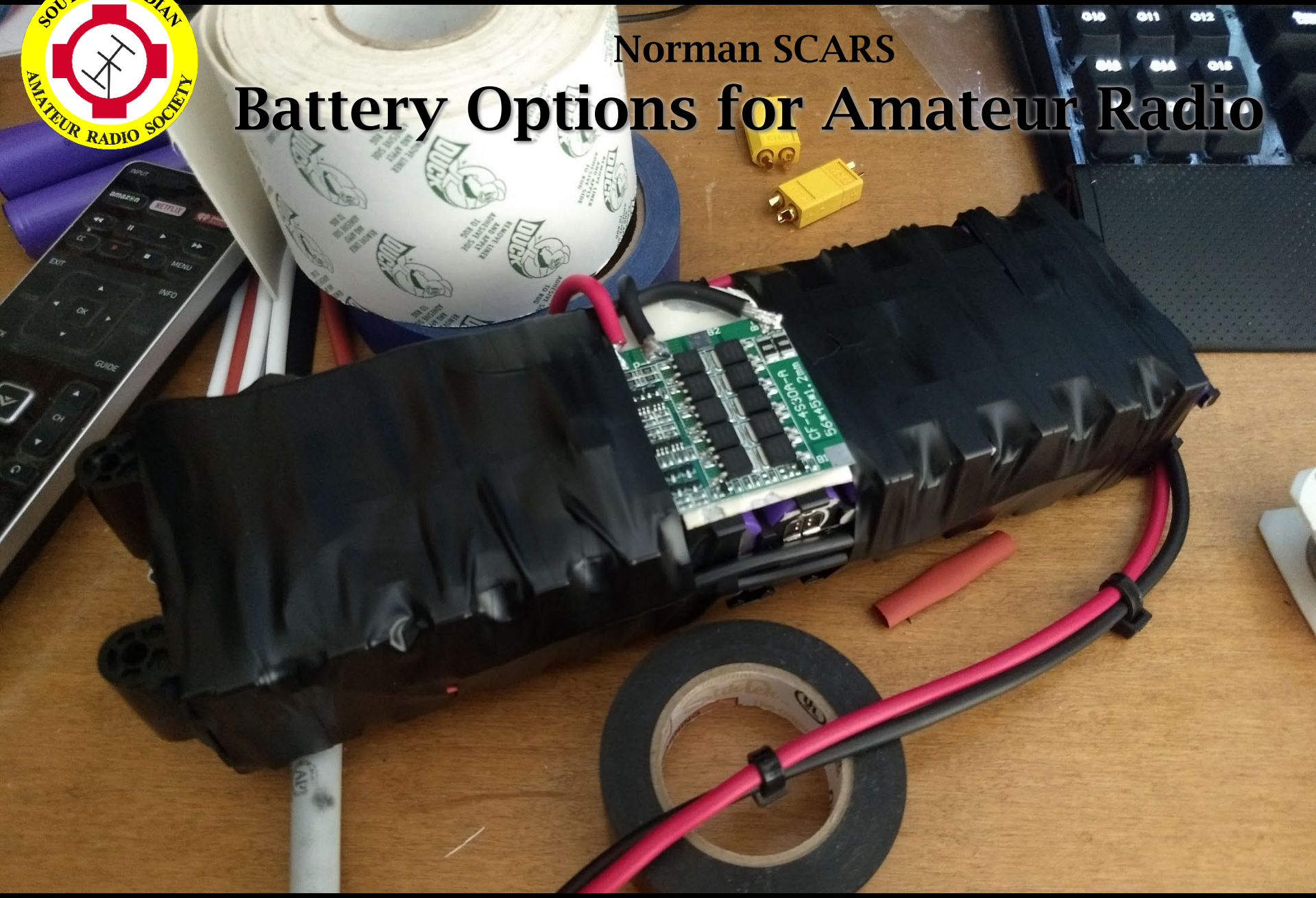
Norman SCARS

# Battery Options for Amateur Radio



Dr. Hays – KI5AIF - University of Oklahoma

# Battery Safety

- High power batteries are always ready to discharge dangerous current and start fires
  - You should build a fuse into the battery!
- Ideally the voltage of your battery system will not be life-endangering.
  - Some professional electric propulsion systems are
    - Cars
    - Wall power storage
    - F1 KERS
- Battery leads should <u>never</u> directly touch
- Batteries should ***<u>always</u>*** be stored in a safety bag to contain flame if they rupture
- It is possible that damage during charging, use, etc. might not cause a “vent” event until hours later (middle of the night in your house)
  - STORE THEM IN LIPO BAGS!

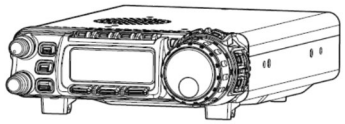
# Build or Buy?

- Bioenno power is a favorite among POTA activators
  - LiFePO4 batteries and chargers made for hams!
  - Vary from 40 dollars to 2700 dollars based on size
  - Solar charging options as well!
- Car battery form-factor liFePO4 batteries exist and can be used with an external charger.
- Purchasing is likely safer, and not as expensive in comparison as you may think.


# Radio Power Requirements

YAESU
The radio

**FT-857D**
**HF/VHF/UHF**
ULTRA-COMPACT TRANSCEIVER
**OPERATING MANUAL**



**Supply Voltage:** Normal: 13.8 VDC ±15 %, Negative Ground
**Current Consumption:** Squelched: 550 mA (Approx.)
Receive: 1 A
Transmit: 22 A

**SPECIFICATION**

**General**

| | |
|---|---|
| **Frequency Range:** | Receive: 0.1-56 MHz, 76-108 MHz, 118-164 MHz, 420-470 MHz<br>Transmit: 160 - 6 Meters (USA: includes 60 meters), 2 Meters, 70 Centimeters (Amateur bands only) |
| **Emission Modes:** | A1A (CW), A3E (AM), J3E (LSB/USB), F3E (FM), F1D (9600 bps packet), F2D (1200 bps packet) |
| **Synthesizer Steps (Min.):** | 10 Hz (CW/SSB), 100 Hz (AM/FM/WFM) |
| **Antenna Impedance:** | 50 Ohms, Unbalanced |
| **Operating Temp. Range:** | 14 °F to 140 °F (–10 °C to +60 °C) |
| **Frequency Stability:** | ±4 ppm from 1 min. to 60 min after power on<br>@25 °C: 1 ppm/hour<br>±0.5 ppm/1 hour @25 °C, after warmup<br>(with optional TCXO-9) |
| **Supply Voltage:** | Normal: 13.8 VDC ±15 %, Negative Ground |
| **Current Consumption:** | Squelched: 550 mA (Approx.)<br>Receive: 1 A<br>Transmit: 22 A |
| **Case Size** (W x H x D): | 6.1" x 2.0" x 9.2" (155 x 52 x 233 mm) |
| **Weight** (Approx.): | 4.6 lb. (2.1 kg) |

**Transmitter**

| **RF Power Output:** (@13.8 V DC) | | SSB/CW/FM | AM Carrier |
|---|---|---|---|
| | 160- 6 M: | 100 W | 25 W |
| | 2 M: | 50 W | 12.5 W |
| | 70 CM: | 20 W | 5 W |

| | |
|---|---|
| **Modulation Types:** | SSB: Balanced Modulator,<br>AM: Early Stage (Low Level),<br>FM: Variable Reactance |
| **FM Maximum Deviation:** | ±5 kHz (FM-N: ±2.5 kHz) |
| **Spurious Radiation:** | –50 dB (1.8-29.7 MHz)<br>–60 dB (50/144/430 MHz) |
| **Carrier Suppression:** | >40 dB |
| **Opp. Sideband Suppression:** | >50 dB |
| **SSB Frequency Response:** | 400 Hz-2600 Hz (–6 dB) |
| **Microphone Impedance:** | 200-10k Ohms (Nominal: 600 Ohms) |



