2.6 RESISTORS’ ATTRIBUTES

1. *Resistance named value*: the value written on the body of the resistor in Ω.
2. *Named power*: the maximum thermal power the resistor can produce towards the environment, without getting destroyed; yet, is provided in a diagram by the manufacturer, in connection with the environment temperature. This is provided in Watts and specifies generally the dimensions of the resistor. Some standard power values are 1/8, 1/4, 1/3, 1/2, 3/4, 1, 2, 3, 4, 6, 7, 8, 10 etc. Watts.
3. *Resistance tolerance*: the % change of the named value and is provided as ±A%. The standardized values of tolerance are for every each series the following: E3 and E6 ±20%, E12 ±10%, E24 ±5%, E48 ±2%, E96 ±1% and E192 ±0.1% or ±25% or ±0.5%. The series E192 for resistors of very high accuracy has also the tolerance values ±0.01%, ±0.02% or 0.05%.
4. *Maximum operation voltage*: that which causes the loss of warmth, as much as the named value of power and is provided by the following equation:

$$U_{max} = \sqrt{P R_{max}} \qquad \left(V_{DC} \quad ή \quad V_{RMS}\right)$$

5. *Voltage factor*: the value expressing the change in the value of resistance, according to the voltage applied in its ends and is provided in ppm/V. this change is expressed approximately by this equation:

$$R_U = R_0\left[1 + k_U\left(U - U_0\right)\right] \qquad (\Omega)$$

   where R_U is the resistance in voltage U, R_0 and U_0 are the resistance and the reference voltage respectively and k_U is the voltage factor of the resistance, in ppm/V.
6. *Temperature coefficient*, in ppm/°C.
7. *Noise voltage*: the equivalent noise power voltage which describes a resistor and is provided in μV/V, in relation with the resistance named value. On Figure 2.8 you can see the change of the noise power voltage for different types of metal film resistors.

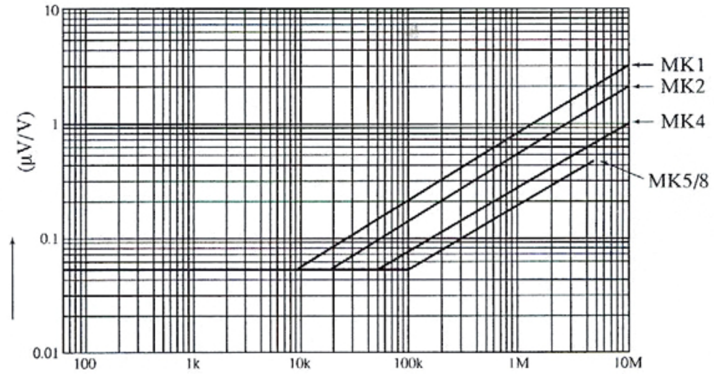


Figure 2.8 Axes: **Y:** Noise voltage (μV/V), **X**: resistance value

8. *Non-linearity:* the % change of resistance which is caused by the applied voltage and is provided by the equation:

$$N.L\,\% = \frac{\Delta R}{U_1}100$$

It is also defined by the:

$$N.L = 20\log\frac{U_1}{U_3} \quad (dB)$$

where N.L is the non-linearity, that is the relationship between voltages of the basic and the third harmonic (the other harmonics are not considered), U_1, U_3 are the voltages of the basic and the third harmonic respectively, which are produced by a resistor. In our measurements, we take the value of 10KHz for basic frequency. In Fig. 2.9 you can see the change of the non-linearity in relation with the value of metal film resistor.

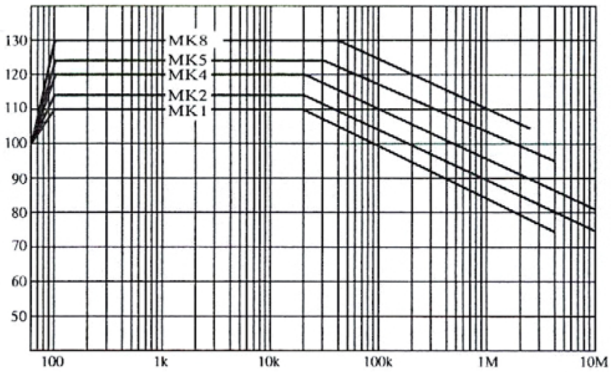


Figure 2.9 Axes* Y*: Non-linearity A_3 (dB), **X**: resistance value

9. *Slide* ΔR/R %: it is the permanent change of the resistance which is provoked by the structural changes of the material. The slide is reducing exponentially in relation with time, which means that the older the resistor the more stable it is. This is why in very accurate circuits there are used components which have been submitted to artificial aging. High temperatures, humidity, large current and other factors can increase the slide of a resistor.
10. *Stability of a resistor*: this is the ratio given by the equation:

$$S\,\% = \frac{R_0 - \Delta R}{R_0}100$$

where R_0 is the resistance in reference conditions and ΔR is the change of resistance. Fig. 2.18 shows how stable is the value of a resistor under specific operational conditions.

