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FREE EBOOK

ROBOTICS AND ELECTRONICS

Electronic Components Handbook

Resistors, capacitors, LEDs, diodes, transistors and more, with how to use each

INSIDE THIS BOOK

- Voltage, current and resistance
- Resistors and the colour code
- Potentiometers, presets and LDRs
- Capacitors
- Diodes, LEDs and Zener diodes
- ...and 6 more chapters, practice questions and a glossary

Beginner

Students building science projects, robotics and electronics

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Electronic Components Handbook

Learn what the common parts in an electronics kit do, how to read their markings and how to connect each one safely. You will use Ohm's law to choose resistors, find the legs of LEDs, diodes and transistors, power a project from batteries and a 7805 regulator, and read a datasheet before you build.

WHO IT IS FOR	Students building science projects, robotics and electronics
LEVEL	Beginner
SUBJECT AREA	Robotics and electronics
WHAT IS INSIDE	11 chapters, practice questions with answers, and a glossary

HOW TO USE IT

Read one chapter at a time and try the examples as you go: on a computer, at your workbench or in your notebook. The boxes give tips, safety points and short activities. When you finish, test yourself with the practice questions and check your answers at the end. Words you may not know are explained in the glossary.



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Voltage, current and resistance

Every part in an electronics kit, such as a resistor or an LED, is called a **component**. This book explains what each one does and how to use it. First you need three ideas that every circuit depends on.

A water tank on the roof

Many Indian homes have a water tank on the roof, and water flows down the pipes when you open a tap. Electricity behaves in a similar way.

- **Voltage** is like the water pressure. It is the push that makes electricity move. It is measured in **volts (V)**.
- **Current** is like the amount of water flowing each second. It is the flow of tiny charged particles called electrons. It is measured in **amperes (A)**, or amps.
- **Resistance** is like a narrow pipe that slows the flow. It is measured in **ohms (Ω)**.

Current flows only around a complete loop, from the battery's positive (+) end, through the parts, and back to its negative (–) end. This loop is a **circuit**. Break it anywhere and the current stops.

Quantity	Symbol in formulas	Unit	How a multimeter measures it
Voltage	V	volt (V)	Probes touch both ends of the part, circuit on
Current	I	ampere (A)	Meter placed in the loop (in series), circuit on
Resistance	R	ohm (Ω)	Probes across the part, power off

Prefixes help with small and large values. A **milliamp** (mA) is one thousandth of an amp, so 1 A = 1,000 mA. A **kilohm** (k Ω) is 1,000 ohms and a **megohm** (M Ω) is 1,000,000 ohms.

Ohm's law

One simple rule, called **Ohm's law**, links all three:

$$V = I \times R$$

Turned round, it finds the other two:

- $I = V \div R$ (current = voltage $\div$ resistance)
- $R = V \div I$ (resistance = voltage $\div$ current)

Always use volts, amps and ohms in the formula. Change mA to A and k Ω to Ω first.

EXAMPLE

Riya connects a 1 k Ω resistor across a 9 V battery. Current $I = 9 \div 1,000 = 0.009$ A, which is 9 mA.

Power

Power tells you how fast a part uses energy, much of it as heat. It is measured in **watts (W)**:

$$P = V \times I$$

In Riya's circuit the power is $9 \times 0.009 = 0.081$ W, far too little to make the resistor warm.

SAFETY

Every project in this book uses cells or batteries of 12 V or less. The mains supply in Indian homes is 230 V AC, and it can kill. Never open, touch or connect anything to mains wiring, sockets or adapters.

TRY THIS

Set a multimeter to DC volts and touch its red probe to the + end of a new AA cell and the black probe to the – end. A fresh alkaline cell usually reads a little over 1.5 V. Swap the probes and the meter shows a minus sign.

Resistors and the colour code

A **resistor** limits current. It protects LEDs, sets the current into a transistor and divides voltages. Most are too small to print numbers on, so coloured bands show the value.

Reading the bands

Hold the resistor so that the gold or silver band is on your right. This band shows the **tolerance**: how far the real value may be from the marked value.

Colour	Digit	Multiplier	Tolerance
Black	0	× 1	
Brown	1	× 10	±1%
Red	2	× 100	±2%
Orange	3	× 1,000	
Yellow	4	× 10,000	
Green	5	× 100,000	±0.5%
Blue	6	× 1,000,000	±0.25%
Violet	7		±0.1%
Grey	8		
White	9		
Gold		× 0.1	±5%
Silver		× 0.01	±10%

A popular way to remember the order from 0 to 9 is "**B B ROY of Great Britain had a Very Good Wife**": Black, Brown, Red, Orange, Yellow, Green, Blue, Violet, Grey, White.

