Performance of MLP and MLS Flatpack Aluminum Capacitors
Written by Laird Macomber

Cornell Dubilier offers two types of flatpack aluminum electrolytic capacitors, the MLP and the MLS. The MLP is rated to 85 ºC and is in a grade 1100 aluminum case. The MLS is rated to 125 ºC and is in a grade 316 stainless-steel case. The MLS is the high-performance version: It costs about twice as much, weighs about 40% more, has much longer expected life and twice the ripple current capability.

These flatpack capacitors are versatile. The high capacitance density in a 12.5 mm pitch permits use in most rack mounting applications. The box shape encourages efficient stacking into module assemblies. The broad, flat sides make heatsinking simple and effective. The units' nearly hermetic seal and high-purity materials assure extremely long life, and for 250 V and less they exhibit superior low-temperature impedance down to –55 °C.

MLPs and MLSs offer high capacitance density. The MLP has over twice the energy density of a 1⅜-diameter, 105 ºC screw-terminal capacitor. It has about four times the energy density of a bank of ½" diameter 105 ºC capacitors. Compared to the space lost with the round-can shape of ordinary capacitors, the flatpack package amplifies the space savings by 27%.

The high-energy storage and convenient low-profile box shape of these flatpack capacitors make them right for low-profile board applications and for stacked assemblies. Power holdup is the most popular application.

The MLP flatpack capacitor started production in 1991, was joined by its stainless-case brother, the MLS a few years later and both have become steadily more popular as the answer to how to put a high-energy capacitor in a square hole. The flatpack box shape fits naturally in low-profile electronics and is easy to heatsink.

The MLPs and MLSs are especially popular in military and avionic systems. MLSs and MLPs are in applications as diverse as shipboard antennae and power holdup in the radio system of a new jet fighter. MLSs are on large commercial aircraft and missile systems. Twenty MLSs are in a helicopter actuator system. MLSs are in military power amplifiers, military power PC cards and modules and avionics power supplies. Avionics programs that use MLP and MLS flatpacks include the KC135, the C17, the F15, The F16, the F18, the F22, the E2C, the X33 Space Shuttle, and many more.

A growing use of MLPs and MLSs is as a replacement for arrays of wet tantalum capacitors. As an illustration, two 3000 µF, 50 V, MLS flatpacks replaced 22 wet-tantalum capacitors in a power-holdup circuit in a military radar. While wet-tantalum capacitors are limited to 125 V, the MLP is offered up to 450 V.

The MLP looks good as a wet-tantalum capacitor replacement because compared to the tantalum-capacitor array, the MLP costs much less and weighs half as much, although it is somewhat bigger. The performance feature that makes it especially attractive is shelf life. Wet-tantalum capacitors boast 25 years shelf life and so does the MLP/MLS even though other aluminum electrolytic capacitors usually claim only 5 to 10 years shelf life.

MLP Shelf Life

What determines the maximum permitted storage shelf-life time for an aluminum electrolytic capacitor is the dc leakage current. DCL increases during long storage, especially at high temperature, and can reach a point where the DCL produces so much hydrogen gas during first electrification of the capacitor that the pressure-relief vent operates and the capacitor fails. Aluminum electrolytic capacitors have improved steadily over the years and it is now commonplace to expect more than 10 years storage capability at a warehouse temperature of 40 °C or less. The Type MLP capacitor is capable of more than 25 years storage. This improved performance results from the strong, welded seal that permits high pressure buildup before operation of the pressure-relief vent and the use of a low-gassing electrolyte system for MLPs rated 250 V or less. In combination with high-purity anode foils and higher formation voltage, the MLP's DCL is inherently low and provides exceptionally long storage capability.

The following table shows that a 1000 µF, 200 V MLP can be stored for 3000 h at 85 °C without a significant increase in DCL. The data shows that the dc-leakage current increases about 0.05 mA per 1000 hours, and at that rate would reach its maximum limit, 0.4 mA, in 12,000 hours. While maximum initial dc leakage is defined as the end-of-life shelf test limit, capacitors with dc leakage two or more times the limit are readily suitable for circuit application without any preconditioning. At a rate of 0.05 mA increase per thousand hours, it will take another 10 years to reach two times the limit and 20 more years to reach three times the limit. And notice in the data that the increase per thousand hours is decreasing each 1000 hours, so 0.05 mA is conservative.