11. *Operational temperatures*: it is the range of values in which a resistor operates without problems. Depending on the type of resistor, those ranges differ: (-55~+155)°C or (-20~+250)°C etc.

2.8.1.2. Between the common resistors we can find those with power ranging from 1/8W to 4W and in their coding, they (usually) comply with their color code.

The stable resistors of common forms are manufactured by various materials and are classified according to them because they have different attributes and consequently, different behavior.

Those resistors are: a) carbon composition, b) carbon film, c) metal film, d) wirewound, e) cermet film.

We are not going to refer at this point to the manufacturing technique and materials of resistors; we are going to work on their attributes, which are essential to technicians for confronting a problem with the right way. We present them in Table 2.3.

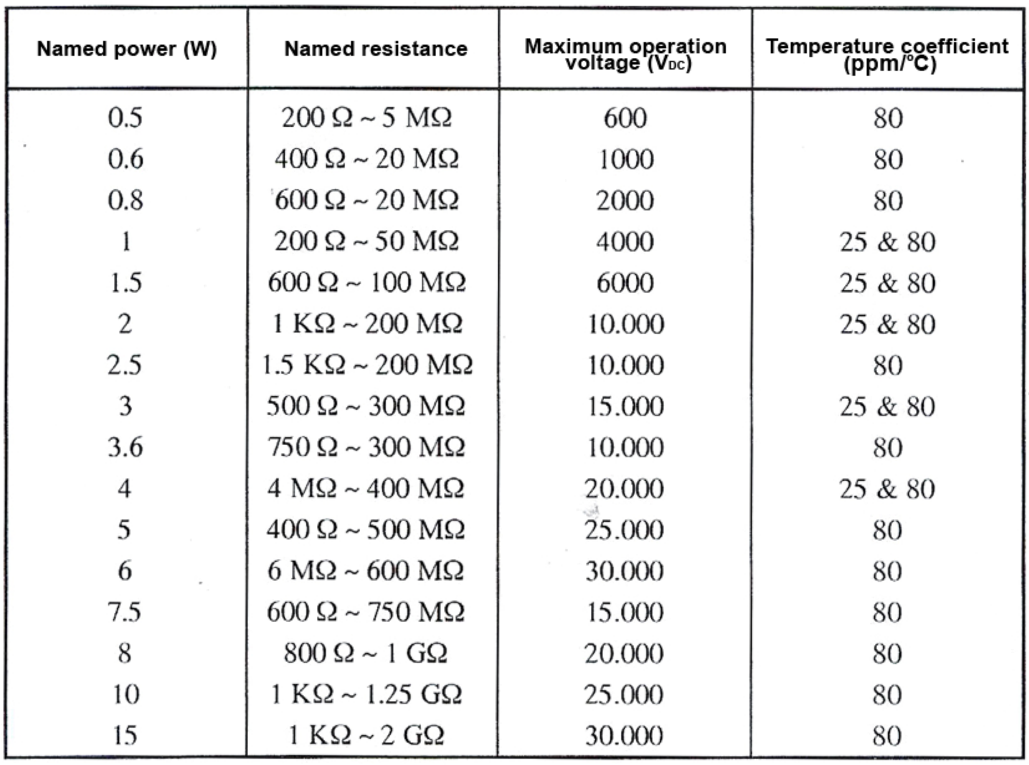
Table 2.3

a/a	Attributes	Carbon composition	Carbon film	Metal film	Wirewound	Cermet film
1	Ονομαστική τιμή	1Ω ~ 10MΩ	1Ω ~ 10MΩ	0.1Ω ~ 125MΩ	0.015Ω ~ 4MΩ	10MΩ ~ 100MΩ
2	Ονομαστική ισχύς (W)	1/8 ~ 2	1/8 ~ 2	1/8 ~ 30	1/10W ~ 1KW	0.4
3	Ανοχή ±%	5, 10, 20	5	0.005 ~ 5	0.01 ~ 10	5
4	Θερμοκρασιακός συντελεστής ppm/°C	– 1200 ~ – 8000	– 150 ~ – 1000	– 100 ~ +150	– 200 ~ +400	± 300
5	Περιοχή θερμοκρασιών λειτουργίας °C	– 55 ~ +130	– 55 ~ +155	– 55 ~ +275	– 55 ~ +450	0 ~ 130
6	Σειρές E	3 ~ 24	24	24 ~ 192	6 ~ 192	24
7	Σταθερότητα	Μέτρια	Καλή	Πολύ καλή	Καλή έως πολύ καλή	Καλή
8	Τάση θορύβου μV/V	2 + log (R/100) R σε Ω 1000	0.1 ~ 6.5	0.1 ~ 1.5	< 0.1	0.1
9	Ισοδύναμη χωρητικότητα pF	< 0.5	0.2 ~ 0.6	—	—	—
10	Μέγιστη τάση λειτουργίας V_{DC}	200 ~ 500	200 ~ 700	(200 ~ 6000) V_{DC} (180 ~ 4000) V_{AC}	35 ~ 2500	≤ 1000

