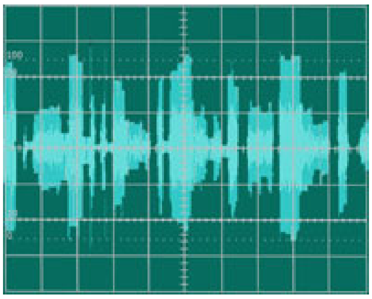
As you study this and the following modules on AC (Alternating Current) theory, notice that the circuits described use two main components, inductors and capacitors, which in many ways seem to have opposite and complimentary effects. It is the way they are connected in a circuit, as well as their individual electrical values that are key to the many uses of these circuits. Although in many cases these basic combinations of inductors and capacitors may now be replaced by new and usually smaller ceramic components, the basic principles of these LCR (inductor - L, capacitor - C and resistor - R) circuits are essential to understanding the operation of many electronic systems and the signals that use them.

AC Waves.

Because waves are the basis of so many signals in electronic circuits, it is important that engineers and technicians can make measurements of the important characteristics of the waves used in AC technology. When AC is mentioned, perhaps the first thing that comes to mind is the "mains" or "line" supply that brings electricity to homes, factories and offices. There are many different applications of AC, and although the meaning of AC, is "Alternating Current" (a current that alternates its direction of flow around a circuit) "AC" is often used in other terms such as "AC signal" and even "AC voltage". Whenever the current in a circuit alternates, so will the voltage, and an alternating voltage will of course, cause an alternating current, even though in many cases one or other of these properties (voltage or current) may be so small as to be insignificant.

Complex Signal Waveforms

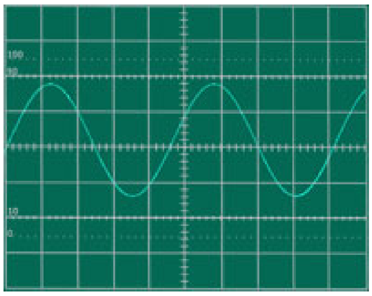
These alternating currents and voltages come in very many forms, the electricity power supply of course, and all sorts of other signals too. Sound, light, video, radio, all produce signals that alternate; meaning, they change their values over time, alternating above and below a particular value (often, but not always zero). Our bodies also produce alternating electrical signals, as do all sorts of natural and man-made objects and devices. These signals are what engineers and technicians are most often interested in when studying electronics, but signals come in many very different forms.



To understand complex signals, there is often a need to simplify them; if the signal can be understood in its simplest form, then that understanding can be applied to the complex signal.

The Sine Wave

Many signal waves tend to be repetitive, or "periodic". They repeat a particular pattern or wave shape over a regular time period. The most important of all the different wave shapes is the sine wave, because any periodic wave can be shown to be made up of a series of pure sine waves, perhaps of many different frequencies and amplitudes. The sine wave is important to electronics engineers because of its purity, it consists of only a single frequency; it alternates regularly above and below its mid value at a constant rate. In a musical note this rate, the frequency, would be referred to as the pitch of the note.



All waves except sine waves contain a number of different frequencies. They have one dominant frequency called "the fundamental", plus (often many) others called "harmonics", that give a wave its particular character. Rather than looking at how a circuit acts with complex periodic waves, which are made up of many of pure sine waves, it is much easier to use single sine waves. Measuring sine waves is therefore important, as the results obtained are a major source of information in understanding the operation of electronic systems of many kinds.

Module 1.1 AC Waves

What are Waves?

Information is passed from one place, or person, to another in many different ways. Whatever way information is carried, the SIGNAL used takes the form of waves. These may be sound waves, electrical waves or light waves, and although these are all physically very different from each other they may all be represented by WAVEFORMS. A waveform is simply a graph, which shows how the property described (e.g. sound or electricity), changes with time.

