Choosing Capacitors and SMD Soldering

Content courtesy of Wikipedia.org

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Common Capacitor Specs.

- Capacitance
- Tolerance
- Maximum Operating Voltage

Less Common Capacitor Specs.

- Equivalent Series Resistance and Dissipation Factor
- Operating Temperature Range
- Stability – i.e. Change of Capacitance over the operating temperature range and with voltage
- Dielectric Type

Equivalent Series Resistance (ESR)

- In a non-electrolytic capacitor and electrolytic capacitors with solid electrolyte, e.g. tantalum, the metallic resistance of the leads and electrodes and losses in the dielectric cause the ESR. Typically quoted values of ESR for ceramic capacitors are between 0.01 and 0.1 Ohms. ESR of non-electrolytic capacitors tends to be fairly stable over time; for most purposes real non-electrolytic capacitors can be treated as ideal components.

- Aluminium and tantalum electrolytic capacitors with non solid electrolyte have much higher ESR values, up to several ohms, and ESR tends to increase with frequency due to effects of the electrolyte. A very serious problem, particularly with aluminium electrolytics, is that ESR increases over time with use; ESR can increase enough to cause circuit malfunction and even component damage,[1] although measured capacitance may remain within tolerance. While this happens with normal aging, high temperatures and large ripple current exacerbate the problem. In a circuit with significant ripple current, an increase in ESR will increase heat dissipation, thus accelerating aging.

Capacitor ESR - continued

- Electrolytic capacitors rated for high-temperature operation and of higher quality than basic consumer-grade parts are less susceptible to become prematurely unusable due to ESR increase. A cheap electrolytic capacitor may be rated for a life of less than 1000 hours at 85°C (a year is about 9000 hours).

Type	22 µF	100 µF
Standard aluminum	0.1 - 3.0 Ω	0.05 - 0.5 Ω
Ceramic	<0.015 Ω	

- Higher-grade pa[illegible]d hours at maximum rated temperature, as can be seen from manufacturers' datasheets.

- Electrolytics of higher capacitance have lower ESR; if ESR is critical, specification of a part of larger capacitance than is otherwise required may be advantageous.

- Polymer capacitors usually have lower ESR than wet-electrolytic of same value, and stable under varying temperature. Therefore polymer capacitors can handle higher ripple current. From about 2007 it became common for better-quality computer motherboards to use only polymer capacitors where wet electrolytics had been used previously.

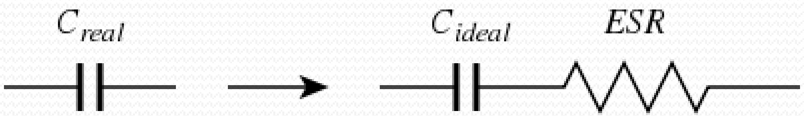
Capacitor ESR – Typical values

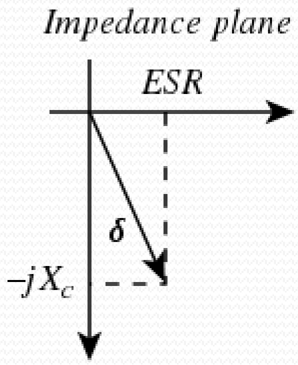
Type	22 µF	100 µF
Standard Aluminum	0.1 - 3.0 Ω	0.05 - 0.5 Ω
Ceramic	<0.015 Ω	

ESR and Dissipation Factor

If the capacitor is used in an AC circuit, the dissipation factor is expressed as the ratio of the resistive power loss in the ESR to the reactive power oscillating in the capacitor, or

$$DF = \frac{i^2 ESR}{i^2 |X_c|} = \omega C \cdot ESR = \frac{\sigma}{\varepsilon \omega} = 1/Q$$





When representing the electrical circuit parameters as vectors in a complex plane, a capacitor's dissipation factor is equal to the tangent of the angle between the capacitor's impedance vector and the negative reactive axis. This gives rise to the loss tangent δ where

$$\tan\delta = \frac{ESR}{|X_c|} = DF$$

Since the *DF* in a good capacitor is usually small, $\delta \sim DF$, and *DF* is often expressed as a percentage.

Capacitor Operating Temperature Range

- Operating temperature range is very important, especially when choosing electrolytics.
- Small, compact, boards will distribute heat from heat generating components such as power I.C.s to other nearby components such as large aluminum electrolytics.
- Must also consider operating ambient temperature, especially when product is used outdoors.

- Cheap, consumer grade electrolytics – -40° – 85° C.
- Better quality electrolytics - -40° – 105° C or -40° – 125° C.
- Even better quality electrolytics - -55° – 105° C or -55° – 125° C.
- Ceramic capacitors have similar operating temperature ranges, some only go down to -25 ° C.

Electronic Industries Alliance (EIA)

The **Electronic Industries Alliance** (EIA, until 1997 *Electronic Industries Association*) was a standards and trade organization composed as an alliance of trade associations for electronics manufacturers in the United States.

They developed standards to ensure the equipment of different manufacturers was compatible and interchangeable.

The EIA ceased operations on February 11, 2011, but the former sectors continue to serve the constituencies of EIA.

EIA Dielectric Classes

- EIA Class 1 dielectrics are usually based on titanate formulas (usually titanium dioxide with calcium titanate) with low or zero content of barium titanate; due to that low content, their susceptibility to microphonics is low. (Cf. EIA Class 2 dielectric.) Their dependence on temperature is linear.
- The dielectric constant of Class 1 dielectric materials is relatively low, so the capacitors tend to be limited to smaller values (typically <5 nF).

