An Optically Isolated HV-IGBT Based Mega-Watt Cascade Inverter Building Block for DER Applications

U.S. Department of Energy SBIR Grant

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Airak, Inc.

Paul Grems Duncan

9058 Euclid Avenue
Manassas, Virginia 20110-5308
voice: (703) 330-4961
fax: (703) 330-4879
pduncan@airak.com

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Project Goals

- Primary: Develop a new full-bridge, three phase, megawatt inverter topology based upon HV-IGBTs with optical current, voltage, and temperature sensing in addition to command/control interfacing.
- Secondary: Compare/contrast advantages of optical sensor and control methodologies over conventional methodologies (e.g. safety, reliability, costs, response, efficiency, phase margin, dynamic range, etc.).

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Team Members

Administrative Management & Funding
- Dr. Imre Gyuk

Technical Management
- Stan Atcitty

Optical Sensor and System Design
- Paul Duncan

Power Electronics Subsystem Design
- Dr. Jason Lai

Motivation

- Optical Sensor Technologies + High Power Systems => Tremendous Advantages
- Commercial Point of View: “Dual Use” for both Power Electronics and Utility Power Industries (i.e. Potential Markets are Large)

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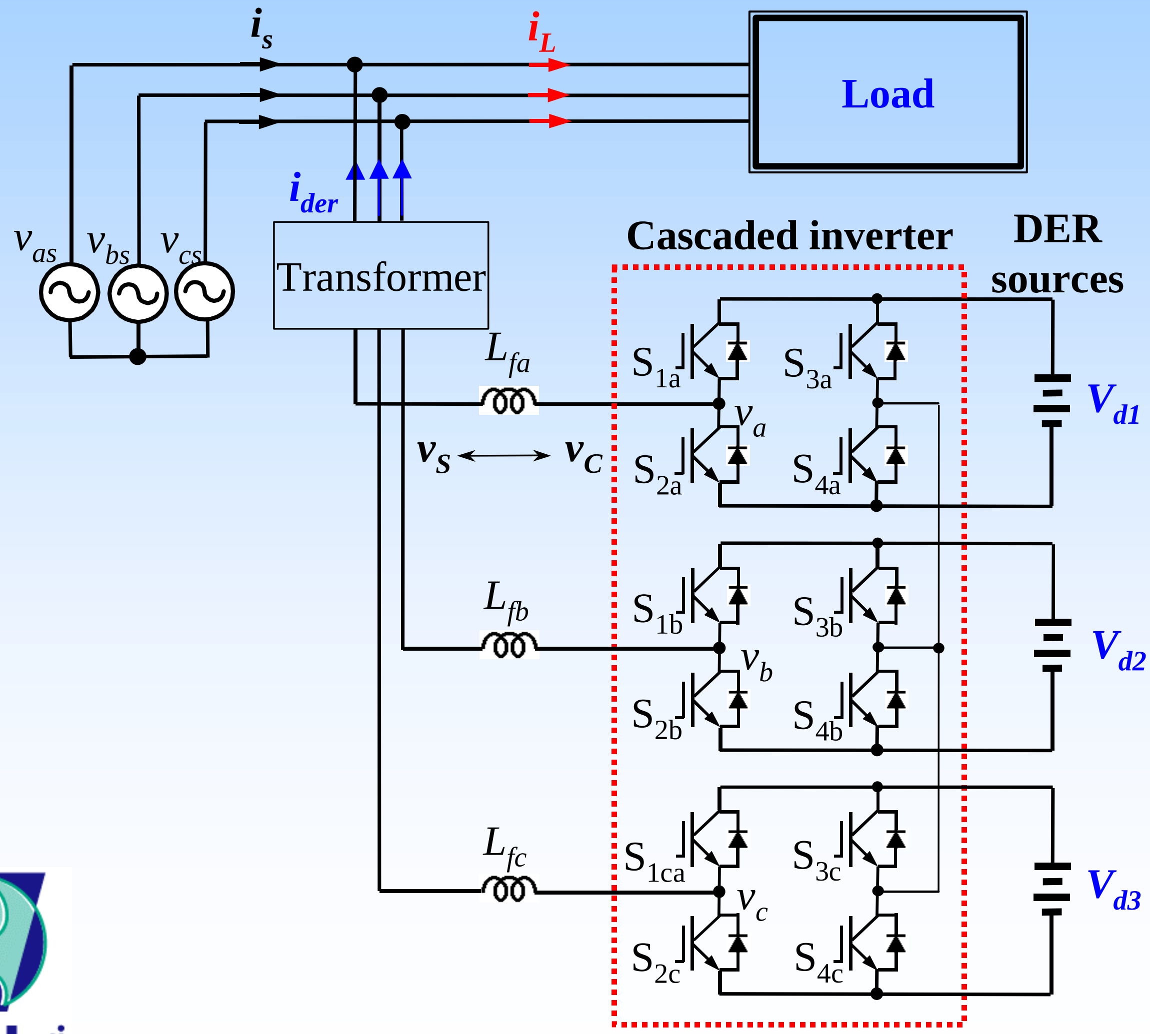
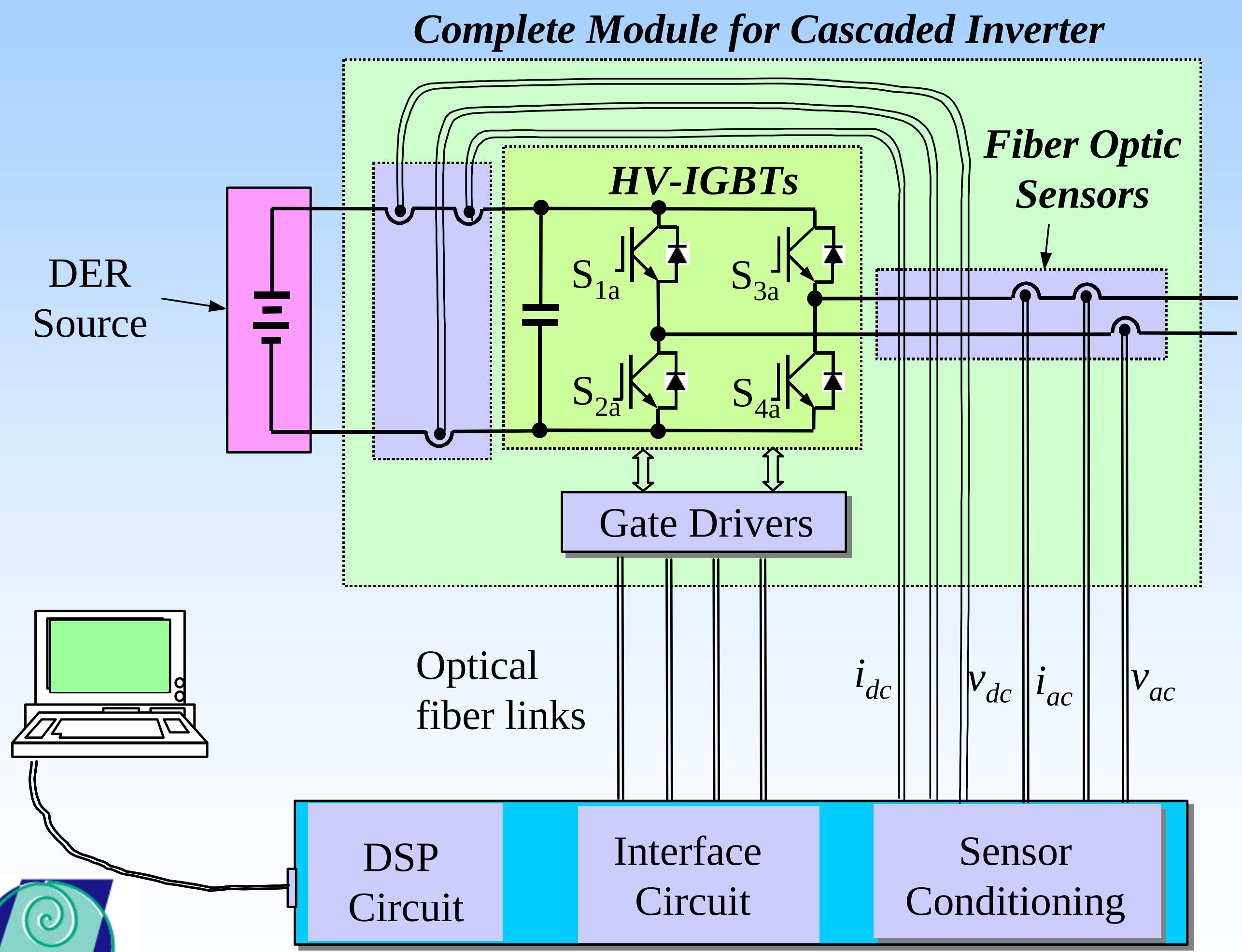
System Configuration



Sensor & Control Configuration



Why HV-IGBTs?