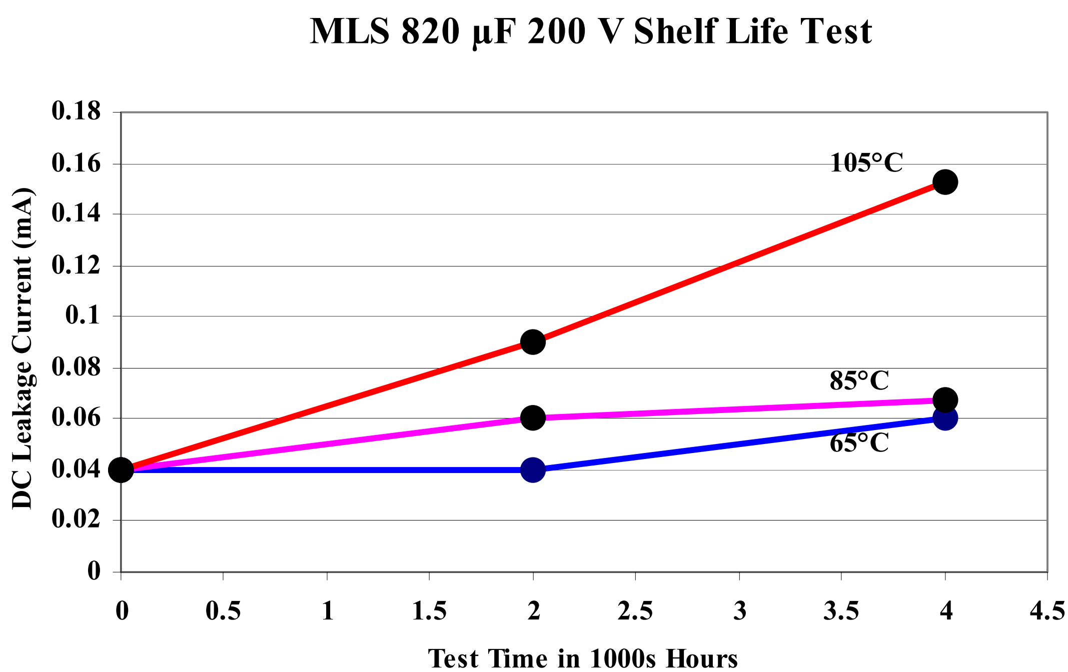
This is for the capacitor stored at 85 °C and tested at 200 V. If your application starts at 90% rated voltage and at 65 °C, the dc leakage current would be about 15 times lower. That would drop the leakage current in a capacitor reading 1 mA down to 0.07 mA, and add 30 years storage.

So the MLP will furnish more than 25 years storage capability at temperatures up to 85 °C. Since the life doubles for each 10 °C that you can lower the temperature, you are well assured of more than 25 years storage capability at all temperatures less than 85 °C.

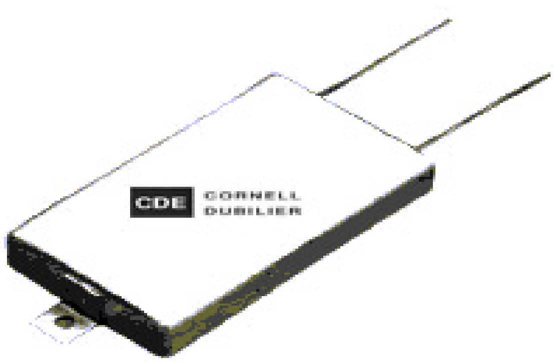
Shelf test of 200 V, 1000 µF MLP at 85 ºC

	0 h	500 h	1000 h	2000 h	3000 h	Δ/kh	Δ/kh
Capacitance (1000 ± 200 µF)							
Average of 6 units	948.0	935.9	927.5	927.8	925.4	-7.5	-0.01%
ESR (158 mΩ max)							
Average of 6 units	89.3	73.2	73.5	67.2	63.1	-8.7	-0.10%
Leakage Current (0.4 mA max)							
Average of 6 units	0.05	0.12	0.15	0.18	0.20	0.05	1.01%

