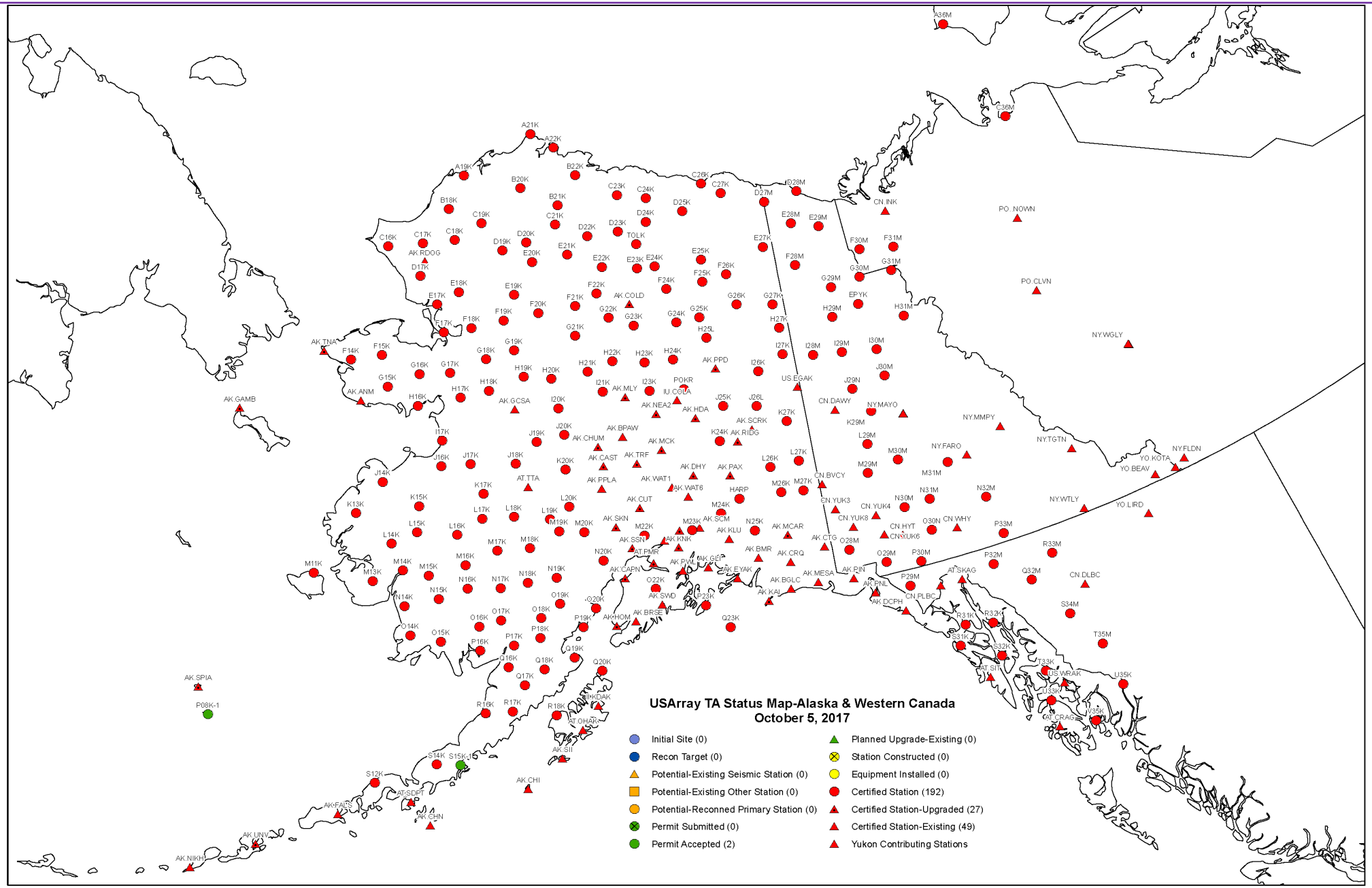
TA-AK - Map of Region

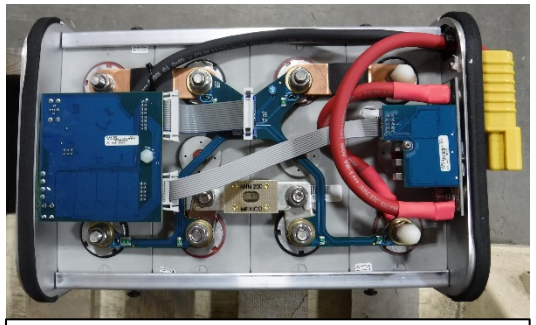


TA-AK - Key Technological Developments for Power and Communication Systems

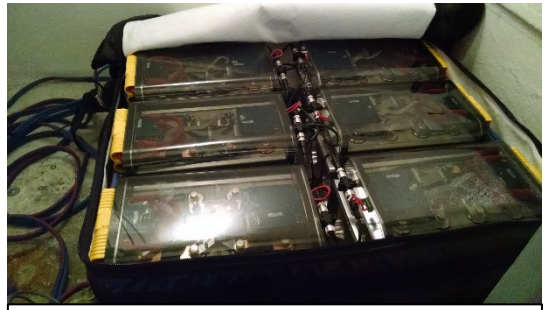
Development of large format lithium-ion batteries designed specifically for off-grid, low power autonomous scientific stations

Why Lithium?

-Significant weight and volume savings (41.9Wh/lb vs 21.25Wh/lb for AGM batteries)
-Improved cold weather and self discharge performance
-Improved lifespan
-Increased cost and complexity
-Hazardous shipping



180Ah $LiFePO_4$ battery manufactured by Genasun



