RESISTOR TYPES

APPENDIX C

C.1 Some history

For a half century people used "leaded" (pronounced lēd′-ed) resistors: if you look inside a very old radio (before ~1950), you'll see colored cylindrical objects with some colored dots painted on them and with a wire wrapped around each end that comes off perpendicularly to the axis ("radial leads"). These carbon-composition resistors evolved into the standard carbon-comp "axial-lead" resistors (still cylindrical, but with colored stripes all the way around, and with the wires now sticking straight out each end) that were dominant through the last half of the 20th century (and that we recommended for noncritical applications in our previous book editions). Axial-lead resistors are still popular for some uses, such as easy breadboarding in the lab. They're also used in applications that require very high resistance ($\geq$100 MΩ), or high voltage or power ratings, or for resistors of very high precision.

However, contemporary electronics has embraced surface-mount packaging, because of its high density (SMT devices are *small*, and you don't have to take up space with holes for the leads). Surface-mount resistors, in common with other two-terminal SMT components (capacitors, inductors), are available in a range of package sizes, characterized by a 4-digit code giving their length and width in units of 0.010″; for example, an "0603" package is 0.06″×0.03″ (1.5 mm × 0.75 mm). We favor that size, or the larger 0805 package, for general prototyping of surface-mount circuits. The smaller packages (0402, 0201, and even "01005") are a major pain – you basically have to work under a microscope (and don't sneeze).

C.2 Available resistance values

You can't get just any old resistance value. Available resistances fall into what's called an EIA Standard Decade, named by the number of values per decade (thus E24 – used for 5% tolerance resistors – has 24 values, spaced approximately 10% apart; see below). Resistors with 1% tolerance are quite inexpensive these days, costing hardly more than an analogous 5% resistor,[1] so you might as well use 1% resistors by default. They come in the E96 set of standard values (96 values per decade, spaced approximately 2% apart; thus 481 values from 10 Ω through 1 MΩ, see below). Resistors of greater precision (e.g., 0.1%) are sometimes available in the **E192** superset,[2] and in convenient round-number values (e.g., 250, 300, 400, or 500) that are not included in the EIA sequences.

Here is the **E24** set of "5%" values (the **E12** subset, used for 10% components, is shown in **bold**):

10	16	**27**	43	**68**
11	**18**	30	**47**	75
12	20	**33**	51	**82**
13	**22**	36	**56**	91
15	24	**39**	62	**100**

And here is the **E96** set of "1%" values (the **E48** set, used for 2% components, or for a reduced set of 1% parts, is in **bold**):

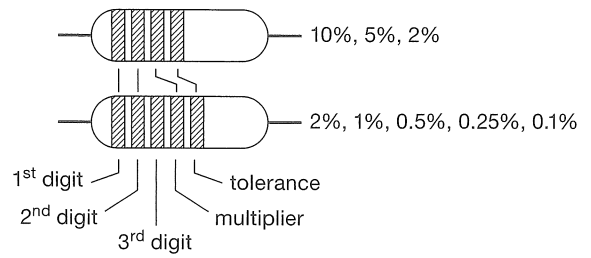
100	137	**187**	255	**348**	475	**649**	887
102	**140**	191	**261**	357	**487**	665	**909**
105	143	**196**	267	**365**	499	**681**	931
107	**147**	200	**274**	374	**511**	698	**953**
110	150	**205**	280	**383**	523	**715**	976
113	**154**	210	**287**	392	**536**	732	
115	158	**215**	294	**402**	549	**750**	
118	**162**	221	**301**	412	**562**	768	
121	165	**226**	309	**422**	576	**787**	
124	**169**	232	**316**	432	**590**	806	
127	174	**237**	324	**442**	604	**825**	
130	**178**	243	**332**	453	**619**	845	
133	182	**249**	340	**464**	634	**866**	

[1] For example, the Digi-Key catalog shows a full selection of Vishay/Dale CRCW-series surface-mount resistors, in sizes from 1210 down to 0201. For the convenient 0603 size, the current prices for 1% and 5% resistors are $0.025 and $0.023 apiece, respectively, in quantity 200. (You'll pay about triple that, in quantity 10, and about a fifth as much, in a full reel of 5000 resistors.)

[2] The full E192 set, along with subsets, is nicely displayed at `http://www.logwell.com/tech/components/resistor_values.html`.

C.3 Resistance marking

Leaded resistors are marked in one of two ways: (a) with a set of four or five color bands, indicating resistance and tolerance; or (b) with a 4-digit resistance code, followed by a letter that indicates the tolerance. Surface-mount resistors use either (a) a 3- or 4-digit resistance code, or, for the smallest package sizes, (b) no marking at all!



color	digit	multiplier	tolerance	(tol. suffix)
black	0	1	–	
brown	1	10	1%	F
red	2	100	2%	G
orange	3	1k	–	
yellow	4	10k	–	
green	5	100k	0.5%	D
blue	6	1M	0.25%	C
violet	7	10M	0.1%	B
gray	8	–	0.05%	A, W
white	9	–	–	
gold	–	0.1	5%	J
silver	–	0.01	10%	K
(none)	–	–	20%	M
			0.02%	N, Q, P
			0.01%	T, L
			0.005%	V
			0.0025%	X
			0.002%	U
			0.001%	S

Figure C.1. The resistor color code, used on some axial-lead resistors (notably carbon-film and carbon-composition types). The resistance is read as a 2- or 3-digit integer (depending on resistor precision) followed by a band indicating the power-of-10 multiplier. For example, yellow-violet-orange-gold is 47 kΩ±5%, and yellow-white-white-black-brown is 499 Ω±1%. The alphabetic tolerance suffix is used on resistors with numerical printed resistance values.

