A Complete Off-Grid Station

Presented by Ethan H. Poole / KW4EK

My Station


KW4EK
7.076.000
7.076 000
2016 Oct 01
01:40:27
2016-10-01 01:40:27 UTC
7.074.500
acer
SPELLING ALPHABET
Letter
Code word
Charlie
Delta
Echo
Foxtrot
Golf
Hotel
India
Juliett/Juliet
Kilo
Lima
Mike
November
Oscar
Papa
Quebec
Romeo
Sierra
Tango
Uniform
Victor
Whiskey
X-ray/Xray
Yankee
Zulu
1:40
SWR & POWER METER
140~525
YAESU
MFJ
STAEDTLER
Mars plastic

Objectives:

- Steady source of clean and stable 12VDC power with no, or negligible, RFI hash.
- Fully uninterruptible power source with extended uptime and no interruption in service or capabilities.
- Goal of better than 12 hours typical runtime at full power with typical transmit duty cycle.
- Ability to quick charge when on generator power (charge from 20% to >90% in under 4 hours).
- Must support a complete station, including a Windows PC and dual 27" HD Monitors plus basic task lighting and other accessory loads.

First figure out our power budget:

Device	Standby / Idle	Peak
FT-950 HF Radio, 100W	2.2A	22A*
FT-8900 Quad Band Radio, 50W	0.25A	8.5A*
NUC PC Quad Core 2GHz Atom Low Power PC, Windows 8.1	6W (0.5A)	10-12W (1.0A)*
Dual 27" HD (1920x1080p) Monitors	0.1W (0.01A)	40-80W (5A Typical)*
Task Lighting, 3.6W LED Desklamp	0.3A	0.3A*
MFJ-929 Automatic Antenna Tuner	0.05A	0.5A

**DC-DC Converters in use, current varies up to +30% with battery state.*

Some Basic Figures:

- Typical standby load with both monitors off is **3A**.*****
- Typical standby load with both monitors in use is **8A**.*****
- Typical averaged load on transmit using HF radio at **100W**: **FM/Digital 22A**, **SSB 15A plus up to 6A** accessory loads (namely PC and monitors).*****
- Typical load on transmit using VHF/UHF quad-band radio at **50W FM** is about **8.5A** plus up to **8A** accessory loads (HF radio, PC and monitors).*****
- **Working Numbers: 3A Idle, no monitors; 8A Idle, with monitors; about 30A worst case transmit at 100W FM using HF radio plus PC and monitors.***

**loads may increase by up to ~30% on depleted battery state*

So let us consider our 12 hour operating goal...

Let us assume that all 12 hours are active operation with the PC and both monitors in active use and that we are, worst case, operating the HF radio at 100W FM or digital with an aggressive 25% duty cycle.

- **9 hours (75%)** will consist of the idle load of **8A**, totaling about **72 amp-hours**.
- **3 hours (25%)** will consist of the equivalent of continuous key-down transmission with a load of about **30A**, totaling **90 amp-hours**.
- This totals **162 amp-hours** in a worst case 12 hours. Fortunately, we are unlikely to really exceed this even at a more realistic 50% duty cycle with SSB or reduced power FM/Digital.

So let us also consider an alternate 12-hour goal...

Let us now consider a second aggressive scenario in which we seek to operate for at least 12 hours using HF at 100W SSB or reduced power FM or Digital at a maximum of 50W, but this time with a 50% duty cycle. We will again assume full power operation with the PC and both monitors fully powered for this 12 hours.

- **6 hours (50%)** will consist of the full idle load of **8A**, totaling about **48 amp-hours**.
- **6 hours (50%)** will consist of the equivalent of continuous key-down transmission with a load of about **21A** (15+6A), totaling **126 amp-hours**.
- This totals **174 amp-hours** in an aggressive operation with a 50% duty cycle over 12 hours.

What do we need at a minimum for our battery?

In our unrealistic worst case **12 hour shift** we figured a simplistic worst case demand of **174Ah**, which was a rather aggressive worst case, but nobody complains about their batteries lasting longer than expected!
You will want to include a 25% reserve in addition to this figure (e.g. **174Ah+25%=218Ah**) to ensure the battery never discharges below 20% so as to preserve battery service life.

For this application **I have selected a pair of 6V 230Ah Golf Cart batteries** (Duracell/Deka GC2 size) which are true deep cycle flooded lead acid batteries providing me **230Ah total capacity at 12VDC**. In the future I will likely double this to 460Ah.

Duracell EGC2 / East Penn Deka GC15 Golf Cart Batteries

Two by 6V@230Ah giving 12V@230Ah

I added **Water Miser™** vent caps to reduce water loss during charging and transport.

These vent caps reduce water loss by condensing aerosol spray back into droplets that drip back into the battery cell rather than venting while still allowing explosive gasses to escape freely.

Batteries installed in battery box for containment and provides a mount point for smart charger, disconnect switch, 150A circuit breaker and 100A fuse per external power cable connection (75A Anderson Powerpoles).

Caveats Concerning Battery Runtime Calculations

Our simplified capacity and runtime estimates are only valid for batteries where the expected average peak discharge rate is typically on the order of 1/10th, or a lesser discharge rate, of the battery's rated **20 hour Amp-hour specification (C/20=230Ah)** when using flooded lead acid batteries (or about 1/4th if AGM).

The greater the discharge rate the less available capacity there is to sustain that load. A battery's amp-hour specification is typically based upon a 20 hour discharge (**C/20**) at a steady current. With a sufficiently large battery this unusable capacity largely falls within the 20% reserve capacity that we initially set aside when determining minimum capacity.