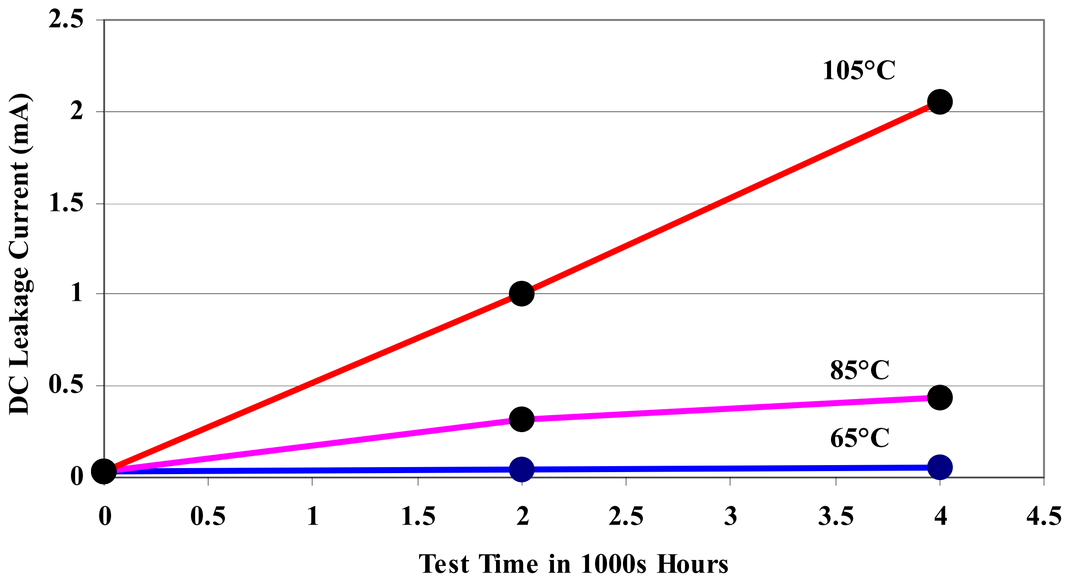
To confirm this finding we put 820 µF, 200 V MLSs in ovens at 65 °C, 85 °C and 105 °C for 2000 and 4000 hours. The DCL results are shown below.



To check storage-life capability for high-voltage MLPs of 300 V and up that include the less stable, ethylene-glycol based electrolyte we put 120 µF, 400 V MLPs in ovens at 65 °C, 85 °C and 105 °C for 2000 and 4000 hours. The DCL results are shown on the next page. The rate of DCL increase at 85 °C is 0.10 mA per 1000 hours, and this is two times the 200-V example. So with MLP capacitors rated 300 V or above we suggest that you plan for a 10-year storage capability at 85 °C and 25 years at normal warehouse temperatures.



MLP 120 µF 400 V Shelf Life



MLP 50-Year life

The basis for projecting a 50-year expected life for the MLP is the MLS. Both have identically the same capacitor elements but for a given capacitance the MLS has a lower rated voltage to permit operation to 125 °C, e.g., the 1000 µF 150 V MLS has the same innards as the 1000 µF 200 V MLP. You cannot do an accelerated 125 C life test on an MLP without clamping it because the aluminum case bulges. But you can correctly infer that if you clamped the MLP to hold it flat, it would last 4000 hours at 125 °C with 75% of its rated voltage applied. The MLS life curves in our catalog confirm 4000 hours capability at 125 °C, and a major military customer confirmed it with six MLPs clamped to hold them flat and tested at 125 °C for 4000 hours.

Based on aluminum electrolytic capacitor life doubling for each 10 degrees you reduce the temperature, 4000 hours at 125 °C is equivalent to 58 years at 55 °C operating continuously. Since typical applications don't run an average temperature as high as 55 °C and don't run 24/7, 50 years is a rational expectation for the MLP capacitors rated less than 300 V. However, the MLPs rated 300 V and higher have no parallel in the MLS capacitors, and indeed are not expected to last 50 years. You can see from the life test curves in the catalog that high-voltage MLP capacitors reach two-times their maximum ESR after about 2000 hours at 105 °C. Defining that as end of life, you would infer an expected life of 7 years at 55 °C unless ESR increase is not important.

In practice high-voltage MLPs last well beyond 10 years because the ESR increase is caused by hydrogen gas trapped in the anode foil by the MLP's excellent seal. The capacitors continue to perform, albeit with high ESR.

