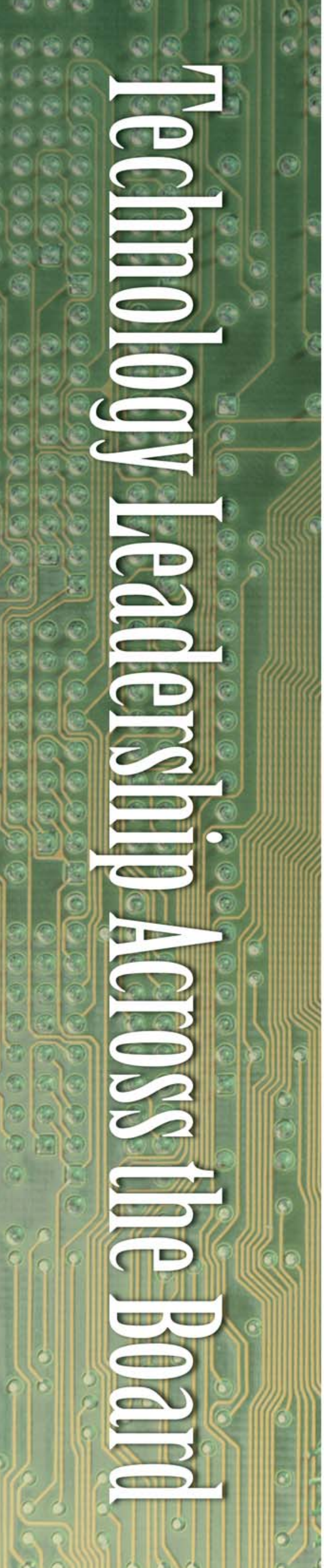

A New Low ESR Fused Solid Tantalum Capacitor

ABSTRACT:

Solid tantalum capacitors are extremely reliable due to the nature of their materials and construction. The construction allows for small DC leakage sites within the device to become isolated electrochemically and thereby insignificant.

Tantalum capacitors can accommodate a variety of environmental conditions such as temperature, humidity, shock, vibration, mechanical and electrical stress, including applied voltage, current, ripple current, transient current and voltage. However, when using solid tantalum capacitors, application guidelines must be followed to insure that the full reliability of the capacitor is realized.

Due to their inherent reliability tantalum capacitors are increasingly utilized in harsh applications. When application guidelines can be exceeded, such as transient conditions, there is the concern that the device could fail, over heat and potentially burn. This concern primarily centers on high voltage product where there is sufficient energy to overcome its natural self-healing properties.

There are commercially available fused tantalum products that provide protection for these rare events by causing the device to "open" when drawing elevated currents. These fused devices utilize a bi-metallic fuse wire. The single wire fuse limits flexibility in design and can increase the Equivalent Series Resistance (ESR) of the complete package 2 fold or more compared to the capacitor itself.

A new style fused solid tantalum capacitor has been designed that incorporates an internal thin-film fuse which provides safety, consistency, reliability, ultra-fast fusing, compactness and a lower ESR product than commercially available fused solid tantalum capacitor product today. The design allows for flexibility in specifying fuse characteristics and/or targeting ESR levels that more directly fit the application, while not sacrificing levels of capacitance available in the case. The availability of fuses with a wide current range and response times allows for specific circuit protection to be designed in.

The configuration of the construction of this device also allows for compliance with the low impedance requirement of MIL-PRF-55365 Weibull grading.

This paper reviews the design, construction and characterization data for this product.

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Introduction


Figure 1:
Finished fused capacitor.

Solid tantalum capacitors are well known for their high levels of reliability and stability. They have become the preferred capacitor to use where high reliability and long service life are paramount. They are used in many critical, long life reliability applications such as aerospace hardware.

For example solid tantalum capacitors are part of the NASA Mission, the Pluto New Horizons Observatory. This is the first mission to the planet Pluto and beyond to the Kuiper Belt. Launched in early 2006, the New Horizons Observatory is scheduled to pass Pluto and its moon Charon as early as 2015 and then on an extended mission to the Kuiper belt. This is at least a nine-year program where solid tantalums have been specified.

High reliability medical applications utilizing solid tantalum capacitors also include medical implantable hardware such as pacemakers, defibrillators and drug delivery systems. High reliability solid tantalum devices, that are built to Mil-PRF-55365 reliability levels and are used at recommended 50% de-rated voltages and 25ºC, can approach failure rates as low as 0.00001% per thousand hours @ 60% confidence level(1).

