Application Note

Aluminum Electrolytic vs. Aluminum Polymer Capacitor and how its benefits are used properly

ANP071 // FRANK PUHANE

1 Understanding Polymer Electrolytic Capacitors

Aluminum polymer capacitor (also called polymer electrolytic capacitors or in short polymer e-caps) is a sub-form of the electrolytic capacitors. The special feature of these capacitor types is that a conductive polymer is used instead of a liquid electrolyte. This requires a special processing step, which is carried out during production. In this chemical reaction, the so-called polymerization, by heating, the still liquid monomer that has been impregnated in place of electrolyte in the separator paper is cross-linked to a solid polymer. This process is typically done at a temperature of about 100 °C. Once completed, the polymer is solidified indefinitely. The various combinations that are possible today for electrolytic capacitors fabrication in terms of electrodes and the property of the electrolyte are shown in Figure 1.

Aluminum		Tantalum		Nioboium	
Non-solid / wet	Solid / dry	Non-solid / wet	Solid / dry	Non-solid / wet	Solid / dry

Table 1: Construction possibilities of electrolytic capacitors

Furthermore, there is the possibility of hybrid construction of electrolytic capacitors. This is a combination of wet electrolyte and solid polymer. Aluminum electrolytic and aluminium polymer capacitors have very good behaviour against bias effects of voltage and temperature. Furthermore, aluminium polymer capacitors have very good aging characteristics. In comparison to ceramic capacitors, polymer electrolytic capacitors offer significant advantages, especially their DC bias performance. In addition, the use of polymer capacitors becomes interesting when increasing the capacitance while maintaining cost. The special design process can also be used to significantly reduce the parasitic effects (here especially the ESL). This means for applications the potential to handle high ripple current, have low parasitic inductances, high reliability and very good temperature properties. The equivalent circuit of a capacitor is shown in Figure 1.

It should be noted that polymer electrolytic capacitors have an increased leakage current compared to normal aluminum electrolytic capacitors and therefore are usually unsuitable for small handheld battery applications.

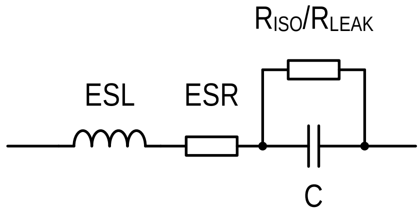


Figure 1: Equivalent circuit diagram of a real capacitor

The high reliability is proven by the significantly longer lifetime of polymer electrolytic capacitors. However, when it comes to high vibration, the specific circumstances of the application should be considered, as aluminum polymer capacitors may not be the optimal choice here. This is due to the property of the solid polymer because it cannot absorb vibrations as well as a liquid electrolyte. However, it has to be considered that in terms of volume for a defined capacity and voltage, the normal electrolytic capacitor still has advantages. At Würth Elektronik eiSos, for aluminium polymer capacitors so far the capacitance values range from 10 µF to 2 mF with a voltage range from 6.3 V to 100 V in a wide variety of designs. Due to their excellent electrical properties, the possibilities of using polymer electrolytic capacitors are very diverse, ranging from traditional backup solutions of voltages, buffering supply voltages from ICs, bypass or decoupling of signals, filter applications to voltage smoothing of switching regulator applications. This Application Note discusses the use of aluminum polymer capacitors in the field of filtering and voltage smoothing.

2 The Buck Converter - General Setup

To demonstrate the positive effects of the polymer electrolytic capacitor a buck converter is used. The input voltage is 12 V and the output voltage has been set to 5 V. The load is a pure ohm load of 5 Ω. This results to a current of 1 A flowing through the resistor. This setup serves as a basis to make the performance of polymer electrolytic capacitors clear. The design is used for both EMC measurement and voltage ripple output measurements with always the same load. From the EMC point of view, a buck converter is much more critical at the input side. This is due to the discontinuous current consumption based on the fast switching processes of the semiconductors. As a result of this topology, there is already an "LC filter" at the output, which integrates the discontinuous current on the high side (refer to Figure 2).

Application Note

Aluminum Electrolytic vs. Aluminum Polymer Capacitor and how its benefits are used properly

