

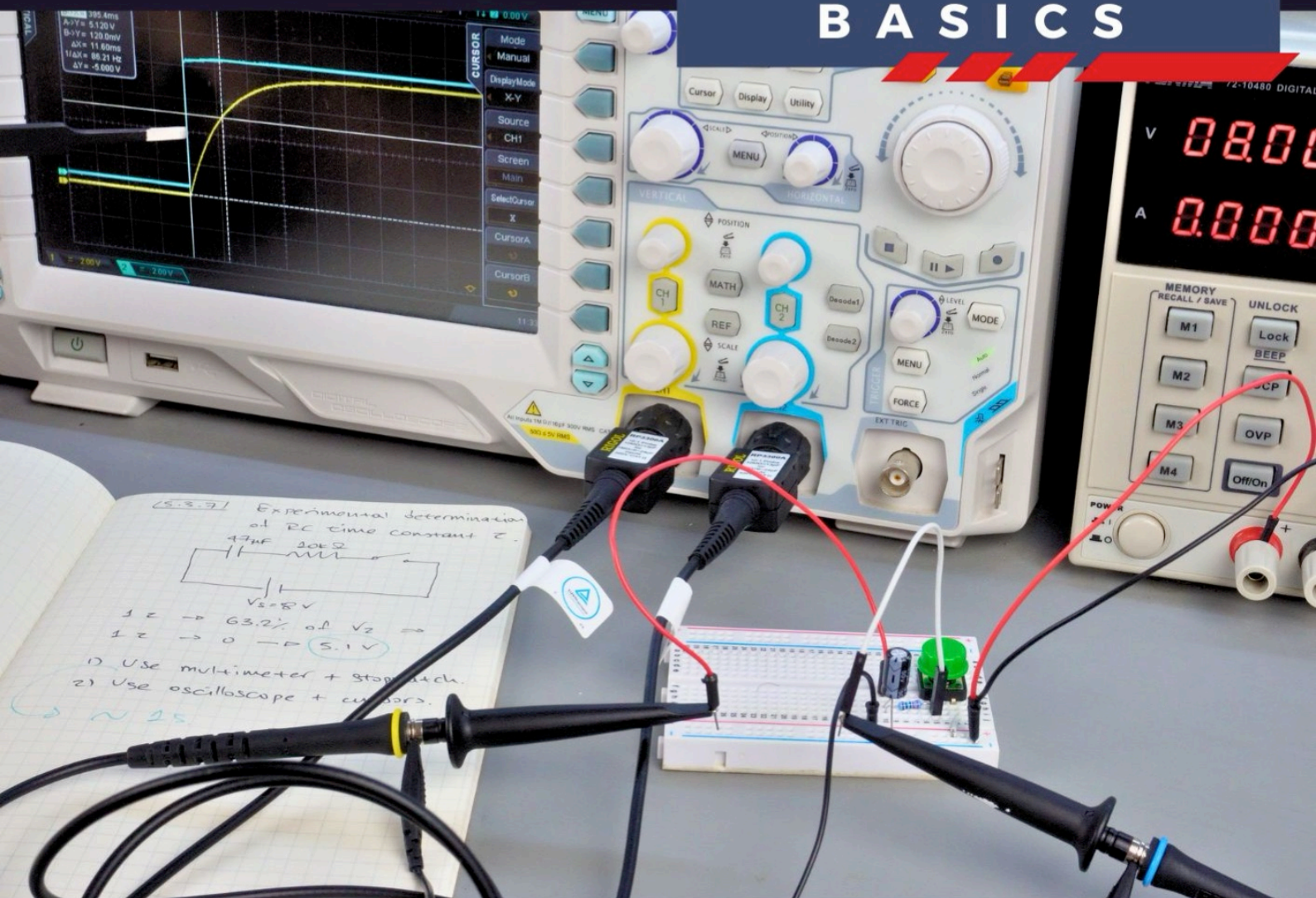
1ST EDITION

# INTRODUCTION TO ELECTRONICS

LEARN THE FUNDAMENTAL CONCEPTS OF ELECTRICITY,  
CIRCUITS, AND COMPONENTS THROUGH A SERIES OF  
ENGAGING, HANDS-ON PROJECTS.

DR PETER DALMARIS

## THE BASICS



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## **Introduction to Electronics - The Basics, 1st Edition**

By Dr Peter Dalmaris

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# Preface

This book began with a recurring question from students and hobbyists alike: “How do I actually get started with electronics?” Many resources either assume too much prior knowledge or move too quickly into abstract theory, leaving beginners feeling lost or overwhelmed. I wrote this book to bridge that gap—to provide a clear, practical, and approachable introduction to the essential concepts and skills that underpin all of electronics.

My aim is to help you build a strong foundation, not just in theory, but in the hands-on skills that make electronics meaningful and useful. Throughout these chapters, you will encounter a blend of explanation, guided experiments, and real-world examples. You will learn how to read circuit diagrams, use a breadboard, measure voltages and currents, and understand what is happening inside the circuits you build. Each topic is introduced with the assumption that you are new to the subject, but curious and ready to learn by doing.

This book is designed for anyone who wants to understand how electronic circuits work, whether you are a student, a maker, or simply someone who wants to demystify the devices you use every day. The focus is on clarity and practical relevance. You will not be asked to memorise formulas without context, nor will you be expected to follow along with abstract derivations before seeing how they apply in practice. Instead, you will be encouraged to experiment, to ask questions, and to develop a sense of intuition about how circuits behave.

You will find that the material is organised to build your confidence step by step. Early chapters focus on the basic building blocks—resistors, capacitors, diodes, and transistors—before moving on to more complex circuits and applications. Along the way, you will use simple tools and accessible components, so you can follow along at your own pace, regardless of your background or resources.

My hope is that, by the end of this book, you will not only understand the basics of electronics, but also feel empowered to explore further. Whether your goal is to design your own projects, pursue further study, or simply satisfy your curiosity, the skills and concepts you learn here will serve as a solid starting point.

I encourage you to approach each chapter with patience and curiosity. Build the circuits, make measurements, and take the time to observe how theory and practice come together. The more you engage with the material, the more rewarding and intuitive your understanding will become.

Welcome to your journey into electronics. I am glad to be your guide as you take your first steps into this fascinating and practical field.

