# How Components Influence Reliability of DC/DC Converter Designs

The pressure to run DC/DC converters at higher operating temperatures to support dense clusters of computing power is growing. It means that converter designers can no longer rely on the limited device specifications that component manufacturers offer at 25°C if they want to produce products that will work reliably over long lifetimes at high operating temperatures. **Ann-Marie Bayliss, Product Marketing Manager, Murata Power Solutions, Fleet, UK**

One of the biggest issues in building large data centers, high-performance mobile networks and other systems that rely on concentrating a lot of computing power in one place is managing the heat they dissipate. Small systems such as cellular base stations manage waste heat using complex heat-sinks and fans. Large data centers face the dual cost of buying energy as electricity to power their systems, and then buying more energy to dispose of the resultant waste heat of computation. The cooling strategies applied to data centers can be so complex to manage that Google recently applied machine-learning algorithms to one of its data center cooling systems and managed to improve its efficiency by 40 %.

The 'hot electronics' issue is only going to get more challenging. As the operating voltages of integrated circuits have dropped from the traditional 5 V to 1.8 V and below in the core of today's fastest chips, to accommodate smaller devices and faster switching, their current consumption has increased. This has led to greater heating in the ICs themselves, as well as greater resistive heating in supporting systems such as the DC/DC converters that power most of this computation.

Large systems are increasingly distributing power on 24 V or 48 V DC buses, relying on local DC/DC converters to deliver the required supply voltages wherever they are needed. As operating voltages fall, though, these converters must accommodate increasingly large step-down ratios – at the cost of reduced conversion efficiency and hence greater thermal load.

In smaller systems, variable-speed fans can be an extremely effective way to cool the on-board electronics. Unfortunately, fans create noise, have bearings that can wear out, and need filters that have to be changed. System designers would prefer their systems not to need this kind of maintenance burden and face this potential reliability issue.

In both cases, being able to run a system at a higher operating temperature can mean direct cost saving in terms of reduced cooling needs – that's why companies that run large server estates specify the use of industrial-grade processors that can run at higher temperatures without reducing their reliability. To run such processors hotter, you also need to run the supporting infrastructure, such as the DC/DC converters, hotter – which is both an opportunity and a challenge.

## Temperature affects component characteristics

How can equipment designers be confident about specifying a DC/DC converter for use at higher temperatures? One consideration is how the converter's components will be affected by higher operating temperatures. There's a rule of thumb says that for each 10°C decrease in operating temperature from a component's maximum rating, the failure rate during its useful life halves. This guidance stems from the Arrhenius equation, which quantifies chemical reaction times at varying temperatures in both the diffusion and migration processes that happen in electronic components. The equation provides a solid basis for predicting mean-time-to-failure due to temperature rises.

Designers have to expect lower performance from many types of components when they are operated above 75°C. The best designers understand the mechanisms that affect each type of component and so choose parts that will work well in the target operating environment. For example, there's a clear correlation between the lifetime of electrolytic capacitors and their operating temperature, electrical stress, and the rate of electrolyte diffusion. This can be expressed in this equation, which predicts a component's lifetime:

$L = L_r \times (T_{max} - T)/5 \times (V_{max}/V)2.5$, where

- L is the predicted lifetime in hours
- Lr is the manufacturer's rated endurance at maximum temperature Tmax, in hours
- T is the operating temperature expected of the capacitor
- $V_{max}$ is the capacitor's maximum operating voltage
- V is the circuit's operating voltage

If a designer operates a 25 V DC rated part at 70 % of its maximum voltage rating, a normal commercial-grade component that is rated for 2,000 hours at 85°C should have a lifetime of around 50,000 hours at 50°C. If the designer substitutes a part rated at 105°C, the operating lifetime could be extended to almost 80,000 hours.

The model demonstrates the effect of component choice on service lifetime. In practice, many designers avoid using aluminium electrolytic capacitors, whose wear-out mechanisms have been shown to be one of the main reasons why power

