

How to Select the Right Aluminum Electrolytic Capacitor

Aluminum electrolytic capacitors assume a special position among the various types of capacitors, thanks to a high capacitance per volume and their potential use in almost any electronic system. They can be used in many applications, including energy storage and filtering undesired AC frequencies. Thanks to their high capacitance values and low impedance values, they are often used in power supplies, inverters, and DC-DC converters.

Aluminum electrolytic capacitor technology has been evolving as a result of new materials and process improvements that increase their reliability and robustness, which allows operation of up to 20 years. They are a crucial part of most electrical designs – when properly selected. But what, exactly, is an aluminum electrolytic capacitor, and how do you know how to properly select one for your projects?

What Is an Aluminum Electrolytic Capacitor?

Capacitors are composed of two electrically conductive material layers (electrodes) separated by a dielectric material (or insulator). Capacitors store energy in an electric field generated by this arrangement, once a current is supplied to charge the capacitor. In an aluminum electrolytic capacitor, the electrodes are made out of aluminum foil. Between the two aluminum electrodes is a conductive liquid, called an electrolyte. Through an electrochemical reaction, an oxide layer (Al_2O_3) is built upon one of the electrodes (the anode), which serves as the dielectric in an aluminum electrolytic capacitor.

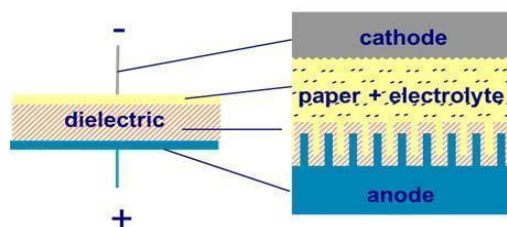


Figure 1: Construction of an aluminum electrolytic capacitor (Source: TDK)

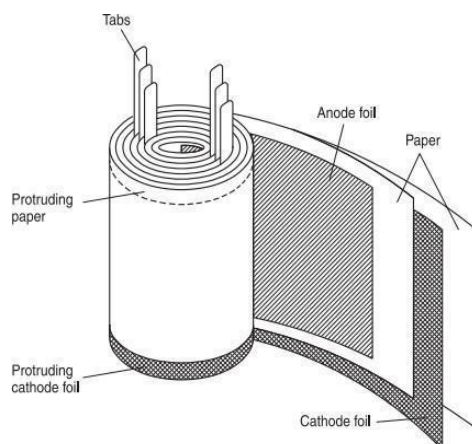


Figure 2: Construction of an aluminum electrolytic capacitor
(Source: <https://rb.gy/hwikrn>)

Electrical Characteristics

The construction and materials of aluminum electrolytic capacitors give them some unique electrical characteristics, making them ideal for many applications.

Characteristic	Description
Large Capacitance	Aluminum electrolytic capacitors offer a large amount of capacitance per unit of volume for a given voltage rating.
High Voltage Rating	Aluminum electrolytic capacitors can be used in a wide variety of applications.
Energy Storage	Aluminum electrolytic capacitors have a large capacitance and high voltage rating, meaning high-energy storage capabilities.

Advantages of Aluminum Electrolytic Capacitors

The biggest advantage of aluminum electrolytic capacitors is that the electrolytics have high volumetric efficiency, i.e., a higher capacitance per volume than any commonly available capacitor. Aluminum electrolytics are often the only possible solution for certain applications. When selected and designed into the circuit properly, this advantage can be maximized.

Another advantage of aluminum electrolytic capacitors is the availability of high voltage ratings. Aluminum electrolytic capacitors with a DC voltage rating of 600 V are readily available, meaning they can be used in a wide variety of applications.

Considering both the high capacitance and high voltage of aluminum electrolytics together produces another big advantage: energy storage. The energy stored in a capacitor is given by the following equation:

$$U = \frac{1}{2} CV^2$$

Equation 1: Energy stored in a capacitor (U = Joules, C = Capacitance, V = Voltage)

The energy stored in a capacitor increases linearly with capacitance and exponentially with voltage.