# How to Use This Book

I wrote this book to be both a practical guide and a reference as you begin your journey into electronics. To get the most out of it, I encourage you to take an active approach—build the circuits, run the experiments, and make your own observations as you go.

I arranged the chapters in a sequence that builds your understanding step by step. Each topic builds on the last, so you will find it easiest to read and work through the chapters in order. As you progress, you will see how the concepts connect and reinforce each other.

You will find many experiments throughout the book. I designed these so you can use an online circuit simulator, a breadboard, and standard test instruments like a multimeter or oscilloscope. When you come to a simulation, I recommend that you recreate the circuit in the online simulator. Try changing component values and input signals, and watch how the circuit responds. This hands-on work will help you see how the theory plays out in practice.

Whenever possible, I encourage you to build the circuits on a breadboard with real components. Use your test instruments to measure voltages, currents, and waveforms. Compare your results with what you saw in the simulator. If you notice differences, take a moment to think about why they might occur—this is a valuable part of learning.

Keep a notebook or digital journal as you work. Record your circuit diagrams, measurements, and any questions or insights that come up. Reflecting on your results, especially when things don't go as expected, will help you develop a deeper and more practical understanding.

I chose all the experiments and examples so that you can complete them with common components and basic equipment. If you do not have access to a particular instrument, you can still follow along with the simulations and the explanations in the text.

Take your time with each chapter. Focus on understanding the ideas and building your confidence with the practical work. Electronics is best learned by doing, observing, and thinking carefully about what you see. By engaging with the material in this way, you will develop both the knowledge and the hands-on skills you need to move forward.

# Did you find an error?

If you have found an error, please let me know.

Go to <https://connect.techexplorations.com/bugs/introduction-to-electronics>,  
and fill in the form.

I'll get it fixed and update the book.

# About the author

Dr. Peter Dalmaris is an educator, an electrical engineer, an electronics hobbyist, and a Maker. Creator of online video courses on DIY electronics and author of several technical books. Peter has recently released his book 'Maker Education Revolution', a book about how Making is changing the way we learn and teach in the 21st century.

As a Chief Tech Explorer since 2013 at Tech Explorations, the company he founded in Sydney, Australia, Peter's mission is to explore technology and help educate the world. Tech Explorations offers educational courses and Bootcamps for electronics hobbyists, STEM students, and STEM teachers.

A lifelong learner, Peter's core skill lies in explaining difficult concepts through video and text. With over 15 years of tertiary teaching experience, Peter has developed a simple yet comprehensive style of teaching that students from all around the world appreciate. His passion for technology and the world of DIY open-source hardware has been a dominant driver that has guided his personal development and his work through Tech Explorations.

# About Tech Explorations

Tech Explorations creates educational products for students and hobbyists of electronics who would rather utilise their time making awesome gadgets instead of searching endlessly through blog posts and YouTube videos. We deliver high-quality instructional videos and books through our online learning platform, [techexplorations.com](http://techexplorations.com). Our priority is supporting our students through their learning journey. We do this through our dedicated online community and course forums.

Founded in 2013 by Peter Dalmaris, Tech Explorations was created after Peter realised how difficult it was to find high-quality definitive guides for the Arduino, written or produced by creators who responded to their reader questions. Peter was frustrated having to search for YouTube videos and blog articles that rarely seemed to be made to convey knowledge.

He decided to create Tech Explorations to produce the educational content he wished he could find back then. Tech Explorations courses are designed to be comprehensive, definitive, and practical. Whether delivered via video, ebook, blog, or email, our delivery is personal and conversational. It is like having a friend showing you something neat... the "AHA" moments flow!

Peter left his career in Academia after his passion for electronics and making was rekindled with the arrival of his first Arduino. Although he was an electronics hobbyist from a young age, something that led him to study electrical and electronics engineering at University, the Arduino signalled a revolution in how electronics is taught and learned. Peter decided to be a part of this revolution and has never looked back.

We know that even today, with all the world's information at your fingertips, thanks to Google and all the components of the world one click away, thanks to eBay, the life of the electronics hobbyist is not easy. Busy lifestyles leave little time for your hobby, and you want this time to count. We strive to help you enjoy your hobby and learn amazing practical things that you can use to make your own awesome gadgets. Electronics is a rewarding

hobby. Science, engineering, mathematics, art, and curiosity converge in a tiny circuit with several components. We want to help you take this journey without delays and frustrations.

Over 150,000 people across the world have used our courses. From prototyping electronics with the Arduino prototyping board to learning full-stack development with the Raspberry Pi or designing professional-looking printed circuit boards for their awesome gadgets, our students enjoyed taking our courses and improved their making skills dramatically.

Here's what some of them had to say:

*"I'm about half way through this course and I am learning so much. Peter is an outstanding instructor. I recommend this course if you really want to learn about the versatility of the amazing Raspberry Pi" -- Scott*

*"The objectives of this course are uniquely defined and very useful. The instructor explains the material very clearly." -- Huan*

*"Logical for the beginner. Many things that I did not know so far about Arduino but easy to understand. Also the voice is easy to understand which is unlike many courses about microcontrollers that I have STARTED in the past. Thanks" -- Anthony*

Please check out our courses at [techexplorations.com](http://techexplorations.com) and let us be part of your tech adventures.



# Back cover text

Introduction to Electronics – The Basics is your step-by-step guide to understanding and building electronic circuits from the ground up. Whether you are a student, hobbyist, or educator, this book gives you the practical knowledge and confidence to start working with real electronic components and test equipment.

Inside, you will find clear explanations of the essential building blocks of electronics, including resistors, capacitors, diodes, LEDs, transistors, and integrated circuits. I guide you through reading circuit diagrams, using breadboards, and making accurate measurements with multimeters and oscilloscopes. Each chapter builds on the last, helping you develop both theoretical understanding and hands-on skills.

You will learn how to:

- Identify and use common discrete electronic components
- Read and interpret simple circuit schematics
- Build and test circuits on a breadboard
- Use an online circuit simulator to explore circuit behaviour
- Measure voltage, current, and signal waveforms with standard bench instruments
- Troubleshoot and analyse simple electronic circuits

Throughout the book, I include guided experiments that you can perform with affordable components and basic tools. You will compare simulation results with real-world measurements, helping you develop practical intuition and problem-solving skills.

