PWR2012

Системы питания автономных портативных устройств

Objectives

- **When you leave this class you should know**
  - More about the battery characteristics that affect embedded applications
  - How to power an embedded design from a single 1.5V battery
  - How to select a battery for an application

Introduction - Battery Basics

Theoretical Voltage (E^0)

- Type of Active Materials
  - Anode (Oxidation Potential) + Cathode (Reduction Potential) = E^0 or Volts (V)

Theoretical Capacity (Coulombic)

- Amount of Active Material
  - Ampere-hour (Ah)

Theoretical Energy

Watt-hour (Wh) = Voltage (V) x Ampere-hour (Ah)
Specific Energy (Watthours / Gram)

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Introduction - Battery Basics

- **"C" Rate**
  - $I = M \times C_n$

    Where:

    I = discharge current, A
    C = numerical value of rated capacity, Ah
    n = time, in hours, at which C is declared
    M = multiple or fraction of C

- **Example**
  - 1.7Ah Li-Ion Battery
    - **1C Rate = 1.7A**
    - **0.1C or C/10 Rate = 170 mA.**

Challenge for Solutions

- **More electronic devices becoming battery powered**
- **Conserving battery power is paramount**
- **Developing solutions together with battery manufacturers**
  - eXtreme Low Power MCUs
  - Battery Life Estimator
  - Battery Selection Webpage
  - Reference Designs
  - Joint Applications Support

Microchip's Battery Related Products

- PIC® Microcontrollers with XLP Technology
  - eXtreme Low Power – World's lowest Run and Sleep Currents, down to 20nA
  - 145 MCUs ranging from 18-pins to 80-pins, memory from 4KB to 128KB Flash
- MCP1640/24/23 Single Battery Booster Family
  - Low Input Voltage, 0.35V and up.
  - Selectable Output Voltage
  - Efficiency as high as 96%
  - Tiny Footprint
- Low Power Radios
  - 433/868/915 MHz & 2.5GHz Radios
  - Industry Standard and Proprietary Protocols

Application

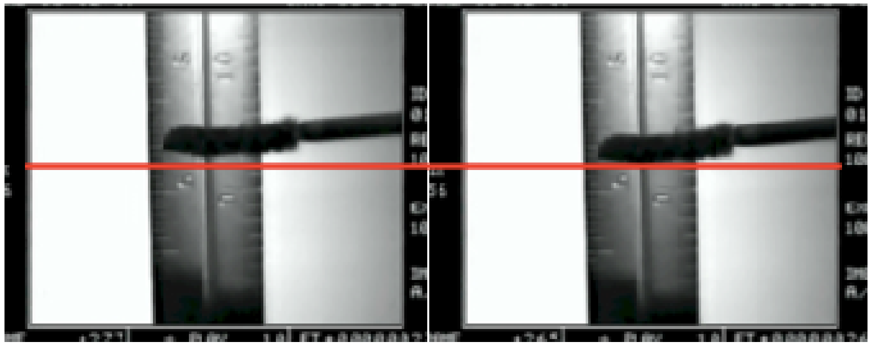
- **Electrical Analysis**
  - Detailed drain data across battery voltage range
  - Evaluation for undesired or abusive drains

<u>Digital Camera:</u>
Abusive drains detected which can lead to leakage

<u>Game Controller:</u>
Original version had significant off-drains leading to frequent battery changes

Application

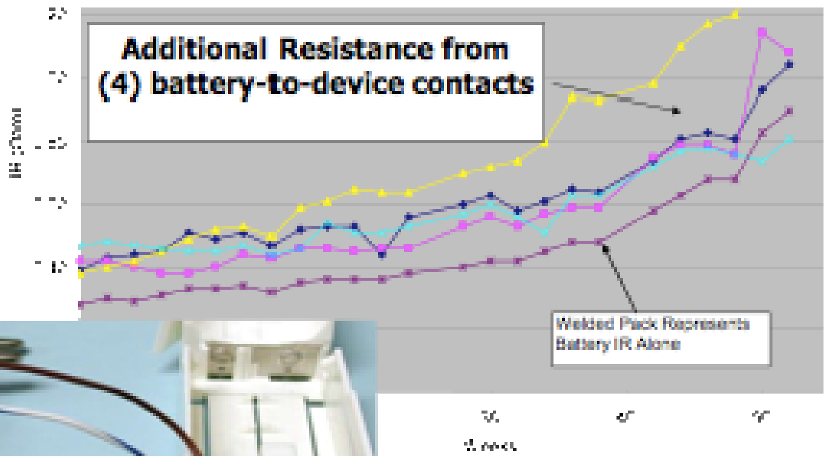
- **Performance Evaluation**
  - Battery comparisons and selection assistance
  - Claim support and substantiation assistance
  - Application simulation
  - In-device testing

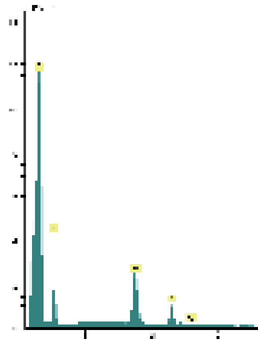


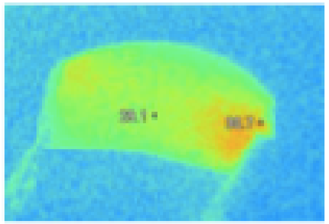
Cosmetic Applicator:
Control unit had noticeable greater deflection than experimental unit

Application

- **Physical Analysis**
  - Contact design and reversal protection
  - Battery installation and external shorting potential
  - Advanced analytical techniques
  - Ventilation and water resistant requirements





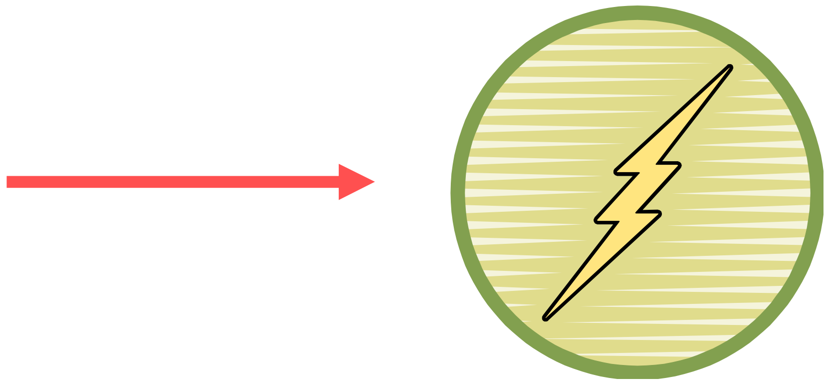


Powered Eyewear:
Demonstrating SEM/EDS capabilities

Basic Battery Characteristics

What is a battery?

A device that converts chemical energy into electrical energy



SELECTED BATTERY CHEMISTRIES

Comparison

Chemistry	Energy Density Weight (W-hr/Kg)	Energy Density Volume (W-hr/L)	Operating Voltage (V)	Open Circuit Voltage (V)	End Voltage (V)	Charge Voltage (V)
Alkaline	145	400	1.5	1.65	0.9	NA
$Li\text{-}MnO_2$	250-300	500-580	2.8	3.0	2.0	NA
NiMH	60-120	160-230	1.2	1.45	0.9	NA
$LiFePO_4$	90-100	200-220	3.2	3.6	2.0	3.6
Li-Ion	110-160	210-320	3.6	4.2	2.9	4.2

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Comparison

Chemistry	Self-Discharge per Month (%)	Internal Resistance (mΩ)	Charge/Discharge Cycles	Discharge Rate (mA-hr.)	Operating Temperature (°C)	Initial Cost
Alkaline	0.3	100-300	1	0.25C	-20 ~ +55	Very Low
Li-MnO_2	0.2-0.3	20-90	1	<0.04C	0 ~ +60	Med
NiMH	20-25	10-400	500	<3C	-20 ~ +60	Low
$LiFePO_4$	1-3	8-10	2000	<30C	-30 ~ +60	High
Li-Ion	6-10	150-250	1000	<2C	-20 ~ +60	Med

Portable Rechargeable Chemistry Comparison

Battery	Advantages	Disadvantages
$LiFePO_4$	High Cycle Life	Solution Is Not Mature
	Excellent Load Performance	Lack of Standard Specifications
	Prone to Thermal Runaway	Heavier and Lower Cell Voltage Compares to Li-Ion Batteries
NiMH	30-40% Higher Capacity Than NiCd	Limited Cycle Life
	Less Prone To "Memory"	Limited Load Performance
	Environmentally Friendly	High Self Discharge
Li-Ion	High Energy Density	Requires Protection Circuitry
	Relatively Low Self Discharge	Subject To Aging Even When Not In Use
	Low Maintenance – No "Memory"	High Initial Cost

Battery Chemistries

- **Primary (Single Use)**
  - Carbon Zinc
  - Silver-Zinc
  - Lithium Thionyl Chloride
  - **Lithium Manganese Dioxide**
  - **Alkaline**
  - **Lithium Iron Disulfide**

- **Secondary (Rechargeable)**
  - Lead Acid
  - NiCd
  - **NiMH**
  - **Li-Ion**
  - **Li-Polymer**

Consumer Replaceable Battery Comparison

Battery Type	Key Attributes	Application & Battery Selection
Alkaline AA, AAA, AAAA 	• Inexpensive • Widely available • Low to High Drain	Wide variety of portable devices   
Lithium Iron Disulfide AA, AAA 	• High Performance • 15+ Year Shelf Life • Cold Temperature • Safe and Reliable • Lightweight	World's Longest Lasting AA/AAA in High Tech Devices   
Nickel Metal Hydride AA, AAA 	• Capacity • Cycle Life • Charge Retention • Consumer Replaceable	Med – High Drain / Heavy Use   
Lithium Coin CR2025, CR2032 	• Small • Lightweight • Low drain, low peaks • 7 – 10 year shelf life	Small, low energy devices   

Battery Voltage

A battery's voltage is determined by the choice of materials used in the anode and cathode.

System (Common Name)	Type	Battery	Anode	Cathode	Rated Voltage
Alkaline	Primary	E91	Zinc (Zn)	Manganese Dioxide (MnO_2)	1.5V
Carbon Zinc	Primary	1215	Zinc (Zn)	Manganese Dioxide (MnO_2)	
Lithium Cylindrical	Primary	L91	Lithium (Li)	Iron Disulfide (FeS_2)	
Silver	Primary	357	Zinc (Zn)	Silver Oxide (Ag_2O)	
Zinc Air	Primary	AC675	Zinc (Zn)	Oxygen (O_2)	
Nickel Metal Hydride	Secondary	NH15	Metal Hydride (MH)	Nickel (Ni)	
Lithium Miniature and Photo	Primary	CR2032 EL123	Lithium (Li)	Manganese Dioxide (MnO_2)	3.0V
Lithium Ion	Secondary	18650	Lithium (Li)	Lithiated Cobalt Oxide ($LiCoO_2$)	3.6V

Battery Voltage

POP QUIZ!!!

System (Common Name)	Type	Unit Cells	Nominal Voltage	Common Application
Alkaline 9V	Primary	6 x E96	9.0V	Smoke Alarms
Alkaline A23	Primary	8 x A76	12.0V	RF Transmitters
Lithium CRV3	Primary	2 x L91	3.0V	Digital Cameras
Various NiMH Packs	Secondary	NH15	Various	Cordless Phones
Various Li-Ion Packs	Secondary	18650	Various	Laptops

Frequently, an application requires voltages other than that provided by a single cell. In this case, the required voltages can be obtained by either connecting cells in series, adding external circuitry, or a combination of both.

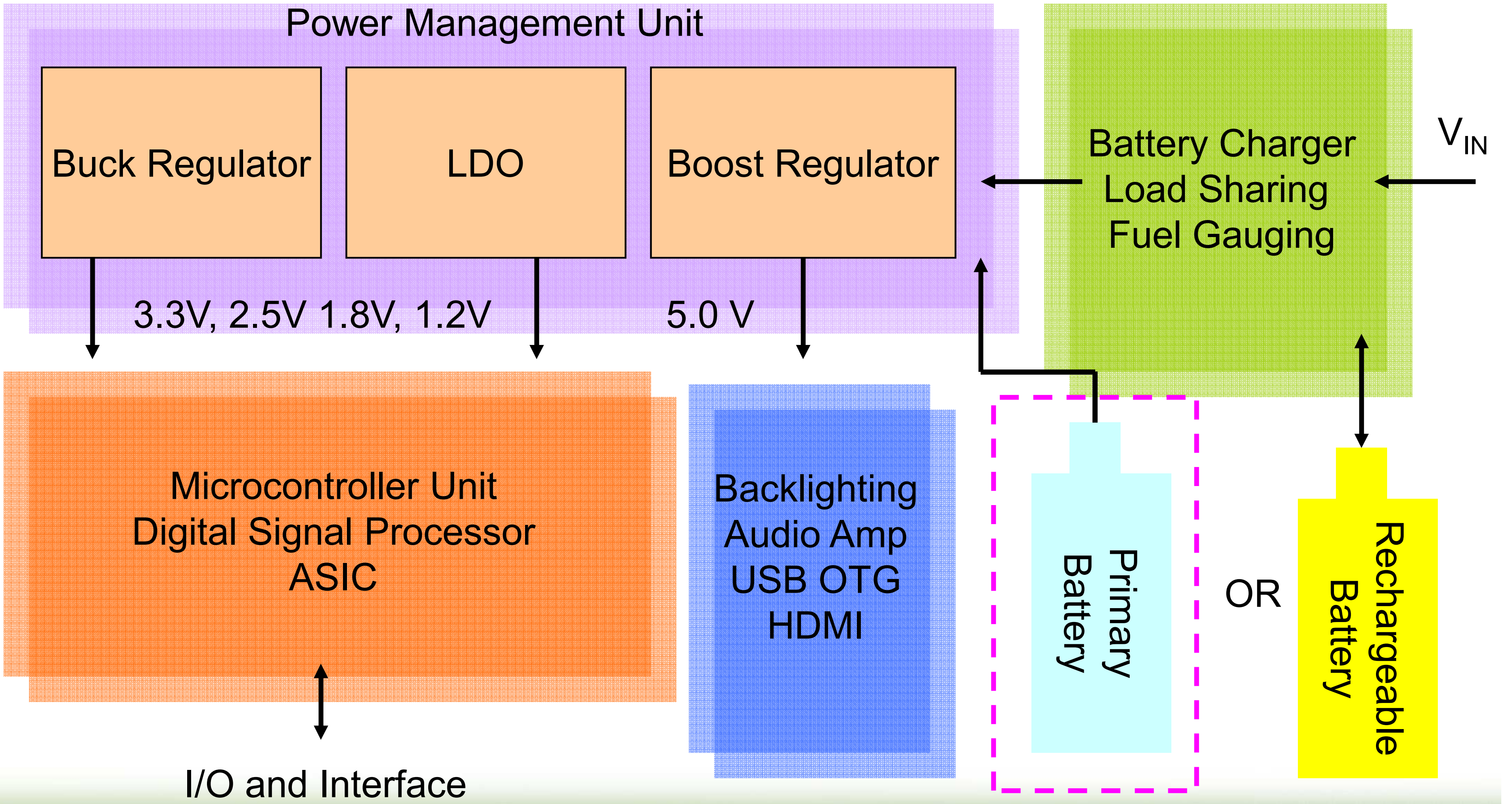
Design Battery Power Systems

Power System Design

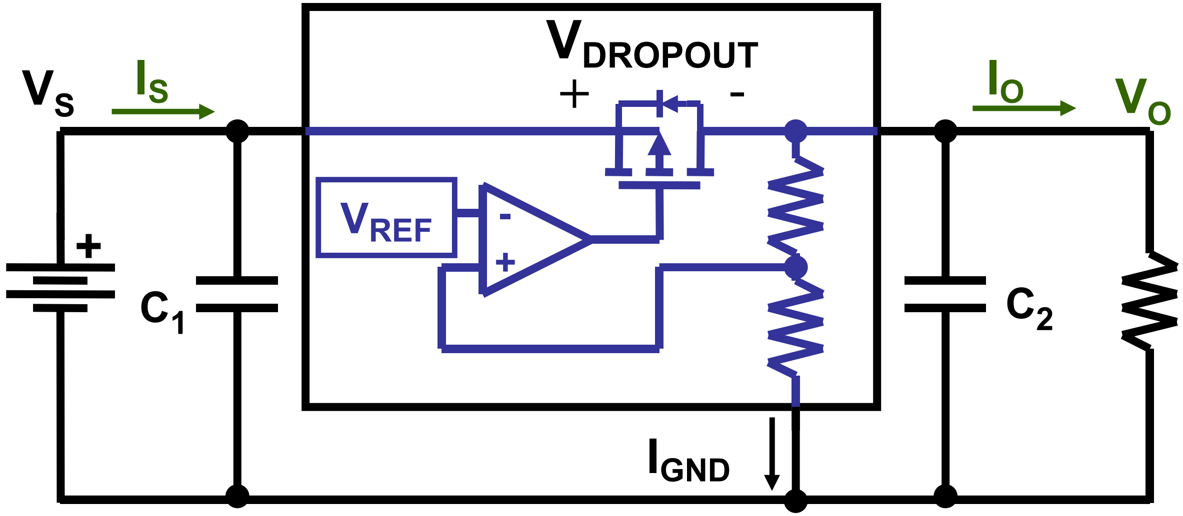
What System Factors Influence the Topology Selection?

- Efficiency
- Charge Current Level
- Input Voltage Range
- Ambient Temperature
- Converter Switching Frequency
- Target PCB Area
- Available System Resources
- Communications to the Battery
- Cost Objectives
- EMI Concerns
- System Load Active During Charge

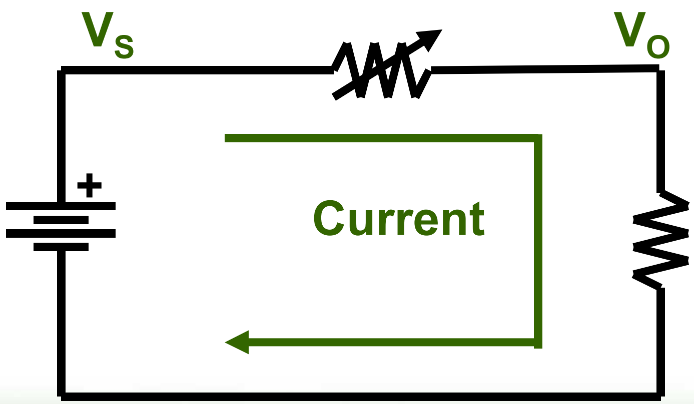
Integrated Circuits in Battery-Powered Applications



Linear Regulator Topology



Equivalent DC Circuit



I_S = Source Current

I_O = Output Current

I_{GND} = LDO Current

$I_S \sim I_O$ when $I_{GND} << I_O$

Linear Regulator Solutions

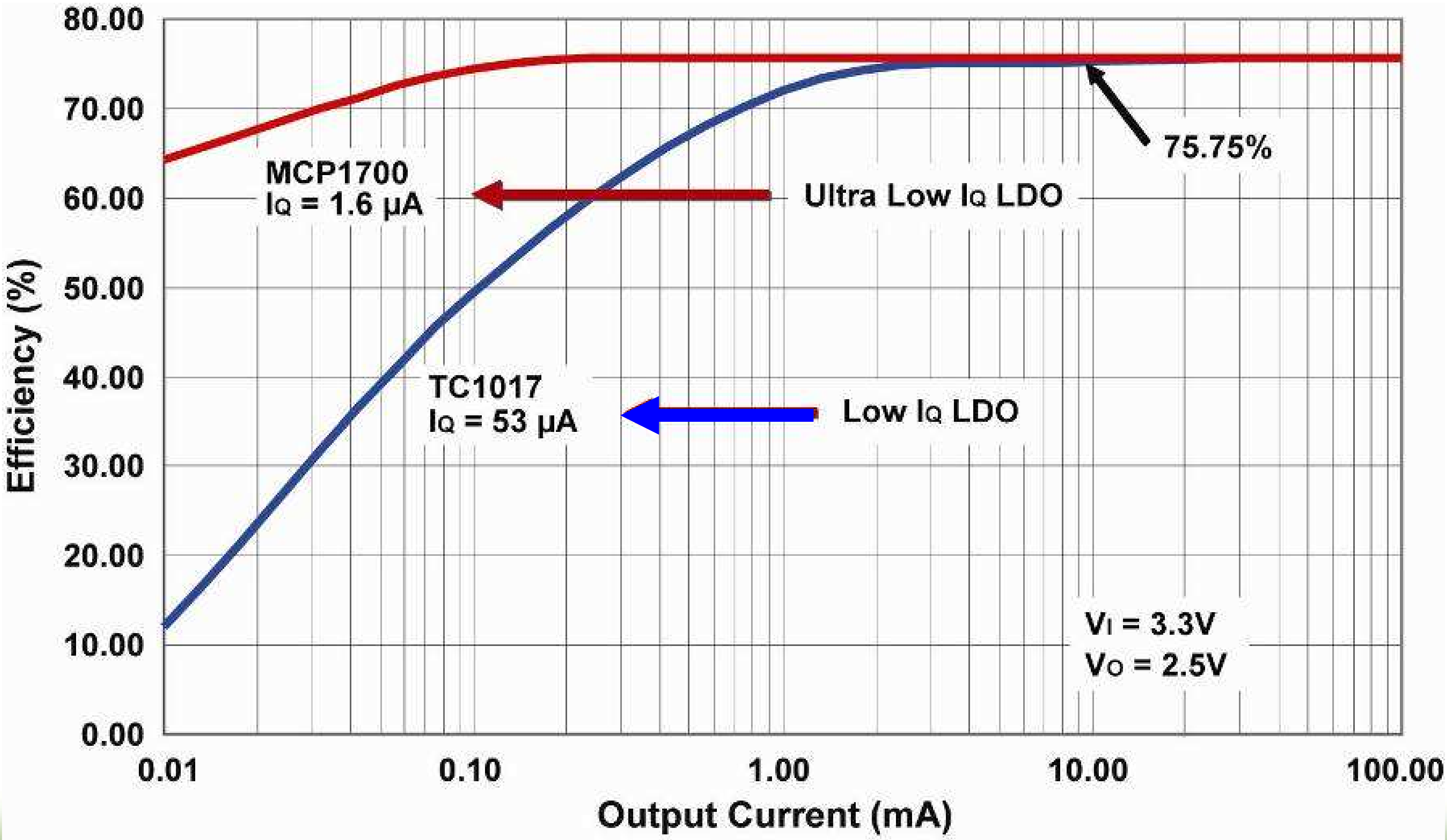
LDO Efficiency?

$$Eff = \frac{Vout * Iout}{Vin * Iout + Vin * Ignd}$$

When $I_{GND} << I_{OUT}$

$$Eff = \frac{Vout}{Vin}$$

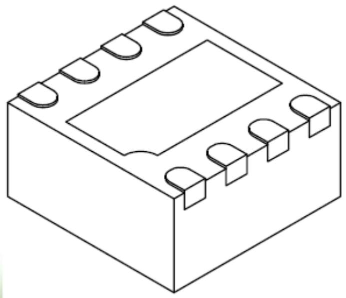
LDO Efficiency



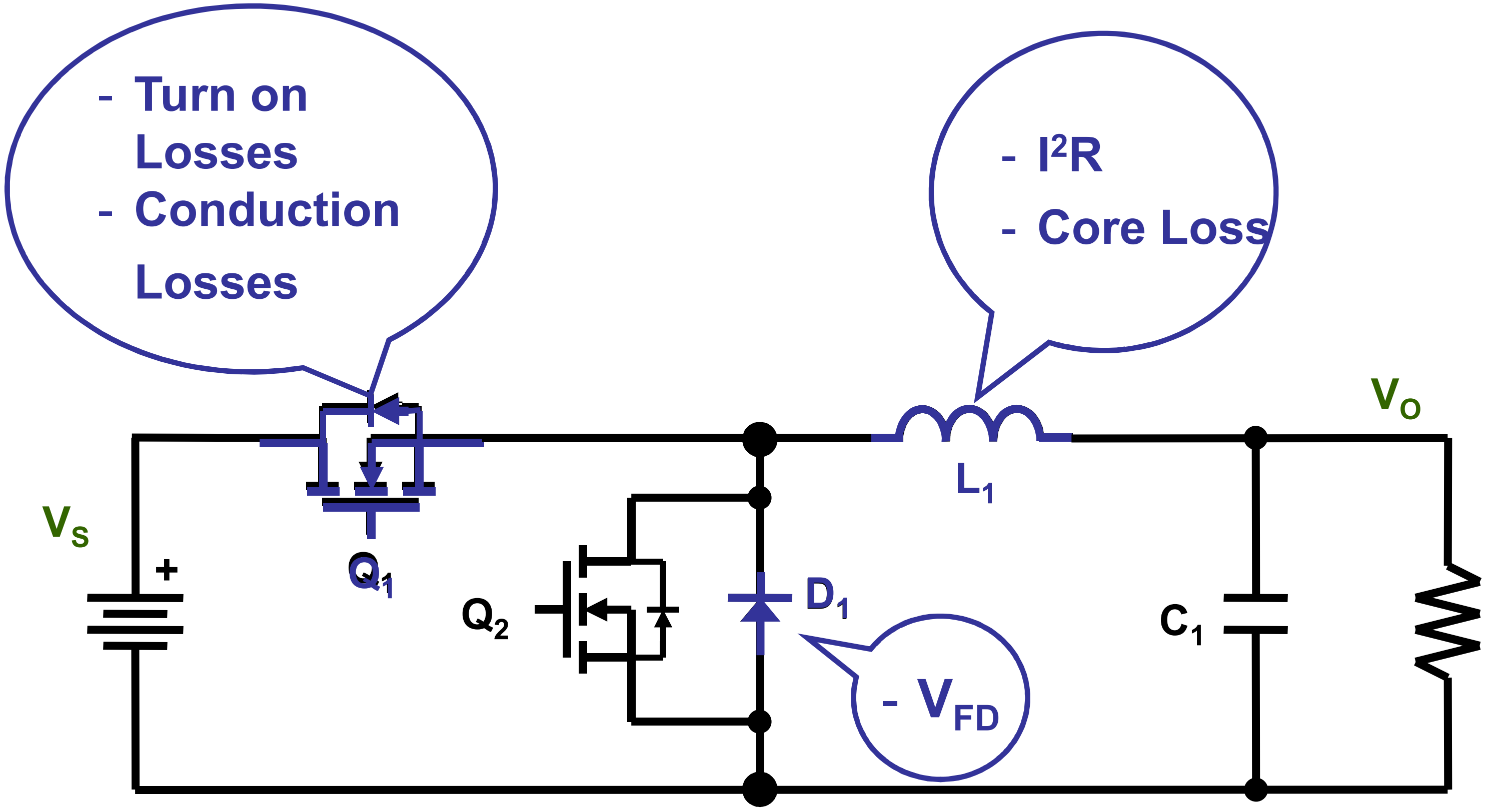
Ultra-Low Quiescent Current LDO RegulatorMCP1710

2012 NEW!

- Ultra-Low 20 nA (typical) Quiescent Current
- Ultra-Low Shutdown Supply Current: 0.1 nA (typical)
- 200 mA Output Current Capability for VOUT < 3.5V
- 100 mA Output Current Capability for VOUT > 3.5V
- Input Operating Voltage Range: 2.7V to 5.5V
- Standard Output Voltages: - 1.2V, 1.8V, 2.5V, 3.3V, 4.2V
- Low-Dropout Voltage: 450 mV Maximum at 200 mA
- Stable with 1.0 µF Ceramic Output Capacitor
- Overcurrent Protection
- Space Saving, 8-Lead Plastic W2mm x L2mm x H0,9mm VDFN-8



Buck Converter: Areas of Power Loss



Synchronous Rectification

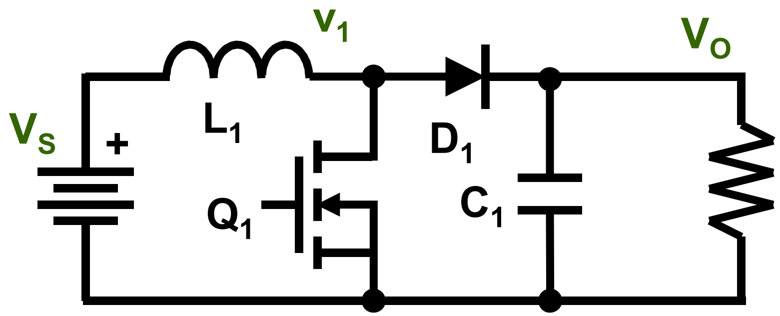
Why Choose a Buck Topology?

- **Advantages**
  - Efficiency
  - Low Complexity
  - Wide Operating Range
  - High Power Step Down
- **Disadvantages**
  - Pulsed Input Current
  - Higher Parts Count than LDO
  - Step Down Only

Boost Converter

- **High Voltage Bias Supply**
- **White LED Lighting**
  - Multiple LEDs in Series
    - **LCD Backlighting**
    - **Flashlights**
- **Display Biasing**
- **Piezo Drive**

- **Boost Circuit**

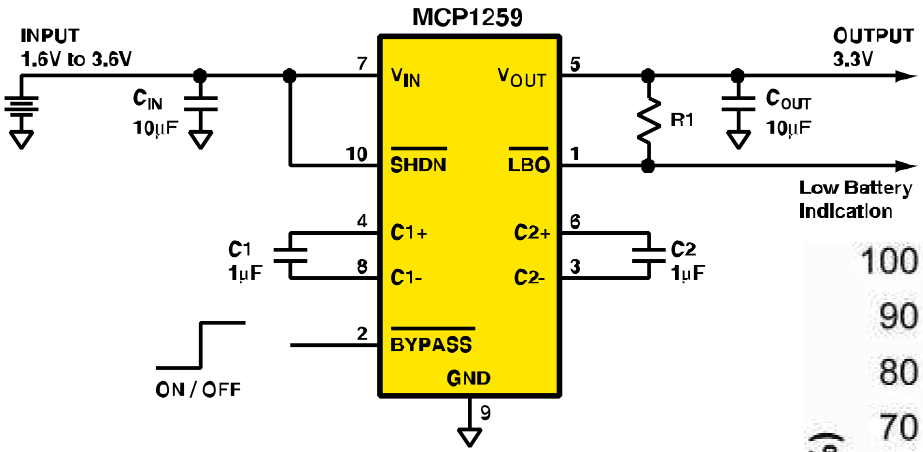


Inductor Volt-Time Must be Equal

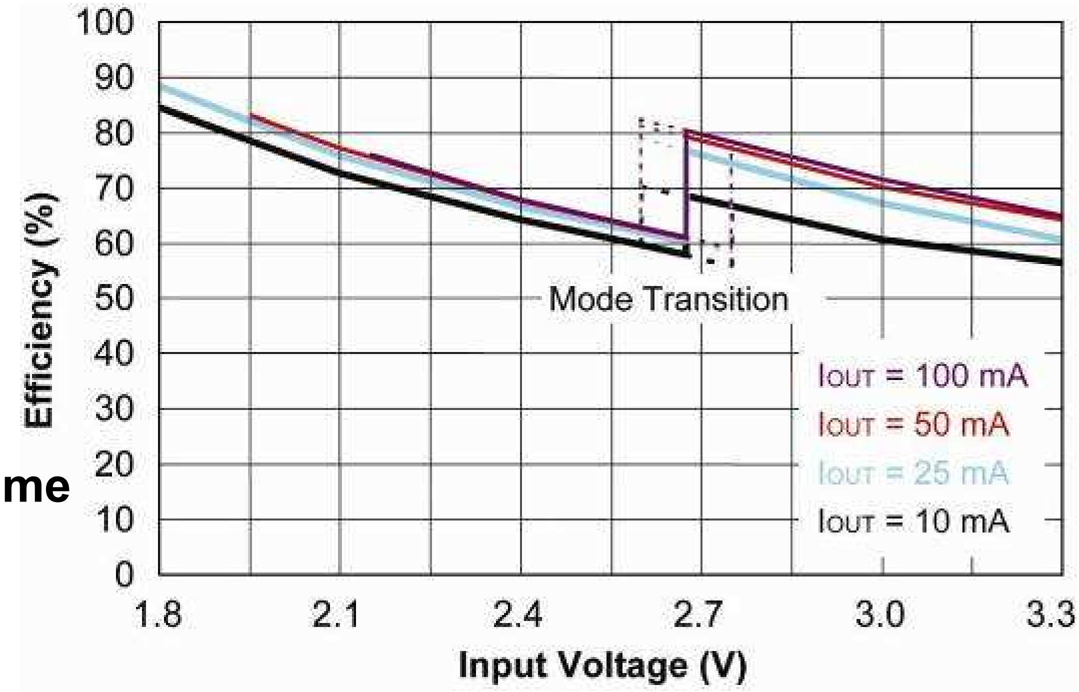
$$V_S * t_{ON} = (V_O - V_S) * t_{OFF}$$

$$D = (V_O - V_S) / V_O$$

Charge Pump Example



TYPICAL APPLICATION WITH POWER GOOD INDICATION



MCP1256/7/8/9 Charge-Pump Efficiency vs. VIN

Features for longer battery runtime

- **1.5X and 2X Dual Mode**
- **Shutdown**
- **Bypass**
- **Sleep Mode—MCP1256**

Battery Voltage

Powering an Application with a Single 1.5V Battery

When series configurations alone are not sufficient, voltage regulators can be used to provide the voltages required for a given application.

Single Cell + Boost Versus Series Configurations

Advantages

- Reduced Volume
- Maximized Runtime Above Functional End Point (FEP)
- Voltage Stability
- Short Circuit Prevention / Current Limiting

Disadvantages

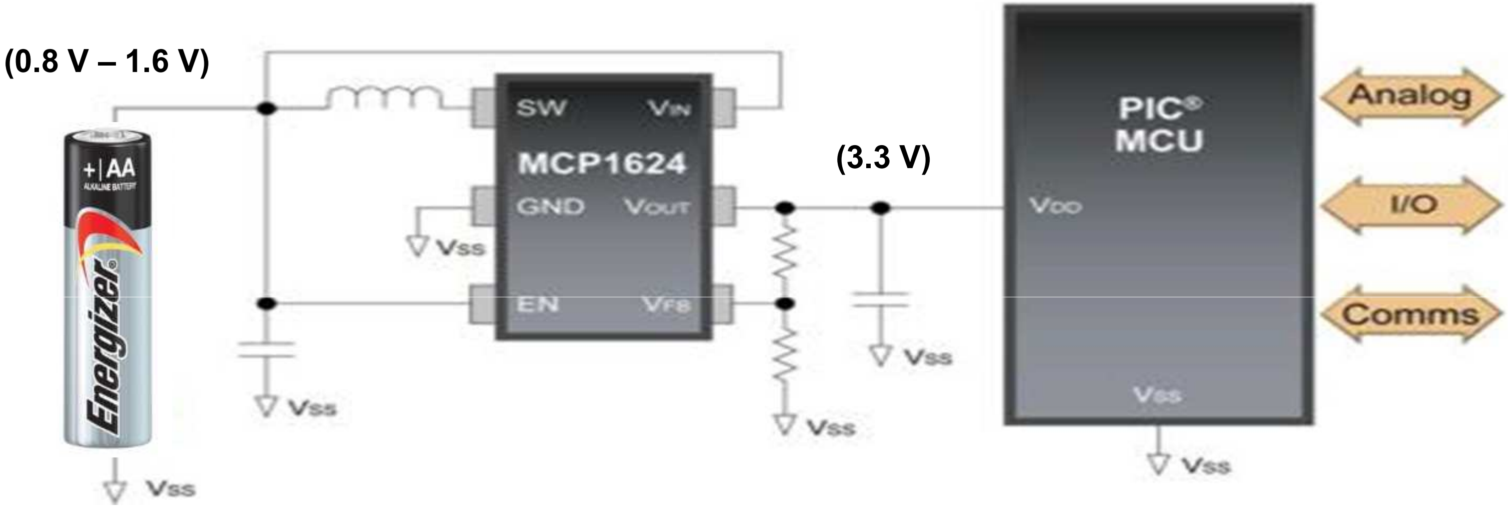
- Efficiency Losses
- Cost

MCP1640 Family Single Cell Battery Boost Converter

- **Features**
  - Low Input Voltage
    - **0.35V to 5.5V, Min. startup 0.65V**
  - Selectable Output Voltage
    - **2.0-5.5V**
  - Efficiency as high as 96%
    - **Dual mode operation**
  - Tiny Footprint, 2x3mm package

- **Advantages**
  - Wide input range and high efficiency utilize nearly all battery capacity
  - Small Footprint and Volume
    - **Small, lightweight saving board space and weight**
  - Fewer batteries required to run application
    - **Enables smaller form factor**
  - Stable output voltage to any PIC® MCU
    - **Even as input voltage varies**
    - **Consistent application performance**

Microchip Boost Converter Schematic



Basic execution is straightforward with minimal additional components.

