INTRODUCTION

Data in data sheets is presented, whenever possible, eaccording to a ‘format’, in which the following chapters are stated:

- TITLE
- FEATURES
- APPLICATIONS
- DESCRIPTION
- QUICK REFERENCE DATA
- ORDERING INFORMATION
- FUNCTIONAL DESCRIPTION
  - Product characterization
  - Limiting values
- MECHANICAL DATA
  - Outlines
  - Mass
  - Marking
  - Mounting
- TESTS AND REQUIREMENTS

The chapters listed above are explained in this section *“General Introduction Leaded resistors”*, with detailed information (including *“Packaging”*) in the relevant data sheet.

DESCRIPTION

Most types of conventional resistors have a cylindrical ceramic body, either rod or tube. For special purposes, a high-grade aluminium ceramic is used. The resistive element is either a carbon film, metal film, thick film or a wound wire element. Film types have been trimmed to the required ohmic resistance by cutting a helical groove in the resistive layer. This process is controlled completely by computer and yields a high reliability. The terminations are usually iron end caps onto which tinned connecting wires of electrolytic copper are welded.

All resistor bodies are coated with a coloured lacquer or enamel for protection. Dependent on types, this lacquer provides electrical, mechanical and/or climatic protection, also against soldering flux and cleaning solvents, in accordance with *“MIL-STD-202E”*, method 215 and *“IEC 68-2-45”*.

ORDERING INFORMATION

Resistors are ordered by their **ordering code**, a 12-digit number. The packaging method and resistance code are integral parts of this number.

FUNCTIONAL DESCRIPTION

The functional description includes: nominal resistance range and tolerance, limiting voltage, temperature coefficient, absolute maximum dissipation, climatic category and stability.

The **limiting voltage** (DC or RMS) is the maximum voltage that may be continuously applied, see *“IEC publications 115-1 and 115-2”*. Where applicable, **derating details** and **performance nomograms** are given, showing the relationship between power dissipation, ambient temperature, hot-spot temperature and maximum resistance drift after prolonged operation. For power resistors, graphs indicate the relationship between temperature rise and dissipation with lead-length or heatsinks as parameters.

The temperature rise in a resistor due to power dissipation, is determined by the laws of heat - conduction, convection and radiation. The maximum body temperature usually occurs in the middle of the resistor and is called the **hot-spot** temperature.

Heat conducted by the leads - which can be considerable in power types - must not reach the melting point of the solder at the joints. This condition may require the use of heatsinks and/or longer leads.

In the normal operating temperature range of film resistors the temperature rise at the hot-spot, ΔT, is proportional to the power dissipated: $\Delta T = A \times P$. The proportionally constant ‘A’ gives the temperature rise per Watt of dissipated power and can be interpreted as a thermal resistance in K/W. This thermal resistance is a function of the dimensions of the resistor, the heat conductivity of the materials used and to a lesser degree, the way of mounting. The sum of the temperature rise and the ambient temperature is:

$$T_m = T_{amb} + \Delta T$$

where:

T_m = hot-spot temperature

T_{amb} = ambient temperature

ΔT = temperature rise at hot-spot.

The stability of a film resistor during endurance tests is mainly determined by the hot-spot temperature and the resistance. The lower the resistance - other conditions remaining constant - the higher the stability due to greater film thickness.

Summarizing

DESCRIPTION	RELATIONSHIP
Dimensions and conductance of materials determine	heat resistance
Heat resistance × dissipation gives	temperature rise
Temperature rise + ambient temperature give	hot-spot temperature
Hot-spot temperature and resistance value determine	stability

Performance

When specifying the performance of a resistor, the dissipation is given as a function of the hot-spot temperature, with the ambient temperature as a parameter.

From $\Delta T = A \times P$ and $T_m = T_{amb} + \Delta T$ it follows that:

$$P = \frac{T_m - T_{amb}}{A}$$

If P is plotted against T_m for a constant value of A, parallel straight lines are obtained for different values of the ambient temperature.

The slope of these lines,

$$\frac{dP}{dT_m} = \frac{I}{A}$$

is the reciprocal of the heat resistance and is the characteristic for the resistor.

