

Special Section

Passive Components



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Low ESR Capacitors: Fact or Fiction?



by Mark Gebbia, Illinois Capacitor, Inc.

With the rapidly changing landscape in ICs and other semiconductors, it is easy to think of the supporting cast of electrolytic capacitors as a design constant. While many electrolytics look similar to their counterparts of a few years ago, capacitor technology has continued to evolve. Today's electrolytics are more reliable, offer higher capacitance densities and more mounting options. One of the parameters that has recently come under closer scrutiny by designers is ESR, or *equivalent series resistance*. Stated in ohms and referenced to specific frequencies, ESR is easier to define than it is to specify.

Characteristics of Low ESR

As switching frequencies have increased, the needs for capacitors with "low ESR" ratings have also increased. Demand for these capacitors has not addressed a need for a clear definition of just what low ESR is. Standards such as JIS 5141 and EIA 395 only address accepted test procedures and definitions of capacitors. This lack of standards has left it up to individual capacitor manufacturers to define what a low ESR capacitor is. In response to this void, most aluminum electrolytic capacitor vendors have established consistent criteria on how they specify a low ESR capacitor. Generally, capacitor makers have characterized low ESR capacitors as having

- longer load-life rating than general-purpose capacitors,
- maximum impedances specified at 100 kHz,
- maximum impedances at +20°C and -10°C,
- ripple currents specified at 100 kHz,
- multiple case sizes available per capacitance value,
- increased stability with temperature (impedance ratios).

To further understand low ESR capacitors and their ratings, it is important to first understand what ESR is and how it affects circuit performance.

The equivalent circuit of a capacitor is made up of four basic characteristics as shown in Figure 1, three of which are frequency dependant (Z, ESR and ESL) and one is DC dependent (Rp). This discussion will be limited to the frequency dependent characteristics of ESL, ESR and Z, along with one additional component called capacitive reactance (Xc).

ESL is the equivalent series inductance, and is expressed mathematically as $ESL = 2 \cdot \pi \cdot f \cdot L$; where $f =$

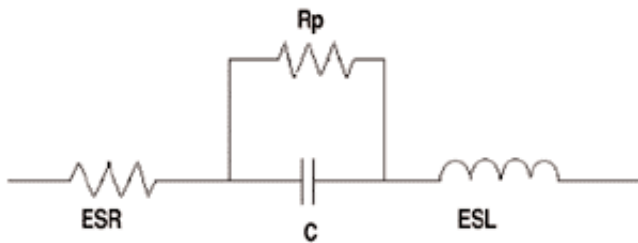


Figure 1. Capacitor equivalent circuit.

frequency and $L =$ inductance. ESL is the sum of all the inductive components within a capacitor. Equivalent series resistance, like ESL, is simply the sum of all the resistive components within a capacitor. Expressed mathematically as $ESR = D.F. / (2 \cdot \pi \cdot f \cdot C) = D.F. \cdot Xc$; where D.F. = dissipation factor, $f =$ frequency, $C =$ capacitance and $Xc =$ capacitive reactance. Xc is defined as $1 / (2 \cdot \pi \cdot f \cdot C)$. Z is the impedance of the capacitor. It is expressed mathematically as

$$Z = \sqrt{(ESR)^2 + (ESL - Xc)^2}$$

The behavior of these characteristics with frequency is illustrated in Figure 2.

Since all capacitors behave in a similar manner, the ESR can be lowered by either using a higher capacitance value or by using a capacitor with a lower D.F. Lowering the ESR by using a higher capacitance value is quite obvious, and no explanation is needed. The lowering of the ESR by use of a dielectric that has a lower D.F. is more illustrative. Table 1 shows this by comparing the ESRs of the most commonly used capacitor dielectrics.

There are some important observations to be taken from Table 1:

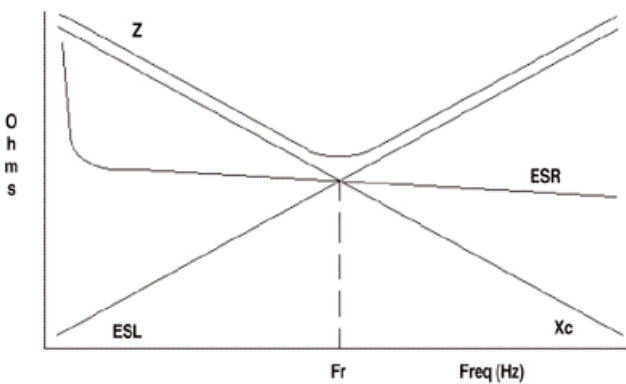


Figure 2. Frequency response characteristics of a capacitor.

