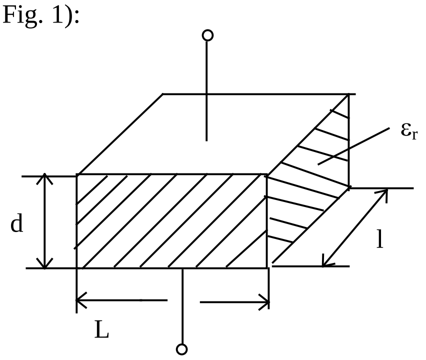
CAPACITORS

1. The purpose of the paper: Knowledge of the characteristic parameters of the constructive structure of various types of capacitors through hole and surface mount; performing specific measurements.

2. Theoretical background:

The capacitor is a passive electronic component with a capacity impedance up to a certain frequency. Capacity, the main characteristic of the capacitor, is the ratio between the charge that accumulates between the conductive plates and the potential difference which arises between the two plates. Regarding the structure a capacitor is composed of a dielectric medium (insulating) placed between two conductive plates. The capacity of a capacitor has the expression (see Fig. 1):



$$C = \frac{\varepsilon_0 \cdot \varepsilon_r \cdot A}{d} \quad (1)$$

Fig1. Plane capacitor .

where - ε_0 is the absolute vacuum permittivity, $\varepsilon_0 = 8.854 \; 10^{-12}$ F/m
- ε_r is the relative dielectric permittivity.
- $A = L \times l$ area of the plates

Note: The conductive elements are specific to electronics, both for the realization of the interconnection between the components and the structure of any electronic components. Between any two conductive elements (routes, conductors, terminals, etc.) there are parasitic (unwanted) capacities which affect more or less the proper functioning of the circuit components. In this sense we can say that a capacitor is a passive electronic component made to obtain a capacity concentrated in a small a space.

Regarding the structure there are fixed and variable capacitors: adjustable and semi-adjustable.

Depending on the dielectric there is the following classification:

Capacitors:
- with solid-dielectric
  - inorganic: glass, mica, ceramic (type I or II)
  - organic: paper, plastic film
  - with metal oxide dielectric: electrolytic capacitors with Al (Elco) and Ta (Elta)
- with gas dielectric (air, gas)
- with liquid dielectric (oil)

Taking into account the constructive aspect, we can list some types of capacitors:
- plane
- rectangular
- pipe
- cylindrical, etc.

2.1. Parameters of the capacitors

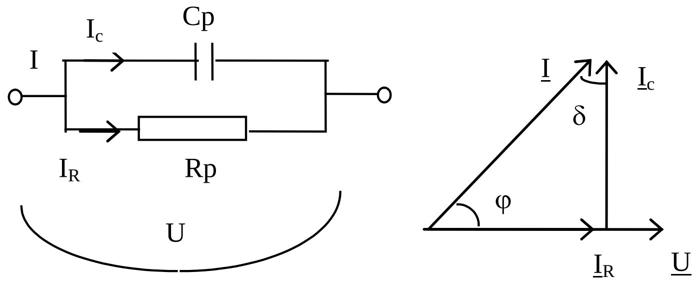
The main parameters of the capacitors are listed below:

Rated capacity C_N [F], is the amount of capacity which is expected to be obtained in the manufacturing process and is generally marked on the body of the capacitor. The rated values are contained in the series of values. For high values, these can be manufactured outside series (as is in the case of electrolytic capacitors).

Tolerance t [%], is the maximum relative deviation from the real value of the capacitor's capacity to rated value. Like in the case of the resistors, the series of rated values are related to capacitor's tolerance. For example the value of 270pF can belong to the series E12 and E24, see Appendix 3. For tolerances of 1%, in the E96 series there isn't this value, but instead it has 274pF. However, especially for SMD components, the capacitors are manufactured with low tolerances and with rated values of the "high" series E6, E12, E24. In electrolytic capacitors and in some type II ceramic capacitors non-symmetrical tolerances are usually specified (e.g: -20%, 80%).

Rated voltage U_N [V], is the maximum continuous voltage or the highest effective value of the AC voltage which can be applied during DC operation at the terminals of the capacitor. It depends on the dielectric strength and on the constructive characteristics of the capacitor.

Loss angle tangent tgδ □is defined as the ratio of active power and reactive power dissipated by the capacitor. In short, it expresses the losses in the capacitor. When using the equivalent circuit of the capacitor from Fig. 2, the loss tangent has the expression:



$$tg\delta = \frac{1}{\omega R_p \cdot C_p} \qquad \textbf{(2)}$$

Fig. 2 The loss angle.

The temperature coefficient [K $^{-1}$] is defined by the relation:

$$\alpha = \frac{1}{C} \cdot \frac{dC}{dT} \qquad (3)$$

If there is a linear variation of the capacity with temperature, the formula (4) can be used:

$$\alpha \cong \frac{1}{C_{25}} \cdot \frac{C - C_{25}}{T - T_{25}} \qquad (4)$$

where:

C_{25} – the value of the capacity at the reference temperature T_{25} (25°C)
C - value of capacity at a temperature T (work temperature)

Insulation resistance R_{iz} [Ω] is defined as the ratio of continuous voltage applied to a capacitor and the current that runs through the capacitor, one minute after applying the voltage. R_{iz} has the following common values (100MΩ – 100GΩ)□ with the observation that R_{iz} depends on the conditions of measurement. Instead of insulation resistance the catalog can give some other parameters. For some capacitors it is given the insulation time constant $\tau_{iz} = R_{iz} \cdot C_N$ [s], and for electrolytic capacitors it is given the leak current $I_f = U_N / R_{iz}$.