The stability $\frac{\Delta R}{R}$ can be determined experimentally, for instance after 1000 h, as a function of the hot-spot temperature with the resistance value as a parameter. It has been found that the resistance changes exponentially with temperature, giving a straight line when $\log \frac{\Delta R}{R}$ is plotted against T_m.

A combination of the graphs of P and $\frac{\Delta R}{R}$ against T_m gives a nomogram from which the values of several variables can be determined for a resistor of a given size under different working conditions. An example of such a nomogram with fictitious values is given in Fig.1. The intersection of the broken line with the horizontal axis gives the hot-spot temperature under chosen conditions.

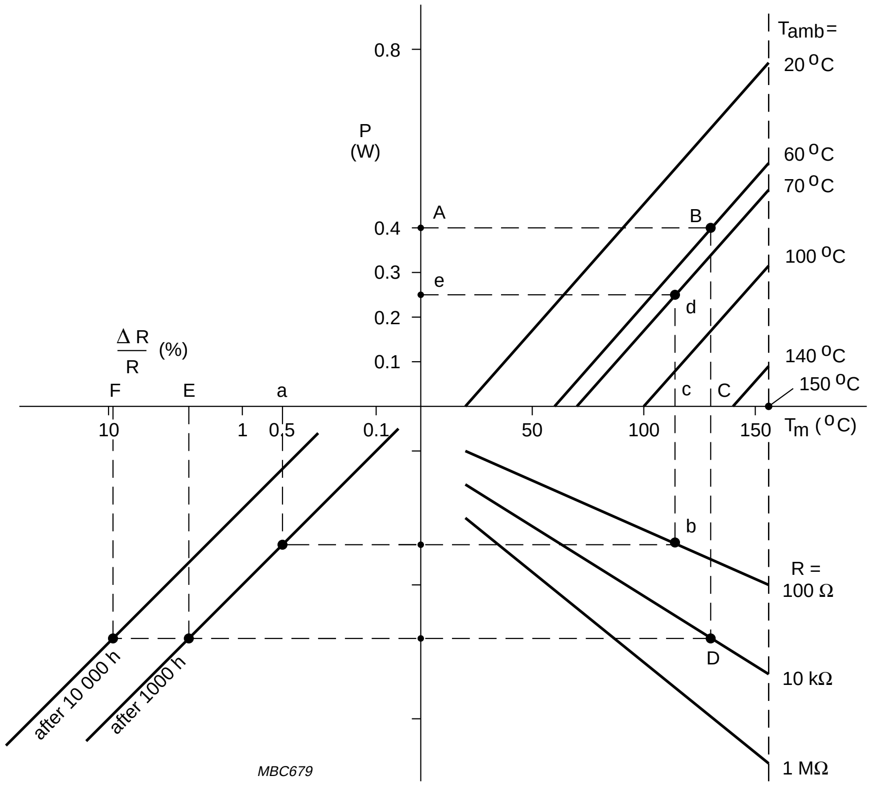


Fig.1 Performance nomogram (for a fictitious resistor) illustrating the way of specifying the performance of film resistors.

Example 1

Assume that a 10 kΩ resistor, whose characteristics are described by the nomogram, is to be operated at a power dissipation of 0.4 W and an ambient temperature of 60 °C. To establish whether this dissipation is allowable at this ambient temperature and, if so, what the expected stability of the resistor will be, draw a horizontal line in the upper half of the nomogram through point A (power dissipation of 0.4 W). This line intersects the 60 °C ambient temperature line at point B, corresponding to a hot-spot temperature of 128 °C (point C). This is safely below the maximum indicated by the broken line at 155 °C; therefore a dissipation of 0.4 W at an ambient temperature of 60 °C is well within the allowable limit.

Extend line BC into the lower half of the nomogram until it intersects the 10 kΩ line at point D. Draw a horizontal line to the left from point D until it intersects the line ‘after 1000 h’ and extend vertically to point E. This means that at a hot-spot temperature of 128 °C a resistance change of about 2.5% (point E) can be expected after 1000 hours of operation. After 10000 hours, the change will be about 9% (point F).