MLP Reliability Calculation

While we have life tests showing that MLP and MLS capacitors can operate 50 years and more before they begin to wearout, we don't have data from established reliability testing that we could use to show failure rates at different electrical and temperature stress levels. However, our Type MLP and MLS capacitors rated 250 V and below are built using essentially the same foils, papers and electrolytes as our M39018 military aluminum electrolytic capacitors, and the manufacturing process is essentially the same. So, it is reasonable to infer that the MLP/MLS failure rate would be similar to our M39018 capacitors. By this logic, we expect that MLP/MLS capacitors would have a failure rate similar to our established reliability aluminum electrolytic capacitors, and the failure rate would be less than 0.1% per thousand hours at 80 % rated voltage and 95 °C core temperature.

Three different models can be used to confirm the 0.1 % failure rate. The capacitor industry method assumes that failure rate doubles for each 10 °C that temperature is increased, and by that method MLP has a failure rate of 0.0256 % per thousand hours. Andy Lauber, Sprague Electric, developed a failure rate method based on Arrhenius, and by that method the MLP failure rate is 0.16 % per thousand hours. And the third method, MIL-HDBK-217, predicts 0.18 % per thousand hours.

Failure Rate for MLP Capacitors

FIT rate is the random failure rate, expressed in ppm/kh. There are 3 models that may be used to predict failure rate of aluminum electrolytic capacitors, ranging from the under-conservative Capacitor Industry Method to the over-conservative MIL-HDBK-217. These calculations are with 20% voltage derating and 95 ºC average core temperature.

1. Capacitor Industry Method:

$FIT = FIT_{BASE} \times 2^{(T-T_{BASE})/10} \times V_A/V_R = (10)(2^5)(0.8) = 256$ ppm/kh = 0.0236 %/kh

2. CDE Model based on Lauber:

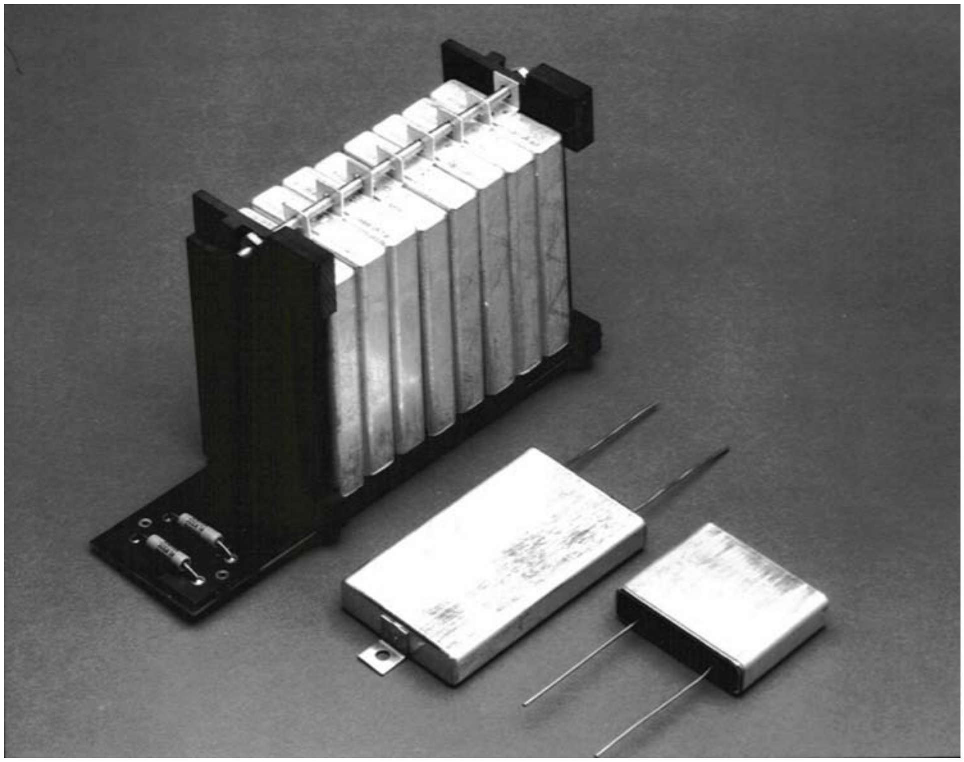
$FIT = FIT_{BASE} \times e^{0.0157T^{2.65}} \times V_A/V_R = (1000)(2.00)(0.8) = 1600$ ppm/kh = 0.16 %/kh

3. MIL-HDBK-217

$FIT = \lambda_b \times \pi_E \times \pi_Q \times \pi_{CV} = (800)(1.0)(3)(0.76) = 1800$ ppm/kh = 0.18 %/kh

While the MLP is rated 85 °C, it is actually a 105 °C design limited to 85 °C because the case expands above 85 °C. The value of 800 for this 105 ºC capacitor is double the value from the 217 table because MIL-HDBK-217 applies to 125 ºC rated capacitors and reliability doubles every 20 ºC.

