Western Michigan University
Sunseeker Solar Car Team

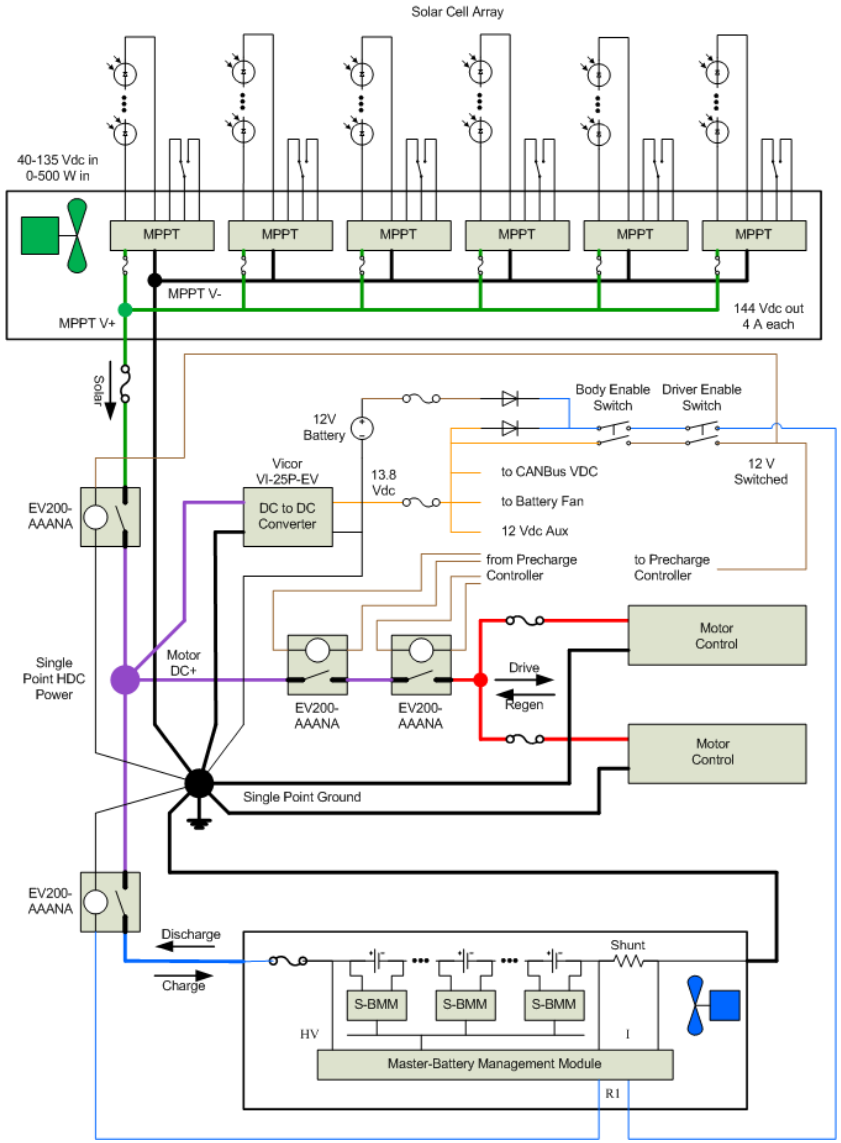
Sunseeker Electrical Systems

22 September 2009

Primary Systems

- There are four primary electrical systems
  - Solar Array and Array DC-to-DC Converters
  - Battery and Battery Protection System
  - Drive Motors (Csiro) and Motor Controller
  - Controller Area Network Based Devices

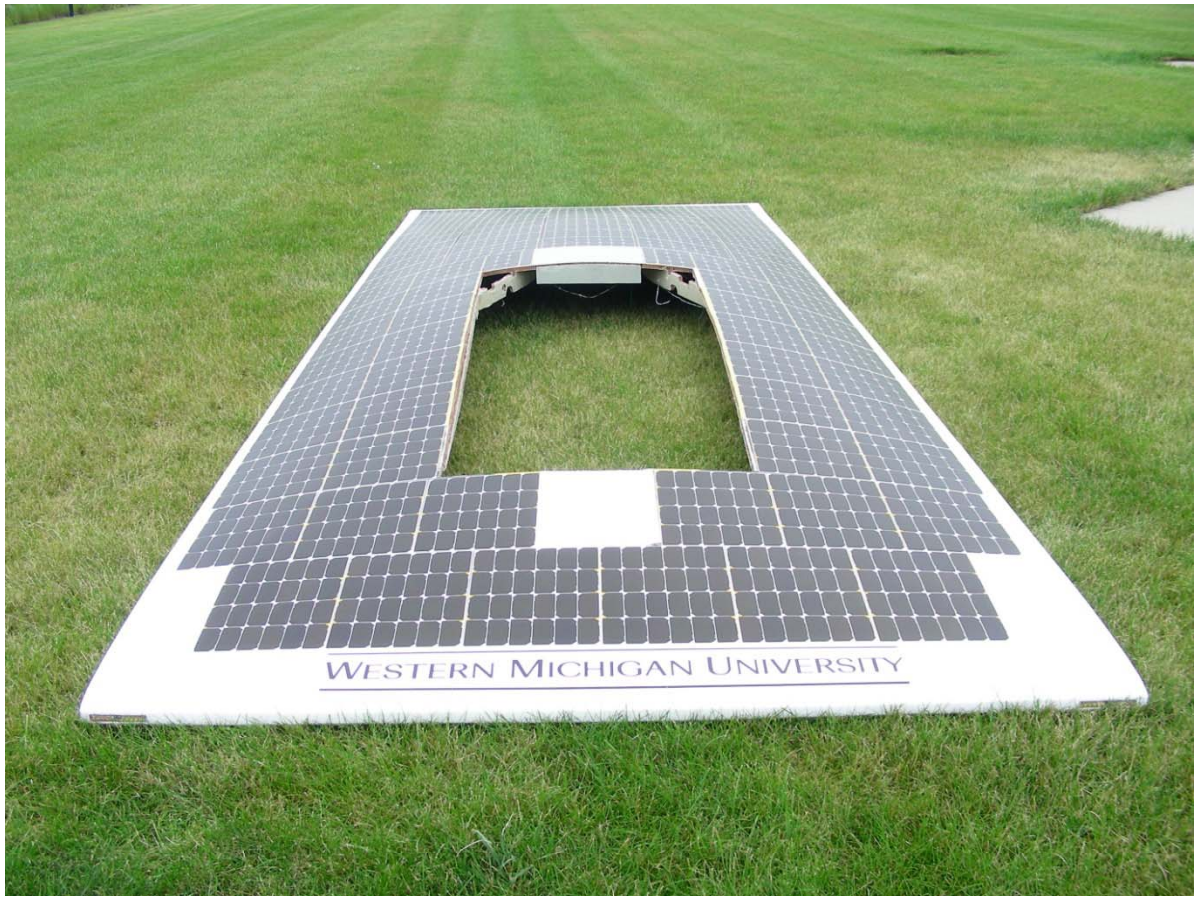
High Power Diagram



- Solar Array Subsystem
  - Solar Cells
  - Maximum Power Point Trackers
- Safety Switches
  - Start-up Battery
  - Master Power Switches
- DC Motors
  - CISIRO Motors
  - Tritium Motor Controllers
- Battery Subsystem
  - Li Batteries
  - Battery Protection System

Solar Array

- Solar Array
  - 6 Separate Array Segments
  - 14 to 16 Panels per Segment
  - 24 Cells per Panel



Solar Panel

- Solar Panel
  - 24 triple junction solar cells
- Solar Cells (full sun)
  - 2.5v at 0.4 Amps (lab est.)
  - Approx. 1 Watt each

