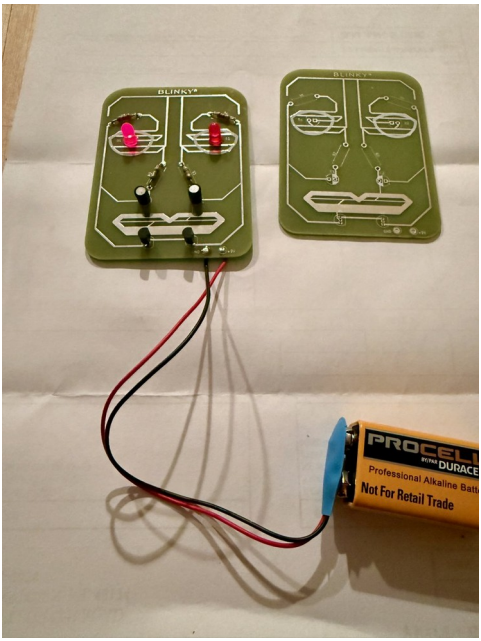
KIT ASSEMBLY MANUAL

BLINKY

Two-Transistor Astable Multivibrator Kit

Version 1.1 rev A



Somerled Design

somerled.design

Welcome

Thank you for choosing the Somerled Design **Blinky** kit. In an evening or less you will build a little circuit-board face whose two LED eyes take turns blinking, all by themselves, for as long as the battery lasts. Along the way you will learn how a **transistor** works, which is the most important idea in all of modern electronics.

This manual is written in the tradition of the classic kit manuals many of us grew up with. Every step has a check box, ( ). When you finish a step, mark the box. If you are interrupted, you will know exactly where to pick up again. Read each step all the way through before you do it, and do the steps in order.

Do not hurry. Kit building is meant to be enjoyed, and careful work the first time is much faster than finding a mistake later.

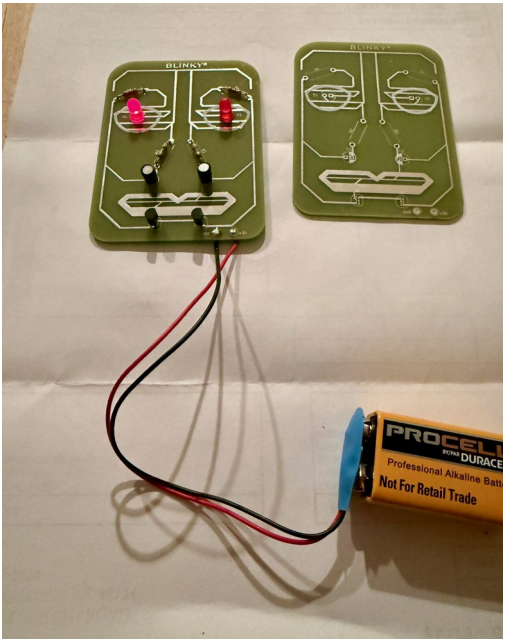


Figure 1. *A finished Blinky (BC548 transistors) running on a 9 V battery*

Where Blinky came from

In 1983 the designer of this kit, Kevin (W8VOS), was in **BED**, Basic Electronics Tech school at Keesler Air Force Base. There they built a project called the **“Pinger Detector.”** That name would not mean

anything to today's kids, so when Kevin turned the circuit into a kit, and called it **Blinky**.

Underneath the new name it is the same circuit: a **two-transistor astable multivibrator** with LEDs for eyes. "Astable" means it has no stable resting state. It can never make up its mind, so it flips back and forth forever. "Multivibrator" is the old name for a circuit that switches between two states. Put those together and you have a classic circuit. Once you understand Blinky, you understand how a transistor works as a switch.

What the kit does

When you connect a 9 V battery, Blinky's two LEDs blink **one at a time, back and forth**: left eye, right eye, left eye, right eye. Each eye stays lit for about **0.72 second**, so a full left-and-right cycle takes about 1.4 seconds. (You will see where those numbers come from in "How It Works.")

- Two **transistors**, Q1 and Q2, act as electronic switches.
- Two **capacitors**, C1 and C2, and two **47K resistors**, R2 and R3, set the timing.
- Two **LEDs**, D1 and D2, are the eyes. Each has a **270 Ω resistor**, R1 or R4, to limit its current.

There is no power switch

Blinky has no on/off switch. Unlike a tester that waits for you, Blinky is always working: one eye or the other is always lit. When you are finished admiring it, **unsnap the battery**. That is the off switch.

About this manual

The manual has three parts. First comes a **short course in transistors**: where they came from, what is inside them, and how they compare with the vacuum tubes they replaced and the MOSFETs that came after them. Then come the **tools, soldering and assembly** steps. Last come **how Blinky works**, troubleshooting, and some experiments to try. If you are eager to start soldering, you can skip ahead to "Tools You Will Need" and come back to the course later. But you will enjoy the build more if you read the course first.

The pictures in this manual are photographs of a finished Blinky and of a rev A production board. Your parts may look slightly different from the

pictures (body colours, markings and shapes vary between makers), but the values and placements will be the same.

If you come across a paragraph starting with, ‘Suggested*:*’, this marks a path to added knowledge which the reader is encouraged to follow on their own.

A Short Course in Transistors

Every phone, computer, game console and car built today contains transistors, often billions of them. Blinky uses just two, big enough to hold in your fingers. This short course explains what they are, where they came from, and why they matter. Take your time. There is a lot here, and every bit of it will help you understand the circuit you are about to build.

Before transistors: the vacuum tube

For the first half of the twentieth century, electronics meant **vacuum tubes** (the British call them **valves**). John Ambrose Fleming built the first practical tube, a two-element **diode**, in 1904. In 1906 Lee de Forest added a third element and made the **Audion**, the first **triode**. The triode could **amplify**: a small signal could control a much larger one. That one idea made radio, long-distance telephone, radar, television and the first electronic computers possible.

A tube works like this. Inside a glass envelope with the air pumped out, a heated **cathode** boils off electrons. A metal **plate** (the anode), held at a high positive voltage, attracts them, so a current flows across the vacuum. Between the two sits the **grid**, a fine wire mesh. The grid is held a little **negative** compared with the cathode. The more negative it is, the more it pushes electrons back, and the less plate current flows. Make the grid a little less negative and the current rises.

Here is the key point for this course: the grid controls the current with its **voltage**. Because the grid is negative, it repels electrons instead of collecting them, so almost **no current flows into the grid**. A vacuum tube is a **voltage-driven** device. Hold on to that idea. We will come back to it twice.

