General Information – Understanding Resistor Value Coding

Introduction
This Technical Note provides information relating to the coding methods generally in use to identify the value of resistors. In addition it also gives an insight into the 'preferred value' system and its origins and provides tables of values covering the most common series in contemporary use.

A Little History
In the early days of electronics a circuit designer was able to precisely specify the value of resistor required at a particular circuit location based on the calculations he performed. This led to difficulties for the resistor manufacturers as there was little or no standardisation and hence all resistors were 'custom made'. What was needed was a system that made available a limited range of nominal values with each adjacent pair in the range separated by a distance small enough to make no practical difference to the circuit designer. Resistor manufacturers could then produce components with these 'preferred values' in greater quantity and keep a stock and hence lower the cost to the user.

The Preferred Value System
This is a system of selecting nominal values, within a given decade, for components based on the accuracy with which they are able to be manufactured. Each of these series is given a name starting with the letter 'E' followed by a number denoting how many nominal values there are within a decade and, thus, the E6 series has 6 discrete values in a given decade.

Table 1 below gives details of the common series in current use and shows for each the corresponding manufacturing tolerance.

The nominal values available are grouped in decades, that is a range of values covering a ratio of 10:1, which, for example, might be 10 ohms to 99 ohms. The next decade up will cover 100 ohms to 999 ohms and so on.

Each of the discrete values in each decade has the same ratio with respect to the first value of its decade so, for example, if there is a value of 15

Series	Tolerance	Values/Decade
E3	±50%	3
E6	±20%	6
E12	±10%	12
E24	±5%	24
E48	±2%	48
E96	±1%	96

Table 1: E Series Details

ohms in the 10 to 99 decade the corresponding value in the 100 ohms to 999 ohms decade is 150 ohms.

This gives the concept of constructing component values from a 'core value' plus a 'multiplier'. In the examples given above the core value is 1.5 and the multipliers are 10 (1.5 x 10 = 15) and 100 (1.5 x 100 = 150) respectively.

The first value in each decade has a core value of 1.0 and the spacing between it and the next is determined by the manufacturing tolerance such that there is a minimum of overlap at the extremes of the tolerance range.

As an example consider the E12 series which has a ±10% tolerance:-

The first value in the 100 ohms decade will be 100 ohms which, at its upper tolerance limit, will have a value of 110 ohms. The next nominal value in this series is 120 ohms which, at its lower tolerance limit, will actually be 108 ohms. This pair of adjacent values do exhibit a slight overlap at the tolerance extremes but it is only slight. The E24 series contains an interim nominal value of 110 ohms but, if this were manufactured with a ±10% tolerance, the value of any particular component could be expected to range from 99 ohms to 121 ohms. This range encompasses the nominal values of its neighbours and, clearly, this interim value is of limited use.

E3	E6	E12	E24	E48	E96	E3	E6	E12	E24	E48	E96
10	10	10	10	10.0	10.0					31.6	31.6
					10.2						32.4
				10.5	10.5		33	33	33	33.2	33.2
					10.7						34.0
			11	11.0	11.0					34.8	34.8
					11.3				36		35.7
				11.5	11.5					36.5	36.5
					11.8						37.4
		12	12	12.1	12.1					38.3	38.3
					12.4			39	39		39.2
				12.7	12.7					40.2	40.2
			13		13.0						41.2
				13.3	13.3					42.2	42.2
					13.7				43		43.2
				14.0	14.0					44.2	44.2
					14.3						45.3
				14.7	14.7					46.4	46.4
	15	15	15		15.0	47	47	47	47		47.5
				15.4	15.4					48.7	48.7
					15.8						49.9
			16	16.2	16.2				51	51.1	51.1
					16.5						52.3
				16.9	16.9					53.6	53.6
					17.4						54.9
				17.8	17.8			56	56	56.2	56.2
		18	18		18.2						57.6
				18.7	18.7					59.0	59.0
					19.1						60.4
				19.6	19.6				62	61.9	61.9
			20		20.0						63.4
				20.5	20.5					64.9	64.9
					21.0						66.5
				21.5	21.5		68	68	68	68.1	68.1
22	22	22	22		22.1						69.8
				22.6	22.6					71.5	71.5
					23.2						73.2
				23.7	23.7				75	75.0	75.0
			24		24.3						76.8
				24.9	24.9					78.7	78.7
					25.5						80.6
				26.1	26.1			82	82	82.5	82.5
		27	27		26.7						84.5
				27.4	27.4					86.6	86.6
					28.0						88.7
				28.7	28.7				91	90.9	90.9
					29.4						93.1
			30	30.1	30.1					95.3	95.3
					30.9						97.6

Table 2: The E Series Nominal Values

The Nominal Values

Table 2 details the nominal values for each of the E series from E3 to E96. The E48 and E96 series offer an extra digit of precision in order to be able to differentiate between values at the lower end of each decade. The smaller series, E3 to E24, provide integer core values, rounded up or down as necessary, that approximate those found in the larger series.