The above values are the extreme values for a type of resistor and are not globally applied to the specific type. For example, the carbon film resistors of 1/4W, the named values range from 1Ω to 10MΩ, while those of 1/8W, the values range from 2.2Ω to 4.7MΩ. Similarly, the temperature coefficient of the first is (-150 ~ -800)ppm/°C, while of the latter is (-100 ~ -700)ppm/°C. The same applies for the rest of the attributes and for all types of resistors. It is wise then, when this is necessary, to consult the manuals written by the manufacturers.

In Table 2.4 we present some values for the metal film resistors of very high voltage (Fig. 2.13). These are used in amplifiers and power packs of threading wave tubes (TWT), systems of x-rays, geophysical measurements, medical equipment and electronic microscopes. They operate between almost -55 and +225 °C and their resistance tolerance value lies between ±0.1 and ±1%.

Table 2.4



Named power (W)	Named resistance	Maximum operation voltage (V_{DC})	Temperature coefficient (ppm/°C)
0.5	200 Ω ~ 5 MΩ	600	80
0.6	400 Ω ~ 20 MΩ	1000	80
0.8	600 Ω ~ 20 MΩ	2000	80
1	200 Ω ~ 50 MΩ	4000	25 & 80
1.5	600 Ω ~ 100 MΩ	6000	25 & 80
2	1 KΩ ~ 200 MΩ	10.000	25 & 80
2.5	1.5 KΩ ~ 200 MΩ	10.000	80
3	500 Ω ~ 300 MΩ	15.000	25 & 80
3.6	750 Ω ~ 300 MΩ	10.000	80
4	4 MΩ ~ 400 MΩ	20.000	25 & 80
5	400 Ω ~ 500 MΩ	25.000	80
6	6 MΩ ~ 600 MΩ	30.000	80
7.5	600 Ω ~ 750 MΩ	15.000	80
8	800 Ω ~ 1 GΩ	20.000	80
10	1 KΩ ~ 1.25 GΩ	25.000	80
15	1 KΩ ~ 2 GΩ	30.000	80

Figure 2.13

Apart from the stable resistors, there are the voltage or current dividers in SIL form, as shown in Figure 2.14.

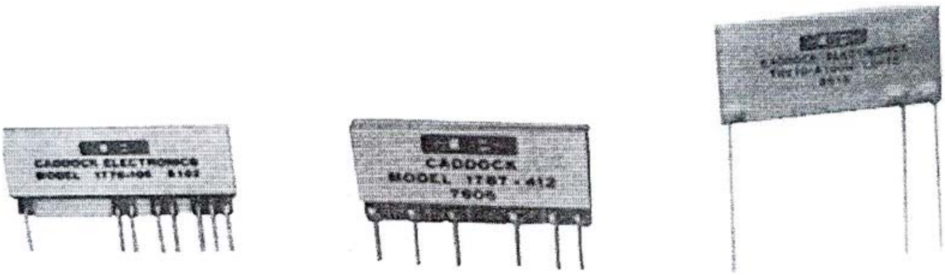

Voltage divider Current divider Voltage divider

Figure 2.14

The voltage dividers are used in the power packs of TWT, in radar and x-rays systems and the high resolution cathodic tubes (screens). The current dividers are used in various meters. The voltage dividers are operating in temperatures between 55 and +175ºC. We can find the voltage dividers in 2, 3, 4 and 5 tens with rations 10:1 to 10.000:1. In Table 2.5, you can see their attributes and figure 1~6 of the table corresponds to those of the Figure 2.15.