Tubes worked, but they had problems. The heater used a lot of power and made a lot of heat. Tubes were large and fragile, they took time to warm up, and they wore out. A big computer full of tubes needed a crew just to find and replace the burned-out ones. The telephone company had another headache: its nationwide network depended on tube amplifiers and on millions of mechanical relays, and both wore out.

Bell Labs, 1947: the transistor is born

The American Telephone and Telegraph Company (**AT&T**) ran a famous research centre called **Bell Telephone Laboratories**, usually just

“Bell Labs.” After World War II, Bell Labs set up a group to look for a **solid-state** amplifier: something made from a solid crystal, with no vacuum, no heater and nothing to wear out. The group was led by physicist **William Shockley**. Two of its members were the theorist **John Bardeen** and the experimenter **Walter Brattain**.

In **December 1947**, Bardeen and Brattain pressed two closely spaced gold contacts onto a small block of **germanium**, a semiconductor. A tiny current into one contact controlled a larger current through the other. It amplified! This first device is called the **point-contact transistor**. It was demonstrated to Bell Labs management just before Christmas 1947, and the date is often given as the birthday of the transistor.

Shockley went on to work out the theory of a sturdier design, the **junction transistor**, made from layers of differently treated semiconductor. Working junction transistors followed within a few years, and the junction transistor, not the point-contact one, became the transistor in Blinky and in almost everything that followed. In **1956** Shockley, Bardeen and Brattain shared the **Nobel Prize in Physics** for their work on semiconductors and the discovery of the transistor effect.

Suggested: The name “transistor” was coined at Bell Labs by engineer John R. Pierce, from “transfer” and “resistor.”

The first transistors were made of germanium. Before long, **silicon** took over, because silicon transistors work at higher temperatures. The transistors in this kit are silicon.

Semiconductors and doping

A **conductor**, such as copper, lets current flow easily. An **insulator**, such as glass or plastic, barely lets it flow at all. A **semiconductor**, such as silicon or germanium, sits in between. What makes semiconductors so useful is that we can **choose** how well they conduct, and whether they conduct with negative or positive charges, by adding tiny amounts of other elements. That process is called **doping**.

Start with pure silicon. Each silicon atom has **four** outer (valence) electrons. In a crystal, every atom shares those four electrons with its four neighbours, so every electron is locked in a bond (Figure 2, left). With no free electrons to move around, pure silicon is a poor conductor.

N-type silicon. Now replace a very few silicon atoms with **phosphorus** (or arsenic), which has **five** valence electrons. Four of them fit into bonds. The fifth has no bond to join, so it is free to wander through the

crystal and carry current (Figure 2, centre). Because the extra carriers are **negative** electrons, this is called **N-type** silicon.

P-type silicon. Instead, replace a few atoms with **boron**, which has only **three** valence electrons. Now one bond is missing an electron. That gap is called a **hole** (Figure 2, right). A nearby electron can hop into the hole, which leaves a new hole where it came from. The hole seems to move, and it acts just like a **positive** charge moving through the crystal. Because the carriers are positive holes, this is called **P-type** silicon.

Remember that N-type and P-type silicon are both still electrically neutral overall. The doping atoms bring their own matching protons. Doping changes **what carries the current**, not the total charge.

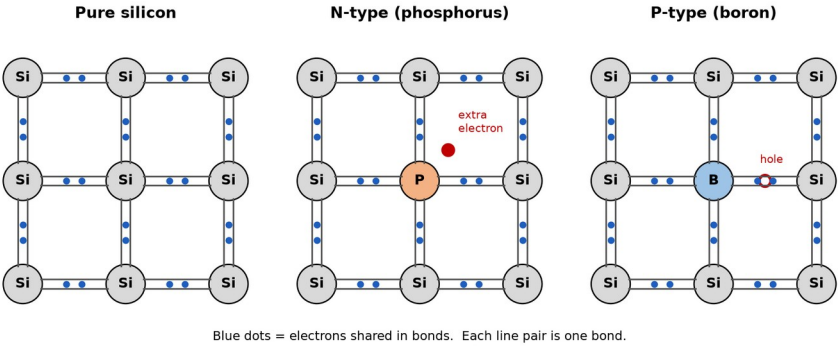


Figure 2. *Pure, N-type and P-type silicon (simplified flat drawing of a crystal that is really three-dimensional).*

The PN junction and the LED

Something remarkable happens where P-type and N-type silicon meet in one crystal. This boundary is called a **PN junction**. Near the junction, free electrons from the N side fill holes on the P side. That leaves a thin layer with no free carriers at all, called the **depletion region**. It acts like a wall.

Connect a battery with **+ to the P side** and **− to the N side**, and the wall shrinks. Once the voltage is high enough (about 0.6–0.7 V for silicon), current flows freely. This is called **forward bias**. Turn the battery around (**reverse bias**) and the wall gets wider. Practically no current flows. A single PN junction is a **diode**: a one-way valve for current. Fleming's vacuum diode of 1904 did the same job with a hot cathode in a glass bulb.

Blinky's eyes are diodes too. An **LED** (light-emitting diode) is a PN junction made from semiconductor compounds chosen so that, when an electron drops into a hole at the junction, the energy comes out as **light**. The material sets the colour: red, green or yellow. Like every diode, an LED conducts in only one direction. The P side is called the **anode** and the N side the **cathode**. You will need to know which is which when you install the LEDs, so remember: **current flows in at the anode and out at the cathode.**

NPN and PNP

A **bipolar junction transistor** (BJT) is a sandwich of three layers, which makes two PN junctions back to back. There are two ways to build the sandwich (Figure 3):

- **NPN**: a thin **P** layer between two **N** layers.
- **PNP**: a thin **N** layer between two **P** layers.

The three layers have names. The **emitter** emits charge carriers into the middle layer. The middle layer is the **base**, and it is very thin. The **collector** collects the carriers that make it across the base. The trick that makes a transistor work is that thin base. When a small current flows from base to emitter, it fills the base with carriers. Because the base is so thin, most of those carriers shoot straight through into the collector instead of leaving through the base lead. A small base current opens the way for a much larger collector current.

In a schematic, the emitter is the lead with the **arrow**. The arrow shows the direction of conventional current through the base-emitter junction, which is the direction from P to N. In an **NPN** transistor the arrow points **out** ("**N**ot **P**ointing i**N**" is an old memory aid). In a **PNP** transistor the arrow points **in**.

NPN and PNP transistors are mirror images. An NPN transistor turns on when its base is a little **positive** compared with its emitter, and its current flows from collector to emitter. A PNP transistor turns on when its base is a little **negative** compared with its emitter, and its current flows the other way. You could build Blinky from two PNP transistors if you turned the battery, the LEDs and the capacitors around. Blinky uses **NPN** transistors, the most common kind.