On a **four-band** resistor:

1. The first band is the first digit.
2. The second band is the second digit.

- 3. The third band is the multiplier (how many zeros to add).
- 4. The fourth band is the tolerance.

EXAMPLE

Brown, black, red, gold means 1, 0, then $\times 100$. That is $10 \times 100 = 1,000 \Omega$, or 1 k Ω , with $\pm 5\%$ tolerance. The real value can be anywhere from 950 Ω to 1,050 Ω .

More examples you will use often:

Bands	Value
Red, red, brown	$22 \times 10 = 220 \Omega$
Yellow, violet, brown	$47 \times 10 = 470 \Omega$
Brown, black, orange	$10 \times 1,000 = 10 \text{ k}\Omega$
Yellow, violet, orange	$47 \times 1,000 = 47 \text{ k}\Omega$

A **five-band** resistor has three digit bands, then the multiplier, then the tolerance. Brown, black, black, brown, brown is $100 \times 10 = 1,000 \Omega$ with $\pm 1\%$ tolerance.

Standard values

Resistors are made in a fixed set of values. The common set uses these numbers in every group of ten: 10, 12, 15, 18, 22, 27, 33, 39, 47, 56, 68 and 82. So you can buy 470 Ω or 4.7 k Ω , but not 467 Ω . When a calculation gives an in-between value, pick the nearest standard value that keeps the current safe.

Power rating

The small resistors in most kits are rated $\frac{1}{4} \text{ W}$ (0.25 W). Use more power than that and the resistor gets very hot and can burn.

EXAMPLE

Kabir puts a 100 Ω resistor straight across a 9 V battery. $I = 9 \div 100 = 0.09 \text{ A}$, and $P = 9 \times 0.09 = 0.81 \text{ W}$. That is more than three times the $\frac{1}{4} \text{ W}$ rating, so it will soon be too hot to touch. A 1 k Ω resistor would use only 0.081 W.

TIP

Choose a resistor whose power rating is at least double the power you calculate, so it stays cool.

TRY THIS

Measure five resistors with a multimeter on its ohms range and compare each reading with the colour code. Do not pinch both probe tips with your fingers, because your body adds a second path and spoils the reading of large values.

CHAPTER 3

Potentiometers, presets and LDRs

Some resistors change their value when you turn a knob, or when light or heat changes. They let a circuit be adjusted or sense the world.

The potentiometer

A **potentiometer**, or pot, has three legs. The two outer legs are the ends of a curved track of resistive material. The middle leg is joined to a **wiper** that slides along the track when you turn the shaft.

- Between the two outer legs, the resistance is always the full value, for example 10 k Ω .
- Between the middle leg and one end, the resistance changes as you turn the knob.

Pots set volume, brightness or the point at which a sensor circuit switches. A marking such as "B10K" means 10 k Ω ; the letter shows how the resistance changes as you turn, and B usually means evenly.

A **preset**, or trimpot, is a tiny pot turned with a small screwdriver. It is set once and then left alone.

The potential divider

Two resistors in series across a supply share its voltage. This is a **potential divider**, and the voltage at the middle point is:

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

Here R1 is the top resistor (joined to +) and R2 is the bottom resistor (joined to -).

EXAMPLE

Sneha uses a 9 V battery with R1 = 20 k Ω and R2 = 10 k Ω . $V_{out} = 9 \times 10 \div 30 = 3$ V. If both resistors are 10 k Ω , V_{out} is 4.5 V, exactly half.

A pot is a ready-made divider. Join its outer legs to + and -, and the middle leg gives any voltage from 0 V to the full supply.

The LDR

An **LDR** (light dependent resistor) has a wavy track on its face and two legs, and it can go either way round. Its resistance falls when light falls on it. In darkness it is very high, often hundreds of kilohms or more; in bright light it can drop to a few hundred ohms or a few kilohms. Every type is different, so measure yours.

Put an LDR in a divider and its changing resistance becomes a changing voltage. Here the LDR is R2, with a fixed 10 k Ω resistor as R1, on a 5 V supply. The LDR values are examples.

Light	LDR resistance	V _{out}
Bright	1 k Ω	$5 \times 1 \div 11 = 0.45$ V
Room light	10 k Ω	$5 \times 10 \div 20 = 2.5$ V
Dark	100 k Ω	$5 \times 100 \div 110 = 4.55$ V

The voltage rises as it gets darker. An automatic night lamp uses this idea.

