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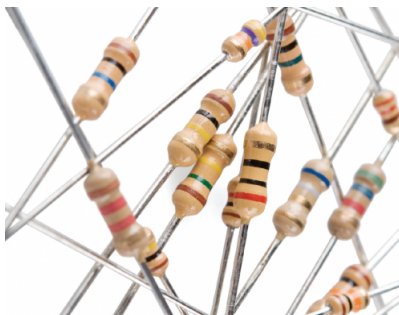SHOP   LEARN   BLOG   SUPPORT

Resistors

CONTRIBUTORS: *JIMB0*

♡ **FAVORITE**   25

Take a Stance, The Resist Stance

Resistors - the most ubiquitous of electronic components. They are a critical piece in just about every circuit. And they play a major role in our favorite equation, Ohm's Law.

In this, our pièce de *résistance*, we'll cover:

- What is a resistor?!
- Resistor units
- Resistor circuit symbol(s)
- Resistors in series and parallel
- Different variations of resistors
- Color coding decoding
- Surface mount resistor decoding
- Example resistor applications

Consider reading…

Some of the concepts in this tutorial build on previous electronics knowledge. Before jumping into this tutorial, consider reading (at least skimming) these first:

- What is Electricity?
- Voltage, Current, Resistance, and Ohm's Law
- What is a Circuit
- Series vs. Parallel Circuits
- How to Use A Multimeter - Specifically check out the measuring resistance section.
- Metric Prefixes

Resistor Basics

Resistors are electronic components which have a specific, never-changing electrical resistance. The resistor's resistance **limits the flow of electrons** through a circuit.

They are **passive** components, meaning they only consume power (and can't generate it). Resistors are usually added to circuits where they complement **active** components like op-amps, microcontrollers, and other integrated circuits. Commonly resistors are used to limit current, divide voltages, and pull-up I/O lines.

Resistor units

The electrical resistance of a resistor is measured in **ohms**. The symbol for an ohm is the greek capital-omega: Ω. The (somewhat roundabout) definition of 1Ω is the resistance between two points where 1 volt (1V) of applied potential energy will push 1 ampere (1A) of current.

As SI units go, larger or smaller values of ohms can be matched with a prefix like kilo-, mega-, or giga-, to make large values easier to read. It's very common to see resistors in the kilohm (kΩ) and megaohm (MΩ) range (much less common to see miliohm (mΩ) resistors). For example, a 4,700Ω resistor is equivalent to a 4.7kΩ resistor, and a 5,600,000Ω resistor can be written as 5,600kΩ or (more commonly as) 5.6MΩ.

Schematic symbol

All resistors have **two terminals**, one connection on each end of the resistor. When modeled on a schematic, a resistor will show up as one of these two symbols:
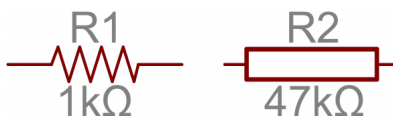
Two common resistor schematic symbols. R1 is an American-style 1kΩ resistor, and R2 is an international-style 47kΩ resistor.

The terminals of the resistor are each of the lines extending from the squiggle (or rectangle). Those are what connect to the rest of the circuit.

The resistor circuit symbols are usually enhanced with both a resistance value and a name. The value, displayed in ohms, is obviously critical for both evaluating and actually constructing the circuit. The name of the resistor is usually an *R* preceding a number. Each resistor in a circuit should have a unique name/number. For example, here's a few resistors in action on a 555 timer circuit:
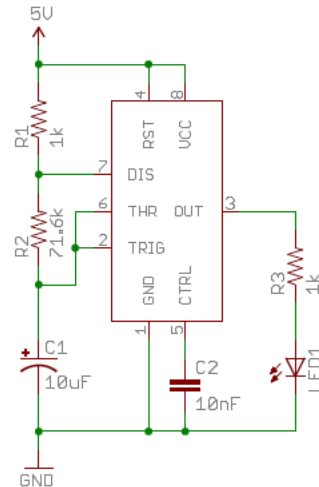
In this circuit, resistors play a key role in setting the frequency of the 555 timer's output. Another resistor (R3) limits the current through an LED.

Types of Resistors

Resistors come in a variety of shapes and sizes. They might be through-hole or surface-mount. They might be a standard, static resistor, a pack of resistors, or a special variable resistor.