Typical resistors in common usage are selected from the smaller series, that is up to and including E24. The E96 series of values is usually reserved for precision components manufactured with very tight initial tolerances and low temperature coefficients. The E48 series is rarely used *per se* but, as shown in Table 2, many of the E96 values are shared by the E48 series.

Identifying Resistor Specifications

To completely specify a resistors characteristics requires knowledge of the following parameters:-
- Value
- Tolerance
- Temperature Coefficient
- Power Rating

The specification of a resistor may be marked on its surface using either of two systems of coding. The first of these uses coloured bands, known as the 'colour code', and the second, more recent, system uses a combination of alpha-numeric characters.

The Colour Code

This system is generally used on components with a cylindrical form and consists of painting the body of the resistor with a set of coloured bands, usually 4, 5 or 6 in number. The coding scheme uses 10 colours plus silver and gold and is able to indicate all but the last of the 4 parameters listed above.

Table 3 below lists the colours and, for each of the band positions, gives the parameter it specifies and the meaning of each of the colours.

Depending on the precision with which the resistor has been made it may be considered unnecessary to identify it using all 6 bands and, indeed, many resistors are marked with only 4 bands.

In order that a resistors specification be interpreted correctly it is necessary to start from the correct end and Figure 1 below shows a typical low-power resistor marked with all 6 bands. The bands are read starting from the end with a (narrow) band placed on the end cap.
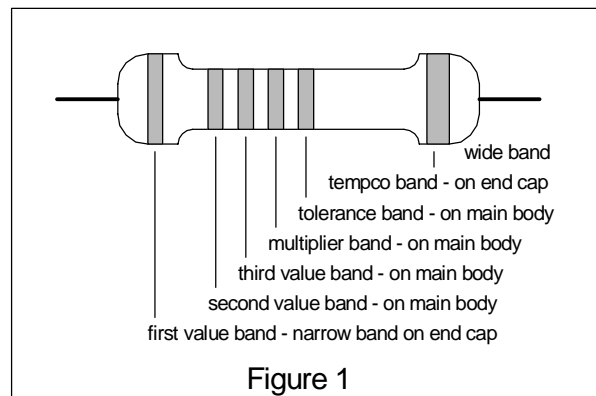

wide band
tempco band - on end cap
tolerance band - on main body
multiplier band - on main body
third value band - on main body
second value band - on main body
first value band - narrow band on end cap

Figure 1

Colour	1st Value	2nd Value	3rd Value	Multiplier	Tolerance	Temp. Co.
Silver				0.01	10%	
Gold				0.1	5%	
Black	0	0	0	1		
Brown	1	1	1	10	1%	100 ppm
Red	2	2	2	100	2%	50 ppm
Orange	3	3	3	1000		15 ppm
Yellow	4	4	4	10,000		25 ppm
Green	5	5	5	100,000	0.5%	
Blue	6	6	6	1,000,000	0.25%	10 ppm
Violet	7	7	7	10,000,000	0.1%	5 ppm
Grey	8	8	8	100,000,000	0.05%	
White	9	9	9	1,000,000,000		1 ppm

Table 3: The Coloured Bands and their Interpretation

4 Band Resistors

Using only 4 bands allows the specification of a resistors value from any series up to E24 along with its tolerance. Figure 2 below shows such a resistor and indicates the function of each of the bands.

tolerance band
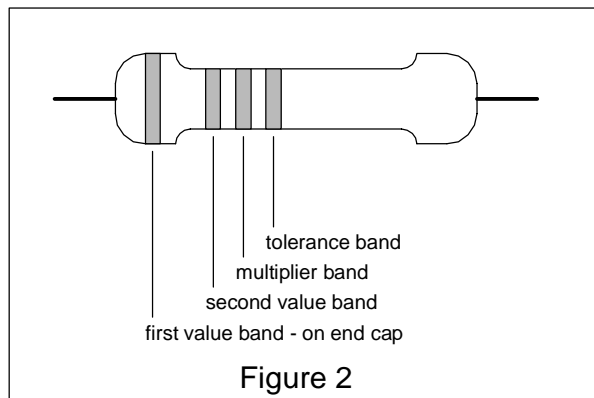multiplier band
second value band
first value band - on end cap

Figure 2

The first three bands are used together to express the value of the resistor and the fourth denotes its tolerance. In order to decode the resistors value the meaning of each coloured bands may be found from Table 3 as illustrated in the following examples.

