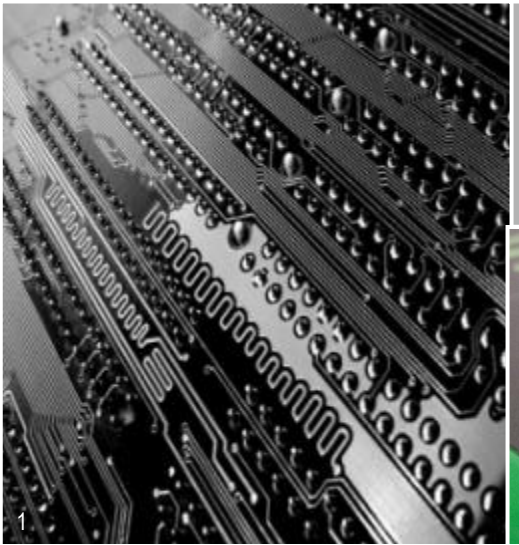
IOXUS
RETHINK POWER

Ioxus Titan Technology

AABC 2017 Mainz Germany *Ken Rudisuela CTO*



Ioxus Company Overview

Founded:

- 2007

Products:

- Large cylindrical and pouch ultracapacitors (EDLC)
- Light-weight and heavy-duty modules

Technology:

- ACN and PC
- High temperature and high voltage

Markets:

- Transportation, Wind, Industrial and Medical
- Worldwide sales and marketing

Manufacturing:

- Engineered and manufactured in America and Japan
- ISO-9001:2008 certified working on TS-16949

Location:

- Oneonta NY
- Kusatsu Japan

Credible and Industry Leading Investor Base

ELLIOTT

BRAEMAR ENERGY VENTURES

CAYUGA VENTURE FUND

ARES

Industry Awards

Global Cleantech 100

Global Cleantech 100

Global Cleantech 100

Global Cleantech 100

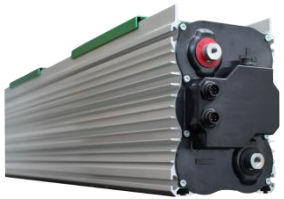
FROST & SULLIVAN 2015 BEST PRACTICES AWARD

Inc. 5000

Deloitte. Technology Fast500

Ioxus Ultracapacitor Modules

- Ioxus designs and manufactures a number of different ultracapacitor modules using both the THiNCAP (pouch) and iCAP (cylindrical) cells.
- Ioxus standard designs are the most rugged and longest lasting in the industry.
- Building block designs, such as the X-Series allows for a cost effective “right sizing”
- Standard 48V modules have the highest rate capability and lowest temperature rise of any commercial product
- Inventive designs such as the new uSTART and liquid cooled modules are in a class all of their own.



Ioxus THiNMOD Applications

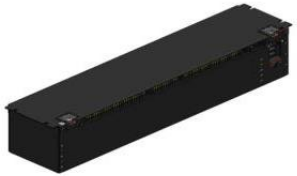
TOSHIBA

Dynamic Voltage Recovery 4MW

GE Healthcare

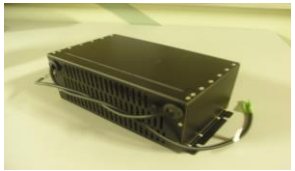
MRI Machines

DAIFUKU



Stacker Crane

TOYOTA



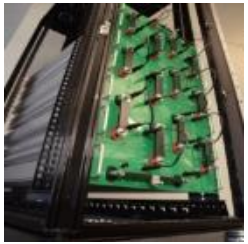
Automated Guided Vehicles

Ioxus iMOD Products Are Field Proven

PACECO ESPAÑA, S.A.

Harbor Crane

FLEXGEN POWER SYSTEMS



Generator Connected 1 MW

DYNEX

Grid Connected 40MW

KBi

City Bus Engine Start 32V

Ioxus Titan HT ™ Cell Technology

Ioxus iCAP® with ***Titan HT***™ technology is a breakthrough in high temperature technology

- Unprecedented electrochemical stability
- Highest temperature durability
- Highest rate capability
- Highest round trip efficiency
- Lowest leakage current
- Lowest gas generation
- Longest life, doubled durability spec
- Patented

Titan Objective

Increase the operating temperature range of EDLC's for under-hood automotive applications and for longer life at any temperature:

- In theory no faradaic reactions but in practice there are

Temperature: $L(T_{Int}) = L_0\, e^{\left(\frac{Ea}{k}\right)\left(\frac{1}{T_{Int}} - \frac{1}{T_0}\right)}$; $T_{Int} = R_{therm}\,[I^2 R_{DC}]\,F_{duty}$

Voltage: $L(V) = L_0\, e^{-\alpha\left(\frac{V}{V_0} - 1\right)}$

Overall: $\mathrm{L(V,T)}_{Float} = L_0\, e^{-\alpha\left(\frac{V}{V_0} - 1\right)} e^{\left[\frac{Ea}{k}\left(\frac{1}{T_{Int}} - \frac{1}{T_0}\right)\right]}$

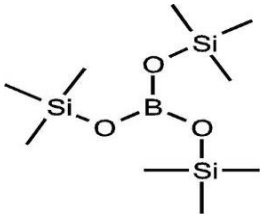
Goal: Increase the activation energy ⇨

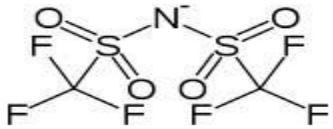
- More thermal dynamically stable product
- Higher temperature capability
- Higher voltage capability
- Longer life

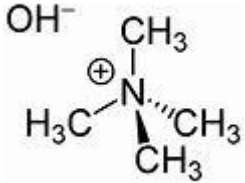
Approach

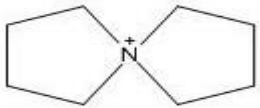
Keep specific capacitance constant
Increase electrolyte stability
Look at a number of:

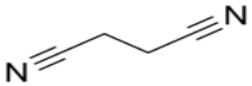
- New salts
- New solvents
- Ionic liquids
- Additives
- Coated electrodes

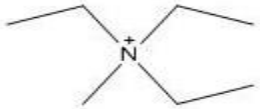


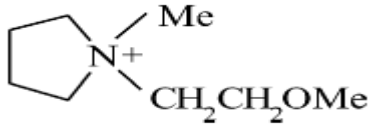


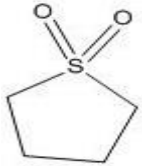












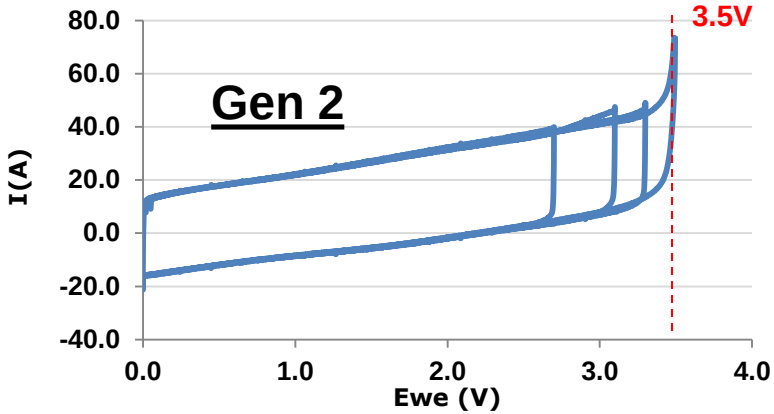
Additives

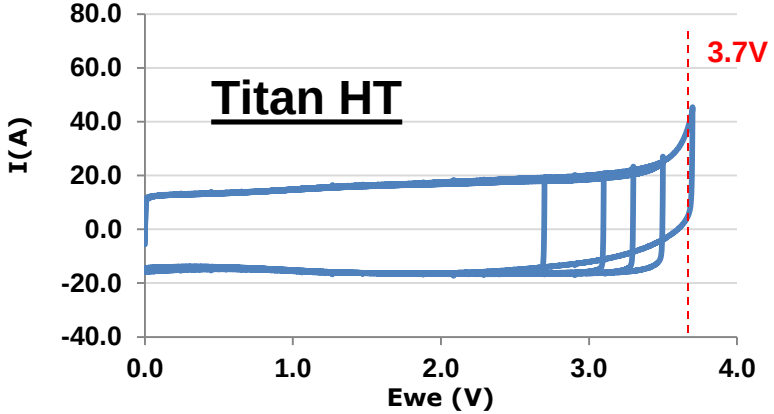
Stabilizing additives:
Reduces capacitance loss, reduces ESR gain and reduces gas generation

