Application Note for T599 Tantalum Polymer Capacitors in Automotive Designs

INTRODUCTION

A tantalum polymer capacitor is one constructed with a tantalum (Ta) anode, a tantalum pentoxide (Ta_2O_5) dielectric, and a solid polymer electrolyte. This construction method offers a variety of advantages, including high temperature ratings and stability over temperature, voltage, and time. These characteristics allow tantalum polymer capacitors to meet, and exceed, AEC-Q200 automotive standard requirements. KEMET's tantalum polymer capacitors (KO-CAP (TM) series) offer low ESR to minimize power losses and unwanted noise, and can withstand the high temperatures of automotive applications. Specifically, the T599 tantalum polymer capacitor has excellent characteristics all the way up to 150°C, offering an ultra extended life expectancy.

ADVANTAGES OF KEMET'S T599 TANTALUM POLYMER CAPACITORS

(Ratings from KEMET series T599 at 100 kHz)

- Low max series resistance, from 25 mΩ to 150 mΩ
- Stable across temperatures, from -55°C to 150°C
- Ultra long life expectancy for high and ultra extended mission profiles

AUTOMOTIVE DC/DC CONVERTER APPLICATION EXAMPLE

Automotive electronics are usually powered by a battery. DC/DC converters are critical for automotive applications because they step down the battery voltage, which is usually +12V DC, to a more usable voltage rail for electronics — +5V, +3.3V, +1.8V, or even lower. The conversions are often also done in stages, such as 12V to 5V, and 5V to 3.3V. DC/DC converters create the voltage for these rails, and capacitors help those converters function and provide stable, clean power.

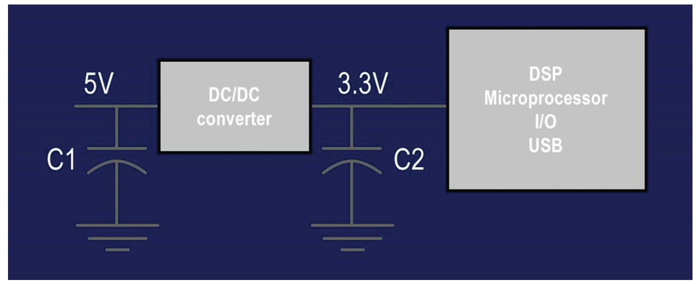

Figure 1 – Simplified DC/DC converter schematic

The simplified schematic above shows what a DC/DC converter used in an automotive application to step down a +5V rail to a +3.3V rail would look like. In a DC/DC converter circuit, capacitance is required at both the input and the output of the converter. The input capacitor(s) (C1) ensures that instantaneous current is available to the converter while it is switching. The output capacitor(s) (C2) ensures that instantaneous current is available to the load (DSP, microprocessor, I/O, USB, etc) while the converter is switching. Each of these capacitors, in an automotive application, must not only be designed to meet the capacitance needs of the circuit, but also selected to meet the high temperatures and harsh conditions of the AEC-Q200 standard, and beyond.

VOLTAGE DERATING FOR HIGH TEMPERATURES

For automotive applications utilizing the T599 series capacitors for max temperatures up to 150°C, KEMET recommends derating the voltage according to the temperature, as follows:

