Chapter 4
Voltage, Current, and Power

Voltage and Current

Resistance and Ohm's Law

AC Voltage and Power

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Review of Electrical Principles

Electric current consists of the movement of charges. The charged particles in matter make currents possible.

- Nucleus made up of Protons (+) and Neutrons (no charge).
- Electrons (-) occupy clouds of probability around nucleus.
- Protons are about 1000 times bigger than electrons.
- Most current is due to electron movement.

Conductors and Insulators

Properties due to bonding (sharing) of electrons between atoms.

- Insulators – strong hold on electrons – not free to move.
- Conductors – outer electrons form a sea of electrons that are free to move within the sea.
- Semiconductors – moderate hold on electrons but electrons will break loose under right conditions.

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Electrons and Fields

The moving charges which make up an electric current are usually due to electrons. Electrons and fields interact.

- Electrons in a conductor create an electric field.
- An electric field causes electrons to move or accelerate.
- Moving electrons create a magnetic field.
- A changing magnetic field causes moving electrons to accelerate or change direction.

Basic Types of Current

Direct Current (DC)

- Electrons move in one direction.
- Can fluctuate (pulse or ripple) in magnitude, but still only in one direction.

Alternating Current (AC)

- Electrons reverse direction at a frequency.
- Current goes from zero to positive to zero to negative to zero ….

AC and DC may be mixed together.

AC may be sinewave, pulse, triangle, random …

Electricity to Water Analogy

• Voltage	E	(Water Pressure)
• Current	I	(Flow of Water Molecules)
• Resistance	R	(Friction and obstructions)

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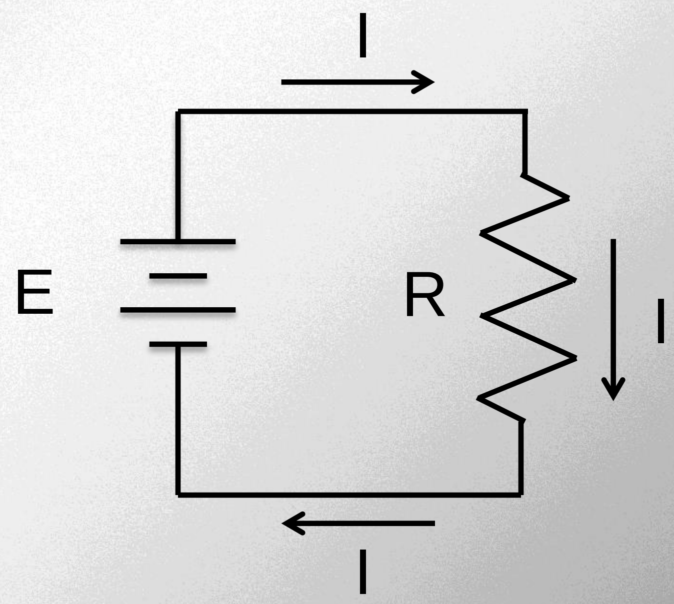
E, I, and R in a Series Circuit

A circuit is a closed path.

E represents the voltage in the circuit – a battery.

I represents the current in the circuit – the same at all points.

R represents the resistance of the circuit.