Example 2

Assume that a 100 Ω resistor, whose characteristics are described by the nomogram, is to be operated at an ambient temperature of 70 °C with a required stability after 1000 h of 0.5% (point a). It is desired to find the maximum permissible power dissipation. In the lower half of the nomogram, a line that corresponds to a stability after 1000 h of 0.5% intersects the 100 Ω resistance line at point b, corresponding to a hot-spot temperature of 112 °C (point c).

Extending the line (b-c) into the upper half of the nomogram, it intersects the line indicating an ambient temperature of 70 °C at point d, corresponding to a maximum permissible power dissipation of 0.25 W (point e).

If the power to be dissipated exceeds the value found, a resistor of higher value should be used.

The temperature coefficient

The temperature coefficient of resistance is a ratio which indicates the rate of increase (decrease) of resistance per Kelvin (K) increase (decrease) of temperature within a specified range, and is expressed in parts per million per K ($\times 10^{-6}$/K).

Example: If the temperature coefficient of a resistor of R_{nom} = 1 MΩ between –55 °C and +155 °C is $\pm 100 \times 10^{-6}$/K its resistance will be,

at 25 °C:

1000000 Ω (nominal = rated value)

at +155 °C:

$1000000\ \Omega \pm (130 \times 100 \times 10^{-6}) \times 1000000\ \Omega$ = 1013000 Ω or 987000 Ω

at –55 °C:

$1000000\ \Omega \pm (80 \times 100 \times 10^{-6}) \times 1000000\ \Omega$ = 1008000 Ω or 992000 Ω

If the temperature coefficient is specified as $\leq 100 \times 10^{-6}$/K the resistance will be within the shaded area as shown in Fig.2.

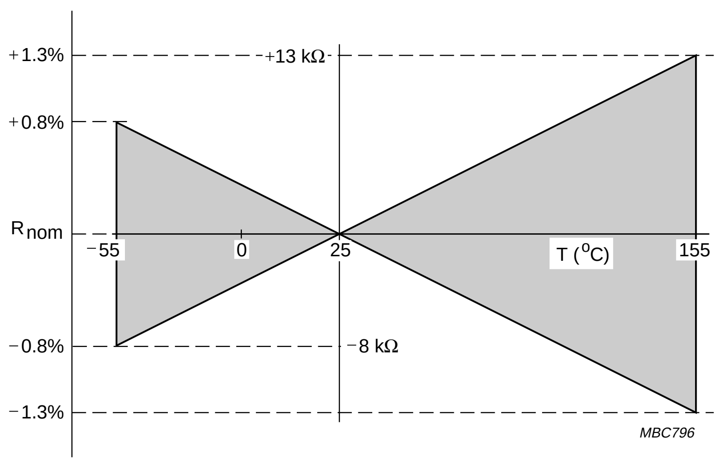


Fig.2 Temperature coefficient.

THERMAL RESISTANCE (R_{th})

Thermal resistance that prohibits the release of heat generated within the resistor to the surrounding environment. It is expressed in K/W and defines the surface temperature (T_{HS}) of the resistor in relation to the ambient temperature (T_{amb}) and the load (P = dissipation) of the resistor, as follows:

$T_{HS} = T_{amb} + P \times R_{th}$

The thermal resistance given in the specification is determined in accordance with DIN 44050 (T_{amb} between 20 and 25 °C).

The resistor is mounted on a PCB (see Fig.3) which is set up vertically, with the resistor horizontal. Using an infrared camera, a thermal image is made of the resistor, thus defining the hot-spot and solder-spot temperatures.

It should be noted that different ways of mounting give differing results, i.e. mounting with a higher heat conductance gives a lower thermal resistance figure; mounting with a lower heat conductance gives a higher thermal resistance figure.

