Trise Testing of the Power Ring Film Capacitor™ for Automotive DC Link Applications

SBE Inc. is a leading developer and manufacturer of film capacitor solutions that provide a much higher degree of reliability, higher power density, and simpler cooling infrastructure in demanding applications, particularly for automotive/transportation, alternative energy, utilities, power supplies/laser and military/aerospace. Originally a Sprague Electric Plant, SBE has been manufacturing capacitors for over 50 years; producing over a billion capacitors, including the renowned Orange Drop™. With the newer development of its Power Ring Film Capacitor™, SBE Inc. was awarded a $9.1 Million grant by the Department of Energy to build a world class facility for the manufacture of this line of capacitors used in drivetrain inverters for plug-in hybrid and electric drive vehicles. The company's headquarters, engineering, product development center and manufacturing operation are located in Barre, Vermont.

Trise Testing

There is no available method [as of January, 2011] to directly measure capacitor ESR at sub milliohm levels.

The best method to evaluate ESR is indirectly by the use of temperature rise testing. By itself, Trise testing can only allow comparisons between capacitors. However, Trise testing coupled with careful simulation can allow comparison of the simulated Trise for a given capacitor model with the Trise of the "real" capacitor for which the model was developed. At this point an ESR value can be specified with confidence.

The results shown in Fig. 1 are impressive in that the absolute value of the temperature rise is very close. A few degrees of rise variation is readily possible within the sheet resistance tolerance on the film metallization [+/-33%!]. So it is no surprise that all parts do not show the same degree of matching as shown above. What is equally important is that the simulated time constant is always very close to the measured value. This serves as a further validation of the model used for the simulation results.

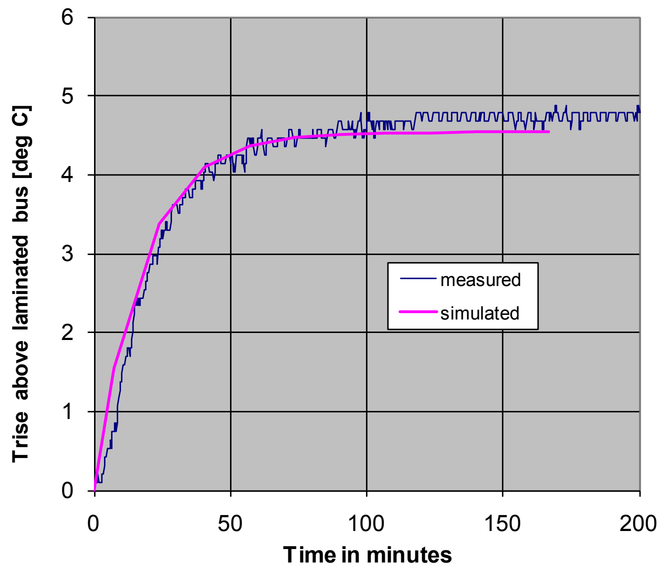

Figure 1: Temporal evolution of hotspot temperature for 700D348 with a 200 Arms ripple current at 20 kHz.

SBE has developed the capability to do continuous sine-wave testing at > 500ARMS @ ~19KHz with the test apparatus described by the functional schematic below (Fig. 2).

It was just as important to also develop a temperature controlled test environment that would closely duplicate the simulation temperature boundary conditions. This environment was created using regulated "water defined temperature sources" and thermal transfer plates to set the terminal and capacitor case bottom temperatures. Extensive apparatus temperature measurement ensures that the test operator has the desired test conditions.

