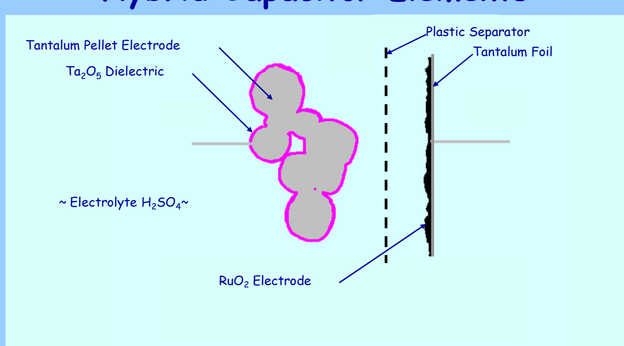
Comparison of Capacitor Power Sources in High Current Pulsed Loads

David A. Evans
Evans Capacitor Company
72 Boyd Avenue
East Providence, RI 02914
401-435-3555
devans@evanscap.com

Presented to the APEC 2011, March 6 – 10, 2011, Ft. Worth, TX

This slide is a photograph of the two capacitors used in the experiments presented here.

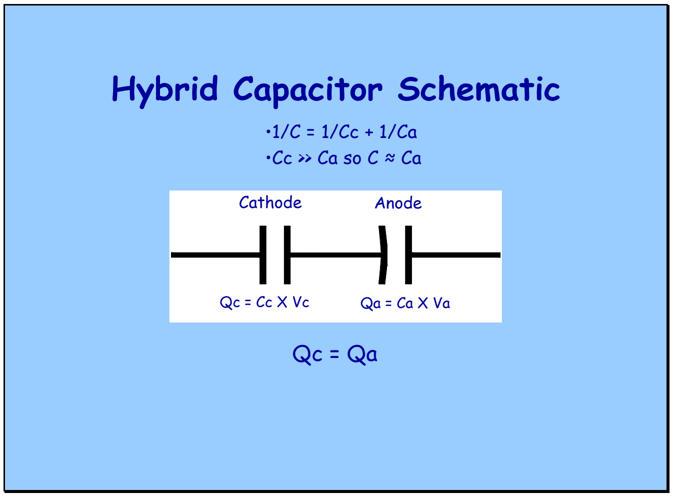
Hybrid Capacitor Elements



This slide begins a background on Hybrid capacitors. It is a cartoon showing all of the essential parts of a hybrid capacitor. A porous electrode made from compacted tantalum powder is oxidized electrochemically. The oxide coating functions as a dielectric. An aluminum capacitor has a similar structure known as an anode foil. This forms the positive electrode of the capacitor. The negative side is comprised of a large capacitance value electrode. In regard to aluminum capacitors, this is usually an aluminum foil which is or is not oxidized. Electrolytic capacitor electrodes function essentially as electrostatic capacitors. In hybrids, the cathode capacitor stores at least some of its charge using a mechanism whereby charge is transferred to or from an electrode involving a process that includes an electrochemical reaction. This battery-like electrochemical or faradaic charge storage has a much higher specific capacitance than electrostatic capacitance. Ruthenium oxide, the cathode material, stores charge in a reversible change of oxidation state.

The two electrodes are in contact with an electrolyte. In the case of a hybrid capacitor, this is sulfuric acid. Both types avoid electrical contact between plus and minus using an electrically insulating separator that conducts electrolyte.

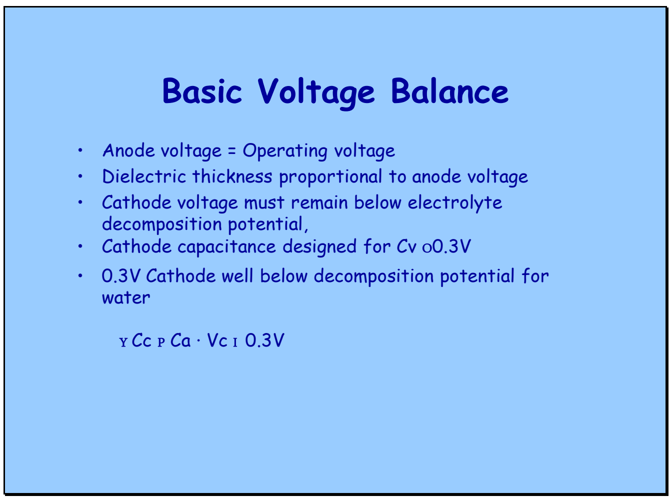
The actual electrodes are a foil about 0.002" thick coated on both sides with active material a couple of mils thick. The anode is a freestanding pellet.



