HOW2POWER TODAY
Your Power Design Newsletter

Exclusive Technology Feature

ISSUE: February 2022

Polymer And Hybrid Styles Improve Performance And Reliability Of Aluminum Electrolytic Capacitors

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The need for bulk capacitors is growing due to a combination of increased production levels of traditional electronics, circuit trends requiring high capacitance values on supply rails, distributed energy/energy harvesting trends and new electronic circuitry replacing non-electronic applications. The most visible examples of these are low-voltage ICs and electronics integrated into items as simple as everyday hand tools (cordless tools, electronic levels, etc.) to Wi-Fi-linked rain gauges, general-purpose IoT modules and more. Electronic proliferation is across all industry sectors and applications.

Electrolytic capacitors are popular in designs since they provide large capacitance values in relatively small packages at acceptable costs. Aluminum electrolytics are popular choices in many applications because they offer high capacitance values with high RMS values at low cost. They also come in a wide range of voltage ratings and package styles. But the conventional aluminum electrolytics employing a liquid electrolyte—wet aluminum electrolytics—have drawbacks such as electrolyte leakage and dryout, which hurt component reliability and limit component lifetime. Wet aluminum electrolytics also exhibit higher ESR and greater variation in ESR over temperature versus other capacitor styles.

However, the development of conductive polymer and hybrid aluminum electrolytics, which replace the liquid electrolyte with a solid polymer or a polymer-liquid combination, has increased reliability and alleviated performance limitations versus wet electrolytics, improving the usefulness of aluminum electrolytics in many applications. This article discusses the benefits offered by recent developments in conductive polymer and hybrid aluminum electrolytic capacitors, and illustrates their use in an example power supply application. But before delving into developments in aluminum electrolytics, we'll review how these capacitors compare with two other popular electrolytic types.

Aluminum Electrolytics Versus Tantalum And Niobium-Oxide Electrolytics

Electrolytics are named after their anode material and that naturally has driven us to think of bulk capacitors as only aluminum electrolytics. However, there are two other common electrolytics—tantalum and niobium oxide. Though the focus of this article is on aluminum electrolytics, we should take a second to put all three common electrolytic types into perspective relative to one another.

From a high level view, Table 1 below characterizes the low relative permittivity of aluminum electrolytics on a comparative basis with tantalum (~26) and niobium oxide (~ 40). At first glance, that comparison might bias readers to think aluminum electrolytics are at a capacitance density (µF/cc) disadvantage relative to tantalum or niobium electrolytics. That's anything but true.

Table 1. Comparison of dielectric properties for Al, Ta, and NbO electrolytic capacitors.

Electrolyte	Anode electrode material	Dielectric	Relative permittivity	Overall properties
Wet and solid	Aluminum (Al)	Al_2O_3	~9.3	General purpose, large value, large RMS
Wet and solid	Tantalum (Ta)	Ta_2O_5	~26	High performance, small size, high reliability
Solid	Niobium oxide (NbO)	Nb_2O_5	~40	Small size, intermediate to low-to-mid power

What aluminum electrolytics lack in terms of permittivity, they more than make up for in the ability to increase surface area by deep etching of the aluminum and thereby increasing the surface area of the electrodes i.e., increased capacitance. Tantalum and niobium oxide electrolytics excel in other areas including lower loss, better electrical stability, a wide range of SMT case sizes including ultra-miniature/low profile options, enhanced frequency response and broad military, medical and flight agency high-reliability specifications.

Aluminum Electrolytics

Aluminum electrolytic capacitors (Al-Els) are widely used because they are cost effective and can reach very high capacitance values relative to their size. Our article concentrates on SMT vertical capacitors but we should note that aluminum electrolytics are available in a large number of package styles and voltage ratings and are used in a wide variety of applications from base stations, industrial power supplies, high-grade white goods, green energy, and automotive, all the way down to the common electronics power charger.

