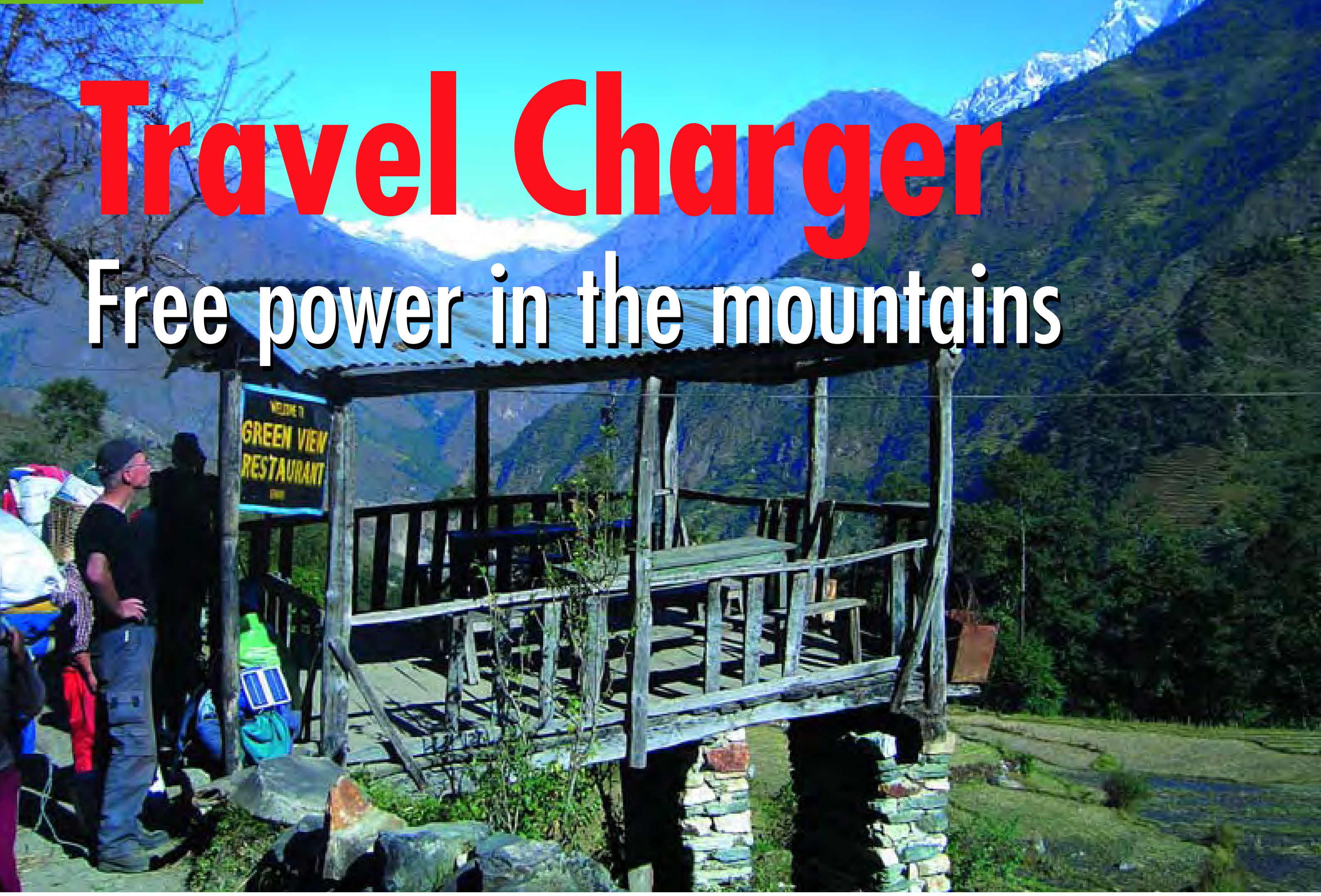
# Travel Charger

## Free power in the mountains

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**Recharging batteries for devices such as digital cameras can be a problem when you're on holiday in a remote or inhospitable region. You won't find an electrical outlet anywhere. Naturally, you can count on an *Elektor Electronics* designer to whip up a solution using a solar panel and a DIY Li-ion battery charger.**

I was due a bit of a holiday, so I suggested to management that I'd step out for half a year. Their response was less than enthusiastic, and my own enthusiasm was soon dampened when I had a good look at what it would cost. The outcome was thus four weeks of trekking through the Annapurna region in Nepal.

