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Aluminum-Electrolytic Capacitor Application Guideline

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August 2014



Electronic Components Industry Association

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Foreword

This specification was prepared by P-2.4 Subcommittee on Aluminum Electrolytic Capacitors of the Electronic Industries Alliance's sector Electronic Components, Assemblies, Equipment & Supplies Association (EIA/ECA).

1 Introduction

1.1 Aluminum-electrolytic construction

1.1.1 Overview

Except for a few surface-mount technology (SMT) aluminum electrolytic capacitor types with solid electrolyte systems an aluminum electrolytic capacitor consists of a wound capacitor element, impregnated with liquid electrolyte, connected to terminals and sealed in a can. The element is comprised of an anode foil, paper separators saturated with electrolyte and a cathode foil. The foils are high-purity aluminum and are etched to increase the surface area in contact with the electrolyte.

While it may appear that the capacitance is between the two foils, actually the capacitance is between the anode foil and the electrolyte. The positive plate is the anode foil; the dielectric is the insulating aluminum oxide on the anode foil; the true negative plate is the conductive, liquid electrolyte, and the cathode foil merely connects to the electrolyte.

This construction delivers colossal capacitance because etching the foils can increase surface area more than 100 times and the aluminum-oxide dielectric is less than a micrometer thick. Thus the resulting capacitor has very large plate area and the plates are awfully close together.

These capacitors routinely offer capacitance values from 0.1 μF to 3 F and voltage ratings from 5 V to 500 V. They are polar devices, having distinct positive and negative terminals, and are offered in an enormous variety of styles which include molded and can-style SMT devices, axial- and radial-leaded can styles, snap-in terminals styles and large-can, screw-terminal styles. Representative capacitance-voltage combinations include:

- 330 μF at 100 V, 1000 μF at 50 V and 6800 μF at 10 V for SMT devices;
- 100 μF at 450 V, 6,800 μF at 50 V and 10,000 μF at 10 V for miniature-can styles;
- 1200 μF at 450 V and 39,000 μF at 50 V for snap-in can styles;
- 9000 μF at 450 V and 390,000 μF at 50 V for large-can screw-terminal styles.

If two, same-value, aluminum electrolytic capacitors are connected in series, back-to-back with the positive terminals or the negative terminals connected, the resulting single capacitor is a nonpolar capacitor equal in capacitance to half the capacitance of either of the original pair at rated voltage. See 3.5 for more on nonpolar capacitors. Figures 1-3 show typical nonsurface-mount aluminum electrolytic capacitor constructions.