This works out to….
15.87 Volts max
11.73 Volts min

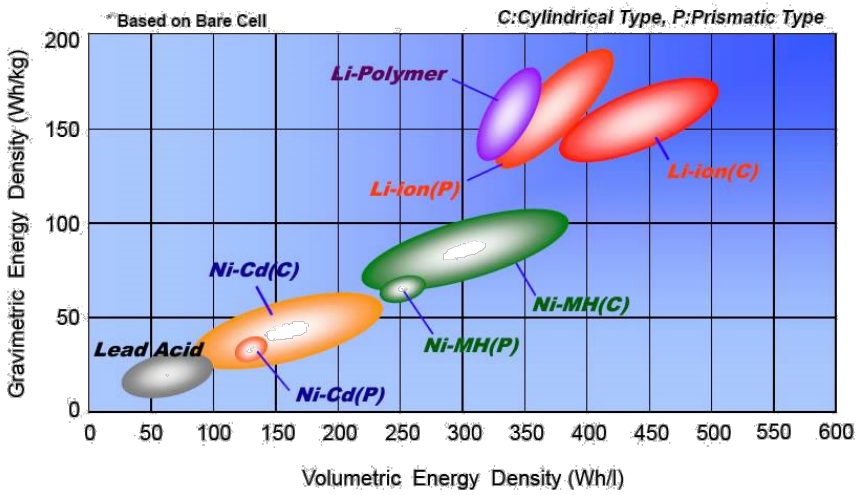
# Battery Chemistries



- Lead Acid – Developed 1801 – Commercialized 1886
- NiCAD – Patent 1902 – US 1946
- NiMH – Developed 1967 – Commercialized 1989
- Lithium ion / LiPO – Dev. 1972 – Still Improving!
  - Lithium polymer
    - LiCoO2 cathode
  - Lithium Manganese
    - LiMn2O4
  - **Lithium Iron**
    - **LiFePo4 cathode**
  - Lithium sulfur
    - Various chemistries under research
    - Generically LiS

# Battery Cost, Weight, and Lifespan

- Lead acid cells
  - $80 to $100 per kWhr
  - Likely will run your radio only for first 50% of discharge
  - Approximately 500 cycle life in this use case
- Lithium Ion cells
  - $300 to $400 per kWhr
    - ($180 used 18650's)
  - Will run your radio to full discharge
  - 1000+ cycle lifespan expectation
  - Lower self-discharge in storage



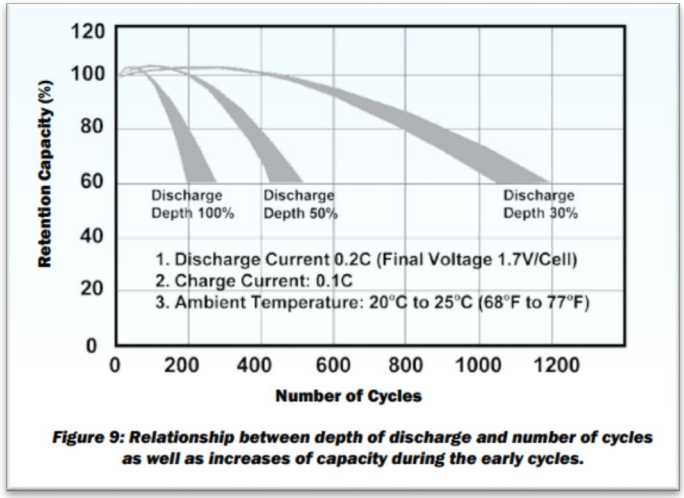




*Figure 9: Relationship between depth of discharge and number of cycles as well as increases of capacity during the early cycles.*

https://www.epectec.com/batteries/cell-comparison.html

https://www.powertechsystems.eu/home/tech-corner/lithium-ion-vs-lead-acid-cost-analysis/

https://www.ultralifecorporation.com/PrivateDocuments/WP_li-ion-vs-lead-acid-WEB_1.pdf

# Battery Chemistry & Voltage per cell

Numbers are per cell

| Chemistry | V average | V full | V depleted |
|---|---|---|---|
| Lead Acid | **2.1** | ~2.4 | ~1.5 |
| NIMH | **1.2** | 1.4 | 0.9 |
| LiPO | **3.7** | 4.2 | ~3.0 |
| **LiFePO4** | **3.2** | **3.65** | **2.5** |

- Most batteries rated by average voltage
  - 14.8V rating at right.
  - Actual peak = 16.8V!!!
  - Peak voltage is too high for most radios

# Lead Acid Discharge Curve

(Group 27 lead acid battery has ~85 AH capacity)

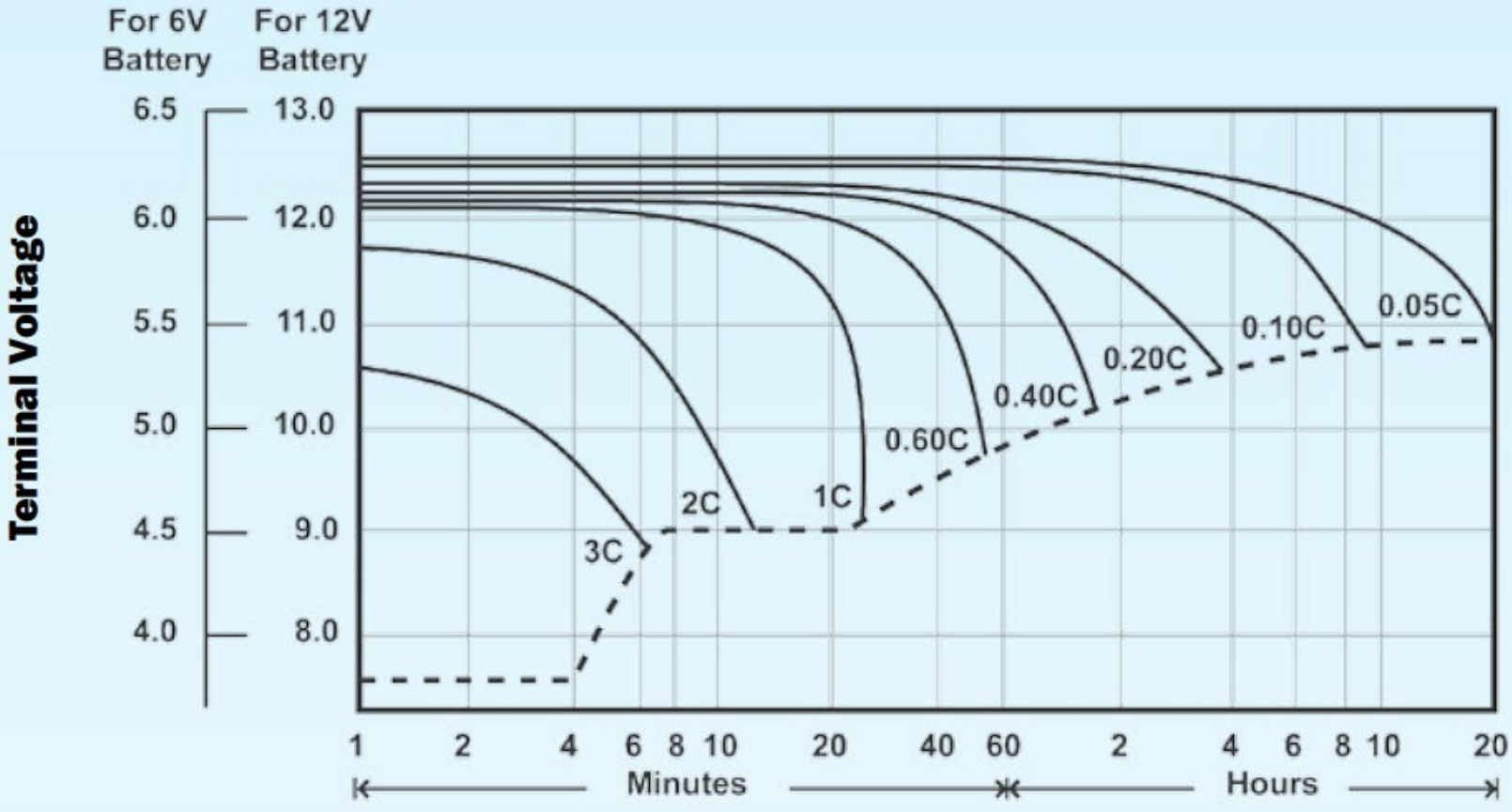
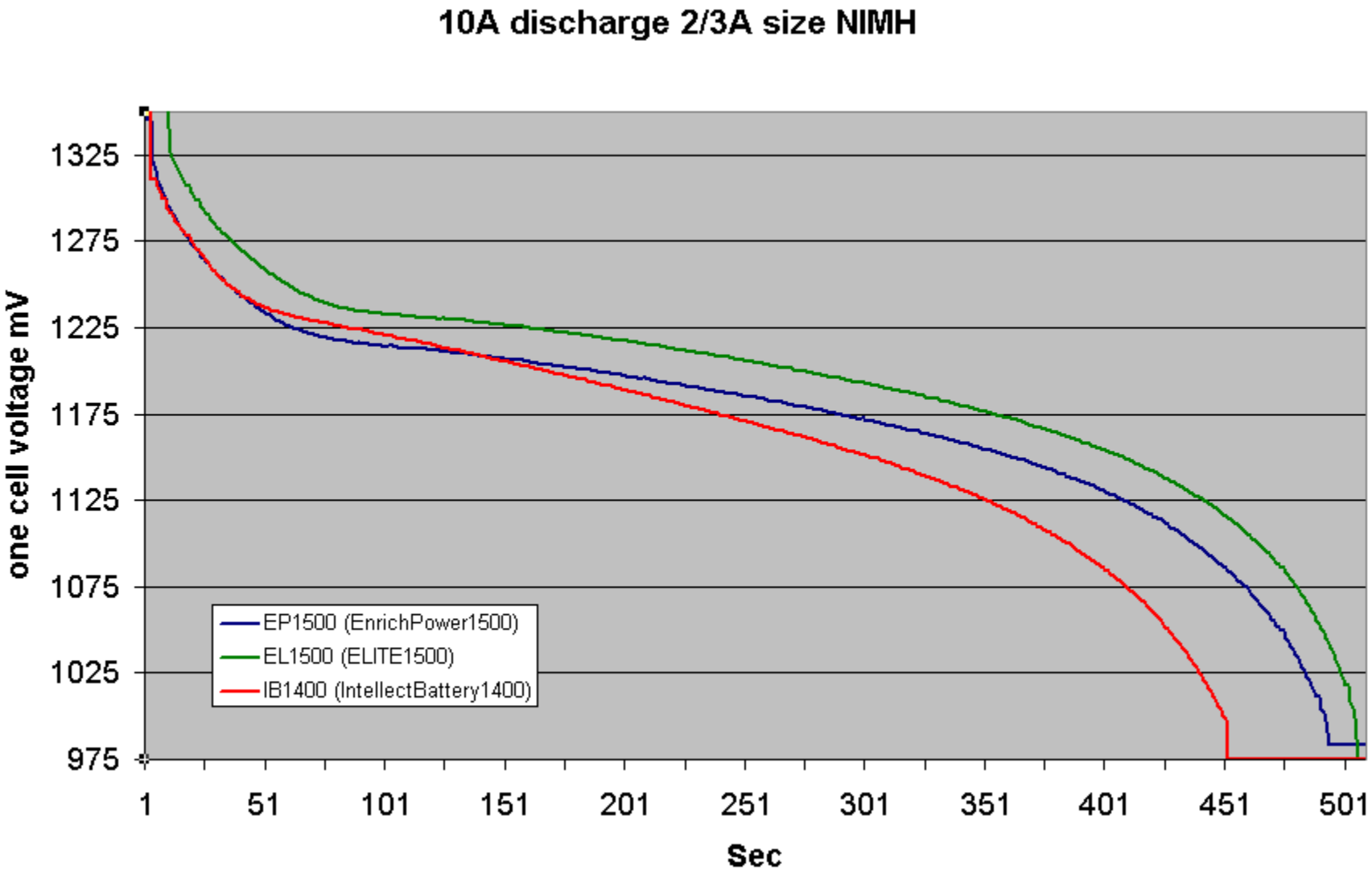