- Compared to GTO or other thyristor-based devices…
  - Eliminate Current Snubbers and Voltage Clamps
  - Simplify Gate Drive Circuitry and Isolation
  - Provide Cost Advantage at System Level
  - Increased Efficiency and Reliability

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Implementation

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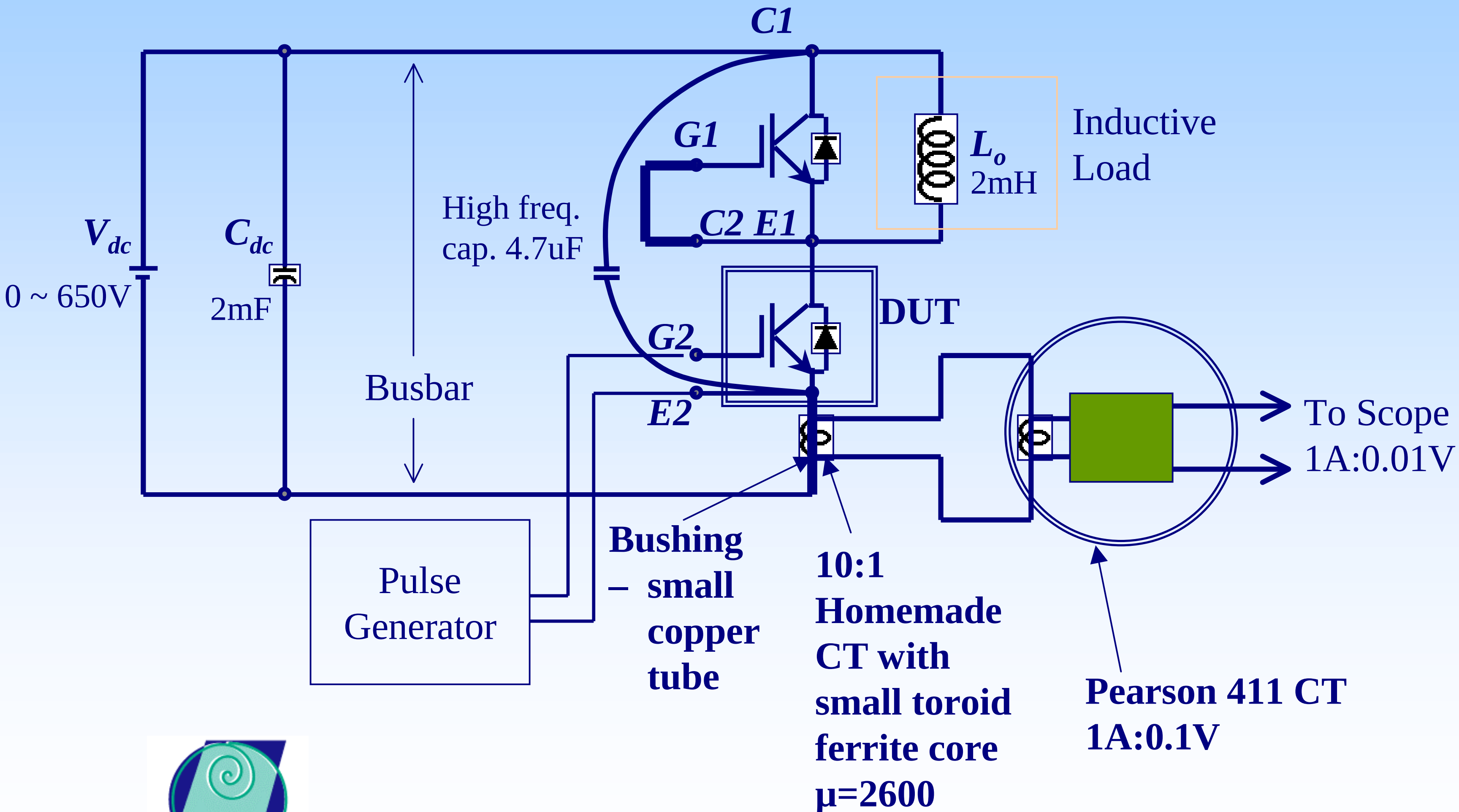
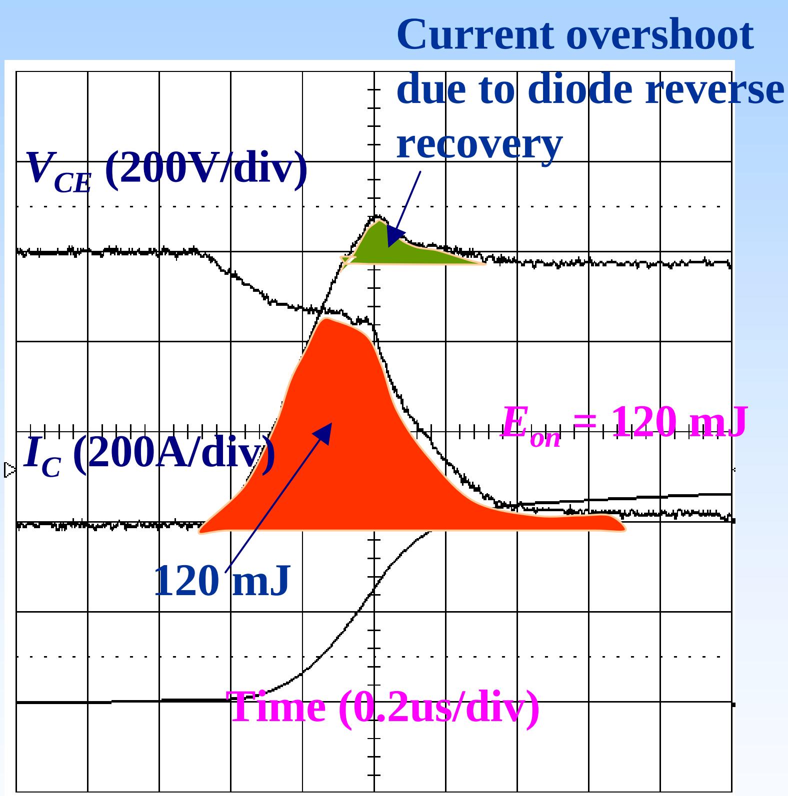
IGBT Module Test Setup