Technology has evolved to allow enhancements in the materials, design and manufacture of traditional aluminum electrolytic capacitors. These advances were implemented in an effort to improve the reliability and electrical characteristics of aluminum electrolytics.

A simplified construction example of vertical chip aluminum electrolytics is shown in Fig. 1 and serves as the basis of wound Al-Els packaged in aluminum cans. Assembly starts with a highly etched aluminum anode that has a dielectric oxide formed on it. A porous paper is used to separate the anode and cathode electrodes. That combination is wound and the structure is then placed in a can. Next, a liquid electrolyte is used to make contact with the electrode foils. Finally, a rubber gasket is used to seal the liquid electrolyte in the can and an SMT base is placed on the bottom of the can for SMT assembly for PCB mounting.

Capacitors built in this fashion—using a liquid electrolyte—are called wet aluminum electrolytics. The chemical make-up of the electrolyte contributes greatly to the capacitors' performance over temperature, pressure, electrical stress and time. The liquid electrolyte connects the anode and cathode electrically, but also the effective surface area now includes all of the etched surface; drastically increasing the capacitance value.

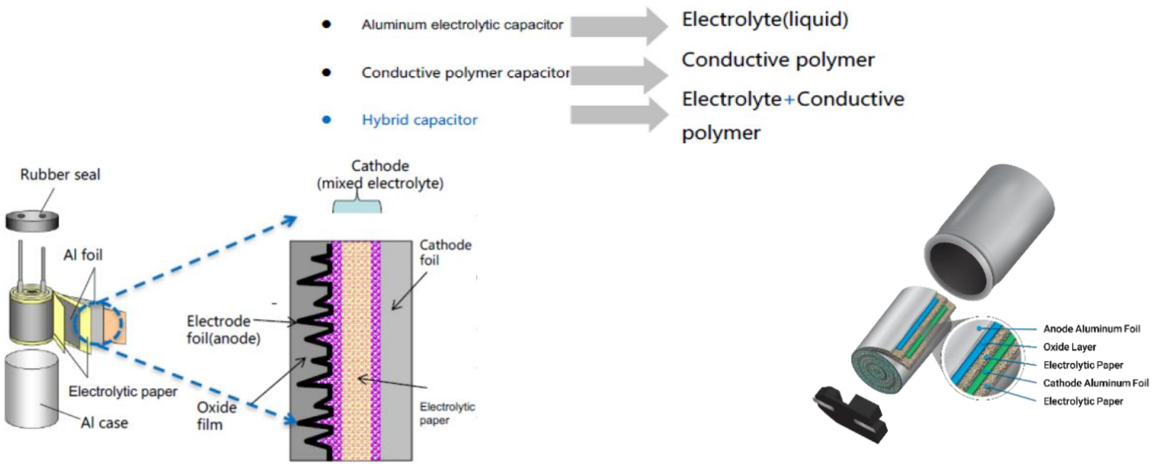


Fig. 1. Simplified construction of a wound aluminum electrolytic capacitor.

Conductive Polymer Electrolytics

The replacement of the wet electrolyte with a conductive polymer resulted in a capacitor where liquid electrolyte leakage between the seal case and leads was totally eliminated. Also, any long term dry-out/aging concerns were fully erased.