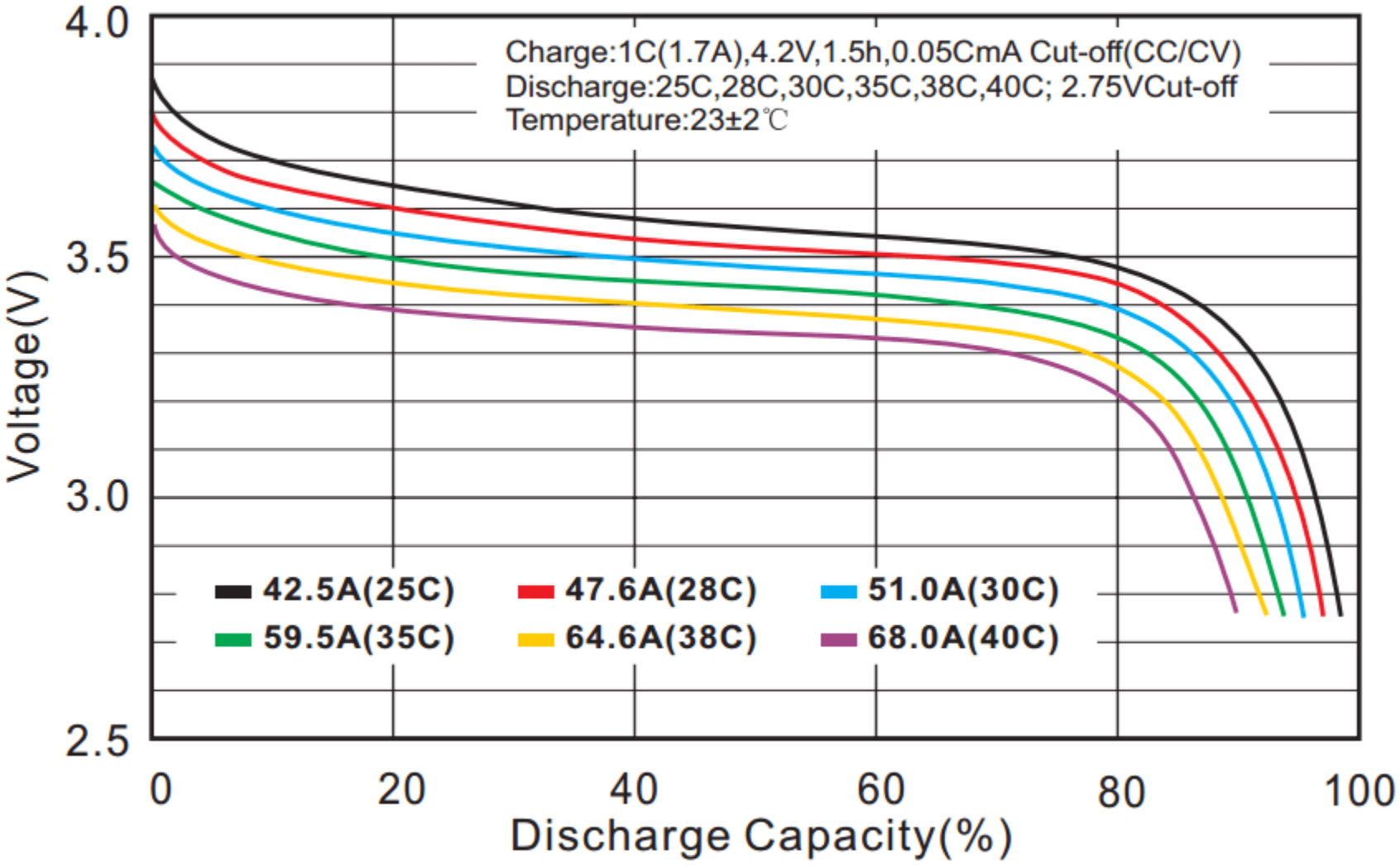

***Figure 4: Discharge Characteristic Curves at 20°C (68°F)***

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

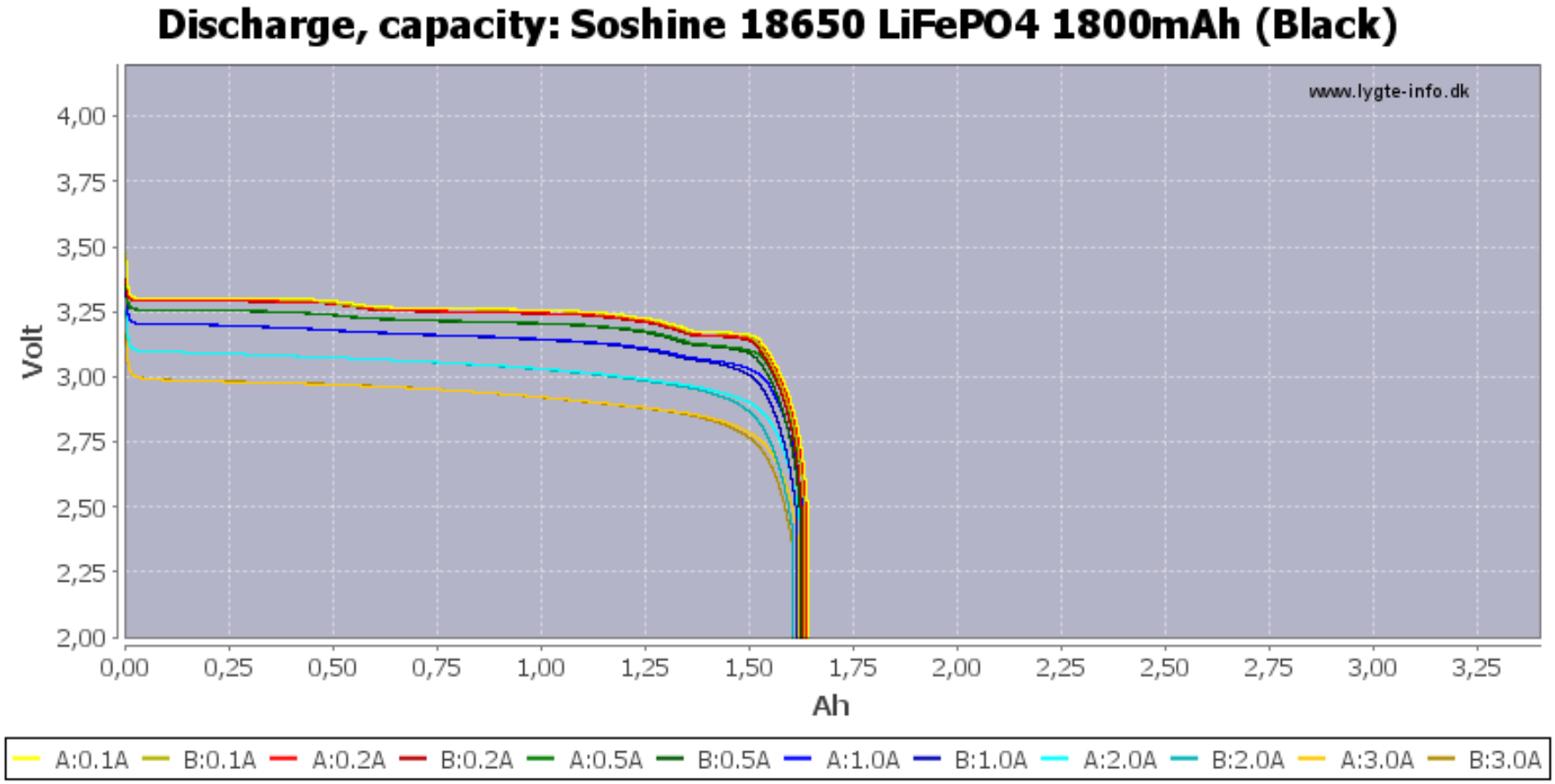
# NIMH Discharge Curve



# Lipo Discharge Curve



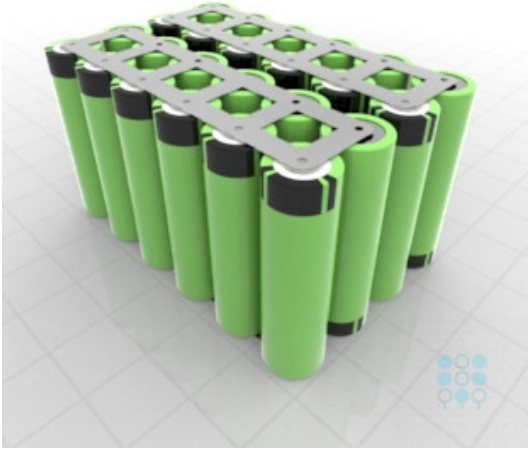
# Lithium Iron Discharge Curve



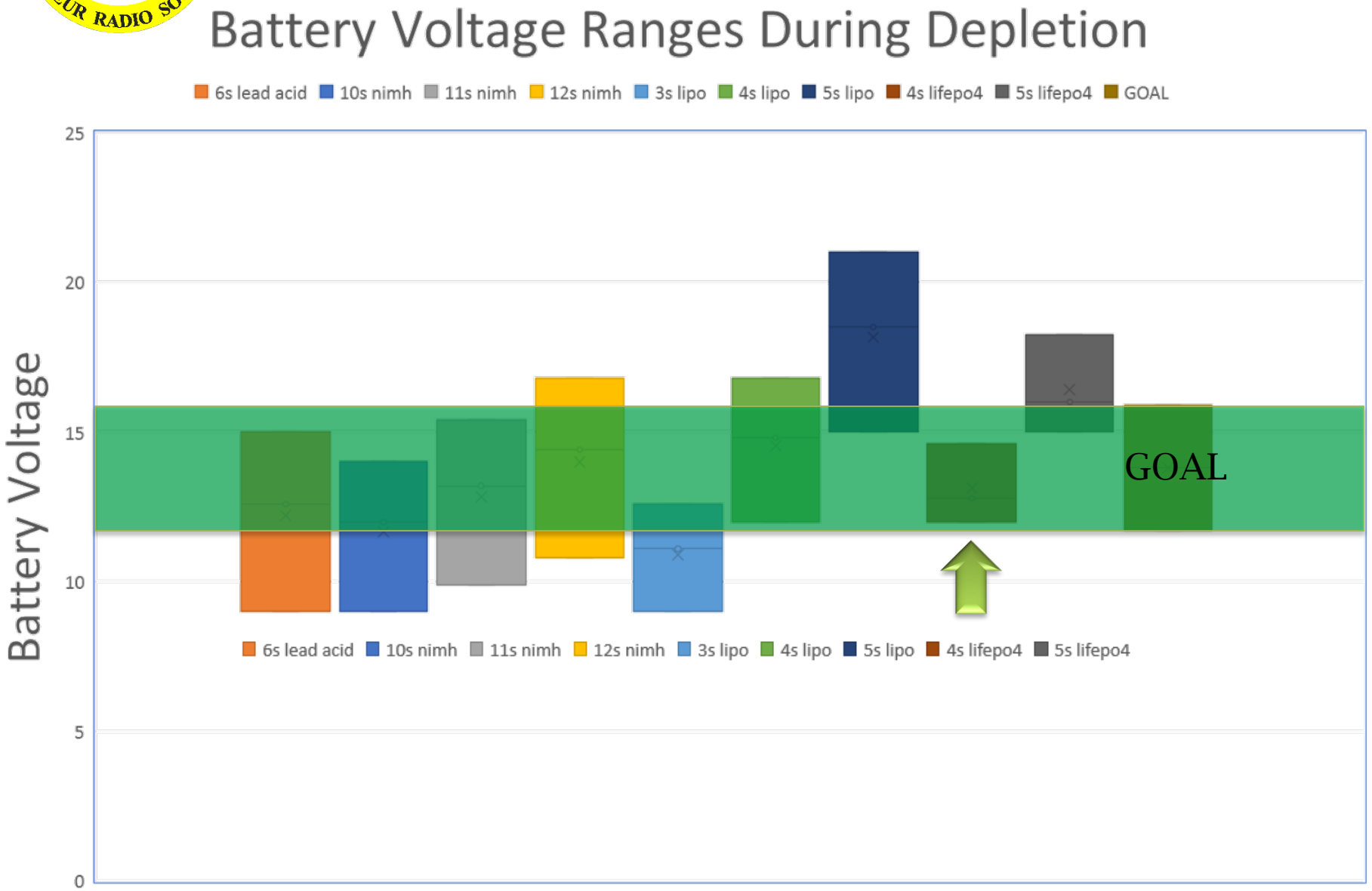

- Note how comparatively flat the curve is…

# Selecting Battery Configuration

- Batteries described as "XsYp"
  - 2s1p would be two cells in series, with no parallelization (2 cells total)
    - AKA "2S" and the "1P" is assumed.
  - 4s6p means 4 series connected groups of 6 cells in parallel. (24 cells total)

