

N9LYA TECHNICAL GUIDES

Electronics

A Technician's Approach

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N9LYA

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About This Book

There are a great many introductory electronics books. Most are written by one of two people.

The first is an academic, and the book is rigorous, mathematical, and largely about circuits that exist on paper. You finish it able to solve for the current through R3 and unable to figure out why the board in front of you doesn't work.

The second is a hobbyist, and the book is friendly, project-based, and stops exactly where things get interesting. Blink an LED, drive a servo, and then you're on your own.

This book is written from a third position: the practicing technician. Someone who has spent thirty years with a meter in one hand and a print in the other, in front of equipment that was running when it broke and needs to be running again by the end of shift.

That perspective changes what gets emphasized.

Safety is treated as an engineering subject, not a disclaimer. Chapter 5 is longer than most books give the topic, because I have worked around equipment where a mistake is not a puff of smoke. Arc flash is real. Stored energy in a capacitor bank is real. The habits that keep you intact are learnable and they belong early.

Test equipment gets real coverage. Four chapters, because a technician's actual skill is not knowing what a transistor does — it's knowing how to find out what this one is doing right now. Most books devote three pages to the multimeter and none to using a scope well.

Troubleshooting is treated as a discipline with its own methodology, and it gets its own chapter. It is the most valuable skill in this field and it is taught almost nowhere.

RF, noise, and grounding get proper treatment. I spent six years building RF test and measurement equipment for the telecom and cable industry, and I have been a licensed amateur radio operator since 1991. Interference problems are where a great many working electronics people get stuck, because the topic sits in a gap between the introductory books and the professional literature.

And there's a chapter on industrial electronics — motors, drives, sensors, controllers — because that's where an enormous amount of real electronics work happens, and almost no beginner book acknowledges it exists.

Who This Is For

Complete beginners. Part I assumes nothing. If you can do basic algebra, you can follow all of it.

Hobbyists who've hit a ceiling. You can follow a schematic and build a kit, and you want to understand why rather than what. Parts II and III are for you.

Technicians and tradespeople. Electricians, maintenance techs, HVAC and controls people who work with electronics and want the underlying theory made concrete. Start at Part II and read Chapter 23 twice.

Amateur radio operators. Chapters 27 and 28 cover material the license manuals treat lightly.

Students. This complements a formal course by covering what the course won't: how to actually work on things.

How to Use It

Each chapter ends with a **Bench Check** — questions and hands-on exercises. Do them. Electronics is a physical craft and reading about it produces the illusion of understanding. The first time you measure something and get a number you didn't expect, you'll learn more than a chapter can teach.

Formulas are given in plain notation — $V = I \times R$ — rather than typeset mathematics, because that's how you'll write them on a scrap of paper at a bench.

Where I recommend equipment, I describe the class and the specifications that matter rather than a model number that will be discontinued.

A Word Before You Start

You will destroy some components. Everyone does. A resistor is a few cents, a transistor is a quarter, and the lesson is worth more than the part.

You will also, if you are careless, hurt yourself. The difference between those two outcomes is Chapter 5, and it is the one chapter in this book I would ask you to read before you touch anything.

About the Author

Jerome M. Kutche holds the amateur radio callsign N9LYA, first licensed in 1991 and upgraded to General class in 2003. His interest in electronics was sparked in the early 1970s by a mentor named Frank Kime, and his understanding of interference and grounding owes a great deal to the late Mike Baugh, W8AKF, an RFI mentor of rare patience.

From 1990 to 1996 he worked at Applied Instruments in Indianapolis, building RF test and measurement equipment for the telecommunications and cable television industries, alongside engineers Doyle Haywood, David Polstra, and Jerry Brown.

He then moved into industrial electrical and controls work, accumulating more than three decades across manufacturing, materials, and heavy industry — Allen-Bradley and Siemens PLC systems, motor control centers, plant electrical maintenance and supervision. He holds NFPA 70E, lockout/tagout, arc flash, and thirty-nine other professional certifications.

He has worked amateur radio contacts through the Space Shuttle SAREX program, the Mir space station, and the International Space Station, using a two-watt handheld radio.

