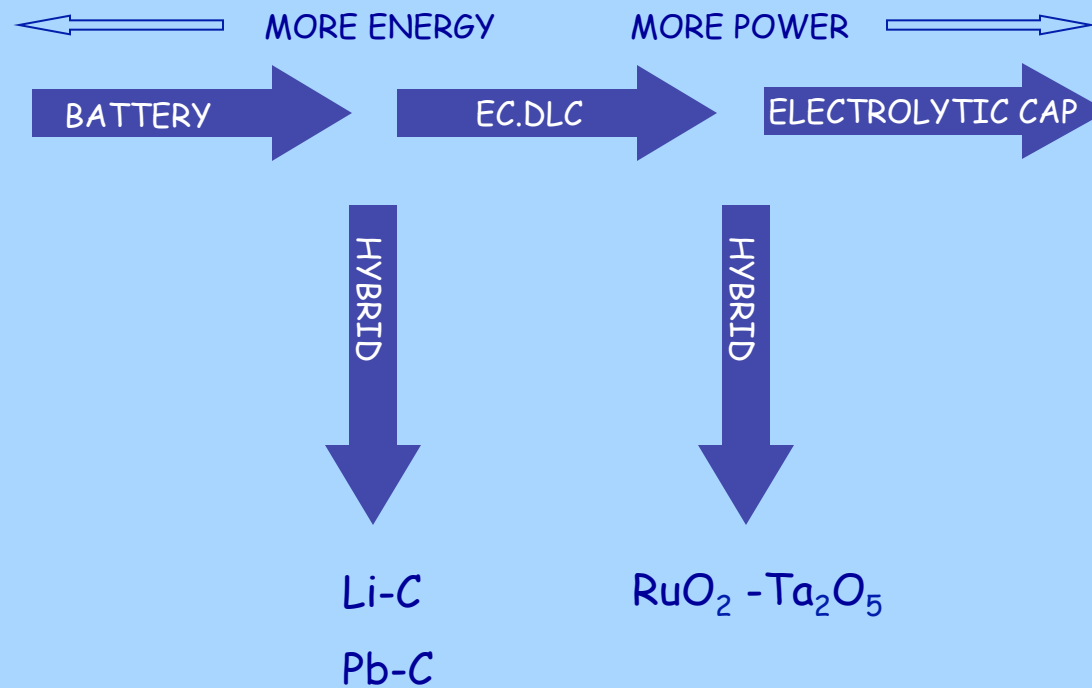


Hybrid Capacitors in Energy Applications

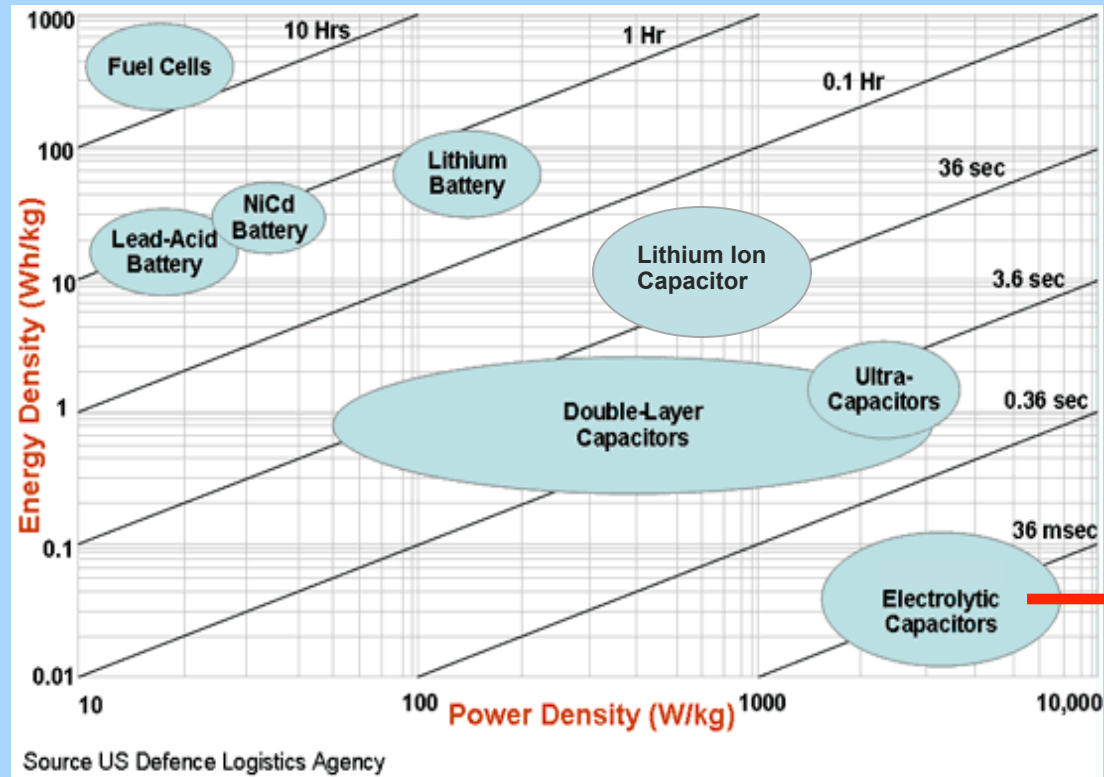
David A. Evans
Evans Capacitor Company
72 Boyd Avenue
East Providence, RI 02914
401-435-3555
devans@evanscap.com

Presented to the CARTS 2013 March 26, 2013, Houston, TX

Hybrid Capacitor Map

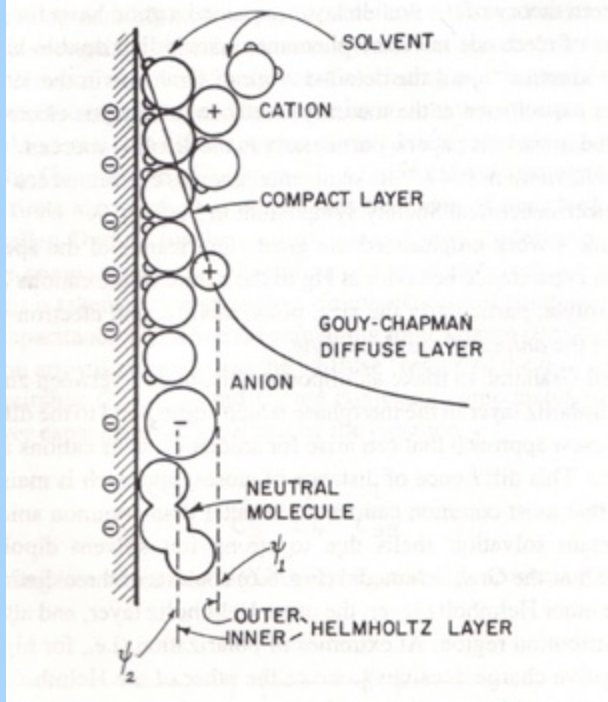


Ragone Diagram



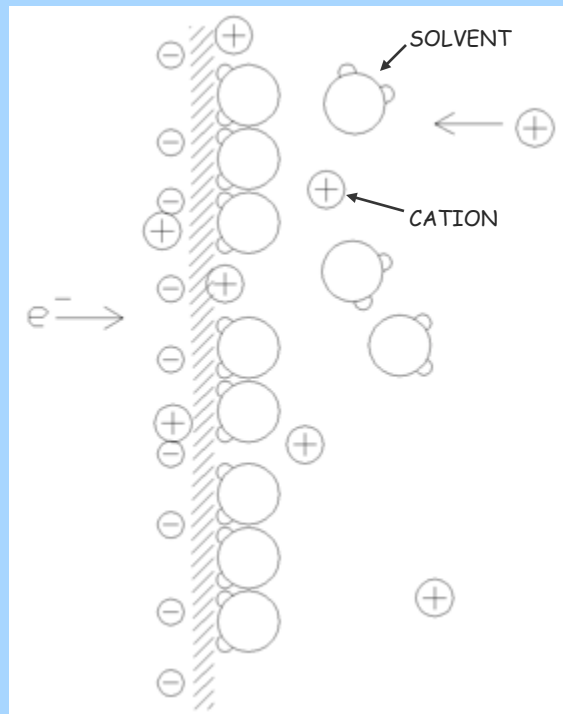
Electric Double Layer

Source: B.E. Conway, "Electrochemical Supercapacitors"

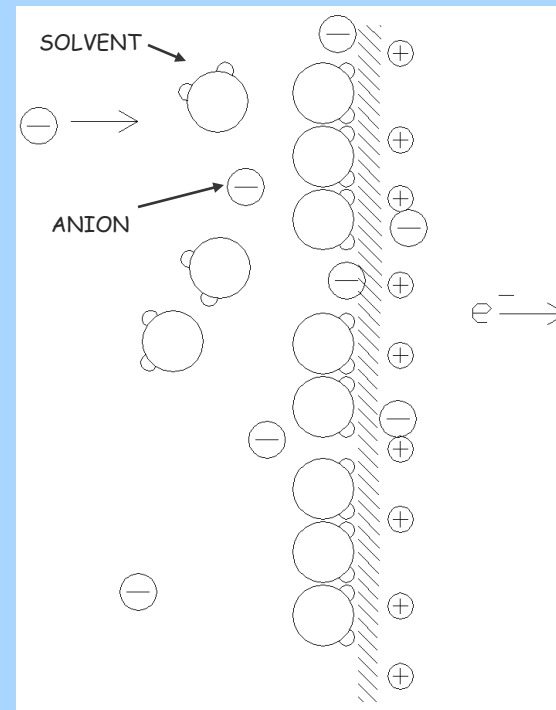


- Exists at every charged electrolyte interface
- Equivalent charge separation about the size of a solvent molecule
- Maximum cell voltage < solvent breakdown voltage
- Small separation results in high series capacitance
- Can often be ignored in calculation of cell capacitance

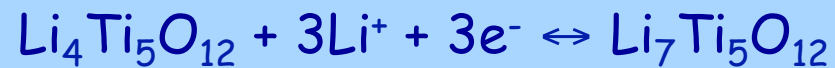
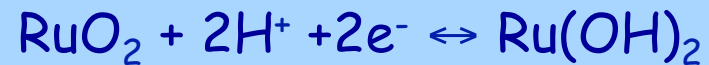
Faradaic Charging



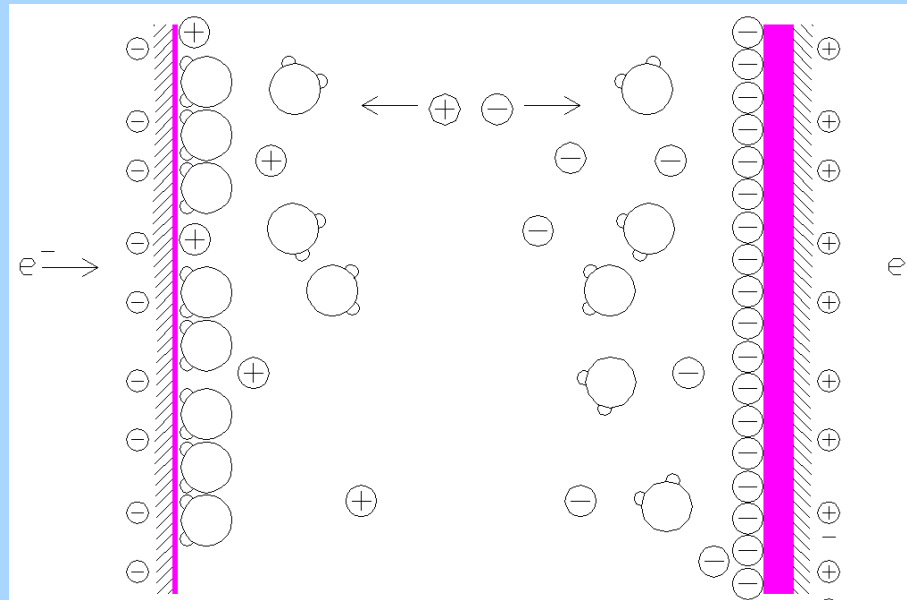
CATHODE



ANODE



Electrolytic Capacitor



- $C = ke_0A/t$
- Equivalent dielectric charge separation about 1 nm / volt
- $k = 27$ for tantalum oxide, 9.3 for aluminum oxide
- Series EDL ever present while electrode is charged

Hybrid Tantalum Capacitor

- One electrode stores charge faradaically in a reversible reaction involving the electrolyte.
- The other electrode stores charge electrostatically.