Solid tantalum capacitors are also widely used for filtering and by-pass applications in electronic circuits due to their small size, reliability and smooth frequency response. Design trends toward more complex modules, with faster switching speeds, require more capacitors per module, denser component packaging and minimum device inductance for the lower ESR required for effective power supply and noise filtering.

The reason for interest in a fused device is that overstressing solid tantalum capacitors can lead to premature failures. Such failures are a concern when the device fails for DC leakage, which can cause the device to heat. The level of heating is dependent upon the energy available and the resistance of the failure. If there is sufficient energy it is possible for the device to over heat.

Typical over-stress conditions can be reverse voltage, excessive voltage, and thermal over load, electrical stress due to high ripple currents or inductive transients. Other conditions that can lead to a typical failure can include circuit faults or high energy availability coupled with low series circuit impedance. These conditions can all potentially cause the capacitor to fail.

Other circuits where fused capacitors may be considered are where capacitors are charged or discharged through low impedances or where large numbers of capacitors are in parallel.

It is important for any electrical device that if it fails that it fails into a high resistance mode and ideally become an open circuit. This open circuit condition may cause the circuit not to function properly but the collateral damage due to overheating will be minimized. Given that a product can be designed to specifically open, then redundancy can be employed for continuous circuit operation in spite of a failure. An intermittent fault condition should also be avoided and fused products have been available for a number of years that provide an open circuit fault condition.

When the fuse exceeds its current limit, the fused capacitor will effectively take itself out of the circuit by creating a high resistance path, typically 10MΩ minimum. In some cases this can mean the difference between a total circuit loss or a barely detectible performance degradation.

Many applications require low ESR and by definition have high current availability. The fuse itself has inherent resistance just due to its nature. This coupled with the natural ESR of the component will elevate ESR levels for the capacitor/fuse module beyond that of stand alone capacitors.

This paper will outline an approach to a fuse/capacitor assembly which reduces ESR to levels lower than currently specified by commercially available modules.

Summary of Fuse Types

One well known method for making a fused capacitor uses a wire as a fusible link within the body of a molded body capacitor. The wire is welded to the internal lead frame so that on the finished product the link is in series with the capacitor. The fusible link is composed of two or more metals, palladium, ruthenium and aluminum, in which exothermic reaction can be initiated by heating to about 650ºC. The heating occurs when excessive current flows. The fusible link is coated with a protective coating to prevent the exothermic reaction (2800ºC) from charring the epoxy body of the capacitor. This type of fuse is known as an electrically activated fuse(2).

In another style fused capacitor the wire for the fuse has a low melting point. In this case the wire simply melts instead of creating an exothermic reaction to open the fuse. This type of fuse is known as a thermally activated fuse.

There are electrical resistances, speed of operation and thermal sensitivity tradeoffs that must be addressed in the manufacture of wire fuses. The length, diameter and composition of the fuse may be modified to vary the fuse parameters.

The manufacture of wire type fuses requires several manufacturing steps. The wire must be fed to a cutter, cut to size, placed on the lead frame, welded and coated with a non-carbonizing material.

Selection of a method that is a pick and place compatible with known and consistent fuse values vs. cutting, placing, welding coating of a wire is most desirable. Ready made thin-film fuses are thus a good choice for this capacitor/fuse module.

Ready Made Fuse

The ready made fuse utilized in this series of capacitor, is based on thin-film techniques. This technology provides a level of control on the component electrical and physical characteristics that is generally not possible with standard fuse technologies. These devices are designed for modern surface mount circuit boards which require protection.

Typically, the thin-film fuse is constructed on an alumina substrate (see Figure 2) and provides significant size and profile advantages over conventional fuse technologies. Their ultra-miniature chip-style package enables easy surface mounting when using automated assembly equipment. The devices' thin-film construction yields precise and predictable fusing characteristics. They're capable of ultra fast fusing reaction times of less than 1/10,000th of a second. The soldered-in fuses also provide for failsafe protection from over-current conditions without the danger of unexpected turn-on associated with self-resetting devices.

Selecting a Fuse

A fuse must be robust enough to withstand surges and in-rush currents that might occur during module manufacturing and testing as well as at start up and during normal operation but sensitive enough to stop the flow at harmful current levels.

Two important parameters are operating voltage rating and the current interrupt rating. The voltage ratings may be different for AC and DC. The current interrupting rating is the maximum current that the fuse can stop at the rated voltage. If voltage or current interrupting ratings are exceeded the fuse can rupture or melt.

