

CHAPTER 7 • REFERENCE DEPTH

Electrical Fundamentals

A radio is, at heart, an electrical machine. Before you can understand how a transmitter pushes your voice 60 miles to a control tower, or why VHF behaves so differently from HF, you must be fluent in the quantities that describe all electricity — and the one equation that ties a circuit to a radio wavelength.

SYLLABUS MAP

Part II (i) Electrical units – volt, ampere, ohm, watt; wavelength, frequency & their relationship

© Learning objectives — by the end of this chapter you will be able to...

- Define voltage, current, resistance and power with their units and symbols.
- Apply Ohm's Law and the power formulae, and solve numerical problems.
- Distinguish AC from DC, and explain RMS, peak, frequency and period.
- State the factors affecting resistance and combine resistors in series and parallel.
- Explain capacitance, inductance and reactance, and why they matter for tuning.
- Relate frequency, wavelength and the speed of radio waves and convert units.

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7.1 The four quantities

7.2 Ohm's Law

7.3 Power

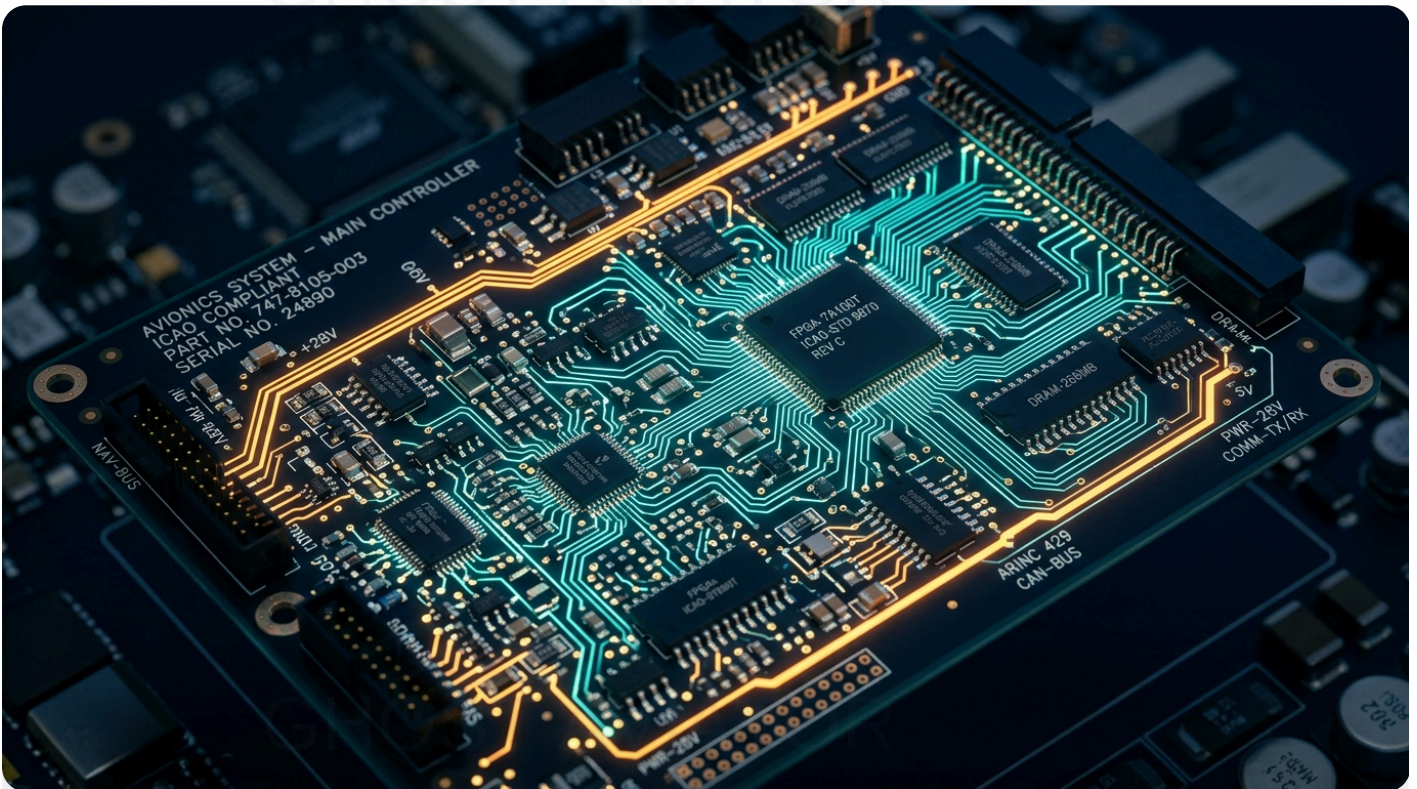
7.4 AC & DC

7.5 Resistance & materials

7.6 Series & parallel circuits

7.7 Capacitance, inductance & reactance

7.8 Frequency, period & wavelength



Understanding the core electrical principles is the first step to mastering radio transmission.

7.1 The four quantities

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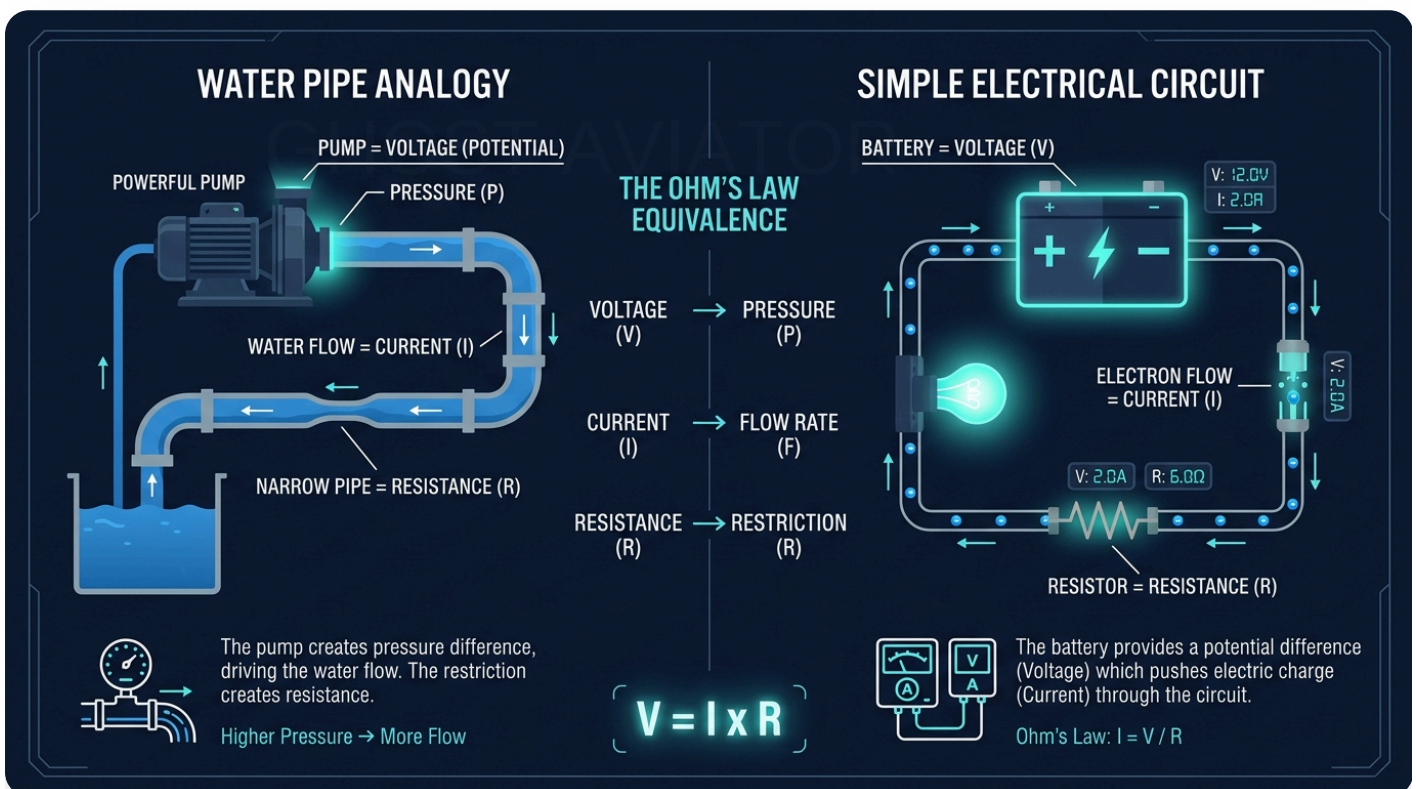
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2 / 34

