Everything you need to know about

Lithium Batteries

Presented by

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AI6MS

Presented at the Pacificon Amateur Radio Convention

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Who is this guy?

- Marcel Stieber, AI6MS
- Licensed in 2008 as KI6QDJ
- Master's in Electrical Engineer

- Cal Poly Amateur Radio Club
- Cupertino ARES Repeater Trustee
- All Out Events Comms Director
- Salinas Valley Repeater Group

- Designs battery and charging systems for consumer electronics products

*Slides available at www.qrz.com/db/ai6ms

Abstract

This presentation will focus on the three common battery types: Lead-Acid (SLA/AGM), Lithium (Li-ion), and Lithium Iron Phosphate (LFP/LiFePO4). We'll discuss the pros and cons of each chemistry, common uses and misuses, and everyday application tips for your latest 12VDC amateur radio project.

This is a bi-directional QSO...

So ask questions!

A brief show of hands

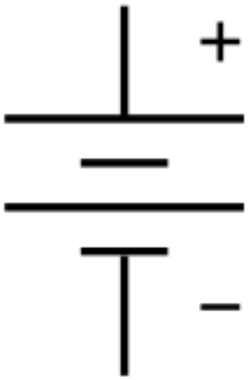
Forum Overview

- Intro to Batteries
  - Brief History and Construction
- Lead-Acid
- Lithium-Ion
- Lithium Iron Phosphate

- Info, pros/cons, and applications

A Brief Intro to Batteries

- Electrochemical energy storage
- Construction in layers
- Anode (-) ~ Electrolyte ~ Cathode (+)
- Origins in 1800 - Alessandro Volta
  - Zinc ~ brine-soaked paper ~ Copper



Intro to Batteries

- Nominal cell voltage
  - Individual cells have a nominal cell voltages
    - 1.5V - Carbon-Zinc (“alkaline battery”)
    - 1.2V – Nickle-Cadmium (NiCd)
    - 2.1V – Lead-Acid
- Full battery voltage
  - To get “12VDC” batteries, need to stack cells together
  - Typical mobile radio spec:
    - 13.8V ±15% (11.7V-15.9V)

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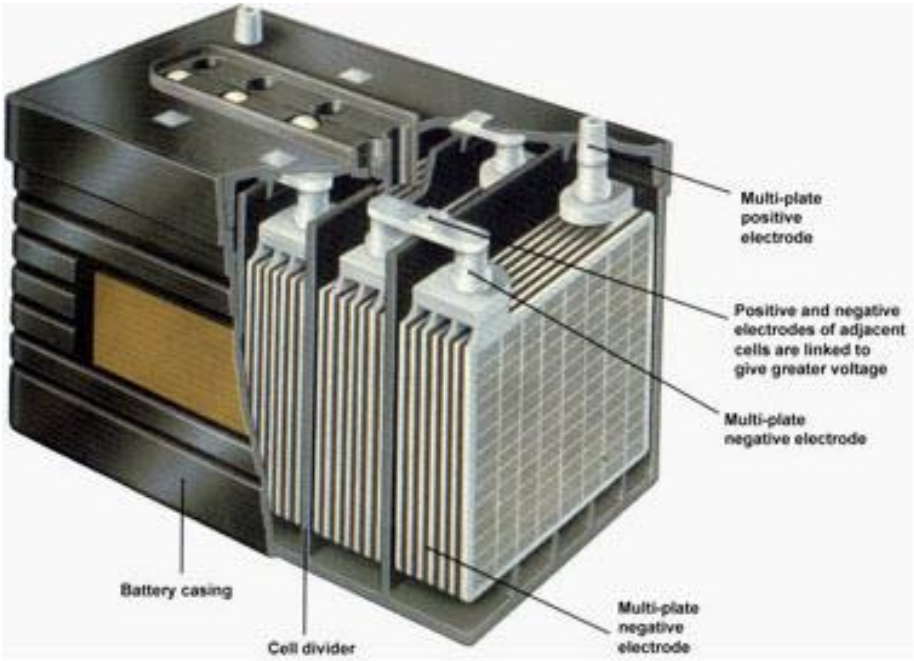
- Full battery voltage
  - To get “12VDC” batteries, need to stack cells together

6 x 1.5V = 9 Volts!