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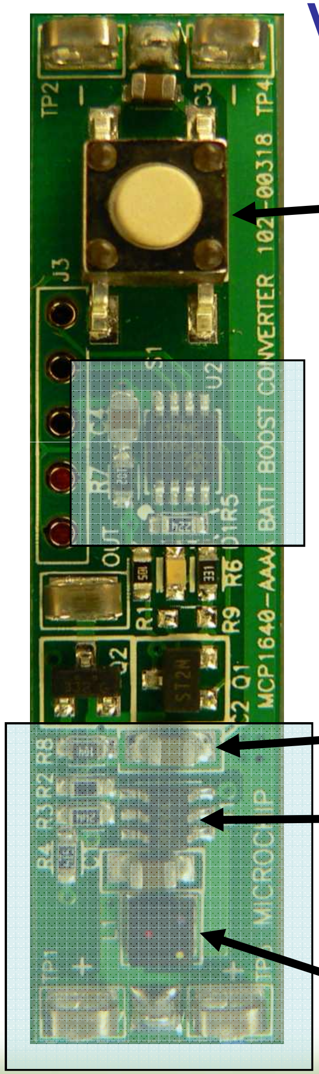
MCP1640 & AAAA Size battery *Max*™ Demo

AAAA Size Battery

V_{OUT}



Pushbutton

PIC® MCU; used to turn MCP1640 ON/OFF
And for application (Motor Drive, Wireless Headset; etc)

C or Output Capacitor

MCP1640 (Switches / Control)

MCP1640 Boost Converter

L or Boost Inductor

V_{IN}

MCP1640 Typical Applications

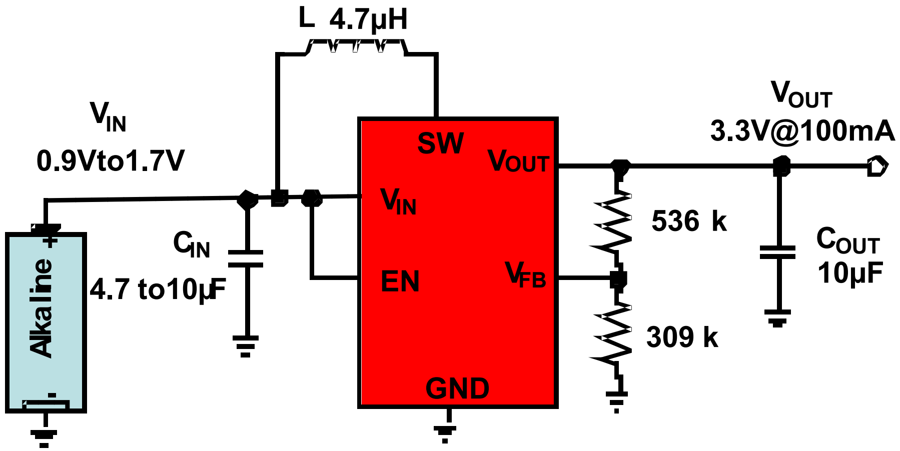


TABLE 1: PART NUMBER SELECTION

Part Number	PWM/ PFM	PWM	True Dis	Bypass
MCP1640	X		X	
MCP1640B		X	X	
MCP1640C	X			X
MCP1640D		X		X

Switching Mode (PWM/PFM, PWM) — Shutdown options (True Dis, Bypass)

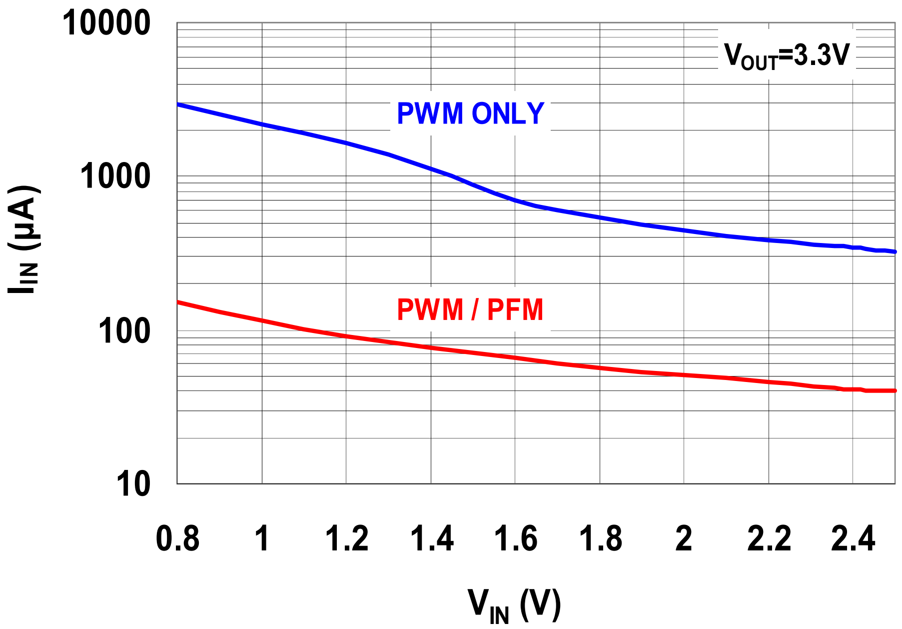
PWM – pulse width modulation
PFM - pulse frequency modulation

800 mA Typical Peak Input Current Limit

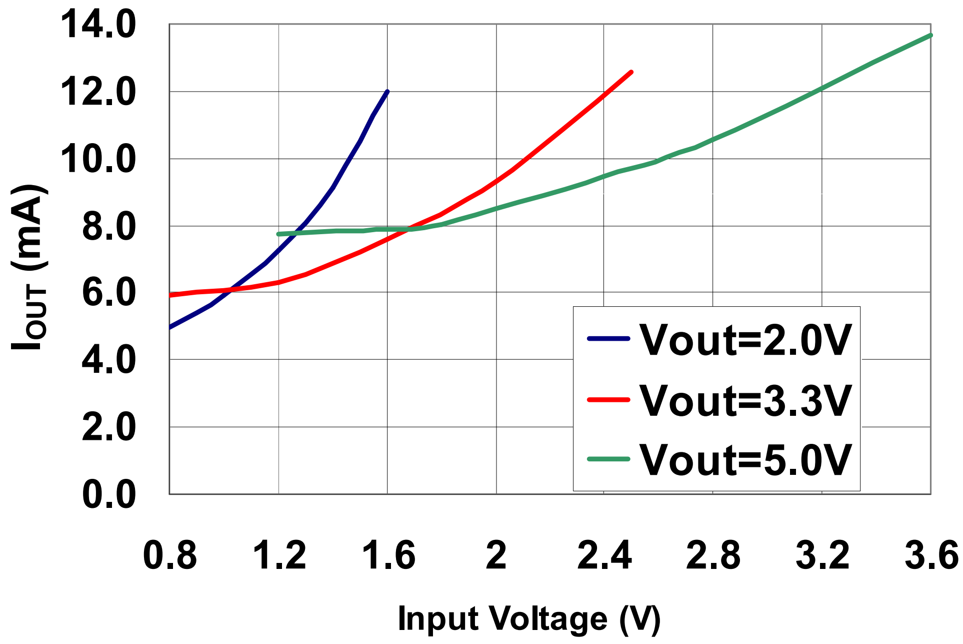
I_{OUT} > 100 mA @ 1.2V VIN, 3.3V VOUT
I_{OUT} > 350 mA @ 2.4V VIN, 3.3V VOUT
I_{OUT} > 350 mA @ 3.3V VIN, 5.0V VOUT

PWM vs. PFM

No Load Input Current

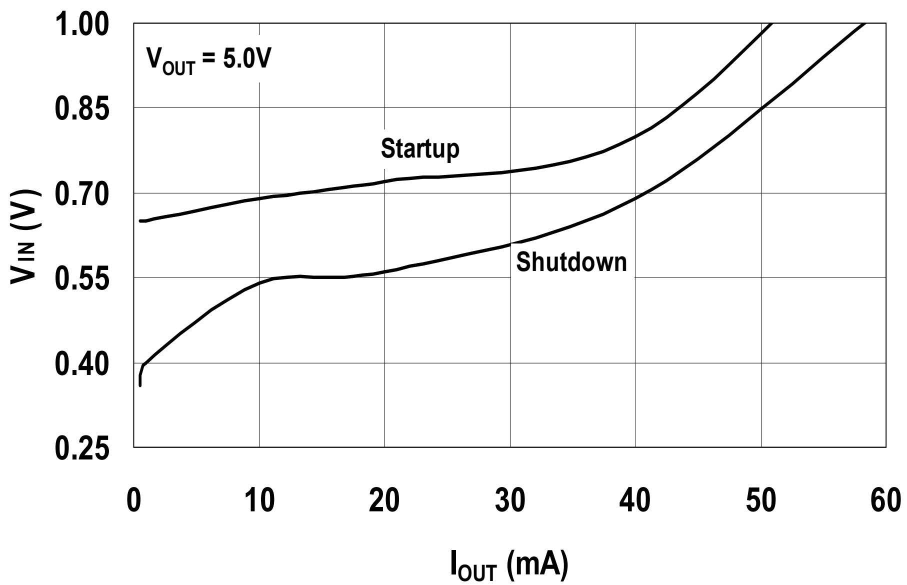


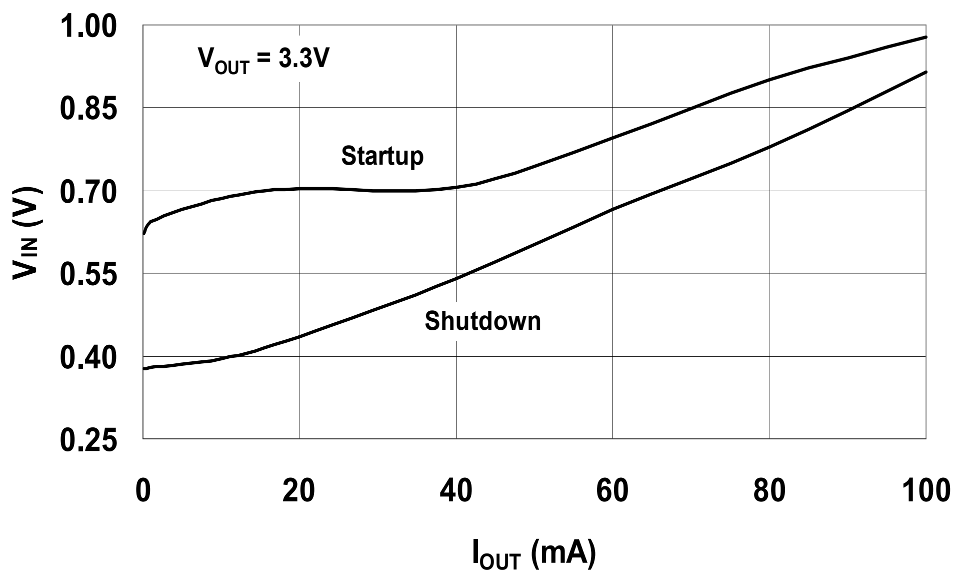
PFM to PWM Threshold



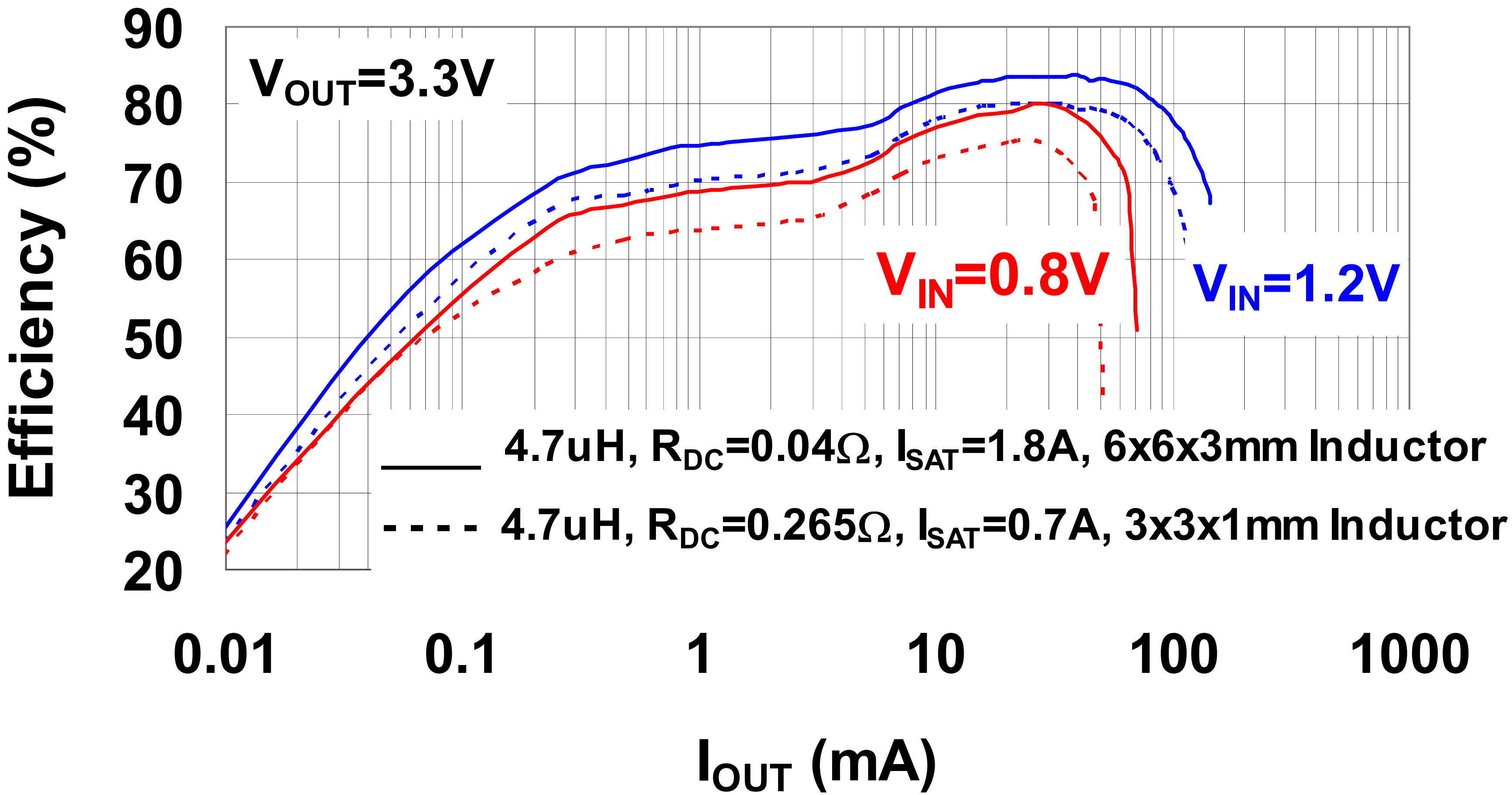
Startup and Shutdown

- **Manufacturer's 'Cutoff' Voltage**
  - Continuously Operation Down to 0.35V with Light Loads



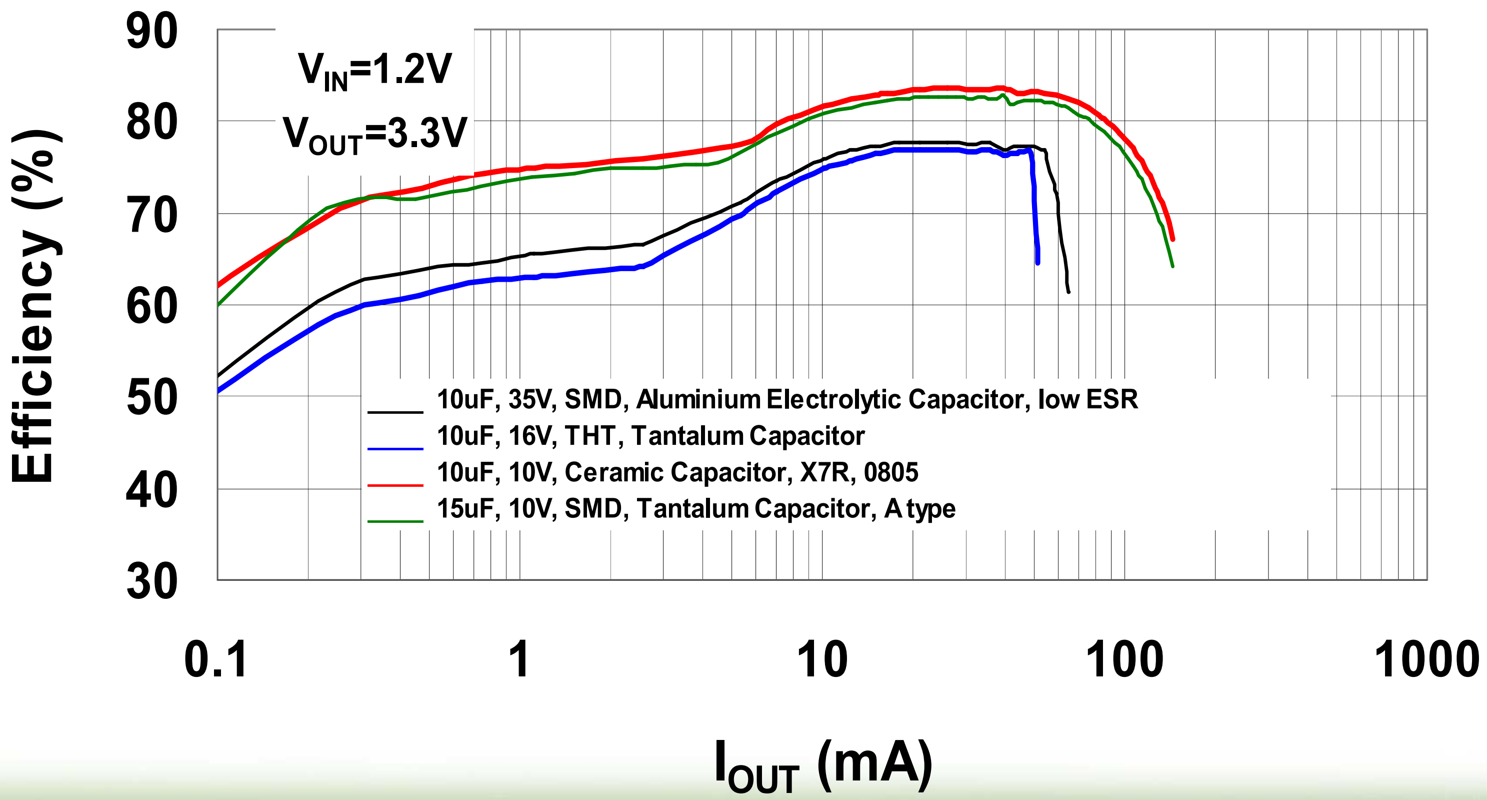


Inductor Size Vs. Efficiency



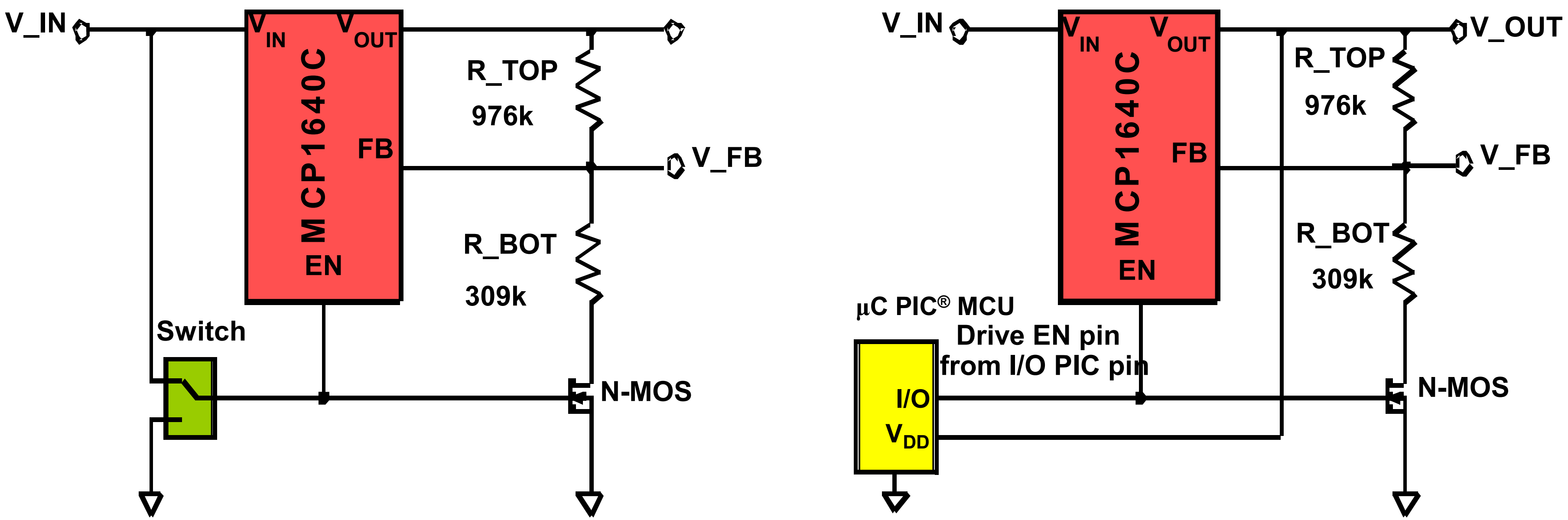
Select Low ESR Capacitors

- Recommend Ceramic Capacitors
- Up to 100 µF Output Capacitance



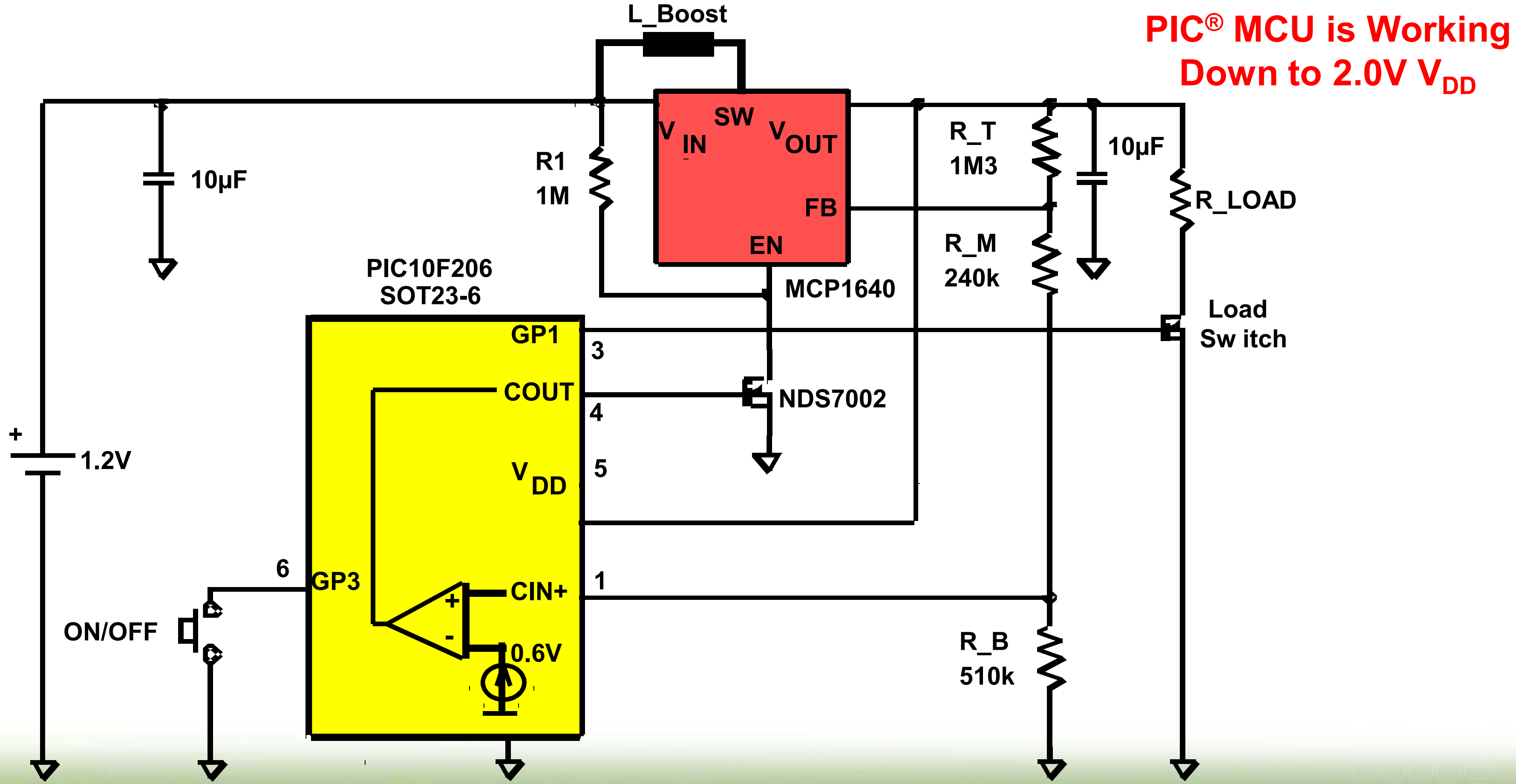
Feedback Sense Resistors

- **DISABLE FEEDBACK RESISTORS DURING SHUTDOWN FOR MCP1640C/D**



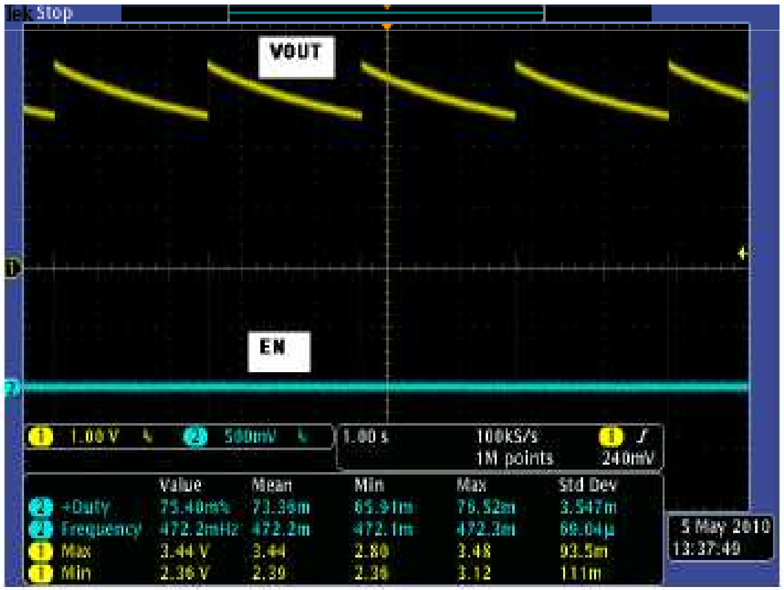
Reduce No Load Input Current

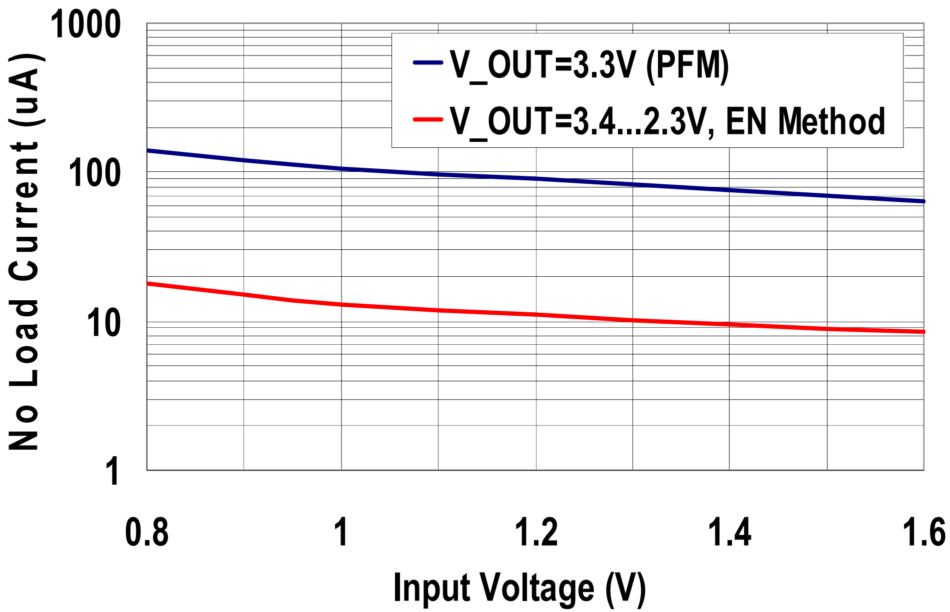
- Drive EN w/ Low Frequency Signal



Reduce No Load Input Current

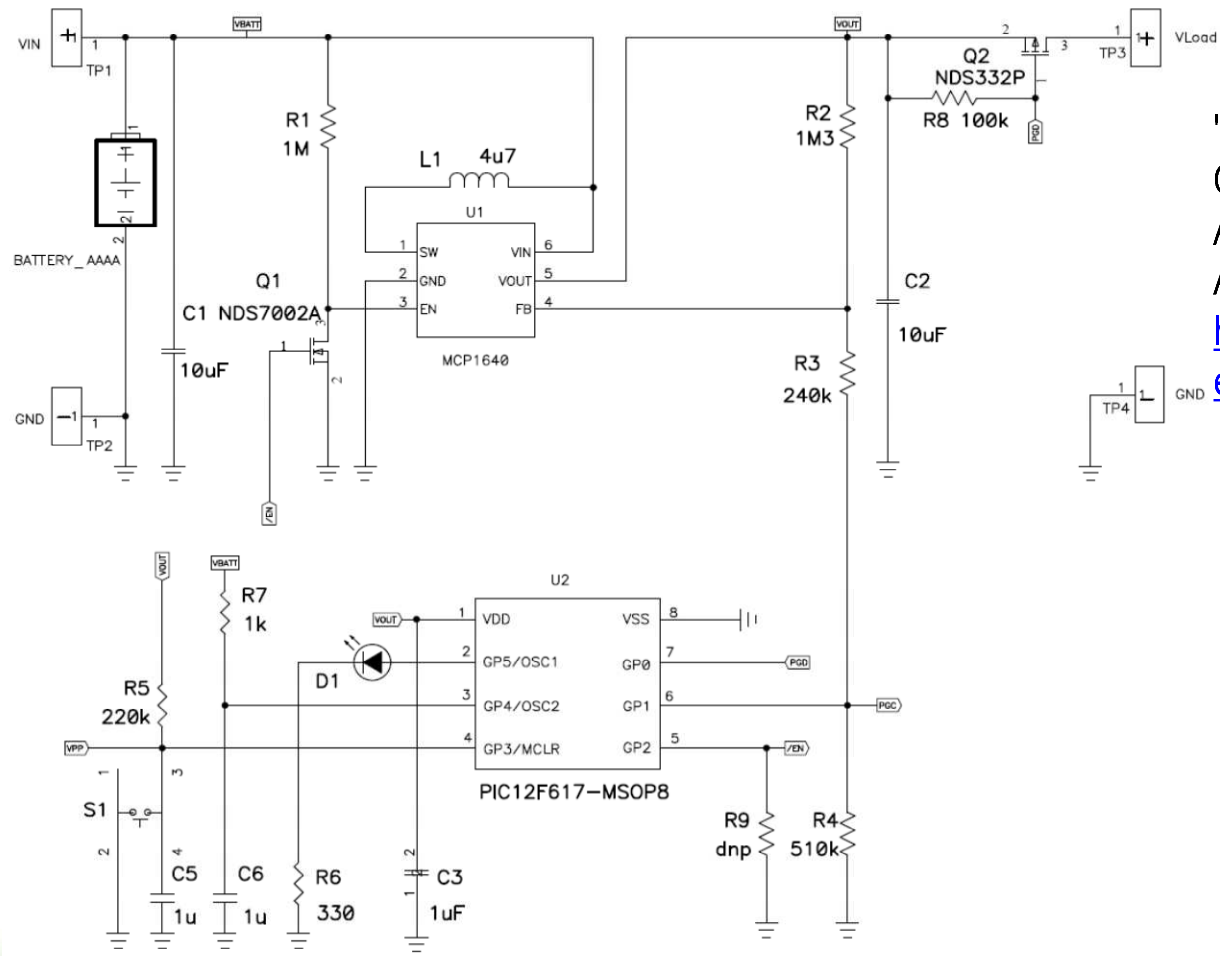
- **Improved: 8X – 9X lower than the typical value**
  - From 90 µA to 11 µ A @ V_{IN}=1.2V
- **EN Duty Cycle < 1%, f=0.5Hz**



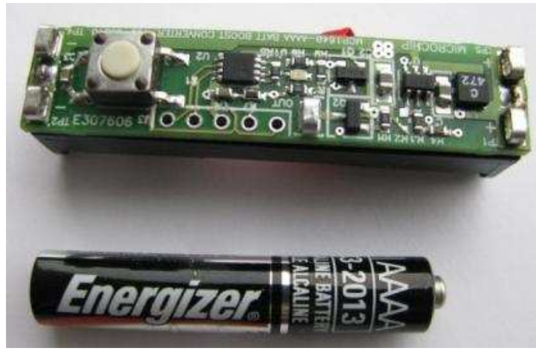


Application Example

- **3.3V$_{OUT}$ @ max.130 mA is powered by one AAAA battery**



"Optimizing Battery Life in DC Boost Converters Using MCP1640".
Application note:
AN1337 Microchip
http://ww1.microchip.com/downloads/en/AppNotes/01337A.pdf



1.67 inches

Key Battery Considerations:

General

Key Battery Considerations

Physical Characteristics
- Construction
- Volume, footprint, shape, contact method

Voltage
- Discharge curve and functional endpoint

Capacity / Energy
- Amount available at a given rate
- Continuous versus pulse

Cycle Life and Charging Method
- For rechargeable options

Shelf Life
- Self-discharge rate (charge retention) and reliability

Temperature Performance
- Can affect many battery characteristics

Internal Resistance
- Pulse capability

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Additional Considerations

Cost

- OEM
- Consumer

Transportation

- Freight Restrictions
- Labels and markings

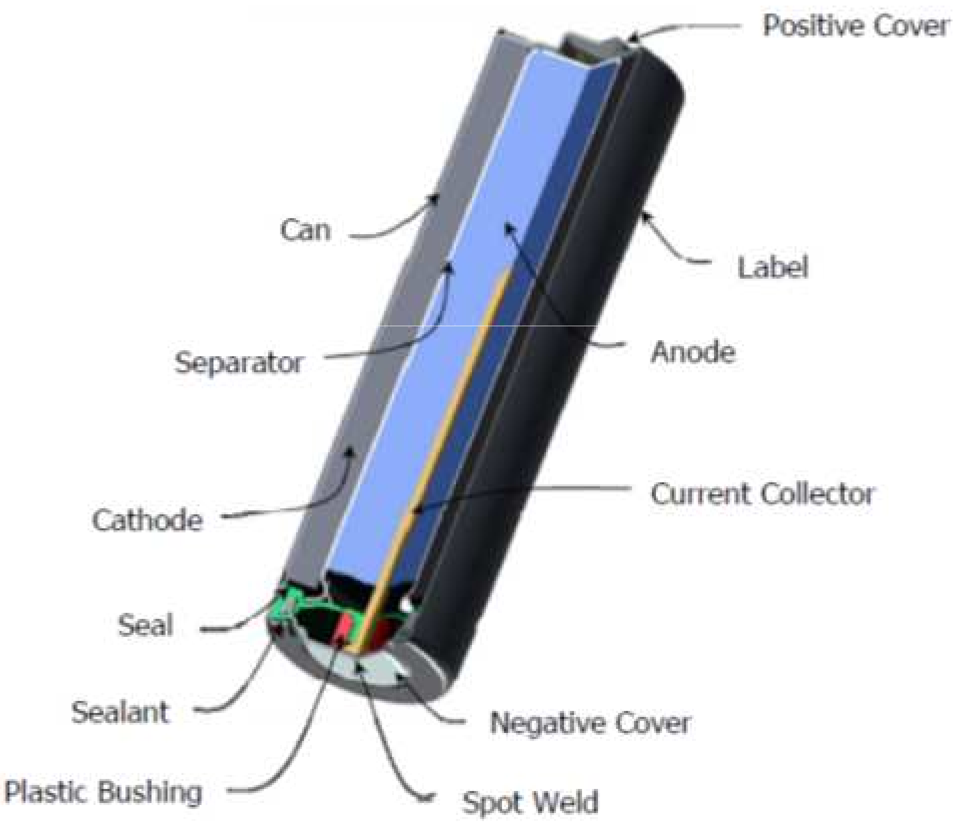
Environmental

- Battery disposal
- Device disposal
- Labels and markings

Key Battery Considerations:

Alkaline

Alkaline
Key Battery Considerations
Physical Characteristics



Battery Components

Anode	Zinc Powder
Cathode	Manganese Dioxide
Separator	Cellulose/PVA Blend
Electrolyte	KOH (Potassium Hydroxide)
Current Collector	Tin Plated or Indium Burnished Brass Nail
Construction	“Bobbin”

Key Attributes

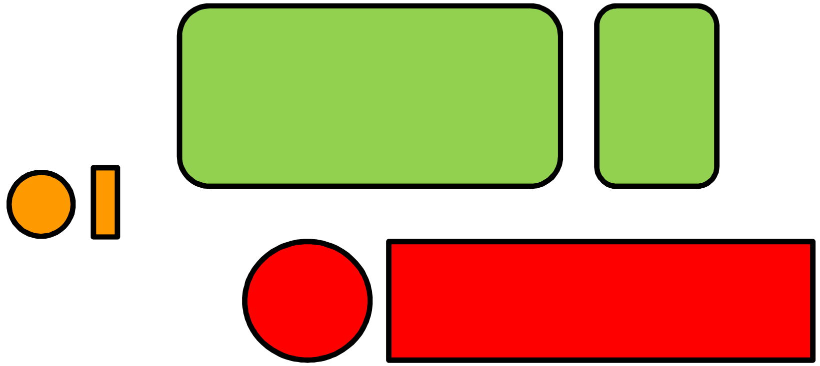
- Long lasting power in high tech devices
- Will not sacrifice performance in low to moderate drain devices
- Good cold temperature performance
- Variety of shapes and sizes
- 7 year shelf life
- Relatively low OEM cost