To meet my electrical energy needs, I took along a solar panel and a simple Li-ion charger built from discrete components. I didn't have a lot of time, and in the spirit of the motto 'better a good copy than a bad design', I cribbed the accompanying circuit from a well-known Chinese company.

As you doubtless know, charging lithium cells is actually quite easy. You generate a well-regulated voltage of exactly 4.1 or 4.2 V (always read the manufacturer's specifications to determine the right value) and add current limiting to keep the current within bounds. The charging current will automatically decrease as the cell becomes charged (see **Figure 1** for the charging characteristic).

You can assume that the cell is fully charged when the charging current drops to 1/20C or less. Just to reiterate, the charging voltage is critical – the allowed tolerance is only 1%. That's not very much, because 1% of 4.2 V is only 42 mV. That means you have to measure the output voltage carefully to ensure that it stays within tolerance.

The nice thing about this circuit (**Figure 2**) is that it's easy to build as a DIY project because it doesn't use any obscure components. The TL431 voltage reference is an old standby that you can obtain almost everywhere. For the rest, it consists of a few ordinary transistors and a power transistor, all of which can be replaced by any reasonable equivalents. The Schottky diode can be any type that can handle 1 A, or if necessary you can use an ordinary 1N4001. The input voltage can also be higher, although beyond a certain point you'll have to fit a heat sink for T1.

### Design philosophy

It's always interesting to examine someone else's design carefully in order to figure out the underlying design philosophy.

### Reference voltage

To start with, the circuit is based on a good, stable reference voltage generated by a Texas Instruments TL431 (IC2). That's a prudent choice, because a good reference is a fundamental requirement if you want to be sure of achieving 1% accuracy for the charging voltage.

The reference IC is followed by an emitter follower (T4) so the reference source can supply more than just a few milliampères. That would normally reduce the output voltage by approximately 0.6 V and trash the stability, but feedback from the transistor via R21 and R23 eliminates those problems.

The IC adjusts its reference potential to maintain a voltage of 2.5 V on its Adjust input. That yields a reference voltage of 3.3 V, which is used everywhere in the circuit. It's important to be able to adjust the value of R21 or R23 when you're building charger if the voltage of the TL431 differs too much from the nominal value. If a check reveals that your reference IC is near the end of the tolerance range, correct the reference voltage by fitting a resistor in parallel with R21 or R23. You can simply use the trial-and-error method by trying a succession of values until you obtain the correct voltage. Once that's done, you can solder the resistor permanently in place.

Naturally, a reference voltage of 3.3 V represents an arbitrary choice. It could also be a bit higher or a bit lower. It shouldn't be all too high, though, to avoid restricting the headroom of the TL431. A more important consideration is that the reference voltage must fall within the common-mode input voltage range of the opamp used in the circuit. We'll say more about that when we talk about selecting the opamp.

A decidedly low reference voltage, such as 2.5 V (as obtained without a voltage divider), is also undesirable because it makes it more difficult to drive LED D1 and increases the sensitivity of the circuit to the input offset voltage of the opamp.

### Control circuitry

Now we come to the actual control circuitry. We want to have:

- a stable output voltage
- current limiting
- battery monitoring (for temperature)
- a clear indication when the battery is fully charged