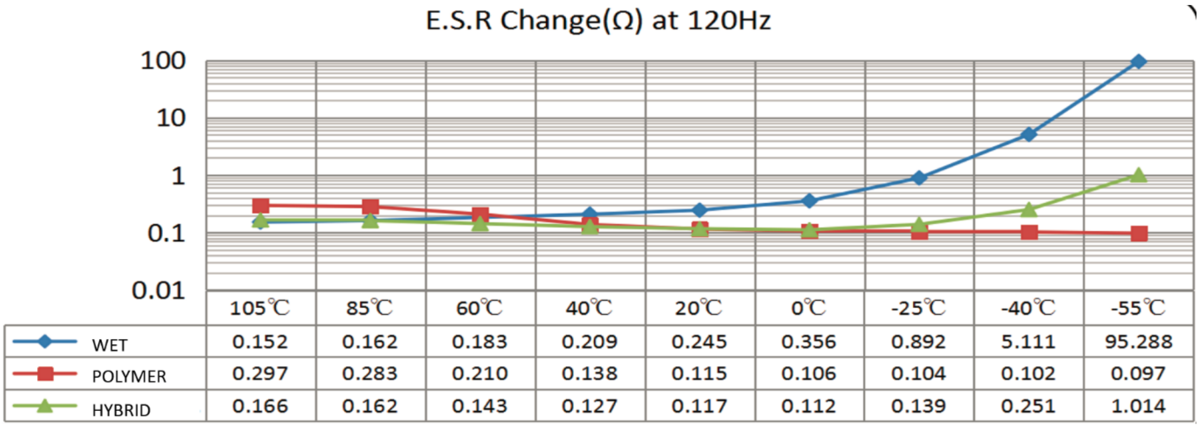
Aluminum conductive polymer capacitors come in either layered or wound styles. The layered devices have an aluminum anode-and-cathode stack with layers of conductive polymers. The stacking process tends to reduce the inductance of the capacitor versus that of wound aluminum polymers—thus extending frequency response.

However that stacking design also reduces the amount of capacitance in the package. So stacked Al-Els have both lower inductance and lower capacitance versus wound aluminum polymers. This drawback with respect to capacitance will go away in time but as of today, this in an inherent tradeoff when choosing between the layered and wound styles.

Another distinction is that layered-aluminum polymers exhibit greatly reduced heights relative to wound aluminum polymers. Lowered height results in better shock and vibration performance as well as ease of implementation in height-constrained designs. The stackup of layered aluminum polymers may sometimes have an intermediate case or coating, which is then encapsulated in resin compound with J leads (see the reference).

Wound conductive epoxy aluminum polymers are based on a conductive polymer electrolyte but utilize a wound electrode structure as in the case of wet aluminum electrolytics versus stacked. As might be expected from the above comments on capacitance in stacked Al-Els, wound aluminum polymers offer a larger capacitance range than layered aluminum polymers.

In addition, wound aluminum polymers provide lower ESR than stacked aluminum polymer technology and proportionally higher current carrying capability. Not only is ESR lower in conductive polymers but it exhibits about three times more stability with temperature than that of wet electrolytics (Fig. 2).



	105℃	85℃	60℃	40℃	20℃	0℃	-25℃	-40℃	-55℃
◆ WET	0.152	0.162	0.183	0.209	0.245	0.356	0.892	5.111	95.288
■ POLYMER	0.297	0.283	0.210	0.138	0.115	0.106	0.104	0.102	0.097
▲ HYBRID	0.166	0.162	0.143	0.127	0.117	0.112	0.139	0.251	1.014

Fig. 2. Comparison of ESR stability in wet, polymer and hybrid electrolytics vs. temperature.

Furthermore, conductive polymer electrolytics exhibit increased reliability over wet electrolytics. If we compare the reliability of components with similar case size, value and voltage over a 20°C decrease, the life expectancy of an aluminum electrolytic increases by a factor of four, while a solid polymer aluminum capacitor increases by approximately a factor of 10. However, conductive polymers do exhibit increased dc leakage, cost, and sensitivity to high shock and vibration environments.

Aluminum electrolytic polymers have been a proven capacitor technology for over a decade. Recent developments in this technology include reduction in ESR, which proportionally increases the RMS current rating of the capacitor. The reduced ESR also drives the temperature rise of parts down thus improving the reliability of the capacitor. These improvements are a result of improved purity of material systems as well as process advances.