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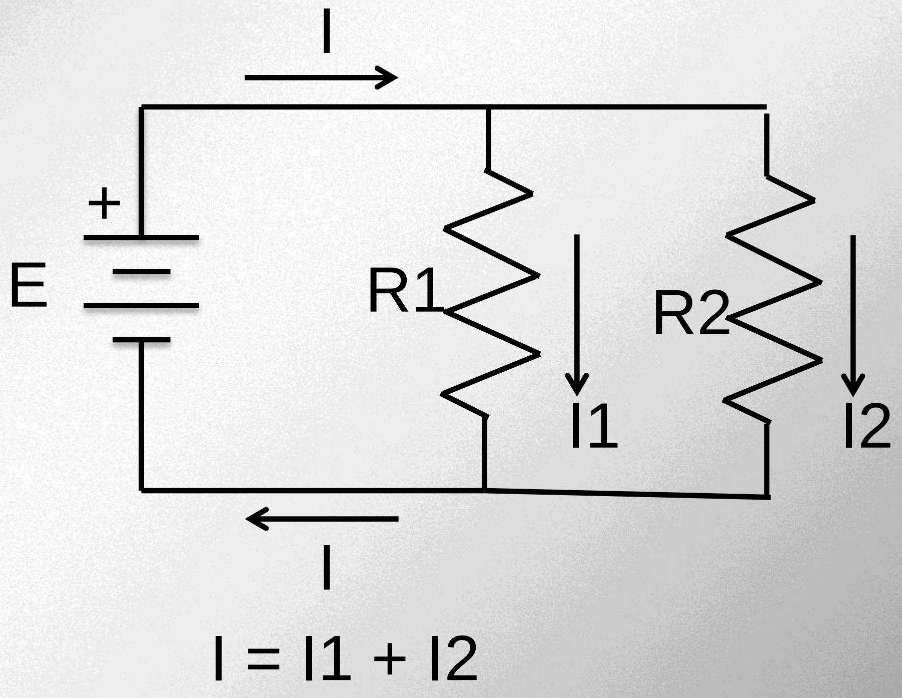
Currents in a Parallel Circuit

When two or more resistors are in parallel, each resistor takes part of the current I.

I = I1 + I2 is part of Kirchoff's Law.



Ohm’s Law (E = I * R)

Ohm’s Law is the proportional relationship between Voltage and Current.

Current is proportional to diameter of conductor but inversely proportional to length of conductor.

- Larger conductor – More current for a given voltage.
- Longer conductor – More voltage for same current.

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Ohm’s Law

A picture to remember Ohm’s Law

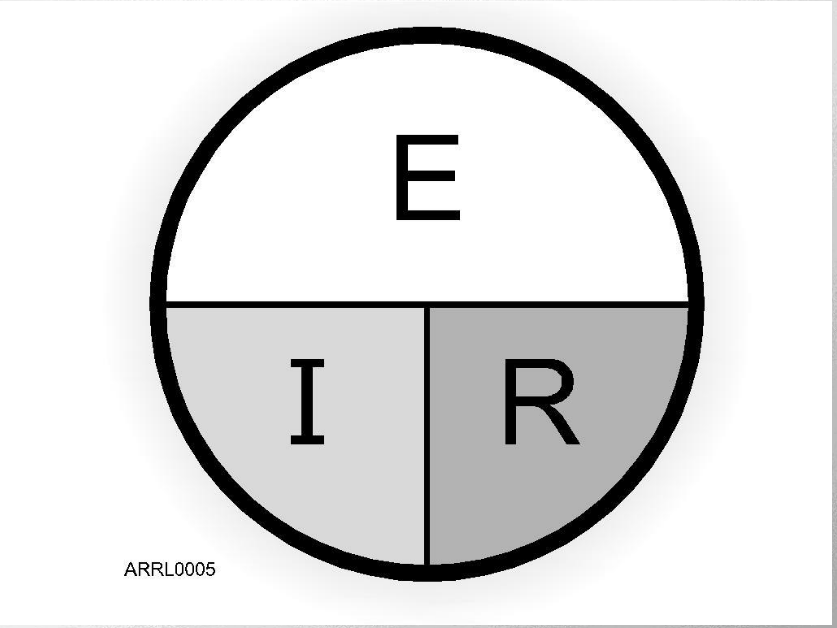
- E is voltage – Volts
- I is current – Amperes
- R is resistance – Ohms

Cover the one you don’t know:

