Low equivalent series resistance electrolytic capacitor leakage current variation due to large temperature changes

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Abstract

Inside an aluminium electrolytic capacitor, the oxide layer that acts as a dielectric in the electrolyte allows for a leakage current, when a DC voltage is applied. The general mechanism predicts that an increase in temperature will speed up the rate of chemical reaction, which results in an increase in leakage current. Low equivalent series resistance aluminium electrolytic capacitors of commercial grade capacitance; 100 μF, 470 μF, 1000 μF and 2200 μF were used to measure the change in leakage current at temperatures between 25°C and 80°C.

1. Introduction

Leakage current is, in principle, a small leakage of current that departs from the capacitor when the component is storing electrical charge. Capacitors are widely used in most electronic devices to stabilise power and when multiple capacitors in one system are continually dissipating a small amount of charge, the losses quickly add up to a non-negligible amount of power in a system. Despite the leakage only being a few microamps, the leakage current can still be significant when compared to the size of the system, for example in a microcontroller the amount of leakage current can be compared to a small amount of current intended to be diverted from the controller to save power. By analysing the leakage current from capacitors in circuits the losses in power can be reduced and the system can become more efficient. [1]

An electrolytic capacitor is a type of capacitor that implements a gel or liquid containing a high concentration of ions (electrolyte), to achieve a greater capacitance. The capacitor is polarised so that the positive terminal is always at a greater electrical potential than the negative terminal. Although, this large capacitance comes with multiple drawbacks including large leakage current, large value tolerances, and a limited lifetime. The larger value tolerance occurs because of capacitance drift in which the capacitance value of the electrolyte varies typically by 20% [2].

The general mechanism for capacitor leakage is due to the increase in temperature which accelerates the chemical reaction in the electrolyte, as a result degrading the dielectric causing an increase in leakage current.

In the experiment, low equivalent series resistance aluminium electrolytic capacitors were used. They are made of two aluminium foils and a paper spacer that is soaked with electrolyte. One foil is covered with an oxide layer, which creates an anode, whilst the other uncoated aluminium foil acts as a cathode. These layers are stacked with a paper separator at the bottom and then rolled into a cylindrical container, as shown in Figure 1. The capacitance of an aluminium electrolytic capacitor is determined by physical attributes such as plate area and the thickness of the electrolyte. Therefore, for a larger capacitance more physical space is required, as the capacitors become more bulky and thicker.

The shelf life for an aluminium electrolytic capacitor if unused is estimated at two years or more. The oxide layer deteriorates without use and must be reformed with a process called capacitor reforming. A method of running a voltage source through a resistor and steadily incrementing the voltage level until the oxide layer has been fully reformed. [2]

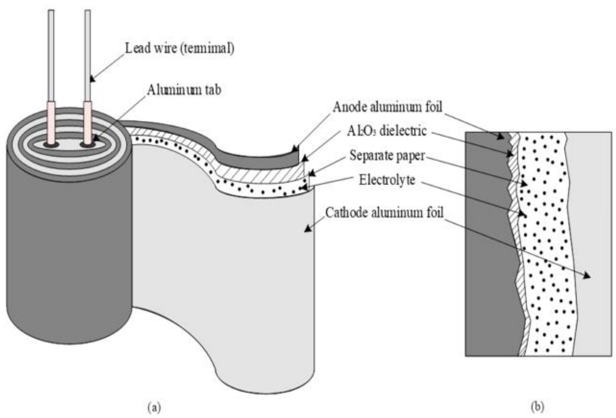


Figure 1. Constructions of an aluminium electrolytic capacitor (Al-Cap): (a) cylinder construction; (b) cross section of cylinder. [5]

2. Experimental Procedure

In total 20 low equivalent series resistance capacitors by the same manufacturer were picked for testing. Five of each of the specified values:100 μF, 470 μF, 1000 μF and 2200 μF with a voltage rating of 25 V and an operating temperature range of -40 °C to +85 °C. The first step taken to remove a source of uncertainty was to put the capacitors through a procedure known as “soaking” or dielectric absorption. This ensures that the capacitor dielectric oxide layer is fully formed before the testing is commenced [3]. The soaking process is done by connecting the capacitors to a very low noise, 20-volt power source and leaving them undisturbed for 12 hours. Afterwards the capacitors are disconnected, discharged, and cleaned thoroughly with isopropyl alcohol to ensure no external high resistance current paths between the leads of the capacitor.

Following this the capacitors are soldered into a metal case which acts as a Faraday cage eliminating external noise, as well as a terminal insulator which eliminates any drift from ambient temperature. An additional high thermal mass binding post and 1.29 mm diameter copper wire was used to reduce thermal noise [4].

