Power saver

Leakage current properties of modern electrolytic capacitors

Modern aluminium electrolytic capacitors with non-solid electrolyte, mainly in the low voltage range up to 63 V, are currently only noticed in modern electronics as a result of their size. Hardly anybody who is aware of all the possible problems in the development of electronic circuits pays any particular attention to them. They just work as long as their polarity has not been reversed. Also they continue to work in ever more difficult conditions. The following considerations focus in particular on the leakage current properties of aluminium electrolytic capacitors with non-solid electrolyte. In fact many users often have a completely false idea of the size of the leakage current properties of modern electrolytic capacitors. In any event they can no longer be described as “power eaters”.

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by Jens Both, BC Components, 31.08.2001

Leakage current

Summer and beach on the Baltic Sea coast. A small trickle of water runs out of a small sand dune, filled with beach grass and rosehips. This beach spring is extremely popular with children. What great fun it is to build dams here in the stream which is just two or three hands in width. Creating a proper lake, it's great fun. But whatever they do, they cannot make a genuine lake, it just remains a small puddle. Somehow or other the water always breaches the dam.

In principle a capacitor is just like a storage reservoir, not for water but for electrical charge carriers. And the leakage current can certainly be compared to the water seeping through the dam. A capacitor will also not become "full" if the discharge current is greater than or equal to the supply current. Anybody who has ever attempted to create a time switch with an electrolytic capacitor experienced that for the generation of a long period of time only a series resistance in the MΩ range does not produce the desired result – the charge simply disappears, the capacitor does not reach the voltage, it simply does not "fill up".

The leakage current of an electrolytic capacitor is based on the physical properties that lead to electrical losses. These are as follows:

- Energy required to build up oxide layers
- Weaknesses in the dielectric which result in a low current flow
- Tunnel effects
- Cross currents outside the electrolytic capacitor winding, for example low currents between the connections over liquid electrolyte films on the inside of the sealing rubber.

The leakage current of an electrolytic capacitor can best be compared to the barrier current of a Zener diode, which is connected in parallel to an ideal capacitor. Because of the structure of the electrolytic capacitor this actually means that there are two diodes, one parallel to the anode capacity and the second parallel to the cathode capacity, which form the equivalent circuit diagram of the electrolytic capacitor in terms of its leakage current. However, this equivalent circuit diagram does not show the cross currents outside the electrolytic capacitor winding. As a result of this it is only an ideal diagram of the leakage current through the oxide layers in the electrolytic capacitor.

However, the leakage current also contributes to the electrolytic capacitor being so inconspicuous in applications in terms of reliability. After all the leakage current gives the electrolytic capacitor the property of self-healing. This continuous "repair" of weak points in the oxide of the dielectric is connected to energy consumption, which is ultimately provided by in the leakage current.

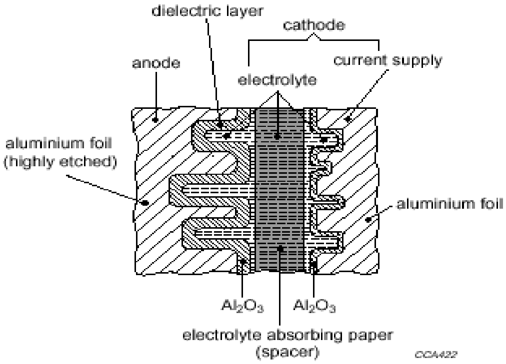


Figure 1
Principle structure of an aluminium electrolytic capacitor with non-solid (wet) electrolyte. The oxide layer on the anode forms the dielectric of the capacitor. The liquid electrolyte acts as a cathode on this large area contacting of the roughened structures of the aluminium foils.

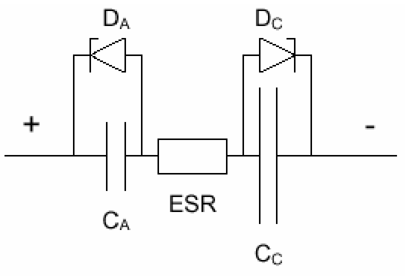


Figure 2
Equivalent circuit diagram for the leakage current properties of an aluminium electrolytic capacitor

Specified leakage current and operating leakage current

In the ideal case the leakage current I_L of an electrolytic capacitor depends on the capacitance value of the capacitor, the applied voltage, a constant adder and, particularly importantly, on the measuring time. Normally the leakage current of an electrolytic capacitor is therefore specified with a formula that contains the capacitance C_R and the rated voltage U_R and which defines the limit value of the leakage current after a certain measuring time (in this case 2 and 5 minutes), for example using the following formulae:

- I_L (2 min) < (0.01 * U_R * C_R) + 3 µA
- I_L (5 min) < (0.002 * U_R * C_R) + 3 µA
  for $U_R \le 100$ V
- I_L (5 min) < (0.01 * U_R * C_R) + 3 µA
  for $U_R > 100$ V

or, in accordance with EN 130300

- I_L (5 min) < (0.3 * U_R * C_R) $^{0.7}$) + 4 µA

However, every manufacturer uses his own calculation formulae, most of which also differ from series to series. The leakage current value calculated with the relevant formula defines the maximum value after the elapse of the measuring time after the rated voltage has been applied. Normally the value of the leakage current will be much smaller.

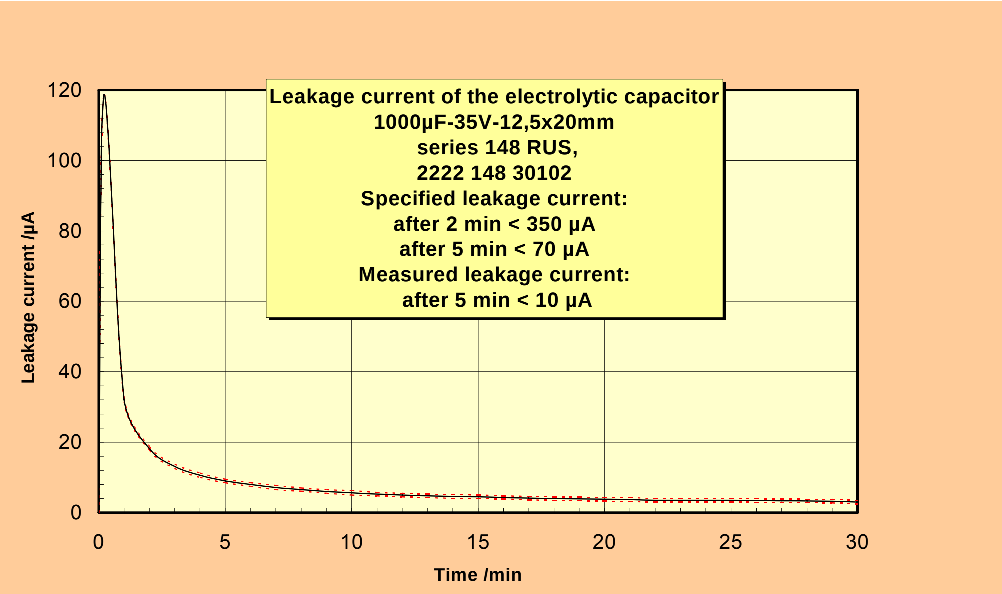


Figure 3
Typical time behavior of the leakage current of an aluminium electrolytic capacitor after switching on