Band	Colour	Meaning
First Value	Red	2
Second Value	Red	2
Multiplier	Red	x 100
Tolerance	Red	2%

22 x 100 = 2,200 ohms ±2%

Band	Colour	Meaning
First Value	Yellow	4
Second Value	Violet	7
Multiplier	Green	x 100,000
Tolerance	Gold	±5%

47 x 100,000 = 4,700,000 ohms ±5%

Band	Colour	Meaning
First Value	Orange	3
Second Value	White	9
Multiplier	Silver	x 0.01
Tolerance	Silver	±10%

39 x 0.01 = 0.39 ohms ±10%

5 Band Resistors

Adding an extra value band allows the specification of the resistors value to greater precision as required by the E48 series and above. The final band specifies the tolerance as above. Figure 3 below shows such a resistor and indicates the function of each of the bands.
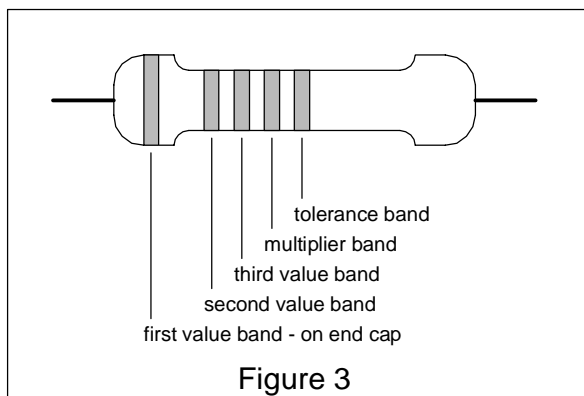

tolerance band
multiplier band
third value band
second value band
first value band - on end cap

Figure 3

The first four bands are used together to express the value of the resistor and the fifth denotes its tolerance. Decoding the resistors value is done in a similar manner to that used in the 4 band code with the following being examples.

Band	Colour	Meaning
First Value	Brown	1
Second Value	Black	0
Third Value	Black	0
Multiplier	Black	x 1
Tolerance	Brown	1%

100 x 1 = 100 ohms ±1%

Band	Colour	Meaning
First Value	Red	2
Second Value	Red	2
Third Value	Black	0
Multiplier	Brown	x 10
Tolerance	Red	2%

220 x 10 = 2,200 ohms ±2%

Notice that the value of the resistor specified in the above example is the same as the first of the 4 band examples but the colours used are very different. This can, and does, lead to confusion and care must be exercised when using the 5 band scheme.

6 Band Resistors

Adding the sixth band allows the addition of the resistors temperature coefficient. The other two parameters are interpreted in the same way as for the 5 band examples given above. Figure 4 below shows such a resistor and indicates the function of each of the bands.

first value band - on end cap
second value band
third value band
multiplier band
tolerance band
tempco band

Figure 4
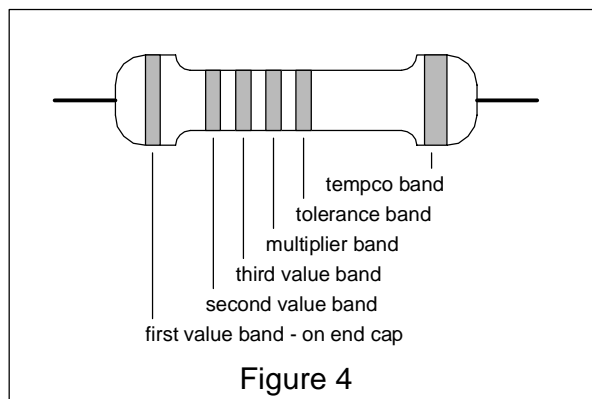
The first four bands are used together to express the value of the resistor, the fifth denotes its tolerance and the sixth its temperature coefficient as given in the following being examples.

Band	Colour	Meaning
First Value	Brown	1
Second Value	Black	0
Third Value	Black	0
Multiplier	Black	x 1
Tolerance	Brown	1%
Temp. Co.	Brown	100 ppm

100 x 1 = 100 ohms ±1% 100 ppm

| Band	Colour	Meaning
First Value	Yellow	4
Second Value	Black	0
Third Value	Red	2
Multiplier	Red	x 100
Tolerance	Blue	0.25%
Temp. Co.	Red	50 ppm

402 x 100 = 40,200 ohms ±0.25% 50 ppm

The example above is a typical one taken from the E96 series and specifies a component with a 'non-integer' core value.

The Alpha-Numeric Code

This system of marking is particularly suited to components with flat surfaces such as the various surface mounted styles and large power resistors.