No prior experience is required—just curiosity and a willingness to learn by doing. By the end of this book, you will be able to build, test, and understand a wide range of basic electronic circuits, setting a strong foundation for further study or personal projects.

About the author:

Peter Dalmaris is an engineer, educator, and lifelong learner. He creates courses and books that make electronics accessible to people of all backgrounds. With a focus on hands-on learning, Peter helps readers and students build real skills

through experimentation and careful observation.

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# Part I

## INTRODUCTION

# 1 Course overview and objectives

This book provides a structured and practical introduction to the fundamentals of electronics. It is written for anyone who wants to develop a working understanding of electronic circuits, regardless of prior experience. Whether you are a student, hobbyist, or educator, you will find a clear path from basic concepts to hands-on skills.

My main goal is to help you connect theory with practice. You will not only learn how electronic components and circuits work, but also how to build, test, and analyse them using real tools and methods. The approach throughout the book is active and experiment-driven. Each new idea is introduced with clear explanations and is reinforced through practical activities.

I have designed the book around three core learning methods: guided reading, online simulation, and hands-on experimentation. You will use an online circuit simulator to explore how circuits behave before you build them. This allows you to quickly test ideas, change component values, and see the results in real time. The simulator is accessible from any modern web browser, so you can follow along easily.

Hands-on experiments are a central part of your learning. You will build circuits on a breadboard using resistors, capacitors, buttons, potentiometers, and wires. With basic bench instruments like a multimeter and more advanced ones, like the oscilloscope and the signal generator, you will measure voltages, currents, and waveforms. These experiments are designed to be accessible and practical, giving you direct experience with the tools and techniques used by engineers and makers.

Throughout the book, I encourage you to compare your simulation results with your real-world measurements. When you notice differences, take the time to investigate and understand why they occur. This habit of careful observation and analysis is essential for developing true engineering skill.

The book is organised to build your knowledge step by step. You will start with the basic properties of electricity and simple components, then move on to more complex circuits and applications. Each chapter builds on the last, so your understanding grows in a logical and manageable way.

By the end of this book, you will be able to:



- Identify and use the most common electronic components
- Read and interpret circuit diagrams
- Build and test circuits on a breadboard
- Use an online simulator to model and analyse circuits
- Make accurate measurements with standard test instruments
- Troubleshoot and understand the behaviour of basic electronic circuits

You will also develop the confidence to continue learning, experiment with your own projects, and explore more advanced topics in electronics. My objective is to make the study of electronics accessible, practical, and engaging. Through a combination of clear explanations, simulation, and hands-on work, you will gain a solid and lasting understanding of the basics of electronics.

## 2 Review of software and hardware

This book is designed to be practical and accessible. To follow the activities and experiments, you will need a small set of software tools and, if possible, some basic hardware. While building physical circuits will deepen your understanding, you can complete all simulations and exercises using only an online circuit simulator.

In this chapter, I review the software and hardware tools recommended for the activities described throughout the book.

### Software Tools

Software tools are central to the learning approach in this book. Simulations allow you to explore how circuits behave, test your ideas, and verify theoretical predictions before building anything on your workbench.

### Online Circuit Simulator

For all simulation activities, I use CircuitLab (<https://circuitlab.com/>). CircuitLab is a browser-based platform that lets you construct, modify, and test circuits graphically, without needing any physical components. You can quickly change component values, adjust input signals, and observe the results in real time.

If you prefer, you may also use other online simulators such as:

- **Falstad Circuit Simulator** (<https://falstad.com/circuit/>):  
An intuitive, browser-based platform for simulating a wide range of analog and digital circuits.
- **Tinkercad Circuits** (<https://www.tinkercad.com/circuits>):  
A web-based simulator that supports breadboard layouts and basic measurement tools.

All simulation examples in this book can be completed using CircuitLab. No installation is required—just a modern web browser.

## Hardware Tools

While not strictly required, having access to basic laboratory equipment will allow you to build and test real circuits, giving you valuable hands-on experience. If you have access to these tools, I encourage you to use them alongside the simulations.

## Breadboard and Components

A standard breadboard, jumper wires, and a selection of common components (resistors and capacitors) are all you need to build the circuits described in the book. I have chosen all experiments so that they can be completed with affordable and widely available parts.

## Test Instruments

For the various experiments in this course, I have used these instruments to measure and trigger them:

- **Multimeter:** For measuring voltage, current, and resistance in your circuits.
- **Oscilloscope:** For observing signal waveforms and time-domain behaviour. A basic two-channel digital oscilloscope is sufficient for all experiments in this book.
- **Signal Generator:** For providing test signals to your circuits. A basic bench signal generator is recommended.

All experiments are designed to be accessible with modest equipment. If you do not have access to a particular instrument, you can still complete the simulations and follow the theoretical discussions.

**Summary table of tools** Here's a summary for the software and hardware tools, marked

Category	Tools and Resources	Requirement
Software	CircuitLab (recommended), Falstad, Tinkercad	Required
Construction	Breadboard, jumper wires, resistors, capacitors	Optional
Measurement	Multimeter, oscilloscope	Optional
Signal Generation	Signal generator	Optional

All essential experiments and demonstrations in this book are shown using CircuitLab. These platforms allow you to build a strong understanding of electronics without the need for extra equipment. If you do have access to the recommended hardware, I encourage you to replicate the experiments physically. Hands-on construction and measurement will deepen your intuition and expose you to real-world effects that simulations cannot fully capture.

No matter what tools you have available, this book is structured so you can achieve all learning objectives and complete every exercise using freely available software resources.

## Part II

ELECTRIC CIRCUITS, ELECTRICITY, SIGNALS

### **3 What are electronic circuits?**

Think of an electronic circuit as pathways through which electrons flow. These pathways are made from various basic electronic components, such as resistors, capacitors, diodes, transistors, and integrated circuits, all interconnected by conductive wires or traces on circuit boards. Electronic circuits process electrical power to perform specific functions, from lighting a bulb to running complex software on a computer.

There are two main types of electronic circuits: linear circuits and digital circuits. Linear circuits, also known as analog circuits, handle a range of voltage and current flow in a continuous manner; think of them as smoothly adjusting the volume on your radio or dimming your living room lights. Digital circuits, on the other hand, operate with discrete voltage levels, representing ones and zeros, like the language spoken by computers.

