

Fig 2.26 — The relationships between RMS, average, peak, and peak-to-peak values of ac voltage and current.

$$I_{pk} = I_{RMS} \times 1.414 \quad (39)$$

Example: What is the peak voltage and the peak-to-peak voltage at the usual household ac outlet, if the RMS voltage is 120 V?

$$E_{pk} = 120 \text{ V} \times 1.414 = 170 \text{ V}$$

$$E_{P-P} = 2 \times 170 \text{ V} = 340 \text{ V}$$

In the time domain of a sine wave, the instantaneous values of voltage and current correspond to the RMS values at the 45°, 135°, 225° and 315° points along the cycle shown in **Fig 2.26**. (The sine of 45° is approximately 0.707.) The instantaneous value of voltage or current is greater than the RMS value for half the cycle and less than the RMS value for half the cycle.

Since circuit specifications will most com-

monly list only RMS voltage and current values, these relationships are important in finding the peak voltages or currents that will stress components.

Example: What is the peak voltage on a capacitor if the RMS voltage of a sinusoidal waveform signal across it is 300 V ac?

$$E_{pk} = 300 \text{ V} \times 1.414 = 424 \text{ V}$$

The capacitor must be able to withstand this higher voltage, plus a safety margin. (The capacitor must also be rated for ac use because of the continually reversing polarity and ac current flow.) In power supplies that convert ac to dc and use capacitive input filters, the output voltage will approach the peak value of the ac voltage rather than the RMS value. (See the **Power Sources** chapter for more

information on specifying components in this application.)

AVERAGE VALUES OF AC VOLTAGE AND CURRENT

Certain kinds of circuits respond to the *average* voltage or current (not power) of an ac waveform. Among these circuits are electrodynamic meter movements and power supplies that convert ac to dc and use heavily inductive (“choke”) input filters, both of which work with the pulsating dc output of a full-wave rectifier. The average value of each ac half cycle is the *mean* of all the instantaneous values in that half cycle. (The average value of a sine wave or any symmetric ac waveform over an entire cycle is zero!) Related to the peak values of voltage and current, average values for each half-cycle of a sine wave are $2/\pi$ (or 0.6366) times the peak value.

$$E_{ave} = 0.6366 E_{pk} \quad (40)$$

$$I_{ave} = 0.6366 I_{pk} \quad (41)$$

For convenience, **Table 2.5** summarizes the relationships between all of the common ac values. All of these relationships apply only to sine waves.

COMPLEX WAVEFORMS AND PEAK-ENVELOPE VALUES

Complex waveforms, as shown earlier in **Fig 2.18**, differ from sine waves. The amplitude of the peak voltage may vary significantly from one cycle to the next, for example. Therefore, other amplitude measures are required, especially for accurate measurement of voltage and power with transmitted speech or data waveforms.

An SSB waveform (either speech or data) contains an RF ac waveform with a frequency many times that of the audio-frequency ac waveform with which it is combined. Therefore, the resultant *composite* waveform appears as an amplitude envelope superimposed upon the RF waveform as illustrated by **Fig 2.27**. For a complex waveform such as this, the *peak envelope voltage* (PEV) is the maximum or peak value of voltage anywhere in the waveform.

Peak envelope voltage is used in the cal-

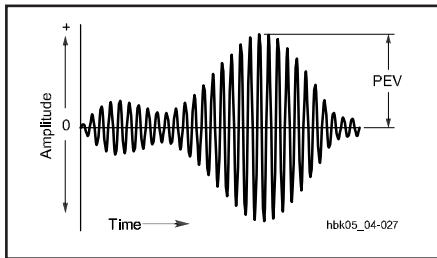


Fig 2.27 — The peak envelope voltage (PEV) for a composite waveform.

Table 2.5

Conversion Factors for Sinusoidal AC Voltage or Current

From	To	Multiply By
Peak	Peak-to-Peak	2
Peak-to-Peak	Peak	0.5
Peak	RMS	$1/\sqrt{2}$ or 0.707
RMS	Peak	$\sqrt{2}$ or 1.414
Peak-to-Peak	RMS	$1/(2 \times \sqrt{2})$ or 0.35355
RMS	Peak-to-Peak	$2 \times \sqrt{2}$ or 2.828
Peak	Average	$2/\pi$ or 0.6366
Average	Peak	$\pi/2$ or 1.5708
RMS	Average	$(2 \times \sqrt{2})/\pi$ or 0.90
Average	RMS	$\pi/(2 \times \sqrt{2})$ or 1.11

Note: These conversion factors apply only to continuous pure sine waves.

ulation of *peak envelope power* (PEP). The Federal Communications Commission (FCC) sets the maximum power levels for amateur transmitters in terms of peak envelope power. PEP is the *average* power supplied to the antenna transmission line by the transmitter during one RF cycle at the crest of the modulation envelope, taken under normal operating conditions. That is, the average power for the RF cycle during which PEV occurs.