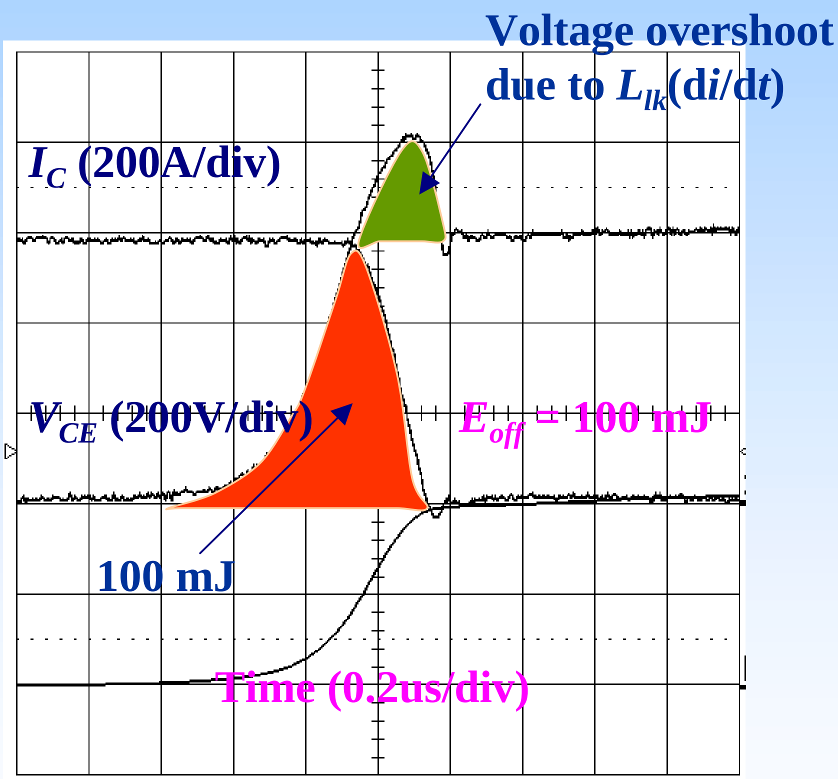


HV-IGBT Turn-on and Turn-off Waveforms

Voltage, Current and Switching Energy at 360 kW



(a) Turn on

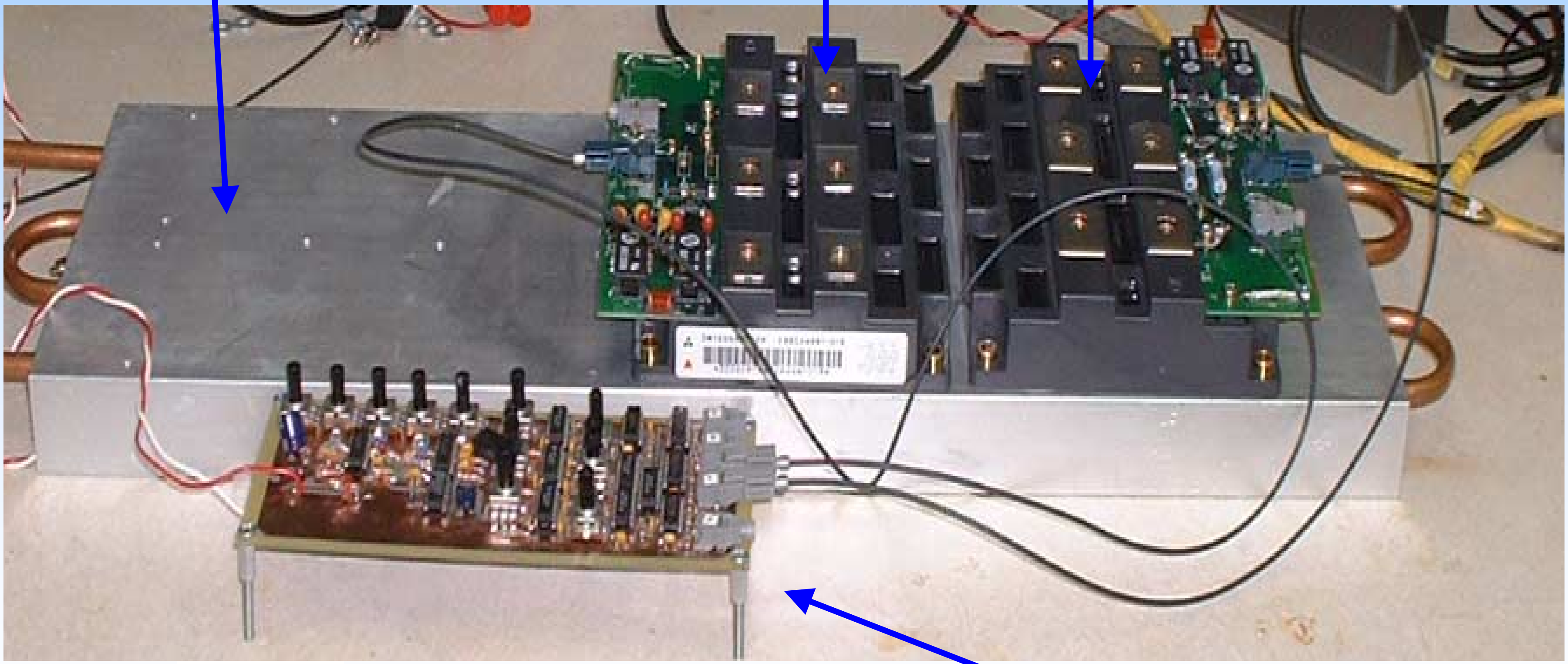


(b) Turn off

IGBT Test Structure

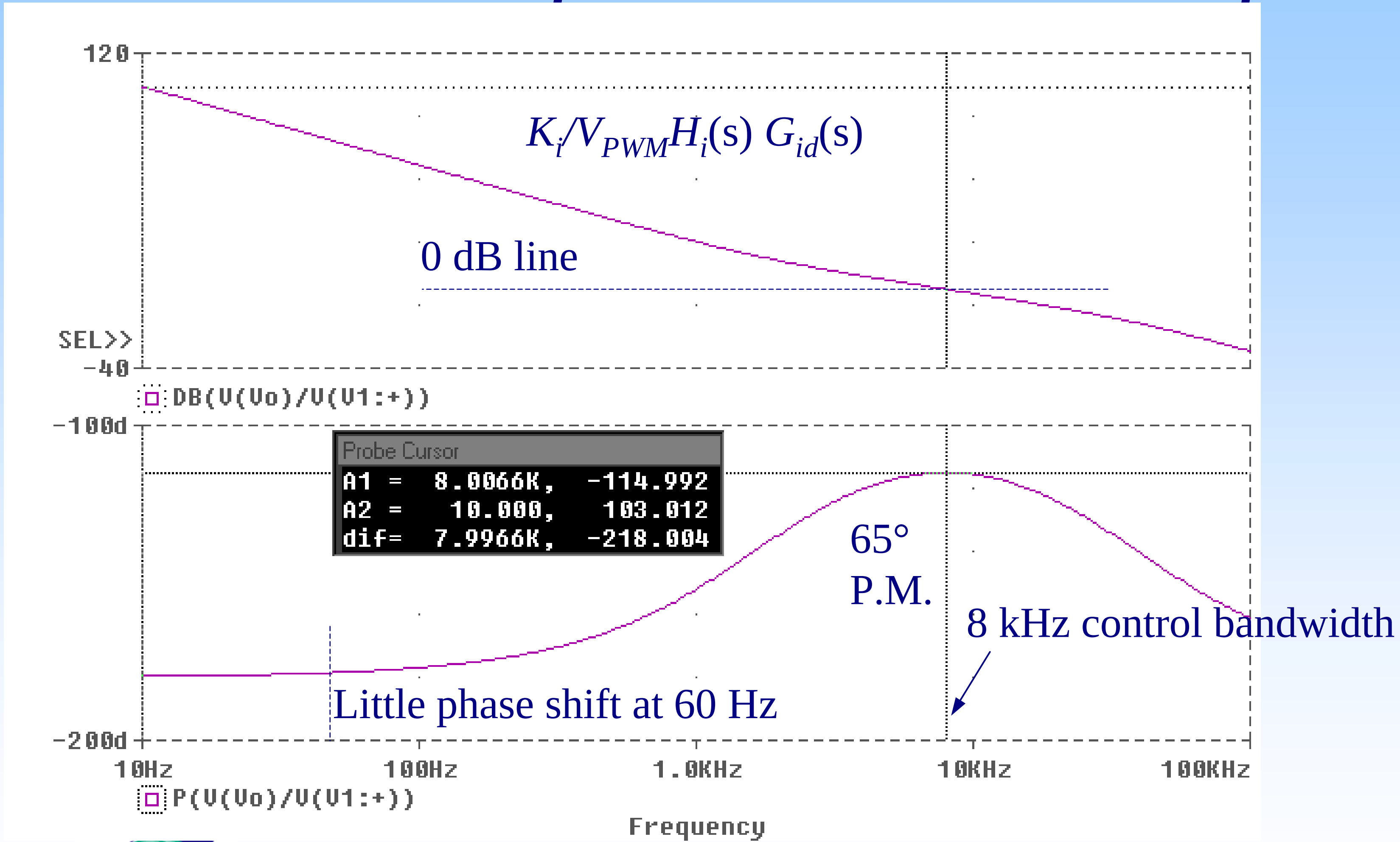
Liquid Cooled
Heat Sink

IGBT

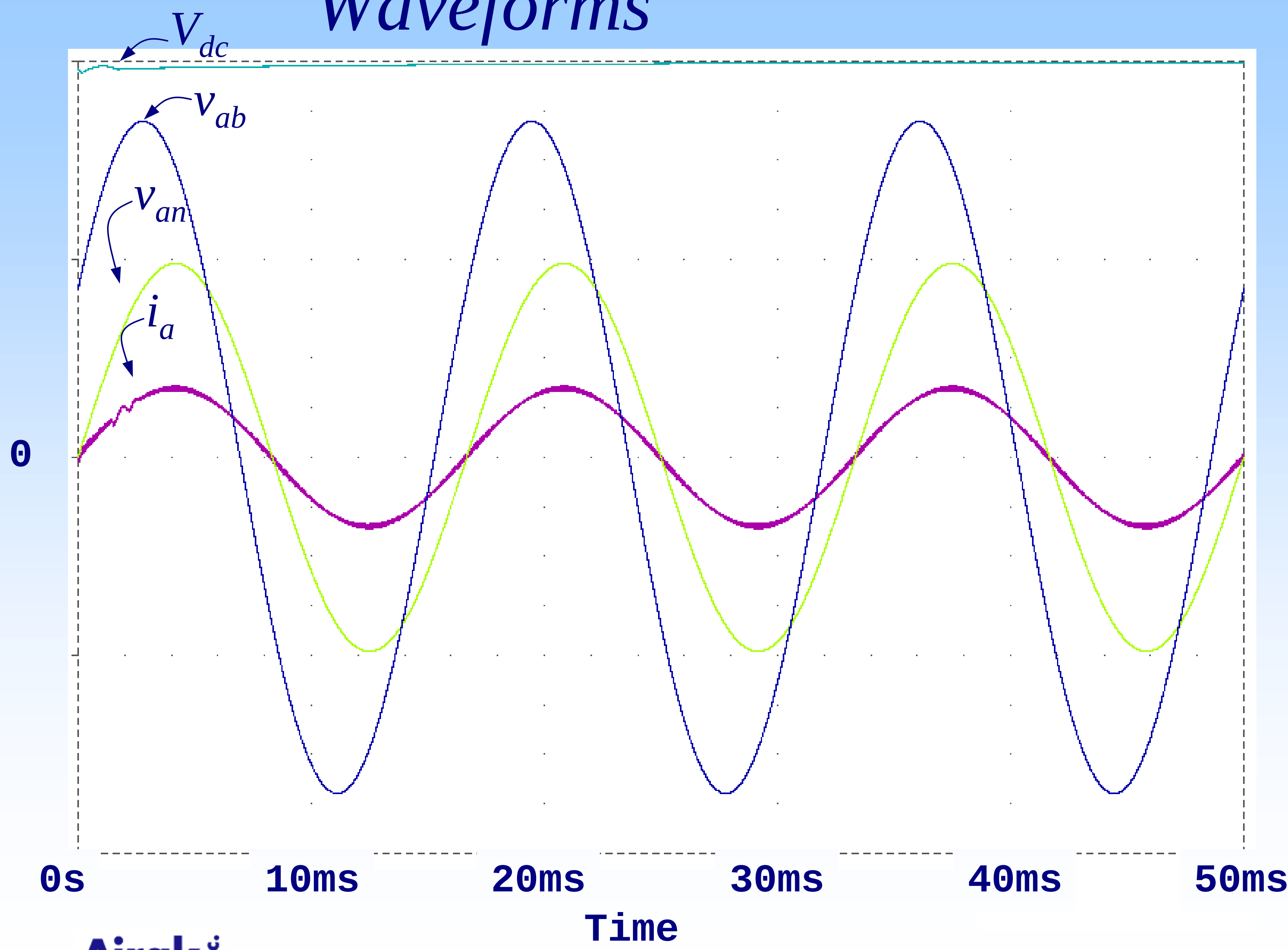


Pulse Tester

Bode Plots of the Control Loop



Simulated Voltage and Current Waveforms



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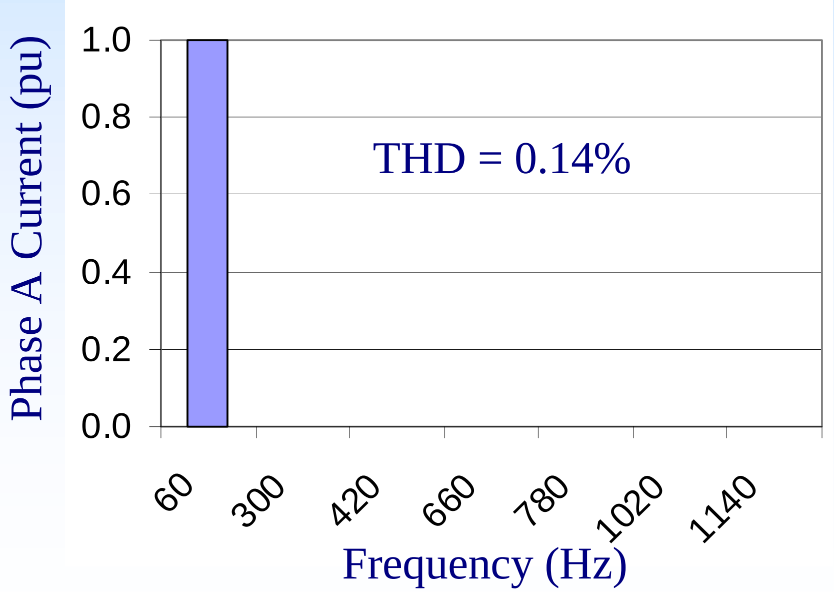
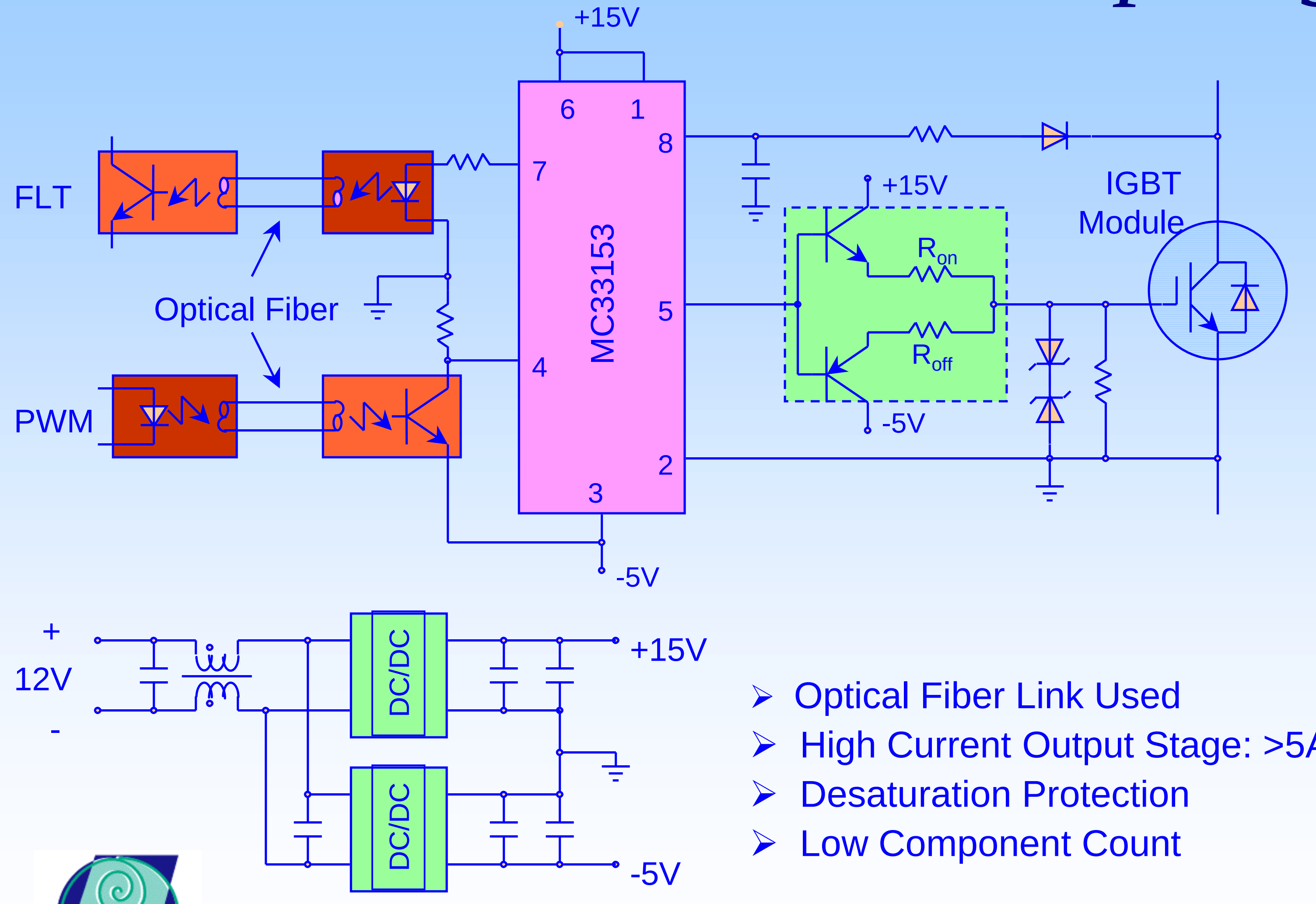
Frequency Spectra of Phase A Current