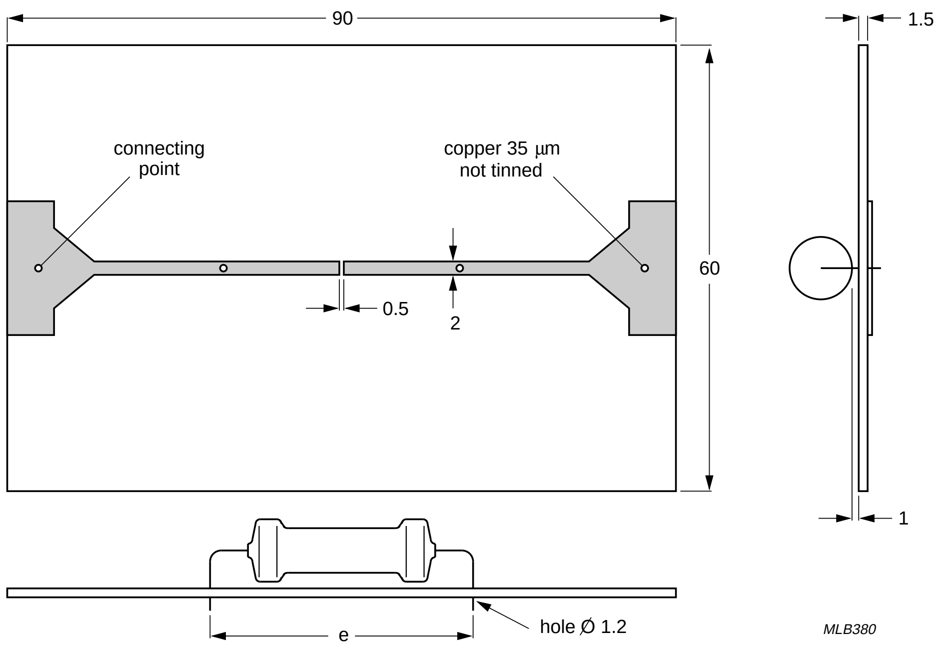
PULSE-LOAD BEHAVIOUR

Knowing the thermal characteristics of a resistor, it is possible to calculate the dissipation due to a single pulse, which will cause a resistor to fail by going open circuit. This theoretical maximum can be expressed in terms of maximum peak pulse power ($\hat{P}_{max}$) and pulse duration (t_i); the straight line in Fig.4 is a typical example for a film resistor. In practice, owing to variations in the resistance film, substrate, or spiralling, resistors fail at loads less than this theoretical maximum; the dashed line in Fig.4 shows the observed maximum for a resistor under single-pulse-load.

The magnitude of a single pulse at which failure occurs is of little practical value. More usually, the resistor must withstand a continuous train of pulses of repetition time t_p during which only a small resistance change is acceptable. This resistance change ΔR/R is equal to the change permissible under continuous load conditions. The continuous pulse train and small permissible resistance change both reduce the maximum handling capability.

Using a computer program which takes account of all factors affecting behaviour under pulse loads, curves similar to those of Fig.4 are being produced for all resistor ranges.

Measurements have shown that the calculated value is accurate to within 10% of the true value. However, maximum peak pulses as indicated in Fig.5 should not be exceeded.



Dimensions in mm.

Fig.3 Mounting dimensions.