As the curve in Figure 3 shows, the leakage current after 5 minutes in this example is by far lower than the 5-minute acceptance limit value of 70 µA. And in this example the measured leakage current value approaches a constant, small value of around 5 to 10 µA on an asymptotic basis. This final value is known as the ***operating leakage current*** and has usually established itself after around one hour. After this time all the weaknesses in the dielectric of the electrolytic capacitor of the modern professional electrolytic capacitor supplied today have been healed and the leakage current has declined to a permanent low value, which now corresponds to the situation in the equivalent circuit diagram in Fig. 2.

The leakage current value after 2 or 5 minutes, the so-called acceptance value, is relatively high compared to the curve shown in figure 3. It is specified at such a high level because normally various influences of the “previous history”, such as lengthy storage with no voltage, have a major effect on the measurement when the capacitor is switched on for the first time.

The influence of the previous history

The time dependence of the leakage current is shown very clearly in the curve in Figure 3. This behaviour results from the self-healing effect of the electrolytic capacitor and the anodic oxidation or forming of the dielectric. After all, weaknesses in the dielectric, which can be created by chemical processes on the oxide layer during storage or as a result of mechanical damage during the production of the device, are healed when a voltage is applied to it. However, time is required for this healing process, also known as the forming process. The weakening of the dielectric, however, is also a question of the previous history of the capacitor. The following example is suitable to explain the term “previous history” in some more detail.

A large customer from the consumer electronics sector reported increasing problems with electrolytic capacitors from a manufacturer. During the automatic alignment of the settings on the television chassis after the assembly process, various test points on the circuit did not reach the specified voltage which meant that the alignment could not be completed. The alignment conditions had not been changed. The alignment process was initiated only 15 seconds after the chassis had been completed. A check of the electrolytic capacitors at these test points showed “excessive leakage current”. The leakage current values of the electrolytic capacitors concerned were actually all below the 5 minutes acceptance limit value. An alignment after only 15 seconds, however, was not based on any data sheet value. But the capacitors from the same manufacturer had not caused any problems in the past. What was discovered in this batch, however, was that this batch had a considerably higher general leakage current level than previous batches.

The cause of this unusual behaviour was ultimately found to be the previous history of the capacitors. The production of these electrolytic capacitors in the Far East took place in August and September in a hall with no air-conditioning. This season in this region is notable for its tropical humidity values. The electrolytic capacitor papers and the hygroscopic electrolyte had drawn in a great deal of water. The water, which reacted extremely aggressively in the electrolytic capacitors, had partially attacked the dielectric during the storage period which was between the production of the electrolytic capacitors and the first time they were switched on, and this resulted in the dielectric being weakened. These weaknesses were the cause of the increased leakage current level shortly after they were switched on by the customer.

Lengthy storage with no voltage, therefore, may weaken the dielectric due to dissolution processes. The properties of different electrolyte systems are clear in this respect. So-called “aqueous” electrolytes generally have considerably worse storage properties than solvent electrolytes. And where we speak about “professional” electrolytic capacitors in this paper, we are talking about series of temperatures of 105 °C or 125 °C which have inert solvent-based electrolytes for example based on GBL solvents.

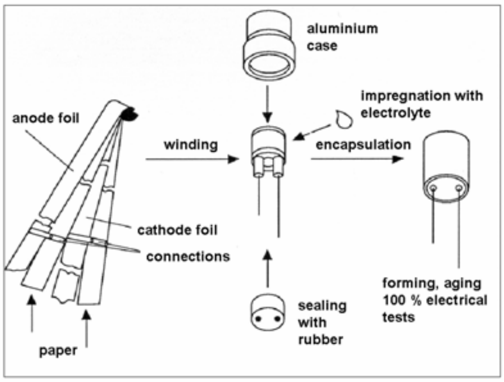


Figure 4 Principle production process of aluminium electrolytic capacitors with non-solid electrolyte

Device production is also part of the previous history

Figure 5
Series 140 CLZ SMD electrolytic capacitors from BCcomponents are designed for applications with temperatures up to 125 °C

Another influence that belongs in the previous history of the electrolytic capacitor is the soldering process. In particular when small sizes are concerned, the heat of the solder enters straight into the capacitor winding ~~coil~~ through the connections. This means that in small parts of the winding the temperature of the metal parts rises well above the boiling point of any non-solid electrolyte. This considerably accelerates the weakening processes of the oxide layer on the anode which results in the leakage current increasing accordingly when the electrolytic capacitor is switched on for the first time.

The soldering process for SMD components has a much greater influence on the electrical parameters. The reflow soldering curve reaches a peak temperature of 260°C. Normally, however, the boiling point of standard electrolytes is around 150°C to 180°C. On SMD components, some of which are extremely small, the boiling temperature inside the electrolytic capacitor is very quickly exceeded. Part of the electrolyte is therefore converted into a gaseous form. The consequences of this are dramatic - a major fall in capacity, a drastic rise in ESR and also in leakage current. Whilst the capacity and the ESR of the electrolytic capacitor normalise again when the temperature falls and after around 6 to 12 hours they will have reached their initial state again with the exception of minor discrepancies, the leakage current will not decrease until voltage is applied for a certain period of time. The accelerated weakening of the dielectric caused by high temperatures must first be healed, and that takes time.

Another influence from the previous history should also not be forgotten. The mechanical stress on the connection wires during production caused by cutting or bending the wires during production, for example, can easily place mechanical forces into the winding, particularly in radial electrolytic capacitors.

The influence of the previous history on the leakage current of an electrolytic capacitor has also determined the measuring regulations relating to electrical parameters in current standards. Among other things, the capacitance value should always be measured **after** the leakage current has been measured. The reason for this is obvious – if the leakage current is too high the capacity measurement will be falsified.