Table 2.5

Figure	R_1	R_2	R_3	R_4	R_5	Resistance tolerance	Ratio resista-nce tolerance	Voltage factor (ppm/V)	Named voltage (V_{DC})	Temperature coefficient of resistance ratio
1	99MΩ	90KΩ	10KΩ	—	—	±0.25%	±0.02% ±0.05%	0.02	1200	5 10
2	9MΩ	900KΩ	90KΩ	10KΩ	—	±0.25%	±0.05% ±0.1%	0.02	1200	10
4	9MΩ	900KΩ	90KΩ	10KΩ	—	0 ~ −0.5%	±0.1%	0.2 0.3	1200	5 10
3	9MΩ 9MΩ	900KΩ 900KΩ	90KΩ 90KΩ	9KΩ 10KΩ	900Ω 1KΩ	±0.1% ±0.25%	±0.05% ±0.1% ±0.25%	0.2 0.3	1200	50
2	900KΩ 900KΩ	90KΩ 90KΩ	9KΩ 9KΩ	900Ω 1KΩ	— —	±0.1% ±0.25%	±0.05% ±0.1% ±0.25%	0.3 0.4	1200	25
3	9MΩ 9MΩ	900KΩ 900KΩ	90KΩ 90KΩ	9KΩ 9KΩ	900Ω 1KΩ	±0.1% ±0.25%	±0.1% ±0.25%	0.5	1200	50
5	10MΩ	1.1111MΩ	101.01KΩ	10.01KΩ	1.0001KΩ	±0.1% ±0.25% ±0.5%	±0.05% ±0.1% ±0.25% ±0.5%	0.1 0.5	1200	10 50
3	9MΩ 9MΩ	900KΩ 900KΩ	90KΩ 90KΩ	9KΩ 9KΩ	900Ω 1KΩ	±0.1%	±0.05% ±0.1%	0.1		10 15
6	99.9MΩ 99MΩ	100KΩ 1MΩ	—	—	—	±1%	±0.25% ±0.5%	-	10.000 στους +125°C	10 25

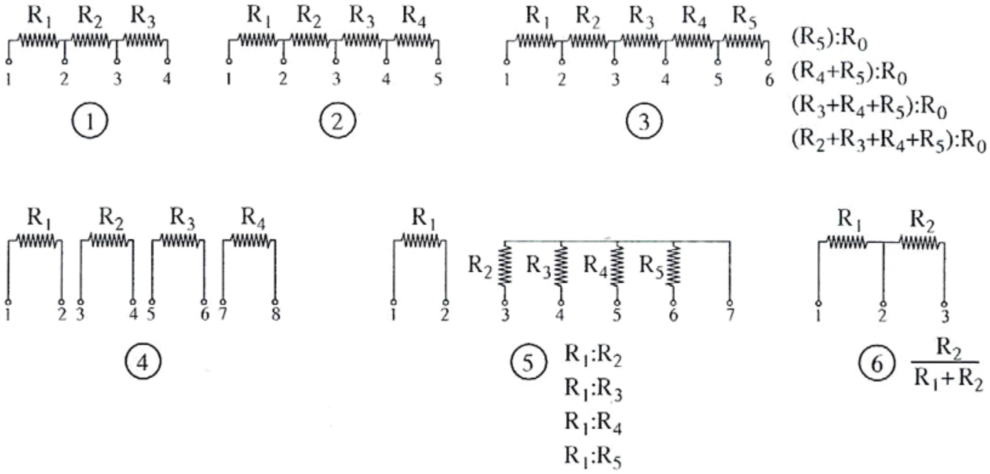


Figure 2.15

In Figure 2.16 you can see the attributes of the current dividers. They operate in temperature ranging from -55 to +125ºC.