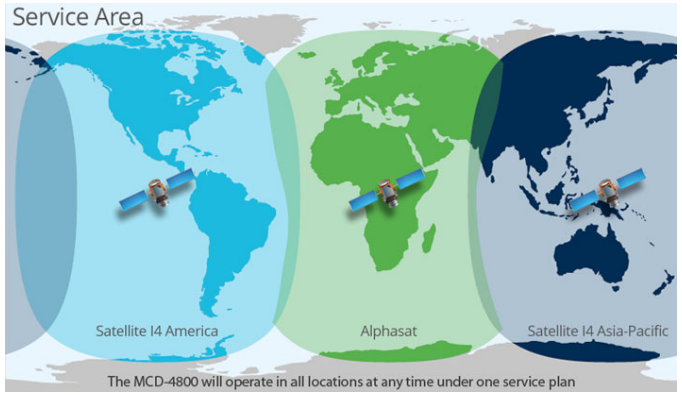
Qty 6 Genasun $LiFePO_4$ batteries installed at a TA-AK site in protective bag

Widespread use of Hughes 9502 BGAN terminals in high latitudes with marginal service coverage

Why BGAN?

-Guaranteed coverage across much of the region
-Very easy to install and antenna does not require precise adjustment or precise pointing
-High bandwidth and low standby power consumption (464kbps down, 448kbps up, 1W standby)
-Data cost (~$1,000 per month)
-No guarantee of coverage in the “notch”

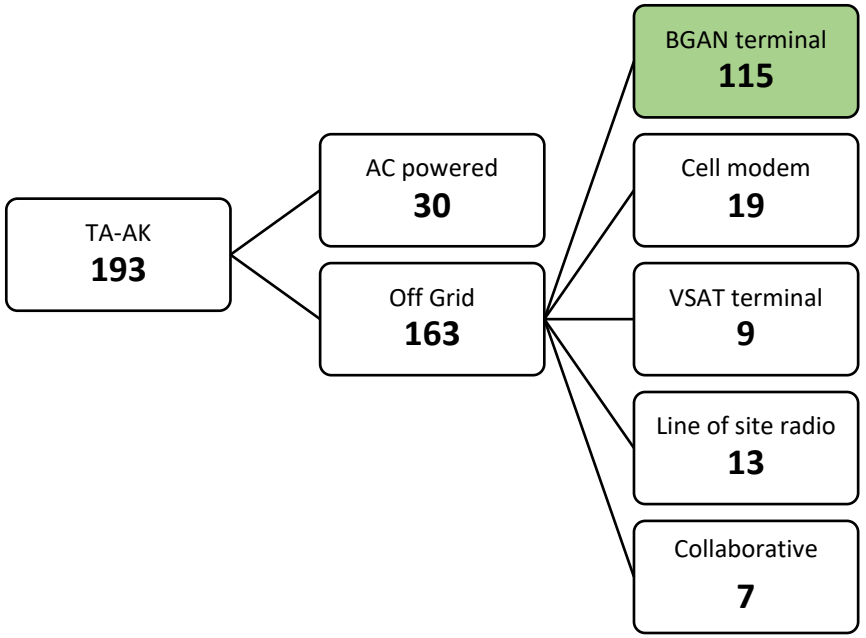
BGAN terminal and panel antenna with Q330 for scale