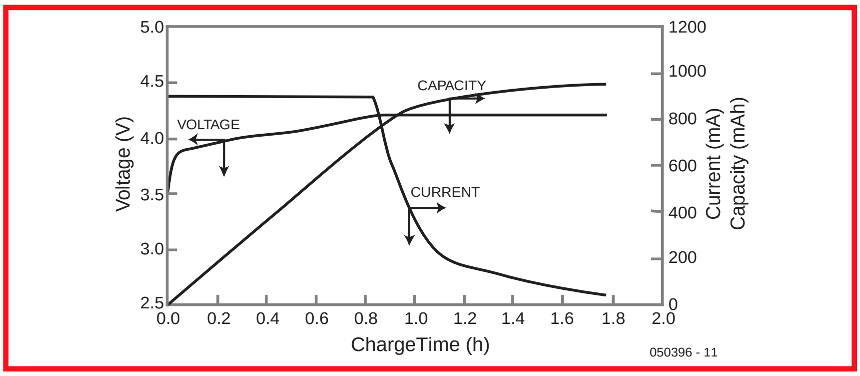


**Figure 1.** Charging characteristic of an Li-ion cell (source: Panasonic).

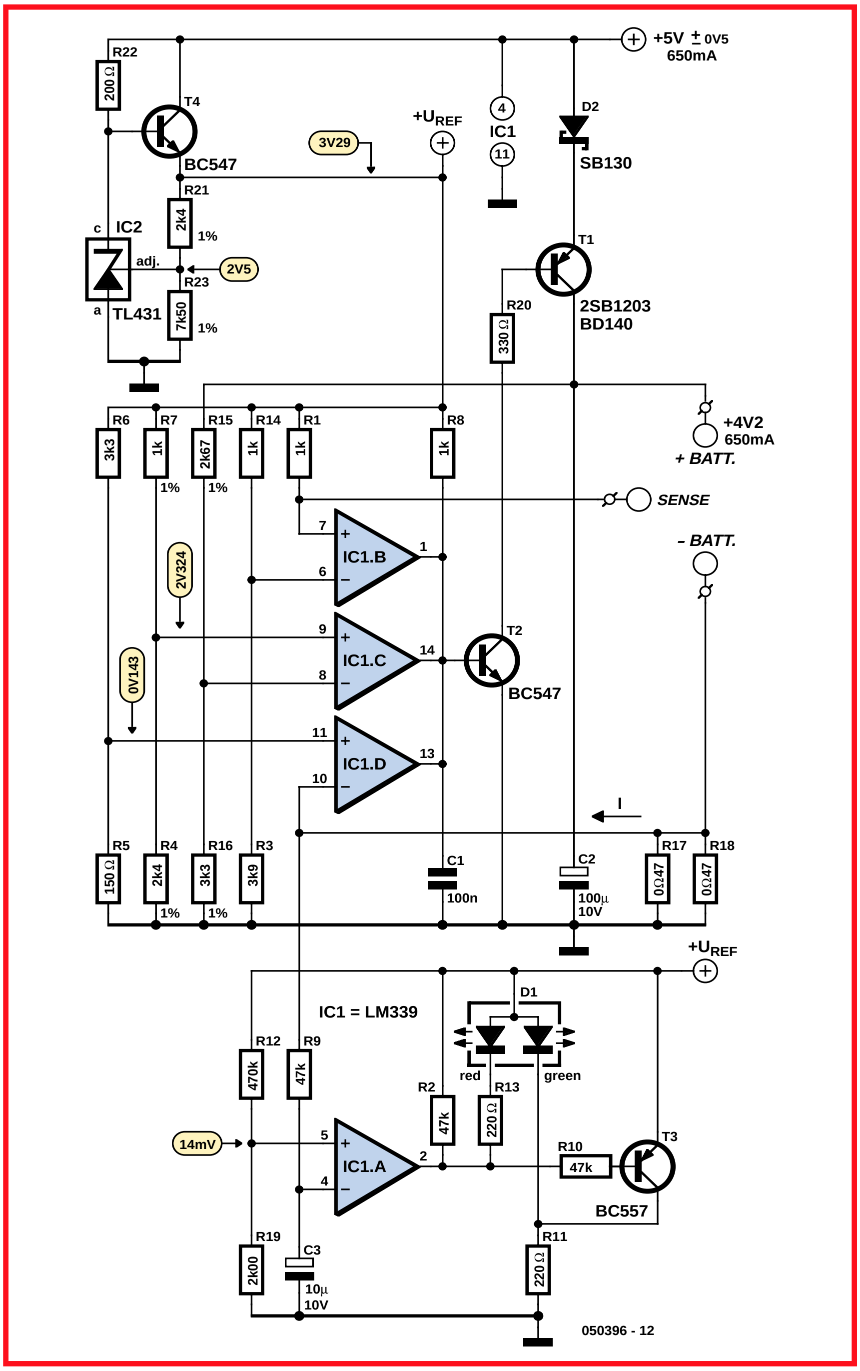


**Figure 2.** The circuit of the charger uses standard components instead of special charger ICs.

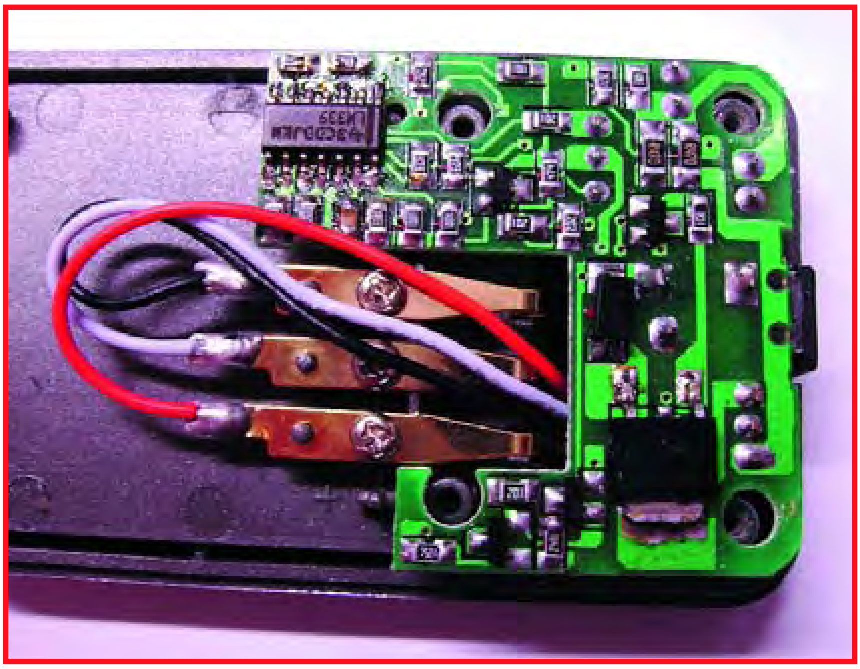


**Figure 3.** **The small printed circuit board for the charging circuit. The spring contacts for the battery pack are at the right.**

The first three items all affect the output voltage. The output current can be reduced by lowering the output voltage, and if the battery becomes hot, the charging current must be reduced by lowering the output voltage.
Here we have a topology in which three opamps (IC1b, IC1c and IC1d) can simultaneously control a single output. That's possible using a sort of OR-gate arrangement. In the schematic diagram, you can see that the outputs are simply connected together. Under normal conditions, that would naturally lead to problems whenever one opamp tries to increase the output voltage while another one tries to reduce it. That problem can be solved by putting diodes or transistors after the opamps.
In this case, a more elegant solution is to use opamps with open-collector outputs. That means each opamp can only *reduce* the voltage on the shared output. Resistor R8 provides the pull-up voltage. It supplies the base current for T2, which in turn drives T1 into conduction and voilà, the positive terminal of the battery is connected to the positive supply voltage. This gives us a system in which each parameter (voltage, current, and temperature) has its own opamp that can reduce the output voltage.

