Ripple Current Confusion

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RIPPLE CURRENT[1]

Ripple current ratings for capacitors can be somewhat arbitrary. Although the EIA has standards for calculating ripple current ratings, some manufactures use their own methods. Among the manufacturers' catalogs, some specify the ripple current capability at 25°C, others at 45°C. Some specify the ripple capability at 100 kHz; others specify ripple capability from 100 kHz through 1 MHz. Some derive their data with a 20°C temperature rise; others allow a 40°C rise.

This makes it difficult for end customers to have a one-to-one comparison.

SEEDS OF CONFUSION

Let us start by considering a general ripple current calculation as given in the EIA standards as well as many manufacturers' catalogs:

$$I_{\max} = \sqrt{\frac{P_{\max}}{ESR}} \qquad \text{Equation [1]}$$

This is the same formula as given in EIA-809[2], which many consider the standard for the industry. It indicates a relationship exists between the maximum power rating (P_{max}) and the ESR (Effective Series Resistance of the capacitor) to establish the maximum ripple current capability (I_{max}).

In the same EIA-809 document, there is specified a "general guideline the capacitor temperature should not be allowed to rise more than 10°C above ambient." It then refers to "manufacturers' literature for relevant power dissipation and ripple ratings."[2]

A second EIA document (EIA/IS-535BAAE[3]) that deals with low *ESR*, surface mount tantalum chips, gives the maximum temperature rises versus ambient temperature as shown in Table 1.

Table 1. Maximum power ratings (Watts) vs. ambient.[3]

Case Size	25°C	55°C	85°C	125°C
6032	0.110 W	0.099 W	0.088 W	0.044 W
7343	0.150 W	0.135 W	0.120 W	0.060 W
7343H	0.165 W	0.148 W	0.132 W	0.066 W
Max Temp Rise	15°C	10°C	5°C	2°C

This table shows a 15°C rise allowed at 25°C ambient, and this conflicts with the previous document. Additionally, there is decay in the allowable rise with increasing ambient temperature that is not explained.

At first glance, the derating of power for each case size at increasing ambient would assume to be related to the decay of allowable temperature rise, but it is not. Looking at the 55°C, 85°C, and 125°C power ratings, the relationship to the 25°C power ratings are 90%, 80%, and 40%, respectively. For these elevated ambient temperatures, the relationship of the allowable rise to the 25°C value is 67%, 33%, and 13%, respectively.

THERMAL MODELS

Getting back to the wording of EIA-809, the reference is to a specified allowable temperature rise for specified power dissipation (°C/W). This relationship is the thermal resistance (R_{th}) for the device, and its function in defining the power dissipation (P_{diss}) is as follows:

$$P_{diss} = \Delta T / R_{th} \qquad \text{Equation [2]}$$

where R_{th} is the thermal resistance (°C/W) and ΔT is the allowable temperature rise of the capacitor (°C)—the temperature difference between the capacitor and the ambient.

The R_{th} is dominated by the thermal conductivity of the elements within the structure of this device. For a given case size, these elements include the leadframe, the pellet structure, the anode riser wire, and the conductive epoxy used to attach the leadframe to the pellet (cathode connection). In tantalum capacitors, these elements are fairly consistent for the various capacitance and voltage ratings within each case size, and as such the R_{th} remains consistent as well as the P_{diss}. The R_{th} will also remain constant over the operating temperature range of the component, and is independent of frequency.

At steady state, the rate of heat generation and heat removal balance, so the two expressions can be set equal and we can solve for the temperature rise due to the ripple current heating:

$$\Delta T = I_{rms}^2 \times ESR \times R_{th} \qquad \text{Equation [3]}$$

Higher the ripple current, ESR, and thermal resistance between the capacitor and ambient, each lead to a higher resulting temperature rise of the capacitor.

To calculate the maximum allowable rms ripple current we need to specify an *arbitrarily* assigned maximum ΔT_{max}. Once ΔT_{max} is substituted for ΔT in Equation [2], the maximum power dissipation can be determined ($P_{max} = P_{diss}$). This power rating is then used in Equation [1] to determine the ripple current maximum.

It is important to see how using a higher allowable temperature rise will result in higher ripple capability.

CATALOG AND DATASHEET RIPPLE CURRENT RATINGS FOR TANTALUM & POLYMER TYPES

The ESR in Formula 1 may be frequency and temperature dependent. The published catalogs from many manufacturers list ripple current capability at 100 kHz or 100 kHz through 500 kHz, 1 MHz, or some other frequency. Keep in mind that with most of these devices, the ESR is reduced in the higher frequencies, and specifying at 100 kHz or in a range of 100 kHz through whatever, will be based on the 100 kHz ESR (the highest in the range) – the results are the same.

The ripple currents are specified at multiple ambient temperatures, and the power ratios derived from Table 1 are used. If the power ratios are applied to the temperature rise, then the temperature rise at 125°C will be 40% that of the 25°C rise, or 6°C. If we are allowing an application with a 6°C rise at maximum temperature (T_{max}) of 125°C, why are there no reports of high failures?