Termination and mounting

Resistors will come in one of two termination-types: through-hole or surface-mount. These types of resistors are usually abbreviated as either PTH (plated through-hole) or SMD/SMT (surface-mount technology or device).

Through-hole resistors come with long, pliable leads which can be stuck into a breadboard or hand-soldered into a prototyping board or printed circuit board (PCB). These resistors are usually more useful in breadboarding, prototyping, or in any case where you'd rather not solder tiny, little 0.6mm-long SMD resistors. The long leads usually require trimming, and these resistors are bound to take up much more space than their surface-mount counterparts.

The most common through-hole resistors come in an axial package. The size of an axial resistor is relative to its power rating. A common ½W resistor measures about 9.2mm across, while a smaller ¼W resistor is about 6.3mm long.

A half-watt (½W) resistor (above) sized up to a quarter-watt (¼W).

Surface-mount resistors are usually tiny black rectangles, terminated on either side with even smaller, shiny, silver, conductive edges. These resistors are intended to sit on top of PCBs, where they're soldered onto mating landing pads. Because these resistors are so small, they're usually set into place by a robot, and sent through an oven where solder melts and holds them in place.
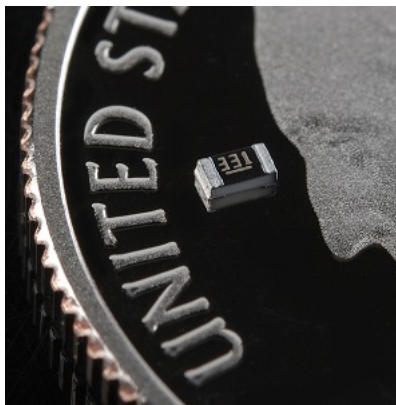

A tiny 0603 330Ω resistor hovering over shiny George Washington's nose on top of a U.S. quarter.

SMD resistors come in standardized sizes; usually either 0805 (0.8mm long by 0.5mm wide), 0603, or 0402. They're great for mass circuit-board-production, or in designs where space is a precious commodity. They take a steady, precise hand to manually solder, though!

Resistor composition

Resistors can be constructed out of a variety of materials. Most common, modern resistors are made out of either a **carbon, metal, or metal-oxide film**. In these resistors, a thin film of conductive (though still resistive) material is wrapped in a helix around and covered by an insulating material. Most of the standard, no-frills, through-hole resistors will come in a carbon-film or metal-film composition.
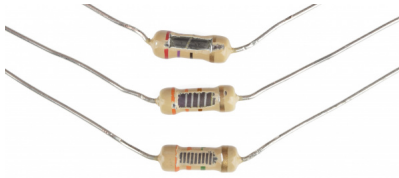
Peek inside the guts of a few carbon-film resistors. Resistance values from top to bottom: 27Ω, 330Ω and a 3.3MΩ. Inside the resistor, a carbon film is wrapped around an insulator. More wraps means a higher resistance. Pretty neat!

Other through-hole resistors might be wirewound or made of super-thin metallic foil. These resistors are usually more expensive, higher-end components specifically chosen for their unique characteristics like a higher power-rating, or maximum temperature range.

Surface-mount resistors are usually either **thick or thin-film** variety. Thick-film is usually cheaper but less precise than thin. In both resistor types, a small film of resistive metal alloy is sandwiched between a ceramic base and glass/epoxy coating, and then connected to the terminating conductive edges.

Special resistor packages

There are a variety of other, special-purpose resistors out there. Resistors may come in pre-wired packs of five-or-so resistor arrays. Resistors in these arrays may share a common pin, or be set up as voltage dividers.
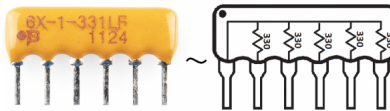
An array of five 330Ω resistors, all tied together at one end.

Resistors don't have to be static either. Variable resistors, known as **rheostats**, are resistors which can be adjusted between a specific range of values. Similar to the rheostat is the **potentiometer**. Pots connect two resistors internally, in series, and adjust a center tap between them creating an adjustable voltage divider. These variable resistors are often used for inputs, like volume knobs, which need to be adjustable.


A smattering of potentiometers. From top-left, clockwise: a standard 10k trimpot, 2-axis joystick, softpot, slide pot, classic right-angle, and a breadboard friendly 10k trimpot.