i FIRST PRINCIPLES — THE WATER ANALOGY, MADE PRECISE

Picture electricity as water in a pipe. **Voltage** is the pressure pushing the water; **current** is how much water flows per second; **resistance** is how narrow the pipe is; **power** is the useful work the flow does. The analogy is exact enough to carry you through every formula in this chapter.



Voltage is the pump, Current is the flow, and Resistance is the pipe's narrow point.

Electrical Quantities

Quantity	Symbol	Unit	Precise meaning
Voltage (EMF / p.d.)	V (or E)	Volt (V)	Energy given to / taken from each coulomb of charge — the "push"

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Quantity	Symbol	Unit	Precise meaning
Current	I	Ampere (A)	Rate of flow of charge: 1 A = 1 coulomb per second
Resistance	R	Ohm (Ω)	Opposition to current flow
Power	P	Watt (W)	Rate of doing work / using energy: 1 W = 1 joule per second

⚡ EMF VS POTENTIAL DIFFERENCE

EMF (electromotive force) is the voltage a source *produces* (e.g. a battery's 12 V).

Potential difference (p.d.) is the voltage *across a component* in the circuit. They differ by the voltage lost across the source's own **internal resistance** when current flows.

| 7.2 Ohm's Law

i THE ONE EQUATION TO KNOW COLD

Push harder (more volts) and more current flows; narrow the pipe (more ohms) and less flows. The three lock together:

$$V = I \times R$$

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Volts = Amps $\times$ Ohms · rearranged: $I = V \div R$ and $R = V \div I$

💡 MNEMONIC — THE VIR TRIANGLE

Draw a triangle: **V** on top, **I** and **R** below. Cover the one you want: cover **V** $\rightarrow I \times R$; cover **I** $\rightarrow V/R$; cover **R** $\rightarrow V/I$. "**V**ery **I**mportant **R**ule."

🔧 WORKED EXAMPLE — OHM'S LAW

A 28 V aircraft bus supplies a 14 Ω heater. Current = $V/R = 28 \div 14 = \mathbf{2\ A}$.

If the resistance halves to 7 Ω , current doubles to **4 A** (inverse relationship). If the bus sags to 24 V across the original 14 Ω , current = $24 \div 14 \approx \mathbf{1.71\ A}$.

| 7.3 Power

$$\mathbf{P = V \times I = I^2 R = V^2 \div R}$$

Watts = Volts $\times$ Amps · three forms, choose what you know

🔧 WORKED EXAMPLE — POWER THREE WAYS

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From 7.2: 28 V across 14 Ω drawing 2 A. **$P = V \times I = 28 \times 2 = 56 \text{ W}$** .

Check with **$I^2R = 2^2 \times 14 = 4 \times 14 = 56 \text{ W}$** . Check with **$V^2/R = 28^2 \div 14 = 784 \div 14 = 56 \text{ W}$** . All agree.

⬆️ UNITS & EFFICIENCY

1 kW = 1000 W. **Efficiency** = useful output power $\div$ input power (always < 100% because some energy becomes heat). A transmitter rated 50 W *output* draws more than 50 W from the bus because the power amplifier is not perfectly efficient.

7.4 AC & DC

⚡ DIRECT VS ALTERNATING CURRENT

DC (Direct Current) flows in one direction at a steady value — e.g. a battery.

AC (Alternating Current) reverses direction periodically, tracing a **sine wave**; the number of complete cycles per second is the **frequency** (hertz), and the time for one cycle is the **period** ($T = 1/f$). Every **radio-frequency signal** is alternating current.

📈 PEAK, PEAK-TO-PEAK & RMS

An AC wave is described by its **peak** value, its **peak-to-peak** (twice peak), and its **RMS** (root-mean-square) — the equivalent DC value that would do the same heating work.

For a sine wave: **RMS = 0.707 × peak** (and peak = 1.414 × RMS). Mains and aircraft AC voltages are quoted as RMS.