With many of the waves that concern electronics engineers, for example sound or radio waves, the actual wave, acting at high speeds within the circuitry cannot be seen in any normal way. They must be viewed with instruments such as the OSCILLOSCOPE, that can draw graphs of these "invisible" waves, and so allow engineers to check that the wave is present, and has not been distorted in shape by the equipment under test. The oscilloscope is also used to measure a number of properties of waves, giving information on the performance of equipment.

Harmonics.

Signal waveforms having very complex shapes are often encountered in electronic equipment, but all repetitive waves, no matter how complex, can be shown mathematically to consist of a series of much simpler waves, each of which has the same shape. This wave shape is known as a SINE WAVE because its graph follows the mathematical SINE function. The shape of a sine wave is quite familiar, although not usually recognised as such, because its waveform or graph is not readily visible. The swinging pendulum of a clock traces out a sine wave, and many naturally occurring vibrations are SINUSOIDAL (that is "of a sine wave shape")

Fig 1.1.1 shows examples of sine waves, plotted mathematically over a series of calculated points (bottom left). A sine wave can also be produced naturally (top right), by fixing a container such as a saltshaker to the end of a swinging pendulum, and moving a sheet of coloured paper at a constant speed beneath it as it swings and deposits its salt. The result is a beautiful sine wave!

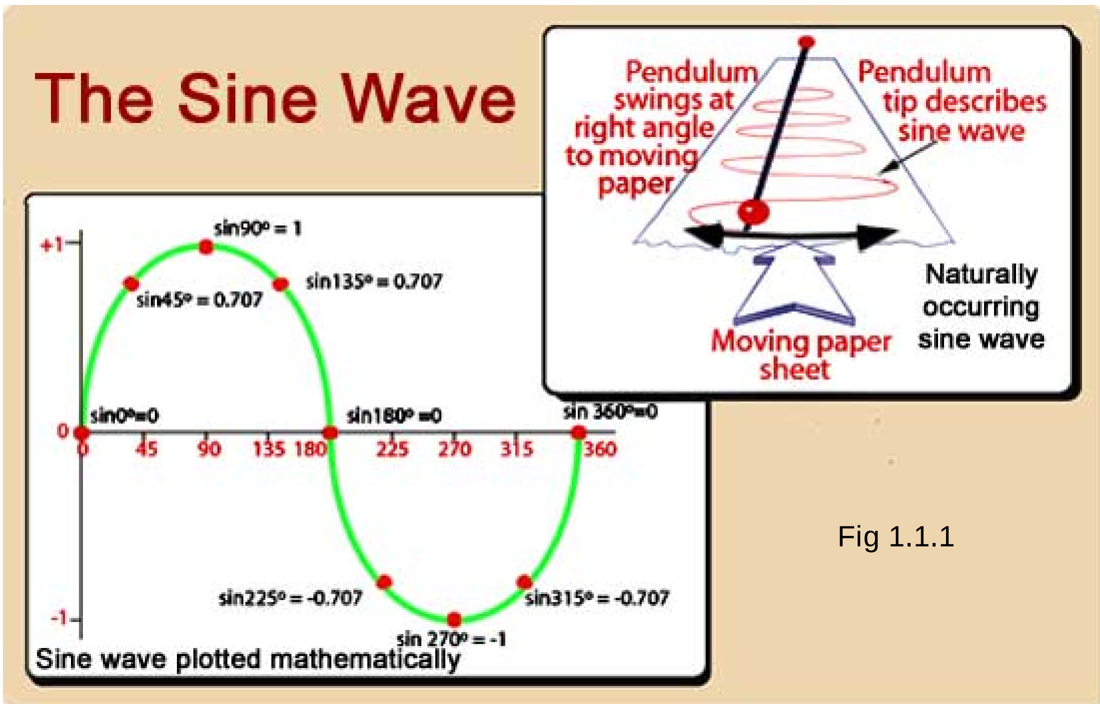


Fig 1.1.1

Sine Waves.