The Consequences of Peukert's Law On Available Battery Capacity Relative to Load

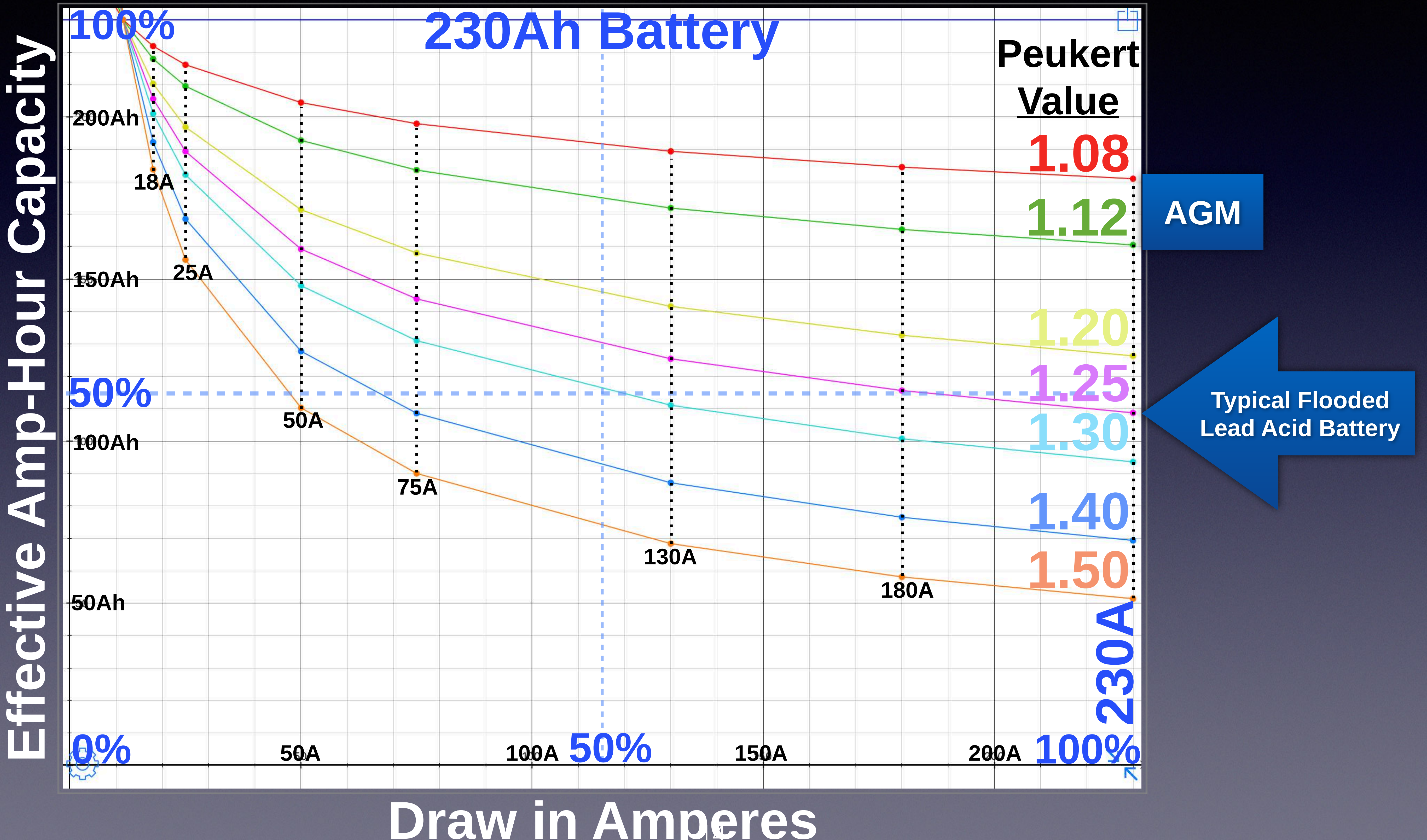
Using our **230Ah battery bank** as an example, below is the actual available capacity at various amp loads.

Discharge Rate (Amps)	**C-Rate** (C/20=230Ah)	**Steady-State Discharge Duration**	**Available Capacity (C)**
11.5A	**C/20**	**20 hours**	**230Ah**
25A	**C/7.2**	**7 hrs, 12 mins**	**180Ah**
75A	**C/2**	**2 hours**	**150Ah**
130A	**C/1**	**1 hours**	**130Ah**

This is why smaller batteries often perform poorly and deliver less runtime under heavy loads than their amp-hour capacity would tend to suggest.

Examples of the Effect of Peukert's Law and Various Peukert Values on Effective Battery Capacity

Our battery has a typical Peukert value of around 1.25 (1.25~1.27)



So...We have a battery, now to keep it charged

We know we want clean and reliable power without RFI hash and which will maximize battery lifetime, minimize water (electrolyte) loss, quick charge the battery when running off generator power in an emergency, and is appropriately sized for our battery.

After much research I settled on the **Progressive Dynamics PD9260**, a 60A 4-stage smart charger/ maintainer that includes a **float/storage stage (13.2V)**, a **normal float charge stage (13.6V)**, and an **equalization and boost** (quick charge) **stage (14.4V)** that will automatically maintain the battery without any user intervention. Research also showed no appreciable RFI hash issues reported with the PD9200 series by other amateur radio operators.

The Progressive Dynamics PD9260

Automatic RV Smart Charger/Battery Maintainer

4-Stage Smart Charger with 60A maximum charge rate

So, now that we have a reliable 12V power source... How do we go about distributing power to our loads?

We use the West Mountain Radio **RigRunner** distribution strips and Anderson Powerpole quick connects (including 75A Powerpoles for the 100A main power buss direct from the battery).

The Station PC (Jetway JBC320U93W-2930)

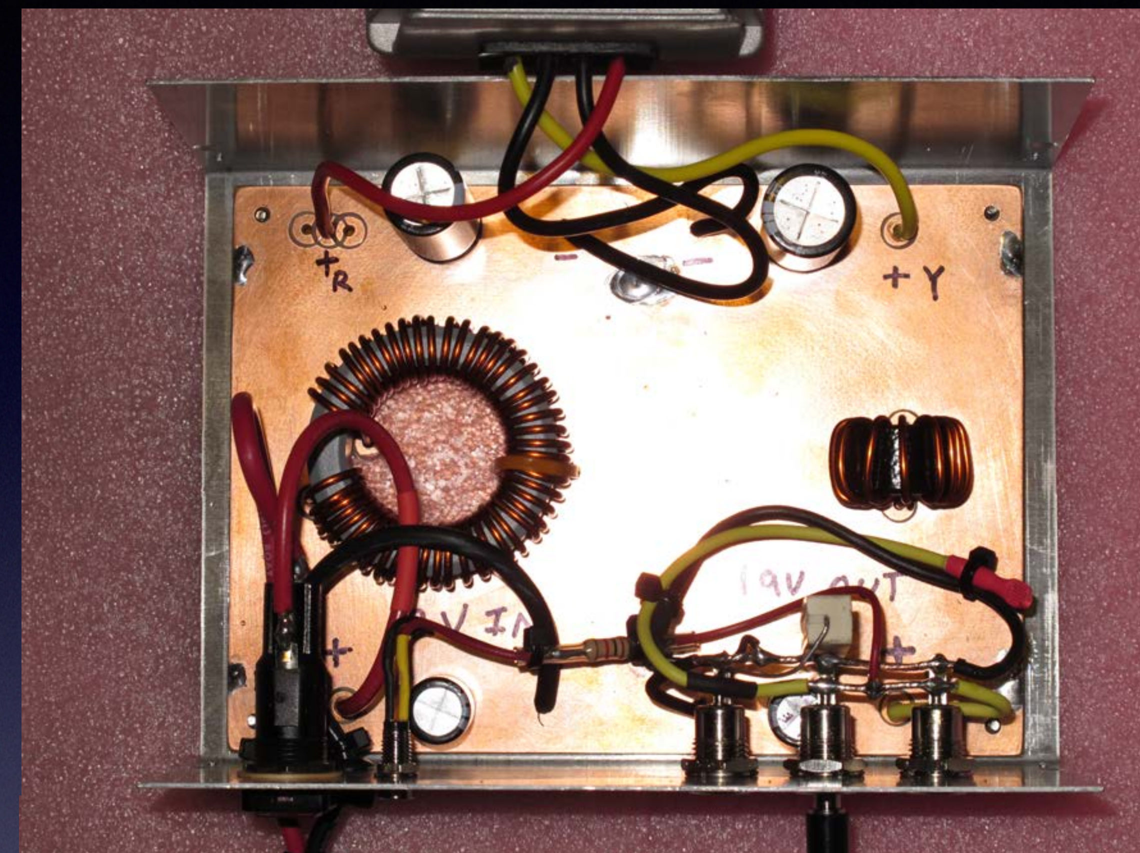
- Intel NUC Quad-core 2GHz Atom CPU
- 8GB DDR3 RAM SODIMM
- SSDs: 240GB 2.5" SATA, 64GB mSATA
- Dual HD (1920x1080p) HDMI Video
- Dual Gigabit Ethernet Ports
- WiFi 2.4GHz plus Bluetooth
- USB: 3x USB 2.0, 1x USB 3.0
- Hardware serial port (COM1)
- Typical Power Use: **6-12W, 9-24VDC**