Today, naturally, no manufacturer of electrolytic capacitors would be well advised to reject returns of his products with reference to the above passage. But the enormous fluctuation of leakage current values on delivery, resulting from the chemical and physical conditions in the previous history of the electrolytic capacitor, makes it appear a good idea to consider leakage current measurement results as a special case, particularly since the components undergo a self-healing process and offer outstanding function when used in practice.

Operating leakage current

Users expect and generally also receive relatively stable aluminium electrolytic capacitors today in terms of their leakage current properties. “Relatively” because the leakage current values of film capacitors or ceramic capacitors can obviously not be achieved by electrolytic capacitors.

Emotionally, the leakage current of an electrolytic capacitor is generally considered to be at a much higher level. This is due to the fact that the 5 minute value for the leakage current specified in data sheets is generally several factors higher than the actual operating leakage current. And the operating leakage current will not be reached, of course, until the capacitor has been operating for a certain length of time, until in fact the weaknesses in the dielectric have been healed properly. And the longer the voltage is applied to the capacitor, the lower the leakage current will be – see Figure 6.

How remarkably low the leakage current may be on good quality professional goods these days is shown clearly by a simple test. First of all charge an electrolytic capacitor to its rated voltage and then disconnect it from the power source. Then measure the remaining voltage on the electrolytic capacitor at hourly intervals. Since the leakage current ensures that the capacitor suffers constant trickle discharge, after a certain time the measured voltage should have fallen to zero. What do you think how long – and this is obviously completely independent of the capacitance value, see leakage current formula – it will take for the voltage to fall to zero?

Hours? Days? Weeks?

And now we come to the amazing bit – even after several months of open storage, it will still be possible to measure a remaining small residual voltage on the electrolytic capacitor. In other words people in general have a completely false impression of the value of the leakage current in aluminium electrolytic capacitors with non-solid electrolyte. Or did you guess that the answer was “months”?

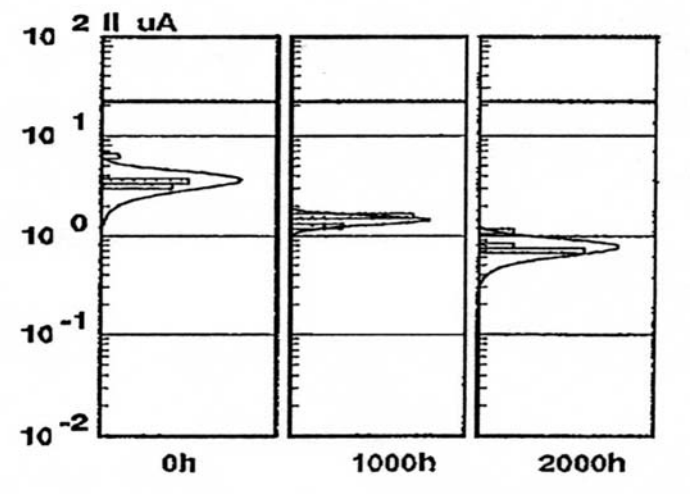


Figure 6
Leakage current properties of electrolytic capacitors during a 2000 hours life test
The longer the voltage is applied to the capacitor, the lower the leakage current becomes

Voltage and temperature dependence of the operating leakage current

As the example described above shows, the operating leakage current is several factors lower than the acceptance value specified in the relevant data sheets. General specifications for the operating leakage current in the form of formulae in the literature contain massive fluctuations. But this is hardly surprising when we consider that the quality of professional electrolytic capacitors has improved massively in terms of leakage current over the last 20 years.

A leakage current value of around 10 µA for a 1000 µF electrolytic capacitor at 35 V (see Figure 3) is therefore by no means uncommon. However, this value is also not stable. The operating leakage current of an aluminium electrolytic capacitor with non-solid electrolyte is extremely dependent on the temperature and voltage. These properties are understandable and can be explained easily using the model of the activation energy. The level of the operating leakage current under operating conditions can be calculated in approximate terms using the factors I_{op} / I_L shown in Figures 7 and 8 below. Figure 9 shows the result of a measurement of the leakage current of a 2100 µF capacitor at two temperatures to show the temperature dependence described above on a practical example.

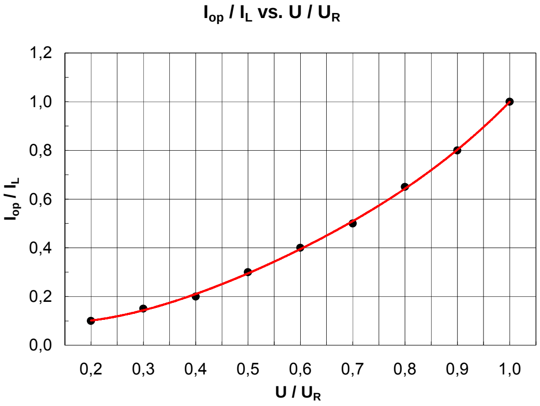


Figure 7
Typical multiplier of the operating leakage current as a function of the voltage applied

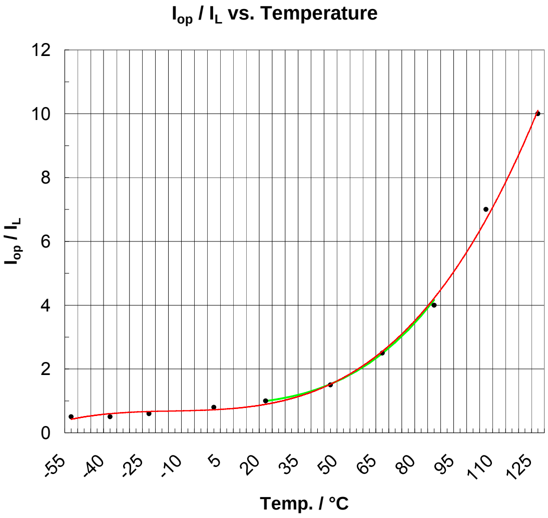


Figure 8
Typical multiplier of the operating leakage current as a function of the capacitor temperature