We suggest that for system reliability calculations you use an MLP failure rate of 0.1% (1000 ppm) per thousand hours at 80 % rated voltage and 95 °C core temperature.



Use of MLPs and MLSs in Military systems

Historically the military has been resistant to using aluminum electrolytic capacitors in military electronics, especially avionic applications. Typical concerns include these furnished by a major military equipment maker:

- **Q**: Although aluminum electrolytic capacitors are sealed, they are not hermetic and have high internal pressures. Can MLPs and MLSs leak electrolyte and vapor?

  A: The largest size, 3-inch long MLP/MLS capacitors like the ones used on the F-15 fighter jet contain roughly 7-10 grams of non-corrosive electrolyte that could potentially escape over the centuries. But the typical escape rate when hot is only a few tens of milligrams per month, and is much less than that at typical ambient temperatures. This takes into account the vapor pressure of the solvents and the cleanliness of the materials, as do the life ratings. The MLP and MLS have the lowest rates of gas and vapor escape of any aluminum electrolytic capacitors on the market, including the military M39018 types.

- **Q**: The foil, electrolyte and the manufacturing equipment must be super clean to avoid capacitor corrosion failures. Impurities can cause chemical attack and short operating life. How do MLPs and MLSs avoid this problem?

  A: Yes, contamination by halides such as chlorides and bromides can and do cause shortened lives in aluminum electrolytic capacitors. And consequently CDE controls the permitted level of halides in materials to parts per billion, and has developed electrolyte additives that chemically tie up the halides and assure long life. In the seven years operating at the new CDE plant in Liberty, SC, there has been no instance of halide corrosion failures attributed to manufacturing. There have been instances of failures from exposure to halides in shipping and in cleaning with solvents, but these don't apply because the MLP and MLS have a protective epoxy endseal that eliminates the chance of halide contamination from external sources. A common source of halide contamination in aluminum electrolytic capacitors is the plastic top, and the welded metal top of the MLP and MLS eliminates that as a possible source of contamination.

- **Q**: USAF airborne applications used to require prior approval by the procuring activity before aluminum electrolytics could be used, and the current revision of MIL-HDBK-198 contains a note that says aluminum electrolytic capacitors are not recommended for airborne equipment applications since they should not be subject to low barometric pressure and low temperatures at high altitudes. It goes on to say that explosions can occur because of gas pressure or a spark ignition of free oxygen and hydrogen liberated at the electrodes. How do these concerns apply to flatpacks?

  A: Today's aluminum electrolytic capacitors are well sealed and altitude is not a problem for most. The MLP/MLS can withstand continuous operation at altitudes up to 80,000 feet. At higher altitudes the atmospheric pressure is so low that the polymers and rubber in the seal eventually can evaporate, however, the evaporation takes years.

  While it is true that an electrolytic capacitor can explode under the right (wrong) conditions, MLS and MLP capacitors don't explode unless a fault occurs during a misuse of the capacitor such as while the safety vent is covered with epoxy or otherwise blocked. Possible faults that build gas pressure in the capacitor are application of reverse voltage, overvoltage and high AC voltage. The amount of hydrogen gas that is liberated is predictable: It's the number of mA-h of leakage current that pass times 0.42 std cc's per mA-h. And a ruptured MLP or MLS does not support combustion.

- **Q**: The published MLS shelf life test for the MLS is 500 hrs at 125 °C. Why doesn't the MLS have the 1000 hours minimum shelf life we prefer?

  A: The shelf-life capability of the MLP and MLS are the best in the world among wet aluminum electrolytics, typically more than 25 years. The shelf life doubles every 10 ºC, so 500 hrs at 125 ºC equates to 128,000 hours at 45 ºC, and the 4000-hour, 105 °C shelf life test results discussed above show that actual capability is even longer than the rating. The specification of 500-hours is an artifact of older aluminum electrolytic capacitor types, and the MLS will pass a 1,000-hour shelf test at 125 ºC.