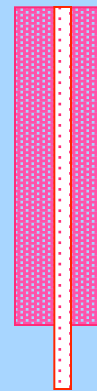
Faradaic Electrode

- RuO_2 on Ta foil
- $\text{RuO}_2 + e^- + \text{H}^+ \leftrightarrow \text{RuO} \cdot \text{OH}$
- Low voltage charge storage

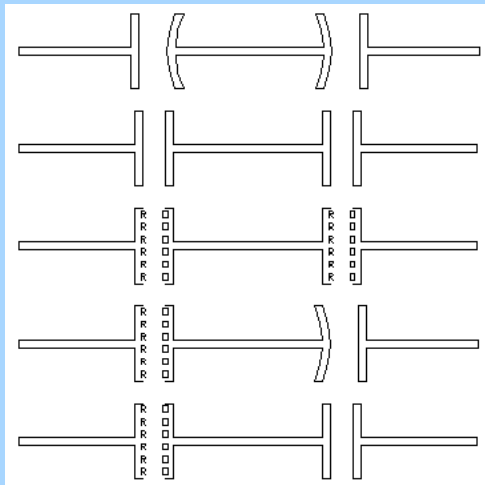


Electrostatic Electrode

- Ta_2O_5 on Ta pellet
- $C = k A/t$ $E = \frac{1}{2} CV^2$
- High voltage charge storage



Electrochemical Capacitors

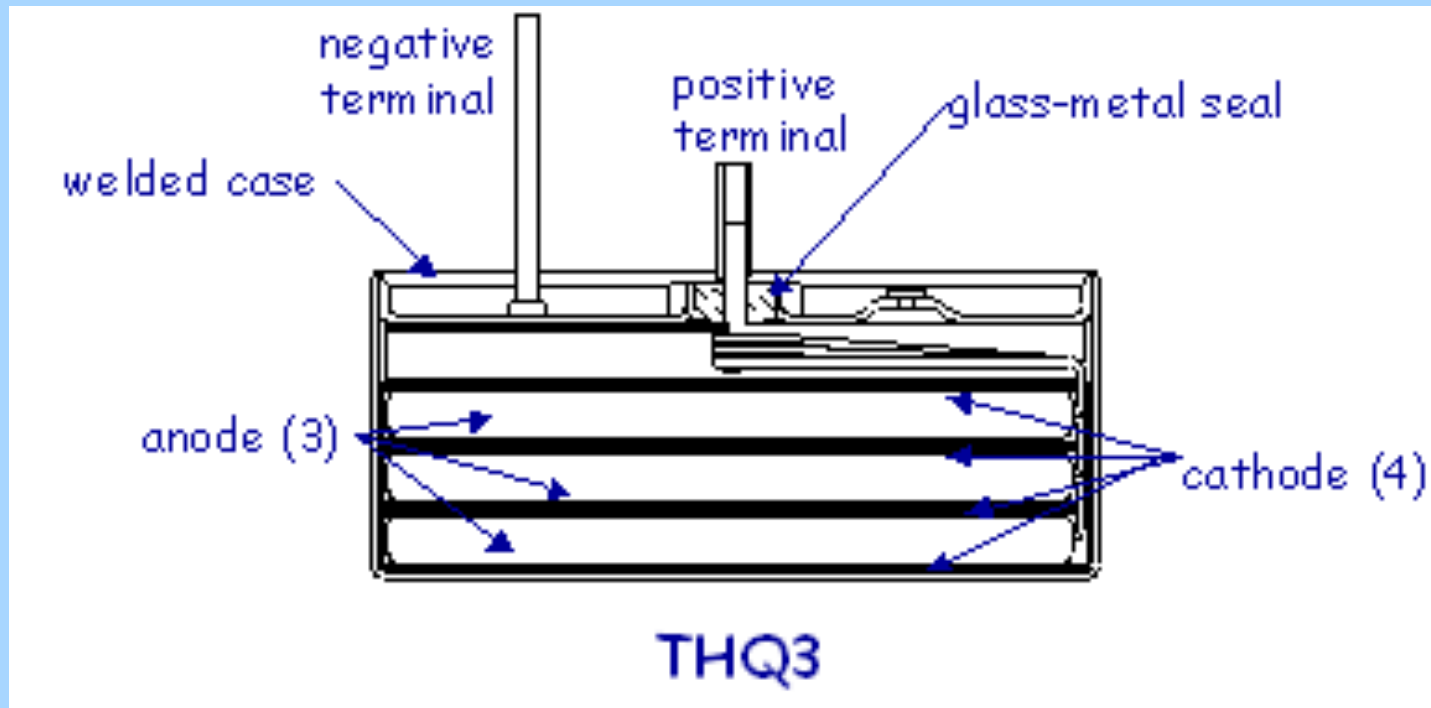


Device	Charge Type	Cell Voltage	Energy Density
A. Electrolytic Capacitor	Electrostatic	High	Low
B. Double Layer Capacitor	Electrostatic	Low	High
C. Pseudocapacitor	Faradaic	Low	High
D. Hybrid Electrolytic	Hybrid	High	Med.
E. Hybrid Electrochemical	Hybrid	Med.	Very High