The metal case had three external holes to be able to accept two k-type thermocouples and a cylindrical ceramic heater. The metal case containing the capacitor is connected in series with a high-precision ammeter and in parallel with a programmable linear power supply. Additionally, the thermocouples which are mounted on either side of the capacitor are used to measure the temperature inside the box by displaying the readings on the two temperature metres. The experimental equipment arrangement can be seen in Figure 2.

After the power supply was engaged the first reading was taken at 25 °C, this was chosen as the starting point as the ambient offset of the room temperature meant a reading at 20 °C was inconsistent. A timer was started instantaneously with the temperature rise and after one minute elapsed a measurement of the leakage current was taken. Afterwards the power supply is turned off, the capacitor is discharged, and the heater is turned on until the capacitor under test is heated to 30 °C. The temperature is increased in 5 °C interval steps until the capacitor reaches 80 °C. All the capacitors were tested with a DC input voltage of 20 V, while the heaters were powered by 9 V.

The experiments were undertaken with strict rules for the engineer's safety. Due to the high temperature of the metal container, tongs with a rubber handle were used to remove the lid to avoid burns from heat conduction. Due to the usage of electrolytic capacitors the polarity of the component was always double checked before testing. If the capacitor becomes reversed biased the insulating dielectric (in this case aluminium oxide), could become damaged and act like a short circuit between the two terminals. This can cause the capacitor to overheat and vaporise the electrolyte causing the enclosure to burst (especially when being tested under high temperatures of 80 °C). The electrolyte may be toxic or corrosive, so this safety measure was continually checked throughout the experiment to make sure there was no polarity error in the circuit. [2]

3. Results and Discussion

The data obtained is displayed in Figure 3. Each of the graphs contain the values from five capacitors of the same value, 100 μF (a), 470 μF (b), 1000 μF (c) and 2200 μF (d). In all four graphs there is a positive correlation between the increase in temperature and the increase in leakage current, which proves the original proposed mechanism. However, upon closer inspection of the 100 μF graphs the leakage current change is not initially linear. All the tested capacitors with the value of 100 μF

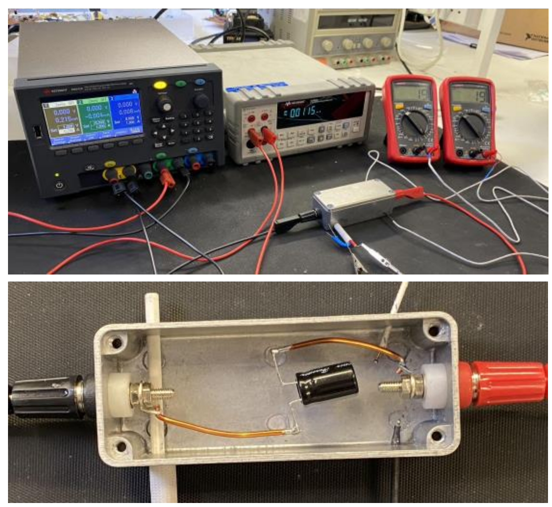
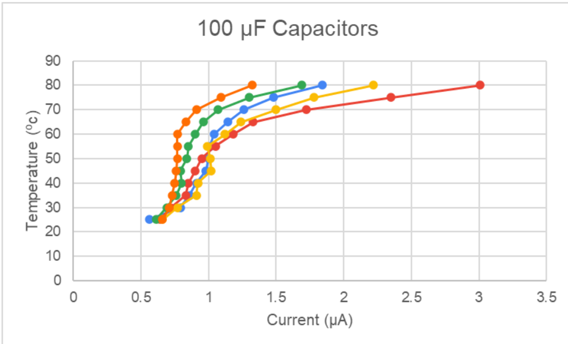
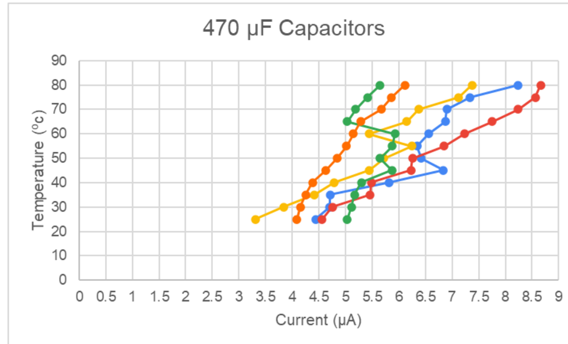