Solar Cell (Example)

Spectrolab

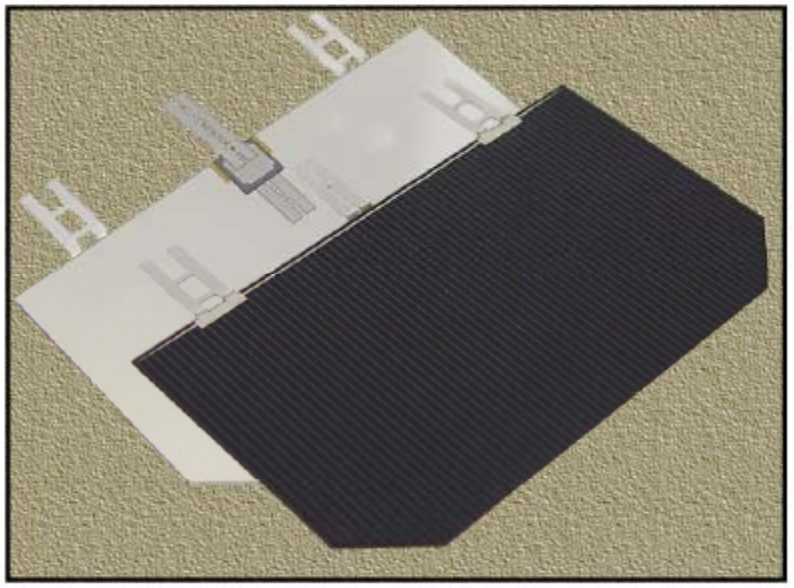
Photovoltaic Products

www.spectrolab.com

28.3% Ultra Triple Junction (UTJ) Solar Cells

Features

- High efficiency n/p design (28°C, AM0)
  -BOL: 28.3% min. average efficiency @ maximum power (28.0% @ load voltage)
  -EOL: 24.3% min. average efficiency @ maximum power, 1 MeV 1E15 e/cm²
- Heritage bypass diode protection
- 140 µm Ge wafer thickness



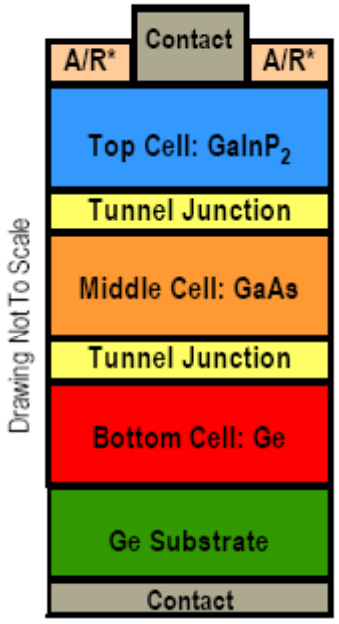
Spectrolab UTJ Solar Cell Data Sheet

Solar Cell Specs (Example)

Typical Electrical Parameters
(AM0 (135.3 mW/cm²) 28 ℃, Bare Cell)

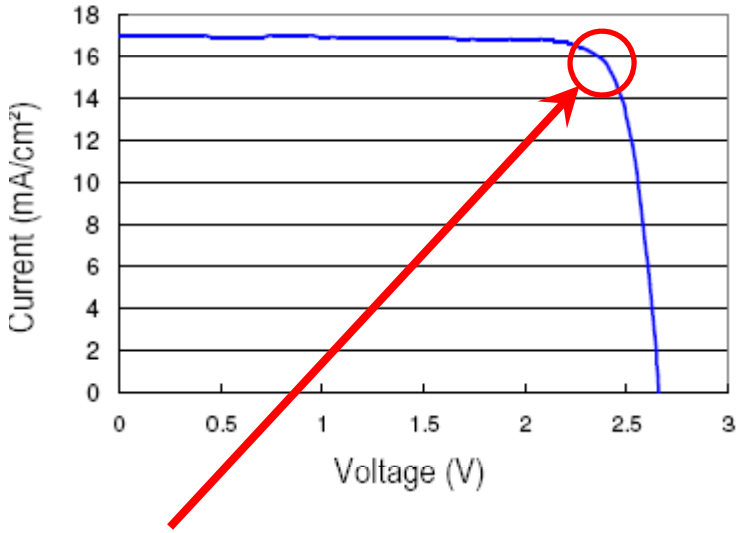
J_{sc}= 17.05 mA/cm²
J_{mp}= 16.30 mA/cm²
$J_{load\ min\ avg}$= 16.40 mA/cm²
V_{oc}= 2.665 V
V_{mp}= 2.350 V
V_{load}= 2.310 V
Cff= 0.84
Eff_{load}= 28.0%
Eff_{mp}= 28.3%