Selecting a Capacitor for Power Applications

Understanding the fundamentals of aluminum electrolytics is the first step towards selecting the right one for a power electronics design. Here are the key design considerations:

Voltage Rating / Derating

Capacitor voltage ratings provide a safe operating range for a capacitor. Operating within these ratings prevents them from being damaged and extends their functional life. Aluminum electrolytic capacitors most commonly provide bulk capacitance to power supply voltage rails.

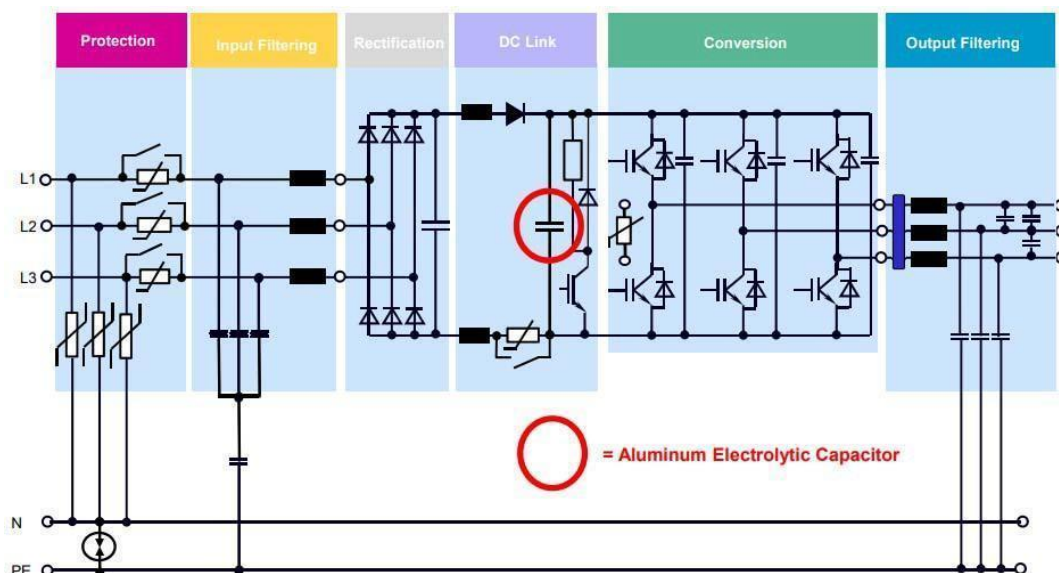


Figure 3: Example frequency converter circuit (Source: TDK)

Because aluminum electrolytic capacitors are polarized, they are only used in DC voltage applications — after DC rectification in the example circuit. A capacitor should be selected taking into consideration the load condition of the application, i.e. operating voltage, surge, and transient voltages, ripple current, ambient temperature, cooling conditions, and expected useful life. It is not recommended to select a voltage rating much higher than required, as higher voltage ratings tend to coincide with higher ESR. In high ripple current applications like this one, higher ESR will cause significant problems.

Equivalent Series Resistance

Engineers learn about ideal capacitors early on in their education, but real-world capacitors are not ideal. Real capacitors can be modeled as an ideal capacitor with a few parasitic elements around it.



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Figure 4: Equivalent circuit of a real capacitor (Source: TDK)

In this image, C_s is the ideal capacitive component of the equivalent series circuit. The capacitance measured will depend on both the temperature and the frequency of the signal used to make the measurement. ESR is the resistive component of the equivalent series circuit. ESR depends on both frequency and temperature, and is related to the dissipation factor by the following equation: $ESR = \tan \delta / \omega * C_s$, where $\tan \delta$ is the dissipation factor and ω is the frequency applied. Finally, ESL is the inductive component of the equivalent circuit, and it results from the internal design of the capacitor and its terminal or lead configuration.

For the power supply application, equivalent series resistance (ESR) is of the most concern. The AC portion of the current seen by the capacitor, or the ripple current, causes power to be dissipated by the ESR in the capacitor. This effect varies with the frequency of the ripple current. The higher the ESR, the more power dissipated inside the capacitor, meaning increased heat generation and a shortened capacitor lifespan.

It is not necessary to select the lowest-possible ESR available when specifying a capacitor for a power supply design, but it is recommended to select an ESR rating that works with the ripple current in the design.