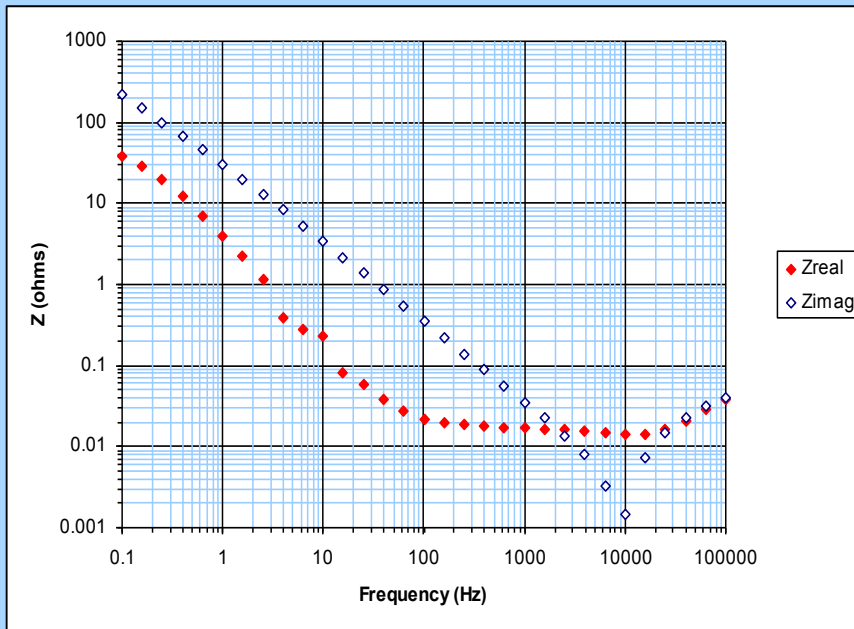
Tantalum Hybrid Capacitors



Tantalum Hybrid Capacitor

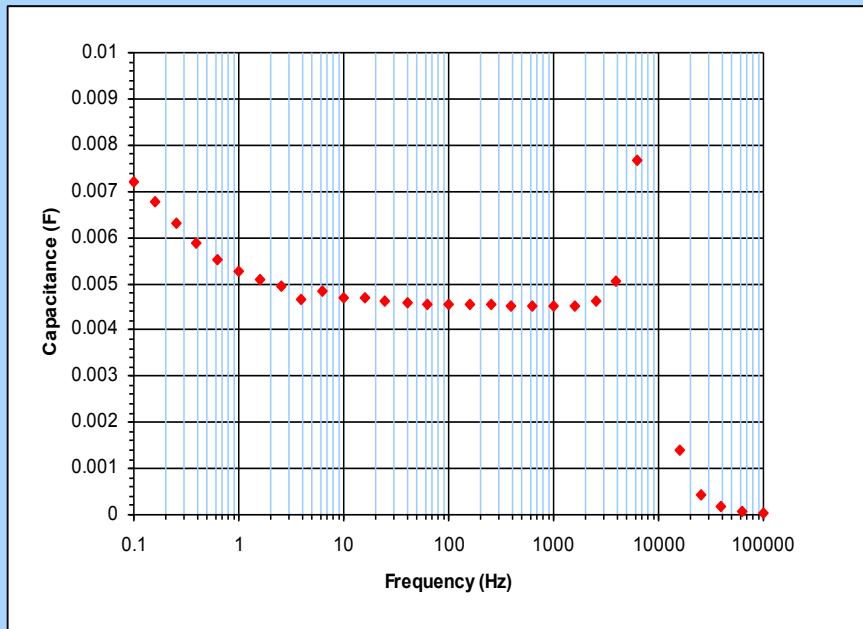


TDD3125



Power

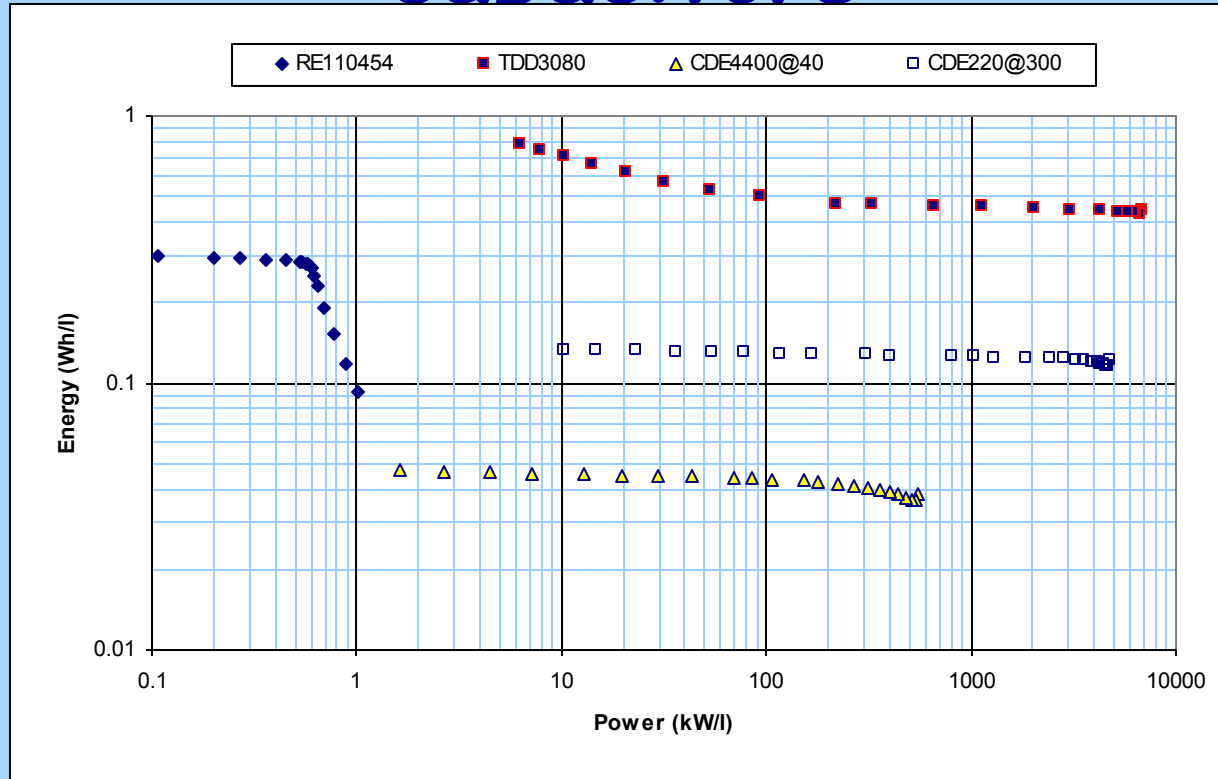
- $P = E I = V^2/R$
- $P_{max} = V_r^2/4R$
- $P_{max} \propto 1/R$



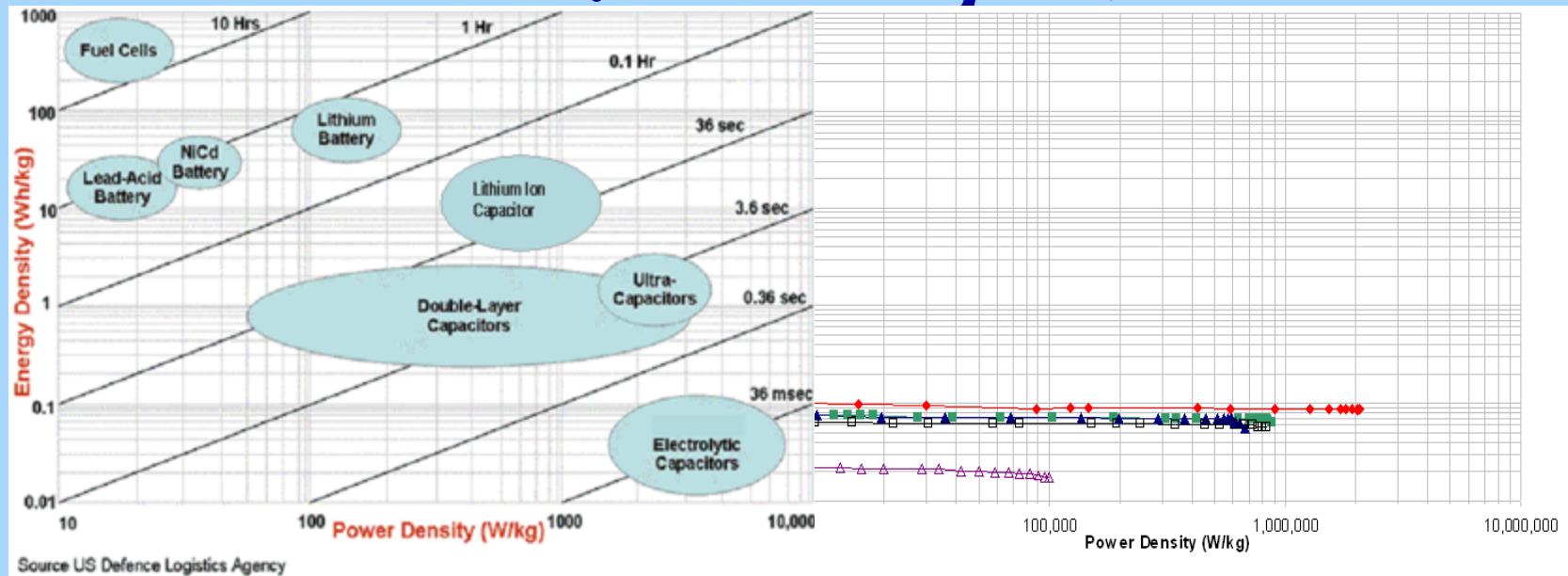
Energy

- $E = \frac{1}{2} C V^2$
- energy is proportional to capacitance at rated voltage

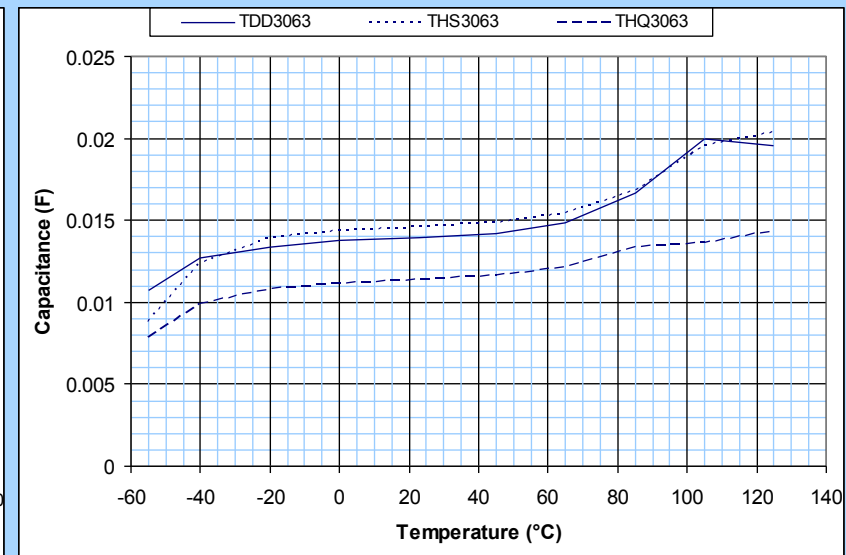
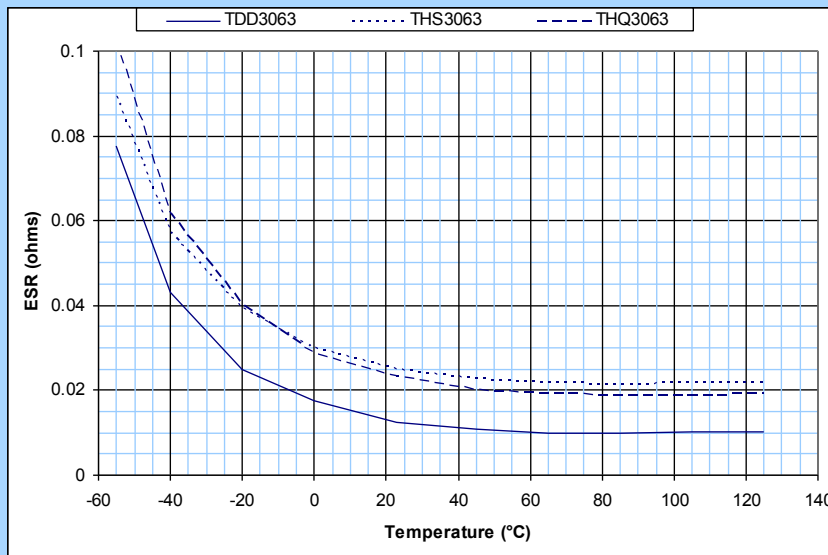
Volumetric comparison of capacitors



Modified Diagram



Performance over temperature



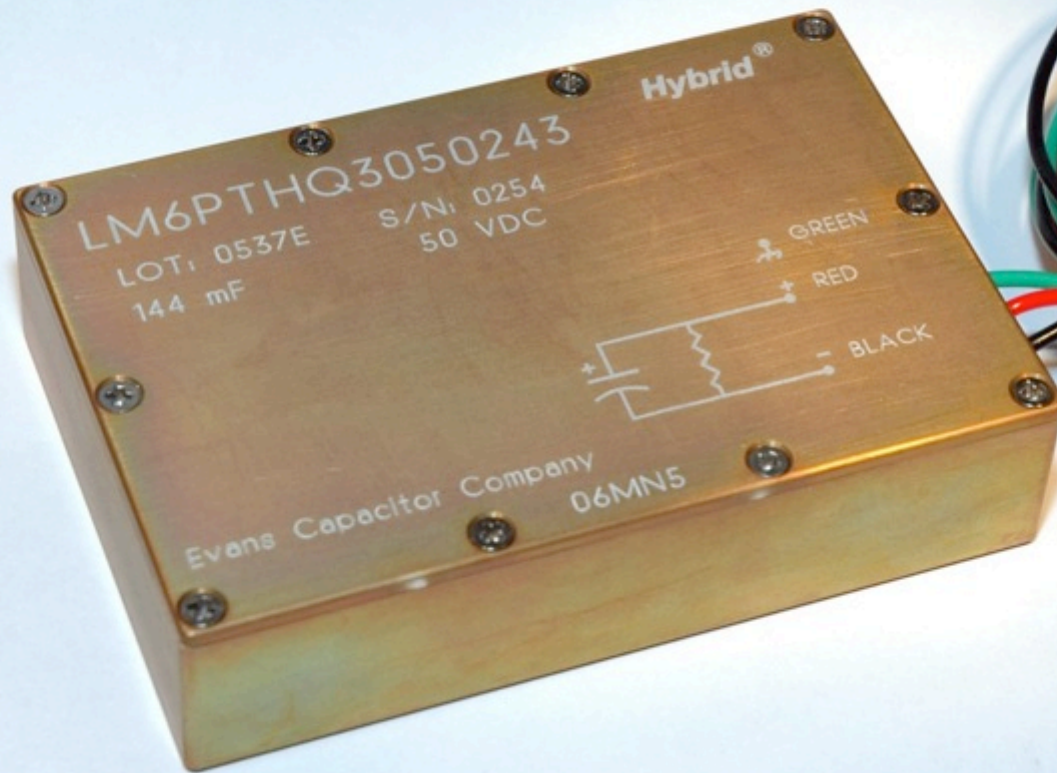
- All parts show marked increase in ESR at temperatures $< -20^{\circ}$