Working temperature range (T_{min} - T_{max}) [°C], is defined as the temperature range in which the capacitor can operate for a long time. This range depends mainly on the nature of the dielectric, but also of other materials used to make the capacitor.

Parasitic elements L, R

Any capacitor has parasitic elements of inductive type and resistive elements that depend on the structure and the materials used. The following equivalent circuit applies to a large class of capacitors:

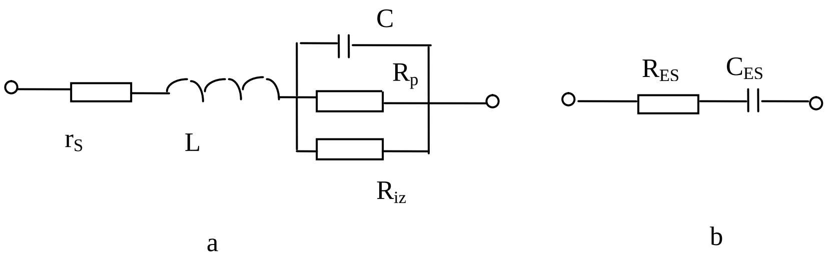


Fig. 3 Equivalent circuit of the real capacitor.

The meaning of the elements in Figure 3 is as follows:

- r_S resistance of the plates and terminals
- L inductance of the plates and terminals
- Rp resistance-of losses in dielectric
- R_{iz} insulation resistance

The diagram in Figure 3-a is equivalent to a series circuit (Figure 3-b) where R_{ES} and C_{ES} are the values given by the formulas (5):

$$R_{ES} = \frac{tg\delta}{\omega C'} \qquad C_{ES} = \frac{C'}{1-\left(\frac{\omega}{\omega_0}\right)^2}$$

$$C' = C\left[1+\left(tg\delta_p + tg\delta_\varepsilon\right)^2\right] \qquad tg\delta = tg\delta_s + tg\delta_p + tg\delta_\varepsilon \tag{5}$$

$$tg\delta_\varepsilon = \frac{1}{\omega C R_p} \quad tg\delta_p = \frac{1}{\omega \cdot C \cdot R_{iz}} \quad tg\delta_s = \omega \cdot C' \cdot r_s$$

This model gives us an insight into the behavior of the capacitor in the frequency range. It can be noted that, working at different frequencies, equivalent capacity C_{ES} varies. It is possible that, beyond the resonance pulsation, for the capacitive nature will be transforming into an inductive behaviour (negative capacity).

2.2 The constructive structure of capacitors

General structure of the capacitors is given in Figure 4

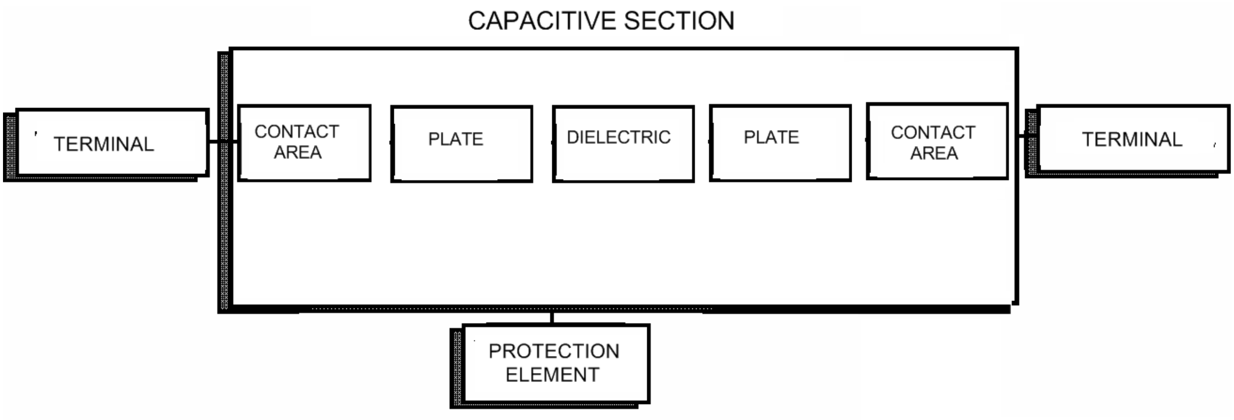
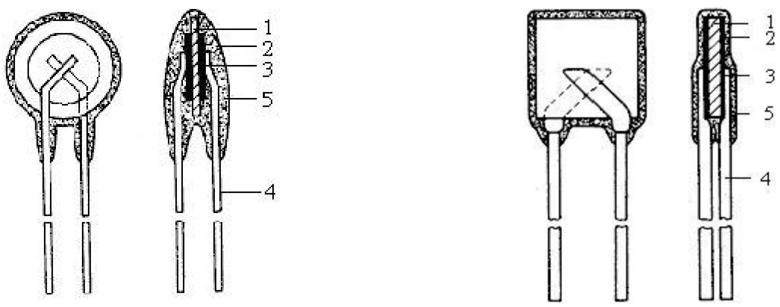


Fig. 4 The constructive structure of capacitors.

Regarding the placement of the terminals there are two main classes of components with axial terminals, that are placed along the axis, and radial, placed practically on the same side of the footprint of the component case.

Next is presented the structure for several types of capacitors through drawings.