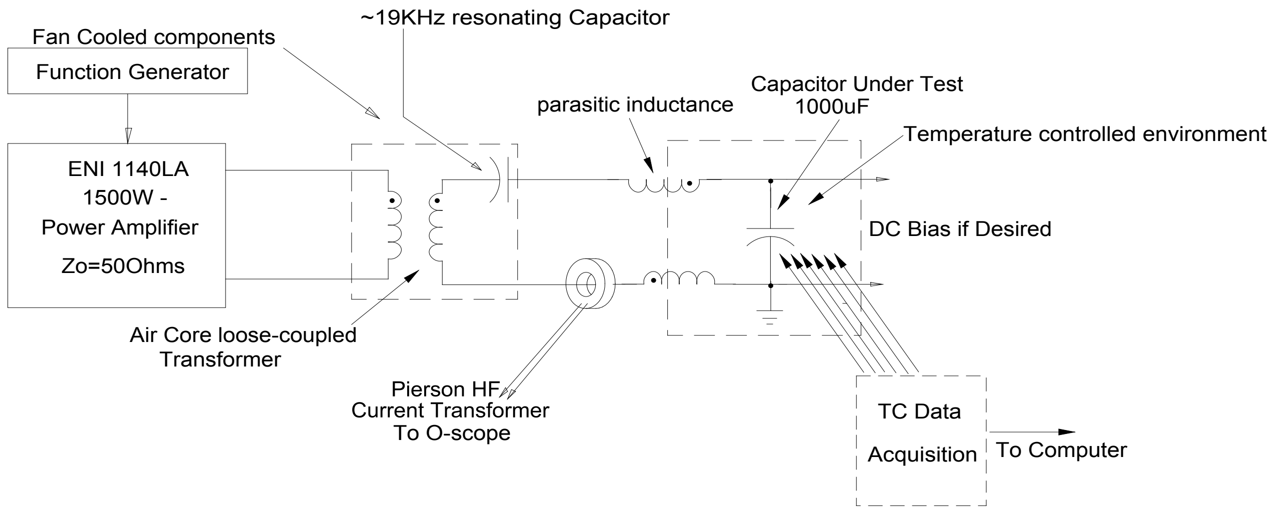

Figure 2: SBE >500ARMS 19KHz Temperature Rise Test Current Source.

The SBE Power Ring is a distributed element device; to make use of its capabilities it must be attached to a laminar bus assembly. The laminar bus assembly used for our Trise tests was designed for internal testing and as a concept piece for engineering discussion. It is not intended to represent an optimal design.

Figure 3: Photograph of instrumented 700D348 capacitor mounted on the bus plate assembly.

Referencing Fig. 3, the test apparatus holds the top bus plate and the case bottom at set temperatures, which could be different if desired to examine how the capacitor responds thermally to application situations where the case bottom and laminar bus assemblies are not at the same temperature. The capacitor and bus are clamped between two heat transfer plates [Fig. 4], with a TIM [zinc oxide filled silicone grease] used to improve heat flow from the two heat transfer plate assemblies to the capacitor under test. The illustrated heat transfer plate shows via the “footprint in the TIM” that this plate was attached to the 700D348 case bottom. Fig. 5 shows a capacitor/laminar bus assembly and capacitor clamped between heat transfer plates.

Figure 4: Heat transfer plate assembly showing thermocouples and thermal grease.

Referencing Fig. 2 and Fig. 5 it should be noted that the high current conductors have cooling and heating capability to maintain those conductors at the desired set point temperature for the laminar bus thermal connection to the capacitor. This prevents heat input or removal via these conductors from altering the test results. This is a major feature often missing in tests such as this.

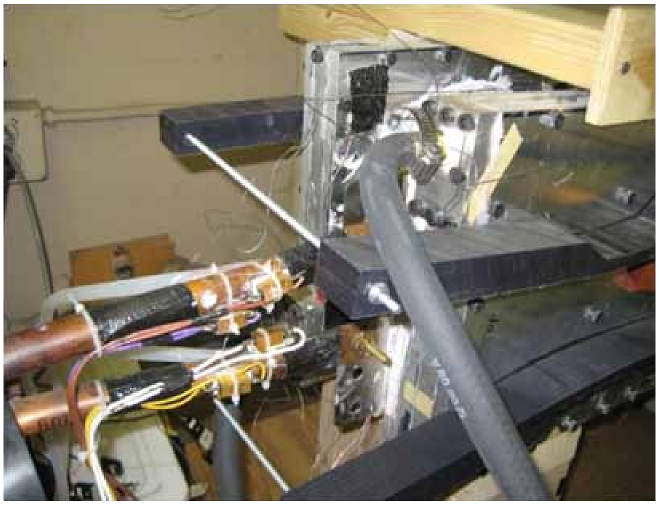

Figure 5: Capacitor assembly clamped between two heat transfer plates showing high current connections to the laminar bus assembly.

Although the above system with liquid heating appears complex, it was found to be far superior to using a classic temperature chamber to provide a thermal test environment. The chamber internal forced air sets the CHAMBER temperature. Chamber based Trise tests took a very long time to reach equilibrium, and capacitor behavior at a specific temperature was extremely difficult to obtain.