- EIA Class 2 dielectrics are usually based on formulas with high content of barium titanate (BT), possibly mixed with other dielectric electroceramics. Due to its piezoelectric properties, they are subject to microphonics. Other oxides added can be the same as used for Class 1 ceramics.

- In comparison with EIA Class 1 dielectrics they tend to have severe temperature drift, high dependence of capacitance on applied voltage, high voltage coefficient of dissipation factor, high frequency coefficient of dissipation, and problems with aging due to gradual change of crystal structure. Aging causes gradual exponential loss of capacitance and decrease of dissipation factor.

Capacitor Temperature Stability

- EIA Class 1 C0G or NP0 is the material with the lowest capacitance/temperature dependence (Negative-Positive zero). C0G/NP0 (NP0, negative positive zero) dielectrics have the lowest losses, and are used in filters, as timing elements, and for balancing crystal oscillators.

- There are two naming conventions. The EIA version relies on letter-digit-letter code for the slope of the temperature-capacitance dependence. The industry version uses a N/P prefix (N for negative, P for positive) and the slope coefficient. See the comparison for some common materials:

EIA -	M7G	C0G	B2G	U1G	P2G	R2G	S2H	T2H	U2J	P3K	R3L
Industry -	P100	NP0	N030	N075	N150	N220	N330	N470	N750	N1500	N2200

EIA Class 1 Dielectric Codes

ppm/°C	
C	0.0
B	0.3
L	0.8
A	0.9
M	1.0
P	1.5
R	2.2
S	3.3
T	4.7
V	5.6
U	7.5

Multiplier	
0	-1
1	-10
2	-100
3	-1000
5	+1
6	+10
7	+100
8	+1000

Tolerance in ppm/°C (25-85 °C)	
G	±30
H	±60
J	±120
K	±250
L	±500
M	±1000
N	±2500

EIA Class 2 Dielectric Codes

Minimum temperature[1]	
X	-55 °C
Y	-30 °C
Z	+10 °C

Maximum temperature[1]	
2	+45 °C
4	+65 °C
5	+85 °C
6	+105 °C
7	+125 °C
8	+150 °C
9	+200 °C

Capacitance change permitted[1]	
A	±1.0%
B	±1.5%
C	±2.2%
D	±3.3%
E	±4.7%
F	±7.5%
L	+15% / -40%[2]
P	±10%
R	±15%
S	±22%
T	+22%/-33%
U	+22%/-56%
V	+22%/-82%

EIA Class 2 Common Dielectric Codes

- X5R performs better than other dielectrics, such as Y5V, and permits the construction of physically smaller capacitors than other dielectrics, such as NP0 and X7R. Typically its temperature variation of capacitance is +/-15% over a range of -55 to +85 degrees Celsius. The temperature variation is, however, non-linear.

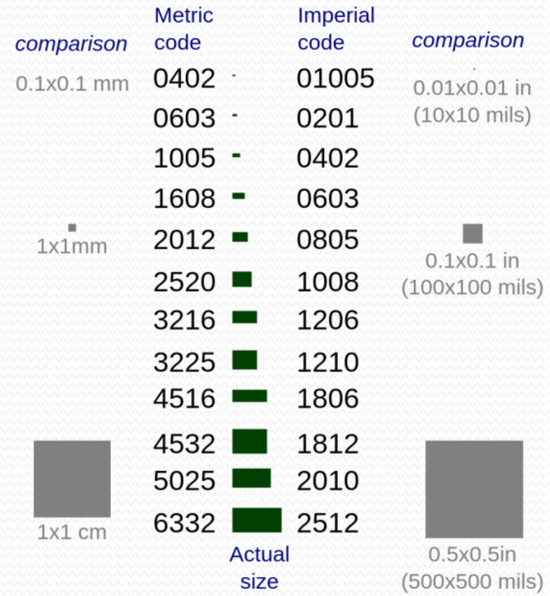
- X7R is designed for capacitors with capacity ranging typically between 3.3 nF to 330 nF (SMT: 100 pF to 10 µF). Good for non-critical coupling, filtering, transient voltage suppression, and timing applications. Has high dielectric constant. Its variation over a temperature range of −55 to +125 °C is ±15%.

- Y5P and Y5V are other class 2 ceramics, with temperature range of −30 to +85 °C and wide capacitance change with temperature of ±10% or +22/-82%. Usually used for capacitances between 150 pF and 2 nF (SMT: 10 nF to 10 µF).

- Z5U is commonly found from 2.2 nF to 2.2 µF, 20%. Good for bypass, coupling applications. Low price and small size, poor temperature stability.

SMD Soldering

- Common case sizes – 1012, 1007, 0805, 0603, 0402 (Imperial)
- Very small case sizes – 0201, 01005 (0.010 x 0.005”)
  No bigger than specks of pepper!



Solder Types

- Leaded solder – most common type for manual electronic work – is 63% Tin with 37% Lead –abbreviated 63/37 Sn/Pb. Melting point is around (183 °C or 361.4 °F).
- "Lead Free" solders – most common type for electronic work – is Sn-Ag-Cu (Tin-Silver-Copper) - Sn96.5% Ag3.0% Cu0.5% (96.5/3/0.5). Melting point is around (217 ˚C or 422 °F).
- This is NOT silver solder! Hard solders are used for brazing, and melt at much higher temperatures. Alloys of copper with either zinc or silver are the most common.

Hand Tools for Soldering

- Temperature controlled soldering iron
- Recommend interchangeable bits
- Fine wire flux cored solder – 0.015” or 0.020” diam.
- Needle nosed tweezers
- Illuminated magnifier lamp
- Steady hands!
- Soldering tweezers for re-work