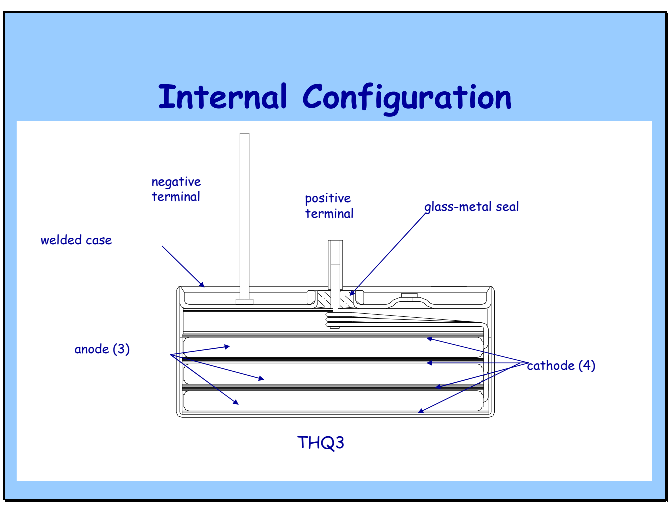
This is a picture of the circuit of an electrolytic capacitor. To the right we have a polar anode having a voltage dependent dielectric and a capacitance. Shown as a direct connection at the center of the illustration is a wire that represents the electrolyte. That is an oversimplification. The resistive property of the capacitor follows the resistance of that element. To the left is connected the cathode.

I have inserted some of the assumed relationships according to long accepted principles. The charge, Q, is the same in each electrode because they are in series. The charge Q is proportional to the capacitance C and the voltage V.

Capacitors in series add according to the formula shown. By making the cathode capacitance very large, the hybrid design realizes a greater fraction of the anode capacitance. At the same time, the amount of volume occupied by the cathode is greatly reduced.



These rules are followed in successful design of hybrid devices. The anode has a known capacitance and is designed to operate at the full voltage rating of the capacitor. It is very important the cathode potential remain below the electrolyte decomposition potential because if not electrolyte will be lost and the capacitor will fail. We designed a wide margin at 0.3V maximum on the cathode, compared to the decomposition potential of 1.2 volts. Manipulation of these numbers allows us to calculate a minimum value for cathode capacitance, which in our device here is in the range of a few farads.



Here is shown how the parts of a hybrid capacitor are physically arranged. This is a view of THQ3, a part similar to the one referred to elsewhere by this work. It has three anode pellets connected in parallel and a corresponding number of cathode foils and separators arranged like a club sandwich. The anodes are connected by riser wires to the central glass to metal seal where they are welded to a tantalum feed through. The hermetically welded tantalum case is filled with electrolyte by impregnation and plugged by the fill hole. A copper wire welded to the case is the negative terminal. The positive terminal is a nickel tube fixed to the outboard end of the feed through pin.

The unit is extremely robust and can withstand tough mechanical environments.

Experiment Setup

23°C 100A peak	100Hz 1 ms	1kHz 20% duty
MLS	X	X
THS	X	X

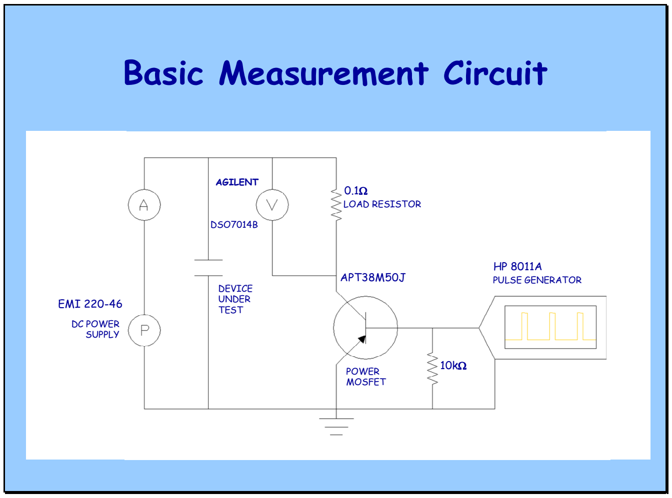
This and the next two slides show performance experiments we ran. We did two different load waveforms at three temperatures.