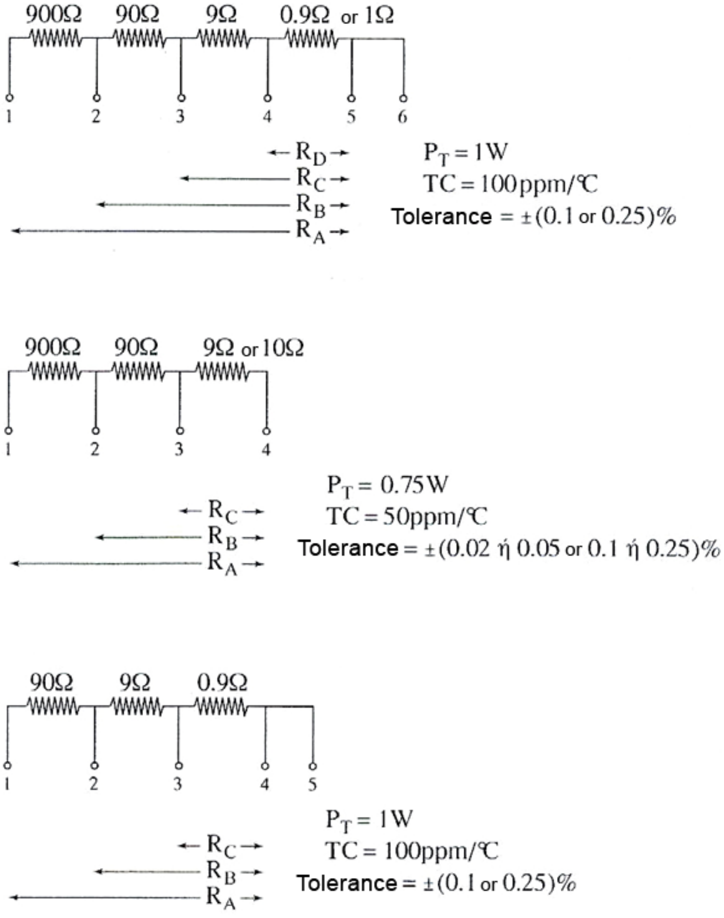


Figure 2.16

The voltage dividers have the code of their elements printed on their cortex, i.e. THV10-A-100M-1.0-10, where THV10 is the type of the divider (manifacturer's element), A=1000:1 is the voltage ratio and B=100:1, 100M-100MΩ is the value of the total resistance, 1.0 is the resistance ratio tolerance in the operational temperatures. We can then have a code like T912-A-10K-010-02 or 1776-C61, which must be encoded by the manual of the manufacturer. The same applies to the current dividers.

Note
In the market you can also find the stable "resistors" called Zero Ohm Link, or else, zero-value resistors, namely short circuits. They usually are yellow (see Figure 2.17) and 1/4W, which values ranging from 0.002Ω to 0.01Ω. They are used for short circuits, that is, for linking two different points in a circuit. They have almost zero distributed capacity and self-inductance.

Figure 2.17

We must mention that the color of the resistor body refers to the category it belongs to according toy the Diagram 2.1.
If the color of the body of a common resistor is:

a. light blue, it is a high value/high voltage resistor;
b. grey, it is a safety resistor;
c. green, it is an accuracy or high accuracy resistor;
d. brown or green, it is a wirewound resistor;
e. red, it is a metal film resistor;
f. black, it is an accuracy wirewound resistor;
g. brown or light green or rarely red-brown, it is a standard resistor.

In f, the resistors don't comply with the color code but with the second way of encoding.
The manufacturers give eigen functions or nomograms for the behavior of resistors, as that of the slide ΔR/R%, of the increase of thermal point temperature in relation with the power or the length of the connectors, of the allowed maximum voltage or power of the pulse peak in relation with the pulse duration etc. In Fig. 2.18a we provide the change in the temperature of the thermal point in relation with the consumption power and in Fig. 2.18b, we provide the respective change for different lengths of resistors connectors.

In Table 2.13 we show the applications of thermistors.

Table 2.13

PTC	Demagnetizing	- color TV - monitor
	Temperature sensor – Protection from temperature	- industrial electronics - power packs - electronic data process
	Protection from overcharging	- telecommunications - car systems - industrial electronics - commercial electronics - electronic data process

NTC	Temperature sensor	- home appliances - car systems - industrial electronics - medical equipment electronics
	Overcharging limiter	- power packs - light - electronic data process
	Temperature compensator	- commercial electronics - industrial electronics - electronic data process

1) NTC

When the temperature rises, the resistance of NTC decreases. The resistance changes according to the equation:

$$R_{T_1} = R_{T_2} \cdot e^{\left(\frac{B}{T_1} - \frac{B}{T_2}\right)} \quad ή \quad R = A \cdot e^{B/T} \quad ή \quad \log R = A + \frac{B}{T}$$

where T is the operational temperature in K and A, B are the dependent on the material factors. B ranges between 2000 and 5000K.

A and B remain almost constant between T_1 and T_2 temperatures, in which NTC operates; our measurement temperatures are 25°C and 85°C respectively. The manufacturers provide us with the resistance of NTC in 25°C and 85°C and the index $B_{25/85}$ in Kelvin. B is given by the equation:

$$B = \frac{\ln \frac{R_1}{R_2}}{\frac{1}{T_1} - \frac{1}{T_2}} \quad (K)$$

where R_1 and R_2 are the measured resistance in T_1 and T_2 temperatures.

There is also the factor α of a NTC given by the equation:

$$\alpha = -\frac{B}{T_2}$$

The eigen function of voltage-intensity for a common NTC is shown in Fig. 2.48, which is printed on logarithmic paper. We notice that apart from the voltage and intensity, we are also provided with the resistance and power of NTC, so in case we know its voltage and intensity, we can conclude its power or its resistance.