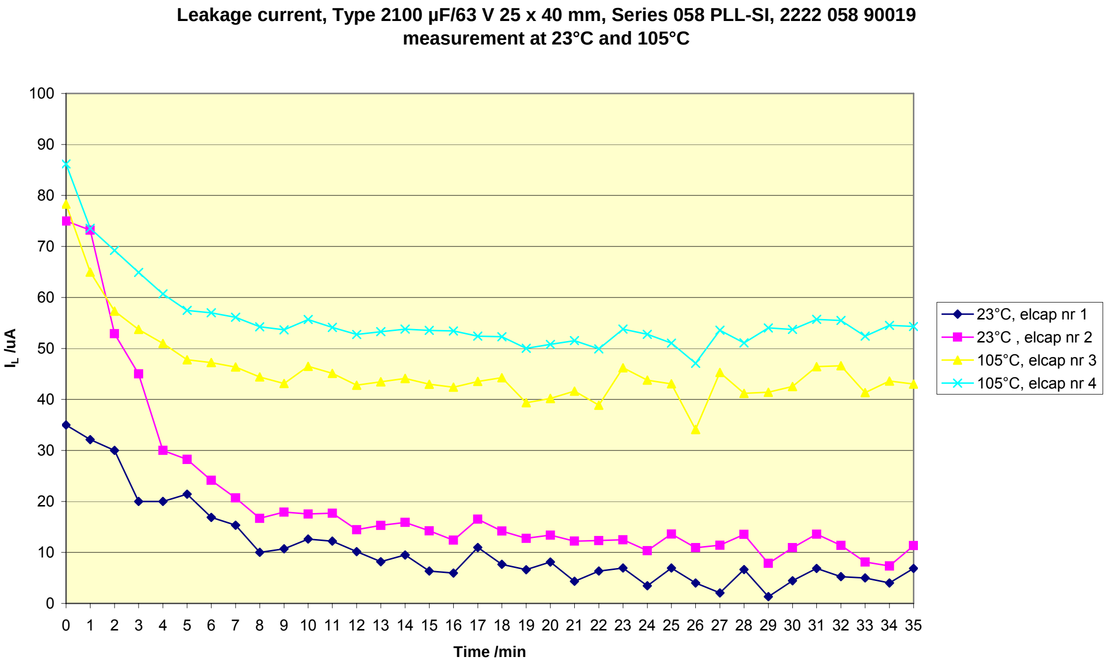


Figure 9
Temperature dependence of the operating leakage current of a 2100 µF/63 V electrolytic capacitor at 23°C and 105°C

Does leakage current influence the useful life or the service life of the electrolytic capacitor?

Many manufacturers also issued instructions and even formulae that describe the influence of the level of the applied voltage on the expected useful life. Since we now know that the level of the applied voltage co-determines the level of the leakage current, it can certainly be assumed that voltage influences useful life. After all, the leakage current is also a measure of the forming work that takes place over the entire life time of the capacitor. Since this forming work ultimately withdraws oxygen from the electrolyte and uses it to repair damaged or weakened oxide layers, the electrolyte is therefore consumed. And the loss of electrolyte determines the useful life of the electrolytic capacitor on the basis of the conventional model. On a purely theoretical basis, therefore, if the full rated voltage is applied to the electrolytic capacitor, the component should offer a shorter useful life than if a lower voltage were to be applied.

However, if we consider the physical causes of the electrolytic capacitor leakage current, it is likely that only part of the leakage current will be found in the form of forming work. The remainder of the electrons will tunnel through the dielectric using tunnelling effects or will flow in the form of cross current through electrolyte films around the rubber seal, in other words they will have no influence whatsoever on the possible loss of electrolyte. If we also take into account the level of the leakage current we come to the conclusion that the influence of leakage current on useful life is in fact rather low. This certainly applies to electrolytic capacitors in the voltage range up to around 100 V (low voltage) and for electrolytic capacitors with solvent, non aqueous electrolytes. For these capacitors the small mechanical variations in the sealing capacity of the gaskets and therefore the distribution of the expected electrolyte loss over the useful life is definitely more significant than the level of the applied voltage and the leakage current related to it.

Low leakage currents – significance in practice

In a normal application, electrolytic capacitors are used as buffer and filtering capacitors in the power supply train to electronic circuits. They generally have a low resistivity for AC currents in the supply. A low leakage current is actually not necessary for the function of the circuit but there are other applications where the level of the losses is significant. Let's consider motor vehicle electronic systems. Every modern car has between 100 and 400 electrolytic capacitors, depending on the technological level of equipment in it. And many of the devices are connected to the battery in standby mode at all times. If the total of all losses amounts to several hundred mA, holiday makers returning from their 14 days in Majorca will quickly lose their good mood if the battery in their parked car has discharged. However, if the values are actually in the "µA" range, and the total from all 200 units then amounts to a value in the "mA" range, the risk of this happening is negligible.

In another former motor vehicle application, however, high efforts have been made to achieve very good leakage current properties from the very beginning. The former flashers in a car were activated using timing elements (RC elements). If the leakage current increases too much, the flasher frequency changes. The motor vehicle approval authorities were very strict in this respect. The flashing frequencies had to be within precisely defined limits. The discussion about timing elements using a resistor and an electrolytic capacitor also resulted in the rule of thumb for the function of a circuit of this type – the current defined by the series resistor should be 10 times as high as the 5 minute value for the leakage current of the electrolytic capacitor.

Figure 10
Electrolytic capacitors in a motor vehicle injection circuit from Bosch

Low leakage current electrolyte capacitors for the very highest demands

Extremely high demands on very low leakage current values are very common in an application that affects many households. This application is heating cost readers installed on heating equipment to transmit the temperatures of the radiators to a central computer by means of pulse coding. The reading circuit has no mains connection. The energy for the transmitted pulses for a useful or service life of 10 years is stored in a battery. A buffer electrolytic capacitor provides the low resistivity supply of the transmission energy for the radio signals required in this circuit. This means that the electrolytic capacitor leakage current influences the overall useful life of the reading circuit. It is noticeable that the manufacturers strive hard to reduce the leakage current of the electrolytic capacitor by every possible µA. The factor that makes this even more difficult is that the circuit on the radiator becomes hot and the leakage current increases with the temperature.

In these applications the electrolytic capacitor manufacturer normally must take special action to ensure that the leakage current values are particularly low. This challenge can be met by the careful selection of suitable anode foils with specially textured oxide layers in extraordinarily homogeneous coatings. This means that the oxide can be crystalline, amorphous or even layered in a suitable sequence. Homogeneous oxide layers reduce the already very low number of weaknesses in the dielectric even further and that results in the leakage current from the electrolytic capacitor being even lower.

