In Table 3.2 we give you the classes insulating materials, sorted by their operational temperature, according to IEC85.

Table 3.2

CLASS	LIST	INSULATING MATERIALS	MAXIMUM OPERATIONAL TEMPERATURE
Y	Main	Cotton, natural silk, synthetic wool, Rayon, paper and its products, wood, polyamide thread, urea resin, compressed paper, etc.	90°C
	Secondary	Polyethylene, polystyrene, vulcanized rubber, etc.	
A	Main	The materials of the Y class ingrained in varnishes or oils, seluzolic film, polyester resin, etc.	105°C
	Secondary	Elastormers of butadiene-acryl-nitride, elastormers of polychloroprene.	
E	Main	Bakelite, polypropylene, acetic resin, polyester, polycarmonated film, polyurethane, polyamide resin.	120°C
B	Main	Whitewash, mica and its products, glass fibers, glass fibers ingrained in varnishes and oils.	130°C
	Secondary	Polymonochlorofluoroethylene, crystallized polycarmonated film	
F	Main	Glass fibers, whitewash	155°C
	Secondary	Inorganic materials ingrained in resins for endurance against high temperatures	
H	Main	What is mentioned previously in the secondary list but in base of silicone resin	180°C
	Secondary	Smalted polyamide	
C	Main	All inorganic materials without additional soldering materials, glasses, mica, crystals, ceramics, porcelains.	>220°C
	Secondary	Polyamide, polytetrafluoroethylene (teflon), etc.	

3.5 EQUIVALENT OF CAPACITOR CIRCUITS

3.5.1 Equivalent circuit of dielectric capacitors

In Fig. 3.7 we show the circuit in which ESR is the Equivalent Series Resistance, C is the capacity of the capacitor and L is the parasitic self-inductance owed to the connectors and the armor of the capacitor.

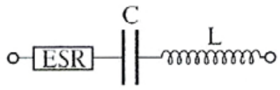


Figure 3.7

The loss power P in such a capacitor is:

$$P = \frac{U_{ESR}^2}{ESR} \qquad (W)$$

As shown in Fig. 3.8, P follows this equation:

$$P = ESR \cdot I^2 \qquad (W)$$

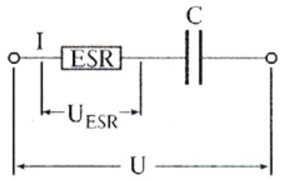


Figure 3.8

There is also the equation:

$$P = \omega C \tan\delta \cdot U^2 \qquad (W)$$

or

$$P = \frac{\tan\delta}{\omega C} \cdot I^2 \qquad (W)$$

From the circuit of Fig 3.7 we have:

$$Z = \sqrt{ESR^2 + \left(\omega L - \frac{1}{\omega C}\right)^2} \qquad (\Omega)$$

where Z is the total resistance of the capacitors in AC, ω is the circular frequency and

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \qquad (Hz)$$

where f_0 is the resonance frequency of the capacitor.
Finally, the phase variation is provided by the relation:

$$\varphi = \tan^{-1} \frac{\omega L - \frac{1}{\omega C}}{ESR}$$

For example, the resonance frequency of an oil capacitor with ESR=2.1mΩ, L=80nH and C=10μF is almost 1.8MHz and produces phase sliding in this frequency of almost 90%. This is why it's not used in high frequencies.

3.5.2 Equivalent circuits of electrolytic capacitors

These capacitors, due to their manufacturing, show ohmic and inductive resistance, which, instead of the efforts of the manufacturers to minimize them, cannot be eliminated because of the way they operate.

In Fig. 3.9, you can see the equivalent circuit of non-polarized capacitor in DC, where R_{μ} is the insulating resistor, R_s is the resistor of electrodes, of connections, of plates and of dielectric losses, R_{δ} is the resistor of the electrolyte, ESL is the parasitic series self-inductance and C is the capacity of the capacitor.