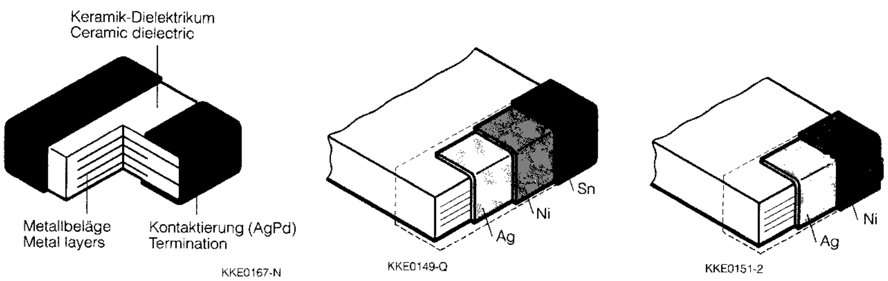
2.2.1 Single-layer ceramic capacitor (disk or wafer)



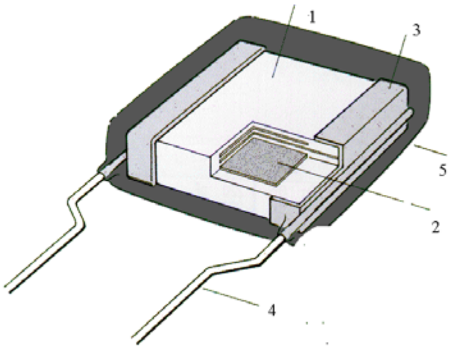
(a). (b)

Fig. 5 Single-layer ceramic capacitor. (a) disk, (b) a flat capacitor.

2.2.2 Multilayer Ceramic Capacitors



a)



b)

Fig. 6 Multilayer ceramic capacitor: a) SMD technology, b) through hole.

2.2.3 Capacitors with aluminum and plastic film (the most common types are with polystyrene under the trading name stiroflex and the paper capacitors). In this type of capacitor two dielectric films and two foils of aluminum are used in order to achieve the circular coil.

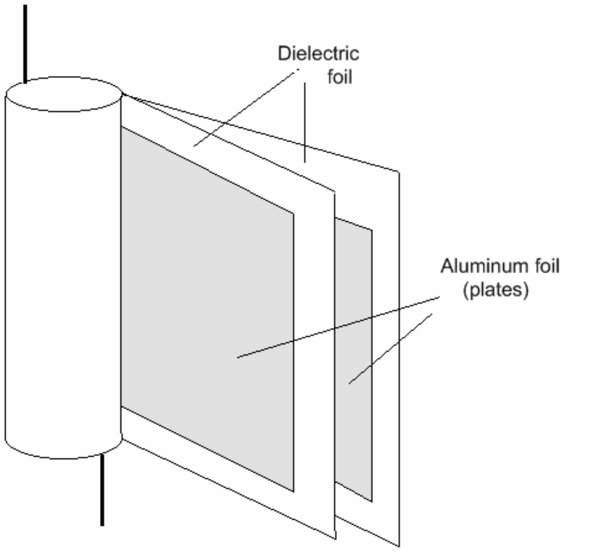


Fig. 7 Capacitor with aluminum foil

Due to possible technical options for making the contact to the plates, they usually are connected in a single place. This fact leads to the current moving from the contact point along the foil, which has a winding shape, thus generating magnetic fluxes and hence a high parasitic inductance. By making the contacts in several areas the inductance can significantly be reduced.

2.2.4 Metallized film capacitors. The most common types are polyester or, more precisely, the polyethylene terephthalate, under the trading name of mylar or PET in short. Another very common type is the capacitor with metallized polyethylene. The two have generic names MKT, MKP respectively. Unlike film capacitor, at this type of capacitor, in order to make the coil only two meal foils are used with a thin layer of aluminum deposited by vacuum evaporation processes. Hence, low parasitic inductances are obtained due to constuctive method of making the contact with metallization at the ends. Before metallization the coil can be pressed, resulting in a form that can be placed in a rectangular package or may be molded in the same format.

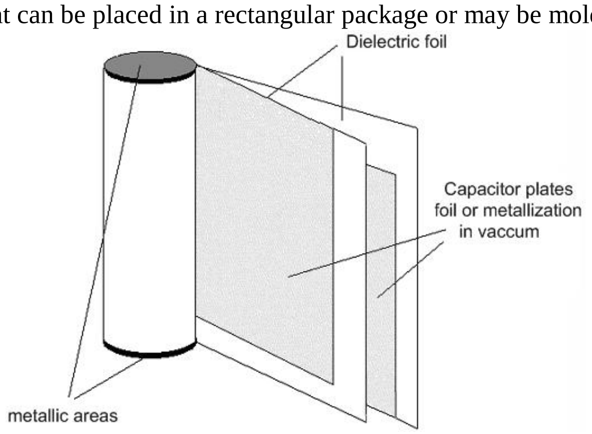
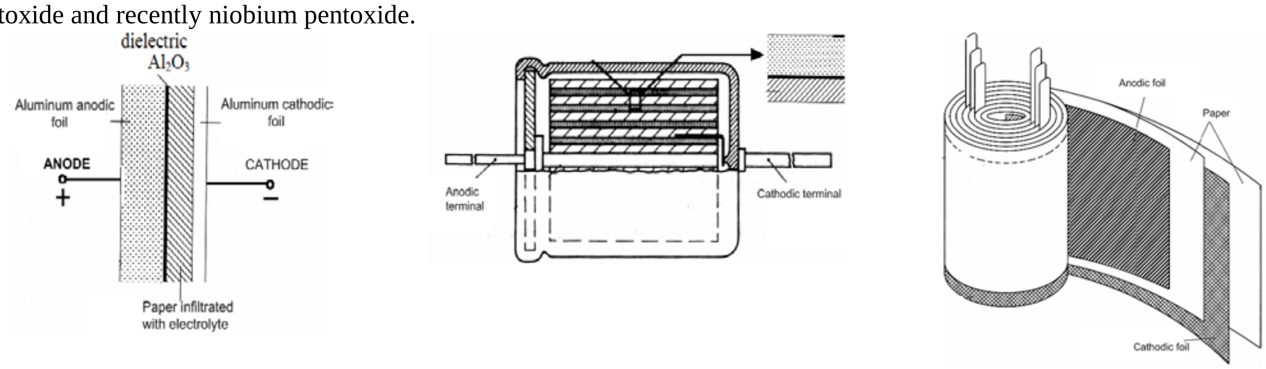