Lead-Acid

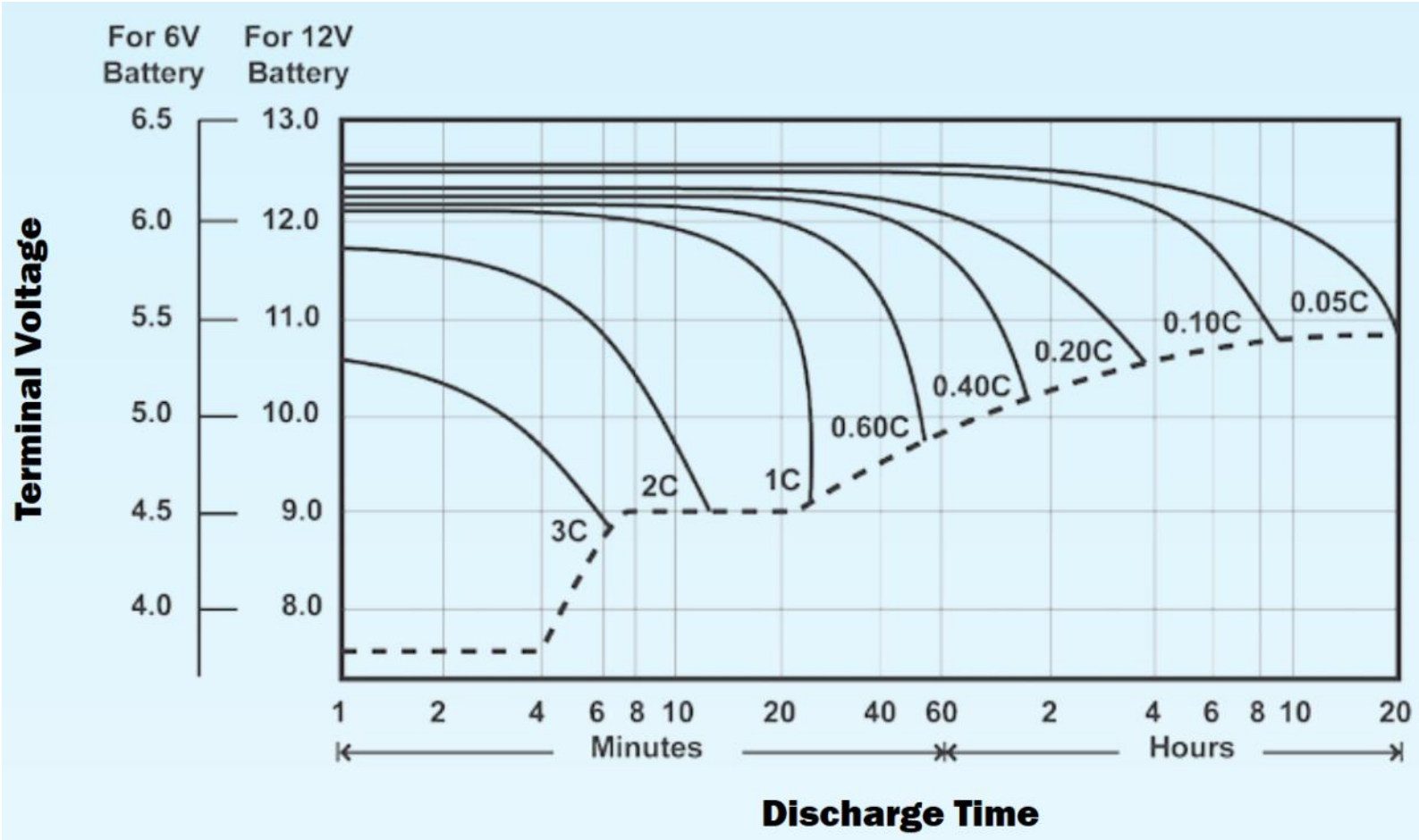
Lead-Acid Construction

- 6 sets of plates soaked in electrolyte
- Pure Lead ~ Sulfuric Acid ~ Lead Oxide (PbO2)



Lead-Acid Voltage

- Single cell voltage ranges
  - 2.1V nominal (typ. min 1.3-1.8V, max 2.35-2.45V)*
- 6 single-cells ≈ 12.6V nominal



*https://www.power-sonic.com/wp-content/uploads/2018/12/Technical-Manual.pdf

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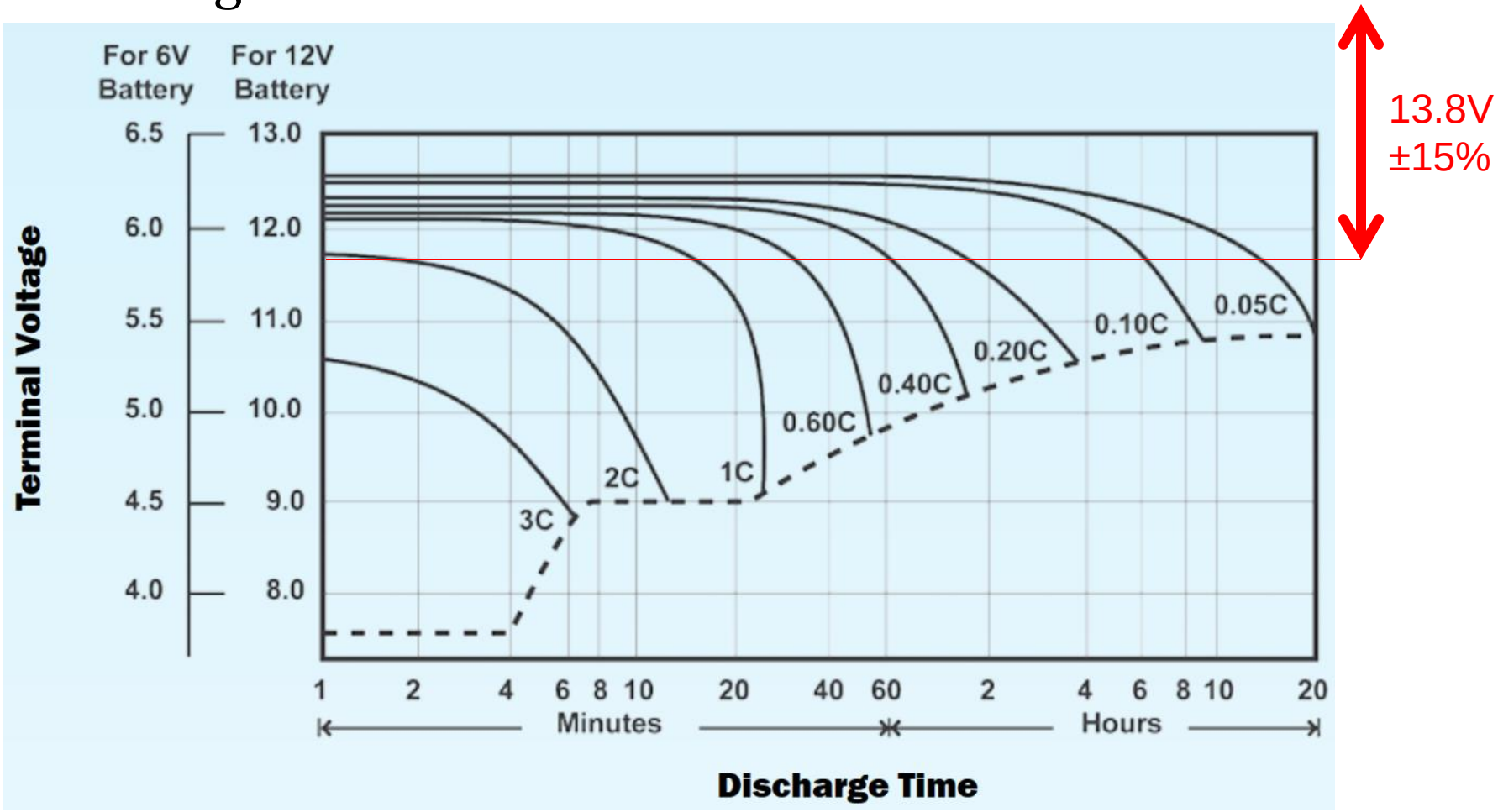

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Lead-Acid Types

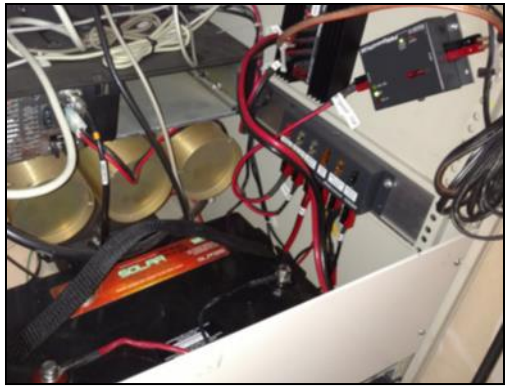
- SLA – Sealed Lead-Acid
  - AGM – Absorbed Glass Mat
    - Electrolyte-Soaked glass fibers
  - Gel cell
    - Gel electrolyte, any-orientation
  - “Deep cycle” variants
- Flooded Cell
  - Liquid electrolyte
  - Vented for outgassing
  - Longer life
  - Vertical only

Lead-Acid Pros/Cons

- Super sensitive to deep discharge
  - Unable to deliver full-rated capacity for 12V radios
    - Mobile radios are typically 13.8V±15% (11.7-15.9V)
  - Resulting reduced cycle count
    - 50% Depth of Discharge means less than 500 cycles
- Low gravimetric energy density
  - HEAVY
- Typical 5 year shelf-life for SLA
- Cheap and readily available

