The Directed Energy Test Science and Technology Non-Intrusive HPM Sensor Program

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Purpose & Topics

- This presentation addresses the non-intrusive RF sensors developed by the Directed Energy Test Science and Technology (DET S&T) effort in response to test shortfalls in military test range capabilities.

E-field sensors
B-field sensors
Radio Frequency Current sensors
Voltage Potential sensors
Envelope Detectors

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Sensor Requirements Determined

- Directed Energy Test and Evaluation Capability (DETEC) Tri-Service Study (T-SS),
  - DETEC is a Test Resource Management Center (TRMC) Central Test and Evaluation Investment Program (CTEIP)
  - Study Dates 2003, 2008, 2011
  - Process
    - SMEs develop test concepts
    - Workshop with Government test stakeholders
    - Determine test requirements
    - Define capability of test ranges to meet requirements
    - Identify test shortfalls
  - Determine which of shortfalls require S&T
  - TRMC funding for both capability and S&T shortfalls

Sensor portion of S&T DE Test shortfalls subject of this presentation

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Currently Available Probes

DETEC Sensor Suite Probes

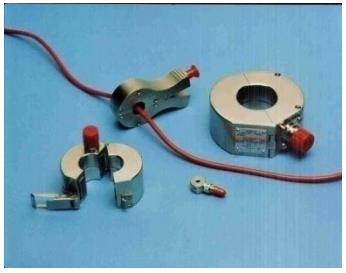
D-dot **EG&G ACD-2 D-dot**

B-dot **EG&G MGL-6 B-dot**

Standard Gain Horns **SGH X-band**

Open Wave Guides **12.5 – 18 GHz**

Current (I) Sensors **Prodyne Tech Inductive probes**



Radio Frequency Diodes **Diode Detector**

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Intrusion of Metal Probes

	Present Sensor Intrusion
• At source	
– H-field (near field)	– 20%
– E-field (near field)	– <5%
• At target – Free field or near the ground	
– H-field	– 15%
– E-field	– 10%
– Beam Shape	– 1%
– Polarization	– 10%
• In target	
– H-field	– 15%
– E-field	– 10%
– Current	– 25%

Estimated from literature – We will see how to measure for E and H-field probes later

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DET S&T Sensor Program

- Sensor Types
  - E-field Sensors
  - B-field Sensors
  - Current Sensors
  - Voltage Potential
- Characteristics
  - Non-intrusive
  - Direct measurement vs. differential sensing
  - Small (to go inside HPM targets)
  - Wide Frequency Bandwidth
  - 3-axis
  - Cheap

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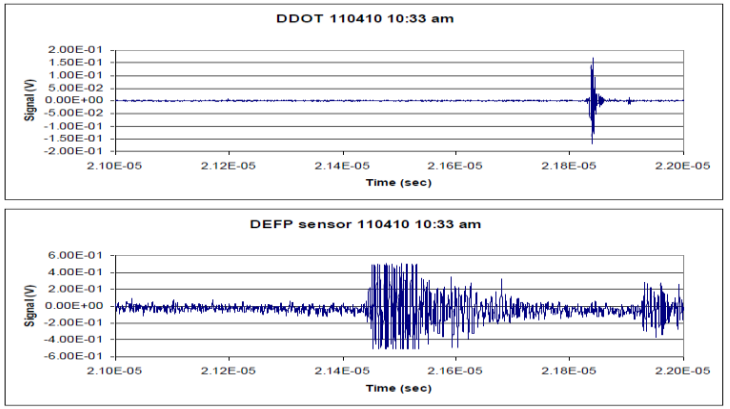
Proof of Concept Projects

Dielectric Electromagnetic Field Probes (DEFP) E-field

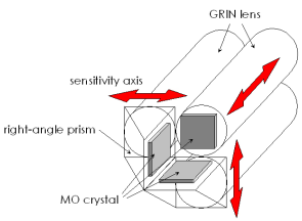
- A Mach-Zehnder Interferometer approach to EO sensor using polymers
- 4 probes were built



White Sands Test against wideband source

Magneto Optical Field Sensor (MOFS) H-field

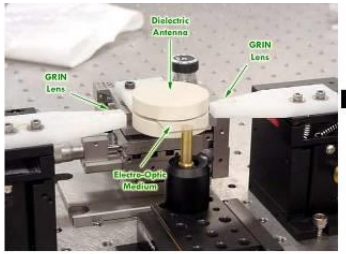
- A single crystal MO approach to building a 3-Axis B-field probe

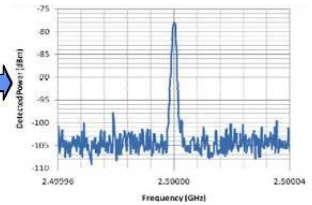


MOFS 3-axis probe

Dielectric Antenna Electro-Optical Sensor (DAEOS) E-field

- Dielectric Antenna based EO sensor to increase sensitivity
- Very narrow band (100MHz)





Detection at 2.5GHz (single frequency)

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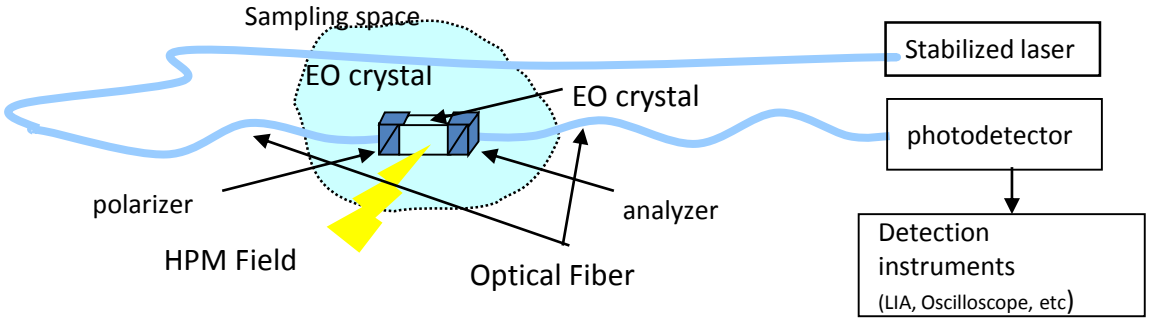
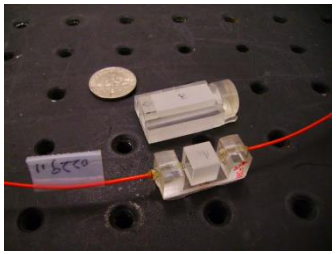
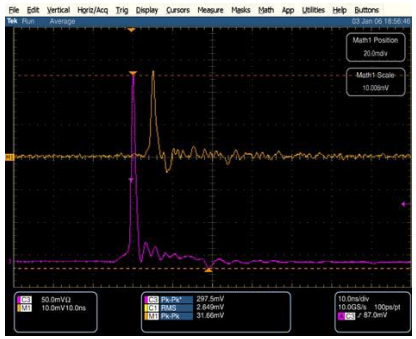
Electro-Optical Sensor Technology (EOST)

- Low hanging fruit EO crystal based direct E-field measurement
  - Moderate size 0.5x1.0x0.5cm plus fixture
  - Technology well known – Pockels effect