Fig. 8 Capacitor with metallized foils (non-inductive)

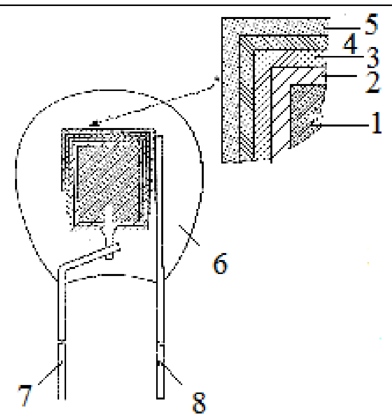
2.2.5 Electrolytic capacitors

Electrolytic capacitors are a special category in the capacitors area, because their operation is based partially on electrochemical processes, which requires knowledge of how to make them. Being polarized, the positive terminal will be called the anode and the negative, cathode. The most common types are aluminum oxide, tantalum pentoxide and recently niobium pentoxide.



(a) (b) (c)

Fig. 9 Aluminum electrolytic capacitors
a) principle of design, b) structure , c) detail



1 - anode plate;
2 - Ta_2O_5 film (dielectric);
3 - MnO_2 (electrolyte);
4 - graphite;
5 - silver;
6 - epoxy resin;
7 - anode terminal;
8 - cathode terminal.

Fig. 10 Constructive structure of electrolytic tantalum capacitors, with solid electrolyte, drop type

The cathode plate is represented by an electrolyte, which allows contact with a very thin oxide layer, but doesn't have a very low resistance which would be necessary. Hence the parameters of electrolytic capacitors are significantly lower than the ones for other types of capacitors. However, due to high levels of the capacity that can be obtained with an electrolytic capacitor they are now indispensable in electronics.

Electrolytic capacitors with niobium have the same performance as with tantalum and were developed specially to avoid breaking the capacitors in case of short circuits. The ones from AVX company are orange which makes them easily distinguishable from those with tantalum.

2.3. Marking capacitors

Inscribing rectangular SMD (chip) capacitors and tantalum capacitors

For their encoding, like SMD resistors, it is widely used the conventional marking using a thousandth of an inch, a 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 changing in mils from millimeters is achieved by multiplying by 40. For example 3mm = 120 mils., 0.5 mm = 20 mils, etc.

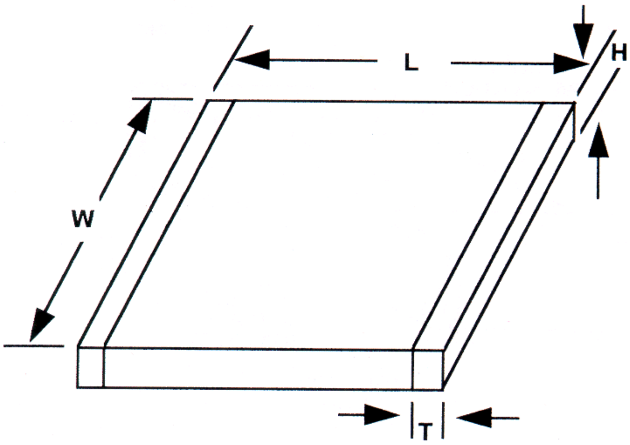


Fig. 11 Dimensions of a rectangular SMD chip type capacitor

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

Inscription of the SMD electrolytic capacitors with (penta) tantalum oxide and (penta) niobium oxide, called in short tantalum and niobium capacitors, is achieved in the metric system. On the laboratory board there are only two constructive variants: 6032 (type C footprint) and 7343 (type D footprint). These footprints have the dimensions 6.0 mm x 3.2 mm and 7.3 mm x 4, 3 mm respectively.

Ceramic capacitors

Note: There are two major categories commonly used in the manufacture of ceramic dielectric capacitors: ceramic dielectric of type I and type II. Speaking about classification, some manufacturers are considering a type III of ceramic dielectric, a type that we are not considering here. The dielectric properties resulted from their chemical nature are given in Table 1. In Table 2 are given some specific applications for single-layer ceramic capacitors.