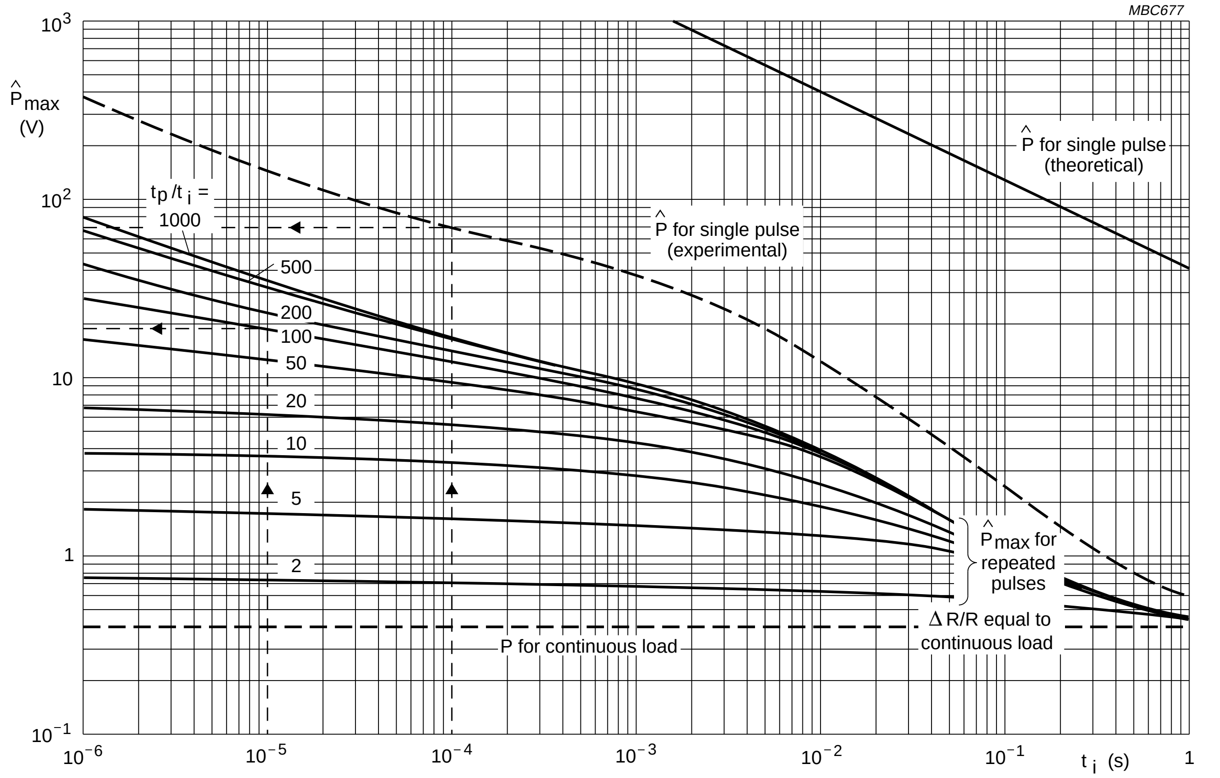


Fig.4 Maximum permissible peak pulse power ($\hat{P}_{max}$) as a function of pulse duration (t_i) for a typical resistor.

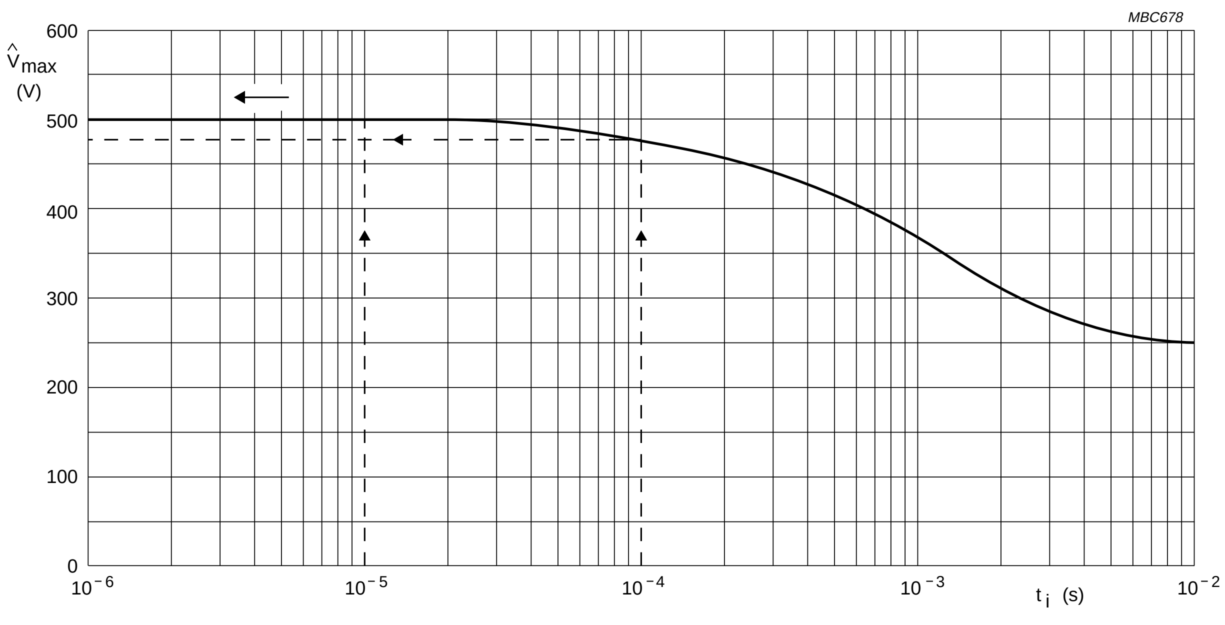


Fig.5 Maximum permissible peak pulse voltage ($\hat{V}_{max}$) as a function of pulse duration (t_i) for a typical resistor.