Why "bipolar"? Because the current in a BJT is carried by **both** kinds of carrier, negative electrons and positive holes. Remember that word. It is the difference between a BJT and a MOSFET.

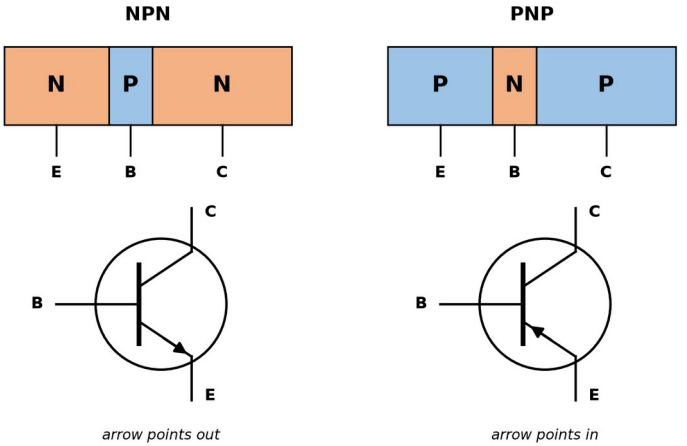


Figure 3. *NPN and PNP layers (top) and their schematic symbols (bottom).*

Current-driven: how a bipolar transistor is controlled

Here is where the transistor is very different from the vacuum tube. The base-emitter junction is a forward-biased diode. Current **must flow into the base** to turn the transistor on. The collector current is the base current multiplied by the transistor's **current gain**, written **hFE** (or β, beta):

Collector current ≈ hFE × base current

If a transistor has an hFE of 100, then 1 mA of base current allows up to 100 mA of collector current. So a bipolar transistor is a **current-driven** device. A tube's grid controls current with voltage and draws almost no current. A transistor's base controls current with **current**. This is the big idea to take away: **tubes are voltage-driven; bipolar transistors are current-driven.**

WHY GAIN VARIES: A transistor's hFE is set mostly by how it is made. The thinner the base layer, the fewer electrons get lost in it on their way to the collector, so hFE goes up. Doping the base lightly and the emitter heavily raises hFE too. Factories cannot hold these exactly, so transistors with the same part number come out with a spread of gains, and they are tested and sorted, or binned, into groups. A BC548A has an hFE of roughly 110–220, a BC548B 200–450, and a BC548C 420–800 (typical data sheet ranges). hFE also changes with temperature and with how much current flows. That is why Blinky's circuit does not depend on an exact hFE.

The base still needs a little voltage, of course: the base-emitter junction must be forward biased. For a silicon transistor that is about 0.6–0.7 V. The BC548 data sheet lists a base-emitter "on" voltage of 0.58 to 0.70 V at 2 mA. Below that, almost no current flows and the transistor is **off**. Give the base enough current and the transistor is fully **on** (engineers call it **saturated**), with only a few tenths of a volt between collector and emitter.

Blinky uses its transistors as **switches**: each one is either fully off or fully on. In Blinky, base current comes through a 47K resistor from the 9 V supply. With about 0.7 V on the base, the base current is about

$$(9\ \text{V} - 0.7\ \text{V}) \div 47{,}000\ \Omega \approx 0.18\ \text{mA}$$

Multiply that by an hFE of 100 and the transistor could pass about 18 mA, which is plenty to run an LED. That is why Blinky is not fussy about which transistor you use. Any ordinary small-signal NPN with a modest current gain will do. The BC548, 2N3904 and PN2222 are all general-purpose NPN transistors. Their data sheets list minimum gains around 100 (BC548 from 110; 2N3904 from 100 at 10 mA; PN2222A from 75 at 10 mA), and they are interchangeable in this circuit. Your kit may contain any of them, as a matched pair. They are **not** interchangeable in one important way, though: **their pins are in a different order**. You will learn about that in the assembly section.

Voltage-driven again: the MOSFET

The story has one more turn. The transistors in the chips inside your phone and computer are not bipolar transistors. They are **MOSFETs**: metal-oxide-semiconductor field-effect transistors.

A MOSFET has a **source**, a **drain** and a **gate**. In an N-channel MOSFET, the source and drain are N-type regions set into P-type silicon. The gate is a metal (or other conductive) plate sitting on top of the silicon, separated from it by a very thin layer of **glass-like oxide**, a near-perfect insulator. Put a positive voltage on the gate and its electric field pulls electrons to the surface just below it. That forms a thin N-type **channel** joining source and drain, and current flows. Remove the voltage and the channel disappears.

Because the gate is insulated, essentially **no current flows into it** once it is charged. The gate controls the drain current with its **voltage**, just as a tube's grid does. So the story comes full circle: **vacuum tubes are voltage-driven, bipolar transistors are current-driven, and**

MOSFETs are voltage-driven again. Note also that only one kind of carrier (electrons, in an N-channel MOSFET) carries the current, which is why MOSFETs are sometimes called **unipolar** transistors.

Suggested: The first working MOSFET was built at Bell Labs in 1959 by Mohamed Atalla and Dawon Kahng.

Because a MOSFET gate draws almost no steady current, billions of tiny MOSFETs can be packed onto one chip without wasting much power holding them on. That is why the MOSFET is the building block of nearly every modern computer chip. Bipolar transistors are still everywhere too, in amplifiers, radio circuits, power supplies and simple switching circuits like Blinky.

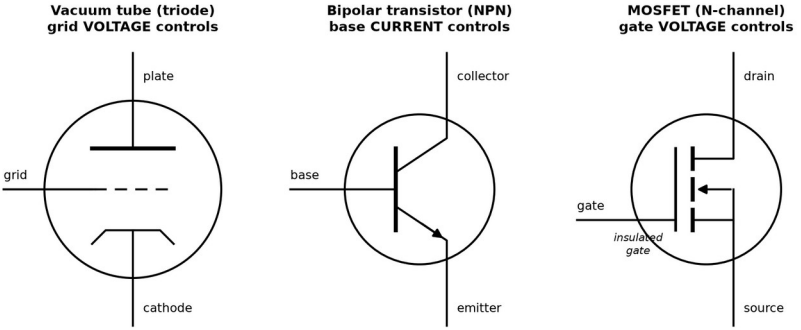


Figure 4. *The three controllers compared: tube grid, transistor base, MOSFET gate.*

Summary

Device	Control terminal	Driven by	Input current
Vacuum tube (triode)	Grid	Voltage	Almost none
Bipolar transistor (NPN, PNP)	Base	Current	Small, but needed
MOSFET	Gate	Voltage	Almost none

Now you know what is inside the two little black parts in your kit. Time to build.