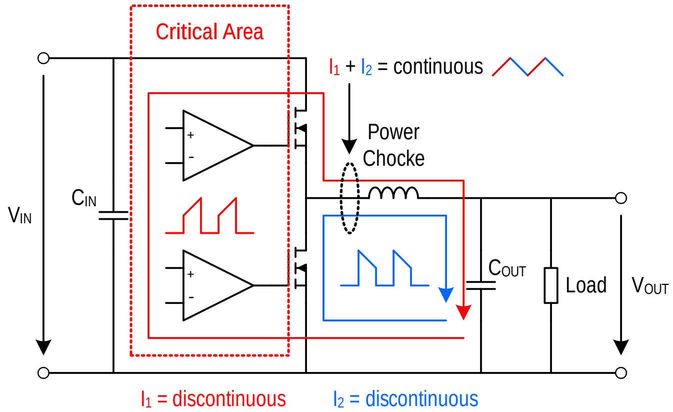


Figure 2: Principle of a buck converter

The construction and design of the buck converter was based on the specifications of the data sheet and designed with the default values for the coil and capacitors. The inductance values of the coil and the capacitance of the input and output capacitors were verified by the manufacturer's data sheet and with their simulation software. This was especially important when using only one aluminum electrolytic capacitor. Due to the very high ESR value, the stability of the regulator was impaired. To counteract this effect, a capacitor was additionally attached to the feedback loop. This additional capacity ensures stability even at high ESR values. In Figure 3 the circuit diagram of the buck converter and in Figure 4 the associated layout is shown. The layout consists of two layers, each with full copper areas on the top and bottom sides with connection to ground. The layout itself could still be improved at various points. Above all, the connection of the components to the ground layer still needs optimization to achieve a better filtering effect. It can clearly be seen in the measurement of the output capacitor that the high parasitic inductance causes voltage peaks on the output signal.

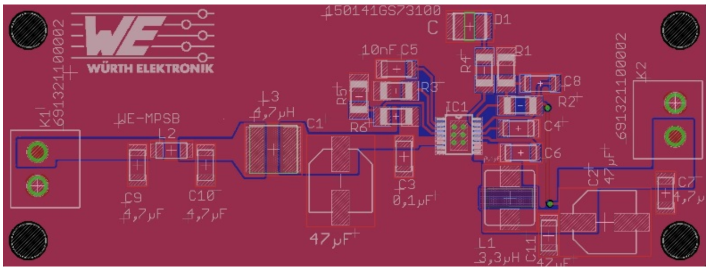


Figure 4: Layout of the buck converter

3 The EMC Measurement

The measurements were made according to the CISPR 32 standard (which replaces CISPR 22 and 15) in an RF-shielded chamber with the corresponding connection to the ground surface of the cabin, see Figure 5. The test receiver was an R&S ESRP 3 and as network simulation an ENV216 two-wire V-net simulation was available.

During the measurement, in the first step, further input filters on the layout were dispensed; only in the last measurement was a T-filter with a separated coil placed. This filter was constructed according to the specifications in the data sheet. For the first measurement, an aluminum electrolytic capacitor WCAP-ASLL 865 060 343 004 was used for the input capacitor C1 (Link to REDEXPERT). The electrical properties of the capacitor are as follows: Capacitance 47 µF, rated voltage 16 V with an ESR 411 mΩ and ESL 19 nH. The associated measurement result is shown in Figure 6.

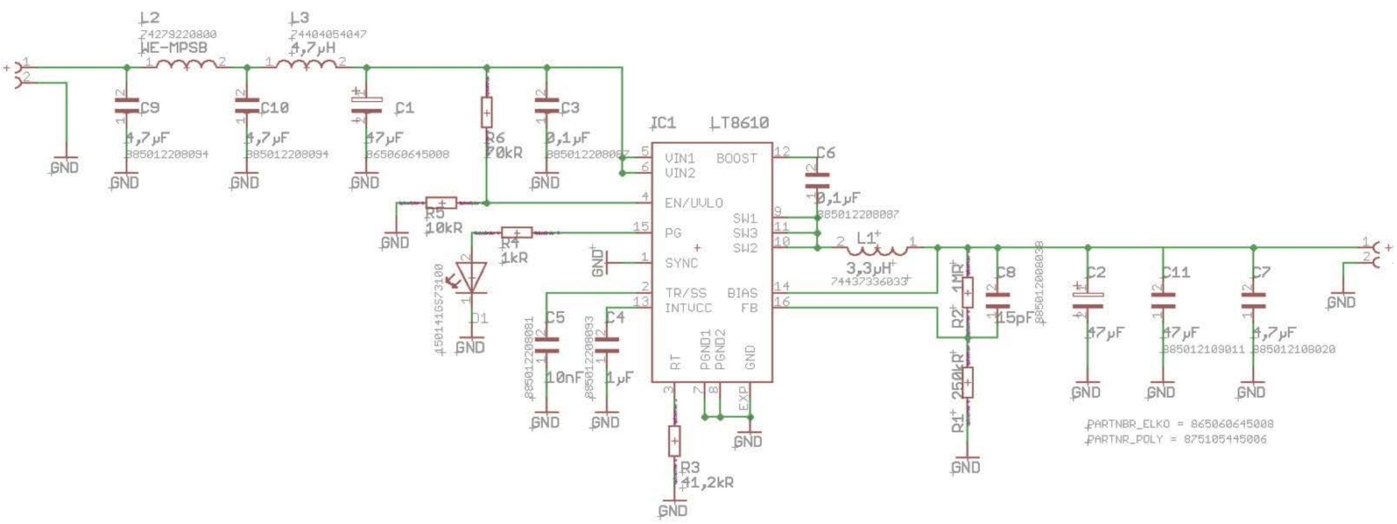
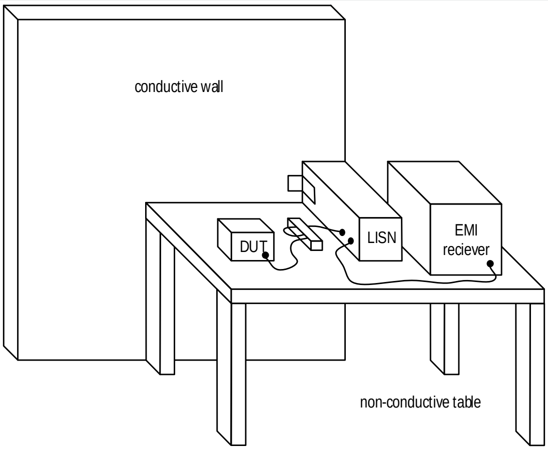