Test Procedure

With the capacitor and bus assembly fixtured as shown in Fig. 5 the heat transfer plates were adjusted to the desired temperature. Current was adjusted [monitored by a Pearson Electronics Inc. CT, Model # 6247A] for amplitude and frequency [refer to Fig. 1]. Data acquisition began, and multichannel temperature data was automatically entered into an Excel spreadsheet with appropriate time-stamps. The tests are run until the capacitor internal temperatures have remained relatively unchanged for 15 minutes. Following that the test current and heat transfer plates were powered down. Data was saved and graphed as appropriate for the desired information. Most of the TC data was used to verify that the test thermal environment was maintained during the time needed for the internal capacitor temperatures to reach equilibrium. Refer to Fig. 6 for a typical test run.

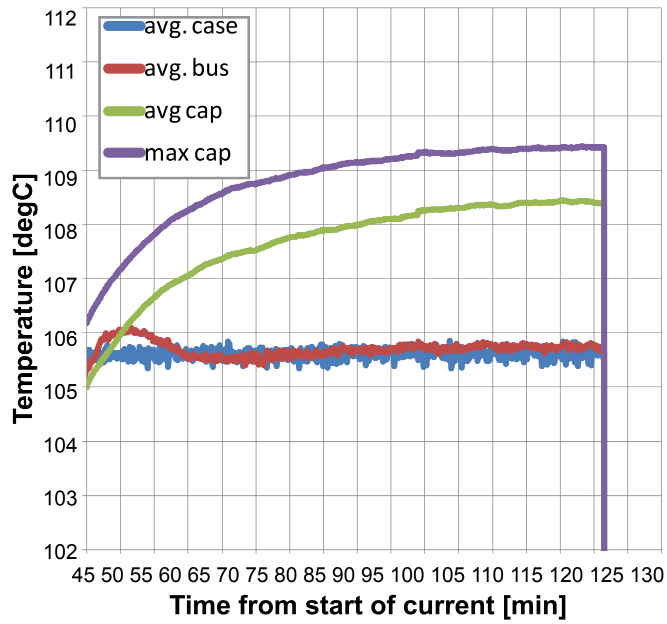

Figure 6: Capacitor and fixture temperature profile for typical Trise test run. Final test 118: 300A, 105°C case, 105°C bus.

Explanation of Fig. 6 Test Run:

Fixture test temperatures were changed at T=0 minutes. After the fixture comes close to thermal equilibrium at about 45 minutes, the useful data is plotted. Note the slight offset high from the desired 105°C test point. Note also the VERY LOW temperature rise measured at 300Arms!

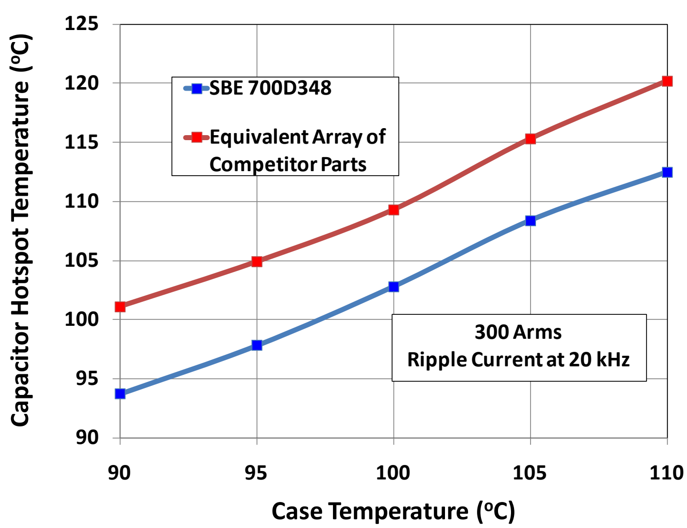

Figure 7: Comparison of temperature rise testing for the SBE 700D348 and an assembly of four 2 terminal conventional construction film capacitors.

The data contained in Fig. 7 was taken at SBE, using a laminar bus assembly as close as possible to the one used to test the 700D348. The testing was done using the same heat transfer plates and fixture orientation. The tested capacitors are representative of several manufacturers, and occupy about the same laminar bus area as does the 700D348.