Har. #	Freq (Hz)	I_a (A)	I_a (%)	$\angle I_a$ (°)
1	60	127.6	100%	1.0
5	300	0.07	0.05%	-97.9
7	420	0.07	0.05%	-99.7
11	660	0.08	0.05%	-98.1
13	780	0.06	0.04%	-124.6
17	1020	0.06	0.00%	-104.2
19	1140	0.07	0.00%	-106.2



Opto-Isolated Gate Driver Topology



- Optical Fiber Link Used
- High Current Output Stage: >5A
- Desaturation Protection
- Low Component Count

HV-IGBTs & Gate Drivers

- During the 2nd Phase of this program intend to move toward Therma-Charge™ heat pipe assemblies.

Therma-Charge™ technology allows the rejection of multiple kilowatts of heat from power semiconductors directly to ambient air. This is an important conclusion considering the potential alternative is a liquid pumped loop system that has inherent long-term reliability (leaks), maintenance (pump failure, fluid cleanliness, filtering) and corresponding cost issues.

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Why Optical Sensors?

- Intrinsic Safety
- Intrinsic Isolation
- Increased Reliability
- Higher Response
- Greater Dynamic Range
- Small Size and Weight

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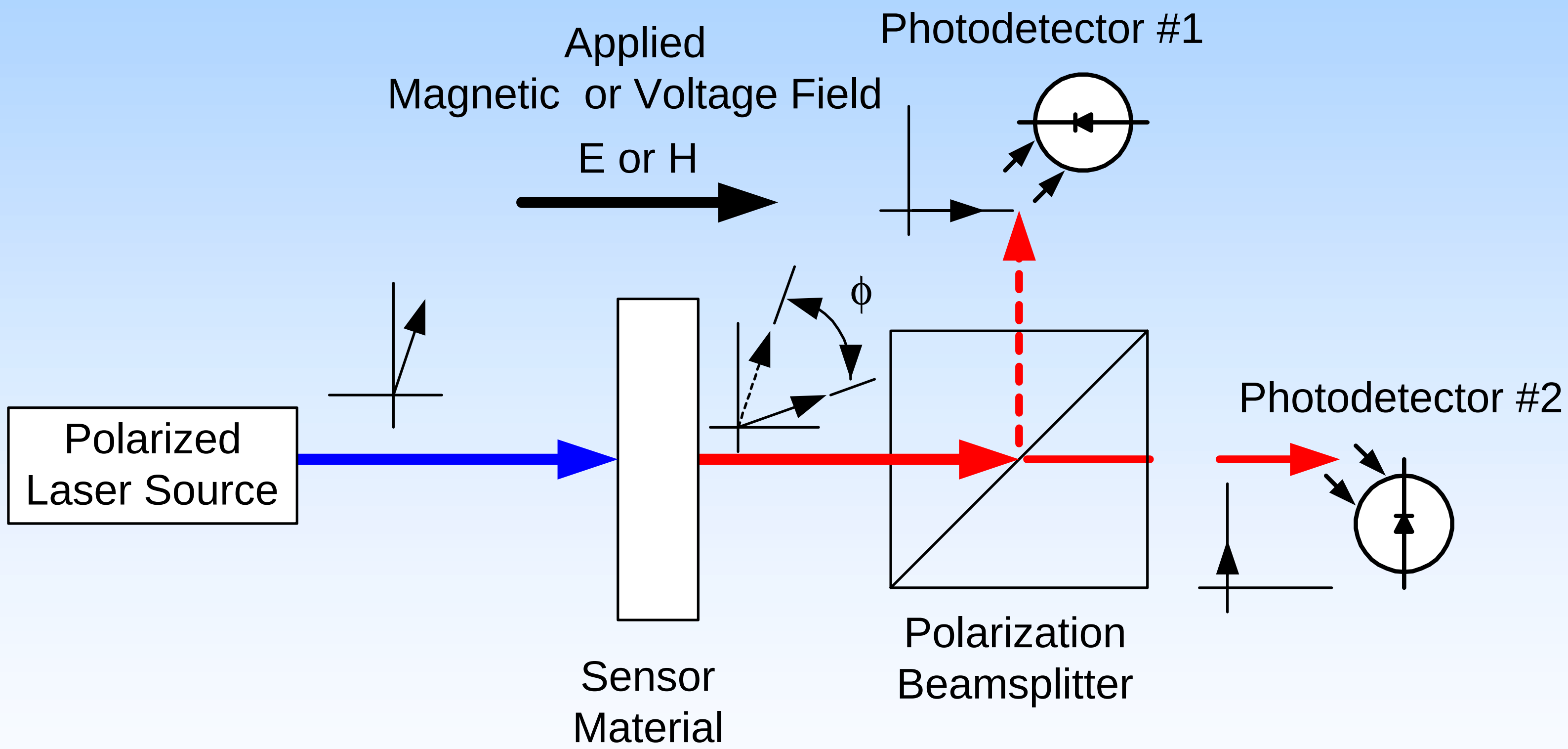
Fundamentals: Sensing with Crystals