Figure 3: Schematic of the buck converter

Application Note

Aluminum Electrolytic vs. Aluminum Polymer Capacitor and how its benefits are used properly



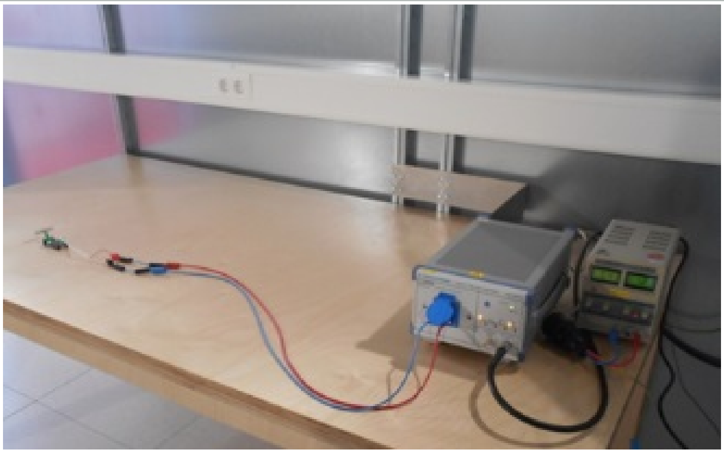


Figure 5: Setup of the EMC measurement according to CISPR 35

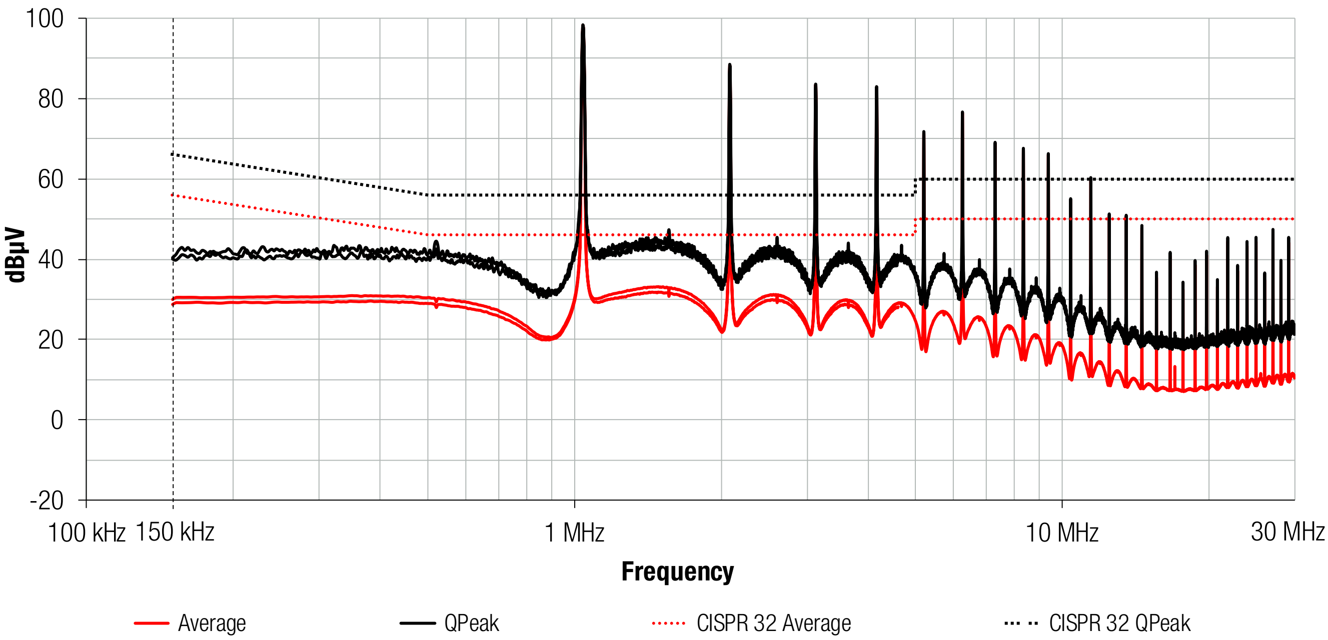


Figure 6: First EMC measurement with an aluminum electrolytic capacitor as C1

It can be seen that the limit values of CISPR 32 class B are clearly exceeded. There are noise levels of up to 100 dBµV detectable. But where do these interfering signals come from? The capacitor as a real component has parasitic effects, particularly the ESR together with the parasitic effects of the layout (the lead inductance) generate a high-frequency voltage drop that can be detected by measurement. This is shown schematically in Figure 7. As a first approach to achieve acceptable levels of emissions and stay below the limits, an aluminum polymer capacitor can