Tools You Will Need

( )	Tool	Notes
( )	Soldering iron	25–40 W pencil iron, or a temperature-controlled station set to about 650–700 °F (340–370 °C). Fine conical or small chisel tip.
( )	Solder	Rosin-core electronics solder, 0.020–0.031 in (0.5–0.8 mm) diameter. Never use acid-core solder.
( )	Iron stand and tip cleaner	A damp sponge or brass wool.
( )	Diagonal cutters	Small flush cutters for trimming leads.
( )	Long-nose pliers	For bending and forming leads.
( )	Multimeter	Needed for the LED check and the experiments, and helpful for checking parts.
( )	Safety glasses	Clipped leads fly. Solder can spit.
( )	Good light and a magnifier	For inspecting solder joints.
( )	Optional	Desoldering braid or a solder sucker, in case you need to correct a mistake.

CAUTION: Work in a ventilated area, keep your fingers away from the hot tip, and wash your hands after handling solder. Most kit solder contains lead.

Soldering

A good solder joint is the single most important thing in a kit. Almost every kit that does not work on the first try has a poor solder joint somewhere. Take the time to learn the method below and you will have few problems.

How to make a good solder joint

( ) Keep the tip clean and **tinned**: wipe it on the sponge and melt a little fresh solder onto it.

( ) Touch the tip so it heats **both** the component lead **and** the copper pad at the same time.

( ) After one or two seconds, feed solder into the joint, **not onto the iron tip**. The solder should flow smoothly around the lead and over the pad.

( ) Remove the solder first, then the iron. Do not move the part while the solder cools (a few seconds).

( ) Trim the lead just above the top of the solder joint with diagonal cutters. Hold the lead end so it does not fly.

What to look for

Good joint	Poor joint
Smooth, shiny (or satin with lead-free) and shaped like a small volcano or tent around the lead.	Dull, grainy, lumpy, or a ball of solder sitting on the pad.
Solder wets the whole pad and climbs the lead.	Solder only on the lead, not the pad (or the reverse). A dark ring around the lead means a cold joint.
Nothing touches the next pad.	A bridge of solder joins two pads that should be separate.

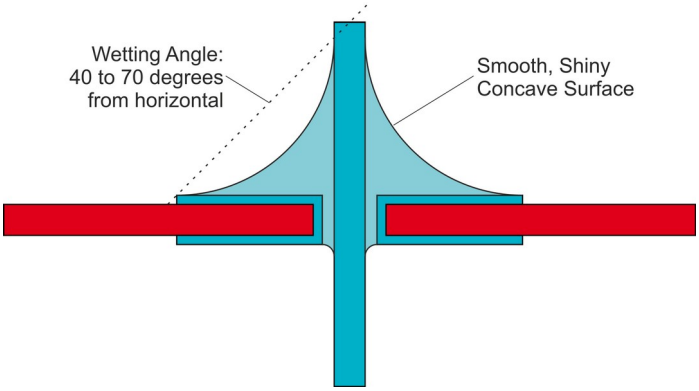


Figure 5. *An ideal solder joint in cross-section. Image: "Solder Joint en.svg" by SLUB Dresden / Carsten Pietzsch, based on an Adafruit diagram by Bill Earl. CC BY-SA 4.0 (creativecommons.org/licenses/by-sa/4.0), via Wikimedia Commons. Converted to PNG.*

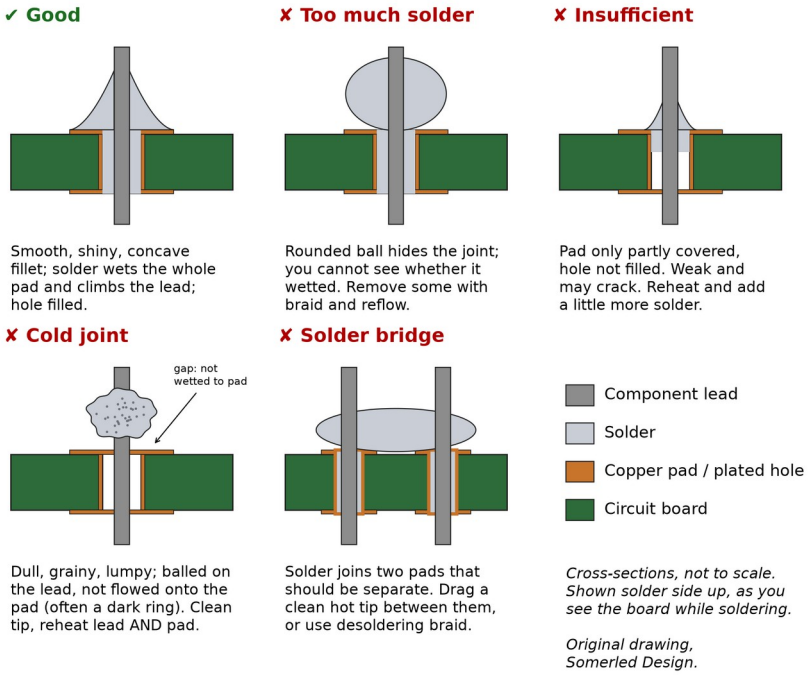


Figure 6. *A good joint and the four most common faults.*

To fix a poor joint, reheat it and add a small amount of fresh solder. To remove a bridge, drag a clean, hot tip between the pads, or use desoldering braid.

NOTE: Heat is the enemy of semiconductors. Do not hold the iron on a LED or transistor lead for more than a few seconds. If a joint is not right, let it cool, then try again.

Unpacking and Parts Inventory

Open the kit over a tray or a light-coloured towel so small parts cannot roll away. Check each part against the list below and mark its box. The Ref column gives the reference designator printed on the circuit board.

( )	Qty	Ref	Description
( )	1	—	Blinky circuit board, v1.1 rev A, 2.500 × 3.400 in (63.5 × 86.4 mm)
( )	2	R1, R4	270 Ω resistor (red-violet-brown, silver band)
( )	2	R2, R3	47K (47,000 Ω) resistor (yellow-violet-orange)
( )	2	D1, D2	5 mm LED (matched colour: red, green, or yellow)
( )	2	C1, C2	22 µF electrolytic capacitor
( )	2	Q1, Q2	Small-signal NPN transistor (BC548, 2N3904, PN2222 or similar; matched pair)
( )	1	—	9 V battery snap with red and black leads

NOTE: A 9 V battery is not included. Any ordinary 9 V alkaline battery will work.

MISSING PARTS? If a part is missing, check the packing material again first. Then email support@somerled.design with your kit version and the missing part.

Identifying the Parts

Resistors: the 4-band colour code

Resistor values are shown by coloured bands. Hold the resistor with the **tolerance band** on the right. It is gold or silver, and often set a little apart from the others. Then read from the left: the first two bands are digits, and the third band is the multiplier (the number of zeros).