Spectrolab UTJ Solar Cell Data Sheet



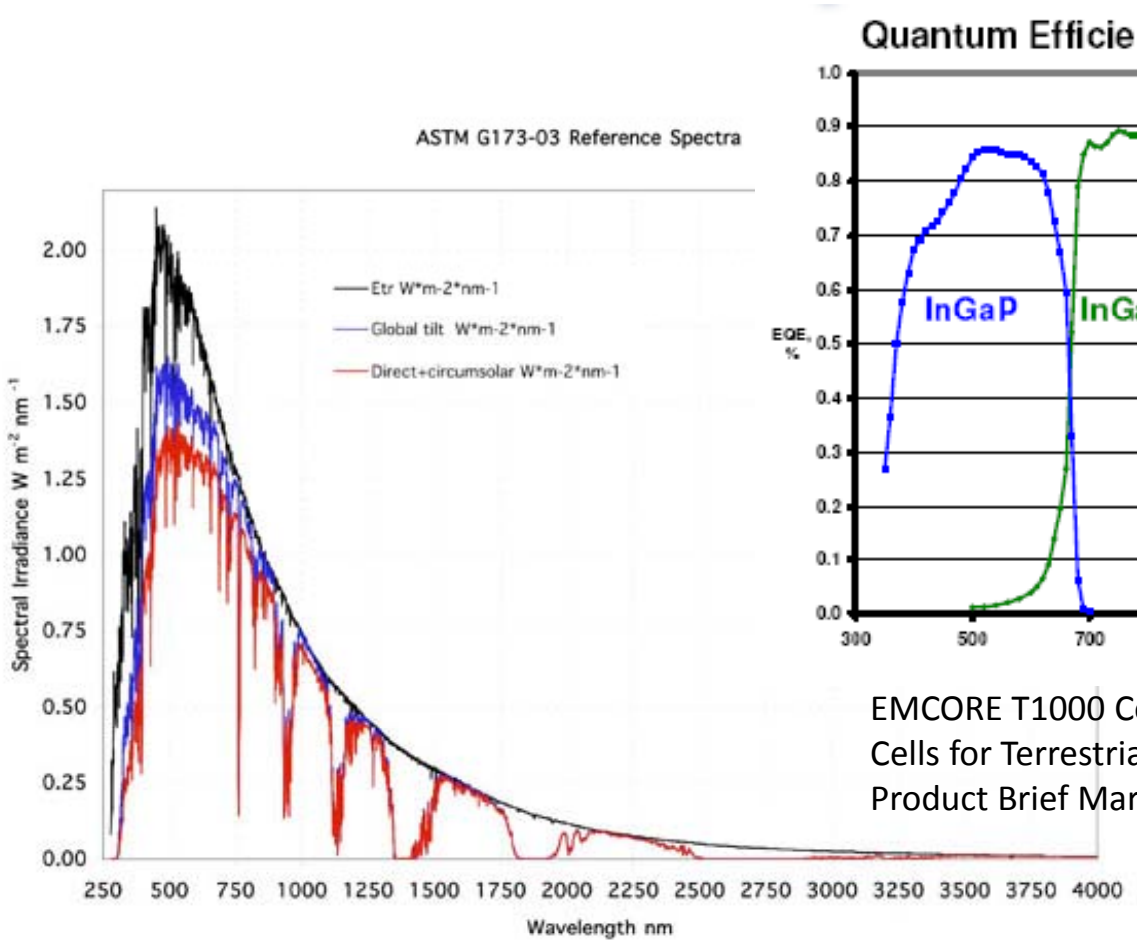
*A/R: Anti-Reflective Coating

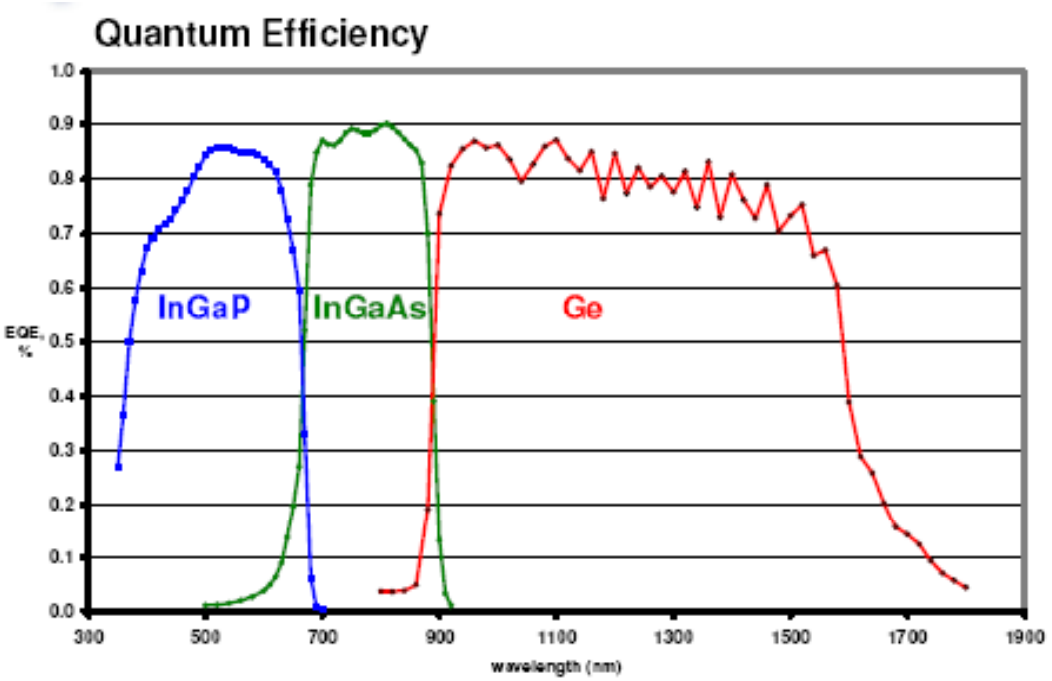
Typical IV Characteristic
AM0 (135.3 mW/cm²) 28°C, Bare Cell



Try to operate at the maximum power point (2.35 V and 16.3 mA/cm² At 26.5 cm² for 432 mA)

Sunlight – Triple Junction Solar Cell Efficiency



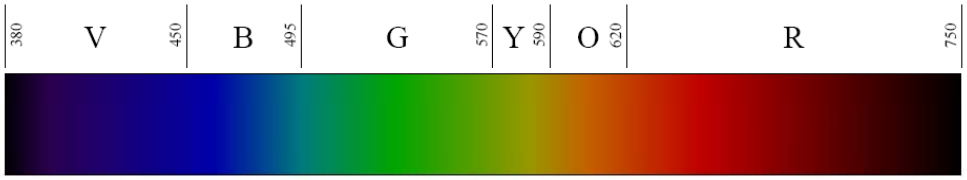


EMCORE T1000 Cell –Triple-Junction High-Efficiency Solar Cells for Terrestrial Concentrated Photovoltaic Applications, Product Brief March 2006

From: http://rredc.nrel.gov/solar/spectra/am1.5/

Solar Cell Wavelengths

- Solar Irradiation
- Visible Spectrum
- Solar Cell Excitation
  - Silicon
  - Gallium Arsenide
  - CIGS



http://en.wikipedia.org/wiki/File:Linear_visible_spectrum.svg

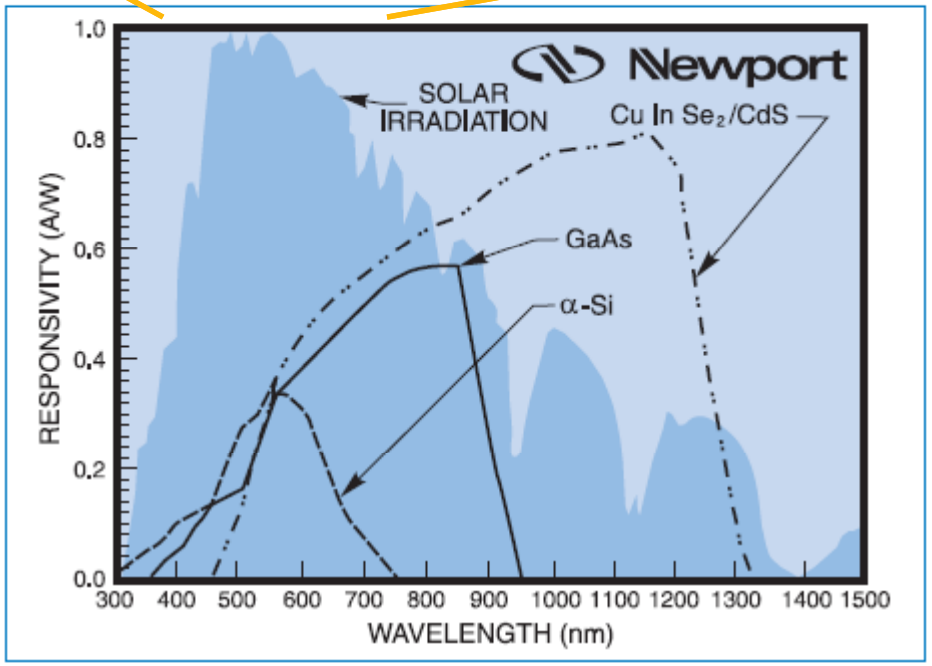
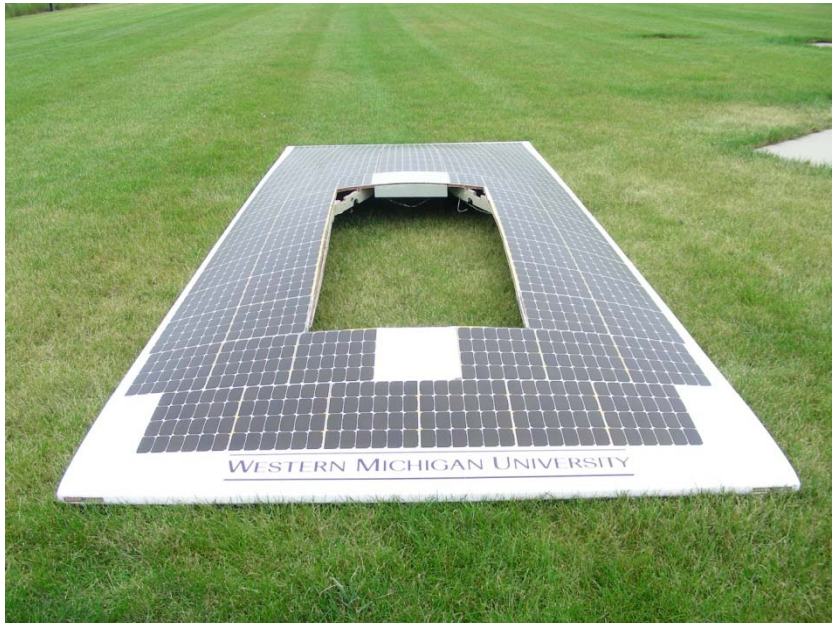


Fig. 31 Responsivity of photovoltaic solar cells.