Decoding Resistor Markings

Though they may not display their value outright, most resistors are marked to show what their resistance is. PTH resistors use a color-coding system (which really adds some flair to circuits), and SMD resistors have their own value-marking system.

Decoding the color bands

Through-hole, axial resistors usually use the color-band system to display their value. Most of these resistors will have four bands of color circling the resistor.
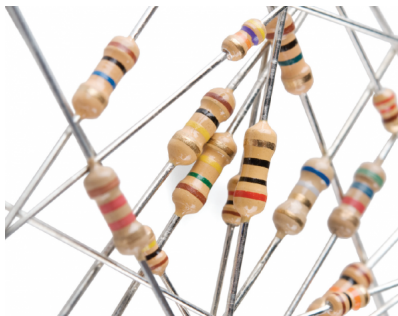
The first two bands indicate the **two most-significant digits** of the resistor's value. The third band is a weight value, which **multiplies** the two significant digits by a power of ten.

The final band indicates the **tolerance** of the resistor. The tolerance explains how much more or less the *actual* resistance of the resistor can be compared to what its nominal value is. No resistor is made to perfection, and different manufacturing processes will result in better or worse tolerances. For example, a 1kΩ resistor with 5% tolerance could actually be anywhere between 0.95kΩ and 1.05kΩ.

How do you tell which band is first and last? The last, tolerance band is often clearly separated from the value bands, and usually it'll either be silver or gold.

Here's a table of each of the colors and which value, multiplier or tolerance they represent:

Color	Digit value	Multiplier	Multiplied Out	Tolerance
Black	0	10^0	1	
Brown	1	10^1	10	
Red	2	10^2	100	
Orange	3	10^3	1,000	
Yellow	4	10^4	10000	
Green	5	10^5	100,000	
Blue	6	10^6	1,000,000	
Violet	7	10^7	10,000,000	
Gray	8	10^8	100,000,000	
White	9	10^9	1,000,000,000	
Gold				±5%
Silver				±10%

Here's an example of a 4.7kΩ resistor with four color bands:

When decoding the resistor color bands, consult a resistor color code table like the one above. For the first two bands, find that color's corresponding digit value. The 4.7kΩ resistor has color bands of yellow and violet to begin - which have digit values of 4 and 7 (47). The third band of the 4.7kΩ is red, which indicates that the 47 should be multiplied by 10^2 (or 100). 47 times 100 is 4,700!

If you're trying to commit the color band code to memory, a mnemonic device might help. There are a handful of (sometimes unsavory) mnemonics out there, to help remember the resistor color code. A good one, which spells out the difference between *b*lack and *b*rown is:

"**B**ig **b**rown **r**abbits **o**ften **y**ield **g**reat **b**ig **v**ocal **g**roans **w**hen **g**ingerly **s**napped."

Or, if you remember "ROY G. BIV", subtract the *indigo* (poor indigo, no one remembers indigo), and add black and brown to the front and gray and white to the back of the classic rainbow color-order.

Color Code Calculator

If you'd rather skip the math (we won't judge :), and just use a handy calculator, give this a try!

Band 1	Band 2	Band 3	Band 4
Value 1 (MSV)	Value 2	Weight	Tolerance
Brown (1) ▼	Black (0) ▼	Red (100) ▼	Gold (± 5%) ▼

Resistance: 1,000 Ω ±5%

Decoding surface-mount markings

SMD resistors, like those in 0603 or 0805 packages, have their own way of displaying their value. There are a few common marking methods you'll see on these resistors. They'll usually have three to four characters – numbers or letters – printed on top of the case.

If the three characters you're seeing are *all numbers*, you're probably looking at an **E24** marked resistor. These markings actually share some similarity with the color-band system used on the PTH resistors. The first two numbers represent the first two most-significant digits of the value, the last number represents a magnitude.

In the above example picture, resistors are marked *104*, *105*, *205*, *751*, and *754*. The resistor marked with *104* should be 100kΩ (10x10^4), *105* would be 1MΩ (10x10^5), and *205* is 2MΩ (20x10^5). *751* is 750Ω (75x10^1), and *754* is 750kΩ (75x10^4).

Another common coding system is **E96**, and it's the most cryptic of the bunch. E96 resistors will be marked with three characters – two numbers at the beginning and a letter at the end. The two numbers tell you the first *three* digits of the value, by corresponding to one of the not-so-obvious values on this lookup table.