Part I — Foundations

Chapter 1: What Electricity Actually Is

Most people arrive at electronics with a vague mental picture of electricity as something that “flows through wires like water.” That analogy is useful and it is also the source of several persistent misconceptions. Let’s start correctly.

Charge

Matter is made of atoms, and atoms contain protons (positive charge), neutrons (no charge), and electrons (negative charge). In a neutral atom the positive and negative charges balance.

Charge is a fundamental property, like mass. Like charges repel, opposite charges attract. That’s the entire basis of everything in this book.

The unit of charge is the **coulomb (C)**. One coulomb is about 6.24×10^{18} elementary charges — an enormous number, which is why we rarely count individual electrons.

Conductors and Insulators

In some materials — metals particularly — the outermost electrons are loosely held and move freely between atoms. These are **conductors**.

In others, electrons are tightly bound and don’t move. These are **insulators** — glass, rubber, most plastics, dry air.

Between them sit **semiconductors** — silicon, germanium — whose conductivity can be controlled. That controllability is the foundation of every transistor, every integrated circuit, and effectively all modern electronics. Part II covers how.

Nothing is a perfect insulator. Given enough voltage, anything conducts — that’s what a lightning strike is, and it’s why insulation has a voltage rating. And nothing except a superconductor is a perfect conductor; every wire has some resistance.

Current

Current is the rate of charge flow. One **ampere (A)** is one coulomb per second past a point.

Two things about current that trip people up:

Electrons move slowly. The drift velocity of electrons in a wire is on the order of millimeters per second — slower than walking. What moves fast is the field, propagating at a substantial fraction of the speed of light. The classic analogy: a pipe already full of water. Push water in one end and water comes out the other immediately, even though any individual molecule moves slowly.

Conventional current flows the “wrong” way. By convention established before the electron was discovered, current is drawn flowing from positive to negative. Electrons actually move from negative to positive. **Every schematic, every datasheet, and every component symbol uses conventional current.** Use it too. The distinction matters in exactly two places — semiconductor physics and vacuum tubes — and nowhere else in practice.

Current requires a complete circuit. Charge must have a path back to where it came from. This is not a rule someone made up; it follows from conservation of charge. A wire connected to only one battery terminal carries no current, no matter how long you wait.

Voltage

Voltage is potential difference — the energy per unit charge available to push charge between two points. One **volt (V)** is one joule per coulomb.

The critical word is difference. **Voltage is always measured between two points.** “The voltage at pin 3” is shorthand for “the voltage between pin 3 and whatever we’ve agreed to call ground.”

This is why a bird sits safely on a high-voltage line: both feet are at the same potential, so there is no difference across the bird, and no current flows. It is also why the most dangerous thing in a workshop is often not high voltage but unexpected potential difference — between a chassis and a bench, between neutral and ground on a miswired circuit.

Ground is a reference, not a magic sink. In most circuits “ground” simply means the node we chose to call zero. Earth ground, chassis ground, and signal ground are three different things that are frequently connected and frequently shouldn’t be. Chapter 27 covers this in depth, and grounding causes more confusion than any other topic in electronics.

Resistance

Resistance opposes current flow. One **ohm (Ω)** allows one ampere to flow under one volt of potential difference.

Resistance in a wire arises from electrons colliding with the atomic lattice, giving up energy as heat. That’s not a side effect — it’s the mechanism.

For a conductor:

$$R = \rho \times L / A$$

Resistance is proportional to resistivity (a property of the material), proportional to length, and inversely proportional to cross-sectional area. Longer wire, more resistance. Thicker wire, less. This is why wire gauge matters, why long runs need heavier conductors, and why a corroded connection — reduced effective contact area — develops resistance and therefore heat.

Resistance changes with temperature. In metals it rises as temperature rises. In most semiconductors it falls. That second fact causes thermal runaway, which Chapter 11 covers and which destroys a lot of power transistors.

The Water Analogy — Its Uses and Limits

Electrical	Hydraulic
Voltage	Pressure
Current	Flow rate
Resistance	Pipe restriction
Capacitor	Elastic diaphragm in the pipe
Inductor	Heavy turbine wheel with inertia
Diode	One-way check valve

Where it works: intuition about series and parallel, about pressure drops, about why a restriction reduces flow.

