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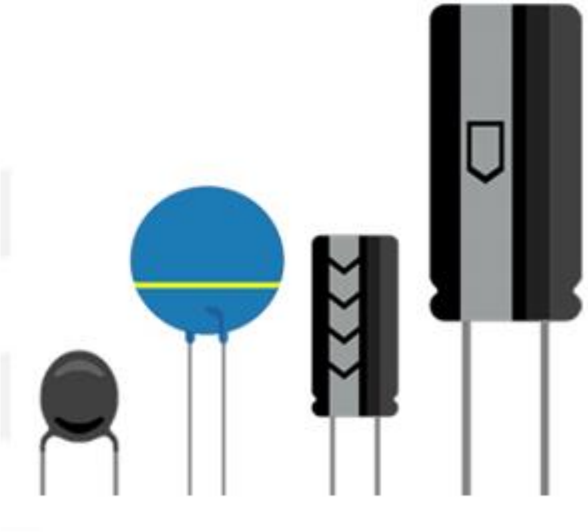
CAPACITOR ESR: SELECTION & DETECTION



INTRODUCTION

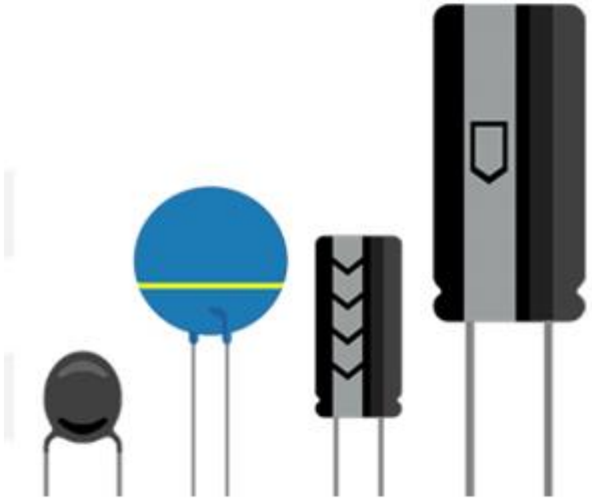
- **Capacitors** are ubiquitous throughout a design for many purposes.
- From charge storing, signal smoothing, filter applications, and more, these components are often the most populated element on a board.
- The capacitance and voltage rating (to handle the expected voltage and any spikes) are the primary factors when selecting capacitors. However, a lesser heralded metric can indicate how well the capacitor approximates its ideal performance
- The equivalent series resistance, or ESR. Capacitor ESR considerations will ensure that board functionality operates as expected over its service life and temperature ratings.

Image Source – aictech-inc

SAMPLE CAPACITOR ESR BY TYPE

	22uF(Ω)	100uF(Ω)
Standard aluminum	7 – 30	2 – 7
Low-ESR aluminum	1 – 5	0.3 – 1.6
Solid aluminum	0.2 – 0.5	N/A
Solid solid tantalum	1.1 – 2.5	0.9 – 1.5
Low-ESR tantalum	0.2 – 1	0.08 – 0.4
Wet-foil tantalum	2.5 – 3.5	1.8 – 3.9
Stacked-foil film	<0.015	0.0022 – 0.0029
Ceramic	<0.015	N/A

ESR & ESL OF CAPACITORS



CAPACITOR ESR MEASURES NON - IDEALNESS

ESR calculated in series with the capacitance value, is a barometer of the component's overall performance and service life. As ESR increases, power dissipation also does, so it's beneficial for any circuit designer and component manufacturer to minimize ESR as much as possible.

ESR is one of the primary considerations when selecting capacitors for a design:

- **Capacitance** – While it may go without saying, the capacitance of a capacitor indicates the charge storage capacity.
- **Inductance** – The lumped element model of a capacitor includes parallel leakage resistance with capacitance (the same capacitance mentioned above), resistance, and inductance in series. The latter three elements act as a damped series resonator. Below the resonant frequency, the capacitor behaves as expected; at the resonant frequency, it acts as a resistor (i.e., inductive and capacitive reactance cancel); above the resonant frequency, it acts as an inductor. With greater equivalent series inductance (ESL) of the capacitor, the inductive reactance overcomes the capacitive reactance at a lower frequency, reducing the resonant frequency.
- **ESR** – The summed resistance in series with the capacitance of the capacitor. It represents the real-valued resistance R of the impedance Z within the general vector form Z = R + jX (for completeness, j is the imaginary number, and X is the reactance).

CAPACITOR ESR MEASURES NON - IDEALNESS

ESR measures the "idealness" of a component with lower values, indicating that the capacitor functions closer to ideal behavior with minimal losses. It's valuable to differentiate ESR from the more thoroughly defined forms of loss that contribute to it:

- The resistance that occurs due to losses from the leads/pads is the conductor resistance. This resistance scales linearly with the frequency.
- Resistance along the path of leakage current is the leakage resistance. The energy dissipated through the leakage resistance is inversely proportional to the frequency; that is, the energy dissipated through the leakage path is low when the frequency is high, and vice versa.
- Resistance owing to polarization in the dielectric is the dielectric loss. Effectively, it acts as a parallel resistance with a large series capacitance in parallel with the actual capacitance. Like the leakage resistance, the energy dissipated through dielectric loss is minuscule, except at low frequencies.

The conductor resistance will dominate at high frequencies, whereas the leakage resistance and dielectric loss will dominate at low frequencies. Since ESR is a summation of all three resistances, it will always be equal to or greater than conductor resistance.

ESR – OVER THE SERVICE LIFE OF A DEVICE

- While part manufacturers indicate ESR at the time of production, ESR can increase dramatically during operation. As component materials age, resistance increases, and excessive temperature cycling or high temperatures accelerate this effect. Therefore, designers and engineers should be aware of some of the common symptoms exhibited by in-circuit capacitors (whether old or freshly replaced) when the ESR is excessive:

- **Temperature** – Overheating up to catastrophic failure/explosion is possible with high ripple currents. Look for signs of material aging or bulging capacitors that may indicate dangerous thermal buildup.
- **Time constants** – An increase in the ESR will affect the time constant of the RC circuit (ESR + capacitance), which can lead to timing issues related to capacitor charge/discharge cycles.
- **Reduced power output** – An increased resistance causes greater dissipation through the capacitor, sapping power delivered.
- **Filter performance** – The change in ESR causes the tuned frequency of a filter to drift, potentially out of range of its intended operating point.

ESR – OVER THE SERVICE LIFE OF A DEVICE

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- It’s also worth mentioning how power cycling can affect the ESR of electrolytic capacitors specifically: these capacitors have an inverse or negative temperature coefficient. That is, as the temperature increases, ESR decreases. Engineers may encounter a situation where functionality/performance is faulty at low temperatures but performs within specifications once operating or warmed up. The best way to avoid this is to measure the ESR of electrolytic capacitors at the device’s intended operating temperature (typically room temperature).

REFERENCES

https://www.vse.com/