Fundamentals: Conversion to Current Measurements

The holy grail: I = total current flowing through a conductor

$$i = \oint_l \vec{H} \bullet dl$$

H=magnetic field intensity

$$\vec{H} = \frac{\vec{B}}{\mu}$$

(a constant)

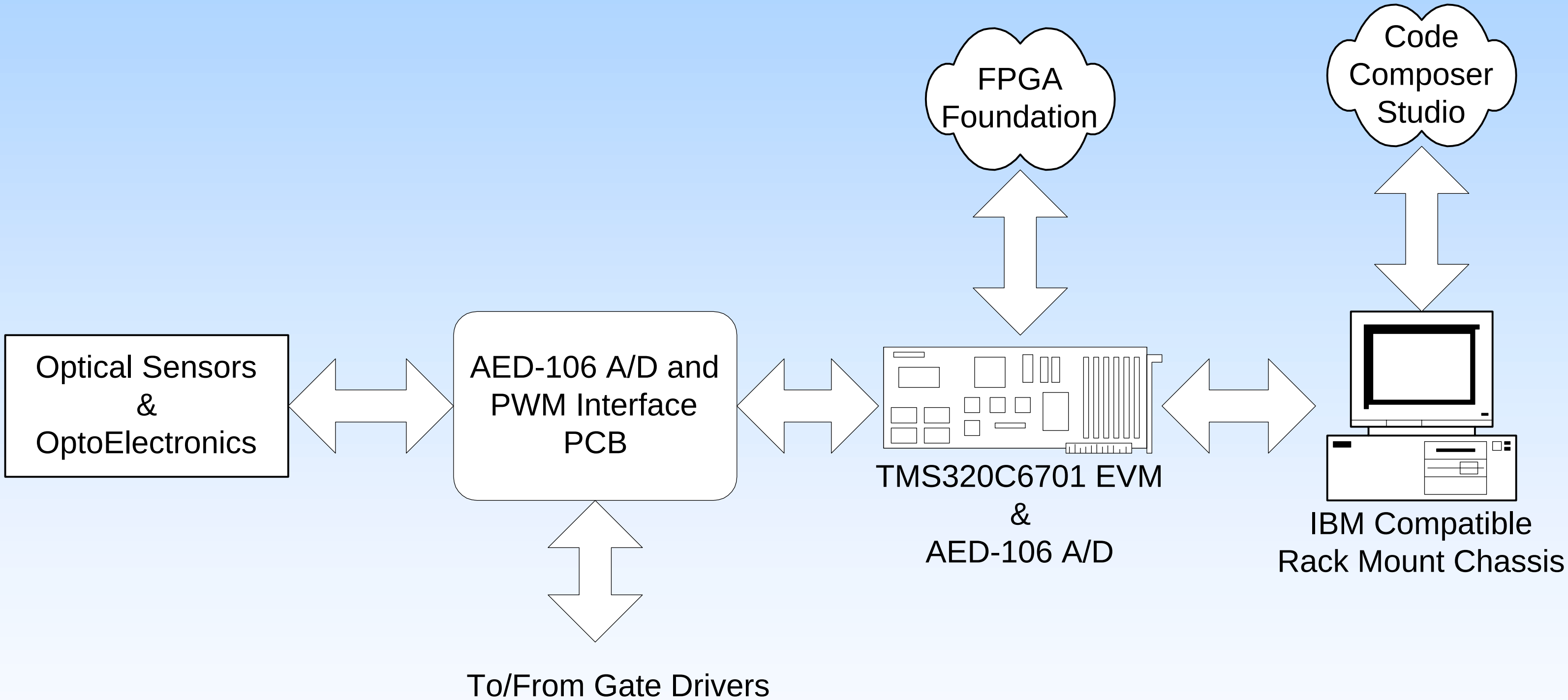
B = magnetic flux density &
μ = permeability

$$B = \frac{\phi}{Vl}$$

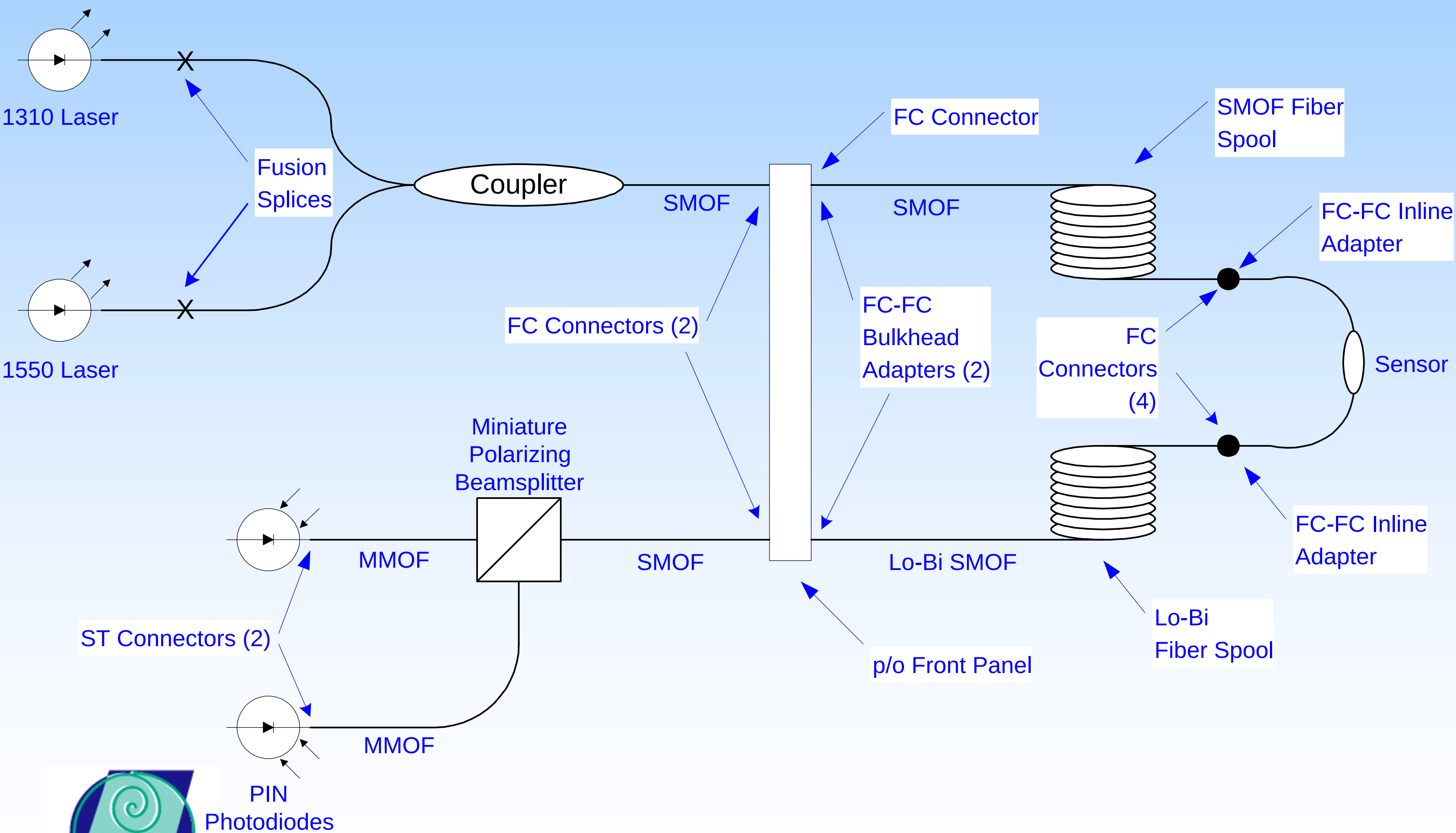
(a constant)