Experiment Setup

85°C 100A peak	100Hz 1 ms	1kHz 20% duty
MLS	X	X
THS	X	X

Experiment Setup

-55°C 100A peak	100Hz 1 ms	1kHz 20% duty
MLS	X	X
THS	X	X

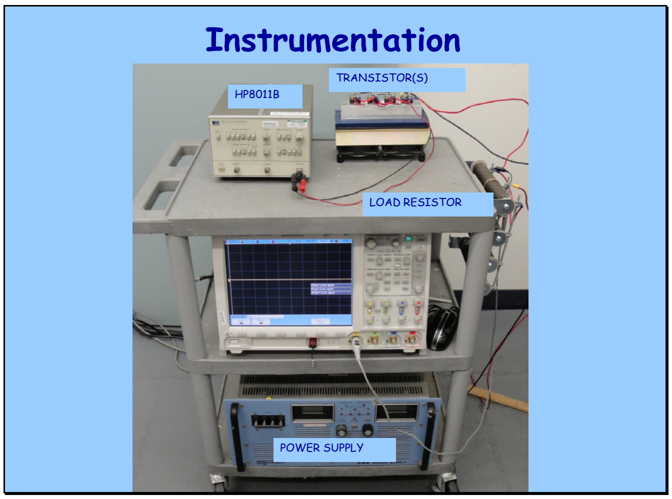


This is a schematic of the experiment circuit and the equipment used. The load resistor consisted of a set of large wirewound elements. It had a value of 0.10 ohm. The capacitor is in shunt with the power supply which is current limited

Since the capacitor and power supply act together in shunt on the switch and load resistor, the power supply current must be subtracted from the peak current to find the capacitor current.

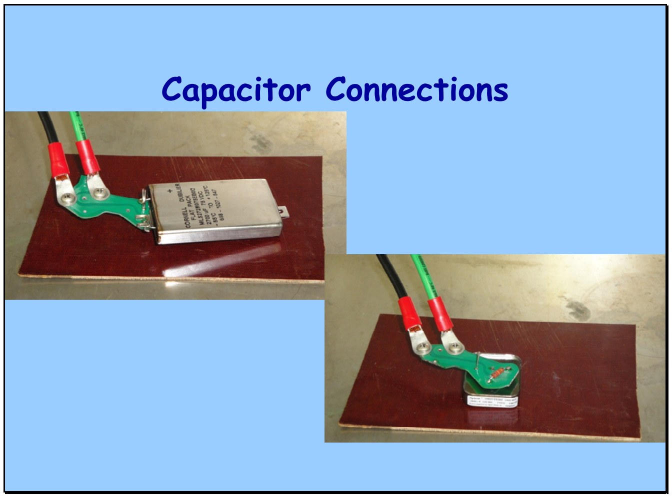
The transistor would more correctly be drawn as a FET but this diagram shows a single transistor switch. In actuality, there were four transistors in parallel.

Using this circuit, we are able to demonstrate a wide assortment of resistor loads.