- High electrochemical stability
- Affinity to the carbon surface
- Polar characteristic
- High dielectric constant
- Water scavenger
- Tertiary amine scavenging
- Low cost

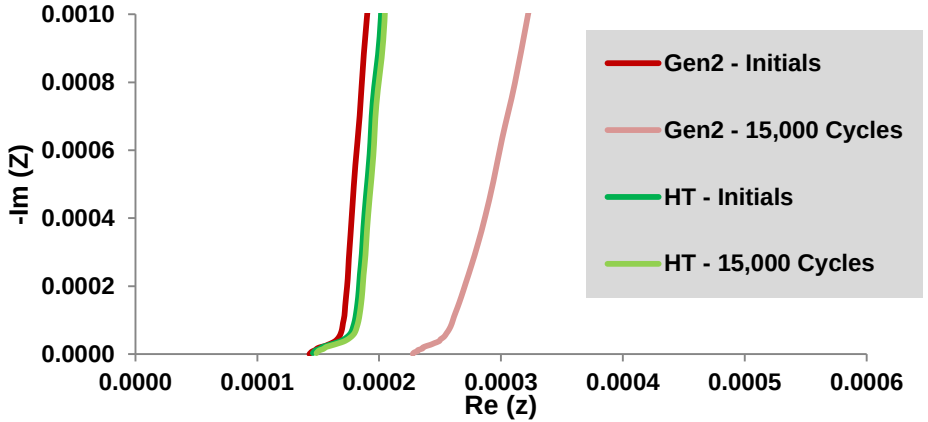
Result:
Absorbed mono-layer on the carbon, producing a protective surface coating, reducing contact between carbon and electrolyte slowing down electrolyte breakdown