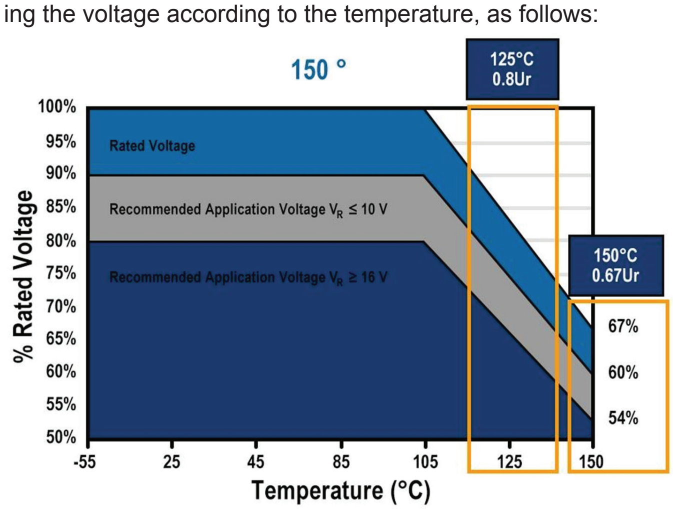

Figure 2 – T599 (150ºC) Series - Temperature and Voltage Derating

		Max Operational Temperature 150°C		
Rated Voltage		Derating Voltage		
-55°C -- 105°C	105°C -- 150°C	-55°C -- 105°C	105°C -- 125°C	125°C -- 150°C
2.5V	1.7V	2.3V	1.8V	1.5V
4V	2.7V	3.6V	2.9V	2.4V
6.3V	4.2V	5.7V	4.6V	3.8V
10V	6.7V	9V	7.2V	6V
16V	10.7V	12.8V	10.2V	8.6V
20V	13.4V	16V	12.8V	10.7V
25V	16.8V	20V	16V	13.4V
35V	23.5V	28V	22.4V	18.8V
50V	33.5V	40V	32V	26.8V

Figure 3 – T599 (150ºC) Series – Temperature and Voltage Derating

SIZING THE CAPACITOR

In the case of selecting the input capacitor (C1) for a DC/DC converter in an automotive application, the DC/DC converter needs to supply 3.3V. Let's assume this regulator is designed for the following conditions:

V_{OUT} = 3.3V
V_{IN} = 5V
Efficiency (η) = 85% (from efficiency curves in DC/DC or module datasheet)
Output transient current (ΔI_{OUT}) = 1.0A

Using this information, the input transient expected can be calculated as follows:

$$\Delta I_{IN} = \frac{V_{OUT}}{V_{IN} \times \eta} \times \Delta I_{OUT}$$

For our example,

$$\Delta I_{IN} = \frac{3.3}{5(0.85)}(1.0) = 0.78A$$

Next, we must determine the series inductance. If the circuit does not include a series filter inductor, the stray inductance introduced by the PCB layout will be the only inductance. If a series filter inductor is used, that inductance value can be added to the inductance introduced by the layout.

Stray microstrip layout inductance can be calculated using the following equation:

$$L_{ms} = (0.00508)L\left[\ln\left(\frac{2L}{W+H}\right) + 0.5 + 0.2235\frac{(W+H)}{L}\right]$$

For our example, we will assume that the layout is such that the stray inductance is 50 nH, and a required filter inductor of 220 nH is used. Effective PCB layout guidelines are important because the stray inductance has a direct effect on the value of bulk capacitance required, as we will see shortly.

Next, a design decision must be made regarding how much voltage variation is permissible on the input voltage bulk capacitor. For this example, we will assume that $\Delta V_{IN(Permissible)} = 0.1V$ With that, the minimum required bulk capacitance is given by the following equation:

$$C = \frac{1.21 \times I_{tr}^2 \times L}{\Delta V^2}$$

where I_{tr} is the input transient current.

For our example, $C = \frac{1.21(0.78)^2(220 \times 10^{-9} + 50 \times 10^{-9})}{0.1^2} = 20\mu F$

This is the absolute minimum bulk capacitance required. Looking at the KEMET T599 datasheet, the closest value above 20 μF with a rating above 10V (15V / 50% derating) is part number T599B336M010ATE070. This part has a capacitance of 33μF and is rated at 10V.

CALCULATING EXPECTED OPERATIONAL LIFE

When designing a new electrical circuit, understanding the expected lifetime of capacitors is important. The expected life of a tantalum polymer capacitor can be given by the following formulas:

$$VAF = \left(\frac{U_C}{U_A}\right)^n$$

where:

VAF = acceleration factor due to voltage, unitless

U_C = category voltage, volt

U_A = application voltage, volt

n = exponent, 16

$$TAF = e^{\left[\frac{E_a}{k}\left(\frac{1}{273+T_A} - \frac{1}{273+T_C}\right)\right]}$$

where:

TAF = acceleration factor due to temperature, unitless

E_a = activation energy, 1.4 eV

k = Boltzmann's constant, 8.617E-5 eV/K

T_A = application temperature, °C

T_C = category temperature, °C

$$AF = VAF * TAF$$

where:

AF = acceleration factor, unitless

TAF = accerlation factor due to temperature, unitless

VAF = acceleration factor due to voltage, unitless

$$Life_{U_A,T_A} = Life_{U_C,T_C} * AF$$

where:

