Choosing the right capacitors to ensure long-term control-circuit stability

Know how tantalum and niobium-oxide technologies meet industry needs for rugged capacitors that maintain high-performance standards even under stress.

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To suit the demanding performance and harsh environmental conditions of automotive applications, component manufacturers have developed professional-grade tantalum capacitors that ensure long-term electrical performance stability. The professional tantalum technology satisfies the automotive industry's need for rugged capacitors that maintain high-performance standards under electrical and mechanical stress. Technical improvements have been made that strengthen the structure of the capacitor and give it more robust performance in a variety of applications.

The primary benefits of using professional-grade tantalum over standard reliability consumer electronic tantalum include:

- The formation ratio of professional tantalum capacitors, (which is the ratio between voltage used for electrolytical creation of dielectrics and rated voltage), is more than 3.0. This results in thicker and higher quality dielectrics.
- Conservative design rules are followed both in design and manufacturing. Strict quality control limits are applied and additional testing is performed. Devices are screened for hard surge current, undergo extended electrical testing, and accelerated burn-in processes are used to achieve and verify robustness.

The use of professional tantalum capacitors results in enhanced reliability (failure rate = 0.5%/1,000 hours) and reduced leakage current of up to 75% less than standard tantalum capacitors. Professional tantalum capacitors are available both in standard and low equivalent series resistance (ESR) options, which make them suitable for a wide range of automotive control circuits in applications such as engine control units, anti-lock brake systems, motor-driven power steering systems, electronic gearboxes, and tire-pressure monitoring sensors.

Ultra low ESR high-performance tantalum capacitors

High-performance, low ESR capacitors combine the robust, reliable, and proven tantalum technology with an innovative multianode construction. These high performance tantalum capacitors utilize several cores in parallel, which pushes ESR levels down to 18.23 mΩ or 25 mΩ, depending on device selected. Such ESR levels enable professional tantalum capacitors to be used in DC/DC converters in various automotive applications, including airbag modules, controller area networks (CAN bus), power supply modules, and engine control modules.

High temperature tantalum capacitors

Standard tantalum capacitor technologies typically have a temperature range of –55C to +125C. Modern automotive electronics placed near heat sources such as engines, headlights, gearboxes, or AC circuits, must operate at temperatures up to 150C or even 175C. With an operating temperature range of –55 to +175C, these tantalum capacitors meet the temperature requirement, while offering enhanced reliability (0.5%/1,000 hours) and higher category voltage at 125C (78% of rated voltage, V_r) than consumer-grade devices (typically 66% of V_r). The category voltage, which is the maximum working voltage when actual operating temperature is considered, is 50% of rated voltage at 175C.

Niobium oxide capacitors

Capacitors that use niobium oxide powder as the main material for the anode electrode have an ignition energy of up to 200 times more than factory standard capacitors. This higher ignition energy is coupled with a much lower burning rate than pure metal materials such as tantalum or niobium. Niobium oxide capacitors will not burn at temperatures up to their category voltage. A typical failure mode is high resistance (typically 20 to 200 kΩ) after overloading by voltage spike or high current surge, which can result in increased leakage current and reduced capacitance. However, a niobium oxide capacitor will continue to provide full capacitance and functionality, and handle increased power consumption.

Standard niobium oxide capacitors have an excellent failure rate of only 0.5%/1,000 hours, however, lower ESR niobium oxide capacitors offer even more reliability with a failure rate of 0.2%/1,000 hours. The low ESR niobium oxide capacitors are suitable for applications with rail voltages of up to 8V, such as in-cabin entertainment systems, seat position modules, and airbag controls.

Application guidelines

For correct tantalum and niobium oxide capacitor design we have to consider all important electrical and physical conditions of the circuit as well as the device where it will be used. The first parameter usually established is the capacitance value, which may be calculated from power line smoothing ratio or maximal voltage drop.