From: http://www.groundcontrol.com/MCD-4800_BGAN_Terminal.htm

TA-AK– Power and Communication System Types

Communications System Design

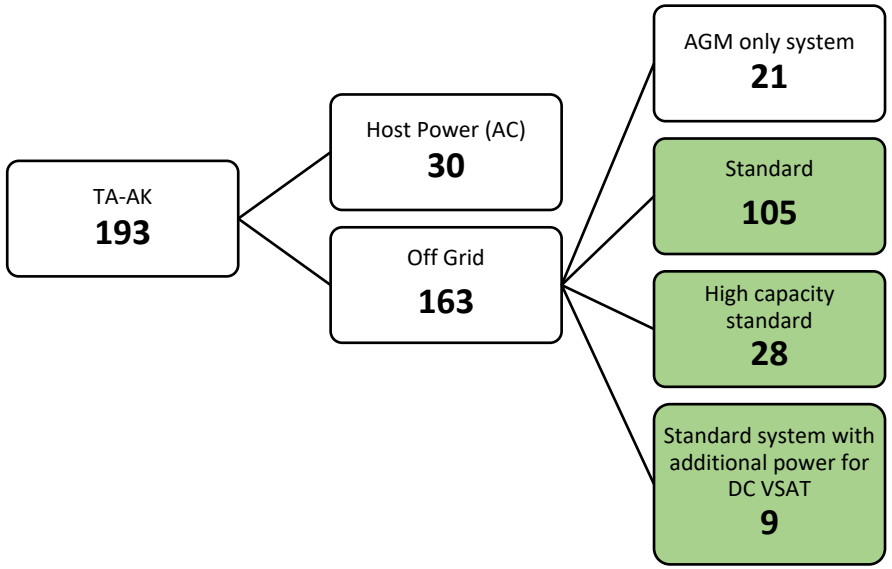


Standard TA-AK Station Communication System Details:

- Broadband seismometer with three channels at 40sps and 1sps
- Barometer pressure sensor at 40sps and 1sps
- Infrasound sensor at 40sps and 1sps
- Weather station with 11 channels at 1sps
- Q330 SOH and additional environmental sensors at 1sps or 0.1sps

Standard site transmits about 40 MB of data each day (14.6 GB/year)