Alkaline
Key Battery Considerations
Physical Characteristics

Volume

- A76 = 0.54cc
- AAAA = 2.2cc
- AAA = 3.8cc
- AA = 8.1cc
- 9V = 21.1cc

Footprint

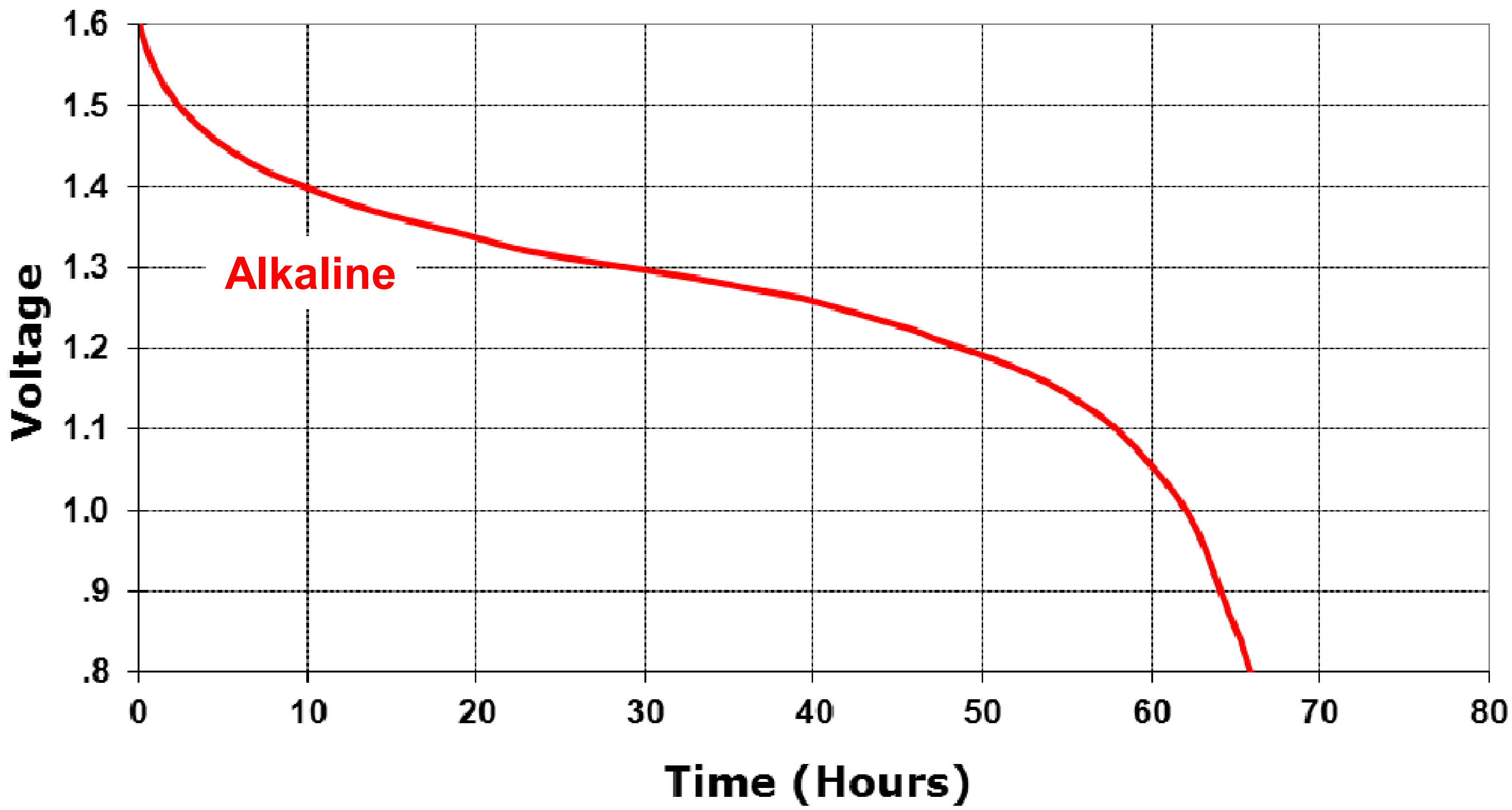


Shape

- Cylindrical
- Prismatic

Contact

Alkaline
Key Battery Considerations
Voltage



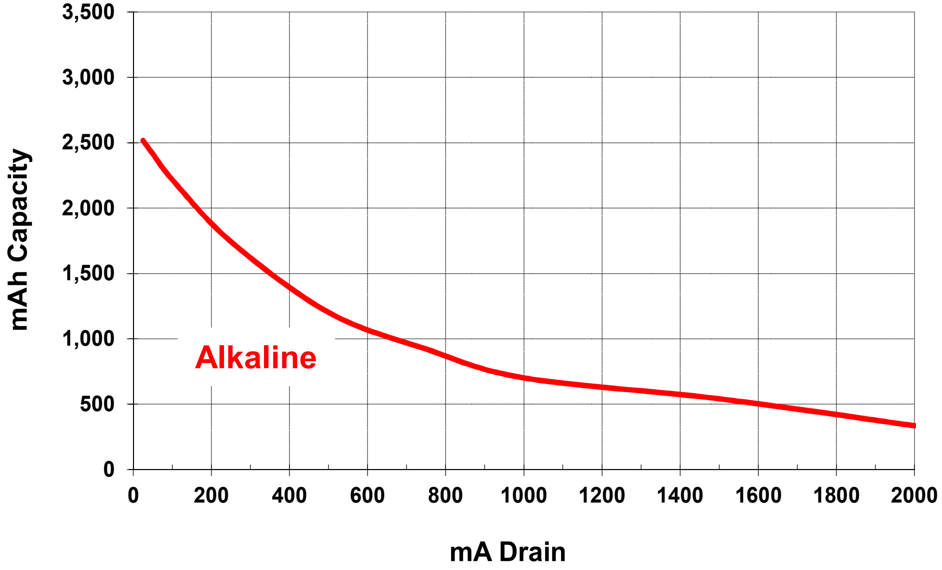
AA size battery; 50mW continuous

Alkaline

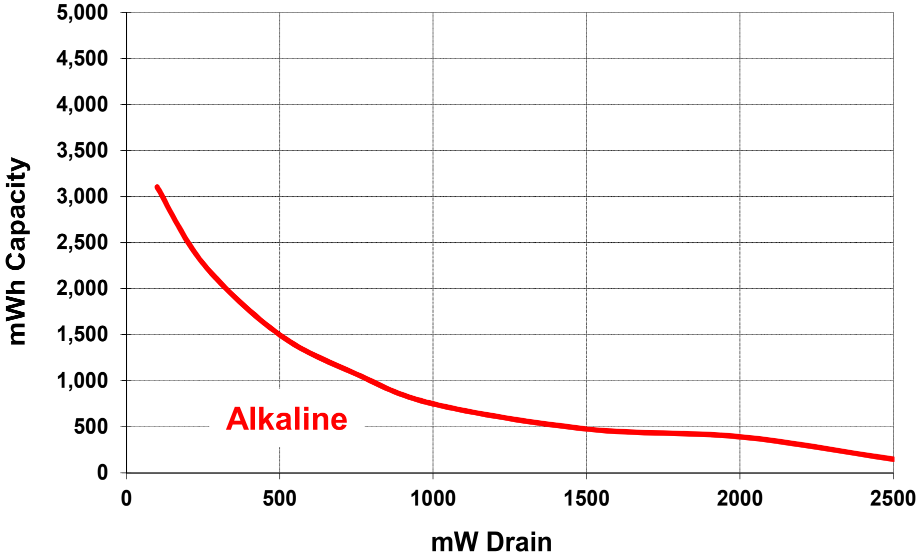
Key Battery Considerations

Capacity / Energy

mA Drain



mW Drain



AA size batteries ; continuous discharge to 1.0V

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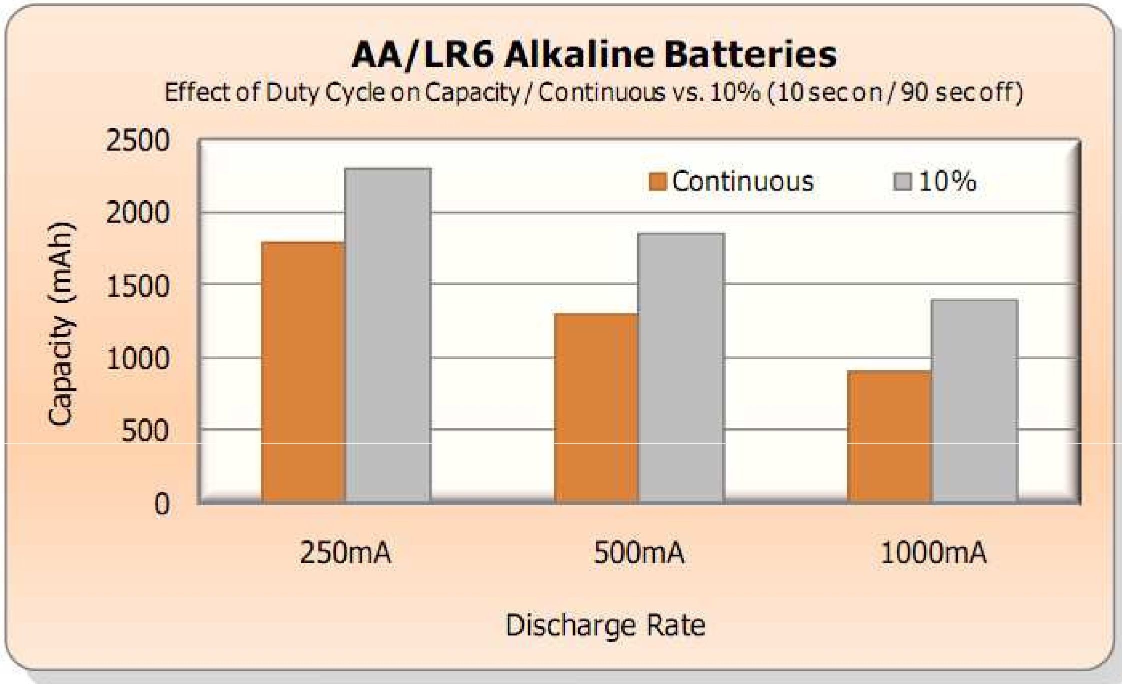
Alkaline
Key Battery Considerations
Capacity / Energy

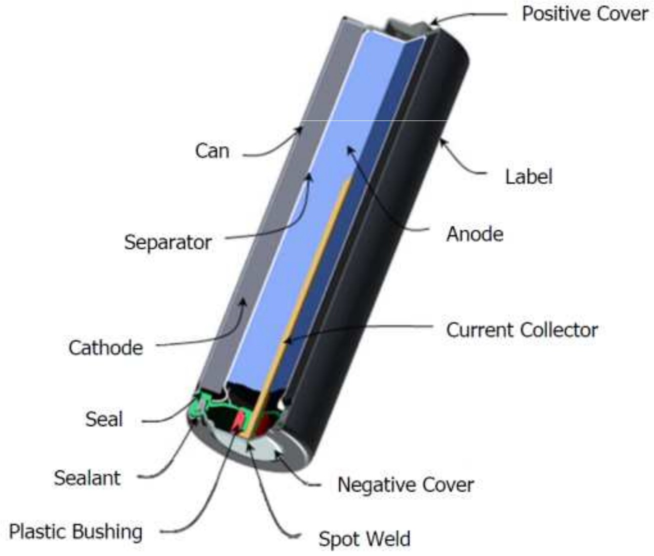


More capacity can be utilized in an alkaline battery in non-continuous applications compared to continuous discharge due to voltage recovery.

Alkaline
Key Battery Considerations
Shelf Life

- **Contributing factors to a battery's shelf life**
  - Self discharge = open circuit energy loss
  - Physical construction and chemical system

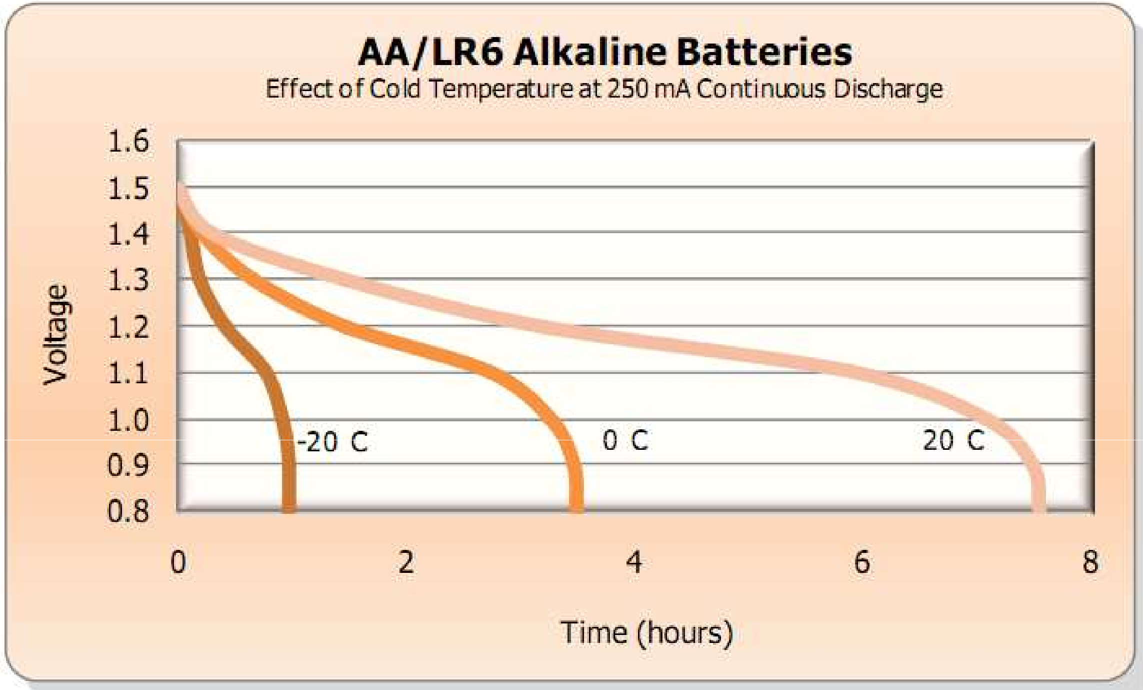
Chemical System	Shelf Life
Lithium iron disulfide	15+ years
Lithium photo and coin	7-10 years
Alkaline	5-7 years
Mini alkaline and silver	7 years
Mini zinc air (hearing aid)	4 years
Rechargeable NiMH	3-5 years on shelf (not between charges)



Cylindrical Alkaline Manganese Dioxide

Alkaline Key Battery Considerations

Temperature Performance

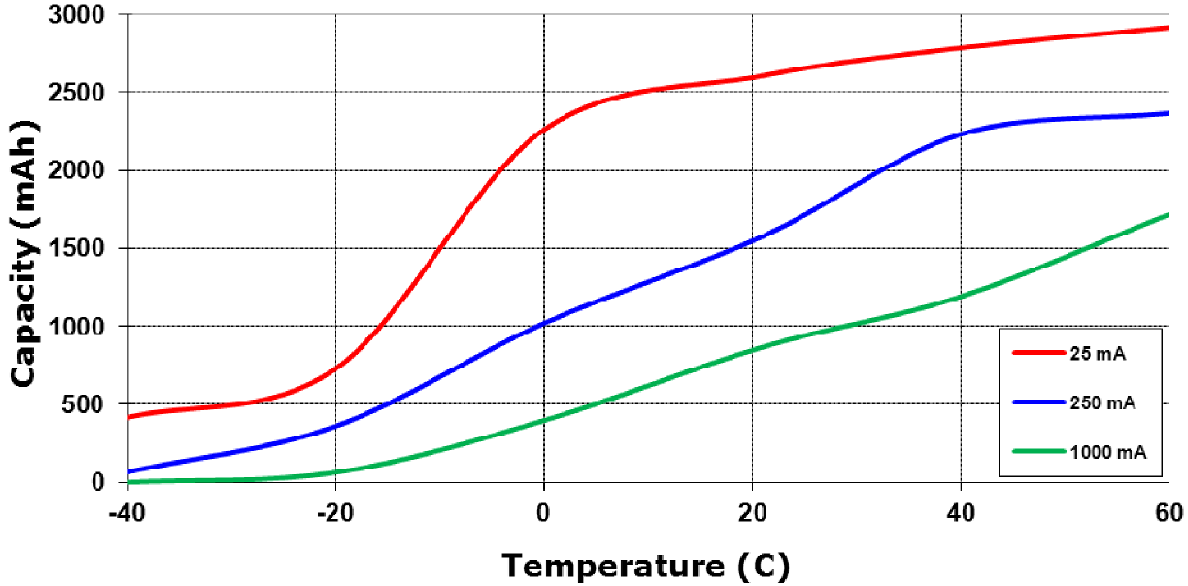


Recommended Operating Temperatures

-18°C – 55°C (0°F – 130°F)

Alkaline batteries provide reduced service at colder temperatures due to slowing ion mobility through a freezing aqueous electrolyte.

Alkaline
Key Battery Considerations
Temperature Performance



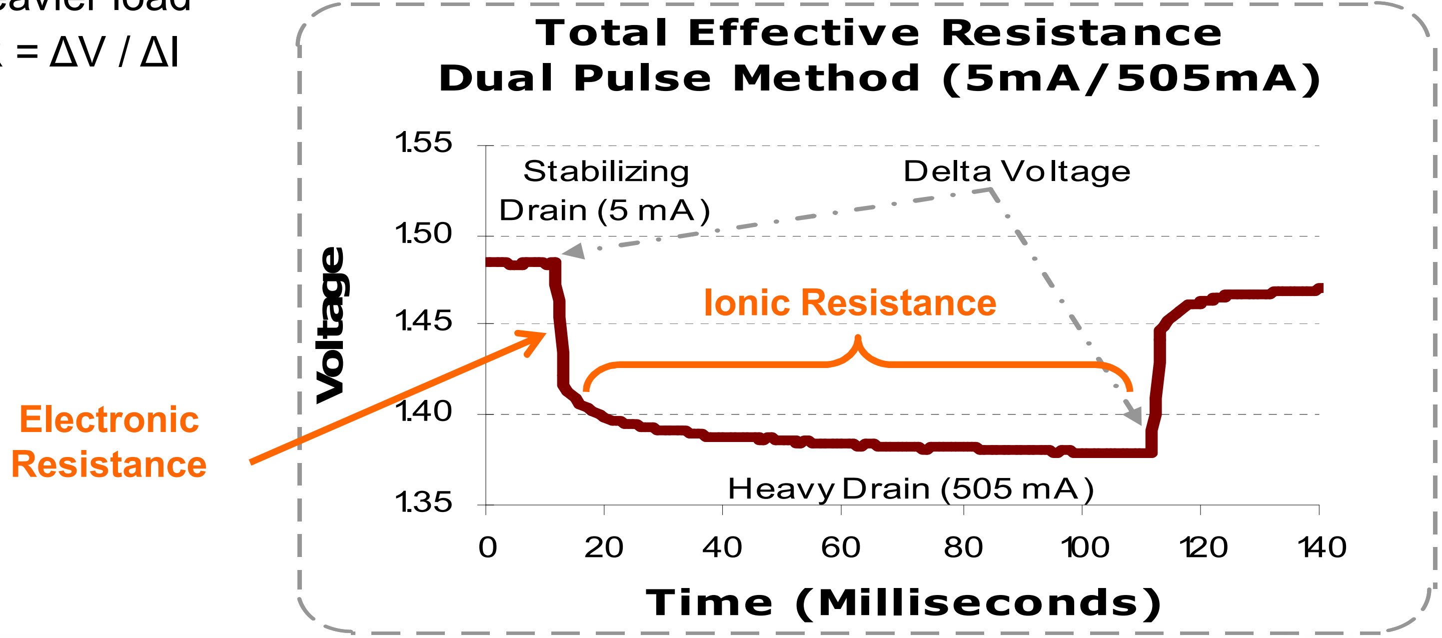
Recommended Operating Temperatures

-18°C – 55°C (0°F – 130°F)

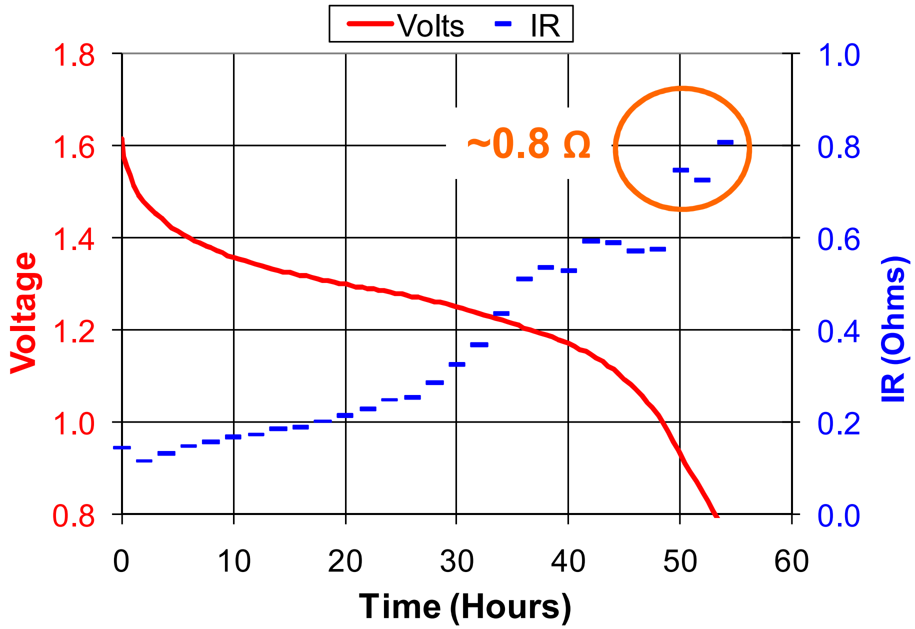
Available capacity is reduced at lower temperatures, and the effect is more pronounced at higher drain rates.

Alkaline
Key Battery Considerations
Internal Resistance

- **Internal Resistance / IR (Total Effective Resistance)**
  - **Electronic resistance (External parts)**
  - **Ionic resistance (Internal chemistry)**
- **Dual Pulse Method**
  - Place battery on a low background drain for voltage stabilization then pulse with a heavier load
  - IR = ΔV / ΔI



Alkaline
Key Battery Considerations
Internal Resistance



Internal resistance of alkaline batteries increases throughout discharge and varies from about 100 milliohms to 800 milliohms.

Key Battery Considerations:

Lithium Iron Disulfide

Lithium Iron Disulfide
Key Battery Considerations
Physical Characteristics

Battery Components

Anode	**Lithium Metal**
Cathode	**Iron Disulfide**
Separator	**Polyolefin**
Electrolyte Compound	**Lithium Salt / Organic Solvent**
Current Collector	**Aluminum Foil**
Construction	**"Jellyroll"**

Key Attributes

- **High Power Capability**
  - **High energy density lithium anode**
  - **Thin electrode, wound construction**
- **Weighs 33% less than alkaline**
- **Works in extreme temperatures (-40°C to 60°C)**
- **15+ year shelf life**
- **Leak resistant even under abusive conditions**
- **Underwriters Laboratory (UL) listed**

Lithium Iron Disulfide

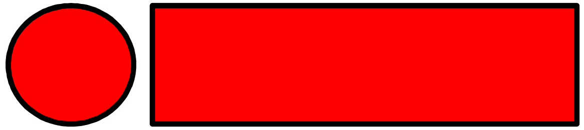
Key Battery Considerations

Physical Characteristics

Volume

- AAA = 3.8cc
- AA = 8.1cc

Footprint

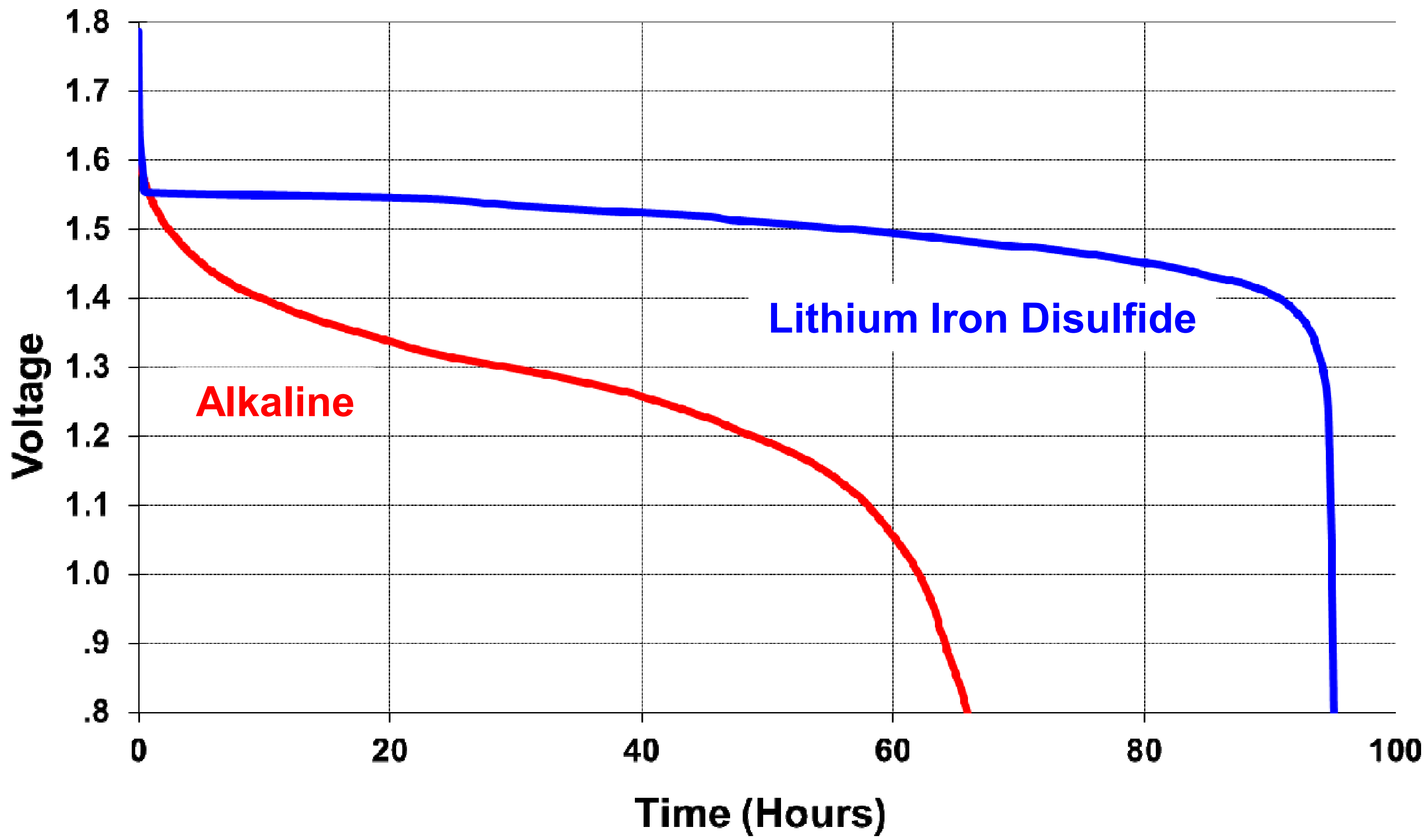


Shape

- Cylindrical

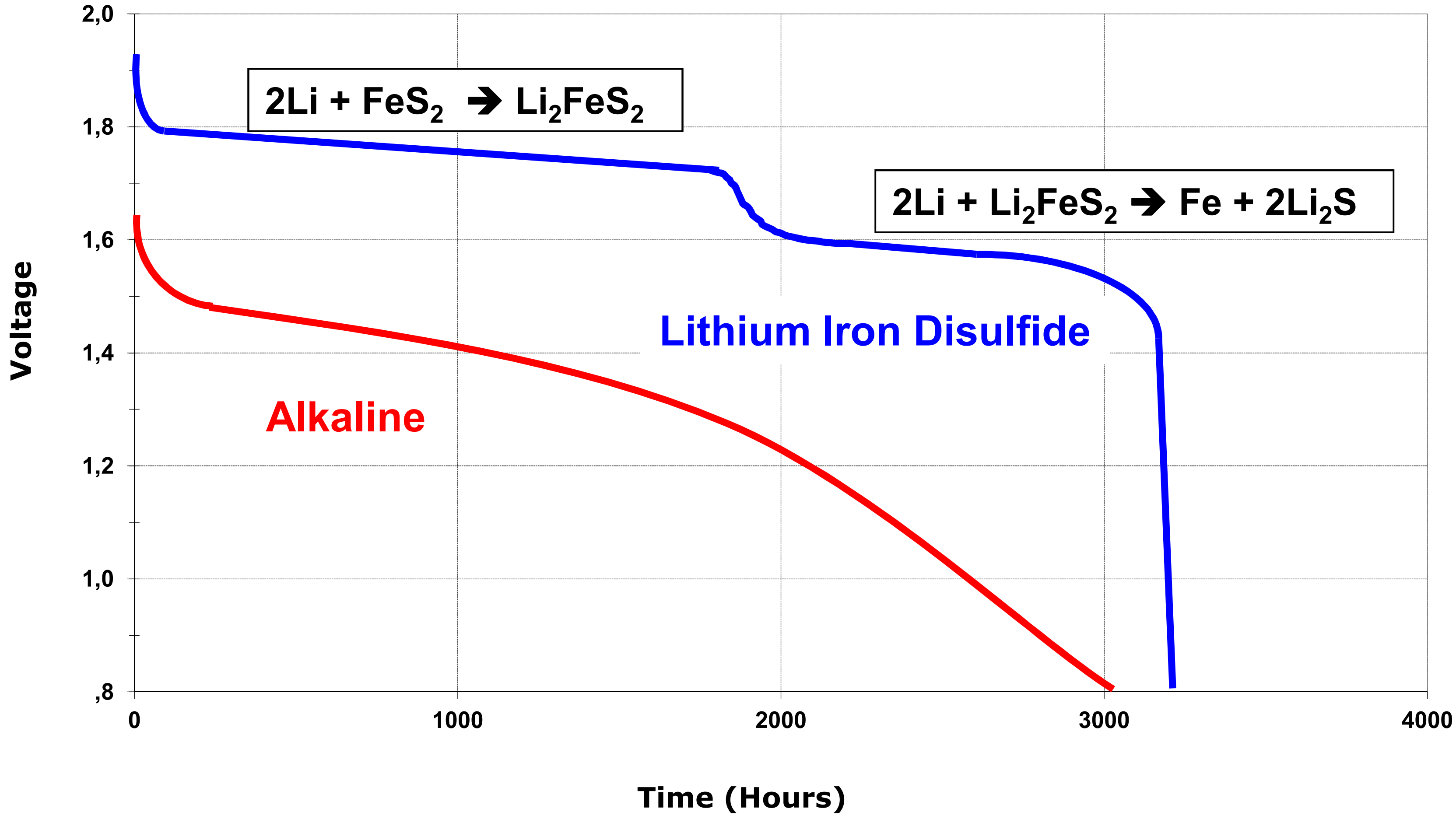
Contact

Lithium Iron Disulfide
Key Battery Considerations
Voltage



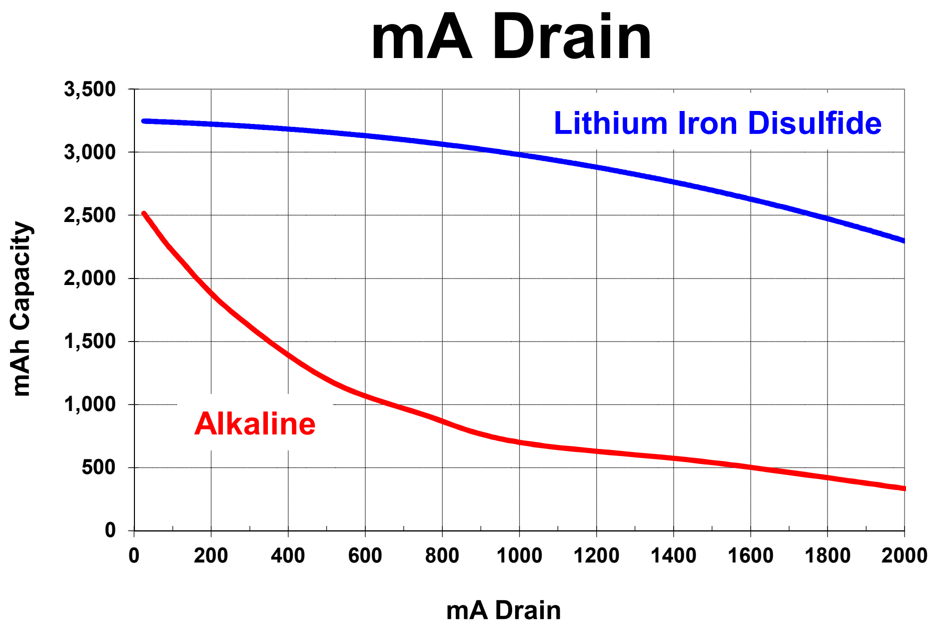
AA size batteries; 50mW continuous

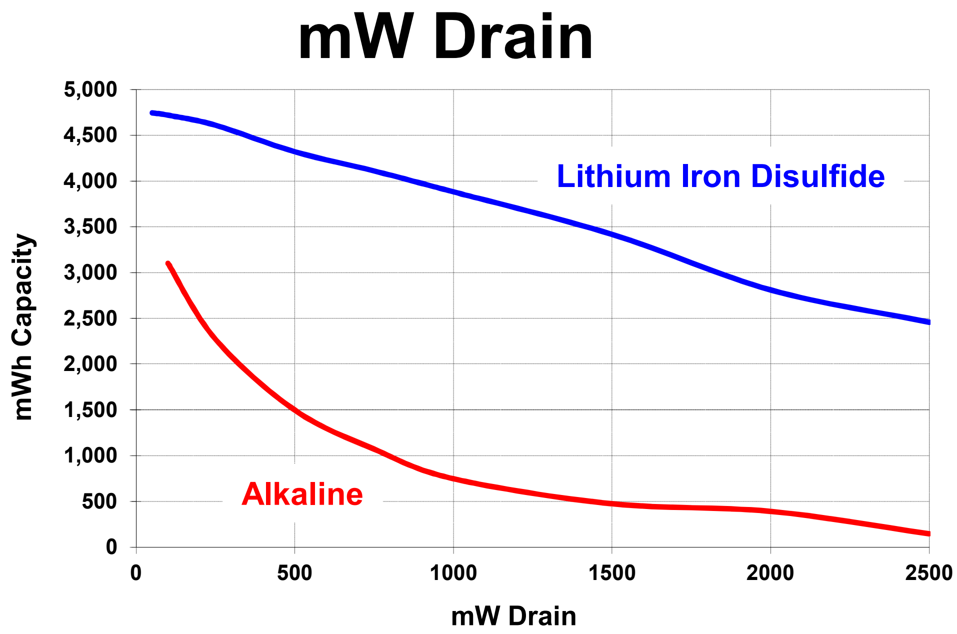
Lithium Iron Disulfide
Key Battery Considerations
Voltage – Low Rate (1mA) Discharge



AA size batteries; 1mA continuous

Lithium Iron Disulfide
Key Battery Considerations
Capacity / Energy



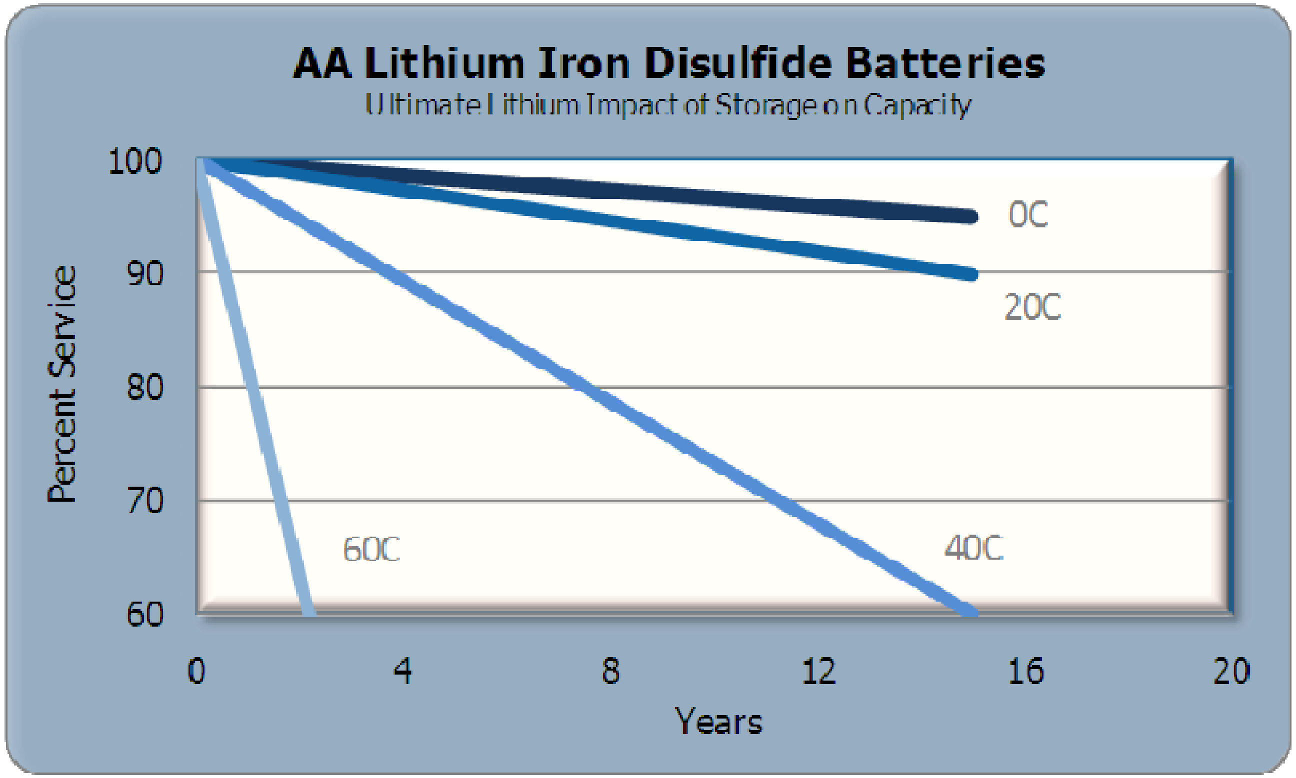


AA size batteries ; continuous discharge to 1.0V

Lithium Iron Disulfide

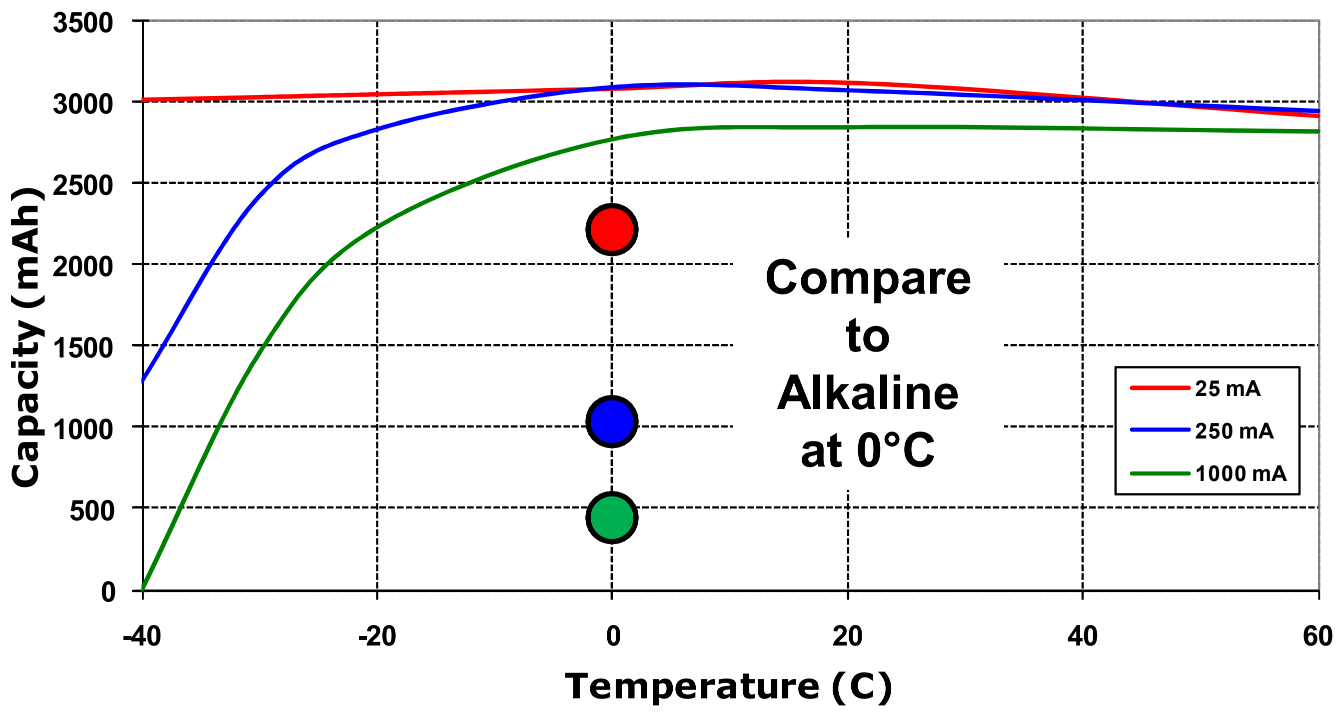
Key Battery Considerations

Shelf Life



- **Shelf life varies with battery chemistry:**
  - Lithium 15+ years at 20ºC
  - Alkaline 5 - 7 years at 20ºC