Since calculation of PEP requires the average power of the cycle, and the deviation of the modulated RF waveform from a sine wave is very small, the error incurred by using the conversion factors for sine waves is insignificant. Multiply PEV by 0.707 to obtain an RMS value. Then calculate PEP by using the square of the voltage divided by the load resistance.

$$\text{PEP} = \frac{(\text{PEV} \times 0.707)^2}{R} \quad (42)$$

Example: What is the PEP of a transmitter's output with a PEV of 100 V into a 50-ohm load?

$$\text{PEP} = \frac{(100 \times 0.707)^2}{R} = \frac{(70.7)^2}{50} = 100 \text{ W}$$

2.6.5 - Glossary — AC Theory and Reactance

Admittance (Y) — The reciprocal of impedance, measured in siemens (S).

Capacitance (C) — The ability to store electrical energy in an electrostatic field, measured in farads (F). A device with capacitance is a capacitor.

Flux density (B) — The number of magnetic-force lines per unit area, measured in gauss.

Frequency (f) — The rate of change of an ac voltage or current, measured in cycles per second, or hertz (Hz).

Fundamental — The lowest frequency in a series of sine waves whose frequencies have an integer relationship.

Harmonic — A sine wave whose frequency is an integer multiple of a fundamental frequency.

Impedance (Z) — The complex combination of resistance and reactance, measured in ohms (Ω).

Inductance (L) — The ability to store electrical energy in a magnetic field, measured in henrys (H). A device, such as a coil of wire, with inductance is an inductor.

Peak (voltage or current) — The maximum value relative to zero that an ac voltage or current attains during any cycle.

Peak-to-peak (voltage or current) — The value of the total swing of an ac voltage or current from its peak negative value to its peak positive value, ordinarily twice the value of the peak voltage or current.

Period (T) — The duration of one ac voltage or current cycle, measured in seconds (s).

Permeability (μ) — The ratio of the magnetic flux density of an iron, ferrite, or similar core in an electromagnet compared to the magnetic flux density of an air core, when the current through the electromagnet is held constant.

Power (P) — The rate of electrical-energy use, measured in watts (W).

Q (quality factor) — The ratio of energy stored in a reactive component (capacitor or inductor) to the energy dissipated, equal

to the reactance divided by the resistance.

Reactance (X) — Opposition to alternating current by storage in an electrical field (by a capacitor) or in a magnetic field (by an inductor), measured in ohms (Ω).

Resonance — Ordinarily, the condition in an ac circuit containing both capacitive and inductive reactance in which the reactances are equal.

RMS (voltage or current) — Literally, "root mean square," the square root of the average of the squares of the instantaneous values for one cycle of a waveform. A dc voltage or current that will produce the same heating effect as the waveform. For a sine wave, the RMS value is equal to 0.707 times the peak value of ac voltage or current.

Susceptance (B) — The reciprocal of reactance, measured in siemens (S).

Time constant (τ) — The time required for the voltage in an RC circuit or the current in an RL circuit to rise from zero to approximately 63.2% of its maximum value or to fall from its maximum value 63.2% toward zero.

Toroid — Literally, any donut-shaped solid; most commonly referring to ferrite or powdered-iron cores supporting inductors and transformers.

Transducer — Any device that converts one form of energy to another; for example an antenna, which converts electrical energy to electromagnetic energy or a speaker, which converts electrical energy to sonic energy.

Transformer — A device consisting of at least two coupled inductors capable of transferring energy through mutual inductance.

2.7 Capacitance and Capacitors

It is possible to build up and hold an electrical charge in an *electrostatic field*. This phenomenon is called *capacitance*, and the devices that exhibit capacitance are called *capacitors*. (Old articles and texts use the obsolete term *condenser*.) Fig 2.28 shows several schematic symbols for capacitors. Part A shows a fixed capacitor; one that has a single value of capacitance. Part B shows the symbol for variable capacitors; these are adjustable over a range of values. If the capacitor is of a type that is *polarized*, meaning that dc voltages must be applied with a specific polarity, the straight line in the symbol should be connected to the most positive voltage, while the curved line goes to the more negative voltage, which is often ground. For clarity, the positive terminal of a polarized capacitor symbol is usually marked with a + symbol. The symbol for *non-polarized* capacitors may

be two straight lines or the + symbol may be omitted. When in doubt, consult the capacitor's specifications or the circuits parts list.

2.7.1 Electrostatic Fields and Energy

An *electrostatic field* is created wherever a voltage exists between two points, such as two opposite electric charges or regions that contain different amounts of charge. The field causes electric charges (such as electrons or ions) in the field to feel a force in the direction of the field. If the charges are not free to move, as in an insulator, they store the field's energy as *potential energy*, just as a weight held in place by a surface stores gravitational energy. If the charges are free to move, the field's stored energy is converted to *kinetic energy* of motion just as if the weight is released to

fall in a gravitational field.

The field is represented by *lines of force* that show the direction of the force felt by the electric charge. Each electric charge is surrounded by an electric field. The lines of force of the field begin on the charge and extend away from charge into space. The lines of force can terminate on another charge (such as lines of force between a proton and an electron) or they can extend to infinity.

The strength of the electrostatic field is measured in *volts per meter* (V/m). Stronger fields cause the moving charges to accelerate more strongly (just as stronger gravity causes weights to fall faster) and stores more energy in fixed charges. The stronger the field in V/m, the more force an electric charge in the field will feel. The strength of the electric field diminishes with the square of the distance from its source, the electric charge.