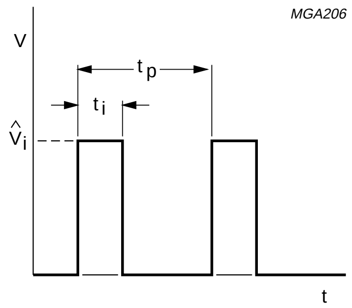


Fig.6 Rectangular pulses.

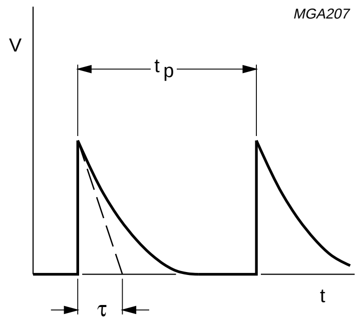


Fig.7 Exponential pulses.

Definition of symbols (see Figs 4, 5, 6 and 7)

SYMBOL	DESCRIPTION
$\hat{P}$	applied peak pulse power
$\hat{P}_{max}$	maximum permissible peak pulse power (Fig.4)
$\hat{V}_i$	applied peak pulse voltage (Figs 6 and 7)
$\hat{V}_{max}$	maximum permissible peak pulse voltage (Fig.5)
R_{nom}	nominal resistance value
t_i	pulse duration (rectangular pulses)
t_p	pulse repetition time
τ	time constant (exponential pulses)
T_{amb}	ambient temperature
$T_{m(max)}$	maximum hot-spot temperature of the resistor

Definitions of pulse-load behaviour; metal film resistors

SINGLE PULSE

The resistor is considered to be operating under single pulse conditions if, during its life, it is loaded with a limited number (approximately 1500) of pulses over long time intervals (greater than one hour).

REPETITIVE PULSE

The resistor is operating under repetitive pulse conditions if it is loaded by a continuous train of pulses of similar power.

Determination of pulse-load

The graphs in Figs 4 and 5 may be used to determine the maximum pulse-load for a resistor. The calculations assume:

T_{amb} = 70 °C

T_m is the maximum permissible hot-spot temperature for the relevant resistor family

$\Delta R/R$ equal to the permitted value for 1000 hours at continuous level.

- For repetitive rectangular pulses:
  - $\frac{\hat{V}_i^2}{R}$ must be lower than the value of $\hat{P}_{max}$ given by the solid lines of Fig.4 for the applicable value of t_i and duty cycle t_p/t_i.
  - $\hat{V}_i$ must be lower than the value of $\hat{V}_{max}$ given in Fig.5 for the applicable value of t_i.
- For repetitive exponential pulses:
  - As for rectangular pulses, except that $t_i = 0.5\ \tau$.
- For single rectangular pulses:
  - $\frac{\hat{V}_i^2}{R}$ must be lower than the $\hat{P}_{max}$ given by the dashed line of Fig.4 for the applicable value of t_i.
  - $\hat{V}_i$ must be lower than the value of $\hat{V}_{max}$ given in Fig.5 for the applicable value of t_i.

Examples

Determine the stability of a typical resistor for operation under the following pulse-load conditions.

CONTINUOUS PULSE TRAIN

A 100 Ω resistor is required to operate under the following conditions: $\hat{V}_i = 40$ V; $t_i = 10^{-5}$ s; $t_p = 10^{-3}$ s.