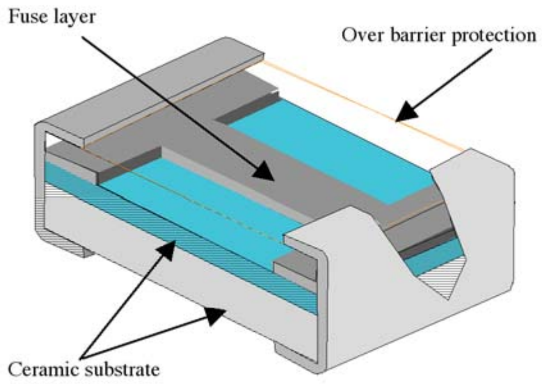

Figure 2:
Schematic diagram for a typical thin-film fuse device.

Steady state AC or DC current levels and current pulses must be addressed for proper fuse selection. The shape, magnitude and duration of the current pulse must be converted to a standardized unit, Current Squared Seconds (I^2t). Current Squared Seconds (I^2t) is the integral of the current squared over time(3). Fuses are categorized based on their melting, I^2t values. This value tells when the fuse will open. I^2t values for steady state and current pulses are the starting point for selection of fuses. This unit of measure is a fundamental value for selection fuses.

The operating characteristics and life of the fuse can be impacted by the operating temperature and exposure to current pulses(4). The fuse selection process must include adjustments for temperature and the number of occurrences of current pulses over the lifetime of the fuse. These adjustments are known as thermal de-rating and pulse de-rating, respectively. De-rating tables are used to determine the increase in current rating required for reliable performance at elevated temperatures or exposure to current pulses. These final de-rated values are compared to fuse data tables to select the correct fuse.

Based on these factors, the manufacture of fused capacitors includes the flexibility in selection of the fuse.

In fact, what is needed is not just a wide range of fuse types and ratings but also associated fuse information. This would include I^2t data tables, time-current curves, thermal de-rating and pulse de-rating information, voltage ratings and current interrupting ratings.

The fact that fuses are available with reliable performance information allows the proper selection of components to match the application. It would be hard to match the quality and reliability that has resulted from the years of development that has gone into the thin-film fuses that are on the market today. Aside from fuse selection based solely on their specifications, the product needs to be manufactured and tested with these components in place to verify fusing and "open" circuit characteristics following failure.

Several studies were conducted using a variety of fuse manufacturers and selected ratings. Tests were run to evaluate fusing properties inside the molded case as well as final resistance of the "open" circuit. The target resistance value for the "open" was 10 megohms or higher with no indication of burning on the package.

As can be seen by the following data (see Table 1), not all products react the same when encapsulated in the epoxy molding compound. All products opened when subjected to a short circuit but some had a final resistance of less than 10 megohms. Based on this, data supplier C was chosen for its consistent value of over 10 megohms when "open".

Supplier - Test Voltage	Sample Size	# pcs over 30 MΩ	# pcs under 10 MΩ
A - 35V	500	490	2
A - 50V	500	490	2
A - 35V	250	250	4
A - 50V	250	250	0
B - 50V	250	249	1
B - 35V	250	248	2
C - 50V	500	500	0
C - 35V	500	500	0
C - 50V	250	250	0
C - 35V	250	250	0

Table 1: Encapsulated Fuse Data.

Component Construction

The device is manufactured by selecting the proper fuse for the application, attaching the fuse in a predetermined location within the package, attaching the solid tantalum capacitor element and then encapsulating the fuse/capacitor 'module'.

A key component to the fused capacitor design is the lead frame configuration. Design constraints include adequate clearance between the lands where the fuse is attached and flexibility that allows for placement of fuses in a variety of case sizes, etc. The design also needs to accommodate the largest solid tantalum capacitor element possible.

Since there are 0402 and 0603 thin-film fuse designs available having desirable fusing characteristics and ESR, a lead frame configuration that allows the use of 0402 and 0603 foot prints was designed (see Figure 3).

This lead frame design allows for up to two fuse configurations. The design also allows for use of a pick and place system for fuse placement and attachment.

Various attachment methods for the fuse are possible depending upon the application. Possible attachment methods include conductive epoxy, high temperature solders, etc.

Following encapsulation and prior to completion of manufacturing, the center fuse by-pass link will be removed (see Figures 4 and 5) to allow the current path to pass from the circuit board to the external lead frame through the fuse to the tantalum element.

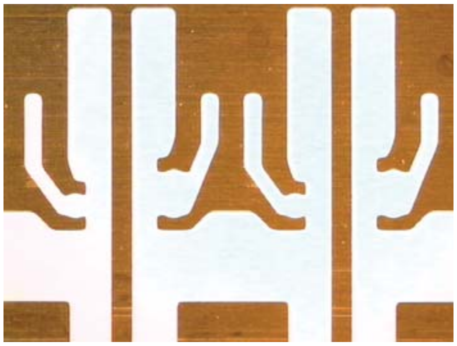

Figure 3:
Lead frame configuration for an 0402 and 0603 fuse.