be used. The electrical properties in terms of capacity and rated voltage of the aluminium polymer capacitor are the same as those of the aluminum electrolytic capacitor.

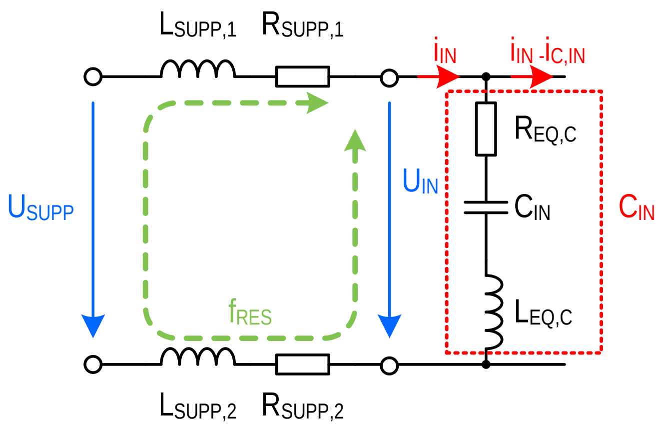


Figure 7: Schematic representation of the cause of the disturbances

Application Note

Aluminum Electrolytic vs. Aluminum Polymer Capacitor and how its benefits are used properly

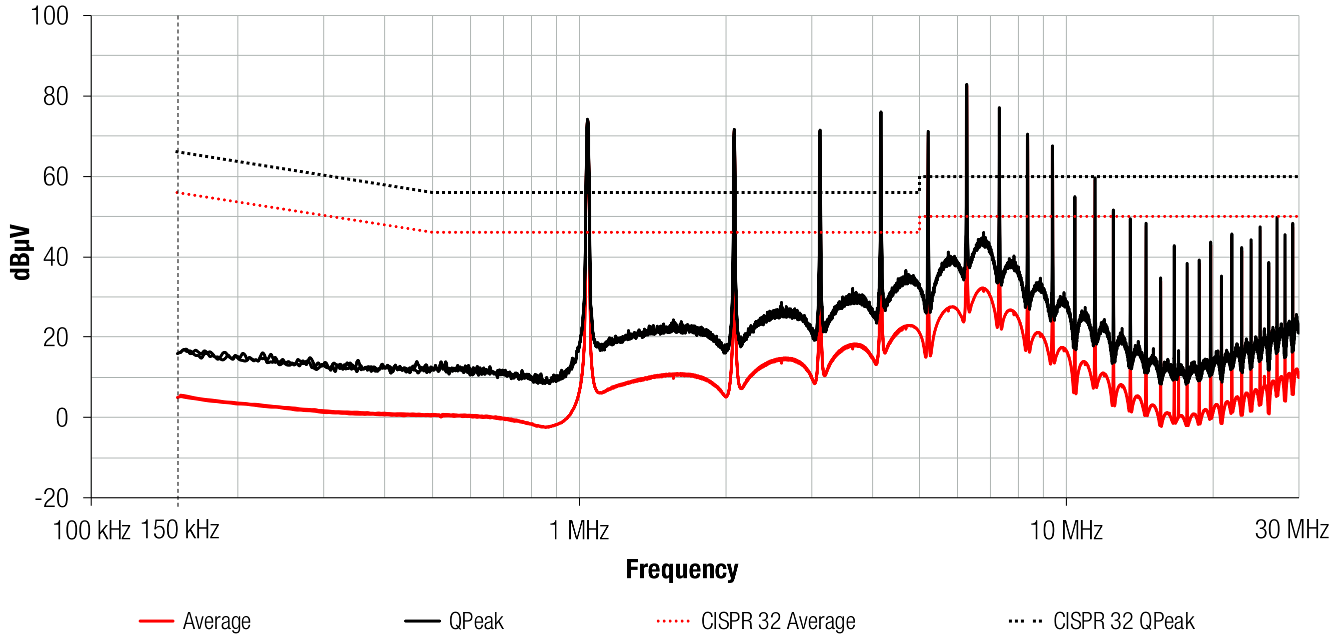


Figure 8: EMC measurement with an aluminum polymer capacitor as input capacitor C_1

The design is also equivalent at the capacitance of 47 µF and the capacitor fits to the original landing pattern. The aluminum polymer capacitor used was a WCAP-PSLP 875 105 344 006 (Link to REDEXPERT) with a capacitance of 47 µF, rated voltage of 16 V and with an ESR of 20.7 mΩ and ESL of 3.9 nH. Due to the very low ESR and ESL, the following measurement of the interference spectrum is achieved, which can be seen in Figure 8.

