

# Moving Capacitors For Mobile Phones To The Dashboard

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## The First AEC-Q200 Qualified Polymer Electrolytic Capacitor

Tantalum polymer capacitors are popular in many decoupling applications including high performance DC to DC converters. This created a perfect fit for polymer capacitors in telecom and industrial high performance applications. Now the automotive segment is showing an increased demand for these type of capacitors for use in infotainment and advanced driver assistance systems (ADAS). Most automotive applications require passive components to be qualified to the Automotive Electronics Council's AEC-Q200 Stress Test Qualification for Passive Components. KEMET Electronics has addressed this need by developing new processes and materials to offer the market's first polymer electrolytic capacitors qualified to AEC-Q200.

This application note introduces polymer electrolytic technology, the electric performance of these parts, advantages relative to other capacitors, and how the commercial grade product was improved to pass the stringent AEC-Q200 guidelines.

## Basic Polymer Construction

Conductive organic polymeric materials were discovered by Alan Heeger, Alan MacDiarmid and Hideki Shirakawa. They were awarded the 2000 Nobel Prize in Chemistry for the discovery and development of conductive polymers. One of first industrial applications of new polymer organic material was to replace manganese dioxide ( $\text{MnO}_2$ ) in tantalum capacitors.

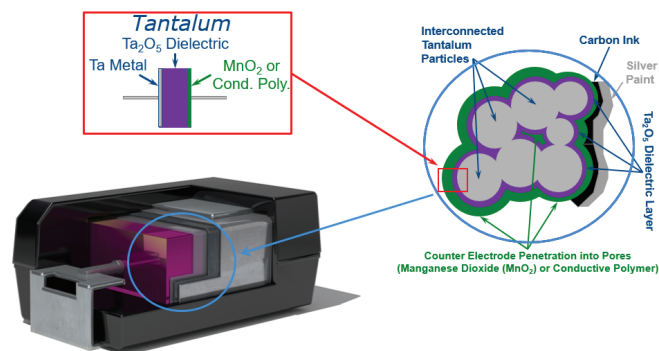


Figure 1. Capacitor basic construction and differences between  $\text{MnO}_2$  and polymer technologies.<sup>1</sup>

The basic capacitor construction consists of two dielectric plates separated by a dielectric. In the case of electrolytic capacitors, one plate consists of a positively charged anode while the other consists a negatively charged anode. The anode of a tantalum capacitor is a porous pellet of sintered Ta metal. This porosity creates a large surface area within the pellet structure, which results in the tantalum capacitor's characteristic high capacitance. The dielectric is tantalum pentoxide ( $\text{Ta}_2\text{O}_5$ ) which is formed by an electrochemical anodic oxidation process ( $2\text{Ta} + 5\text{H}_2\text{O} \rightarrow \text{Ta}_2\text{O}_5 + 5\text{H}_2$ ). The cathode is a semiconductor material, either  $\text{MnO}_2$  or a conductive polymer. A carbon layer chemically isolates the  $\text{MnO}_2$  or the conductive polymer from the external silver coating. For surface mount applications, the capacitor element is attached to a leadframe and encapsulated with an epoxy compound. The overall size and dimensions are consistent with EIA standards.

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## Cathode and Self-Healing

The important properties required for the primary cathode material in a solid electrolytic capacitor are (a) the ability to impregnate small pores, (b) high conductivity, (c) low cost, and the most restrictive requirement, (d) the ability to “self-heal” leakage sites in the dielectric layer.

In traditional  $\text{MnO}_2$  technology, joule heating at a leakage site converts the primary cathode material to a non-conductive material ( $\text{MnO}_2 \rightarrow \text{Mn}_2\text{O}_3$ ). The polymer technology also presents a healing effect by oxidization, evaporation or decomposition.

