Michael Wood, Engineer
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Research & Design Portfolio

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Solaflect Context

- DOE SunShot Tier 1 ($1M) and Tier 2 ($1M) awards – 2011-2014
  - Program to reduce cost of solar to $1/W in utility scale
  - Concentrating Solar Power (CSP) contender because of thermal energy storage
  - Economical CSP requires heliostat (mirrored collector) cost target of $75/m^2
  - Patented cable “tensegrity” structure economical and efficient
  - Required heliostat pointing accuracy <0.06° RMS
- Solaflect R&D – 2014-present
  - Decline invitation to Tier 3, swap mirrors for PV modules and sell product
  - Nearly 2 MW installed capacity in VT, NH, and MA

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Development of Low-Cost Suspension Heliostat

Solaflect Energy

Dr. William Bender

SunShot Incubator Tier 1 Recipient: $1M Funding

CONCENTRATING SOLAR POWER: COLLECTORS

Solaflect Background:

- R&D in Norwich, Vermont USA
  - 2007 - Present
  - Patented Suspension Heliostat™
  - Vetted by CSP experts worldwide
- Awarded $1M grant to DOE's 2011 Sunshot Incubator Program
  - Refinement of Suspension Heliostat

Overview:

Solaflect Energy has created a new heliostat design that is the most material efficient heliostat in the world. The Suspension Heliostat™ incorporates a novel, patented tension-compression system to support and stabilize mirrors with great accuracy. The design also allows the simultaneous, rapid, symmetrical and accurate canting of all mirror facets so that the facets on each heliostat can be adjusted to its exact slant range.

Cost Reduction:

- Manufacturing costs directly related to material efficiency in volume.
- Structure composed of standard steel shapes and sizes already produced in huge volumes
- Steel accounts for 33-50% of typical heliostat cost.[1]
- Next generation concepts of the Suspension Heliostat™ demonstrate further steel reduction.

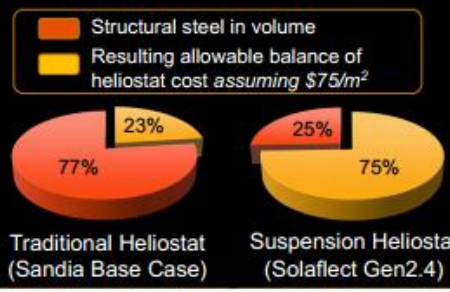
Heliostat Design

Conventional "Truss" design	Solaflect Suspension design
Heavy structural support	Mirrors secured with cables
Material inefficient	Material efficient
Significant fabrication cost	Greatly reduced cost

Benefits of Suspension Heliostat:

- Cost reduction from eliminating steel
- Simple construction and ease of shipping
- Continuously adjustable focus
- Accurate symmetric canting
- Flexible foundation options

Goal: Achieving $75 per m²



Structural Steel per m²

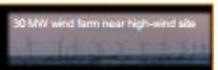
	Traditional Heliostats	Solaflect Suspension Heliostats		
Model	Sandia Base Case	Gen 1	Gen 2.1	Gen 2.4
Structural Steel	100%	71.5%	40.1%	33%

Modular for Easy Handling

- Efficient Shipping
  - Packs nearly field ready

- Modular Installation
- Compact pedestal assembly
- Simple mirror installation

Robust Field Testing



- Early prototype on extreme VT mountaintop
- Multi-unit installation in Cheyenne, WY test site
- 40 years of Phoenix wind events in 1 year in Cheyenne

Incubator Progress To-Date

- Over 50lbs of steel reduced from structure
  - Reduction in parts, hardware and complexity
- Dynamic optical and survival testing in progress
- Custom controller design in progress

References:

[1] J. Gregory Kolb, Scott Jones, Matthew Donnelly, David Gorman, Robert Thomas, Roger Davenport, Ron Lumia (2007), Heliostat Cost Reduction Study, SAND2007-3293, Sandia National Laboratories, Albuquerque, NM.

[2] US National Renewable Energy Laboratory (2007), Concentrating Solar Power Projects of the Southwest United States.