Lithium Iron Disulfide
Key Battery Considerations
Temperature Performance



Recommended Operating Temperatures

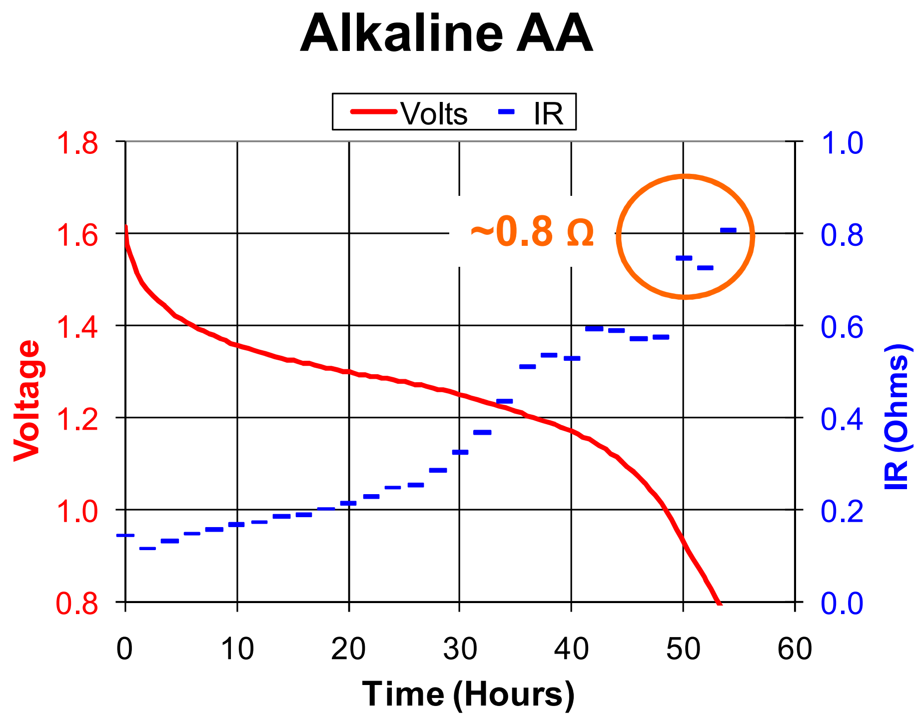
-40°C – 60°C
(-40°F – 140°F)

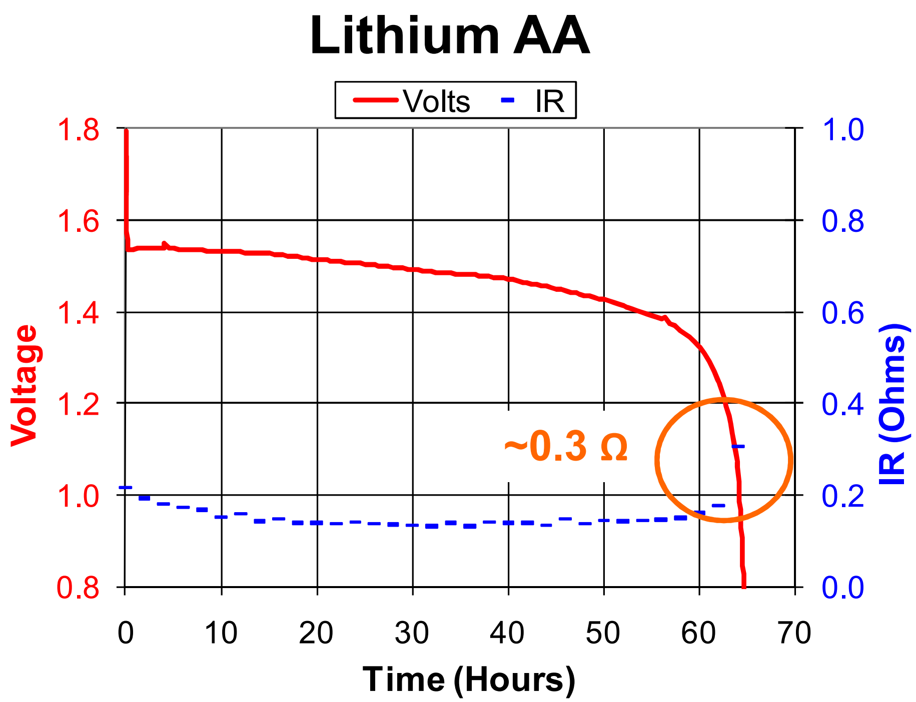
AA size batteries; continuous discharge to 1.0V

Lithium Iron Disulfide

Key Battery Considerations

Internal Resistance



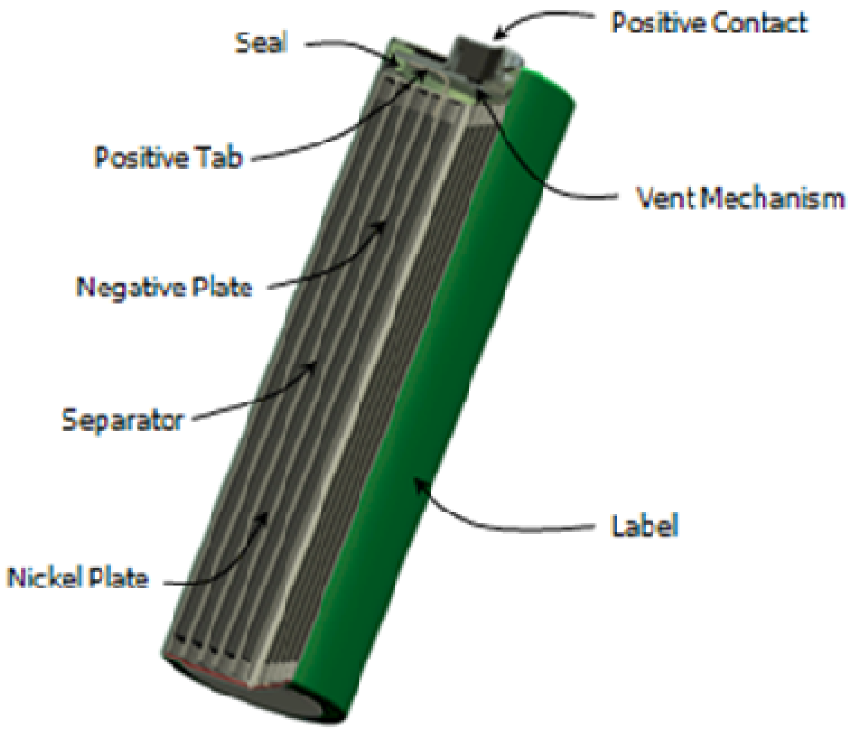


50 mA Continuous Discharge with Intermittent Pulse

Key Battery Considerations:

Nickel Metal Hydride

Nickel Metal Hydride
Key Battery Considerations
Physical Characteristics



Battery Components

Anode	**Metal Hydride**
Cathode	**Nickel Oxy-hydroxide**
Separator	**Nylon**
Electrolyte	**Potassium Hydroxide**
Construction	**“Jellyroll”**

Key Attributes

- Designed for high power capability
- Thin electrode, wound construction
- Welded/high surface area contact system reduces IR
- Rechargeable up to ≈ 500 cycles; dependent on cell capacity and charge rate
- Less absolute energy available compared to primary equivalents
- Requires AC for recharging
- Limited shelf life

Nickel Metal Hydride

Key Battery Considerations

The 3 C's

The balance of 3 main battery components determines overall battery performance:

Positive Electrodes (Metal Hydride)
More positive electrodes
= more runtime capacity

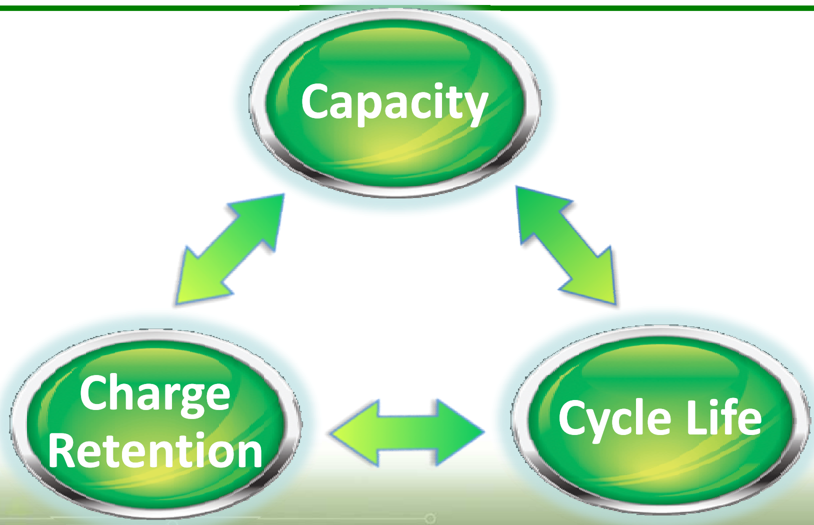
Fewer Positive electrodes
= less runtime capacity

Negative Electrodes (Ni alloy)
More negative electrodes
= more cycles

Fewer negative electrodes
= fewer cycles

Separator Paper
Thicker Separator
= greater charge retention

Thinner Separator
= less charge retention



Nickel Metal Hydride

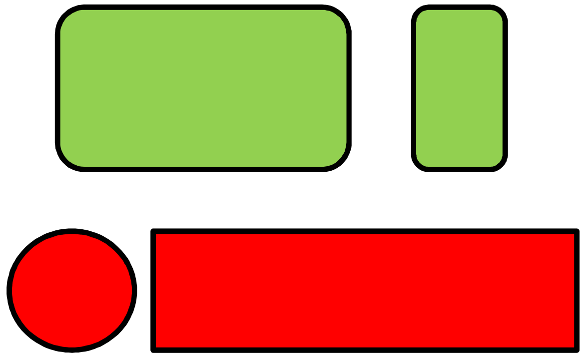
Key Battery Considerations

Physical Characteristics

Volume

- AAA = 3.8cc
- AA = 8.1cc
- 9V = 22.0cc

Footprint



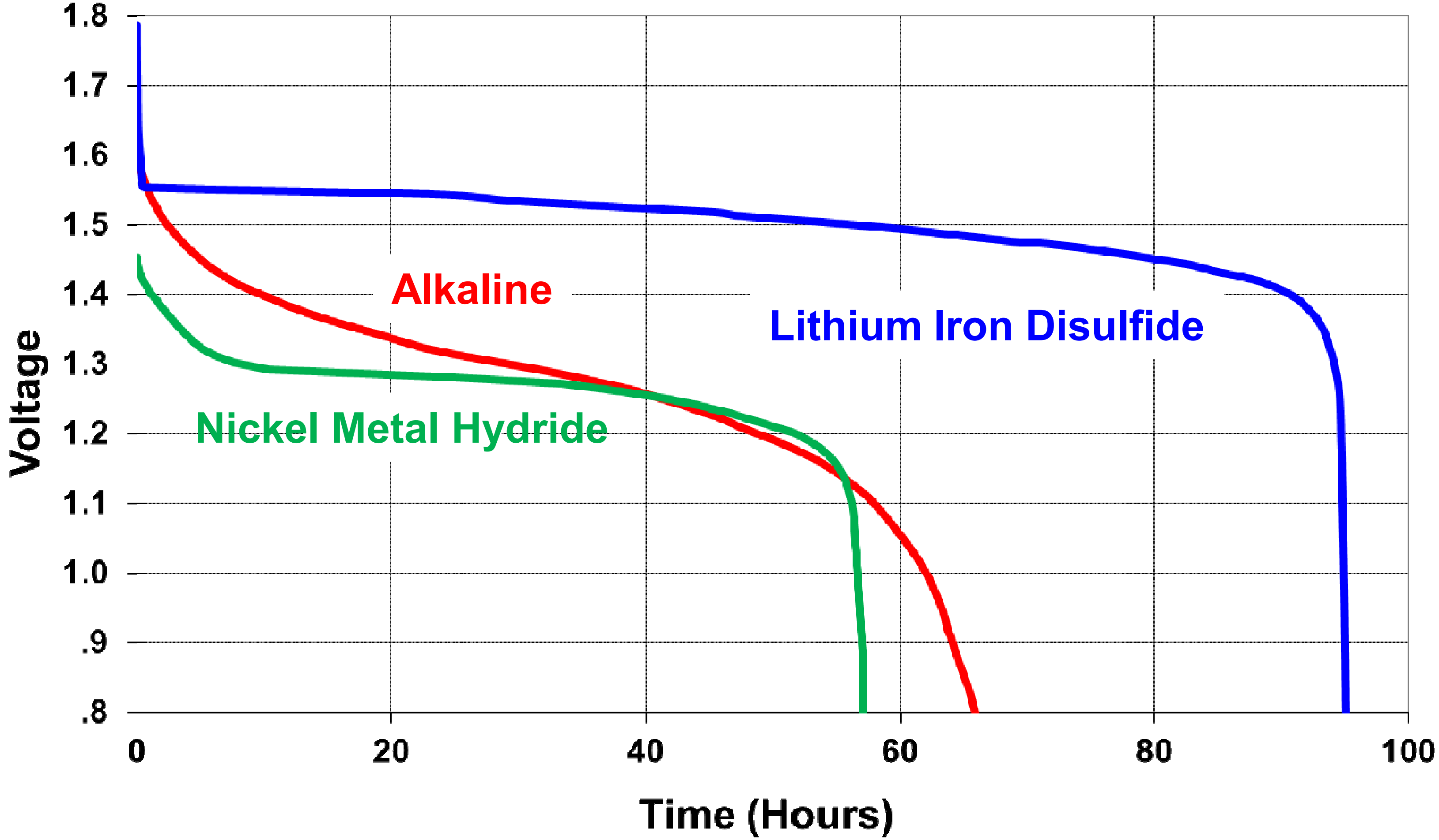
Shape

- Cylindrical
- Rectangular

Contact

Nickel Metal Hydride
Key Battery Considerations

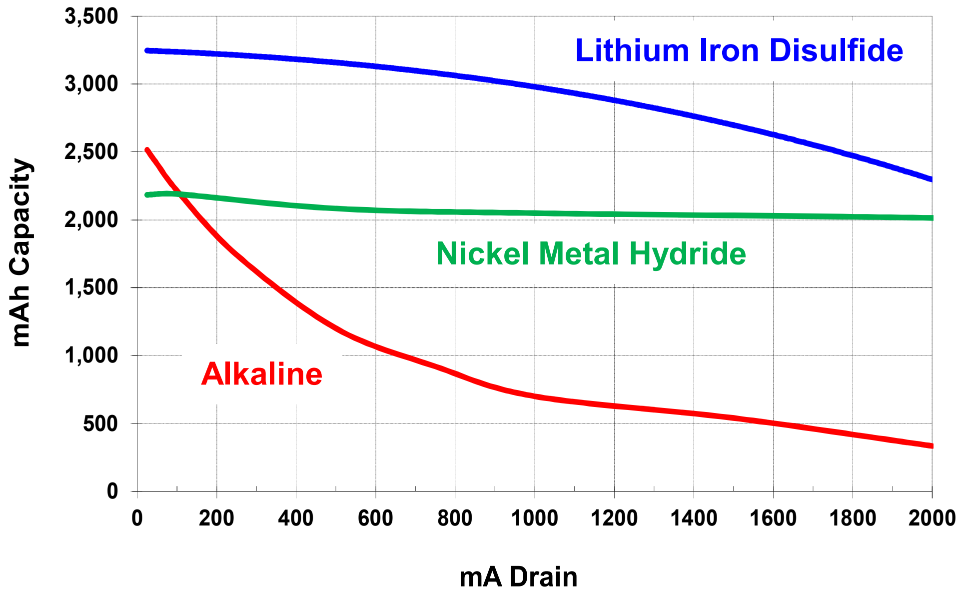
Voltage



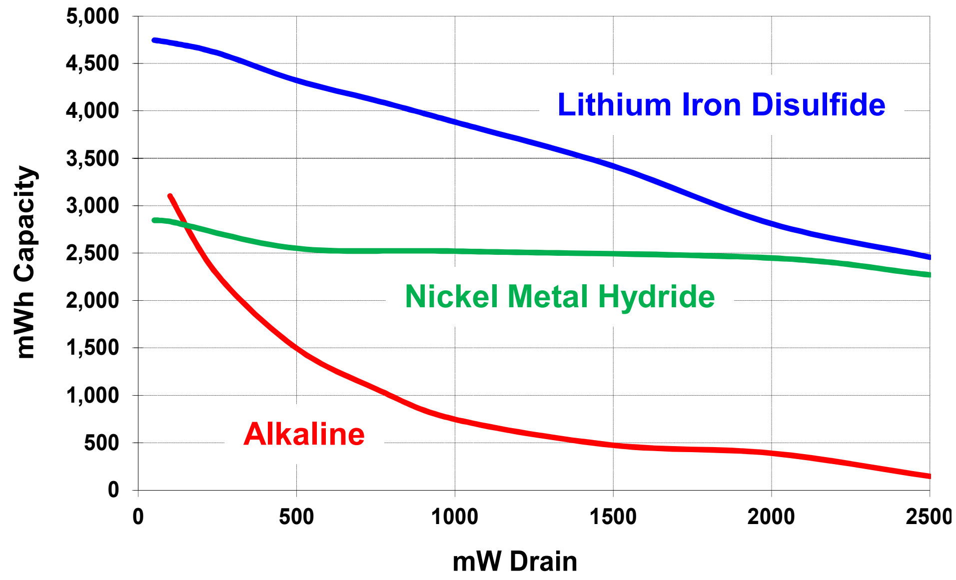
AA size batteries; 50mW continuous; NiMH = 2300mAh

Nickel Metal Hydride
Key Battery Considerations
Capacity / Energy

mA Drain



mW Drain

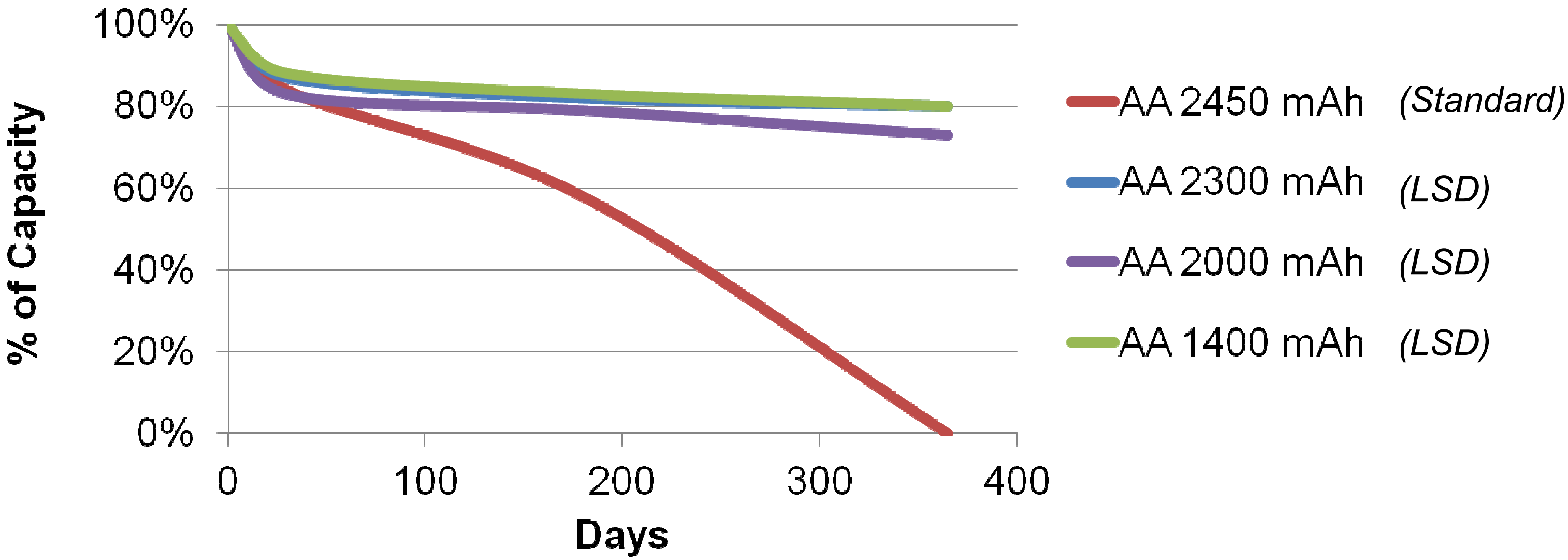


AA size batteries; continuous discharge to 1.0V;
NiMH = fresh 2300mAh (1st cycle)

Nickel Metal Hydride

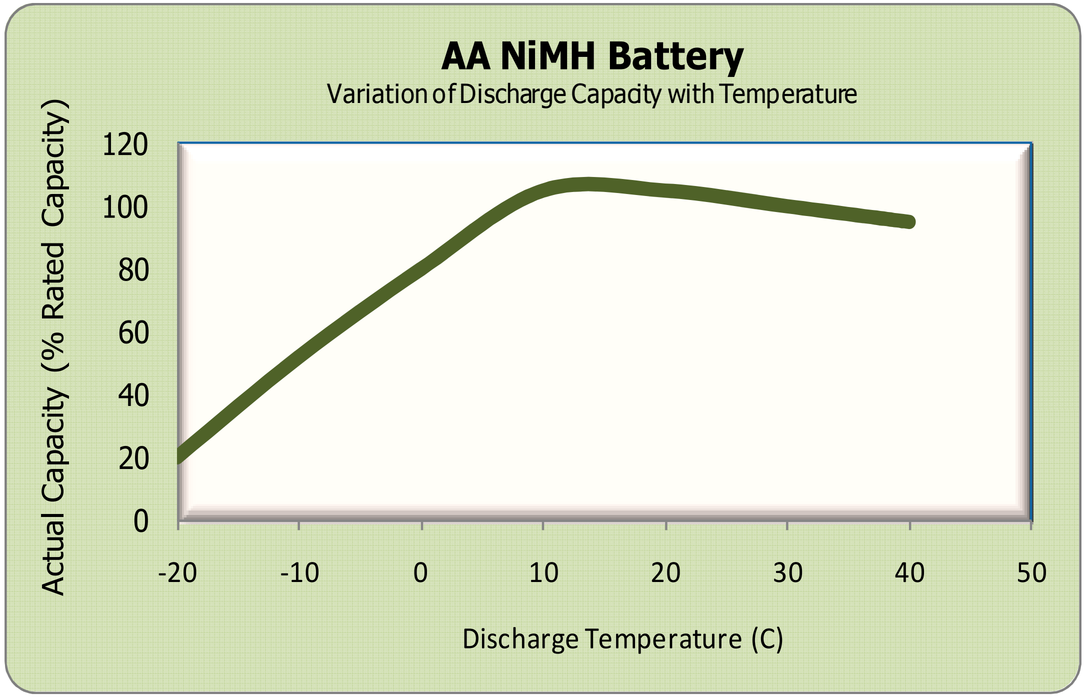
Key Battery Considerations

Shelf Life / Charge Retention / Low Self Discharge (LSD)



- **Charge Retention –"*Number of days a battery holds a charge while not in use*"**
- **Low self-discharge (LSD) NiMH is an incremental improvement of "standard" NiMH**
- ***Current NiMH products hold charge for 1 year***

Nickel Metal Hydride
Key Battery Considerations
Temperature Performance

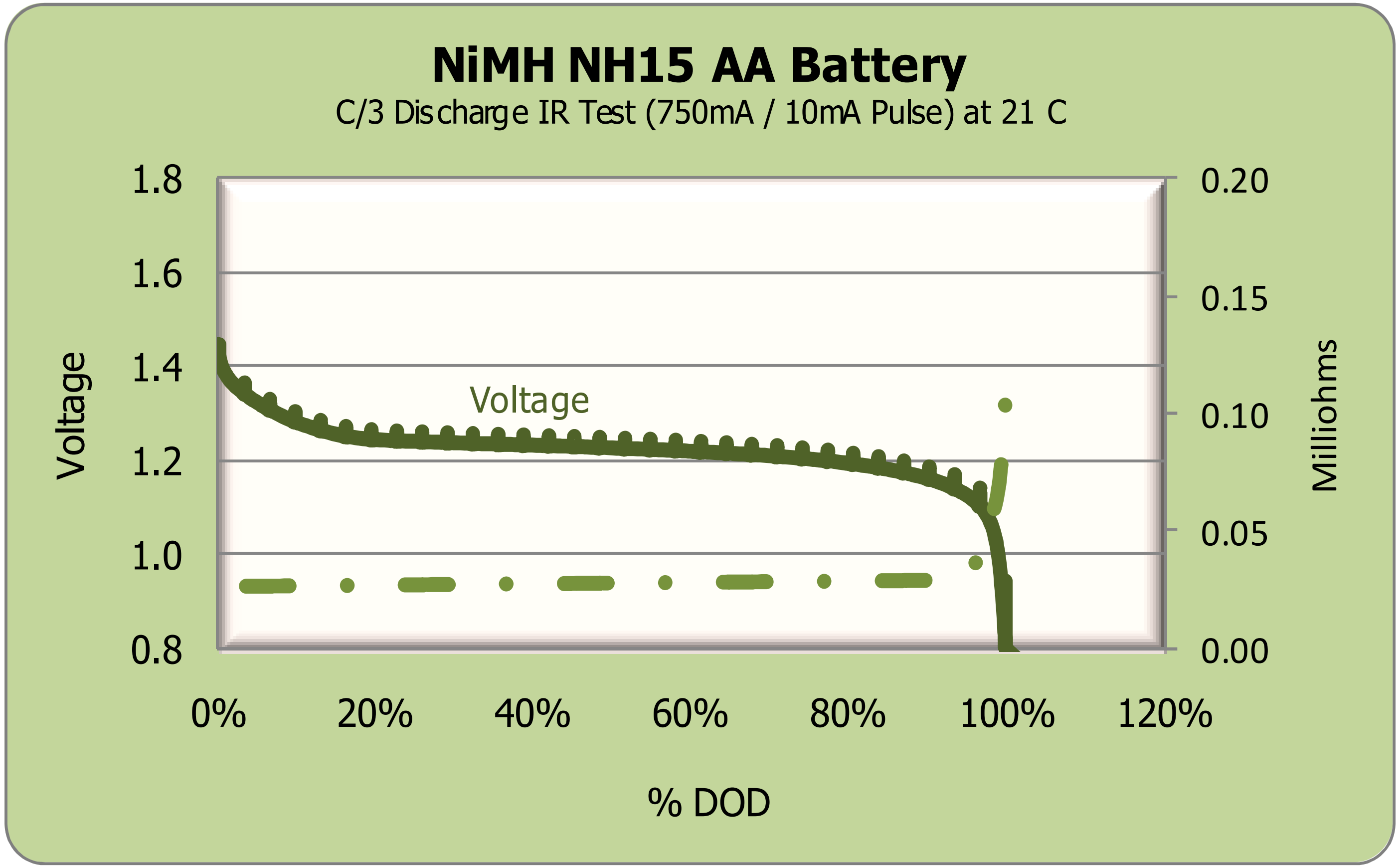


Recommended Operating Temperatures

-20°C – 50°C
(-4°F – 122°F)

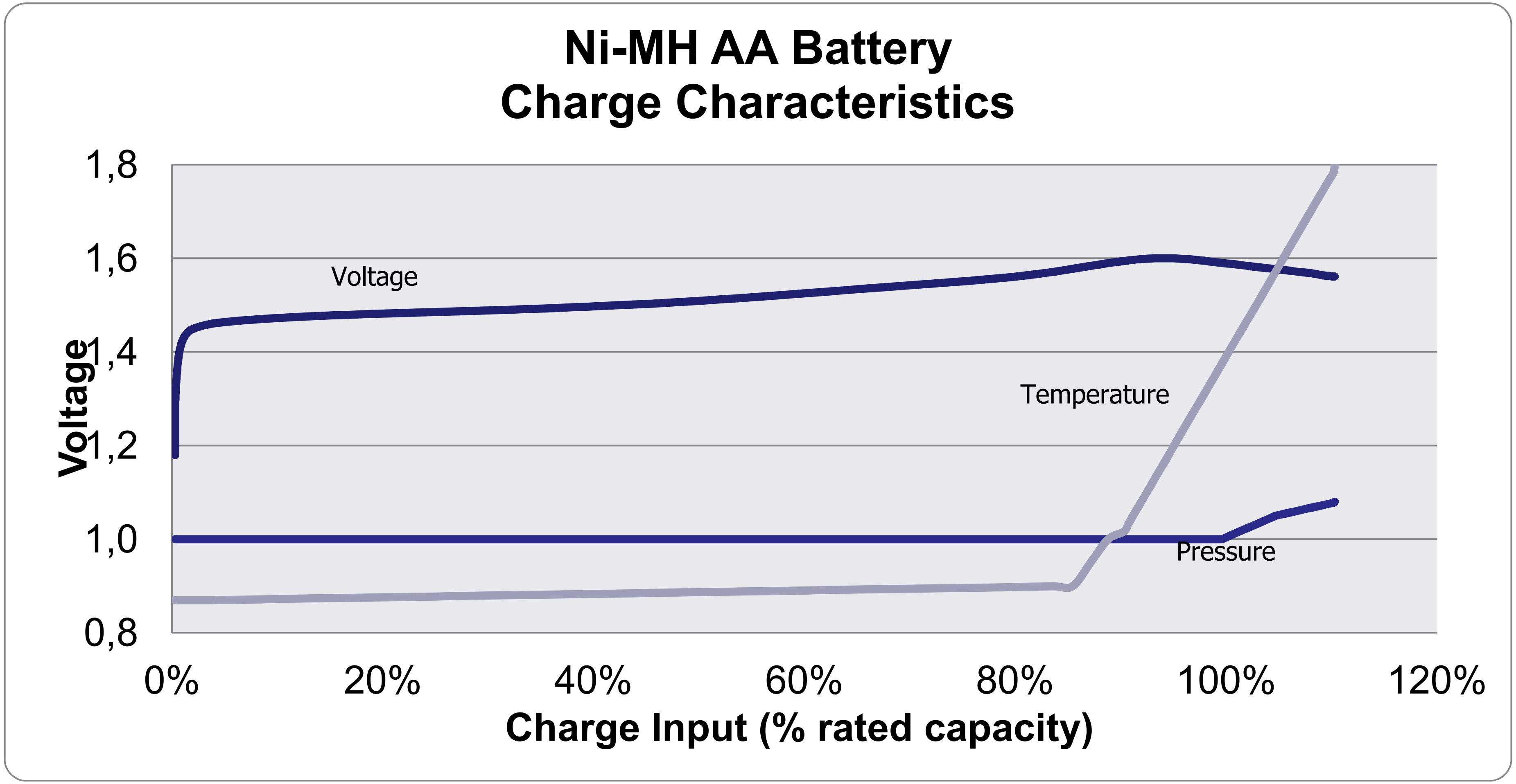
- **Effects of battery temperature on dischargeable capacity are greater at lower temperatures (<0°C).**
- **Use of nickel metal hydride batteries in cold environments requires significant capacity derating from room-temperature values.**

Nickel Metal Hydride
Key Battery Considerations
Internal Resistance



750 mA Continuous Discharge with Intermittent Pulse

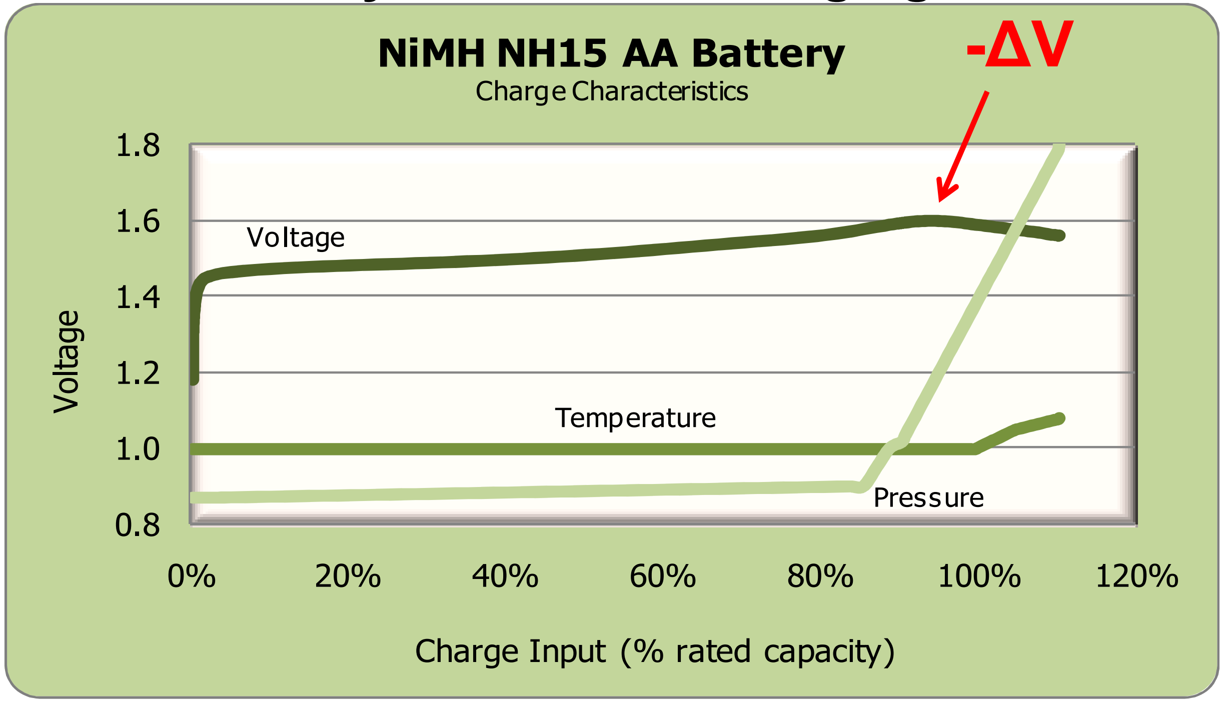
Ni-MH Charge Profile



Nickel Metal Hydride

Key Battery Considerations

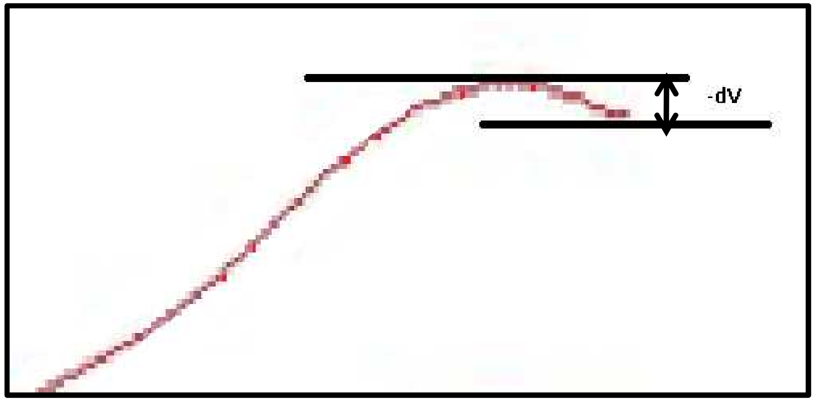
Cycle Life and Charging Method



- **Typical behavior of a nickel-metal hydride battery being charged**
- **“Minus delta V” (-ΔV) is the most common charge termination method**
- **Cycle life of nickel-metal hydride batteries is typically in the 100s when treated properly**