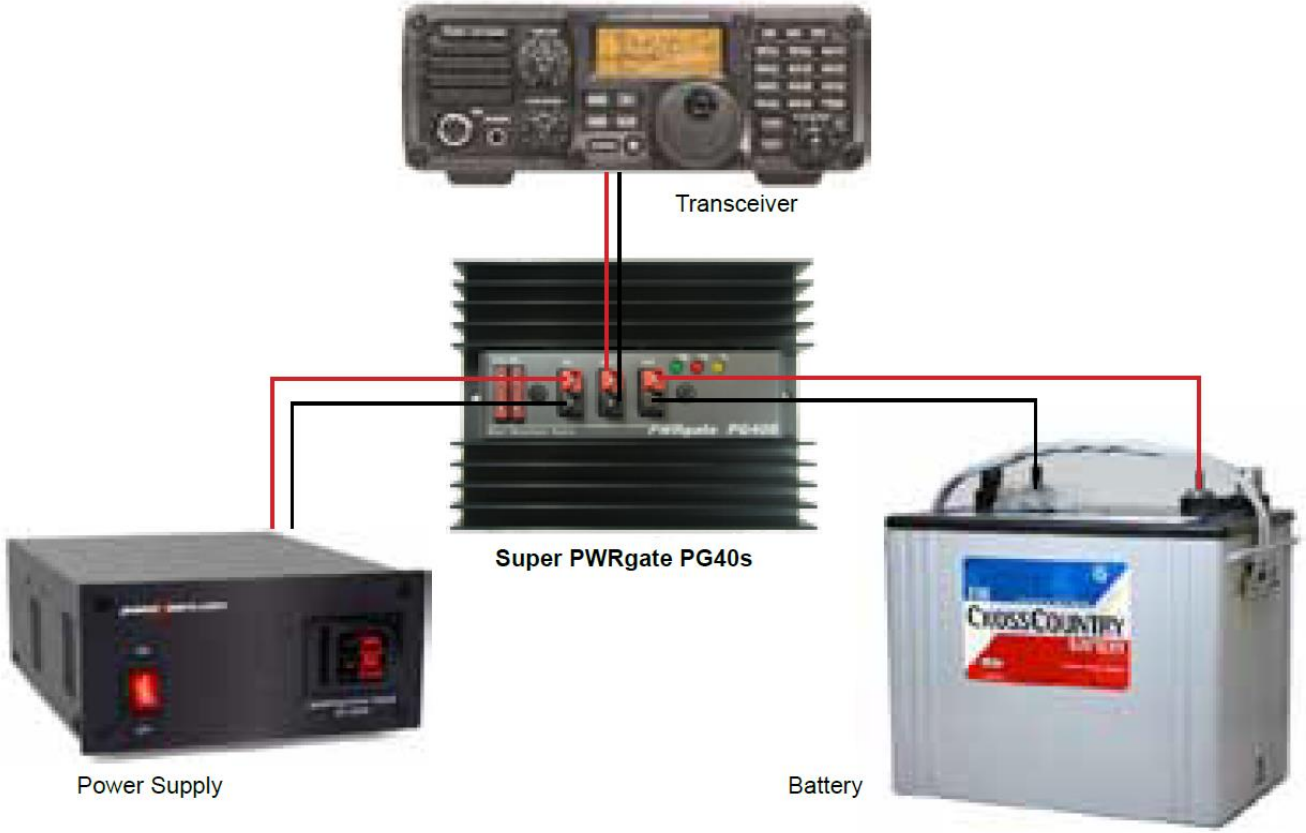
Lead-Acid Applications

- Powerpole to your radios!
- Standard “12V” battery chargers (automotive)
- Can use many charge controllers and transfer boxes
  - e.g. Powerwerx and West Mountain Radio
- Lots of integrated battery pack solutions available
- Extremely common for stationary backup power
  - Emergency Power for your Shack
  - Backup battery systems for radios sites and repeaters