ϕ=polarization rotation

Sensor and Power Conditioning Function



Optical Configuration (Voltage or Current Sensor)



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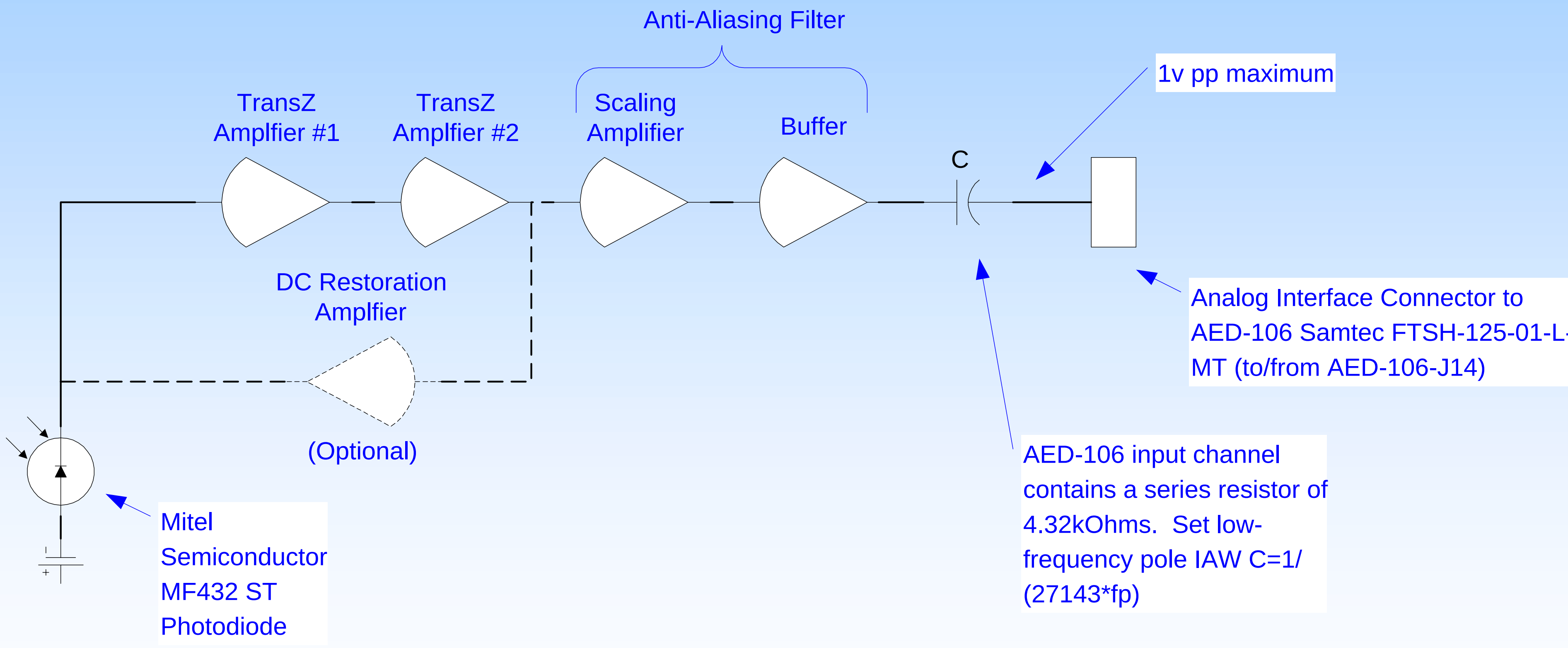
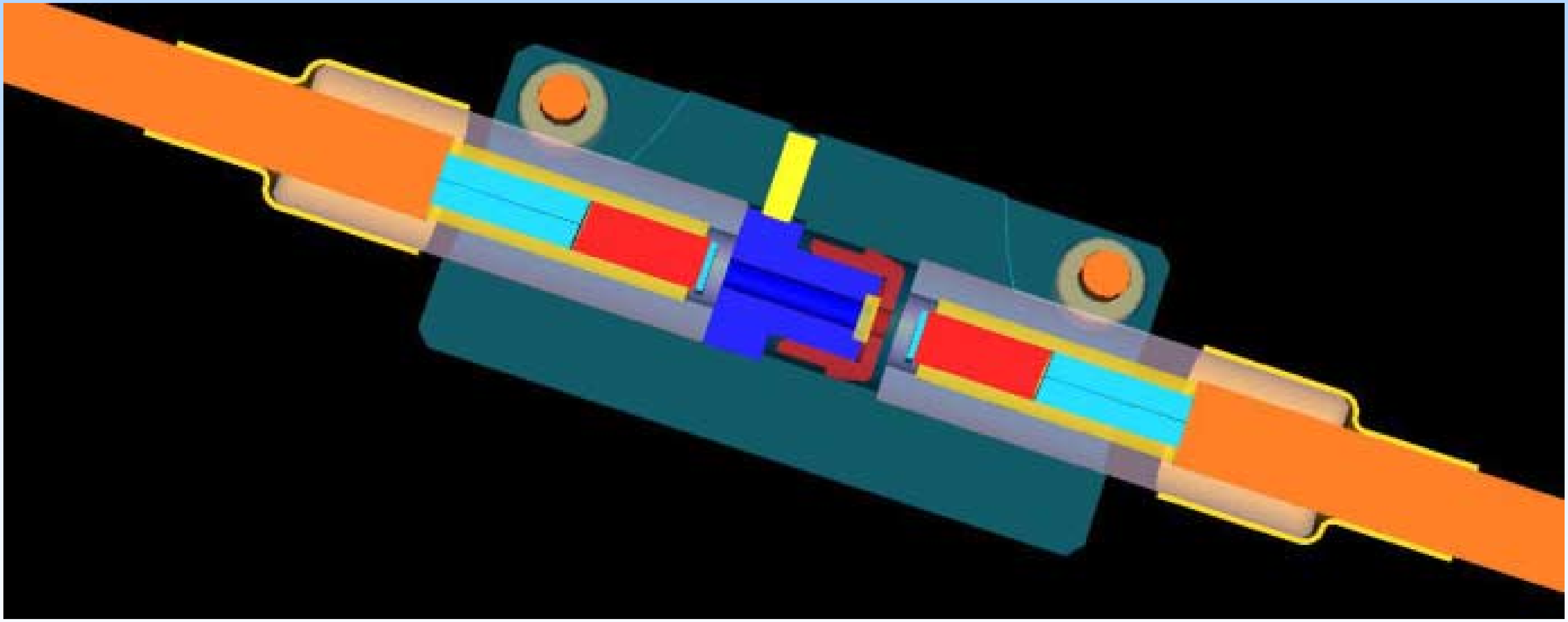
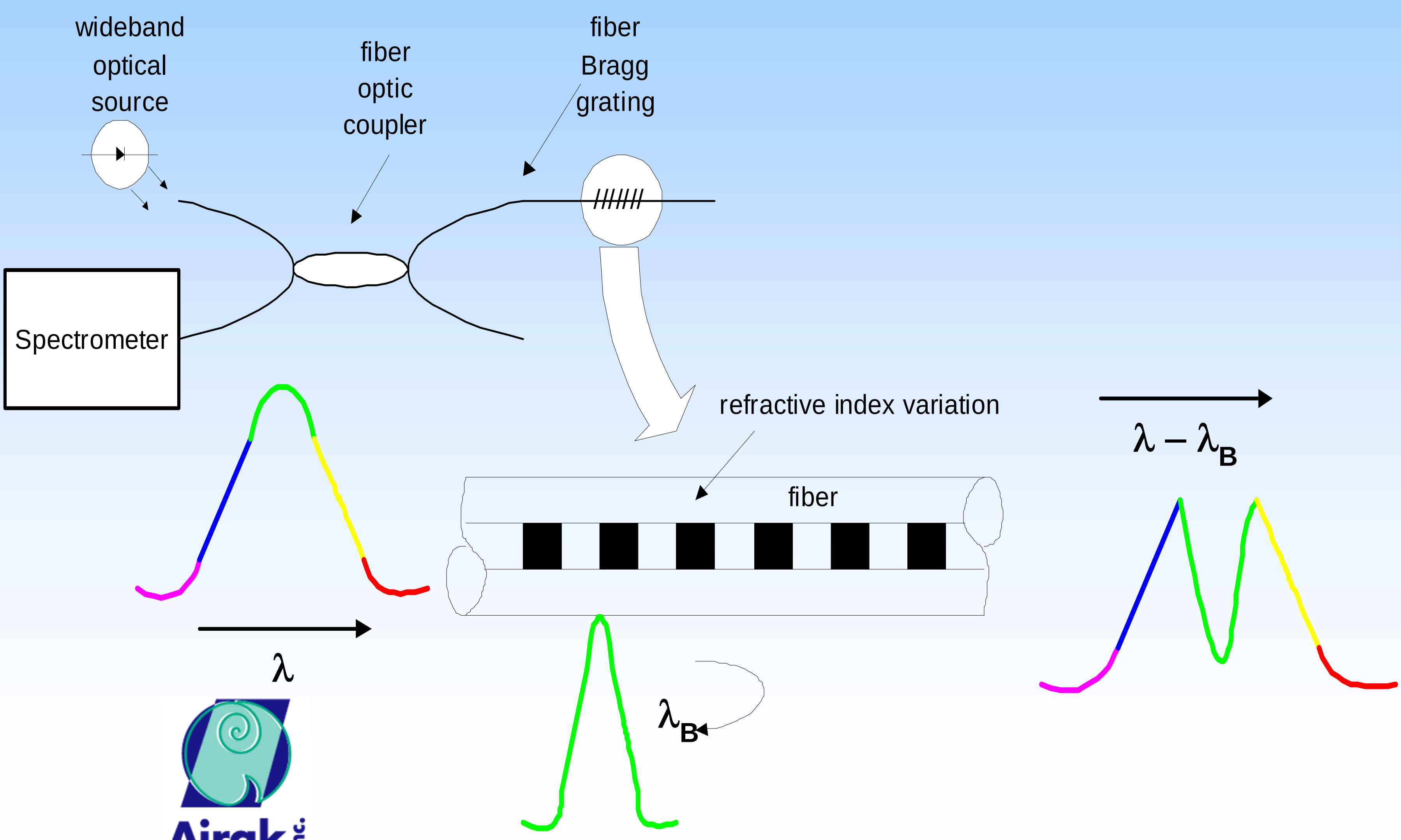
Optical Sensor Analog Conditioning