Hybrid Electrolytics

Hybrid electrolytics, which contain an optimized combination of both liquid and solid materials, were developed in an attempt to reduce dc leakage of polymers while lowering the ESR of wet electrolytics, thus improving on both wet and polymer reliability and performance. In addition, hybrid electrolytics perform exceptionally well in high humidity environments. Hybrid electrolytics have some CV limitations—though those are being overcome. Additionally, hybrid electrolytics have higher costs associated with them.

Recent hybrid aluminum electrolytic developments center on higher purity metal material systems, advances in the purity and composition of the solid and wet portions of the electrolyte as well as optimized mixing and disbursement of electrolyte materials. Additionally, seal technology as well as internal connections have been improved. The result of these advances is increased capacitance, lower parasitic losses, improved reliability and lower temperature rises at comparable levels of RMS current.

A brief summary of wet, conductive polymer and hybrid aluminum electrolytics is shown in Table 2 where advantages and areas in need of design verification are highlighted by technology.

Table 2. Comparison of Al-El technology attributes.

Attribute	Wet	Polymer	Hybrid
Benefits	• Low cost • Low DCL • Broad value range	• Ultra-low ESR • Higher ripple • Enhanced life	• Low ESR • Low DCL • Higher reliability
Points to check	• Reliabilty • ESR	• Higher DCL • Higher cost	• Higher cost • Range limits

Application Use by Electrolytic Type

No single aluminum electrolytic exhibits ideal characteristics across all parameters but the spectrum of aluminum electrolytic options provides designers with solid options for today’s market sectors.

Typically, traditional wet electrolytic capacitors can be considered for general purpose, consumer/high replacement non-critical electronics. These capacitors can be commonly found in power conversion circuitry and audio applications.

Polymer electrolytic capacitors’ low ESR and improved reliability characteristics push their use into higher value sectors such as the industrial, transportation and communication sectors. However, their increased dc leakage tends to limit their use in higher temperature circuitry as well as energy harvesting or battery-powered applications. Increased RMS current ratings make them the ideal candidate for miniaturized power conversion applications.

Hybrid aluminum electrolytics are ideal in high-performance, high-value electronics where stable, low-loss parameters and enhanced reliability performance are needed. Hybrid electrolytics fail in a benign, open mode. As can be expected, this failure mode is greatly desired in many end sectors and applications from lighting to transportation.

Application Example

The use of polymer and hybrid electrolytics is highlighted in the use case of a high-voltage monolithic synchronous buck-boost dc-dc converter. The particular chip selected was an LTC3115 due to its wide input and output voltage ranges of 2.7 V to 40 V. This wide operating range allows this device to be used in a variety of automotive and industrial power supplies, lighting applications, etc. In the particular design case shown in the Fig. 3 photo, the input voltage was 17 V and output was 12 V.

This design requires the capacitors used as input and output filters to have low ESR and the ability to handle larger ac currents associated with the switch converter in order to reduce the output voltage ripple. Many capacitor types can potentially be chosen for this application—from ceramic to tantalum, tantalum polymer and aluminum electrolytics.

The design case shown considered tradeoffs in cost, size, leakage and reliability. In the end a polymer aluminum electrolytic was chosen (KYOCERA AVX 68 µF, 35 V, AVX P/N APA0609680M035R) due to its small size, low ESR, acceptable RMS current capability and cost.

The output capacitor was chosen to be a hybrid aluminum electrolytic (KYOCERA AVX 27 µF, 25 V, AVX P/N AHA0608270M025R) for similar reasons as the polymer (low ESR, small size). But the hybrid also provides additional stability and reliability for the regulated output, which was desired in the high-performance converter.