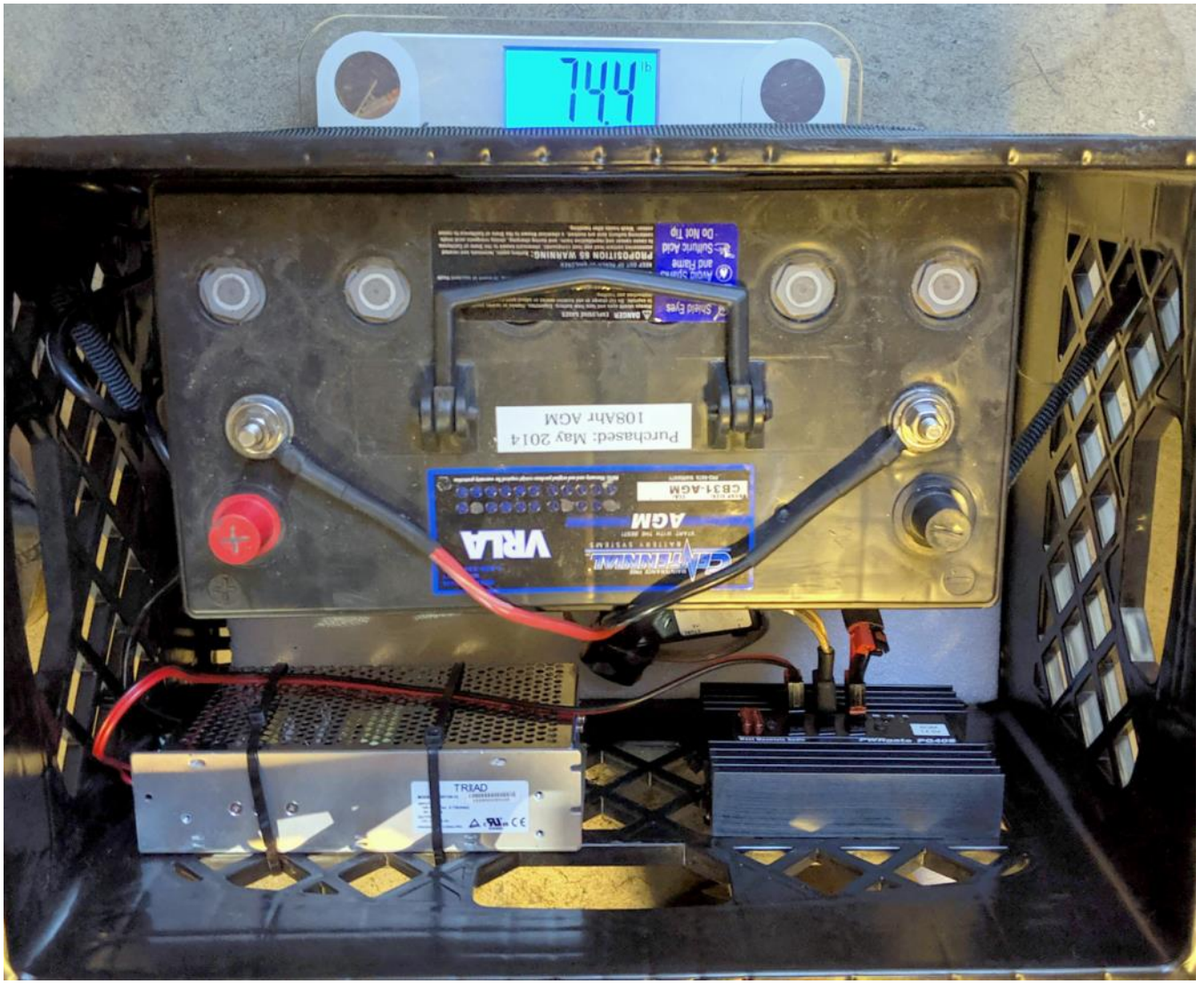


Lead-Acid Applications

- Typical Block Diagram



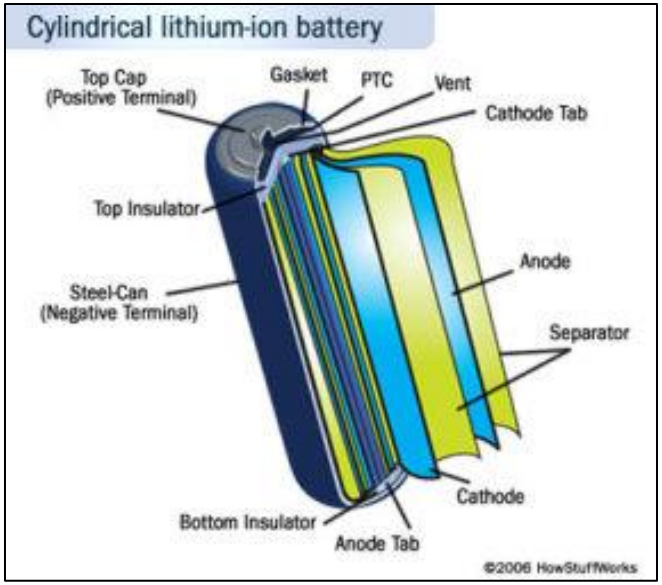
Lead-Acid Applications



Lithium-Ion (Li-ion)

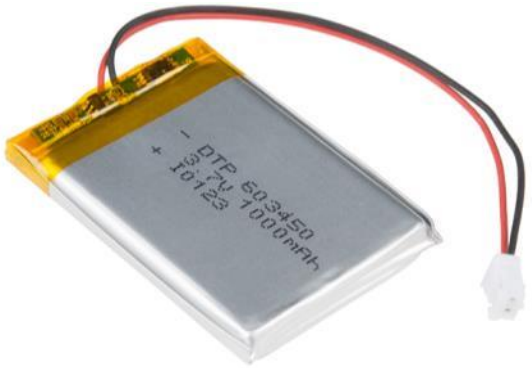
Li-ion Construction

- Jelly roll construction = much larger surface area
  - Just like an electrolytic capacitor
  - Anode/Cathode/Electrolyte/Separator
- Allows for much higher specific energy vs lead-acid
  - 460kJ/kg vs 140kJ/kg



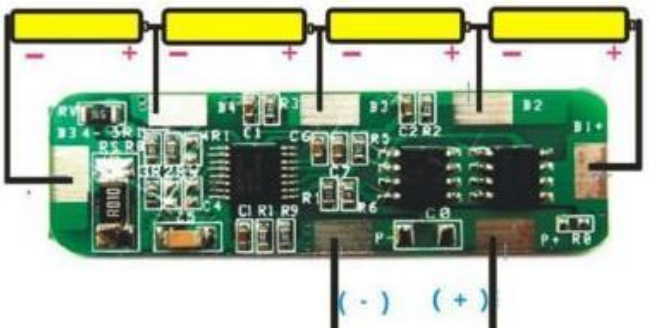
Li-ion Types and Voltages

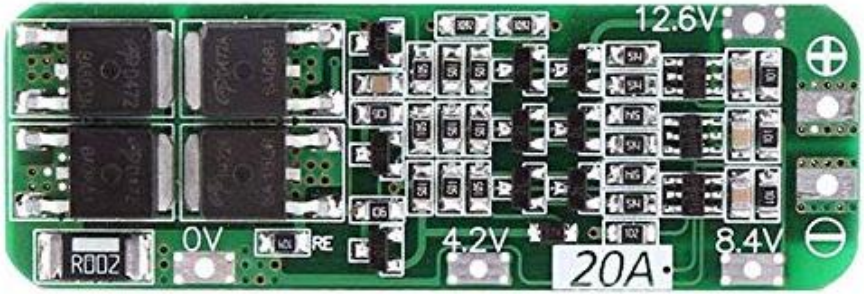
- Nominal 3.6V, typical range is 3.0V-4.2V
- Many different chemistries for specific applications:
  - NCA, NMC, LMO, LFP
    - (nickel, cobalt, aluminum, manganese, iron, phosphate)
- Typical form factors
  - Pouch cells (phones, tablets, HT, RC planes, quads)
  - Cylindrical cells (18650, 21700) (Laptops, EVs, tools)



Li-ion Integration

- Highly sensitive to over-voltage and over-current events that can cause thermal runaway
  - Need protection circuits built-in
- Specific charger profiles needed with mV accuracy
- Multi-cell packs need BMS (battery management system)
  - Minimum protections: OVP, OCP, OTP
  - Ideally: UVLO, Cell Balancing, Fuel Gauging, etc.





Li-ion Integration

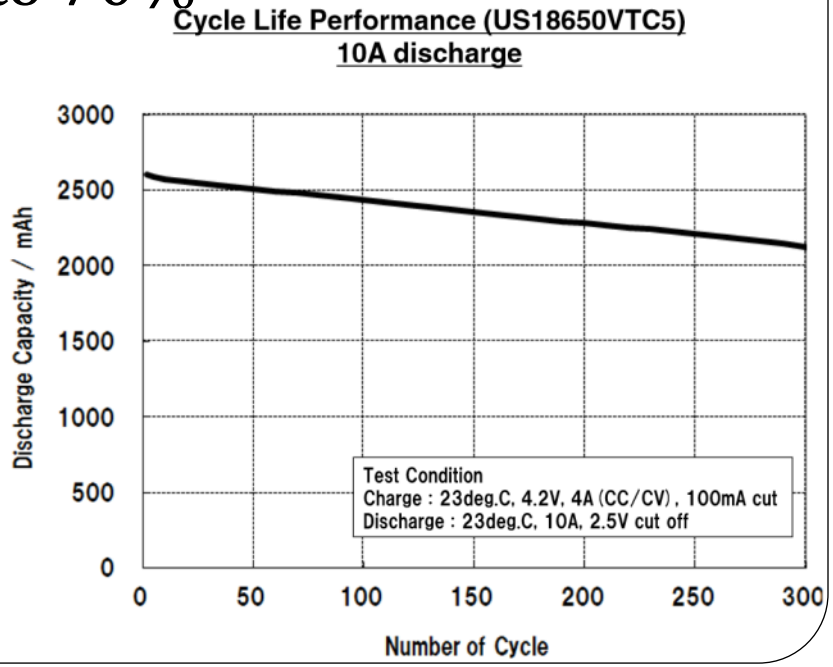
- Typical pack configurations XsYp
  - Series and Parallel strings of cells (4s1p, 7s10p)
  - Series for voltage range, parallel for capacity