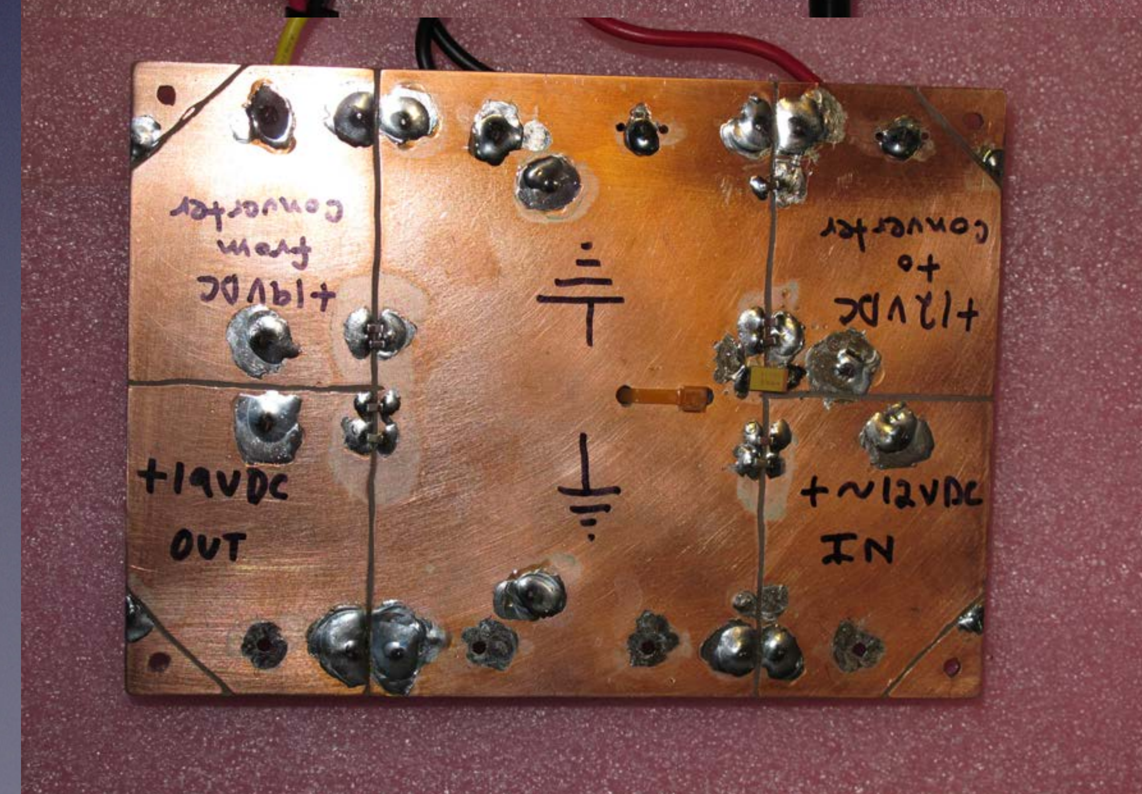
The First Big Challenge - Monitors!

- To have a complete all-modes station we need a PC and a PC needs a **monitor**! Preferably two!
- All monitors in the desired size class (around 24-27") typically require **19VDC** to power them.
- Only one way to solve this dilemma -- we need a **DC-DC Boost Converter** to create 19VDC from ~12VDC.
- Thankfully eBay has ready made converter modules for reasonable prices direct from China.
- The only catch...the fast switching spikes were producing a fair bit of RFI hash on MF and HF frequencies, including some LC ringing at ~80MHz.
- We need some filtering to clean things up!

The 19V DC-DC Boost Converter

Rated Output: 19VDC at 5A or 95W





The Next Challenge - Part I
Batteries Have a Wide Voltage Spread

- The reality is lead acid battery voltage varies considerably from a nearly dead battery to full float voltage (10.5V to 14V, not including wiring losses).
- Radios tend to fair best with stable input voltages within well defined ranges that have minimal ripple.
- These requirements are usually easily met during the first half of a lead acid battery's discharge curve, but voltage drops faster and varies more with varying load in the latter half of a lead acid battery's capacity.
- Drooping voltage and excessive ripple with load variation can lead to transmit power reductions and unwanted signal artifacts like IMD.

The Next Challenge - Part II

Batteries Have a Wide Voltage Spread

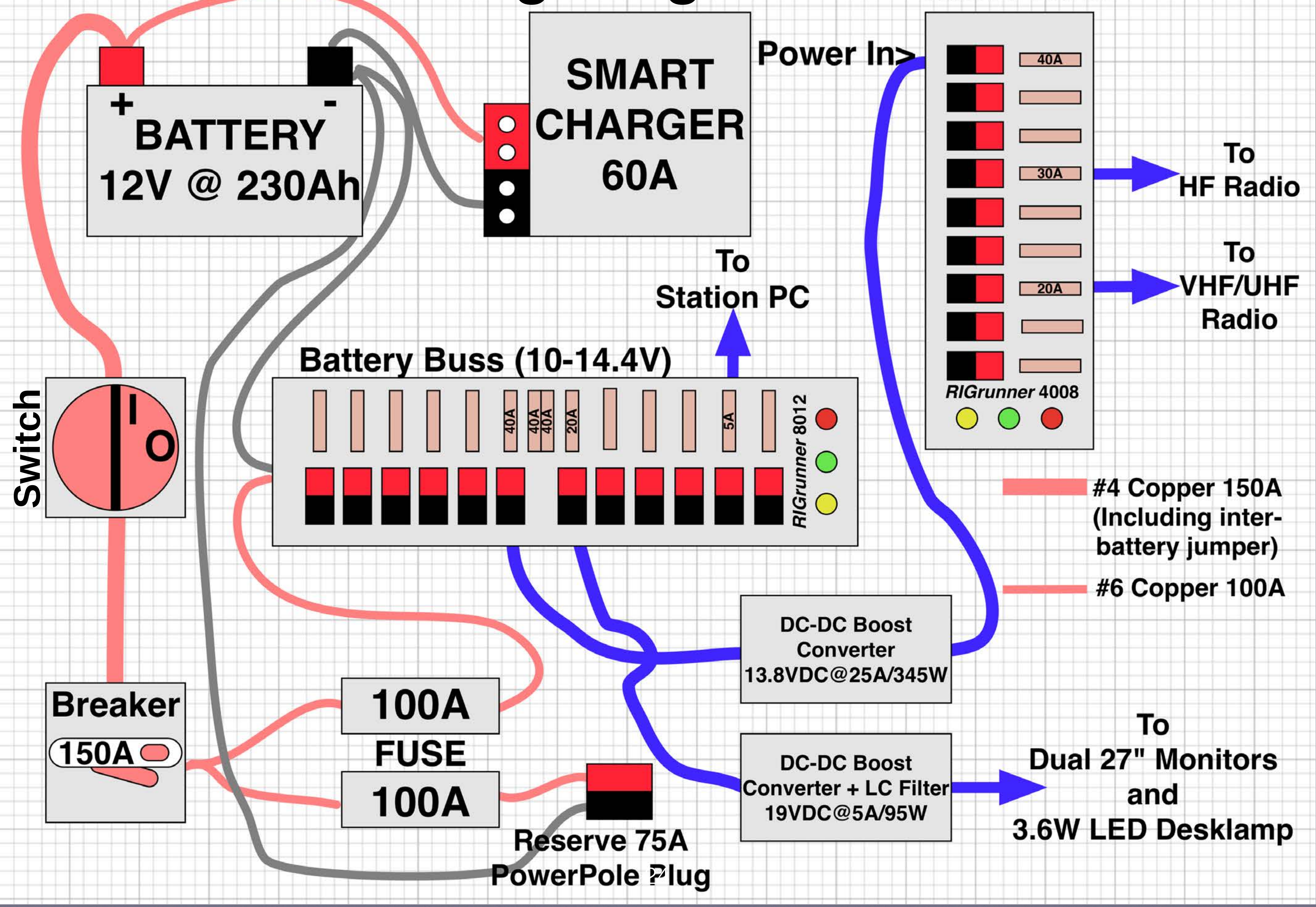
- Some transceivers handle low input voltages and/or load induced input ripple better than others, but all have a limit at some point and will eventually scale back power with low voltage. They may also glitch, hang, or shutdown unpredictably at some point as well.
- Fortunately, there is a simple solution -- use another DC-DC Boost Converter to guarantee that the radio(s) will always see a stable input voltage of 13.8VDC, or more, regardless of the battery's state of charge.
- Once again, eBay and Amazon abound with reasonably priced DC-DC Converters direct from China.
- This time RFI hash was minimal in use and no major effort to correct such was deemed necessary.