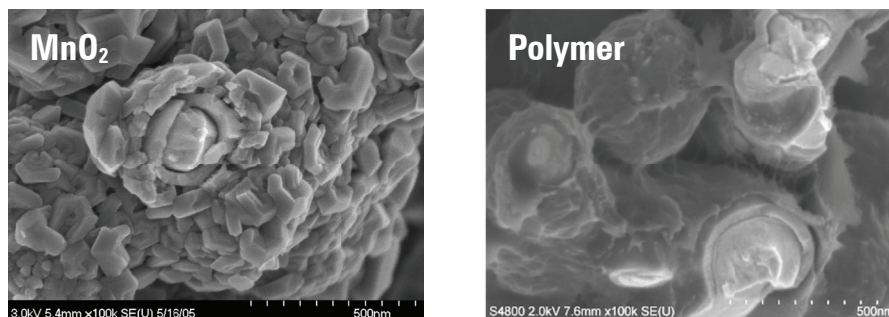


Figure 2. SEM photos from  $\text{MnO}_2$  and conductive polymer cathodes.<sup>1</sup>

## Electrical Performance Characteristics

### Low ESR

Polymer tantalum capacitors achieve much lower equivalent series resistance (ESR) as compared to tantalum capacitors built with  $\text{MnO}_2$  cathodes. The resistivity of the polymer material is in range of 0.05 – 0.50 ohms per centimeter. That is significantly lower than  $\text{MnO}_2$ , which is in the range of 5 – 10 ohms per centimeter.

The temperature coefficient of resistance (TCR) for that ESR is much lower than the standard  $\text{MnO}_2$  capacitor, although the TCR is negative for both, as shown in Figure 3.

### Capacitance Roll-Off

An effect referred to as “capacitance roll-off” is illustrated in Figure 4. The capacitance of an electrolytic capacitor is reduced as frequency increases. Because polymer capacitors have such low ESR, they maintain high capacitance at high frequencies relative to their  $\text{MnO}_2$  counterparts.

At low frequency, the capacitance is dominated by the temperature dependence of the  $\text{Ta}_2\text{O}_5$  dielectric constant, which is the same for both types of capacitors.

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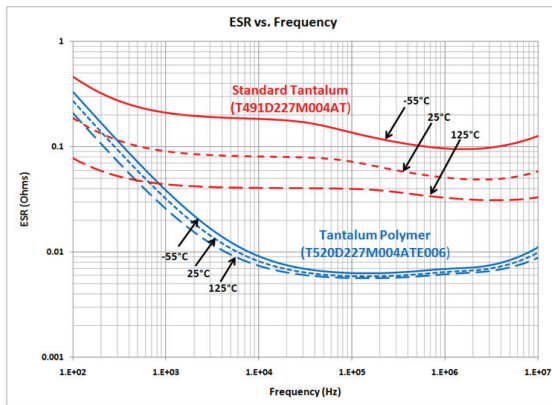


Figure 3. Frequency vs. ESR: MnO<sub>2</sub> compared to polymer cathode.<sup>1</sup>

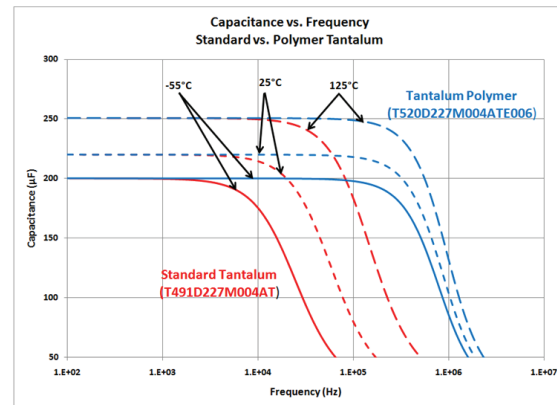


Figure 4. Frequency vs. capacitance MnO<sub>2</sub> compared to polymer cathode.<sup>1</sup>

## Ripple Current

The maximum allowable ripple current capability is a factor of the capacitor's ESR. High ripple current capability is possible with polymer capacitors due to very low ESR. Table 1 compares two tantalum capacitors and their rated ripple current. The T491 capacitor has a MnO<sub>2</sub> cathode while the T520 has a polymer cathode.