Oriel Product Training: Section Two Solar Simulator
http://www.newport.com/file_store/Supporting_Documents/Tech_Ref_Solar_Simulation4.pdf

Solar Array Power (2005 est.)

- Solar Cell
  - 2.5 V at 0.4 Amps →1 Watt
- 24 Cell Panel
  - Series Connected Cells
  - 60 V at 0.4 Amps →24 Watts
- 16 Panel Subarray
  - 8 parallel, 2 series
  - 120 V at 3.2 Amps →384 Watts
- 6 Subarrays
  - 4-16 Panel and 2-14 Panel
  - 120 V at 18.4 Amps →2208 Watts

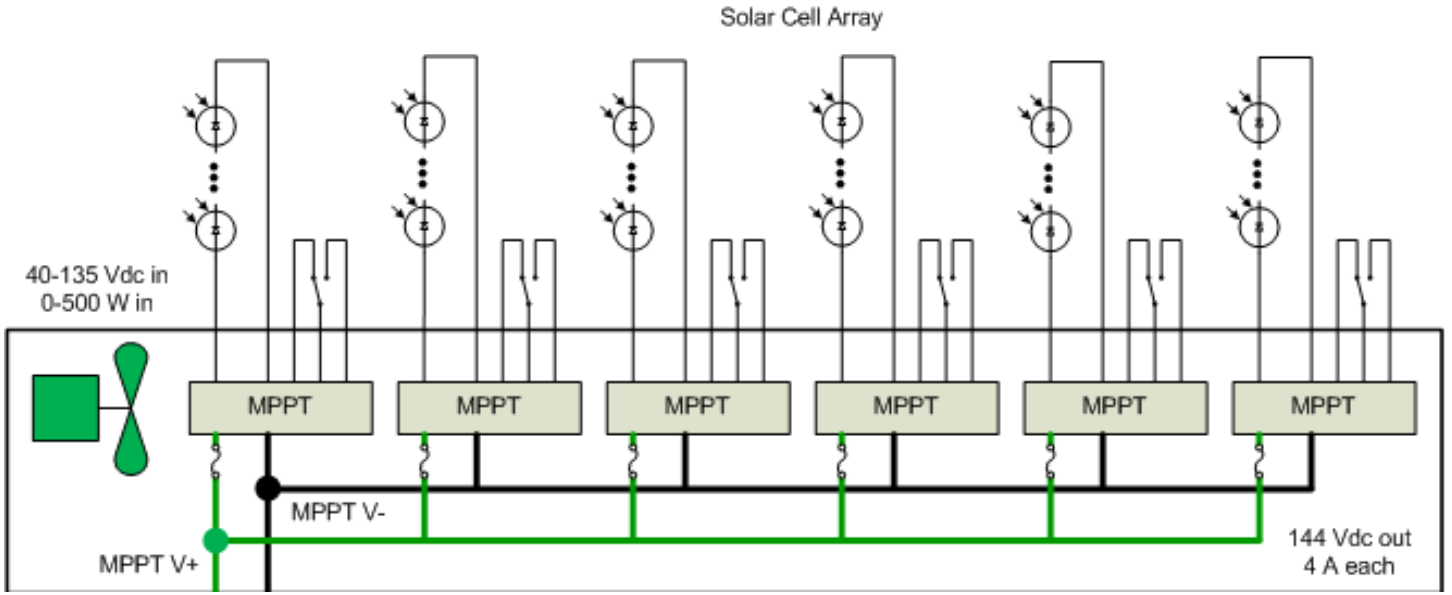


SunPower Corp. solar cells,
sold and encapsulated into panels
by SunCat Solar

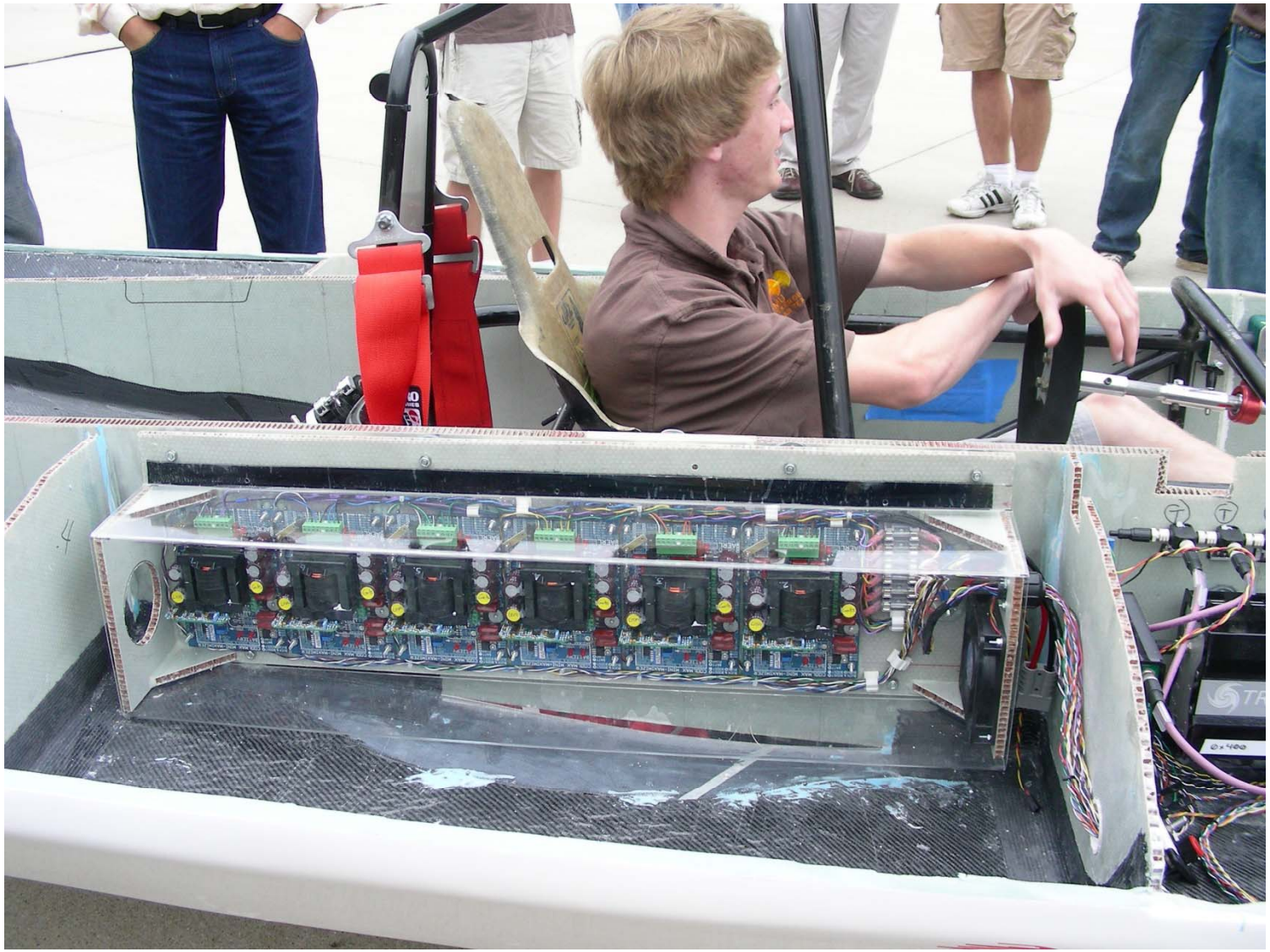
Cost: approx. $50 per encapsulated cell

MPPT

- Maximum Power Point Trackers
  - High efficiency DC-to-DC converters (Boost type)
  - Solar power converted to useful car power bus, Nom 144 V
  - Power used to drive motors or charge batteries



