FIXED LINEAR RESISTORS

1. The purpose of the paper: Knowledge of the characteristic parameters, of the constructive structure of various types of resistors with terminals for insertion and surface mounting, performing specific measurements.

2. Theoretical background: The resistor is a passive electronic component, predominantly resistive in nature up to a certain frequency. Resistance, the main parameter of the resistor, is the ratio of the voltage at its terminals and the current running through the resistor.

Resistors may be linear or nonlinear, fixed or variable. In this paper, the fixed linear resistors are being discussed, which exhibit a linear U(I) characteristic and the value of the resistance can't be changed during use.

The measure unit for the resistance is the Ohm (1 Ω = 1V / 1A) with its multiples and sub-multiples: $1\ \mu\Omega = 10^{-6}\ \Omega$, $1\text{m}\ \Omega = 10^{-3}\ \Omega$, $1\text{k}\ \Omega = 10^{3}\ \Omega$, $1\text{M}\ \Omega = 10^{6}\ \Omega$, $1\text{G}\ \Omega = 10^{9}\ \Omega$.

2.1 Parameters of the resistors

Rated resistance R_N, is the desired resistance value to be obtained during the manufacturing process and it is inscribed on the body of the resistor. The rated values are internationally standardized and are presented in Annex 5.

Tolerance t [%], is the maximum relative deviation of the actual R value of the resistance from the rated value R_N. One can determine it using the formulas:

$$t_+ = \frac{R_{\max} - R_N}{R_N}\text{, positive tolerance,} \qquad (1)$$

$$t_- = \frac{R_{\min} - R_N}{R_N}\text{, negative tolerance,} \qquad (2)$$

$$t = +/-\ maxim\{|t_-|, t_+\} = +/-\ maxim\frac{|R - R_N|}{|R_N|} \qquad (3)$$

where R is the actual resistance's value of the resistor.

Tolerance values are standardized and are presented in Table 2. Tolerance **t** is the tolerance resulting in the production process. Both $\boldsymbol{R_N}$ and ***t*** are measured at room temperature (20°C or 25°C).

Range for the working temperature, $[T_m, T_M]$, is the range of the temperature values T_m and T_M from which the manufacturer assures proper behaviour of the resistor. Temperatures T_m, and T_M respectively, are the minimum, and respectively the maximum temperature that can be reached at any point of the resistor during operation.

Rated power P_N [W], the maximum power that a resistor can be subjected to during a long operating time in an environment with a temperature equal to the rated temperature T_N. It is given by:

$$P_N = D(T_M - T_N) = \frac{T_M - T_N}{R_{th}} \qquad (4)$$

Coefficient for heat dissipation D [W/°C];

Thermal resistance R_{th} [°C/W], characterizing the heat transfer from the resistive element to the environment. Relation of determination results from (4):

$$D = \frac{P_N}{T_M - T_N} = \frac{1}{R_{th}} \qquad (5)$$

Rated temperature T_N [°C], is the maximum ambient temperature a resistor can withstand for a long operating time when subjected to the rated power, P_N.

Maximum allowable thermal power $P_{A\theta}$ [W], is a working parameter and it indicates the maximum power that can be applied onto a resistor for a long operating time in an ambient temperature $T_a \in [T_m, T_M]$..

It can be determined with the relations:

$\boldsymbol{P_{A\theta} = P_N}$, for $\mathbf{T_a \leq T_N}$;

$$P_{A\theta} = P_N \frac{T_M - T_a}{T_M - T_N}, where\, T_a \in (T_N, T_M) \qquad (6)$$

Basically, the catalog presents the plot of this dependency, called the derating diagram showing the dissipation or more precisely the reduction of the dissipation.

Rated voltage (limit) V_N [V], is the maximum voltage that can be applied at the terminals of a resistor during lengthy operation, being limited due to dielectric breakdown. In practice, it does not mean that this voltage can be applied to a resistor regardless of its value, since the limitation due to the dissipated power of the resistor also intervenes. The value of the resistance where we pass from the limitation caused by the power dissipation to that caused by the voltage, (= V_N) is the critical resistance.

Maximum allowable voltage V_A [V], is the maximum voltage that can be applied at the terminals of a resistor with a certain R_N value during long term operation.

$$V_A = \sqrt{P_N \cdot R_N} \leq V_N \qquad (7)$$

If the ambient temperature exceeds T_N instead of the P_N power, $P_{A\theta}$ is chosen.

Critical resistance R_c [Ω], is the value of a resistor's resistance to which terminals the rated voltage V_N is applied and which is subjected to the rated power P_N.

$$R_c = \frac{V_N^2}{P_N} \qquad (8)$$

The coefficient of variation with temperature α_R, [ppm/°C], expresses the relative deviation of the resistor's resistance to changes in temperature. The acronym TCR - Temperature Coefficient of Resistance is widely used. It is defined by:

$$\alpha_R = \frac{1}{R}\frac{dR}{dT} \qquad (9)$$

The resistance usually has a linear variation with temperature, resulting in this case:

$$\alpha_R = \frac{\Delta R}{R_O} / {}^oC \qquad (10)$$

where ΔR is the change in the value of the resistance R_0 to a change of the resistor's body temperature by 1°C.

Noise factor F [μV/V], is the ratio between the amount of noise voltage that appears at the terminals of a resistor, expressed in μV when applying a continuous voltage of 1V. The noise index is also used, measured in dB. NI = 20log (F) [dB]

Reactive parasitic elements L, C

Any type resistor has reactive elements such as inductance and capacity which depend on the structure of the resistor. The equivalent circuit of a resistor with the resistance value R at high frequencies is given in Figure 1.

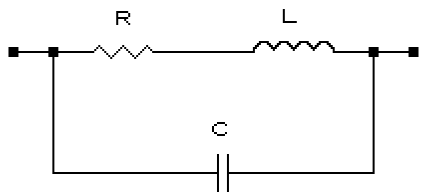

Fig.1 Equivalent circuit of a resistor

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Insulation resistance R_{iz}, is the resistance measured between resistor's terminals and the body, the measurement being performed under certain conditions. Sometimes the manufacturers of components provide the breakdown voltage (maximum) of the insulation for element of protection.

2.2 The constructive structure of the resistors

Resistor generally have the constructive structure shown in Figure 2.