**Current regulation**
As a rule of thumb, you can assume that the maximum charging current of a normal Li-ion battery is around 0.7 to 1 times its capacity. This charger delivers a maximum current of 0.65 A, which makes it suitable for batteries rated at 0.65 Ah or more.
The current with a fully discharged battery would ordinarily be higher than the above-mentioned 0.65 A. The current can be easily measured by connecting a small resistance in series. Here that role is fulfilled by R17 and R18, with two resistors being used due to the magnitude of the current and the power dissipation. The current generates a voltage across these resistors, and IC1d compares this voltage with a reduced reference voltage obtained from a voltage divider. If the voltage generated by the charging current is higher than the comparison voltage, IC1d takes control by reducing the voltage on the shared output. That lowers the charging voltage for the battery and thus reduces the charging current to the desired level.
When the battery becomes fully charged, the control function provided by IC1c prevents the voltage from rising above 4.2 V. The battery voltage is compared with the reference voltage via two voltage dividers (R15/R16 and R7/R4, respectively), and if necessary IC1c reduces the voltage on the shared output.
The logic of the temperature monitoring circuitry with IC1b is similar. A thermistor (NTC resistor) is built into the battery, and its resistance decreases as the temperature increases. The thermistor forms a voltage divider in combination with R1, and IC1b compares the voltage at the junction of this divider with a reduced reference voltage obtained from divider R14/R3. It restricts the charging process if the temperature rises too high.
By the way, this temperature protection is not fail-safe, so charging will proceed as normal if there is bad contact or an open lead.
If you've ever built a circuit with an opamp followed by two transistors (which also provide gain), you know you can expect problems. Such a circuit is guaranteed to oscillate. That problem is solved here by using a hefty capacitance (C1) to slow down the entire control loop. An additional capacitor (C2) connected at the output, in combination with voltage divider R15/R16, keeps the circuit stable in the no-load state, and the divider provides a minimum load.

**Indicator**
We haven't said anything yet about the indicator portion of the circuit, which consists of the circuitry around IC1a. This bit of electronics is not essential to the operation of the circuit, but it is nevertheless very important. As a user, you naturally want to know where things stand. The nice thing about this indicator is that it responds to the charging *current*. That means you can be sure that charging is actually taking place, which avoids simple errors such as forgetting to connect the mains adapter or a bad battery contact.
Here again the reference voltage is divided down, this time by R12/R19, to a voltage of approximately 14 mV. If the voltage drop resulting from the charging current through R17/R18 is less than this value (with no battery connected or a fully charged battery), the internal open-collector output transistor of IC1a will be cut off. The red LED in D1 will be off in that case, but the green one will be on because it is connected to 3.3 V and to ground via a 220-Ω resistor.

In the opposite case, with sufficient charging current flowing, IC1a will pull its output low. In that case LED will be on and T3 will conduct to short out the green LED and keep it dark. Using a bi-colour LED for D1 thus provides a perfectly clear charging indicator.
Have you already realised the significance of selecting 14 mV as the refer-

ence voltage for IC1a? The maximum charging current of 650 mA generates a voltage drop of 153 mV across R17/R18. 14 mV is approximately 1/11 of this value, so the battery is considered to be fully charged as soon as the current drops to 1/11 of the maximum value. The charging process will continue as usual, but the LED will indicate that the battery is fully charged.

You could also add another stage to the circuit, because it's better to limit the charging current to 1/10 of the battery capacity if the battery has been discharged to below 2.9 V. That can be easily implemented by using another opamp to connect a resistor in parallel with R5 to reduce the divided reference voltage for current limiting to 14 mV. However, the manufacturer decided not to do this, presumably because it would require an additional IC.

## Component selection

Now for a few remarks about selecting the opamp. When you design a circuit, you can choose from hundreds of IC types. All the different options don't make the choice any easier. However, in this case a standard opamp type without any special properties is sufficient. It doesn't need to have especially high accuracy (a millivolt more or less doesn't matter), it doesn't have to have a special temperature range, and noise and speed are also unimportant. However, there are two aspects that deserve further attention.

The first is the common-mode range. When you select an opamp for a circuit, it's important to keep all the voltages that may be present on its inputs within the limits of the common-mode range, or to select an opamp that can handle the expected range of voltages. The data sheet for the LM399 says that the lower limit is 0 V and the upper limit is 1.5 V below the supply voltage. If we had chosen an LM741, the lower limit would have been 1.5 V, so a voltage such as 14 mV would not have been allowed. That means it's essential to chose an opamp for this design that can work properly with voltages close to zero.

The second aspect is the offset voltage. From the data sheet, you can see that the input offset voltage is 2 mV. (The manufacturer supplies this opamp in various versions with different offset voltage ratings. As you might expect, better specs always cost more.) That means the IC introduces an error of approximately 2 mV at its inputs. As a result, although you think (or hope) that the charging indicator will change state at 14 mV, it may actually change as early as 16 mV or not until 12 mV. That's an error of more than 10%, which is considerable. That isn't a problem for the charging indicator, but such an error in the charging voltage would be unacceptable. That's why the reference value for the charging voltage is much higher at around 2.4 V. An error of 2 mV at 2325 mV is only around 1 part in a thousand, which is negligible.