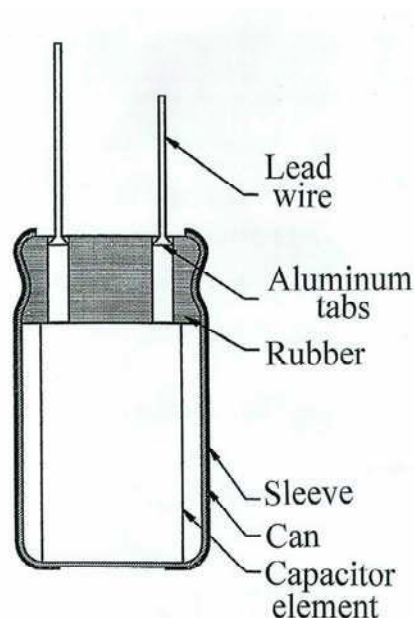


Figure 1—Miniature, radial-leaded type capacitor

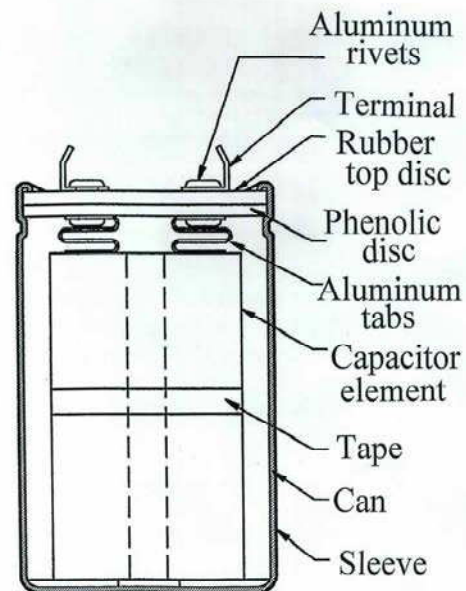
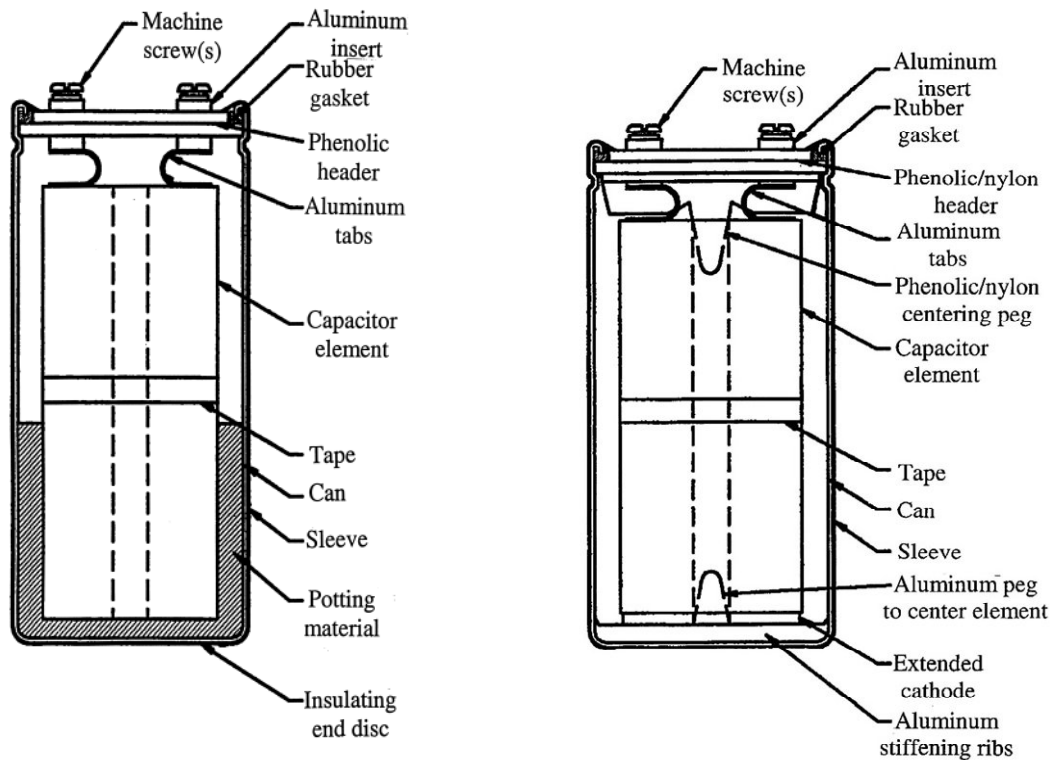


Figure 2—Snap-in type capacitor



a) Conventional construction

b) Pitchless construction

Figure 3—Large-can, screw-terminal type capacitors

1.1.2 Etching

The anode and cathode foils are made of high purity, thin aluminum foil, 0.02 mm to 0.1 mm thick. To increase the plate area and the capacitance, the surface area in contact with the electrolyte, is increased by etching the foils to dissolve aluminum and create a dense network of billions of microscopic tunnels penetrating the foil.

Etching involves pulling the aluminum foil on rollers through a chloride solution while applying an AC, DC or AC-and-DC voltage between the etch solution and the aluminum foil. Surface area can increase as much as 100 times for foil in low-voltage capacitors and 20 to 25 times for high-voltage capacitors.

