TECHNICAL PAPER

Investigation Into the Effects of Connecting Tantalum Capacitors in Series

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Abstract:
This paper demonstrates how high voltage capacitors can be made by connecting lower voltage rated parts in series. How to create large banks of capacitance by parallel and series combinations of capacitors without sacrificing reliability is also discussed.

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Introduction

Tantalum capacitors are being used as input filter capacitors in dc/dc converters and other types of power supply. The capacitors are thus likely to be subjected to both voltage and current transients.

An example application would be a 12 volt battery driving a portable PC. A 12 volt battery can vary in voltage from 9 volts to 18 volts depending on its state of charge. Thus if we apply the 50% derating rule, as recommended by tantalum capacitor manufacturers to increase dynamic reliability, the minimum input capacitor allowed would be a 35 volt part. A range of such capacitors is available. But if the input is say 24 volts, no part is available which will keep the derate rule.

Discussion of results

20 TAJD22M25 parts were characterized for capacitance at 120 Hertz, DF at 120 Hertz, ESR at 100 KHz and leakage current at 25 volts. The parts were then connected in series with parts 1 and 2 forming one unit, 3 and 4 another and so on. These units were then characterized for the same parameters together with 10 pieces of TAJD10M35. The results are shown in table 1.

Table 1

(a) 20 pieces of TAJD22M25

Sample no.	Cap@ 120Hz (µF)	DF @ 120Hz	ESR @ 100KHz(Ohms)	DCL @ 25V (µA)
1	21.98	1.89	0.105	0.062
2	21.40	1.77	0.105	0.054
3	21.30	0.59	0.109	0.270
4	21.84	1.76	0.107	0.104
5	22.91	2.28	0.124	0.062
6	22.51	2.15	0.129	0.060
7	22.14	1.79	0.114	0.056
8	21.70	1.81	0.108	0.064
9	22.32	2.14	0.124	0.063
10	21.13	0.62	0.110	0.040
11	22.35	2.35	0.157	0.064
12	23.32	2.09	0.118	0.126
13	22.58	1.62	0.106	0.192
14	22.10	1.75	0.105	0.077
15	22.31	1.77	0.100	0.064
16	21.35	0.59	0.105	0.039
17	21.93	1.97	0.108	0.060
18	22.91	1.81	0.104	0.059
19	23.15	1.95	0.121	0.176
20	22.03	1.79	0.105	0.113

(b) Parts in series

Sample no.	Cap @ 120Hz(µF)	DF@ 120Hz	ESR@ 100KHz(Ohms)	DCL@25V (µA)
1 (1+2)	10.87	1.60	0.197	0.021
2 (3+4)	10.81	0.97	0.199	0.034
3 (5+6)	11.40	2.02	0.237	0.028
4 (7+8)	11.00	1.67	0.203	0.026
5 (9+10)	10.88	1.13	0.214	0.020
6 (11+12)	11.46	2.07	0.240	0.030
7 (13+14)	11.22	1.62	0.191	0.041
8 (15+16)	10.94	0.96	0.187	0.022
9 (17+18)	11.24	1.76	0.246	0.028
10 (19+20)	11.33	1.69	0.212	0.037

(c) TAJD10M35 parts

Sample no.	Cap @ 120Hz (µF)	DF @ 120Hz	ESR @ 100KHz (Ohms)	DCL @ 25V (µA)
1	10.14	1.69	0.245	0.024
2	10.23	1.51	0.226	0.023
3	10.09	1.47	0.251	0.024
4	10.21	1.46	0.231	0.024
5	10.06	1.70	0.238	0.026
6	10.08	1.50	0.234	0.024
7	10.22	1.65	0.252	0.026
8	10.30	1.55	0.251	0.024
9	10.25	1.57	0.292	0.027
10	10.27	1.46	0.263	0.024

Adding the 22µF 25V parts 1 and 2 together would give a theoretical ESR of

$$\begin{aligned} ESR &= ESR_1 + ESR_2 \\ &= 0.105 + 0.105 \\ &= 0.210 \text{ Ohms} \end{aligned}$$

which when compared with the measured result gives good correlation. The capacitance of the part should be

$$\begin{aligned} 1/Cap &= 1/Cap + 1/Cap_2 \\ 1/Cap &= 1/21.98\mu + 1/21.40\mu \\ \Rightarrow \quad Cap &= 10.84\mu F \end{aligned}$$

Again this compares very well with the measured value.