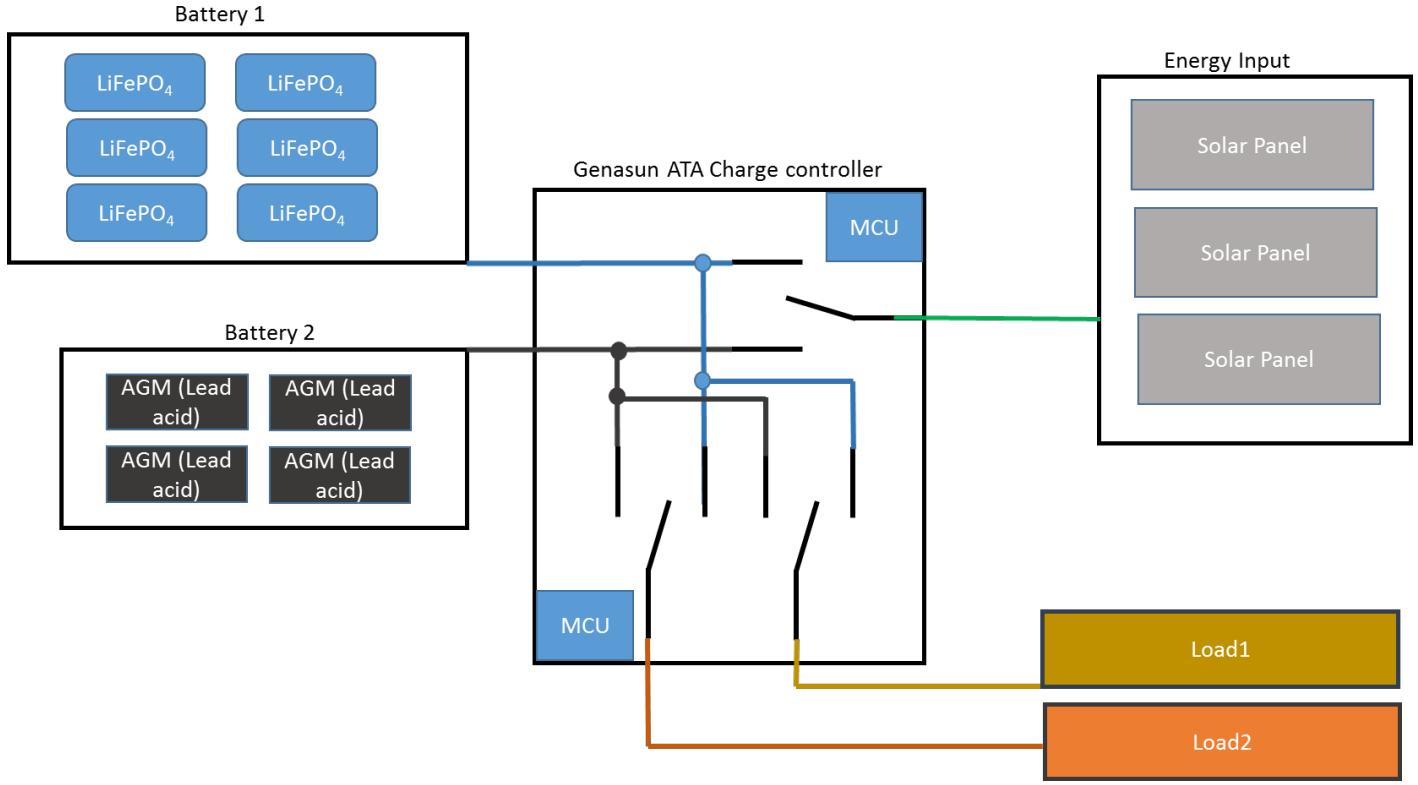
Power System Design

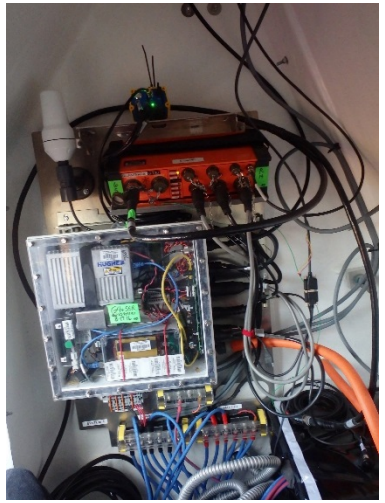


Standard TA-AK Station Power System Details:

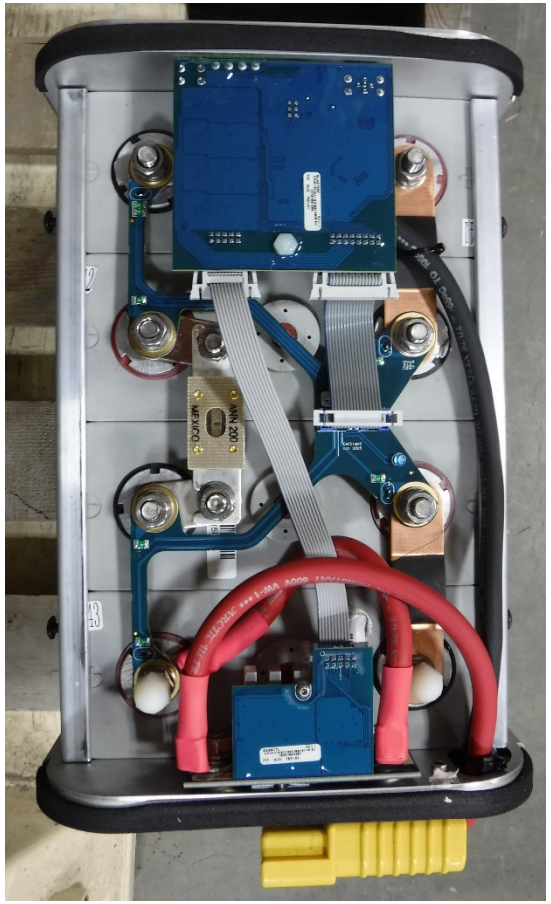
- Real time summer operation power consumption = 8.3W
- 1 hour latency winter operation power consumption = 6.3W
- North of 67°N – 8 Lithium batteries @ 180Ah and 4 AGM batteries @ 108Ah (24.45kWh)
- South of 67°N – 6 Lithium batteries @ 180Ah and 4 AGM batteries @ 108Ah (19.7kWh)

