# TECHNICAL INFORMATION

## ANALYSIS OF FUSING TECHNOLOGY FOR TANTALUM CAPACITORS

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**Abstract:**

Introduction of the fused capacitor, makes the failure mode of the device similar to a semiconductor. The fine wire fuse connected in series with the capacitor, similar to the wire bond used in the semiconductor, will open circuit under fault conditions and disconnect the capacitor from the circuit thereby failing safe.

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## Introduction

An important aim for any electrical component, is that if it fails in operation, it will fail in a safe way, not causing burn damage to the equipment or cause electrical overload to the electrical circuit to which it is connected. This requirement is for any component such as Semiconductors, Resistors, Transformers and Capacitors.

In the case of semiconductors most of these are constructed using wire bonding to connect from the customer termination to the chip face, and if the semiconductor junction fails the current capacity of this fine wire used to connect the semiconductor to the circuit, overloads and acts as a fuse which disconnects the semiconductor from the circuit.

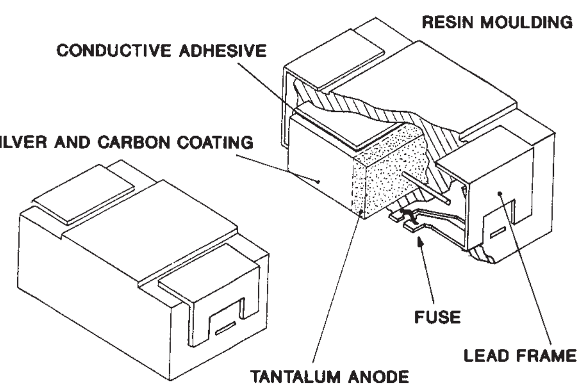
Resistors have a different failure mode. In most cases under steady state conditions, the resistor element will age to a higher resistance, thereby limiting the current. But if the voltage across the resistor is increased by a fault condition in the circuit then the resistor will carry more current and therefore dissipate more power, this can cause overheating, a burning of the area around the resistor.

The Tantalum capacitor is similar to the resistor, in an overload condition. This can be due to the capacitor being connected the wrong way round in the circuit, which will apply reverse voltage to the capacitor. Excess voltage above its rated voltage, electrical stress due to high ripple currents or very high surge currents, can all induce a dielectric failure, and cause the capacitor to fail.

The mode of failure is the same as a resistor. The capacitor will suffer a dielectric breakdown and act as a resistor with a low resistance in general between 3 ohms and 0.2 ohms, which will cause heating of the capacitor. The degree of heating will depend on the energy available from the power source. If sufficient energy is available, the capacitor may get very hot causing burning to the PCB.

Introduction of the fused capacitor, makes the failure mode of the device similar to a semiconductor. The fine wire fuse connected in series with the capacitor, similar to the wire bond used in the semiconductor, will open circuit under fault conditions and disconnect the capacitor from the circuit thereby failing safe.

**CONSTRUCTION OF A TANTALUM CAPACITOR WITH FUSE**




The aim of this paper is to review the Tantalum capacitor, in the dielectric breakdown condition, and the various fusing methods used in the industry to fuse the capacitor.

Why have the customers requested a fuse capacitor? It would appear that it is for mixed reasons:

- wrong way round
- over voltage
- a.c. ripple
- circuit fault conditions
- high energy with low impedance

On assembly if the capacitor is connected into the circuit the wrong way round, it will be subjected to reverse voltage. The Tantalum capacitor can operate with a small reverse voltage, but will fail low resistance under larger reverse voltage stresses. It may operate for long periods before failing, therefore this incorrect assembly is not readily detectable on final test of the equipment, but when it does fail, it will fail low resistance. Depending on the energy available in the circuit to which the capacitor is connected, the capacitor can pass high currents and burn. A fused capacitor would ensure that under these conditions the capacitor will be disconnected from the circuit.

If a capacitor is subject to a voltage in excess of the rated voltage, either by a transient spike or a continuous voltage overload then the capacitor may suffer a dielectric breakdown and become a low resistor. If sufficient power is available from the power source the capacitor may get hot and can cause burning to the PCB, or it may take current and cause the power source to fail or overheat.

If a capacitor is subjected to excess a.c. ripple current then dielectric heating occurs and this can cause the dielectric to rupture, and become low resistance, again causing heating and possible burning of the PCB to which it is mounted.

In some of the d.c/d.c. converters, and motor control circuits high transient spikes can occur under fault or use conditions, then dielectric failure can occur again causing heating of the capacitor. The fitting of a higher voltage working capacitor or a fused capacitor will insure a safe operation.