The basic scheme uses combinations of numbers and letters to indicate the components value and tolerance and has two variants as shown in Figure 5 below. Both the resistors in the figure have the same specification; that is 4700 ohms with a ±5% tolerance.

472J   4K7J

Figure 5
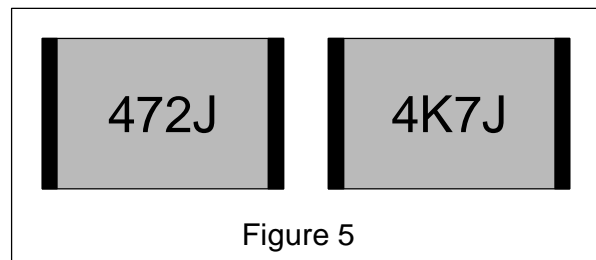
The first of these uses a system very similar to the colour code, i.e. the concept of a core value specified by two symbols followed by a multiplier, except that the values are printed directly using the numbers.

The second scheme uses a letter, denoting and specifying a 'multiplier', to indicate the 'decimal point'. The value in the figure above is 4.7K or 4700 ohms. Three multipliers are used to denote resistances measured in ohms (R), thousands of ohms (K) and millions of ohms (M). See the **Multiples and Sub-Multiples** section below for further details.

The letter following the value encoding represents the tolerance and Table 4 below lists the characters in common use and their meanings.

Letter	B	D	F	G	J	K	M
Meaning	0.1%	0.5%	1%	2%	5%	10%	20%

Table 4: Alphabetic Tolerance Codes

The following examples give resistor specifications and the characters used in both schemes.

Resistor Specification	Scheme 1	Scheme 2
2,200 ohms ±2%	222G	2K2G
3,300,000 ohms ±20%	335M	3M3M
150 ohms ±5%	151J	K15J
27 ohms ±5%	270J	27RJ
1.8 ohms ±1%	N/A	1R8F
470,000 ohms ±2%	474G	M47G

Because scheme 2 uses only 3 multipliers values such as 150 ohms are denoted as 0.15 x 1,000 and 470,000 ohms as 0.47 x 1,000,000.

Like the 4 band colour coding scheme the usage by scheme 1 of two digits to specify the value and a single digit to denote the multiplier works for all series up to E24. For E48 and above there is a variant of this scheme with an extra value digit and Figure 6 below shows the two methods in use on components with the same specification, i.e. 10,000 ohms ±5%.
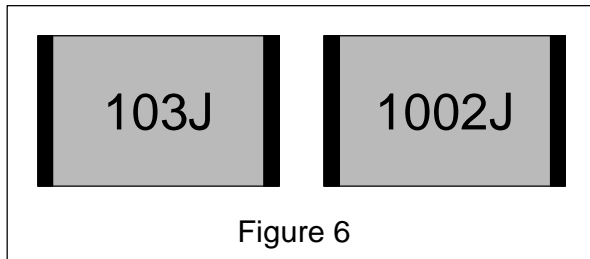

Figure 6

Note that, like the 5 band colour coding scheme, the alpha-numeric scheme is easily subject to misinterpretation. Consider the components shown in Figure 7.
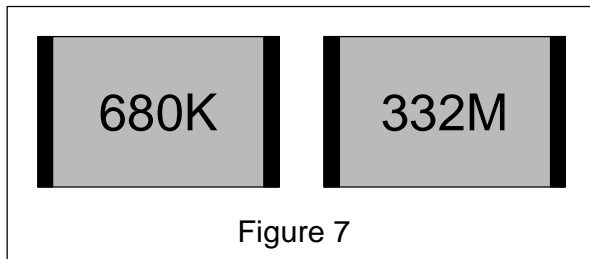

Figure 7

The first of these intuitively reads as 680,000 ohms but it is, in fact, 68 ohm ±10% derived from 68 with no zeros added. Similarly the second example reads, in English, as 332,000,000 ohms but is actually 33 with 2 zeros added or 3300 ohms with a ±20% tolerance.

Multiples and Sub-Multiples

In order to reduce 'wordiness' of resistor values such as '470,000 ohms' there are number of abbreviations in common use. These are a sub-set of those used by the scientific community and are used to denote ratios of 1000 in both directions and are given in Table 5 below.

Multiplication Factor		Description	Symbol
1,000,000,000	10^9	giga ohm	G
1,000,000	10^6	mega ohm	M
1,000	10^3	kilo ohm	k
1	10^0	ohm	
0.001	10^{-3}	milli ohm	m
0.000,001	10^{-6}	micro ohm	μ

Table 5: Multiples and Sub-Multiples

Although resistors can be purchased over the full range of values as indicated in Table 5 the vast majority fall into the ohm to mega-ohm range with values at the extremes reserved for special applications.

Notes

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