Where it fails: it gives no useful picture of AC phase relationships, of electromagnetic fields, of radiation, or of semiconductor behavior. And it encourages the idea that current gets “used up” as it flows through a circuit, which is false — current is the same everywhere in a series loop.

Use the analogy as a stepping stone and abandon it when it stops helping.

Bench Check

1. Explain why a bird on a power line is unharmed, in terms of potential difference.
2. If current flows from positive to negative by convention but electrons go the other way, which do you use when reading a schematic?
3. Why does a corroded connection get hot under load?
4. Name three things called “ground” that are not necessarily the same node.

Chapter 2: Ohm’s Law and the Working Relationships

Three quantities, one relationship, and it underlies everything else in the book.

The Law

$$V = I \times R$$

$$I = V / R$$

$$R = V / I$$

Voltage equals current times resistance. That’s it.

What it means practically:

- For a fixed resistance, doubling voltage doubles current.
- For a fixed voltage, doubling resistance halves current.
- For a fixed current, doubling resistance doubles the voltage across it.

That last one is worth sitting with, because it’s the basis of every voltage divider, every current-sense resistor, and most of how you’ll measure things.

Worked Examples

An LED with a series resistor. You have a 5 V supply. Your LED drops about 2 V and wants about 15 mA.

The resistor must drop the remaining 3 V at 15 mA:

$$R = V / I = 3 / 0.015 = 200 \, \Omega$$

Voltage, Current, and Resistance

The core quantities describe one connected system

VOLTAGE

Electrical potential
Measured across

CURRENT

Charge flow
Measured through

RESISTANCE

Opposes current
Dissipates heat

OHM'S LAW

$V = I \times R$
Use units

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Figure 1: Voltage, current, resistance, and Ohm's law

The nearest standard value is 220 Ω , giving about 13.6 mA. Fine.

Notice what happened there: we didn't apply Ohm's law to the LED. We applied it to the resistor. LEDs are not resistors and do not obey Ohm's law — Chapter 9 explains why, and why an LED without a current-limiting resistor destroys itself.

A voltage divider. Two resistors in series across a supply:

$$V_{out} = V_{in} \times R_2 / (R_1 + R_2)$$

With 12 V in, $R_1 = 10\text{ k}\Omega$, $R_2 = 10\text{ k}\Omega$, you get 6 V out.

The catch nobody mentions to beginners: that 6 V holds only if nothing is drawing current from the output. Connect a load and the load's resistance appears in parallel with R_2 , changing the ratio. A divider made from 1 M Ω resistors feeding a 10 k Ω load doesn't produce the voltage you calculated at all.

The rule of thumb: make the divider's current at least ten times the load current. If you need a stiff voltage regardless of load, you need a regulator, not a divider.

Units and Prefixes

You will use these constantly.

Prefix	Symbol	Multiplier
giga	G	10^9
mega	M	10^6
kilo	k	10^3
—	—	1
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

Case matters. M is mega, m is milli — a factor of a billion apart. K and k both appear for kilo in practice, but write k.

Common shorthand: 4k7 means 4.7 k Ω , 2R2 means 2.2 Ω , 1n5 means 1.5 nF. The letter replaces the decimal point, because decimal points disappear on photocopies and smudged schematics. You will see this constantly on European schematics and it's a good habit.

Work in base units when calculating. Convert milliamps to amps and kilohms to ohms before you start. Mixing prefixes mid-calculation is the single most common arithmetic error in electronics, and the answer is always wrong by a factor of a thousand.

Ohm's Law Doesn't Always Apply

Ohm's law describes resistors. Specifically, it describes components whose current is proportional to voltage — ohmic devices.

Non-ohmic devices, where it does not directly apply:

- **Diodes and LEDs** — current rises exponentially with voltage above a threshold
- **Transistors** — current is controlled by a third terminal
- **Incandescent lamps** — resistance rises sharply as the filament heats, which is why they draw a large inrush current
- **Thermistors and varistors** — resistance deliberately varies with temperature or voltage
- **Batteries and supplies** — sources, not loads

You can still use Ohm's law around these devices — on the resistors in series with them, on the load they drive — and that's how most practical circuits get analyzed.