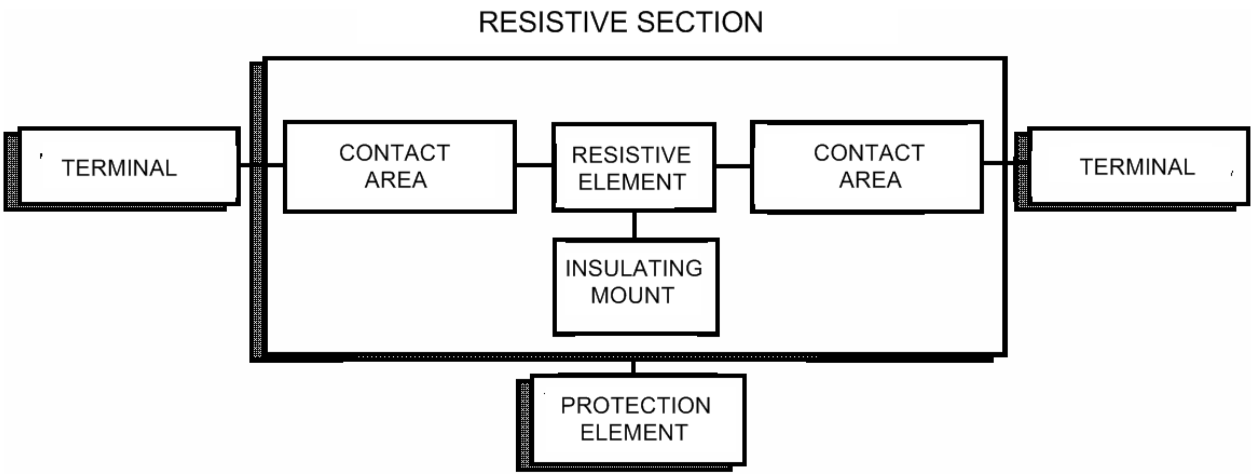

Fig.2 The constructive structure of the resistor

The main classification of the fixed linear resistors results from the technology used in producing the resistive element, thus distinguishing between film resistors, wirewound and volume. The most frequently used are the film resistors, whose resistive element has a resistive film with a thickness range from 0.1μm to tens of μm. We can distinguish between different types, namely: carbon film, metal film (produced by thin layers technology), coated metal resistors(obtained by thick layers technology), metal oxides film.

Carbon film resistors with axial terminals have the structure presented in figure 3.

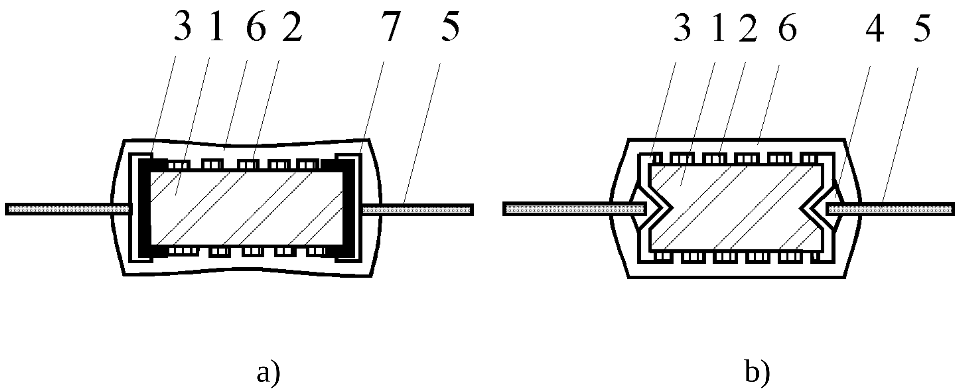

Fig.3 The structure of the carbon film resistors with axial terminals

According to Figure 3 the carbon film resistor has the following constituent parts:

1 - insulating mount, a cylindrical shape of different sizes depending on the future resistor's rated power. It is made of ceramic materials.

2 - resistive element, a carbon film deposited by pyrolysis on the insulating support. To increase the value of the resistance, the resistive film, at first a cylindrical form is screwed with abrasive disks, in the end resulting into a spiral resistive element that affects the growth of the parasitic inductance and capacity of the future resistor.

3 - a film of nickel, electrochemically deposited on the ends of insulating support, in order to achieve the connection terminal – the resistive element.

4 - the solder, which makes the connection of the terminal to the Ni film. This is achieved by soldering with an Sn-Pb alloy.

5 - the terminal, of tinned Cu, with a cylindrical form of various diameters.

6 - protective element made of a thermo-resistant varnish.

The structure shown in Figure **3.b** corresponds to the carbon film resistors with $P_N \in [0.25, 2]$W with the terminals attached. Other variants are those with the structure of Figure **3.a,** differing only by the contact area, namely the terminal is welded to a cap of Ni (7), and this is pressed on the body of the resistor making the contact with the Ni film (3).

Metal film resistors

The structure of these resistors is similar to that shown in Figure 3, the only difference being the resistive element. Specific to these resistors is the metal film (the resistive element) which is made using the thin layers technology, hence the name thin film resistor. The film has a thickness from 50 nm to 1 mm, being much thinner than that of thick film. In order to achieve the resistive metal film the materials that can be used are metal alloys (Cr-Ni, Ni-Cr-Fe, Ni-Cu, Cr-Co, Cu-Mn-Ni), tantalum nitrides, cermets based on metal oxides, etc. These can be made in two variants of SMD (Surface Mounted Devices-ie surface mount component) a) MELF (Metal Electrode Face-Bonded) and parallelepipe (chip).

Metal oxides film resistors

These resistors have a similar construction to that of the carbon film and metal film resistors. The resistive film is mostly tin oxide and is deposited using the hydrolysis of tin chloride and has a thickness of 0.5 ... 1.5 μm. The advantage of these resistors is the possibility to load the resistance up to a temperature of 300 °C, thus achieving relatively high power film resistors and small sizes. Being equivalent to the wirewound resistors they are not used in the circuits where accuracy is important.

Coated metal film resistors have the structure shown in Figure 4.