Ripple Current

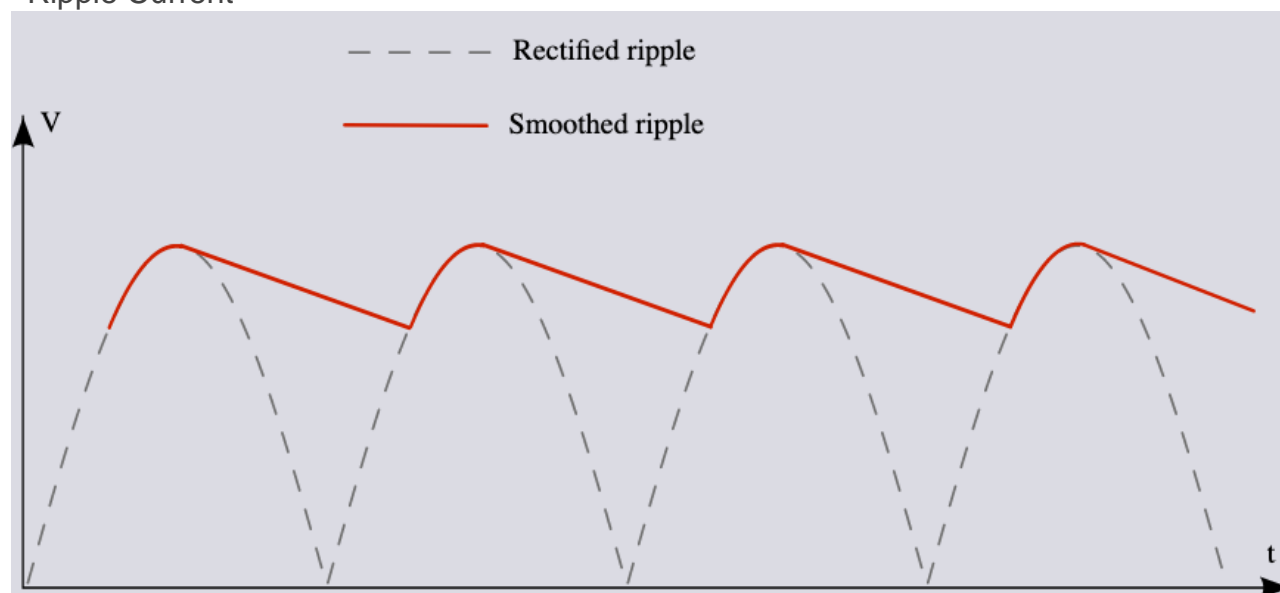


Figure 5: A rectified voltage smoothed by capacitance
(source: [https://en.wikipedia.org/wiki/Ripple_\(electrical\)](https://en.wikipedia.org/wiki/Ripple_(electrical)))

The term ripple current is used for the root mean square (RMS) value of the alternating current that flows through a device as a result of any pulsating or ripple voltage. Power losses resulting from this ripple current induce self-heating of the capacitor. The maximum permissible value of the ripple current depends on the ambient temperature, the ESR at the frequency of the AC signal, the thermal resistance, which is mainly determined by the surface area of the capacitor (i.e. heat dissipation area), and the applied cooling. Moreover, it is restricted by the ripple current capability of the contact elements.

The rated ripple current ($I_{AC,R}$) is usually specified at the upper category temperature and the reference frequency.

As thermal stress has a decisive effect on the capacitor's life expectancy, the heat generated by the ripple current is an important factor affecting the useful life. These thermal considerations imply that it may be necessary under certain circumstances to select a capacitor with a higher voltage or capacitance rating than would normally be required by the respective application.

Surge, Transients, and Reverse Voltages

Capacitors are sensitive to transients, overvoltages, and reverse voltages. Typical aluminum electrolytic capacitors can withstand surge voltages 10 percent over their rating for short periods of time. Some capacitor types can withstand voltage pulses exceeding the surge voltage. As the requirements differ largely depending on the individual application, it is recommended to select the capacitor design to meet application specifications. It is always recommended that engineers understand the transients and overvoltages possible for capacitors in their designs.