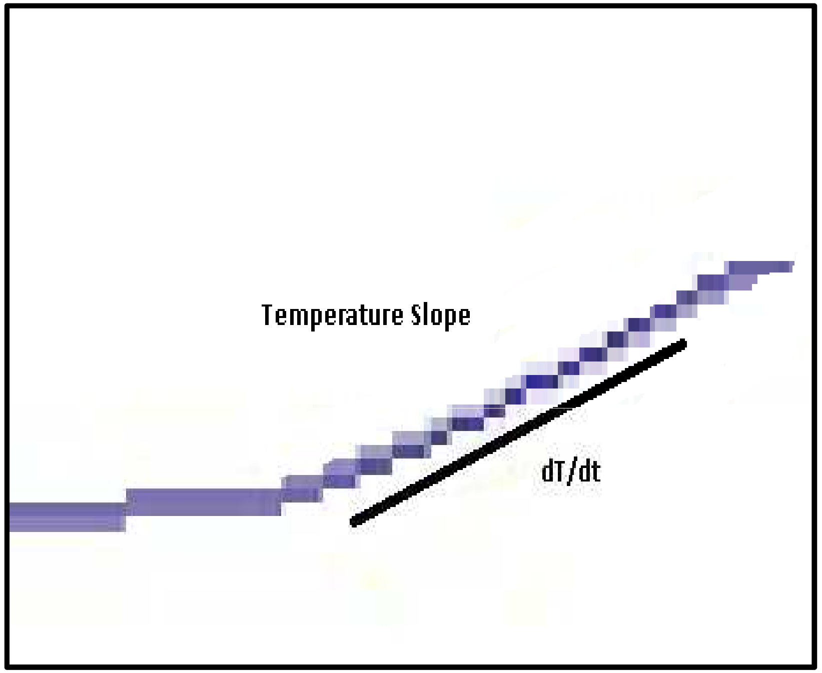
Negative Delta V

- Charge termination protocol that monitors the peak of the charging voltage
- It triggers the end of the charge when voltage drops to a certain value under the last recorded peak
- Used in nickel chemistry cells



Temperature Slope

- Temperature slope termination monitors cell temperature rise rate



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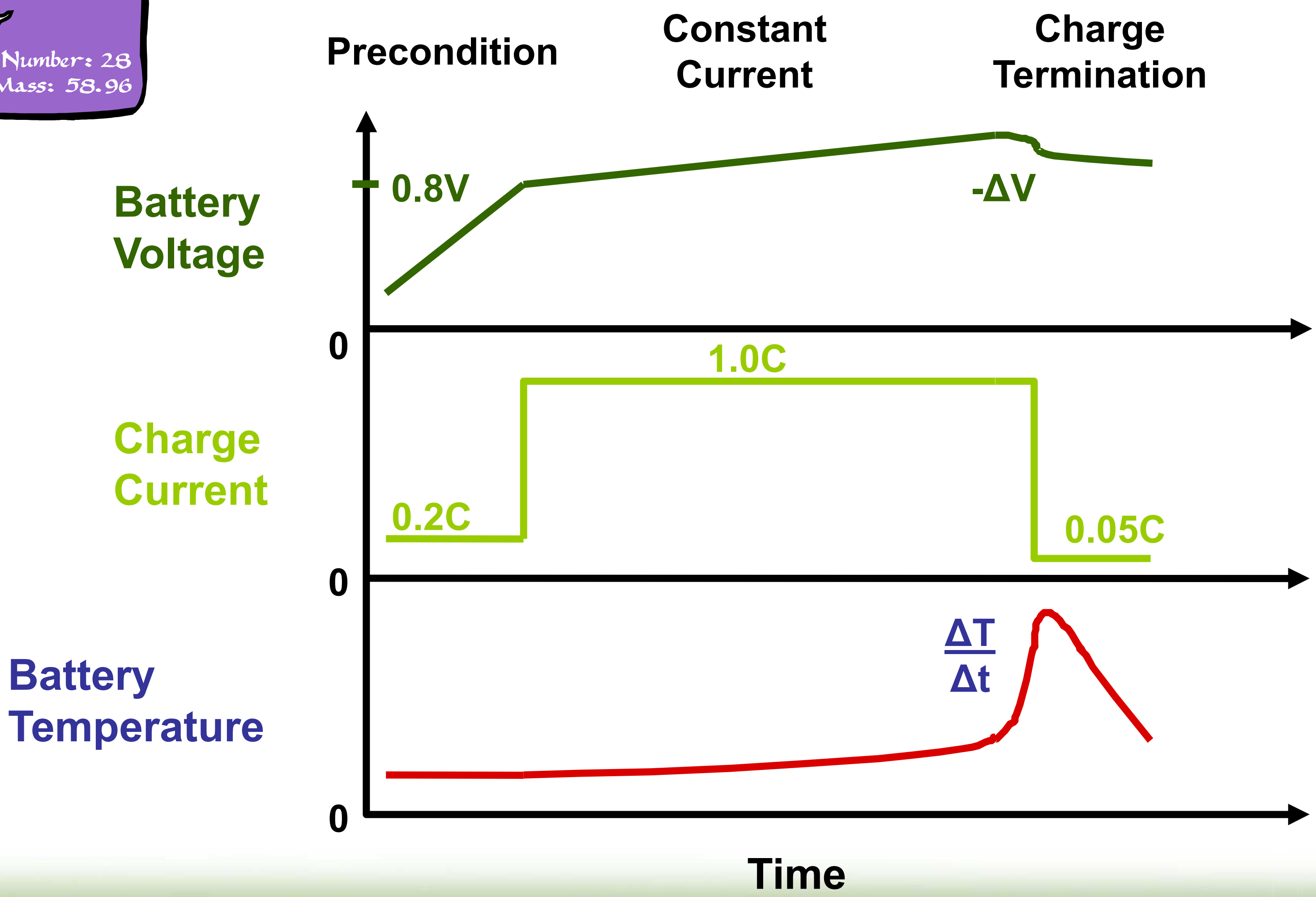
NiCd/NiMH Charge Algorithm



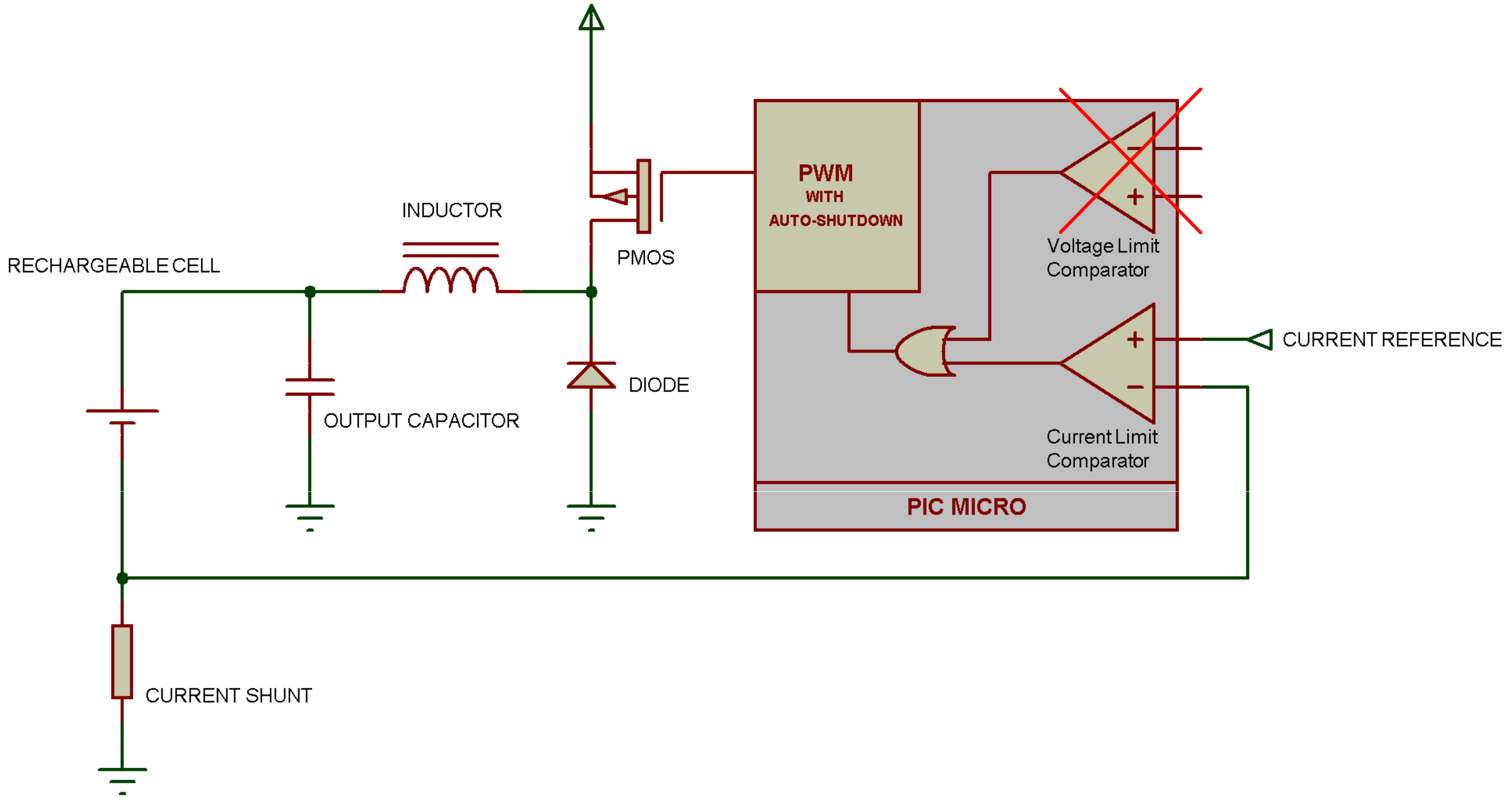
Charging Methods

- Constant Current (CC)
- Constant Voltage with Current Limit (CC/CV)

Charging Methods – Nickel Chemistries

- **Ni-Cd and Ni-MH cells**
  - A fast three-stage constant current (CC) charger yields the best results
  - Cell preconditioning to about 1.0V at C/10 rate or less is needed to initiate fast charge
    - **Fast charging at C rate**
    - **Top-off charge at C/10 (if fast charge ended by temperature slope or voltage inflection point)**
    - **Maintenance charge at C/40**

Constant Current Charger



- Current limit set by reference input
- Maximum output voltage will not exceed input

Nickel Metal Hydride VARTA

Батарея для ЭРА-Глонасс

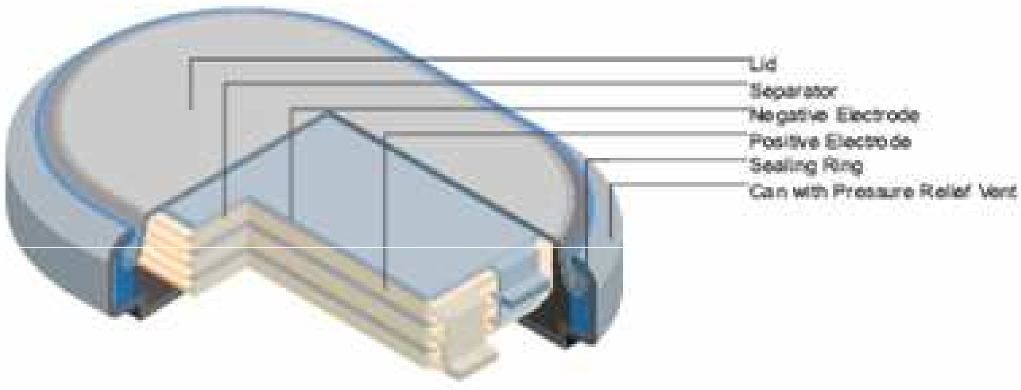
- Токи (для GSM связи) нагрузки до 2,5А
- Срок службы до 10 лет
- Стабильная емкость в диапазоне температур от -40 до +85°С (нагревательная пленка при минусе)
- Рассчитана на длительный ток перезаряда
- Простая электроника для заряда

Technology Ni-MH Button cell powerful85 family

VARTA

A <u>precision seal</u>, with long diffusion path, ensures excellent sealing properties. The cup of the casing acts as the positive terminal and the lid is the negative terminal. The <u>punched positive sign</u> with precisely defined rest wall thickness on the cell serves as safety device which opens smoothly at predetermined internal pressure, in case of gross abuse. The new <u>Multi-Electrode</u> technology is the reason for more power.

FIG. 15
Schematic view of a Ni-MH High Rate Button Cell from VARTA Microbattery



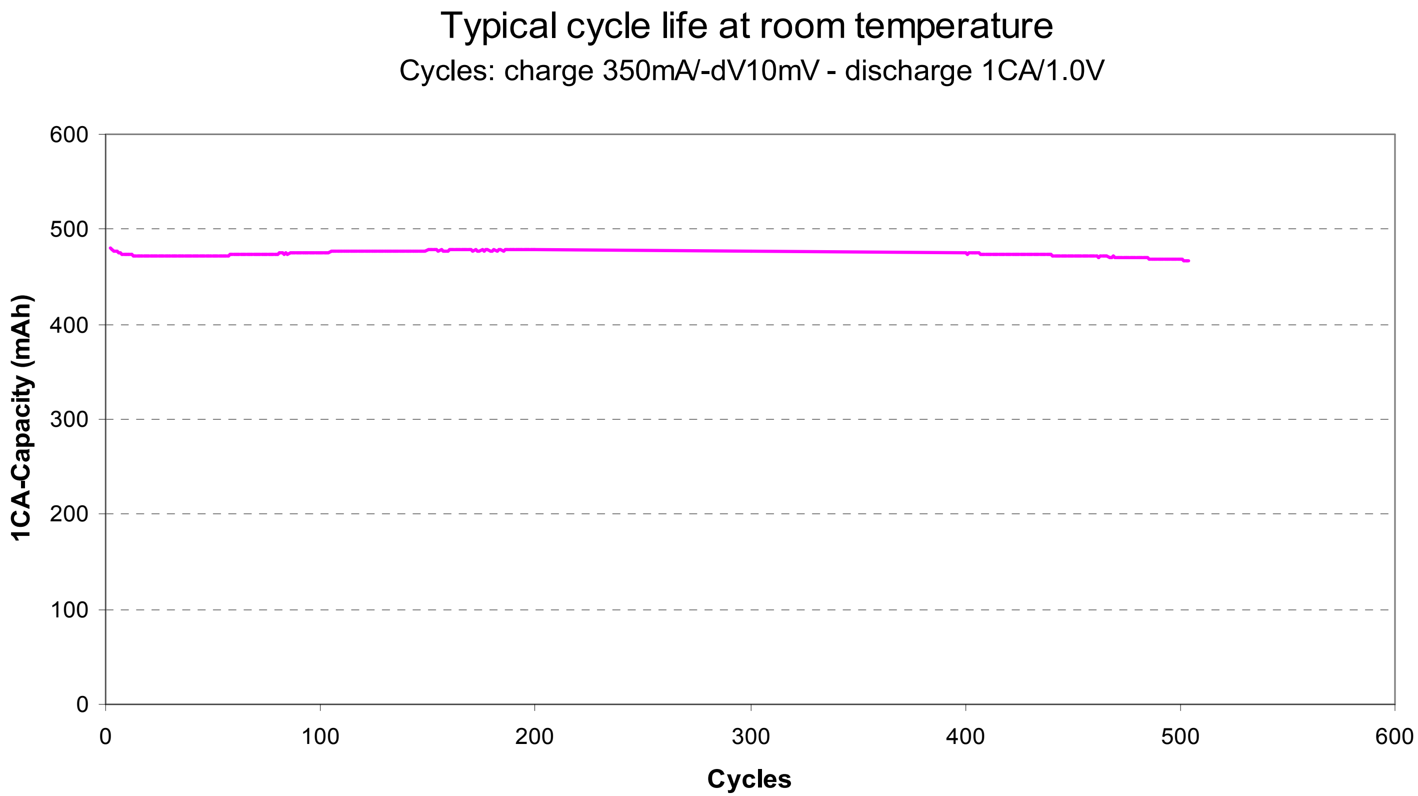
Confidential !

The sealed Ni-MH cell requires that, towards the end of charging, oxygen which is generated at the positive electrode must be recombined to avoid pressure to be build up. The <u>extra charge reserve</u> capacity is responsible for this process.

Additionally a <u>discharge reserve</u> is necessary to prevent degradation of the negative electrode at the end of discharge. This is why the negative electrode is over dimensioned compared with the positive. The positive electrode determines the useable cell capacity.

The cells are equipped with <u>new synthetic sealing material</u> for high reliability at extreme temperature requirements.

Lifetime influence factors → number of charge / discharge cycles



C o n f i d e n t i a l !

Lifetime influence factors → overcharge stress

VARTA

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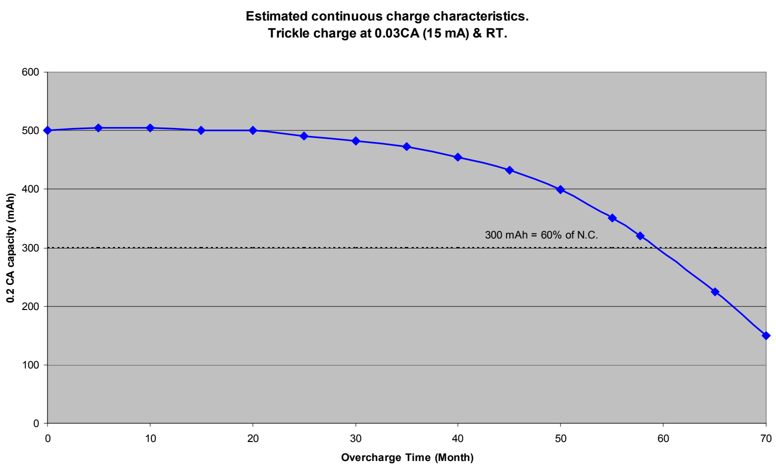
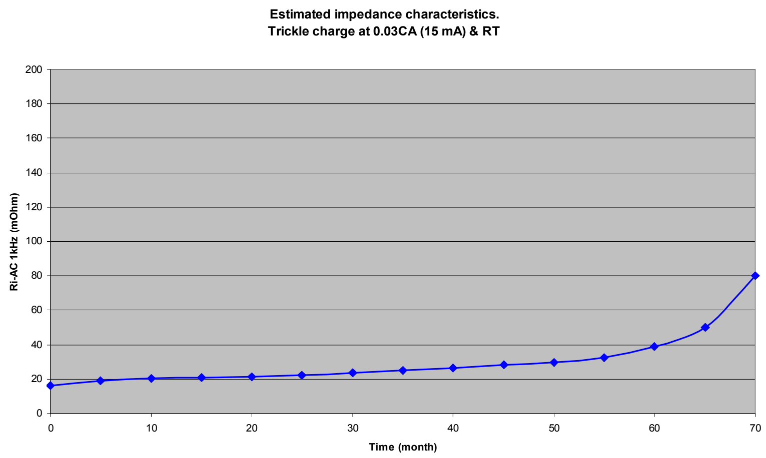
- According charge recommendations from VARTA, batteries are overcharged with 0.01CA (average 5mA). This is needed to recover the capacity loss due to self discharge in extended temperature and keep the battery in continuous full state.
- VARTA tests show stable performance of the cell during continuous overcharge with 0.03CA





After 40 months (28.800h) in overcharge with 0.03CA, still 90% of capacity is available.

Lifetime influence factors → overcharge stress

- According to the typical temperature profile during one year, the batteries are only charged when ignition is on which means 1000h of in total 8760h (per year). This means in 10 years the batteries are overcharged for 1000x10=10.000h.

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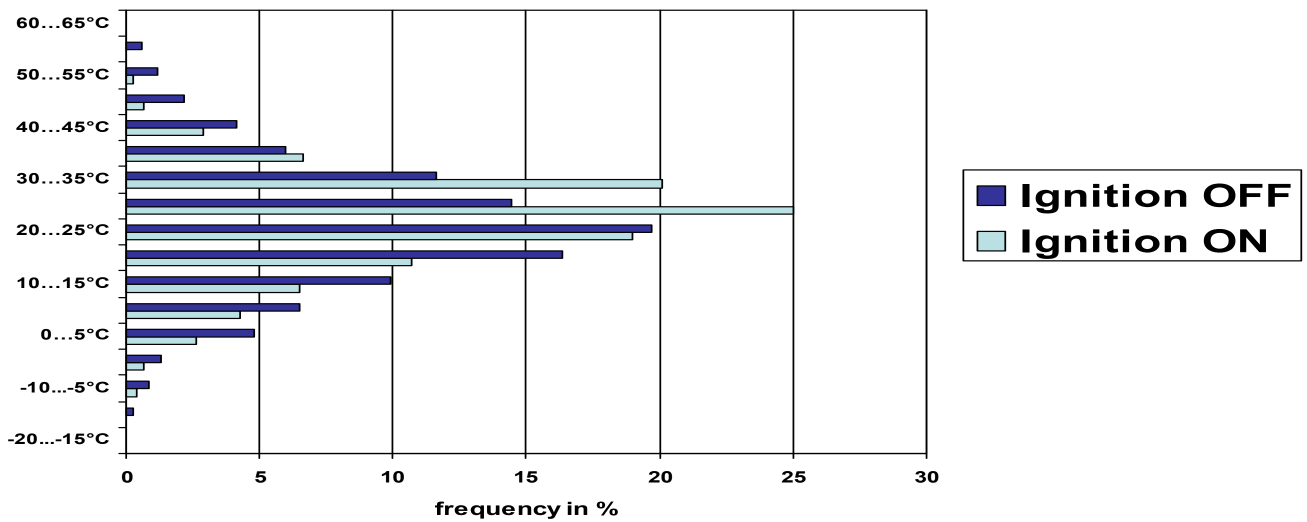

During 1 year the car will be about 1000h ON and 7760h OFF (99% users covered) battery will be in overcharge for a max of 10.000h in 10 years due to this profile.

Lifetime influence factors → temperature

- According to the mission profile, during one year the batteries are used in an average temperature range of 35 degC.
- The influence of temperature on lifetime at trickle charge has to be considered.
- Standard overcharge tests at VARTA are done at 45°C

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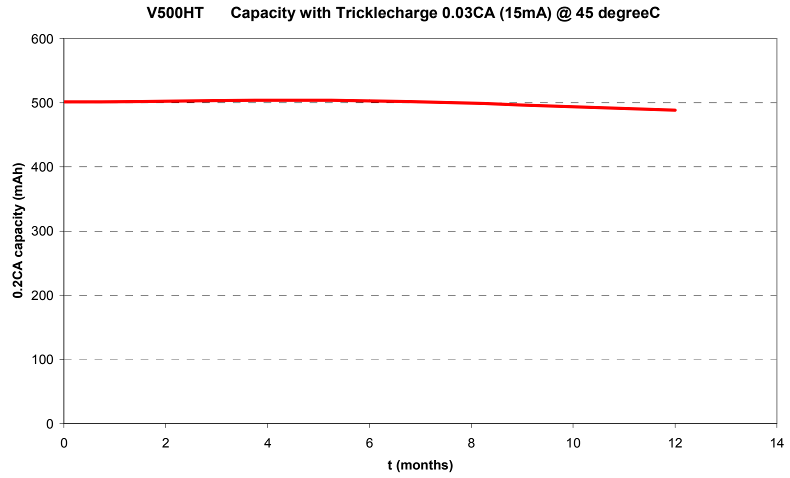
After 12 months (8.640h) in overcharge with 0.03CA at 45° C (!), still >90% of capacity is available.



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VARTA

Lifetime influence factors → conclusion

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Testresults and assumptions:

- 20 charge / discharge cycles compared to 500 cycles will not be decisive for the lifetime estimation of the battery.
- Test result: After 40 months (28.800h) in overcharge with 0.03CA, still 90% of capacity is available
- Assumption: During 10 years the battery will be in overcharge with 0.01CA for a max of 10.000h due to mission profile at an average temperature of 35° C.
- Test result: After 12 months (8.640h) in overcharge with 0.03CA at 45° C (!), still >90% of capacity is available.

Conclusion:

→ Testing of cells shows overcharge stability of cells of more than 8.640h with 0.03CA overcharge at 45° C.

→ Compared with an expected overcharge with of 10.000h (worst case) with >30% lower overcharge (0.01CA) at 10° C lower temperature (35° C average) a lifetime expectation of 10 years in this application is possible.

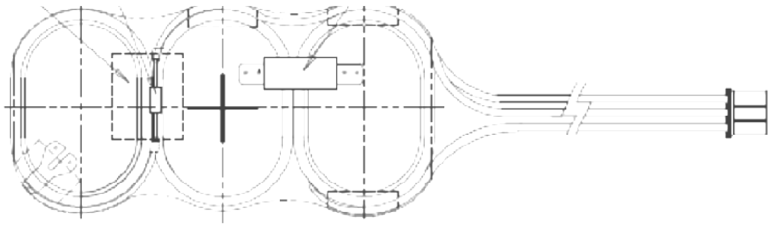
Note:

→ Usage time at the given discharge profile at extreme temperatures has to be tested.

Charging strategies

Confidential !

- Charge algorithm
  - 3/V500HT
  - 4/V500HT



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VARTA

3/V500HT: Pulse Charge strategy for automotive applications

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Note:

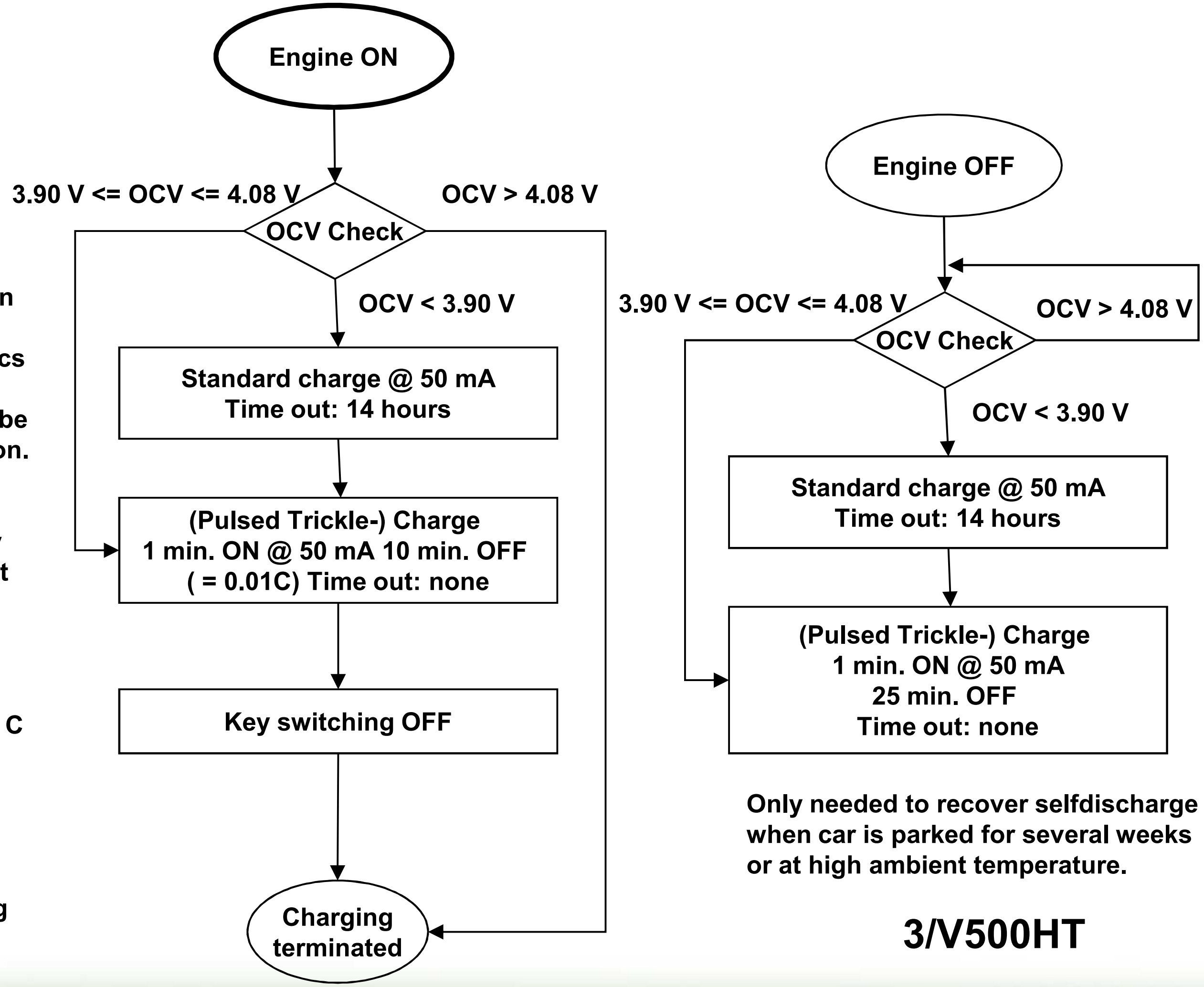
1. Discharge the battery below 2.7 V (0.9V/cell) and storage in deep discharge condition damage the cell characteristics and must be avoided. Deep discharge protection should be implemented in the application.

2. If OCV > 4.08 V than can be supposed that battery is fully charged. Trickle charge is not necessary.

3. Standard charge and trickle charge are allowed for whole temperature range from -20° C up to +85° C

4. OCV = Open Circuit Voltage

5. OCV is independent of temperature and is stabilizing 30 min after charge or discharge operation.



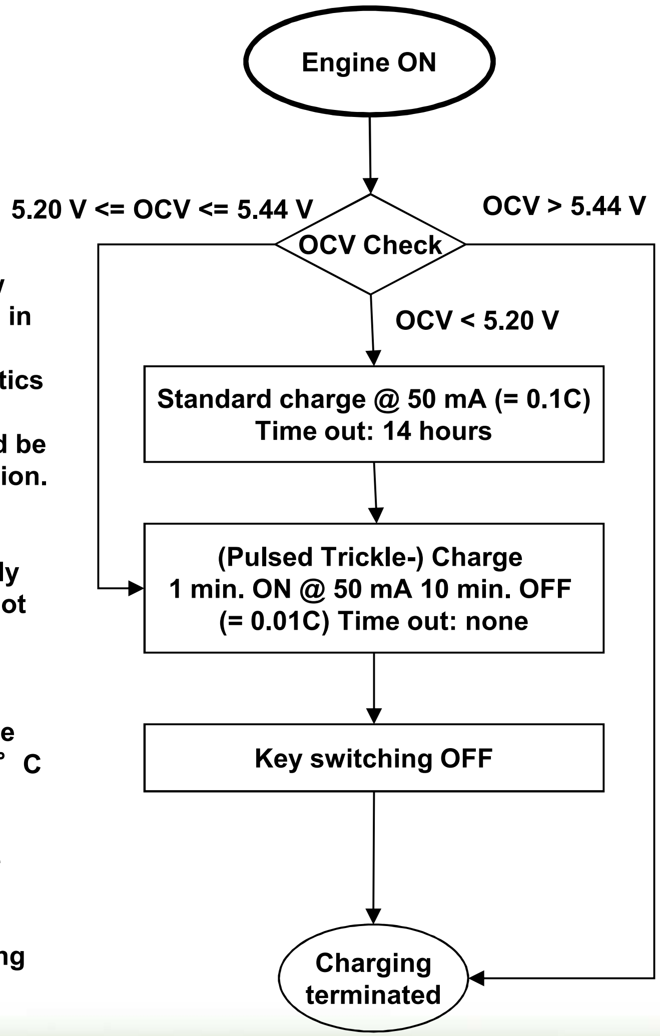
Only needed to recover selfdischarge when car is parked for several weeks or at high ambient temperature.

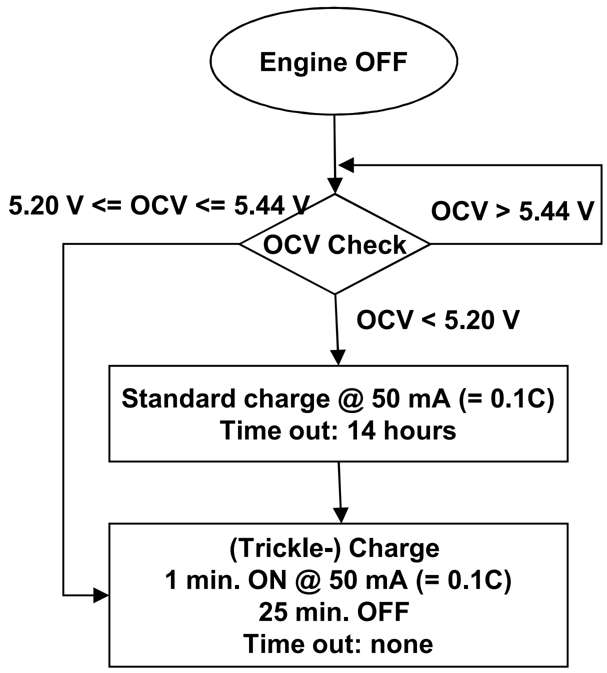
3/V500HT

4/V500HT: Pulse Charge strategy for automotive applications

Note:

1. Discharge the battery below 3.6 V (0.9V/cell) and storage in deep discharge condition damage the cell characteristics and must be avoided. Deep discharge protection should be implemented in the application.
2. If OCV > 5.44 V than can be supposed that battery is fully charged. Trickle charge is not necessary.
3. Standard charge and trickle charge are allowed for whole temperature range from -20° C up to +85° C
4. OCV = Open Circuit Voltage
5. OCV is independent of temperature and is stabilizing 30 min after charge or discharge operation.

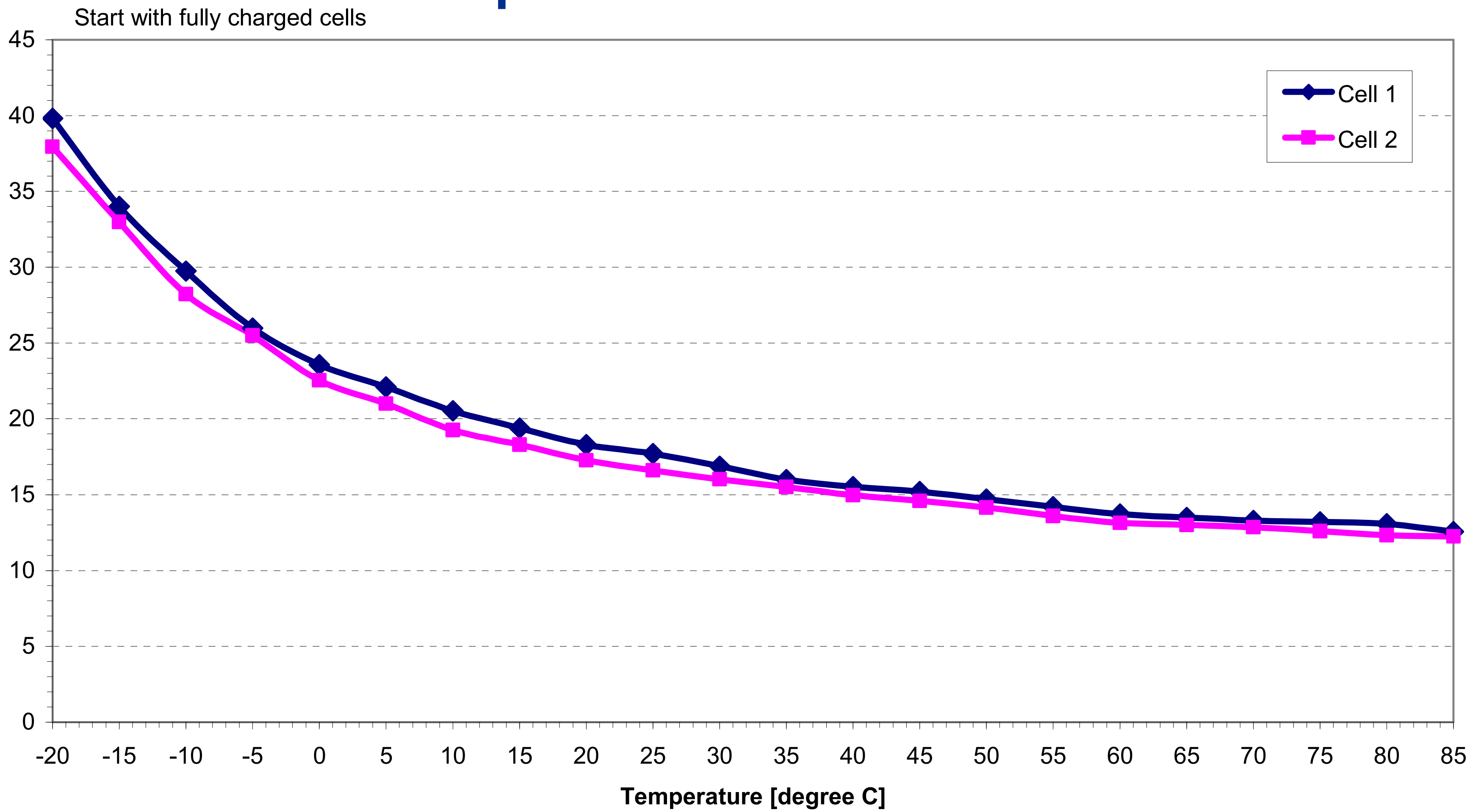




Only needed to recover selfdischarge when car is parked for several weeks or at high ambient temperature.