REMEMBER

Swap the LDR and the fixed resistor, and the voltage falls as it gets darker instead. Choose the order that suits your circuit.

LDRs react slowly, so they are fine for telling day from night but not for counting fast flashes.

Capacitors

A **capacitor** stores a small amount of electric charge, like a tiny tank that fills and empties. Inside are two metal plates or foils separated by an insulator. Capacitors smooth supplies, set time delays and block steady voltages while letting changing signals through.

Units

Capacitance is measured in **farads (F)**. One farad is huge, so real values use the microfarad (μF , one millionth of a farad), the nanofarad (nF) and the picofarad (pF). $1\ \mu\text{F} = 1,000\ \text{nF} = 1,000,000\ \text{pF}$.

Common types

Type	Typical values	Polarity	Common uses
Ceramic	Small: picofarads up to about $1\ \mu\text{F}$	Either way round	Removing electrical noise, timing
Polyester film	About $1\ \text{nF}$ to a few μF	Either way round	Timing, audio
Electrolytic	About $0.1\ \mu\text{F}$ to thousands of μF	Has + and – legs	Smoothing supplies, storing energy, slow timing

Reading the markings

Small ceramic capacitors use a three-digit code in picofarads. The first two digits are the value and the third is the number of zeros to add.

- 104 = 10 followed by four zeros = $100,000\ \text{pF} = 100\ \text{nF} = 0.1\ \mu\text{F}$
- 103 = $10,000\ \text{pF} = 10\ \text{nF}$
- 473 = $47,000\ \text{pF} = 47\ \text{nF}$

Electrolytic capacitors have the value and a **voltage rating** printed on the side, for example " $100\ \mu\text{F}\ 25\ \text{V}$ ". A stripe with minus signs marks the negative leg, and on a new capacitor the positive leg is longer.

SAFETY

Connect an electrolytic capacitor the right way round, and choose a voltage rating higher than your supply, for example 16 V or 25 V for a 9 V circuit. A reversed or over-voltage electrolytic can heat up, swell and burst with a bang. Keep your face away when you first power a circuit.

Charging takes time

A capacitor fills through a resistor gradually, not instantly. The **time constant** tells you how fast:

time constant (seconds) = $R \text{ (ohms)} \times C \text{ (farads)}$

In one time constant the capacitor charges to about 63% of the supply voltage. After about five time constants it is nearly full.

EXAMPLE

Mohan uses a 10 k Ω resistor and a 100 μF capacitor. 100 μF is 0.0001 F, so the time constant = $10,000 \times 0.0001 = 1$ second. The capacitor is nearly full after about 5 seconds.

Everyday jobs

- **Smoothing:** a large electrolytic, such as 100 μF , across the supply keeps the voltage steady when a motor suddenly draws current.
- **Decoupling:** a 100 nF ceramic capacitor close to a chip's power pins removes fast electrical noise.
- **Timing:** a capacitor and a resistor set the speed of a blink or the length of a delay.

TRY THIS

Charge a 1,000 μF , 16 V capacitor from a 9 V battery through a 1 k Ω resistor for ten seconds, with the + leg towards the battery's + end. Remove the battery, then connect the capacitor to a red LED (long leg to the + leg) with a 470 Ω resistor in series. The LED glows and fades out within a second or two.

Diodes, LEDs and Zener diodes

The diode

A **diode** lets current flow one way only, like a one-way valve in a pipe. Its legs are the **anode** (+) and the **cathode** (–), and a band round one end marks the cathode.

A silicon diode starts to conduct when its anode is about 0.6 to 0.7 V more positive than its cathode. This small loss is called the **forward voltage**. Connected the other way, it blocks current, up to its rated reverse voltage.

Kits usually have the **1N4007**, a sturdy diode for up to 1 A, and the **1N4148**, a small, fast diode for signals. Diodes are used for:

1. **Reverse polarity protection:** a diode in series with the battery prevents damage if the battery is connected the wrong way round.
2. **Flyback protection:** a diode across a relay coil or motor absorbs the spike made when it is switched off.
3. **Logic:** diodes can combine signals, as in a simple OR gate.

The LED

An **LED** (light emitting diode) gives out light when current flows forward through it. Like any diode, it works only one way round.

- The **longer leg** is the anode (+).
- The rim of a round LED has a **flat edge** next to the cathode (–).

Each colour needs a different forward voltage. These are typical values; the datasheet gives the exact range.