Code	Value	Code	Value	Code	Value	Code	Value	Code	Value	Code	Value
01	100	17	147	33	215	49	316	65	464	81	681
02	102	18	150	34	221	50	324	66	475	82	698
03	105	19	154	35	226	51	332	67	487	83	715
04	107	20	158	36	232	52	340	68	499	84	732
05	110	21	162	37	237	53	348	69	511	85	750
06	113	22	165	38	243	54	357	70	523	86	768
07	115	23	169	39	249	55	365	71	536	87	787
08	118	24	174	40	255	56	374	72	549	88	806
09	121	25	178	41	261	57	383	73	562	89	825
10	124	26	182	42	267	58	392	74	576	90	845
11	127	27	187	43	274	59	402	75	590	91	866
12	130	28	191	44	280	60	412	76	604	92	887
13	133	29	196	45	287	61	422	77	619	93	909
14	137	30	200	46	294	62	432	78	634	94	931
15	140	31	205	47	301	63	442	79	649	95	953

16   143   32   210   48   309   64   453   80   665   96   976

The letter at the end represents a multiplier, matching up to something on this table:

Letter	Multiplier	Letter	Multiplier	Letter	Multiplier
Z	0.001	A	1	D	1000
Y or R	0.01	B or H	10	E	10000
X or S	0.1	C	100	F	100000

So a *01C* resistor is our good friend, 10kΩ (100x100), *01B* is 1kΩ (100x10), and *01D* is 100kΩ. Those are easy, other codes may not be. *85A* from the picture above is 750Ω (750x1) and *30C* is actually 20kΩ.

Power Rating

The power rating of a resistor is one of the more hidden values. Nevertheless it can be important, and it's a topic that'll come up when selecting a resistor type.

Power is the rate at which energy is transformed into something else. It's calculated by multiplying the voltage difference across two points by the current running between them, and is measured in units of a watt (W). Light bulbs, for example, power electricity into light. But a resistor can only turn electrical energy running through it into **heat**. Heat isn't usually a nice playmate with electronics; too much heat leads to smoke, sparks, and fire!

Every resistor has a specific maximum power rating. In order to keep the resistor from heating up too much, it's important to make sure the power across a resistor is kept under it's maximum rating. The power rating of a resistor is measured in watts, and it's usually somewhere between ⅛W (0.125W) and 1W. Resistors with power ratings of more than 1W are usually referred to as power resistors, and are used specifically for their power dissipating abilities.

Finding a resistor's power rating

A resistor's power rating can usually be deduced by observing its package size. Standard through-hole resistors usually come with ¼W or ½W ratings. More special purpose, power resistors might actually list their power rating on the resistor.

These power resistors can handle a lot more power before they blow. From top-right to bottom-left there are examples of 25W, 5W and 3W resistors, with values of 2Ω, 3Ω 0.1Ω and 22kΩ. Smaller power-resistors are often used to sense current.

The power ratings of surface mount resistors can usually be judged by their size as well. Both 0402 and 0603-size resistors are usually rated for 1/16W, and 0805's can take 1/10W.

Measuring power across a resistor

Power is usually calculated by multiplying voltage and current (P = IV). But, by applying Ohm's law, we can also use the resistance value in calculating power. If we know the current running through a resistor, we can calculate the power as:

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

Or, if we know the voltage across a resistor, the power can be calculated as:

$$P = \frac{V^2}{R}$$

Series and Parallel Resistors

Resistors are paired together all the time in electronics, usually in either a series or parallel circuit. When resistors are combined in series or parallel, they create a **total resistance**, which can be calculated using one of two equations. Knowing how resistor values combine comes in handy if you need to create a specific resistor value.

Series resistors

When connected in series resistor values simply add up.

$$R_{tot} = R_1 + R_2 + ... + R_{N-1} + R_N$$

N resistors in series. The total resistance is the sum of all series resistors.

So, for example, if you just *have to have* a 12.33kΩ resistor, seek out some of the more common resistor values of 12kΩ and 330Ω, and butt them up together in series.