The leakage of the series part is the best leakage of the two 22µF parts measured at a voltage of 12.5 Volts, i.e. half the input voltage.

The dynamic performance of a series combination and a 10µF part was then compared by causing a large transient current to flow. As can be seen from the results, figures 1 and 2, there is no discernible difference in the waveforms observed.

The final test performed was a voltage step stress test (VSST) style test where increasing voltage was applied to the capacitor under test until it had a leakage greater than 2000µA. The results are shown in table 2 and graphically in figure 2. VSST results are proportional to the rated voltage of a tantalum capacitor.

The results show, as expected, that the series parts have a higher breakdown voltage than the 10µF 35 volt part. Thus, they will perform better in an input capacitor application.

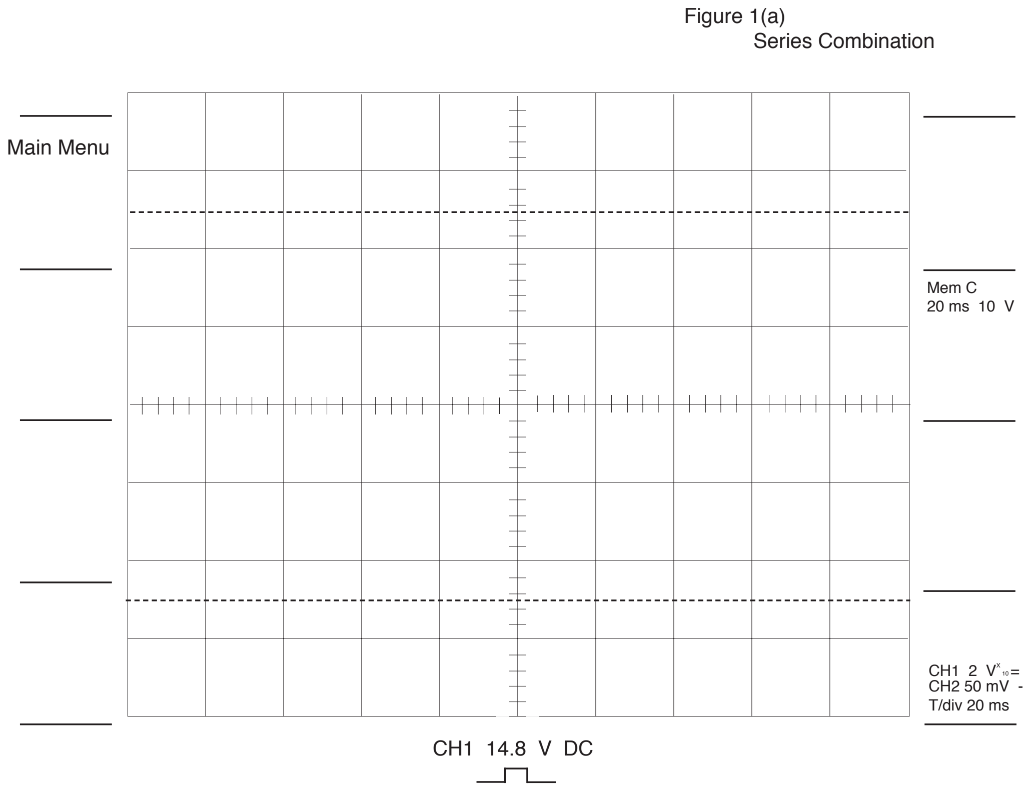


Figure 1 (a)