Capacitor	Ripple Current (RT, mA @ 100 kHz)
T491D227M004AT (ESR=800)	412 mA
T520D227M004ATE006	6,100 mA

Table 1. Ripple current capability comparison between MnO<sub>2</sub> and polymer technology.<sup>2</sup>

## Voltage Derating

The most common failure mode for a tantalum capacitor is when voltage is applied to the part, typically when a system is powered on. To reduce this failure rate, manufacturers provide recommended voltage derating. Figure 5 shows the voltage derating differences between an MnO<sub>2</sub> and polymer capacitor. Polymer capacitors maintain a lower recommended derating.

The soft conductive polymeric film reduces mechanical stresses inside the capacitor element amid extreme temperature changes, for example, during reflow soldering. Smaller mechanical stress on the dielectric layer results in fewer and less extreme fault sites.

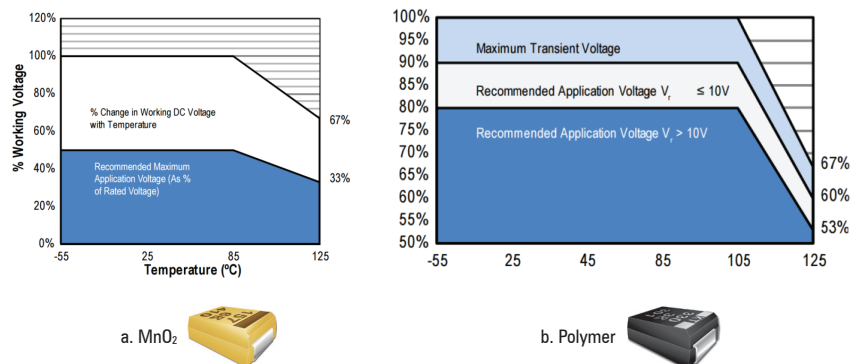


Figure 5. Voltage and temperature derating recommendation for tantalum SMD capacitors (a) MnO<sub>2</sub> technology and (b) polymer technology.

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The cathode material provides some self-healing for the fault sites in the dielectric layer. If a fault site is created that the cathode layer is unable to heal, a failure may occur. When this occurs, the intrinsic chemical characteristics of  $\text{MnO}_2$  and the conductive polymer determine an important difference in the failure conditions.

## Preventing Ignition and Thermal Events

$\text{MnO}_2$  is an oxide semiconductor that acts as oxygen donator during the self-healing reaction ( $4\text{MnO}_2 \rightarrow 2\text{Mn}_2\text{O}_3 + \text{O}_2$ ). When large current flows through a dielectric fault, the oxygen can react with the Ta creating a thermal event, also known as ignition.

The conductive polymer, however, is not an oxygen donator. This difference enables a benign or safe failure mode. With a polymer cathode, the polymer will locally oxidize due to the heat created by the high leakage current, healing the leakage site and preventing ignition (Figure 6). In this case, the capacitor is still considered failed as a short, but the failure mode does not result in ignition.