The next selection factor of a capacitor is the DC application voltage. The general rule of recommended voltage application derating is 50% for all tantalum capacitors and 20% for niobium oxide devices. Thus the recommended guidelines for tantalum capacitors is up to half their rated voltage (V_r) and for oxicaps up to 80% of V_r. It is important to follow these guidelines as a protection measure against unexpected current surges and overvoltage conditions, which occur frequently in automotive circuits. The derating margin for tantalum capacitors can be reduced for primary output circuits, circuits with protection against overvoltage, and circuits with slow power-up modes (soft-start circuits). In output sections of low power DC/DC converters, derating at 20% is acceptable.

The application temperature range tells us what capacitor series to choose, dictated by the maximum operating temperature. Note that additional voltage temperature derating must be applied at temperatures above 85C. The maximum DC voltage allowed for a capacitor (dependent on actual temperature) is known as the category voltage (rated voltage is just one catalog value for room temperature 25C) (**figure 1**).

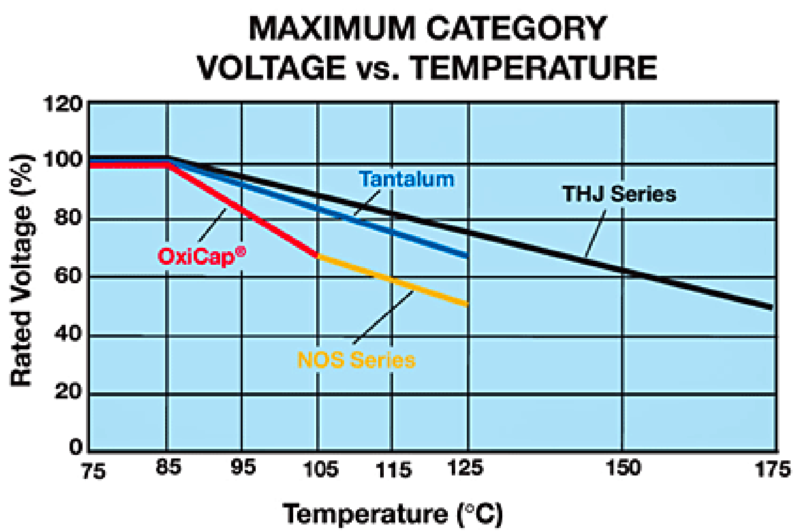

Figure 1: Maximum category voltage vs. temperature.

If normal operating temperature exceeds 85C permanently, both application and temperature derating should be combined. For example, consider a tantalum capacitor working at 125C in a circuit, which is expected to see surges and voltage spikes. Application derating is 50%, (max voltage is 50% of V_r); temperature derating at 125C (worst case) is 33% (max voltage can be 66% of V_r). Combining gives 0.5 x 0.66 = 0.33; meaning, for permanent usage at 125C, the capacitor can be used at a maximum of 33% of rated voltage, V_r.

Surge and ripple currents

It is important to know the maximum application surge current (single peak) allowed through the capacitor in order to avoid overloading the capacitor on power-up or startup. Overload current can be calculated using the internal voltage of the power source and the internal resistances of all devices in series with the capacitor, including its ESR. The maximum surge current should be lower than the capacitor's maximum allowed surge current $I_{pmax} = (1.1xV_r)/ (0.45+ESR)$. If the application current is too high, additional derating can be applied and a higher V_r capacitor must be chosen.

The capacitor's maximum ripple current is dependent on the maximum AC current flowing through the capacitor. Ripple has two main parameters, effective value (rms, ACI_{rms}, I_r) and frequency (f). Ripple current is limited by maximum power dissipation (P_d), which is generated by the ESR of the capacitor. The bigger the case size, the higher the allowed power dissipation; each case size has a constant value. A lower ESR results in less power to dissipate, allowing a higher ripple current, according to:

$P_d = ESR \times (I_r)^2$

Thus, for an application that calls for a high ripple current and low ESR, where the case size is not an issue, a multianode device is the best choice
The operating frequency mainly affects two parameters: capacitance and ESR (**figure 2**).

