Web Exclusive: An Introduction to Low ESR Capacitors

by Jim Wright, NIC Components

There is rapidly increasing demand for low equivalent series resistance (ESR) capacitors in small case, surface mount format. But what exactly is ESR, why is it important and what products are available to satisfy the market's hunger for these devices?

What is ESR?

Figure 1. NSPE Series hybrid electrolyte SMT aluminum electrolytic capacitors from NIC Components

ESR is an abbreviation for equivalent series resistance, the characteristic representing the sum of resistive (ohmic) losses within a capacitor. While ESR is undesirable, all capacitors exhibit ESR to some degree. Materials and construction techniques used to produce the capacitor all contribute to the component's ESR value. ESR is a frequency dependent characteristic, so comparison between component types should be referenced to same frequency. Industry standard reference for ESR is 100 kHz, +25°C. ESR is an important characteristic, as the powder dissipation (Watts) within the capacitor, and the effectiveness of the capacitor's noise suppression characteristics, will be related directly to the ESR value.

What's Driving the Demand for Low ESR?

An industry-wide trend towards lower voltage/higher current circuit design, fueled by lower voltage silicon devices is causing designers to specify capacitors with minimal ESR. Higher levels of functionality in today's designs means that despite voltage levels falling, circuit power levels have not dropped accordingly. Ohms law tells us, in very simple fashion, that at the same power dissipation level, lower voltage operation will mean higher current levels. This greatly increases the demands on the power management circuit (power supply or DC/DC converter) to deliver energy during periods of high current load stepping. Lower voltage circuit operation also imposes greater restrictions upon the output voltage variation levels. The output capacitors or capacitor bank, used in the power management circuit, need to exhibit low ESR characteristics. Ripple voltage (noise) on the output supply voltage will be directly proportional to the ESR of the capacitors used. By using the formula: $Vr = I \times R$, where Vr is the ripple voltage and R is the ESR, consider that if the current (I) increases from 4 A to 20 A, then the ripple voltage will also increase by a factor of five. Increased ripple voltage (Vr) cannot be tolerated in today's and next-generation designs. This is fueling demand for even lower ESR capacitors.

What Types of Low ESR Capacitors are Available?

Capacitance values greater than 10 µF are often required to supply energy to today's electronic circuits during load current stepping (low to high current stepping). This requirement is met through the use of single or multiple surface mount (SMT) electrolytic capacitors. Surface mount configurations are preferred as it allows closer component placement, reduces performance-robbing series inductance and can reduce total PCB assembly costs. Recent low ESR electrolytic capacitor development has focused on techniques and materials designed to reduced the resistance of the cathode connection, either with improved liquid electrolytes or by replacing the liquid electrolyte with a lower resistivity solid electrolyte. The cathode connection is the largest contributor to the electrolytic capacitor's total ESR figure.

Low ESR SMT Electrolytic Capacitors available today chiefly fall into six types (see Table 1 for comparison data):

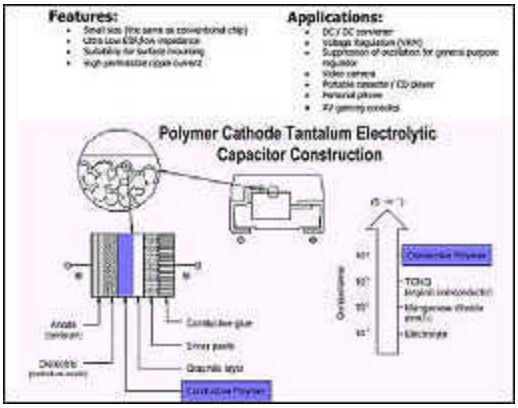

Figure 2. Conductive polymer cathode capacitor construction.

ESR: Equivalent Series Resistance (ohm)

RCR: Ripple Current Rating (Amp)

1. Liquid Electrolyte, Vertical Can Chip Aluminum Electrolytic Capacitors. Standard wound element aluminum electrolytic capacitor construction produced using low resistivity liquid electrolyte.

Pros: High capacitance values, high voltage ratings, moderate to low ESR, moderate RCR and lowest cost.

Cons: Liquid electrolyte exhibits dry-out under high temperature, medium to large sizes.

2. Hybrid Electrolyte, Vertical Can Chip Aluminum Electrolytic Capacitors. Standard wound element aluminum electrolytic capacitor construction produced using hybrid-combination solid and liquid electrolyte. Provides solid electrolyte performance (very low ESR) at much lower cost than solid electrolyte types.