The Next Challenge - Part III
The Rise of the DC-DC Boost Converter

- **Input:** 9-13.8VDC, up to 38A
- **Output:** 13.8VDC, 25A nominal, 28A max., 345W

*If input voltage exceeds 13.6V then output equals input plus 0.2VDC (e.g. 14.4V in, 14.6V out)

Wiring Diagram



Tasks to Be Continued...

Build a *"**Battery Minder**"* to monitor battery voltage and sound an alarm on a high or low battery voltage to alert me to tend to the battery. Mostly, it is a reminder to turn the charger back on if I forget to do so after my bi-weekly tests where my station runs exclusively on battery for 6-12 hours as a system test. I will likely implement this using simple comparators to set the alarm threshold voltages and a 555 timer IC to pulse the alert buzzer.

In the future, consider adding a 500-1000 watt solar charger to the setup (after our move to Florida). This would allow full operation in the absence of utility power even without a functioning generator or fuel.

My Reflections...

- Absolutely take plenty of time upfront to **do your research and think your project through**. Such pays big dividends later and saves you money by avoiding unnecessary dead ends.
- If your budget allows, **build the setup you want the first time around** rather than waste money on cheaper alternatives that you plan to upgrade later. But, if you must, prioritize according to your budget.
- You will pay a significant premium for such, but I really suggest using <u>Marine Grade</u> wiring due to its superior flexibility and heavy insulation. But, if necessary, you can save a fair bit by using regular electrical grade wire of identical gauge and insulation temperature (use 105°C or 90°C rated insulation).

Q&A Period

"If you've got questions...
We've got blank stares."

—Radio Shack circa late 1990's

QRT

–de KW4EK

Addendum

Additional Reading and Reference Material

Types of Flooded Lead Acid Battery

- **Starter or SLI** (**S**tarter, **L**ighting, **I**gnition) - Ideal for brief duration discharges and optimized for very high current demands. Should never be discharged by more than **10-20%** or life is significantly shortened. Typically used to start combustion engines. Always lists a Cranking Amps specification but rarely states Amp-hours.
- **Hybrid or Dual Purpose** - Often labeled as *"Marine Deep Cycle"*, or similarly misleading labels. These batteries have a construction that is a compromise between Starter and Deep Cycle batteries and may be discharged by no more than **50%** or life is greatly shortened. Can be differentiated from true Deep Cycles by the presence of a Cranking Amps specification along with Amp-hours.
- **Deep Cycle** - True Deep Cycle batteries are the toughest of all lead acid batteries with heavy, thick, lead plates and may be repeatedly discharged by up to **80%** without undue wear and still deliver many hundreds of charge-discharge cycles. These never list a Cranking Amps specification, only Amp-hours. **Well suited to Amateur Radio use** where weight is not a major concern and/or low cost is a significant factor.

Types of Sealed Lead Acid (SLA) Battery

These batteries are sealed and are essentially leak free even when punctured, may be used in any orientation, and only vent explosive gasses if severely overcharged. All are inherently maintenance free.

- **AGM or Absorbed Glass Mat** - These are very tough batteries with very low internal resistance that are well suited to high current demands and deep cycle discharges with very good recovery from deep discharge cycles. Such are frequently used for uninterruptible and emergency power applications wherever flooded batteries are deemed less than ideal for various reasons. About three to four times the cost of comparable capacity flooded lead acid batteries.
- **Gel Cell** - These use a gelled electrolyte and are also leak free and usable in any orientation. However, the greater immobilization of their gelled electrolyte and higher internal resistance limits them to relatively low discharge rate applications (unlike AGM). Specialized charging gear is required to safely charge gel cells. Slightly higher cost than AGM, but wide variety in smaller packages (more limited in higher capacities where AGM dominates). For these reasons, **AGM** is generally the preferred **SLA** battery for Amateur Radio use.

Alternative Battery Options (non lead acid)

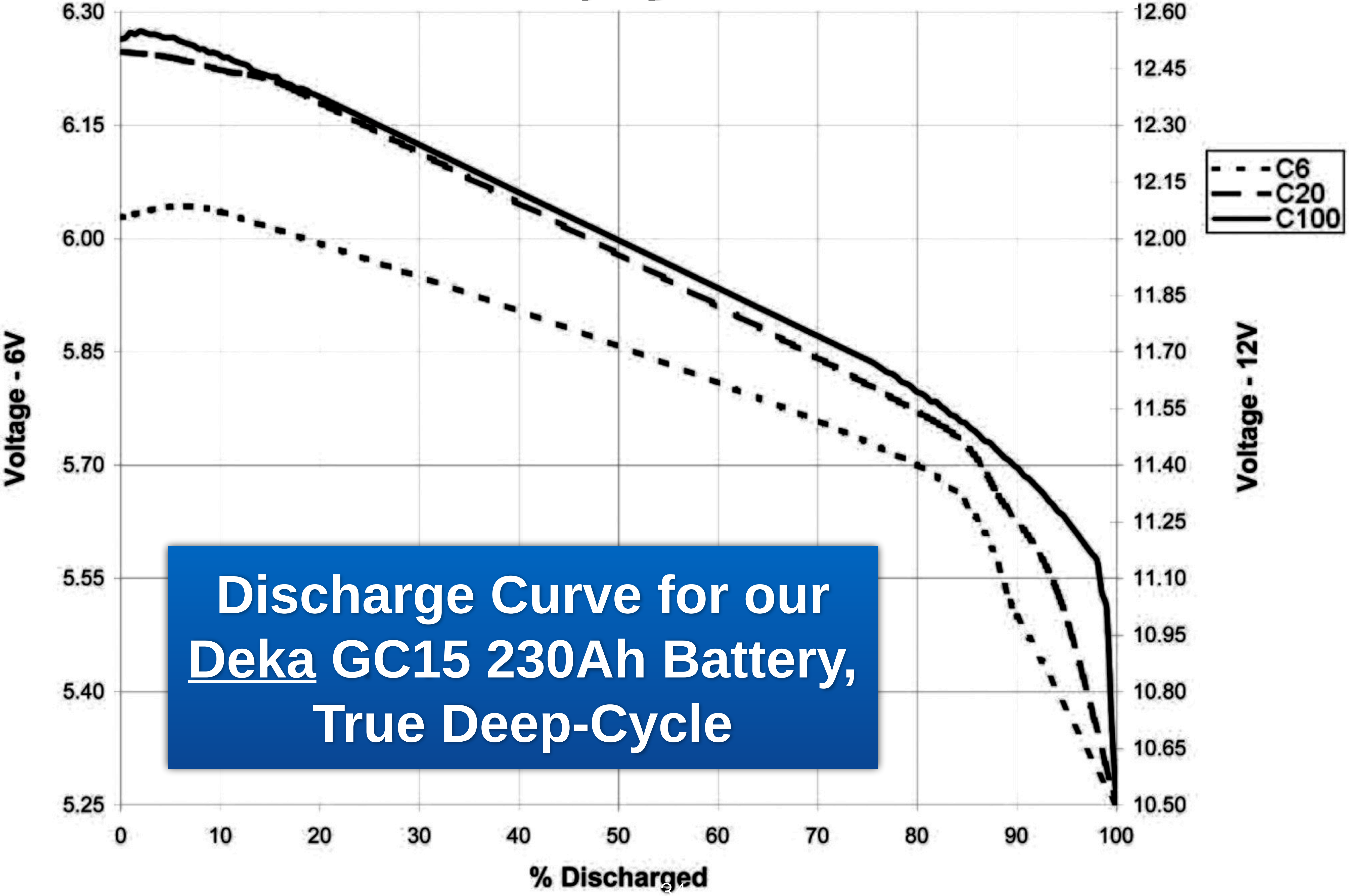
- **LiFePO4 or Lithium Iron Phosphate** - Although quite expensive for a given capacity they are exceptionally light for their amp-hour capacity, only moderately heavier than a comparable Lithium Ion or Polymer battery, and are drop-in replacements for sealed lead acid battery applications, like AGM, with essentially identical charging voltages and immune from the thermal runaway issues of Lithium Ion/Polymer batteries. Extreme lightweight and ease of charging coupled with deep discharge cycles makes them ideal where portability matters most.
- **Lithium Ion and Polymer** - These are extremely lightweight and compact battery packs with very high energy densities. May wish to avoid chemistries that include Cobalt as they are much more prone to thermal runaway. These batteries require custom charging circuits and also require added inline circuitry to insure that they can never be over-discharged lest thermal runaway is possible. Cell voltage range varies from about 3.2V when discharged to as high as 4.2V when fully charged, spending much of their time around 3.6V. Due to this broad voltage range a 3-series pack can range from 9.6V to 12.6V, which means your radio equipment may require the addition of a DC-DC Converter to transform this broad voltage range into a range better suited to your radio's power input requirements.