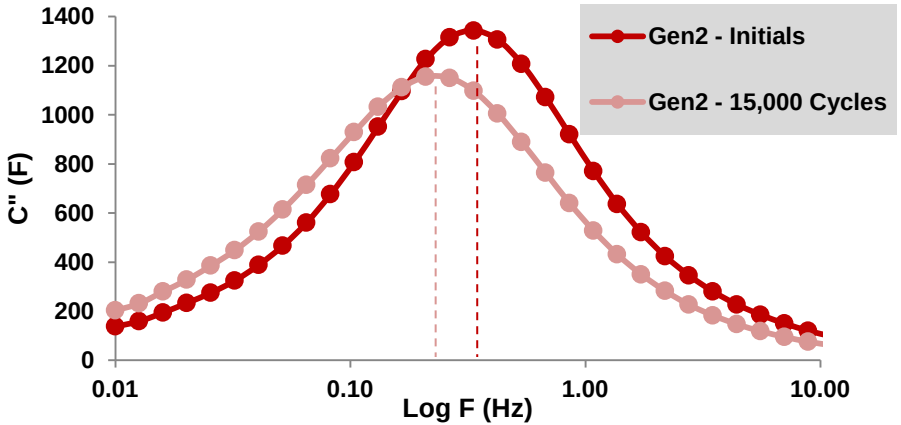
Cyclic Voltammetry at 65ºC

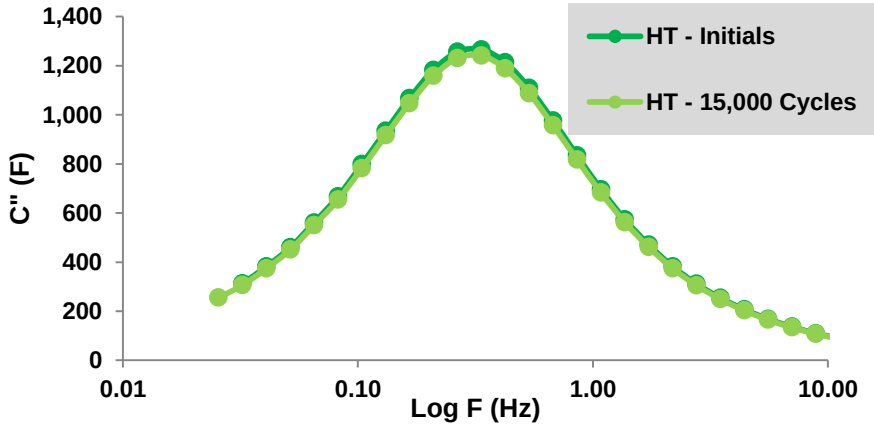




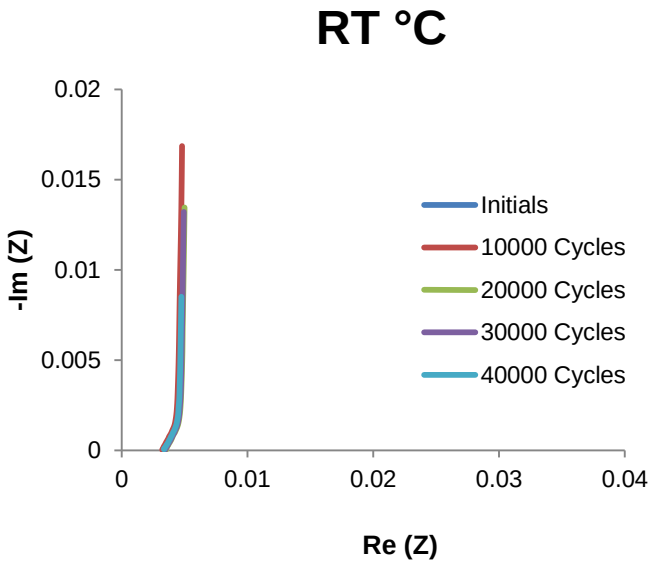
EIS Cycling at 25 °C

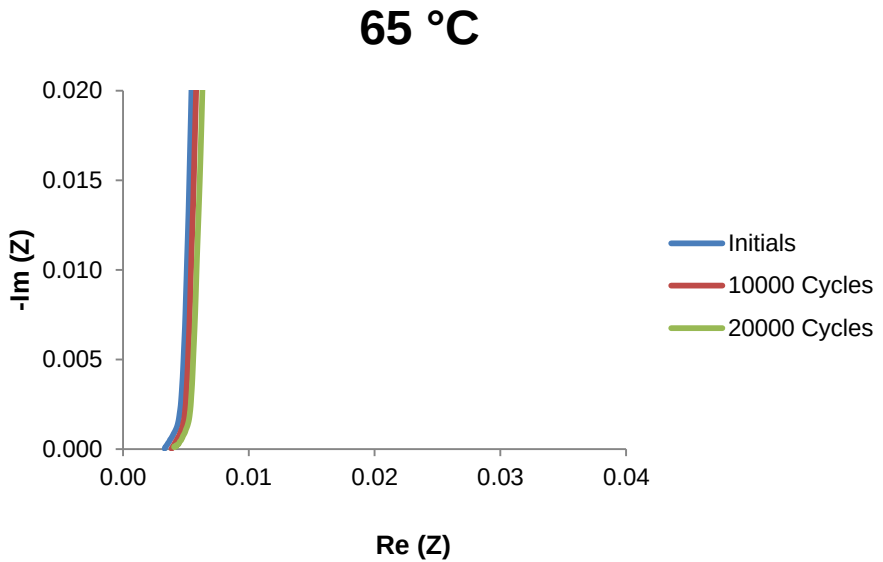






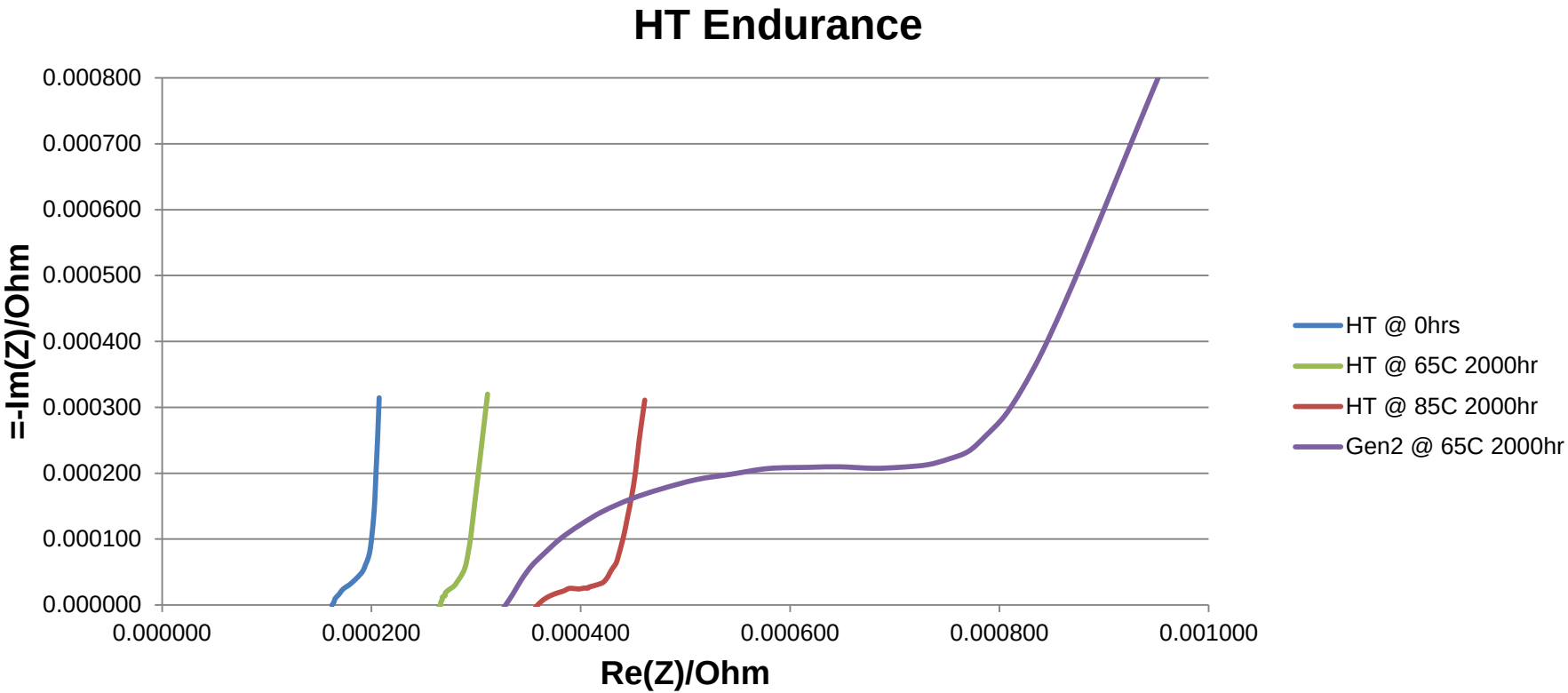
EIS of HT Cycled at RT/65



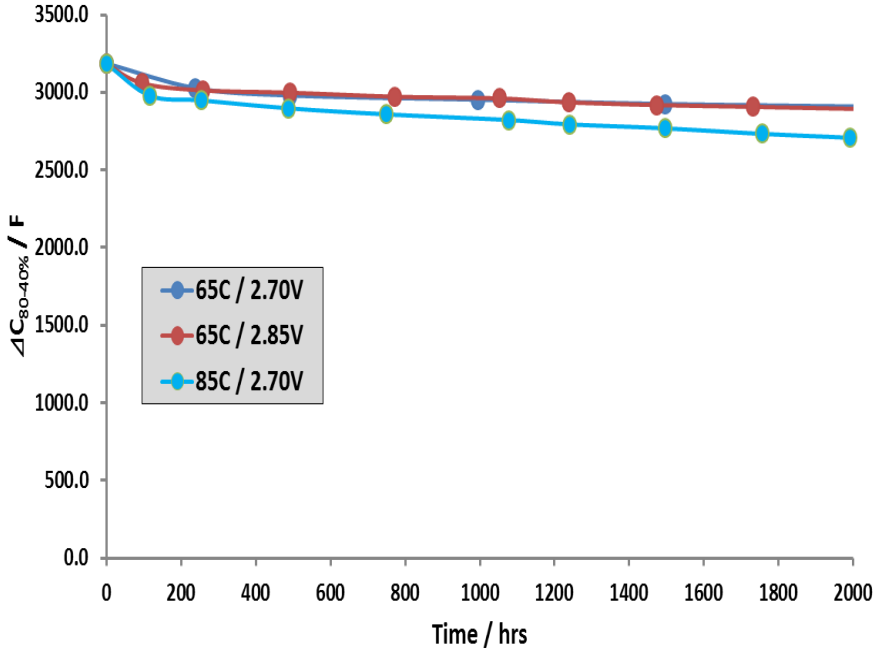


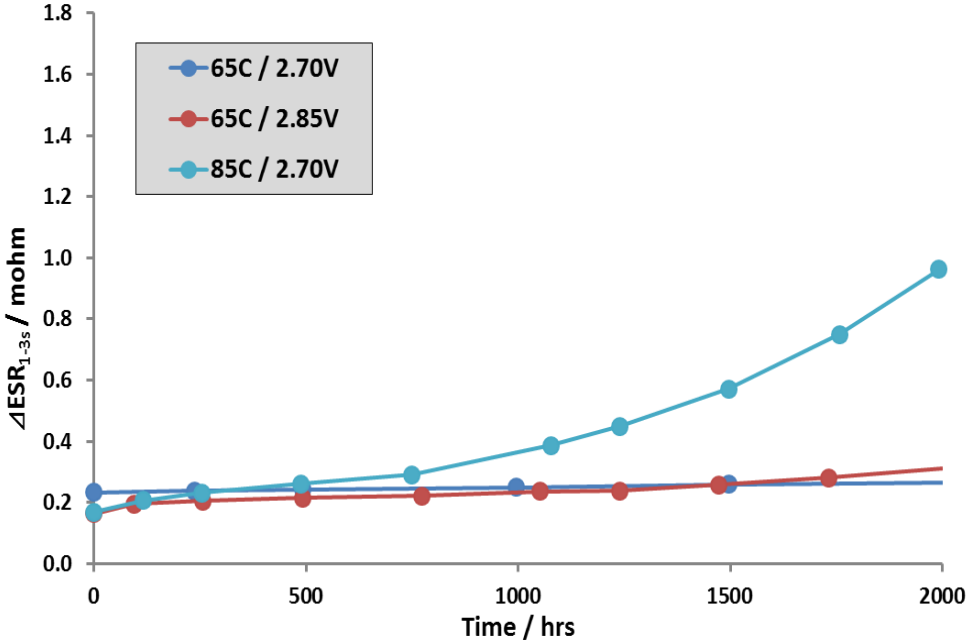
Almost no change under high rate high temperature cycling