E = I R

I = E Over R

R = E Over I



One Ohm, one Amp, one Volt

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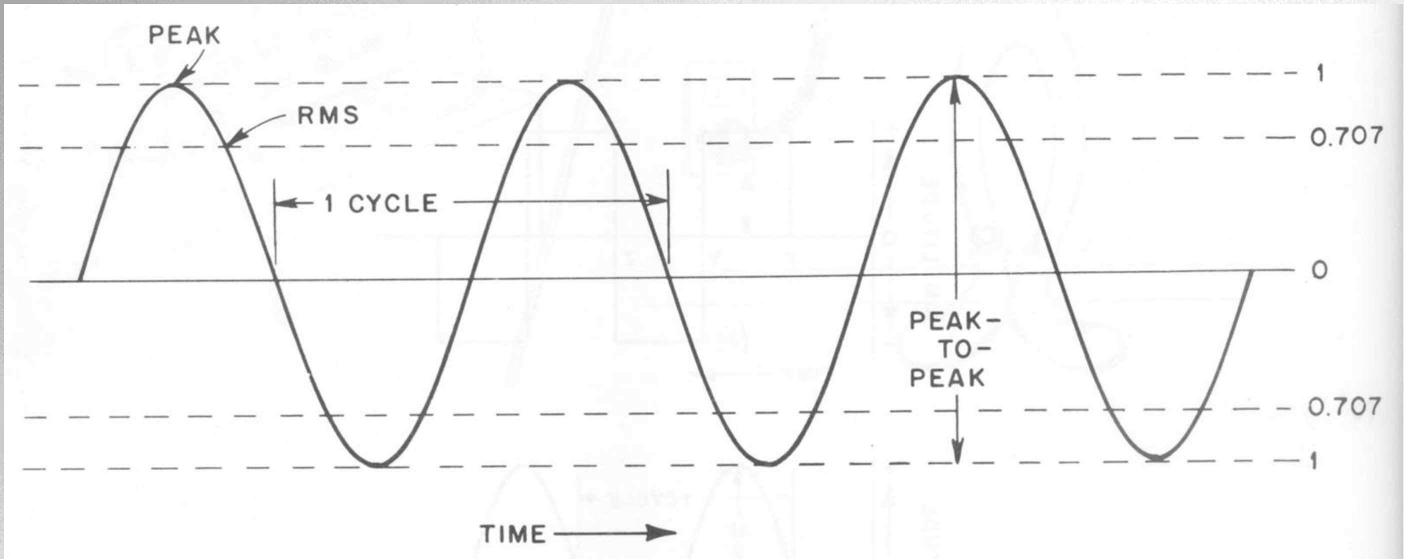
Alternating Current Defined

An Alternating Voltage reverses polarity periodically in a cycle from positive to negative.

- The alternating voltage forces charges (electrons) to move back and forth through the conductor.
- The current is called Alternating Current or AC.
- The combination of a Positive period and a Negative period is called a Cycle.
- Frequency is the number of cycles in one second. (Hertz or Hz) ⟶

AC Vocabulary



This AC Voltage is a Sine Wave.
Other AC Voltages may be rectangular or triangular or irregular shapes.

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Electrical Power

Power (Watts) is the rate of doing work. Work is equivalent to Energy (Joules). Work is basically the effort expended to move a mass.

- Movement caused by a Force over a distance.
- Movement caused by a Pressure over a distance.

If something doesn't move, there is no work produced.

Heat produced is also a measure of work.

Power can be different at different points of a circuit.

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Power in Electricity

Work equals a Force times a distance moved and Power is the amount of work per second. One horsepower moves 33,000 lbs. one foot in one second.

- In a circuit, Voltage acts as the force.
- The current is the charge moved per second.
- Power in Watts is defined as Voltage times Current. P = I * E; One Volt, One Amp, One Watt
- 750 Watts = 1 Horsepower

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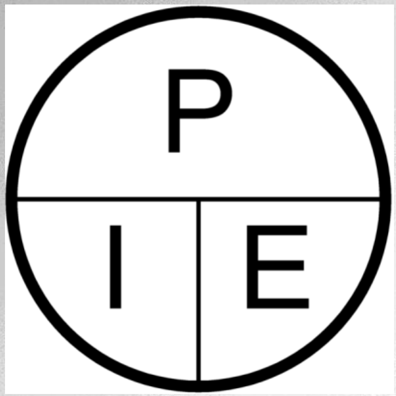
Memory Device for Power Formula



The Pie Chart – Cover the one you want.