Apache with Arrowhead System



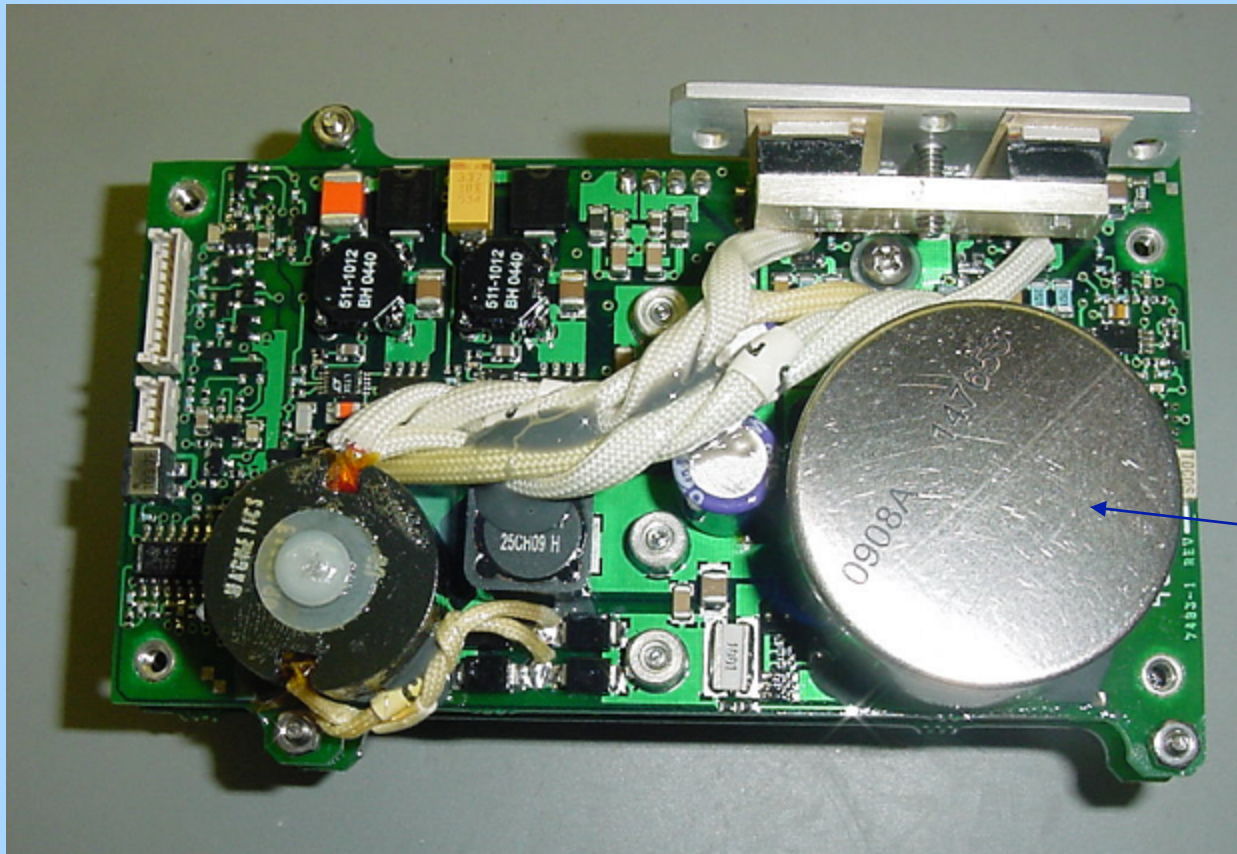
Arrowhead Night Vision System



LRFD Adapter Kit



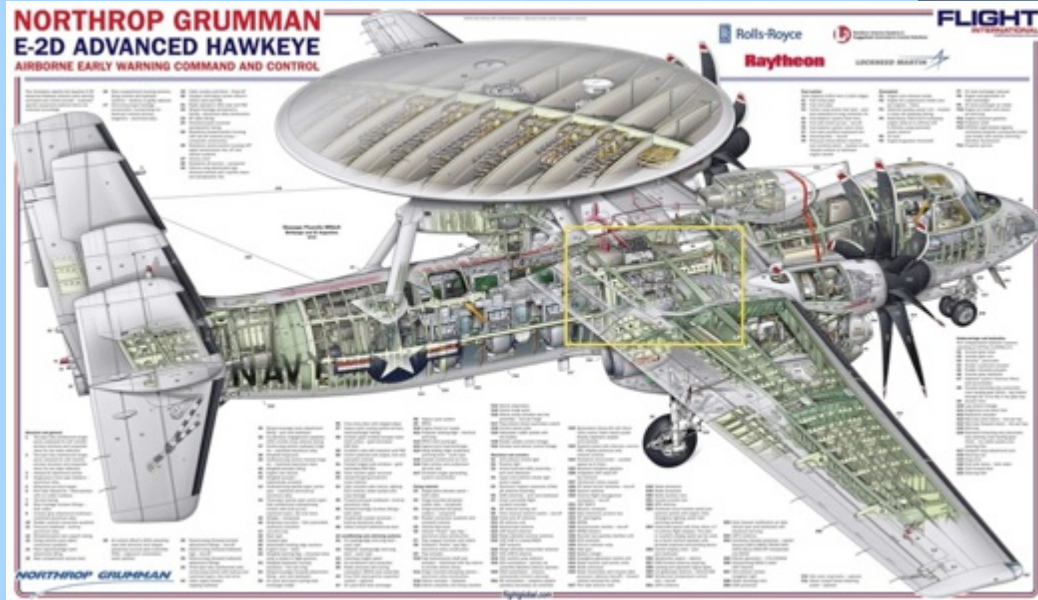
**Day Sensor
Electronics Unit (DEU)**



THQ5125452
4500uF at 125V

Source: Analog Modules Inc.

E-2D Hawkeye



THS3125442

TDD3080 into 0.1 ohm

Load Circuit

$$\begin{aligned} \bullet R_{\text{tot}} &= R_{\text{load}} + R_{\text{switch}} \\ &= 0.06 + 0.04 \text{ ohms} \end{aligned}$$

Load Profile

- 320A peak 1kHz, 10% duty

Capacitor Performance

- Rise time 35us
- Runs continuous duty with active cooling on capacitor and switch. Higher current exceeds switch capacity



High Temperature HC Caps

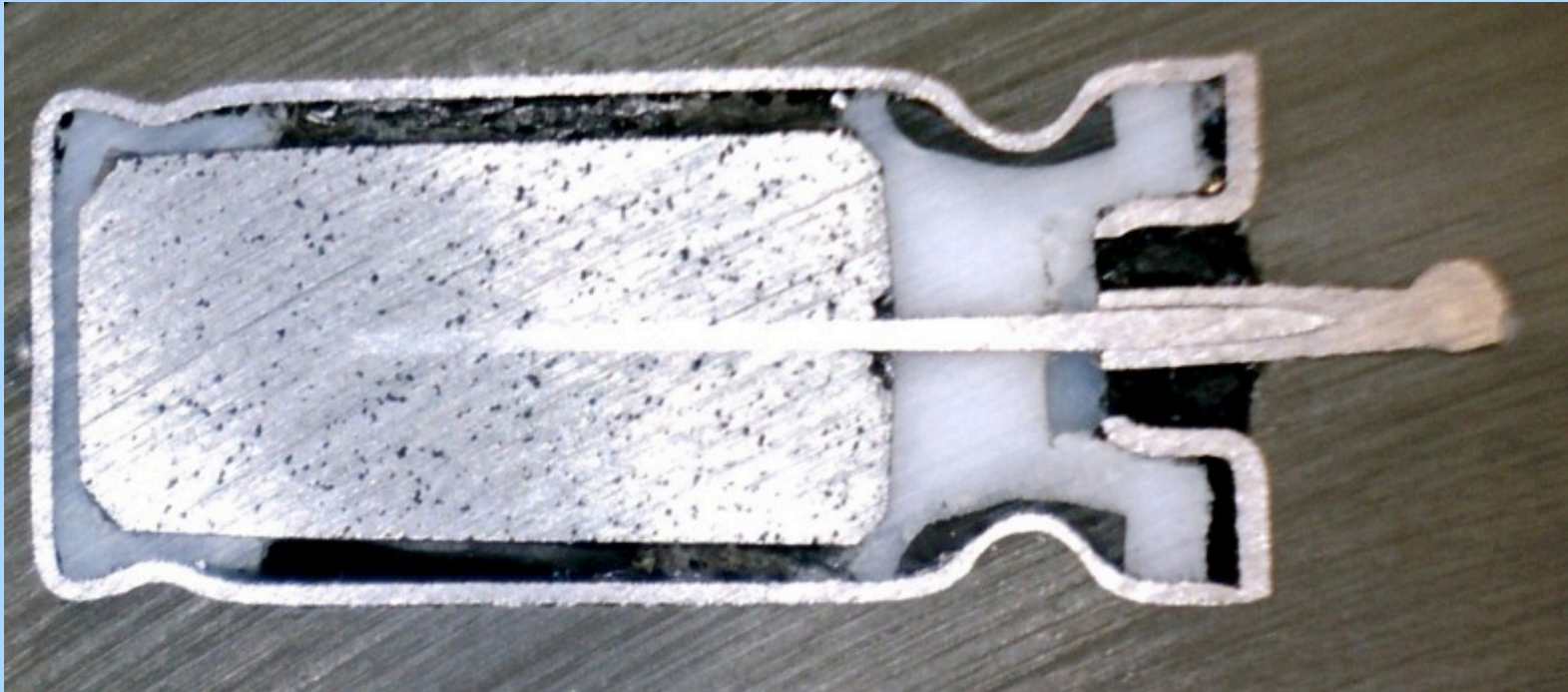


Part Number	C (uF)	Vr 85°	Vr 200°
HC2D075941HT	940	75	37
HC2B060331HT	330	60	30
HC2A100330HT	33	100	50

Part Number	Cap	V (175°C)	V (200°C)	Case Size
HC2A050101HT	100μF	30V	25V	A (T1)
HC2A075560HT	56μF	45V	37V	A (T1)
HC2A100330HT	33μF	60V	50V	A (T1)
HCB075111HT	110μF	50V	45V	B (T2)
HCB100680HT	68μF	70V	60V	B (T2)
HC2B050471HT	470μF	30V	25V	B (T2)
HC2B060331HT	330μF	36V	30V	B (T2)
HC2B075221HT	220μF	45V	37V	B (T2)
HC2B100151HT	150μF	60V	50V	B (T2)
HCD050681HT	680μF	35V	30V	D (T4)
HCD060561HT	560μF	42V	36V	D (T4)
HCD075471HT	470μF	50V	45V	D (T4)
HCD100221HT	220μF	70V	60V	D (T4)
HCD125151HT	150μF	85V	75V	D (T4)
HC2D050152HT	1500μF	30V	25V	D (T4)
HC2D060122HT	1200μF	36V	30V	D (T4)
HC2D075941HT	940μF	45V	37V	D (T4)
HC2D100471HT	470μF	60V	50V	D (T4)
HC2D125331HT	330μF	75V	62V	D (T4)