Initial tests into this application which is extremely demanding for aluminium electrolytic capacitors were conducted using anode foils that had been preconditioned very homogeneously. In further tests and during the initial field trials, however, it turned out that capacitors from the existing commercially offered series – so-called “Low Leakage Current” series – yielded fairly good results with regard to the residual current. The fact that the on-load voltage in this application was only 3 V further facilitated this approach through the voltage dependence of the residual current of these capacitors rated at 16 V. In further long term tests it could be confirmed that, after several days of continuous operation at room temperature, residual current values of only a few tens of nA were achieved. These residual current values that one normally does not credit “wet” aluminium electrolytic capacitors with are sufficiently low to come up even to the most demanding requirements.

Figures 11 and 12
Heat metering devices, Techem

The heat meter circuit is powered by a lithium battery which supplies the circuit with energy for a period of 10 years without requiring any maintenance.

Influence of leakage current in electrolytic capacitors connected in series

Connecting aluminium electrolytic capacitors in series results in the voltage being split between the components and in turn this is influenced by the leakage current difference between the individual capacitors in a series. It is therefore very important that the leakage current differences are balanced in the circuit design since even very small differences can cause problems. These differences normally become apparent when the circuits are activated in the form of overvoltage on the component with the lowest leakage current. Since considerable fluctuations can be found between individual capacitors from the very same production run in terms of their leakage currents, it is also possible that large voltage differences may occur. If this results in exceeding the rated voltage of a capacitor, under certain circumstances this can result in premature failure.

This leakage current difference is normally kept under control by using balancing (Figure 13, R_1, R_2) resistors over each of the individual components. The method to calculate the symmetry resistors is set out in the "Guideline for the use of aluminium electrolytic capacitors, DIN 45811".

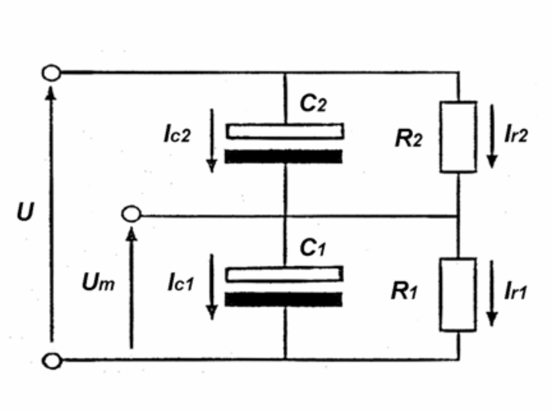


Figure 13
Electrolytic capacitors connected in series have to be balanced by using external balancing resistors R_1, R_2 in order to avoid voltage differences based on different leakage currents I_{c1} and I_{c2}.

Leakage current, a historical view

Why is leakage current still such a common topic of discussion with customers? In most applications electrolytic capacitors are used for buffering in power supply train and as such will have sufficient current passing through them. In these cases the leakage current parameter is fairly insignificant. And even if devices are left on shelves for lengthy periods, device failures caused by excessive leakage currents in the electrolytic capacitors are extremely rare.

The explanation can only be found if we consider the development of electronic circuits over the last 50 years. Even younger developers have been indoctrinated with a certain amount of prejudice about the term of “leakage current” related to “wet” electrolytic capacitors, generally during their training. The literature rarely quotes the low leakage current achievable today accurately. There is still often a notion originating from problems in the early days of electrolytic capacitor production. In fact corrosion was the cause of many problems experienced in the sixties. High leakage current and even short circuits were often found in electrolytic capacitors at that time. The reason for the corrosion problems in electrolytic capacitors included impurities, particularly with halogens such as chloride. Chloride acts as a catalyst for aluminium corrosion in the electrolytic capacitor. This process goes hand in hand with increased forming work, in other words with increased leakage current.

Acknowledgement of this situation led to stringent purity regulations, particularly relating to impurities with halogens in the production of electrolytic capacitors. This resulted in leakage current values in almost chloride-free capacitors falling massively. Corrosion problems caused by impurities involving halogens no longer exist in the electrolytic capacitors manufactured today. But the discussion about leakage current has remained. However, nowadays, the quantitative consideration has taken on a completely different value.

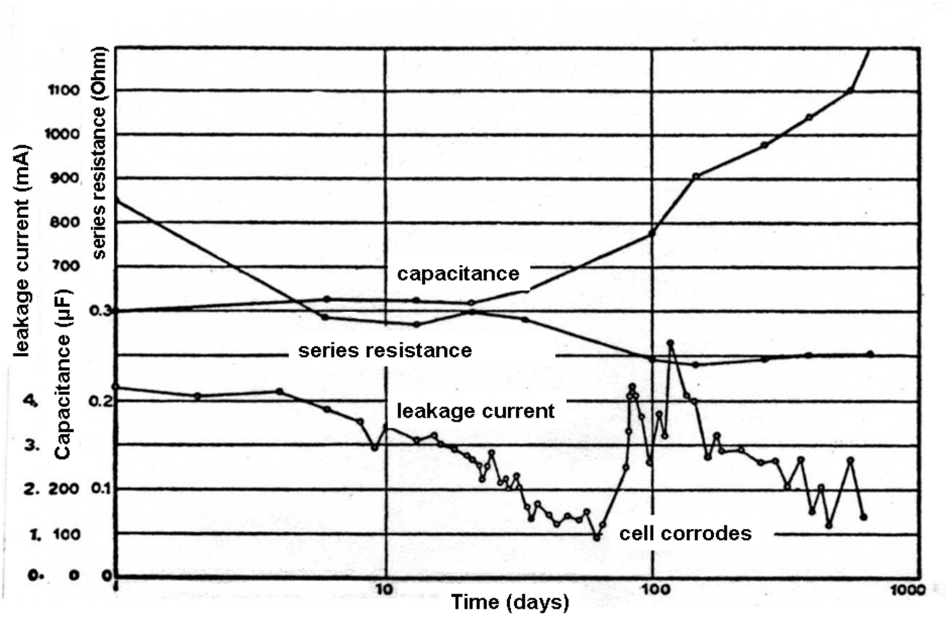


Figure 14
Curves showing the capacitance, the series resistance and the leakage current in an 1000 hours endurance test on a 700 µF/65 V electrolytic capacitor dating from 1929
Peculiarity: Corrosion and its influence on the leakage current

A very wide choice, relevance of leakage current?

Naturally there are differences in the self-healing or reforming and the leakage current properties of modern electrolytic capacitors. These differences can be extreme in some cases. How can a developer now find out how the selected electrolytic capacitor will act in terms of its leakage current properties? After all, the 5 minute limit value in the relevant data sheets really does not provide sufficient information. Well, first of all the developer must first decide whether this question makes any sense at all.