4/V500HT

V500HT: 1kHz Impedance as function of the cell temperature – fresh cells



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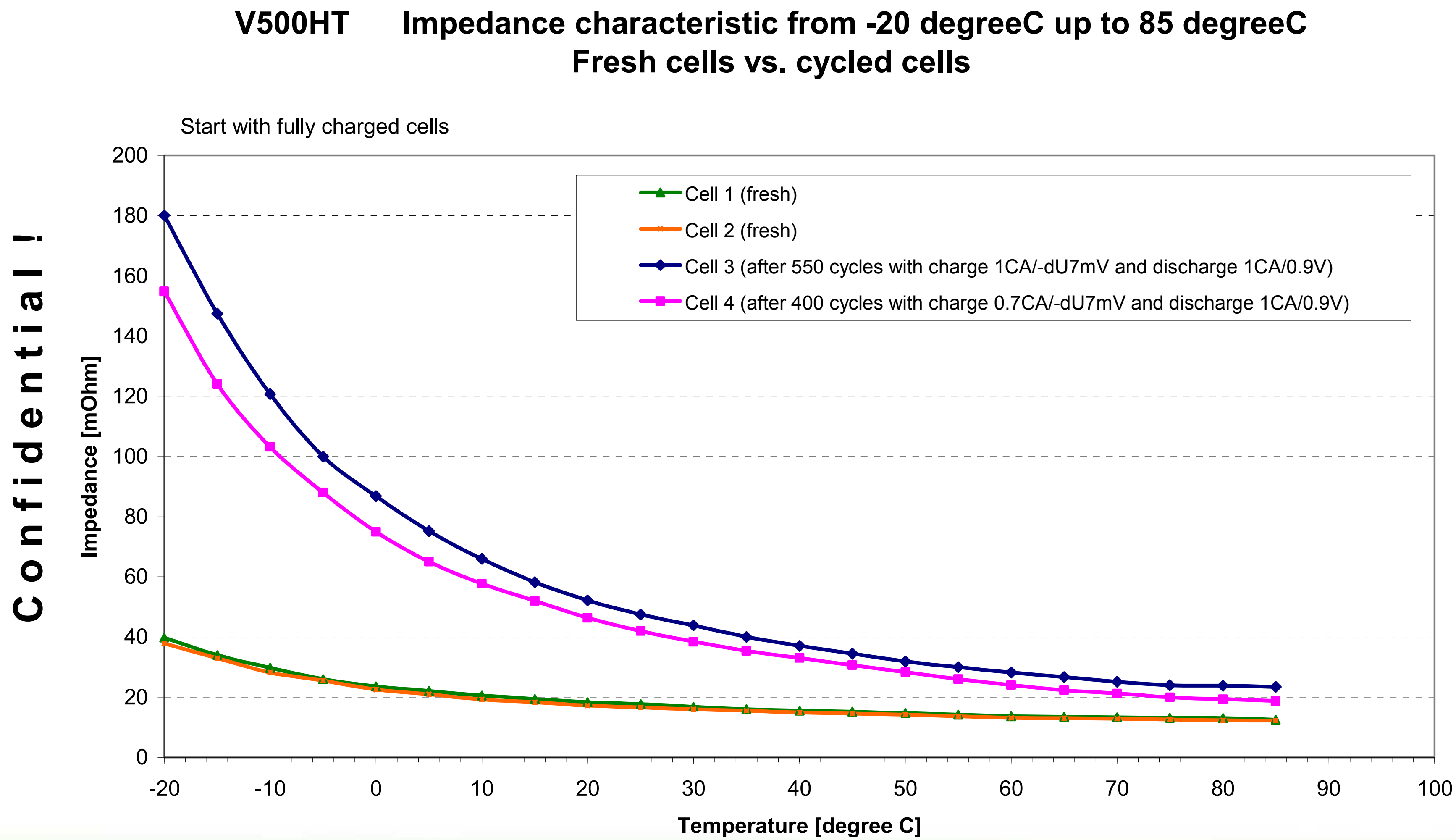
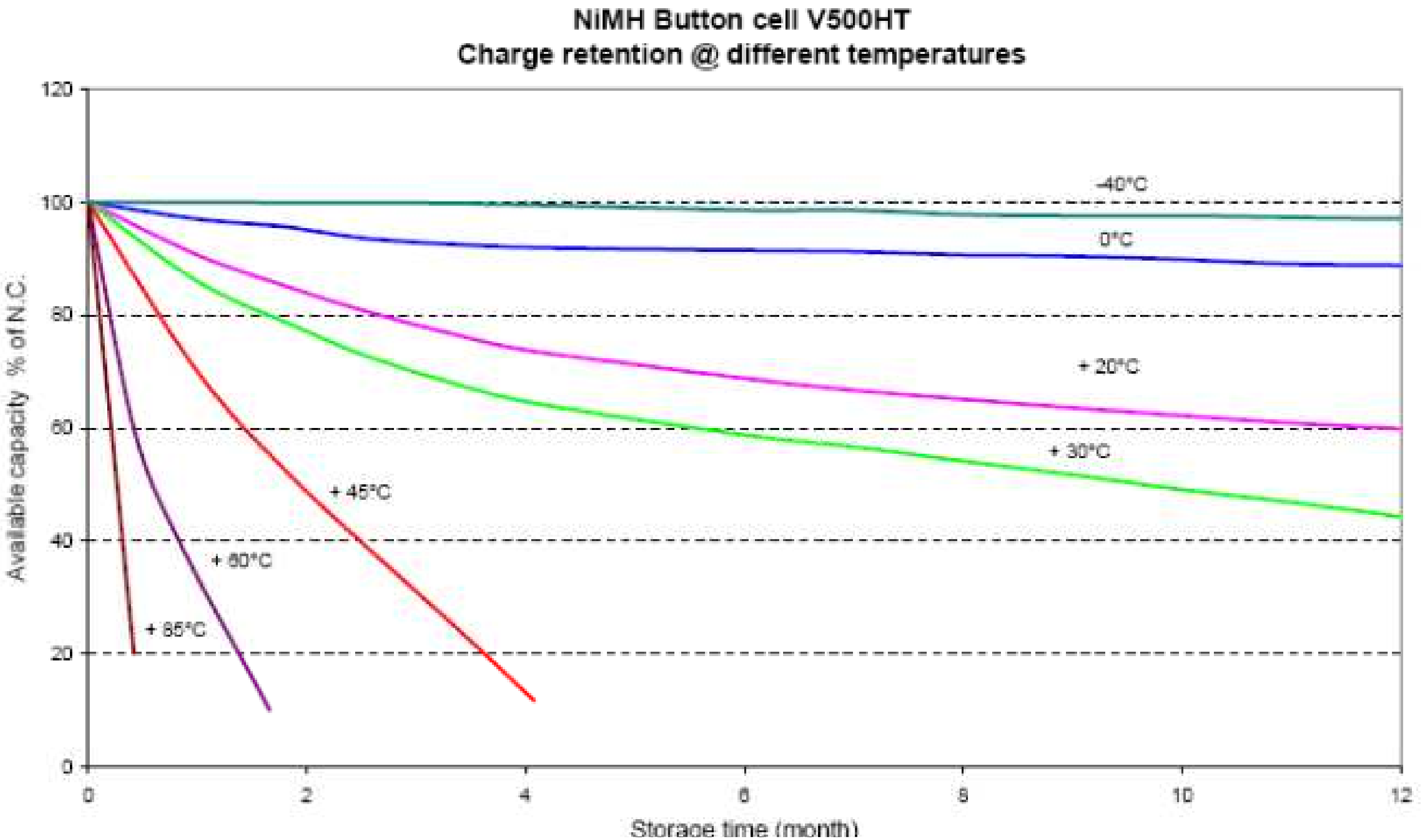
V500HT: 1kHz Impedance as function of the cell temperature



V500HT: Charge retention



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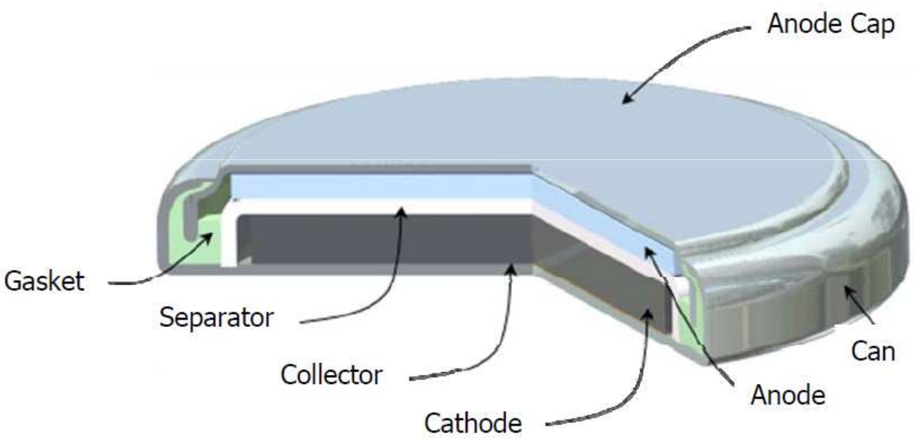
Key Battery Considerations:

Lithium Manganese Dioxide (Lithium Coin)

Lithium Manganese Dioxide (Coin)
Key Battery Considerations
Physical Characteristics



Battery Components

Anode	**Lithium Metal**
Cathode	**Manganese Dioxide**
Separator	**Polypropylene**
Electrolyte	**Lithium Salt Compound**
	Organic Solvent

Key Attributes

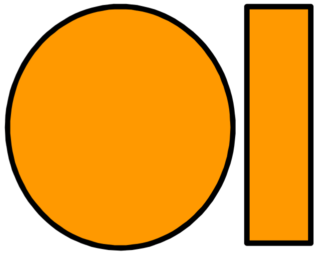
- High energy density
- High voltage (3.0V nominal)
- Long shelf life
- Suitable for pulse discharge
- Thin form factor

Lithium Manganese Dioxide (Coin)
Key Battery Considerations
Physical Characteristics

Volume

- CR2016 = 0.5cc
- CR2025 = 0.8cc
- CR2032 = 1.0cc
- CR2450 = 2.4cc

Footprint



Shape

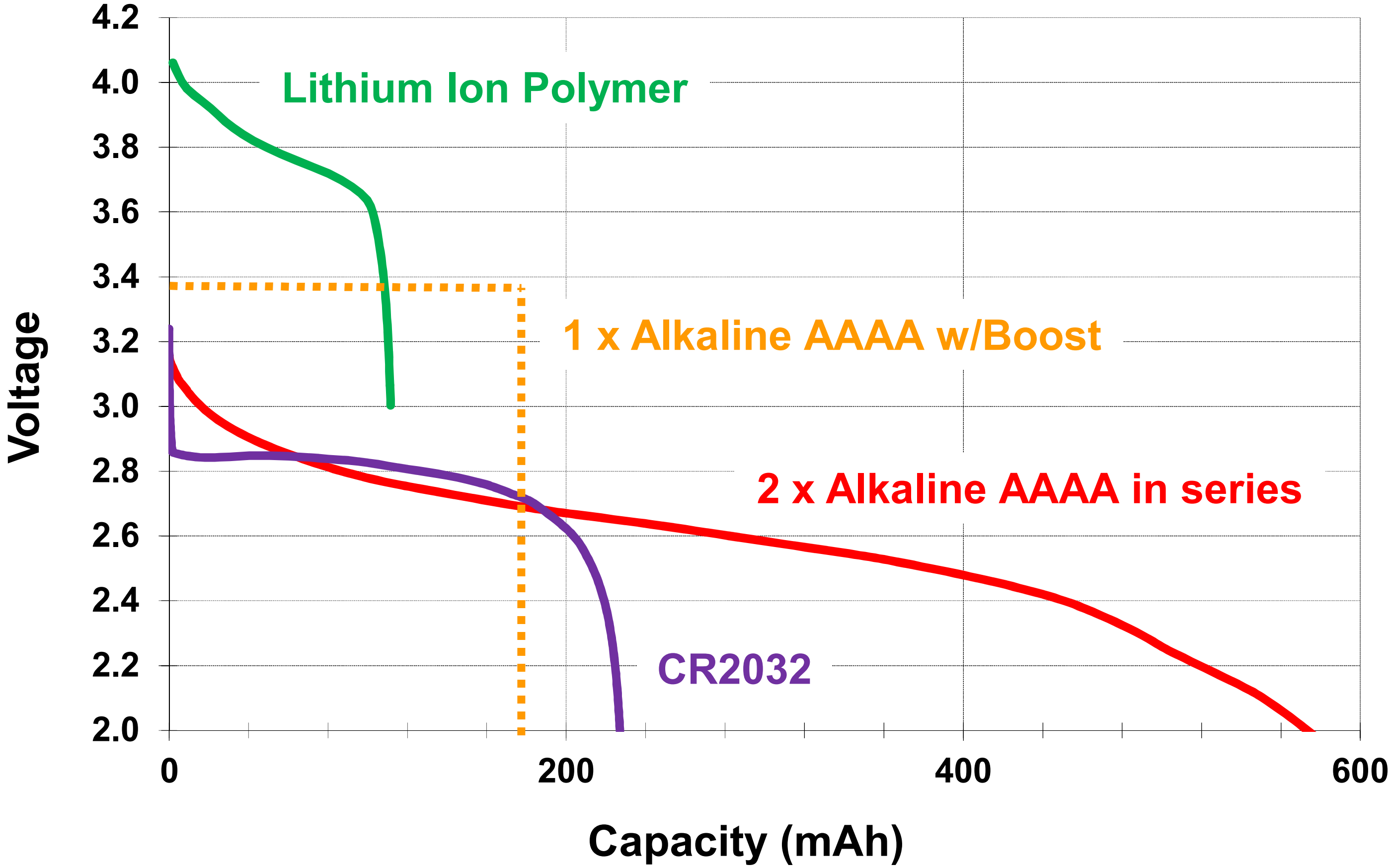
- Coin

Contact

Lithium Manganese Dioxide (Coin)

Key Battery Considerations

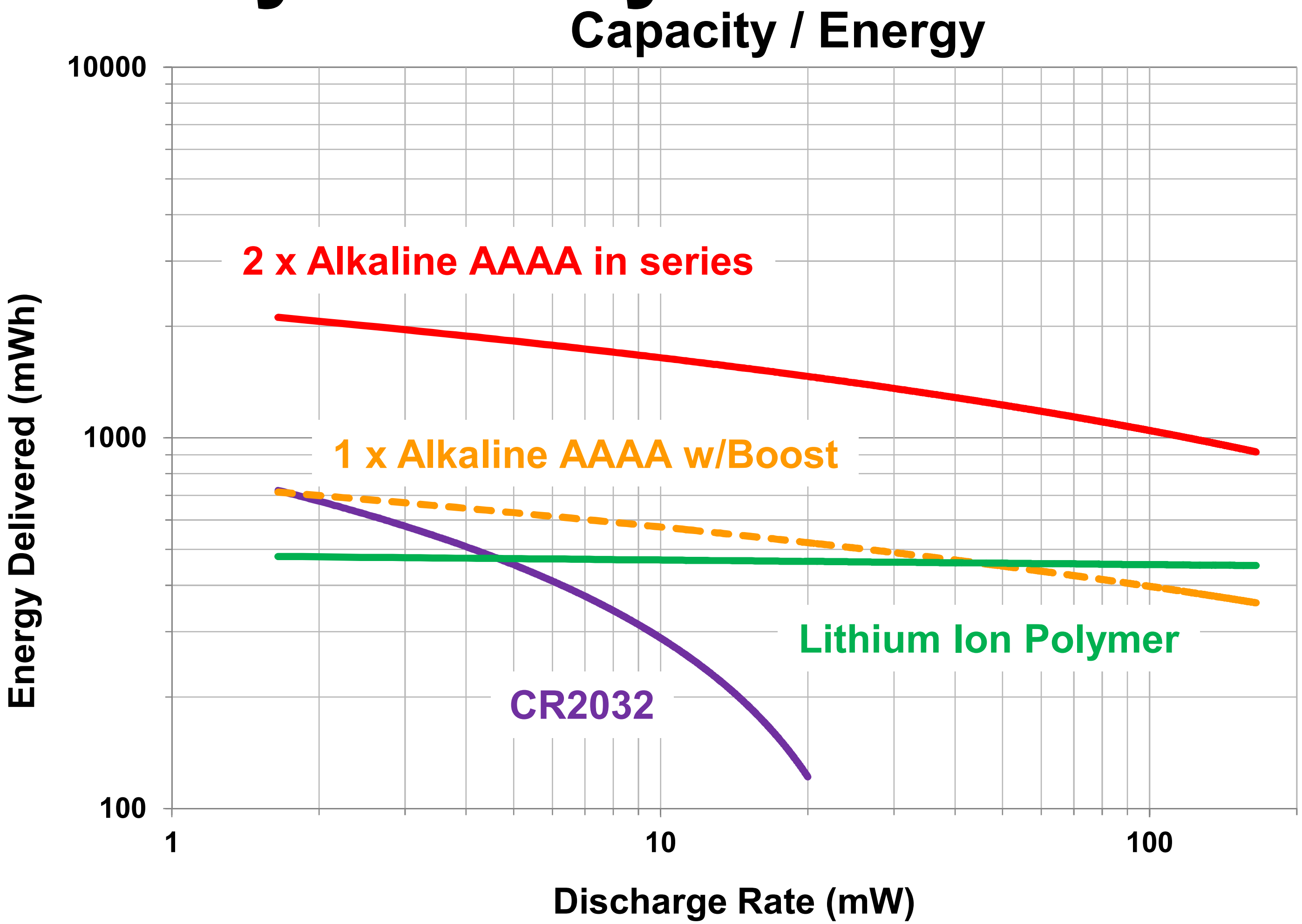
Voltage



1mA continuous; Lithium ion polymer = 120mAh; Boost = Microchip MCP1640 output to 3.3V

Lithium Manganese Dioxide (Coin)

Key Battery Considerations

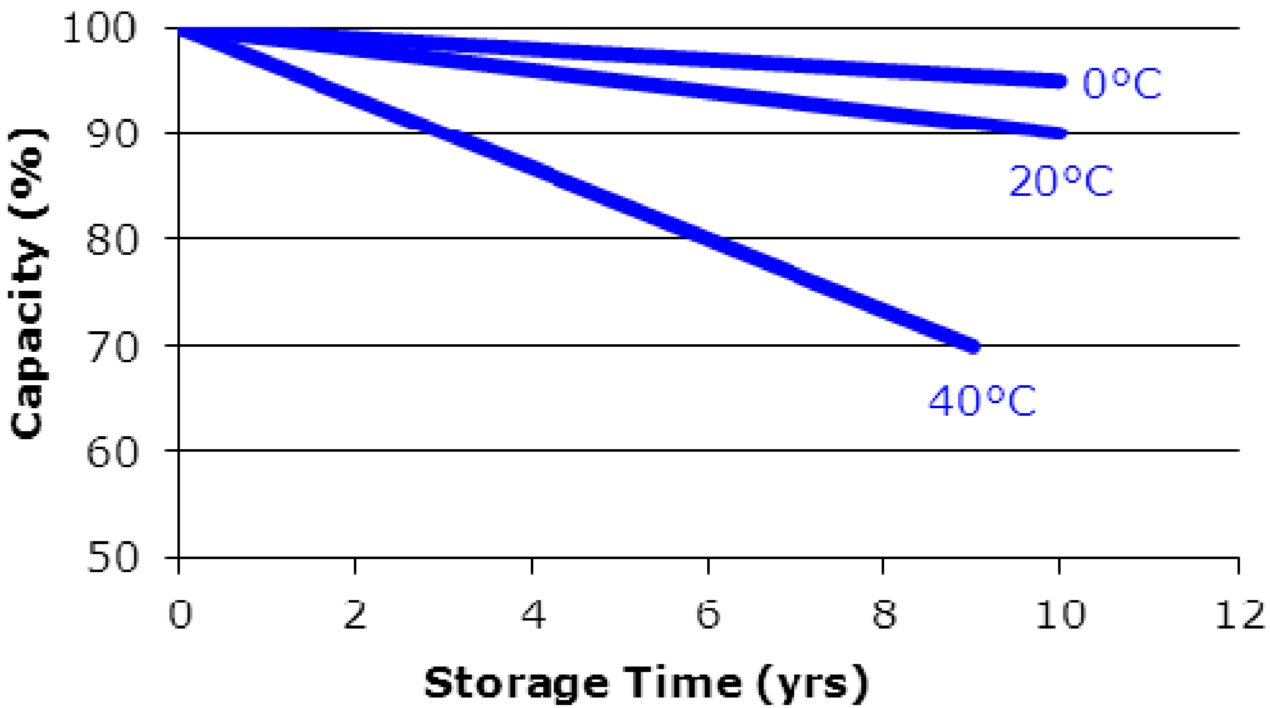


Continuous discharge; Lithium ion polymer = 120mAh; Boost = Microchip MCP1640 output to 3.3V

Lithium Manganese Dioxide (Coin)

Key Battery Considerations

Shelf Life

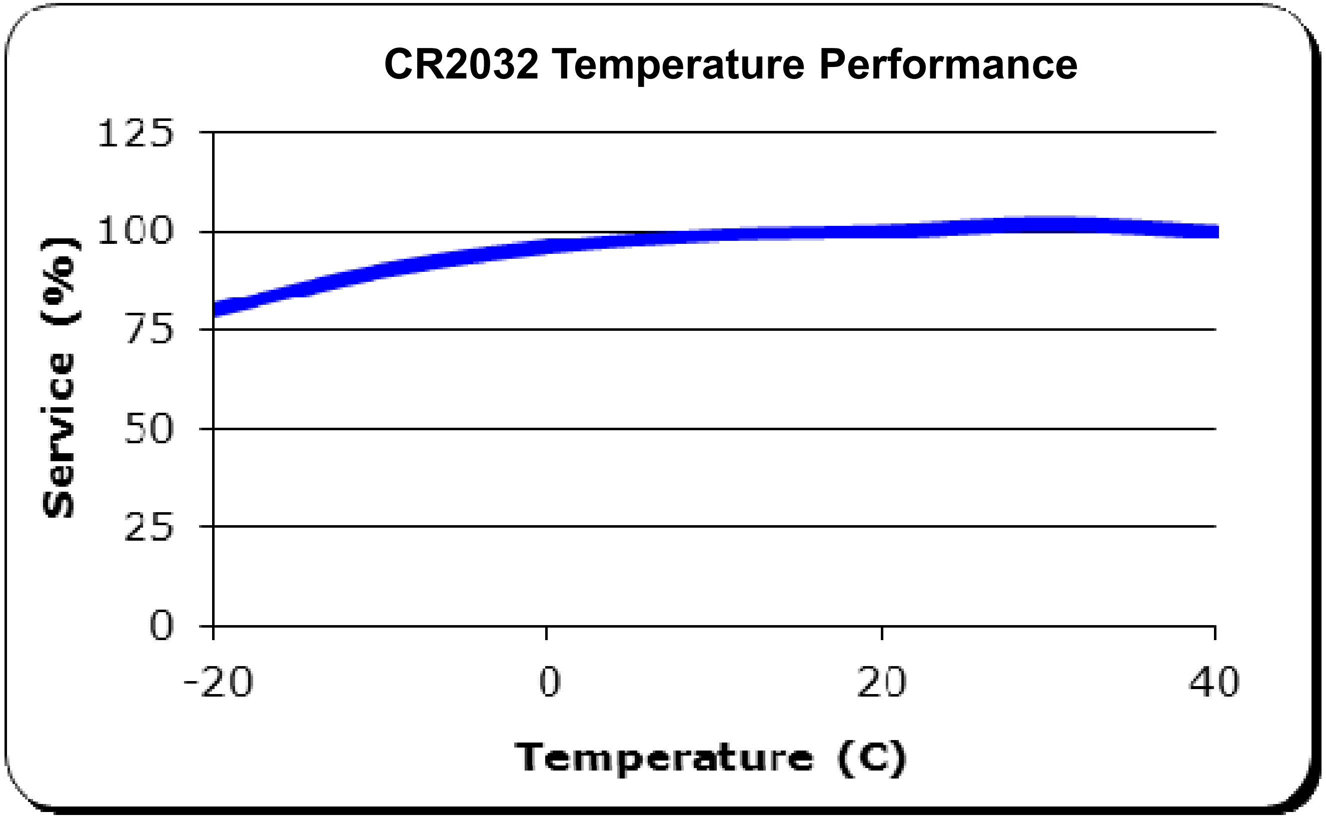


Shelf life is between 7 and 10 years at 20˚C, depending on cell size.

Lithium Manganese Dioxide (Coin)

Key Battery Considerations

Temperature Performance



Recommended Operating Temperatures

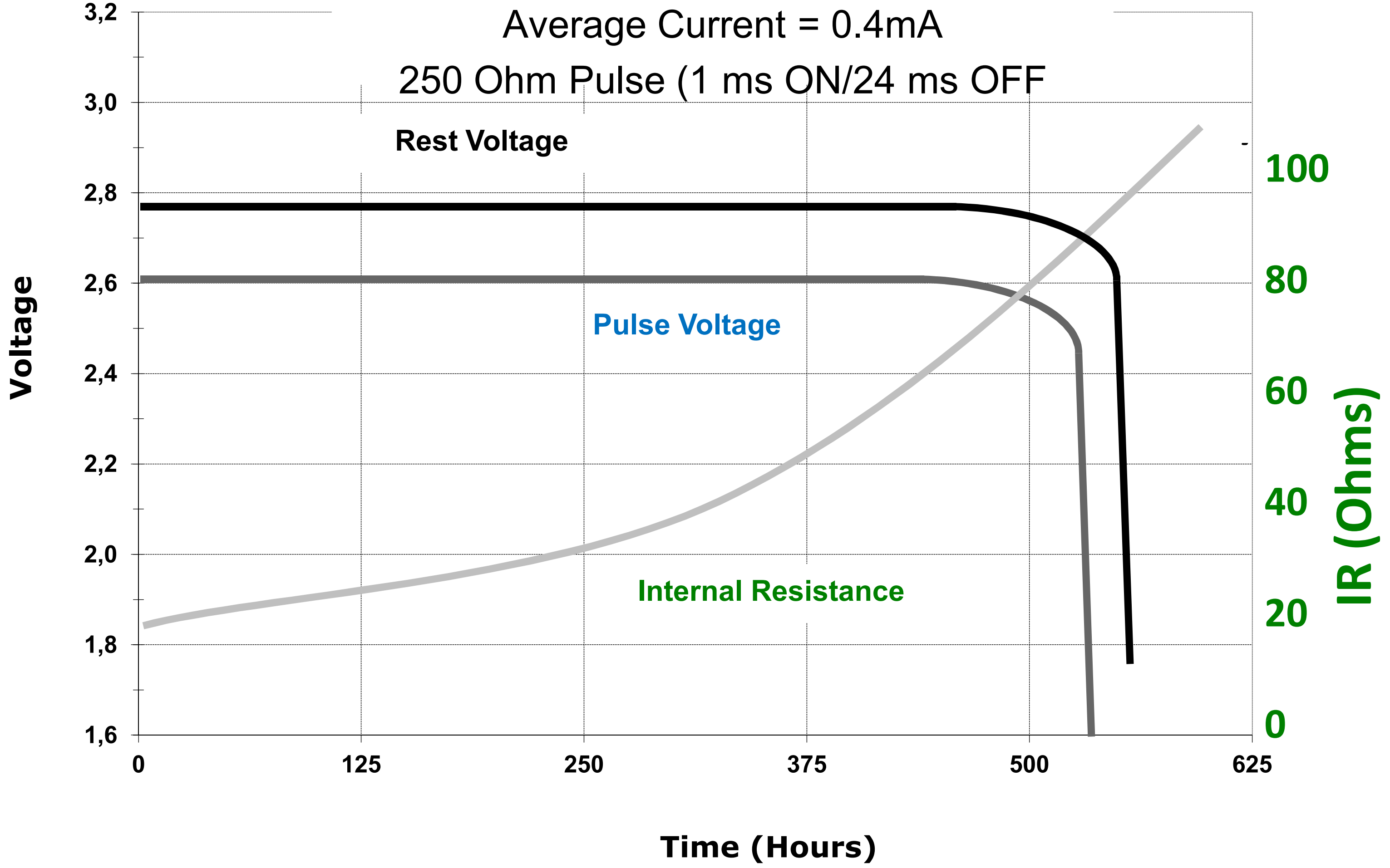
-40°C – 60°C (-40°F – 140°F)

CR2032 size batteries; continuous discharge to 1.8V

Lithium Manganese Dioxide (Coin)

Key Battery Considerations

Internal Resistance



Key Battery Considerations:

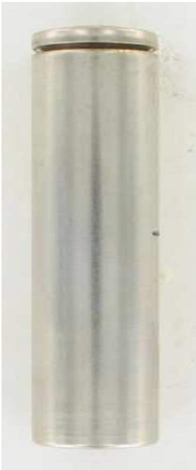
Lithium Ion

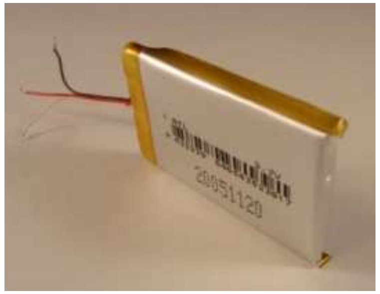
Lithium Ion

Key Battery Considerations

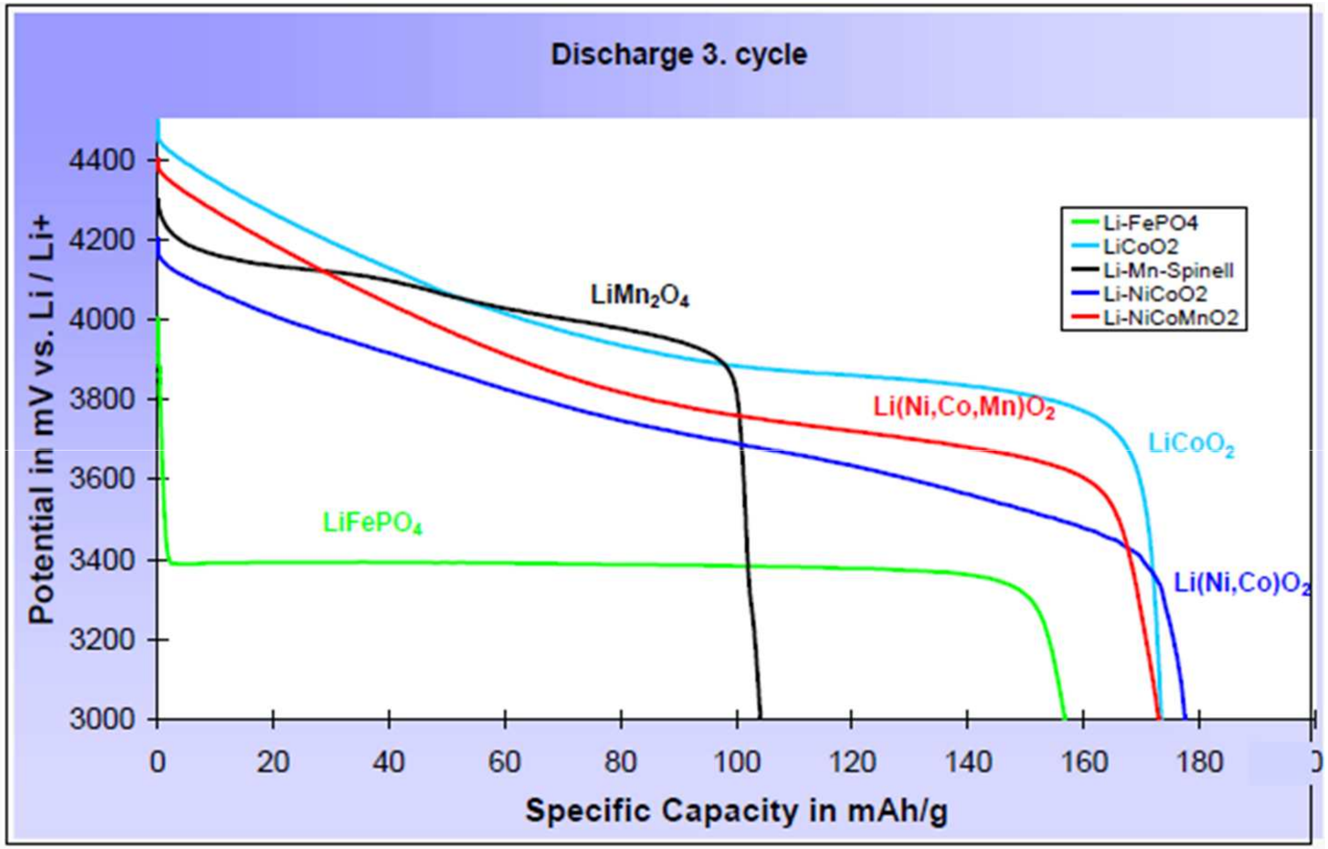
- **One name, but many systems**

Cylindrical | **Prismatic** | **Pouch**





Lithium Ion
Key Battery Considerations



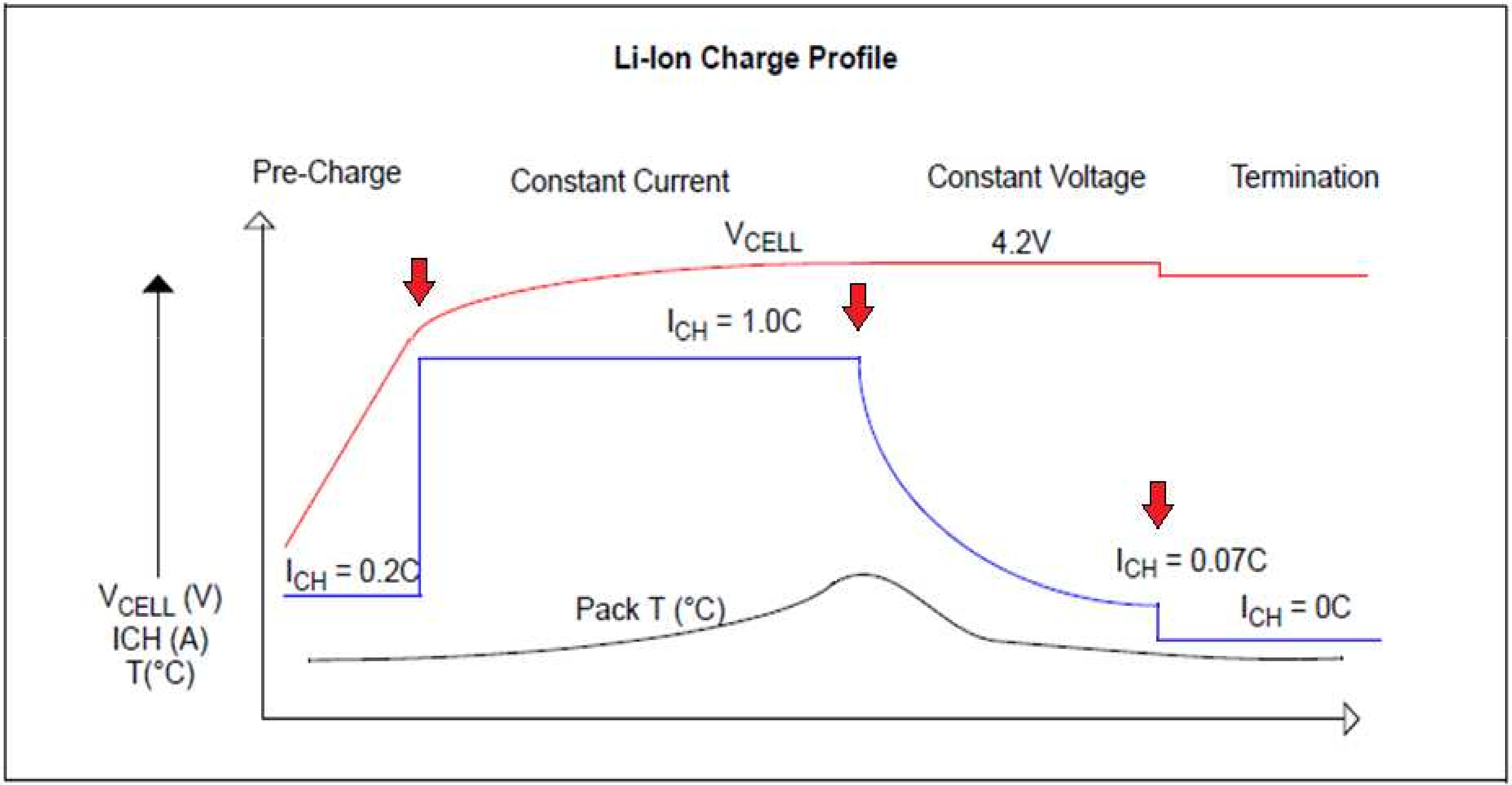
Different cathode chemistries have different voltage requirements and behavior