Manufacturing considerations are interesting in that the fuse by-pass link can be removed either before or after burn in, surge, etc. These considerations should be reviewed based on application and circuit requirements prior to manufacturing.

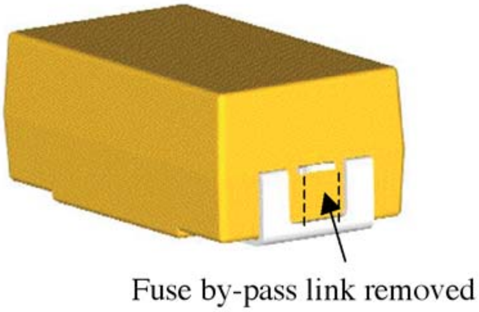

Figure 4:
Location of fuse by-pass link removal after encapsulation.

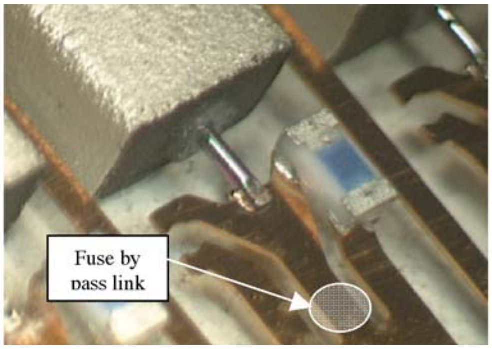

Figure 5:
Location for fuse by-pass link removal after encapsulation.

Electrical Properties

The functional electrical properties for a fused module are straight forward. The ESR of the tantalum element and the fuse are known so the resulting ESR is additive since they are mounted in series.

Figure 6 shows the simple schematic for the single fuse configuration.

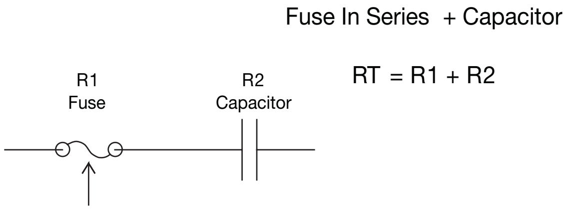

Figure 6:
Capacitor with Single Fuse Schematic.

The following graphs show typical impedance and ESR verses frequency plots for three capacitor ratings with internal fuses. Figure 7 shows the frequency response of a single fuse configuration for a D case 6.8µF @ 35V device.

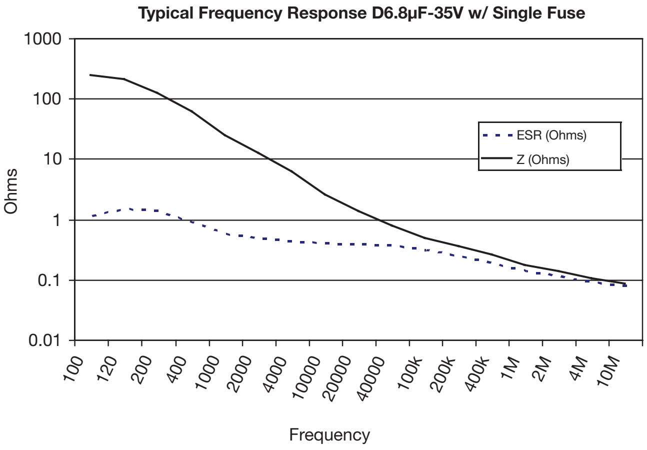

Figure 7:
D6.8-35 single frequency plot.

Figure 8 shows the frequency response of a single fuse configuration for a D case 47µF @ 15V.

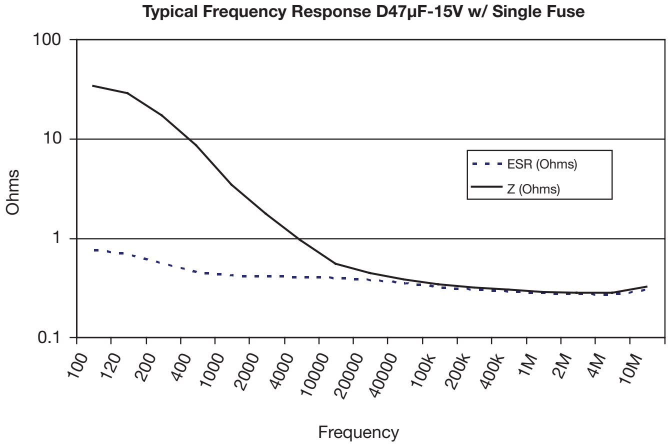

Figure 8:
D47-15 single frequency plot.