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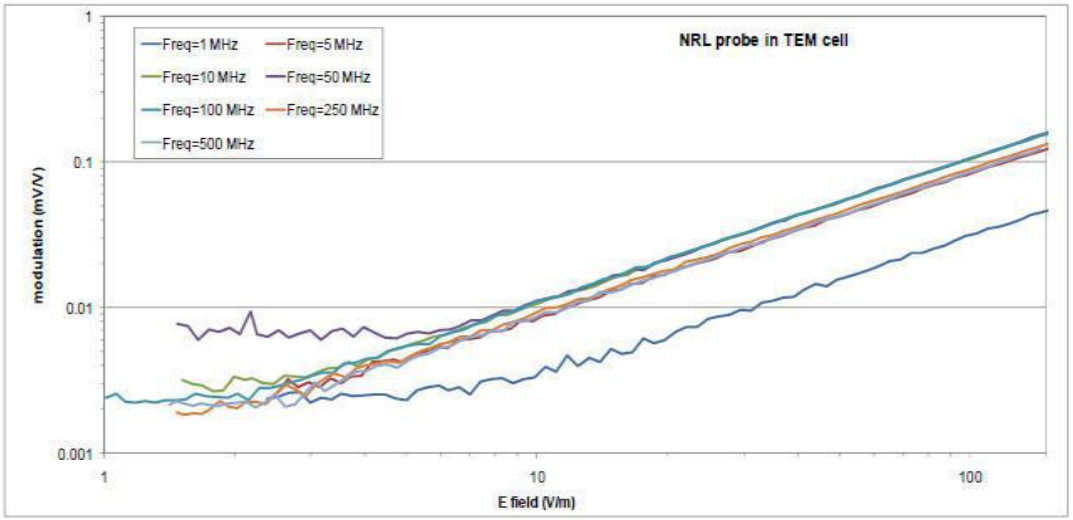
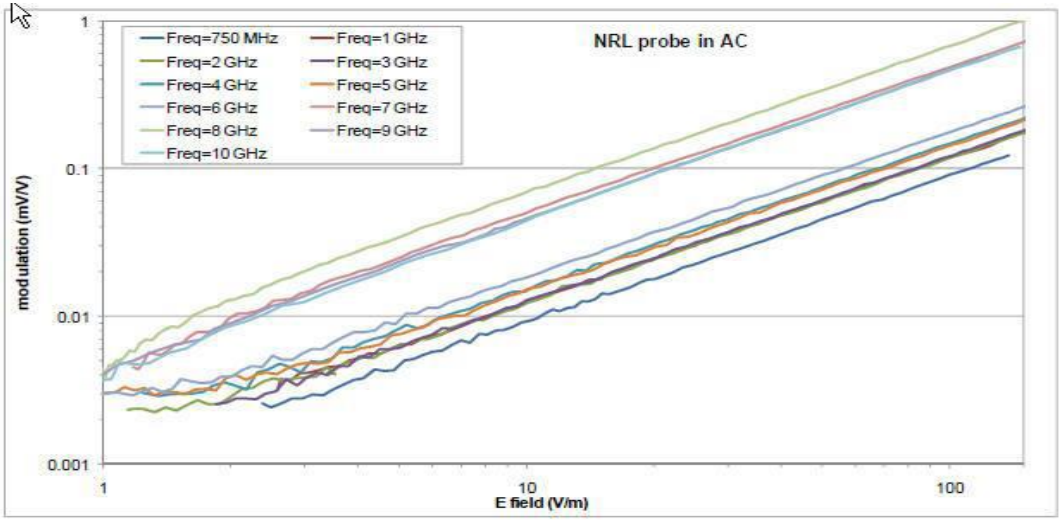
NIST Testing

EOST





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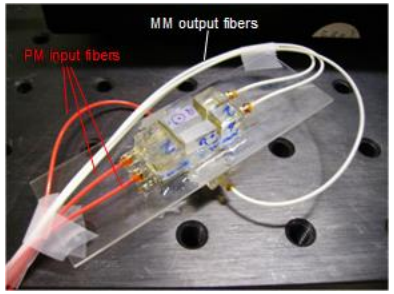
E-Field Non-Intrusive Probes

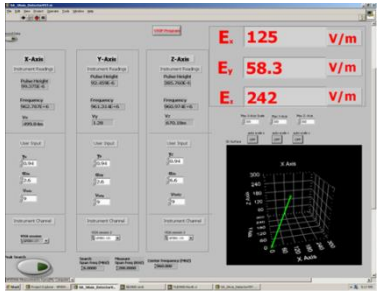
Compact Three-Axis Sensor (CTAS)

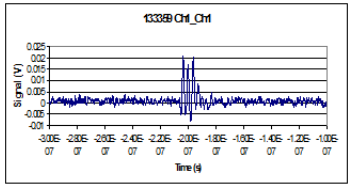
- Demonstrate EO sensing of E-field
- Turn capability into three orthogonal axes
- Field Test

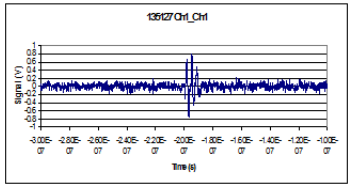
Advanced Polymer Optical Sensors(APOS)

- 3-Axis polymer E-field probe
  - Greater Sensitivity than many crystal
  - Lower index of refraction – insertion loss
- Novel E-field sensing approach
  - Slab Coupled Optical Sensor (SCOS)
  - Same size as fiber, actually part of the fiber









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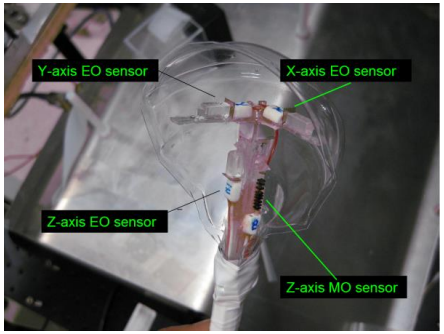
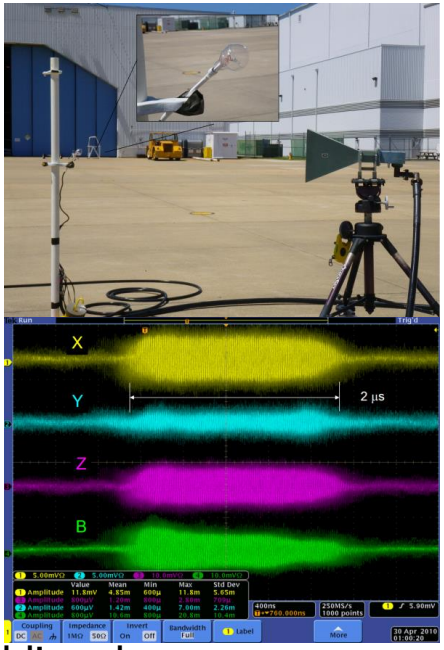
Combined E and H-Field Probes

Integrated Electro-Magneto-optic Sensor (IEMS)