$Life_{UA,TA}$ = guaranteed life application voltage and temperature, years

$Life_{UC,TC}$ = guaranteed life category voltage and temperature, years

AF = acceleration factor, unitless

To calculate the acceleration factor due to voltage (VAF), the category voltage (U_C) is the voltage rating of the capacitor, adjusted according to empirical scientific measurements performed by KEMET's reliability team. The T599 Series with <16V rated voltage is qualified at 150ºC, 0.67xUr up to 2000h. So in our example scenario, the equation is as follows:

$$\mathrm{VAF} = \left(\frac{10 \times 0.67}{5}\right)^{16} = 108$$

To calculate the acceleration factor due to temperature (TAF), we will assume an application temperature (TA) of 130°C, and the category temperature (TC) is the rated temperature of the T599, 150°C.

$$\mathrm{TAF} = 11$$

These two calculations lead us to the total acceleration factor (AF):

$$\mathrm{AF} = 108 \times 11 = 1188$$

Finally, using the final equation to calculate the guaranteed life at the application voltage and temperature (LifeUA, TA), in years, we get the following:

$$\mathrm{Life}_{\mathrm{UA,TA}} = 2000 \times 1188 = 2376000 \text{ hours} = 3254 \text{ months} = 271 \text{ years}$$

ESTIMATING CAPACITOR FAILURE RATE (FIT)

While expected life and ability to support mission profiles is important, in automotive applications it is also critically important to estimate capacitor failure rates. The common measurement in the industry is FIT, or Failures in Time, which equates to one failure per billion hours. Another way of saying this is that 1 FIT is equal to a mean time between failures (MTBF) of 1 billion hours. The reference failure rate for tantalum polymer capacitors is stipulated to be 0.5% per 1000 hours.

The total FIT for an application is the sum of the FIT at each environmental condition the design will experience, proportional to the time the design will spend at each condition. This can be represented as follows:

$$\mathrm{FIT}(\text{mission profile}) = \mathrm{FIT}_{\frac{t1}{T1}} + \mathrm{FIT}_{\frac{t2}{T2}} + \ldots + \mathrm{FIT}_{\frac{tn}{TN}} = \sum \mathrm{FIT}_{\frac{ti}{Ti}}$$

Where,

t_i = time in condition i (hours)

T_i = average temperature in condition i

In each condition i, the FIT calculation is described by the equation,

$$\lambda_P = \left(\lambda_b \times \pi_T \times \pi_C \times \pi_V \times \pi_{SR} \times \pi_Q \times \pi_E\right)$$

Where,
λ_P: predicted reliability, failed parts per million part-hours
λ_b: established base reliability, failed parts per million part-hours
π_T: temperature factor
π_C: capacitance factor
π_V: voltage factor[1]
π_{SR}: series resistance factor
π_Q: quality factor
π_E: environment factor

Base Reliability, λ_b

For base reliability, KEMET provides the baseline reference for tantalum polymer capacitors at $\lambda_b = 0.00005$.

Temperature Factor, π_T

The temperature factor, as provided by the Military Handbook (Mil-HDBK-217F- Notice 2), is provided by the following equation:

$$\pi_T = \exp\left(\frac{-E_a}{8.617 \times 10^{-5}}\left(\frac{1}{T+273} - \frac{1}{298}\right)\right)$$

Where,
E_a = Activation Energy; 0.15eV for CWR Style Polymer technology;
T = Temperature, ˚C

Capacitance Factor, π_C

The capacitance factor, as provided by the Military Handbook, is provided by the following equation:

$$\pi_C = C^{0.23}$$

Where,
C = capacitance, uF

Voltage Factor, π_V

The voltage factor, corrected from the Military Handbook, is provided by the following equation. Note that the operating voltage is the sum of applied DC voltage and peak AC voltage:

$$\pi_V = \left(\frac{S}{0.8}\right)^{17} + 1$$

Where,
S: ratio of operating voltage to rated voltage, unitless

Series Resistance Factor, π_{SR}

For tantalum polymer technology, we assume <0.1 Ω/V, providing series resistance factor per the following table:

Circuit Resistance (CR) Ω/V	π_{SR}
> 0.8	0.66
> 0.6 to 0.8	1.0
> 0.4 to 0.6	1.3
>0.2 to 0.4	2.0
>0.1 to 0.2	2.7
0 to 0.1	3.3

Quality Factor, π_Q

For KEMET's tantalum polymer technology (KO-CAP) the established failure rate is 0.5%/1000h. This translates to a quality factor of SQRT(0.5) = 0.707.