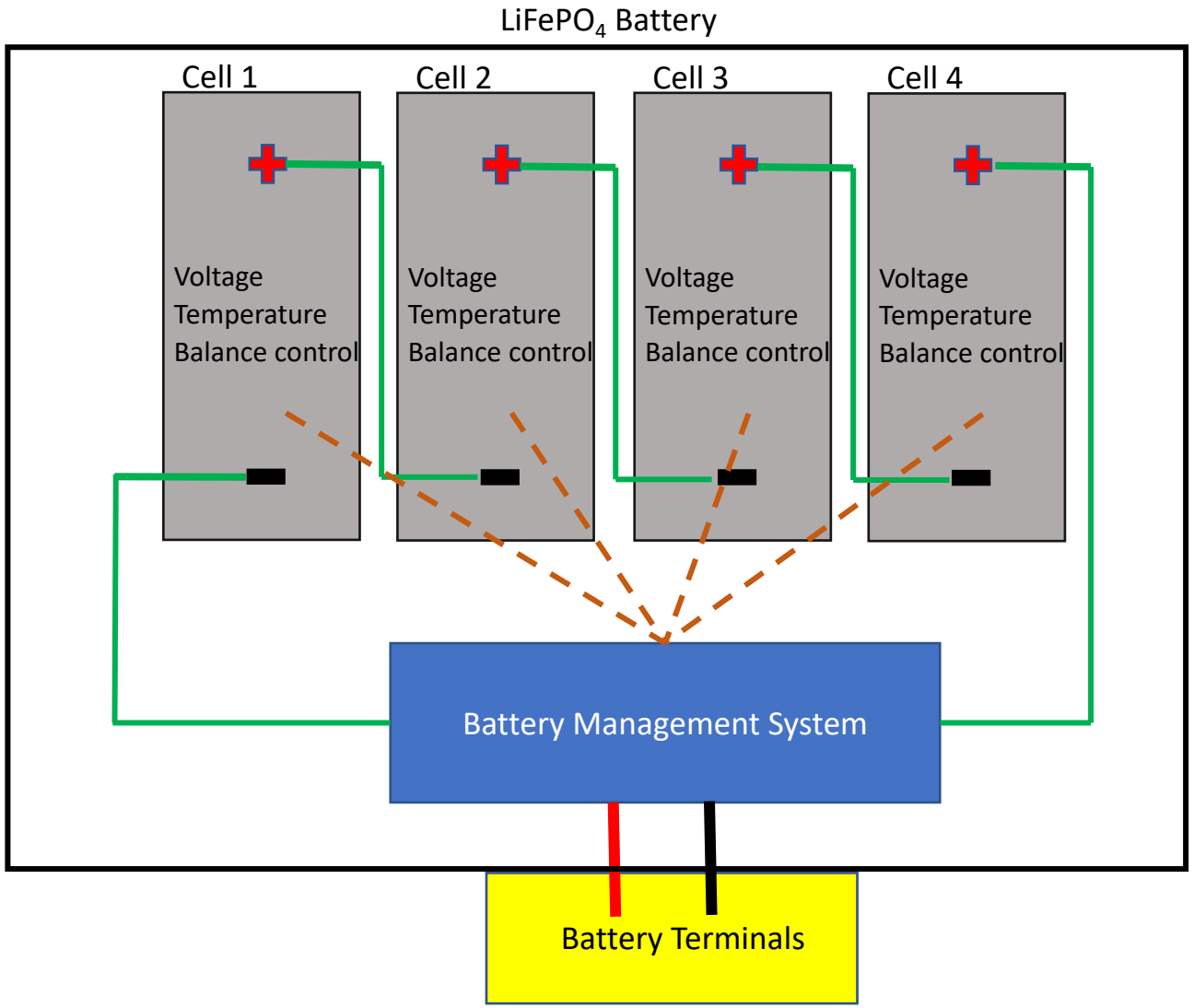
TA-AK Power System Overview





TA-AK Power System – Lithium Battery Block Diagram



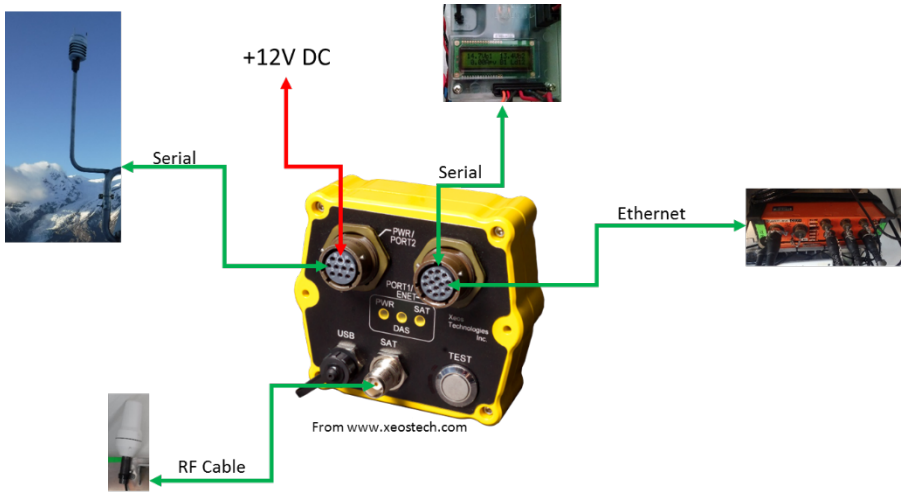


- Four 3.4V, 180Ah cells in each battery
- Voltage and temperature sensing on each cell
- Active cell balancing to prevent capacity mismatch
- Sub millisecond control of output terminals
  - Short circuit, under/over voltage, under/over temperature protections

TA-AK Power System Performance

Off-grid TA-AK stations utilize XI-202 Iridium terminals made by Xeos Technologies Inc. as a backup source of SOH data and to transmit power system data from the Genasun Charge Controller:

- Battery voltages, charging current and solar panel voltage data once per hour
- Allows for careful tracking of battery state of charge and power system performance



Minimal data transmission removes the need for optimal antenna sky view and allows for installation in the hut

Analysis of 13 TA-AK stations that reached LVD during the 2017-2018 winter:

- Average Lithium Battery Performance (Actual Energy Delivered/Expected Energy) = **97%**
- Average AGM battery Performance (Actual Energy Delivered/Expected Energy) = **48%**

  Disclaimer – Charging algorithm favors lithium battery charging over AGM charging. Many stations have used AGM batteries
- Power a 6.3W load for 4 months (18.45kWh):
  - 7.7 180Ah Genasun LiFePO4 batteries needed (470 lbs) – assumes no derate
  - 22.6 108Ah AGM batteries needed (1469 lbs) – assumes 60% derate

TA-AK BGAN Communications System