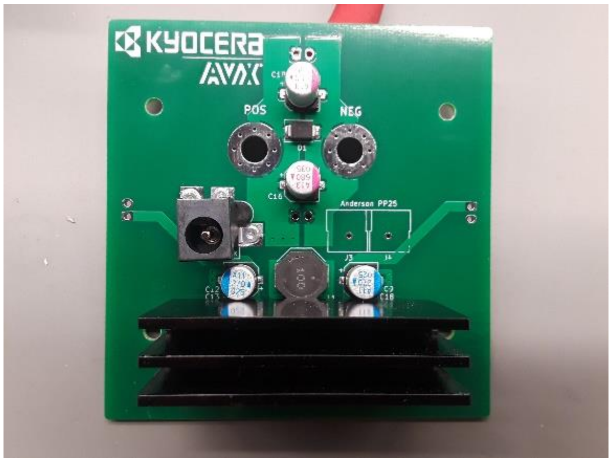


Fig. 3. An LTC3115 buck-boost board with 12-V output.

A tabular recap of key sectors and each technology's relative performance is shown in Table 3.

Table 3. Relative performance and recommended applications.

Application	Wet	Polymer	Hybrid
Power conversion	++	+++	+++
Filtering	+++	+++	+++
Battery	+++	+	+++
Audio	+++	+++	+++
Base station	+	++	+++
Industrial	+	+++	+++
Low temperature	+	+++	++
High temperature	++	+	+++
Extended reliability	+	++	+++
High vibration	+++	+	+++

Summary

Aluminum electrolytics are experiencing solid growth in electronic designs due to constant improvements as evidenced by the introduction of conductive polymer and hybrid electrolytic families. Though not specifically discussed in this article, an ever-expanding range of electrolytic packages are becoming available for specific use cases and applications.

The vertical SMT aluminum capacitor offering is also expanding in terms of capacitance values, voltage and ESR range as well as package sizes. Vertical aluminum capacitor families provide high-CV performance in small packages and compatibility with lead-free and RoHS requirements.

Polymer and hybrid electrolytics provide a further reduction in equivalent series resistance (ESR), while increasing RMS capacity and improving parametric stability. Polymer- and hybrid-based devices also enhance life and endurance characteristics in circuit.

It is possible for conductive polymer and hybrid electrolytic solutions to provide smaller case sizes with higher ripple current and inrush current capability. What's more, they can exceed the temperature ratings of standard wet aluminum electrolytic solutions.

Currently, all aluminum technologies are experiencing developments surrounding novel connection methods and pin outs. In many instances, these connections will help improve both electrical performance and capacitor reliability as it relates to specific applications.

Vertical SMT aluminum electrolytics—regardless of the specific electrolyte type—offer a wide breadth of solutions for the growing need of bulk capacitors on robust supply rails, innovative energy harvesting applications, and new modules replacing historically non-electronic processes.

Reference

"Tantalum Polymer vs Aluminum Polymer Performance as an Output Filter Capacitor for Miniature Switching Power Supplies" by Ron Demcko, Ashley Stanziola and Daniel West, KYOCERA AVX website, 2020.

About The Authors

Currently an AVX Fellow, Ron Demcko manages the TSG team at AVX headquarters in Fountain Inn, SC. This role centers on projects ranging from simulation models for passive components to product support/new product identification and applied development. Prior to that Ron was the EMC lab manager for AVX in Raleigh N.C. This lab concentrated on subassembly testing and passive component fixes for harsh electrical and environmental applications. Before the EMC lab work, he held an application engineering position at AVX. Product work included integrated passive components, EMI filters and transient voltage suppression devices.

Previously Ron worked as a product engineer and later as a product engineering manager at Corning Glass Works' electronics division. In this role he supported production, sale and development of pulse-resistant capacitors, high-temperature capacitors and radiation-resistant capacitors. He developed high-frequency test methods and co-developed high-temperature test systems. Ron received a BSEE from Clarkson College of Technology. He can be reached at ron.demcko@avx.com.

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Previously, Daniel served in the U.S. Army 82nd Airborne Division where he was a team leader and combat veteran. He received a BSEE from Mercer University. Daniel *currently resides in Greenville, SC with his wife and two children and is an amateur radio operator. He can be reached at daniel.west@kyocera-avx.com.*

For more information on capacitors, see How2Power's Design Guide, locate the Component category and click on "Capacitors".