Understanding how these circuits work can initially seem daunting, but let's demystify the technology by breaking it into its basic components and principles. An electrical circuit requires an electrical voltage source to provide energy for moving electrons. As they flow, they pass through and interact with various electrical components, each serving a distinct purpose. For example, if you allow electrons to flow through a motor, the motor will spin. If the same electrons move through a speaker, you will hear a noise. And if these electrons move through a relay switch, the switch will close making a clicking sound. This flow of electrons is what we call "electricity".

### **4 What is electricity?**

Electricity is a form of energy resulting from the presence and flow of electric charge. This electric charge can be produced by charged particles such as electrons or protons. Electricity can occur in various forms including static electricity, current electricity, and electromagnetic waves.

In our work in electronics, we work with electricity in the form of electrical current, which refers to the flow of electric charge through a conductor. This flow is driven by a potential difference, or voltage, across the conductor, which creates an electric field that pushes the electrons, through the material. We use the unit Amperes to count the strength of the electrical current.

Just a note here: While we tend to think of electricity as the result of moving electrons through a wire, broadly speaking, you can make electricity by moving other charged particles, such as protons. While electrons have a negative charge, protons are positively charged. The reason that you will not find proton-based electricity outside research labs is that protons exist trapped inside atoms. Unlike electrons, protons can't move freely, and so they do not contribute to the electric current like electrons do.

In certain conditions, such as in plasma or ionized gases, both protons (positive ions) and electrons (negative ions) can move and contribute to electrical phenomena. However, this is not typical in solid conductors used in most electrical systems. Another example of protons used in an electrical system is in fuel cells, where protons do move through a proton exchange membrane, but this is a specific application and not representative of general electrical conduction.

Let's get back to "normal" electronics.

## 5 Key principles in electronics

There are a few physical Laws that are important for understanding and designing electronic circuits. I'll mention a few here, but don't worry about understanding them as we'll do that later in this course. For now, I only want to give you a preview of what is coming up.

Key principles govern the behaviour of electronic circuits, such as Ohm's Law, which relates voltage, current, and resistance, and the concept of direct and alternating current (DC and AC). Direct current is electricity flowing in one direction, while alternating current changes direction periodically.

Another key law in electronics is Kirchhoff's Law, which is actually two Laws: Kirchhoff's Current Law (KCL) and Kirchhoff's Voltage Law (KVL). KCL states that the total current entering a junction equals the total current leaving the junction. KVL states that the sum of all electrical potential differences around a loop is zero. These laws are essential for analysing complex circuits.

I also want to mention semiconductor physics, because these physics form the foundation of modern electronics. Materials like silicon have electrical properties that can be altered by adding impurities, a process known as doping. This allows the creation of components like diodes and transistors, which are integral to electronic devices.

Transistors are semiconductor devices that can amplify or switch electronic signals, and integrated circuits integrate multiple electronic components on a single chip, dramatically enhancing the

functionality of electronic devices while reducing size and cost. Virtually any modern electronic device more complex than a flashlight depends on semiconductors, and modern life itself would not be possible without the transistor.

Circuits can range from the very simple, like a flashlight, to the very complex, like a processor.

## **6 Direct Current (DC) and Alternating Current (AC) circuits**

Direct Current (DC) and Alternating Current (AC) are two types of electrical current used in circuits. The primary difference between them lies in the direction in which the electric charge flows. In a DC circuit, the electric charge flows in a single, constant direction. This type of current is typically produced by sources such as batteries and solar cells. DC is commonly used in low-voltage applications like electronic devices and automotive systems.

In contrast, AC circuits have electric charges that periodically reverse direction. This alternating nature of the current is characterized by its frequency, measured in Hertz (Hz). In most countries, the standard frequency of AC power supply is either 50 Hz or 60 Hz. AC is generated by power plants and is the form of electricity delivered to homes and businesses via the power grid. The ability of AC to be easily transformed to different voltages using transformers makes it more suitable for long-distance transmission, reducing energy losses.

This table (see next page) highlights the key differences and similarities between Direct Current (DC) and Alternating Current (AC) circuits:

Feature	Direct Current (DC)	Alternating Current (AC)
Definition	Unidirectional flow of electric charge	Bidirectional flow of electric charge
Direction of Current	Flows in one constant direction	Changes direction periodically
Voltage	Constant	Varies sinusoidally with time
Frequency	Zero (0 Hz)	Typically 50 or 60 Hz
Source	Batteries, DC power supplies	Power plants, AC generators
Applications	Electronic devices, automotive systems	Household appliances, industrial equipment
Transmission	Inefficient for long distances due to higher energy losses	Efficient for long-distance transmission
Waveform	Straight line (constant value)	Sinusoidal wave
Conversion	Requires inverter to convert DC to AC	Requires rectifier to convert AC to DC
Safety	Generally safer at low voltages	Higher risk due to voltage fluctuations and higher voltages used in distribution
Energy Loss	Higher losses due to resistance in wires	Lower losses over long distances due to lower current
Power Factor <sup>1</sup>	Always 1 (purely resistive loads)	Can be less than 1 due to reactive loads (inductive/capacitive)

<sup>1</sup> *Power Factor: how effectively electrical power is being used by a system*

Direct Current (DC) circuits are commonly used in applications where a stable and constant voltage is required. Examples include battery-powered devices such as smartphones, laptops, and electric vehicles. DC is also utilised in solar power systems where photovoltaic cells generate DC electricity, which is then either used directly or converted to AC for grid compatibility. Additionally, DC is employed in low-voltage applications like LED lighting and electronic circuits in consumer electronics.

Alternating Current (AC) circuits are predominantly used in residential, commercial, and industrial power distribution systems due to their efficiency in transmitting electricity over long distances. Household appliances such as refrigerators, air conditioners, and washing machines operate on AC power. AC is also used in large-scale electrical systems like power grids, where transformers can easily step up or step down voltages to minimise energy loss during transmission.



The choice between DC and AC circuits depends on the specific requirements of the application, such as the need for stable voltage, efficiency in transmission, or compatibility with existing infrastructure.

