

## Capacitors for Critical Applications Get Better by Design

*Wherever electronic equipment is used – such as in the home, at work, in-car, or in defence equipment - users typically expect perfect reliability while the technology itself should ideally be invisible or transparent. Numerous aspects of today's components are evolving to realise this goal, from leading-edge nanometre semiconductor process nodes and chip-scale packages to improvements in devices such as capacitors.*

*By James C. Lewis, Technical Marketing Director, KEMET Electronics Corporation*

The latest capacitor design features and screening methods ensure that devices in critical systems such as automotive electronics, street lighting, aircraft radar and missile-guidance systems can meet various different but equally challenging demands that may be imposed at any point during their lifetime.

### Capacitors in Constant Use

Power supplies for systems such as street lights or automotive controllers are subjected to prolonged operation but must remain serviceable for periods of 10 years or sometimes more. Some street lighting applications, for example, are required to remain in service for 20 years or more. The operational lifetime of electrolytic capacitors ( $L_{OP}$ ) can be a major factor limiting the effective life of the application. The End of Life (EOL) of a capacitor can be defined in terms of parametric changes such as reduced capacitance, increased dissipation factor ( $\tan \delta$ ), increased Equivalent Series Resistance (ESR), or excessive leakage current ( $I_L$ ) compared to the initial value ( $I_{RL}$ ).  $I_{RL}$  can vary greatly between manufacturers. As far as the EOL criteria for ESR are concerned, some manufacturers may specify a value of ESR, while others may specify a percentage change.

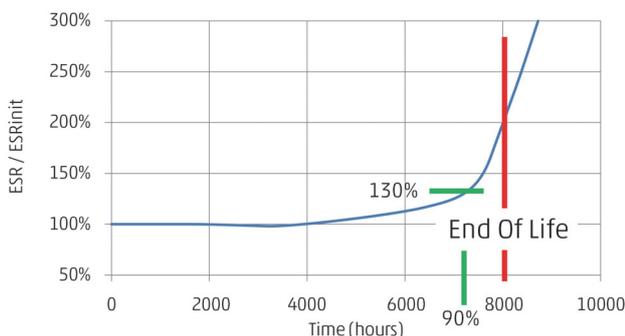


Figure 1: Aluminium Electrolytic capacitors are designed for longer operational life

Electrolytic capacitors often have an almost linear increase of ESR over time in operation. They can also be designed to have more stable ESR. With a more stable ESR, it is acceptable the design can be based on 130% of the specified maximum initial ESR value. This approach is valid provided the required application lifetime is no more than 90% of the specified capacitor's  $L_{OP}$ . The dissipation factor,  $\tan \delta$ , normally has an ageing characteristic similar to that of ESR. The capacitance value also displays an almost linear change over the capacitor lifetime. The capacitance is at its lowest value at end

of life, and should be calculated to be adequate to meet the needs of the application at this point. The leakage current during the operating lifetime is normally significantly lower than the specified value.

### Electrolytic Design for Longer $L_{OP}$

Aspects of electrolytic capacitor construction such as electrolyte chemistry and thermal stability, the amount of electrolyte, and the gasket and lid design, have major impact on the capacitor's operational life. The ESR and thermal performance are also crucial factor influencing  $L_{OP}$ .

Gamma-butyrolactone based electrolytes are usually preferred in capacitors designed for high temperature stability, such as the KEMET PEG124 series of axial electrolytic capacitors. These devices have very stable parameters over the operational life: figure 1 shows that ESR and  $\tan \delta$  are typically within  $\pm 30\%$  of their initial values for the first 90% of  $L_{OP}$ , and tests have indicated decreasing values compared with initial values during the test period of 7000 hours.

For axial and single-ended type electrolytic capacitors, EOL typically occurs due to drying out of the internal windings. The design of the capacitor and lid can have a significant impact on solvent diffusion, and therefore can be designed to keep diffusion at a low level so as to prevent drying. Care is required, however, to permit adequate diffusion so as to relieve the pressure due to internally generated gases such as hydrogen. Excessively low diffusion can cause parametric drift, or even catastrophic device failure. Axial electrolytic capacitors typically have an aluminium lid, which is immune to delamination. The PEG124 series also has a specially designed gasket that minimises diffusion while preventing excessive internal pressure.

The capacitor ESR can significantly influence  $L_{OP}$ , particularly if high ripple current is present, since internal heat generation and temperature rise due to the ripple current is proportional to ESR. A temperature increase of 10-12°C will reduce  $L_{OP}$  by 50%. Consequently, low thermal resistance from capacitor winding to ambient air also has an important effect on  $L_{OP}$  by promoting thermal dissipation and so helping maintain a lower internal temperature. The capacitor's internal thermal resistance has a minor impact on the temperature increase. The main factor is the external thermal resistance, which is minimised by positioning the capacitor to ensure adequate convection cooling and connecting efficiently to a heatsink. KEMET's PEG225 and PEG226 axial leaded electrolytic capacitors are optimised for mounting with heatsink, and all capacitors are designed with uniquely low internal thermal resistance.

### Applications Applying Sudden Loads

At the other end of the usage spectrum, some types of equipment are required to remain dormant in the field for an extended period until suddenly called into action. At this point, they must be relied upon to perform faultlessly. Some types of defence equipment, such as Submarine-Launched Ballistic Missiles (SLBMs), can be included in this category. Surface-mount tantalum capacitors have been used to replace tantalum through-hole capacitors to reduce the size of electronic circuit boards in an SLBM, as part of a recent weapons-upgrade project. The missile is designed to have a maximum lifetime of more than 20 years, but the circuitry must start up immediately and function perfectly any time the missile is fired during this period.