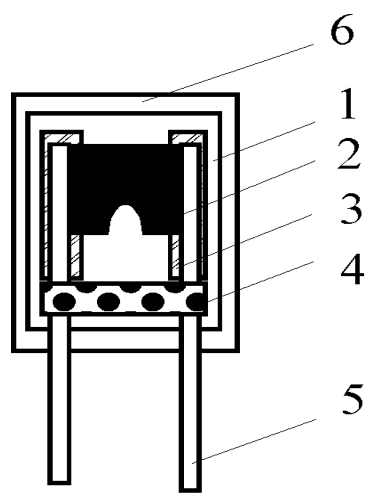

Fig.4 Structure of a coated metal film resistor

According to Figure 4, coated metal resistor consists of the following elements:

1 – insulating mount which is made of alumina, a material with high mechanical strength, enabling it to obtain an almost flat form, having a relatively small thickness while the other dimensions are proportional to the rated power of the future resistor.

2 - resistive element, comprising a screen film obtained by the serigraphic depositing of a resistive paste. It has a rectangular or hat-like form. After the screen printing, the thermal treatment and other technological steps, the resistive film is adjusted to the desired value using an abrasive powder, i.e. a certain portion of the film is removed until the desired rated value is achieved for the expected tolerance.

3 - Ag-Pd film, deposition by screening in view of connecting the terminal to the resistive element.

4 – the mounting, a plate of Pertinax, used to increase the mechanical resistance of resistor. Not all resistors are provided with it.

5 – tinned copper **terminal,**

6 – thermo-resistive resin protective **element.**

Terminals are connected to the AgPd film with a SnPb solder alloy.

A similar structure is exhibited by the SMD resistors of type CHIP, high voltage resistors and resistive networks (these have obvious differences, arising in accordance to the number of the resistances in the network). The resistor for surface mount SMD CHIP, have the structure according to Figure 5.

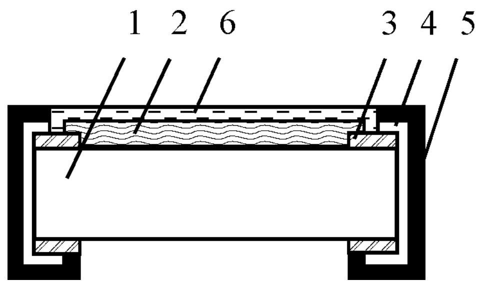

Fig.5 Constructive structure of a SMD type thick film resistor.

1 – insulating mount, made from alumina;
2 – resistive thick film;
3 - Ag-Pd film.
4 - Ni cap.
5 - Solder coating (Nickel and Pb 60% Sn 40%).
6 - film of an electro-insulating varnish.

Wirewound resistors are obtained by winding a conductor of high resistance (Cr-Ni alloys, Cu-Ni) onto an insulating supporting cylinder. Constructively they have a greater diversity, and can be classified as follows: cement, ceramic and coated resistors.

The outline of the cement wire wound resistor is given in Figure 6

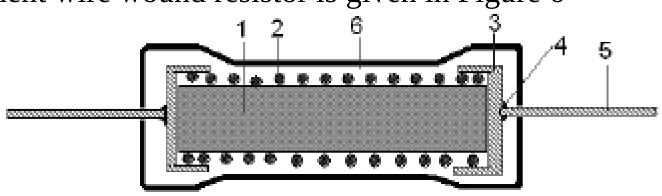

Fig.6 Structure of a cement wire wound resistor.

According to Figure 6, the cement wire wound resistor consists of:

1 - insulating mount made of glass fiber, cylindrical form, in various sizes depending on the rated power of the future resistor.

2 - resistive element obtained by winding a conductor of Cr-Ni onto the insulating mount.

3 - Ni cap through which the terminal connects to the resistive element. The terminal is welded to the cap and cap- resistive element connection is achieved by clamping.

4 - terminal made of tinned Cu.

5 - element of protection made of silicone cement.

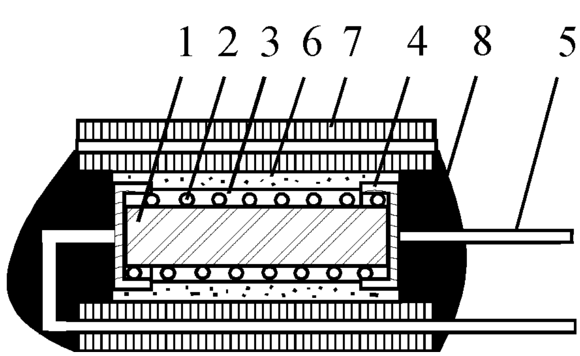

Fig.7 Wire wound Resistor with ceramic body.

In Fig.7 is shown the structure of a wire wound resistor in ceramic body, in which:

1 – insulating mount is fiberglass
2 - resistive element obtained by winding a conductor of high resistance.
3 - Silicone cement, hardening resistive element (protection against vibration).
4 - Ni cap, the same role as in cemented wire wound resistor.
5 - terminal
6 - quartz sand, filling the space inside the body Ceramic in order to improve thermal conduction.
7 - ceramic body having dual role for resistor protection against external factors and for decreasing the convection thermal resistance. The section may be circular, square, or shaped into various sizes, depending on the rated power of the resistor.
8 - cement sealing the ends of resistor.

Carbon composition Resistor

Carbon composition resistors are the resistors where, unlike film resistors, the conduction of electricity takes place throughout the entire resistor's body. It is made of carbon granules and a binder such as a formaldehyde resin. The mechanical mount of the resistor is also a resistive element in this case.

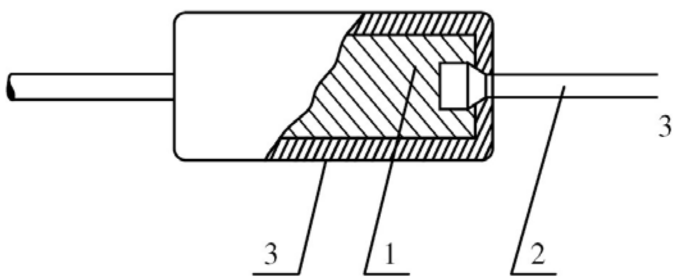

Fig.8 Carbon Composition Resistor 1 - carbon-based resistive element, 2 - terminal, 3 - pressure protection factor (may be absent in some versions)

Carbon composition resistors are carbon-based resistors and are not very efficient. They don't have low tolerance (cannot be adjusted), are not very stable with temperature (high temperature coefficient) and with voltage (high voltage variation coefficient). The main advantage is their ability to withstand high overloads without damage due to energy distribution throughout the resistor not only through the resistive film as is the case of film resistors. Also they have previously been used for their very low parasitic inductance. Because of the composite structure they have a very large noise current. There have been and are still widely used in industrial equipment in the U.S., less in Europe, and they have proven over the last nearly 60 years of use a very good reliability.