- Cover P: P = I * E
- Cover I: I = P / E
- Cover E: E = P / I

One Volt, One Amp, One Watt

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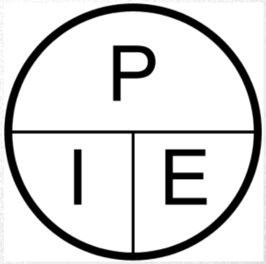
Other Formulas for Power

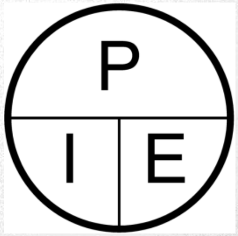


P = I * E works when you know I and E. But if you only know E and R or I and R you can do some substitution.

1) $P = I * E$;   2) $E = I * R$;   3) $I = E/R$

- Substitute I*R for E ➔ $P = I * (I*R)$ ➔ $P = I^2 R$
- Substitute E/R for I ➔ $P= E * (E/R)$ ➔ $P = E^2/R$
- Use $P = I^2 R$ when you know I and R.
- Use $P = E^2/R$ when you know E and R.

DC Power vs. AC Power



P = I * E works for DC circuits where voltage and current are constant.

- 12 Volts pushing 2 Amps = 24 Watts
- 1.5 Volts pushing 300 mA = 450 mW

But in an AC circuit, the voltage and current are constantly changing.

- Power at an instant is voltage at that instant times current at that instant.
- Sometimes the power is zero and sometimes it is maximum.

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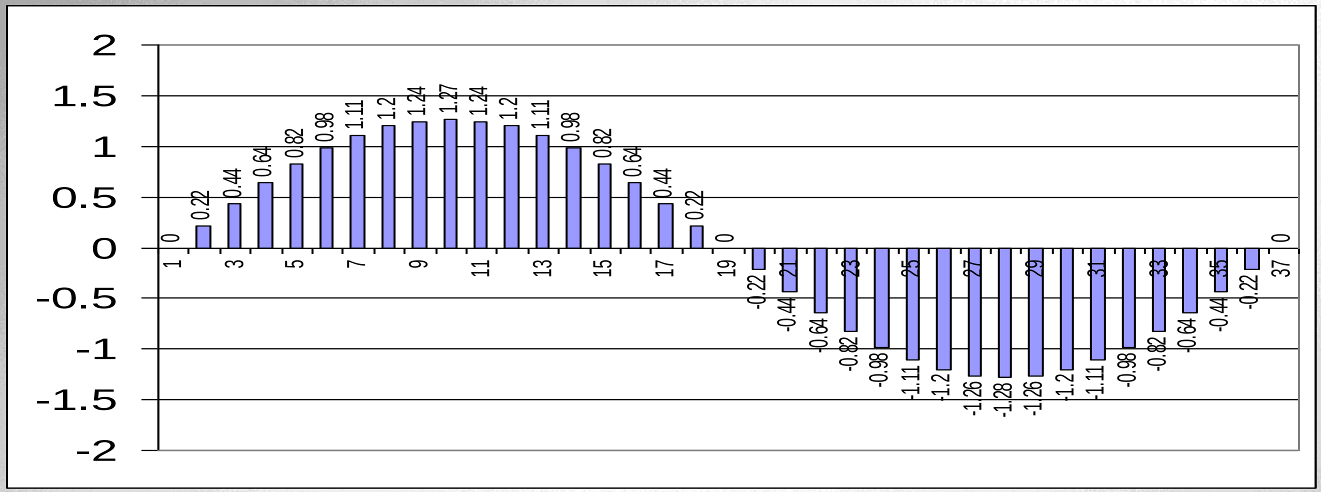
Voltages at Points of a Sine Wave



- The maximum value is +1.27 V. or -1.27 V.
- The average is obtained by adding all the values and dividing by the number of values.
- Positive average will be same as negative average but different in sign.

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Average vs. Effective value of AC

For a sine wave, the mathematical average is 0.636 times the peak. (For the sine wave in the previous figure, 0.636 * 1.27 = 0.808)

- The **effective** voltage is obtained by averaging the power over the cycle.
- But since power is proportional to the voltage squared, the power for voltages higher than average is much greater.
- Therefore the effective voltage will be higher than the average.

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RMS – Root of the Mean of the Square

Since power is proportional to V^2, we square the individual values, add them up, take the average (mean), then take the square root of the average. This is the Root Mean Square or RMS.