To explain what is meant by this, let us look at an example. For a plug-in power supply, which is subject to extreme cost pressure and on which there are no special requirements in terms of useful or service life, it makes no sense whatsoever to discuss additional benefits since no customer will pay for a particularly low leakage current if he has no concept of what it actually means. The situation is different, for example, in motor vehicle electronics. As described above, it makes a great deal of sense to ensure that the goods in this case have low operating leakage currents.

However, for the well-informed developer there is a relationship, a test, which, whilst it does not indicate particularly low leakage current values, nevertheless shows that the electrolytic capacitor will offer good long term stability. This is the hot storage test. This relates to a test which is conducted at the upper category temperature without any voltage being applied. No voltage means that no self-healing can take place. And since the test is conducted at high temperature, all the chemical dissolution processes will be accelerated greatly. The international standard IEC 60384-4 defines a minimum test time of 100 hours. A hot storage test time of 500 or 1000 hours therefore means that the manufacturer is sure that the electrolyte is essentially chemically inert, that the oxide layer does not suffer weakness and therefore that no increased residual current will occur. The lack of any such specification in a data sheet or a test time of only 100 hours could therefore indicate that the electrolytic capacitor may not be very stable in terms of this parameter.

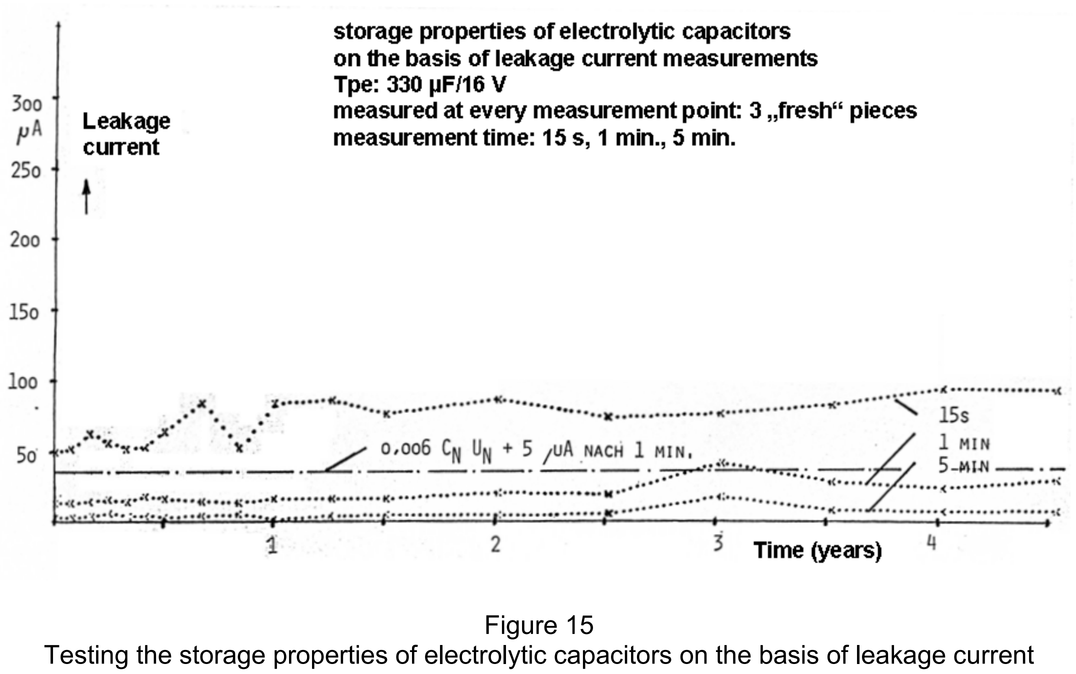
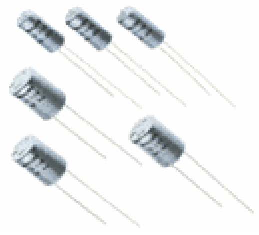
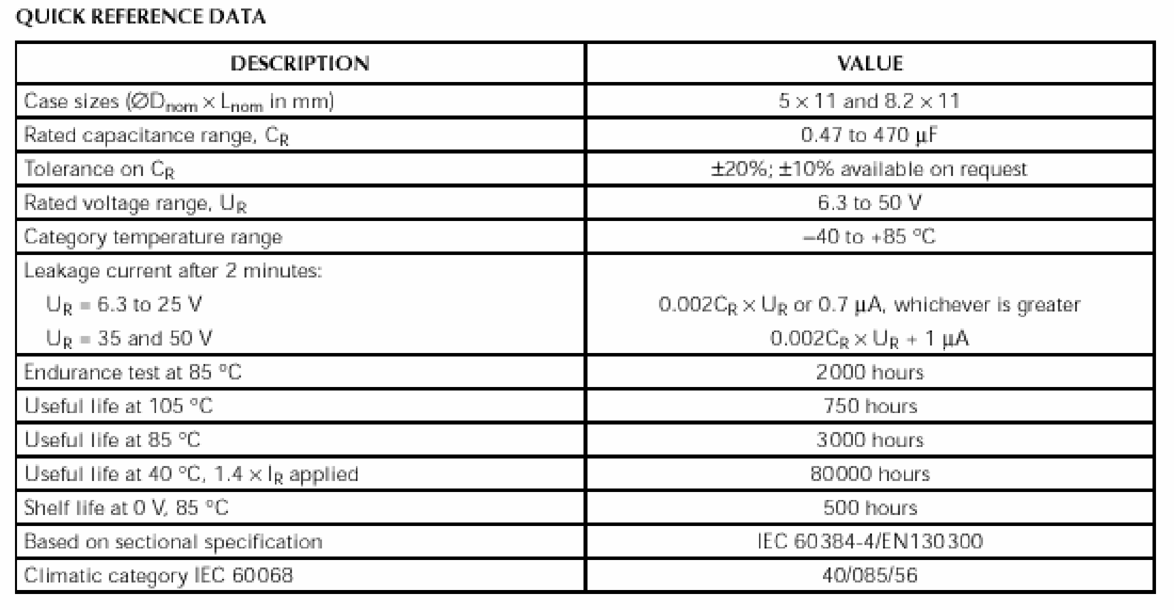


Figure 15
Testing the storage properties of electrolytic capacitors on the basis of leakage current measurements on 3 “fresh” capacitors after the specified storage period
Even after 4 years, no increased leakage current values were found
on these electrolytic capacitors from BCc