Colour	Typical forward voltage
Red	1.8 to 2.2 V
Yellow or orange	about 2.0 to 2.2 V
Green	2.0 to 3.2 V, depending on type
Blue or white	2.8 to 3.4 V

A standard 5 mm LED usually works at 10 to 20 mA, and many are clearly bright at 5 mA.

The current-limiting resistor

An LED must always have a resistor in series. Without one, the current rises until the LED burns out, often within a second. Use this formula:

$$R = (\text{supply voltage} - \text{LED forward voltage}) \div \text{current}$$

EXAMPLE

Sana has a 9 V battery and a red LED (2 V) that she wants to run at 15 mA (0.015 A). $R = (9 - 2) \div 0.015 = 467 \, \Omega$. The next standard value up is 470 Ω . The resistor's power is $7 \times 0.015 = 0.105 \text{ W}$, so a $\frac{1}{4} \text{ W}$ resistor is fine.

EXAMPLE

Two red LEDs in series on 9 V share the battery: $R = (9 - 2 - 2) \div 0.015 = 333 \, \Omega$. Choose 390 Ω , the next standard value up, for about 13 mA.

REMEMBER

If you are unsure, start with a bigger resistor, such as 1 k Ω . The LED will be dimmer but safe. You can lower the value later.

The Zener diode

A **Zener diode** is a special diode made to conduct backwards at a fixed voltage, called its Zener voltage, for example 5.1 V. It is connected "backwards", with its band towards the positive side, and always with a series resistor. The voltage across it then stays close to its Zener voltage, so it can make a simple reference voltage.

EXAMPLE

A 9 V battery feeds a 470 Ω resistor and a 5.1 V Zener. Current = $(9 - 5.1) \div 470$, which is about 8.3 mA. The Zener uses 5.1×0.0083 , about 0.04 W, well within a small Zener's rating.

A Zener circuit can only supply a tiny current to anything connected to it. To power a project at 5 V, use a voltage regulator such as the 7805.

Transistors as switches

A **transistor** lets a small current control a much bigger one. Here we use it as an electronic switch: a microcontroller pin or a sensor gives a tiny current, and the transistor switches a buzzer, some LEDs or a relay.

NPN transistors

The most common type in kits is the **NPN** transistor, such as the **BC547**. It has three legs:

- **Base (B):** the control input.
- **Collector (C):** where the load's current goes in.
- **Emitter (E):** where the current comes out, to the negative side (ground).

Hold a BC547 with its flat face towards you and its legs pointing down. The legs are usually collector, base, emitter from left to right. Other transistors use different orders. The common 2N2222 in a plastic case, for example, is often emitter, base, collector. Always check the datasheet for your exact part.

How the switch works

1. With no current into the base, the collector-to-emitter path is off, like an open switch.
2. When the base is about 0.7 V above the emitter, a small base current flows and the path starts to conduct.
3. With enough base current, the transistor is fully on, like a closed switch.

The transistor's **gain** (written h_{FE} or β) tells you how many times bigger the collector current can be than the base current. A BC547 has a gain of at least 110, and much more in its higher grades. To be sure the transistor turns fully on, a safe habit is to make the base current about one tenth of the load current.

EXAMPLE

Rohit wants an Arduino pin (5 V) to switch a group of LEDs that draws 40 mA from a 9 V battery. Base current = $40 \div 10 = 4$ mA. Base resistor = $(5 - 0.7) \div 0.004$, which is about 1,075 Ω . He uses 1 k Ω , which gives a little more, about 4.3 mA: good for switching and well within what the pin can give.

Wiring a low-side switch

Here is Rohit's circuit, described connection by connection:

1. The battery's + goes to the LED group (each LED with its own resistor).
2. The other end of the LED group goes to the transistor's collector.
3. The emitter goes to the battery's -.
4. The Arduino pin goes through the 1 k Ω resistor to the base.
5. The Arduino's GND is joined to the battery's -. Without this shared ground, the circuit will not work.

REMEMBER

Never connect the base straight to a supply or a pin without a resistor. Too much base current destroys the transistor.

Know the limits

A BC547 can carry up to 100 mA through its collector: enough for LEDs and small buzzers, but not for most motors. For bigger loads use a transistor rated for more current, a motor driver, or a MOSFET (a kind of transistor controlled by voltage).

A **PNP** transistor works the other way round: it sits on the positive side of the load and turns on when its base is pulled lower than its emitter.

Relays, switches and push buttons

Switch words

Switches are described by **poles** and **throws**. The number of poles is how many separate circuits the switch controls. The number of throws is how many positions each pole can connect to.