Figure 2. Experimental setup

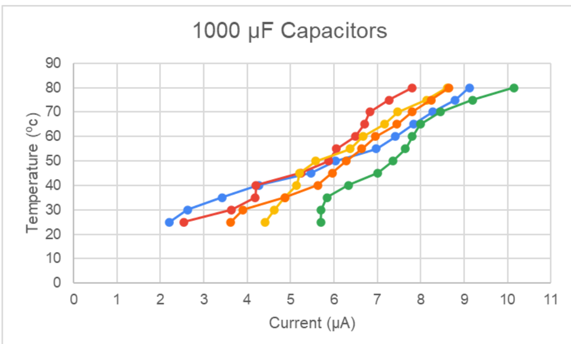
displayed an uncharacteristic positive exponential curve until approximately 60 °C beyond this point the graph realigns with the linear property of the other graphs, until 80 °C. This phenomenon was only observed in the 100 μF capacitors and is highly probable that it is due to a rapid degradation and breakdown of the electrolyte. The other three capacitor values indicated a clear positive linear correlation between temperature and leakage current.



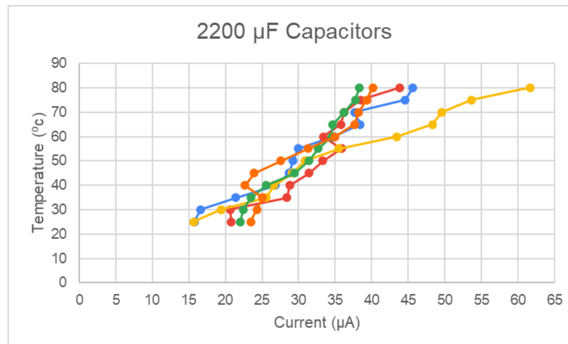
(a)



(b)



(c)



(d)

Figure 3. Shows the leakage current against temperature for all 20 capacitors

Despite the overlying positive trend, upon observing the graphs there are small differences between them. This is a direct result of the large value tolerance of capacitance inside aluminium electrolytic capacitors that can be explained due to the manufacturing process as a tight tolerance range is not the one of the dominant factors for mass produced capacitors.

Additionally, the capacitors are affected by the degradation time which is the deterioration of the insulating layer in the capacitor after a prolonged time in storage [6].

The time spent being inactive is unknown for each capacitor as they were picked from different batches. This selection process was used to be able to easily detect any outliers by taking a wider sample range instead of a singular batch, which could have been faulty. It should be mentioned that the operational leakage current measured for all capacitors at ambient temperature correlates to the values given by the manufacturer at delivery. The formula used to
calculate the leakage current at delivery is given as [7]:

$$I_{Leakage} = 0.01 \times CV \qquad (1)$$

The table containing the initial leakage values for the capacitor values can be seen in Table 1. The table demonstrates a higher leakage current for larger capacitor values upon delivery as the capacitors have not gone through dielectric absorption.

Table 1: Initial leakage current values

100 µF	470 µF	1000 µF	2200 µF
25 µA	118 µA	250 µA	550 µA

4. Conclusion

This study provides insight into the correct operating temperatures for aluminium electrolytic capacitors. The results from the graphs show that there is a proportional increase in leakage current as temperature rises. The testing confirms that for a large range of capacitance values a linear increase is observed. The general mechanism for the correlation of the electrolyte chemistry and temperature is proven to be a sufficiently accurate model for predicting the change in capacitor leakage.

References

[1] Axel Schmidt, (2019 April 23). *Analysing the leakage current from capacitors in the circuit of smart devices and selecting alternative components to reduce leakage could allow smart devices to last longer*. [Online]. Available: https://www.allaboutcircuits.com/industry-articles/understanding-capacitor-leakage-to-make-smart-things-run-longer/

[2] P. Horowitz and W. Hill, *The Art of Electronics*, 3rd Edition. Cambridge University Press, 2015.

[3] Devin K. Hubbard, "*The use of Dielectric Absorption as a Method for Characterizing Dielectric Materials in Capacitors",* [Online], 2010. Available: https://cdr.lib.unc.edu

[4] F. N. H. Robinson, *Noise in Electrical Circuits*. Oxford University, 1962.

[5] MDPI, (2020 July 3). *Review of Health Monitoring Techniques for Capacitors Used in Power Electronics Converters* [Online]. Available: https://www.mdpi.com/1424-8220/20/13/3740/htm

[6] Anunay Gupta, Om Prakash Yadav, Douglas DeVoto, and Joshua Major."A Review of Degradation Behaviour and Modelling of Capacitors", National Renewable Energy Laboratory, 2018. Available: https://www.nrel.gov/docs/fy19osti/71386.pdf.

[7] "85 °C Radial electrolytic capacitors" 2015. Available: https://static.rapidonline.com/pdf/11-0205e.pdf