2.3. Influence the overall tolerance of the resistors on the parameters of electronic circuits

The value of a resistor used in an electronic circuit may have a greater or lesser deviation from the rated value depending on the resistor tolerance, temperature variation, the coefficient of variation with temperature and other irregularities due to various factors such as humidity, vibration, thermal and electrical shocks, etc.

All these influences can be highlighted by global tolerance, given by:

$$t_g = t_f + t_T + \sum_{i=1}^{n} t_i \tag{11}$$

where:

t_g - global tolerance;

t_f - manufacturing tolerance;

t_i – tolerance due to the influence of the i factor;

t_T - tolerance due to temperature changes, determined by the relationship: $t_T = \pm|\alpha_R|\Delta T_{max}$

$\Delta T_{max} = \max\{(T_{max} - T_o), (T_o - T_{min})\}$

where: T_o = 25°C, temperature where the rated value R_N is measured.

T_{max}, T_{min} is the maximum temperature and minimum temperature respectively that the resistor can reach while operating in an environment with $T_a \in [T_{amin}, T_{amax}]$ and disipating the power P.

$$T_{max} = T_{amax} + \frac{P}{D}$$

$$T_{min} = T_{amin}$$

Taking into account an electronic circuit characterized by a parameter **f,** dependent on the values of the resistance, through the relationship:

$$f = f(R_1, R_2 \ldots.. R_n) \tag{12}$$

Knowing the tolerances of the resistors the parameter **f** can be determined by the formula:

$$t_f = \sum_{i=1}^{n} \left|\frac{\partial f}{\partial R_i}\frac{R_i}{f}\right| \cdot t_i \tag{13}$$

where t_f is the tolerance of the parameter **f** due to tolerances t_i of the R_i resistors.

Knowing the coefficients of variation of temperature α_i of the R_i resistors the coefficient of variation with temperature of the parameter **f** is determined by the relationship:

$$\alpha_f = \sum_{i=1}^{n} \frac{R_i}{f}\frac{\partial f}{\partial R_i}\alpha_i \tag{14}$$

2.4 Resistors encoding

Resistors are characterized by a code specific to all electronic components. A former Romanian manufacturer used an alphanumeric code, for example RCG1050, RBA3004, etc. The literal part of the code suggests the family the resistor belongs to, and the number is usually related to the rated power, size, or other construction details.

Inscribing the dimension of the rectangular SMD resistors (Chip)

For their encoding, as is the case also for the SMD capacitors, is widely used the encoding convention using thousandths of inches, the unit called mil 1 mil = 1 / 1000 inch. One inch equals 25.4 mm. It is customary to approximate 40 mils = 1 mm, which means that changes in millimeters to mils are done by multiplying by 40. For example 3mm = 120 mils., 0.5 mm = 20 mils, etc.

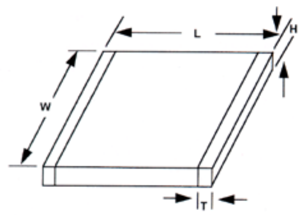

Fig. 9 Dimensions of the rectangular SMD chip type resistor

For example, the resistor whose code is 1206, according to the convention, has about 120 mils on the larger side L = 3mm and on the small side W 60 mils = 1.5 mm. Other dimensions (H and T) are defined in the datasheet.

2.5 Parameters of the resistors studied in laboratory

Before any parameter can be obtained the identification of the resistor must be done. For the laboratory platform, reference numbers for the components are used: R1, R2, RME1, RN2, etc. Based on the table with the manufacturer's code, for example 4608X-104-221/331L for the resistive network RN1 one can move on to study the datasheets. Useful information is given by the presence of the marks written on the resistor's body. It should be noted from the very beginning that the method of marking is specific to each type of resistor and it is mandatory to check the catalog sheets of those resistors. However, a few rules are respected; such as the color code marking rules, according to IEC publication 62, the code in the format Mantissa code + superscript, EIA96 code, clearly writing the rated resistance and tolerance and in some wire wound resistors of rated power.

On the body of any resistor only a part of its parameters are inscribed, usually the rated resistance and tolerance, and sometimes the rated power and less frequently the coefficient of variation with temperature.

Rated resistance of any resistor is marked on the body, using either color code or clearly marking (an alphanumeric code). Marks on the body of the resistor do not include the symbol **Ω** but only the value, for large values of the order of kΩ or MΩ instead of the comma the multiplication order K, respectively M is placed. For lower values, around the units of ohms the letter R is used. In Table 2 there are some examples.

Table 1 Examples of Inscriptions

Inscription	0.1	1	8R2	82R	510	1k	3k3	33k	820k	1M	1M8	10M
RN [Ω]	0,1	1	8,2	82	510	1000	3300	33000	820000	10^6	$1,8 \cdot 10^6$	10^7

Tolerance is marked on the body of any type of resistor, using the mark in color code, the literal code according to Table 2 or the clear marks with or without the symbol **%.**

Table 2 The literal inscription for marking the tolerance of the resistors.

Tolerance[%]	±0,005	±0,001	±0,02	±0,05	±0,1	±0,25	±0,5	±1	±2	±2,5	±5	±10	±20
Literal Code	E	L	P	W	B	C	D	F	G	H	J	K	M

The SMD Chip Resistor is usually marked in code Mantissa + superscript and can have 3 or 4 significant digits. The rule is valid (and can be applied) usually to values exceeding 10 Ω with 3 figures and over 100 Ω for the 4-digit case. The first digits (Mantissa) are the significant numbers of the rated value and the last digit (exponent) is the power of 10 to express the amount, or in short the multiplier. Examples of representations: 101, 473, 224, 560, 3010, 5112. The rated values are, according to the rule: $10 \times 10^{1} = 100\ \Omega$, $47\ \Omega \times 10^{3} = 47k$, $220k = 22 \times 10^{4}\ \Omega$, $56 \times 10^{0} = 56\ \Omega$, $301 \times 10^{0} = 301\ \Omega$, $511 \times 10^{2} = 51.1\ k\Omega$.

NOTE: The rated values with 2 significant digits correspond to a series of values with higher tolerances than 2% and the 3-digit rated values mean lower tolerances than 2%, inclusive.