Aluminum electrolytics are polarized capacitors that can suffer catastrophic damage from reverse voltages. Where necessary, voltages of opposite polarity should be prevented by connecting a diode. Reverse voltage of $\leq 1.5V$ are tolerable for a duration of less than one second, making diode protection viable. Aluminum electrolytics cannot withstand reverse voltages, even at levels $\leq 1.5V$, continuously or repetitive operation.

Cooling

The useful life values stated in our datasheets apply to aluminum electrolytic capacitors with natural cooling (i.e., the heat generated in the winding is dissipated through the case). It is possible to increase the permissible ripple current and/or prolong the useful life by means of additional cooling measures (e.g. heat sink or forced ventilation).

As a large amount of heat is dissipated through the base of the case, a heat sink connected to the capacitor base provides the most efficient cooling. TDK offers specially designed versions of high voltage capacitors with screw or snap-in terminals that can be mounted on a heat sink in order to ensure optimal heat transfer from the heat generation area via the base of the case of a heat sink.

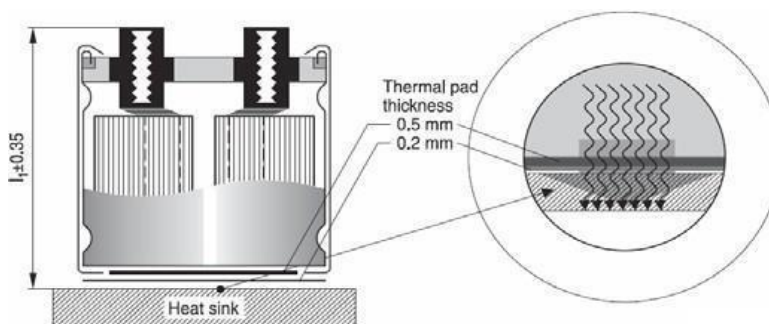


Figure 6: Aluminum electrolytic capacitor with heatsink (Source: TDK)

Required Useful Life

The final key design consideration is the required useful life of the capacitor in the design. It is necessary to understand all of the factors already discussed, plus the life requirement, for an engineer to know that their design will last.

There are a lot of factors and nuances involved, but engineers do not need to become in-depth expert specialists on aluminum electrolytic capacitors to be able to use them properly. One of the premier capacitor manufacturers, TDK, provides the web-based application [AlCap Useful Life Calculation Tool](https://www.tdk-electronics.tdk.com/alcap) on their website. This tool helps engineers by calculating the useful life of their capacitors under the engineer's design conditions.

Figure 7: TDK's AlCap Useful Life Calculation Tool

Link: <https://www.tdk-electronics.tdk.com/en/180482/design-support/design-tools/alcap-useful-life-calculation-tool>

Putting it all Together: A Step-by-Step Selection Guide Using AlCap Useful Life Calculation Tool

Step 1: Determine the capacitance required by the design.

Step 2: Define the expected ambient operating temperature.

Step 3: Define the DC operating voltage to be applied to the capacitor.

Step 4: Bound the space available for the capacitor (if available space is a concern).

Step 5: Calculate the expected ripple current on the capacitor, per the design.

Step 6: Select some candidate capacitors. Select the minimum required for capacitance, temperature, and voltage ratings (steps 1, 2, & 3).

Step 7: Calculate the ripple current for the top candidates. Calculate using expected ripple current and the ESR of the candidate capacitors.

Step 8: Define required useful life of the capacitor per the design application.

Step 9: Calculate the useful life of the top candidates. Use TDK's convenient online calculator that allows to input 15 load conditions that will provide accurate useful life information.

Step 10: Decide whether a heatsink, forced air, or natural cooling is required for the capacitor, using the AlCap Useful Life Calculation tool to simulate the output.

Step 11: Select the best candidate for the design.

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Expertise: Aluminum Capacitors

Norton Brissac is a senior marketing manager at TDK Electronics Inc. He has three decades of experience in aluminum capacitors product engineering and management, including working on a team that developed single-phase electric motors for HVAC / appliances. He holds a BSEE from PUCRS of Southern Brazil.