The fourth band is the tolerance: how far the actual resistance may be from the marked value. Gold means within ±5%. Silver means within ±10%. A resistor with no fourth band is ±20%. Brown (±1%) and red (±2%) tolerance bands are found on 5-band precision resistors. Resistors are made in standard series of values. The ±10% series, called E12, has twelve values per decade: 10, 12, 15, 18, 22, 27, 33, 39, 47, 56, 68, 82. The ±5% series, E24, adds twelve more in between. 27 and 47 are in both series, so 270 Ω and 47K resistors are made in both tolerances. R1 and R4 in this kit are ±10% (silver band). Check the fourth band on your resistors to see which you have.

Colour		Digit	Multiplier	Tolerance
Black		0	×1	
Brown		1	×10	±1%
Red		2	×100	±2%
Orange		3	×1 k	
Yellow		4	×10 k	
Green		5	×100 k	
Blue		6	×1 M	
Violet		7	×10 M	
Gray		8	—	
White		9	—	
Gold		—	×0.1	±5%
Silver		—	×0.01	±10%

R1 and R4, 270 Ω: red (2), violet (7), brown (×10), silver (±10%) = 270 Ω.

R2 and R3, 47K: yellow (4), violet (7), orange (×1 k) = 47,000 Ω, written 47K or 47 kΩ.

The fourth band on each is the tolerance band. Do not mix the two values up. They are the same size, so read the bands of every resistor before you install it.

Electrolytic capacitors C1 and C2

An electrolytic capacitor is a small can with two leads coming out of one end. It is marked with its value (22 µF) and a voltage rating. Electrolytics are **polarized**: they must be installed the right way round. A stripe down one side of the can, usually printed with minus signs (−), marks the **negative** lead. The **longer lead is positive (+)**. The circuit board has a + printed beside one hole of each capacitor outline.

LEDs D1 and D2

An LED has two leads of different lengths. The **longer lead is the anode (+)**. The **shorter lead is the cathode (−)**, and the rim of the LED body usually has a small **flat** on the cathode side. Your two LEDs are a matched pair: both red, both green, or both yellow.

Transistors Q1 and Q2

The transistors are in the **TO-92** package: a small black plastic body with one **flat face** carrying the printing, and three leads in a row. The part number is printed on the flat face. Read it now and write it here: _____. You will need it in the transistor step, because **different transistor types have their pins in a different order**.

Circuit Board Assembly

Look over the bare circuit board. It is shaped like a face. The two LEDs are the eyes, with R1 and R4 above them like eyebrows and R2 and R3 just below the nose. C1 and C2 sit at the corners of the mouth, and Q1 and Q2 are at the bottom. All parts mount on the top (printed) side and are soldered on the bottom. The battery snap's red and black wires solder straight into the two holes marked **+9V** and **GND** at the lower right.

NOTE: Install each part flat against the board (or at the height given in the step), solder all of its leads, then trim the leads. Mark the ( ) box as you go.

Resistors

( ) **R1: 270 Ω** (red-violet-brown, silver band), above the left eye. Bend each lead at a right angle close to the body to fit the holes, insert R1 at R1, and push it flat against the board. Resistors are not polarized, so either direction is fine.

( ) **R4: 270 Ω** (red-violet-brown, silver band), above the right eye. Install it the same way.

( ) **R2: 47K** (yellow-violet-orange), the left side of the nose.

( ) **R3: 47K** (yellow-violet-orange), the right side of the nose.

( ) Bend the leads slightly outward on the bottom so the parts cannot fall out. Solder all eight leads and trim them.

LEDs

CAUTION: THE LED OUTLINES PRINTED ON THE BOARD ARE WRONG. On the production boards, the printed flat on each LED outline sits on the OUTER side of the eye. That is wrong. Mount each LED with its flat (the cathode, the SHORT lead) facing INWARD, toward the centre of the face. The long lead (anode) goes in the outer hole. The anode connects to the +9V line, and the cathode connects through the 270 Ω resistor (R1 or R4) to the transistor.

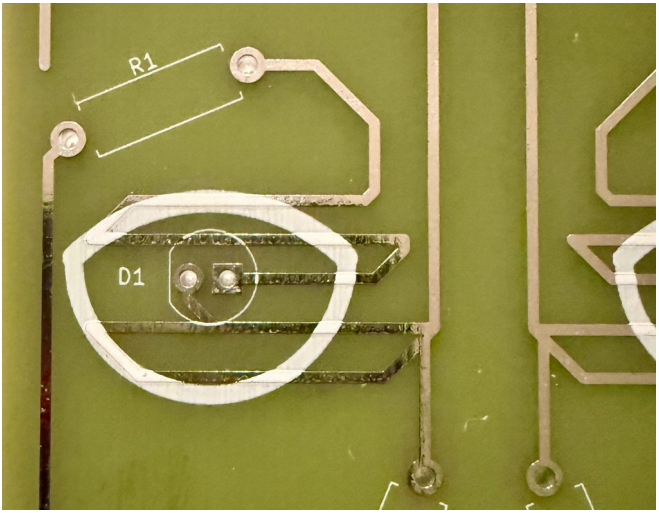


Figure 7. *D1 on a production board. The printed flat on the LED outline is on the outer side of the eye, by the round pad. That is wrong: the LED's flat (cathode, short lead) goes inward, toward the centre of the face.*

( ) **D1:** hold the LED so you can see its flat and which lead is longer. Turn it so the **flat (short lead, cathode) faces inward**, toward the centre of the face, and the long lead (anode) is on the outer side of the eye. Ignore the flat on the printed outline.

( ) Push D1 down close to the board. Solder one lead, check that the LED stands straight, then solder the second lead.

( ) **D2:** install it the same way, with its **flat (short lead) facing inward**, toward the centre of the face. The two LEDs are mirror images: their flats face each other across the nose.

( ) Trim the LED leads.

Don't trust the silkscreen: check with the schematic

Real engineers make mistakes, and real products ship with them. The printing (called the **silkscreen**) on this board has the LED outlines reversed. Instead of hiding that, let us use it, because finding a mistake like this is exactly what good technicians do. Here is how you can prove the correct direction for yourself, without trusting anybody's printing.

1. Read the schematic. In the schematic (Figure 11, in "How It Works"), each LED's triangle points **downward**, from the +9V line toward its 270 Ω resistor. The point of the triangle, with the bar across it, is the **cathode**.

So the anode goes to +9V and the cathode goes to the resistor. Current flows from +9V, in at the anode, out at the cathode, through the resistor, and down through the transistor to ground, just as in the PN-junction section of the course.