Most common is LCO and NMC, LFP increasing

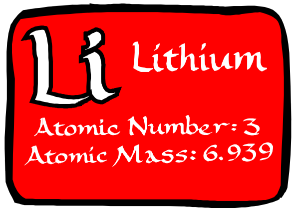
Charging Methods – Li-Ion

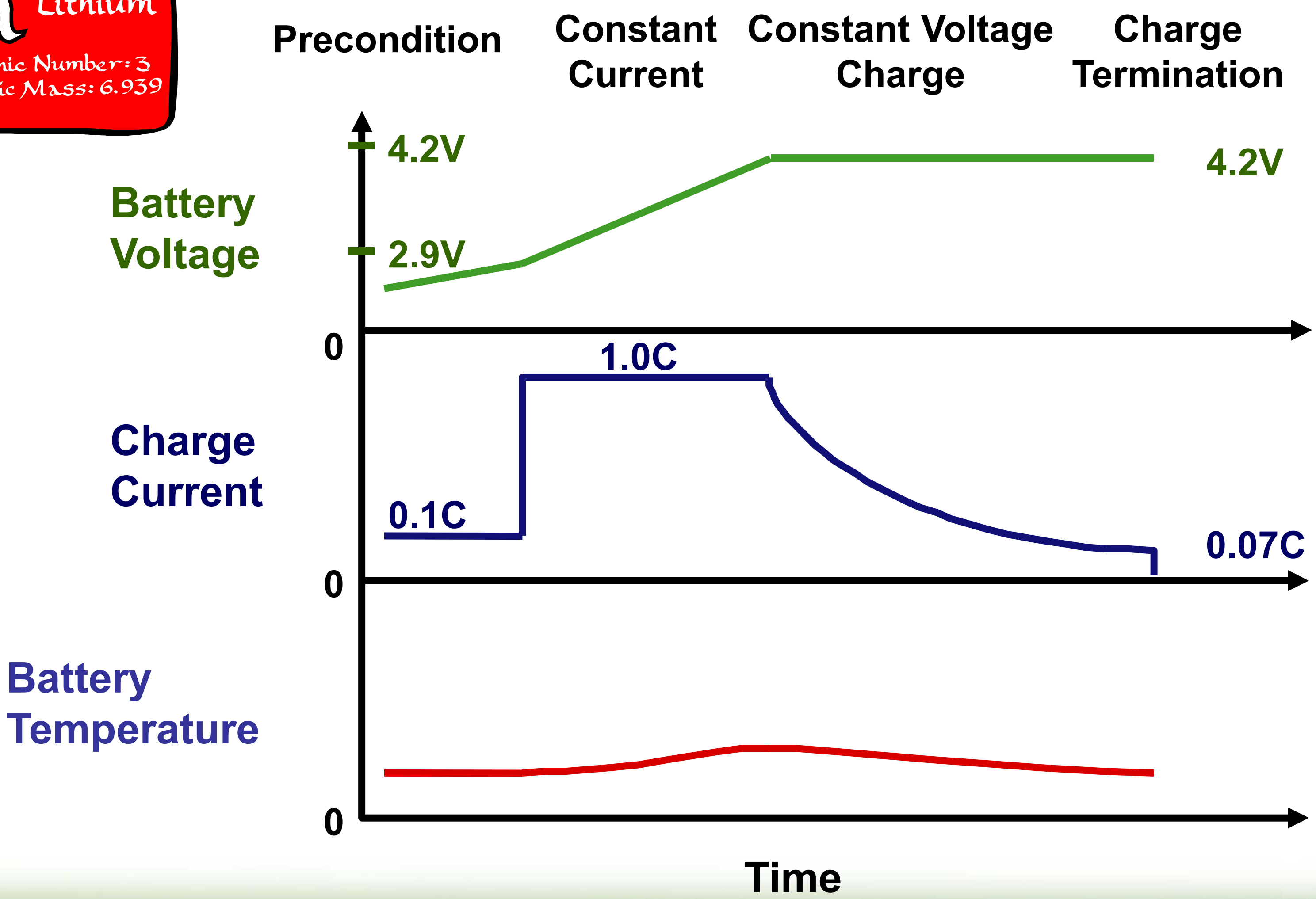
- **Li-Ion chargers use a two stage charging process**
- **The cell should be preconditioned to about 3.0V using a low rate charge before initiating charge**
  - A constant current charging stage (C/2 usually) which restores about 70% of the capacity
  - A constant voltage stage at 4.20V/cell
  - There is no maintenance charge because the Li-Ion battery is unable to absorb overcharge without damage

Charging Methods – Li-Ion

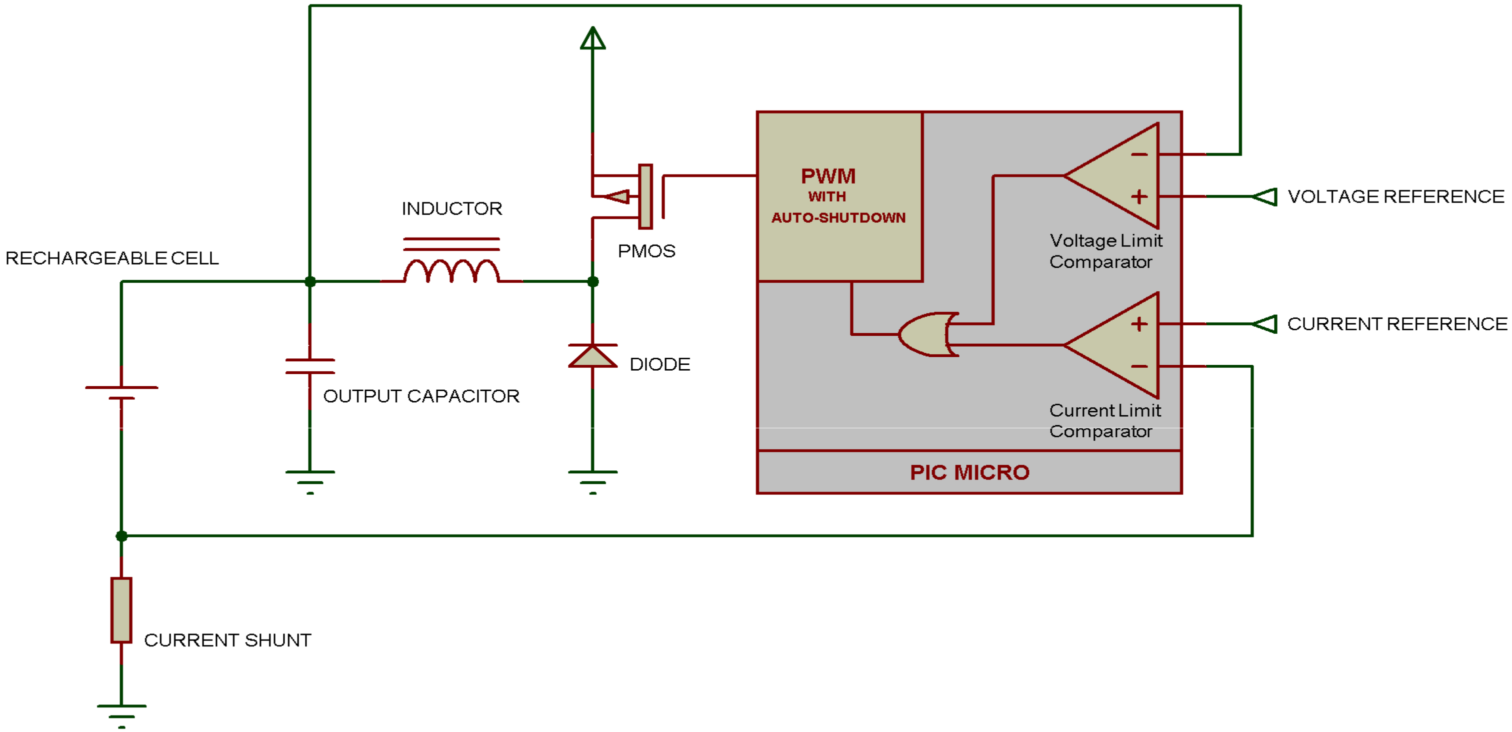


Li-Ion/Li-Poly Charge Algorithm



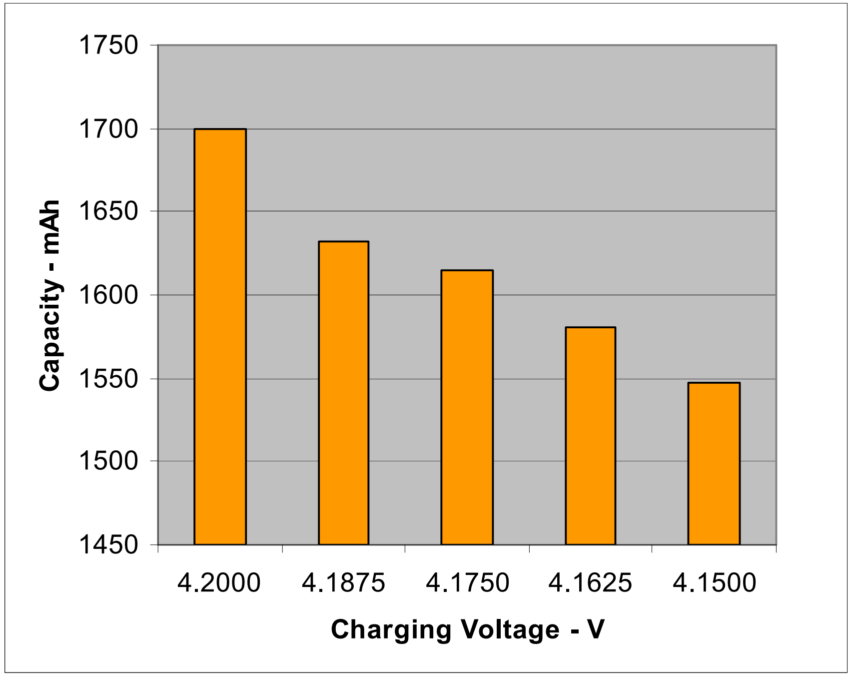


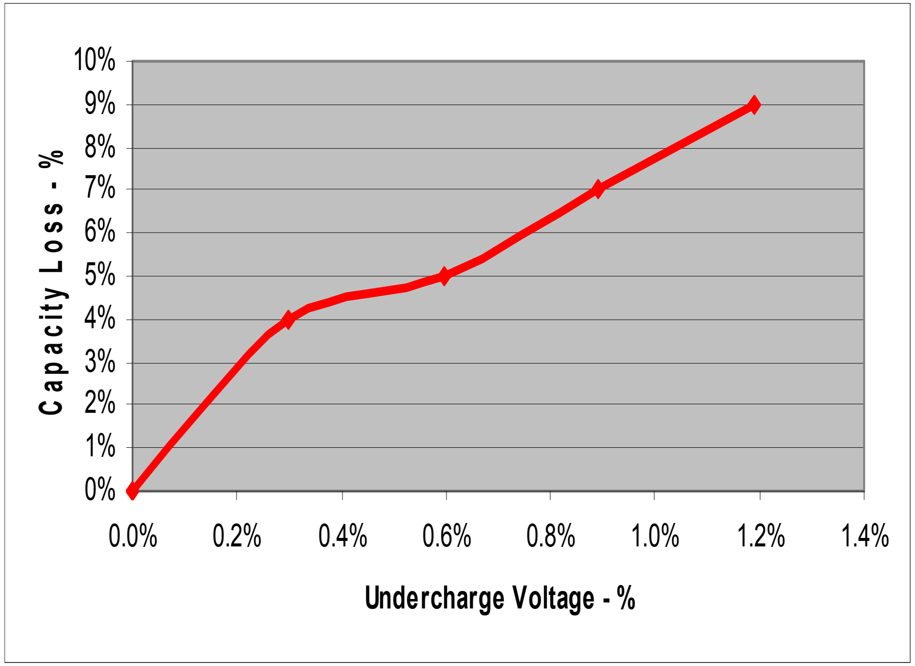
Constant Voltage with Current Limit Charger



- Constant voltage output with current limit
- Voltage and current limits set by references

Li-Ion Regulation Voltage





A small decrease in voltage accuracy results in a large decrease in capacity!

Battery Protection

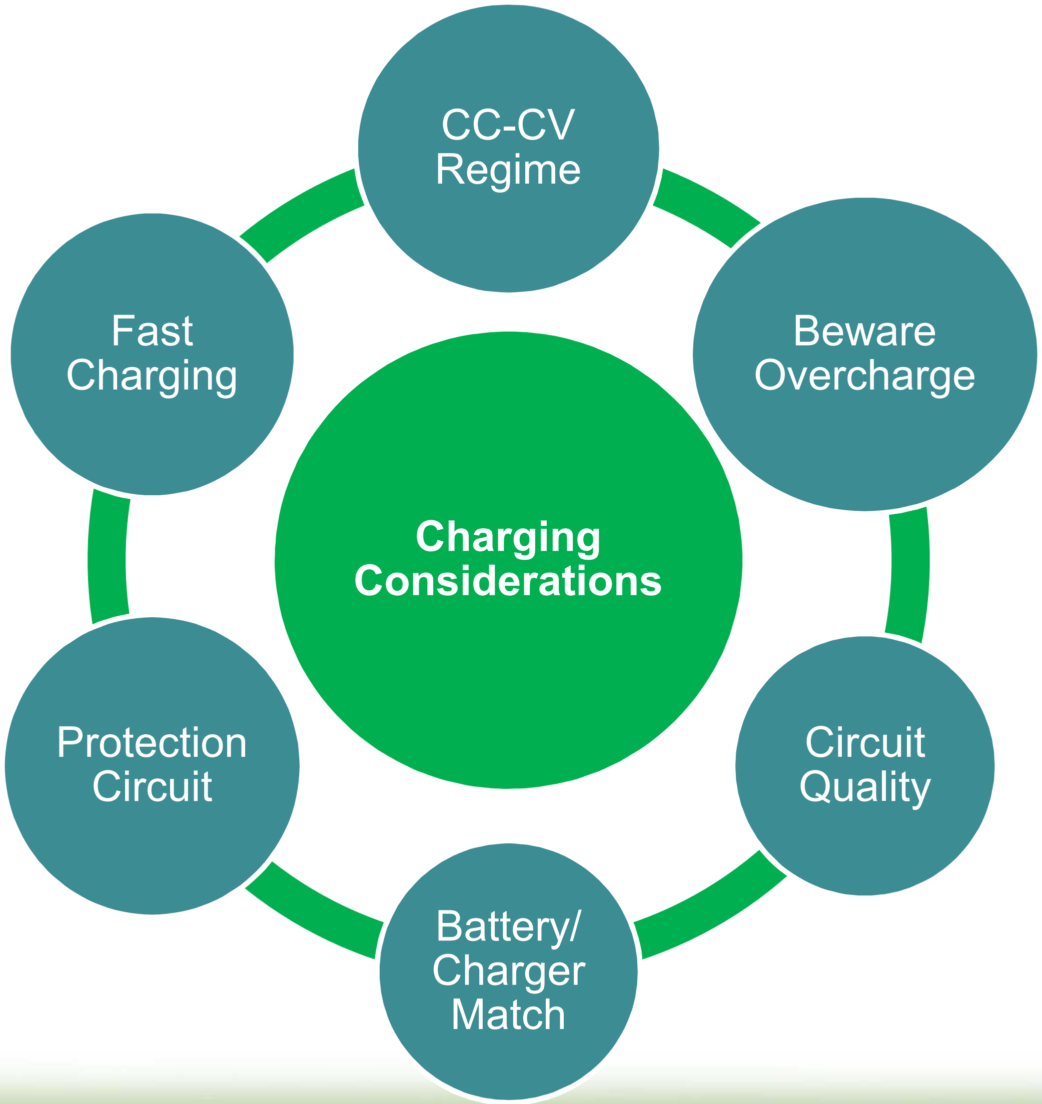
Why is Battery Protection Needed in Li-Ion Cells and Packs?

SAFETY: Overcharging Lithium Ion batteries can result in sudden, automatic and rapid disassembly.

Lithium Ion
Key Battery Considerations

- Many sizes and form factors
- Rechargeable with good shelf life for rechargeable and good cycle life
- Higher energy density (run time) than other rechargeable batteries
- Low temperature good, but not in same class as lithium primary
- Safety and Transportation Issues
- Not all cells are made equal – choose wisely!

Lithium Ion
Key Battery Considerations



Battery Comparison

	Первичная литиевая VARTA 3/CR 2/3AH	Li-Ion аккумулятор, VARTA LIC18650-15PCJ	Ni-MH аккумулятор, VARTA 4/V500HT
Емкость, мАч	1500	1400	500
Напряжение, В	9.0	3.7	4.8
Остаток заряда после хранения 1000 часов при +85˚C	Саморазряд >5%	Саморазряд >70%	Саморазряд >90%
Восстанавливаемая емкость после хранения 1000 часов при +85˚C	0%	80%	98%
Мониторинг состояния батареи (status of health)	Очень сложно. Зависит от температуры и требуется очень точный АЦП	Возможно, но требуется полный заряд/разряд аккумулятора	Очень простой. Измеряется напряжение XX и напряжение на известной нагрузке. EOL когда Ri в 5 раз больше исходного
Доступная емкость	Непредсказуемая. Зависит от саморазряда (от температуры)	Требуется регулярная проверка с полным разрядом аккумулятора	Всегда более 95%
Зарядка	Не требуется	CC/CV стандартная Li-Ion схема заряда	Зарядка “trickle charge” + зарядка постоянным током, реализуется с помощью любого МК

Battery Comparison

	Li-Ion аккумулятор	Ni-MH аккумулятор
Срок службы	5 лет	10 лет
Работа при высоких температурах	Необратимая потеря восполняемой емкости	Возможно хранение >2000 часов при +85˚C
Емкость	1400 мАч	500 мАч
Конструктив	Сложный дизайн с электроникой	Простой дизайн, объединение ячеек
Защита	Электрическая схема защиты требуется	Развитые технологии с присущим процессом электрохимической рекомбинации
Режимы заряда	Должен быть адаптирован к стандартным алгоритмам	Простая зарядка, алгоритм заряда для оптимизации срока службы
Типичные приложения	Более ориентирован на циклическое использование, чем на резервное питание	Расширенные возможности защиты от перезаряда, идеален для резервного питания
Верхний диапазон рабочих температур	Спецификация до +60˚C, фактически до +80˚C со сниженными характеристиками и необратимой потерей восполняемой емкости	Стабильная работа до +85˚C
Нижний диапазон рабочих температур	До -20˚C	До -40˚C с применением нагревательного элемента
Напряжение	3.7 В	Может быть скомбинировано кратно 1.2 В (3.6 В, 4.8 В, …)
Саморазряд	10% в год + ток утечки PCM схемы защиты	15% в течение 2-х месяцев (+25˚C), 40% в год (+25˚C)

Battery Chemistry Charging Summary

Preconditioning	$LiFePO_4$	NiCd	NiMH	Li-Ion
Precondition Current	0.1C	0.1 C	0.1 C	0.1 C
Cell Voltage Threshold (V)	2.00	0.90	0.90	2.90
Ambient Temp Range (°C)	0 to 60	0 to 45	0 to 45	0 to 45
Safety Termination	Timer	Timer	Timer	Timer
Fast Charge				
Fast Charge Current	1C – 30C	$\geq$ 1 C	$\geq$ 1 C	1 C
Cell Voltage (V)	3.60	1.50	1.50	4.20
Time (hrs.)	0.5 - 1	2.0	1.5	2.0
Ambient Temp Range (°C)	0 to 60	5 to 40	10 to 40	10 to 40
Primary Termination Methods	IMIN	- ΔV ΔT/Δ t	- ΔV or 0 ΔV ΔT/Δt	IMIN
Secondary Termination Methods	TCO Timer	TCO Timer	TCO Timer	TCO Timer

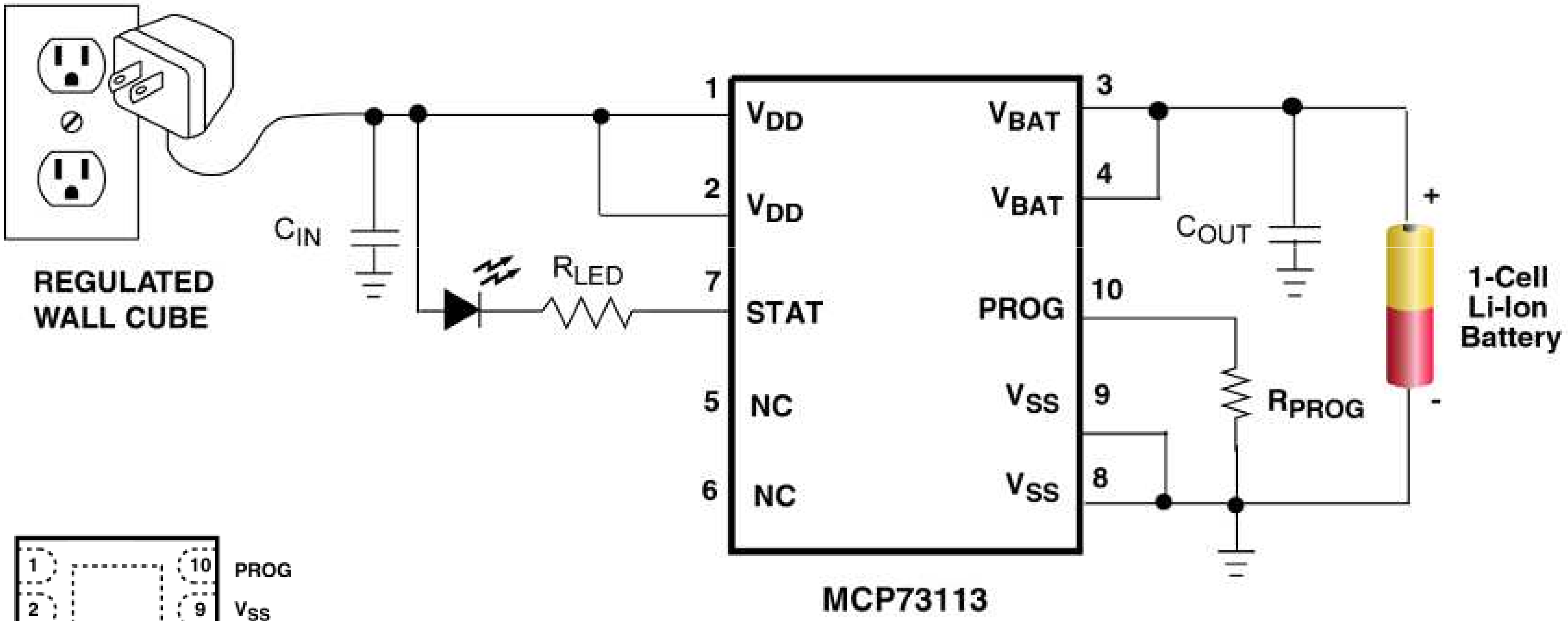
Battery Charging

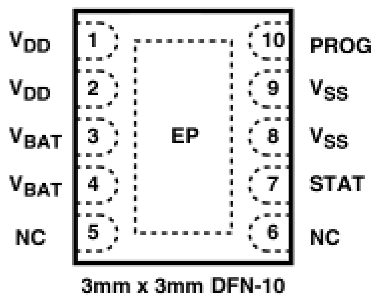
- **Second Question to Ask Yourself:**
  - What Solution Suits This Application Best?
    - **Stand-alone Solution (Int. FET or Ext. FET)**
    - **MCU Controlled Solution**
    - **Integrated Load Sharing System (Power Path Management)**

Simple Design Concept

18V Absolute Maximum

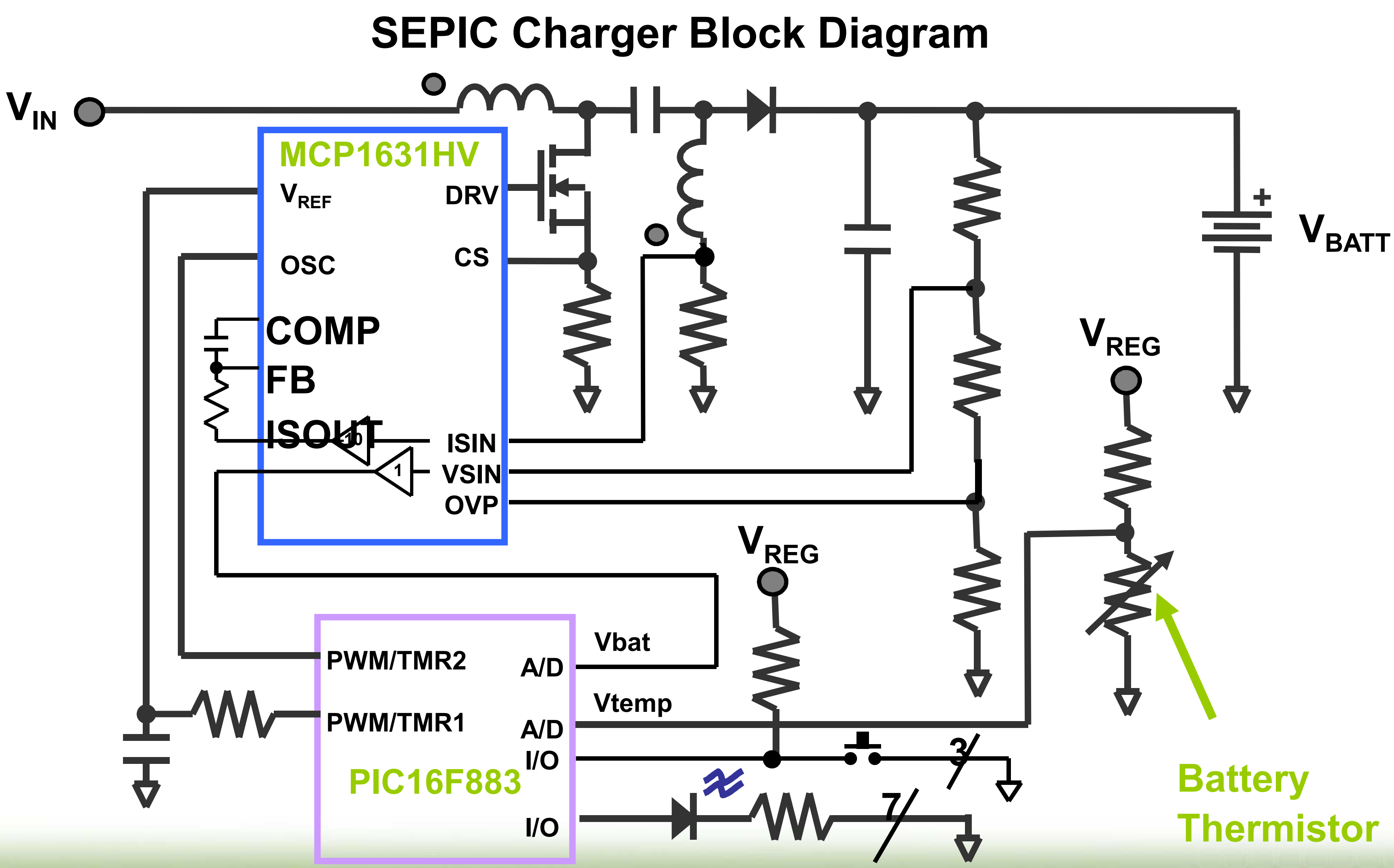
Minimum 3 External Components



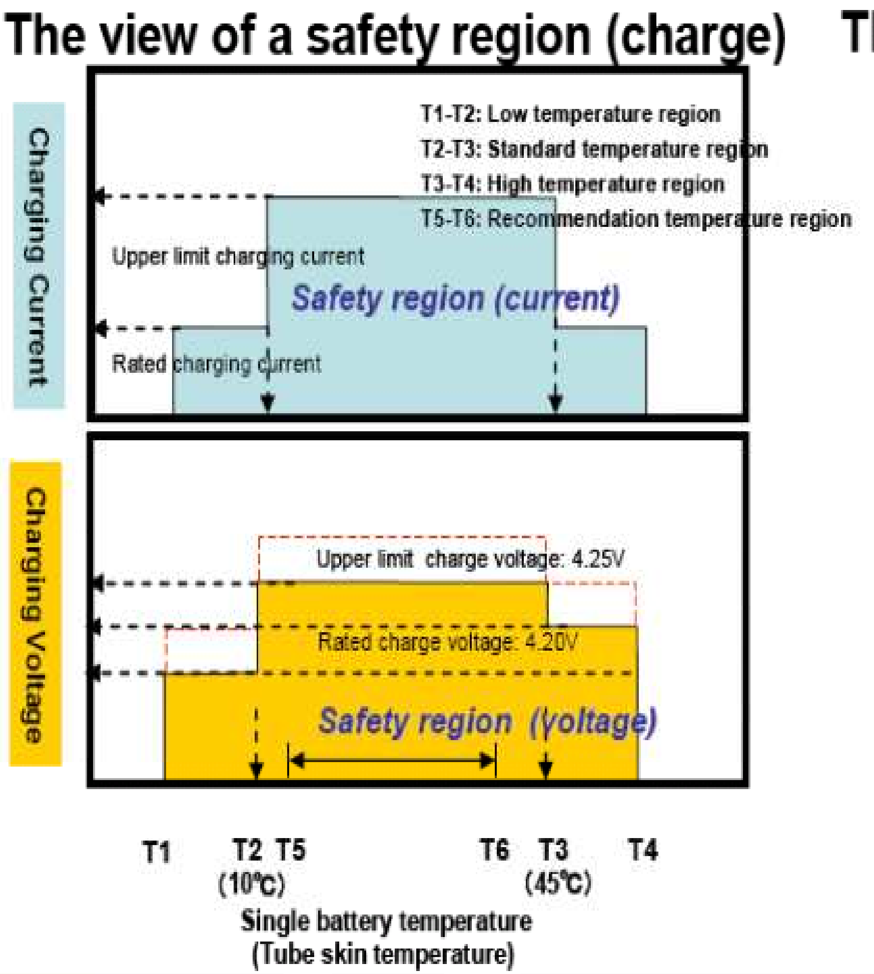


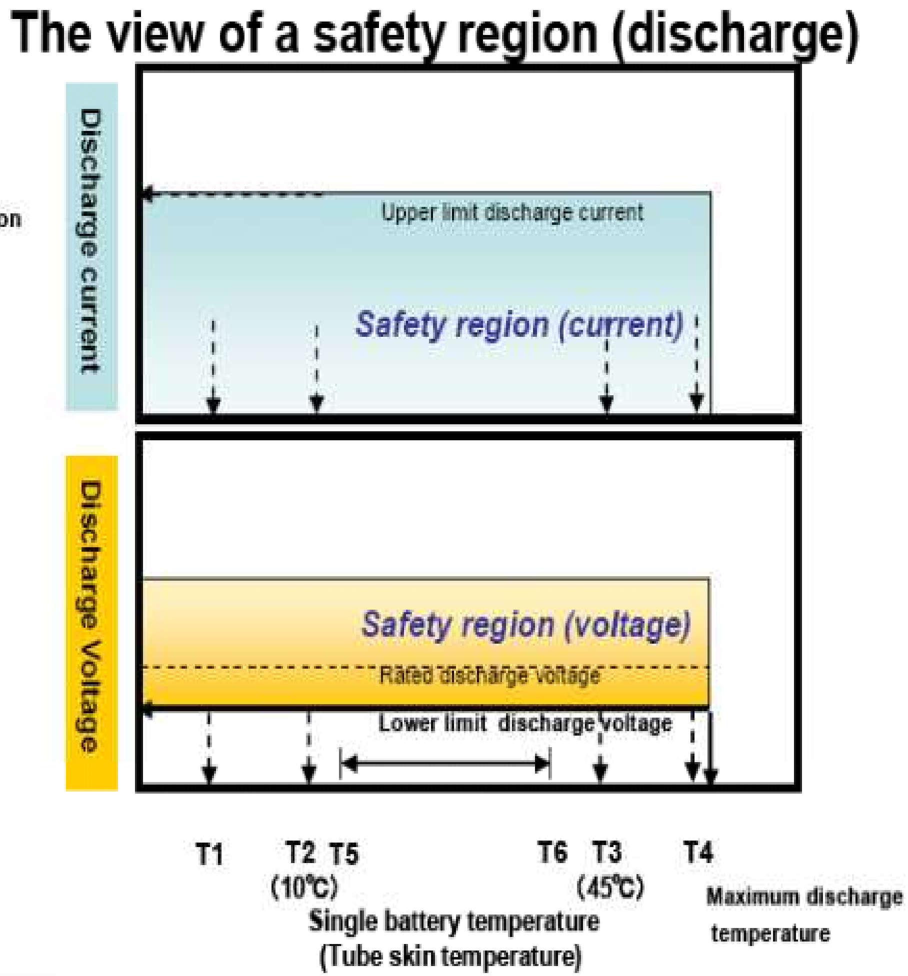
Package Information

Embedded Design – Multiple Chemistry



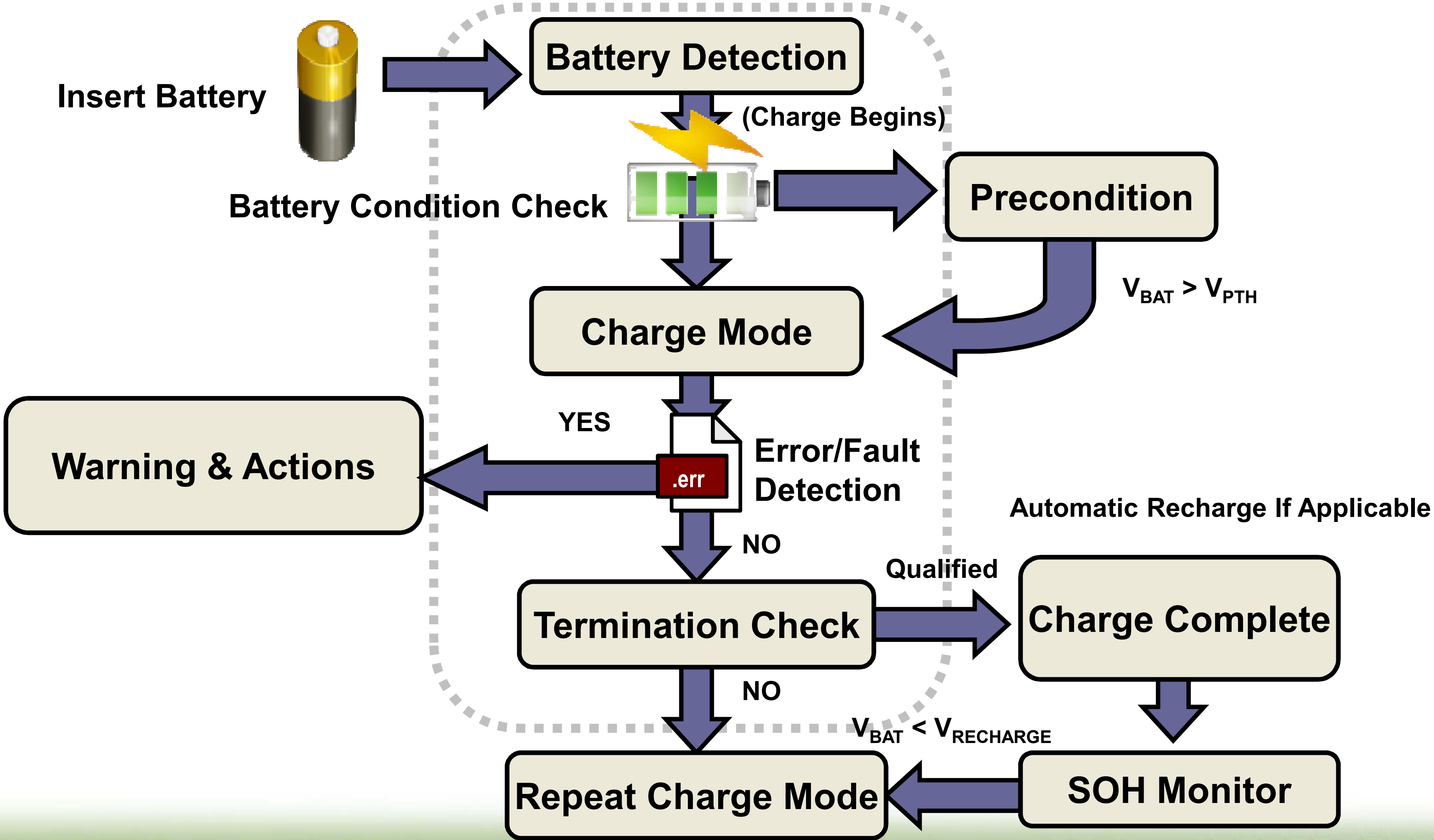
Range of Safe Use For Rechargeable Li-Ion Batteries





Source: JEITA

Example of Charger Flow Chart



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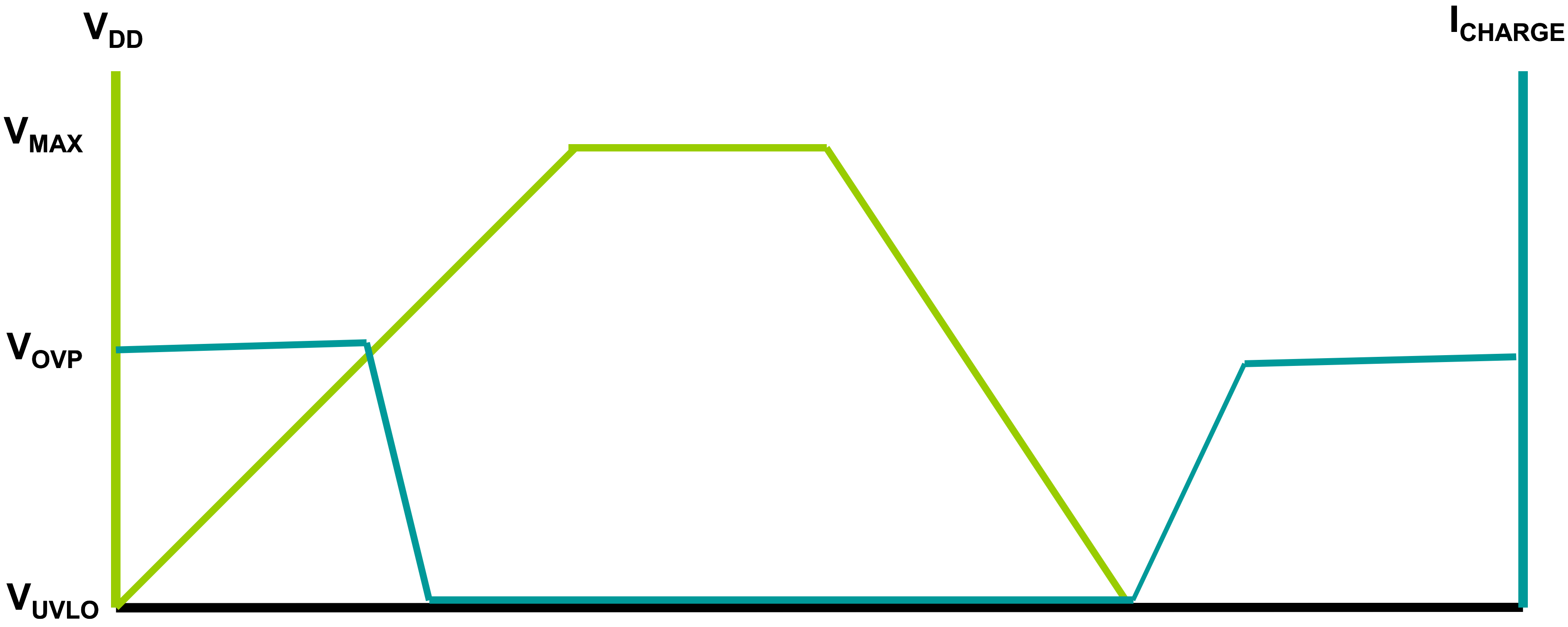
Input Over Voltage Protection