It can clearly be seen that by changing only one component, the EMC performance was significantly improved. The voltage drop which is generated by the fundamental frequency and the first harmonic of this frequency is reduced and thus less interference is generated. However, the limit could not be met and therefore further filters have to be placed. The structure of the input filter was based on the information in the data sheet. Therefore, the filter has the following insertion loss (in a 50 Ω system), as shown in Figure 9. The input filter was then included on the PCB and another measurement performed. The result is shown in Figure 10 where the interaction between the aluminum polymer capacitor and the input filter is visible. The combination of input filter and low ESR and low ESL of the polymer electrolytic capacitance makes it possible to push the level broadband below the limit of class B. Values of less than 40 dBµV (Average & Quasi Peak) are easily possible (compared to the first measurement with around 100 dBµV) and so, the measurement is passed.

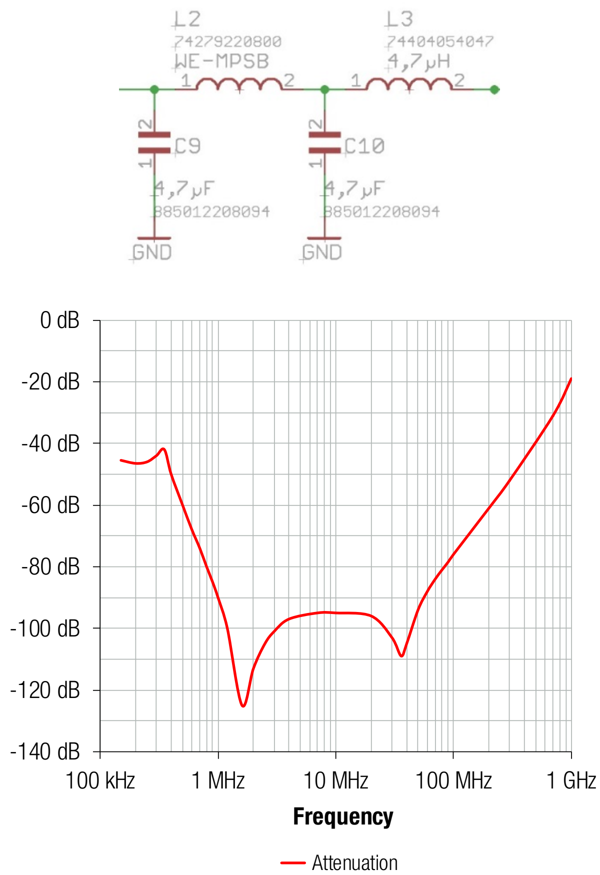


Figure 9: Built-in input filter with simulated filter performance

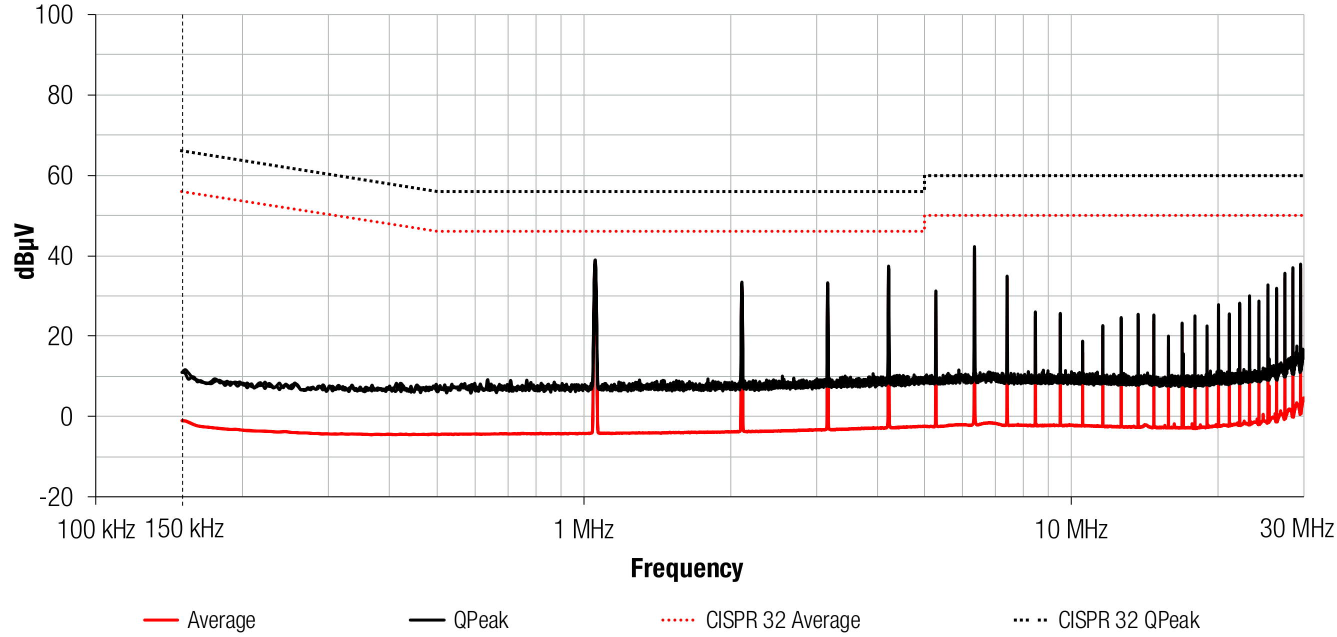


Figure 10: EMC measurement with input filter and aluminum polymer capacitor C_1

4 Comparison of the Ripple of the Output Signal

For the output capacitor of a buck converter, a certain capacitance is required in order to keep the control loop stable and hence the output voltage stable. If the output voltage reduces the capacitance value, the worst-case scenario is that the converter can no longer meet its specification (for example during load changes). This must be taken into account, especially when operating with class 