For very small resistors the EIA code 96 can be applied, which reduces with a digit the number of characters inscribed, see Appendix 3.

The coefficient of variation with temperature, $\alpha_{R,}$ (TCR) is marked sometimes onto the resistor's body using the color code (6 color bars). Each company may have a specific code, for example for the resistors of the RPM series produced by IPEE Curtea de Arges the code was: **a** for ± 50ppm/°C, **b** for ± 100ppm/°C and **c** for ± 250 ppm/°C.

Rated power is to be marked (clearly) only in certain wire wound resistors and some metal oxides film resistors, which are used in particular for large values of this parameter.

Other parameters are identified from the datasheet, keeping in mind that it is possible that the manufacturer does not provide certain parameters that he finds irrelevant. For example, for the wire wound resistors the noise factor is not present, although it has small values, these resistors not being used in small signal applications. For the carbon composition resistors the noise factor is not given too, as it is known to have high levels, since they have other applications than low noise amplifiers.

3. Work procedure:

3.1 Table 6a of Annex 2 will be completed, where the resistive networks are not included. They have some specific elements and will be dealt in a separate table, Table 6b. For the types of resistors shown in Figure 9 the parameters marked and the other parameters characterizing those resistors are determined using the resistor catalog sheet. All data, both measured and determined are written in a table as the one given in Annex 2.

Procedure:

a) Identify the resistors by the code given in Table 5, Annex 1. The code allows in most cases the unequivocal identification of the rated value and of the tolerance as well as other specific parameters.

b) Identify the rated value and tolerance, and where appropriate the rated power using the inscription, which has priority over the code. Any differences that arise between the code and the inscription may be caused by placing onto the board of an equivalent resistor.

c) Also the marking in the color code is to be studied, then it is considered for some resistors.

d) Study the datasheets in order to fill in the information for table 6. In order to check as many types of resistors, for the beginning one resistor will be chosen from each category and then the list will be completed for the rest of the items.
Laboratory board is shown in Figure 10

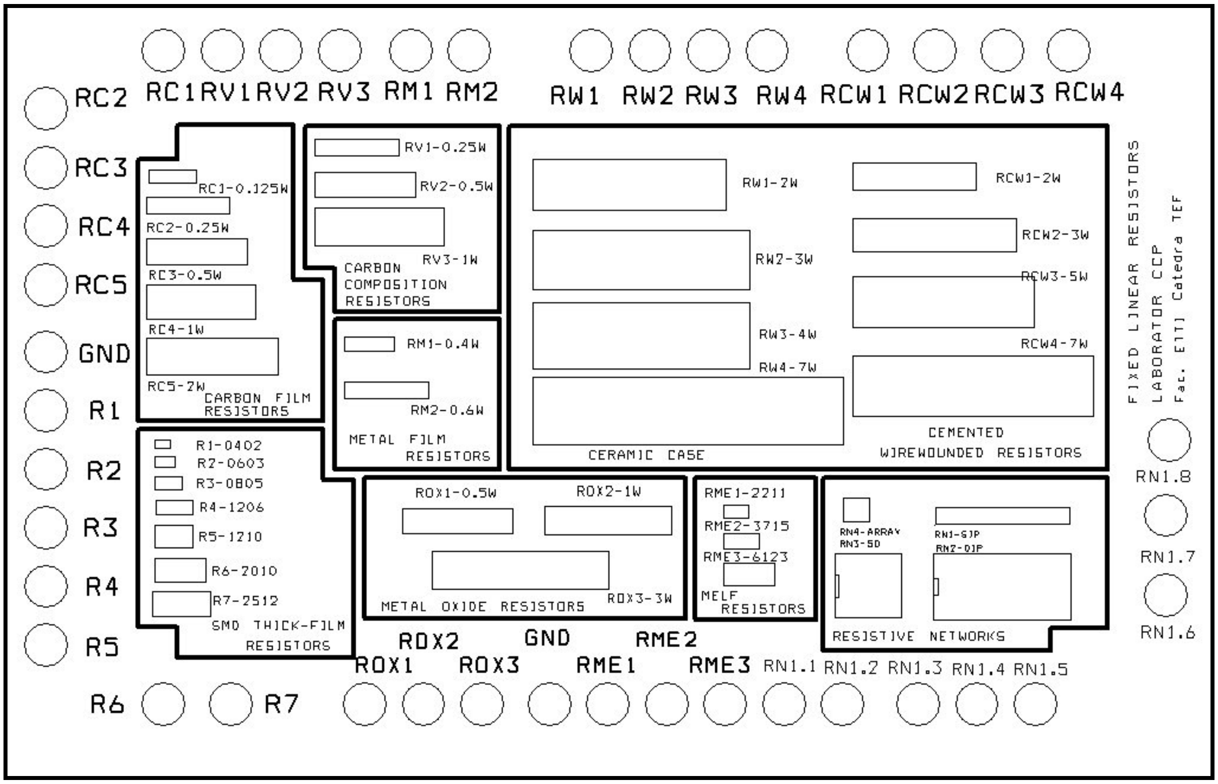

Fig.10 Representation of the board for the study of resistors

The resistors were divided into 8 groups: 1. Carbon film resistors RC1-RC5, 2. SMD chip type resistors, thick film resistors R1-R7, 3, carbon composite resistors RV1-RV3, 4, metal film resistors RM1-RM2, 5. SMD MELF resistors (cylindrical) RME1-RME3, 6. Resistors with metal oxides ROx1-ROx3, 7. Wire wound resistors: with ceramic body RW1-RW4 and cemented RCW1-RCW4, 8. Integrated resistors, resistive networks RN1-RN4

3.2. Measure the resistance for the resistors which have measurement terminals and the resistors which are placed onto the board shown in Figure 10. In the paper $t_{m,}$ the tolerance resulted from measurements is computed, with the formula:

$$t_m = \frac{R_m - R_N}{R_N} \tag{15}$$

$R_{m,}$ the value of the measured resistance, $R_{N,}$ rated resistance.

3.3 The fields for Table 6b are completed for the resistive networks, by identifying the components and studying the datasheets. For the placement of the resistors, will be written according to each case: isolated, bus, double termination or termination type, etc. as given by the datasheet.

3.4 The influence of the resistors' tolerances is determined for a resistive divider, upon the voltage at the divider's output. Use a setup that involves the RN1 resistive network made like in the schematics shown in Figure 11.