Parallel resistors

Finding the resistance of resistors in parallel isn't quite so easy. The total resistance of *N* resistors in parallel is the inverse of the sum of all inverse resistances. This equation might make more sense than that last sentence:

$$\frac{1}{R_{tot}} = \frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_{N-1}} + \frac{1}{R_N}$$
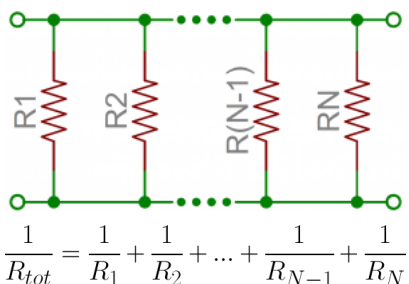
N resistors in parallel. To find the total resistance, invert each resistance value, add them up, and then invert that.

(The inverse of resistance is actually called **conductance**, so put more succinctly: the *conductance* of parallel resistors is the sum of each of their conductances).

As a special case of this equation: if you have **just two** resistors in parallel, their total resistance can be calculated with this slightly-less-inverted equation:

$$R_{tot} = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

As an even *more special* case of that equation, if you have two parallel resistors of **equal value** the total resistance is half of their value. For example, if two 10kΩ resistors are in parallel, their total resistance is 5kΩ.

A shorthand way of saying two resistors are in parallel is by using the parallel operator: **||**. For example, if R_1 is in parallel with R_2, the conceptual equation could be written as $R_1||R_2$. Much cleaner, and hides all those nasty fractions!

Resistor networks

As a special introduction to calculating total resistances, electronics teachers just *love* to subject their students to finding that of crazy, convoluted resistor networks.

A tame resistor network question might be something like: "what's the resistance from terminals *A* to *B* in this circuit?"
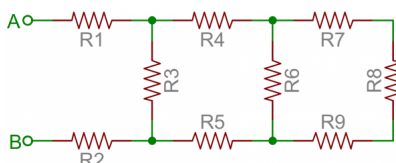
To solve such a problem, start at the back-end of the circuit and simplify towards the two terminals. In this case R_7, R_8 and R_9 are all in series and can be added together. Those three resistors are in parallel with R_6, so those four resistors could be turned into one with a resistance of $R_6||(R_7+R_8+R_9)$. Making our circuit:
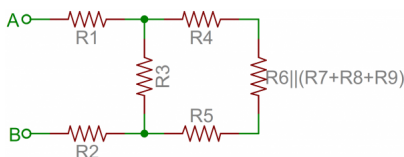
Now the four right-most resistors can be simplified even further. R_4, R_5 and our conglomeration of R_6 - R_9 are all in series and can be added. Then those series resistors are all in parallel with R_3.
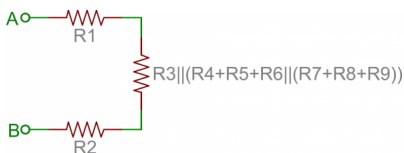
And that's just three series resistors between the *A* and *B* terminals. Add 'em on up! So the total resistance of that circuit is: $R_1+R_2+R_3||(R_4+R_5+R_6||(R_7+R_8+R_9))$.

Example Applications

Resistors exist in just about every electronic circuit ever. Here are a few examples of circuits, which heavily depend on our resistor friends.

LED Current Limiting

Resistors are key in making sure LEDs don't blow up when power is applied. By connecting a resistor **in series** with an LED, current flowing through the two components can be limited to a safe value.
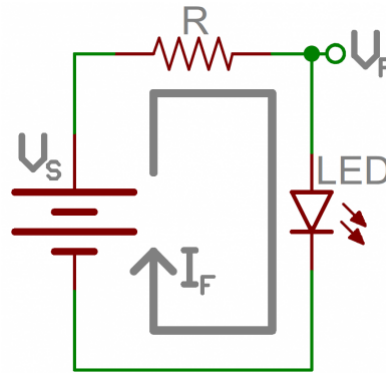
When sizing out a current-limiting resistor, look for two characteristic values of the LED: the **typical forward voltage**, and the **maximum forward current**. The typical forward voltage is the voltage which is required to make an LED light up, and it varies (usually somewhere between 1.7V and 3.4V) depending upon the color of the LED. The maximum forward current is usually around 20mA for basic LEDs; continuous current through the LED should always be equal to or less than that current rating.

Once you've gotten ahold of those two values, you can size up a current-limiting resistor with this equation:

$$R = \frac{V_S - V_F}{I_F}$$

V_S is the source voltage – usually a battery or power supply voltage. V_F and I_F are the LED's forward voltage and the desired current that runs through it.