Therefore:

$$\hat{P} = \frac{40^2}{100} = 16 \text{ W and } \frac{t_p}{t_i} = \frac{10^{-3}}{10^{-5}} = 100$$

For $t_i = 10^{-5}$ s and $\frac{t_p}{t_i} = 100$, Fig.4 gives $\hat{P}_{max} = 19$ W

and Fig.5 gives $\hat{V}_{max} = 500$ V. As the operating conditions $\hat{P} = 16$ W and $\hat{V}_i = 40$ V are lower than these limiting values, this resistor can be safely used.

SINGLE PULSE

A 1000 Ω resistor is required to operate under the following conditions:

$\hat{V}_i = 200$ V; $t_i = 10^{-4}$ s

Therefore:

$$\hat{P}_{max} = \frac{200^2}{1000} = 40 \text{ W}$$

The dashed curve of Fig.4 shows that at $t_i = 10^{-4}$ s, the permissible $\hat{P}_{max} = 70$ W and Fig.5 shows a permissible $\hat{V}_{max}$ of 480 V, so this resistor may be used.

MECHANICAL DATA

A dimensional sketch and if applicable, a table of dimensions is given. The lead length of axial types is not usually stated if the resistors are only available on tape.

The sketch (see Fig.8) does include however, length (L), diameter of the body (∅D) and the lead diameter (∅d). For certain types, the length is stated as L_1 and L_2; L_1 is the body length, L_2 is the body length plus lacquer on the leads. By specifying L_1/L_2, the dimensional ‘clean lead to clean lead’ properties can be determined.

The length of the cylindrical body (L_1) is measured by inserting the leads into the holes of two identical gauge plates (Fig.9) and moving these plates parallel to each other, until the resistor body is clamped without deformation *(“IEC publication 194”)*.

This method does not apply to rectangular resistors, ‘stand-up’ types and wirewound resistors with side terminations.

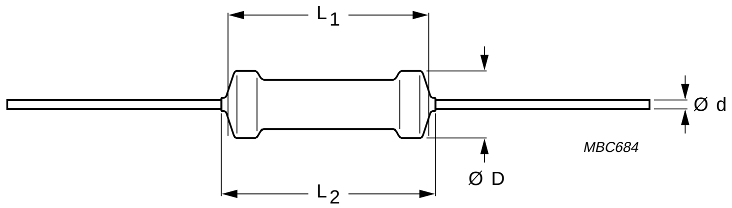
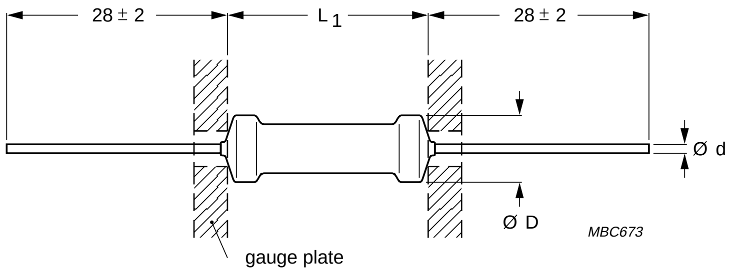
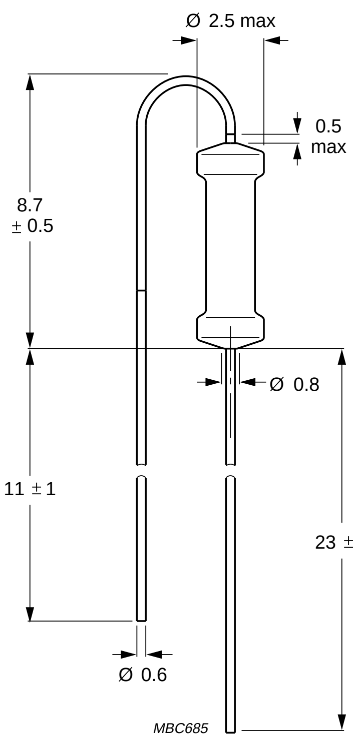


Fig.8 Component outline.



Dimensions in mm.
For dimensions see Table 1.

Fig.9 Measurement of dimension L_1.



Dimensions in mm.

Fig.10 SFR25 and VR25A are available as 'stand-up' types and shown in the 'mounted' position.

The relationship between the diameter of the leads and the diameter of the holes in the gauge plate is shown in Table 1.