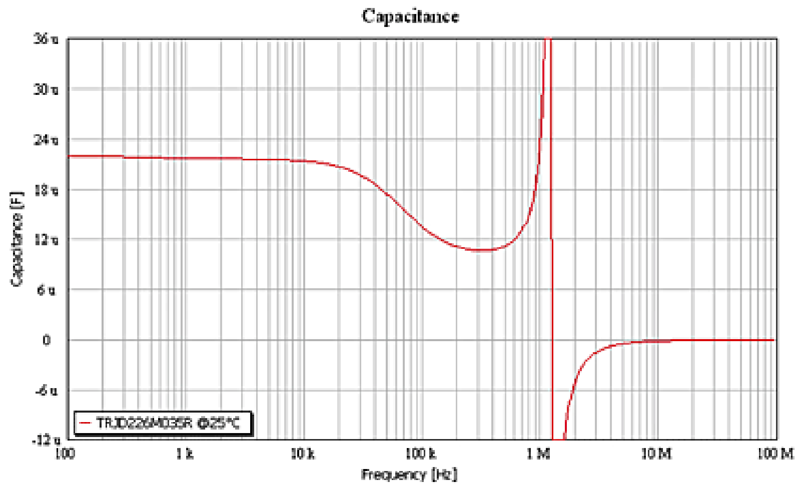

Figure 2a: Decreased capacitance at higher frequencies.

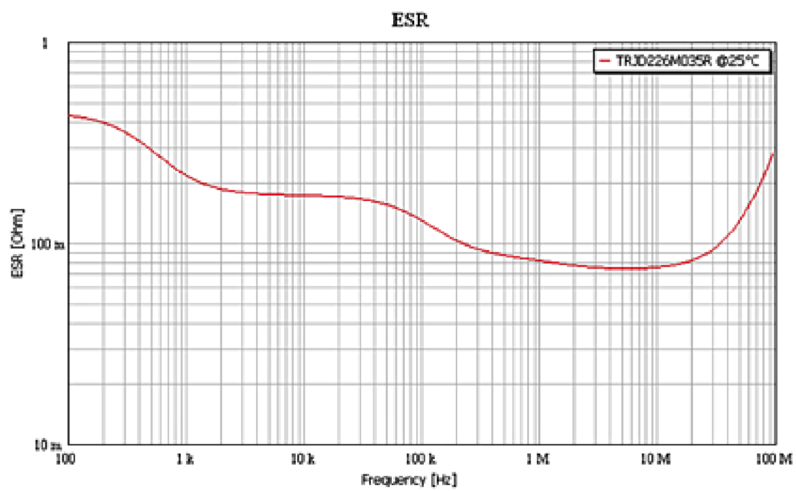

Figure 2b: Increased ESR at lower frequencies.

Figure 2a displays decreased capacitance at higher frequencies, while the **figure2b** shows increased ESR at lower frequencies. Both dependencies should be considered to assure sufficient capacitance and an ESR rate low enough for the required ripple current.

Conclusions
The combination of application guidelines listed above will result in the correct capacitor selection. Alternatively, if the case size has to be prioritized for miniature or low profile applications, the selection process must be adjusted accordingly.
Sometimes, one capacitor alone is not sufficient, so two or more devices may be necessary. In these instances, only the same capacitor types are recommended to be used in combination. Parallel connection increases capacitance (multiplies) and decreases ESR (divides); serial connection increases total allowed DC voltage (rated voltage multiplied), but decreases capacitance (divided) and increases ESR (multiplied). For serial connection, capacitors should be connected in parallel with a resistor divider, where resistance of the divider resistors is calculated using a figure of 10 times the DC leakage current of the capacitor's catalog value. ■

About the author
Radovan Faltus is a field application engineer at AVX.