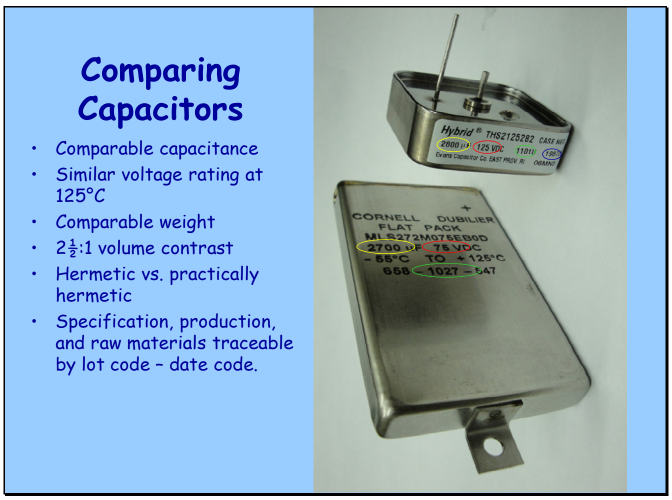


Here is a photograph of the equipment used. On the top shelf are the transistor switch and cold plate and the pulse signal generator. The load resistor is attached to the cart at the right, and the power supply is on the bottom shelf.

We used this environmental chamber to control temperature. The test capacitor can be seen at the bottom of the chamber.



The capacitors were soldered to circuit boards that were fastened by screws to wires of a large gage.



The capacitors were selected such that each had very comparable capacitance and voltage rating. The two seemingly different voltage ratings circled in red are assumed to be the same for the purpose of this work. The voltage on the MLS capacitor corresponds to its value derated to 125°C. The voltage on the THS capacitor is the 85° rated voltage. Simple analysis finds these voltage ratings similar at 85°C.

The parts weigh almost the same. The THS part is a little heavier and a lot denser, tantalum having a specific gravity of 16.

[I would like to get one of the folks from Cornell Dubilier to comment about how their MLS is sealed. We did not do an autopsy and can't comment further.]

Useful in researching problems and keeping track of product modifications, both products contain a manufacturing date code and lot code which can trace raw material, process, and inspection steps. The THS capacitor can be traced further to the individual specific data including electrical measurements by a serial number circled in blue.

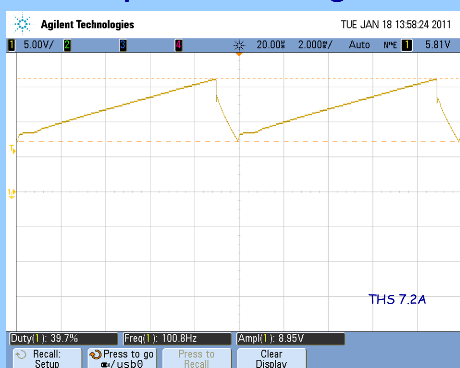
This slide is an attempt to compare the relative volume occupied by each device. The THS is a little thicker, but the heights are comparable.

Vital Statistics

	Voltage Rating	Cap uF (120Hz)	ESR mohms (1kHz)	Weight (g)	Volume (in³)	Capacitance Density (uF/in³)	Specific Capacitance (uF/g)	Cost
MLS	75	2686	26.14	93.5	2.42	1110	28.7	low
THS	125	2786	80.7	95.6	0.98	2843	29.1	high

I will caution the audience to the meaning of rated voltage here.

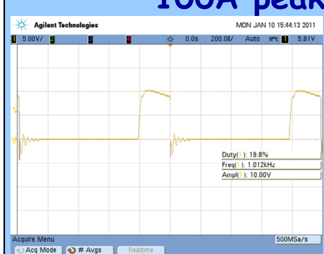
Capacitor Voltage



This slide shows a typical capacitor voltage waveform. This one was taken using THS at a 7.2A charging current limit. This corresponds to the 100A 100Hz peak current data to follow.

We have 5 volts per box on the vertical axis and time forward to the right about 2ms per box. Starting on the lower left, we have the switch open and the capacitor charging at constant current. At the instant of switch closure (plus a little time for inductance), the voltage suddenly drops about 3 volts. This represents the ESR induced voltage drop at about 93A. The next phase is of a capacitor discharging into a resistor, terminated by switch opening and the repeat of the wave.