Bench Check

1. A 470 Ω resistor has 9 V across it. What current flows?
2. You need 20 mA through a load from a 12 V supply with a 3 V drop across the load. What series resistance?
3. Build a divider giving 3.3 V from 12 V. Then measure it with a 1 k Ω load attached and explain the difference.
4. Why does an incandescent bulb draw more current at switch-on than when running?

Chapter 3: Power, Energy, and Heat

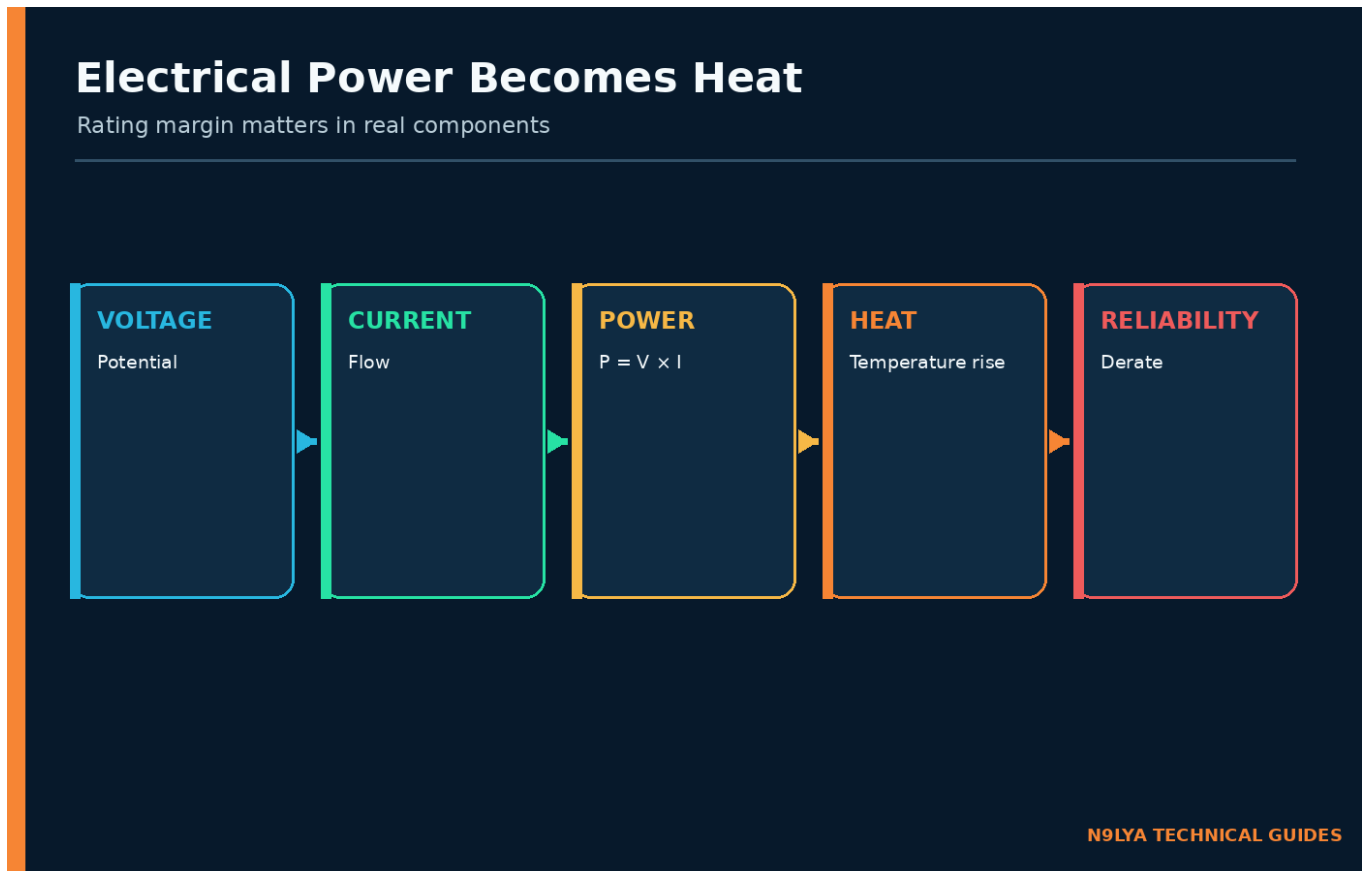


Figure 2: The relationship between power, heat, and reliability

Everything that fails in electronics fails because of heat, and heat comes from power. This chapter is about not letting the smoke out.

