Applied Physics For Engineers

Contents:

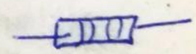
Resistors

Some earlier discussions may have left the impression that resistance is a consistently undesirable property for a material to have. On the contrary, in many practical applications, it is necessary to insert resistance in a circuit for the express purpose of limiting or controlling the flow of current. For example, if a 24-V voltage source is available and it is necessary to establish a current of 2 A, we would wish to connect $R = 24\ \text{V}/2\ \text{A} = 12\ \Omega$ of resistance across the source to obtain that current. A *resistor* is a device that is manufactured so that it has a specific amount of resistance, and it is used in circuits for precisely the purposes we have described.

Resistors are available with a wide range of resistance values and in many different physical sizes. Figure 3.8 shows some examples. The physical size of a resistor is not necessarily related to its resistance value, but rather to its *power rating*. Recall that heat energy is produced when current flows through resistance, and that a resistor must be capable of dissipating that heat. If the power rating of a resistor is too small for a particular application, the resistor will not be able to dissipate heat at a rate rapid enough to prevent destructive temperature buildup. Resistors that have large power ratings (i.e., those that are capable of dissipating heat at a rapid rate) are physically large because a large surface area is required to promote the transfer of heat into the surrounding air.

Example 3.6

A 200-Ω resistor has a 2-W power rating. What is the maximum current that can flow in the resistor without exceeding the power rating?



SOLUTION From equation (3.5),

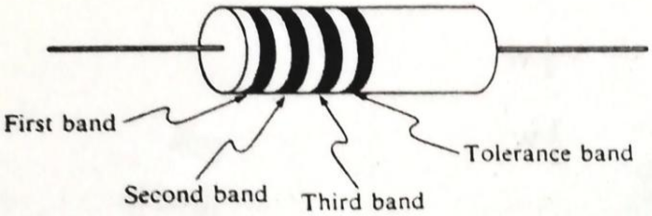
$$P = I^2R \leq 2\ \text{W}$$
$$I^2(200) \leq 2$$
$$I^2 \leq 0.01$$
$$I \leq 0.1\ \text{A} = 100\ \text{mA}$$

In integrated circuits, resistors with specific resistance values are fabricated by controlling the dimensions and the number of free electrons in a tiny strip of semiconductor material. We will discuss those techniques in more detail in Chapter 8. Unlike integrated-circuit resistors, *discrete* resistors are individual components that can be connected at will to other components. The discrete resistors that are most commonly used in electronic circuits are of the *carbon-composition* type, as shown in Figure 3.9. These cylinder-shaped devices are available with resistance values ranging from 2.7 Ω to 22 MΩ and with power ratings of $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, 1, and 2 W. Notice in Figure 3.9 that resistors with higher power ratings are physically larger than those with smaller ratings. The size of these resistors has no relation to their resistance values.

The Color Code

The resistance value of many resistors, including carbon-composition types, can be determined by "reading" a series of colored bands imprinted on the resistor body. In this scheme, called the resistor *color code*, each color represents a different decimal digit. Figure 3.10 shows the sequence of four (sometimes three) color bands on the body of a resistor and the digits corresponding to each color. Note that the fourth band is called a *tolerance* band and identifies a percentage rather than a decimal digit.

The first three bands of the color code are used to specify the *nominal* value of the resistance, and the fourth, or tolerance, band gives the percent variation from the nominal value that the *actual* resistance may have. In other words, due to manufacturing variations, the actual resistance may be anywhere in a range equal to the nominal value plus



Digit	*Color*	*Digit*	*Color*	
0	Black	7	Violet	
1	Brown	8	Gray	
2	Red	9	White	
3	Orange	5%	Gold	Tolerance band
4	Yellow	10%	Silver	
5	Green	20%	None	
6	Blue			

FIGURE 3.10 Resistor color code.

or minus a certain percentage of that value. The first two color bands specify the first two digits of the nominal value, and the third band represents the power of 10 by which the first two digits are multiplied. The next example demonstrates these computations.

Example 3.7

Find the nominal resistance and the possible range of actual resistance values corresponding to each of the following color codes.