✈️ **COCKPIT REALITY — AIRCRAFT POWER**

A typical aircraft has a **28 V DC** system (battery/bus feeding avionics) and a **115 V AC at 400 Hz** system (for many instruments and as the form every radio signal takes on the way to the antenna). 400 Hz is used rather than 50/60 Hz because transformers and motors can be smaller and lighter at the higher frequency — a real weight saving.

7.5 Resistance & materials

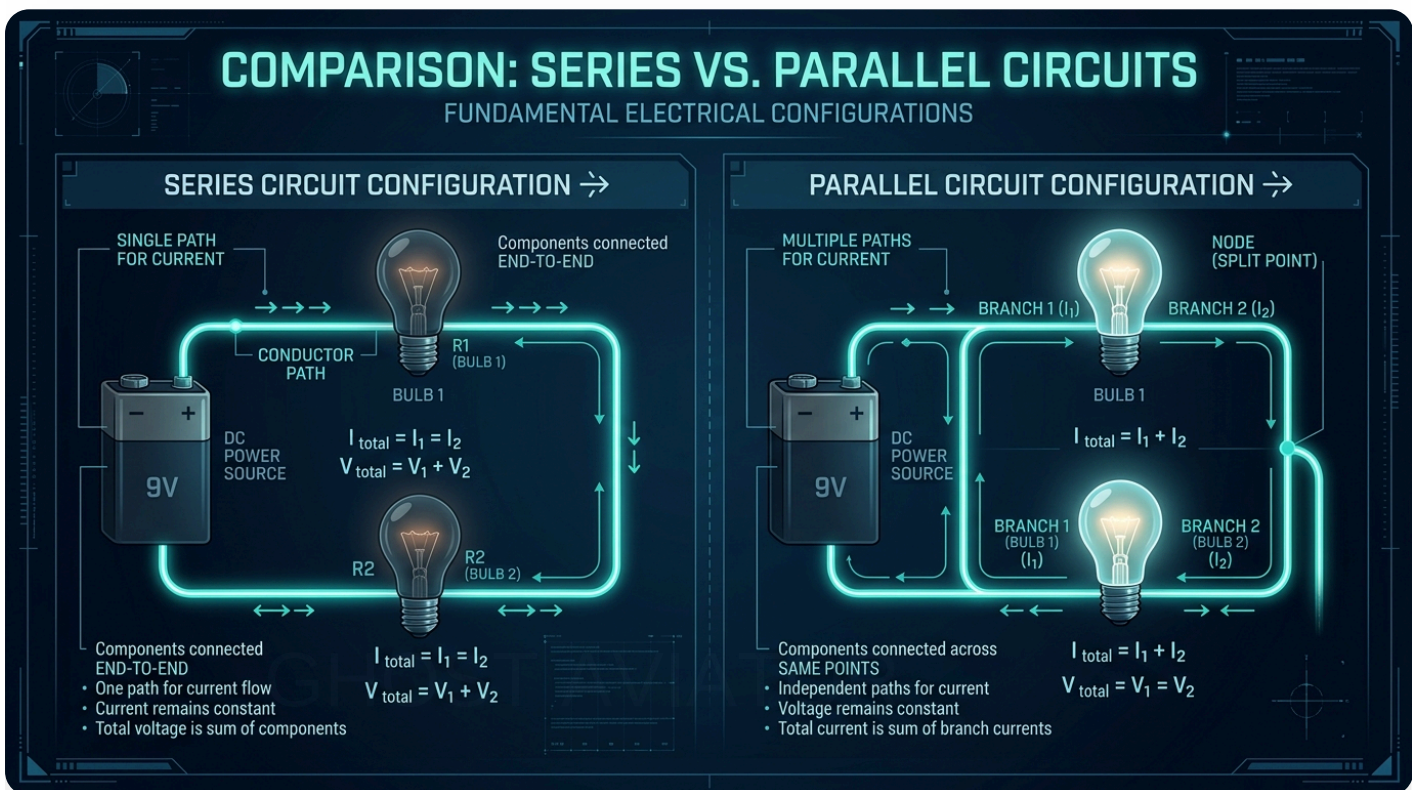
Material Types		
Material type	Behaviour	Example
Conductor	Many free electrons — low resistance	Copper, aluminium, silver
Insulator	Almost no free electrons — very high resistance	PVC, rubber, glass, air
Semiconductor	In between; conductivity controllable — the basis of all radio electronics	Silicon, germanium (diodes, transistors)

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🔌 WHAT SETS A CONDUCTOR'S RESISTANCE

Resistance increases with **length**, decreases with cross-sectional **area** (a thicker wire conducts better), depends on the **material** (its resistivity), and — for most metals — **increases with temperature**. Hence a long, thin, hot wire has the highest resistance.