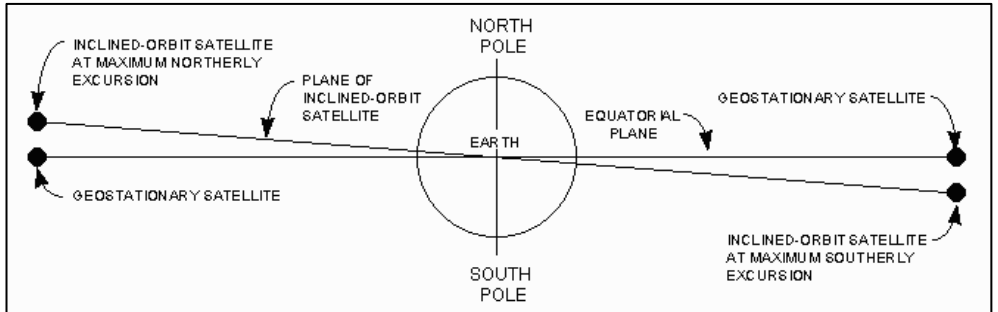
9502 Terminal and Panel Antenna:

- Utilize Inmarsat 4-F Satellites
- Near global coverage
- Terminal Power consumption when streaming seismic data in real time = **4.2W**
- Terminal Power consumption when bursting data once per hour = **2.2W**
- Wake on LAN feature lowers power consumption to **10mW**.

Technical Difficulties:

- At high latitudes, satellites are low on the horizon and may be partially blocked by terrain.
  - Daily loss of service.
  - "Worst case" site has no service for 16 hours every day
- Single ethernet connection
  - Multiple devices require a hub/switch/router
- Nine terminals have failed in the field
  - 5 of the 9 failed due to corrupted RAM chip. Problem mostly eliminated thanks to operational changes and newer hardware
  - 3 of 9 failed to operate at colder temperatures. Problem mostly eliminated due to removal of terminals from field
  - 1 of 9 failed due to unknown causes
- One antenna has failed in the field, likely due to wind loading

Inmarsat 4-F Satellites operate with an inclined geostationary orbit
Net affect is an approximately +/-3deg North/South satellite drift each day



From http://www.sbe24.org/techdocs/geosat/satgeom5.asp

Overall, the technology has worked well. The terminals are easy to configure, install and service. The bandwidth and power consumption trade off is excellent. The main downside is the monthly data cost. The units performance in regions without guaranteed coverage has been much better than expected