1.1.3 Forming

The anode foil carries the capacitor's dielectric. The dielectric is a thin layer of aluminum oxide, Al_2O_3 , that is chemically grown on the anode foil during a process called "formation." Formation is accomplished by pulling the anode foil on rollers through an electrolyte bath and continuously applying a DC voltage between the bath and the foil. The voltage is 135% to 200% of the final capacitor's rated voltage. The thickness of the aluminum oxide is about 1.4 nm to 1.5 nm for each volt of the formation voltage, e.g., the anode foil in a 450 V capacitor may get a formation voltage in excess of 600 V and have an oxide thickness of about 900 nm. That's less than a hundredth the thickness of a human hair. Formation reduces the effective foil surface area because the microscopic tunnels are partially occluded by the oxide.

The tunnel etch pattern is adjusted by choice of foil and etching process so that low-voltage anodes have dense tunnel patterns compatible with thin oxide and high-voltage anodes have coarse tunnel patterns compatible with thick oxide. The cathode foil is not formed and it retains its high surface area and dense etch pattern.

1.1.4 Slitting

Foil is etched and formed in jumbo rolls of 40 cm to 50 cm wide and then slit into various widths according to the lengths of the final capacitors.

1.1.5 Winding

The capacitor element is wound on a winding machine with spindles for one-to-four separator papers, the anode foil, another set of one-to-four separator papers and the cathode foil. These are wound into a cylinder and wrapped with a strip of pressure-sensitive tape to prevent unwinding. The separators prevent the foils from touching and shorting, and the separators later hold the reservoir of electrolyte.

Before or during winding aluminum tabs are attached to the foils for later connection to the capacitor terminals. One method is by cold-welding of the tabs to the foils. The tab locations are microprocessor controlled during winding so that the capacitor element's inductance can be less than 2 nH. Another method of attachment is by staking. This is a process of punching the tab through the foil and folding down the punched metal. There is some evidence that cold welding reduces short-circuit failures and performs better in high-ripple current and discharge applications. Wound-capacitor elements are shown in figure 4.

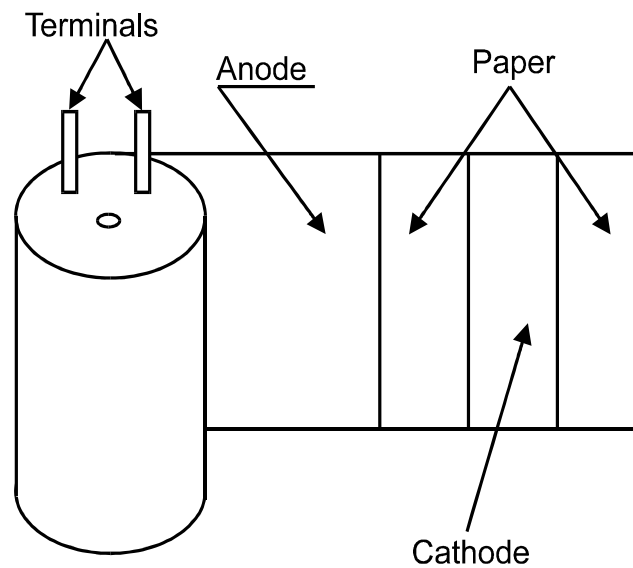


Figure 4— Wound capacitor elements

1.1.6 Connecting terminals

In SMT capacitors and miniature capacitors with rubber-bungs, extensions of the tabs are the capacitor terminals. But in large-can capacitors like snap-ins and screw-terminal styles, the tabs are riveted or welded on the underside of the capacitor tops to terminal inserts. Welding produces the lowest contact resistance and highest current handling. Both resistive welding and ultrasonic welding are used. The up to 12 tab pairs that may be used in large screw-terminal capacitors often require more mechanical support during assembly so the tabs in such capacitors may be both riveted to post extensions on the terminals and then welded. In an axial-lead capacitor the cathode tab is welded to the can before sealing.