NOTE: A-case under development; all others currently available

Axial Leaded Tantalum Hybrid Capacitor



DGA Focused Gamma Tool

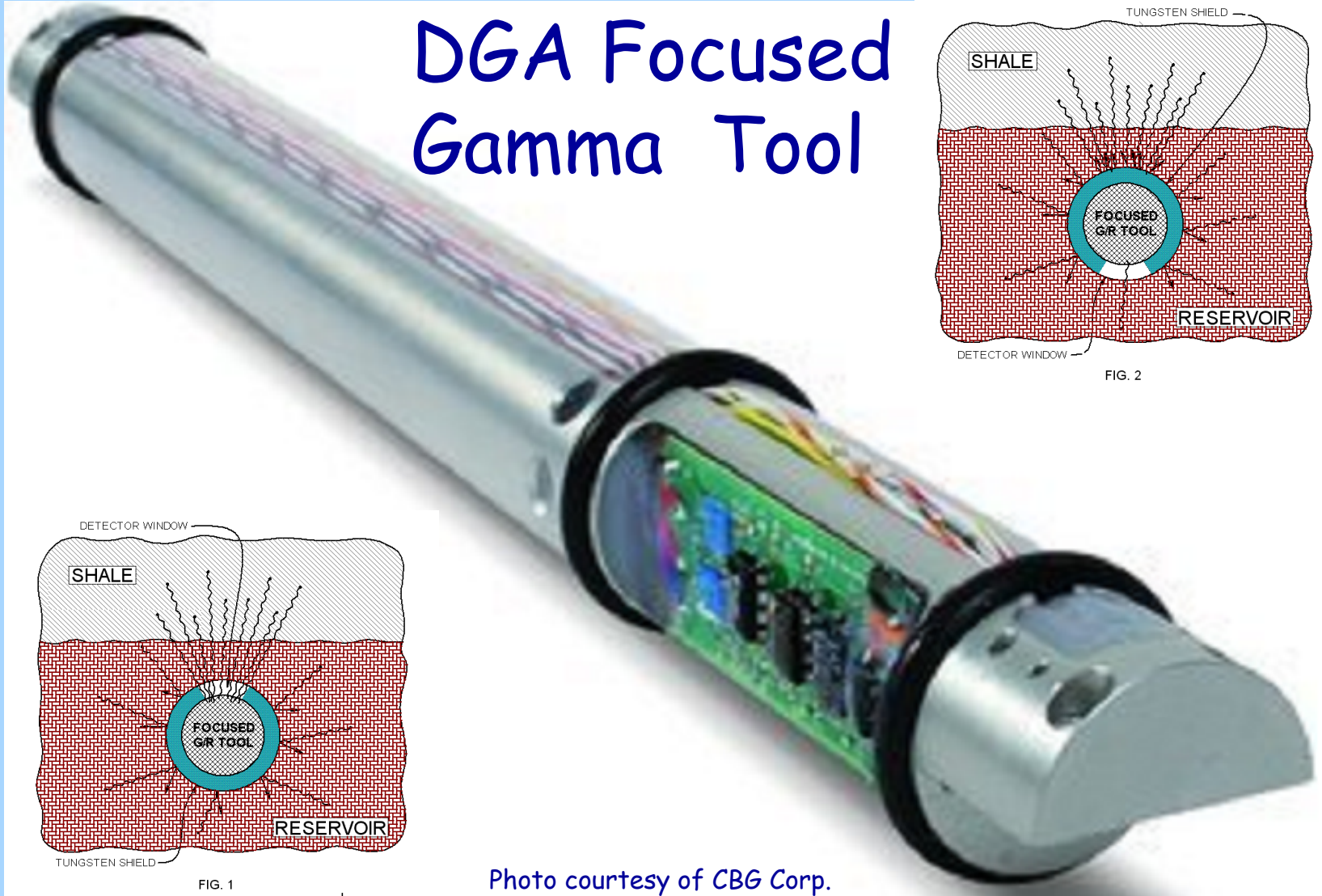


Photo courtesy of CBG Corp.

Motor controller for down-hole use

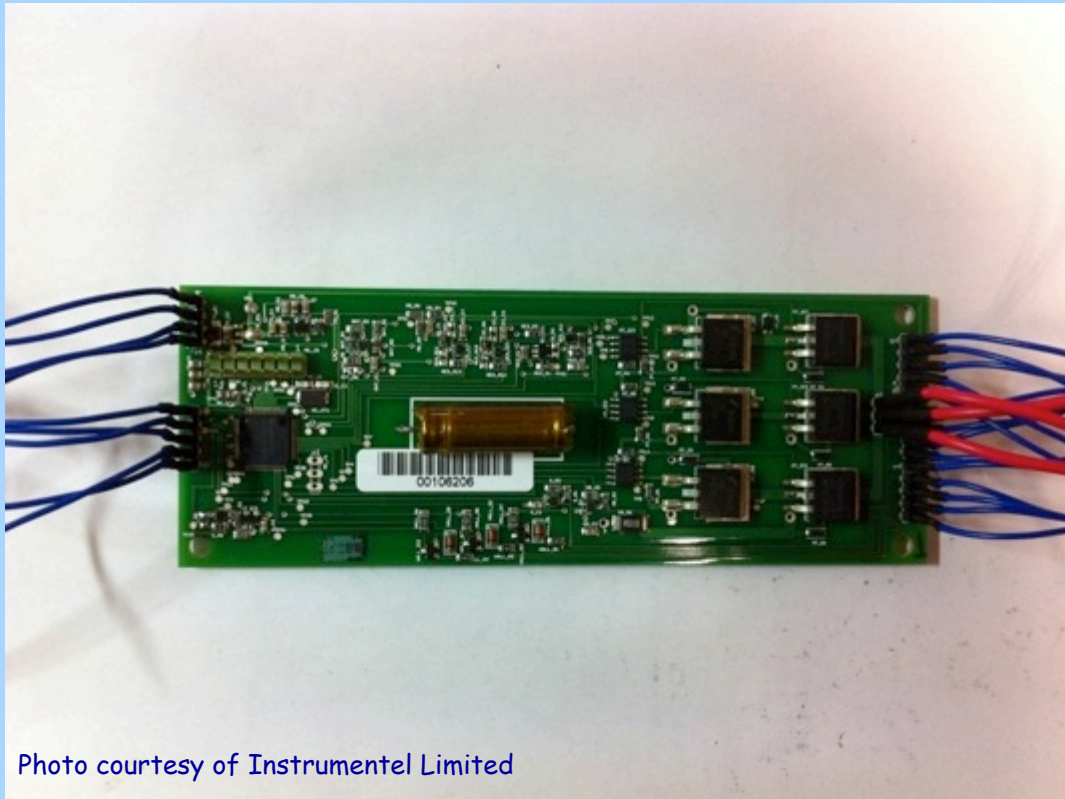


Photo courtesy of Instrumentel Limited

Instrumentel have been tasked with creating a high temperature motor controller circuit for a down well application. The motor controller is capable of driving a number of motor variants, including AC resolvers, although for this application it will control a DC motor. The controller will be able to withstand down-hole environments.

MWD Environment ratings:
Shock Limit 1000g, 0.5ms
Vibration Limit, 20G RMS random
50-500Hz, at 175°C.

The motors for this application require a high drive current, and the Evans capacitor was chosen for its high energy density, lifetime, and voltage capability.

HEAT EVM

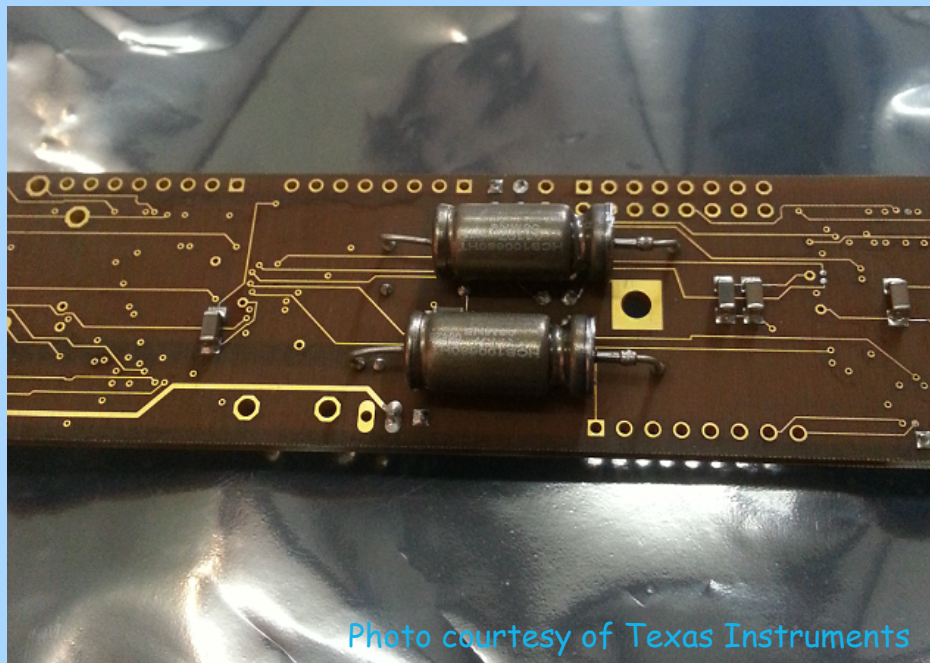


Photo courtesy of Texas Instruments

“The location of these decoupling capacitors becomes even more critical in high temperature operations since, in addition to the higher costs, larger valued capacitors become the life limiting component in many high temperature systems. Most capacitor types have falling capacitance values and increasing IR values as the ambient temperature increases which present trade offs when working with capacitors at elevated temperatures. The Harsh Environment Acquisition Terminal Evaluation Module uses a nominal number of capacitors and value of capacitance.”