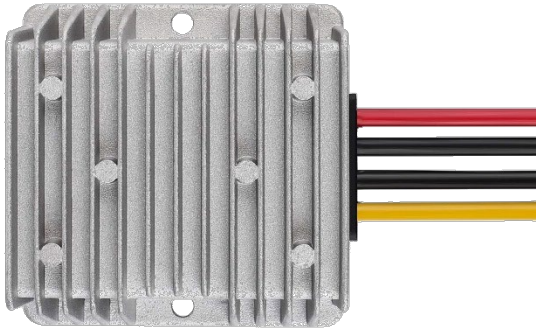



# Voltage Options

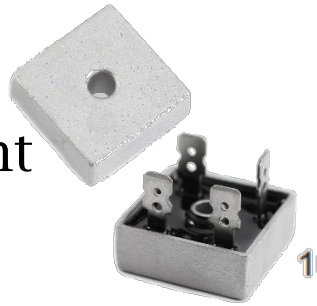


# Voltage Regulation

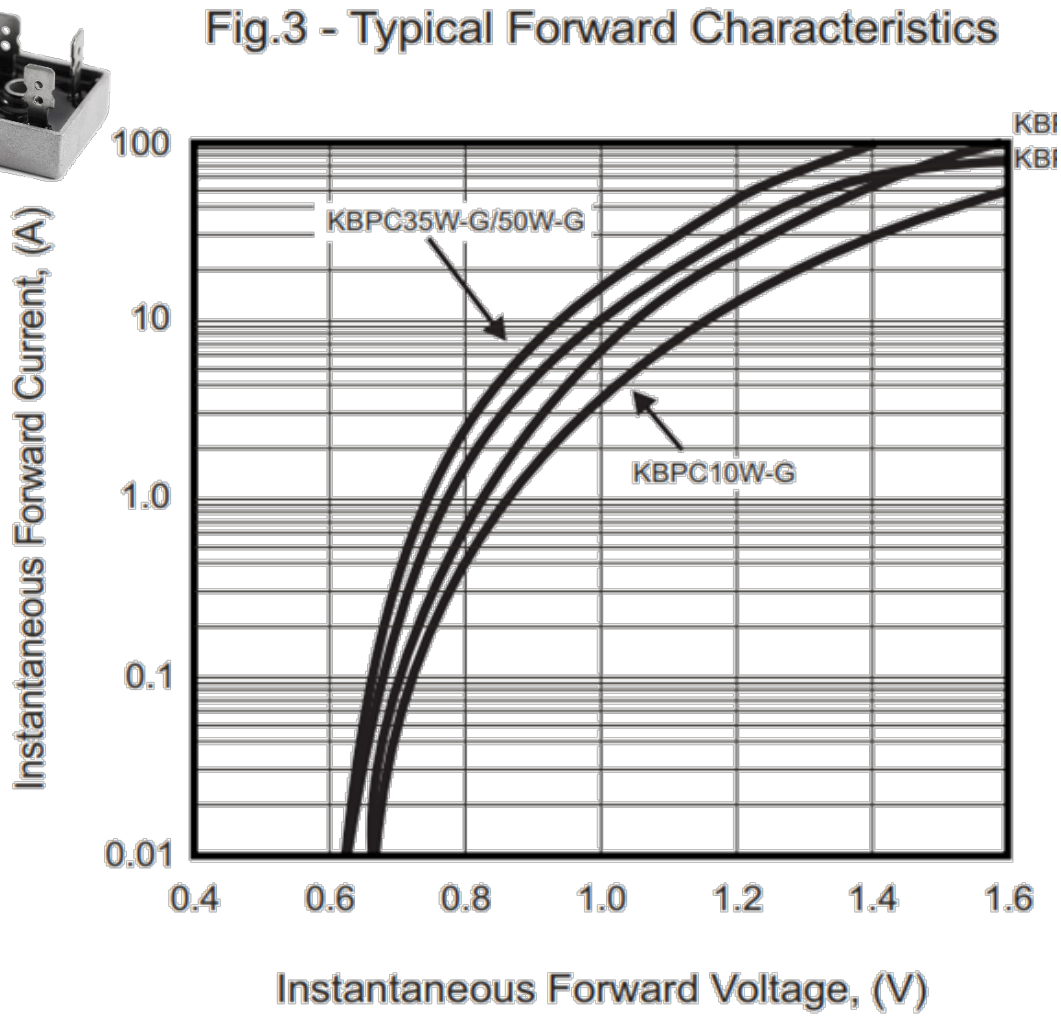
- Switching voltage regulators
  - 8V to 40V input
  - 13.8 output
  - SIGNIFICANT RF noise
- MFJ voltage booster
  - 9V to 13.8V input
  - Regulated output
  - Reportedly RF quiet
  - Add $170 to your battery cost



# Noiseless Voltage Regulation

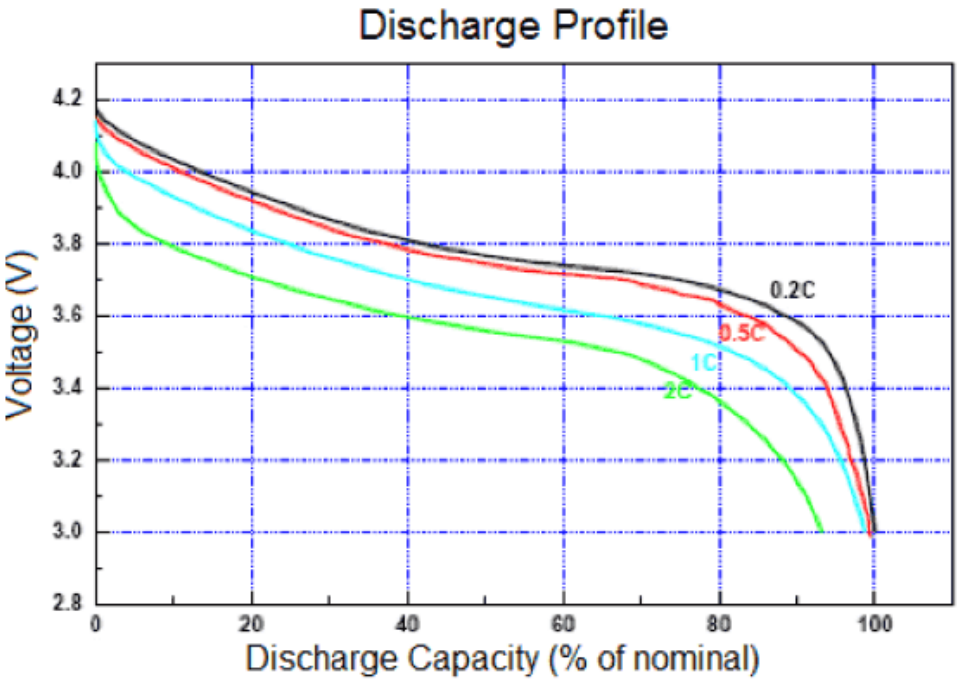


- Low cost, high current bridge rectifier
  - One dollar!
  - Constant (enough) voltage drop
  - Add into circuit when 4s lipo is fully charged
  - Either remove or short the diode when the voltage drop is not needed
- The risk is you might **forget** to put this in circuit when using your battery, and over-volt your radio



# Load Dependent Capacity

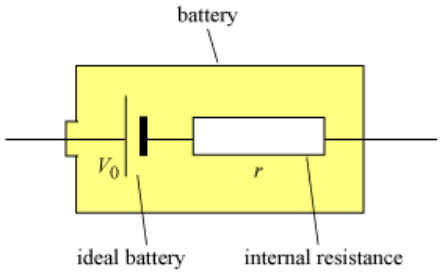
- Battery energy output decreases at higher discharge rates
  - Internal resistance losses
- Some chemistries are VERY rate limited by internal resistance
  - Lead acid per gram outputs very little power
  - High rate lithium batteries minimize heating through low I.R.
    - 70C to 100C batteries are “claimed” by manufacturers
    - Higher C discharge ratings imply lower IR




Discharge: 3.0V cutoff at room temperature.

# Internal Resistance

- Controls how much voltage “sags” under load
- High internal resistance:
  - Heats the battery
  - Limits power output
  - Lowers voltage provided by the battery
- deltaV=I*internal_resistance

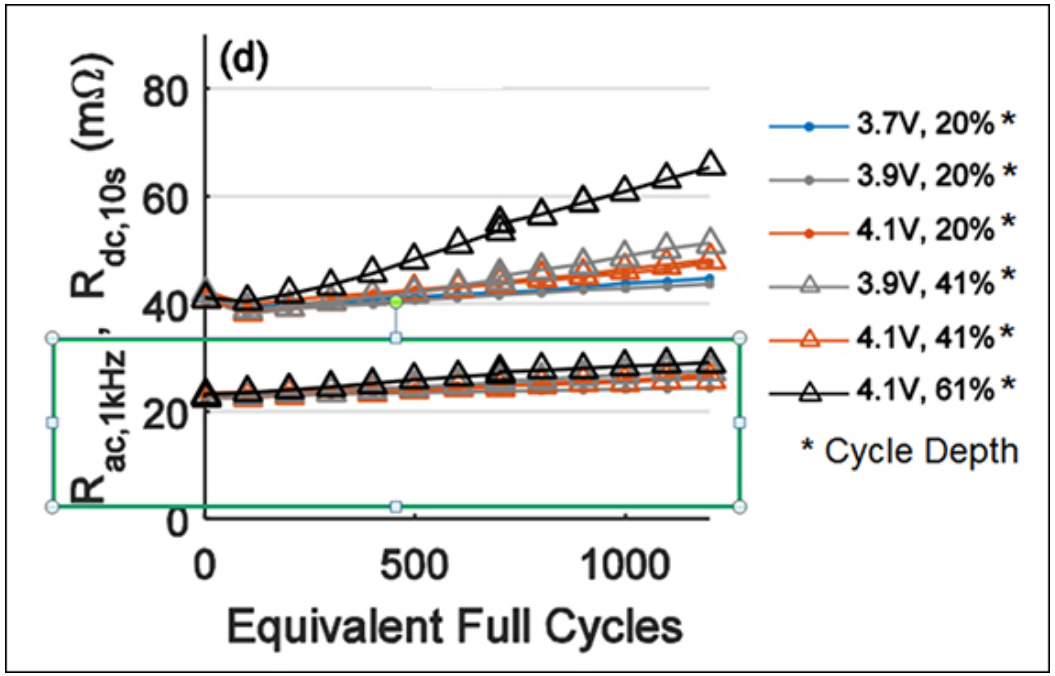




- I attempted to use my jump- starting box to run mobile radio (POTA)
  - Worked fine transmitting 100W for ~15 minutes
  - Radio suddenly turned off when I transmitted and came back on when I released the key.
  - Low-load voltage of the battery was fine to run the radio, but under 22A transmitting load, voltage was dropping to ~9V and lower.
- Some lead acid batteries have IR’s approaching 1 ohm!!!