Although it may seem diabolical to the beginner, the practice of color banding makes it easy to recognize resistor values in a circuit or parts bin, without having to search for a printed legend. Each color corresponds to a digit, in a sort of floating-point format (with the final digit indicating the power of ten); a last color band signifies the tolerance. See Figure C.1. Resistors with numerical markings use the same system, but with the digits themselves printed along the body of the resistor (for leaded resistors), or on the top side of a surface-mount package; a final letter signifies the tolerance, as shown in the figure.

C.4 Resistor types

The usual choices for general-purpose use are metal-film (axial-lead) or thick-film (surface-mount) parts. Thin-film surface-mount resistors offer improved characteristics (accuracy, stability, and ability to operate in cryogenic environments). For power applications you usually use wire-wound resistors, either in an air-cooled ceramic package or a conduction-cooled ("Dale-type") metal package. High-value resistors (>10 MΩ, say) are usually of metal-oxide construction (e.g., Ohmite "Mini-Mox" or "Super Mox," or Vishay RNX-series). Film resistors are not tolerant of high peak power; for such applications use something like ceramic or carbon composition, or other styles specified for peak-power use. For the utmost in stability and low temperature coefficient (tempco), you can't beat the excellent metal-foil types from Vishay. They exploit a clever design, in which the positive tempco of the resistive metal element (firmly attached to an insulating substrate) is cancelled by the negative strain-induced tempco caused by differential expansion of the substrate.[3] We've listed some comparative resistor properties in Table C.1; for much more detail see §*1x.2*.

General-purpose resistors are ridiculously inexpensive – thick-film surface-mount resistors cost a few cents apiece in small quantities, and just fractions of a cent apiece in full reel quantities (5000 pieces, for 0603 size). Distributors may be unwilling to sell fewer than 25 to 50 pieces of one value; thus an assortment box (e.g., from Yageo or Vishay/BC) may be a wise purchase. We particularly like the nice packaging and good pricing of the kits from SMT Zone (www.smtzone.com).

C.5 Confusion derby

Component markings should be clear and unambiguous. Sometimes it just ain't so! See Figure 1.130 for some real head-scratchers, both resistive and otherwise.

[3] Check it out: Felix Zandman's 1982 US patent #4,318,072, "Precision resistor with improved temperature characteristics."

Table C.1 Selected Resistor Types

	Resistor Type					
Parameter	carbon comp axial (RC-07)	thick film SMT-0603 (Vishay CRCW)	thin film SMT-0603 (KOA Speer RN73)	metal film axial (RN-55D)	metal foil SMT (Vishay VSMP)	Units
Tolerances	5%, 10%	1%, 5%	0.05%-1%	0.1%-1%	0.01%-1%	$\Delta R/R$
Temp coef	~1000	100, 200	5, 10, 25, 50, 100	50, 100	0.05 (typ)	ppm/C
Load life	10%	2%	0.25%	0.5%	0.01%	$\Delta R/R$
Moisture	10%	2%	0.5%	0.5%	0.02%	$\Delta R/R$
Thermal cycle	2%	2%	0.25%	0.25%	0.01%	$\Delta R/R$
Low temp	3%	-	-	0.25%	0.01%	$\Delta R/R$
Overload	2%	0.5%	0.1%	0.25%	0.01%	$\Delta R/R$
Soldering	3%	0.5%	0.1%	0.25%	0.01%	$\Delta R/R$
Vibration	2%	-	-	0.25%	-	$\Delta R/R$
Voltage coef	-	-	-	5	0.1	ppm/V
Self-heating	-	-	-	-	5ppm	$\Delta R/R$
Price (approx) (for tol and TC)	$0.35 (5%)	$0.025 (1%, TC=200)	$0.32 (0.1%, TC=25)	$0.05 (1%, TC=100)	$10 (0.01%, TC=0.05)	ea, qty 100

Properties of selected resistor types. The legendary axial-lead "carbon-composition" resistors have been superseded by inexpensive metal-film (or carbon-film) types, with greatly improved properties (except for peak-power endurance, see Chapter *1x*). We like Vishay's CMF-55 metal-film resistors (industrial version of MIL RN-55D). For most surface-mount applications the "thick-film" (a metal-ceramic composite) types are fine, though thin-film and metal-film resistors have somewhat better properties. The extraordinary Vishay "Z-foil" ultraprecision hermetically sealed resistor is listed to show the best that is currently available (but if you have to ask the price, you probably can't afford it). It's useful to note that a parameter like a voltage coefficient of 5 ppm/V corresponds to a change of 0.1% over a full 200 V operating range.