When a component fails, it can cause overstressing of other components. If it is considered that such a condition is likely to occur then fitting a fused capacitor would be a safe option.

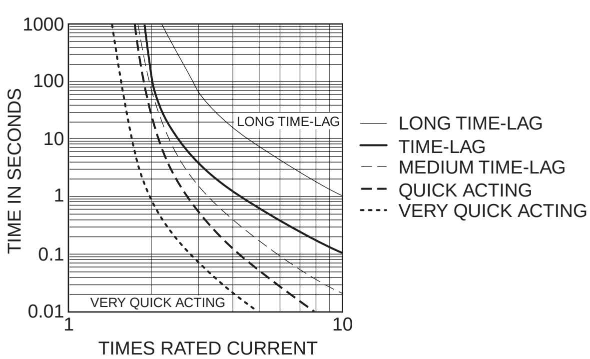
These five conditions are the main reasons why circuit designers have requested a fuse capacitor.

## Fuse Specification Requirements

The assembly of a capacitor to a PCB by the equipment manufacturer is generally either by solder or conductive resin attachment. The temperature of the capacitor body can achieve 300c during an I/R reflow soldering process, therefore the construction of the capacitor, and the thermal design of a fuse has to be designed to withstand this temperature.

When the capacitor is subjected to discharge and charge conditions at maximum rated voltage with minimum impedance, the fuse must be able to withstand large currents flowing in and out of the capacitor without blowing the fuse. The typical standard fusing characteristics in the industry are as shown,

**TYPICAL DIFFERENT FUSE SPEED RATINGS**
**TYPICAL TIME/CURRENT CHARACTERISTICS**




The time delay fuse is used to allow large currents to flow for a short time, such as occurs in a television when it is switched on, but will fuse at a low current in a longer time interval. The disadvantage of this fuse is that the initial let-through current is high and could cause damage to the circuit in operation. The other end of the fusing is the very fast fuse which will cut the current flow in a short time, limiting the let-through current in turn limiting damage to the power source and other components in the circuit.

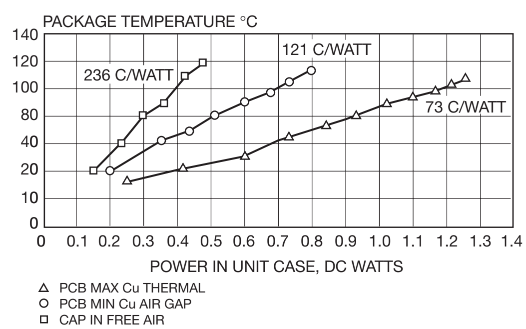
Many applications for capacitors require a low ESR (equivalent series resistance). The fuse is a heat generating device. As current is passed through the fuse element, it heats up causing the fuse element to melt which then forms an open circuit, isolating the circuit from the power source. We have conflicting requirements. The fuse must have resistance to operate, but the fused capacitor must have low ESR. The circuit designer would like zero resistance. In general the fuse will add resistance of the order of 70 milohms to the ESR of the tantalum capacitor.

The trend in the industry is for smaller component sizes. Typical dimensions are 7.3mm long, 3.2mm wide, known as the D case size; and 3.5mm long and 2.8mm wide, known as the B case size.

## Fuse Design Criteria

The thermal rating of the small size of the capacitor depends on the method of mounting in the equipment. This can vary from 70c/ watt to 350c/ watt. The capacitor anode body can withstand 350c internal temperature for a short time before a risk of burning occurs.

**THERMAL IMPEDANCE GRAPH**
**C CASE SIZE CAPACITOR BODY**




If a breakdown of the Tantalum dielectric occurs, the failed capacitor resistance can vary from 3 ohms to 0.2 ohms depending on the mode by which it failed.

From the thermal rating and the failed resistance we can calculate the maximum current flowing to achieve a temperature of 350c.

For 350c /watt and a failed resistance of 3 ohms

Isq = watts/resistance = 1/3 = 0.33
I = 0.57 amps

For 350c/watt and a failed resistance of 0.2 ohms

Isq = watts/resistance = 1/0.2 = 5
I = 2.2 amps

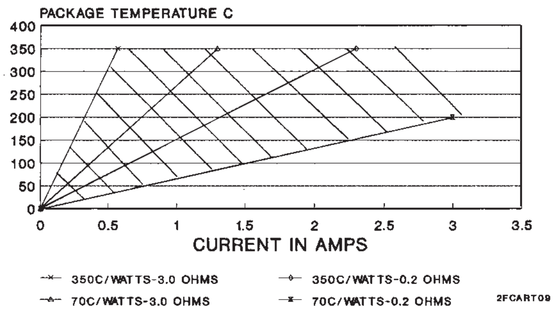
For 70c/watt and a failed resistance of 3 ohms