Part of this conflict lies in the fact that there are few applications where these devices are applied at their maximum ratings. Another part of this conflict is that by using the 25°C ESR reading to calculate this, the actual ESR at 125°C is much lower, and the temperature rise is much less than 6°C. Typical ESR at 125°C is 25% that of the 25°C level for the traditional tantalum-MnO_2 device. With the temperature rise proportional to the ESR (Equation [3]), the actual rise is 1.25°C.

Since we have this buried correction (ESR decreasing), why not ignore the conflicts, and leave the ripple calculations alone? Because these corrections do not take place with tantalum-polymer capacitors, and the results are wrong. These devices have extremely low ESRs, and they change little over their temperature range. The self-correcting feature that was historically embedded in the tantalum-MnO_2 devices no longer applies. The ESR at 125°C is very close to the ESR at 25°C.

PORPOSED EIA CHANGES

We are proposing that the EIA use the following guidelines for establishing ripple current capability.

1. R_{th} be published for each case size.
2. Allowable ΔT_{max} be specified.
3. (Ambient + ΔT_{max}) <= (T_{max} + 2°C).
4. The power is calculated using Formula 2.
5. The ripple current be calculated using Equation [1], for a defined ambient temperature and frequency.

All of these factors will allow a comparison of manufacturers' data. If the EIA specifies the ambient temperature and allowable temperature rise, then the customer will have a value-to-value, direct comparison. If the supplier has data unlike another's, request that the data be adjusted. Ask the supplier what rise is allowed with the calculation because this element is rarely listed in the catalogs.

KEMET SPICE[4]

This free software allows the operator to select the ambient and rise conditions, but works with typical ESR values instead of maximum allowable ESRs.

In Figure 1, the power dissipation and allowable rise (+20°C) are constant through 105°C. Because the ESR in this device (tantalum-MnO_2) decreases with increasing temperature, the ripple capability is increasing from 25°C through 105°C. At the next two temperatures, the ripple current decreases even though the ESR continues to decrease, because the ΔT_{max} must be reduced to not exceed T_{max}.

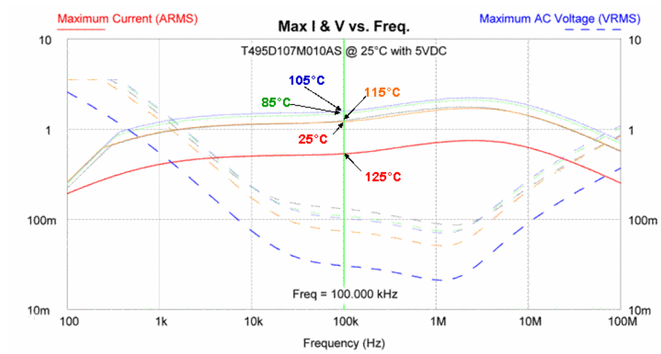

Figure 1. Ta-MnO_2 - Ripple current (ΔT_{max}=20°C) vs. ambient.

What happens when tantalum-polymer is selected in the software? The 25°C ripple capability is the same up to 85°C, because the ΔT_{max} remains the same, and the ESR remains nearly the same. The derating of ΔT_{max} begins at 95°C because the maximum temperature for this device is 105°C.

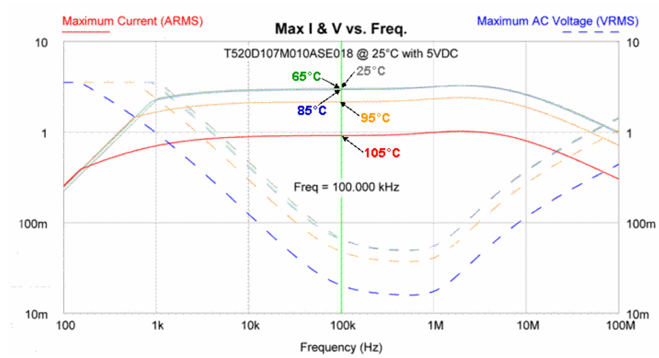

Figure 2. Ta-Polymer - Ripple current (ΔT_{max}=20°C) vs. ambient.

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[1] Lessner, P., Prevallet, M., Prymak, J., "Technical Update – Explanation of Ripple Current Capabilities", KEMET Free Literature, KEMET Electronics Corp., Greenville, SC

[2] EIA Standard, "EIA-809 Solid Tantalum Capacitor Application Guideline", ELECTRONIC INDUSTRIES ALLIANCE, 1999

[3] EIA Interim Specification, "EIA/IS-535BAAE Detail Specification for Low ESR Molded Tantalum Chip", ELECTRONIC INDUSTRIES ALLIANCE, December 1998

[4] Prymak, J., KEMET Spice, KEMET Free Software, KEMET Electronics Corp., http://www.kemet.com