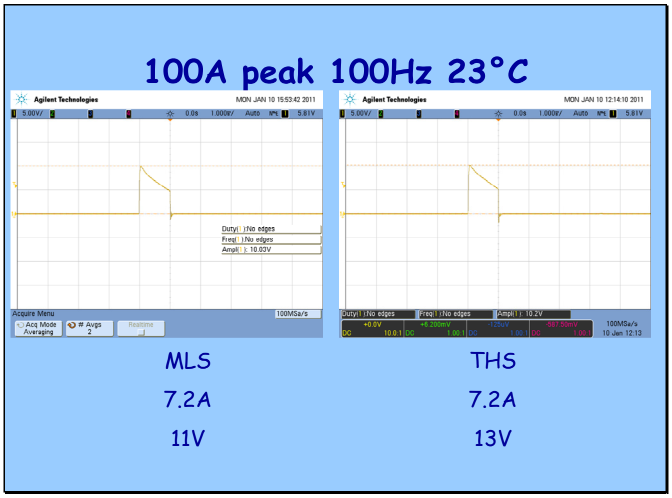
100A peak 1kHz 23°C

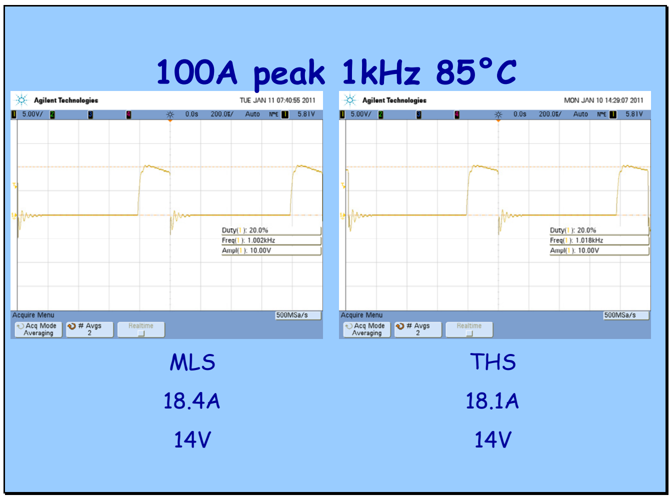


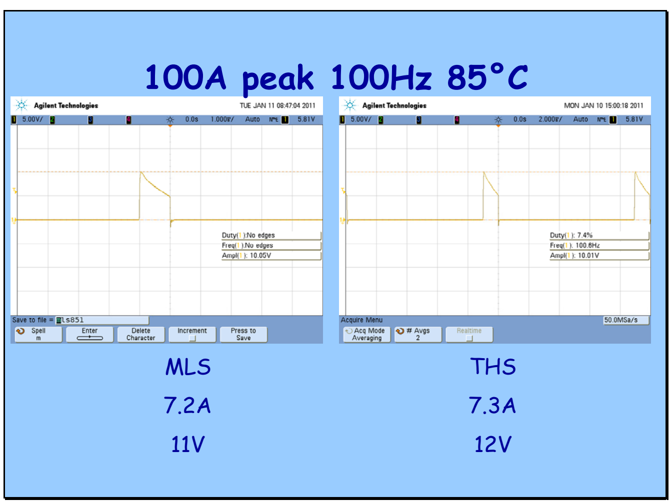
MLS	THS
18.2A	18.9A
14V	14V

This and the five slides that follow show our results in the form of the load current wave. Again, we have on the vertical axis 5V per box. Because this is the voltage across the load resistor having a value of 0.10 ohm, the vertical axis is equivalent to 50A per box. The capacitor current is the current shown minus the power supply current. Listed below the charts are the indicated currents and voltage at the power supply.

All results indicate good performance for both capacitors.





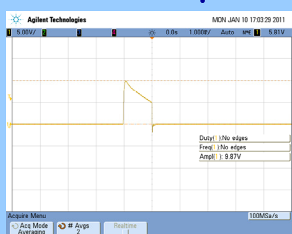


I must apologize that the chart on the right is drawn to a different time scale. The output waves are similar.

100A peak 1kHz -55°C

MLS	THS
18.2A	19.1A
15V	15V

100A peak 100Hz -55°C



MLS	THS
7.3A	7.3A
13V	13V

Conclusion

- Devices performed very similarly into 0.1 ohm resistive load at 100A peak over a range of temperatures and load characteristics.
- Weight is similar. Specific capacitance is similar.
- 2.6 : 1 capacitance density advantage to THS device of nearly equal capacitance.
- Recommend further research and experimentation to characterize capacitor life and failure mechanisms under various electrical and environmental conditions.