2. Trace the copper. Tilt the board under a good light. On the front of the board, follow the copper from the **round pad** on the outer side of each eye. It runs through the forehead and under-eye tracks, which join the round pads of both LEDs to the tops of R2 and R3. On the back of the board, **+9V** goes directly to that same copper. So the round pad is the **anode**, and the long lead goes there. Now follow the copper from the **square pad** on the inner side of the eye. It runs to the 270 Ω resistor (R1 or R4), so the square pad is the **cathode**, and the LED's flat belongs on the inner side, the opposite of the printed outline. Here is the exact error. On the production board, the printed flat, the mark that means cathode, is drawn beside the round pad. But the copper shows that the round pad is on +9V, so it is the anode. The printed mark says cathode, the copper says anode, and **the copper wins**. The copper is what the electrons actually follow.

3. Test the LED with a meter. Most digital multimeters have a **diode test** setting, marked with the diode symbol. Touch the **red** probe to the LED's long lead and the **black** probe to the short lead. On many meters the LED glows faintly and the meter shows its forward voltage. Reverse the probes and the meter reads **OL** (open): no current flows. This is the PN junction from the course at work: forward bias conducts, and reverse bias blocks. The lead touching the red probe when the LED lights is the anode.

A dedicated LED tester makes this even easier. A tester like our **Somerled Design LED Tester** lights an LED safely at a current you choose, so you can check both its polarity and its colour before you solder it.

Checking a part against the schematic and the copper, instead of trusting the label, is a habit that will save you over and over, in kits and in real work.

Capacitors

( ) **C1: 22 µF.** C1 is at the lower left, at the corner of the mouth. Find the **+** printed beside one of its two holes. Insert the **long (+) lead**

into that hole, so the stripe (−) faces the other hole. Push C1 down flat against the board.

( ) **C2: 22 µF.** C2 is at the lower right. Again, the **long (+) lead** goes into the hole marked **+**. The + is in a different place from C1's, so check the board, not the first capacitor.

( ) Solder all four leads and trim them.

Transistors

The board outlines for Q1 and Q2 were drawn for the **BC548**. Its pins, numbered 1-2-3 on the board, are **collector, base, emitter** (C-B-E) when you look at the flat face with the leads pointing down. The 2N3904 and PN2222 have their pins the other way round: **emitter, base, collector** (E-B-C). So which way the transistor goes depends on which type you have.

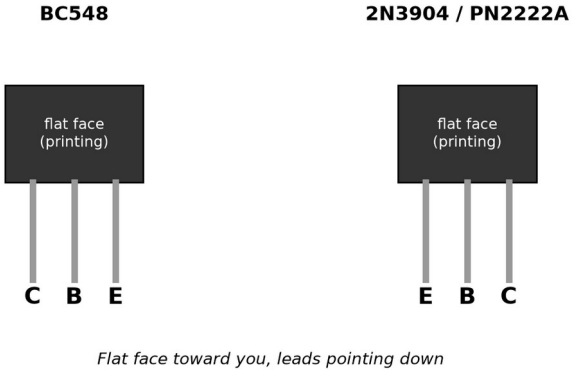


Figure 8. *TO-92 pinouts, from the BC548, 2N3904 and PN2222A data sheets.*

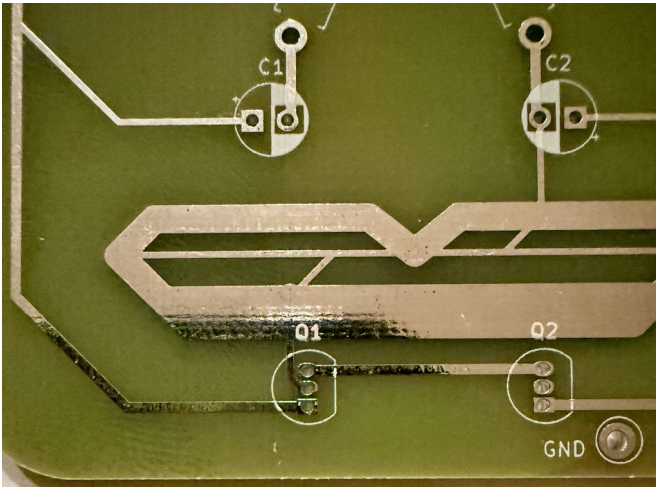


Figure 9. *Q1 and Q2 outlines on a production board, with C1, C2 and the GND hole. The outlines are drawn for the BC548.*

Transistor	Pins (flat face toward you, leads down)	How to mount
BC548	C - B - E	Flat face matches the flat of the printed outline
2N3904	E - B - C	Turned 180°: flat face opposite the flat of the printed outline
PN2222 (PN2222A)	E - B - C	Turned 180°: flat face opposite the flat of the printed outline

CAUTION: CHECK YOUR TRANSISTOR TYPE BEFORE YOU SOLDER. Read the part number on the flat face. A BC548 goes in with its flat face matching the printed outline. A 2N3904 or PN2222 must be turned 180°, with its flat face OPPOSITE the flat of the printed outline. Installed the wrong way, the collector and emitter are swapped and Blinky will not blink properly. If you have a different type, look up its data sheet and match its collector, base and emitter to the BC548 order above.

This is the second lesson from this little kit: **the same schematic symbol does not mean the same pins.** Every NPN transistor uses the same symbol in a schematic, but the manufacturers of different parts put the leads in different orders. Professional technicians check the **data sheet pinout** for every part, every time. The same goes for other packages: never assume.

( ) **Q1:** read the part number and find your type in the table above. Hold Q1 over the Q1 outline in the correct direction for your type and insert the three leads into the three holes. Do not force the part flat. Leave about 1/8 to 1/4 in (3–6 mm) of lead between the body and the board.

( ) Double-check the direction against the table, then solder the three leads. Work quickly: about two seconds per lead. Check that no solder bridges the closely spaced pads.

( ) **Q2:** install it the same way, in the same direction relative to its outline as Q1. Q1 and Q2 must be the same type.

( ) Trim the transistor leads.

Battery snap

( ) **9 V battery snap:** push the **red** wire through the hole marked **+9V** from the top of the board, and the **black** wire through the hole marked **GND**. No pins are needed: the wires solder straight into the holes.

( ) Solder both leads on the bottom and trim the excess wire.

( ) For strain relief you may put a small dab of hot-melt glue over the two wires on the top of the board (optional).

Final Inspection

Before you connect a battery, go over the board carefully with a magnifier and good light. Most problems are caught here.