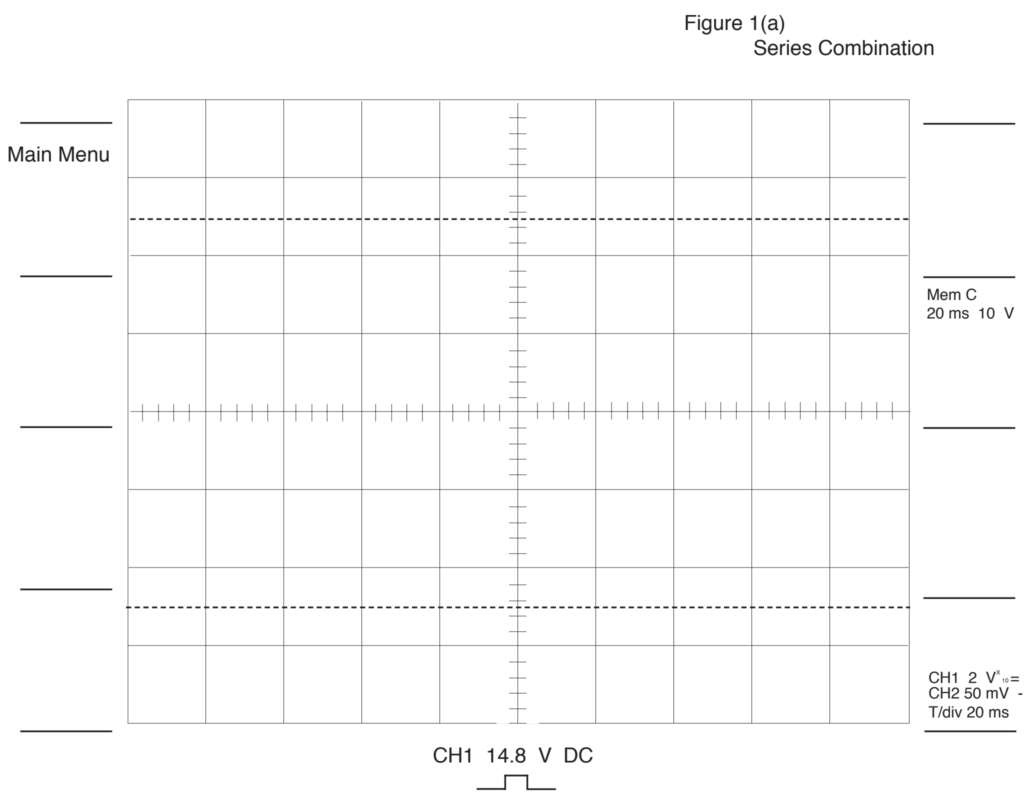
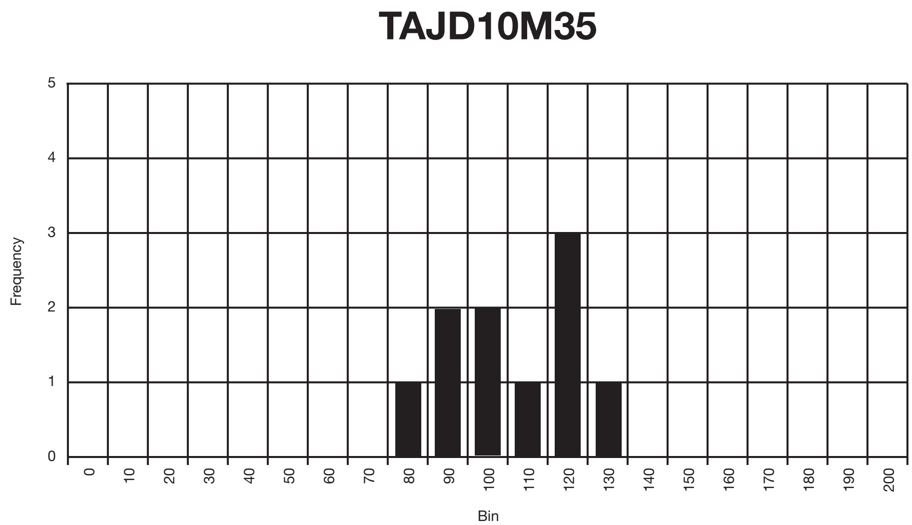
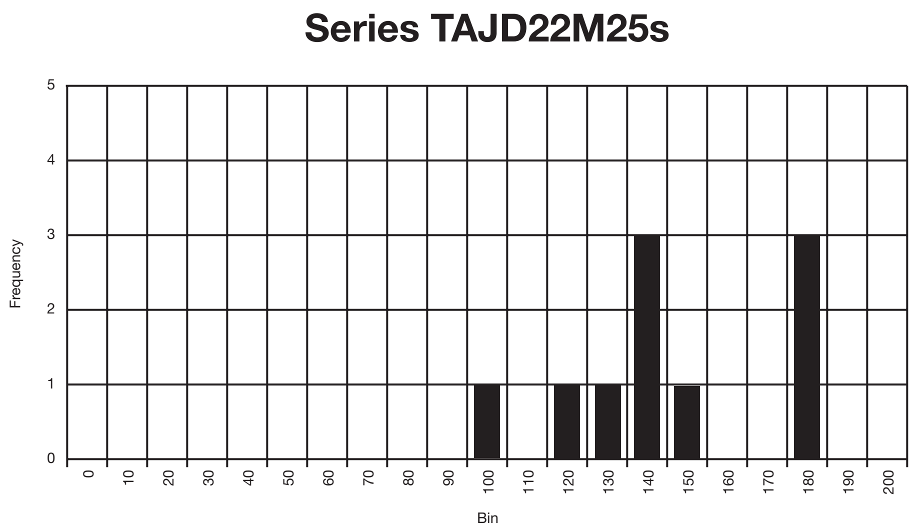