Name	What it does	Example use
SPST (single pole, single throw)	Simple on and off	A power switch
SPDT (single pole, double throw)	Connects one wire to either of two others	Choosing between two LEDs
DPDT (double pole, double throw)	Two SPDT switches moved together	Reversing a motor
Push button	On only while you press it	A doorbell or a reset button
Reed switch	Closes when a magnet comes near	A door or window sensor

Push buttons

The small square **tactile push buttons** in kits have four legs. Inside, they are joined in two pairs, and pressing the button connects the pairs. If you are unsure which legs are which, use two legs that are **diagonally opposite**. They are always on different sides of the switch.

When metal contacts close, they bounce for a few thousandths of a second, making several quick on-off pulses. This is called **bounce**. A microcontroller sees every pulse, so programs wait about 20 to 50 milliseconds after a change before trusting it. This is called **debouncing**.

REMEMBER

A microcontroller input that is connected to nothing is said to be **floating**, and it reads random values. Add a 10 k Ω **pull-down resistor** (input to ground) or **pull-up resistor** (input to +), so that the pin reads a fixed value when the button is not pressed.

Relays

A **relay** is a switch worked by an electromagnet. It has two sides that are not electrically connected:

- **The coil side:** a coil of wire. When current flows, it becomes a magnet and pulls a metal arm. You can hear a click.
- **The contact side:** the moving arm, called **COM** (common), touches either **NC** (normally closed, joined when the coil is off) or **NO** (normally open, joined when the coil is on).

A relay coil is rated for a voltage such as 5 V or 12 V. It usually needs more current than a microcontroller pin should give, so a transistor drives it. A **relay module** is a small board that already has the transistor, a protection diode and an LED.

The flyback diode

When the coil is switched off, its magnetic field collapses and makes a sudden high-voltage spike. That spike can destroy the transistor driving it. A diode such as a 1N4007 connected across the coil, with its band towards the positive side, gives the spike a safe path. Fit one every time you drive a coil or motor with a transistor.

SAFETY

Relays often carry markings for mains voltages. Ignore them. Students use relays only to switch low-voltage loads, such as a 6 V pump or a 12 V lamp running from batteries. Never connect a relay, or anything else, to mains wiring.

Buzzers and DC motors

Active and passive buzzers

	Active buzzer	Passive buzzer
Inside	Has its own oscillator circuit	Only the sound-making part
What it needs	A steady DC voltage	A signal that switches on and off quickly
Sound	One fixed tone	Any note you send it
Polarity	Has + and – legs, often marked	Often marked, but works either way in most cases

To tell them apart, connect a buzzer briefly to its rated DC voltage. An active buzzer beeps; a passive one only clicks.

A passive buzzer is played by a 555 timer circuit or by an Arduino using `tone()`. Small buzzers draw a few tens of milliamps or less, but check the rating; if it is more than a pin should give, use a transistor.

TRY THIS

Wire an active buzzer, a push button and a 9 V battery in a loop (use a buzzer rated for 9 V). You have built a doorbell. Now add an LED and a 470 Ω resistor across the buzzer (long leg towards +), so that it lights with each ring.

DC motors

A small DC motor spins when current flows through it, and swapping its two wires reverses it. Toy motors usually run on 3 to 6 V. Many robot kits in India use **BO motors**: small DC motors with a plastic gearbox that turn slowly but strongly.

Motors need much more current than LEDs: often a few hundred milliamps while running, and several times more at the moment they start or when the shaft is stuck (stalled).

REMEMBER

Never connect a motor straight to a microcontroller pin. Use a transistor rated for the motor's current, or a motor driver board such as one based on the L293D or L298N chip.

Taming motor noise

The brushes inside a motor make tiny sparks that create electrical noise, which can reset a microcontroller. Two simple fixes:

1. Solder a 100 nF ceramic capacitor across the motor's two terminals (with adult help).
2. Put a large electrolytic capacitor, such as 100 μ F, across the motor's battery supply.

Also fit a flyback diode when a single transistor switches a motor, just as for a relay.

SAFETY

Keep fingers, hair and loose clothing away from spinning motors, gears and wheels. If a motor stalls, switch off at once, because a stuck motor gets hot quickly.

CHAPTER 9

Batteries, holders and voltage regulators

Cells and batteries

A **cell** is a single unit that makes electricity from chemicals. A **battery** is strictly a group of cells, though we use the word for both.