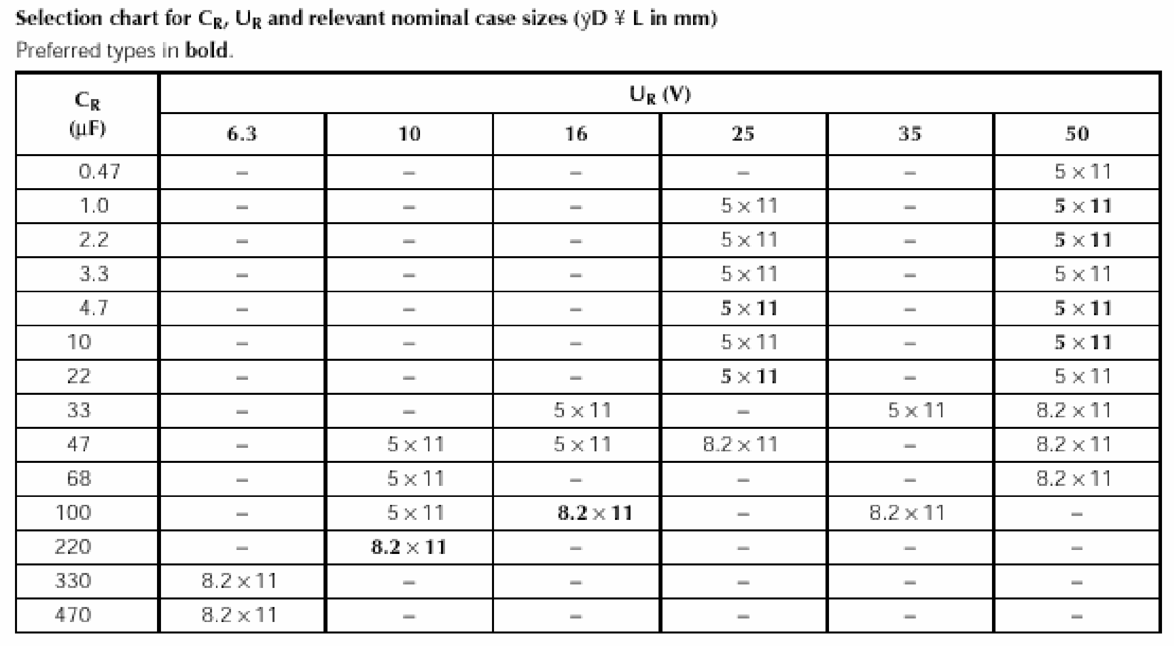
BCcomponents, recommended series

Series 013 RLC



QUICK REFERENCE DATA

DESCRIPTION	VALUE
Case sizes (ØD$_{nom}$ × L$_{nom}$ in mm)	5 × 11 and 8.2 × 11
Rated capacitance range, C$_R$	0.47 to 470 µF
Tolerance on C$_R$	±20%; ±10% available on request
Rated voltage range, U$_R$	6.3 to 50 V
Category temperature range	−40 to +85 °C
Leakage current after 2 minutes: U$_R$ = 6.3 to 25 V U$_R$ = 35 and 50 V	 0.002C$_R$ × U$_R$ or 0.7 µA, whichever is greater 0.002C$_R$ × U$_R$ + 1 µA
Endurance test at 85 °C	2000 hours
Useful life at 105 °C	750 hours
Useful life at 85 °C	3000 hours
Useful life at 40 °C, 1.4 × I$_R$ applied	80000 hours
Shelf life at 0 V, 85 °C	500 hours
Based on sectional specification	IEC 60384-4/EN130300
Climatic category IEC 60068	40/085/56



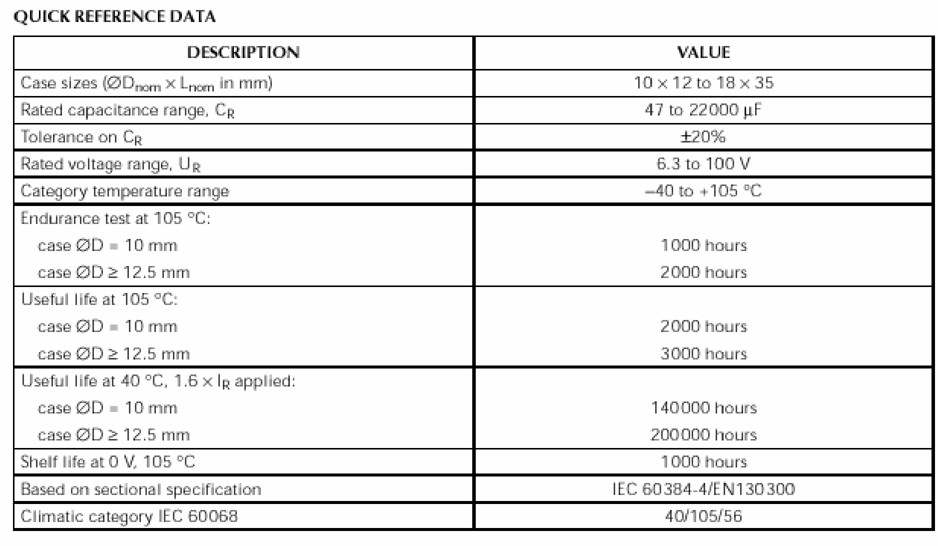
Selection chart for C$_R$, U$_R$ and relevant nominal case sizes (yD ¥ L in mm)

Preferred types in **bold**.

C$_R$ (µF)	U$_R$ (V)					
	6.3	**10**	**16**	**25**	**35**	**50**
0.47	–	–	–	–	–	5 × 11
1.0	–	–	–	5 × 11	–	**5 × 11**
2.2	–	–	–	5 × 11	–	**5 × 11**
3.3	–	–	–	5 × 11	–	5 × 11
4.7	–	–	–	**5 × 11**	–	**5 × 11**
10	–	–	–	5 × 11	–	**5 × 11**
22	–	–	–	**5 × 11**	–	5 × 11
33	–	–	5 × 11	–	5 × 11	8.2 × 11
47	–	5 × 11	5 × 11	8.2 × 11	–	8.2 × 11
68	–	5 × 11	–	–	–	8.2 × 11
100	–	5 × 11	**8.2 × 11**	–	8.2 × 11	–
220	–	**8.2 × 11**	–	–	–	–
330	8.2 × 11	–	–	–	–	–
470	8.2 × 11	–	–	–	–	–