3s1p

3s2p

Li-ion Pros/Cons

- Voltage range mismatch for “13.8V” input radios
- Can be a great fit for non-standard radios with appropriate input voltage ranges (e.g. HTs)
- Hazards at highest cell voltages
- Typically ~300-500 cycles to 70%
- High energy density
- Aging, temperature
- Low-cost per Ahr
- Used everywhere



Li-ion Applications

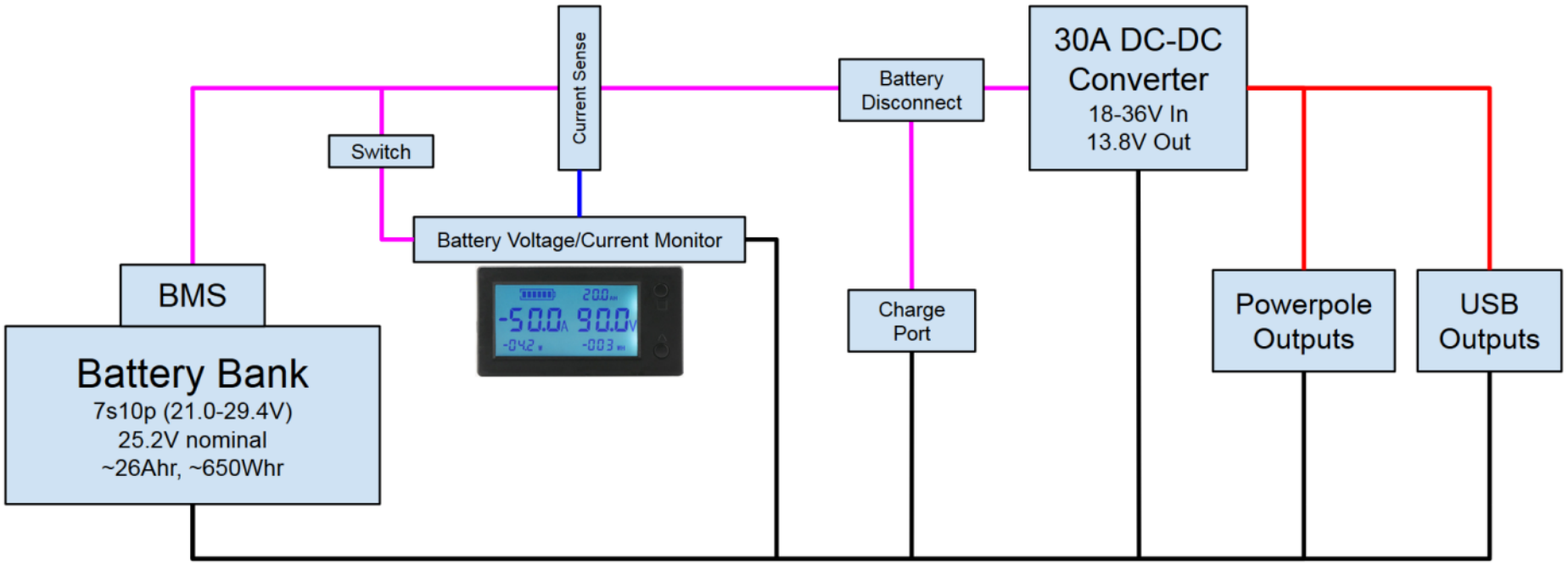
- For typical mobile radios (13.8V+/-15%) need to use voltage regulation (**11.73-15.87V**)
  - ≤3s pack = 10.8V nominal (9.0-**12.6V**)
    - Needs a boost converter
  - 4s pack = **14.4V** nominal (**12.0**-16.8V)
    - Needs a buck-boost converter or other method to limit the upper voltage range to avoid damage
    - Consider limited max charge voltage (~3.95V)(-10-20%)
  - ≥5s pack = 18.0V nominal (**15.0**-21.0V)
    - Needs a buck converter
- Problems with converters? Noise and efficiency.

	Battery Pack		BMS		Converter to 13.8V
<3s		+		+	
4s		+		+	
>4s		+		+	

DIY Powerwall Battery Pack

- DIY Powerwall + Buck Converter!
- Designed by Jehu Garcia and Justin Kenny KJ6KST
- 7s10p battery pack with built-in BMS
- Capacity ≈ 26Ahr (~650Whr)
- 13.8V 30A buck converter (18-36V input)

Block Diagram



DIY Powerwall Battery Pack

- $15 USB Charger Port: https://www.amazon.com/gp/product/B07FXH5ZZK
  or https://powerwerx.com/panel-dual-usb-quick-charge-qc30-blue
- $16 Battery Disconnect Switch: https://www.amazon.com/gp/product/B07PN9CT9H
  or https://powerwerx.com/blue-sea-6007-dual-battery-switch-selector
- $8 Charging Port: https://www.amazon.com/gp/product/B01A99T37C
- $11 Powerpole Port: https://powerwerx.com/powerpole-connector-chassis-mount-4
- $29 Battery Monitor: https://www.amazon.com/gp/product/B07B4CWKRJ
- $12 Charger: https://www.amazon.com/gp/product/B075TYQZYX
- $26 30A Buck Converter: https://www.amazon.com/gp/product/B07NZNLRLT
- $49 BMS Kit: https://jag35.com/products/bms-module-kit
- $90 Powerwall PCBs: https://jag35.com/products/18650-battery-module-diy-pcb-kit
- $30 Case: https://www.harborfreight.com/2800-weatherproof-protective-case-medium-63926.html
- $350 Sony VTC5A Cells ($5/each): https://www.18650batterystore.com/product-p/sony-vtc5a.htm
- $636 in parts + wires, crimps, parts – salvaged cells

DIY Powerwall Buck Converter Efficiency

Input Power	Output Power	Output Current	Power Efficiency
17.4W	15.1W	1.1A	87%
210W	202W	14.6A	92%
310W	298W	21.7A	96%

DIY Powerwall Discharge Test

- Calculated: 590Wh, Measured: 608Wh
  - ~90% efficiency at 5A discharge from 13.8V output (~8.7hrs at 70W)
  - 3.6V x 7 cells x 26 Ahr x 0.9 = 590Wh