1.1.7 Impregnation

The capacitor element is impregnated with electrolyte to saturate the paper separators and penetrate the etch tunnels. The method of impregnation may involve immersion of the elements and application of vacuum-pressure cycles with or without heat or, in the case of small units, just simple absorption. The electrolyte is a complex blend of ingredients with different formulations according to voltage and operating temperature range. The principal ingredients are a solvent and a conductive salt – a solute – to produce electrical conduction. Common solvents are ethylene glycol (EG), dimethylformamide (DMF) and gammabutyrolacetone (GBL). Common solutes are ammonium borate and other ammonium salts. EG is typically used for capacitors rated -20°C or -40°C . DMF and GBL are often used for capacitors rated -55°C . Capacitor-element materials are shown in figure 5.

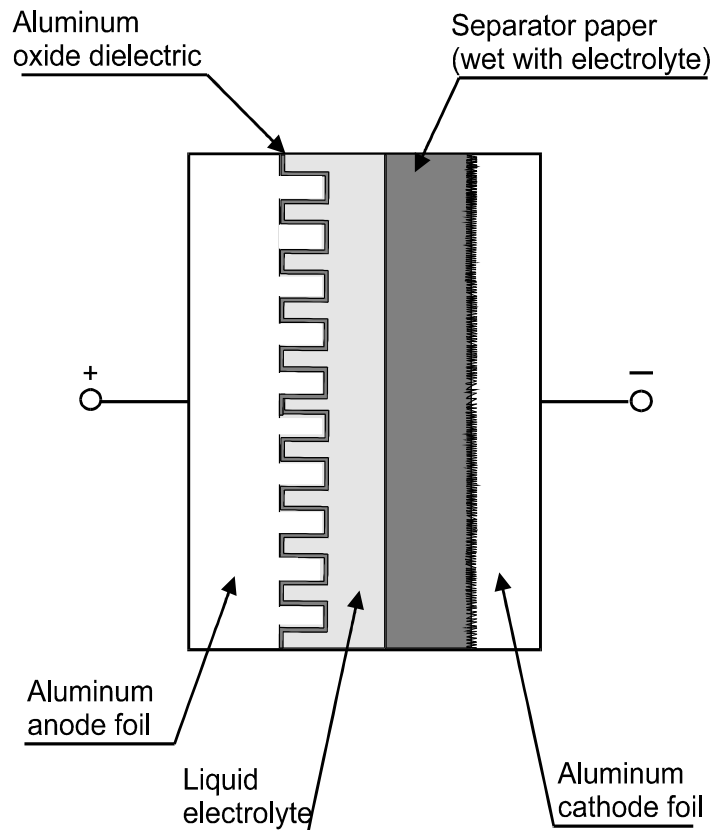


Figure 5— Capacitor-element materials

Water in the electrolyte plays a big role. It increases conductivity thereby reducing the capacitor's resistance, but it reduces the boiling point so it interferes with high temperature performance, and it reduces shelf life. A few percent of water is necessary because the electrolyte maintains the integrity of the aluminum oxide dielectric. When leakage current flows, water is broken into hydrogen and oxygen by hydrolysis. The oxygen is bonded to the anode foil to heal leakage sites by growing more oxide. The hydrogen escapes by passing through the capacitor's rubber seal.

1.1.8 Sealing

The capacitor element is sealed into a can. While most cans are aluminum, phenolic cans are often used for motor-start capacitors. In order to release the hydrogen the seal is not hermetic. The seal is usually a pressure closure made by rolling the can edge into a rubber gasket, a rubber end-plug or into rubber laminated to a phenolic board. In small capacitors molded phenolic resin or polyphenylene sulfide may replace the rubber. Too tight a seal causes pressure build up, and too loose a seal shortens the life by permitting drying out, loss of electrolyte.

1.1.9 Aging

Here the capacitor assembly comes full circle. The last manufacturing step is “aging” during which a DC voltage greater than the rated voltage but less than the formation voltage is applied to the capacitor. Usually the voltage is applied at the capacitor’s rated temperature, but other temperatures and even room temperature may be used. This step also reforms the cut edges and any damaged spots on the anode foil and covers any bare aluminum with aluminum oxide dielectric. Aging acts as burn-in and reduces or eliminates early life failures (infant mortals). Low, initial DC leakage current is a sign of effective aging.