# Notional Internal Resistances

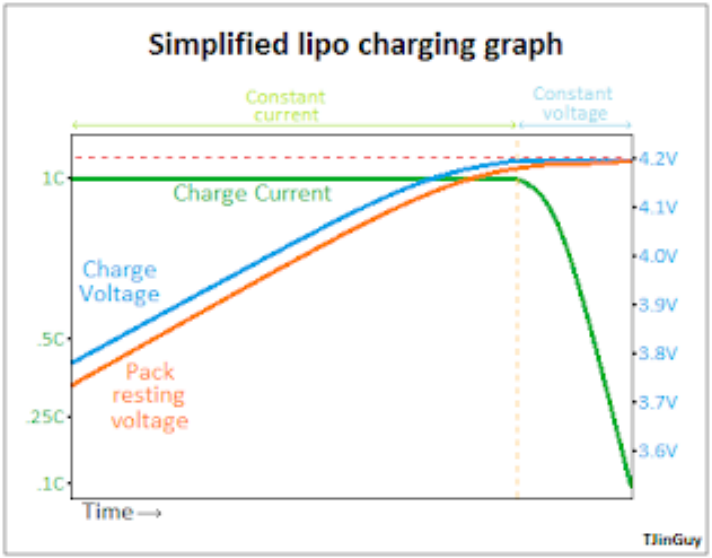
- Keep in mind your standard series and parallel resistance equivalencies apply!
  - Large banks of <u>parallel</u> lead acid cells don't have to worry as much about IR.
- Lead Acid = ~0.2Ω to 1.0Ω and up
- NIMH = ~15mΩ at best
- Lithium = ~3mΩ in many cases

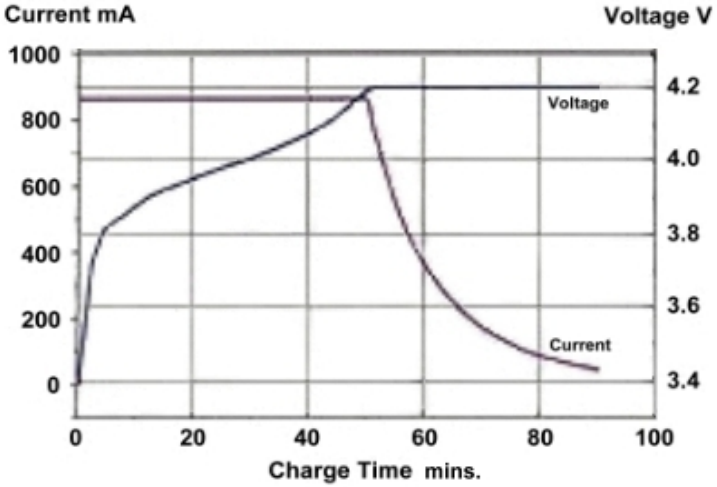



Lead Acid fully charged @ 22A = **4.4 volt drop!**
LiPO fully charged @ 22A = **0.66 volt drop**

# Charging Batteries

- Battery setting and voltage profile is very important!
- Nickel batteries charge at constant voltage until a “peak” voltage is detected as battery is full
- Lithium batteries charge at constant current when mostly empty, but then switch to constant voltage as to not exceed their maximum voltage.
  - This is why your phone charges faster to ~70% to 80% and then “slows down”.



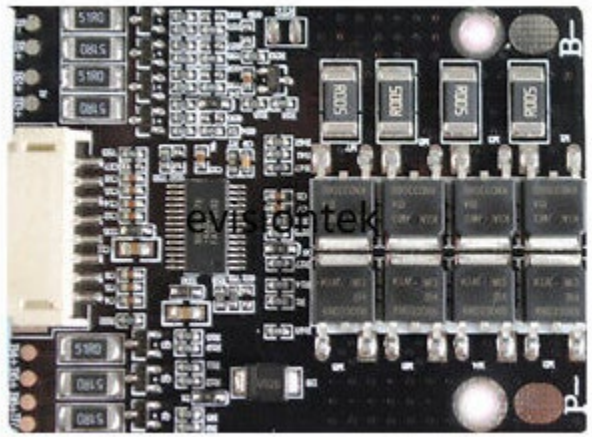



# Hobby Battery Charger

- Quite capable
- Most recent versions are even touch screen
- Incorporate cell balancing and monitoring
  - This is what the multicolored, multiwire port is for.
- One charger can charge MANY different types of batteries.
- ~80 dollars

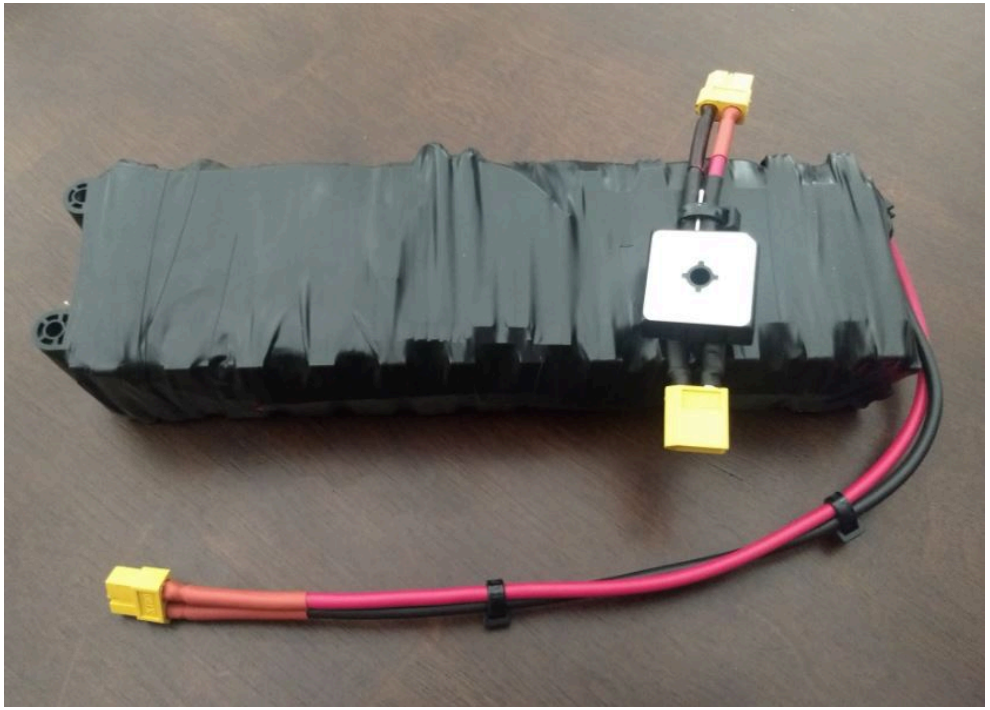
# Battery Balancing

- Packs are made of many cells in series, and each battery cell must stay at similar voltage (typically 0.01 or 0.02 range)
- Imbalanced packs will charge/discharge with increasing disparity
- Pack eventually flames out during use, charging, or even storage!
- Some battery packs come with on-board battery management systems (BMS)

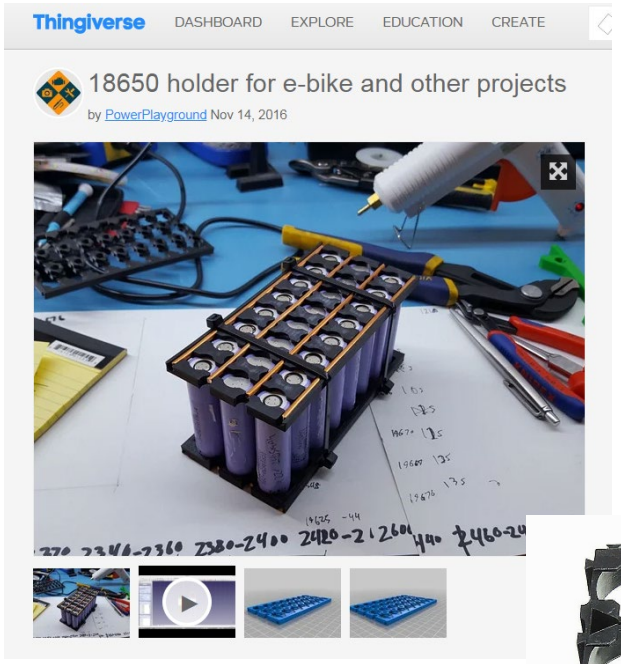
# Making Your own Battery

- Please work safely!
- No metal rings, watches, belts, etc.
- Non-conductive worktable.
- It took considerably longer than I thought
  - With all materials present, I still spent ~6 hours making my first battery.