## 7 Analog and Digital Electronics

As an electronics student, it is essential to understand the difference between analog and digital systems, as they are both crucial in the development and function of electronic devices. Analog electronics are characterised by signals that change continuously and smoothly over time. These changes can represent fluctuations in sound, light, temperature, or pressure, and they mirror the natural variability found in the real world.

Digital electronics, in comparison, operate using discrete signals. These come in the form of binary values, meaning they switch between two distinct states: usually represented as a 1 (high voltage) or a 0 (low voltage). Digital systems depend on these on-off states, which are the fundamental language of computers and digital communication systems, understanding and processing complex data with remarkable speed and precision.

This table provides a brief comparison of these two types of electronics:

Feature	Analog Electronics	Digital Electronics
Signal Type	Continuous range of values	Discrete binary values
Represent Data as	... variable voltage, current or frequency	... binary numbers (ones and zeros)
Susceptibility to Noise	More susceptible to noise and distortion	Less susceptible to noise and distortion
Examples	Vinyl record players, AM/FM radios	Computers, smartphones
Complexity	Simpler circuits (often)	More complex circuitry (typically)
Precision	Less precise	Highly precise

Analog electronics are widely used in applications where continuous signal processing is essential. For instance, audio amplification systems, such as those found in home stereo systems and

musical instrument amplifiers, rely on analog circuits to amplify sound signals. Another common application is in radio frequency (RF) communication systems, where analog circuits are used to modulate and demodulate signals for transmission and reception. Additionally, analog sensors and transducers, such as thermocouples and strain gauges, convert physical quantities like temperature and pressure into continuous electrical signals for monitoring and control purposes.

Digital electronics, on the other hand, are prevalent in applications requiring discrete signal processing and logic operations. Computers and microcontrollers are prime examples, where digital circuits perform computations and control tasks. Digital electronics are also integral to communication systems, such as in the encoding, transmission, and decoding of digital data over networks. Consumer electronics, including smartphones, digital cameras, and gaming consoles, heavily rely on digital circuits for processing and storing information. Furthermore, digital signal processing (DSP) techniques are employed in various applications, such as audio and image processing, to enhance and manipulate digital signals.

## 8 Electronic components and tools

Let's examine the basic electronic components used to create electrical circuits. I have created this table to summarise them, and I will look at each one in a moment. While there are many different sub-types of each component, at a high level, all electrical circuits, from the simplest to the most complex, are based on the components in this table.

Component	Function
Resistors	Manage the flow of electrons, affecting current and voltage within a circuit.
Capacitors	Store and release electrical power momentarily.
Inductors	An inductor is a passive electrical component that stores energy in its magnetic field when electric current flows through it.
Transistors	Amplify or switch electronic signals.
Diodes	Allow current to flow in one direction, blocking it in the other.
Integrated Circuits	Miniaturised circuits that perform various electronic functions.

I'll introduce a few important concepts in electronics next. There is no need to go into the details now, as we will gradually do that later in this book.

## 8.1 Resistors

Resistors are perhaps the simplest of the basic electronics components. As their name implies, they resist the flow of electric current, and in doing so, they control the current flow within an electronic circuit. A resistor's primary purpose is to ensure that other components receive the correct amount of current. Too little current can lead to a sluggish performance of the circuit; too much can potentially damage the components. Every resistor has a resistance value, which is measured in ohms ( $\Omega$ ). This value dictates how much it will impede the current flow. If you've encountered a circuit board, you'll notice resistors come in various shapes and sizes, with colour bands that indicate their resistance value.

*Resistor key facts:*

- Function: To limit or regulate current flow
- Unit of Measurement: Ohms ( $\Omega$ )

## 8.2 Capacitors

Capacitors are components that store and release electrical energy in an electronic circuit. They play a few vital roles in various circuits: from smoothing out fluctuations in voltage to time-keeping in watches, and from filtering noise to storing power temporarily. A capacitor is typically composed of two conductive plates separated by an insulating material called a dielectric. Electrical voltage is applied to charge the capacitor, and once charged, it holds the energy until discharged. The ability of a capacitor to store charge is measured in Farads (F), and capacitors can vary widely in their capacitance values based on their intended use in an electrical circuit.

*Capacitor key facts:*

- Function: To store and release electrical power
- Unit of Measurement: Farads (F)
- Role: Filtering, timing, and energy storage

## 8.3 Inductors

An inductor, also known as a coil, is a passive electrical component that stores electrical energy in the form of a magnetic field. Unlike capacitors, which store energy electrically, inductors store energy magnetically. Inductors are commonly used in circuits for various purposes, such as in switching regulators and for filtering.

*Inductor key facts:*

- An inductor is a coil of wire that creates a magnetic field when current flows through it.
- The impedance of an inductor varies with frequency, acting as a closed switch to DC signals and an open switch to high-frequency oscillating signals. You probably have not heard of the term “impedance” before. For now, just think of impedance as a measure of opposition that a circuit presents to the flow of alternating current (AC). It is similar to resistance in a direct current (DC) circuit but also accounts for the more complex effects of capacitance and inductance in an AC circuit.
- Inductors are less common than resistors and capacitors but are essential components in many electronic circuits.
- Inductors are used for energy storage, filtering, and inductive coupling in various electronic devices.
- The symbol for an inductor consists of a coil-shaped element.

## 8.4 Diodes

Diodes are electronic components that serve a significant role—they allow current to flow in only one direction, acting as a one-way valve within electrical circuits. This directional flow is useful for converting alternating current (AC) into direct current (DC), a process known as rectification. Diodes are also used in circuits to protect sensitive components from potential damage caused by reverse voltage. In diode circuits, the unique behaviour of allowing current flow in one direction while blocking it in the opposite direction is governed by the diode’s threshold voltage. When the voltage applied across a diode exceeds this threshold in the correct direction, current flows; if not, the diode remains off.

*Diode key facts:*

- Function: To permit current flow in one direction
- Importance: Diodes are useful in rectification and protection

## 8.5 Transistors

You can think of transistors as switches or amplifiers within electronic circuits. They are semiconductor devices that can either block or open the way for the flow of electrons, thus regulating current. Transistors are super-important in modern electronics because of their importance in devices like amplifiers, oscillators, and integrated circuits. There are various types of transistors, with bipolar junction transistors (BJT) and field-effect transistors (FET) being among the most common. The ability of transistors to amplify signals makes them critical in both analog and digital circuits. For instance, in a linear circuit, transistors can precisely control the voltage transfer characteristics, such as the amplification in an audio system.