2 ceramic capacitor (e.g. X7R and X5R). In the following chapter, the effect of the resulting ripple on the output signal will be considered. The first measurement in Figure 11 shows the result of the output ripple of the switching regulator when only one aluminum electrolytic capacitor is used. The capacitor used is a WCAP-ASLL 865 060 343 004, the same as used previously (REDEXPERT). The electrical properties of the capacitor are as follows: Capacitance 47 µF, rated voltage 16 V with an ESR 411 mΩ and ESL 19 nH. The high ESR value results in a peak-to-peak value of 400 mV. At least, this means a voltage ripple of 8 % at an output voltage of 5 V. Even with two aluminum electrolytic capacitors of the same type in parallel, the resulting ESR is still 205.5 mΩ and thus clearly too high. Another aspect that should not be neglected is the ripple current through the capacitor. This leads to heating of the component and leads to the failure of the capacitor. Therefore, the ripple current capability of aluminum electrolytic capacitors must always be checked.

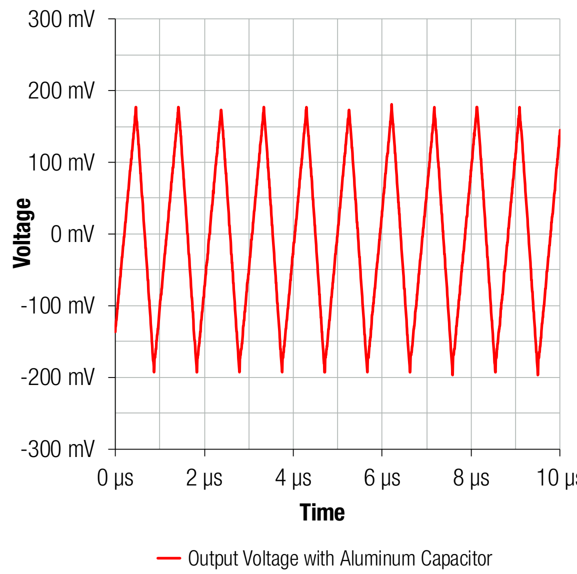


Figure 11: Ripple voltage at the output of the buck converter if only one aluminum electrolytic capacitor is used

In the case of polymer electrolytic capacitors, due to the low ESR, the heating of the component at the same ripple current is significantly lower and, in comparison, therefore significantly larger ripple currents are capable without thermally overloading the component. A comparison of the ESR of the aluminum electrolytic capacitor and the ESR of the polymer electrolytic capacitor is as shown in Figure 12.

Application Note

Aluminum Electrolytic vs. Aluminum Polymer Capacitor and how its benefits are used properly

