

# TECHNICAL PAPER

## Ripple Rating of Tantalum Chip Capacitors

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### **Abstract:**

The ripple current and voltage limits of tantalum chip capacitors are discussed and limits are established for reliable operation.

# RIPPLE RATING OF TANTALUM CHIP CAPACITORS

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## General

Heat is generated within the capacitor both by the a.c. component signal and by d.c. leakage current. This heat is dissipated to the surroundings by a combination of convection, conduction and radiation, the rate of dissipation depending on both the temperature difference between the anode (where the heat is generated) and the ambient temperature itself.

## Heat Generation

**Ripple.** The heat generated by ripple is  $I^2R$  where  $I$  is the rms value of the current at a given frequency and  $R$  is the capacitor ESR at that same frequency. The ripple is seldom sinusoidal and so, for any practical application it is necessary to convert the measured current waveform into its rms equivalent. It is very important when the data sheet is used for interpretation of a real circuit design. Equations for a number of waveforms can be found in reference books and for those not so covered it is usually possible to approximate based on the nearest given waveform.

The ESR value to be taken is the worst case value to be expected at that temperature (usually based on the values calculated from DF limit at 120Hz and impedance limits at higher frequencies).

**Leakage Current.** The heat generated by leakage current is the current times the applied voltage. For the purposes of calculation this is assumed to be the maximum leakage limit at the rated voltage. There will be occasions when the voltage rises to the surge voltage level and therefore more heat will be generated, however the duration of the surges is usually short enough to be ignored. Obviously the heat generation will increase with temperature as the leakage current can increase tenfold from room temperature to 85°C. Above 85°C the reduction in permitted voltage more than compensates for the increase in current due to temperature.

## Heat Dissipation

**Conduction.** The only mechanism for heat transfer away from the anode is conduction. This is through the resin encapsulant and through the leadframe. Once the heat has reached the outside of the capacitor molding it can continue to be conducted away along the terminations to the solder and hence to the substrate. If the chip is also held on the substrate by adhesive

there is heat transfer by conduction from the molded resin to the substrate via the adhesive.

The chip will be one of many heat generating components on the substrate. How far the heat can be conducted along the substrate will depend on spacings and so for the purpose of calculations a worst case situation will be assumed, i.e., the area of substrate that can absorb the heat is that within the outermost extremes of the solder lands times the maximum width of the body or the lands (whichever is the greater). This is shown in Figure 1.

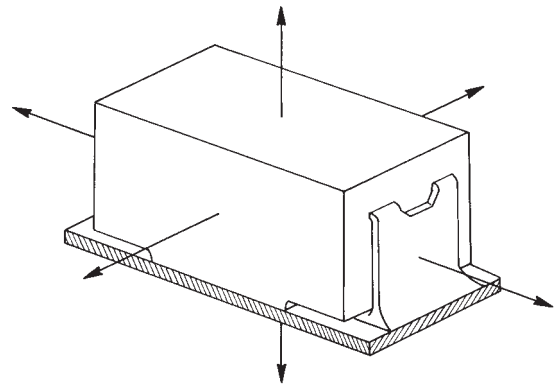


Figure 1. Arrows Indicate Convection and Radiation Heat Dissipation

**Convection.** Once the thermal energy has reached the outside of the molding, or the terminations or the substrate, it can be dissipated by convection and radiation. A variation on convection is forced air circulation. For ripple ratings forced air is not considered but in some applications analysis it can be very important.

Heat can be lost by convection from all surfaces exposed to air including the solder fillets and lands and the underside of the substrate. The temperature difference between the air and the mounted chip causes localized air movements which distribute the heat. The way in which this movement can happen depends strongly on the orientation of the substrate (i.e., vertical or horizontal) and on the presence of other components or substrates close to the mounted chip. For the purpose of setting ripple ratings it is assumed that the substrate is horizontal, is in "still" air and is separated from other components or hardware by at least 25mm.

The rate of heat transfer is approximately proportional to the temperature difference and to the surface area.