Endurance EIS 3000F after 2000hr

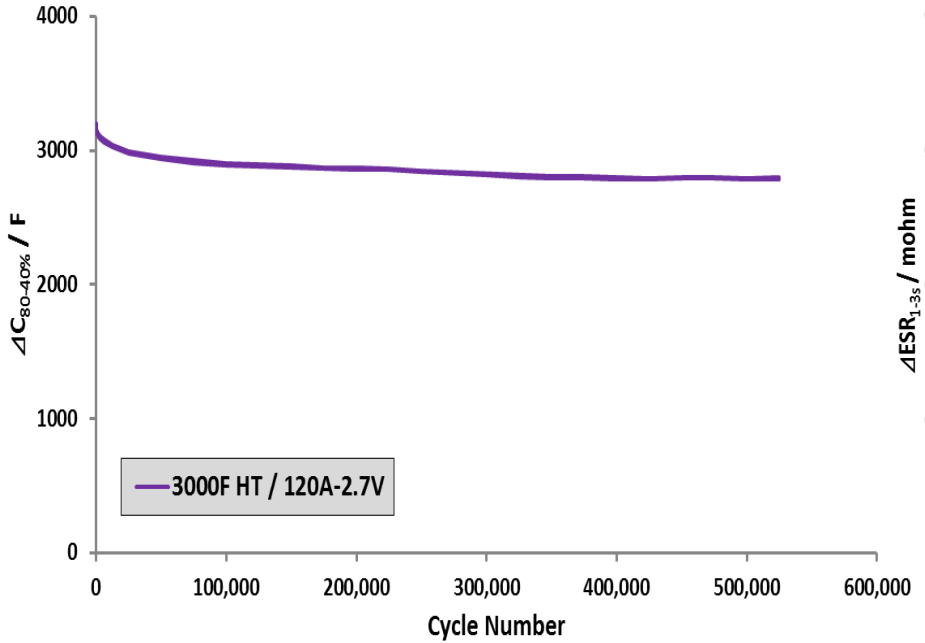


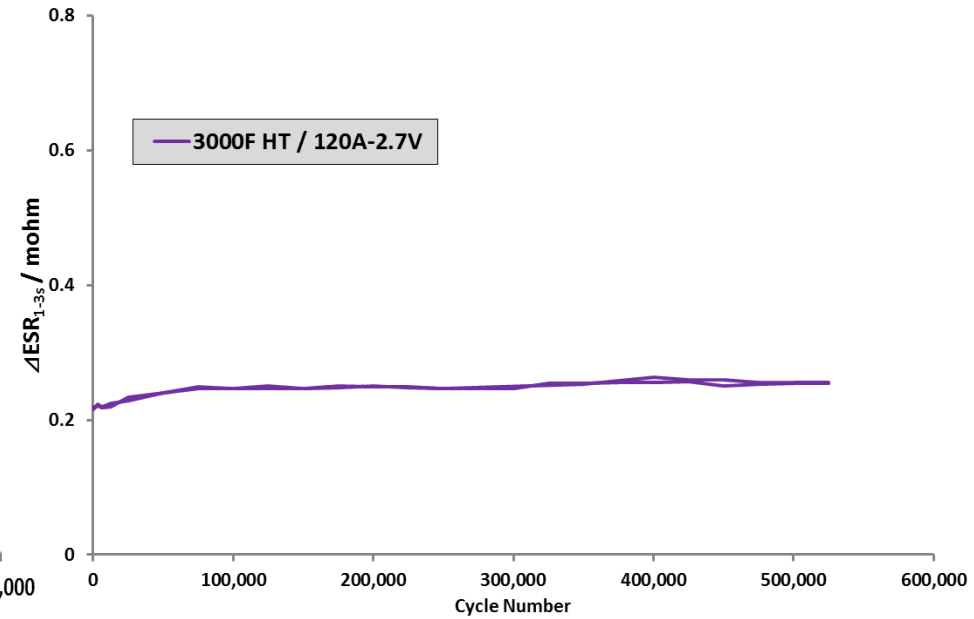
Endurance Capacitance and ESR



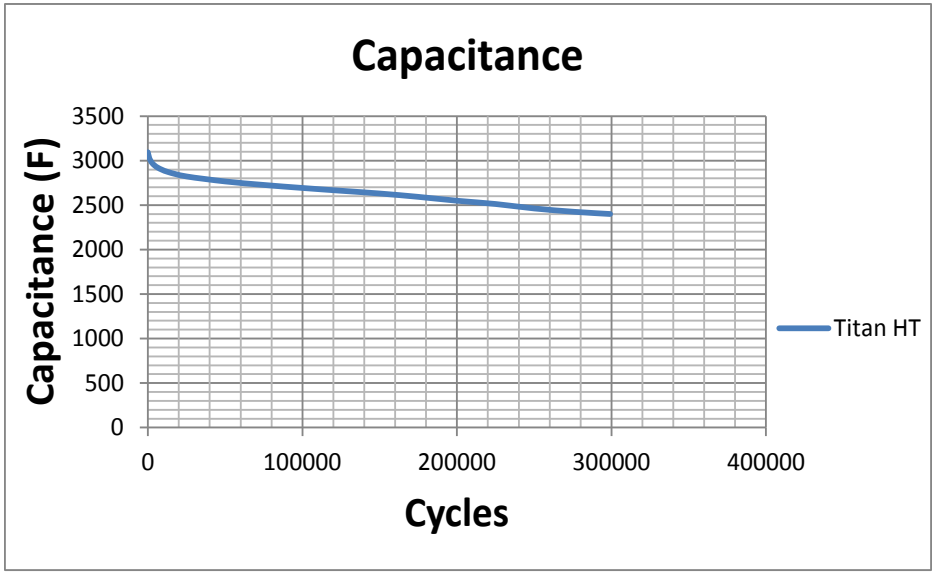


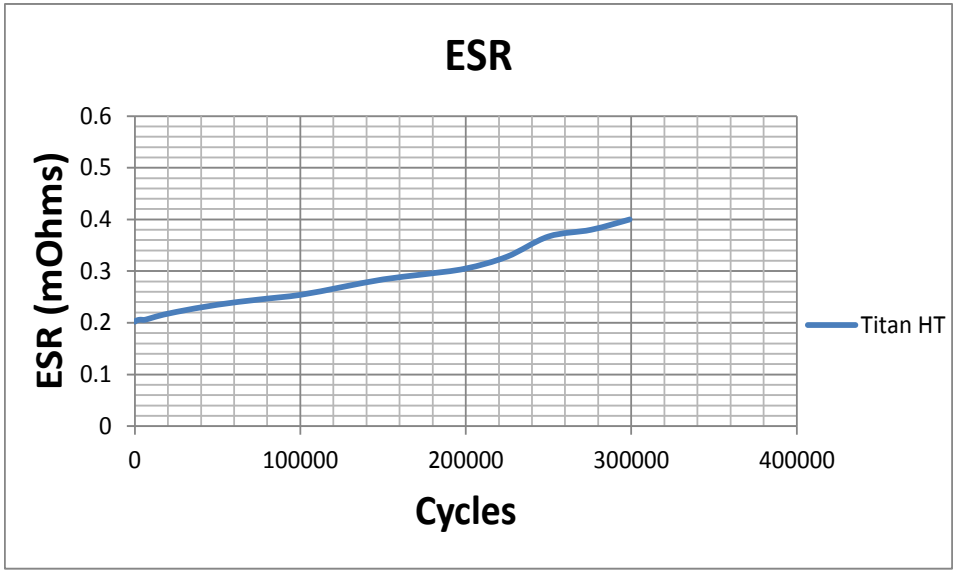
High Rate Cycling at RT





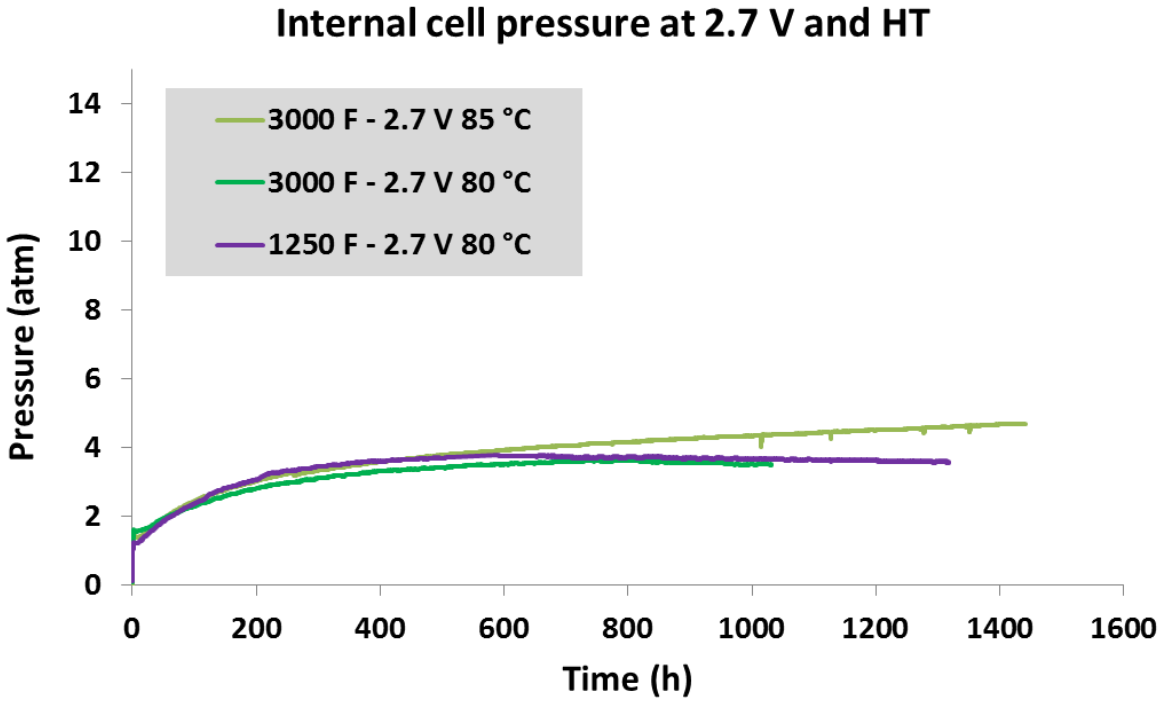
High Rate Cycling at 65ºC



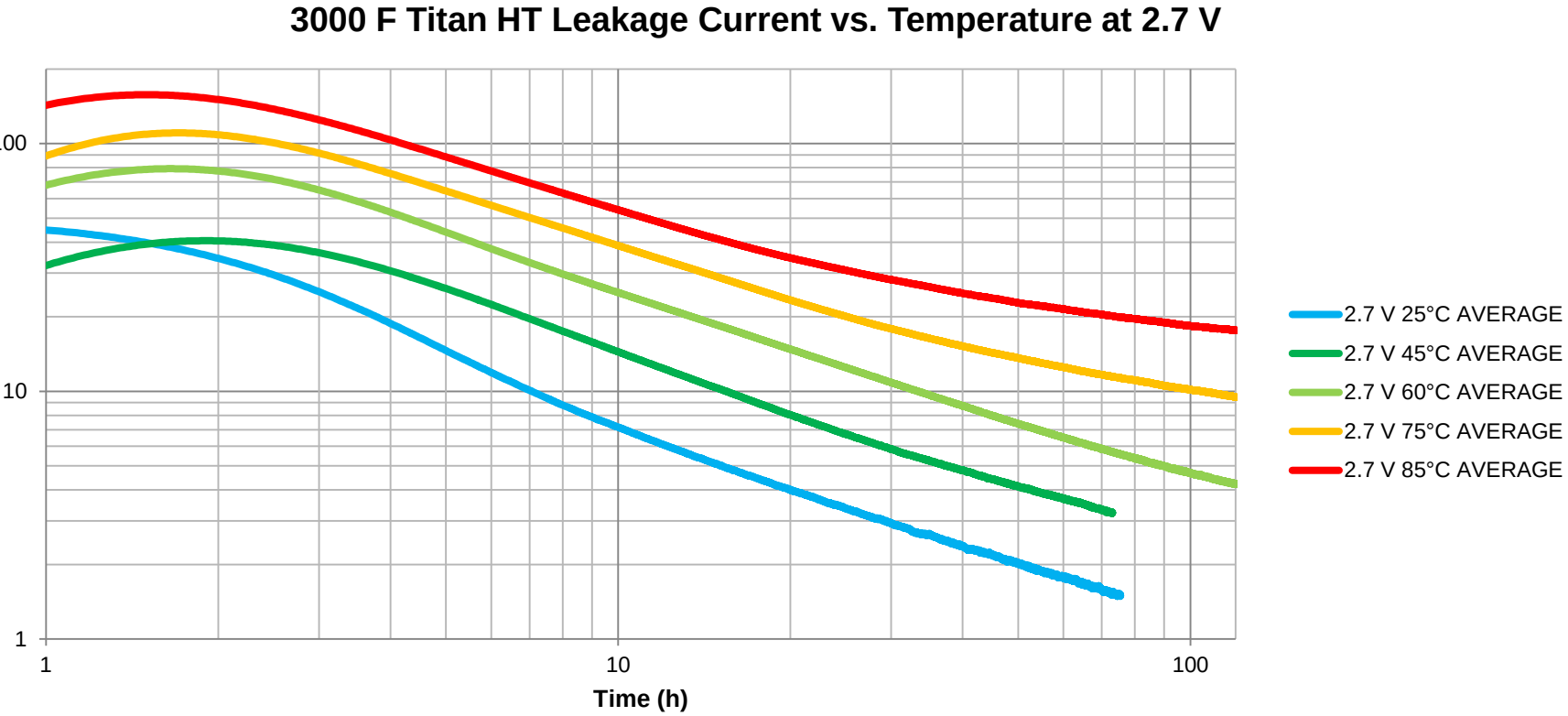