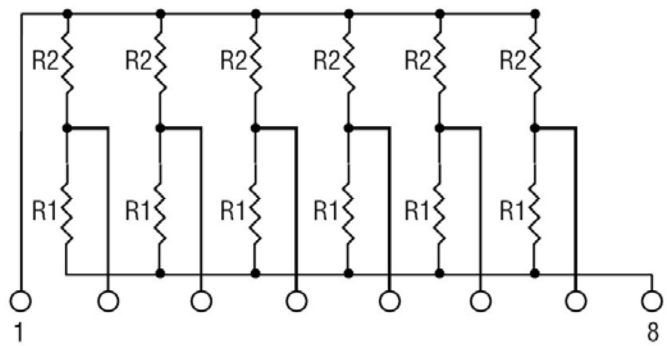

Fig.11 Wiring diagram used to determine the influence of the resistors' tolerance onto the divider's voltage using the resistive network RN1

Connect between the pins RN1 and RN8, corresponding to pins 1 and 8 of a resistive network a voltage U_A = 5V, from the power supply. The MINUS terminal is RN8, the reference in this case. The voltage with respect to the reference is measured with a voltage meter at the pins of RN2 to RN7. The results are written in Table 3. Reverse the polarity of the voltage between pins 1 and 8 and measure the voltage at pin pins 2-7 with respect to 1. Write the data in the table.

Table 3 Voltage at the output of the divider consisting of resistive network elements

		U_A	U RN2	U RN3	U RN 4	U RN5	U RN6	U RN7	U_N
Case 1RN1 to PLUS terminal	Voltage U[V]	(5V)							(calc.)
	t [%]								
Case 2RN8 to PLUS terminal	Voltage U[V]	(5V)							(calc.)
	t [%]								

Using the measurements highlight any deviation due to the tolerances of the resistors, t_1 or t_2 of the resistors R_1, R_2 respectively. The voltage at the output of the divider, U for the reference placed to pin 8 has the expression:

$$U = \frac{R_1}{R_1 + R_2} U_A \tag{16}$$

If the pin RN8 is powered with PLUS and MINUS is placed to pin 1 and the output voltage is measured with respect to pin 1, then for the output voltage of (16) R_1 and R_2 are reversed.

The tolerance t_u is assessed by comparison to the "ideal" case, that is when the resistors have the rated values, using (17):

$$t_u = \frac{U - U_N}{U_N} \tag{17}$$

where U_N is the computed value of the voltage with R_1 and R_2 having their resistance equal to the rated value.

3.5. Measure the resistance between different pins of the resistive network. Because the resistors are not insulated, all contribute to the resistance's value. The results must be written in Table 4.

Table 4

Measurement pins	1-8	1-2	2-3	2-4	2-8
Measured R.[Ω]					
Computed R [Ω]					

In the paper the theoretical values will be computed (circuit and explanations) and Table 4 will be completed.

4. Questions, conclusions, data processing:

4.1. Based on division presented on the laboratory board present by comparison the 8 families of discrete and integrated resistors. Indicate the main distinguishing elements, constructive details, key characteristics, parameters which are highlighted for a particular category, areas of application.

4.2. Given the results in 3.1 (Table 6a), compare the resistors in terms of the parameters listed in the table.

4.3. Compare the measured tolerance $\mathbf{t_m}$ with the marked one **t,** according to the data in Table 6. Why are there differences between $\mathbf{t_m}$ and **t?** What do these differences mean? Is a positive tolerance good? What about negative?

4.4. Based on the table 6b and the datasheets compare the resistive networks in terms of the parameters listed in the table. What are the advantages of resistive networks regarding the variation with temperature?

4.5. Compute the power dissipated by the resistive network and by each resistor for the supply voltage of 1V and 10V. The same requirements if the net with the code 4608X-104-161/241L is chosen.

4.6. Compute the overall tolerance of resistive divider from point 3.4 considering that there is only one pair of resistors R_1 and R_2 with the data from the catalog and that the ambient temperature is 85°C in the cases: a) the supply voltage U_A is precisely and rigorously constant (t_{UN} = 0, α_{UN} = 0) and has a low value which allows disregarding the power dissipated, UA = 1V, b) t_{UN} = ± 5%, α_{UN} = 0, U_A = 1V, c) t_{UN} = ± 5%, α_{UN} = ± 500 ppm/°C, U_A = 1V, d) t_{UN} = 0, α_{UN} = 0 U = 10V e) t_{UN} = ± 5%, α_{UN} = 0, U_A = 10V, f) t_{UN} = ± 5%, α_{UN} = ± 500 ppm /°C, U_A= 10V. Comment the results and the differences between the 6 cases.

4.7. Determine overall tolerances for carbon film resistors and metal film resistors considering that manufacturing tolerances are equal. If there no resistors with equal tolerances choose the lowest common value for tolerance. It is assumed that the resistors work environment with a temperature $\mathbf{T_{of}} \in$ [-10.100] ° C and do not dissipate power. Discuss the results. What conclusion follows from this comparison?

4.8. Calculate the resistance of the resistive network between the pins shown in table 4, section 3.5. Compare the results with those of the measurements.

4.9. Determine the heat dissipation coefficients **D,** respectively the convection thermal resistances for a minimum of 2 resistors in each family. Compare the coefficients of thermal dissipation for the same type of resistors, but for different powers and those of different types of resistor, but having the same power. Why are there differences between these coefficients? Present data in tabular form.

4.10. Determine the maximum allowable voltage of a resistor, one of each type of minimal resistance, considering that operates at an environment temperature $T_a \in$[-10, 100]°C.
4.11. Determine the maximum allowable thermal power $\mathbf{P_{A\theta}}$ of all categories of resistors on the

board laboratory, considering that they operate at a temperature of 100 ° C. Present data in tabular form.

4.12. Explain the influence of the constructive solutions upon the parasitic elements of the resistors measured. Compare in this regard the resistors, seeking an approximation of relations for calculating the parasitic inductance and capacity.

4.13. Why are the wire wound resistors connected by clamping and not by soldering?

4.14. Depending on the frequency at which the resistor is used, it can have

1) a resistive behavior;
2) an inductive behavior;
3) capacitive behavior;
4) can implement a signal amplifier.

4.15. Rated power of a resistor depends on:

1) the voltage applied to the resistor terminals;
2) geometrical dimensions of the resistor;
3) rated resistance;
4) type of material used to achieve resistive element.