The sine wave therefore is a mathematical function and a naturally occurring shape; it is also the basis of many other wave shapes and is therefore the most important waveform in the study of AC theory. Other important (complex) waveforms commonly encountered in electronics are:

- The Square wave:
- The Triangular wave:
- The Saw-tooth wave:

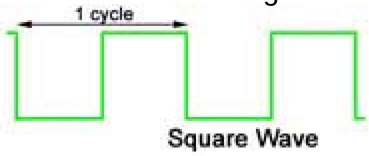
Complex Waves.

A complex wave is a wave made up of a series of sine waves; it is therefore more complex than a single pure sine wave. This series of sine waves always contains a sine wave called the "FUNDAMENTAL", which has the same FREQUENCY (repetition rate) as the COMPLEX WAVE being created.

As well as the fundamental, a complex wave contains a series of HARMONICS. These sine waves have frequencies that are WHOLE NUMBER MULTIPLES of the fundamental; that is, the fundamental x 2, the fundamental x 3 etc. The fundamental and the harmonics are called the COMPONENTS of a complex wave. One further component is often present in a complex wave. That is a D.C. COMPONENT. This is a component "wave" whose frequency is ZERO, i.e. it is not really a wave but merely a DC value that affects the resultant complex wave. Square, Triangular and Saw-tooth waves can be shown to consist of a fairly straightforward series of components, you should remember which series of harmonics makes up which of these three complex waves.

The SQUARE WAVE

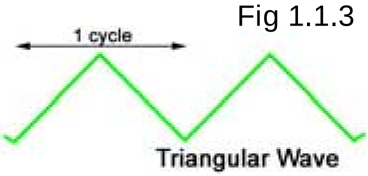
Fig 1.1.2



The square wave contains a fundamental and a series of ODD HARMONICS; that is harmonics which are odd number multiples of the fundamental (x3 x5 x7 etc.) These are called the 3rd harmonic, 5th harmonic etc.

The TRIANGULAR WAVE

Fig 1.1.3

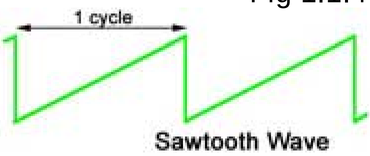


The triangular wave also contains a fundamental and a series of ODD HARMONICS, but in this case, each successive harmonic component starts in the opposite PHASE to the previous one. i.e. the 3rd harmonic starts by going positive, the 5th harmonic begins by going negative, the 7th positive and so on.

This phase change of alternate harmonics is the only difference from the square wave components, whose harmonics all start in a positive direction, yet the resultant waves are completely different.

The SAWTOOTH WAVE

Fig 1.1.4

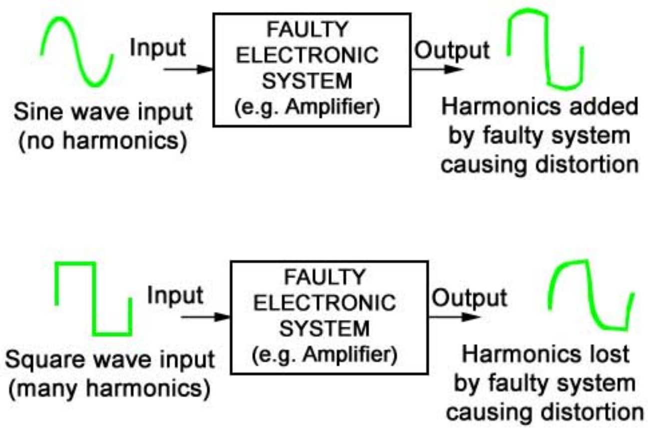


The saw tooth wave contains a fundamental and both ODD and EVEN HARMONICS.