PAX River
Field Testing



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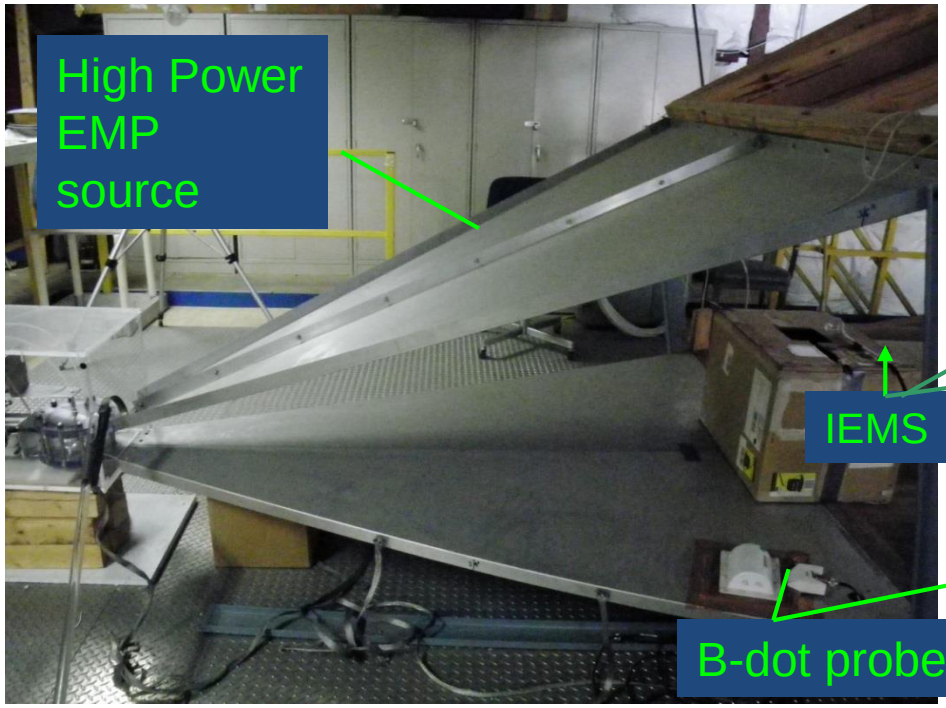
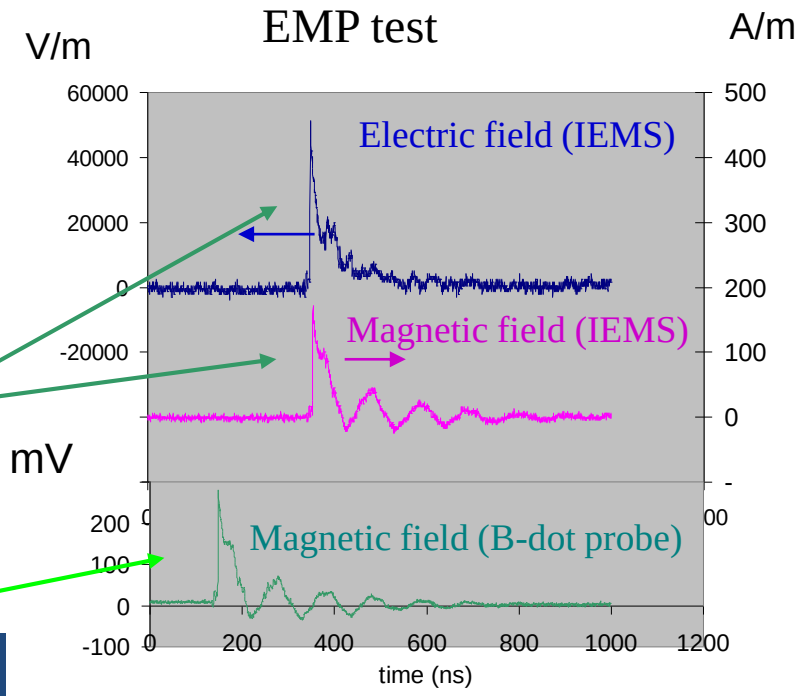
IEMS At Lower Frequencies

EMP measurements

IEMS advantages over conventional B-dot probe

- IEMS much smaller in size (10-100x)
- IEMS provides instantaneous output data (no intervening signal processing)





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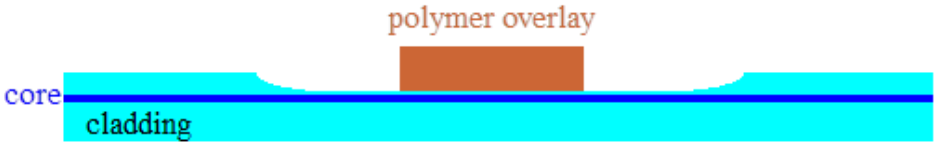
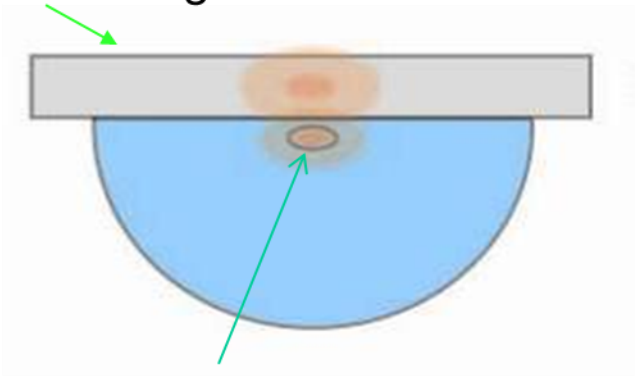
APOS E-Field Sensors

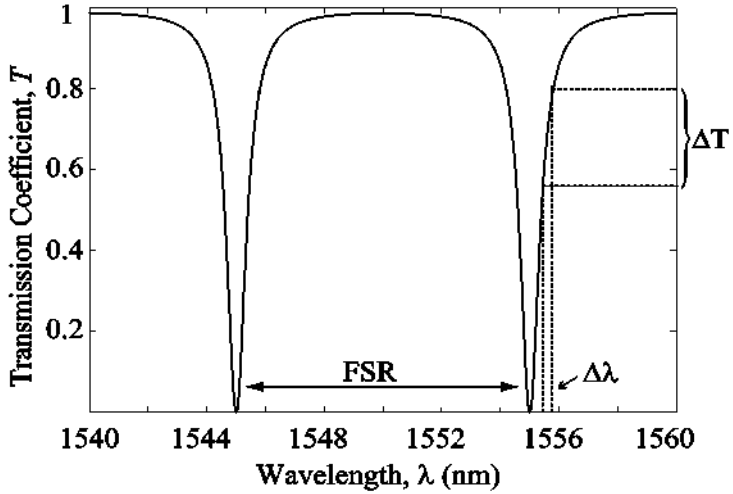
Crystal and Polymer
Slab Coupled Optical Sensor (SCOC)
Intended for electronics boards in single axis format



Slab Waveguide



Polarizing Maintaining Fiber
(D-fiber)



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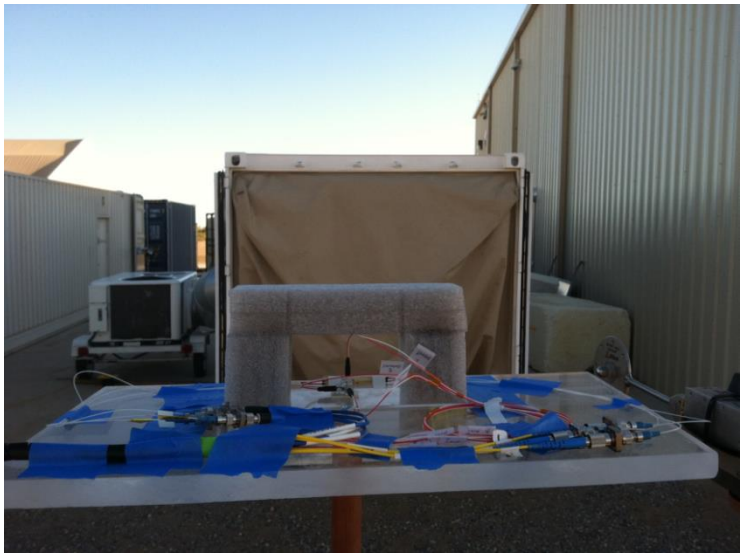
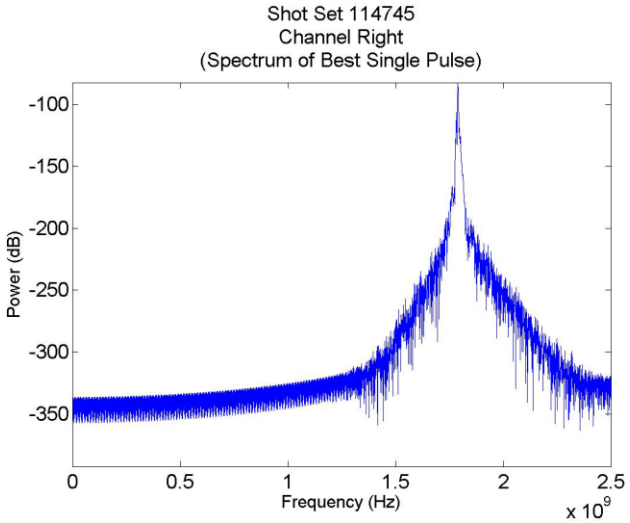
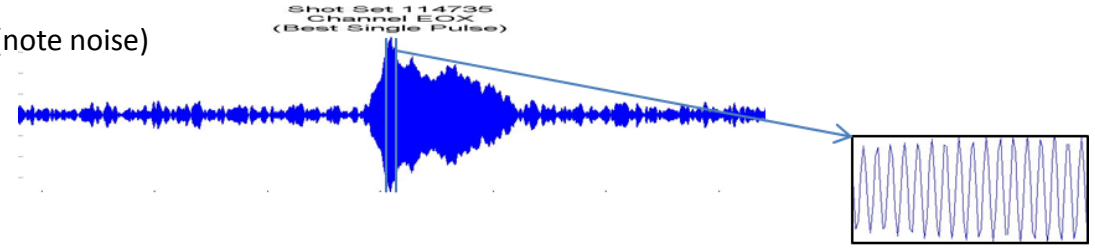
Field Testing APOS