Deka GC15 Deep Cycle Battery (230Ah)
State of Charge vs. Voltage (measured at battery)

SoC / Load	C/100 (~3A)	C/20 (11.5A)
100%	12.60V+	12.55V+
90%	12.50V	12.45V
80%	12.35V	12.33V
70%	12.25V	12.20V
60%	12.10V	12.07V
50%	12.00V	11.95V
40%	11.90V	11.80V
30%	11.75V	11.65V
20%	11.60V	11.55V
10%	11.40V	11.25V
0%	10.50V	10.50V

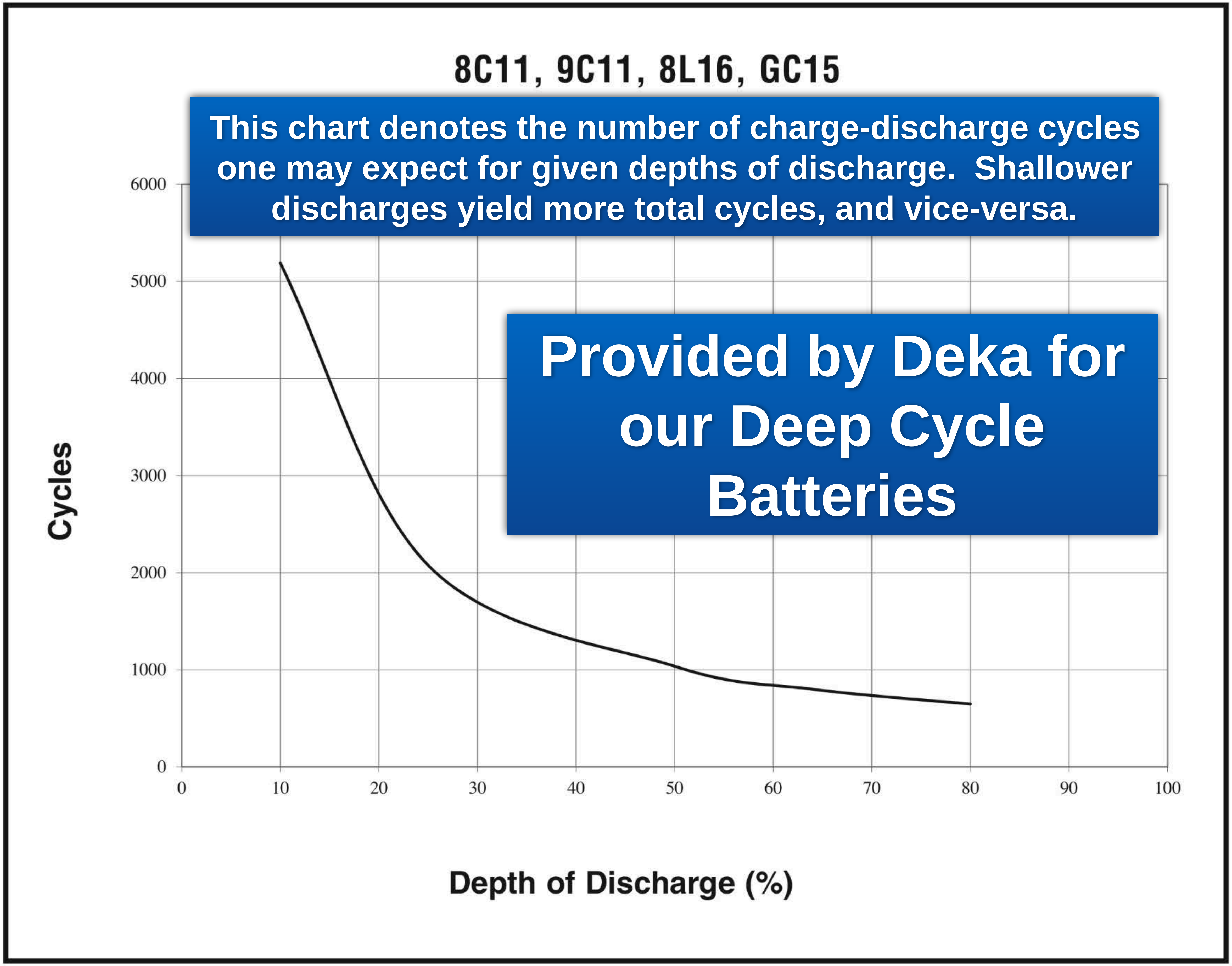
***Taken from chart in following slide.**