Figure 1 (b)





Figures 2(a) and 2(b)

Sample number	Series combination	10μF 35V part
1	140 v	129 v
2	143 v	93 v
3	155 v	102 v
4	174 v	80 v
5	100 v	130 v
6	142 v	104 v
7	134 v	116 v
8	175 v	129 v
9	126 v	123 v
10	174 v	92 v

One important fact which should be noted is that the power ripple rating for two series parts is **twice** that for a single unit. Thus for example if a 10μF 35 volt part were specified as less than 300 milliohms, its maximum allowable ripple current at 25°C would be

$$P = I^2R \qquad \text{thus} \qquad I = \sqrt{\frac{P}{R}}$$

i.e.

Ripple current = SQRT (150 mW / 0.300 Ohms)
= 707mA

for the series part P = 300 mW, thus

Ripple current = SQRT (300 mW/0.300 Ohms)
= 1 Amp

Creating large capacitor banks

An attempt was made to produce a 66 µF 48V capacitor by using series and parallel combinations of capacitors. The capacitor used was a TPSE100M16. The first attempt schematic is shown in Figure 3.

The voltage across C1-C6 were investigated in order to determine what effect the differences in voltage may have on each capacitor's reliability. The results are shown in Table 3, together with the leakage current and capacitance at 120Hz of the capacitor in each location.

Table 3

Capacitor	Voltage (Volts)	DCL (µA)	Capacitance (µF)
C1	9.78	0.72	99.18
C2	10.07	0.56	96.76
C3	10.15	0.65	96.47
C4	9.73	0.60	98.79
C5	10.02	0.44	97.76
C6	10.25	0.72	95.58

As can be seen from the results in Table 3, the voltage drop across each capacitor appears to be independent of the leakage current, but inversely proportional to the capacitance. For example C4 has the largest capacitance in that series leg and V4 is the smallest, and C6 is the smallest capacitance but the largest voltage.

This is because of Coulomb's Law. If we consider the capacitors to be pure parallel plates the charge on the negative plate of C1 must have been drawn from the positive plate of C2, thus the charge on C1 is the same as C2, and so on through the chain. Coulomb's Law states

$$Q = CV$$

where Q = charge in Coulombs
C = capacitance in Farads
and V = voltage across capacitor in Volts

If rearranged this shows V to be inversely proportional to C, which is as was found.

Connection between capacitor nodes as shown in Figure 4, helps the capacitors current share when transient loads are switched, or the ripple current caused by filtering a voltage signal. This current sharing improves reliability by reducing the heating seen by each individual capacitor. The effective parallel capacitance of each pair and the measured voltages are shown in Table 4, which again demonstrates the inverse capacitance relationship.

Table 4

Capacitance Pair	Voltage (Volts)	Capacitance (µF)
C1//C4	9.70	197.97
C2//C5	9.98	194.52
C3//C6	10.30	192.05

The differences between the voltages across each of the capacitor pairs will adversely affect the reliability of the pair with the highest voltage (see Catalogue or AVX publication "Tantalum Capacitors Technical Summary" for further details). The introduction of a resistor ladder as shown in Figure 5, forces the voltage across each pair to be one third the supply voltage, thus each capacitor will have the same reliability figure.

A 66 µF 48V part can thus be made by using the configuration shown in Figure 5. This unit will have a high reliability factor.

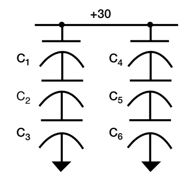


Figure 3

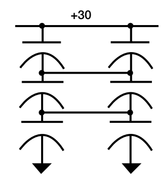


Figure 4

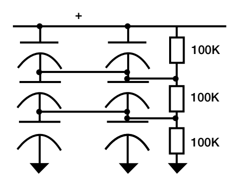


Figure 5

Conclusion

A 50V part can be made by connecting two 25 volt parts in series. In the example chosen the series combination of two 22 µF 25V parts has the following characteristics when compared to 10 µF 35V parts.

a) lower ESR levels

b) similar leakage levels

c) Higher breakdown voltage levels

d) Higher capacitance levels

e) Similar dynamic circuit performance

Very large capacitances can be successfully made by a combination of parallel and series connections.

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