APOS Testing against NBTS-A' ~ 1.8 GHz

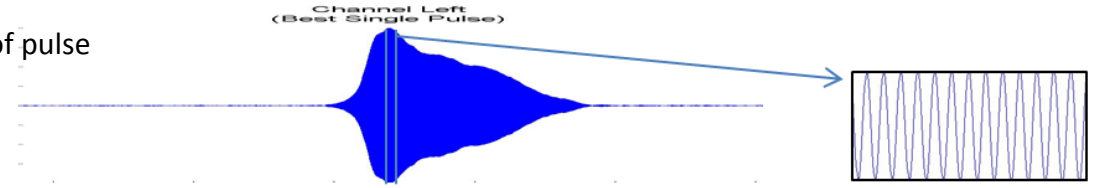




One axis of APOS (note noise)



D-dot equivalent of pulse



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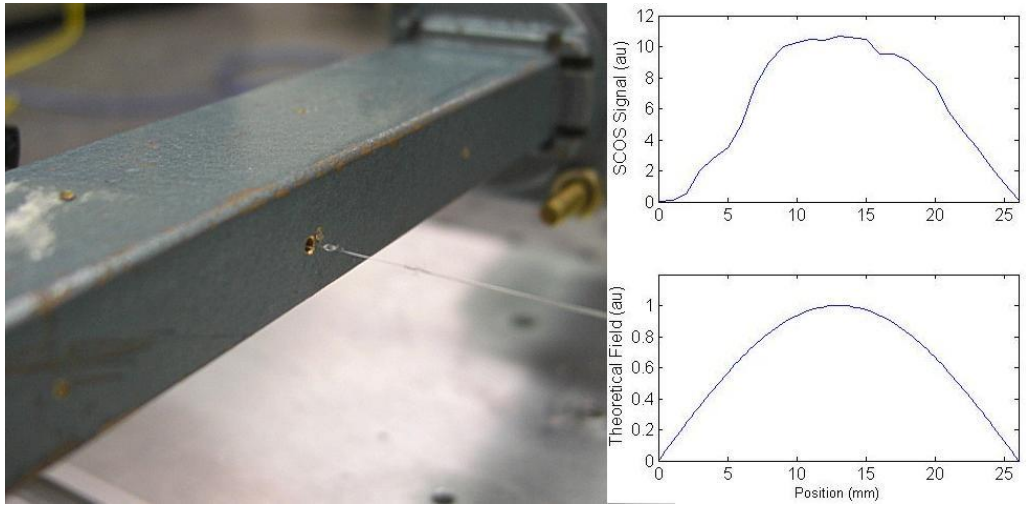
DET Measured Sensor Intrusion

APOS
SCOS
Probe



Material	Diameter (μm)	Q	Loss/pass
Air	0	1696	~1%
Fiber probe	125	1651	~1%
Wire	10	297	6%
Wire	50	131	11%
Wire	70	75	18%

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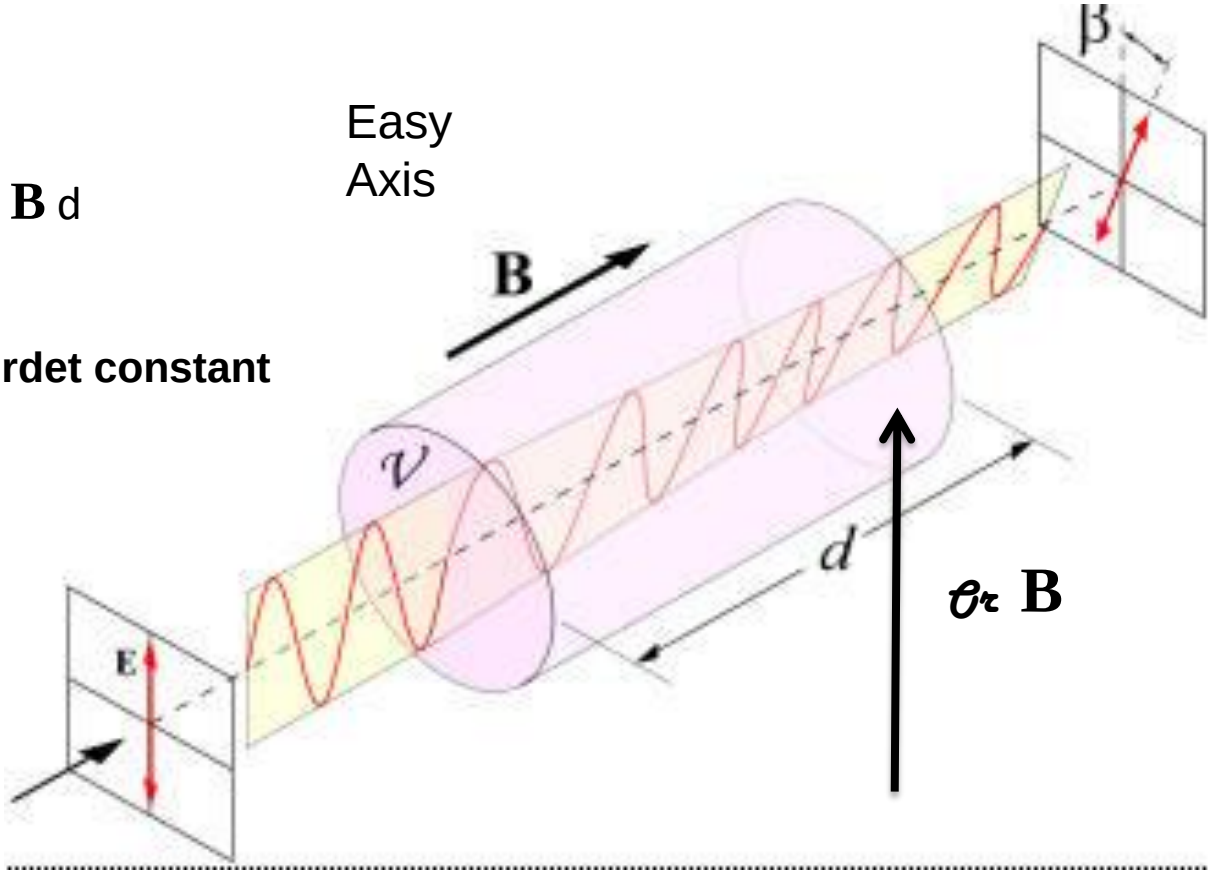
B-Field Sensors
Faraday Effect

$\beta = \nu B d$

ν^* ≡ **Verdet constant**



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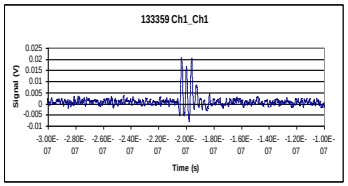
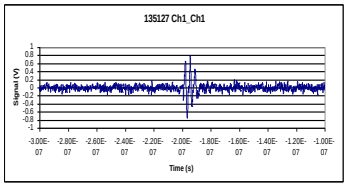
Field Testing H-Field Sensors

- White Sands 2010 Brass Board Test MO Probe





- IPITEK is Provider
- 3-Axis Small MO Probe
  - Single Fiber Access
- Modern Communication Lasers
  - Laser ≈ 1550 nm
- Brass Board Field Tested WSMR
  - MO 0.2 mA/m $Hz^{1/2}$