HEAT EVM

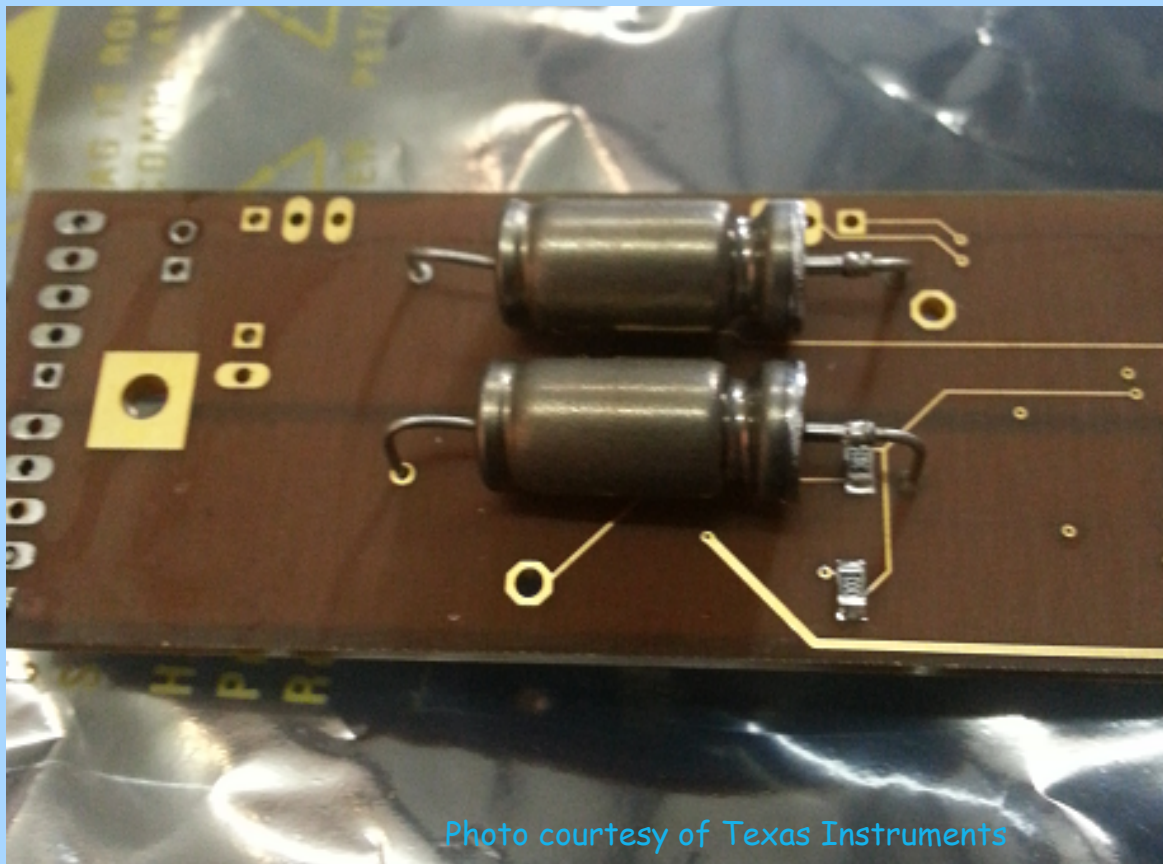


Photo courtesy of Texas Instruments

HEAT EVM

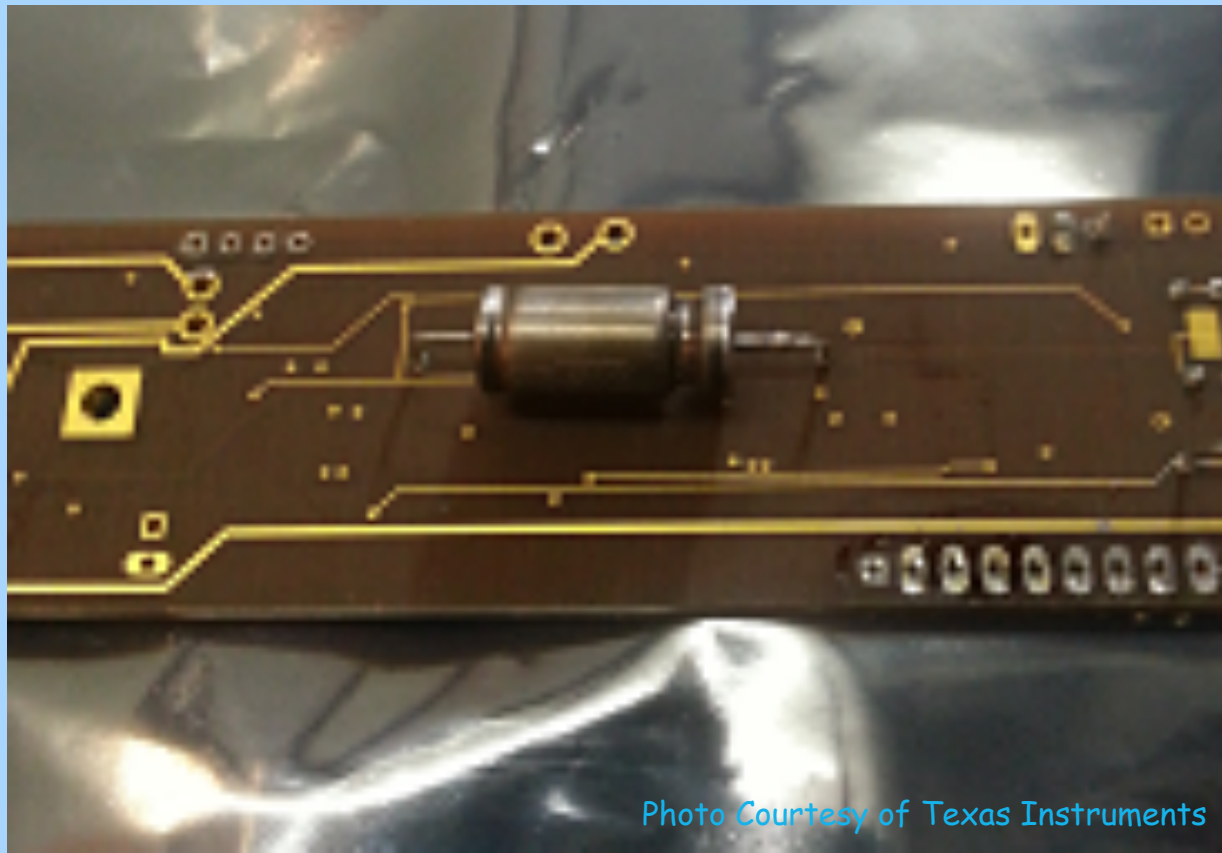
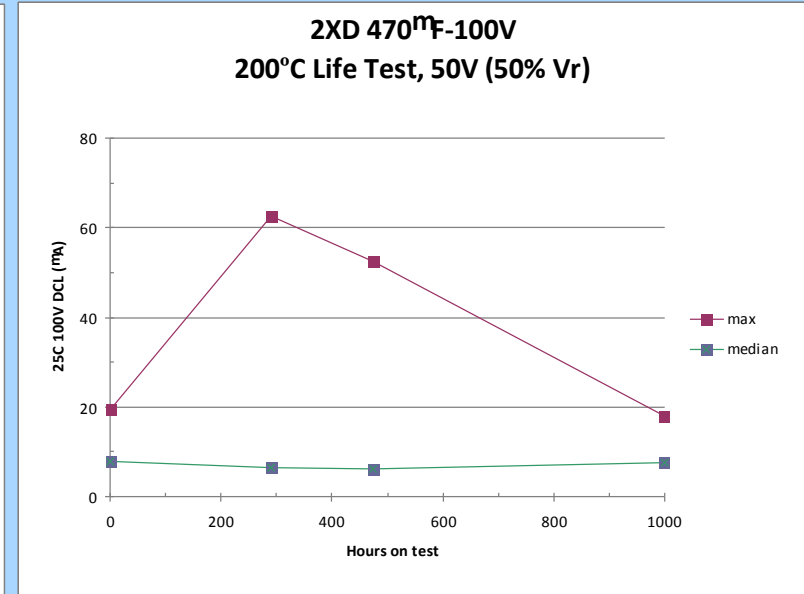
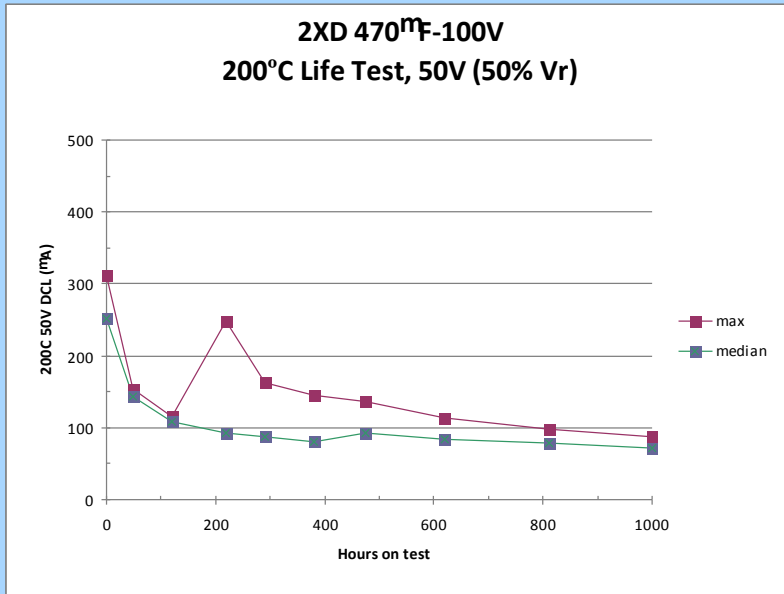
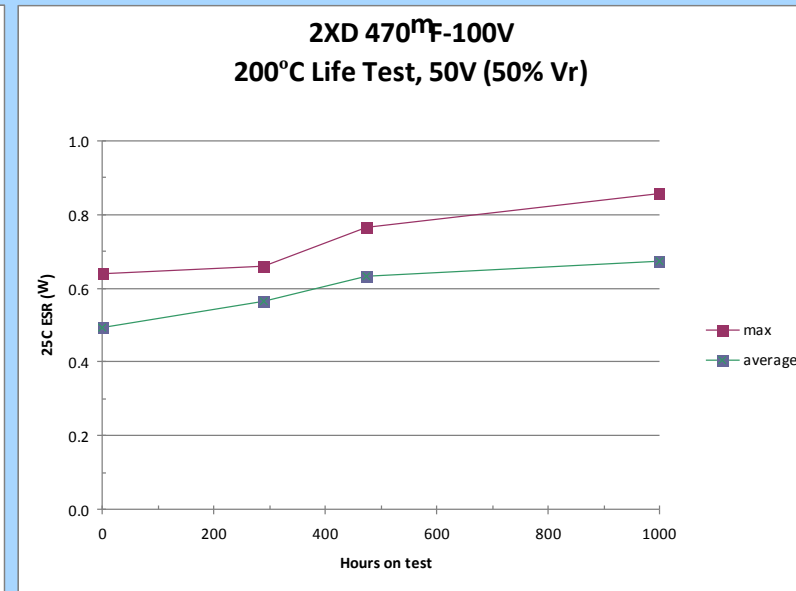
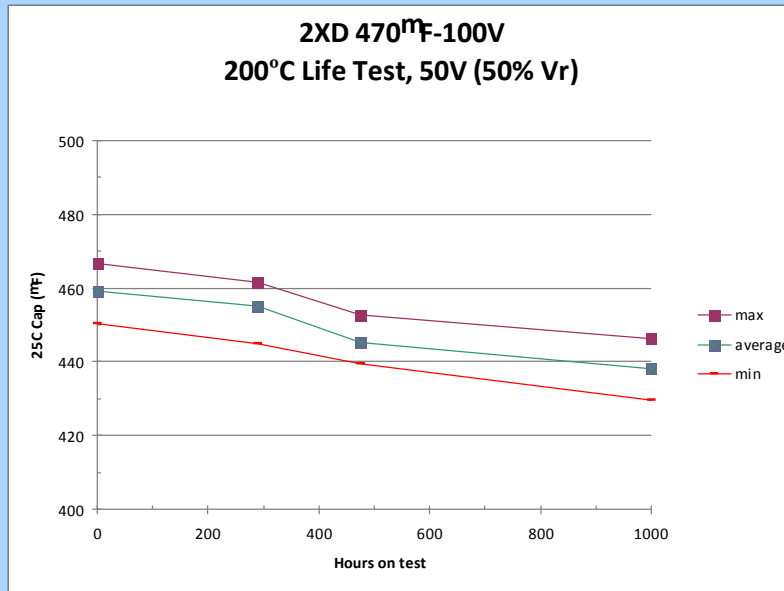