1.2 Comparison to other types of capacitors

1.2.1 Ceramic capacitors

Ceramic capacitors have become the preeminent, general-purpose capacitor, especially in SMT chip devices where their low cost makes them especially attractive. With the emergence of thinner-dielectric, multilayer units with rated voltages of less than 10 V capacitance values in the hundreds of microfarads have become available. This competes with traditional, high-capacitance aluminum electrolytic capacitors.

Ceramic capacitors are available in three classes according to dielectric constant and temperature performance. Class 1 (NPO, COG) is suitable for low capacitance, tight tolerance applications in the range of 1 pF to a few mF. Class 2 (X7R) has 20 times to 70 times as much capacitance per case size, but capacitance typically varies about $\pm 10\%$ over its $-55\text{ }^{\circ}\text{C}$ to $+125\text{ }^{\circ}\text{C}$ temperature range. The maximum change is $\pm 15\%$. Class 3 (Y5V) with about 5 times the capacitance of class 2 has wild swings of capacitance with voltage and temperature. The temperature range is $-30\text{ }^{\circ}\text{C}$ to $+85\text{ }^{\circ}\text{C}$, and capacitance varies about $+20\%$, -65% over the range. Ceramic chip capacitors are brittle and sensitive to thermal shock, so precautions need to be taken to avoid cracking during mounting, especially for high-capacitance large sizes.

The typical temperature range for aluminum electrolytic capacitors is $-40\text{ }^{\circ}\text{C}$ to $+85\text{ }^{\circ}\text{C}$ or $105\text{ }^{\circ}\text{C}$. Capacitance varies about $+5\%$, -40% over the range with the capacitance loss all at cold temperatures. Capacitors rated $-55\text{ }^{\circ}\text{C}$ generally only have -10% to -20% capacitance loss at $-40\text{ }^{\circ}\text{C}$. Cold temperature performance for rated voltages of 300 V and higher is often worse, and temperature performance varies by manufacturer. Thus class 1 and 2 ceramic capacitors perform better than aluminum electrolytic capacitors at cold temperatures, and class 3 ceramic capacitors perform worse at all temperatures.

Aluminum electrolytic capacitors readily deliver much more capacitance. Aluminum electrolytic capacitors give more capacitance and energy storage per unit volume than ceramic capacitors for all types except for low-voltage, class 3 ceramic SMT chip capacitors. While tolerances of $\pm 5\%$ and $\pm 10\%$ are routine for ceramic capacitors, $\pm 20\%$ and -10% , $+50\%$ are the norms for aluminum electrolytic. This makes aluminum electrolytic capacitors the choice for high-capacitance applications like rectification filters and power hold up where more capacitance is a bonus and ceramic is the choice for lower capacitance, high-frequency applications like decoupling.

Ceramic capacitors are not polarized and therefore can be used in AC applications. The low dissipation factor (DF) and high capacitance stability of class 1 and 2 are especially suited to AC and RF applications. By comparison, aluminum electrolytic capacitors are polarized and cannot withstand voltage reversal in excess of 1.5 V. While nonpolar aluminum electrolytic capacitors are available for momentary-duty AC applications like motor starting and voltage-reversing applications, the high DF of aluminum electrolytic capacitors – from 5% to 150% – causes excess heating and short life in most AC applications.

Ceramic capacitors are generally more reliable than aluminum electrolytic capacitors because of their simpler construction and stability of ceramics. However, since high-capacitance ceramic capacitors may develop micro-cracks, aluminum electrolytic capacitors are preferred for high capacitance values. But, small sizes of aluminum electrolytic capacitors may have limited life due to dry-out, and so consider reliability in your choice for applications operating at high temperatures, over $65\text{ }^{\circ}\text{C}$.