Lithium Iron Phosphate

LiFePO4

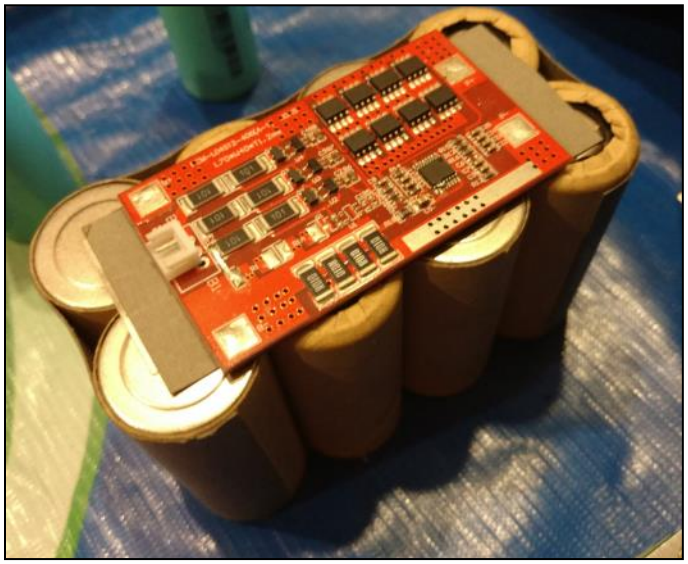
LFP

LiFePO4 Construction

- Same jelly roll construction as other Li-ion types
- Different chemistry gives different nominal voltage!
  - 3.2V nominal (2.5V-3.65V)
  - 4S pack is then ~10.0-14.6V *(compare to 11.7-15.9V)*

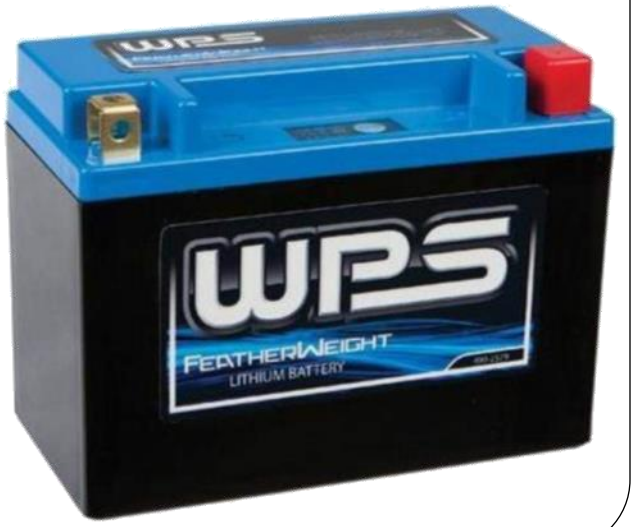
LiFePO4 Types

- Highly-available as 12V battery replacements
  - Assembled packs with powerpole hook ups
  - Built in battery protection modules (PCMs)
    - OVP, OTP, UVLO, OCP, balancing



LiFePO4 Pro/Cons

- Intrinsically safer chemistry that other Li-ion
- Direct hook up to most mobile radios
- Almost a direct replacement for 12VDC applications
- Lower energy density vs Lithium-ion
  - 360kJ/kg vs 460kJ/kg
- More expensive per amp-hour
  - 12v 20Ah LPF $200
  - 12V 20Ah Li-ion ~$120 (~3s8p)
  - 12v 20Ah Lead-Acid $30-60

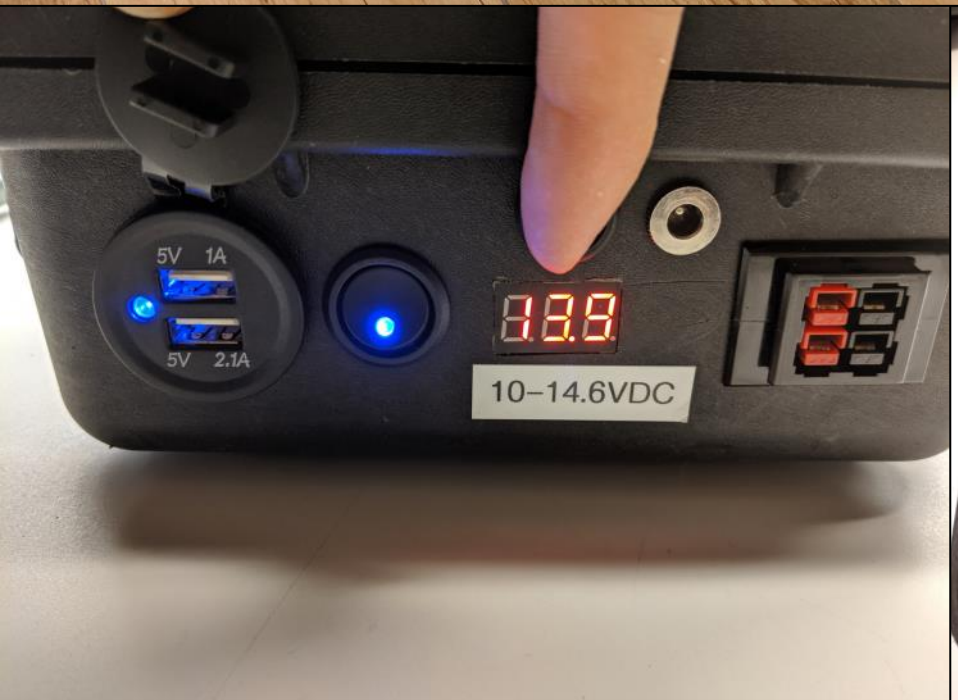


LiFePO4 Applications

- Build a pack or buy a pack
  - Bioenno is extremely popular
    - “lead-acid drop-in replacement”
    - Built-in BMS with protections and balancing!
    - Provided charger handles specific charge profiles

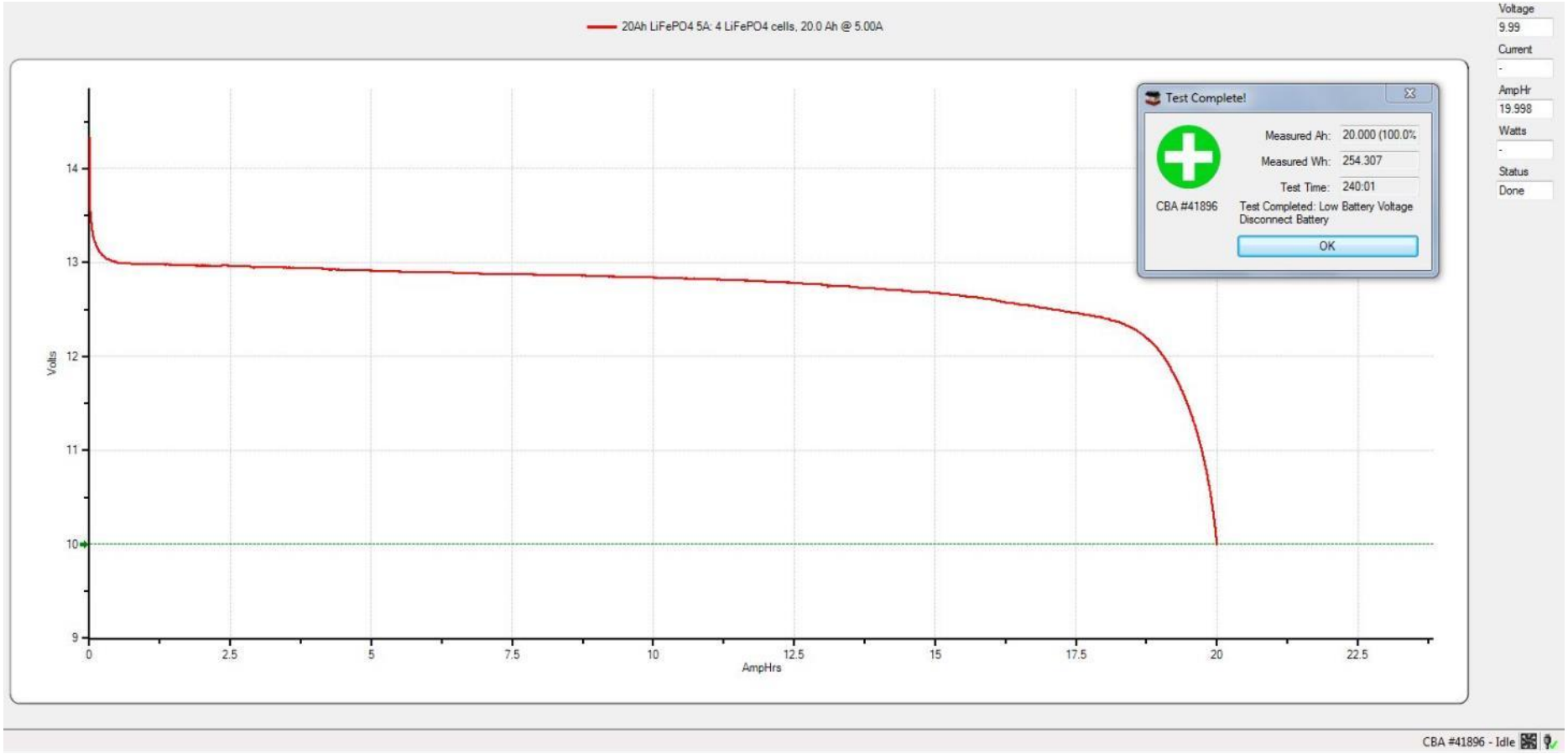
- Buy: 12V, 20Ah LFP Battery BLF-1220A - $192
- Add hard case, charger, USB, powerpole ~$300