3000F cells cycled at 120A continuous IEC measurement

Gas Generation



Leakage Current at Temperature



Leakage Current after Cycling

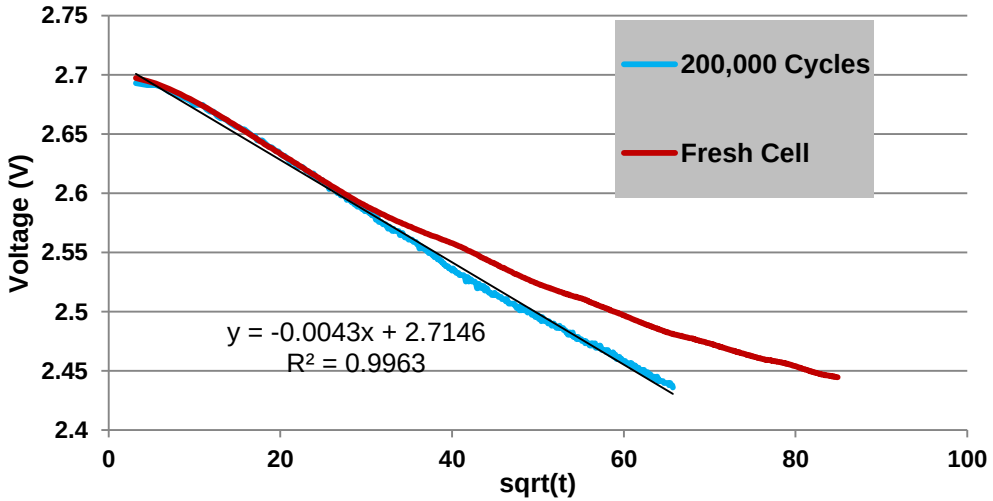
Leakage current is pure diffusion controlled after cycling; charge re-distribution between electrode and electrolyte and inter-electrode

Governing Equation $$V_t = V_i - \frac{2zFAD^{1/2}\pi^{1/2}c_0}{C}t^{1/2}$$

V ∝ sqrt(t)