CASE	CAP.	VOLTAGE	RIPPLE CURRENT (mA)				RIPPLE VOLTAGE (rms)			
			120Hz	1KHz	10KHz	100KHz	120Hz	1KHz	10KHz	100KHz
A	0.1	50	1.3	8	11	13	17.7	13.2	2.1	.7
	0.1	35	.9	8	11	13	12.4	12.4	2.1	.7
	0.15	35	1.4	8	11	12	12.4	8.8	1.5	.6
	0.22	35	2.0	9	11	12	12.4	6.9	1.2	.6
	0.33	35	3.0	10	12	13	12.4	5.1	.9	.4
	0.47	25	3.1	12	14	15	8.8	4.5	.8	.4
	0.68	20	3.5	14	17	18	7.1	3.6	.7	.4
	1	16	4.2	16	19	21	5.7	2.8	.5	.3
	1.5	10	3.7	16	19	21	3.5	2.1	.4	.3
	2.2	6.3	3.6	17	20	21	2.2	1.5	.4	.3
3.3	4	3.4	21	23	24	1.4	1.3	.3	.2	
B	0.15	50	2.0	9	12	14	17.7	9.9	1.7	.7
	0.22	50	2.9	10	12	14	17.7	7.7	1.3	.7
	0.33	50	4.3	13	16	18	17.7	6.6	1.0	.5
	0.47	35	4.4	14	17	19	12.4	5.2	.9	.4
	0.68	35	6.3	22	28	32	12.4	5.6	.8	.3
	1	35	9.2	24	30	34	12.4	4.1	.6	.3
	1.5	25	9.8	26	35	40	8.8	3.3	.5	.2
	2.2	20	11	28	36	40	7.1	2.3	.4	.2
	2.2	16	9.3	22	26	28	5.7	1.9	.4	.3
	3.3	16	14	29	36	40	5.7	1.7	.4	.2
	4.7	10	12	30	37	40	3.5	1.2	.3	.2
	6.8	6.3	11	32	38	40	2.2	.9	.3	.2
	10	4	10	35	38	40	1.4	.7	.2	.2
C	0.47	50	6.2	22	27	30	17.7	8.0	1.4	.6
	0.68	50	8.9	30	38	43	17.7	7.6	1.1	.4
	1	50	13	32	46	54	17.7	5.4	.8	.3
	1.5	35	14	32	46	54	12.4	3.9	.6	.3
	2.2	35	20	35	48	54	12.4	2.8	.5	.3
	3.3	25	22	38	48	54	8.8	2.1	.4	.3
	4.7	20	25	42	49	54	7.1	1.7	.3	.3
	4.7	16	20	42	49	54	5.7	1.7	.4	.3
	6.8	16	28	48	55	61	5.7	1.3	.3	.2
	10	10	25	57	64	70	3.5	1.1	.3	.2
	15	6.3	24	63	68	70	2.2	.9	.3	.2
	22	4	22	78	85	86	1.4	.7	.2	.2
	33	4	33	83	86	86	1.4	.5	.2	.2
	D	1.5	50	20	50	70	85	17.7	6.0	.9
2.2		50	24	50	75	105	15.1	4.0	.7	.2
3.3		50	30	50	70	85	12.3	2.7	.4	.2
3.3		35	30	50	73	105	12.3	2.7	.6	.3
4.7		50	36	55	78	105	10.3	2.1	.4	.2
4.7		35	46	55	78	105	10.3	2.1	.4	.2
6.8		35	43	64	85	105	8.7	1.6	.3	.2
6.8		25	43	64	85	105	8.7	1.6	.3	.2
10		35	52	85	122	166	7.2	1.4	.3	.2
10		35	52	85	122	166	7.2	1.4	.3	.2
10		25	52	85	122	166	1.5	.2	.2	.2
10		16	41	67	78	85	5.7	1.6	.3	.3
15		25	64	95	129	166	5.9	1.2	.2	.2
15		20	64	95	129	166	5.9	1.2	.3	.2
22		20	78	100	129	156	4.9	.9	.2	.2
22		16	78	100	129	156	4.9	.9	.2	.2
22		6.3	35	92	100	105	2.2	.8	.2	.2
33		16	95	114	138	156	4.0	.6	.2	.2
33		10	52	114	138	156	3.5	.6	.2	.2
47		10	114	147	183	221	3.3	.6	.2	.1
47		6.3	76	138	147	156	2.2	.5	.2	.2
47	4	48	138	147	156	1.4	.5	.2	.2	
68	6.3	110	166	200	221	2.2	.5	.1	.1	
68	4	70	166	200	221	1.4	.5	.1	.1	
100	6.3	157	183	200	221	2.2	.5	.1	.1	

Table I. TAJ Ripple Ratings

**Radiation.** The rate at which heat is radiated from a surface depends on the fourth power of the absolute temperature and on the emissivity of the surface. The first of these factors shows that the rate of radiation is significantly higher at 85°C than at 20°C (by a factor of 2.2). For maximum rate of heat transfer the component should be a thermally black body (emissivity = 1) and it should be surrounded by an enclosure which is also a black body and which is at a lower temperature. In practice none of these conditions apply. The emissivity of shiny surfaces such as solder is low. That of the body, the substrate and the enclosure will also be less than 1. Heat will be radiated onto the chip from neighboring hot components and some of the heat radiated from the chip will be reflected back onto it. For calculation purposes it is best to assume that there is no useful contribution to heat dissipation from radiation. However, when confirmation tests are carried out with isolated chips in an enclosure, conditions will be nearer to the black body requirements and so there will be some contribution from radiation, and temperature rises should be lower than the calculated value. This difference will be more noticeable the higher the ambient temperature.