Input Overvoltage Protection Begins

Charge Resumes

Battery Authentication

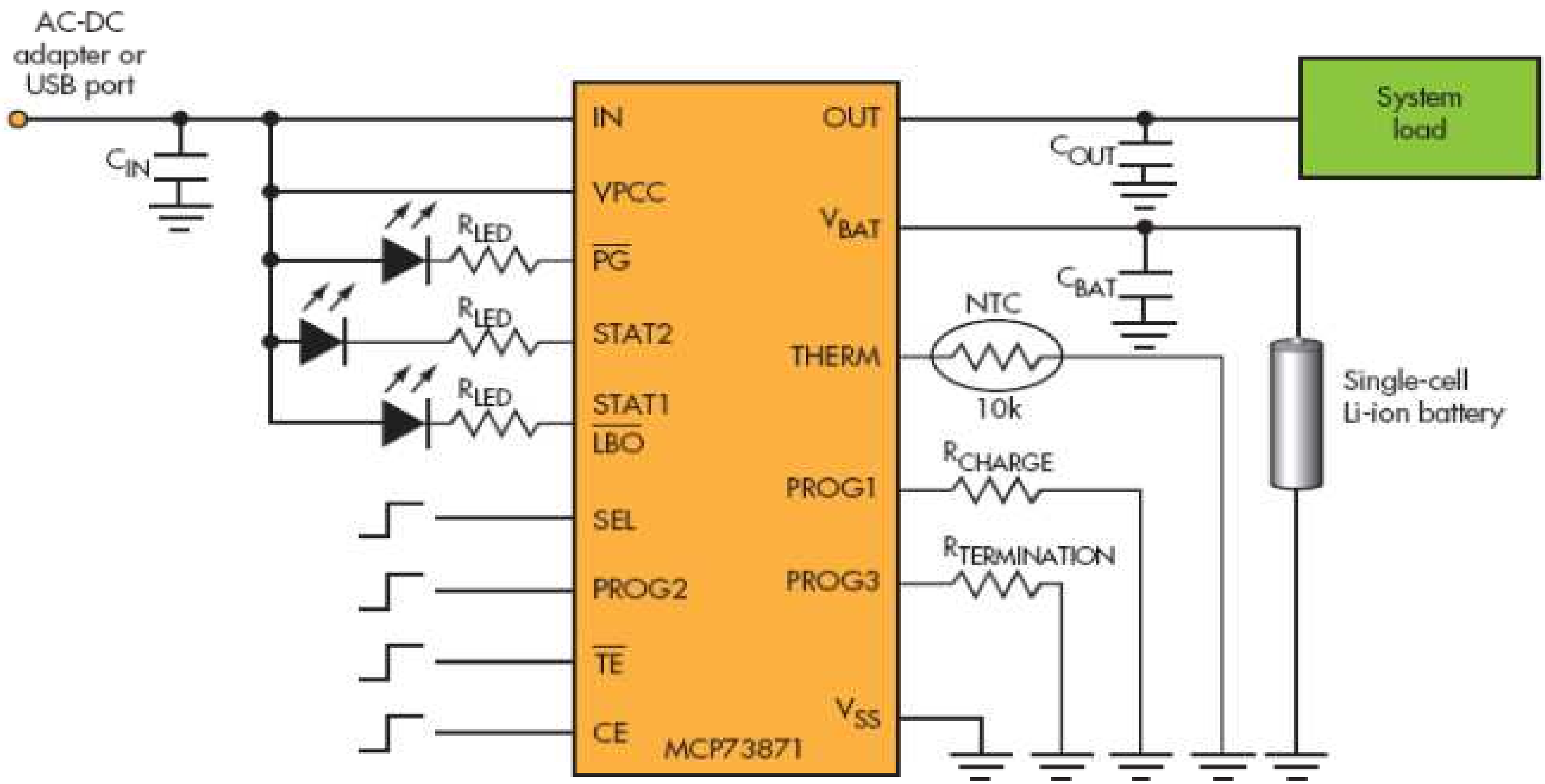
- **Prevents overstressing a counterfeit or incompatible battery**
  - Primarily a safety concern
  - Needed before charging and discharging

- **Low Security Examples**
  - Mechanical Key
  - Thermistor
  - Battery Serial Number Validation

- **High Security Examples**
  - KEELOQ® Encryption
  - XTEA Encryption

System Power Path Management Applications

Add transistors inside



Microchip
Battery Management Products

Charge ICs:

http://www.microchip.com/ParamChartSearch/chart.aspx?branchID=9011&mid=10&lang=en

1*Li-Ion Cell: MCP73811, MCP73812, MCP73831, MCP73832, MCP73830L, MCP73833, MCP73834, MCP73826, MCP73830, MCP73827, MCP73828, MCP73838, MCP73837, MCP73114, MCP73123 , MCP73113 , MCP73843 , MCP73841 , MCP73855 , MCP73853 , MCP73871

2*Li-Ion Cells: MCP73842, MCP73223, MCP73213

Microchip's Charger Portfolio

- **Integrated chargers for Li-Ion/Li-Polymer/Lithium Iron Phosphate batteries**
  - Fastest growing chemistry (high energy density per size)
  - Formable into custom shapes
  - Most consumer electronics use these chemistries
- **NiCd and NiMH chemistries supported through PIC+MCP1630/1 solutions**

Important Features

- Charging Current
- Charging Voltage
- Charging Voltage Accuracy
- Internal/External FET
- Dual-input
- Load-sharing
- Overvoltage Protection
- Shutdown Controls

Battery Charger Features

- **Internal/External FET**
  - Integrated Pass Transistors allows smaller solution size. External Pass Transistors allow more flexibility in charger design
- **Dual-input**
  - MCP73837/8 or MCP73871 allow two types of power sources, such as USB and AC/DC
  - Allows two different charging profiles depending on the power source

Battery Charger Features

- **Integrated System Load Sharing and Battery Charge Management**
  - Simultaneously power the system and charge the Li-Ion battery
  - Ensures system load has priority over Li-Ion battery charge current
  - MCP73871 or MCP7383X ref. design
- **Overvoltage Protection**
  - In case of a voltage spike on the input, the charger shuts down to prevent damage to self or the device

Battery Charger Features

- **Shutdown Controls**
  - Thermistor Input - Allows to monitor the temperature of battery cells and shutdown charging in case of overheating
  - Timers – allow to shutdown charging after a predetermined amount of time
  - Automatic-shutdown – stops charging once the battery voltage reaches predetermined set point
  - UVLO (Under Voltage Lockout) – prevents charger from operating if input voltage is too low

Battery Charger Portfolio – Single-cell

	MCP73830L	MCP73831/2	MCP73830	MCP73833/4	MCP73837/8	MCP73113/4	MCP73871
VDD Range (V)	3.75-6	3.75-6	3.75-6	3.75-6	3.75-6	4-16	3.75-6
Vreg (V)	4.2	4.20, 4.35, 4.40, 4.50	4.2	4.20, 4.35, 4.40, 4.50	4.20, 4.35, 4.40, 4.50	4.10, 4.20, 4.35, 4.40	4.10, 4.20, 4.35, 4.40
Icharge	20 - 200	15-500	100 - 1000	50-1000	15-1000	130-1100	50-1000
Soft start	Yes	-	Yes	-	-	Yes	Yes
Charge Enable Pin	Yes	-	Yes	-	-	-	Yes
Load sharing	external	external	external	external	external	external	Yes
Dual Input	-	-	-	-	Yes	-	Yes
Temp Mon.	-	-	-	Yes	Yes	-	Yes
OVP	-	-	-	-	-	6.5V/5.8V	-
Package	2x2 TDFN-6	SOT23-5 2x3 DFN-8	2x2 TDFN-6	3x3 DFN-10 MSOP-10	3x3 DFN-10 MSOP-10	3x3 DFN-10	4x4 QFN-20

*** See MCP7383X Li-Ion System Power Path Management Reference Design**

**** LiFePO4 battery chemistry**

Battery Charger Portfolio – Dual-cell

	Vcc Range (V)	Vreg (V)	FET	Icharge	Temp Monitor	OVP
MCP73842/4	4.5-12	8.2, 8.4	External	-	Yes	-
MCP73213	4-16	8.2, 8.4, 8.7, 8.8	Internal	1.1A	-	13V
MCP73223*	4-16	7.2	Internal	1.1A	-	13V

*** LiFePO4 battery chemistry**

Other Solutions

- **MCP7383X Li-Ion System Power Path Management Reference Design**
  - Use MCP7383x parts for Load Sharing
- **PIC + MCP1630/1**
  - Multi-cell Li-Ion charger (1-4 cell)
  - Single-cell Li-Ion SEPIC charger for up to 2A
  - Three-cell NiMH charger
  - Four-cell bi-direction Li-Ion charger
  - 1- to 4-cell multi-chemistry charger

Design Trends Summary

SAFETY

FLEXIBILITY

INTEGRATION

COST

Battery Selection
Case Study

Problem Statement

- Chip supplier needed help with low power wireless devices
- Customer complaints about devices "dying" too soon
- Customer focused efforts on reducing average current drain from design
  - Was it enough?

Lithium Coin History

- **Late 1960's – Early 1970's**
  - Initial interest in Lithium chemical systems ($LiFeS_2$ and $LiMnO_2$)
  - Energizer (then Union Carbide) introduced Lithium FeS_2 button cells in the mid-1970's in response to rapidly increasing silver prices used in Zn/Ag_2O batteries
- **Late 1970's**
  - Electronics watches demanded a new thinner profile power source to illuminate the display or backlight
  - Energizer (then Union Carbide) introduced Lithium MnO_2 Coin batteries
  - Testing ranges of 30k-500k Ohm background loads (6-100uA)
  - Pulse ranges of 400-1000 Ohm loads (3-7.5mA)
  - Standard Test: 30kOhm (100uA) background with a 2Sec 400 Ohm (7.5mA) pulse once per day

Initial Lithium Coin applications were lower drain with longer pulse widths. Current datasheets often report these values

CR2032 Continuous Discharge

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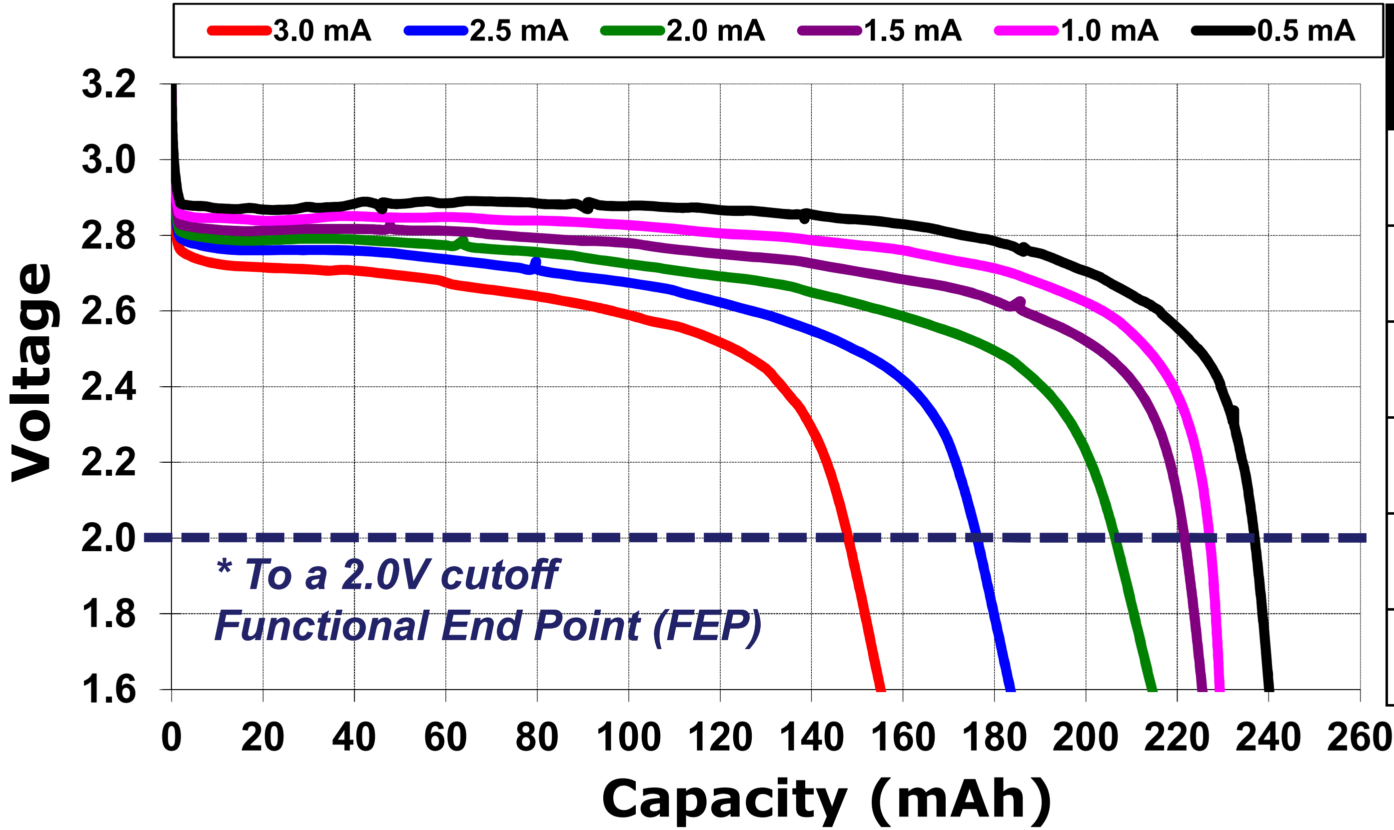
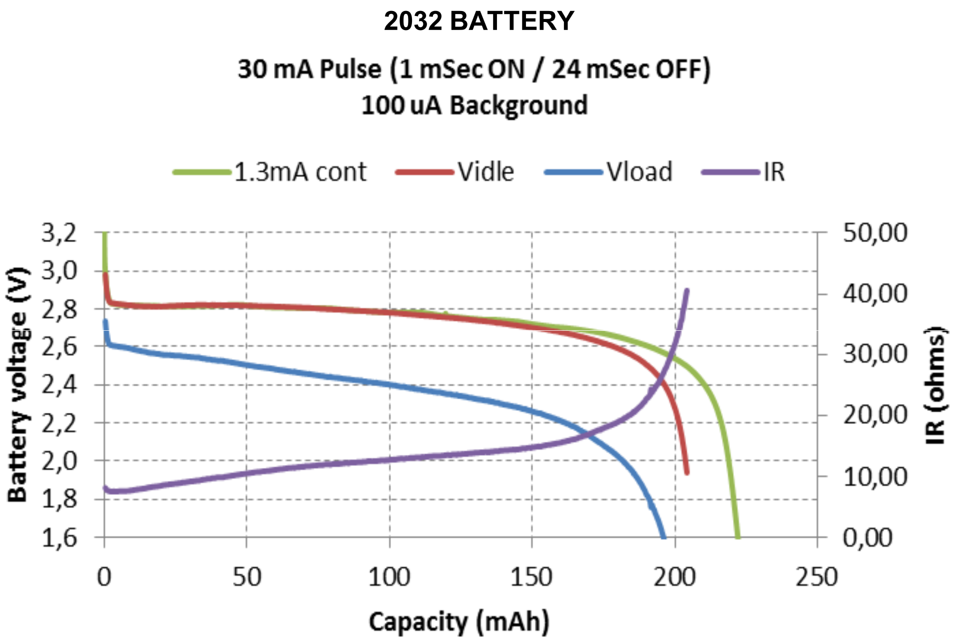


Drain Rate	Capacity (mAh)*	% of Rated Capacity
0.5 mA	234	98%
1.0 mA	226	94%
1.5 mA	222	93%
2.0 mA	206	86%
2.5 mA	176	73%
3.0 mA	148	62%

Constant current discharge is more efficient at lower drains

Increasing drain rate decreases available capacity

Pulse vs. No Pulse Comparison



Pulse

- **30mA (1mSec ON / 24 mSec OFF)**
- **Average current of 1.3mA**
- ***Shown as red and blue lines***

No Pulse

- **Constant current of 1.3mA, no pulse**
- ***Shown as green line***

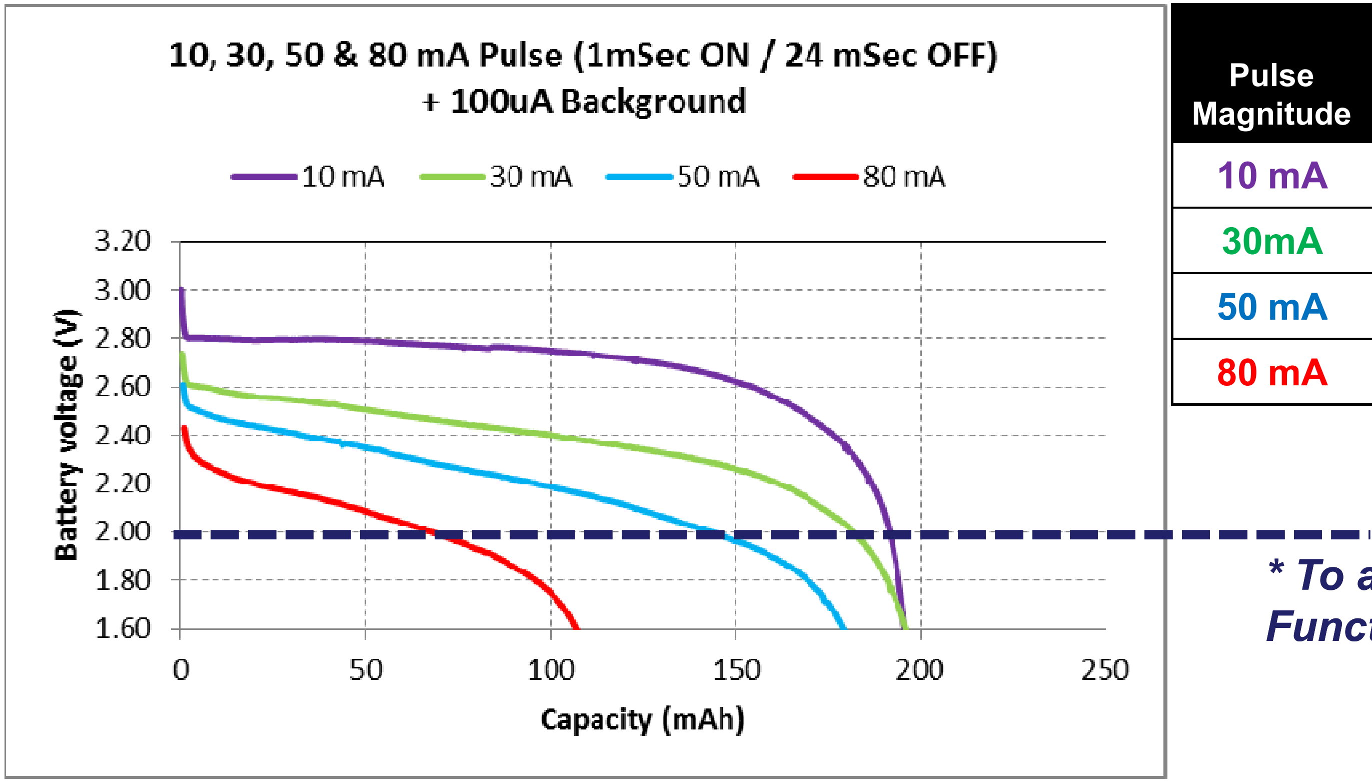
Key Difference:

- **Capacity reduction**
- **V_{load} line determines FEP**

Between pulses V_{idle} approaches continuous drain line
Functional end point (FEP) is dictated by the V_{load} line

Pulse Magnitude Test

CR2032 Pulse Voltage (V_{load}) and Capacity Delivered



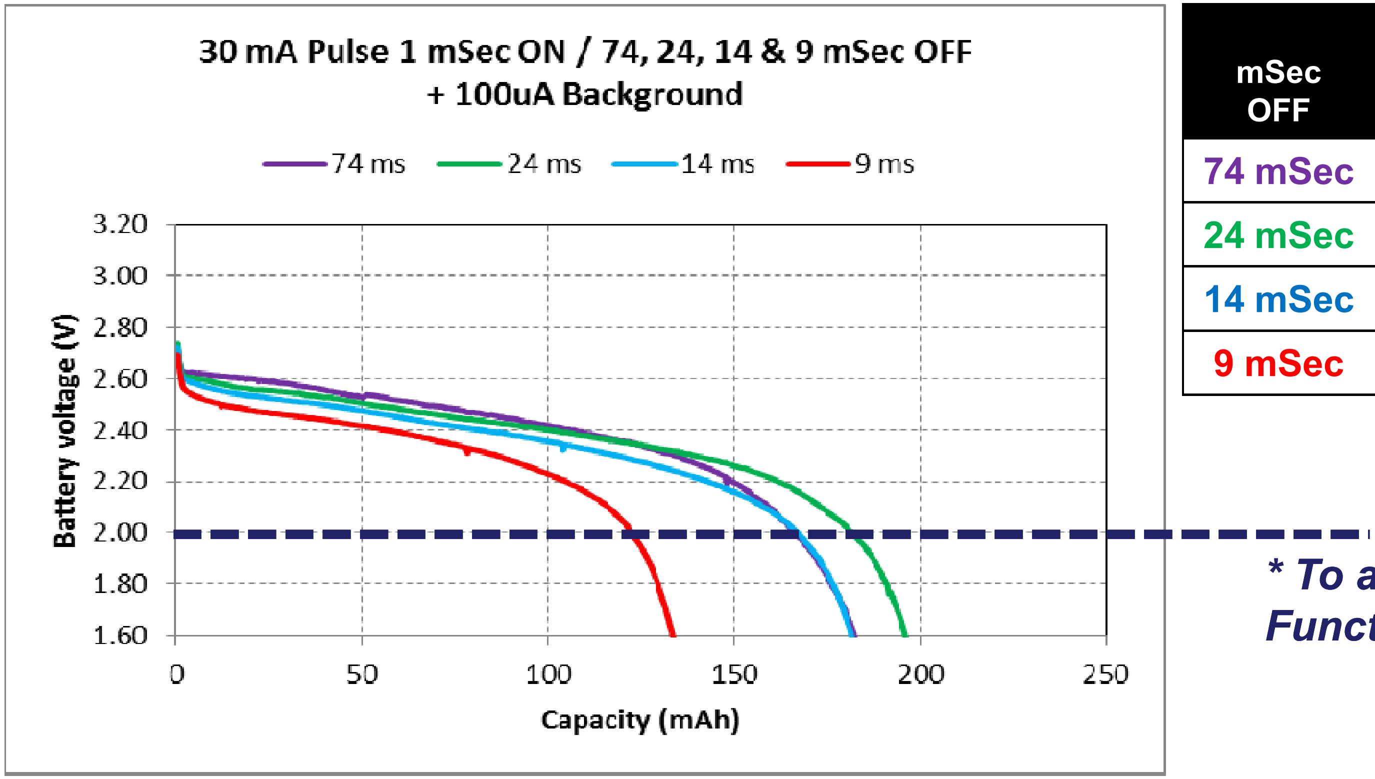
Pulse Magnitude	I avg (mA)	Capacity (mAh)*	% of Rated Capacity
10 mA	0.5	191	80%
30mA	1.3	181	76%
50 mA	2.1	143	60%
80 mA	3.3	70	29%

** To a 2.0V cutoff*
Functional End Point (FEP)

Higher magnitude pulses decrease available capacity primarily by depressing operating voltage due to *electronic resistance*

Pulse Duty Cycle Test

CR2032 Pulse Voltage (V_{load}) and Capacity Delivered



mSec OFF	I avg (mA)	Capacity (mAh)*	% of Rated Capacity
74 mSec	0.5	166	69%
24 mSec	1.3	181	76%
14 mSec	2.1	167	70%
9 mSec	3.3	123	51%

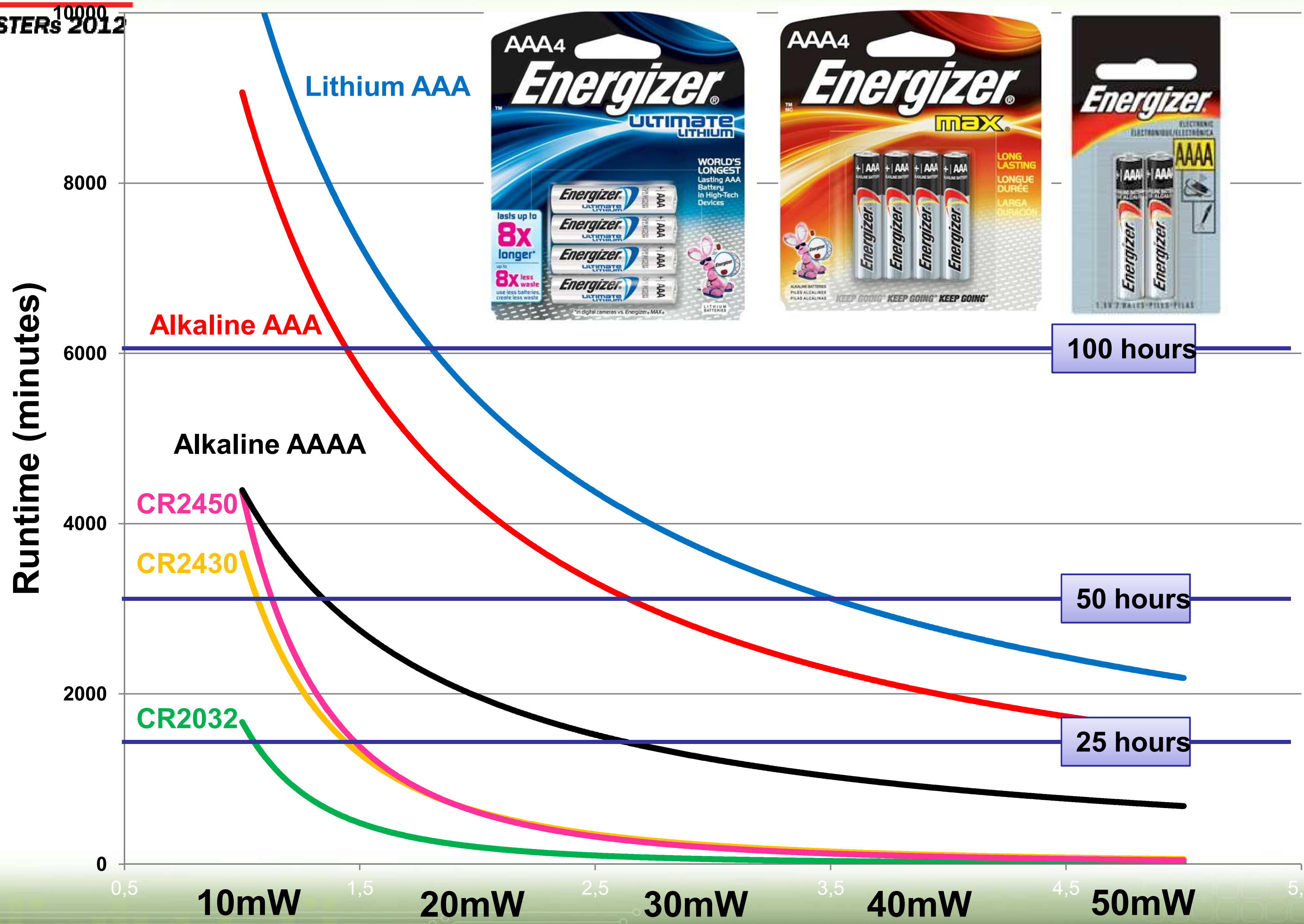
** To a 2.0V cutoff*
Functional End Point (FEP)

Higher duty cycle pulses decrease available capacity primarily by increasing average drain, but operating voltages are much tighter

Conclusions for Low Power Wireless Applications

- **Minimize pulse magnitude to minimize voltage drop due to *electronic resistance***
- **Minimize pulse duty cycle to keep average current as low as possible and thus minimize affect of *ionic resistance* voltage drop**
- **Know the worst case scenario. It will be the limiting factor for applications with dynamic duty cycles.**
- **Design for a low Functional End Point (FEP)**
- **Design with a "system" view in mind. The RF portion may not be the highest load.**
  - Stagger loads if possible to minimize pulse magnitude
  - Mind the FEP of all parts of the system

Other Potential Solutions for Low Power Wireless



Summary

Today we covered:

- ☑ Various battery characteristics that affect embedded applications
- ☑ How to power an embedded design from a single 1.5V battery
- ☑ How to select a battery for an application

Additional Resources Provided by Microchip and Energizer

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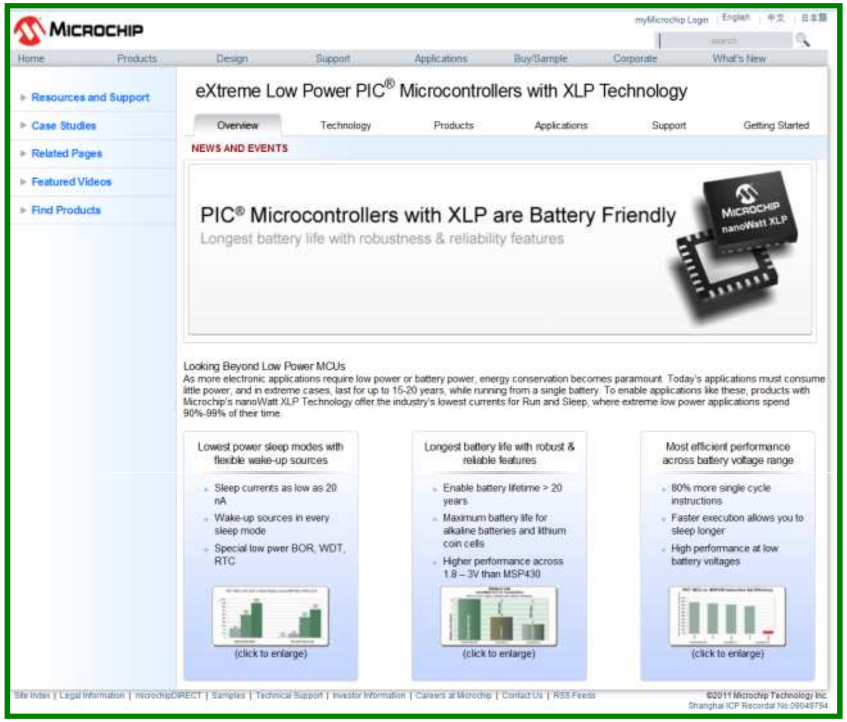

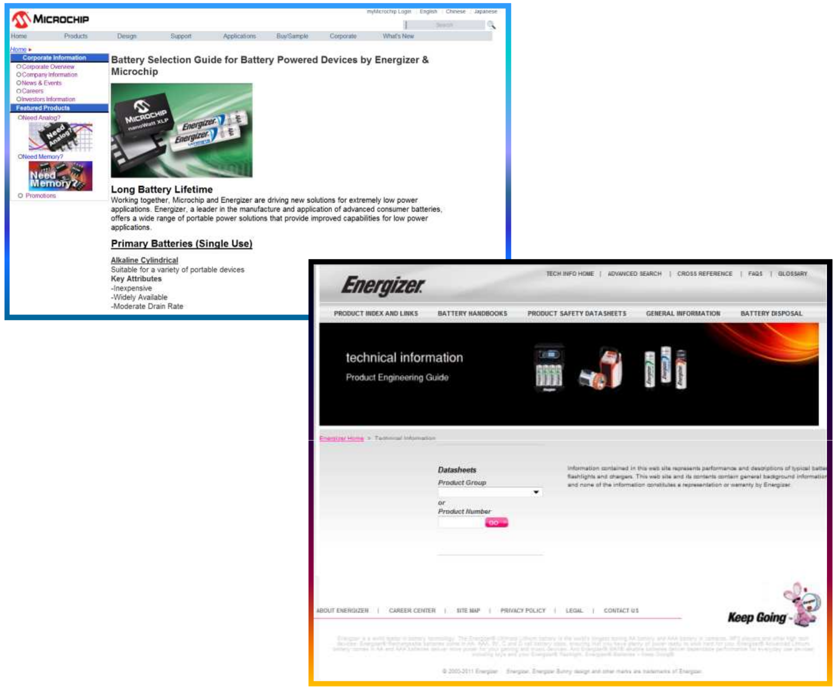

www.microchip.com/xlp

- Application Notes
- White Papers, Tips n' Tricks
- Battery Selection Guide
- Battery Life Estimator

www.microchip.com/batteryguide

http://data.energizer.com

- Data Sheets
- Application Manuals
- Power Solution Comparisons
- Environmental / Transportation

Direct Technical Support:

Email: Application.Support@Energizer.com

Samsung SDI --- GAMMA

- SDI производитель Li-Ion аккумуляторов №1 в мире
- ООО «Гамма-Санкт-Петербург» – официальный дистрибьютор Samsung SDI с октября 2012 г

Samsung SDI

- Li-Ion призматические
- Li-Ion цилиндрические
  - **ICR18650**
    - High-Capacity 2.25-3.20 Ah
    - High-Power 5-25 A
- Li-Polymer

GAMMA – VARTA Microbattery GmbH

- 125 лет на рынке систем питания
- ООО «Гамма-Санкт-Петербург» - официальный дистрибьютор VARTA Microbattery GmbH

VARTA Microbattery GmbH

Первичные

Перезаряжаемые

Литиевые

Щелочные

Ni-MH

LiMnO2

LiSOCl2

Первичные литий-тионил-хлоридные LiSOCl2 батареи

- Емкость 1200-19000 мАч
- Диапазон температур: -55…+85ºC
- Саморазряд <1% в год при +25ºC
- Срок службы более 20 лет, в зависимости от профиля нагрузки
- Стандартные корпуса: ½ AA, AA, C, D
- Различные конфигурации выводов: аксиальные, для пайки, с коннектором…

1200 мАч | 2500 мАч | 8500 мАч | 19000 мАч

References

Application Notes

- AN246: *Driving the Analog Inputs of a SAR A/D Converter*
- AN693: *Understanding A/D Converter Performance*
- AN793: *Power Management in Portable Applications: Understanding the Buck Switch Mode Power Converter*
- AN947: *Power Management in Portable Applications: Charging Lithium Polymer Batteries*
- AN960: *New Components and Design Methods Bring Intelligence to Battery Charger Applications*
- AN968: *Simple Synchronous Buck Regulator - MCP1612*
- AN971: *USB Port-Powered Li-Ion/Li-Polymer Battery Charging*
- AN1088: *Selecting the Right Battery System for Cost-Sensitive Portable Applications While Maintaining Excellent Quality*
- AN1137: *Using the MCP1631 Family to Develop Low-Cost Battery Chargers*
- AN1149: *Design A Load Sharing System Power Path Management with Microchip's Stand-Alone Li-Ion Battery Charger*
- AN1260: *MCP73871 Design Guide*
- AN1276: *Design $LiFePO_4$ Battery Charger with MCP73123*
- AN1293 *Multiple Chemistry Battery Charger Solution Using MCP1631HV PIC® MCU Attach PWM Controller*
- AN1311: *Single Cell Input Boost Converter Design*

References

Data Sheets

- MCP73831/2 Data Sheet, DS21984
- MCP73833/4 Data Sheet, DS22005
- MCP73871 Data Sheet, DS22090
- MCP73113/4 Data Sheet, DS22183
- MCP73213 Data Sheet, DS22190
- MCP73123/223 Data Sheet, DS22191
- MCP1256/7/8/9 Data Sheet, DS21989
- MCP1700 Data Sheet, DS21826
- TC1017 Data Sheet, DS21813
- MCP1631/V/HV/VHV Data Sheet, DS22063
- MCP1640/B/C/D Data Sheet, DS22234
- PIC10F206 Data Sheet, DS41239
- PIC12F617 Data Sheet, DS41302
- PIC12F683 Data Sheet, DS41211
- PIC16F684 Data Sheet, DS41202

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References

- David Linden, Thomas B. Reddy, *Handbook of Batteries, Third Edition* (New York: McGraw-Hill, Inc., 2002).
- Royal Society of Chemistry

  http://www.rsc.org
- MSNBC Technology and Science 8/16/2005
- Sanyo
  http://sanyo.com/batteries/lithium_ion.cfm
- Rocket Electronics
  http://www.rocket.co.kr
- LG Chemistry
  http://lgchem.com
- Toshiba
  http://toshiba.com/
- Office of Hazardous Materials Safety, Department of Transportation
  http://hazmat.dot.gov
- Alkaline Manganese Dioxide – Handbook and Application Manual, Energizer Battery Manufacturing Inc., ©2008
- Energizer E91 Product Data Sheet, Energizer Holdings, Inc.
- MN1500_US_CT, AA(LR6), Zn/MnO2 battery Product Data Sheet, Duracell, ©2008

Additional Resources

Weblinks

- www.batteryuniversity.com

Application Notes

- Ni-MH Battery Charger Application Library (AN1384), Microchip Technology Inc.
- Nickel-Metal Hydride Application Manual, Eveready Battery Co. Inc. (Energizer)

Questions

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Trademarks