MPPT



Motor

- CSIRO DC hub motor
  - Commonwealth Scientific and Industrial Research Organisation , Australia's national science agency

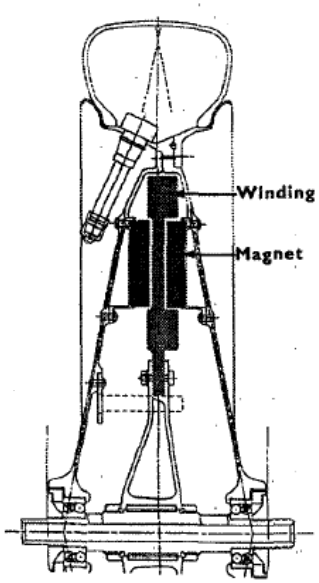


Figure 2: Cross-sectional drawing of motor

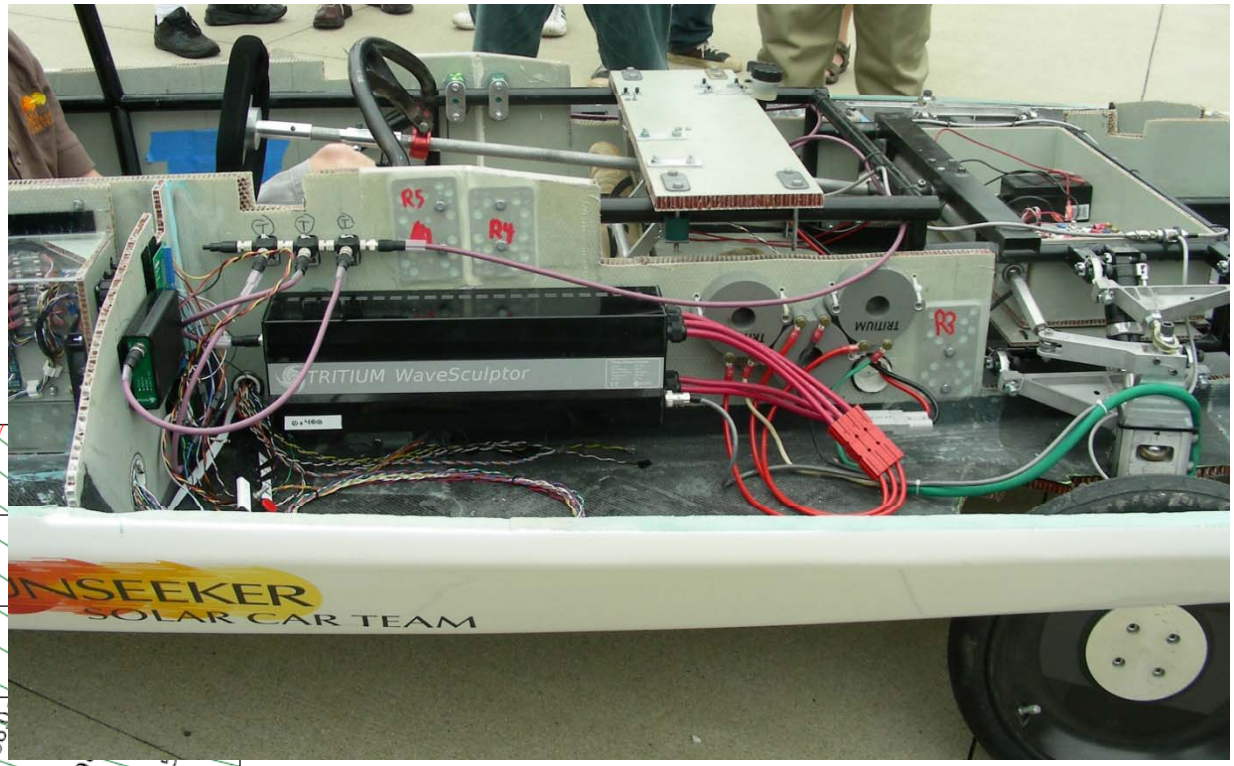
H.C. Lovatt, V.S. Ramsden, and B.C. Mecrow, Design of an in-wheel motor for a solar-powered electric vehicle, IEE Proc., Electr. Power Appl. -- September 1998 -- Volume 145, Issue 5, p.402–408.