## Temperature Rises

At high frequencies most of the heat is generated in the outer regions of the anode. As the heat is dissipated outward from the anode the highest temperature at equilibrium will normally be in the center of the anode even in the high frequency case.

Generally, the higher the ambient temperature, the lower the temperature differential which can be allowed. The differential is split between that from hot spot to surface of case and that from case to ambient air. The latter can be more readily measured and so it is usual to state a design maximum for this and to assume that the difference between hot spot and case surface is a smaller value, small enough to be ignored.

For solid tantalum capacitors typical differentials between case surface and ambient are 10°C at room temperature dropping to 2° at 125°C. Any such values are somewhat arbitrary but as they are reasonable and conservative they could be the basis of our calculations. With the irregular shape of the chip mounted on its

section of substrate, as in Figure 1, it can be seen that the temperature differential will vary over the assembly. Infrared scanning can be used to establish which is the hottest region and how the temperature varies with location.

## Method for Calculation of Ripple Ratings

The stages in the calculation are:

- (a) Set the case-to-ambient differential.
- (b) Establish the power which can be dissipated in the capacitors for this differential (either by experiment or calculation) ( $P_c$ ).
- (c) Deduct the contribution from leakage current ( $P_L$ ).
- (d) Establish maximum ESR limits for the range of frequencies and temperatures to be covered (R).
- (e) Calculate the current from  $I^2R = P_c - P_L$  for the complete frequency and temperature range.

## TAJ Ripple Ratings

The bases set up have been used to calculate the 20°C ripple ratings for all the TAJ codes (Table I). These numbers are displayed graphically in Figure 2 for each of the four case sizes. Note however that to simplify the voltage curves, the value shown is an average of different capacitance values at the same voltage rating. The current curves are complex with much crossing of lines in the region 100-1KHz. This is because the rating is not limited by the power handling capability but by the requirement that the peak to peak ripple voltage must not exceed the rated voltage.

The effect of temperature on the ripple ratings are shown in Table II. There will be no effect where the peak voltage is the limiting factor.