# Cell Holders

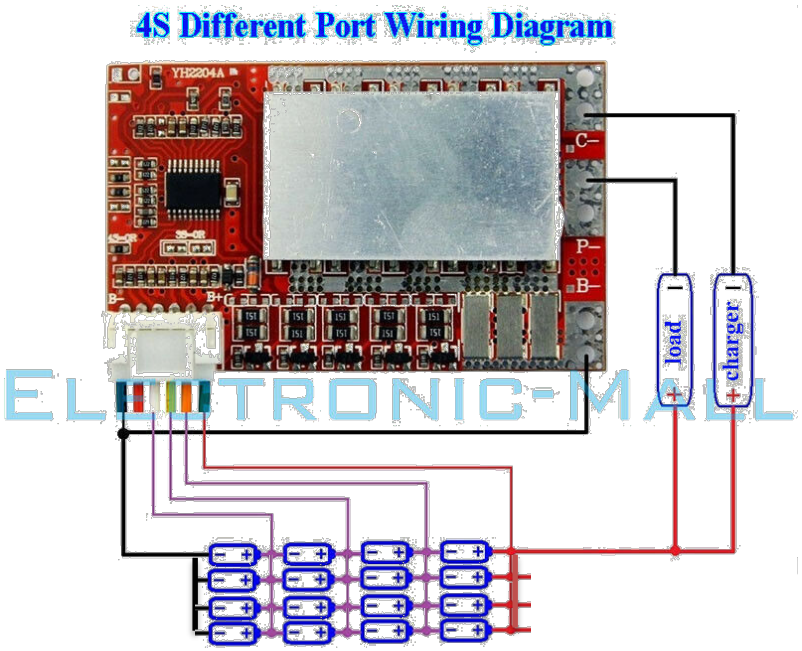
- Begin with something to securely hold your batteries
  - 3D print spacers
  - Many sources for very cheap 18650 holders




10x for 4.98 on Ebay

# Battery Management Systems (BMS)

- BMS boards serve multiple functios:
  - Prevents over charging
  - Disconnects to prevent over discharge
  - Some have current limiting capabilities
  - Most automatically balance packs




Make sure you buy the CORRECT BMS

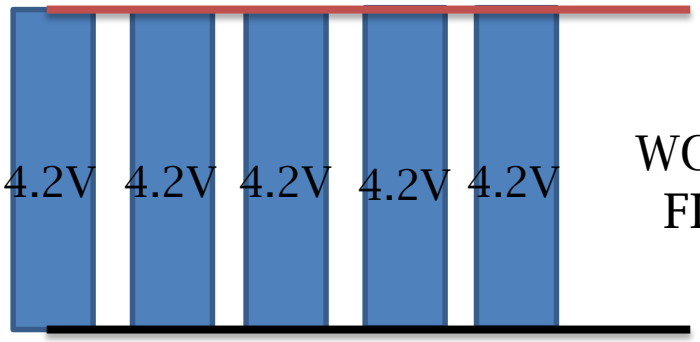
LiPO and LiFePO4 BMS's have different firmware settings! Incorrect application will ruin your battery and may start a fire.

# Wiring Ratings

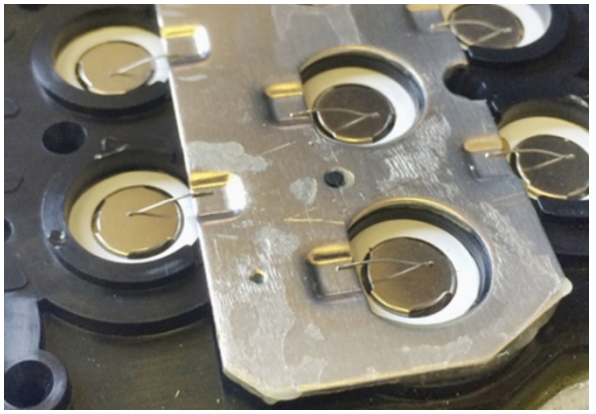
CM/A = circular mils per amp = current density

| AWG MM SWG | Unit | Bare Diameter Inches | Bare Diameter MM | Nearest Equivilent Size AWG | SWG | BWG | Area in Circular Mils | Milli-Ohms Per Foot | Milli-Ohms Per Meter | Max Current @ 60 CM/A | Max Current @ 75 CM/A | Max Current @ 300 CM/A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | SWG | 0.212000 | 5.3848 | 4 | 5 | 5 | 44,942.7 | 0.2307 | 0.7569 | 749.05 | 599.24 | 149.81 |
| 4 | AWG | 0.204000 | 5.1816 | 4 | 5 | 6 | 41,614.8 | 0.2492 | 0.8175 | 693.58 | 554.86 | 138.72 |
| 6 | BWG | 0.203000 | 5.1562 | 4 | 6 | 6 | 41,207.8 | 0.2516 | 0.8255 | 686.80 | 549.44 | 137.36 |
| 4.5 | AWG | 0.192800 | 4.8971 | 4.5 | 6 | 7 | 37,170.8 | 0.2790 | 0.9152 | 619.51 | 495.61 | 123.90 |
| 5 | AWG | 0.182000 | 4.6228 | 5 | 7 | 7 | 33,123.0 | 0.3130 | 1.027 | 552.05 | 441.64 | 110.41 |
| 7 | BWG | 0.179000 | 4.5466 | 5 | 8 | 7 | 32,040.1 | 0.3236 | 1.062 | 534.00 | 427.20 | 106.80 |
| 5.5 | AWG | 0.171693 | 4.3610 | 5.5 | 7 | 8 | 29,477.6 | 0.3518 | 1.154 | 491.29 | 393.04 | 98.259 |
| 8 | BWG | 0.164000 | 4.1656 | 6 | 8 | 8 | 26,895.2 | 0.3855 | 1.265 | 448.25 | 358.60 | 89.651 |
| 6 | AWG | 0.162023 | 4.1154 | 6 | 7 | 8 | 26,250.7 | 0.3950 | 1.296 | 437.51 | 350.01 | 87.502 |
| 6.5 | AWG | 0.152897 | 3.8836 | 6.5 | 9 | 9 | 23,376.8 | 0.4436 | 1.455 | 389.61 | 311.69 | 77.923 |
| 9 | BWG | 0.147000 | 3.7338 | 7 | 9 | 9 | 21,608.4 | 0.4799 | 1.574 | 360.14 | 288.11 | 72.028 |
| 7 | AWG | 0.144285 | 3.6648 | 7 | 9 | 9 | 20,817.6 | 0.4981 | 1.634 | 346.96 | 277.57 | 69.392 |
| 9 | SWG | 0.144000 | 3.6576 | 7 | 9 | 9 | 20,735.4 | 0.5001 | 1.641 | 345.59 | 276.47 | 69.118 |
| 7.5 | AWG | 0.136459 | 3.4661 | 7.5 | 9 | 10 | 18,620.5 | 0.5569 | 1.827 | 310.34 | 248.27 | 62.068 |
| 10 | BWG | 0.134000 | 3.4036 | 8 | 10 | 10 | 17,955.5 | 0.5775 | 1.895 | 299.26 | 239.41 | 59.852 |
| 3.35 | MM | 0.131890 | 3.3500 | 8 | 9 | 10 | 17,394.3 | 0.5961 | 1.956 | 289.91 | 231.92 | 57.981 |
| 8 | AWG | 0.128500 | 3.2639 | 8 | 10 | 10 | 16,511.8 | 0.6280 | 2.060 | 275.20 | 220.16 | 55.039 |
| 10 | SWG | 0.128000 | 3.2512 | 8 | 10 | 10 | 16,383.5 | 0.6329 | 2.076 | 273.06 | 218.45 | 54.612 |
| 3.15 | MM | 0.124016 | 3.1500 | 8 | 10 | 11 | 15,379.4 | 0.6742 | 2.212 | 256.32 | 205.06 | 51.265 |
| 8.5 | AWG | 0.121253 | 3.0798 | 8.5 | 10 | 11 | 14,701.9 | 0.7053 | 2.314 | 245.03 | 196.02 | 49.006 |
| 11 | BWG | 0.120000 | 3.0480 | 9 | 11 | 11 | 14,399.6 | 0.7201 | 2.362 | 239.99 | 191.99 | 47.999 |
| 3 | MM | 0.118110 | 3.0000 | 9 | 10 | 11 | 13,949.6 | 0.7433 | 2.439 | 232.49 | 185.99 | 46.499 |
| 11 | SWG | 0.116000 | 2.9464 | 9 | 11 | 11 | 13,455.6 | 0.7706 | 2.528 | 224.26 | 179.41 | 44.852 |
| 9 | AWG | 0.114400 | 2.9058 | 9 | 11 | 11 | 13,087.0 | 0.7923 | 2.599 | 218.12 | 174.49 | 43.623 |
| 2.8 | MM | 0.110236 | 2.8000 | 9 | 11 | 12 | 12,151.6 | 0.8533 | 2.800 | 202.53 | 162.02 | 40.505 |
| 12 | BWG | 0.109000 | 2.7686 | 10 | 12 | 12 | 11,880.7 | 0.8728 | 2.863 | 198.01 | 158.41 | 39.602 |
| 9.5 | AWG | 0.107979 | 2.7427 | 9.5 | 11 | 12 | 11,659.1 | 0.8893 | 2.918 | 194.32 | 155.46 | 38.864 |
| 2.65 | MM | 0.104331 | 2.6500 | 10 | 11 | 12 | 10,884.5 | 0.9526 | 3.125 | 181.41 | 145.13 | 36.282 |
| 12 | SWG | 0.104000 | 2.6416 | 10 | 12 | 12 | 10,815.7 | 0.9587 | 3.145 | 180.26 | 144.21 | 36.052 |
| 10 | AWG | 0.101900 | 2.5883 | 10 | 12 | 12 | 10,383.3 | 0.9986 | 3.276 | 173.06 | 138.44 | 34.611 |
| 2.5 | MM | 0.098425 | 2.5000 | 10 | 12 | 13 | 9,687.20 | 1.070 | 3.512 | 161.45 | 129.16 | 32.291 |
| 10.5 | AWG | 0.096158 | 2.4424 | 10.5 | 12 | 13 | 9,246.10 | 1.121 | 3.679 | 154.10 | 123.28 | 30.820 |