7.6 Series & parallel circuits



A series circuit has one single path; a parallel circuit offers multiple paths for current.

Circuit Comparisons

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	Series	Parallel
Path	One single loop	Multiple branches
Current	Same through every component	Splits between branches
Voltage	Divides across components	Same across each branch
Total resistance	$R = R_1 + R_2 + \dots$ (adds up)	$1/R = 1/R_1 + 1/R_2 + \dots$ (less than the smallest)
If one opens	Whole circuit stops	Other branches keep working

WORKED EXAMPLE — COMBINING RESISTORS

Series: $10\ \Omega + 20\ \Omega = 30\ \Omega$. Across 30 V the current = $30/30 = 1\text{ A}$; the $10\ \Omega$ drops 10 V and the $20\ \Omega$ drops 20 V (voltage divides).

Parallel: two $10\ \Omega$ resistors $\rightarrow 1/R = 1/10 + 1/10 = 2/10$, so $R = 5\ \Omega$ (half of one). For two equal resistors, parallel total = half the value; the current splits equally.

MNEMONIC

Series = Same current; Parallel = same Pressure (voltage). Resistances *add* in series and *reduce* in parallel.

7.7 Capacitance, inductance & reactance

WHY A RADIO NEEDS MORE THAN RESISTORS

Resistors oppose current the same at any frequency. **Capacitors** and **inductors** oppose AC by an amount that *depends on frequency* — and that frequency dependence is exactly what lets a radio **tune** to one station and reject the rest.

THE TWO REACTIVE COMPONENTS

Capacitor — stores energy in an electric field; blocks DC, passes AC more easily as frequency rises (its reactance **falls** with frequency). Unit: **farad (F)**.

Inductor — stores energy in a magnetic field; passes DC, opposes AC more as frequency rises (its reactance **rises** with frequency). Unit: **henry (H)**.

Their frequency-dependent opposition is called **reactance (X)**, measured in ohms.

RESONANCE — THE HEART OF TUNING

Put an inductor and capacitor together and at one special **resonant frequency** their reactances cancel, giving a sharp peak in response. A **tuned LC circuit** selects that frequency and rejects others — this is how a receiver is "tuned" to a station and how a transmitter sets its operating frequency.

7.8 Frequency, period & wavelength

IN PLAIN TERMS

Every radio wave travels at the speed of light. Its **frequency** (cycles per second) and its **wavelength** (length of one cycle) are two views of the same wave — fix the speed and one decides the other.

$$c = f \times \lambda$$

speed = frequency $\times$ wavelength $\cdot c = 3 \times 10^8$ m/s $\cdot$ so $\lambda = c/f$ and $f = 1/T$

UNIT CONVERSIONS

1 kHz = 1,000 Hz $\cdot$ 1 MHz = 1,000,000 Hz $\cdot$ 1 GHz = 1,000 MHz. Period and frequency are reciprocals: a 1 MHz signal has a period of 1 microsecond.

WORKED EXAMPLE — WAVELENGTH OF AVIATION VHF

A 120 MHz VHF signal: $\lambda = c/f = (3 \times 10^8) \div (120 \times 10^6) = \mathbf{2.5 \text{ m}}$.

A 300 MHz signal: $\lambda = (3 \times 10^8) \div (300 \times 10^6) = \mathbf{1 \text{ m}}$. A 3 MHz HF signal: $\lambda = (3 \times 10^8) \div (3 \times 10^6) = \mathbf{100 \text{ m}}$. Higher frequency $\rightarrow$ shorter wavelength.

⚠ EXAM TRAP

Frequency and wavelength are **inversely proportional**: as frequency goes up, wavelength comes down. Mixing this round is the classic error, and it explains why high-frequency aerals are short and low-frequency aerals are long.