Table 1 Lead diameter and hole dimensions

∅d (mm)	**HOLE DIAMETER (mm)**
0.5	0.8
0.6	1.0
0.7	1.0
0.8	1.2

Mass

The mass is given per 100 resistors.

Marking

The resistors are either colour coded or provided with an identification stamp. The colour code consists of a number of coloured bands in accordance with IEC publication 62: *"Colour code for fixed resistors"*. See also *"IEC 115-1"*, clause 4.5. The coloured bands indicate the **nominal resistance**, the **tolerance** on the resistance and, if applicable, the **temperature coefficient**. A maximum of bands may be used, but in some instances there are fewer, e.g. if the products are too small.

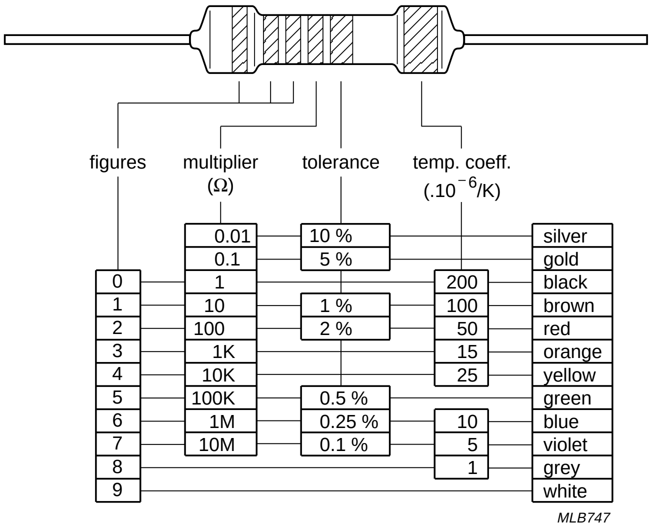


Fig.11 Marking.

The **resistance code** consists of either three or four bands and is followed by a band representing the **tolerance**. The **temperature coefficient** is to the right of the tolerance band and is usually positioned on the cap (MRS types), as a wide band. When five or six bands in total are used, the last band will always be the wider one.

The **resistance code** includes the first two or three **significant figures** of the resistance value (in ohms), followed by an **indicator**. This is a factor by which the significant-figure value must be multiplied to find the relevant resistance value. Whether two or three significant figures are represented depends on the tolerance: ±2% and higher requires two bands; ±1% and lower requires three bands.

The 'figures' refer to the first two or three digits of the resistance value of the standard series of values in a decade, in accordance with *"IEC publication 63"* as indicated in the relevant data sheet and shown on the inside back cover of this handbook.

Certain resistors are not coded by colour bands but by a stamp giving pertinent data (alphanumeric marking). This is adopted with MIL types MR24E/C/D, MR34E/C/D, MR54E/C/D and MR74E/C/D, as well as PR37 and PR52. Resistors outside the standard *"IEC 63"* series of types MPR24 and MPR34, are stamped. All wirewound resistors are stamped.

Body colours

Table 2 The resistor bodies are lacquered in different colours to simplify identification

COLOUR	TYPE
Tan	CR25
Light green	SFR25/SFR16
Grey	NFR25, NFR25H
Green	MR25, MR30, MR52, MR24E/C/D, MR34E/C/D, MR54E/C/D, MR74E/C/D, MPR24, MPR34, MRS16T, MRS25, AC04, AC05, AC07, AC10, AC15, AC20
Light blue	VR25, VR37, VR68, SFR16S
Red	PR37, PR52, PR01, PR02, PR03
Brown	WR0167E, WR0842E, WR0825E, WR0865E
Red-brown	SFR25H

Mounting

Most types with straight axial leads and most in the 'stand-up' version (radial leads; see Fig.10) are suitable for processing on automatic insertion equipment, cutting and bending machines.

TESTS AND REQUIREMENTS

Essentially all tests on resistors are carried out in accordance with the schedule of *"IEC publication 115-1"* in the specified climatic category and in accordance with IEC publication 68, *"Recommended basic climatic and mechanical robustness testing procedure for electronic components"*. In some instances deviations from the IEC recommendations are made.