Power

Power is the rate of energy transfer, measured in **watts (W)**. One watt is one joule per second.

$$P = V \times I$$

Combined with Ohm's law this gives two more forms, both of which you'll use constantly:

$$P = I^2 \times R$$

$$P = V^2 / R$$

The I^2R form is the important one. Power dissipated in a resistance rises with the square of current. Double the current, quadruple the heat. This single relationship explains:

- Why undersized wire overheats

- Why a loose connection with slight resistance becomes a hot connection and then a failed one
- Why power distribution uses high voltage and low current over distance
- Why a motor drawing locked-rotor current burns out fast

Component Ratings

Every component has a maximum power dissipation. Exceed it and it heats until something changes — the value drifts, the package cracks, or it opens.

Common resistor ratings: 1/8 W, 1/4 W, 1/2 W, 1 W, 2 W, 5 W and up. Surface-mount parts are rated by package size.

Design for at most half the rating in normal operation. A resistor at 100% of its rating runs extremely hot — often 100 °C above ambient — which cooks nearby components, discolors the board, and shortens everything's life. Running at 50% costs a few cents and is what a professional does.

Worked example. A 100 Ω resistor with 12 V across it:

$$P = V^2 / R = 144 / 100 = 1.44 \text{ W}$$

A quarter-watt resistor here will fail, probably quickly and possibly dramatically. You need a 3 W part, or a different circuit.

This calculation, run before building, prevents most beginner smoke.

Heat and How It Escapes

Heat leaves a component three ways: **conduction** (through leads, solder, and mounting), **convection** (into moving air), and **radiation** (infrared, significant only when hot).

Thermal resistance describes how well heat escapes, in degrees Celsius per watt (°C/W). A device with 60 °C/W junction-to-ambient dissipating 1 W runs 60 °C above ambient. At 25 °C ambient that's 85 °C — survivable. At 2 W it's 145 °C, which is past the limit for most silicon.

Thermal resistances add in series, just like electrical ones:

$$\text{Total} = R(\text{junction-to-case}) + R(\text{case-to-sink}) + R(\text{sink-to-ambient})$$

Which tells you where to intervene. Junction-to-case is fixed by the manufacturer. Case-to-sink you control with mounting quality and thermal compound. Sink-to-ambient you control with heatsink size and airflow.

Thermal compound fills microscopic gaps. It is a worse conductor than metal-to-metal contact and a far better conductor than the air it displaces. Use a thin, even layer — more is not better, and a thick layer is worse than none in the wrong places.

Insulating washers electrically isolate a device whose tab is connected to a terminal, at the cost of added thermal resistance. Mica with compound, or modern silicone pads. Always check with a meter after assembly that the isolation is actually there.

Recognizing Thermal Problems

Things that tell you something is running too hot:

- Discolored board under or around a component
- Cracked or bulging packages
- A distinctive smell — you learn it once and never forget it
- Values drifting as the circuit warms
- A fault that appears after ten minutes and disappears after cooling
- Solder joints that look disturbed or crystalline

Use your senses deliberately, and safely. The back of a finger, quickly, on a de-energized board tells you a great deal. An infrared thermometer or thermal camera tells you more, and a cheap

thermal camera has become one of the most useful diagnostic tools available for both electronics and electrical work.

Never touch a live circuit above about 30 V to check temperature. Chapter 5.

Efficiency

$$\text{Efficiency} = P(\text{out}) / P(\text{in}) \times 100\%$$

The difference becomes heat. A 12 V, 5 A supply delivering 60 W at 80% efficiency draws 75 W and dissipates 15 W internally. That 15 W has to go somewhere, which is why power supplies have vents and why blocking them kills them.

Linear regulators are inefficient by nature. A linear regulator dropping 12 V to 5 V at 1 A dissipates 7 W as heat while delivering 5 W. That's 42% efficiency and 7 W of heat from a part the size of your fingernail. Chapter 15 covers when that's acceptable and when you need a switching supply.

Energy

Power is the rate; **energy** is the total.

$$\text{Energy (Wh)} = \text{Power (W)} \times \text{Time (h)}$$

This is what your utility bills you for, in kilowatt-hours. It's also how battery capacity works: a battery rated 2000 mAh at 3.7 V stores about 7.4 Wh.