5. Additional Questions

a. Explain the influence of the resistive element onto the parameters of a resistor.

b. Explain the influence of constitutive elements of a resistor, made of insulating materials (insulating mount, protective element) on its parameters.

c. Explain the influence of contact area onto the parameters of a resistor.

d. How is a resistor influenced if the rated power is exceeded? What about exceeding the rated voltage, i.e. voltage allowable?

e. How is the operation of a resistor affected by exceeding (towards negative values) of the minimum temperature?

f. How is the operation of a resistor influenced by thermal shocks, or electric ones? Which of the resistor on the laboratory board resistor do you think are more sensitive and less sensible to such influences?

6. Content of the paper

6.1. Experimental data, data processing, conclusions, interpretations, determinations.

6.2. Answers to questions

References

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Crt No.	Name Ref.	Capacitor type	Manufacturer code	Manufacturer
1.	R1	thick film SMD resistor 0402	2322 70570151	PHYCOMP (YAGEO)
2.	R2	thick film SMD resistor 0603	232270260103	PHYCOMP (YAGEO)
3.	R3	thick film SMD resistor 0805	232273061181	PHYCOMP (YAGEO)
4.	R4	thick film SMD resistor 1206	232271161224	PHYCOMP (YAGEO)
5.	R5	thick film SMD resistor 1210	SR732ETTD10R0F	Koa
6.	R6	thick film SMD resistor 2010	232276162202	PHYCOMP (YAGEO)
7.	R7	thick film SMD resistor 2512	232276260221	PHYCOMP (YAGEO)
8.	RC1	carbon film resistor 0.125W	MCCFR0W8	Multicomp
9.	RC2	carbon film resistor 0.25W	MCCFR0W4J05630	Multicomp
10.	RC3	carbon film resistor 0.5W	MCCFR0S2xxxxxx	Multicomp
11.	RC4	carbon film resistor 1W	Not used	
12.	RC5	carbon film resistor 2W	Not used	
13.	RV1	carbon composition resistor 0.25 W	CBT25J15R	Tyco Electronics
14.	RV2	carbon composition resistor 0.5 W	CBT50J680K	Tyco Electronics
15.	RM1	metal film resistor 0.4 W	MRS25 180K 1%.	Vishay
16.	RM2	metal film resist 0.6 W	MRS25 15R8 1%.	Vishay
17.	ROX1	metal film resistor 0.5 W	Not used	
18.	ROX2	metal oxide resistor 1W	MO1S-100RJI	Welwyn
19.	ROX3	metal oxide resistor 3W	MO3S-10RJI	Welwyn
20.	RME1	metal film Resistor 0102	231216511102	Vishay-BC Comp.
21.	RME2	metal film Resistor 0204	2312 142 71803	Vishay-BC Comp.
22.	RME3	SMD MELFmetal film Resistor 0207	2312 195 11503	Vishay-BC Comp.
23.	RW1	Ceramic body wire wound Resistor 2W	Not used	
24.	RW2	Ceramic body wire wound Resistor 3W	Not used	
25.	RW3	Ceramic body wire wound Resistor	SQP5-6R8JB14	Welwyn
26.	RW4	Ceramic body wire wound Resistor 7W	SQP7S-0R68JB15	Welwyn
27.	RCW1	WA83 cemented wire wound Resistor 2W	Not used	
28.	RCW2	WA84 cemented wire wound Resistor 3W	WA84-12RJI	Welwyn
29.	RCW3	WA85 cemented wire wound Resistor 5W	WA85Z-100RJI	Welwyn
30.	RN1	Resistive Network SIP8	4608X-104221/331L	BOURNS
31.	RN2	Resistive Network DIP16	4116R-1-101LF	BOURNS
32.	RN3	Resistive Network SO14	4814P-T01-472LF	BOURNS
33.	RN4	Resistive Network 1206 type RNA310	235023010479	PHYCOMP(YAGEO)

Table 6a. Discrete resistors

No. crt.	Name ref.	RN	t [%]	PN [W]	α [ppm/°C]	UN [V]	T_m [^oC]	T_M [^oC]	T_N [^oC]	F [µV/V or NI [dB]	Riz [GΩ] or Uiz [V]	R meas.	t [%] calc.
1.	R1												
2.	R2												
3.	R3												
4.	R4												
5.	R5												
6.	R6												
7.	R7												
8.	RC1												
9.	RC2												
10.	RC3												
11.	RC4												
12.	RC5												
13.	RV1				N/A								
14.	RV2				N/A								
15.	RM1									N/A	N/A		
16.	RM2									N/A	N/A		
17.	ROX1									N/A			
18.	ROX2									N/A			
19.	ROX3									N/A			
20.	RME1										N/A		
21.	RME2										N/A		
22.	RME3										N/A		
23.	RW1									N/A			
24.	RW2									N/A			
25.	RW3									N/A			
26.	RW4									N/A			
27.	RCW1									N/A			
28.	RCW2									N/A			
29.	RCW3									N/A			

Table 6b. Integrated resistors – resistive networks

No crt	Name ref.	Resistors position in the package	R1 [Ω]	R2 [Ω]	t [%]	PN package [W]	PN resistor [W]	α [ppm/°C]	VN [V]	T_m [^oC]	T_M [^oC]	T_N [^oC]	Riz [GΩ] or Uiz [V]
1	RN1												
2	RN2												
3	RN3												
4	RN4												

ANNEX 3 EIA-96 code

Numeric code for significant digits

Code	Value	Code	Value	Code	Value	Code	Value
01	100	25	178	49	316	73	562
02	102	26	182	50	324	74	576
03	105	27	187	51	332	75	590
04	107	28	191	52	340	76	604
05	110	29	196	53	348	77	619
06	113	30	200	54	357	78	634
07	115	31	205	55	365	79	649
08	118	32	210	56	374	80	665
09	121	33	215	57	383	81	681
10	124	34	221	58	392	82	698
11	127	35	226	59	402	83	715
12	130	36	232	60	412	84	732
13	133	37	237	61	422	85	750
14	137	38	243	62	432	86	768
15	140	39	249	63	442	87	787
16	143	40	255	64	453	88	806
17	147	41	261	65	464	89	825
18	150	42	267	66	475	90	845
19	154	43	274	67	487	91	866
20	158	44	280	68	499	92	887
21	162	45	287	69	511	93	909
22	165	46	294	70	523	94	931
23	169	47	301	71	536	95	953
24	174	48	309	72	549	96	976

Literal code for the multiplier.