Type	Voltage	Rechargeable?	Notes
AA or AAA alkaline	1.5 V	No	Common; good for low and medium currents
AA or AAA NiMH	1.2 V	Yes	Good for motors; use a NiMH charger
9 V (PP3)	9 V	Usually no	Small capacity; fine for LEDs and 555 circuits, poor for motors

Type	Voltage	Rechargeable?	Notes
Coin cell (such as CR2032)	3 V	No	Tiny; very dangerous if swallowed
18650 lithium-ion	3.7 V (about 4.2 V when full)	Yes	Powerful; needs a proper charger and adult supervision
Sealed lead-acid	6 V or 12 V	Yes	Heavy; used in bigger robots

A **battery holder** joins cells in series. Four 1.5 V cells in series give $4 \times 1.5 = 6$ V. Use cells of the same type and age together.

How long will it last?

A battery's **capacity** is given in milliamp-hours (mAh). In theory, 2,000 mAh could give 200 mA for 10 hours. Real batteries give less at high currents, so treat the answer as a rough guide.

EXAMPLE

Pooja's robot draws about 400 mA from a pack of AA cells rated 2,000 mAh. $2,000 \div 400 = 5$, so she expects up to about 5 hours, and plans for less.

SAFETY

Never short-circuit a battery: the wire and the battery can get dangerously hot. Never puncture, crush or heat a lithium cell, and charge it only with the correct charger, with an adult present. Keep coin cells away from small children. Remove cells from projects stored for months, because old cells can leak, and give dead ones to an e-waste collection point.

The 7805 voltage regulator

Many chips need a steady 5 V, but a battery's voltage falls as it runs down. A **voltage regulator** gives a fixed output. The classic 5 V regulator, the **7805**, has three legs. Looking at its printed front with the legs pointing down, they are:

1. Input (from the battery)
2. Ground (common negative)
3. Output (steady 5 V)

Its metal tab is joined to the ground leg. Points to remember:

- The input must be at least about 2 V higher than the output, so give it 7 V or more. In student projects keep it at 12 V or less.
- Fit a small capacitor from input to ground and another from output to ground, close to the legs. The datasheet suggests values such as 0.33 μF on the input and 0.1 μF on the output.
- It can give up to about 1 A, but only with a heat sink.

The regulator gets warm

A 7805 turns the extra voltage into heat. The wasted power is:

$$P = (\text{input voltage} - 5) \times \text{current}$$

EXAMPLE

On 9 V at 150 mA, $P = 4 \times 0.15 = 0.6 \text{ W}$, so it is warm. On 12 V at 500 mA, $P = 7 \times 0.5 = 3.5 \text{ W}$, which is far too hot without a large heat sink. As a rough guide, fit a heat sink if the wasted power is more than about 1 W.

Other regulators include the 7809 (9 V), the 7812 (12 V) and the adjustable LM317. Small **buck converter** modules waste far less energy as heat, so batteries last longer.

CHAPTER 10

Integrated circuits: the 555 and the LM358

An **integrated circuit** (IC), or chip, holds many transistors and other parts on one tiny piece of silicon. Most student chips come in a **DIP** package: a black body with two rows of legs that fits a breadboard.

Finding pin 1

Look for a notch or a small dot at one end of the chip. Hold it with the notch pointing away from you (at the top). Pin 1 is at the top left, and the pins are counted **anticlockwise** (down the left side and up the right side) when seen from above. On an 8-pin chip, pin 8 is at the top right.

TIP

Solder an IC socket on your board, not the chip itself. The chip never meets the hot iron and is easy to replace.

The 555 timer

The 555 makes timed pulses: it can blink LEDs, make tones and switch something on for a set time.

Pin	Name	What it does
1	Ground	Battery –
2	Trigger	Starts a timing cycle when pulled low
3	Output	The pulse comes out here
4	Reset	Join to + for normal use
5	Control voltage	Usually a 10 nF capacitor to ground
6	Threshold	Ends the timing cycle
7	Discharge	Empties the timing capacitor
8	Supply (+)	4.5 V to 15 V for the common NE555

In **astable** mode the 555 keeps switching on and off by itself. The timing uses two resistors, R1 and R2, and a capacitor C. The frequency (flashes per second) is about:

$$f = 1.44 \div ((R1 + 2 \times R2) \times C)$$

EXAMPLE

Aman uses R1 = 1 k Ω , R2 = 10 k Ω and C = 100 μ F (0.0001 F). $R1 + 2 \times R2 = 21,000 \Omega$. $f = 1.44 \div (21,000 \times 0.0001) = 1.44 \div 2.1$, which is about 0.69 flashes per second, or one flash about every 1.5 seconds. Change C to 100 nF and the frequency becomes about 690 per second: a tone you can hear on a buzzer.