RMS Formula:

$$RMS = \sqrt{\frac{\sum_{0}^{N} V^2}{N}}$$

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RMS of a Sine Wave

The actual RMS voltage of a sine wave is 0.707 times the peak voltage.

- Remember 1 / square root of 2 = 0.707
- The RMS voltage of a sine wave with peak voltage of 1.27 V = 0.897V.
- The average was 0.809 V (10% too low) which would give a power 19% low
- Power calculated from the RMS voltage is referred to as the Average Power or Power.
- Power calculated from the Average voltage usually has no meaning. →

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Important Points about RMS

AC RMS voltage is equivalent to a DC voltage which will do the same work.

- RMS is used in Power and Ohms Law formulas for AC voltages.
- **For Sine Waves Only**, the RMS voltage is 0.707 times the peak voltage. (!!!!)
- AC volt meters may indicate RMS voltage, but value may be wrong if wave is distorted.
- Some Digital Multimeters measure *True RMS* and are more accurate on distorted waves.

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Converting Peak Voltage to RMS

$$V_{Peak} = 1.414\left(V_{RMS}\right)$$

$$V_{RMS} = \frac{V_{Peak}}{1.414} = .707\left(V_{Peak}\right)$$

$$V_{P-to-P} = 2\left(V_{Peak}\right)$$

Remember:

1.414 = Square root of 2

0.707 = 1 / Square root of 2

$$V_{Peak} = 1.414(V_{RMS}) \qquad V_{RMS} = \frac{V_{Peak}}{1.414} = .707(V_{Peak})$$

$$V_{P-to-P} = 2(V_{Peak})$$

Calculate the missing values.

$\text{Volts}_{\text{Peak}}$	$\text{Volts}_{\text{Peak-to-Peak}}$	$\text{Volts}_{\text{RMS}}$
17	?	?
?	240	?
?	?	120

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Peak Envelope Power

Peak Envelope Power, PEP, is the power based on the highest Peak Voltage. Sometimes we know the R and can measure $V_{Pk\text{-}Pk}$ on an oscilloscope.

Convert Peak or Peak-to-Peak voltage to RMS. Then:

$$PEP = \frac{(V_{RMS})^2}{R}$$

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$$PEP = \frac{(V_{RMS})^2}{R}$$

$$V_{Peak} = 1.414(V_{RMS})$$

Calculate the missing values for these sine waves.

Volts $_{Pk - Pk}$	Volts $_{RMS}$	Load	PEP
200		50	?
?		50	1000
100		75	?

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Using Decibels

Decibels (dB) are used to compare power levels and gains or losses in a system.

- Gains and losses of a system in dB are additive.
- Decibels are logarithmic.
- Matches the physical responses of hearing and sight.
- A large range of decades of values can be compared with smaller numbers, i.e., a Gain of 1,000,000 is 60dB, 1,000 is 30dB, 100 is 20dB

Commonly used to compare input to output power. Positive ➔ Gain; Negative ➔ Loss.

dB and Power Ratio Calculations

If you know the powers at two points, P2 and P1, in a system, you can calculate the gain in dB.

Gain as a ratio: $$Gain = \frac{P2}{P1}$$

Gain in db: $$G_{db} = 10\log_{10}(Gain)$$

G_{db} to ratio: $$Gain = 10^{\frac{G_{dB}}{10}} = \frac{P2}{P1}$$

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$\longrightarrow$

$$G_{db} = 10\log_{10}(Gain) \qquad Gain = 10^{\frac{G_{dB}}{10}} = \frac{P2}{P1}$$

P_1	P_2	P_2/P_1	dB
25	?	+2	?
100	50	?	?
250	?	4	?
-	2000	?	9
50	500	?	?
100	1000	?	?
100	2000	?	?

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$$G_{db} = 10\log_{10}(Gain) \qquad Gain = 10^{\frac{G_{dB}}{10}} = \frac{P2}{P1}$$

P_1	P_2	P_2/P_1	dB
25	50	+2	3
100	50	0.5	-3
250	1000	4	6
250	2000	8	9
50	500	5	7
100	1000	10	10
100	2000	20	13

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