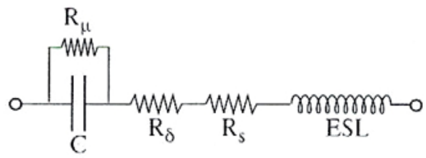


Figure 3.9

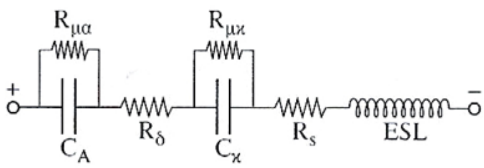


Figure 3.10

In Fig. 3.10 you can see the equivalent circuit of polarized capacitor in DC where $R_{\mu\alpha}$ is the resistor of the anode insulation, $R_{\mu\kappa}$ is the resistor of cathode insulation, C_A is the anode capacity, C_K is the cathode capacity, R_{δ}, R_S and ESL as previously.

Figure 3.10 is explained because actually there are formed two capacitors, one in anode and one in cathode. Consequently, the total capacity will be:

$$C = \frac{C_A C_k}{C_A + C_k} \qquad (F)$$

because C_A is in series with C_K. The total capacity is owed to C_A for manufacturing reasons. If the capacitor of Fig. 3.10 is not polarized, then goes the equation:

$$C = \frac{C_A}{2} \qquad (F)$$

and this is happening because this capacitor is the same in anode and in cathode, something that doesn't apply to the polarized capacitors. It's now obvious that the general equivalent of Fig. 3.10 converts to that of Fig. 3.9, as long as $R_{\mu}=R_{\mu\alpha}+R_{\mu\kappa}$ and $C=C_A$ in series with $C_A=C_A/2$.

In Fig. 3.11, you can see the simplified equivalent of electrolytic capacitors in DC, where R_L is the leak resistor and ESR is the equivalent series resistor.

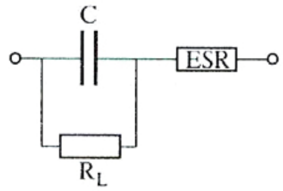


Figure 3.11

Figure 3.12

In fig. 3.12, we show the equivalent of electrolytic capacitors in AC, where ESL is the equivalent series self-inductance. The similarity with Fig. 3.7 of the dielectric capacitors is obvious.

3.5.3 Tantamount circuit of super capacitors (power storage)

Those capacitors are differently constructed and operating form the rest, that's why their equivalent is different, as well as their use.

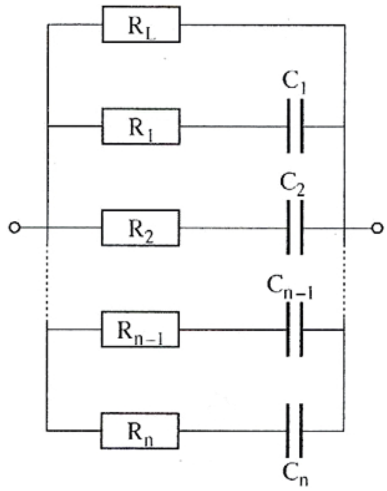


Figure 3.13

In Fig. 3.13, which is the simplified equivalent, R_L represents the loss resistor, the R_1, R_2, …R_n the total passage resistors and C_1, C_2, …C_n the total capacities of the fundamental capacitors. We refer to them as total because they (resistors and capacitors) exist on both sides of an ion-passed film which lies between the two armors. Fig. 3.13 shows that a supercapacitor can be considered as a parallel combination of many, in series networks, which we can imagine as 1Ω/10μF, 10Ω/100μF, 100Ω/1F, 1KΩ, 10F, etc. This why the capacity is experimentally specified and much depended on the conditions of the measurements. One of their attributes, besides the large capacity, is the proportionally very big equivalent series resistance ESR, which depends on the measurement frequency. The manufacturers give an estimated ESR, which because of its size, doesn't recommend the use of supercapacitors in AC.