- ( ) Every lead is soldered. Count them: R1–R4 (8), D1–D2 (4), C1–C2 (4), Q1–Q2 (6), battery snap (2): 24 joints.
- ( ) No solder bridges, especially between the three closely spaced pads of each transistor.
- ( ) The 270 Ω resistors (red-violet-brown, silver band) are at R1 and R4. The 47K resistors (yellow-violet-orange) are at R2 and R3.
- ( ) Each LED has its **flat (short lead) facing inward**, toward the centre of the face, not toward the printed flat.
- ( ) Each capacitor has its **long (+) lead in the hole marked +**.
- ( ) Both transistors are the same type and face the correct way for that type (see the table in the transistor step).
- ( ) Battery snap: red lead at +9V, black lead at GND.
- ( ) No clipped leads or solder splashes are stuck to the board. Brush the board off.

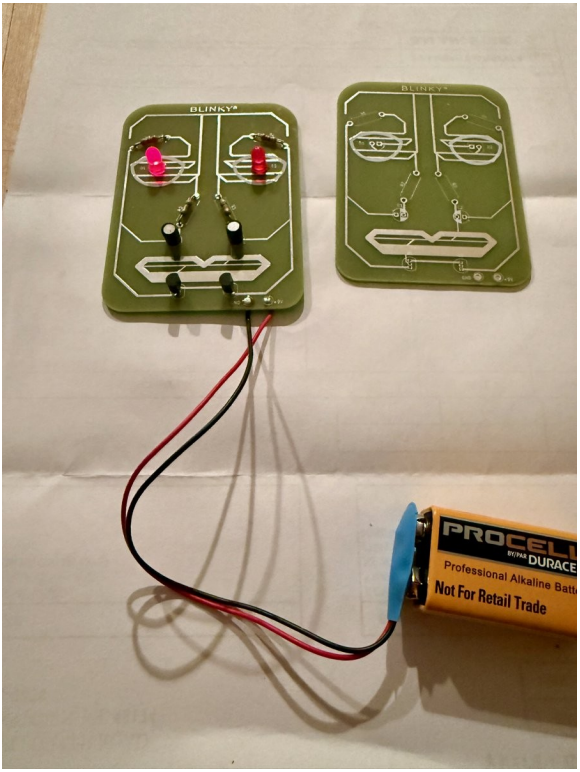


Figure 10. *The finished Blinky.*

Using Blinky

( ) Snap a 9 V battery onto the battery snap. The eyes should start blinking at once, one after the other, each staying lit for a little under a second.

( ) To turn Blinky off, unsnap the battery. Blinky always has one eye lit, so it is always drawing current from the battery.

Troubleshooting

Most problems are caused by solder joints or by parts installed the wrong way round. Recheck the Final Inspection list first.

Symptom	Check
Neither LED lights	Battery good and snap firmly on. Red lead at +9V, black at GND. All joints soldered. Both LEDs with their flat (short lead) facing inward.
One LED never lights, the other blinks or stays on	That LED is probably reversed (remember the reversed silkscreen). Test it with your meter's diode setting. Check its 270 Ω resistor and joints.
One LED stays on and the other stays off	Check C1 and C2: correct polarity and good joints. Check that R2 and R3 are 47K, not 270 Ω. Check the transistor direction for your type.
Both LEDs dim or on together, no blinking	A transistor may be turned the wrong way for its type (2N3904 and PN2222 must be turned 180° from a BC548). Look for solder bridges between transistor pads.
Blinks much too fast or too slow	Check that C1 and C2 are 22 µF and R2 and R3 are 47K (yellow-violet-orange).
LEDs dim	The battery may be low. Check that R1 and R4 are 270 Ω (red-violet-brown), not 2.7K (red-violet-red).

Still stuck? Email **support@somerled.design**. Include your kit version (v1.1 rev A), what you see, and, if you can, clear photos of both sides of the board. The support page, **shop.somerled.design/support/**, has updates.

How It Works

Look at the schematic (Figure 11). The circuit is perfectly symmetrical: the left half (Q1, D1, R1, C1, R2) is a mirror of the right half (Q2, D2, R4, C2, R3). The trick is the **cross-coupling**: each transistor's collector is connected through a capacitor to the **other** transistor's base. C1 connects Q1's collector to Q2's base, and C2 connects Q2's collector to Q1's base.

One cycle, step by step

1. Q1 turns on. Suppose Q1 has just switched on. Current flows from +9V through D1, R1 and Q1 to ground, so **the left eye (D1) lights**. Q1's collector drops quickly from near +9 V to near 0 V.

2. C1 kicks Q2 off. A capacitor's voltage cannot change instantly. When the left side of C1 (Q1's collector) suddenly drops by several volts, the right side of C1 (Q2's base) drops by the same amount, from about +0.7 V to well **below** zero. A base below zero means Q2 is firmly **off**, so **the right eye (D2) is dark**.

3. R2 charges C1. Now 47K resistor R2 slowly charges C1, pulling Q2's base back up from below zero toward +9 V. This takes time. That time is the blink.

4. Q2 turns on. When Q2's base climbs back to about +0.6 V, Q2 starts to conduct. **The right eye lights**, and Q2's collector drops. Through C2, that drop yanks Q1's base below zero, so Q1 snaps **off** and **the left eye goes dark**.

5. And back again. Now R3 charges C2 until Q1's base gets back to about +0.6 V. Q1 turns on, C1 kicks Q2 off, and the whole cycle repeats for as long as the battery lasts.

Each switch-over happens very fast, because each transistor turning on pushes the other one off harder. Engineers call that **positive feedback**. It is why the eyes snap cleanly from one to the other instead of fading.

How fast does it blink?

How long each eye stays lit depends on how long a resistor takes to charge a capacitor. The product of resistance and capacitance, **R × C**, is called the **time constant**. In this circuit, the time for each half of the cycle is approximately

$$t \approx 0.693 \times R \times C$$

Where does 0.693 come from? In the textbook version of this circuit, the base starts about one supply voltage below zero and charges toward one supply voltage above zero. The transistor turns on when the base gets back to about zero, which is **halfway**. The time to charge halfway is 0.693 time constants. (The number 0.693 is the natural logarithm of 2.)

For Blinky, R = R2 or R3 = 47K = 47,000 Ω, and C = C1 or C2 = 22 µF = 0.000022 F:

$$t \approx 0.693 \times 47{,}000\ \Omega \times 0.000022\ \text{F} \approx 0.72\ \text{s}$$

So each eye stays lit for about **0.72 second**. A full cycle, left and right, takes about 2 × 0.72 ≈ **1.43 seconds**. That is about 0.7 cycles per second, or about **42 blinks of each eye per minute**.

On a real Blinky the eyes blink roughly once a second, give or take, because electrolytic capacitors and transistors vary from part to part. Your Blinky may run a little faster or slower than the math says, and that is normal.

Expect your Blinky to differ a little from the formula. Electrolytic capacitors have wide tolerances, and in this circuit the LED sits in each collector path, so the voltage swing is less than the full 9 V. The formula is a good estimate, not a promise.

