

Solid tantalum capacitors are extremely reliable electronic components. However, large numbers of them are required at times, with some redundancy, in a single system. In such cases fail-open designs offer a proven means to increase the effective reliability of the capacitors by several orders of magnitude.

This issue of *Tech Topics...The Leading Edge*, summarizes contributions by numerous members of KEMET's technical staff over more than a decade and describes KEMET's very successful approach to the design of fail-open solid tantalum capacitors.

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## Fail-Open Solid Tantalum Capacitors

Solid tantalum capacitors are very reliable components, however they can be inserted into circuits backwards and they to some extent are susceptible to high voltage or high current surges. For these reasons a fail-open (or fused) tantalum capacitor should be an option for circuit component engineers. This is especially true where large quantities of tantalum capacitors are used in parallel. Main frame computers and power suppliers are excellent examples.

KEMET's experience with fail-open tantalum capacitors started about 15 years ago. The technology practiced elsewhere in our industry then, and to a large extent now, consists of placing a fuse in series with the capacitor element. This is a fusible (heat-melting) link much like a household or automobile fuse.

Our testing showed three major weaknesses with fusible links in capacitors:

- Fuse actuation characteristics are variable.
- Fuses provided protection in some circumstances, but not in others.
- A design problem exists in molded packages, in that the molten metal is trapped in the molded cavity and doesn't always open the circuit.

This last problem is illustrated by a simple experiment. Fused tantalum capacitors were placed in circuits backwards the most common means of misapplication. The rated voltage of the part was applied with an available current of 5 to 8 amperes. Fuse actuation occurred

rapidly and the conductivity of the part with continued voltage applied was determined after 3 minutes. The results are shown in Figure 1 and contrasted with the subsequent KEMET design tested under the same conditions. With extended time under voltage, some parts burned. A superior design was needed.

KEMET took a rigorous approach to design a truly reliable fail-open capacitor:

1. to understand and characterize the mechanics of catastrophic failure in tantalum capacitors, and then
2. to tailor a fuse system to match those failure mechanics

The approach led to highly reliable capacitor fuse designs (1,2) which we have continuously refined (3,4,5).

### Failure Mechanisms

Studies of the failure mechanics of solid tantalum capacitors were carried out by exposing capacitors to extreme conditions of voltage, available current and temperature. These "stress-to-failure" studies show three failure mechanisms.

1. If the tantalum oxide dielectric is heated from any cause above approximately 500°C, the layer crystallizes, shrinks and cracks. The electrical leakage of the capacitor increases, and in combination with breakage of the encapsulant surrounding the capacitor element, hot tantalum can be exposed to air creating the potential for fire.
2. If the tantalum oxide dielectric breaks down due to the applied voltage stress, it occurs at a highly localized point causing almost instantaneous heating and the results described above. On rare occasions the heat is sufficiently intense and it ignites a reaction between the tantalum metal and the oxygen-containing manganese dioxide, which acts as the electrolyte and counter-electrode in the capacitor.
3. If the epoxy encapsulant is heated to 300-400°C, decomposition and charring can occur. The latter makes the epoxy conductive, potentially generating a leakage path independent of the internal conductors in the capacitor.

Obviously, any well-designed fuse or other fail-open means should guard against these mechanisms as well as opening the circuit. Of course it must also withstand, without degradation, the ripple currents and charging current surges which the capacitor will encounter during use.

### Fuse Design

These requirements lead to two design “windows” for the fail-open mechanism. Under “continuous” conditions the fuse must withstand reasonable ripple currents, but activate prior to excessive heating of the capacitor. Under “instantaneous” conditions, it must withstand capacitor-charging currents, but activate prior to excessive heating at a localized failure site. Selection of a target continuous current actuation level varies with capacitor rating. Designing fuses to the chosen targets is straight forward, considering the resistivity and cross-section of the fuse, and heat dissipation through end effects, encapsulant, etc.

We found the “instantaneous” fusing requirements to be much more demanding. Fusing with a meltable metal link was just too slow. In destructive tests where capacitors protected by these fuses were subjected to very high voltages, usually 3 -4 times rated voltage, we were able to ignite tantalum-manganese dioxide reactions in capacitors the upper curve in Figure 2.

For a technical solution, we turned to the munitions industry, which used reactive fuse wires. The difference in actuation performance is illustrated in Figure 3. The faster actuation of reactive fuses dramatically reduces the likelihood of ignitions as shown in the lower curve in Figure 2.

The result was highly reliable fail-open systems specifically designed to address the particular failure characteristics of solid tantalum capacitors. Millions of KEMET fail-safe tantalums used in highly critical applications attest to this distinctive competence. Because of growing interest in fail-safe surface mount tantalums with standard footprints, KEMET is responding with products using these unique designs. This will be the topic of the next *Tech Topics*.

### References

1. H. V. DeMatos, “Design of an Internal Fuse for Solid Tantalum Capacitor”, *IEEE Transactions CHMT*, Vol. CHMT-3, pp. 244-249, June 1980.
2. H. V. DeMatos, “Internal Fuse Modules for Solid Tantalum Capacitors”, *Proceedings of the Conference on Capacitor Technologies, Applications and Reliability*, Marshall Space flight Center, February 24-25, 1981 (NASA Conference Publication 2186, pp. 63-68).
3. Patent #4,224,656
4. U. S. Patent #4,814,946
5. U. S. Patent #4,907,131

Figure 1

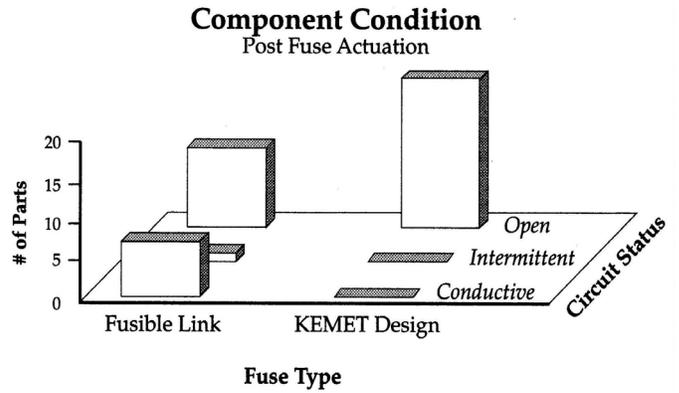


Figure 2

### High Voltage Stress to Failure Fuse Tantalum Capacitors

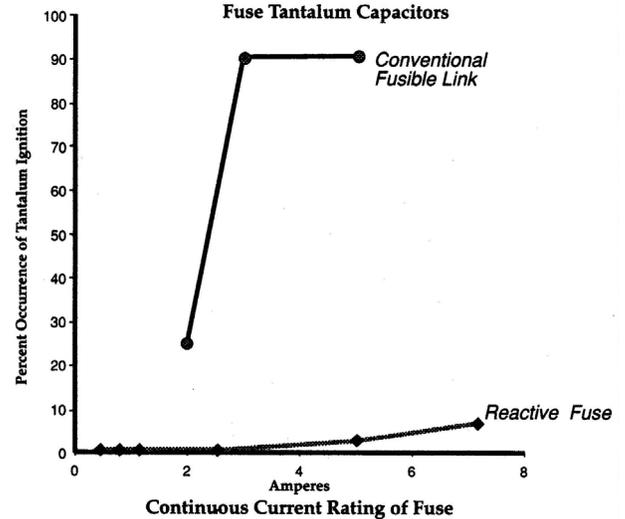


Figure 3

### Fuse Actuation Characteristics