SunShot U.S. Department of Energy

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www.solar.energy.gov/sunshot/csp.html

SunShot Tier 1 – 2012
Tracking controller update I

Accomplishments

Hardware

- Drive motors with optical position encoders move from “home” (e.g. due north and pointing straight up) to sun’s position
- PWM motor driver for servo speed control and possible regenerative braking (when tracker is moving down)
- Wireless 2.4 GHz ZigBee self-healing mesh network plus redundant wired RS-485

Software

- Uses NREL’s Solar Position Algorithm, time of day, lat & lon, and atmospheric constants to calculate sun’s angular position and control motors

Analytics

- Machine vision for tracking pointing error
- Wireless communication link quality
- System characterization

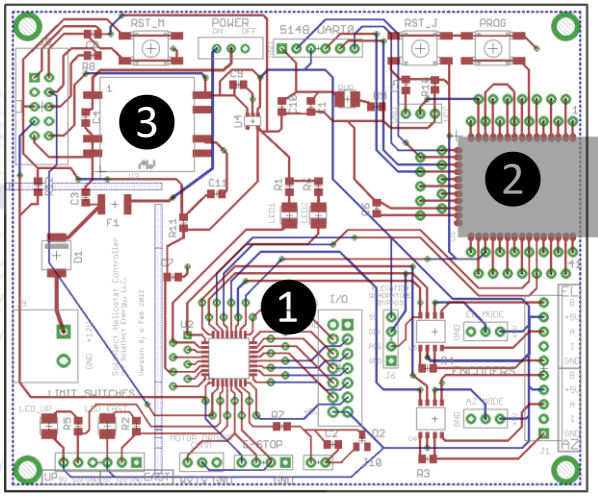
Role

Support

Support

Support

Solar Tracking Controller



1. 8-bit MCU
2. Wireless module
3. Power supply

Motor driver (not pictured)

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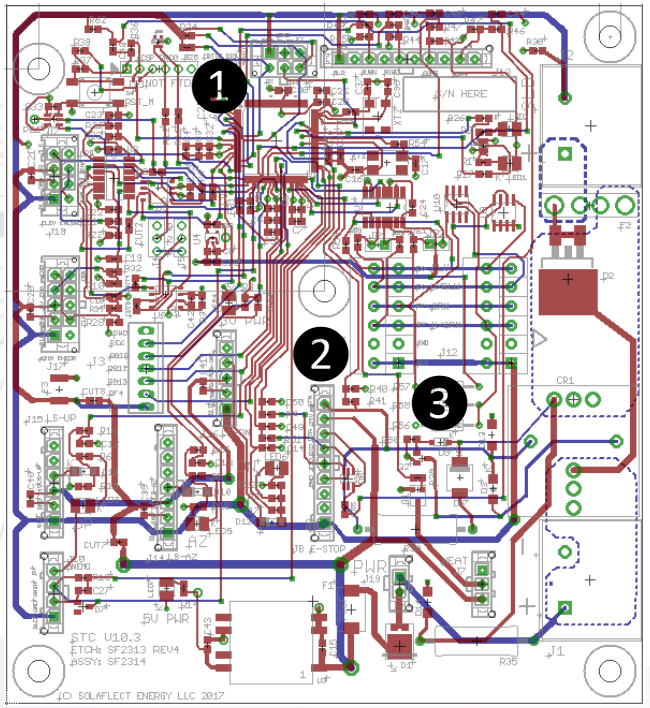
SunShot Tier 2 – 2013-14

Tracking controller update II

	Accomplishments	Role
Hardware	• High power, three stage surge filtering • Motor driver capacitive inrush current limiting	Support
Software	• Fully embed Solar Position Algorithm • Digital low pass EMI filter • Tune speed and servo control based on second order mechanical characteristics	Lead
Analytics	• Lasers and precision compass for tracking pointing error	Lead

Solar Tracking Controller



1. Modern 32-bit MCU
2. Surge filtering
3. Capacitive inrush current limiting

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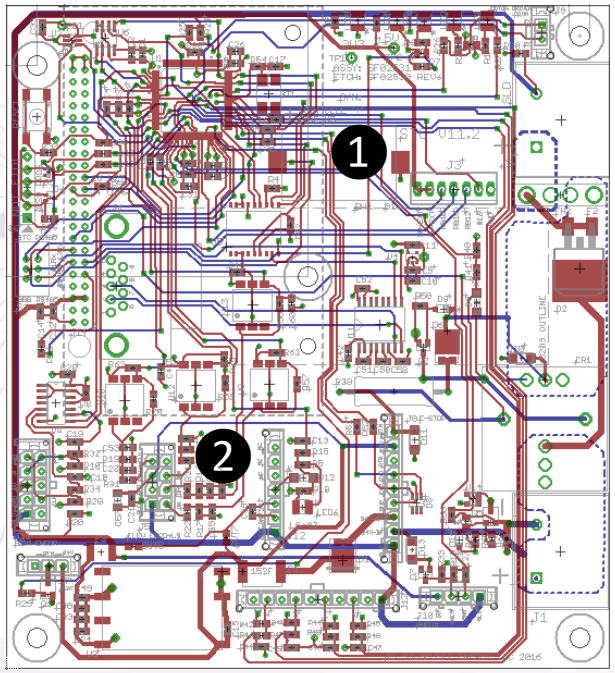
Solaflect R&D – 2014-present