Table 1Parameters for type I and type II ceramic capacitors

Parameter	Type I ceramic dielectric	Type II ceramic dielectric
εr	60 ¸ 120	2000¸ 10000
Temperature coefficient	-1500, -750 ¸ +100, deviation ± 250 ppm/°C 0± 30 ppm/°C (NP0)	nonlinear variation, undefined coefficient, but within the limits imposed for the given temperature range
tg δ (typical)	1-5 × 10-4	10-3- 10-2
composition	TiO_2 mixed in different proportions with $AgCO_3$, $BaCO_3$, CaF_2, $CaCO_3$, ZrO, talc,clay, etc.	solid solution of $BaTiO_3$ (barium titanate) plus $SrTiO_3$, $CaTiO_3$, etc.
frequency range	high frequency (oscillators, amplifiers, pulse circuits)	dc. decoupling., high frequency

Table 2 Typical applications for ceramic capacitors type I and type II

Capacitor type	Range of values	Applications
Type I ceramic capacitors	0,8 pF, 1 nF	industrial and professional electronics high frequency, especially in resonant and pulse circuits where the stability of the capacity with respect to temperature and the quality factor are essential
Type II ceramic capacitors	33 pF¸ 220nF	coupling and decoupling circuits, filters in telecommunications and industrial equipment, high voltage circuits, which can accept a considerable variation with temperature and where losses are not essential.

Encoding of **type I ceramic dielectrics** is made after several standards. The coding is simple, for example N750 means negative temperature coefficient of variation of -750 ppm /°C. The most stable type I ceramic is symbolized as COG or NP0 with a null temperature coefficient (TCC) and with a temperature deviation of ± 30 ppm /°C.

For **type II ceramic capacitors** alphanumeric codes are used.
According to EIA - Standard RS198B, a **code such as L_1CL_2** is used:

- **L_1, the first letter,** signifies the lower limit of temperature, using the code: Z = 10°C, Y = - 30°C, X = - 55°C;
- ***C*, figure,** signifies the upper limit of temperature, using the code: 4 = 65°C, 5 = 85°C, 6 = 105°C, 7 = 125°C, 8 = 150°C
- **L_2, the second letter,** expresses the maximum capacity deviation with temperature, in percentage, against the capacity at 25°C, and the code is: *A* = ±1, *B* = ±1.5, *C* = ±2.2 *D* = ±3.3, *E* = ±4.7, *F* = ±7.5, *P* = ±10, *R* = ±15, *S* = ±22, *T* = +22 /-33, *U* =+22 / -56, *V* =+22 / -82.

For example, a capacitor type *X7R*, has a maximum capacity deviation with temperature of ±15% in the temperature range [-55, 125] °C. Other variants: Z5U, Y5V, X8R.

The parameters of capacitors studied in the laboratory

Firstly, the identification of the capacitor must be done. For the laboratory board, reference numbers for the components are used C1, CC3, CCD1, CPP1, etc. Based on the table with the manufacturer's code, for example KEPF015 for a ceramic disc capacitor CCD1, one can move on to study the datasheets. Useful information is given by the presence of marking on the body of the capacitor. It should be noted from the very beginning that the method of marking is specific to each type of capacitor and it is mandatory to check the catalog sheets of those components. However, a few rules are respected, such as the color code marking rules, Mantissa + exponent code, code EIA96, clearly writing the capacity, rated voltage and tolerance. The encoding Mantissa + exponent applied to the capacitor usually has only 3 significant figures as high accuracy is more difficult to obtain than with resistors. The rule usually applies to values above 100 pF. The first digits (Mantissa) are the significant numbers of the rated value and the last digit (the exponent) is the power of 10 to express the amount, or in short the multiplier. Examples of marking, 102, 472, 224. The rated values are,according to the aforementioned rule: 10×10^2 = 1nF, 47×10^2 = 4.7 nF, 22×10^4 = 220nF,. Low capacity values are marked precisely. However, one should investigate the marking from the manufacturer.

On the body of a capacitor only some of the parameters that characterize it are inscribed, usually the rated capacity, the tolerance, and sometimes the rated voltage. For the temperature coefficient there used to be various encodings in the color code.

Rated capacity is usually marked on the body of the capacitor. If the value is expressed with precission, instead of the floating point the multiplier order is written: p(pico) and n(nano). For example 2n2 is 2.2 nF.
Tolerance can be clearly marked or a literal code can be used, as with the resistors, code presented in Table 3.

Table 3 Literal code for marking the tolerance of the capacitors

Tolerance [%]	±0,05	±0,01	±0,2	±0,5	±1	±2	±2,5	±5	±10	±15	±20
Literal code	W	B	C	D	F	G	H	J	K	L	M

- Ceramic capacitors typically have lower values and are marked usually in picofarads for the monolayer structure. For type II and for the multilayer capacitors nanofarads could also be marked.
- Metallized foil capacitors, MKT type or Mylar (polyethylene terephthalate) and polypropylene MKP typically have high values and the rated value can be marked in μF.
- Electrolytic capacitors having very high values are marked with the rated value in μF. Also the rated voltage and terminal polarities (+) or (-) are inscribed. Example: 25/16 means C = 25μF, U = 16V. The maximum temperature, production date as well as other certain details of the series, such as "Low ESR" i.e. low series resistance could appear, too.

3. Work procedure

3.1 Table 5 in Annex 2 has to be filled out. For the types of capacitors shown in Figure 12, determine the parameters marked and other parameters characterizing these capacitors through the help of the datasheet. All data, both measured and determined goes in the table with the format given in Annex 2.

Procedure:

a) Identify the capacitors after the code given in Table 4, Annex 1. The code allows in most cases the unequivocal identification of rated value and tolerance as well as other specific parameters.
b) Identify the rated value and tolerance, and where appropriate the rated voltage after the marking, which has priority over the code. Any differences that arise between the code and marking may be caused by the placing of an equivalent capacitor on board.
c) Study other methods of marking, for example the Mantissa + superscript code.

d) Study the datasheets in order to fill in table 5. In order to check as many types of capacitors, at the beginning one capacitor in each category will be studied and then the list will be completed for the other items.