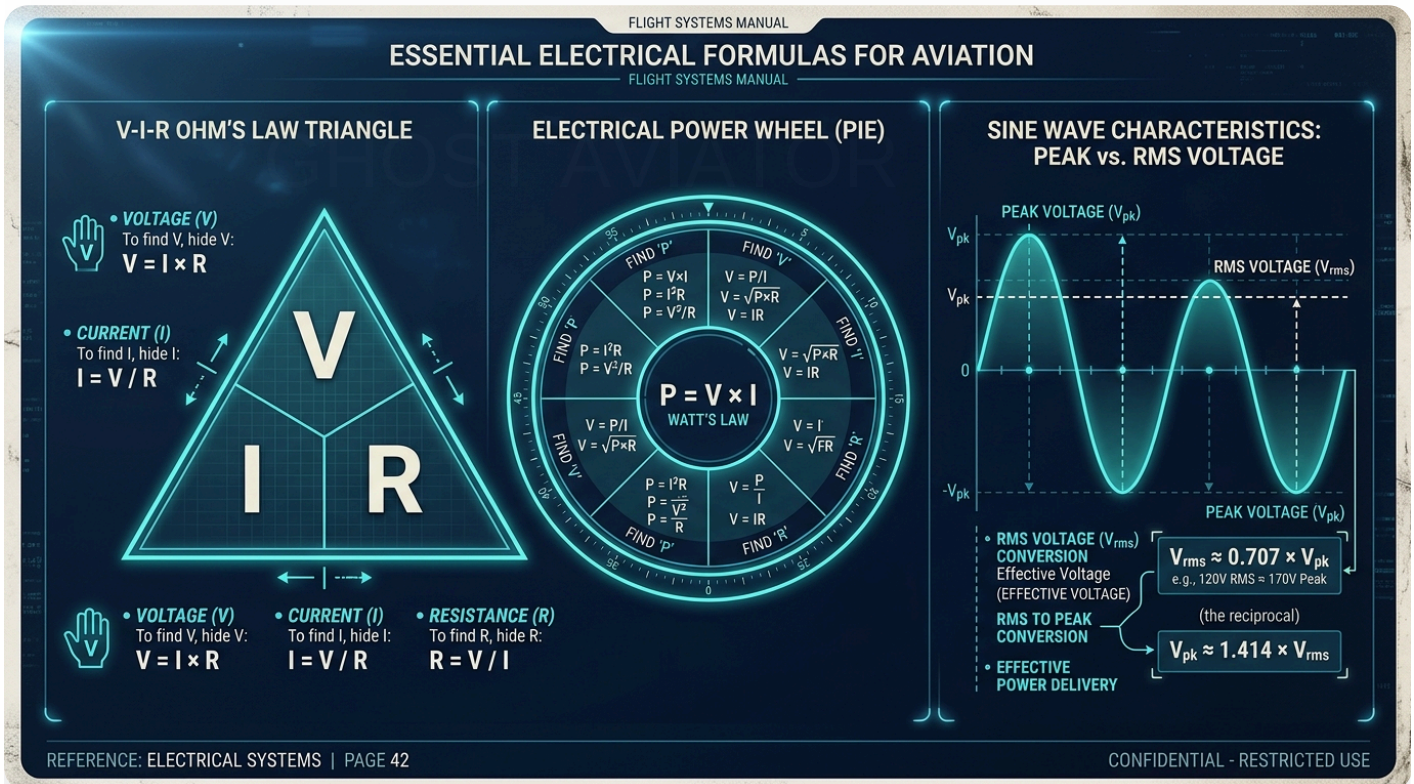


Figure 7.1 — Ohm's Law triangle · the power wheel · the sine wave.