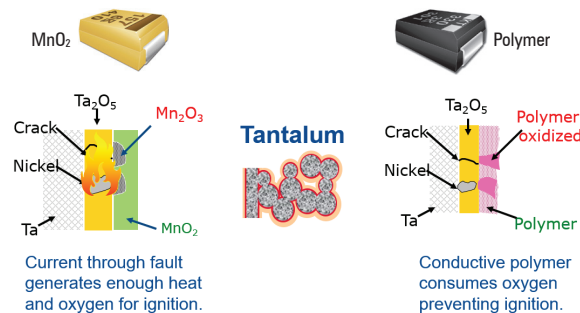


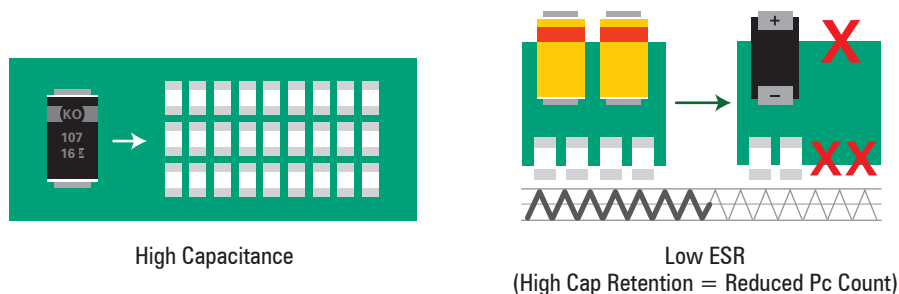
Figure 6. Self-healing, dielectric breakdown ignition failure mode.<sup>1</sup>

## Advantages of Polymer Electrolytic Capacitors

When considering these performance characteristics, polymer electrolytic capacitors can provide a variety of design advantages.

### Reduced Solution Cost

Fewer components result in lower cost. The high capacitance in a small package is referred to as high volumetric efficiency. Polymer capacitors are stable in regards to voltage, temperature and frequency, which means they can typically replace several ceramic or traditional  $\text{MnO}_2$  capacitors in a design. Fewer parts also means fewer pick and placements.



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## Smaller Electronics

Each generation of electronics becomes smaller and thinner. The low profile height of polymer electrolytic capacitors potentially reduces the overall height of a system. When moving from a 50% MnO<sub>2</sub> derating to a 10% polymer derating, lower voltage parts can be selected, which are typically smaller.

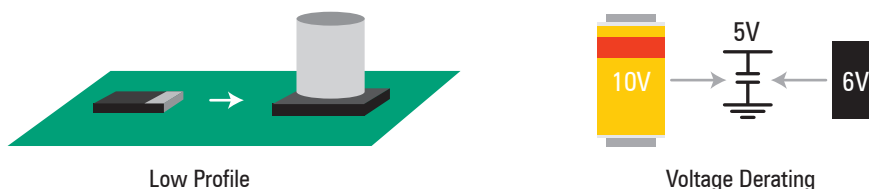


Table 2 compares the electrical characteristics from a customer's application. The DC to DC converter required 220  $\mu$ F for a 5 V rail. Using a polymer component, surface area was reduced by 68%.

Capacitor Type	Number of Pieces / Footprint (mm <sup>2</sup> )	Component
Ta SMD MnO <sub>2</sub>	1 piece / 7.7 x 4.3 = 31.4 mm <sup>2</sup>	T495D227M010ATE100
Ta SMD Polymer	1 piece / 3.5 x 2.8 = 9.8 mm <sup>2</sup>	T520B227M006ATE070

Table 2. Comparison of space footprint usage using polymer technology.<sup>2</sup>

## Distinctive Characteristics of new Automotive Grade

Since its introduction, polymer technology has been very popular in every electronics segment, except automotive. The reasons were not related to the electrical characteristics but because polymer capacitors could not pass the AEC-Q200 qualification, specifically tests involving high humidity and high temperature.

Table 3 compares the areas where commercial polymer capacitors (T520/1) struggled with AEC-Q200 tests to the performance of the T598. KEMET introduced the T598 Series as the first polymer electrolytic capacitors to pass AEC-Q200 qualifications.

Stress Test Name	Conditions	T598 Series	T520/T521 Series
		KO-CAP Auto	KO-CAP Commercial
High Temperature Exposure (Storage)	125°C, Unbiased, 1000 Hours	✓	✗
Temperature Cycling	-55°C to 125°C, 1000 Cycles	✓	✓
Biased Humidity	85°C, 85% RH, Biased, 1000 Hours	✓	✗
Operational Life	125°C, Biased, 1000 Hours	✓	✗
Resistance to Solvents	MIL-STD-202, Meth. 215	✓	✓
Mechanical Shock	MIL-STD-202, Meth. 213, Cond. F	✓	✓
Vibration	MIL-STD-202, Meth. 208, 5 Gs/20 mins.	✓	✓
Resistance to Soldering Heat	MIL-STD-202, Meth. 210, Cond. D	✓	✓
ESD	AEC-Q200-002 or ISO/DIS 10605	✓	✓
Solderability	J-STD-002	✓	✓
Terminal Strength	AEC Q200-006	✓	✓

Table 3. Testing specification comparison.