Environment Factor, π_E

For tantalum polymer technology we assume ground, benign factor

Environment	π_E
G_B (ground, benign)	1.0

FIT Calculations

Putting it all together into example FIT calculations, using a 3.3V voltage in a DC/DC circuit example, we get the results shown in the following tables. From them, we can see that we estimate a FIT of 0.9 in old legacy 8000h high temperature profile, and a FIT of 0.6 in the new 130000h ultra-extended mission profile.

[1] This is only applicable for polymer technologies.

MISSION PROFILE (old)

Failure Rate Conversion Factor - MIL-HDBK-217k Note 2 (Polymer Changes)

Temperature (°C)	% / Time		λ base	Temperature Π_T	Voltage Π_V	Capacitance Π_C	Quality Π_Q	Series Resistance Π_{SR}	FIT	FIT x %Time
-40	5%	400	0,00005	0,905	1,001	3,166	0,707	3,300	0,335	0,017
-20	0%	0	0,00005	0,905	1,001	3,166	0,707	3,300	0,335	0,000
20	20%	1600	0,00005	0,905	1,001	3,166	0,707	3,300	0,335	0,067
40	0%	0	0,00005	1,323	1,001	3,166	0,707	3,300	0,489	0,000
60	0%	0	0,00005	1,847	1,001	3,166	0,707	3,300	0,683	0,000
85	65%	5200	0,00005	2,661	1,001	3,166	0,707	3,300	0,984	0,639
130	7%	560	0,00005	4,579	1,001	3,166	0,707	3,300	1,693	0,118
140	2%	160	0,00005	5,083	1,001	3,166	0,707	3,300	1,879	0,038
150	1%	80	0,00005	5,616	1,001	3,166	0,707	3,300	2,076	0,021
		8000							FIT Total	0,8998003501

Basic FR 0,5%/1000h (150°C/0,67Ur) = 5000FIT
Application Voltage - 3,3V
Temperatare < 23°C - use RT calculation
Environmental, Ground = 1

$$\pi_T = \exp\left(\frac{-E_a}{8.617\times10^{-5}}\left(\frac{1}{T+273}-\frac{1}{298}\right)\right) \qquad \pi_V = \left(\frac{S}{0.8}\right)^{17}+1 \qquad C^{0.23}$$

assume < 0,1V/Ohm

1FIT = 1E-9/h

S= (Uapp/Ur)
0,523

MISSION PROFILE (NEW)

Failure Rate Conversion Factor - MIL-HDBK-217k Note 2 (Polymet Changes)

Temperature (°C)	% / Time		λ base	Temperature Π_T	Voltage Π_V	Capacitance Π_C	Quality Π_Q	Series Resistance ΠSR	FIT	FIT x %Time
-40	3%	3942	0,00005	0,961	1,001	3,166	0,707	3,300	0,355345	0,010661
-20	3%	3942	0,00005	0,961	1,001	3,166	0,707	3,300	0,355345	0,010661
20	10%	13140	0,00005	0,961	1,001	3,166	0,707	3,300	0,355345	0,035536
40	43%	55845	0,00005	1,323	1,001	3,166	0,707	3,300	0,489013	0,207837
60	32%	42701	0,00005	1,847	1,001	3,166	0,707	3,300	0,682864	0,221917
75	4%	5256	0,00005	2,314	1,001	3,166	0,707	3,300	0,855374	0,034216
85	1%	657	0,00005	2,661	1,001	3,166	0,707	3,300	0,983596	0,004918
90	4%	5256	0,00005	2,845	1,001	3,166	0,707	3,300	1,051704	0,042069
105	1%	657	0,00005	3,441	1,001	3,166	0,707	3,300	1,272064	0,006361
		131396							FIT Total	0,5741745643

Basic FR 0,5%/1000h (150°C/0,67Ur) = 5000FIT
Application Voltage - 3,3V
Temperatare < 23°C - use RT calculation
Environmental, Ground = 1

$$\pi_T = \exp\left(\frac{-E_a}{8.617\times10^{-5}}\left(\frac{1}{T+273}-\frac{1}{298}\right)\right) \qquad \pi_V = \left(\frac{S}{0.8}\right)^{17}+1 \qquad C^{0.23}$$

assume < 0,1V/Ohm

1FIT = 1E-9/h

S= Uapp/Ur
0,523

To learn more, visit KEMET's website at https://www.kemet.com/T599

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