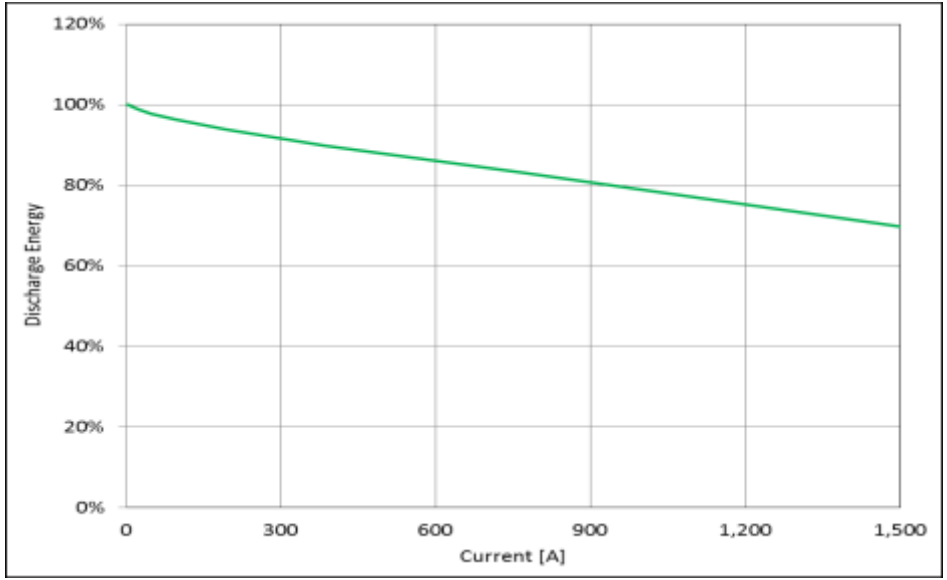
Fresh cells show mostly Faradaic reaction controlled

Cycled cells exhibit excellent agreement with pure diffusion controlled self-discharge

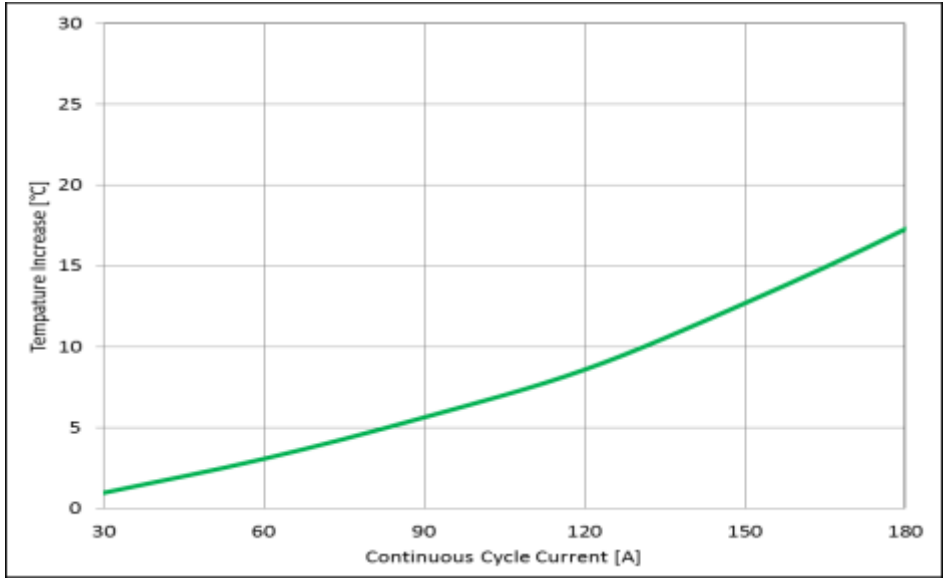


Influence of Charge-discharge Rate

iCAP HT 3000F – Discharge Energy vs. Discharge Current



iCAP HT 3000F - Temperature Increase in Continuous Cycle



Ioxus uSTART™: Benefits for Vehicle

uSTART™ Stabilizes the Vehicle Bus Voltage

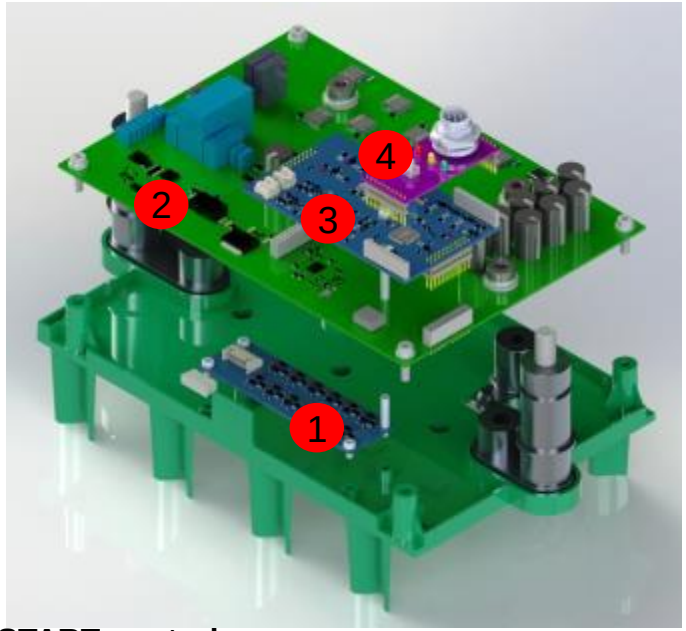
- **Improved Performance:** uSTART™ provides greater starting power than battery only solutions and cranks engines faster
- **Improved Reliability:** uSTART™ reduces breakdowns by eliminating conditions where the battery is too discharged to start a vehicle
- **Improved Efficiency:** uSTART™ reduces battery discharge, so alternator load and emissions are lower
- **Lower Costs:** uSTART™ reduces battery cycling, so battery life is extended

Ioxus uSTART™

uSTART™ Stabilizes the Vehicle Bus Voltage

- Lead-acid batteries have a limited charge/discharge cycle life and will have the least amount of degradation if they are kept at a high state of charge.
- By managing the vehicles bus voltage, uSTART handles the high current loads and reduces the amount of discharge on the batteries.
- uSTART maintains a higher system voltage reducing stress on the battery and increasing its life.
- The engine starts faster with uSTART reducing stress on the starter therefore increasing its life.
- The more times an engine is stopped and started, the greater the benefit uSTART provides, e.g. engine auto-stop or delivery vehicle applications

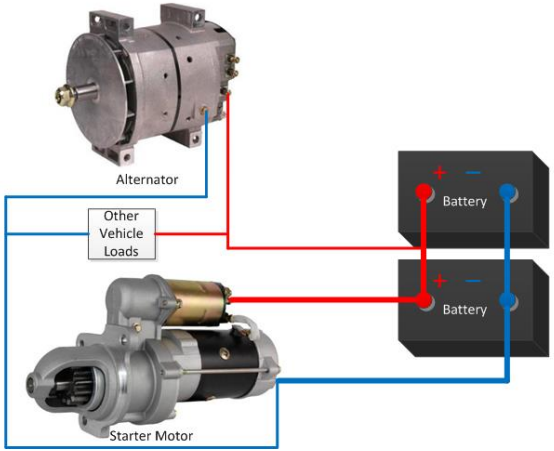
Ioxus uSTART™: Assembly



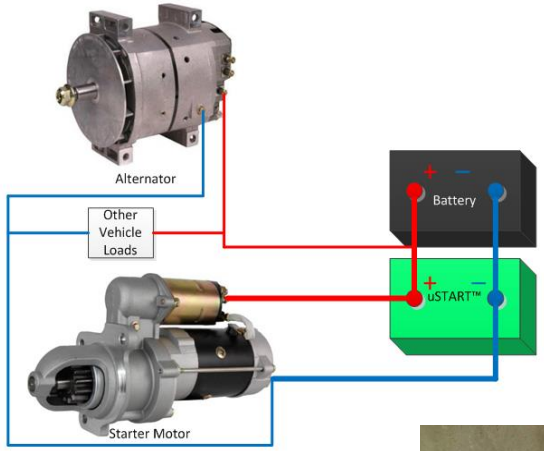
uSTART controls;