Laboratory board is shown in Figure 12.

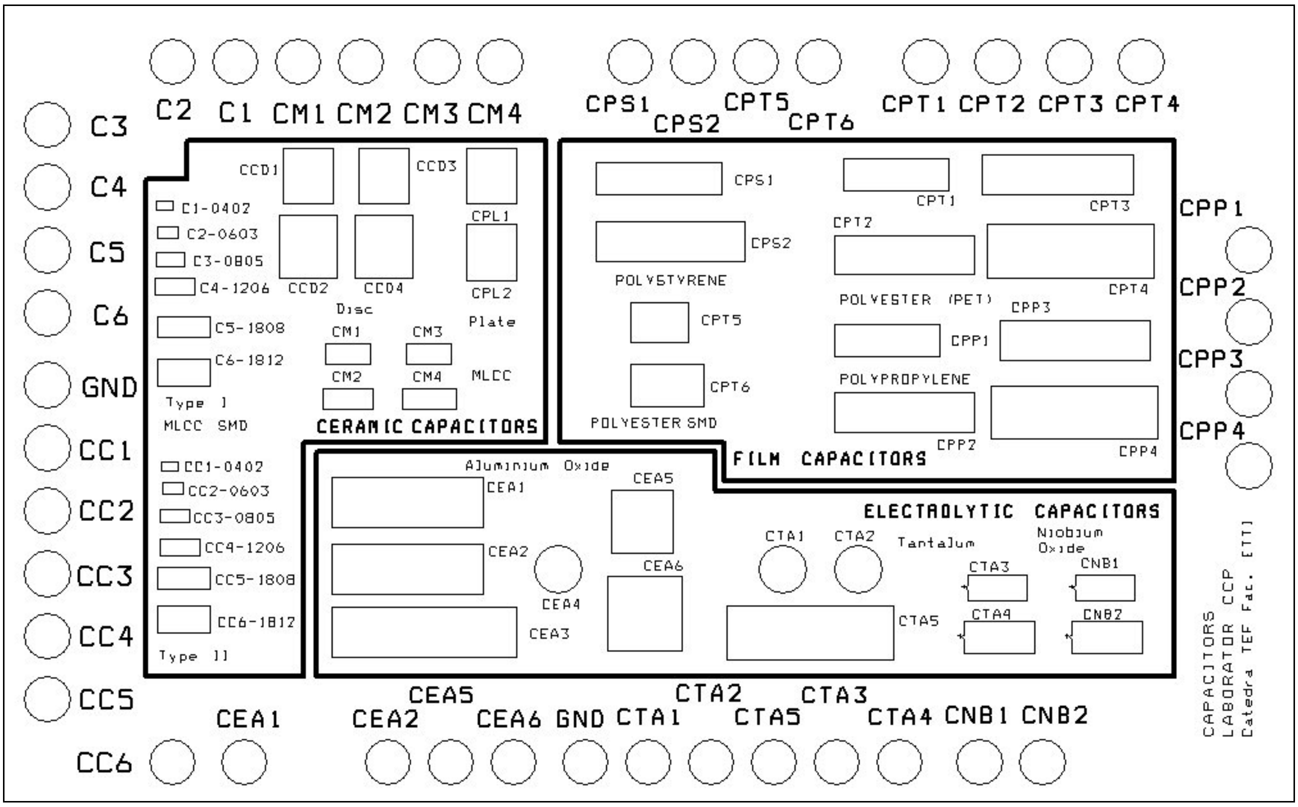


Fig. 12 Representation of the board for the study of capacitors

Capacitors were divided into three groups:

- **Ceramic capacitors:** multilayer ceramic capacitor SMD type I (NP0) C1-C6, type II SMD Multilayer Ceramic Capacitor (X7R and Z5U) CC1-CC6, type I radial multilayer ceramic capacitor CM1, CM2, type II radial multilayer ceramic capacitor, CM3, CM4, type I ceramic disc capacitor CCD1 CCD2, type II ceramic disc capacitor CCD3 CCD4, type I wafer ceramic capacitor CPL1, wafer type II ceramic capacitor CPL2.
- **Foil Capacitors:** polystyrene axial capacitor CPS1, CPS2, metallized polyester radial capacitor CPT1-CPT2, metallized polyester axial capacitor CPT3-CPT4, SMD metallized polyester capacitor CPT5-CPT6, CPP1 metallized polypropylene radial capacitors, CPP2, axial capacitors with metallized polypropylene CPP3, CPP4
- **Electrolytic capacitors:** aluminum electrolytic axial capacitor CEA1-CEA3, CEA4 aluminum electrolytic radial capacitor, aluminum electrolytic SMD capacitor CEA5-CEA6, tantalum electrolytic radial capacitor CTA1-CTA2, SMD tantalum electrolytic capacitor CTA3-CTA4, tantalum electrolytic axial capacitor CTA5, niobium electrolytic SMD capacitor CNB1-CNB2.

Note. NOT ALL capacitors have measurement terminals. The parameters will be measured only where appropriate.

3.2. Measure the capacity for the capacitors which have measuring terminals and are placed on the board shown in Figure 12. In the paper t_m, the resulting tolerance from measurements, is computed by:

$$t_m = \frac{C_m - C_N}{C_N} \qquad (6)$$

with C_m being the measured value of the capacity, C_N rated capacity

The loss factor (tg δ) is also measured with a RLC bridge, which simultaneously displays the loss factor and the capacity For electrolytic capacitors the serial mode of the device must be chosen (CS mode). In this way one can also measure the equivalent series resistance (ESR), a very important operating parameter in pulsating current regime of the capacitor.