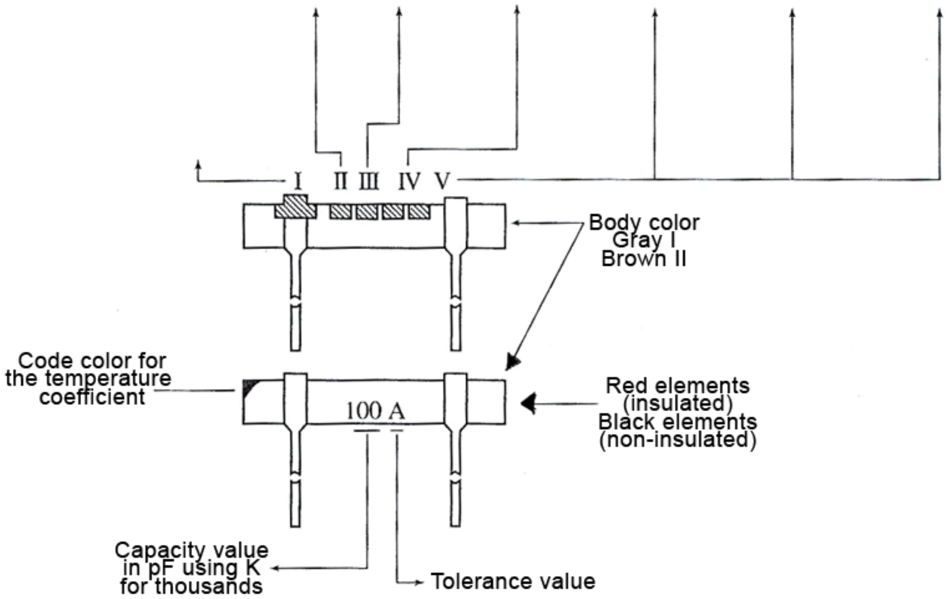
3.7.6.6 Codes of ceramic capacitors

From the beginning we must point out the fact that the encoding of ceramics capacitors is different for the categories I, II and III.
On the level discs without connectors and on the trapezoidal ones their value, tolerance and operational voltage are read on them.
On the cylindrical with or without connectors, on the hydro-cooled, the feed-through and the level discs of low or high voltage or of temperature compensation, their value, tolerance, named operational voltage DC or AC, temperature coefficient, named operational current and other attributes are read on their box.
Last, on the level rectangular or radial discs and on the cylindrical miniature types, several codes are applied for reading more or less of their attributes.
In Fig. 3.26 the color code and other symbols for the type I and II capacitors are presented. We notice that there are two ways of encoding; color encoding or numbers and letters encoding.

Figure 3.26

COLOR CODE OF CERAMIC CAPACITORS OF TYPE I AND II

COLOR	Temperature coefficient ppm/°C	CAPACITY VALUE (pF)			CAPACITY TOLERANCE		
					TYPE I		TYPE II
		1st digit	2nd digit	Multiplier	C≤10PF± (pF)	C≤10PF± (%)	±(%)
Red/Purple	P100	-	-	-	-	-	-
Black	NP0	-	0	1	±2	±20	±20
Brown	N033	1	1	10	±0.1	±1	-
Red	N075	2	2	10^2	±0.25*	±2	-
Orange	N150	3	3	10^3	-	±2.5	-
Yellow	N220	4	4	10^4	-	-	-0~+100
Green	N330	5	5	-	±0.5	±5	-
Blue	N470	6	6	-	-	-	-
Purple	N750	7	7	-	-	-	-20~+80
Gray	P033	8	8	10^{-2}	-	-	±10
White	-	9	9	10^{-1}	±1	±10	
Black/Brown	N47						
Light green	N110						
Orange/Orange	N1500						
Yellow/Orange	N2200						
Blue/Orange	N4700						



C≤10PF			C>10PF		
Code Spraque	**Code EIA****	**Tolerance (pF)**	**Tolerance ±(pF)**	**Code EIA****	**Code Spraque**
-	A	0.05	1	F	X1
-	B	0.1	2	G	X2
F1	C	0.25	2.5	H	X7
F2	D	0.5	5	J	X5
X1	F	1	10	K	X9
X2	G	2	15	L	X8
			20	M	X0
			30	N	G3
			0~+100	P	A8
			-20~+40	V	D4
			-20~+50	S or Y	D5
			-20~+80	Z	D8
			0~+200	GMV*	-

** In the American code the tolerance ±0.25pF is shown with gray color and the tolerance GMV is 0~+1--% (Guaranteed Minimum Value).*
*** EIA (Electronic Industries Association)*

For the level rectangular or radial discs, the colors of the temperature coefficient are the same and symbolized with a bullet on the top of the capacitor; in type I they are color. They can also have the symbols of the Table 3.6.1 and 3.6.2.
The types of capacitors we just mentioned, if they belong to type II, they will be brown or bister (earthen color) and if they belong to type III, they will be blue.
The codes for each category are presented in Tables 3.6.3, 3.6.4, 3.6.5 and 3.6.6 respectively.