Tantalum capacitors are preferred in this application to prevent unacceptable reduction in capacitor performance due to loss of capacitance caused by ageing. However, post-assembly reliability of surface-mount tantalum capacitors is known to be lower than that of through-hole devices. Hence a suitable tantalum capacitor must be able to withstand the reflow soldering process without acquiring latent defects that will lead to failure on power-up at the time the missile is fired.

KEMET engineers provided a solution to these challenges by specifying tantalum SMD capacitors featuring F-Tech Flawless Technology and subjected to Simulated-Breakdown Screening (SBDS).

KEMET's F-Tech technology eliminates imperfections in the dielectric layer caused during device manufacture. Such imperfections are known to be the major cause of failures in solid tantalum capacitors. Although capacitor-grade tantalum powder is chemically pure, an organic lubricant is added during the anode manufacturing process, which can become trapped and form tantalum carbide during subsequent sintering. This causes local thinning or partial pores, while cooling of the anode after sintering also precipitates crystalline tantalum oxide in localised areas that can permit cracks to form in the dielectric.

KEMET's F-Tech Flawless technology utilises organic lubricants that can be washed off the anodes at low temperatures. Carbon is tested in every production lot after de-lubrication, and the process is repeated if necessary until the carbon level is equivalent to that in the original powder. The anodes are also de-oxidised, and a special passivation process is applied to minimise surface oxidation after sintering. In addition, F-Tech features argon welding to ensure a strong and reliable bond between the tantalum lead wire and the sintered anode.

### Non-Destructive Screening

Tantalum capacitors are traditionally screened for dielectric defects by testing DC Leakage (DCL) at rated voltage. Although a high DCL can indicate impurities in the dielectric, a low DCL is not a reliable indication of a pure dielectric. Testing at high voltages approaching the breakdown voltage (BDV) is known to be the most efficient way to detect hidden defects in the dielectric. A low BDV indicates flaws in the dielectric, while high BDV close to the formation voltage indicates excellent purity. However, BDV testing is destructive, and hence cannot be used to perform 100% screening. In addition, testing at higher than rated voltage can introduce failure sites that may result in latent failures in application.

KEMET developed Simulated Breakdown Screening (SBDS) to isolate tantalum capacitors with low BDV without causing damage to good devices. SBDS analyses the voltage vs. time charging curve for the capacitor in series with a resistor. Prior to screening, the average

BDV is determined by sampling from every production lot. Generally BDV can be up to 2x the rated voltage. A voltage equal to 1.3-1.5 times the average BDV is applied to the capacitor/resistor network, and is disconnected either when the voltage drop across the capacitor reaches the average BDV or after approximately one minute of charging. The final screening voltage correlates with the actual device BDV. Hence the purity of the dielectric can be inferred without exposing the capacitor to damaging over-stresses. This allows SBDS to be applied to 100% of units in any given lot.

A Surge Step Stress Test (SSST) also supplements F-Tech and SBDS, to ensure that the cathode top coating is adequate to protect the dielectric from thermal and mechanical stresses that can induce power-on failures. In SSST, a sample of capacitors is subjected to one or several reflow cycles, and then several short pulses of increasing amplitude are applied until all the capacitors fail short-circuit. The failure rate vs. pulse voltage allows the failure rate at a given applied voltage to be predicted.

### High Pulse Loads

Other applications that require high reliability, such as aircraft radar systems, can subject capacitors to high pulse loads that impose extreme stresses, albeit for a short duration.

A military airborne radar system containing a conformally coated array of 330 $\mu$ F/25V MnO<sub>2</sub> tantalum capacitors encountered component failures as the high-power radar pulse was applied to the capacitors. In addition to reduced system performance, the failures resulted in thermal events causing undesirable flash and smoke in the aircraft cockpit.

In the MnO<sub>2</sub> capacitors originally used in this application, the pulse was found to expose the deficiencies in the capacitors arising from imperfections in the dielectric, leading to device failure. The cathode system provides fuel for the thermal event.

To prevent further failures, these capacitors were replaced with alternative surface-mount devices featuring a multi-anode design and polymer cathode system. The new devices were used in combination with a robust testing protocol called Polymer Capacitor Reliability Assessment Test (PCRAT), as well as SBDS screening.

PCRAT is applicable to polymer capacitors only. A sample of devices is tested under highly accelerated voltage and temperature conditions to determine long-term device reliability. This enables an accurate failure rate to be assigned to the entire lot of material.

In the military radar application, changing to the alternative capacitors, with PCRAT and SBDS, significantly reduced the failure rate. Further advantages included improved system performance using only 3100 capacitors instead of 4200, as well as the benign failure mode of the organic, high-reliability COTS capacitors, which prevents ignition thereby avoiding occurrence of smoke in the cockpit.

### Conclusion

Various types of electronic equipment that absolutely must perform reliably may need to withstand usage patterns such as continuous operation over an extended period, or long periods of inactivity followed by sudden use in an emergency or sudden high loading. These use modes can expose defects induced by ageing, or latent defects existing since manufacture. Fortunately, the design features and screening methods applied to electrolytic and tantalum capacitors typically used in critical or high-reliability applications are highly effective in preventing long-term deterioration or sudden unexpected failures.