http://www.csiro.au/resources/pf11g.html

Approximate Cost: $10,500 per motor

Motor Controller

- Tritium WaveSculpter Motor Controller
  - Tritium Pty Ltd



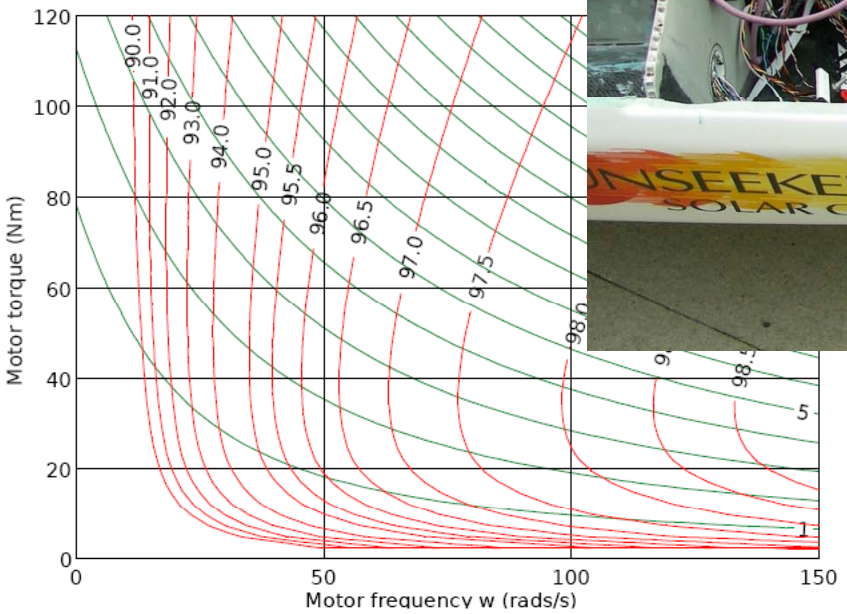
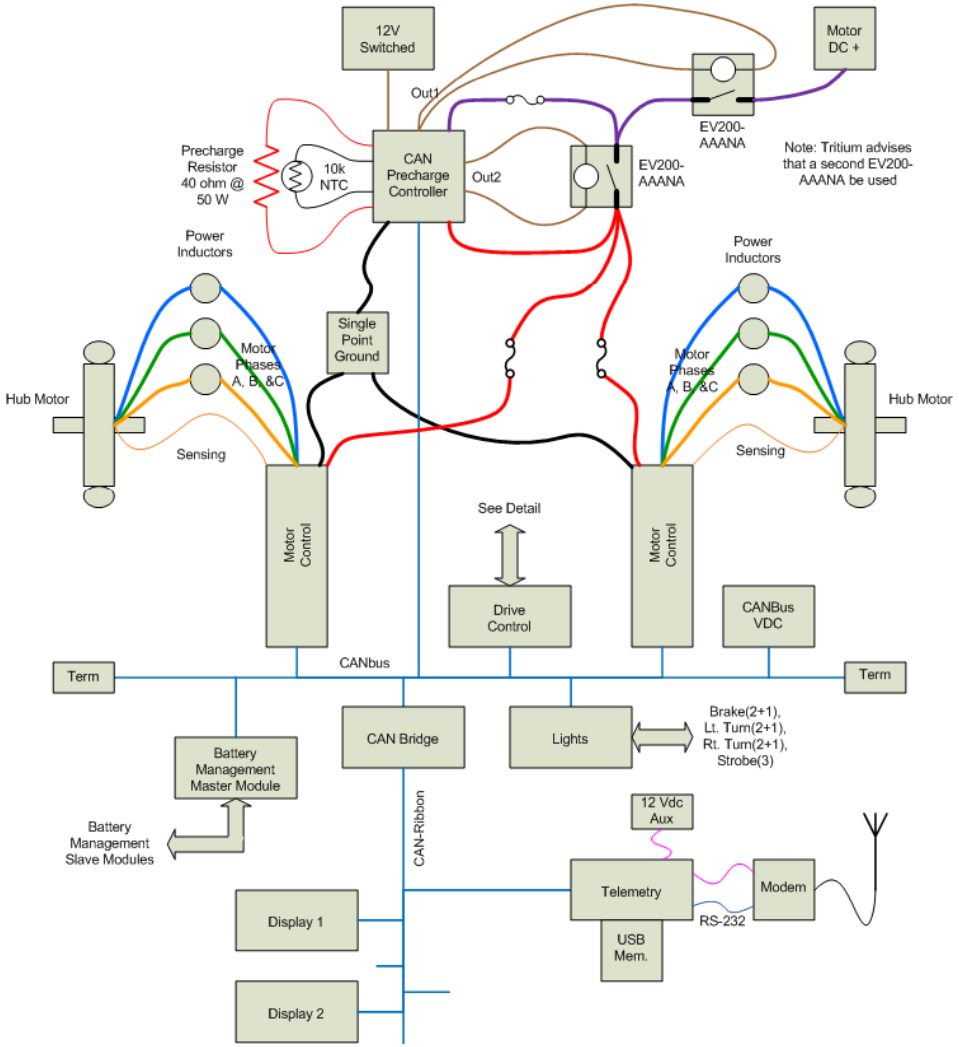


Illustration 1: Predicted efficiency map of the WaveSculptor controller with a 160V DC bus

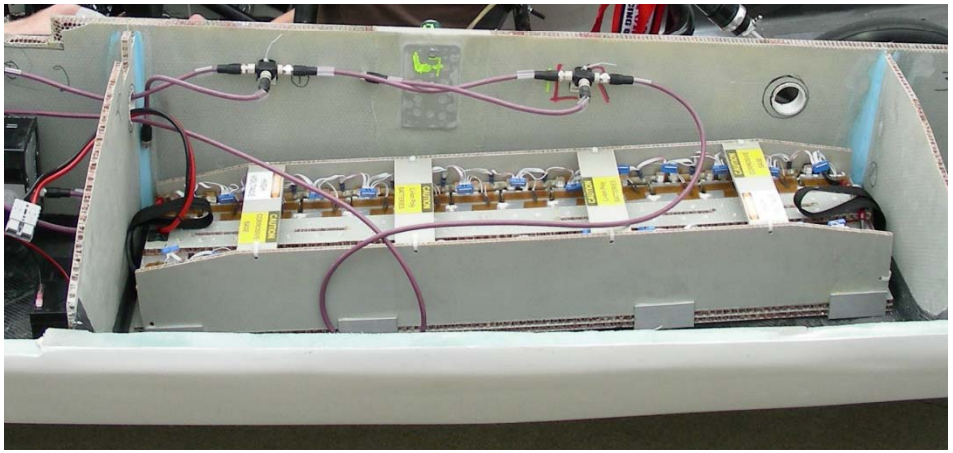
Motor and CAN

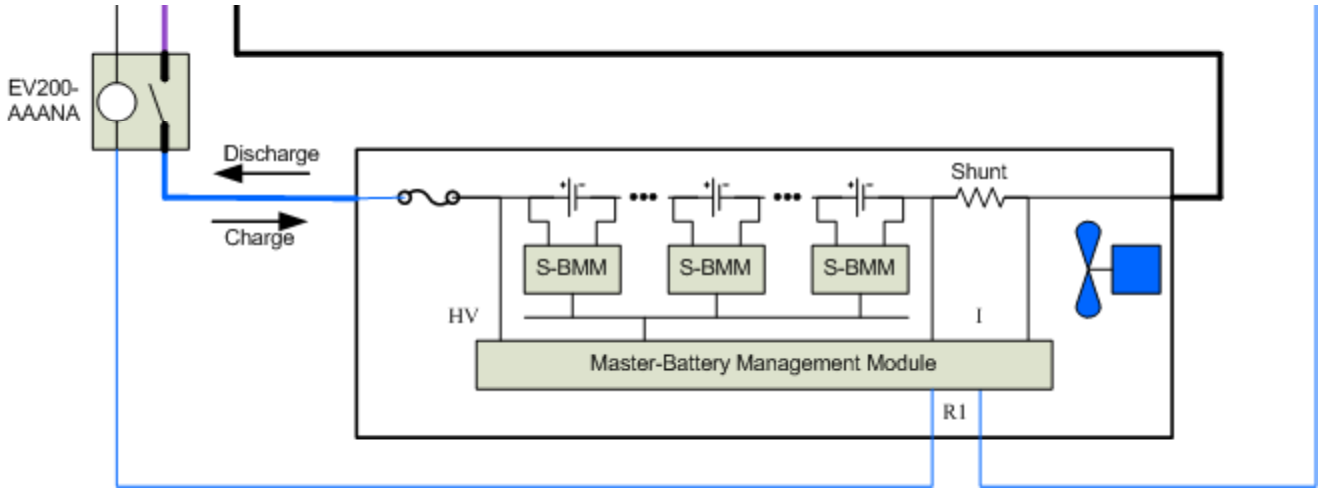


- Motor Controller
  - CAN Commands and Status
  - Power Inductors to motor
- Precharge Controller
  - Charge Motor Capacitors before operation
  - Fuses to limit current
  - New module has CAN interface