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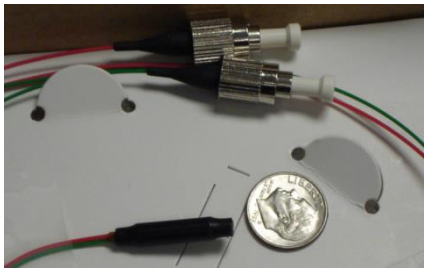
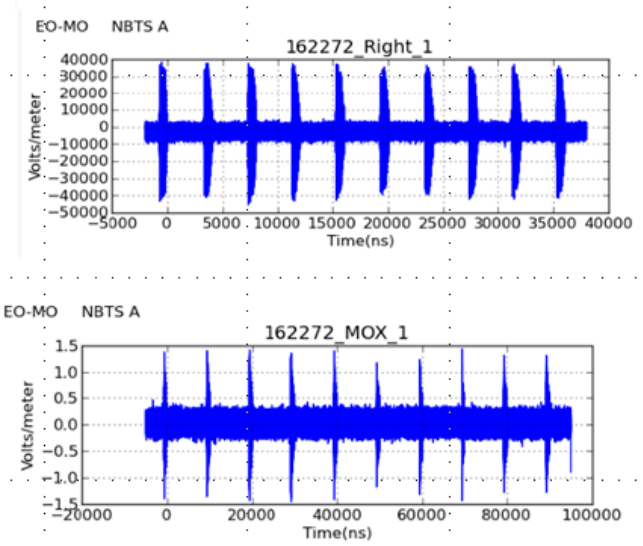
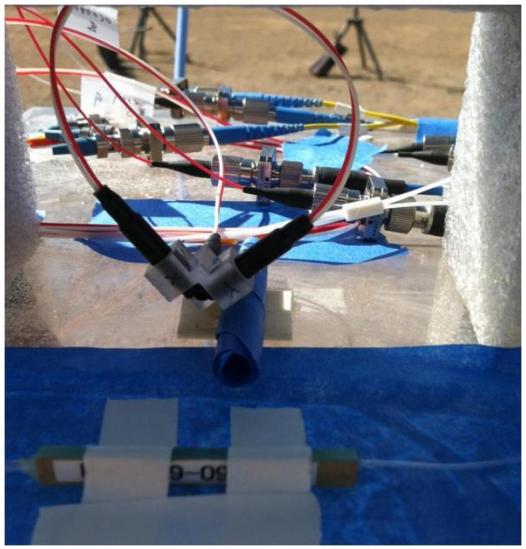
Further MO Probe Testing

- White Sands 2011 Prototype Test MO Probe



Single Axis MO sensor
tested at White Sands





3-Axis MO Probe Tested at
White Sands High Power Test Site

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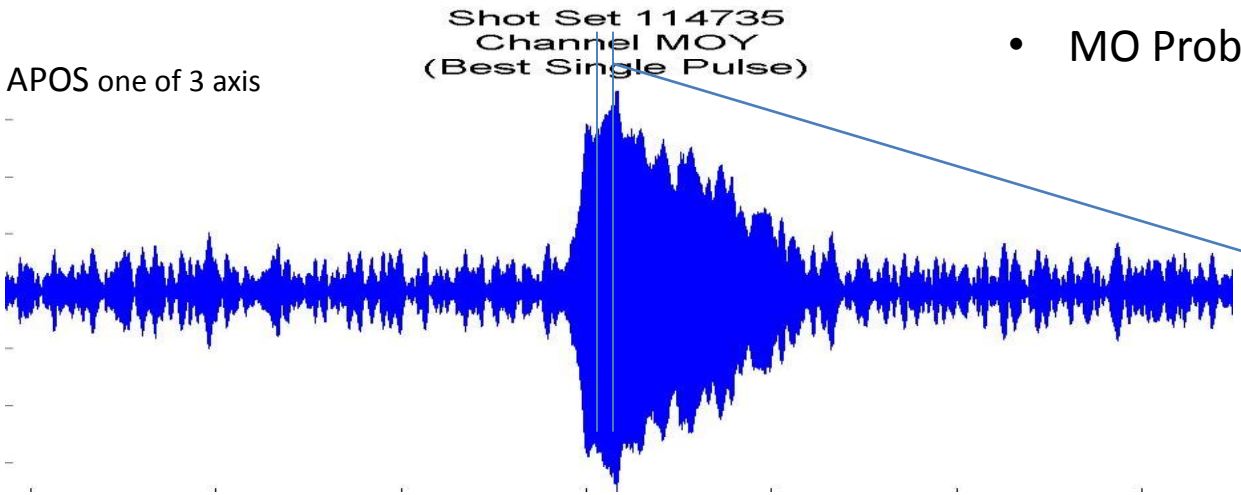
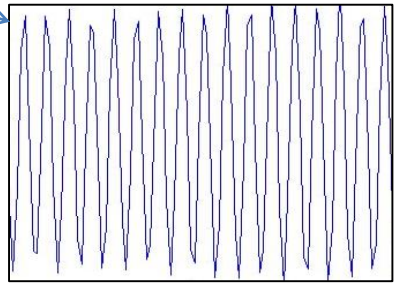
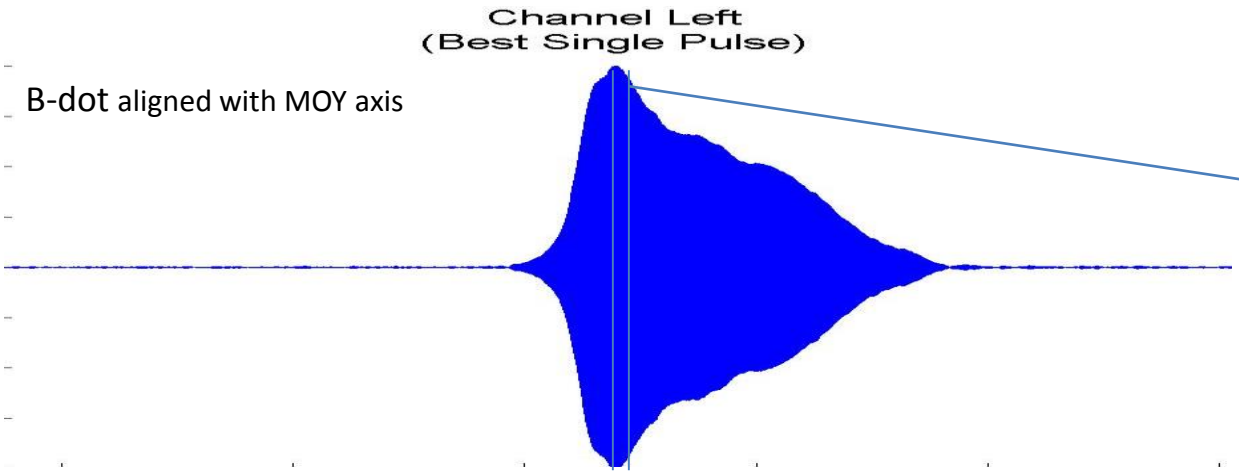
Noise Correction on MO Probes