1. Cell balancing board
2. Power board; DC/DC converter, transfer MOFETS
3. Control board; micro processor
4. Function board

Easy Installation

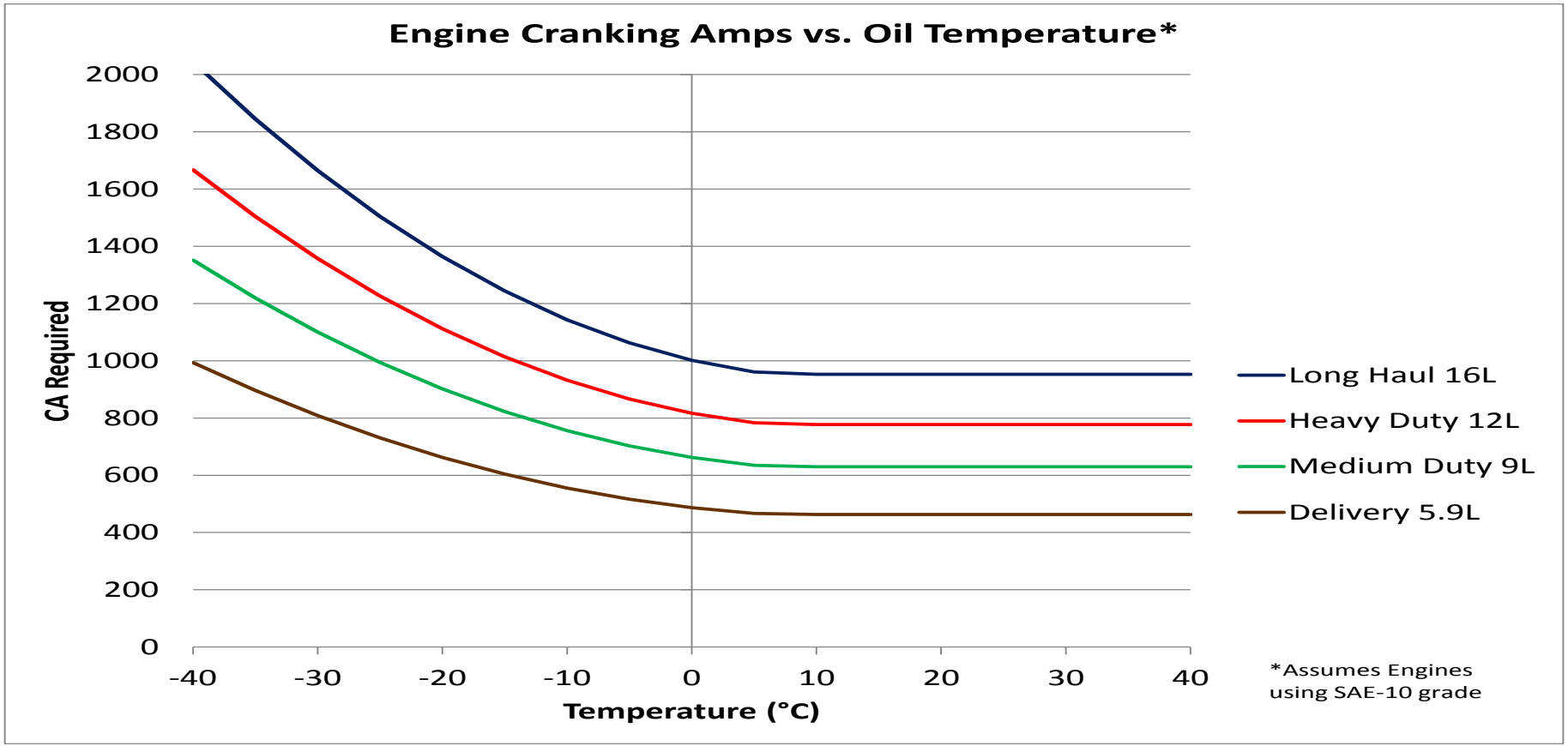


Wiring before uSTART installed



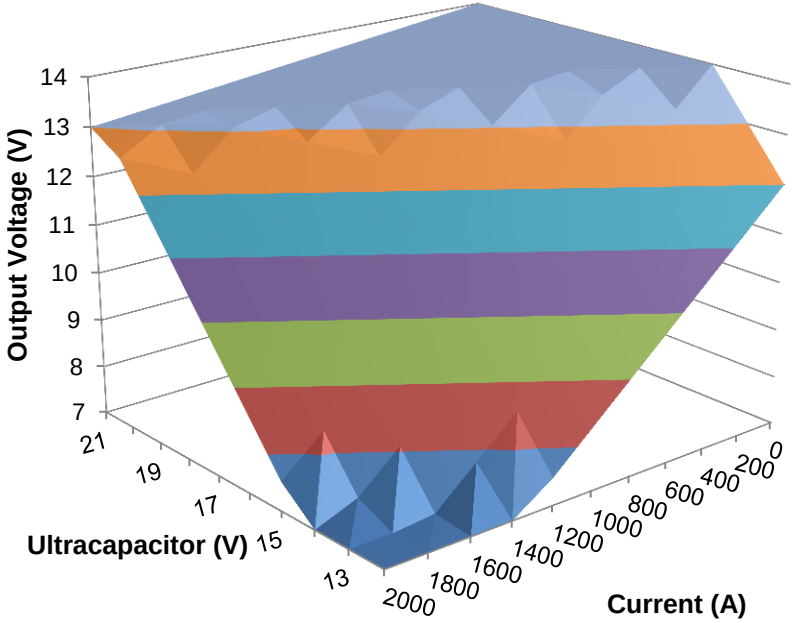
Wiring after uSTART installed

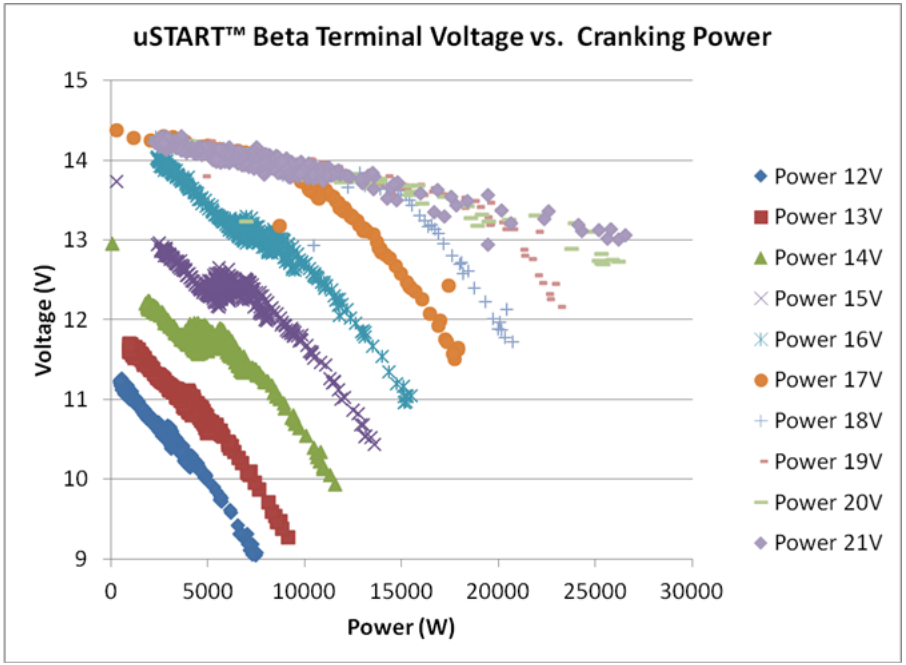
Engine Cranking Current 12V System



Power Output vs Ultracapacitor Voltage

Multiple engine starts with 1100 CCA uSTART ultracapacitors at different starting voltages