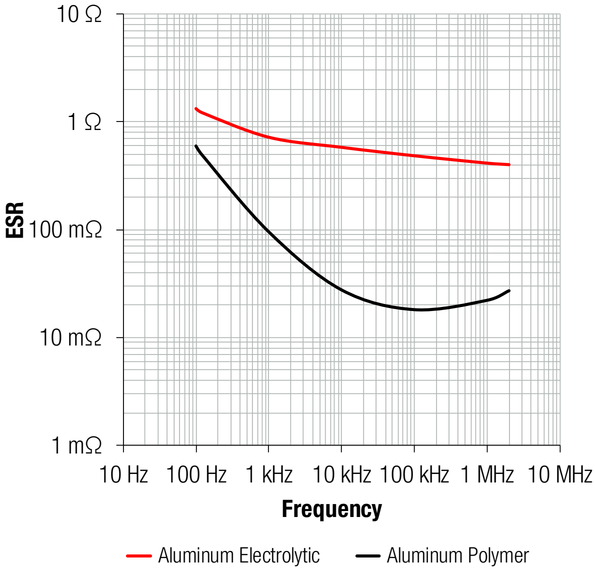


Figure 12: Comparison of the ESR of the aluminum and aluminum polymer capacitor

The measurement of the residual ripple of the output signal with the polymer capacitor as an output capacitor is shown in Figure 13. The aluminum polymer capacitor used was a WCAP-PSLP 875 105 344 006 (Link to REDEXPERT) with a capacitance of 47 µF, rated voltage of 16 V and with an ESR 20.7 mΩ and ESL 3.9 nH.

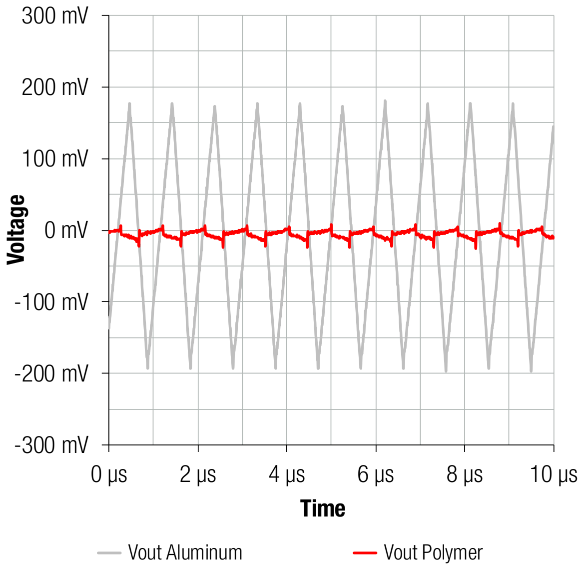


Figure 13: Measurement of ripple voltage when using the aluminum polymer capacitor at the output

The peak-to-peak value of the measurement is now only 35 mV and therefore within an acceptable range. The voltage peaks seen in Figure 13 are caused by parasitic inductance during the switching. Since, no one would use single aluminum polymer electrolytes alone in a real application; it is advisable to place an MLCC in parallel to the aluminum polymer capacitor. Thus, the parasitic effects can be minimized and a very clean output signal is achieved, as shown in Figure 14.

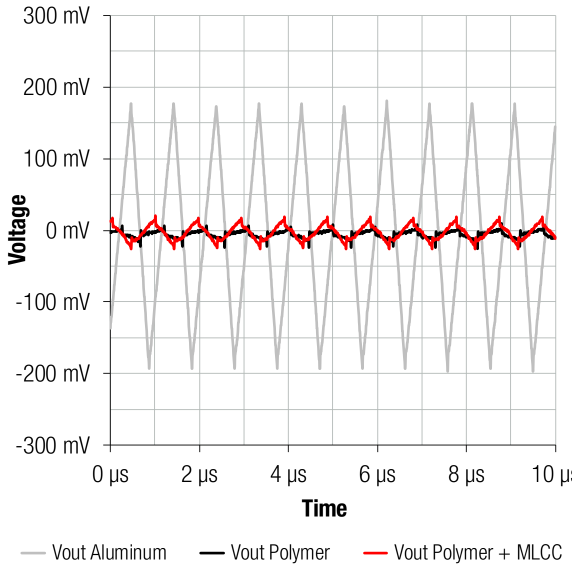


Figure 14: Measurement of ripple voltage using am aluminum polymer capacitor and an MLCC

The MLCC used was a X7R ceramic with a capacitance of 4.7 µF and rated voltage of 16 V (Link to REDEXPERT). If the layout of the PCB will be optimized too, a peak-to-peak value of 20 mV is expected, see also Figure 14.

5 Lifetime Consideration

The lifetime of electrolytic capacitors is very important in industrial applications and other application where a high lifetime is required. Here, the capacitor is not used as a kind of predetermined breaking point (also called planned obsolescence) as it is in consumer electronics but is as a durable and reliable component. The life of a capacitor depends on many factors of the application. An important factor is the temperature or rather thermal load, as it is responsible for the fact that internal structures age over time and the electrical properties deteriorate. This results in increased leakage current, increasing the ESR, which in turn leads to a further increase of the temperature. The reason for the temperature increase is the power loss generated by the ESR. If these limits are not exceeded, high lifetime expectancies are possible when the inner temperature load of the component is in a lower range. A comparison of the lifetime of aluminum electrolytic and aluminum polymer capacitors by temperature load is listed here. The bases of this consideration are two formulas. With liquid electrolytic capacitors, the expected lifetime doubles when the temperature at the component is reduced by 10 °C (2). For polymer electrolytic capacitors, the life increases tenfold when the temperature at the component is reduced by 20 °C (1).