Photo Courtesy of Texas Instruments

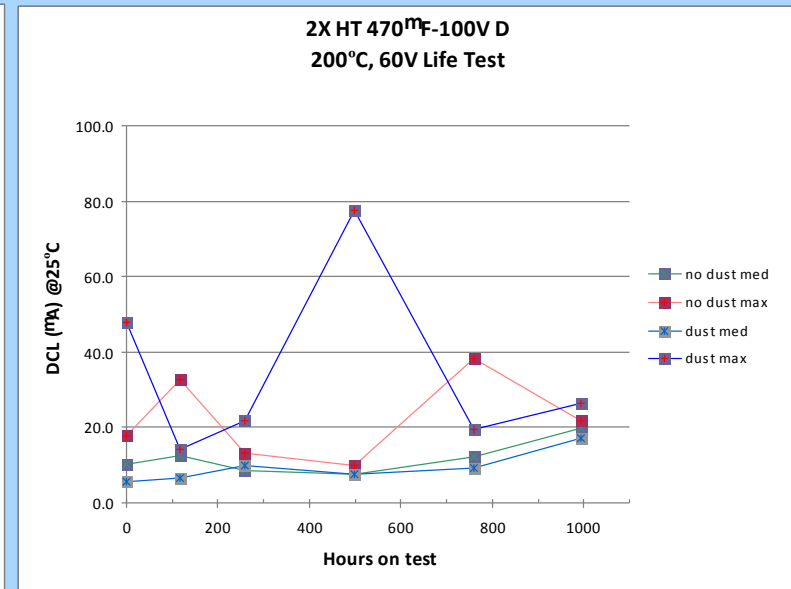
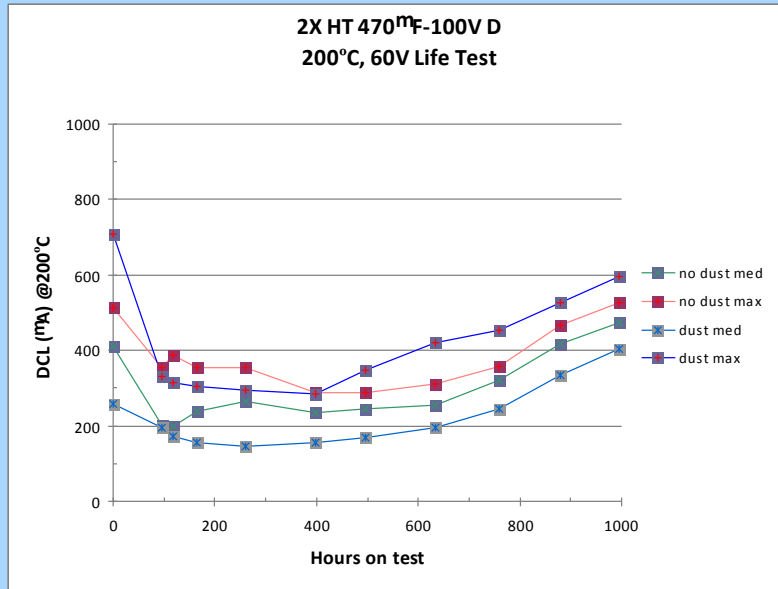
HC2D100 Life Test at 200°C



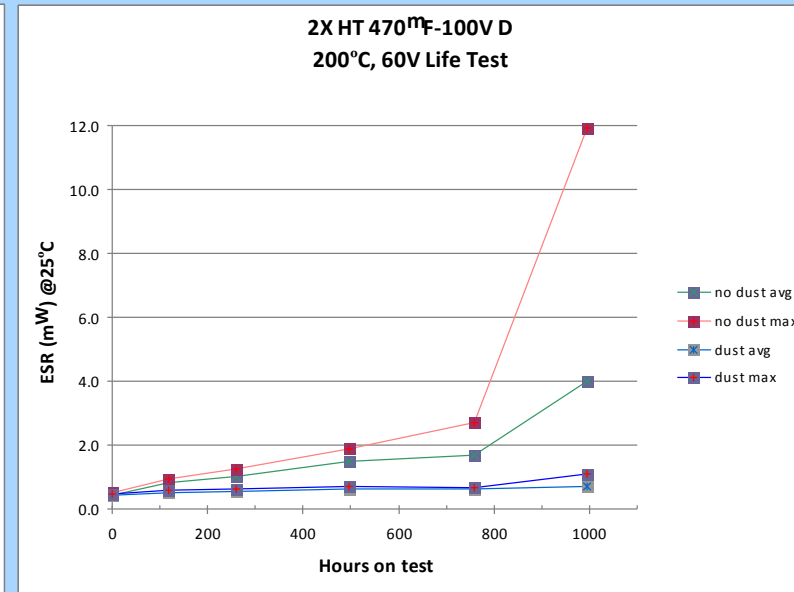
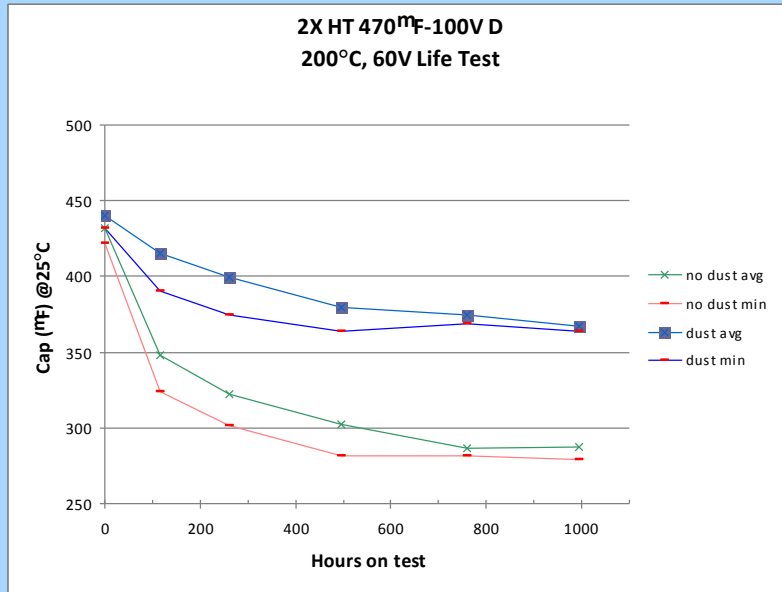
HC2D100 Life Test at 200°C

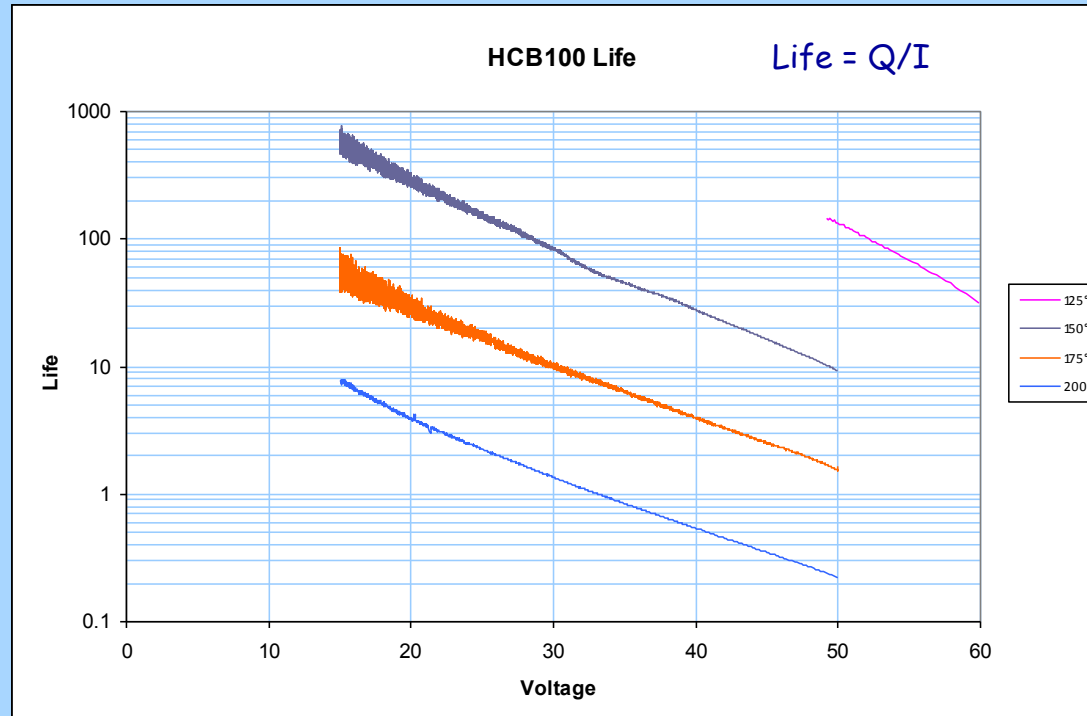
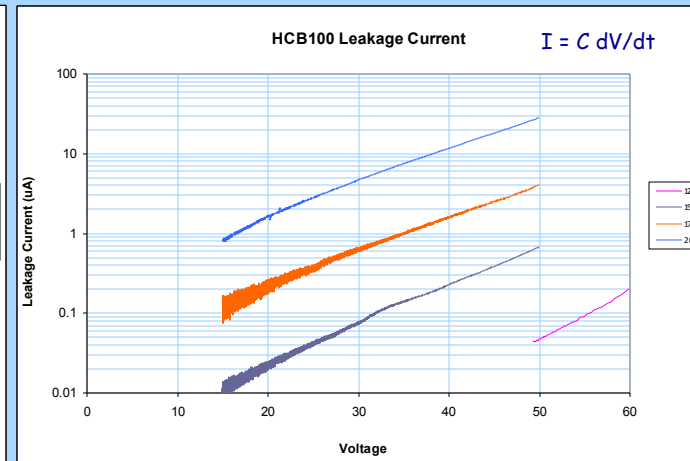
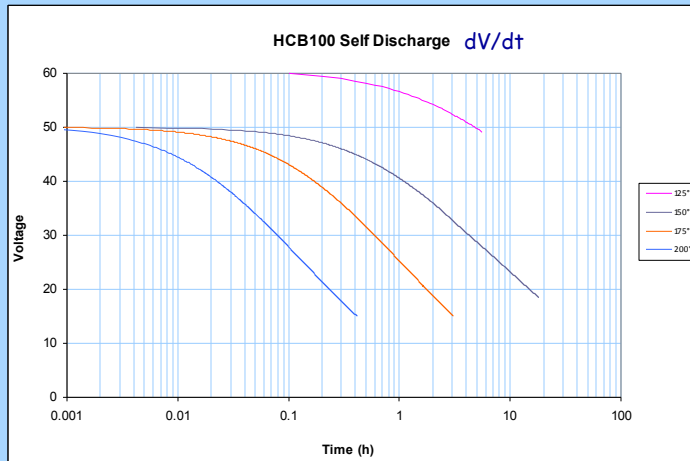