Battery capacity in mAh is only meaningful with the voltage. Comparing a 2000 mAh cell at 3.7 V against a 2000 mAh pack at 12 V is comparing 7.4 Wh against 24 Wh.

And capacity depends on discharge rate. Draw a battery hard and you get less total energy out of it than you would at a gentle rate — sometimes far less.

Bench Check

1. A 47 Ω resistor carries 100 mA. What power does it dissipate, and what rating do you specify?
2. Calculate the dissipation in a linear regulator dropping 24 V to 5 V at 500 mA. Is a heatsink required?
3. Find the hottest component on a working board you own. Measure it.
4. Compute the watt-hours in a battery you have on hand.

Chapter 4: Circuits — Series, Parallel, and the Two Laws

Real circuits are networks. These are the tools for analyzing them.

Series

Components in series share one current path. Current is the same through all of them.

$$R_{\text{total}} = R_1 + R_2 + R_3 + \dots$$

Voltage divides across them in proportion to resistance. The sum of the individual drops equals the applied voltage.

Practical consequences:

- One open component breaks the whole string. Old Christmas lights.
- The largest resistance drops the most voltage.
- Adding series resistance reduces total current everywhere in the loop.

Series and Parallel Circuits

Topology determines which quantities are shared

SERIES

Same current
Voltages add

PARALLEL

Same voltage
Currents add

KVL

Loop voltage sum
Equals zero

KCL

Node current sum
Balances

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Figure 3: Series and parallel circuit relationships

Parallel

Components in parallel share the same two nodes. Voltage is the same across all of them.

$$1/R_{\text{total}} = 1/R_1 + 1/R_2 + 1/R_3 + \dots$$

For exactly two resistors, the convenient form:

$$R_{\text{total}} = (R_1 \times R_2) / (R_1 + R_2)$$

Two useful facts: parallel resistance is always less than the smallest resistor in the group. And N equal resistors in parallel give R/N .

Practical consequences:

- Each branch is independent. One open branch doesn't stop the others.
- Total current is the sum of branch currents.
- Adding parallel loads increases total current draw. This is why household circuits trip when you plug in one more thing.

Kirchhoff's Laws

These generalize series and parallel to any network, and they follow from conservation laws rather than from anything electrical.

Kirchhoff's Current Law (KCL): the sum of currents entering a node equals the sum leaving. Charge doesn't accumulate at a junction.

Kirchhoff's Voltage Law (KVL): the sum of voltage rises and drops around any closed loop is zero. Energy per charge is conserved going around a loop.

These two laws will solve any resistive network, given enough patience and simultaneous equations. In practice you'll use them informally far more than formally:

"There's 12 V here and 12 V there, so nothing's dropping across this component — it must be shorted."

That's KVL, applied at a bench. Most practical troubleshooting is Kirchhoff's laws used as intuition rather than algebra.

Voltage Dividers, Properly

$$V_{\text{out}} = V_{\text{in}} \times R_2 / (R_1 + R_2)$$

Beyond the basic case, three things worth knowing:

Loading. Covered in Chapter 2 and worth repeating: the divider ratio changes when you connect a load. Keep divider current roughly ten times load current, or use a buffer.

Dividers appear where you didn't put them. Any series impedance forms a divider with what follows it. A corroded connector in series with a load is a divider dropping voltage where you don't want it. A signal source with output impedance driving a low-impedance input is a divider attenuating your signal. Recognizing accidental dividers is a genuinely useful troubleshooting skill.

Your meter is a load. A modern digital multimeter has about 10 M Ω input impedance, which is negligible in most circuits and very much not negligible in high-impedance ones. Measuring a 1 M Ω divider with a 10 M Ω meter changes the reading. Old analog meters, at 20 k Ω/V , changed almost everything they touched.

Source Impedance

Every real source has internal resistance. A battery, a power supply, a signal generator — none is ideal.

The consequence: terminal voltage falls as you draw more current, because the internal resistance forms a divider with the load.

End of the free sample

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That was the first 12 of 83 pages. The full book continues with the practical detail, worked examples and recovery steps that don't fit in a sample.

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