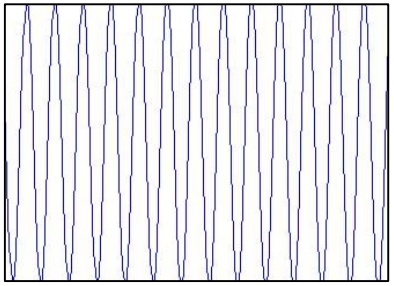
APOS one of 3 axis

- MO Probe Narrow Band Source





B-dot aligned with MOY axis



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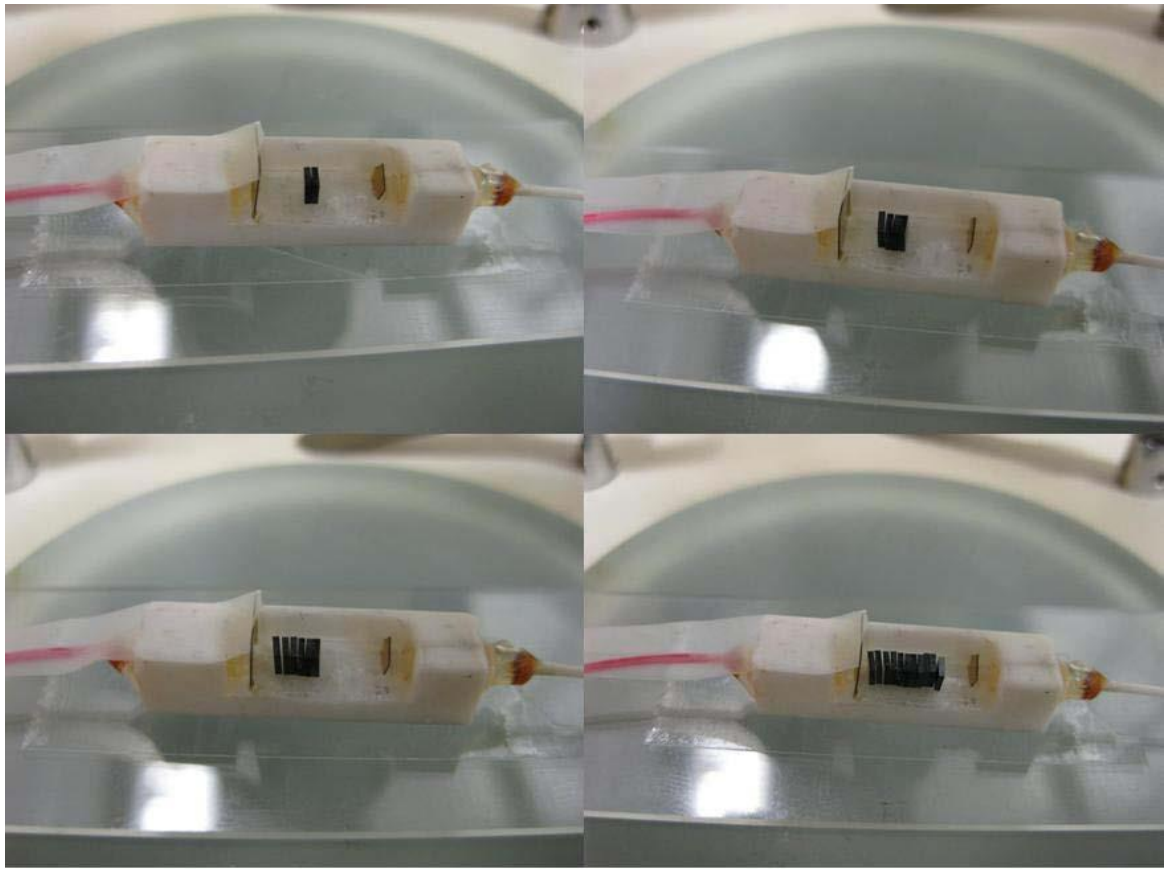
Magnetic Optical Sensitivity

Testing the field response of successive Bi:RIG crystals



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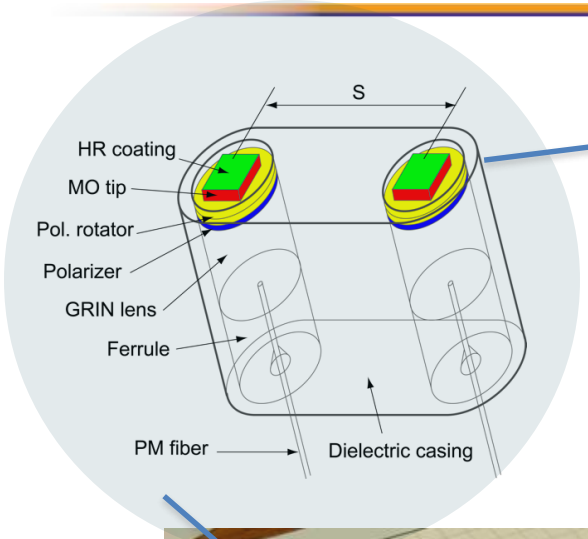
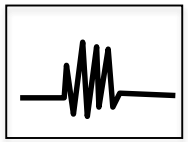
Differential Optically Based Current Sensing System (DOCS)



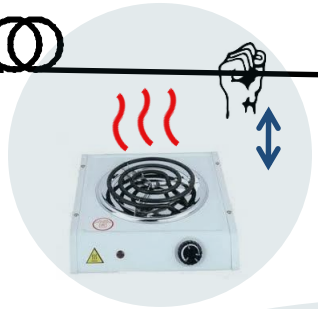
"Direct-power-conversion" probes

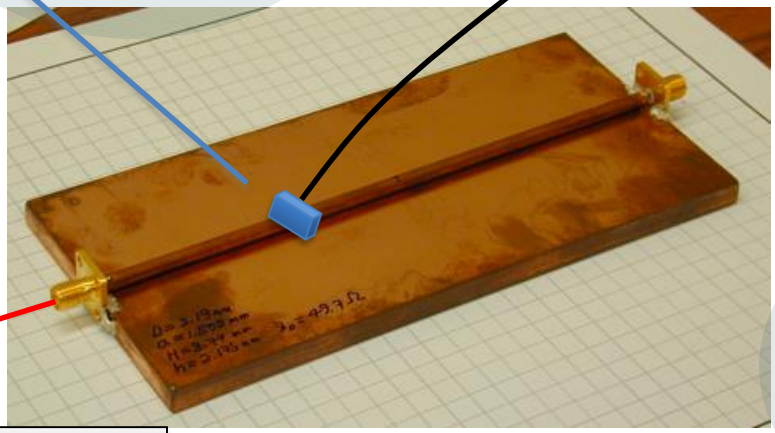


Scope

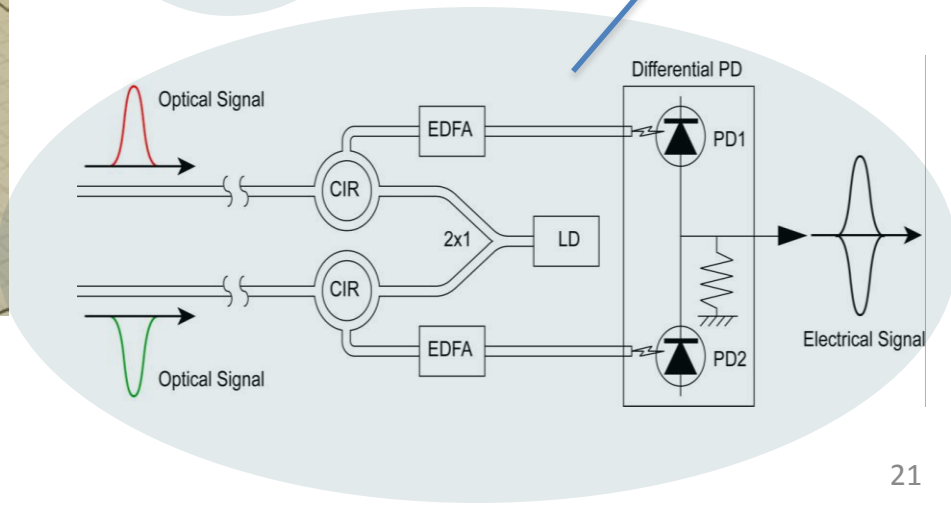
PM fiber

Optical source/ analyzer





Test bed/Cal fixture



Emulated HPM-induced current input

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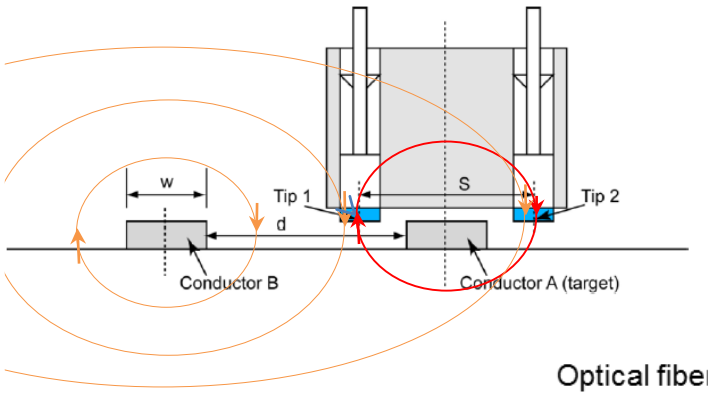
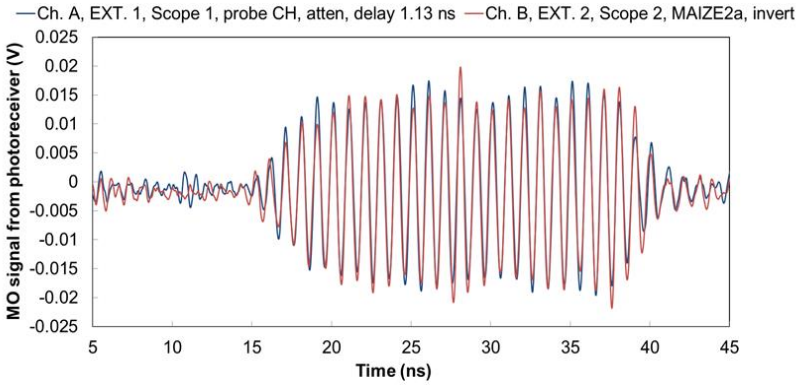
Sensitivity of DOCS MO Probes