Table 3.6.1

MIL CODES OF THE TEMPERATURE COEFFICIENT AND OF ITS TOLERANCE. TYPE I	
A = +100 ppm/°C	F = ±15 ppm/°C
B = +33 »	G = ±30 »
C = ±0 »	H = ±60 »
H = -33 »	J = ±120 »
L = -75 »	K = ±250 »
P = -150 »	L = ±500 »
R = -220 »	M = ±1000 »
S = -330 »	N = ±2500 »
T = -470 »	
U = -750 »	
V = -1500 »	
K = -2200 »	

Example: CH = 0±60 ppm/°C
VK = -1500±250 ppm/°C

Table 3.6.2

EIA CODES OF THE TEMPERATURE COEFFICIENT AND OF ITS TOLERANCE. TYPE I		
TEMPERATURE COEFFICIENT ppm/°C		TOLERANCE ppm/°C
DIGIT	MULTIPLIER	
C = 0.0	0 = -1	G = ±30
M = 1.0	1 = -10	H = ±60
P = 1.5	2 = -100	J = ±120
R = 2.2	3 = -1000	K = ±250
S = 3.3	5 = +1	L = ±500
T = 4.7	6 = +10	M = ±1000
U = 7.5	7 = +100	N = ±2500
	8 = +1000	

Example: COG = 0±30 ppm/°C
VK = -330±1000 ppm/°C

Table 3.6.3

MIL CODES OF MAXIMUM CHANGE OF OPERATING CAPACITY AND TEMPERATURES OF HIGH-K CAPACITORS. TYPE II			
RANGE OF OPERATIONAL TEMPERATURES (°C)	MAXIMUM CHANGE OF CAPACITY		RANGE OF OPERATIONAL TEMPERATURES (°C)
	WITHOUT VOLTAGE	WITH VOLTAGE	
A = -55 ~ +85	P = 0±30ppm/°C	0±30ppm/°C	1 = -55 ~ +1254
B = -55 ~ +125	B = ±10%	(-15~+10)%	2 = -55 ~ +85
C = -55 ~ +150	X = ±15%	(-25~+10)%	3 = -40 ~ +85
-	R = ±15%	(-40~+15)%	4 = -25 ~ +85
-	C = ±20%	(-30~+20)%	5 = -10 ~ +70
-	D = (-30~+20)%	(-40~+20)%	6 = -5 ~ +70
-	E = (-55~+20)%	(-70~+22)%	-
-	W = (-56~+22)%	(-66~+22)%	-
-	Y = (-70~+30)%	(-80~+30)%	-
-	F = (-80~+30)%	(-80~+30)%	-
-	FZ = (-85~+30)%	-	-
-	TF = (-90~+30)%	-	-
			-

Table 3.6.4

CODES OF DIELECTRIC HIGH-K CONSTANT. TYPE II		
Yellow	Z	2000
Blue	E	5000
Without color	-	6000
Black	-	10000
Green	-	14000

Table 3.6.5

EIA CODES OF DIELECTRIC MATERIALS HIGH-K. TYPE II		
MINIMUM TEMPERATURE	MAXIMUM TEMPERATURE	MAXIMUM CHANGE OF CAPACITY
X = -55°C Y = -30°C Z = +10°C	2 = +45°C 4 = +65°C 5 = +85°C 6 = +105°C 7 = +125°C	A = ±1% B = ±1.5% C = ±2.2% D = ±3.3% E = ±4.7% F = ±7.5% P = ±10% R = ±15% S = ±22% T = (-33~+22)% U = (-56~+22)% V = (-82~+22)%

Table 3.6.6

CODES OF MAXIMUM CHANGE OF CAPACITY. TYPE III
SF = ±7.5% B or BC = ±10% X or SR = ±15% E = (-55~+20)% F = (-80~+30)%

Notes

I) *Table 3.6.3 gives us dielectrics as BX or AR or CF etc. BX=tolerance ±15% without voltage or (-25~+15)% with voltage in temperatures (-55~+125) C. We also have dielectrics from the combination of the second and the last column, i.e. 2C5=type ii, Max ΔC/C=±20% in temperatures (-10~+70)°C or similarly 2E4…*