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## Steps to Pass AEC-Q200

The results of our initial effort to improve the environmental performance were published at the 2014 CARTS conference by Jayson Young et al.<sup>3</sup> Research and development work focused on addressing the two failure mechanisms polymer counter electrode degradation and ionic migration.

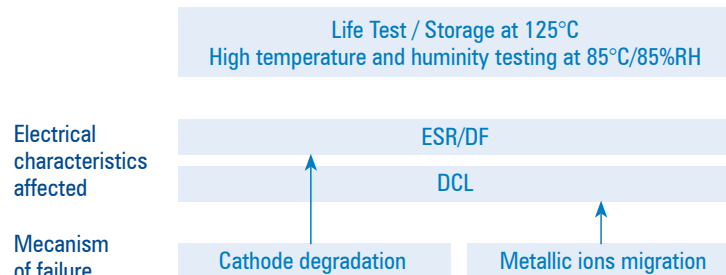


Figure 7. Failure mechanism and impacted electrical characteristics.

### Cathode Degradation

The polymer cathode degradation directly increases the ESR and dissipation factor of the component. Degradation can be seen with parts when subjected to two tests: (1) life test and storage at 125°C, and (2) high temperature and humidity (85°C, 85% RH, biased).

From previous evaluations, extended exposure to air at elevated temperatures caused the polymer material to oxidize.<sup>4</sup> This suggested that the increased ESR and DF from the 125°C life and storage test was due to interstitial diffusion of oxygen, which resulted in oxidation of the polymer cathode layer. The diffusion occurred through both the epoxy encapsulation and interfaces between the leadframe and epoxy.

### Metallic Ion Migration

During the high temperature and high humidity tests, humidity permeated the component through the same leadframe and epoxy interfaces, causing metallic ionic migration. This migration results in an increase of the dielectric leakage current.

## Solving the Polymer Challenges

The primary design change in the new T598 Series is a new moisture protection layer. The second major improvement is a new epoxy material which reduces the permeability of oxygen and humidity. The case integrity was also improved with this new material.

With the new case material and moisture protection layer in place, the T598 mitigates the negative impact on ESR, DF and leakage current when parts are exposed to high humidity.

### The Results

Figure 8 demonstrates the ESR improvement of a T520 (commercial polymer) and a T598 (new automotive polymer) when exposed to the AEC-Q200 85°C/85% RH test.

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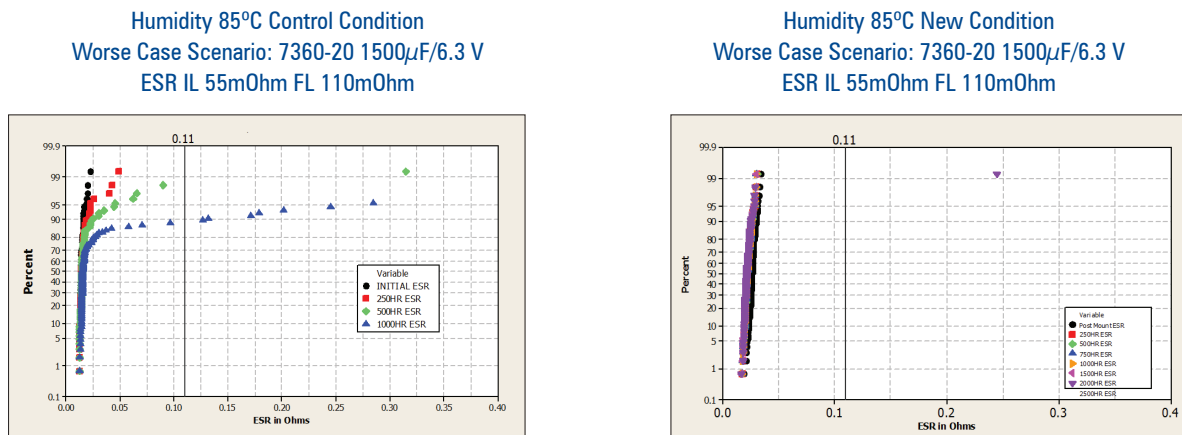


Figure 8. Comparing T520 (commercial) and T598 (automotive) 85°C/85% ESR performance.