In each of the above cases, the fundamental and just a few harmonic components will give the resultant wave an approximate shape to the ideal waveforms illustrated. If more harmonics are included in the series the resultant wave-shape is better, and the more harmonics that are included, the nearer the complex wave will be to a perfect square or triangular shape. This fact is important in equipment such as hi−fi amplifiers because the waveform at the loudspeaker should ideally be exactly the same shape as the waveform at the system's input - so the sound we hear is as close to the original as possible. This means that it is necessary to reproduce every sine wave component of the original wave accurately without "losing" any components on the way. Neither should the system add any harmonics which were not in the original signal. In either case the final output signal would not be the same shape as the original and unwanted DISTORTION has been introduced into the system.

Fig 1.1.5 Harmonic Distortion

In practice however it is possible to ignore many of the harmonic components without a noticeable effect on the waveform. This is because the harmonics that are closest to the fundamental frequency (2nd, 3rd etc.) have large amplitudes. They therefore have a greater effect on the shape of the resultant wave, the high frequency harmonics (15th, 16th for example) are very small in comparison to the lower harmonics and fundamental, so they only change the resultant wave very slightly.



Module 1.2 Measuring the Sine Wave.

Fig 1.2.1 Characteristics of a Sine Wave

A waveform is a graph showing the variation, usually of voltage or current, against time. The horizontal axis shows the passing of time, progressing from left to right. The vertical axis shows the quantity measured (this is voltage in Fig 1.2.1).

Six of the most important characteristics of a sine wave are;

- The PEAK TO PEAK value.
- The AMPLITUDE.
- The PEAK value.
- The PERIODIC TIME.
- The AVERAGE value.
- The RMS value.

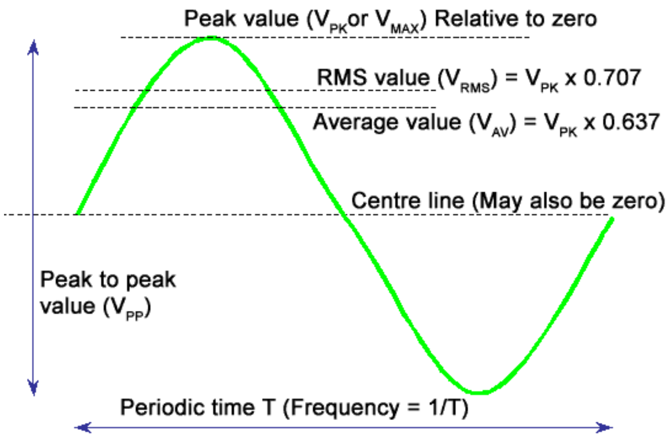


Fig 1.2.1

These characteristics are illustrated in Fig 1.2.1

Peak to Peak value

The PEAK-TO-PEAK value is the vertical distance between the top and bottom of the wave. It will be measured in volts on a voltage waveform, and may be labelled V_{PP} or V_{PK-PK}. In a current waveform it would be labelled I_{PP} or I_{PK-PK} as I (not C) is used to represent current.

Amplitude

The AMPLITUDE of a sine wave is the maximum vertical distance reached, in either direction from the centre line of the wave. As a sine wave is symmetrical about its centre line, the amplitude of the wave is half the peak-to-peak value, as shown in Fig 1.2.2.

Peak value

The PEAK value of the wave is the highest value the wave reaches above a reference value. The reference value normally used is zero. In a voltage waveform the peak value may be labelled V_{PK} or V_{MAX} (I_{PK} or I_{MAX} in a current waveform).

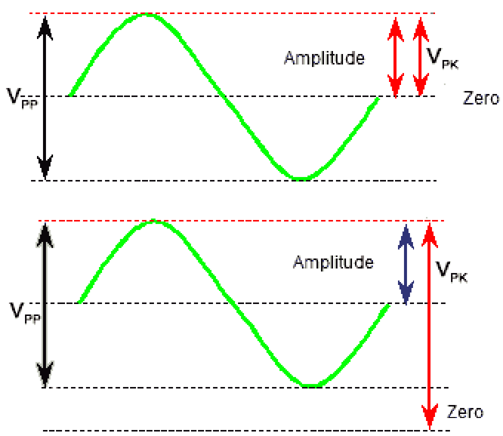


Fig 1.2.2 Defining the Peak value V_{PK}

If the sine wave being measured is symmetrical either side of zero volts (or zero amperes), meaning that the dc level or dc component of the wave is zero volts, then the peak value must be the same as the amplitude, that is half of the peak to peak value.