Isq = watts/resistance = 5/3 = 1.66
I = 1.29 amps

For 70c/watt and a failed resistance of 0.2 ohms

Isq = watts/resistance = 5/0.2 = 25
I = 5.0 amps

**FUSED CAPACITOR THERMAL/ELECTRICAL TEMPERATURE RISE, PACKAGE RATING WATTS/C WITH VARIOUS FAILED RESISTANCE VALUES**




From these calculations the current which can cause the capacitor to overheat from 0.57 to 5 amps, depending on how the capacitor is mounted (which will effect its thermal rating), and the type of failure, which controls the failed resistance.

When a Tantalum capacitor manufacturer supplies a capacitor to the industry, they do not know under what conditions it is to be used, therefore the design of the fuse in the capacitor has to cater for all conditions.

From the above discussion the main aim of a fused capacitor is:

1. Limit the temperature of the capacitor body to stop burning under a fault condition.

2. Disconnect the capacitor from the circuit as quickly as possible to reduce the risk of damage to the power source and other circuit elements.

3. To withstand the solder mounting at 300c and other thermal stresses experienced in assembly and operation of the equipment.

**DIFFERENT FUSE ELEMENT CONCEPTS**

LOW MELTING POINT FUSE ELEMENTS - APPROX 300C

HIGH TEMPERATURE SINGLE METAL WIRE OR TAPE - 1000C

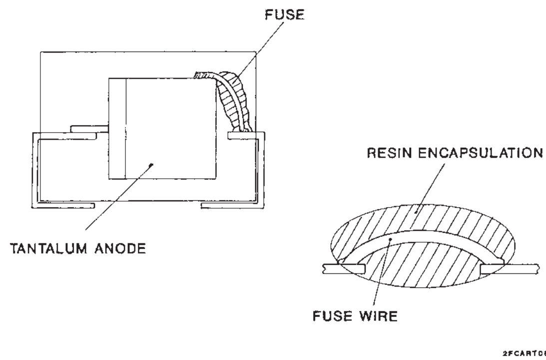
HIGH TEMPERATURE TWO METAL WIRE 650 to 1000C

HIGH TEMPERATURE WIRE CLAD WITH LOW MELTING POINT METAL

## Low Melting Point Fuse Elements

The clear requirement is the thermal limit of 350c for the capacitor element. One way is to place inside the capacitor body a low melting point link close to the capacitor element, and wire it electrical in series with the capacitor, so when the fuse link melts due to the heat from the capacitor body, it will disconnect the capacitor from the circuit.

**LOW MELTING POINT FUSE WIRE STRUCTURE**

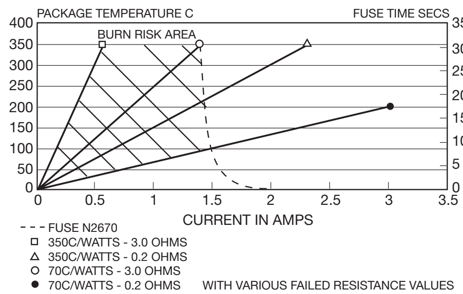



The use of a solder wire which melts above 300c, (so that it will not degrade during the component solder reflow), has the advantage that it will become unstable with temperature above the melting point. In domestic fusing applications when this type of fuse element is used, the construction is such that the fuse element is suspended in free air, so that when the fuse wire melts it can fall into the free space, to give a clean electrical break. Due to the small size of the Tantalum capacitor which requires a very small fuse and the method of manufacture, adding a free space around the fuse element to date has not been possible. Therefore, the material surrounding the fuse element has to degrade to form a space, or absorb the melted metal, or the solder has to be converted into an insulating oxide. To date the reported performance is that with the solder wire size available of 0.1mm dia. with 5 amps flowing, there is sufficient energy to obtain an acceptable fusing speed, but at low currents the fuse will take a long time to blow due to the molten metal being absorbed by the surrounding encapsulation and is reported to be inconsistent in interrupting the current flow.

## Fuse Wire High Melting Point

A fuse design using a wire of high melting point will not sense the critical temperature of 300 to 350c. In order to fully protect the capacitor, it will have to set the fusing conditions such that it will in the worst case of high failed resistance, and worst case thermal impedance of the capacitor. In the worst case reviewed earlier in the paper this could be as low as 0.57 amp with failed resistance of 3 ohms. Tantalum capacitors are marketed with this type of fuse wire. Some of the fuses contain a fuse element of two materials which have an exothermic reaction at about 650c. This results in a high temperature which generates its own cavity allowing the alloy to disperse, giving a clean electrical break. This will only occur if sufficient energy is dissipated in the fuse.