The EIA7360-20 case size with 1500  $\mu$ F, rated for 6.3 V (T520H158M006ATE055) was chosen because it represents this test's worst case challenge. This capacitor size presents a large surface area of epoxy with a large internal anode, minimizing epoxy thickness.

In the control group, the negative impact in the polymer degradation starts to be seen at 250 hours and continues to degrade. At 1,000 hours, 40% of the population exhibits drifting. Out of 100 capacitors, 8 have already shown parametric failure, with higher than post-acceptance limit. In contrast, the new process conditions show stable ESR past 1,000 hours. One capacitor failure can be seen under these harsh conditions after 2,000 hours.

Examples of the ESR and DC leakage (DCL) are shown in Figure 9. This data is based on an EIA7343-31 case size, 100  $\mu$ F capacitor rated for 16 V (T598D107M016ATE050).

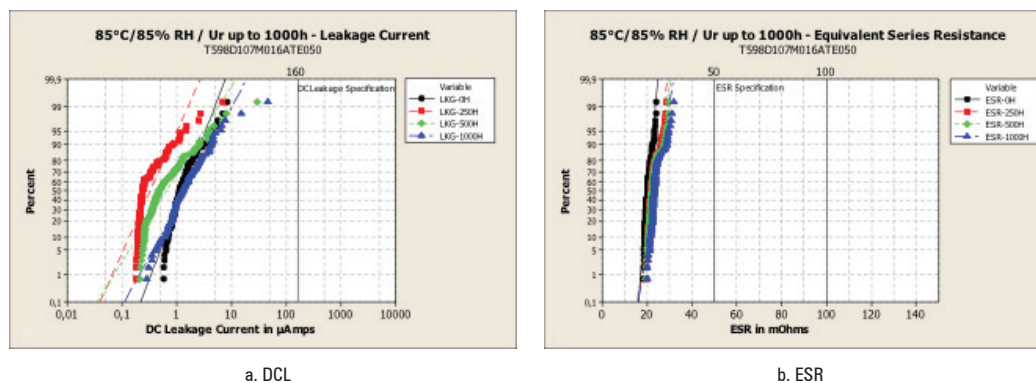


Figure 9. T598D107M016ATE050 automotive grade polymer electrolytic 85°C/85% RH rated voltage for 1,000 hours (a) DCL, and (b) ESR.

Notice that the leakage current drops from the 0 hour measurement to the 250 hour measurement. This shift is related to the self-healing effect of the polymer cathode and is common with tantalum capacitors. The acceptance criteria post-test is within the initial specified limit of 160  $\mu$ A.



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The ESR shows stable performance up to 1,000 hour testing with the entire population within the initial specified limit of 50 mOhm. The behavior of ESR provides experimental evidence for the improvements mentioned.

Research and development continues to expand the full AEC-Q200 capabilities to higher rated voltages. Currently, 25 – 50 V voltage ratings are under development. The preliminary results are positive. Figure 10 compares a commercial 25 V capacitor (T521V336M025ATE060) to an under development automotive 25 V capacitor (T598D336M025ATE060).