Battery and BPS

- Li-Polymer Batteries
  - Max. 168 V, Nom. 144V
  - Max. Current ~60 Amps

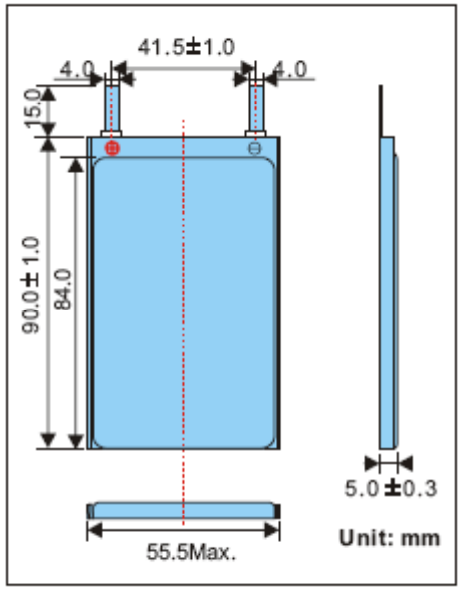




Li-Polymer Battery

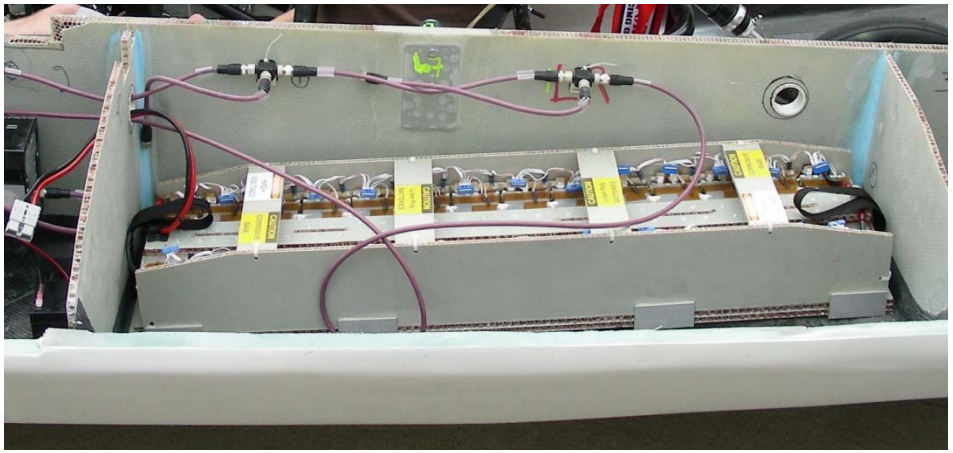
- EEMB Battery: LP505590 Cell
  - Data sheet information: Nom. 3.7 V, C = 2600 mAh
  - 1 C charge and 2 C discharge
  - 52.5+/-5 grams each

1	Battery Type		LP 505590
2	Nominal Capacity	Typical	2800mAh (0.2C discharge)
		Minimum	2600mAh (0.2C discharge)
3	Nominal Voltage		3.7V(0.2C discharge)
4	Charging Voltage		4.2V±0.05V
5	Standard Charge		Method: CC/CV (constant current/constant voltage) Current:1300mA (0.5C) Voltage:4.2V EndCurrent:52mA (0.02C)
6	Maximum Charge Current		2600mA (1C)
7	Standard Discharge		Method: CC (constant current) Current:520mA (0.2C) End Voltage:2.75V
8	Maximum Discharge Current		5200mA (2C)
9	Weight		Approx.52.5±5.0g
10	Operating temperature		Charge: 0℃ to 45℃ Discharge: -20℃ to 60℃
11	Storage Temperature		-20℃ to 45℃
12	Cycle life		500cycles (at 0.5C charge and discharge, 23℃)

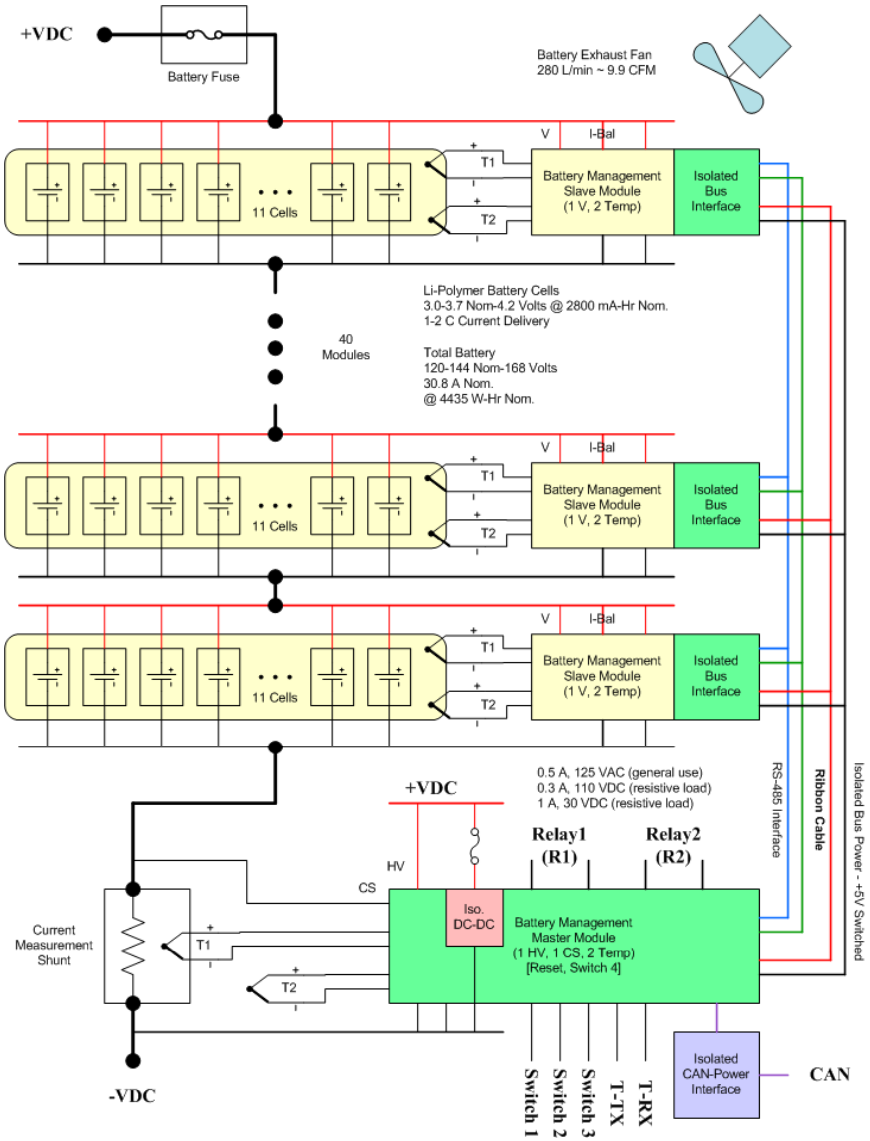


Sunseeker NASC Design

- 25 kg of Li-Polymer batteries allowed, NASC Regulation
- How do we get 144V at 30 A?
  - Using 3.6 V, there are 40 batteries in series
  - Based on 25 kg, there can be ~476+/- batteries
  - Therefore, 11 cells in parallel x 40 modules in series (440 used)
- Nominal 144V at 28.6 Ah (peak discharge 57.2 Amps)