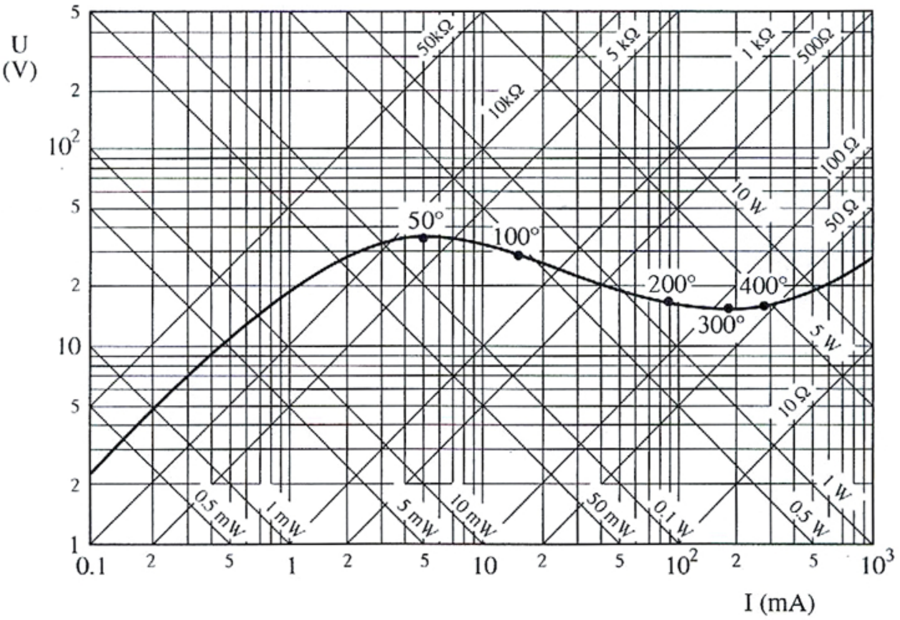


Figure 2.48

- The thermal time constant of the element expresses in sec the time needed for the thermal balance between element and environment to come. This results from the equation $\tau=H/\delta$, where H is the thermal capacity in J/K and δ is the loss factor in W/K.

- The tolerance on the resistance named value of NTC is the one given for the reference temperature of 25°C, that is for R_{25}, and is a result of the divergence of B. In Fig. 2.49 you can see the change of R_{25} in relation with the temperature for some given tolerance.

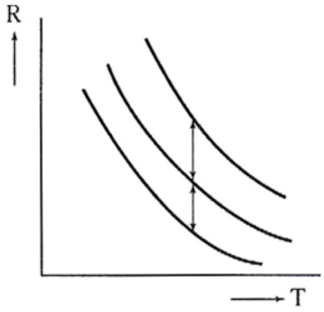


Figure 2.49

- Temperature divergence ΔT is the range of temperatures in which NTC has a stable resistance value and results from the equation:

$$\Delta T = \frac{Z}{\alpha}$$

where Z is the total divergence and is about Z=Y+X, where X is the tolerance R_{25} and Y is the divergence of the resistance value which is owed to B, that is $\Delta R/B_{total}$.
If for instance X=±5%, Y=0.89% and α=5.09%K in 0°C for R_{25}=10KΩ, then Z=5+0.89=5.89% and ΔT=5.89/5.08=1.16, which means that this particular NTC is 32.51KΩ in ±1.16°C. The value 32.51KΩ comes from the tables RT/R25 of the manufacturers.

In Fig. 2.50, we show the eigen functions R=f(T_j), that is from 85°C to 25°C, R=f($t_{heating}$), that is from 25°C to 85°C and U_{DC}=f(I_{DC}) for a set of common NTC.