CAPACITOR WITH HIGH TEMP ELECTRICAL/FUSE TEMPERATURE RISE, PACKAGE RATING WATTS/C, WITH TYPICAL HIGH TEMPERATURE FUSE



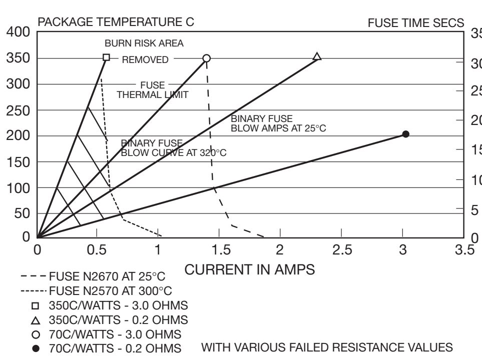

The disadvantage of this type of fuse is that it does not sense temperature, and if it is set with a very low fuse setting it has to be a delay fuse, in order that the fuse will not open circuit under capacitor charge and discharge conditions. This fuse design is a compromise between setting the fuse current to withstand the charge/discharge, and at the same time stop the capacitor burning, under the worst case condition of high failed resistance. This will require a fuse setting about 0.5 amps.

# AVX Binary Fuse Construction

This type of fuse design comprises a two metal system, the innercore of the fuse wire is a high temperature metal, with the outer cladding of a low melting metal. When the fuse element reaches a temperature of 320c, the outer cladding melts and exposes the inner core. This action changes the fuse characteristics to a low current blow fuse, which fuses at a temperature of above 1000c creating a cavity and giving a clean, fast electrical open circuit.

The advantage of this type of fuse is that it is a thermal and a low current electrical fuse.

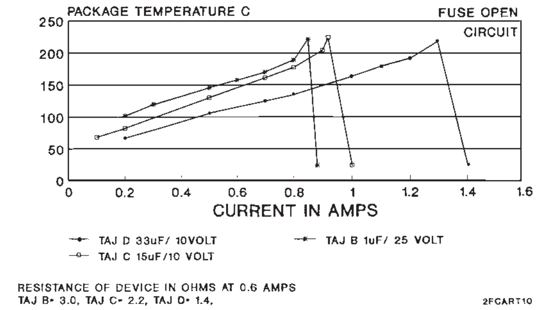
CAPACITOR + BINARY THERMAL/ELECTRICAL TEMPERATURE RISE, PACKAGE RATING WATTS/C, WITH BINARY FUSE




It can be seen from the graph, the two fusing curves one at 25c the other at 320c, this demonstrates the change in sensitivity once the fuse element has achieved 320c. The fuse can therefore be set, to a fuse blow rating well away from the charge/discharge currents, over the capacitor operating temperature range, yet limit the fault current at 25c to a low value when the capacitor fails with low resistance.

If the capacitor failed high resistance, the capacitor will get hot, then the fuse will change sensitivity at 320c, and the fuse will blow to disconnect the capacitor from the circuit.

TAJ B,C,D FUSED TANTALUM CAPACITORS PACKAGE TEMPERATURE TO CURRENT IN AMPS CAPACITOR MOUNTED ONTO PCB 1 INCH SQ




The graph of TAJ B, C & B fused tantalum, give results obtained during fusing trials, in all these cases the short circuit current was sufficient to heat the capacitor, but not electrical activate the fuse, the fuse was activated when the capacitor element achieved 320c, and it can be seen from the graph package temperature was 240c.

# Summary

1. It must be remembered by the circuit designer, that with any fuse system there must be sufficient energy designed in and available to blow the fuse, under fault conditions.

2. The choice of fuse technology is important, for example:

a. With a Non-thermal fuse, if the capacitor fails, with a failed resistance of 3 ohms, and the fuse is set to blow at 2 amps, then the voltage across the capacitor has to be in excess of 6 volts, and the power supply has to be capable of activating the fuse. Therefore, the circuit designer has to ensure that his circuit is capable of supplying the energy to blow the fuse.

b. The Thermal electrical fuse, which is either a low melting point metal or Binary fuse, will start to activate the approx 300c, and the electrical energy will cause the fuse to become open circuit.

The low melting point fuse will be less sensitive at low currents approx 0.7 amps, and is reported to have a slow blow, and inconsistent blow rate.

The Binary fuse will give a clean blow rate at low currents of 0.6 amps, and or with a fuse temperature of 330c.

3. If the circuit electrical loading conditions are in the low current area then it is recommended to consult the capacitor manufacturer on his best product for the application.

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S-AFTT00M301-R