TEMPERATURE	RIPPLE VOLTAGE	RIPPLE CURRENT
- 55°C	1.4	.7
+ 85°C	0.5	1.0
+ 125°C	0.3	.6

Table II. Multiplier for Ripple Rating, 1K-100KHz

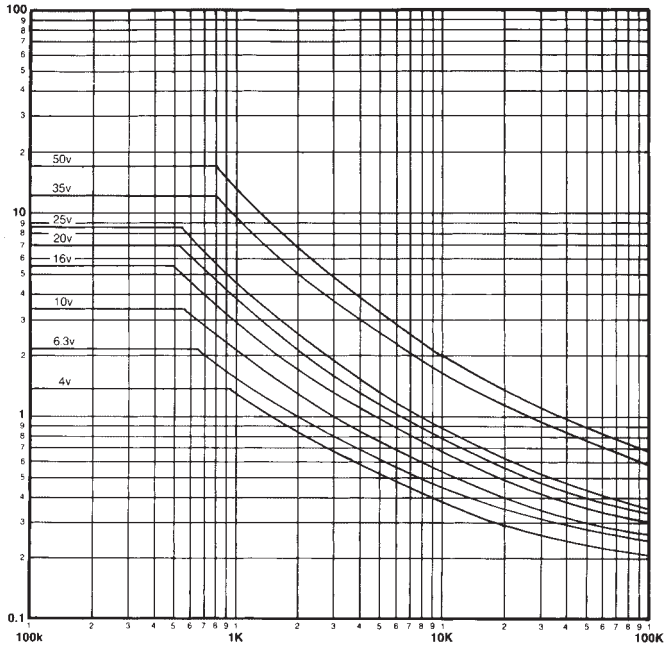


Figure 2. TAJ A Case Size

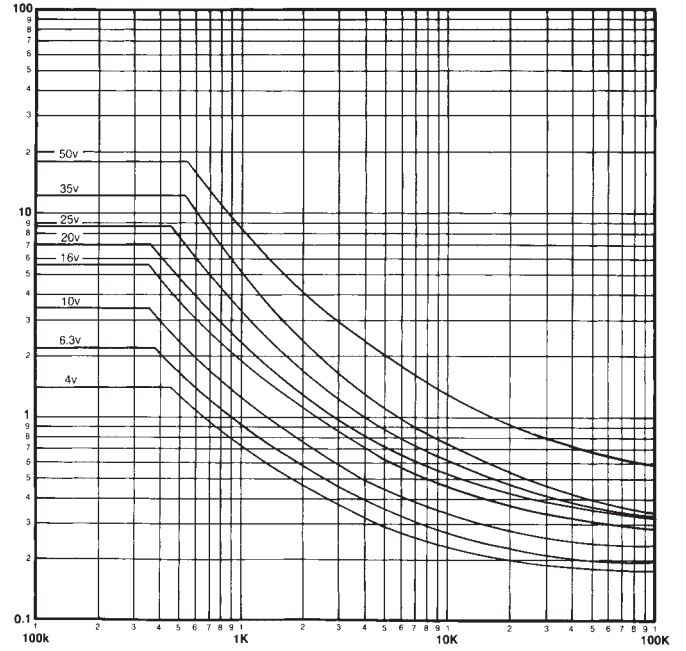


Figure 2. TAJ B Case Size

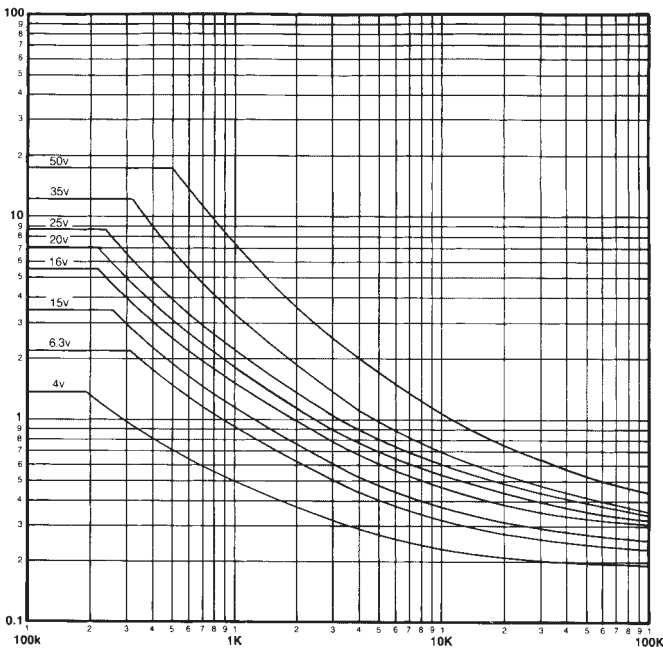


Figure 2. TAJ C Case Size

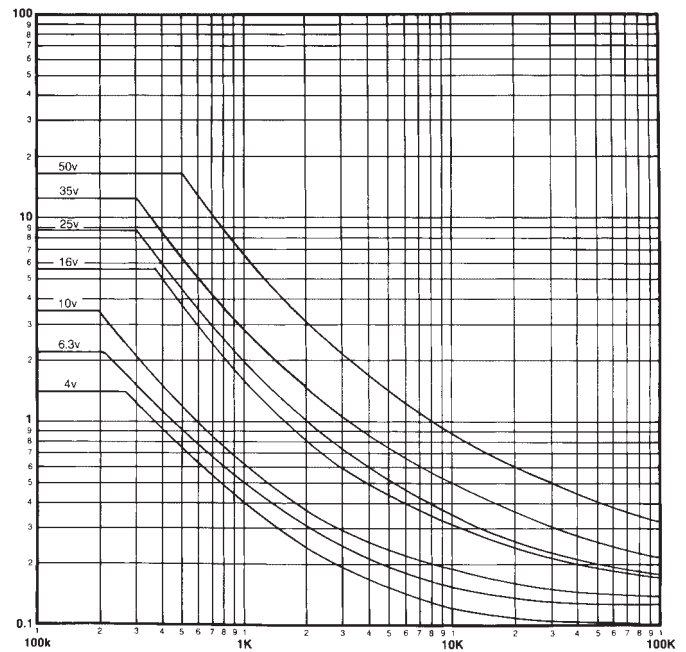


Figure 2. TAJ D Case Size



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