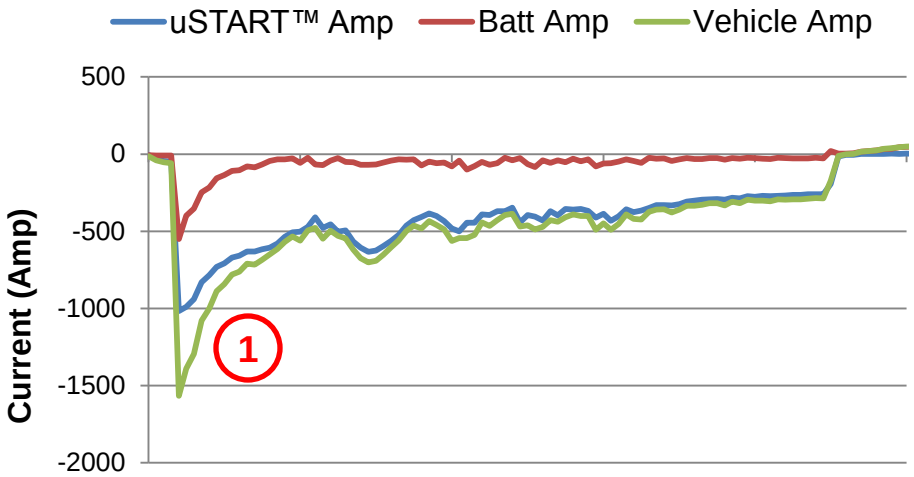




Output terminal voltage and delivered power is a function of the ultracapacitor voltage

uSTART Field Operation Class 6 Delivery Truck

Typical Engine Cranking Load Sharing between Battery and uSTART

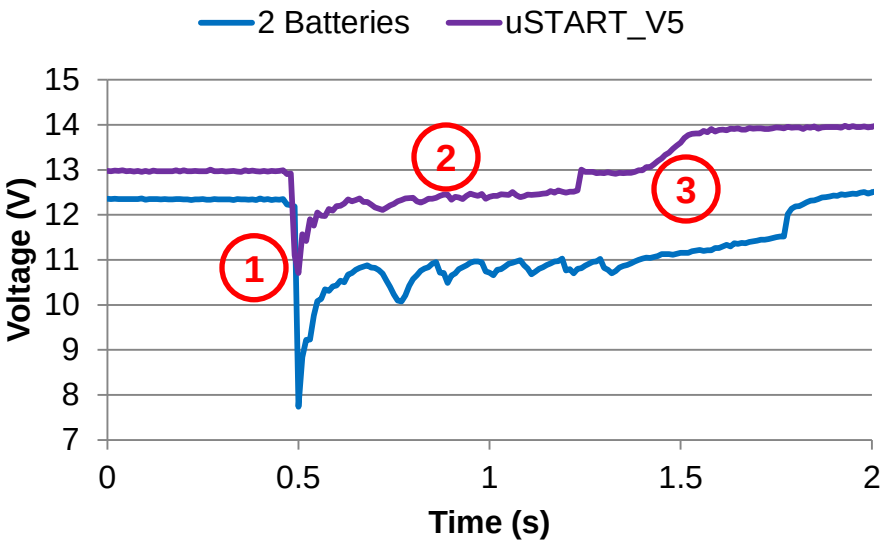


1) The current that the systems sees is strictly determined by the internal combustion drive system but the uSTART absorbs the majority of the demand reducing stress on the battery significantly

uSTART handles the majority of the starting current reducing drastically the current on the battery, maximizing its' life

uSTART Field Operation Class 6 Delivery Truck

Typical Engine Cranking Voltage on a 6L diesel with and without uSTART

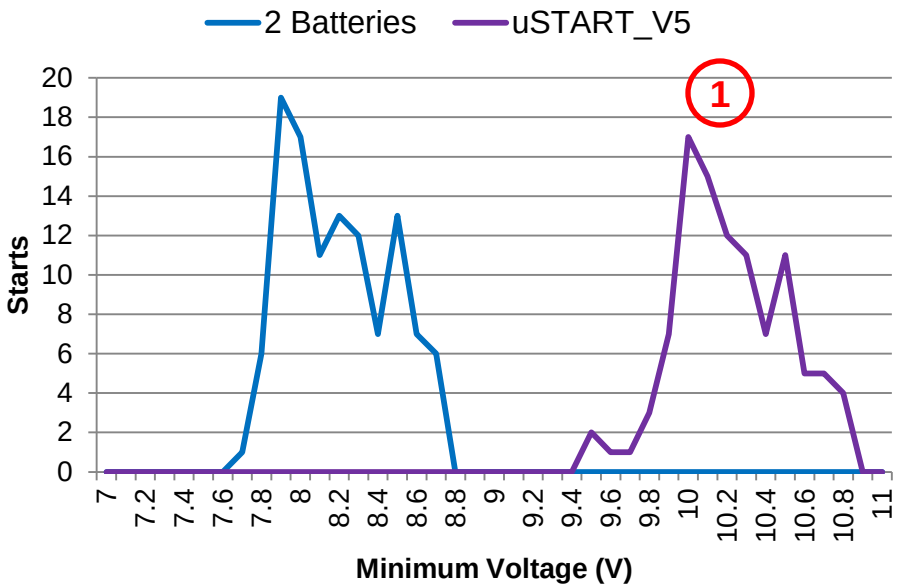


1) Minimum voltage during cranking is increased by approximately 3V
2) Average cranking voltage is increased by 1.8V
3) Cranking time is reduced by 540 mille-sec

- uSTART maintains a higher system voltage reducing stress on the battery and increasing its life
- The engine starts faster with uSTART reducing stress on the starter therefore increasing its life

uSTART Field Operation Class 6 Delivery Truck

Typical Daily Minimum Bus Voltage per Start



1) During each day of operation the delivery vehicle stops over 125 times, the average minimum voltage is nearly 2V higher with uSTART compared to without dramatically increasing the battery life
2) Telematics monitoring of nearly 200 delivery trucks, over the last 16 months, shows an average minimum +2V and start time reduction of > 700 m-sec

Operation

Maintenance Mode (Safe Mode)

- No energy at uSTART terminals
- Safe to install or remove from vehicle
- Press and hold button for 10 seconds to enter Run Mode

Run Mode

- uSTART is on and supporting the vehicle battery
- Press and hold button for 10 seconds to switch to Maintenance Mode, or 3 seconds to initiate Jump Start

Jump Start Mode

- uSTART will charge up from the battery for a jump start and the green and yellow lights will flash while charging
- The yellow light will stay solid when the uSTART is fully charged
- Start the vehicle

Mode	GREEN	YELLOW	RED	Description
Maintenance	OFF	SOLID	OFF	uSTART™ is connected to battery. There is no energy at terminals. To switch to **Run Mode,** press button for **10 seconds.**
Run	SOLID	OFF	OFF	uSTART™ is active. To switch to **Maintenance Mode,** press button for **10 seconds.** To initiate **Jump Start Mode**, press button for **3 seconds.**
Jump Start	FLASH	FLASH	OFF	uSTART™ is charging for jump start.
	FLASH	SOLID	OFF	uSTART™ is ready for jump start. **Start the vehicle immediately.**
Fault	OFF	OFF	SOLID	uSTART™ is experiencing a fault. Please see user manual for instructions.

uSTART™ Safety Features

uSTART™ Electronics Safety Features

- **Maintenance Mode**
  - No power available at terminals
  - Protection against reverse bias to -30 V
  - Protection against input voltage surge up to +80 V
- **Run Mode**
  - Under and over voltage lockouts
  - Protection against input voltage surge up to +80 V
  - Short circuit protection
  - Thermal protection

Ioxus uSTART™ Next Products

- **1100 CCA 12V uSTART; intended for trucks Class 3 to Class 6**
- **2000 CCA 12V uSTART; intended for trucks Class 7 to Class 8**
- **1000 CCA 24V uSTART; intended for Europe and Japan**
- **Remote start capability will be available on all uSTART products in Feb 2017**
- **Certified to standards: UL810A, SAE J1455 and J930**

THANK YOU !

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