*Transistor key facts:*

- Function: Transistors switch or amplify electronic signals
- Types: BJT, FET among others
- Importance: Core component in amplification and signal processing

## 8.6 Integrated circuits

Integrated circuits, also known as ICs or microchips, are essential components in electronics that have revolutionised the way electronic devices are designed and built. These small semiconductor wafers contain a collection of tiny resistors, capacitors, and transistors, allowing for a wide range of electronic functions to be performed within a single chip.

*Integrated Circuits key facts:*

- Integrated circuits are made from semiconductor materials, usually silicon.
- They incorporate various electrical components, such as transistors, diodes, resistors, and capacitors, into a single piece of semiconductor material.
- Signals between components within an integrated circuit can travel much faster without any power loss compared to circuits made up of discrete components.
- Texas Instruments is the company that invented the integrated circuit, with engineer Jack Kilby being credited for this groundbreaking technology.
- Integrated circuits have made complex computer chips and electronic devices possible, enabling advancements in technology and innovation.

## 8.7 Circuit boards

Circuit boards, also known as printed circuit boards (PCBs), are the physical platforms that hold and connect the electrical components necessary for an electronic device to function. These boards are the backbone of most modern electronic devices and play a crucial role in their operation.

A PCB usually consists of:

- **Substrate:** The non-conductive base material, often made of fibreglass, that lends the board its rigidity.
- **Copper layers:** These conductive tracks etched onto the board, replace wires and connect the components to form circuits.
- **Solder mask:** The insulating layer that protects the copper, usually green, ensures that components don't short-circuit.
- **Silkscreen:** This layer contains labels for component placement and other markings essential for assembling and debugging the board.

Electronic components, such as resistors, capacitors, and integrated circuits, are then attached to the circuit board, typically through a process known as soldering. There are several types of circuit boards, including:

- **Single-sided PCBs:** Have the conductive copper and components on one side of the board.
- **Double-sided PCBs:** Have circuits on both sides of the substrate.
- **Multilayer PCBs:** Include multiple layers of substrate with insulating materials in between; these are used for complex circuitry.

PCBs, along with integrated circuits, allow for small, complex, and more reliable electronic devices. From the most straightforward amp circuits to highly intricate computer systems, PCBs provide the essential platform for electronic connections and interactions.

## 8.8 Breadboards

PCBs are critical in commercial electronics, but not practical for the study of basic electronics because they are relatively expensive to make, they require planning, and tend to be single purpose.

Instead of creating our experimental physical circuits on PCBs, we will be using breadboards. A breadboard is a reusable platform used for building and testing electronic circuits without soldering. It allows engineers, students, and hobbyists to quickly prototype and modify circuit designs.

Breadboards offer several advantages for experimenting in electronics. Firstly, they are solderless, allowing for quick and easy assembly and disassembly of components without the need for specialised tools. This makes breadboards ideal for rapid prototyping and testing different circuit configurations.

Additionally, breadboards are reusable, allowing for multiple experiments to be conducted using the same board. They also provide a visual layout of the circuit, making it easier to troubleshoot and modify as needed.

Overall, breadboards are a versatile and cost-effective tool for testing and developing electronic circuits.

## 8.9 Ohm's Law

Earlier in this course I gave you an introduction to a few fundamental concepts in electronics, such as Ohm Law and Kirchhoff's Laws. Now, it's time to add a few more concepts to the list.

Understanding the behaviour of electronic circuits begins with three fundamental concepts: voltage, current, and resistance. Let's break these down into simple terms. Voltage, often referred to as electrical difference, is the driving force that pushes electric charge through a circuit. You can think of it much like pressure pushing water through a pipe. It's measured in volts and symbolised by the letter ' $V$ '.

Current is the flow of electric charge in a circuit. It's the actual movement of electrons through conductors, like the water flowing through that pipe we mentioned earlier. Current is measured in amperes or amps and represented by the letter ' $A$ '.

Resistance is the opposition to current flow within a material. Materials in a circuit can hinder the flow of electrons to varying degrees – this is resistance. It's akin to friction that slows down the water flow. Resistance is measured in ohms and denoted by the Greek letter omega ( $\Omega$ ).

These three are interrelated in a way that's defined by Ohm's Law, which states that the current ( $I$ ) flowing through a conductor between two points is directly proportional to the voltage ( $V$ ) across the two points, and inversely proportional to the resistance ( $R$ ). This relationship is neatly summarised by the formula:

$$I = V/R$$

Think of a basic electronics circuit as a loop. The voltage source, such as a battery, provides the necessary energy. Electrical components, which could be anything from a light bulb to a resistor, regulate the current flow and control the output of the circuit. The resistance determines how freely current can flow, ultimately affecting the function of the device.

Concept	Symbol	Unit	Measurement
<b>Voltage</b>	$V$	Volts ( $V$ )	Voltmeter
<b>Current</b>	$I$	Amperes ( $A$ )	Ammeter
<b>Resistance</b>	$R$	Ohms ( $\Omega$ )	Ohmmeter

The relation between voltage, current and resistance is described by Ohm's Law. This Law was proposed by Georg Simon Ohm, a German physicist and mathematician born in 1789. As it is common in science, initially, Ohm's findings were met with skepticism, and he struggled to gain recognition for his work. However, his persistence paid off, and by the late 1830s, his contributions were acknowledged by the scientific community. He was awarded the prestigious Copley Medal by the Royal Society of London in 1841. Ohm also worked in physics, making significant contributions to the understanding of acoustics and thermodynamics.

This Law states that the current ( $I$ ) passing through a conductor between two points is directly proportional to the voltage ( $V$ ) and inversely proportional to the resistance ( $R$ ), or simply  $V = IR$ .

Let's use the simulator to see first-hand how Ohm's Law brings together voltage, current, and resistance. I will use CircuitLab, but feel free to use any simulator you are comfortable with.