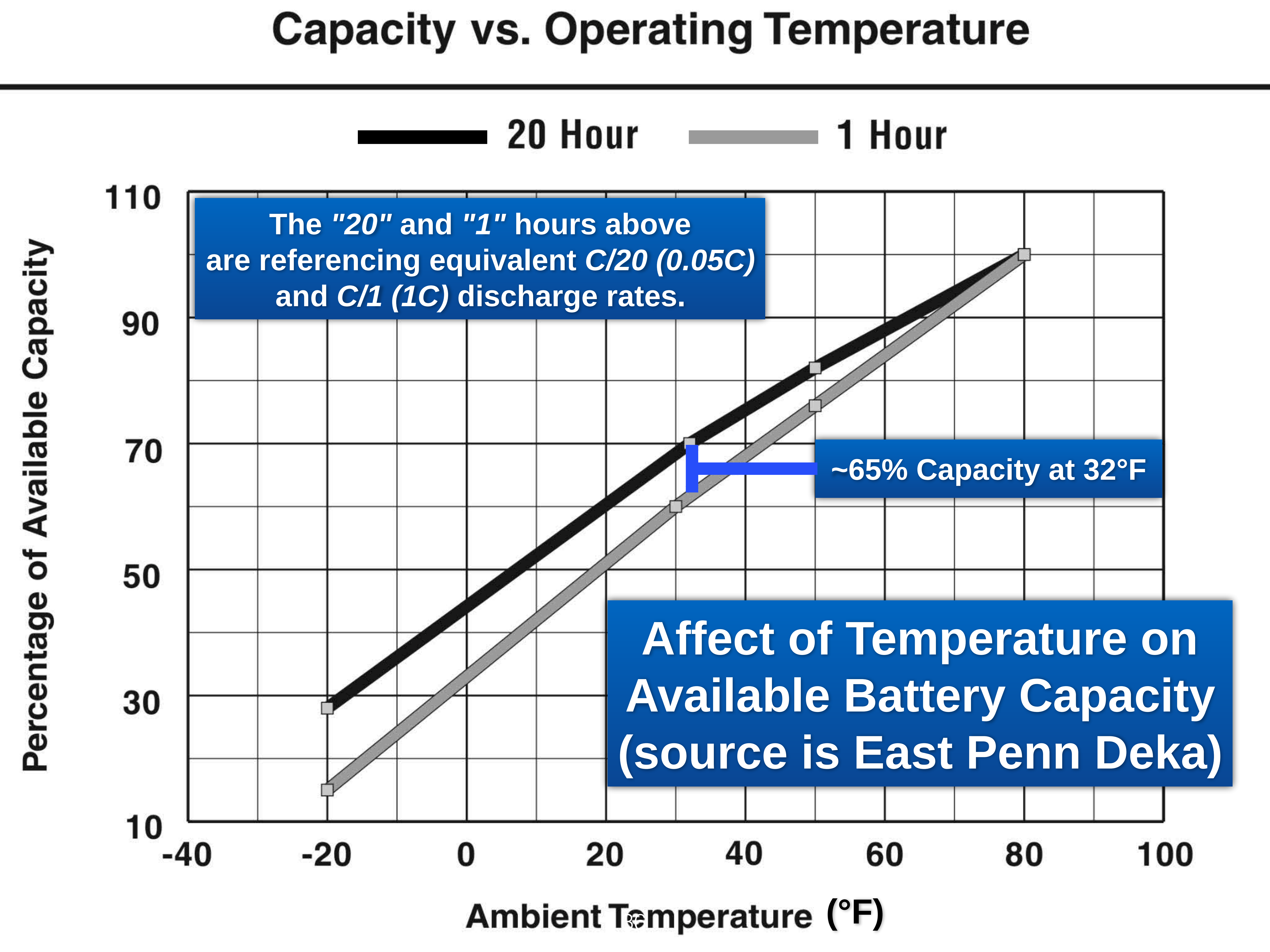
Discharge Voltage Curves for East Penn Deka Deep Cycle Lead Acid Batteries



Discharge Curve for our Deka GC15 230Ah Battery, True Deep-Cycle

Cycle Life vs Depth of Discharge at +25°C (77°F)*





Capacity vs. Operating Temperature
20 Hour
1 Hour
The "20" and "1" hours above
are referencing equivalent C/20 (0.05C)
and C/1 (1C) discharge rates.
~65% Capacity at 32°F
Affect of Temperature on
Available Battery Capacity
(source is East Penn Deka)
Percentage of Available Capacity
110
90
70
50
30
10
-40
-20
0
20
40
60
80
100
Ambient Temperature (°F)

Deka SOLAR

PHOTOVOLTAIC BATTERIES

FLOODED – MONOBLOC

DEKA SOLAR FLOODED MONOBLOC BATTERIES **are designed to offer reliable, low-maintenance power for renewable energy applications where frequent deep cycles are required and minimum maintenance is desirable.**

The *DEKA SOLAR FLOODED MONOBLOC* include 3 cell (6 volt) and 6 cell (12 volt) photovoltaic batteries.

FEATURES & BENEFITS	
Case and Cover	Heat sealed, lightweight, crack resistant, molded high impact polypropylene.
Separators	Microporous polyethylene envelopes/separators
Retainers	20 mil glass mat (DC27- 10 mil).
Positive and Negative Plate	Antimony flat plate
Specific Gravity (fully charged)	1.275 @ 25°C (77°F).
Cell Connections	TP welded (through partition)
Vents	Individual quarter - turn bayonet vent cap (DC27 - removable pod vents, 3 cells per vent)
Self discharge	4% per month
Cycle life for 8C11, 9C11, 8L16, GC15	700 cycles @ 60% DOD, 1150 cycles @ 20% DOD (Number of cycles based on 75 amp discharge to 1.75 vpc @ 32°C (90°F)
Cycle life for DC27	200 cycles @ 80% DOD, 900 cycles @ 20% DOD (Number of cycles based on 25 amp discharge to 1.75 vpc @ 29°C (85°F)

Deka SOLAR PHOTOVOLTAIC BATTERIES

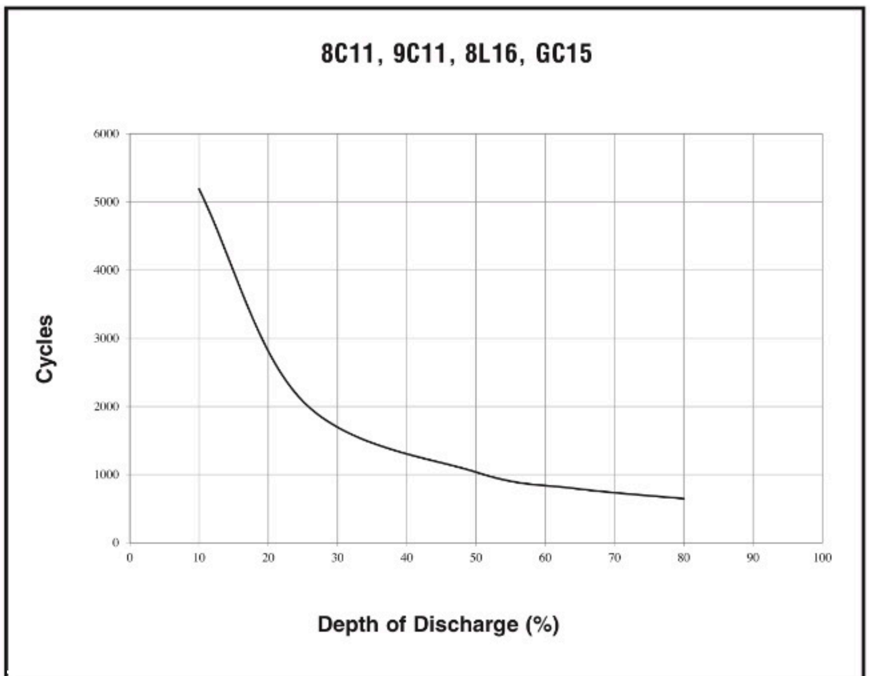
QUALITY SYSTEM CERTIFIED ISO 9001 ISO/TS 16949 ENVIRONMENTAL SYSTEM CERTIFIED ISO 14001

Photovoltaic Charging Parameters		
Bulk Charge	Max Current (amps)	30% of 20 Hr Rate
Absorption (Regulation) Charge	Constant Voltage	2.40 - 2.45 vpc
Float Charge	Constant Voltage	2.30 - 2.35 vpc
Equalize Charge	Constant Voltage	2.50 - 2.55 vpc
Temperature Coefficient	0.003 v / °C	

Above are per cell voltages, six cells total for 12V battery.