4. Questions, conclusions

4.1 Based on the grouping of the capacitors onto the laboratory board compare the categories of capacitors. Indicate the main distinctive elements, the constructive details, main characteristics, parameters highlighted in a particular category, application areas.

4.2. Given the results in section 3.1 (Table 5), provide a comparison of the capacitors in terms of the parameters listed in the table.
4.3. Compare the tolerance measured, $\mathbf{t_m}$ with the one marked on the capacitor, **t,** according to data in Table 5. Why are there differences between $\mathbf{t_m}$ and **t?** What this difference mean? Is a positive good? What about a negative one?
4.4. Compute the overall tolerance for one type I single-layer ceramic capacitor type I and for one type II, similar to the ones on the board, assuming they have the same capacity and operate in an environment with temperature in the range [-10, 85]°C and assuming that the manufacturing tolerances are equal to ±2.5%.
4.5. In what type of applications are type I ceramic capacitors preferred? And type II? Discuss based on an analysis conducted on the Internet.
4.6. Analyze in terms of losses from Table 5, including the measured ones, various types of capacitors. Also take into account the ESR parameter for the electrolytic capacitors.
4.7 According to you, which are the advantages of the multilayer ceramic capacitors MLCC? Are there disadvantages, too?
4.8. Which are the advantages of SMD components? The disadvantages? Comments.
4.9 What differences exist between the ceramic disc capacitors and the wafer ones in terms of the parameters? Note the greater thickness for the disc versus the wafer.
4.10. Try to describe in detail the constructive elements of Fig. 9 for the electrolytic capacitor.
4.11. How do you explain the same dimension for the capacitors 10μF/100V and 100 μF/10V?
4.12 Based on the catalog data, including those in Table 5, try to identify which parameters differ between aluminum and tantalum electrolytic capacitors and in what type of application is preferred each one.
4.13 Given the structure, which capacitor has a higher parasitic inductance, the capacitor with the Al foils or the capacitor with metallic foil?
4.14. What constructive and material parameter (parameters) depends on the rated voltage of a capacitor?
4.15 Compare (based on Table 5) various types of capacitors in terms of the insulation resistance. Is there any relation to the loss tangent?
4.16. What does the fact that an electrolytic capacitor is polarized mean? Can non-polaryzed electrolytic capacitors be achieved?
4.17.Can a capacitor with polystyrene (stiroflex) be replaced in an assembly, which requires a good stability with respect to temperature? (Please explain with what type it can be replaced based on the table you made)
4.18. The temperature coefficient of a capacitor depends primarily on:

1) The variation with temperature of the permittivity of the dielectric.
2) The variation with temperature of the geometric dimensions.
3) The variation with temperature of the contact area.
4) The variation with temperature of the permittivity of the protection elements.

4.19. The quality factor of a capacitor depends on:

1) dielectric type.
2) Rated voltage.
3) Plates.
4) Rated current.

4.20. The insulation resistance of a capacitor depends on:

1) Terminals.
2) Plates.
3) The element of protection.
4) Dielectric.

4.21. The temperature range that is specific to a capacitor states:

1) The temperature range in which the component changes its value with the tolerance.
2) Minimum range for the temperature of the component's body for long operation cycles.
3) The range for which the component maintains its value within the allowed tolerance.
4) Ambient temperature range in which the component can be used.

4.22. The change in the capacity of the variable capacitor is achieved by:

1) Changing the distance between plates.
2) Changing the permittivity of the dielectric material.
3) Changing the thickness of the dielectric.
4) Changing the overlapping area of the plates.

Content of the essay:

Table 5 completed, comments, answers to questions.

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ANNEX 1 - Table 4 lists and code of the components