II) *Table 3.6.5 gives us dielectrics as X7R, Y5R etc.*

III) *Exceptions in Table 3.6.2:*
S2L = -750≤TC≤100ppm/°C
U2M = -1500≤TC≤150ppm/°C They can take any value inside those areas.
S3N = -5200≤TC≤1000ppm/°C

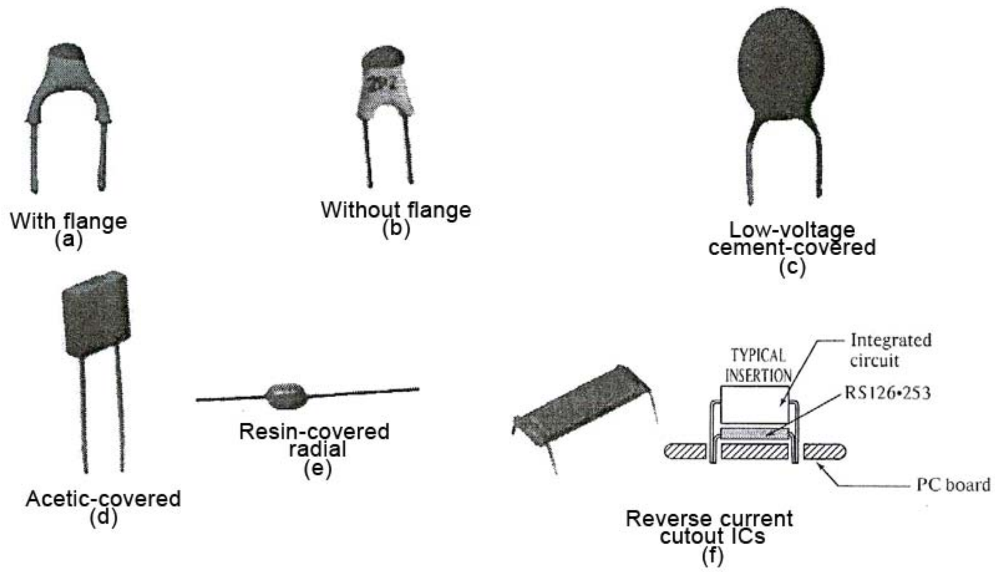


Figure 3.27

Examples

Table 3.6.3 gives us dielectrics as the 2F4 which represents a type II capacitor with maximum change of capacity (-80~+30)% and operational temperatures in the area (-25~+85)°C. Similarly, we have the dielectrics 2C1, IC4 etc.

Table 3.6.5 gives us dielectrics as the X7R which represents a capacitor with operational temperatures in the area (-55~+125)°C an equal to ±15%. Similarly, we have dielectrics the Z5U, Z5T, Y5P, X5R etc.

The manufacturers provide in their manuals the codes we mentioned, for each capacitor they produce with those dielectrics.

A capacitor colored gray, as the one in Fig. 3.27a or b, with a bullet colored purple and the symbol 3p9, shows that it belongs to type I, with capacity 3.9pF and. A corresponding one, on the other side, can be, for example, 5000; that means it works until it reaches $500V_{DC}$.

A third one, with yellow color, a blue bullet and the symbol 1n0 belongs to type II, it has dielectric material equal to 5000 and capacity of 1nF.

They can also be gray, with an orange bullet and the symbol 151J, namely of type I, with temperature coefficient -150ppm/°C, capacity 150pF and tolerance ±5%. They may not have a bullet but just the symbol, for example, 223Z, which means capacity of 22000pF and tolerance (-20~+80)%.

If they have symbols like X9/332, with brown body color, they belong to type II, with capacity 3300pF and tolerance ±10%. They can also be gray with the symbols CH/22, that is type I, temperature coefficient 0~±60ppm/°C and capacity 22pF.

Last, they can be brown with a yellow bullet and the symbols 1n8/500, that is type II with dielectric material 2000, capacity 1.8nF and operational voltage $500V_{DC}$. With the bullet and with symbol, for example, 5n6, it belongs to type II, with dielectric material 6000 and capacity 5.6nF.