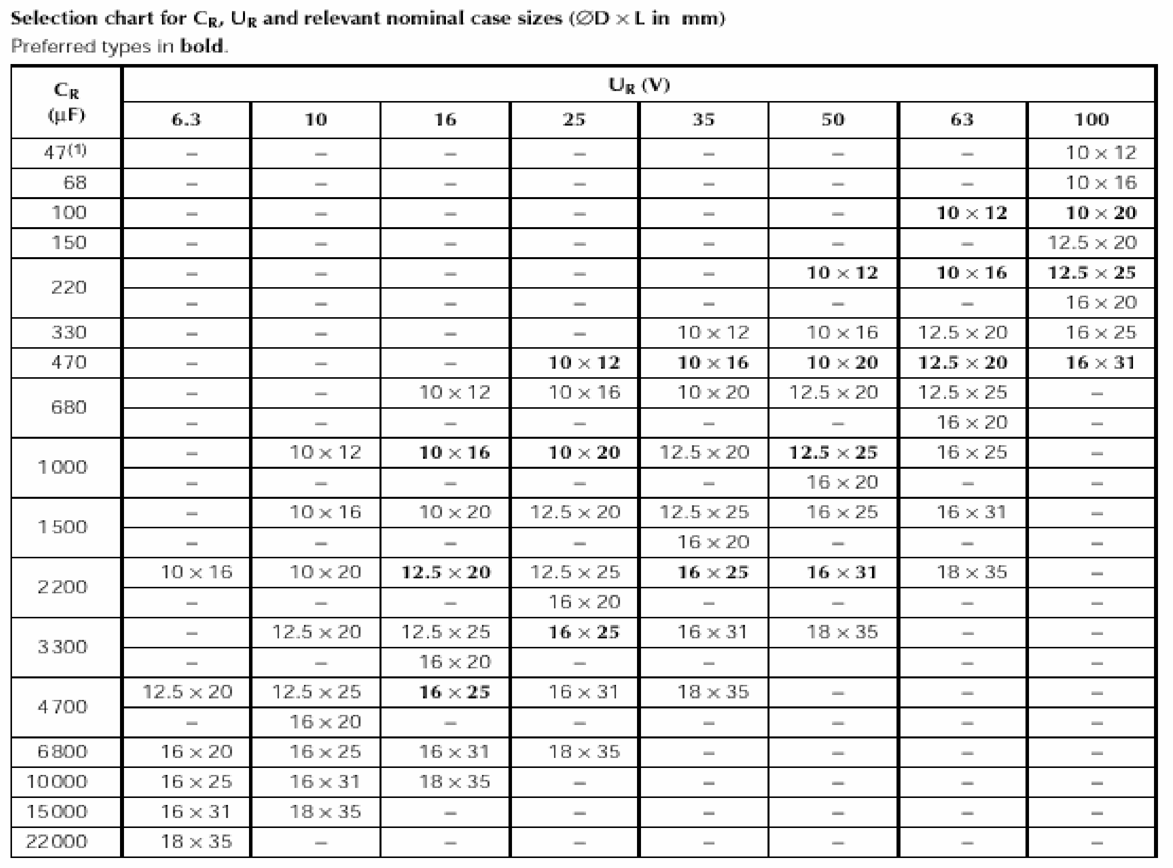
BCcomponents, recommended series

Series 148 RUS



QUICK REFERENCE DATA

DESCRIPTION	VALUE
Case sizes ($\varnothing D_{nom} \times L_{nom}$ in mm)	10 × 12 to 18 × 35
Rated capacitance range, C_R	47 to 22000 µF
Tolerance on C_R	±20%
Rated voltage range, U_R	6.3 to 100 V
Category temperature range	−40 to +105 °C
Endurance test at 105 °C:	
case ØD = 10 mm	1000 hours
case ØD ≥ 12.5 mm	2000 hours
Useful life at 105 °C:	
case ØD = 10 mm	2000 hours
case ØD ≥ 12.5 mm	3000 hours
Useful life at 40 °C, 1.6 × I_R applied:	
case ØD = 10 mm	140000 hours
case ØD ≥ 12.5 mm	200000 hours
Shelf life at 0 V, 105 °C	1000 hours
Based on sectional specification	IEC 60384-4/EN130300
Climatic category IEC 60068	40/105/56



Selection chart for C_R, U_R and relevant nominal case sizes (ØD × L in mm)

Preferred types in **bold**.

C_R (µF)	**U_R (V)**							
	6.3	**10**	**16**	**25**	**35**	**50**	**63**	**100**
47[1]	–	–	–	–	–	–	–	10 × 12
68	–	–	–	–	–	–	–	10 × 16
100	–	–	–	–	–	–	**10 × 12**	**10 × 20**
150	–	–	–	–	–	–	–	12.5 × 20
220	–	–	–	–	–	**10 × 12**	**10 × 16**	**12.5 × 25**
	–	–	–	–	–	–	–	16 × 20
330	–	–	–	–	10 × 12	10 × 16	12.5 × 20	16 × 25
470	–	–	–	**10 × 12**	**10 × 16**	**10 × 20**	**12.5 × 20**	**16 × 31**
680	–	–	10 × 12	10 × 16	10 × 20	12.5 × 20	12.5 × 25	–
	–	–	–	–	–	–	16 × 20	–
1000	–	10 × 12	**10 × 16**	**10 × 20**	12.5 × 20	**12.5 × 25**	16 × 25	–
	–	–	–	–	–	16 × 20	–	–
1500	–	10 × 16	10 × 20	12.5 × 20	12.5 × 25	16 × 25	16 × 31	–
	–	–	–	–	16 × 20	–	–	–
2200	10 × 16	10 × 20	**12.5 × 20**	12.5 × 25	**16 × 25**	**16 × 31**	18 × 35	–
	–	–	–	16 × 20	–	–	–	–
3300	–	12.5 × 20	12.5 × 25	**16 × 25**	16 × 31	18 × 35	–	–
	–	–	16 × 20	–	–		–	–
4700	12.5 × 20	12.5 × 25	**16 × 25**	16 × 31	18 × 35	–	–	–
	–	16 × 20	–	–	–	–	–	–
6800	16 × 20	16 × 25	16 × 31	18 × 35	–	–	–	–
10000	16 × 25	16 × 31	18 × 35	–	–	–	–	–
15000	16 × 31	18 × 35	–	–	–	–	–	–
22000	18 × 35	–	–	–	–	–	–	–

Tadiran Batteries GmbH
Industriestr. 22
D-63654 Büdingen, Germany
Tel.: +49(0)6042/954-0
Fax: +49(0)6042/954-190
E-Mail: info@tadiranbatteries.de
Internet: www.tadiranbatteries.de

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