Optical Current Sensor Sectional



Fundamentals: Bragg Grating Temperature Sensor



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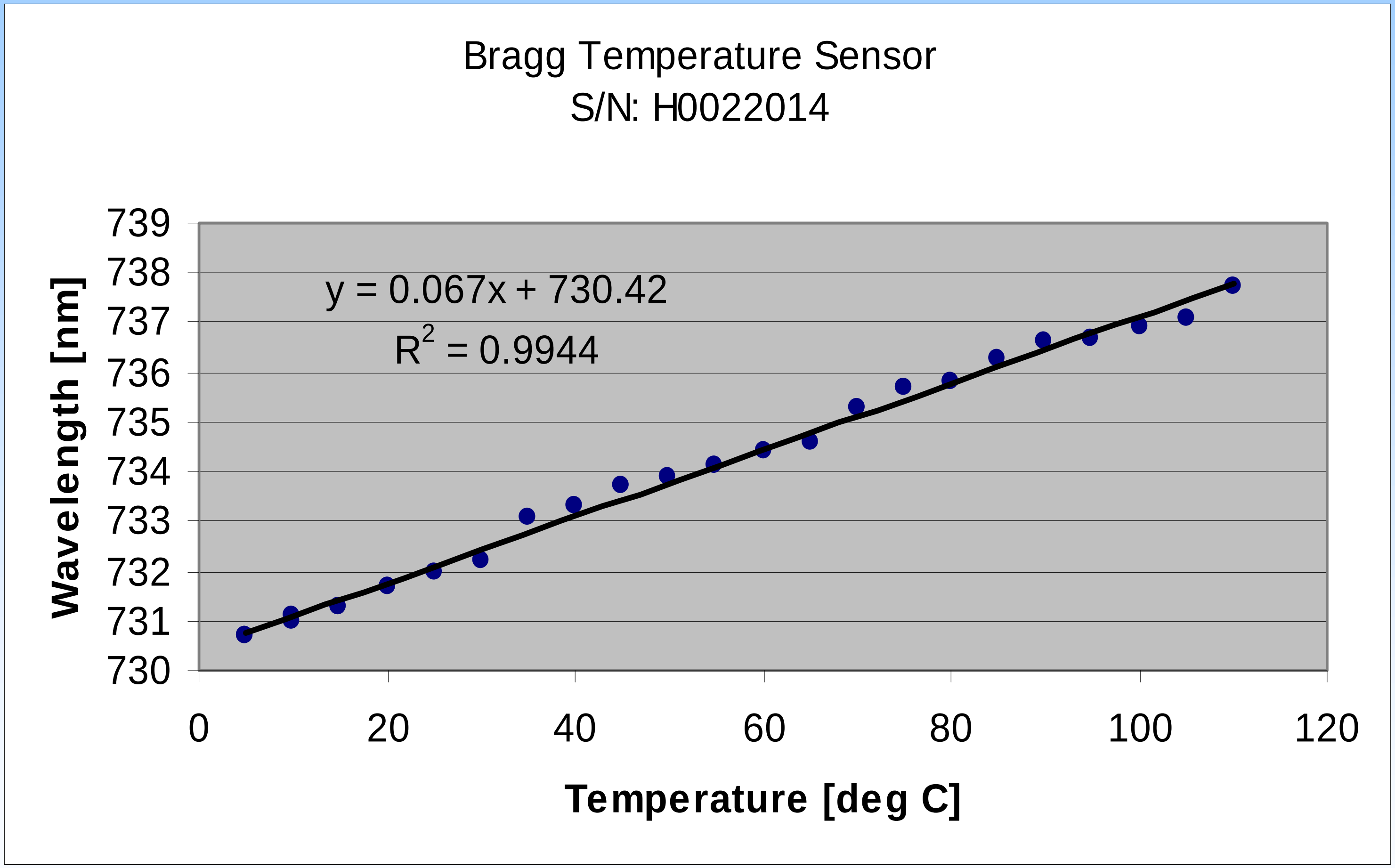
Bragg Temperature Sensor Data



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Pending Milestones

- Power Electronics Subsystem Integration (Dec ‘01)
- Optical Subsystem Integration (Dec ’01)
- Systems Integration (Jan ’02)
- Systems Testing/Comparative Analysis (Jan/Feb ’02)
- U.S. DoE Demonstration (Feb/Mar ’02)
- U.S. DoE Follow-on Proposal (Mar ’02)

- U.S. DoE 3-Phase System Development (Jun ’02+)

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Next Steps

- Demonstration of MW-Level HV-IGBT and Optical Technologies for Industry Partners
- Joint Collaboration and Development of Technologies for Specific Power Electronics and Utility-Scale Applications

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Q&A / Discussion

For Further Information Contact:

Paul Grems Duncan

9058 Euclid Avenue

Manassas, VA 20110-5308

Voice: 703-330-4961

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