Dielectric	D.F. (maximum)	ESR (for 1µF capacitor)
Aluminum Electrolytic (50V)	10% at 120 Hz	132.629 Ohms
Tantalum (50V)	4% at 120 Hz	53.05 Ohms
Polyester	1% at 1 kHz	1.592 Ohms
Polypropylene	0.1% at 1 kHz	0.1592 Ohms

Table 1. ESR comparisons of common capacitor dielectrics.

1. Observe the frequencies at which the ESRs were calculated. It is important to note that ESR will change to a lower value as the frequency increases. So, when specifying a low ESR capacitor with a specific ESR value, it is necessary to specify the frequency of the ESR or else the wrong capacitor may be selected.

Temperature would also be an important factor and should be considered when evaluating a capacitor, especially when the capacitors are operated at temperatures below freezing. This is especially true for aluminum electrolytic capacitors. It is not uncommon for these capacitors to experience a 10 percent to 40 percent decrease in capacitance and the D.F.s to increase 10-fold at very low temperatures, so care must be taken when selecting capacitors to be used in cold environments.

2. Different dielectrics have different ESR values. The ESR can be lowered by changing the dielectric material used. As an example, note the dramatic difference between aluminum electrolytics and polypropylene capacitors.

Film Capacitors Versus Aluminum Electrolytic Capacitors

There are also differences between film and aluminum electrolytics, which make each capacitor type desirable in a variety of applications.

Film capacitors have their own advantages, most notably non-polar construction, high voltage, low capacitance values, a variety of terminations and case shapes, tight capacitance tolerances, self healing (metallized construction only), very high reliability and high ripple current carrying capability.

Film capacitors are commonly used in such low ESR applications as RFI and EMI suppression. However, aluminum electrolytic capacitors, which are used extensively

Type (10µF/50V)	ESR 120Hz/100kHz	Ripple current 120Hz/100kHz	Z ratio -40°C /20°C	Z (20°C)	Load Life	Dimensions
Standard	5.637/1.5	20/34	3	1.517	2000	5x11mm
Hi temp	1.595/1.98	69/117	3	2.008	4000	5x11mm
Low Z	2.611/0.805	66/135	2	0.648	8000	5x11mm
Low ESR	3.935/1.06	51/100	3	1.1	8000	5x11mm

Table 2. Capacitors that look alike may not perform alike. All of the capacitors shown above measure the same size, yet other parameters are significantly different.

in switching converters, will be covered hereafter.

Some of the advantages of low ESR aluminum electrolytic capacitors over standard electrolytics are their extended life (over 5,000 hours); higher ripple current ratings (compared to standard electrolytics); a large variety of case sizes and load-life ratings are available; larger capacitance values and standardized packages.

Table 2 illustrates some of the differences between standard general purpose (Standard), high temperature general purpose (Hi temp), low impedance (Low Z) and small size low impedance (Low ESR) capacitors.

The most outstanding differences are the load-life, impedances (Z), and ESRs at 100 kHz. These differences are why low ESR and low impedance capacitors are used extensively in switching power supplies to maintain the performance of the power supplies. Capacitors with too high an ESR will self-heat too much and not regulate the current properly. Obviously the self-heating will also reduce the operating life of the capacitors, and the switching power supply performance and life will be reduced accordingly. Additionally, low impedance capacitors have

higher ripple current ratings than standard capacitors, thus reducing the number of capacitors needed and helping reduce the size of the switcher.

Conclusion

If a circuit requires low ESR capacitors,

determine the acceptable limits and select capacitors that "match" its requirements. It is important to review the test conditions used by the capacitor manufacturer, as different test conditions can significantly alter operation in the circuit. Also, manufacturers such as Illinois Capacitor (www.illcap.com) offer applications engineering support to assist designers in evaluating their needs and to recommend appropriate capacitor types. Some also offer Web-based tools, such as the capability to search their database by operating parameter.



Low ESR aluminum electrolytic capacitors from Illinois Capacitor.

Mark Gebbia is an applications engineer at Illinois Capacitor, Inc., 3757 West Touhy Ave., Lincolnwood, IL 60712; (847) 675-1760; Fax: (847) 673-2850; mgebbia@illcap.com; www.illcap.com.

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