How DOCS Works

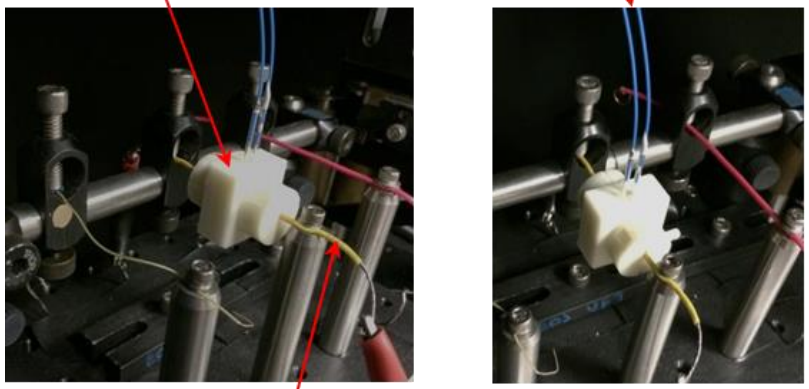


Two arms of DOCS with 1GHz, 20ns Pulse, one arm offset 180°

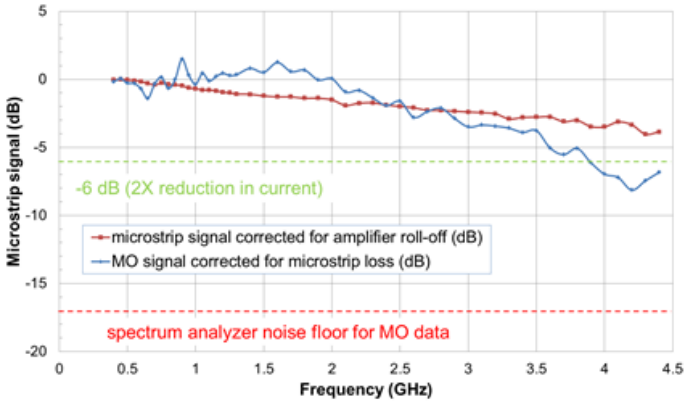


Probe holder/fixture

Optical fibers terminated in MO probes



20 AWG wire carrying test currents



Bi:RIG MO Crystals roll off above 4GHz

Need S&T for higher frequency Crystals

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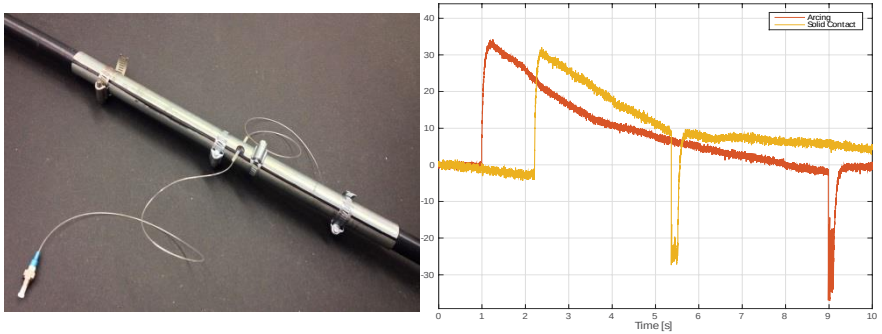
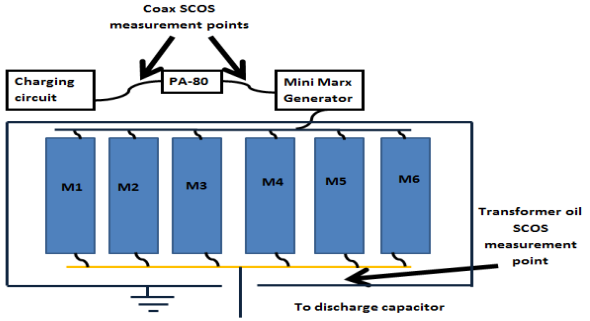
Optical Fiber Sensors for Non-intrusive Voltage Measurements (ONiT) - Voltage Potential Probe