Cut-off parameters per charge & equalize intervals are application specific and will vary dependent upon site specific characteristics such as temperature, days of autonomy, array to load ratio, etc.

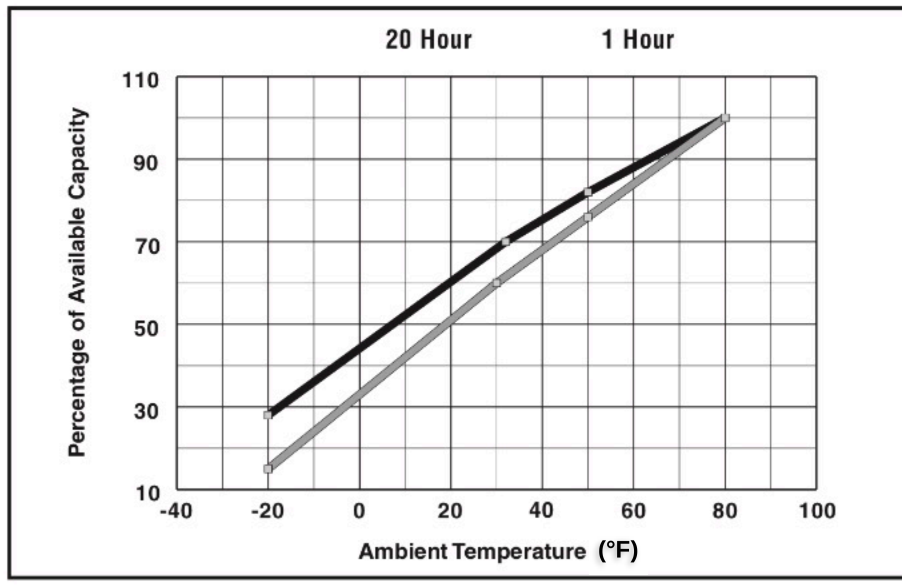
Cycle Life vs Depth of Discharge at +25°C (77°F)*



Cycle Chart applies to types with similiar design characteristics, ex., U1, 22NF, 24, 27, 31.

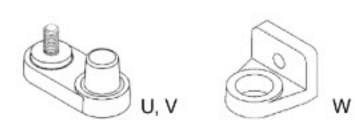
The solar battery excels in cycling applications.
**Dependent upon proper charging and ambient temperatures.*

Capacity vs. Operating Temperature



Capacity vs. Operating Temperatures: Above are the changes in capacity for wider ambient temperature range, giving the available capacity, as a percentage of the rated capacity, at different ambient temperatures. The curves show the behavior of the battery after a number of cycles.

Terminal Information



TYPE NO.		FOOTNOTES	PERFORMANCE		SHORT CIRCUIT CURRENT (AMPS)	QUARTS (LITERS) OF ACID	APPROXIMATE WEIGHT lbs. (kgs.)		MAXIMUM OVERALL DIMENSIONS inches (mm)		
WET	DRY		20 AMP HR. RATE	100 AMP HR. RATE			WET	DRY	L	W	H
6-VOLT SOLAR FLOODED MONOBLOC											
8C11	8C11D	11,17,19,25,30,34,V	235	260	2636	8 (7.6)	66.5 (30.2)	48 (21.8)	11¾ (298)	7 (178)	11½ (292)
9C11	9C11D	11,17,19,25,30,34,V	250	290	2465	7½ (7.1)	73 (33.1)	52½ (23.8)	11¾ (298)	7 (178)	11½ (292)
8L16	8L16D	11,17,19,25,30,34,W	370	420	2339	11½ (10.9)	113 (51.3)	83 (37.6)	11¾ (298)	7 (178)	16½ (419)
GC15	GC15D	11,30,34,U	230	—	2620	—	63 (28.6)	44 (20)	10¼ (260)	7⅛ (181)	10⅞ (276)
12-VOLT SOLAR FLOODED MONOBLOC											
DC27	—	11,17,35,U	90	95.5	2339	—	53 (24.0)	—	12½ (318)	6¾ (171)	9⅜ (238)

FOOTNOTES:

- **11** - Low maintenance-low antimony grids
- **17** - Includes Handle
- **19** - Includes lifting ledges
- **25** - With individual vent caps
- **30** - Available dry-add "D" suffix to part number
- **34** - Ratings after 15 cycles
- **U** - Molded-in offset SAE post and vertical 5/16" NEG., 5/16" POS. stainless studs & locking hex nuts
- **V** - Molded-in offset SAE post and vertical 5/16" NEG., 5/16" POS. stainless studs
- **W** - "L" type terminal w/ 5/16" diameter hole (T882)

All batteries manufactured with gray polypropylene cases and covers except where noted.

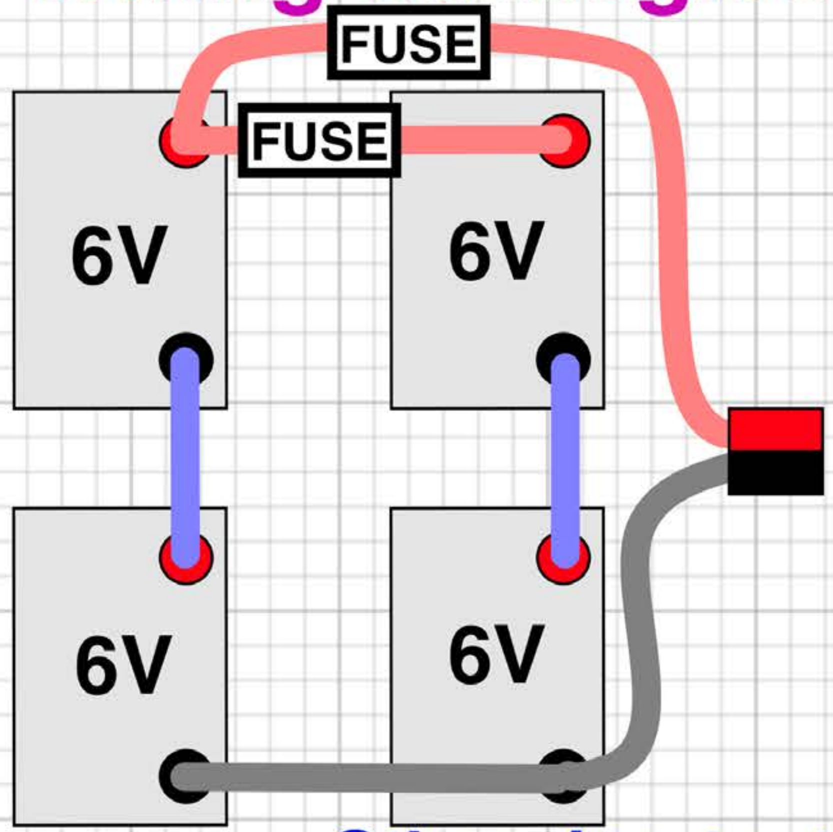
- **IMPORTANT CHARGING INSTRUCTIONS:** Do not install in a sealed container. Constant under or overcharging will damage any battery and shorten its life! Use a good constant potential, voltage-regulated charger.