Pros: Very low ESR, high RCR, moderate capacitance values and moderate cost.

Cons: Liquid electrolyte component exhibits dry-out under high temperature, low voltage ratings and medium sizes.

3. Solid Electrolyte, Vertical Can Chip Aluminum Electrolytic Capacitors. Standard wound element aluminum electrolytic capacitor construction produced using solid polymer electrolyte. Lowest ESR and highest RCR of the vertical can chip types, but at highest cost.

Pros: Very low ESR, high RCR, moderate capacitance values and solid electrolyte for good long-term performance at high temperature.

Cons: High cost, low voltage ratings and medium sizes.

4. Solid Electrolyte Resin Encapsulated Flat Chip Aluminum Electrolytic Capacitors. Specialty folded element aluminum electrolytic capacitor construction produced using solid polymer electrolyte. Low ESR and high RCR, but at highest cost of all aluminum electrolytic types.

Pros: Very low ESR, high RCR, smallest size aluminum electrolytic type, moderate capacitance values and solid electrolyte for good long-term performance at high temperature.

Cons: High cost and low voltage ratings.

5. Solid Electrolyte, Resin Encapsulated Flat Chip MnO_2 Cathode Tantalum Electrolytic Capacitors. Standard tantalum chip capacitor construction processed for low ESR.

Pros: Moderate to low ESR, moderate RCR, small size, low ESR versions produced with manganese dioxide cathode (MnO_2) construction and solid electrolyte for good long-term performance at high temperature.

Cons: Low voltage ratings and limited transient (reverse or surge conditions) tolerance, could combust upon failure.

6. Solid Electrolyte, Resin Encapsulate Flat Chip Polymer Cathode Tantalum Electrolytic Capacitors.

Low ESR versions produced with recently developed specialty polymer cathode construction. Standard manganese dioxide cathode (MnO_2) is replaced by a highly conductive polymer (polypyrrole) cathode that considerably reduces ESR. The conductivity of polypyrolle is more than 100 times that of manganese dioxide.

Pros: Very low ESR, high RCR, small size, polymer cathode construction suppresses combustion (increased safety factor) and solid electrolyte for good long-term performance at high temperature.

Cons: High cost and low voltage ratings.

TABLE 1

DESCRIPTION	TYPE	CAPACITANCE LIMIT	100KHZ ESR (+25°C)	100KHZ RIPPLE CURRENT RATINGS (+25°C)	NOTES
Liquid Electrolyte, Vertical Can Chip Aluminium Electrolytic Capacitors		VALUES UP TO **6800uF**	DOWN TO 0.028	UP TO **2.5Arms**	Lowest cost
Hybrid Electrolyte, Vertical Can Chip Aluminium Electrolytic Capacitors		VALUES UP TO **820uF**	DOWN TO 0.023	UP TO **2.2Arms**	Hybrid Electrolyte Aluminium; Very good performance at low cost
Solid Electrolyte, Vertical Can Chip Aluminium Electrolytic Capacitors		VALUES UP TO **680uF**	DOWN TO 0.025	UP TO **2.5Arms**	Solid Aluminium
Solid Electrolyte, Resin Encapsulated Flat Chip Aluminium Electrolytic Capacitors		VALUES UP TO **270uF**	DOWN TO 0.010	UP TO **3.5Arms**	Solid Aluminium
Solid Electrolyte, Resin Encapsulated Flat Chip MnO_2 Cathode Tantalum Electrolytic Capacitors		VALUES UP TO **330uF**	DOWN TO 0.100	UP TO **1.10Arms**	MnO_2 Cathode Tantalum
Solid Electrolyte, Resin Encapsulated Flat Chip Polymer Cathode Tantalum Electrolytic Capacitors		VALUES UP TO **470uF**	DOWN TO 0.040	UP TO **1.83Arms**	Polymer Cathode Tantalum

Table 1. A comparison of the six types of low ESR SMT electrolytic capacitors.

Conclusion

Circuit designs incorporating lower voltage semiconductors and IC's are driving increasing demand for better and lower ESR capacitors. SMT low ESR type electrolytic capacitors offer the combined solution of high capacitance, to supply energy during high-speed load stepping, and low ESR to reduce the output filter ripple (noise) voltage to meet the needs of today's and tomorrow's power management design challenges.

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