Figure 9 shows the frequency response of a single fuse configuration for a D case 4.7-50 product. The ESR plot stops at 400000 hz and the impedance increased dramatically beyond that frequency. This is due to some inductive reactance at the higher frequencies.

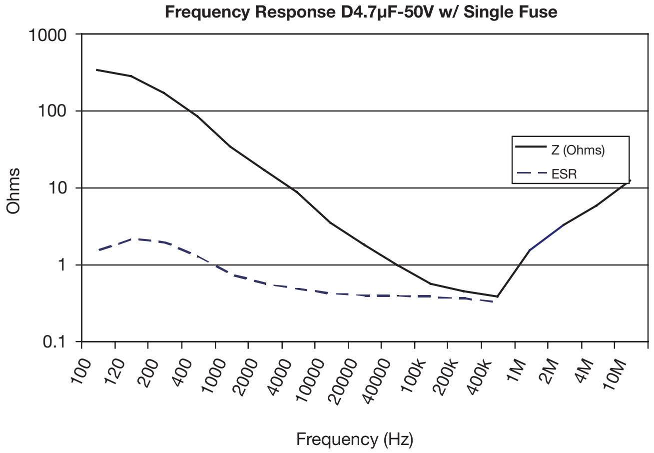

Figure 9:
D4.7-50 single fuse frequency plot.

To explore design options, a double fuse part was made. This device used the same fuse type in both fuse locations, putting them in parallel (see Figure 11). This configuration eliminated the impedance spike in the megahertz range, as seen in Figure 10. This would be useful if a D case 4.7-50V device is needed beyond the 400k hz range. The two fuse system shows a smooth response up to 10 megahertz. The double fuse configuration still protected the capacitor even though the current rating was effectively doubled, due to the fast blow characteristics of the fuses.

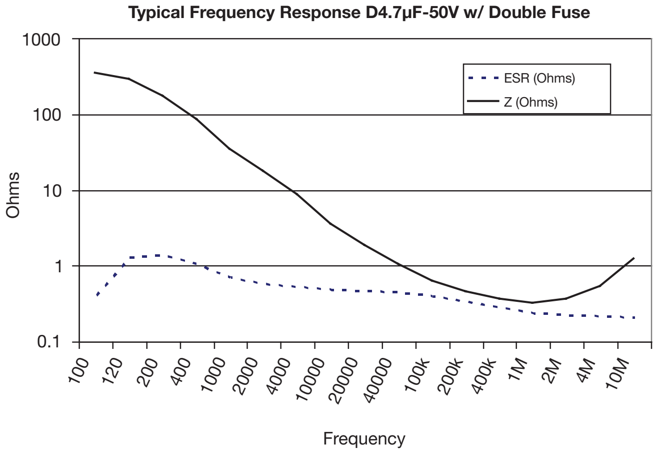

Figure 10:
D4.7-50 double fuse frequency plot.

Reliability

The solid tantalum element itself can be manufactured to an established reliability rating when processed according to Mil-PRF-55365. This means that as minimum COTS+ parts with the internal fuse can be readily manufactured. Rating matrix availability is limited to 15V and higher and to EIA standard case sizes D and E case at this point in time.

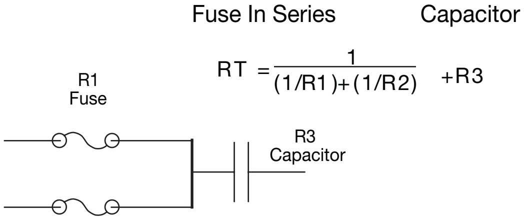

Figure 11:
Capacitor with Double Fuse Schematic.

These devices can be Weibull, established reliability graded, and surged with the fuse link in place so the component itself receives the full surge and accelerated burn-in conditions, with no protection from the fuse ESR.

Summary

A simplified approach to manufacturing a fused solid tantalum capacitor module had been developed. Fuse selection criteria and module design is enhanced by utilizing a ready made thin-film fuse which allows for a wide range of fuse selection options, ease of placement and excellent fuse consistency and predictability. It also allows for shortened development time and a wider range of choices for specific applications.

The ESR levels of the finished fused products are very low. Most commercially available high voltage fused solid tantalum capacitors offer ESR specification limits at or above 1.0 ohm (D case 4.7 µF-50V and 6.8 µF-35V). The DSCC drawing, 04053 for fused solid tantalums, offers a limit of 1.3 ohms for the D case 6.8-35V product. The typical ESR of a comparable product manufactured with the surface mountable thin-film fuse is less than .5 ohms.

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