9.5lbs



Bioenno BLF-1220A Discharge Test

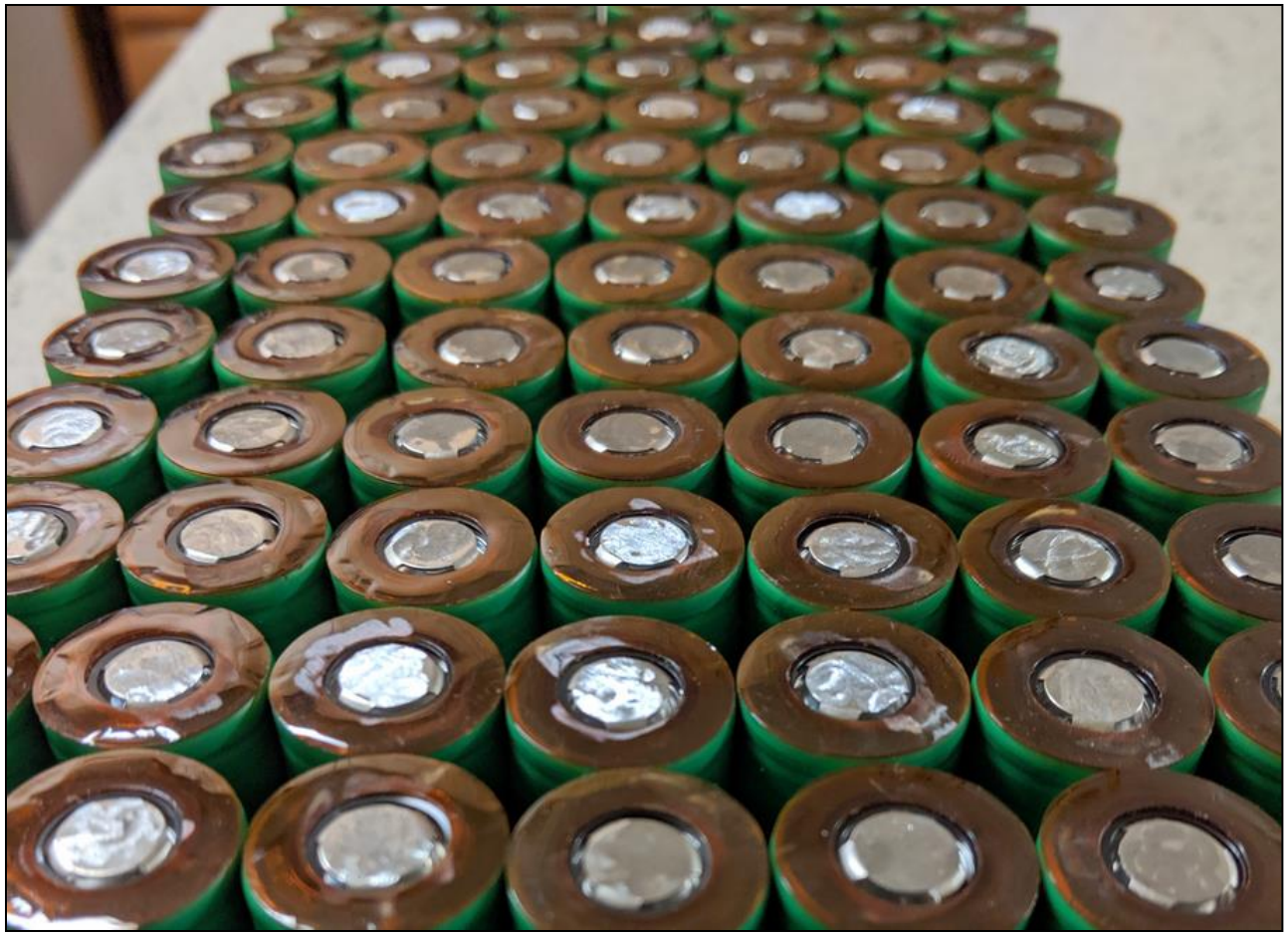
- Spec: 220Wh, Measured: 254Wh



Comparison Table

	Lead-Acid	**Li-ion**	**LiFePO4**
“12VDC” usage	Good	Ok/Bad	Great
Cost per AHr	Low	Med	High
Energy Density	Low	High	Med
Relative Weight	High	Med	Low
Under-voltage Impact	High	Med	Med
Over-voltage Impact	Med	High	Med
Integration Difficulty	Low	High	Low
Protections Needed	None	Lots	Lots
Noise Considerations	None	Concern	None

Questions - Comments - Discussion



Presentation will be available at: www.QRZ.com/db/AI6MS

Marcel Stieber, AI6MS@arrl.net

Want me to speak to your club or organization? Need a volunteer tower climber? Contact me!