In **monostable** mode, a short low pulse on pin 2 makes the output go high for a set time, $t = 1.1 \times R \times C$. With 100 k Ω and 100 μ F, $t = 1.1 \times 100,000 \times 0.0001 = 11$ seconds.

The LM358

The LM358 holds two **op-amps** (operational amplifiers) in one 8-pin package. Students most often use one as a **comparator**: a circuit that compares two voltages and answers "which is bigger?".

Pin	Use	Pin	Use
1	Output A	8	Supply (+), 3 V to 32 V
2	Input A (-)	7	Output B
3	Input A (+)	6	Input B (-)
4	Ground	5	Input B (+)

When the voltage on the + input is higher than on the - input, the output goes high. Otherwise it goes low.

EXAMPLE

Lakshmi joins an LDR divider (fixed resistor on top, LDR at the bottom) to pin 3, and the middle leg of a 10 k Ω pot (outer legs to + and -) to pin 2. Pin 1 drives an LED through a 1 k Ω resistor. When it gets dark, the LDR voltage rises above the pot's setting and the LED lights. Turning the pot sets how dark it must be.

DID YOU KNOW

Many ready-made sensor modules have a blue preset and an 8-pin chip, often an LM393 comparator, doing just what Lakshmi's circuit does.

CHAPTER 11

Datasheets, safety and storage

Reading a datasheet

Every component has a **datasheet**, a document from its maker that gives the facts about it. Search for the part number and the word "datasheet".

Section	What it tells you
Pin diagram (pinout)	Which leg is which
Absolute maximum ratings	Limits that damage the part if crossed, even briefly. Never design to these
Recommended operating conditions	The safe range to work in
Electrical characteristics	Measured values, often given as minimum, typical and maximum
Typical application	A suggested circuit to copy

EXAMPLE

The BC547 datasheet lists a maximum collector current of 100 mA and a maximum collector-to-emitter voltage of 45 V. Aman wants to switch a 150 mA lamp, so he knows at once that the BC547 is the wrong choice.

Start with the pinout, the maximum ratings and the typical application.

Safety rules for every build

1. Use cells and batteries of 12 V or less. Never work on mains wiring.
2. Check polarity before connecting power: LEDs, diodes, electrolytic capacitors, chips and batteries all have a right way round.
3. Disconnect the battery before changing any wiring.
4. If something smells hot, smokes or hisses, disconnect the power at once and let it cool.
5. Soldering, hot glue, wire cutters and chemicals need an adult present. Use a stand for the iron, keep the room ventilated, and wash your hands after soldering.
6. Point legs downwards when you cut them, because the cut ends can fly.

SAFETY

Check whether a part is hot by holding a finger near it first. Never grab it.

Storing components

- Keep resistors in labelled strips or packets, sorted by value.

- Use a small box with compartments for LEDs, capacitors and transistors, and label each compartment.
- Keep ICs in their tubes, in anti-static bags or pushed into anti-static foam. Hold them by the body, not the legs. A spark of static electricity, too small to feel, can damage some chips, especially in dry weather.
- Store batteries away from loose metal parts, with tape over exposed terminals.
- Keep everything dry. A packet of silica gel in the box helps during the monsoon.

EXAMPLE

Suppose Harpreet buys a ! 500 starter kit and sorts it into a ! 100 compartment box on day one. Six months later she still finds every part in seconds, and nothing is bent or lost.

CHECK YOURSELF

Practice questions

1. What are the units of voltage, current and resistance?
2. A 9 V battery is connected across a 3 k Ω resistor. What current flows?
3. A part has 5 V across it and 25 mA flowing through it. What is its resistance?
4. Read this resistor: yellow, violet, red, gold.
5. A 220 Ω resistor has 9 V across it. What power does it use, and is a $\frac{1}{4}$ W resistor safe?
6. What does a potentiometer's middle leg connect to?
7. In a divider with $R_1 = 10$ k Ω on top and $R_2 = 30$ k Ω below, on 8 V, what is V_{out} ?
8. What happens to an LDR's resistance when a torch shines on it?
9. What value is a ceramic capacitor marked 104?
10. Why must an electrolytic capacitor have a voltage rating higher than the supply?
11. A 47 k Ω resistor charges a 100 μ F capacitor. What is the time constant?
12. How do you find the cathode of a round LED?