Crt No	Name ref.	Capacitor type	Manufacturer code	Manufacturer
1.	C1	Multilayer ceramic capacitor 0402, NP0	04023A271JAT2A	AVX
2.	C2	Multilayer ceramic capacitor 0603 NPO 100V	06031A101JAT2A	AVX
3.	C3	Multilayer ceramic capacitor 0805 NPO 100V	08051A330JAT2A	AVX
4.	C4	Multilayer ceramic capacitor 1206 NPO 100V	12061A470JAT2A	AVX
5.	C5	Multilayer ceramic capacitor 1808 NPO 2000V	1808GA680JAT1A	AVX
6.	C6	Multilayer ceramic capacitor 1812 NPO 1000V	1812AA471JAT1A	AVX
7.	CC1	Multilayer ceramic capacitor 0402 16V X7R	0402YC223KAT2A	AVX
8.	CC2	Multilayer ceramic capacitor 0603 Y5V 50V	06035G103ZAT2A	AVX
9.	CC3	Multilayer ceramic capacitor 0805 X7R 25V	08053C224KAT2A	AVX
10.	CC4	Multilayer ceramic capacitor 1206 X7R	12065C223KAT2A	AVX
11.	CC5	Multilayer ceramic capacitor 1808 X7R ,1000V	1808AC102KAT1A	AVX
12.	CC6	Multilayer ceramic capacitor 1812 X7R /50V	18125C224KAT00J	AVX
13.	CCD1	Disc ceramic capacitor NPO	KEPF015	JYA-NAI
14.	CCD2	Disc ceramic capacitor NP0	KEPF010-500V	JYA-NAI
15.	CCD3	Disc ceramic capacitor Z5U 100V	KENF002,2	JYA-NAI
16.	CCD4	Disc ceramic capacitor Z5U 500V	KENF001-500V	JYA-NAI
17.	CPL1	Wafer capacitor NP0	2222 680 10129	BCE-SUD
18.	CPL2	Wafer capacitorY5V	2222 629 08222	BCE-SUD
19.	CM1	Multilayer radial ceramic cap. MLCC 4.7p/100V COG	B37979G1470J	EPCOS
20.	CM2	MLCC cap. 4.7n/50V COG	B37986G5472J	EPCOS
21.	CM3	MLCC radial cap.10n/50V X7R	B37981F5103K	EPCOS
22.	CM4	MLCC radial cap. 100n/50V X7R	B37987M5104K	EPCOS
23.	CPS1	Polystyrene capacitor (PS) 10pF/160V	FSC 160V	LCR COMP.
24.	CPS2	Polystyrene capacitor (PS) 1n/160V	FSC 160V	LCR COMP.
25.	CPT1	Rad cap. PET 10mm MKT 10nF/400V	MKT1820310405	VISHAY
26.	CPT2	Rad cap. PET 15mm MKT,330n/250V	MKT1820433255	VISHAY
27.	CPT3	Axial cap. PET 11mm 1.5nF/630V	MKT1813-215/63-5-G	VISHAY
28.	CPT4	Axial cap. PET 14mm 0.022 uF/400V	MKT1813-322/40-5-G	VISHAY
29.	CPT5	PET SMD cap. 2220 22n/100V	SMD2220 100V 0.022UF	WIMA
30.	CPT6	PET SMD cap. 2824 68n/100V	10602824116820T	WIMA
31.	CPP1	rad PP cap 10mm Y2,1nF/300V	B32021A3102M	EPCOS
32.	CPP2	rad PP cap. 15mm Y2, 15nF/300V	B32022A3153M	EPCOS
33.	CPP3	PP axial cap. 11mm MKP 22n/400V	MKP1839322404	VISHAY
34.	CPP4	PP axial cap. 14mm MKP 47nF/400V	MKP1839347404	VISHAY
35.	CEA1	Electrolytic axial cap 100u/10V	TVX1A101MAD	NICHICON
36.	CEA2	Electrolytic axial cap 10u/100V	TVX2A100MAD	NICHICON
37.	CEA4	Electrolytic radial cap 100u/16V	UPM1C101MED	NICHICON
38.	CEA5	SMD el. Cap. 33u/25V	PCF1E330MCL1GS	NICHICON
39.	CEA6	SMD el. Cap. 220u/50V	UUD1H221MNL1GS	NICHICON
40.	CTA1	Tantalum droplike cap. 22u/16V CASE F	T350F226K016AT	KEMET
41.	CTA2	Tantalum droplike cap. 2.2u/35V CASE C	T356C225K035AT	KEMET
42.	CTA5	Tantalum axial cap. 1u/35V CASE A	T110A105K035AT	KEMET
43.	CTA3	SMD Electrolytic tantalum cap, 6032	TAJC226M025R	AVX
44.	CTA4	SMD Electrolytic tantalum cap, 7343	TAJD107M020R	AVX
45.	CNB1	SMD niobium oxide electrolytic cap 6032	NOJC157M002R	AVX
46.	CNB2	SMD niobium oxide electrolytic cap 7343	NOJD227M004R	AVX

Crt no	Name Ref.	C_N*	t[%]	UN [V]	tgδ	α [ppm/°C]	ΔC/C [%] în interv. de temp. [°C]	Riz [GΩ]	τ [s]	If [μA]	Io [mA]	ESR [mΩ]	Tmin [°C]	Tmax [°C]	Measured parameters			
															C*	tgδ	ESR [mΩ]	tm [%]
1.	C1																	
2.	C2																	
3.	C3																	
4.	C4																	
5.	C5																	
6.	C6																	
7.	CC1																	
8.	CC2																	
9.	CC3																	
10.	CC4																	
11.	CC5																	
12.	CC6																	
13.	CCD1																	
14.	CCD2																	
15.	CCD3																	
16.	CCD4																	
17.	CPL1																	
18.	CPL2																	
19.	CM1																	
20.	CM2																	
21.	CM3																	
22.	CM4																	
23.	CPS1																	
24.	CPS2																	
25.	CPT1																	
26.	CPT2																	
27.	CPT3																	
28.	CPT4																	
29.	CPT5						N/A											
30.	CPT6						N/A											
31.	CPP1					N/A	N/A											
32.	CPP2					N/A	N/A											
33.	CPP3																	
34.	CPP4																	
35.	CEA1																	
36.	CEA2																	
37.	CEA4																	
38.	CEA5																	
39.	CEA6																	
40.	CTA1																	
41.	CTA2																	
42.	CTA5																	
43.	CTA3																	
44.	CTA4																	
45.	CNB1																	
46.	CNB2																	

ANEXA 2 Table 5: Measured and identified parameters

Annex 3

Rated values of the series E6 … E192

E6 ±20%	E12 ±10%	E24 ±5%	E48 ±2%	E96 ±1%	E192 ±0,5%
100	100	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			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		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%
	560	560	562	562
				576
			590	590
				604
		620	619	619
				634
			649	649
				665
680	680	680	681	681
				698
			715	715
				732
		750	750	750
				768
			787	787
				806
	820	820	825	825
				845
			866	866
				887
		910	909	909
				931
			953	953
				976