Measure Prime Power

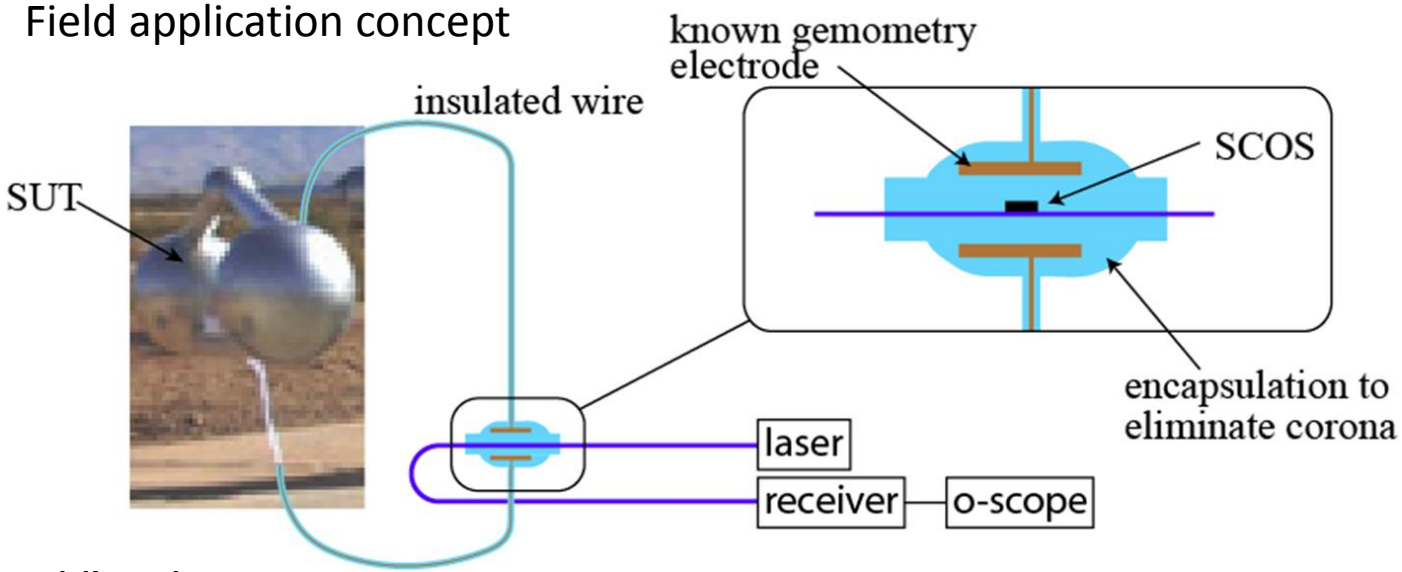


Measure Power Conditioning



Measure Source Generation

- Field application concept



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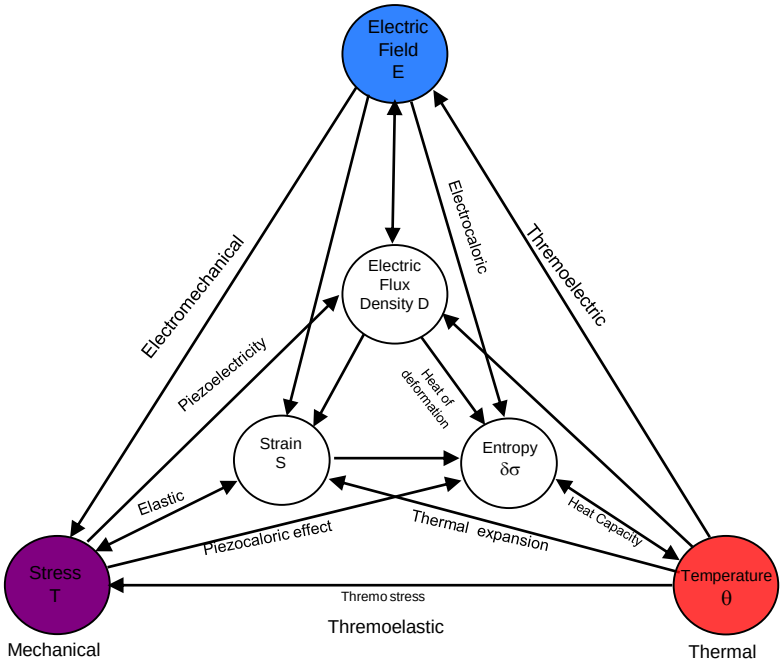
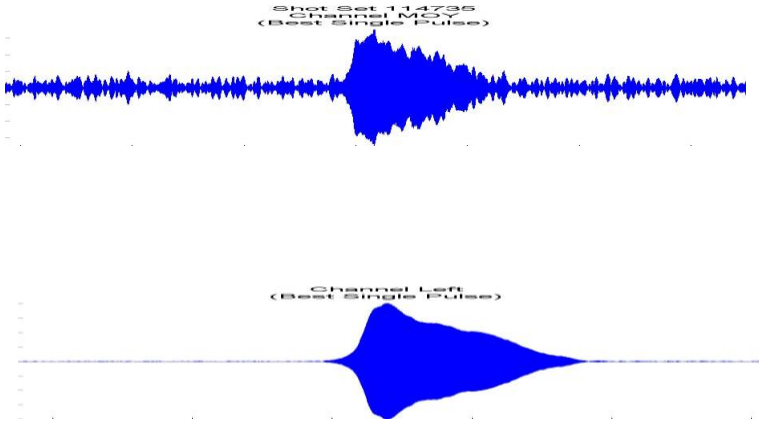
EO Probe Issues

- E-field vs Stress vs Thermal Changes



- Fiber Noise



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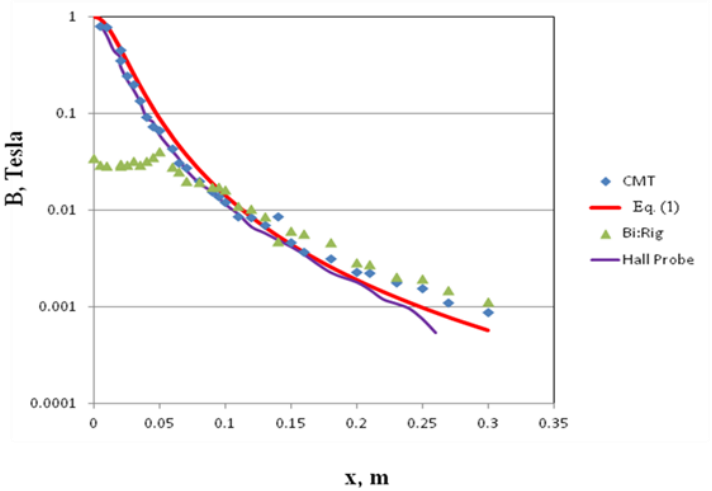
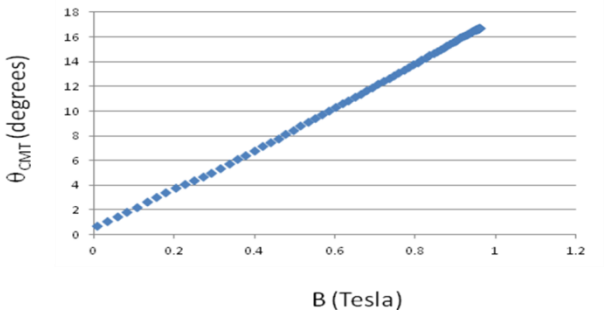
MO Probe Issues

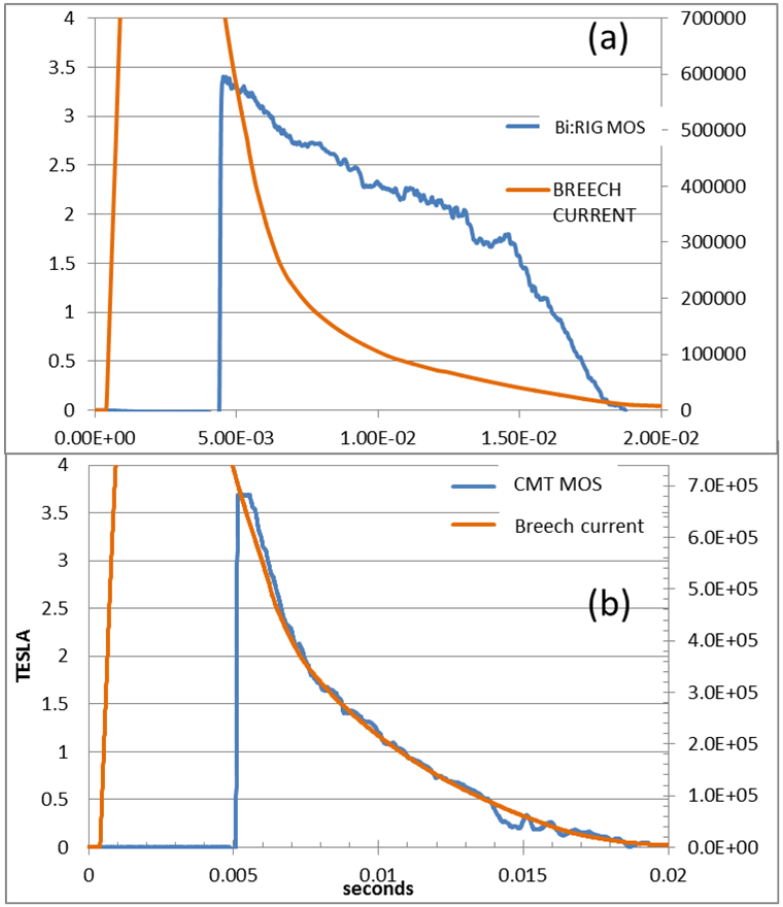
- MO Material tested in coil where distance (x) Determines B-field Field



- BiRIG used because of sensitivity and linear response with laser wavelength



- Saturation problems highlighted in rail gun testing



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Unaddressed S&T Probe Issues

Thermally Stable Envelope Detector

- Previous probes addressed various aspects of characterizing HPRF waveform and effects
  - All require expensive high end scopes to implement
- In electronic attack with many targets many locations need be instrumented
  - Prohibitively expensive and not needed everywhere
  - Many locations need rise time, pulse width and peak power
- In those situations cheap diodes and envelope detectors suffice
- Unfortunately envelop detectors turn out to be thermally unstable
- New S&T Topic looking for thermally stable envelope detectors that preserve the cost advantages of the sensors

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Conclusions

- A wide variety of Advanced Radio Frequency probes are required to:
  - Non-intrusively observe High Power RF signals
    - E-field
    - H-field (B-field)
    - Currents
    - Voltage Potential
  - In small spaces
  - 3-axis
  - Wide Spectral Range
  - Good sensitivity
  - Cheap is nice (probe not laser or optics part of sensor)
- DET S&T is developing those probe technology – some S&T tasks remain

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Questions?

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