In June 2009, SBE worked with the National Transportation Research Center [NTRC] at Oak Ridge National Labs [ORNL] to measure comparative Trise behavior for capacitor assemblies currently in use or proposed for use in EV applications[1]. These tests included the SBE Power Ring capacitors 700D348 [1000µF] and 700D349 [500µF]. The NTRC test took place in a classic temperature chamber. Based on data from this ORNL external testing, a summary of Trise from case to hottest measured spot within the capacitors is shown in Fig. 8.

Reference: 1. Hosking, Terry. *Comparative Evaluation and Analysis of the 2008 Toyota Lexus, Camry and 2004 Prius DC Link Capacitor Assembly vs. the SBE Power Ring DC Link Capacitor.* Paper presented at VPPC 2009.

Measured Temperature Rise @ 200ARMS, 5KHz

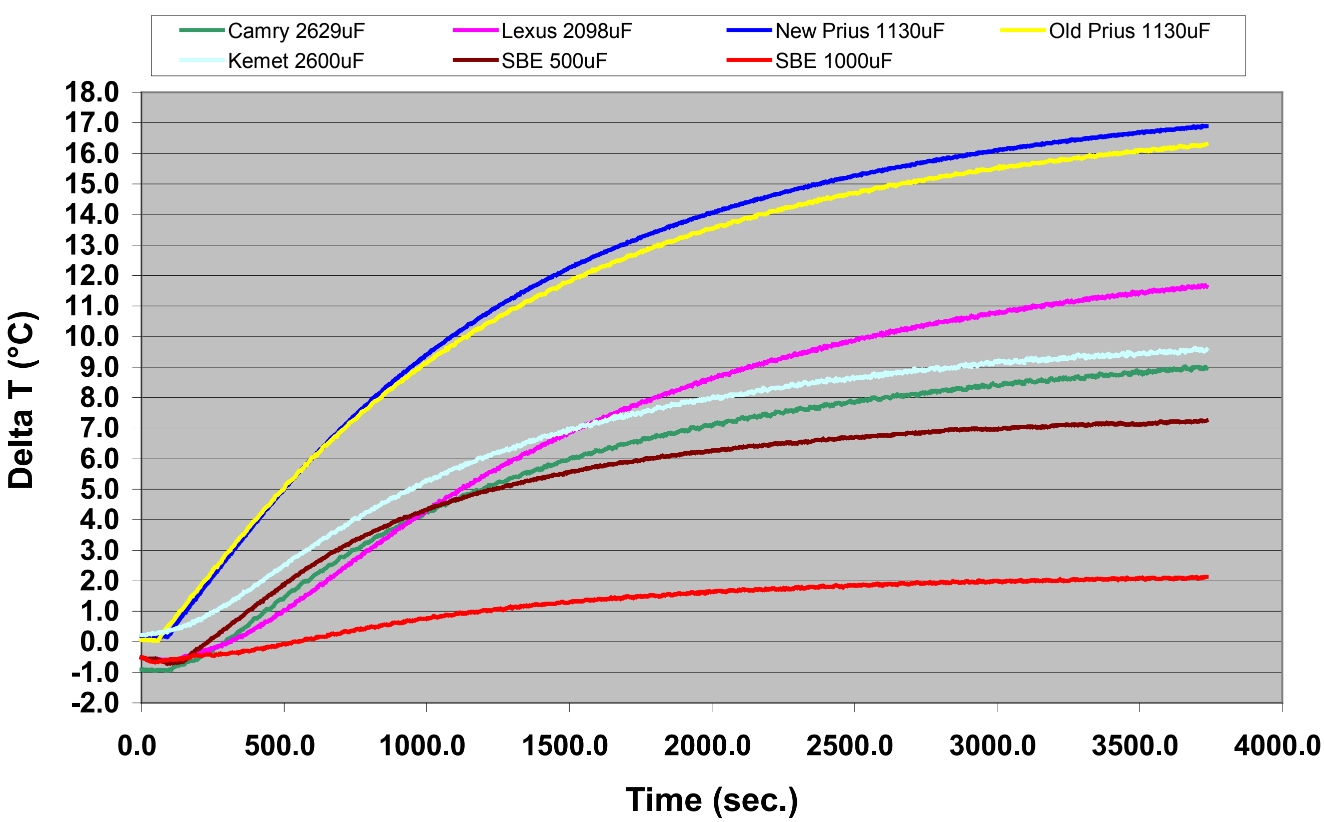

Figure 8: Comparative Trise for several automotive DC link capacitors at the NTRC Knoxville TN facility June,2009.

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