Literal code	S	R	A	B	C	D	E	F
Multiplier	10-^2	10^{-1}	100	10^1	10^2	10^3	10^4	10^5

The code is used for tolerances of ±0,1 %, ±0,5 %, ±1 %. This marking, by comparison to the previous variant (alpahanumeric code variant 3) reduces the marking by one digit. For instance, if a resistor is marked with 10C, it results R_N=12,4 kΩ.

ANNEX 4 Color code in accordance with IEC 62

Color	Significant digit	Multiplier	Tolerance (%)	Temperature coefficient (ppm/°C)
Black	0	1	-	±250
Brown	1	10	±1	±100
Red	2	10^2	±2	±50
Orange	3	10^3	-	±15
Yellow	4	10^4	-	±25
Green	5	10^5	±0,5	±20
Blue	6	10^6	±0,25	±10
Indigo	7	10^7	±0,1	±5
Gray	8	10^8	±0,05	±1
White	9	10^9		-
Gold	-	10^{-1}	±5	-
Silver	-	10^{-2}	±10	±200
Colorless	-		±20	

Using the color code one can mark the rated resistance, tolerance, coefficient of variation with temperature and sometimes the reliability (failure rate). To mark the rated resistance, as a function of tolerance two or three significant digits are necessary. Mark is used for cylindrical resistor, both trough hole and surface mount.

The order in reading the color is from the nearest edge (see Figure 1 a and b) or the last color is twice as large as the others (see Figure 1 c, d, e, f). Marking in Figure 1 is used for resistors with tolerances of ± 20%, when the marking is done only for the rated resistance with three colored rings.

Example: A carbon film resistor is considered marked in red *(C_1),* red *(C_2),* orange *(m)*, resulting $R_N = 22 \cdot 10^3\ \Omega = 22\ \text{k}\ \Omega$.

The inscription from Figure 1b is used for resistors with tolerances of ± 10% and ± 5% (without marking the coefficient of variation with temperature, such as carbon film resistors). In this case the rated resistance (colors C1, C2, m) and tolerance are marked.

Example: A resistor is marked with red *(C_1),* yellow *(C_2),* brown *(m)* and gold, resulting $R_N = 24 \cdot 10\ \Omega = 240\ \Omega$ with tolerance $T = \pm 5\%$.

The inscription in Figure 1c is used for marking the rated resistance and tolerance, where the tolerance is less than ± 2.5%. In this case it is necessary to use the third significant figure C3. The coefficient of variation with temperature, is the last color (see Figure 1d and e) or a point colored according to Figure1f.

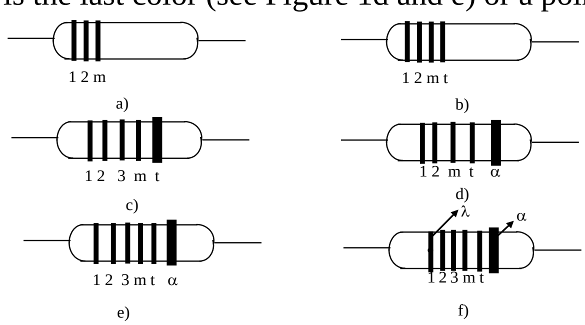

Figure 1. Marking the resistors using the color code: 1-first significant digit 2 - the second significant digit, 3 - the third significant figure, m - multiplier, t - tolerance, α - temperature coefficient, λ - reliability (failure rate).

Annex 5

Rated values for the series E6 … E192

E24 ±5%	E48 ±2%	E96 ±1%	E192 ±0,5%
100	100	100	100
			101
		102	102
			104
	105	105	105
			106
		107	107
			109
110	110	110	110
			111
		113	113
			114
	115	115	115
			117
		118	118
120			120
	121	121	121
			123
		124	124
			126
	127	127	127
			129
130		130	130
			132
	133	133	133
			135
		137	137
			138
	140	140	140
			142
		143	143
			145
	147	147	147
			149
150		150	150
			152
	154	154	154
			156
		158	158
160			160
	162	162	162
			164
		165	165
			167
	169	169	169
			172
		174	174
			176

E6 ±20%	E12 ±10%	E24 ±5%	E48 ±2%	E96 ±1%	E192 ±0,5%
			178	178	178
	180	180			180
				182	182
					184
			187	187	187
					189
				191	191
					193
			196	196	196
					198
		200		200	200
					203
			205	205	205
					208
				210	210
					213
			215	215	215
					218
220	220	220		221	221
					223
			226	226	226
					229
				232	232
					234
			237	237	237
		240			240
				243	243
					246
			249	249	249
					252
				255	255
					258
			261	261	261
					264
				267	267
	270	270			271
			274	274	274
					277
				280	280
					284
			287	287	287
					291
				294	294
					298
		300	301	301	301
					305
				309	309
					312

E6 ±20%	E12 ±10%	E24 ±5%	E48 ±2%	E96 ±1%	E192 ±0,5%
			316	316	316
					320
				324	324
					328
330	330	330	332	332	332
					336
				340	340
					344
			348	348	348
					352
				357	357
		360			361
			365	365	365
					370
				374	374
					379
			383	383	383
					388
	390	390		392	392
					397
			402	402	402
					407
				412	412
					417
			422	422	422
					427
		430		432	432
					437
			442	442	442
					448
				453	453
					459
			464	464	464
470	470	470			470
				475	475
					481
			487	487	487
					493
				499	499
					505
		510	511	511	511
					517
				523	523
					530
			536	536	536
					542
				549	549
					556

E6 ±20%	E12 ±10%	E24 ±5%	E48 ±2%	E96 ±1%	E192 ±0,5%
	560	560	562	562	562
					569
				576	576
					583
			590	590	590
					597
				604	604
					612
		620	619	619	619
					626
				634	634
					642
			649	649	649
					657
				665	665
					673
680	680	680	681	681	681
					690
				698	698
					706
			715	715	715
					723
				732	732
					741
		750	750	750	750
					759
				768	768
					777
			787	787	787
					796
				806	806
					816
	820	820	825	825	825
					835
				845	845
					856
			866	866	866
					876
				887	887
					898
		910	909	909	909
					919
				931	931
					942
			953	953	953
					965
				976	976
					988