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## CONSTRUCTION GUIDELINES

Elektor Electronics (Publishing) does not provide **parts and components other than** PCBs, fornt panel foils and software on diskette or IC (not necessarily for all projects). Components are usually available form a number of retailers – see the adverts in the magazine.

**Large and small values** of components are indicated by means of one of the following prefixes :

| | |
|---|---|
| E (exa) = $10^{18}$ | a (atto) = $10^{-18}$ |
| P (peta) = $10^{15}$ | f (femto) = $10^{-15}$ |
| T (tera) = $10^{12}$ | p (pico) = $10^{-12}$ |
| G (giga) = $10^{9}$ | n (nano) = $10^{-9}$ |
| M (mega) = $10^{6}$ | $\mu$ (micro) = $10^{-6}$ |
| k (kilo) = $10^{3}$ | m (milli) = $10^{-3}$ |
| h (hecto) = $10^{2}$ | c (centi) = $10^{-2}$ |
| da (deca) = $10^{1}$ | d (deci) = $10^{-1}$ |

In some circuit diagrams, to avoid confusion, but contrary to IEC and BS recommandations, the value of components is given by substituting the relevant prefix for the decimal point. For example,

3k9 = 3.9 kΩ    4µ7 = 4.7 µF

Unless otherwise indicated, the tolerance of resistors is ±5% and their rating is ⅓–½ watt. The working voltage of capacitors is ≥ 50 V.

In **populating a** PCB, always start with the smallest passive components, that is, wire bridges, resistors and small capacitors; and then IC sockets, relays, electrolytic and other large capacitors, and connectors. Vulnerable semiconductors and ICS should be done last.

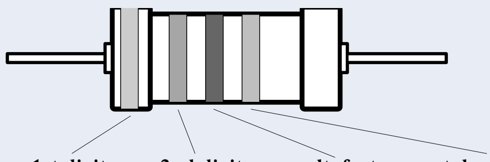
**Soldering.** Use a 15–30 W soldering iron with a fine tip and tin with a resin core (60/40) Insert the terminals of components in the board, bend them slightly, cut them short, and solder: wait 1–2 seconds for the tin to flow smoothly and remove the iron. Do not overheat, particularly when soldering ICS and semiconductors. Unsoldering is best done with a suction iron or special unsoldering braid.

**Faultfinding.** If the circuit does not work, carefully compare the populated board with the published component layout and parts list. Are all the components in the correct position? Has correct polarity been observed? Have the powerlines been reversed? Are all solder joints sound? Have any wire bridges been forgotten?

If voltage levels have been given on the circuit diagram, do those measured on the board match them – note that deviations up to ±10% from the specified values are acceptable.

Possible corrections to published projects are published from time to time in this magazine. Also, the readers letters column often contains useful comments/additions to the published projects.

The value of a resistor is indicated by a **colour code** as follows.



| color | 1st digit | 2nd digit | mult. factor | tolerance |
|---|---|---|---|---|
| black | – | 0 | – | – |
| brown | 1 | 1 | $\times 10^{1}$ | ±1% |
| red | 2 | 2 | $\times 10^{2}$ | ±2% |
| orange | 3 | 3 | $\times 10^{3}$ | – |
| yellow | 4 | 4 | $\times 10^{4}$ | – |
| green | 5 | 5 | $\times 10^{5}$ | ±0,5% |
| blue | 6 | 6 | $\times 10^{6}$ | – |
| violet | 7 | 7 | – | – |
| grey | 8 | 8 | – | – |
| white | 9 | 9 | – | – |
| gold | – | – | $\times 10^{-1}$ | ±5% |
| silver | – | – | $\times 10^{-2}$ | ±10% |
| none | – | – | – | ±20% |

Examples:
brown-red-brown-gold = 120 Ω, 5%
yellow-violet-orange-gold = 47 kΩ, 5%