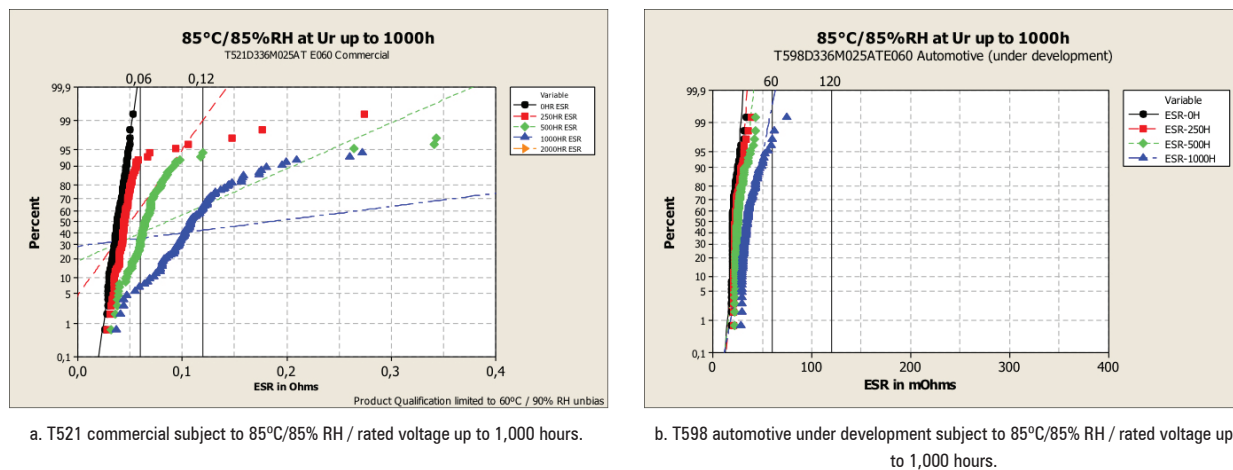


Figure 10. Equivalent series resistance performance comparison under 85°C/85% RH / rated voltage up to 1,000 hours between commercial and automotive part numbers.

The T598 includes these new design changes, achieving the industry's first AEC-Q200 qualified polymer electrolytic capacitor. Initial part number offerings includes capacitance up to 330  $\mu$ F and 16 V rated voltage.

## From the Hand to the Dashboard

For over 15 years, polymer electrolytic capacitors have been successfully utilized in high volume applications such as laptops, tablets and mobile-phones. The full AEC-Q200 qualification of the T598 eliminates the roadblock polymer electrolytic technology by the automotive segment.

The electrical and physical benefits of polymers can be employed by automotive designers in infotainment and advanced driver assistance (ADAS) applications, such as in the DC-DC converter shown in Figure 11.

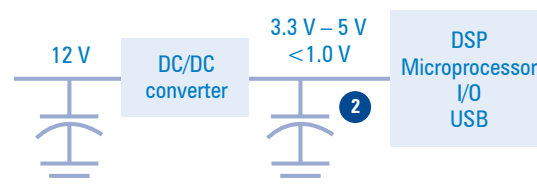


Figure 11. DC-DC converter with a polymer capacitor in Position 2.



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For such an application, the capacitors in Table 4 are recommended. For detailed information and specifications on the T598 Series, please visit <http://www.kemet.com/T598>.

Series	Description	Part Number	Cap	Voltage	ESR (mΩ)	Temperature	Size
T598	Polymer Automotive	T598B476M006ATE070	47	6	70	125	3528-21
		T598B476M010ATE070	47	10	70	125	3528-21
		T598D337M006ATE025	330	6	25	125	7343-31
		T598D227M010ATE025	220	10	25	125	7343-31
		T598D107M016ATE050	100	16	50	125	7343-31

Table 4. Example T598 capacitors for DC-DC converters.

## Conclusion

KEMET's new T598 Automotive Polymer Electrolytic capacitors are a result of several years of research and development efforts. By utilizing new processes and materials, it was possible to introduce the first polymer electrolytic capacitor fully qualified to AEC-Q200 Revision D.

KEMET will continue its development efforts to expand the range of components available for harsh environmental conditions.

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For more information, samples and engineering kits, please visit us  
at [www.kemet.com](http://www.kemet.com) or call 1.877.myKEMET.