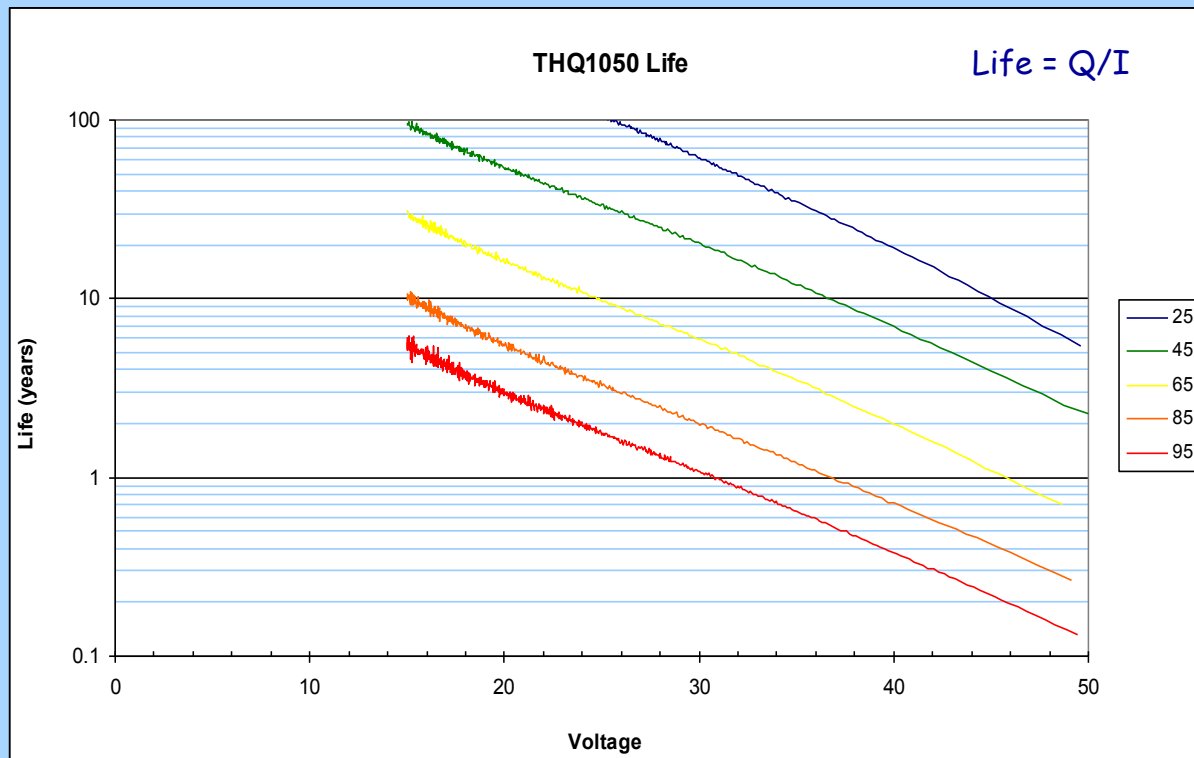
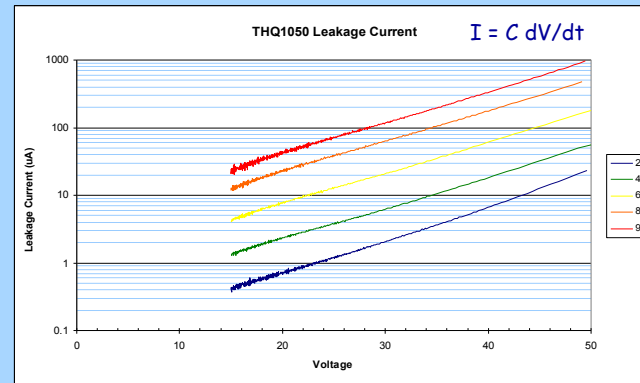
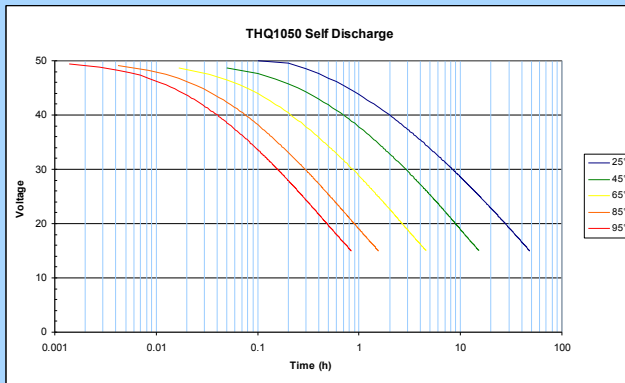
HC2D100 Life Test at 200°C



HC2D100 Life Test at 200°C



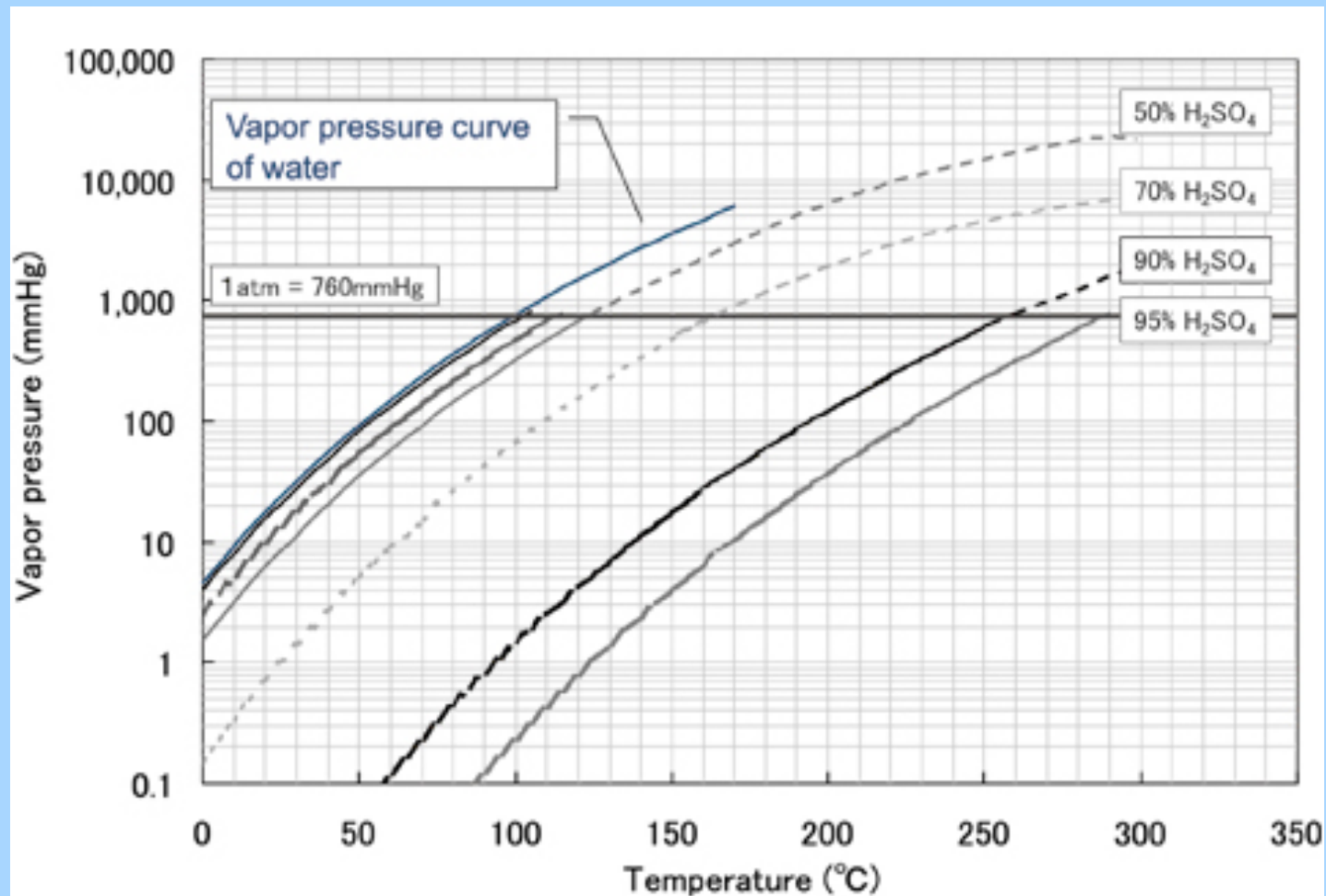




THQA2 at 230°

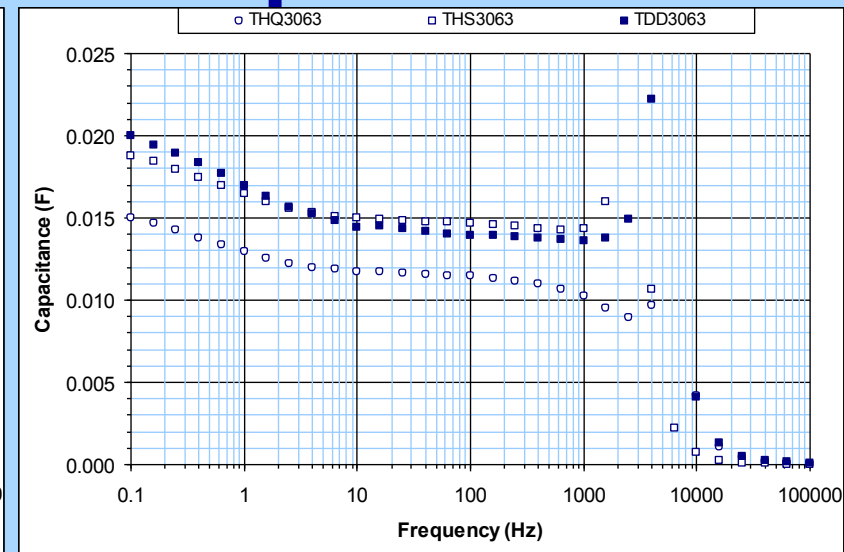
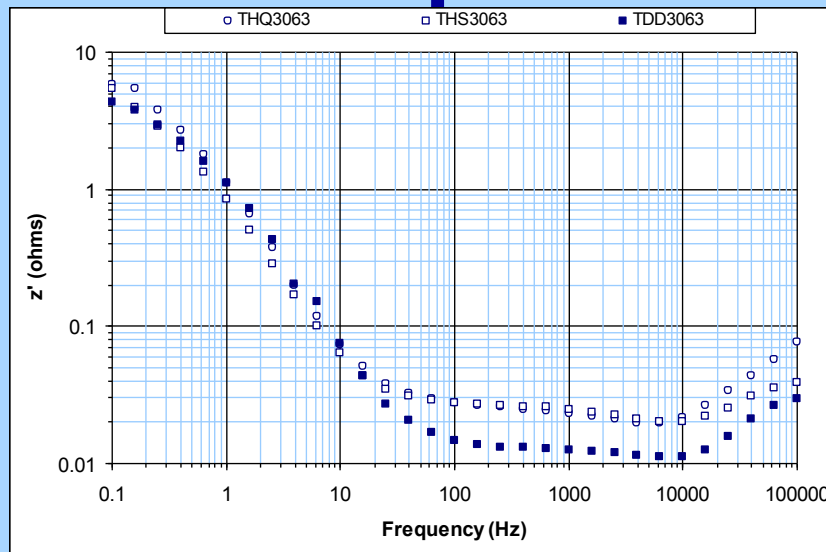


Photo courtesy of Petromar Technologies



Copyright © NEC Corporation 1994-2013. All rights reserved.

Capacitor Development



- THQ3 (1999) THS3 (2004) TDD3 (2011)
- Half the resistance and better frequency response
- Hermetic seal
- Excellent heat transfer

Summary

- Hybrid capacitors combining a faradaic with an electrostatic electrode have a combination of characteristics that improve performance.
- Wet tantalum hybrid capacitors suitable for high temperatures were developed. Life test results at 1000 hours at 200°C and 50% rated voltage predict life > 2000 hours for HC2D100HT.
- A method using simple measurements for predicting life based on leakage current at voltage and temperature was described.