However this is not always the case, if a dc component other than zero volts is also present, the sine wave will be symmetrical about this level rather than zero. The bottom waveform in Fig 1.2.2 shows that the peak value can now be even larger than the peak to peak value, (the amplitude of the wave however, remains the same, and is the difference between the peak value and the "centre line" of the waveform).

Periodic Time & Frequency

The PERIODIC TIME (given the symbol T) is the time, in seconds milliseconds etc. taken for one complete cycle of the wave. It can be used to find the FREQUENCY of the wave f using the formula:

$$\mathbf{T = 1/}f$$

Thus if the periodic time of a wave is 20ms (or 1/50th of a second) then there must be 50 complete cycles of the wave in one second. A frequency of 50 Hz. Note that when you use this formula, if the periodic time is in seconds then the frequency will be in Hz.

Determining the Average Value of a Sine Wave

The Average Value.

This is normally taken to mean the average value of only half a cycle of the wave. If the average of the full cycle was taken it would of course be zero, as in a sine wave symmetrical about zero, there are equal excursions above and below the zero line.

Using only half a cycle, as illustrated in Fig 1.2.3 the average value (voltage or current) is always 0.637 of the peak value of the wave.

$V_{AV} = V_{PK} \times 0.637$

or

$I_{AV} = I_{PK} \text{ X } 0.637$

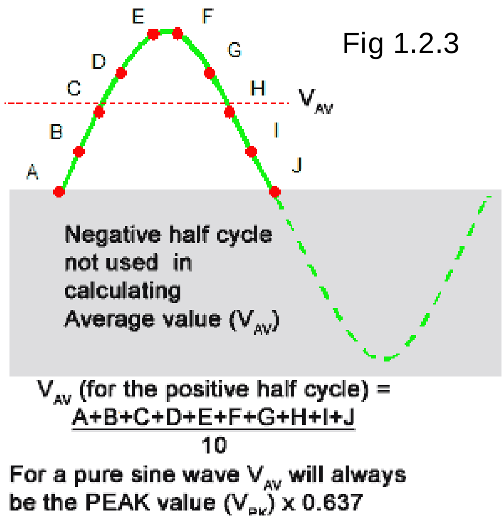


Fig 1.2.3

The average value is the value that usually determines the voltage or current indicated on a test meter. There are however some meters that will read the RMS value, these are called "True RMS meters".

The RMS or Root Mean Squared Value

This is the value of the equivalent direct (non varying) voltage or current which would provide the same energy to a circuit as the sine wave measured. That is, if an AC sine wave has a RMS value of 240 volts, it will provide the same energy to a circuit as a DC supply of 240 volts.

It can be shown that the RMS value of a sine wave is 0.707 of the peak value.

$V_{RMS} = V_{PK} \times 0.707$ and $I_{RMS} = I_{PK} \times 0.707$

Also, the peak value of a sine wave is equal to 1.414 x the RMS value.

The Form Factor

If V_{AV} (0.637) is multiplied by 1.11 the answer is 0.707, which is the RMS value. This difference is called the Form Factor of the wave, and the relationship of 1.11 is only true for a perfect sine wave. If the wave is some other shape, either the RMS or the average value (or both) will change, and so will the relationship between them. This is important when measuring AC voltages with a meter as it is the average value that most meters actually measure. However they display the RMS value simply by multiplying the voltage by 1.11. Therefore if the AC wave being measured is not a perfect sine wave the reading will be slightly wrong. If you pay enough money however, you can buy a true RMS meter that actually calculates the RMS value of non-sine waves.