13. Calculate the resistor for a blue LED (3 V) at 10 mA from a 5 V supply.
14. What does a Zener diode do that an ordinary diode does not?
15. Why does a relay coil need a flyback diode?
16. How can you tell an active buzzer from a passive one?
17. Why must a DC motor never be connected straight to a microcontroller pin?
18. A 7805 runs from 12 V and supplies 200 mA. How much power does it waste as heat?
19. On an 8-pin IC, where is pin 1 and which way do you count?
20. In the 555 astable formula, what is the frequency with $R1 = 1\text{ k}\Omega$, $R2 = 1\text{ k}\Omega$ and $C = 10\text{ }\mu\text{F}$?

ANSWER KEY

Answers

1. Volts (V), amperes (A) and ohms (Ω).
2. $I = V \div R = 9 \div 3,000 = 0.003\text{ A}$, which is 3 mA.
3. $R = V \div I = 5 \div 0.025 = 200\text{ }\Omega$.
4. 4, 7, then $\times 100$: $4,700\text{ }\Omega$, which is $4.7\text{ k}\Omega$, with $\pm 5\%$ tolerance.
5. $I = 9 \div 220$, about 0.041 A , so $P = 9 \times 0.041$, about 0.37 W . That is more than $\frac{1}{4}\text{ W}$, so it would overheat. Use a 1 W resistor, which is more than double the power, or a bigger resistance.
6. The wiper, which slides along the resistive track as you turn the shaft.
7. $V_{\text{out}} = 8 \times 30 \div (10 + 30) = 8 \times 30 \div 40 = 6\text{ V}$.
8. It falls, because an LDR's resistance drops as more light reaches it.
9. 10 followed by four zeros, which is $100,000\text{ pF} = 100\text{ nF} = 0.1\text{ }\mu\text{F}$.
10. Too much voltage, or the wrong polarity, can make it heat up, swell and burst.
11. $47,000 \times 0.0001 = 4.7\text{ seconds}$.
12. Look for the flat edge on the rim, or the shorter leg. Both mark the cathode (–).
13. $R = (5 - 3) \div 0.01 = 200\text{ }\Omega$. Use $220\text{ }\Omega$, the next standard value up, for about 9 mA .
14. It conducts backwards at a fixed voltage, so it can hold a steady reference voltage when used with a series resistor.
15. Switching off the coil makes a high-voltage spike that can destroy the transistor. The diode gives the spike a safe path.

- 16.** Connect it briefly to its rated DC voltage.
An active buzzer beeps by itself; a passive buzzer only clicks and needs a changing signal.
- 17.** A motor needs far more current than a pin can give, and its spikes and noise can damage or reset the microcontroller. Use a transistor or a motor driver.
- 18.** $P = (12 - 5) \times 0.2 = 1.4 \text{ W}$. That is enough to need a heat sink.
- 19.** With the notch at the top, pin 1 is at the top left. Count anticlockwise, down the left side and up the right side.
- 20.** $R1 + 2 \times R2 = 3,000 \, \Omega$, so $f = 1.44 \div (3,000 \times 0.00001) = 1.44 \div 0.03 = 48$ flashes per second. An LED flashing this fast looks almost steady.

WORD LIST

Glossary

Anode

the positive (+) leg of a diode or LED, where current goes in.

Capacitor

a component that stores a small amount of electric charge.

Cathode

the negative (–) leg of a diode or LED, marked by a band or a flat edge.

Comparator

a circuit that compares two voltages and switches its output to show which is bigger.

Datasheet

the maker's document giving the facts and limits of a component.

Diode

a component that lets current flow in one direction only.

Flyback diode

a diode across a coil or motor that absorbs the spike made when it is switched off.

Forward voltage

the voltage a diode or LED needs before it conducts.

LDR

a light dependent resistor, whose resistance falls in light.

LED

a light emitting diode, which glows when current flows forward through it.

Ohm's law

the rule $V = I \times R$ linking voltage, current and resistance.

Potential divider

two resistors in series that share a supply voltage to give a smaller one.

Potentiometer

a resistor with a sliding contact, adjusted by turning a knob.

Pull-down resistor

a resistor that holds an input at 0 V when nothing else drives it.

Relay

a switch worked by an electromagnet.

Resistance

how strongly a material opposes current, measured in ohms.

Time constant

$R \times C$, the time a capacitor takes to charge to about 63% through a resistor.

Tolerance

how far a component's real value may differ from its marked value.

Transistor

a component that lets a small current control a larger one.

Voltage regulator

a component that gives a steady output voltage from a changing input.



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