★ Numbers to memorise

Essential Facts for Chapter 7

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Fact	Value
Units	Volt (V) · Ampere (A) · Ohm (Ω) · Watt (W) · Farad (F) · Henry (H)
Ohm's Law	$V = I \times R$
Power	$P = V \times I = I^2 R = V^2 / R$
RMS (sine)	$RMS = 0.707 \times \text{peak}$ · $\text{peak} = 1.414 \times RMS$
Aircraft power	28 V DC · 115 V AC 400 Hz
Series / parallel	Series: R adds, same current · Parallel: R reduces, same voltage
Reactance	Capacitor falls with f · Inductor rises with f · LC resonance = tuning
Wave relationship	$c = f \times \lambda$ · $c = 3 \times 10^8$ m/s · $f = 1/T$

Question bank

Part A — MCQs (click an option to check)

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1. The unit of electrical resistance is the:

Volt

Ampere

Ohm

Watt

Answer: Ohm.

Resistance — ohm (Ω). Volt = voltage, ampere = current, watt = power.

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2. One ampere is a flow of charge of:

One volt per second

One coulomb per second

One ohm per second

One joule per second

Answer: One coulomb per second.

$1\text{ A} = 1\text{ coulomb of charge per second.}$

3. Ohm's Law states:

$$P = V \times I$$

$$V = I \times R$$

$$\lambda = f \times c$$

$$I = R \times P$$

Answer: $V = I \times R$.

$V = I \times R$. Power is a separate relationship.

4. A 24 V supply across a 6 Ω resistor draws:

2 A

4 A

6 A

144 A

Answer: 4 A.

$$I = V/R = 24/6 = 4 \text{ A.}$$

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5. The power dissipated by 4 A through 14 Ω is:

56 W

224 W

3.5 W

784 W

Answer: 224 W.

$$P = I^2 R = 4^2 \times 14 = 16 \times 14 = 224 \text{ W.}$$

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6. For a sine wave, the RMS value is:

$1.414 \times \text{peak}$

$0.707 \times \text{peak}$

Equal to peak

Twice peak

Answer: $0.707 \times \text{peak}$.

$\text{RMS} = 0.707 \times \text{peak}$ (and $\text{peak} = 1.414 \times \text{RMS}$).

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7. A radio-frequency signal is a form of:

Alternating current

Direct current

Static charge

Resistance

Answer: Alternating current.

Radio signals are AC — oscillating at the carrier frequency.

8. Typical aircraft AC power is:

230 V 50 Hz

115 V 400 Hz

12 V DC

28 V 60 Hz

Answer: 115 V 400 Hz.

Aircraft use 115 V AC at 400 Hz (and 28 V DC); 400 Hz allows lighter components.

9. Resistance of a wire increases when it is:

Shorter and thicker

Longer, thinner and hotter

Made of silver

Cooled

Answer: Longer, thinner and hotter.

Resistance rises with length and temperature, falls with cross-sectional area.

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10. Two $10\ \Omega$ resistors in series give a total of:

$5\ \Omega$

$20\ \Omega$

$10\ \Omega$

$100\ \Omega$

Answer: $20\ \Omega$.

Series resistances add: $10 + 10 = 20\ \Omega$.

11. Two $10\ \Omega$ resistors in parallel give a total of:

$20\ \Omega$

$5\ \Omega$

$10\ \Omega$

$0\ \Omega$

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Answer: $5\ \Omega$.

For two equal resistors, parallel total = half the value = $5\ \Omega$.

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12. In a series circuit, the current is:

The same through every component

Different in each component

Zero

Always alternating

Answer: The same through every component.

Series = one path = same current; the voltage divides.

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13. The reactance of a capacitor as frequency increases:

Decreases

Increases

Stays the same

Becomes infinite

Answer: Decreases.

Capacitive reactance falls with frequency (a capacitor passes high frequencies more easily).

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14. A tuned LC circuit is used in a radio to:

Generate DC

Select one frequency and reject others (tuning)

Increase resistance

Store charge only

Answer: Select one frequency and reject others (tuning).

At resonance an LC circuit responds sharply to one frequency — the basis of tuning.

15. The speed of radio waves in free space is approximately:

$3 \times 10^6 \text{ m/s}$

$3 \times 10^8 \text{ m/s}$

300 m/s

1013 m/s

Answer: $3 \times 10^8 \text{ m/s}$.

Radio waves travel at the speed of light $\approx 3 \times 10^8 \text{ m/s}$.

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16. As frequency increases, wavelength:

Decreases

Increases

Stays the same

Doubles

Answer: Decreases.

Inversely proportional: $c = f \times \lambda$ with c fixed.