(a) yellow, violet, orange, silver
(b) brown, black, red
(c) blue, gray, black, gold

SOLUTION

(a) Yellow, violet, orange, silver

$$47 \times 10^3 \pm 10\%$$

Thus, the nominal resistance is 47 kΩ, and the possible range of actual values is 47 kΩ ± 0.1(47 kΩ) = 47 kΩ ± 4.7 kΩ, or

$$\text{from } 47\ \text{k}\Omega - 4.7\ \text{k}\Omega \text{ to } 47\ \text{k}\Omega + 4.7\ \text{k}\Omega$$
$$\text{that is, from } 42.3\ \text{k}\Omega \text{ to } 51.7\ \text{k}\Omega.$$

(b) Brown, black, red, (none)

$$10 \times 10^2 \pm 20\%$$
$$= 10^3\ \Omega \pm 0.2 \times 10^3$$
$$= 1\ \text{k}\Omega \pm 200\ \Omega$$
$$\text{range} = 800\ \Omega \text{ to } 1.2\ \text{k}\Omega$$

(c) Blue, gray, black, gold

$$
\begin{aligned}
&68 \times 10^{0} \pm 5\% \\
&= 68\ \Omega \pm 0.05(68\ \Omega) \\
&= 68\ \Omega \pm 3.4\ \Omega \\
\text{range} &= 64.6\ \Omega \text{ to } 71.4\ \Omega
\end{aligned}
$$

Drill Exercise 3.7

What is the color code of a 2.7 MΩ 5% resistor?

ANSWER: red-violet-green-gold. □

Standard Values

Resistors having 5 and 10% tolerances are not manufactured in every possible nominal value. (20% resistors are rarely found in modern circuits.) Obviously, there would be no point in manufacturing a 1 kΩ ± 10% resistor and a 950 Ω ± 10% resistor, since the possible range of values of the 1-kΩ resistor includes 950 Ω. In many practical

TABLE 3.1 Standard values of 5% and 10% resistors[a]

Ohms (Ω)					Kilohms (kΩ)		Megohms (MΩ)	
0.10	**1.0**	**10**	**100**	**1000**	**10**	**100**	**1.0**	**10.0**
0.11	1.1	11	110	1100	11	110	1.1	11.0
0.12	**1.2**	**12**	**120**	**1200**	**12**	**120**	**1.2**	**12.0**
0.13	1.3	13	130	1300	13	130	1.3	13.0
0.15	**1.5**	**15**	**150**	**1500**	**15**	**150**	**1.5**	**15.0**
0.16	1.6	16	160	1600	16	160	1.6	16.0
0.18	**1.8**	**18**	**180**	**1800**	**18**	**180**	**1.8**	**18.0**
0.20	2.0	20	200	2000	20	200	2.0	20.0
0.22	**2.2**	**22**	**220**	**2200**	**22**	**220**	**2.2**	**22.0**
0.24	2.4	24	240	2400	24	240	2.4	
0.27	**2.7**	**27**	**270**	**2700**	**27**	**270**	**2.7**	
0.30	3.0	30	300	3000	30	300	3.0	
0.33	**3.3**	**33**	**330**	**3300**	**33**	**330**	**3.3**	
0.36	3.6	36	360	3600	36	360	3.6	
0.39	**3.9**	**39**	**390**	**3900**	**39**	**390**	**3.9**	
0.43	4.3	43	430	4300	43	430	4.3	
0.47	**4.7**	**47**	**470**	**4700**	**47**	**470**	**4.7**	
0.51	5.1	51	510	5100	51	510	5.1	
0.56	**5.6**	**56**	**560**	**5600**	**56**	**560**	**5.6**	
0.62	6.2	62	620	6200	62	620	6.2	
0.68	**6.8**	**68**	**680**	**6800**	**68**	**680**	**6.8**	
0.75	7.5	75	750	7500	75	750	7.5	
0.82	**8.2**	**82**	**820**	**8200**	**82**	**820**	**8.2**	
0.91	9.1	91	910	9100	91	910	9.1	

[a] 5% resistors are available in all the values listed; 10% resistors are available only in the boldface values.

Conductance

Conductance is the *reciprocal* of resistance, that is, 1 divided by resistance. Thus, a large resistance corresponds to a small conductance, and vice versa. The symbol for conductance is G and its units are *siemens* (S):

$$G = \frac{1}{R} \quad \text{siemens} \tag{3.8}$$

Of course, it follows that $R = 1/G$ ohms.

Example 3.8

(a) Find the conductance of a resistor whose resistance is 40 Ω.

(b) Find the resistance of a resistor whose conductance is 0.5 mS.

SOLUTION

(a) $G = \dfrac{1}{R} = \dfrac{1}{40\ \Omega} = 0.025\ \text{S}$

(b) $R = \dfrac{1}{G} = \dfrac{1}{0.5 \times 10^{-3}\ \text{S}} = 2\ \text{k}\Omega$

Drill Exercise 3.8

What is the maximum possible conductance of a 75-kΩ 10% resistor?

ANSWER: 14.81 μS. □

Substituting $R = 1/G$ into Ohm's law, we find

$$I = \frac{E}{R} = \frac{1}{R}(E) = GE$$

Equivalently, $E = I/G$ and $G = I/E$.