Application Note

Aluminum Electrolytic vs. Aluminum Polymer Capacitor and how its benefits are used properly

Formula for aluminum polymer capacitors:

$$L_x = L_{nom} * 10^{\frac{T_0 - T_a}{20}} \quad (1)$$

Formula for aluminium electrolytic capacitors:

$$L_x = L_{nom} * 2^{\frac{T_0 - T_a}{10}} \quad (2)$$

To further illustrate this, the calculated lifetime values are shown in Table 1 for some example temperature values. Here, the maximum specified component temperature is used to compare aluminum electrolytic and aluminum polymer capacitors.

Temp. (°C)	Aluminum-Polymer-Capacitor (h)		Aluminum-Electrolytic-Capacitor (h)		
125	2.000		2.000		
105	20.000	2.000	8.000	2.000	1.000
85	200.000	20.000	32.000	8.000	4.000
65	2.000.000	200.000	128.000	32.000	16.000

Table 2: Lifetime overview with different ambient temperatures

The table is divided into four columns. The application temperature is defined in the formulas (1) and (2) as the ambient temperature T_a. The hour's definition at 105 °C in the two following columns for the aluminum polymer and aluminum electrolytic capacitor is the nominal lifetime of the component L_{NOM}. This is linked to the maximum specified temperature at the component and is defined as T_0. The other hours in the table are the calculated lifetimes L_X using the formulas (1) and (2). In the aluminum polymer capacitor column, the calculated lifetime is 2.000.000 h at 65 °C ambient temperature. This means a theoretical lifetime of 228 years. To guarantee such a lifetime is not possible. The typical maximum expected lifetime varies for different vendor and is between 13 and 15 years.

Furthermore, you can clearly see in this table at which ambient temperature aluminum polymer capacitors have their advantage in lifetime. If the specified component temperature for aluminum electrolytic and aluminum polymer capacitors is the same (for example 2000 h at 105 °C), it can be seen at 85 °C the polymer electrolytic capacitor has a longer lifetime. Only in cases of aluminum electrolytic capacitors with a long specified lifetime at the maximum specified component temperature has a higher intersection point but the point of intersection will always occur (see Figure 15). The specified hours in this diagram are always the nominal lifetime value of the component at this temperature. Apart from this advantage, of course, the other parameters of the capacitors must be compared. It may be that in a special application the expected lifetime is the same, but the better ESR and ESL are critical to the application and speaks for the aluminium polymer capacitor.

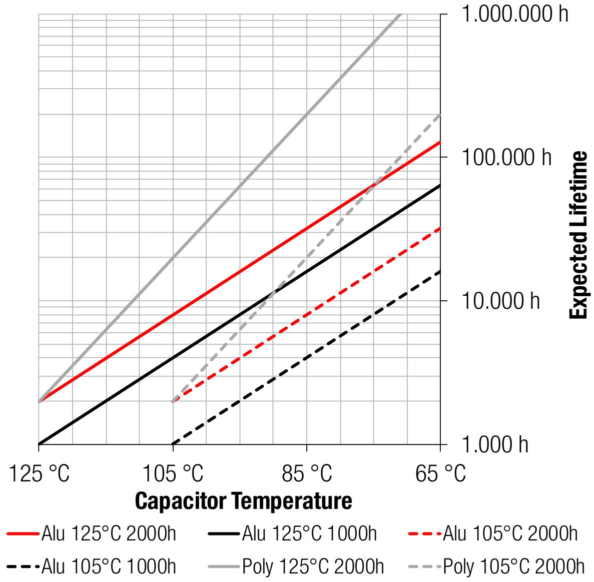


Figure 15: Overview of the expected lifetime of aluminum and aluminum polymer capacitors

6 Summary

Aluminum polymer capacitors, because of their construction, have significant advantages for electronic applications. Low ESR and low ESL values in addition to very high expected lifetime make this technology extremely interesting for many diverse applications. Therefore, the possible use should be considered based on the information provided in this Application Note. This can improve the behavior of the design and ultimately increase the performance of the application.

Application Note

Aluminum Electrolytic vs. Aluminum Polymer Capacitor and how its benefits are used properly

WÜRTH ELEKTRONIK

IMPORTANT NOTICE

USEFUL LINKS

Application Notes
www.we-online.com/appnotes

REDEXPERT Design Tool
www.we-online.com/redexpert

Toolbox
www.we-online.com/toolbox

Produkt Katalog
www.we-online.com/products

CONTACT INFORMATION

appnotes@we-online.com
Tel. +49 7942 945 - 0

Würth Elektronik eiSos GmbH & Co. KG
Max-Eyth-Str. 1 · 74638 Waldenburg · Germany

www.we-online.com