How much current do the LEDs get?

Each LED's current is set by its 270 Ω resistor. The 9 V from the battery is shared between the LED, the resistor and the transistor, which drops only a few tenths of a volt when it is fully on. The LED takes its own **forward voltage**, which depends on its colour. The resistor gets what is left over:

$$I \approx (9\ \text{V} - \text{LED forward voltage} - \text{transistor voltage}) \div 270\ \Omega$$

Even if the LED and transistor took no voltage at all, the current could never be more than 9 V ÷ 270 Ω ≈ 33 mA. With a real LED of any of the kit colours (red, green or yellow) it is less than that. You can measure it yourself in the experiments.

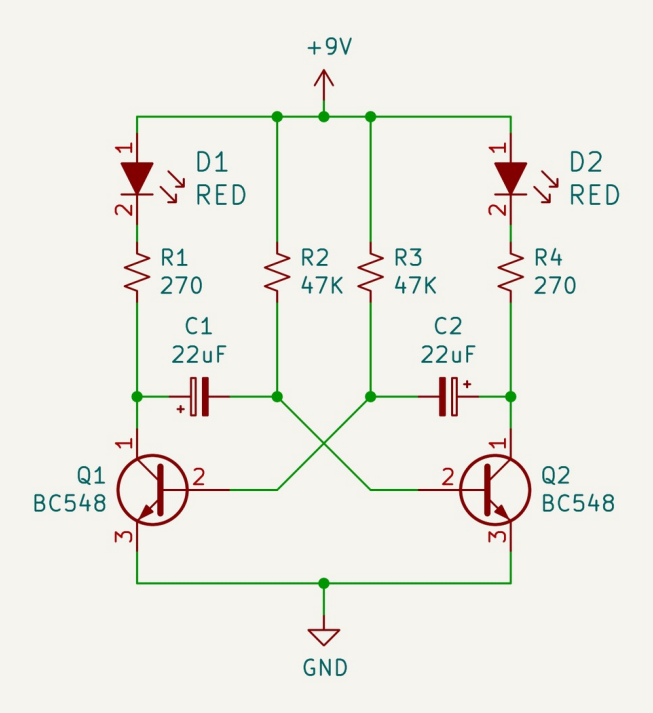


Figure 11. *Blinky v1.1 schematic (from Blinky.kicad_sch). Rev A and rev B boards use the same circuit and parts. Q1 and Q2 are drawn as BC548. Any small-signal NPN of the types listed may be used.*

Experiments

Suggested: Once Blinky is working, try these experiments. None of them needs any desoldering. You will need your multimeter, a pair of clip leads, and a few extra electrolytic capacitors. Disconnect the battery whenever you connect or remove a part.

1. Slow it down

Suggested: Capacitors connected **in parallel** add up. Clip a second 22 µF capacitor across C1, with its **+ lead on the + side of C1**, and another across C2, the same way. Each side now has 44 µF. Predict the new rate before you reconnect the battery:

t ≈ 0.693 × 47,000 Ω × 0.000044 F ≈ 1.43 s per eye

Did Blinky slow to about half speed? Try other values. With 47 µF added (69 µF total) the formula gives about 2.2 s per eye.

2. A lopsided wink

Suggested: Add the extra capacitor across **C1 only**. C1 sets how long Q2 is held off, which is how long the **left** eye (D1) stays lit. Predict which eye will now stay on longer, then try it. Now you can make Blinky wink.

3. Watch the voltages

Suggested: Set your meter to DC volts. Put the black probe on the GND pad and touch the red probe to the collector lead of Q1 (check your transistor's pinout). Watch the reading jump between a high voltage and a few tenths of a volt as the eyes change. Then try a base lead. On many meters you will see the base dip **below zero** for a moment after the other transistor turns on. That is C1 or C2 kicking it off, just as described in "How It Works."

4. Measure the LED current

Suggested: With the meter on DC volts, measure the voltage across R1 (one probe on each end) while D1 is lit. Then use **Ohm's law** to find the current: I = V ÷ R. For example, if you read 6.6 V, the current is 6.6 V ÷ 270 Ω ≈ 0.0244 A, or about 24 mA. That reading is only an example: measure yours. Then measure the voltage across D1 itself. That is the LED's forward voltage. If you have kits with different LED colours, compare them.

5. Check the math

Suggested: Use a stopwatch (or a phone) to time 10 complete cycles, then divide by 10. Compare your answer with the 1.43-second prediction. Why might they differ? (Hint: look at the tolerance of electrolytic capacitors and at the note about the LEDs in “How It Works.”)

Specifications

Item	Value
Circuit	Two-transistor astable multivibrator
Transistors	Q1, Q2: small-signal NPN (BC548, 2N3904, PN2222 or similar; matched pair)
Blink rate	About 0.72 s per eye, 1.43 s per full cycle (0.693 × 47 kΩ × 22 µF per half)
Timing parts	R2, R3: 47K. C1, C2: 22 µF electrolytic
LEDs	D1, D2: 5 mm, matched colour (red, green, or yellow), each with a 270 Ω series resistor (R1, R4)
LED current	Less than 9 V ÷ 270 Ω ≈ 33 mA; set by the LED forward voltage
Power	One 9 V battery (not included), via snap. No power switch: unsnap the battery to turn off
Board size	2.500 × 3.400 in (63.50 × 86.36 mm)
Board version	v1.1 rev A (Gerber files dated 2021-11-02)

Credits

Blinky is based on the “Pinger Detector” that Kevin Murphy built in Allee Hall, during Basic Electronics Tech School at Keesler Air Force Base way back in 1983.

Kit design, circuit board and manual: Somerled Design, LLC (Kevin Murphy).

Hardware design © 2021 Somerled Design, LLC and Kevin Murphy, licensed under the CERN Open Hardware Licence v1.2 (as stated on the schematic).

Transistor pinouts and gains from the Fairchild BC546–BC550, STMicroelectronics 2N3904 and Fairchild PN2222A data sheets.

Support

Email: **support@somerled.design**

Support page, with updates: **shop.somerled.design/support/**

Illustrations: photographs of a finished Blinky and a rev A production board. Schematic exported from Blinky.kicad_sch. Silicon lattice, NPN/PNP, tube/transistor/MOSFET and TO-92 pinout drawings: new for this manual. Good/faulty joint drawing: original, Somerled Design. Ideal joint diagram: “Solder Joint en.svg”, SLUB Dresden / Carsten Pietzsch

after Bill Earl (Adafruit), CC BY-SA 4.0, commons.wikimedia.org/wiki/File:Solder_Joint_en.svg (converted to PNG).

Manual revision: November 2026, for board v1.1 rev A.