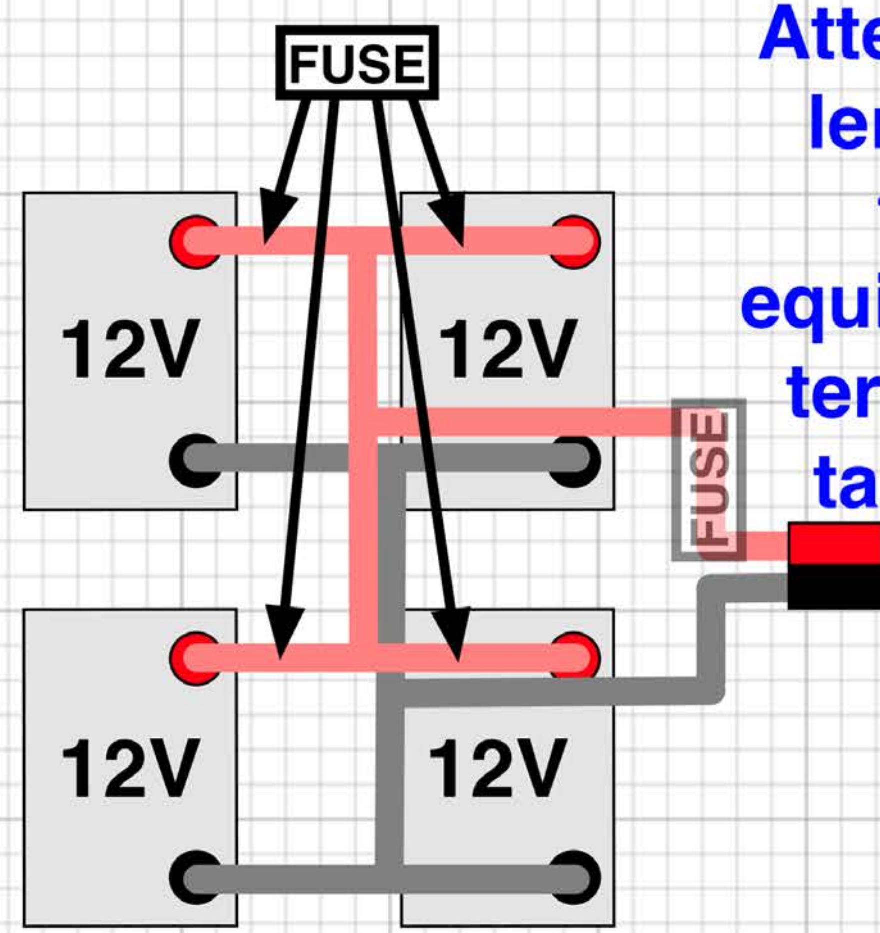
The open circuit voltage of a fully charge battery is 2.13 v.p.c. at 77°F (25°C).

EASTPENN
East Penn Manufacturing Co., Lyon Station, PA 19536-0147
Domestic & International Inquiries Call: 610-682-3263
Phone: 610-682-6361 • Fax: 610-682-0891
www.dekabatteries.com • e-mail: reservepowersales@dekabatteries.com

MK POWERED
Domestic Inquiries Call: 1-800-372-9253
www.mkbattery.com • e-mail: sales@mkbattery.com

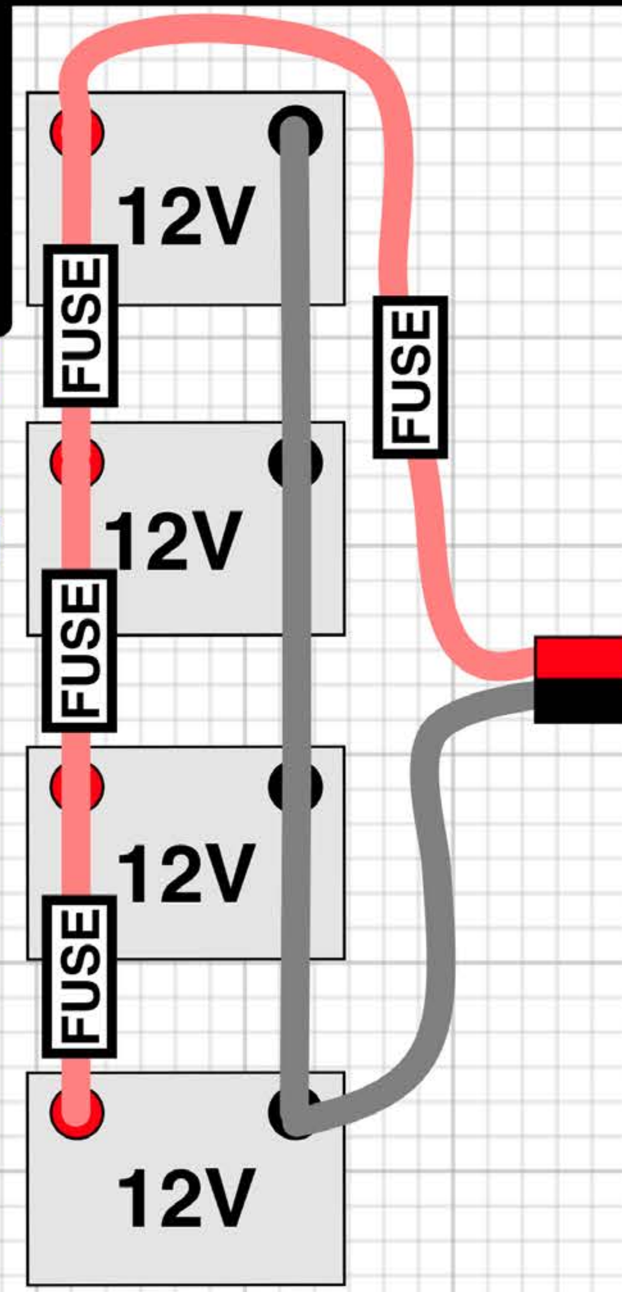
Optimal Battery Bank Wiring Strategies

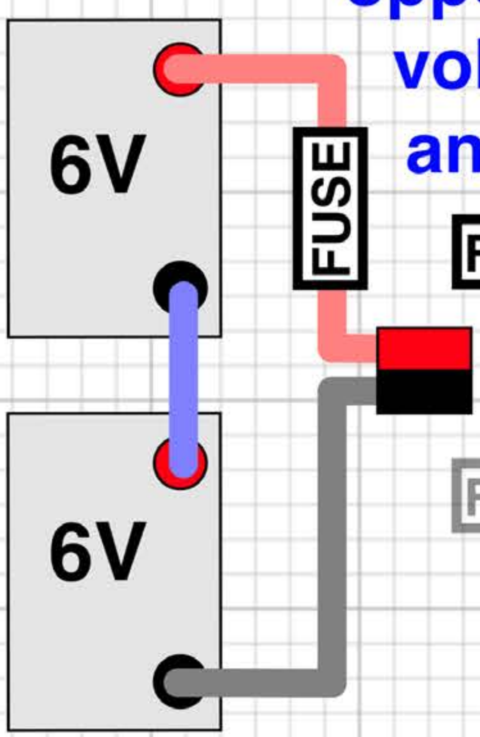




Attempt to keep the path length to each battery terminal as nearly equidistant between each terminal and the power tap point as possible.

Otherwise try to keep inter-battery jumpers equal length, then draw power (and charge) from opposing battery ends so each battery sees equal voltage drop and load share. Think of each link and fuse as part of a resistor-divider network.





FUSE Mandatory fuse to isolate each bank in a fault and protect wiring.

FUSE Optional fuse if wiring can not handle full current from each fused battery or bank.