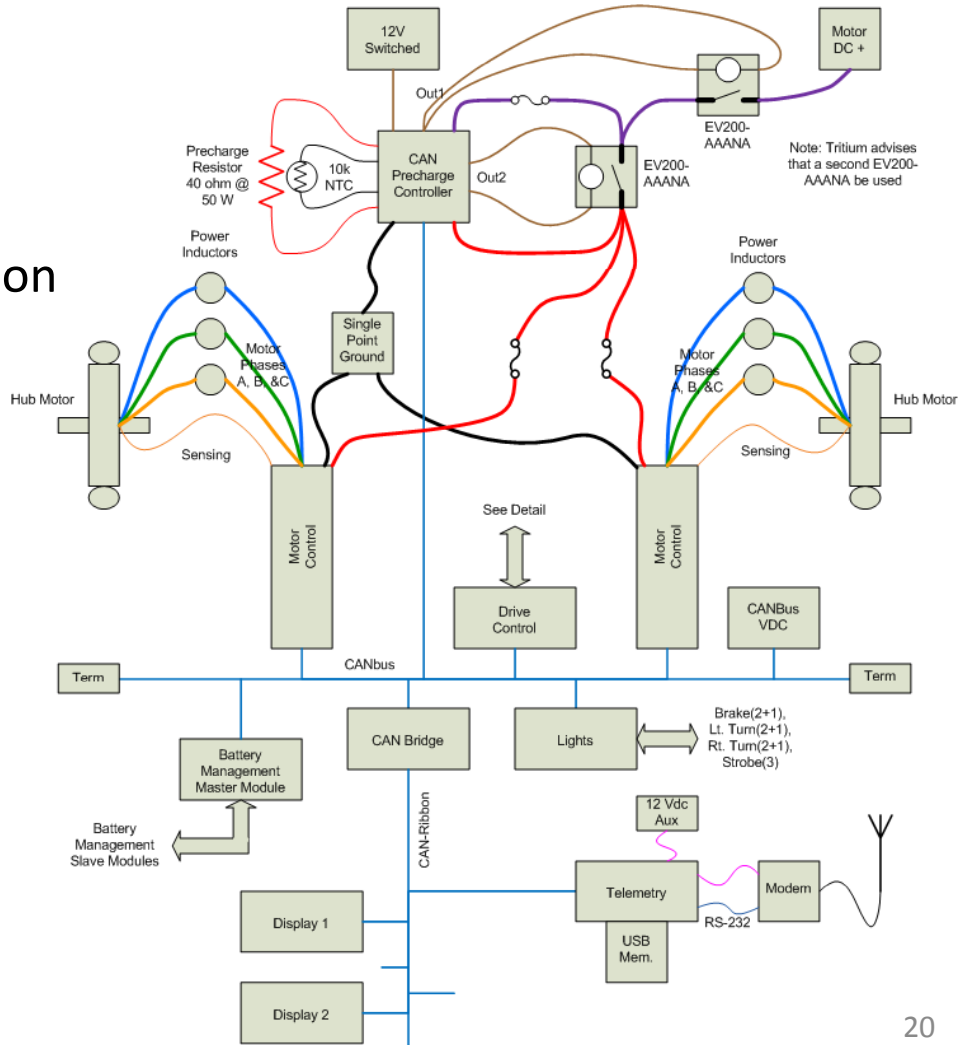
Battery System Design



- 40-Series modules
  - 11 Parallel Batteries
  - Slave battery protection monitor
- Battery Protection System
  - One slave per module
  - One master w/ CAN I/F
  - Measure:
    - Total V, Cell V, Total Current, Temperature

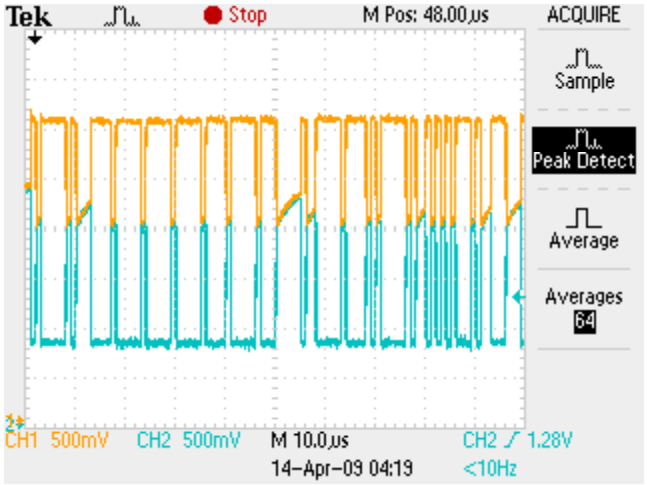
Controller Area Network

- Controller Area Network
  - An automotive serial data bus
  - Accelerate by wire
  - Commands and status information
- Connections
  - Motor Controller
  - Driver Controller
  - Motor Precharge Controller
  - Driver Displays
  - Battery Protection System
  - Telemetry
  - Light Controller



What is CAN?

- CAN (Controller Area Network) is a host-less, vehicle bus standard that allows for communication between microcontrollers
- CAN packets sent across the network can be read and interpreted by the various microcontrollers
- CAN is naturally redundant
  - CAN-Hi
  - CAN-Low



CAN Modules

- Tritium Design
  - Motor Controller
  - Precharge Controller
  - Driver Controller
  - Battery Protection System
  - CAN Bridge
  - CAN Displays
- WMU Design
  - Light Controller, v1 and v2
  - Telemetry, v1 and v2
- Future Designs
  - Coulomb Counter
    - Battery state of charge
  - Battery Protection System (2012)
  - Driver Controller (2012)
  - CAN Bridge (2010?)

Light Controller Board Function and Updates

- Responds to driver control switch position CAN data
  - Apply power to appropriate indicator lights:
    Brake lights, turn signals and hazard lights

- V2 Updates to Light Controller Board
  - CAN clock for MSP430
  - Allow high data rate for CAN operation (eliminated bug)
  - Improved Power Scheme
  - Removed ribbon components

Telemetry Board Operation

- Captures all CAN packets and stores/transmits CAN data
  - Wireless modem communication to chase vehicle (RS-232)
  - USB memory stick storage of telemetry data (black box)

- V2 Updates to Telemetry Board
  - More advanced MSP430 microcontroller
  - CAN Clock for improved UART operation
  - Dual CAN capable with improved power scheme
  - UART USB storage implementation

Telemetry Message Structure and Content

- Read from CAN packets (address and data)
  - Motor Controller: 14 addresses with data
  - Driver Controller: 4 addresses with data
- Fixed ASCII character string
  - Sent to chase vehicle
  - Saved to local USB memory storage

```
MC_LIM,0x00000000,0x0000803F
MC_BUS,0x00002043,0xE04DFE36
MC_VEL,0x0000807F,0x0000807F
MC_PHA,0x00000000,0x00000000
MC_VVC,0x00000000,0x00000000
MC_IVC,0x00000000,0x00000000
MC_BEM,0x00000000,0x00000000
MC_RL1,0x3333D33F,0x00007041
MC_RL2,0x9A99993F,0x00002040
MC_FAN,0x00009642,0x0000FA44
MC_TP1,0x1C03C841,0x1C03C841
MC_TP2,0x1C03C841,0x0000C841
MC_TP3,0x6300C841,0x6300C841
MC_CML,0x0000807F,0x00803F44
DC_CML,0x01000000,0x62495254
DC_DRV,0x00000000,0x00000000
DC_PWR,0x00000000,0x0000803F
DC_RET,0x00000000,0x00000000
DC_SWT,0x60000000,0x00000000
```

Initial CAN Test Bench Demonstration

Operation (1/10th speed)

- CAN Driver Controller
  - Ignition switch
  - Accelerator
  - Brakes
  - Indicator Lights
- CAN Motor Controller Sim
  - Respond with motor operations
- Lights According to Driver Controller Switches

Visual

- Lights applied
- CAN Packets on oscilloscope
- CAN-USB printout of CAN packet addresses and data
- Modem packet output

Test Bench As a Sunseeker Mock-up

- All expected CAN activity
- Allow all modules to be tested under normal and abnormal conditions
- Allow all software to be integrated before being installed in the car

- Expect easier support, faster installation, better performance

… leading to a faster and safer vehicle.

Sunseeker Electrical Teams

- Battery
  - Characterize batteries
  - Build and maintain 2010 battery
- Solar Array
  - Construct an I-V curve tester
  - I-V curve testing of existing module: good, bad, array groups
- CAN Support
  - Debug v2 PCBs: debug, find and fix errors and layout and fab new PCBs
  - Software documentation, testing, corrections, and updates
    - Driver controller, light controller, and telemetry.

Future Projects

- Coulomb Counter
  - Battery state of charge
- Battery Protection System
- Custom Driver Controller with displays
  - Eliminate CAN bridge