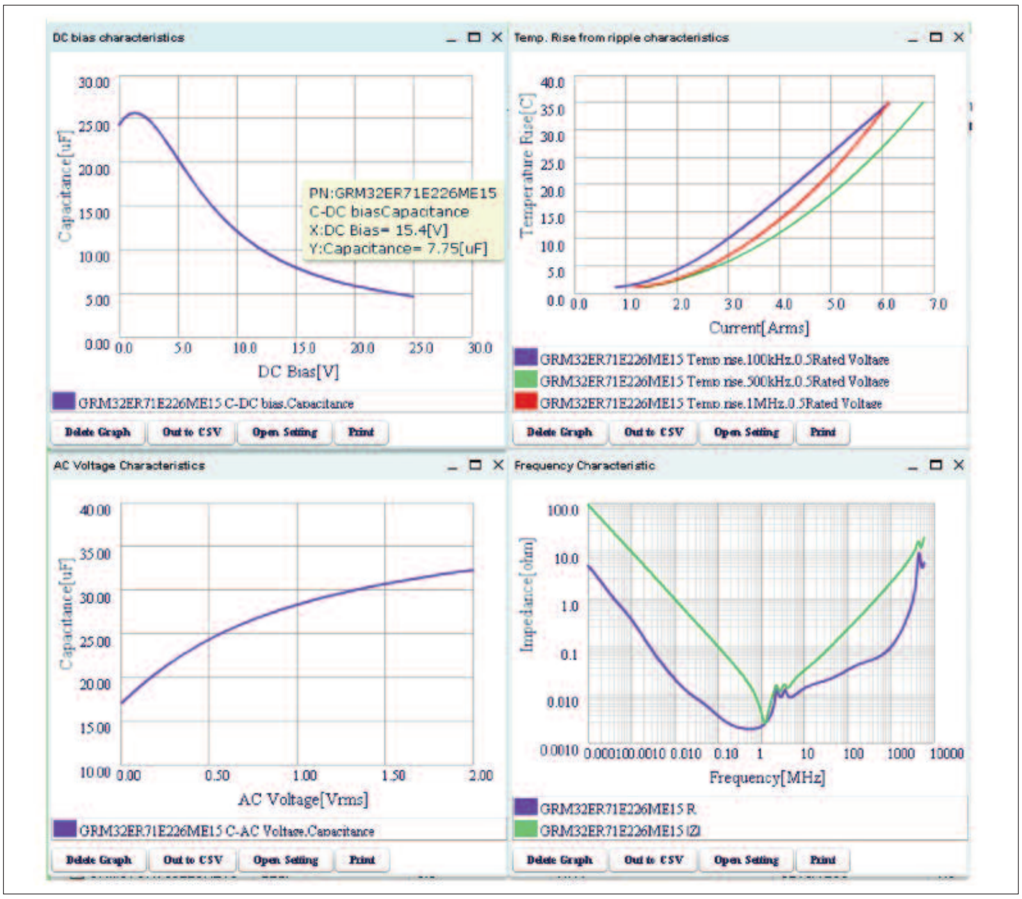


**Figure 1: The SimSurfing simulator shows the behavior of ceramic capacitors and inductors under varying conditions. This plot shows the characteristics of a 22 μF / 25 V capacitor**

supplies fail.

The main reason ceramic capacitors fail is because they are mishandled, but they can also be affected by excess temperature and voltage stresses. These effects depend upon the dielectric material and become more significant as capacitance values approach the technology's limits. The parts lose effective capacitance rather than fail. For instance, the X7R material often used as a dielectric has a basic capacitance tolerance of ±15 % from -55 to +125°C. In contrast, the capacitance of the Y5V dielectric material can fall by more than 80 % at +85°C. A ceramic capacitor's effective value will also decrease significantly under DC bias, due to an intrinsic characteristic of the $BaTiO_3$ ceramic material of which it is made.

Similar considerations apply to power inductors, whose performance depends upon their core material. Different materials exhibit different amounts of loss at different temperatures, depending on circuit conditions. However, power inductors rarely fail unless they have been grossly overloaded.

## Exploring component behavior online

Murata offers a browser-based simulation tool called SimSurfing, which engineers can use to explore the effects of AC and DC bias levels, frequency and temperature on a wide range of capacitors and inductors. It can produce unexpected results. For example, the DC bias pane of Figure 1 shows that a 22 μF, 25 V DC X7R part has an effective capacitance of just 7.75 μF when subjected to 15 V DC bias. The Temp Rise pane in the figure shows that capacitors that handle ripple currents can also be subject to internal temperature rises.

Engineers are used to taking into account the temperature-dependent characteristics of semiconductors in their designs, calculating junction temperatures using thermal-resistance models to ensue they stay below 150–175°C. However, the characteristics of Schottky diodes can create an issue in DC/DC converter design, because they become increasingly 'leaky' as their temperature rises. This can produce high dissipation when they are reverse biased, eventually causing component failure. Similarly, the feedback circuits in DC/DC converters often use opto-isolators, the current-transfer ratios of which can vary as they age and are exposed to high temperatures. The changing characteristics of these opto-isolators can cause instability and, eventually, premature converter failure.

If designers choose MOSFETs rather than diodes in synchronous-rectifier configurations, this can combat the issues with Schottky rectifiers – and improve efficiency. For designs where it is hard to avoid using a Schottky rectifier, such as for the freewheeling diode across the synchronous switch of a buck converter, it is possible to find Schottky diodes and opto-isolators that will withstand junction temperatures of 150°C. Using these means choosing the other components and the circuit design with care, to avoid hot-spots and so enable circuits to operate reliably at high temperatures. As is usual in any design, other systemic issues need to be considered, such as maximum operating temperatures of 130°C for typical circuit boards.

## Choosing appropriate components

Designers can no longer rely on the limited device specifications that component manufacturers offer at 25°C if they want to produce products that will work reliably over long lifetimes at high operating temperatures. To produce such converters, designers need to develop a deeper understanding of each component's characteristics, and then center their designs on an efficiency sweet spot within the intended operating temperature range. Designers must also find out where the temperature of components should be measured, and ensure that they make such measurements within a representative operating environment, with an air temperature and flow that reflects the target application. It's only by taking these steps that DC/DC converter designers can hope to produce robust designs that will serve the increasingly challenging needs of systems that use dense clusters of computing, reliably and for the long term.