Here's what you'll need to set up in the simulator:

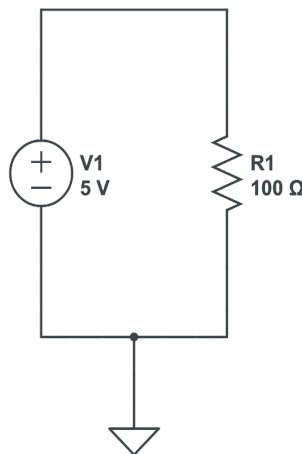
- A voltage source
- A resistor
- An simulated ammeter (to measure current)



- A simulated voltmeter (to measure voltage)

Let's connect our components:

1. Drop the voltage source and resistor on the drawing area of the simulator.
2. Connect the positive terminal of the voltage source to one end of the resistor.
3. Connect the other end of the resistor back to the negative terminal of the voltage source to complete the circuit.
4. Set the voltage source to  $5V$ , and the resistor to  $100\ \Omega$ .
5. Run the simulation and write down the resulting current on the resistor.
6. Repeat the simulation with a variety of voltage values.
7. For each voltage, use Ohm's Law to calculate the current.
8. Compare the simulated and calculated results. Are they the same?
9. Later, repeat this experiment with real components on a breadboard. Use a multimeter to take measurements.



Here's a table to keep track of your measurements:

You should see a straight line on your graph. This line tells us that the relationship between voltage and current is linear, confirming Ohm's Law. The steeper the slope, the higher the resistance. This was only a quick introduction to Ohm's. We'll come back to this topic in the second part of this course where you will learn how to apply it on more interesting and complicated circuits.

Voltage ( $V$ )	Current ( $I$ ) Simulated	Current ( $I$ ) from Ohm's Law
1V		
2V		
3V		
4V		
5V		

## 8.10 Basic tools in electronics

Let's turn our focus on the fundamental toolkit you will need to work with electronics. These tools will help you to build, test, and troubleshoot electrical circuits and electronic components. Let's take a closer look at each one of them.

**Multimeter** One of the most versatile instruments you'll encounter is the multimeter. This device is used to measure voltage, current, and resistance – the core concepts of electrical engineering.

By selecting the appropriate function and range of voltage or current, you can use it to troubleshoot electrical circuits, test batteries, or check the continuity of a wire or circuit board.

It can also provide you with the voltage transfer characteristics for diode circuits and other semiconductor devices. A multimeter is indispensable for both basic and advanced work with electric circuits.

**Breadboard** The breadboard, is a fantastic tool for prototyping and experimenting with electronic circuit designs.

Breadboards have a grid of holes where you can insert electronic components and wires without the need for soldering. This allows for a plethora of potential arrangements of components, facilitating the study of basic circuit concepts, as well as the testing of complex circuit designs.

Understanding breadboard layout and usage is a foundational skill for any budding electrical engineer or electronics hobbyist.

**Soldering iron** For putting together a more permanent electronic circuit, a soldering iron is required. This tool is used to solder electronic components to a printed circuit board (PCB). When the soldering iron heats the solder, it melts and flows around the connection, creating a durable electrical bond between the component and the board. Proper use of a soldering iron is essential for reliable circuit construction.

In this course we will do all experiments on a simulator and a breadboard, so you will not need a soldering iron at this point.

**Wire strippers** Wire strippers are used to remove the insulation from electric wires so that the conductor can be connected to other wires or components. They are especially important when dealing with various wire gauges in electrical power and signal connections. Accurate and clean stripping is crucial to avoid damaging the wire's conductor.

**Tweezers** Tweezers are very helpful when trying to place and manipulate small components on circuit boards. They come in different shapes and sizes to accommodate the wide array of electrical components you might encounter. I use a collection of tweezers with different shape and size of tips, all of them with antistatic properties to prevent damaging sensitive components like integrated circuits.

**Magnifying glass or headset** Many electronic components are tiny. To see the fine details of your electronic components and solder joints, a magnifying glass or a magnifying headset is a huge help. This helps ensure that components are placed accurately and that solder joints are made correctly without any bridges or cold solder joints. Also, along with a magnifying glass or headset, be sure to use adequate lighting on your workbench.

**Power Supply** A reliable power supply provides a stable source of electricity at various voltages and currents to an electronic circuit. It's used to power and test circuits without the need for batteries, giving a constant and adjustable electrical power supply needed for amp circuits, integrated circuits, and much more.

On my workbench, I have two identical power supplies so that I can have two simultaneous power sources.

If you don't want to invest on a dedicated bench power supply, you can get away with batteries. For the purposes of this course, batteries will be sufficient.

**Component Organizer** Staying organised is essential in electronics work. Without a basic level of organisation, your component will tend to disappear, and you will spend more and more time trying to find them (without success).

A component organiser will help you keep electronic components and small parts tidy and readily available for your projects. This prevents loss and damage to electrical components that are essential to your work.

## 8.11 Circuit simulators

Circuit simulators are software programs that allow users to design, test, and simulate electronic circuits without the need for physical components. I already demonstrated how to use one to

construct a simple circuit and see Ohm's Law in action. Simulators are essential for electronics engineers and hobbyists alike to experiment with circuit designs and troubleshoot potential issues before physically building the circuit.

There are two main types of circuit simulators: online web simulators and those that run on a computer or phone/tablet. Online web simulators, such as CircuitLab, provide a user-friendly interface that can be accessed through a web browser. Users can drag and drop components onto a virtual breadboard, connect them with virtual wires, and simulate the behaviour of the circuit in real-time.

On the other hand, computer or phone/tablet-based simulators, such as CircuitLogix (<https://www.circuitlogix.com/>) or Multisim (<https://www.multisim.com/>), offer more advanced features and capabilities. These simulators can handle complex circuits and provide detailed analysis tools for in-depth circuit design.

Simulators are valuable learning tools for both beginners and experienced electronics enthusiasts. They enable users to experiment with different circuit configurations, test the effects of component changes, and visualise circuit behaviour in real time. By using simulators, users can develop a deeper understanding of electronics theory and enhance their circuit design skills without needing physical components.

## Part III

### FUNDAMENTALS OF ELECTRICAL CIRCUITS

## 9 Introduction and focus on Ohm's Law

As you learned in the introduction of this course, Ohm's Law lies at the heart of our study of electronics. This fundamental principle in electronics and electrical engineering relates the voltage ( $V$ ), current ( $I$ ), and resistance ( $R$ ) in an electrical circuit.