	Accomplishments	Role
Hardware	• Real time clock & firmware • Optical isolation	Lead
Software	• State machine and auto calibration • Linux network gateway, online portal	Coordination
System	• 4 kW up to 150 kW PV plants • DC gearmotor specification and contract design • PV inverter and module level electronics • Tesla battery system • Concentrating PV assesssment • Fiber optic local area network	Coordination & support
Analytics	• Component reliability and failure analysis • Power production modelling	Lead & support

Solar Tracking Controller



❶ Real time clock
❷ Optical isolation
Linux network gateway (not pictured)

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Lightning EMI Investigation - 2016

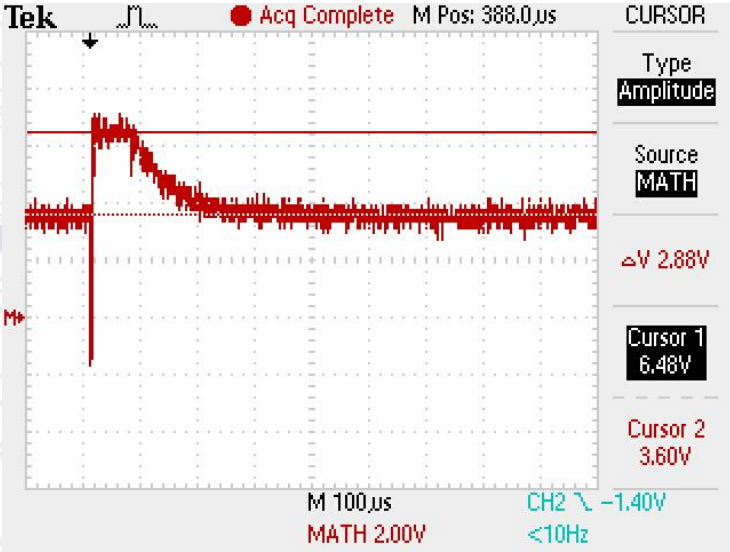
Problem: wireless communication unreliable and long wired bus susceptible to inductively coupled electromagnetic interference (EMI) in electrical storms

Research – lead: EMI theory, board EMI protection, industry best practices, grounding, silicon vs. gas tube characteristics

Investigation – lead: simulate EMI with 6 kV 1.2/50 µs waveform generator, hypothesize and test propagation and response, clamp as much as possible

Results: careful grounding and high power 3-stage surge arrestors usually attenuate large surges, but in practice can be more difficult and expensive than switching to fiber optic

Clamped -2 kV surge response



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Bifacial PV Investigation - 2017

Need: characteristics of bifacial (double-sided) PV modules above high albedo surface with changing elevation angle

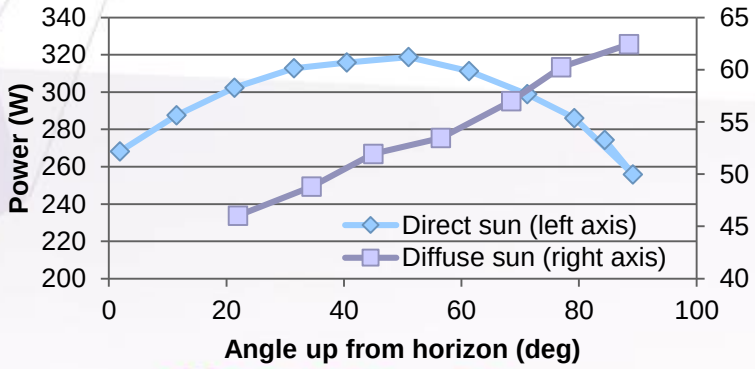
Research – lead: Bifacial literature, SMA and NREL SAM models

Investigation – lead: in various light conditions and various elevations angles measure max power and bifacial "gain" compared to identical panel with back face covered

Results: (i) over snow bifacial gain can be 23% in direct sun and 70% in diffuse sun, and (ii) in diffuse sun pointing to 90 degrees above the horizon can result in an additional 20% gain

Gain testing apparatus

Optimal pointing angle



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Questions?

Cheyenne High Wind Test Site