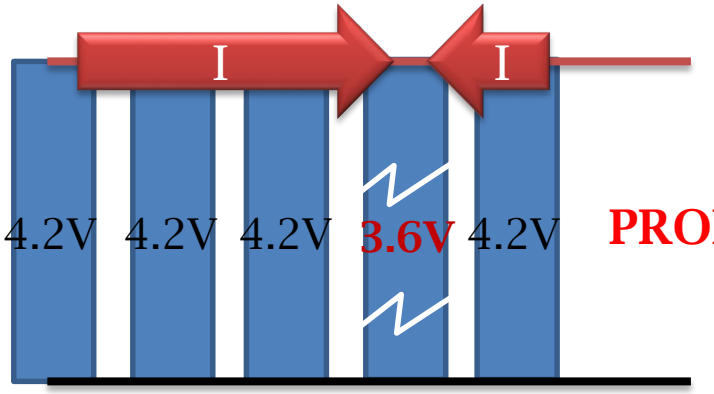
# Risks of Parallelization




WORKS FINE!



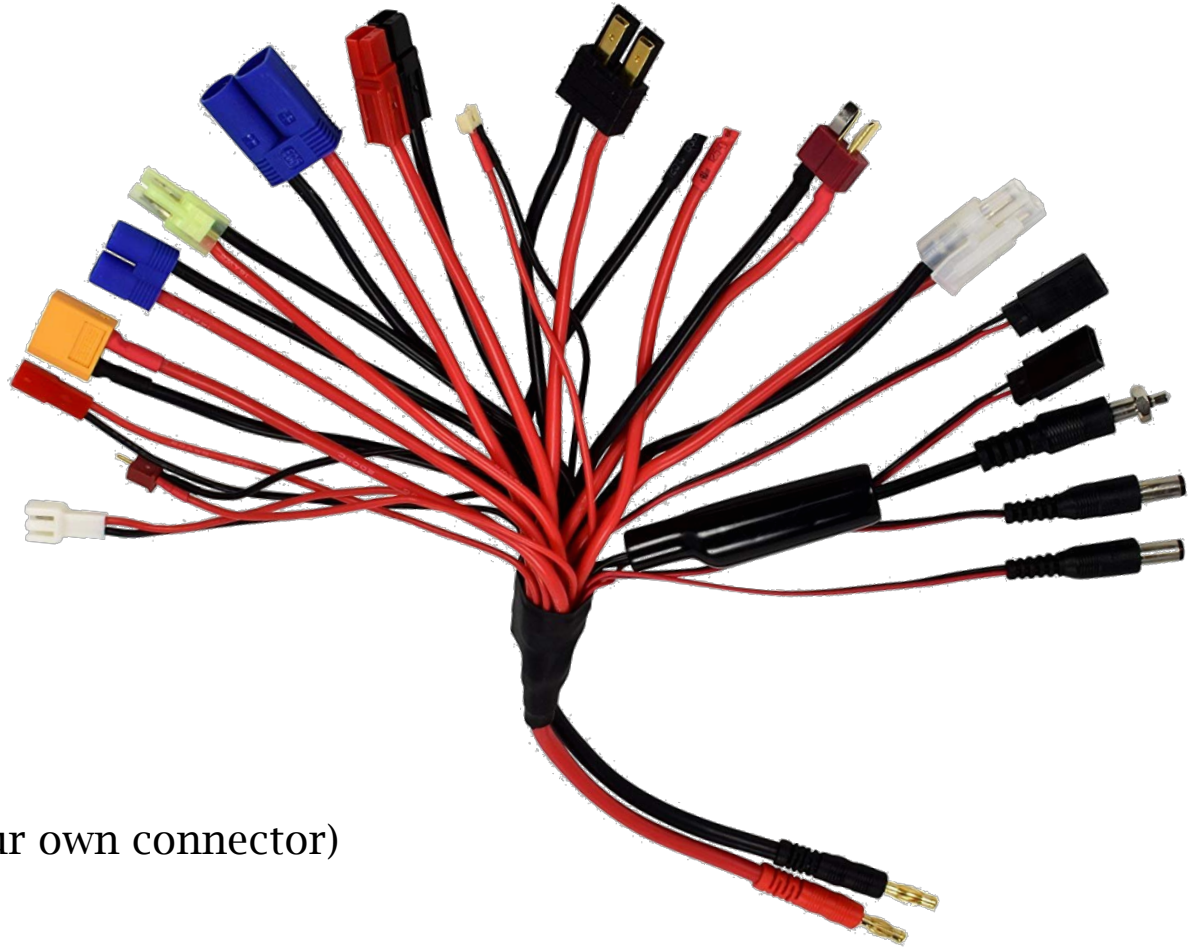
Tesla battery cells are connected through small fuse wires to the bus bars




**PROBLEM!**

If **one** cell goes bad, it will bring the other cells down with it
…Often with very high current flow and heat.

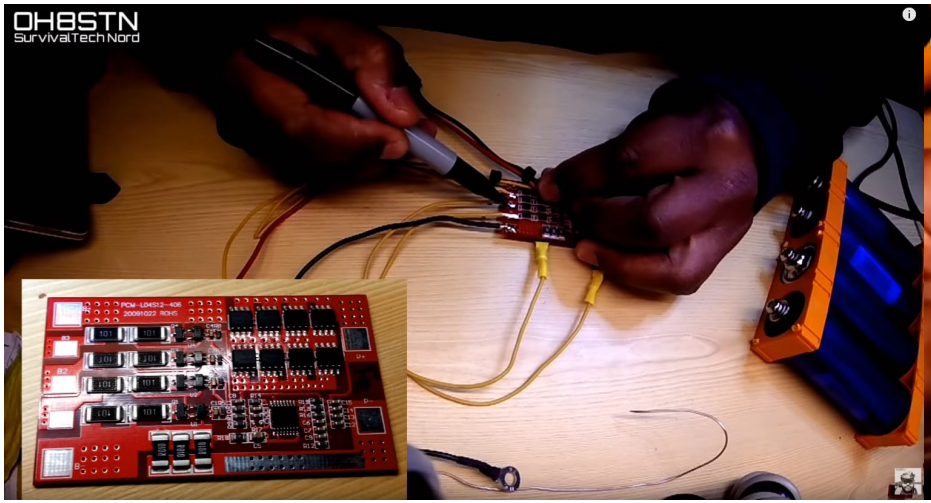
# Battery Charger Connectors



- The “squid” has:
  - TRX
  - XT60
  - T-Plug
  - JST
  - EC3
  - EC5
  - Mini Tamiya
  - Sermos
  - Tamiya
  - Futaba Receiver
  - Futaba Transmitter
  - Glow Ignitor
  - JR Receiver
  - JR Transmitter
  - Micro Connector
  - Micro Ultra Plug Style
  - Pico Connector
  - Pigtails (to solder on your own connector)

AMAZON purchase link

# Video Tutorials for portable LiFePO4 Batteries




[Portable Ham Radio Battery Pack | DIY LiFePO4 QRP 128wh]


[Portable Ham Radio Battery | DIY LiFePO4 QRP 56wh]

[LiFePo4 battery and solar setup for ham radio]

# GO USE YOUR BATTERY

Thom W8TAM
K-3314
Ionia Rec Area
Michigan


Mobile HF Station
LiIon battery (4S6P)
10-21-19
University of Oklahoma
Aerospace Capstone Class
SOUTH CANADIAN
AMATEUR RADIO SOCIETY
Thank You