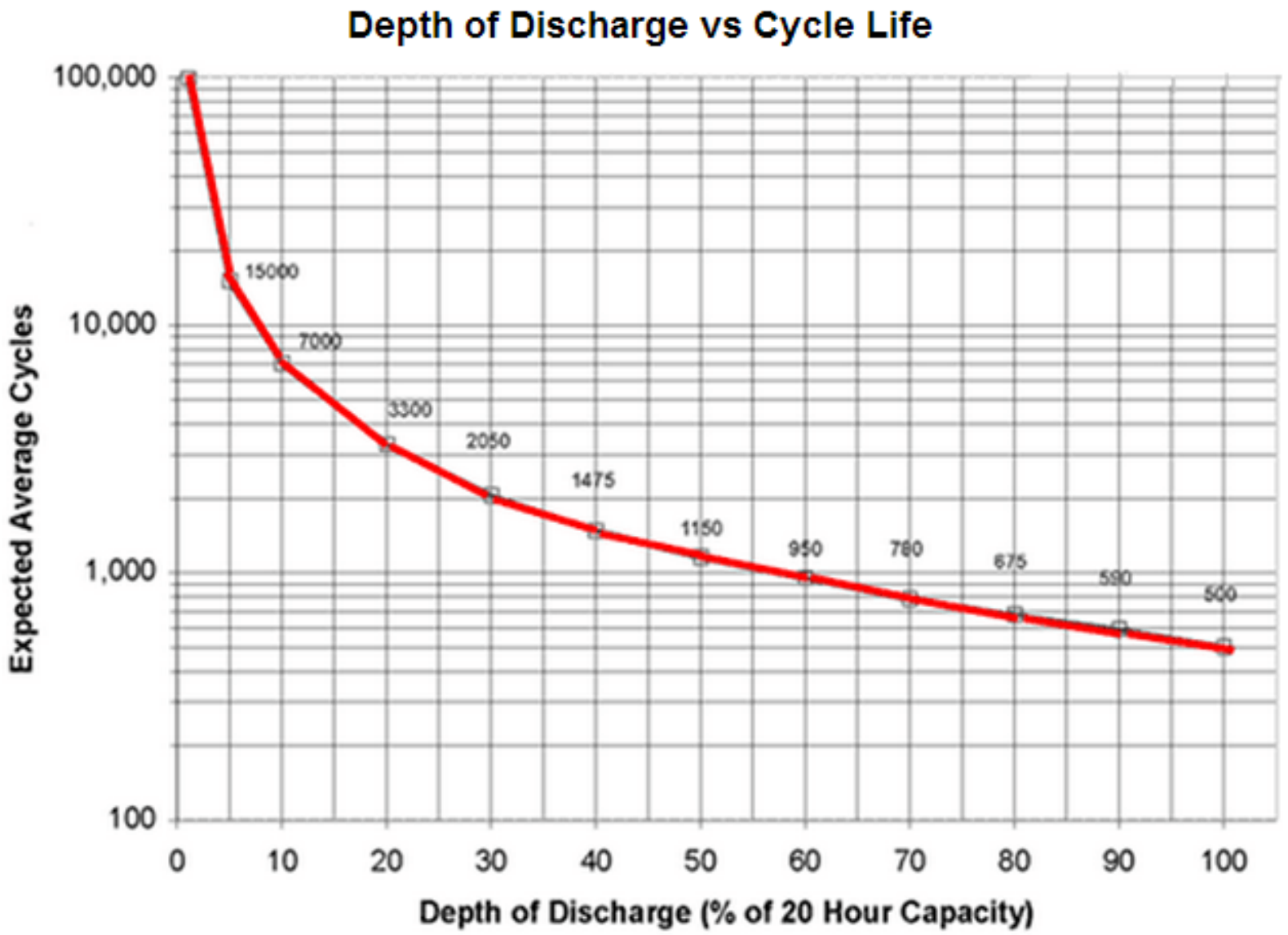
Future Study

- www.BatteryUniversity.com
- TI BMS application notes
  - http://www.ti.com/analog/docs/analogtechdoc_hh.tsp?viewType=mostuseful&rootFamilyId=64&familyId=411&docCategoryId=1
- Jehu Garcia YouTube for DIY pack building
  - https://www.youtube.com/user/jehugarcia
- https://powerwerx.com/dc-power-products

References and Further Reading

- https://en.wikipedia.org/wiki/Electric_battery
- https://lygte-info.dk/info/BatteryDisassembly9VAlkaline%20UK.html
- https://www.geek.com/geek-pick/how-a-lead-acid-battery-works-1501045/
- https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2018/182505r.pdf
- https://www.power-sonic.com/wp-content/uploads/2018/12/Technical-Manual.pdf
- https://www.edgefx.in/wp-content/uploads/2014/07/21.jpg
- https://www.amazon.com/Powerwerx-PWRbox-PP-Portable-PowerBox-Batteries/dp/B07HHJNGB3
- https://en.wikipedia.org/wiki/Lithium-ion_battery
- https://www.nobelprize.org/prizes/chemistry/2019/press-release/
- https://www.quora.com/What-safety-hazards-come-about-if-a-lithium-ion-battery-is-opened-Does-it-release-toxic-gas-Does-it-explode-What-happens
- https://electronics.howstuffworks.com/everyday-tech/lithium-ion-battery1.htm
- https://en.wikipedia.org/wiki/Lithium-ion_battery
- https://en.wikipedia.org/wiki/Lithium_iron_phosphate_battery
- https://www.bioennopower.com/collections/12v-series-lifepo4-batteries
- https://www.batteryjunction.com/samsung-30q-18650-3000-flat.html
- https://www.sparkfun.com/products/13813
- https://www.homedepot.com/p/RYOBI-18-Volt-ONE-Lithium-Ion-Battery-Pack-4-0-Ah-2-Pack-P145/306703572
- https://www.amazon.com/6800Mah-Rechargeable-Li-Ion-Battery-3400Mah/dp/B072J329Q8
- https://www.amazon.com/4A-5A-Protection-Li-ion-lithium-Battery/dp/B01M0CA4QF
- https://www.amazon.com/Comidox-Lithium-Protection-Module-AUTO-Recovery/dp/B07KD2CN3F
- https://www.powerstream.com/p/us18650vtc5-vtc5.pdf
- https://www.youtube.com/watch?v=2ETeLFqGzjo
- https://www.youtube.com/watch?v=sjqQZSRlWAA
- https://www.amazon.com/Stayhome-Converter-9V-12VDC-13-8VDC-Inverter/dp/B07SSXV9TK
- https://www.amazon.com/Stayhome-Voltage-Regulator-Stabilizer-Automatic/dp/B07SRTX89L
- https://www.amazon.com/FirePower-Featherweight-Lithium-Battery-HJTZ5S-FP-IL/dp/B00DX894B2
- https://www.alibaba.com/product-detail/Customized-li-ion-battery-12v-24v_60796851746.html

For Lead-Acid Battery



https://mozaw.com/diy-off-grid-solar-system/

Mobile Radio Input Voltage Spec

Radio	Spec
Yaesu FT-857D	13.8V±15%
Yaesu FT-1900R	13.8V±15%
Yaesu FTM-10R	11.7-15.8V
Yaesu FT-920	13.5V±10%
Yaesu FTM-350R	11.7-15.8V
Yaesu FTM-400DR	13.8V
Yaesu FT-817	13.8V±15%
Kenwood D710A	13.8V±15%
Kenwood TM-61A	13.8V±15%