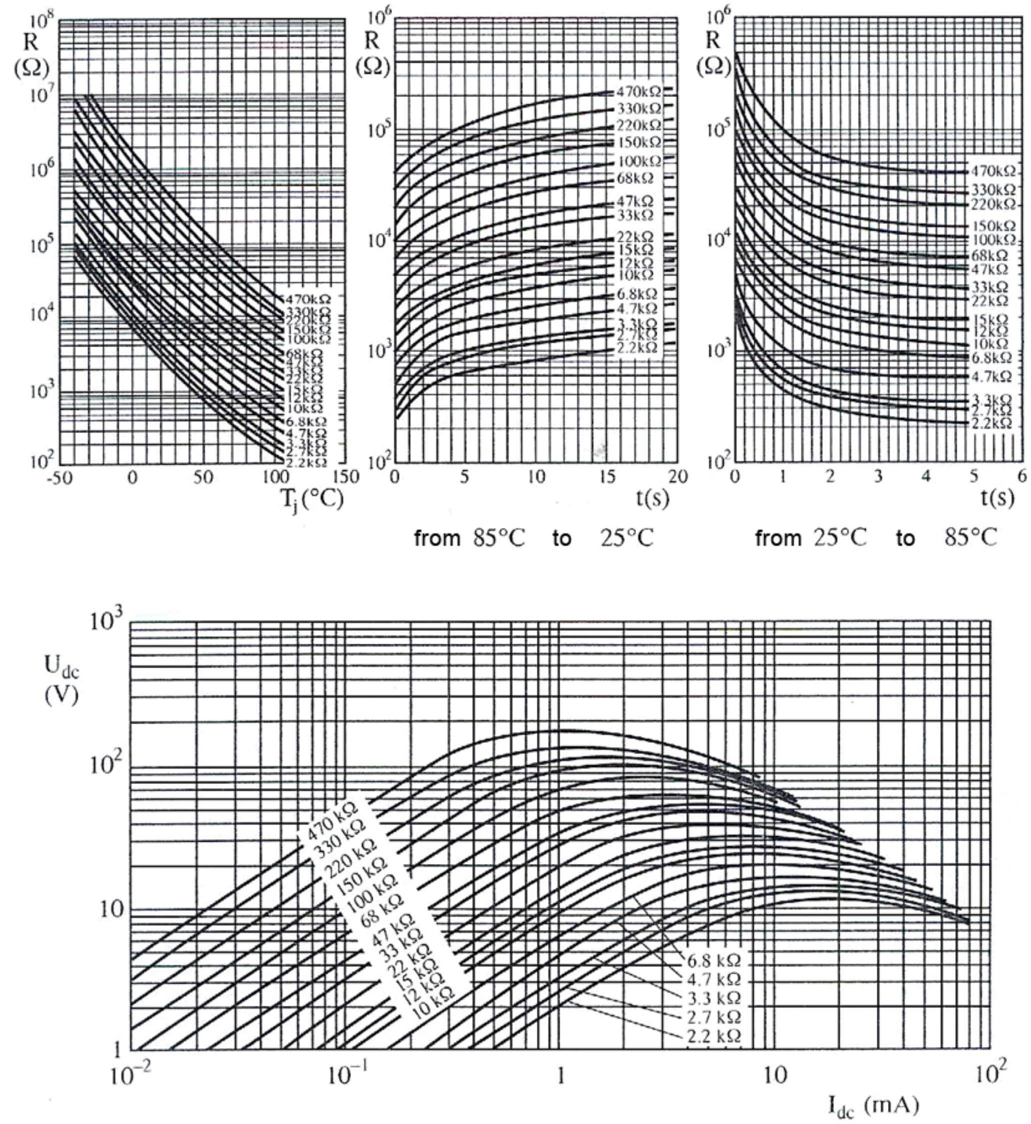


Figure 2.50

In Table 2.14 we present attributes of different NTC types.

Table 2.14

NTC (overcurrent limiters)

s/n	Attributes	Without connectors	High power	High current
1	R_{25} (Ω)	5	4-8-15-33	2.5~20
2	Tolerance R_{25} (±%)	20	10-20	25
3	$B_{25/85}$ (K)	2975	2850-3250	2950-3600
4	Tolerance $B_{25/85}$ (±%)	-	5	-
5	Operational temperatures (°C)	-25~+155	-25~+125	-25~+155
6	Maximum power (mW)	$I_{RMS(max)}$ 8A*	1000	$I_{RMS(max)}$ (2.5~15)A*
7	Thermal constant of time (sec)	-	60	148
8	Code	Red stain in the centre	Color code	-

** We are provided with $I_{RMS(max)}$ in A and not the power.*

NTC are used in industrial and medical thermometers, in temperature measurements in radiators, in indicators of fluid and liquid levels, as temperature sensors with bridge amplifier, thermostats, action hysterisis in relays, correction of temperature in push-pull amplifier, overcurrent limiters in power supplying of bulbs etc.

Table 2.14

NTC (Temperature sensors and correction of temperature)

s/n	Attributes	Special accuracy	Various temperatures	Low temperatures	Medium temperature	Special manufacturing	Big connectors	Screw type	Glass box	Without connectors	Miniatures	SOD 27*	SOD 80*	Low resistance
1	R25	(2.7~470)K (2.2~470)K	(4.7~100)K	R_{-10}=15.3KΩ R_{-30}=48.5KΩ R_{25}=5KΩ	5KΩ 10KΩ	12KΩ 310KΩ	10KΩ	(2.2~470)K 3.3Ω~1.5K	1K~1M	930Ω~2.6K	1K~1M	220KΩ	10K~30K	3.3Ω~1.5K
2	Tolerance R25 (±%)	1-2-3-5 2-3-5-10	0.5	5 6 3	2 3	5-7 7	5	5-10	5-10	10	5-10	5-10	5-10	-
3	$B_{25/85}$ (K)	3977~4570	3977~4190	3977 3965 -	3977	3750 4300	3993	3977~4750 2675~3975	2075~4100	3500~4100	2075~4100	3797	-	2675~3975
4	Tolerance $B_{25/85}$ (±%)	0.73~3	-	- - 0.5	0.5	-	1.2	0.75~3 -	5	5	5	3	-	5
5	Operational temperatures (°C)	-40~+125	-40~+125	- -55~+125 -40~+125	-40~+125	-10~+125 -25~+200	-40~+125	-25~+100	+200 -55~ +200 +300	-55~+200	-55~+200	+25~+300	0~+555	-25~+125
6	Maximum power (mW)	100 500	250	250	100	250	100	500	60 100 100	-	-	100	100	500
7	Thermal constant of time (sec)	13 11	11	11	-	5^{+}~33 8.5^{+}~33	-	7.5 20	5.5 10 7.5	-	-	-	6	17
8	Code	Black body Color code	Grey body	Brown blue in grey body Grey body -	Grey body	Grey stain Blue stain	Black body	- -	Color code Color code -	Orange or yellow ring	-	-	-	Color code