For example, assume you have a 9V battery to power an LED. If your LED is red, it might have a forward voltage around 1.8V. If you want to limit the current to 10mA, use a series resistor of about 720Ω.

$$R = \frac{V_S - V_F}{I_F} = \frac{9 - 1.8}{0.010} = 720\Omega$$

Voltage Dividers

A voltage divider is a resistor circuit which turns a large voltage into a smaller one. Using just two resistors in series, an output voltage can be created that's a fraction of the input voltage.

Here's the voltage divider circuit:
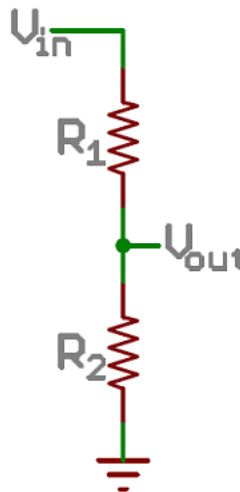
Two resistors, R_1 and R_2, are connected in series and a voltage source (V_{in}) is connected across them. The voltage from V_{out} to GND can be calculated as:

$$V_{out} = V_{in} \cdot \frac{R_2}{R_1 + R_2}$$

For example, if R_1 was 1.7kΩ and R_2 was 3.3kΩ, a 5V input voltage could be turned into 3.3V at the V_{out} terminal.

Voltage dividers are very handy for reading resistive sensors, like photocells, flex sensors, and force-sensitive resistors. One half of the voltage divider is the sensor, and the part is a static resistor. The output voltage between the two components is connected to an analog-to-digital converter on a microcontroller (MCU) to read the sensor's value.
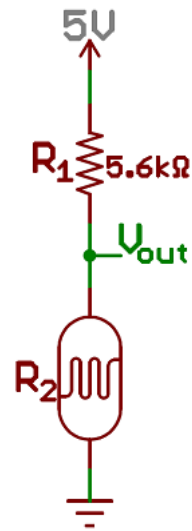
Here a resistor R_1 and a photocell create a voltage divider to create a variable voltage output.

Pull-up Resistors

A pull-up resistor is used when you need to bias a microcontroller's input pin to a known state. One end of the resistor is connected to the MCU's pin, and the other end is connected to a high voltage (usually 5V or 3.3V).

Without a pull-up resistor, inputs on the MCU could be left *floating*. There's no guarantee that a floating pin is either high (5V) or low (0V).

Pull-up resistors are often used when interfacing with a button or switch input. The pull-up resistor can bias the input-pin when the switch is open. And it will protect the circuit from a short when the switch is closed.
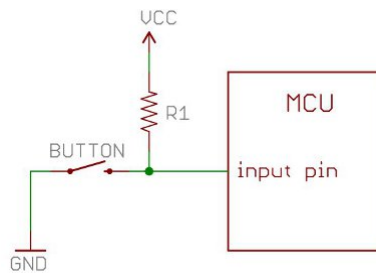
In the circuit above, when the switch is open the MCU's input pin is connected through the resistor to 5V. When the switch closes, the input pin is connected directly to GND.

The value of a pull-up resistor doesn't usually need to be anything specific. But it should be high enough that not too much power is lost if 5V or so is applied across it. Usually values around 10kΩ work well.

Purchasing Resistors

Don't limit your flow of resistors. We've got kits, packs, and single pieces that you just can't *resist*.
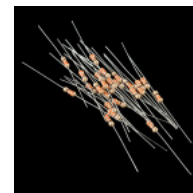
Our recommendations:
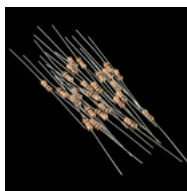

Resistor Kit - 1/4W (500 total)
◉ COM-10969
$7.95
★ ★ ★ ★ ½ 133

Resistor 330 Ohm 1/6 Watt PTH - 20 pack
◉ COM-11507
$0.95
★ ★ ★ ★ ½ 2

Resistor 10K Ohm 1/6th Watt PTH - 20 pack   Power Resistor Kit - 10W (25 pack)

◉ COM-11508   ◉ KIT-13053

$0.95   **$5.95**

★ ★ ★ ★ ⯪ 2

Resources and Going Further

Now that you're a budding expert on all things resistor, how 'bout exploring some more fundamental electronics concepts! Resistors certainly aren't the only basic component we use in electronics, there's also:

- Capacitors
- Diodes
- Transistors
- Integrated Circuits (ICs)

Or maybe you'd like to further explore resistor applications?

- Voltage Dividers
- Pull-up Resistors