The resistance to the use of aluminum electrolytic capacitors in military electronics is based largely on a belief in performance problems that no longer apply and have been solved in the last forty years. The lightweight, high energy density and high voltage capability of aluminum electrolytic capacitors are advantages that attract their use in military and avionic applications, and the MLP and MLS are breaking new ground because they are best of class.

More on Flatpacks

The standard case sizes are 0.5 inches high, 1.75 inches wide and 1.5, 2.0 or 3.0 inches long. Other lengths between 1.5 and 3.0 inches are also available. The cases are available with or without mounting tabs for mounting to a heatsink or printed-circuit board. The tabs are electrically connected to the case so you need insulated mounting hardware unless the mounting is at the same potential as the negative lead. For Type MLP four-lead mounting is available with three of the leads attached to the case and at the negative-lead potential.

The rugged construction is a can within a can construction. The case is an extruded, rectangular can, and the top is an extruded rectangular can that is fitted into the end of the case and TIG welded in place. This is nearly a hermetic seal and the only elastomer seal is where the positive-lead rivet comes through the top. While the MLP has its negative lead welded directly to the top, the MLS has a second rivet in the top for the negative lead. Thus the MLP has slightly lower inductance since the cathode tab and negative terminal are welded to the case while the MLS has a feed-through so the case is only connected through the electrolyte.

The MLS extends the performance of the MLP from 85 °C to 125 °C. The MLP can operate up to 105 °C if the case is clamped to prevent expansion, and the MLP can operate up to 125 °C with the case clamped and with the applied voltage of no more than 80% of rated voltage. To clamp the MLP use a 0.5 inches wide, 0.04 inches thick steel strap located more than 1⅛ inches from leads-end of the MLP to avoid interfering with safety vent operation. For other clamping schemes design the clamp capable of 50 psi or 250 lbs total.

The MLS is designed as a 125 °C capacitor, and it's stainless case permits operation to that temperature, 125 °C. A strap is not needed with stainless because even if there were an expansion issue, the stainless case returns to its original height while aluminum creeps and the case remains expanded. And in any case, a strap would not permit operation above 125 °C, as that is a limitation of the anode foil and electrolyte.

Heatsinking MLP and MLS Capacitors

Clamping an MLP or MLS capacitor between two heatsink surfaces like between two aluminum plates can significantly reduce operating temperature and extend the expected lifetime. Heatsinking one side by mounting using the two mounting tabs and a thermal pad is nearly as effective as both sides because the case conducts the heat to the side of the case that is attached to the heatsink. Heatsinking only one large side is about 80% as effective as heatsinking both sides.

The thermal resistances for various configurations are in the table below:

Case	# Large sides with heatsinks	3" MLP ºC/W	1.5" MLP ºC/W	3" MLS ºC/W	1.5" MLS ºC/W
Bare	1	1.2	3	1.3	3.3
Insulated	1	1.7	4.3	1.8	4.5
Bare	2	1.1	2.8	1.1	2.8
Insulated	2	1.6	4	1.6	4

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High-Voltage MLPs

The MLP capacitors rated 300 V through 450 V use special, advanced electrolytes permitting operation at these high voltages. However the principal solvent in the electrolyte is ethylene glycol, which has the unfortunate property of trapping the hydrogen gas released by dc leakage current. The hydrogen is trapped in the electrolyte because the MLP is so well sealed. The hydrogen interferes with conduction and increases the ESR of the capacitor with time. So, while MLP capacitors rated 250 V or less can typically go more than 50,000 hours at 85 °C and rated voltage, MLP capacitors rated 300 V and up can typically only go about 2000 hours at 85 °C and rated voltage before the ESR has doubled. If the application has little ripple current, such as a power holdup application, the increasing ESR is of little consequence and the high-voltage MLP will have long life. However, if there is a high level of ripple current, the increasing ESR will cause increased heating, and the MLP may exhibit short life.

To put this in perspective, MLPs aren't usually required to operate at full rated conditions. So, while the ESR in a high-voltage MLP may double in 2000 hours at full-rated conditions, at 45 °C and 80% of rated voltage it would again take more than 50,000 hours for the ESR to double.