* Box types

$^{+}$ With cooler

In Fig. 2.51 we present various packages of NTC.

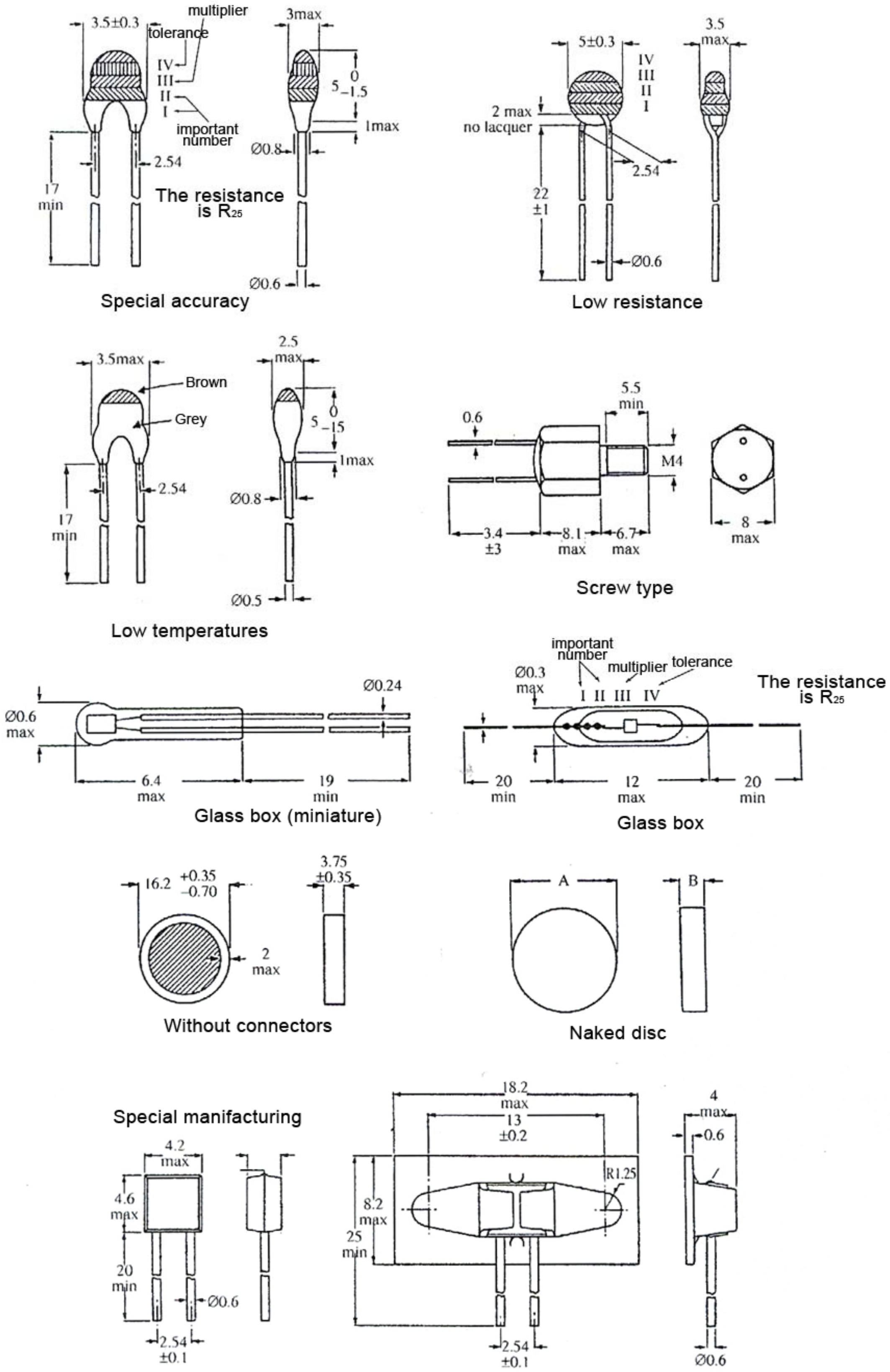


Figure 2.51