17. The wavelength of a 150 MHz signal is:

0.5 m

2 m

20 m

200 m

Answer: 2 m.

$$\lambda = c/f = 3 \times 10^8 \div 150 \times 10^6 = 2 \text{ m.}$$

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18. The period of a 1 MHz signal is:

1 second

1 millisecond

1 microsecond

1 nanosecond

Answer: 1 microsecond.

$$T = 1/f = 1 \div 1,000,000 = 1 \mu\text{s}.$$

Part B — Oral / viva (tap to reveal model answers)

▼ ? **Name the four basic electrical quantities and their units.**

Model Answer:

Voltage — volt (V); current — ampere (A); resistance — ohm (Ω); power — watt (W).

▼ ? **State Ohm's Law and the three forms of the power formula.**

Model Answer:

Ohm's Law: $V = I \times R$. Power: $P = V \times I$, also I^2R and V^2/R .

▼ ? **What is the difference between AC and DC, and what is RMS?**

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Model Answer:

DC flows in one direction at a steady value; AC reverses periodically as a sine wave, its cycles per second being the frequency. The RMS value is the equivalent DC that does the same heating — for a sine wave, 0.707 times the peak. Radio signals are AC.

▼ ? What factors affect the resistance of a conductor?**Model Answer:**

Its length (more = higher), cross-sectional area (more = lower), the material's resistivity, and temperature (higher temperature = higher resistance for most metals).

▼ ? How do resistances combine in series and in parallel?**Model Answer:**

In series they add ($R = R_1 + R_2 + \dots$), with the same current through each. In parallel the reciprocals add ($1/R = 1/R_1 + 1/R_2 + \dots$), giving a total less than the smallest, with the same voltage across each.

▼ ? Why does a radio need capacitors and inductors, not just resistors?**Model Answer:**

Their opposition to AC (reactance) depends on frequency — capacitive reactance falls and inductive reactance rises with frequency. Combined as a tuned LC circuit they resonate at one frequency, which is how a radio is tuned to a station.

▼ ? State the relationship between frequency and wavelength.**Model Answer:**

$c = f \times \lambda$, where c is the speed of radio waves (3×10^8 m/s). They are inversely

proportional — higher frequency means shorter wavelength, $\lambda = c/f$.

Part C — Numerical problems (tap for worked solutions)

▼  **P1. A 12 V battery with 0.5 Ω internal resistance drives a 5.5 Ω lamp. Find the current and the lamp voltage.**

Solution:

total $R = 0.5 + 5.5 = 6 \Omega$; $I = 12/6 = \mathbf{2 \text{ A}}$; lamp p.d. = $I \times 5.5 = \mathbf{11 \text{ V}}$ (1 V is lost internally).

▼  **P2. A transmitter draws 4 A from the 28 V bus. What input power, and if it is 60% efficient, what is the RF output?**

Solution:

input $P = 28 \times 4 = \mathbf{112 \text{ W}}$; output = $0.6 \times 112 \approx \mathbf{67 \text{ W}}$.

▼  **P3. Find the wavelength of the emergency frequency 121.5 MHz.**

Solution:

$\lambda = 3 \times 10^8 \div 121.5 \times 10^6; \approx \mathbf{2.47 \text{ m}}$.

▼  **P4. Three resistors 6 Ω , 3 Ω and 2 Ω in parallel — find the total.**

Solution:

$1/R = 1/6 + 1/3 + 1/2 = 1/6 + 2/6 + 3/6 = 6/6 = 1$, so $R = \mathbf{1 \Omega}$.

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Volt · Ampere · Ohm · Watt — pressure, flow, opposition, work. $V = I \times R$, $P = VI = I^2R = V^2/R$.

AC reverses (sine); $RMS = 0.707 \times \text{peak}$. Aircraft: **28 V DC / 115 V 400 Hz AC**.

Resistance: $\uparrow$ length/temperature, $\downarrow$ area. **Series** adds R (same current); **parallel** reduces R (same voltage).

Capacitor reactance $\downarrow$ with f; inductor reactance $\uparrow$ with f; **LC resonance = tuning**.

$c = f \times \lambda$, $c = 3 \times 10^8$ m/s; higher f $\rightarrow$ shorter λ ; $f = 1/T$.