In this section, you will focus on Ohm's Law and understand how voltage, current, and resistance interact in predictable circuits. You will do this by first looking at the simple mathematics of Ohm's Law and then applying the math to simple circuits on paper and in the simulator.

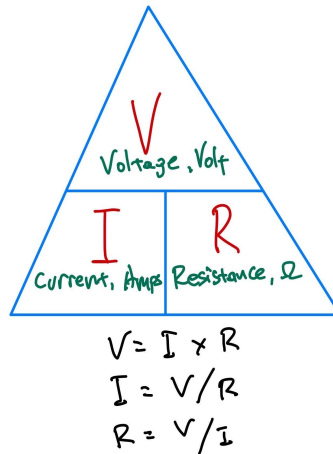
Before we begin, please remember that this section includes the first few practical exercises of the course. To simplify things, I'll only ask you to use paper and pencil to draw and calculate voltage, current, and resistance. I will also use an online circuit simulator to demonstrate how our paper circuits and their Ohm's Law calculations correspond to their counterparts in the simulated world.

In the next section, I'll show you how to use the breadboard to assemble real circuits and the multimeter to measure the electrical values. From then on, you'll use the breadboard, multimeter, pencil, paper, and calculator to study various topics. Of course, I'll continue to use the simulator as an alternative to the breadboard and the real parts and to help us experiment with variations of circuits and component values.

### The Relationship between Voltage, Current, and Resistance

As you already know, Ohm's Law captures the interrelation between a circuit's voltage, current, and resistance. This relationship forms the basis of understanding electrical circuits. According to Ohm's Law, voltage ( $V$ ) is equal to the product of current ( $I$ ) and resistance ( $R$ ), expressed as  $V = I \times R$ .

The "Ohm's Law Triangle" is a visual mnemonic tool used to remember and apply Ohm's Law (see next page for the triangle).



### Ohm's Law Triangle

Using the triangle is easy. Here's how to use it:

- To calculate voltage, cover  $V$ . This leaves  $I$  and  $R$  next to each other, indicating multiplication ( $V = I \times R$ ).
- To calculate current, cover  $I$ . This positions  $V$  over  $R$ , indicating division ( $I = V/R$ ).
- To calculate resistance, cover  $R$ . This positions  $V$  over  $I$ , also indicating division ( $R = V/I$ ).

Next, we'll look at two examples to help understand the basics of Ohm's Law. In the first one, you'll learn how to calculate voltage when you know the resistor value and the desired current flowing through it. In the second one, you will calculate the current flowing through a known resistor when you know the power supply voltage.

#### Example #1: calculate voltage

Here is a simple example that demonstrates the use of Ohm's Law. Imagine you have a simple circuit consisting of a battery, a resistor, and connecting wires. You want to determine the voltage required to produce a certain current through the resistor.

Here are the component values:

- Resistor value ( $R$ ):  $5\ \Omega$
- Desired current ( $I$ ):  $2\ \text{A}$

To find the voltage ( $V$ ) required to produce the desired current through the resistor, use Ohm's Law:

$$V = I \times R$$

Follow these steps:

1. Identify the known values:

- Current ( $I$ ) = 2 A
- Resistance ( $R$ ) = 5  $\Omega$

2. Apply Ohm's Law:  $V = I \times R \Rightarrow V = 2 \text{ A} \times 5 \Omega$

3. Calculate the voltage:  $V = 10 \text{ V}$  A voltage of 10 V is required to produce a current of 2 A through a resistor of 5  $\Omega$ .

### **Example #2: calculate current**

You have a circuit with a resistor connected to a voltage source, and you want to determine the current flowing through the resistor.

Here are the given values:

- Voltage ( $V$ ): 12 V
- Resistance ( $R$ ): 6  $\Omega$

To find the current ( $I$ ) flowing through the resistor, use Ohm's Law:

$$I = V/R$$

Follow these steps to do the calculations:

1. Identify the known values:

- Voltage ( $V$ ) = 12 V
- Resistance ( $R$ ) = 6  $\Omega$



2. Apply Ohm's Law:  $I = V/R$
3. Calculate the current:  $I = 12\text{ V}/6\ \Omega$
4. Simplify the equation:  $I = 2\text{ A}$

So, what did we discover? With a voltage of 12 V applied across a resistor of 6  $\Omega$ , the current flowing through the resistor is 2 A.

## 10 Power Calculations

Power is a fundamental concept in physics and engineering, describing the rate at which energy is transferred or converted from one form to another. In electrical systems, power measures how much electrical energy is being used by a device or transmitted through a circuit over a given period. Watt's Law, named after Scottish inventor James Watt, is a basic principle that defines the relationship between power, voltage, and current in an electrical circuit. It states that the power ( $P$ ) in watts is equal to the voltage ( $V$ ) in volts multiplied by the current ( $I$ ) in amperes. This relationship is described by the equation:

$$P = V \times I$$

Where:

- $P$  = Power (measured in watts)
- $V$  = Voltage (measured in volts)
- $I$  = Current (measured in amperes)

Watt's Law is useful for determining electrical device power consumption and helps design circuits that can handle the required power levels without overheating or failing.

The relationship between Watt's Law and Ohm's Law can be understood by combining the two equations. By substituting the Ohm's Law equation ( $V = I \times R$ ) into the Watt's Law equation ( $P = V \times I$ ), we can derive a relationship that includes power, voltage, current, and resistance:

$$P = I \times R \times I$$

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

This equation shows that power equals the square of the current multiplied by the resistance. It demonstrates that the power consumed by a device is directly proportional to the square of the current flowing through it and the device's resistance. Additionally, by manipulating the Ohm's Law equation, we can express power in terms of voltage and resistance:

$$P = (V/R) \times V$$

$$P = V^2/R$$

This equation illustrates that power equals the voltage square divided by the resistance. It shows that the power a device consumes is directly proportional to the square of the voltage across it and inversely proportional to the device's resistance. These formulas are visually represented in the Power Triangle, which depicts the relationships among power, voltage, and current.

Formula	Calculation
Ohm's Law (Voltage)	$V = IR$
Power (Using Voltage & Current)	$P = VI$
Power (Using Voltage & Resistance)	$P = V^2/R$
Power (Using Current & Resistance)	$P = I^2R$