The Mains (Line) Supply

To demonstrate some of these characteristics in use, consider a very common sine wave, the mains supply or line waveform, which in many parts of the world is a nominal 230V.

Electrical equipment that connects to the mains supply always carries a label giving information about what supply the equipment can be connected to. These labels are quite variable in appearance, but often there is a picture of a sine wave showing that an AC supply must be used. The voltage quoted will be 230V (or 120V in the USA) or range of voltages including these values. These voltages actually refer to the RMS value of the mains sine wave. The label also states that the frequency of the supply, which is 50Hz in Europe or 60Hz in the USA.

From this small amount of information other values can be worked out:

a. The peak voltage of the waveform, as $V_{PK} = V_{RMS}$ x 1.414

b. The AVERAGE value of the waveform, as $V_{AV} = V_{PK}$ x 0.637

c. The PEAK-TO-PEAK value of the waveform. Because V_{PK} is already known from a. it follows that $V_{PP} = V_{PK}$ x 2

> V_{PP} in this case is twice the AMPLITUDE, (because the mains waveform is symmetrical about zero volts the amplitude is the same value as V_{PK}) .

d. The PERIODIC TIME which is given by T =1/f

Module 1.3 AC Waves Quiz

What you should know.

After studying Module 1, you should:

Be able to describe waves relating to electronic systems.

Be able to describe measurements used in AC electronics

Be able to calculate AC values from other given values, relating to AC waves

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Try our quiz, based on the information you can find in Module 1. Check your answers on line at http://www.learnabout-electronics.org/ac_theory/ac_waves03.php

1. If a sine wave has a RMS voltage of 12volts, what will be its Peak-to-Peak voltage?

   a) 33.9V b) 8.484V c) 16.9V d) 15.3V

2. What is the peak value of a sine wave whose V_{AV} value is 15V?

   a) 19V b) 9.5V c) 21.2V d) 23.5V

3. Select the most accurate description of an AC signal

   a) An AC signal is any complex wave

   b) Has a rapidly changing voltage and a steady current

   c) Has values that change above and below a particular level

   d) An AC signal is always repetitive

4. Complete the sentence "A sine wave...

   a) ...has many harmonics"

   b) ...is a complex wave"

   c)...consists of a fundamental only"

   d) ...always has the same frequency"

5. If an AC waveform has a periodic time of 2ms, what will be its frequency?

a) 2kHz b) 500Hz c) 2MHz d) 50Hz

Continued..,

6.With reference to Fig 1.3.1, what is the value labelled A?

a) Periodic time

b) Amplitude

c) Frequency

d) RMS value

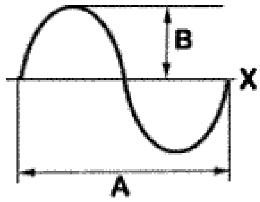

Fig 1.3.1

7. With reference to Fig 1.3.1, if the level labelled X has a value of 2V what is the value labelled B?

a) The Root Mean Squared value.

b) The Amplitude.

c) The Average value.

d) The Peak value.

8. In Fig 1.3.2, how many complete cycles are shown?

a) 2

b) 3

c) 4

d) 7

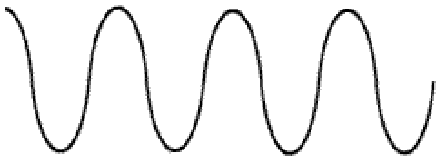
Fig 1.3.2

9. What value is given by the formula V_{PK} x 0.637?

a) V_{RMS}

b) V_{MAX}

c) The Form Factor

d) V_{AV}

10. Which of the following features is true of a square wave signal?

a) It consists of a fundamental and an even number of harmonics

b) It consists of a fundamental and a number of even harmonics.

c) It consists of a fundamental and a number of odd harmonics.

d) It never has a DC component.

