National Aeronautics and Space Administration

Early Stage Technology Workshop

Astrophysics and Heliophysics

March 3-4, 2015

Miniaturizable High Performance Fiber Optic Gyroscopes for Small Satellites

Intelligent Fiber Optic Systems, Inc (IFOS)
Joey Costa
Director of Engineering

TECHNOLOGY DRIVES EXPLORATION

www.nasa.gov

Non-Proprietary

Company Overview

- Intelligent Fiber Optic Systems Corporation (IFOS)
- Santa Clara, CA
- Privately held / Incorporated CA 2001
- 8 employees and regular consultants
- Distinguished board of advisors & directors
- Focusing on advanced fiber optic sensing for high value assets in demanding environments
- 33 issued patents / 15 pending
- 95% government / 5% commercial (and increasing)
- Lockheed (FOG) / Welaco (DTS) / UCalgary (NeuroArm)

Company Overview

Staff	*Behzad Moslehi* – Founder, CEO/CTO , Stanford
	Joey Costa – Director of Engineering, CalTech/UCSD
	Richard Black – Chief Scientist, Australian National University
	Vahid Sotoudeh – Director of Products, Stanford
	Mehrdad Pakmehr – Aerospace Research Engineer, GeorgiaTech
	Levy Oblea – Senior Engineer, SJSU
	Ronak Patel – Systems Engineer, London Metropolitan
	Sargis Babakhanian – Controller
Senior Consultants	*Ram Yahalom* – Gyros, Technion
	Hanna Hoffman – Science, UCSD
	Len LaCroix – Missile systems, Lockheed
	George Lu – Electronics, UCSD
Board of Directors	*Dan Price* – Corporate & IP attorney
	Taher Elgamal – Data security expert
	Behzad Moslehi – Founder
Board of Advisors	*Bill Whitmore* – Medical Director, Verathon
	Leonard Bond – Director Center for NDE, ISU
	Ram Yahalom – Gyro systems expert, Technion

Program & Technology Overview

- Miniaturizable High Performance Fiber Optic Gyroscopes for Small Satellites
- NASA(GSFC) STTR NNX13CG43C / COTR Kenneth Hall
- 2011 T4.01 Innovative Sensors, Support Subsystems, & Detectors for Small Satellite Applications

- *Short wavelength* compact FOG heads / Components and test infrastructure development / Active damping
- TRL 3 / Phase 1 proof of concept
- TRL 4 / Phase 2 prototype parts in lab environment

- Compact all fiber (light contained) sensing system
- Open loop fast demodulation electronics / Novel firmware
- Harnessing & developing *emerging* SW FO technologies

Alignment with NASA Requirements

- NASA needs small satellites (& formations thereof) with advanced sensor capabilities for Astrophysics and other programs
- Need assessment of spacecraft formations – rate sensors must measure and correct attitude, position, velocity, & acceleration
- Subsystems limited to 44lb (20kg) & 610in^3 (10,000cm^3)
- Compatibility with launch dynamics, environmental constraints, radiation, & low earth orbital missions out to 500mi (800km) for up to 2 years
- LEO satellites subjected to higher orbital velocities
- Challenging project due to deployment requirements – bias stability, accuracy, & long life

Commercialization & Infusion Plans

BOEING indicates technology need for small satellite programs such as ESPA ring secondary launch

LOCKHEED MARTIN needs small low cost guidance systems for ballistic missile defense applications

Invocon negotiating corporate partnership to enhance gyro system offerings with smaller & rugged electronics

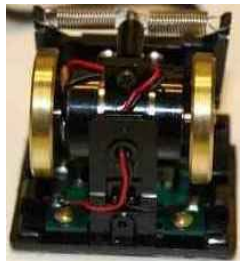
Phase 2 Enhancement – submission planned and will initiate technology infusion path with NASA

Lightwave Venture will secure venture funding for commercialization work in Phase 3

Technology – Comparison

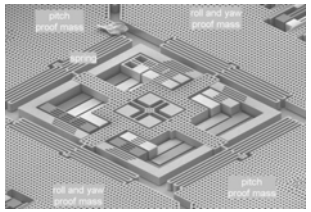
Comparison examples:

- Mechanical gyros – no moving parts / wear, more compact, less mass, no orientation resistance



- Ring laser gyros – no alignment issues, more suited for space use, no antilock “dither” needed

- MEMS gyros – better shock / vibration resistance & orders of magnitude better performance



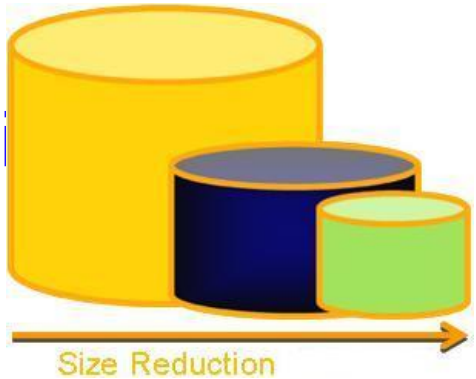
- Deployed FOGs (e.g. NG LN-200) – better bias performance (<<1°/hr) & much better noise performance (<<0.05°/√hr)

Technology – Background

- Advanced state of the art open loop FOG
- Existing gyros with same performance are either too large and / or too expensive
- A true “solid state” device
- All fiber implementation
- Low cost components
- Design for manufacturing
- Light weight & rugged construction
- Low noise & large bandwidth nature
- Engineering exercise to achieve SWaP-C

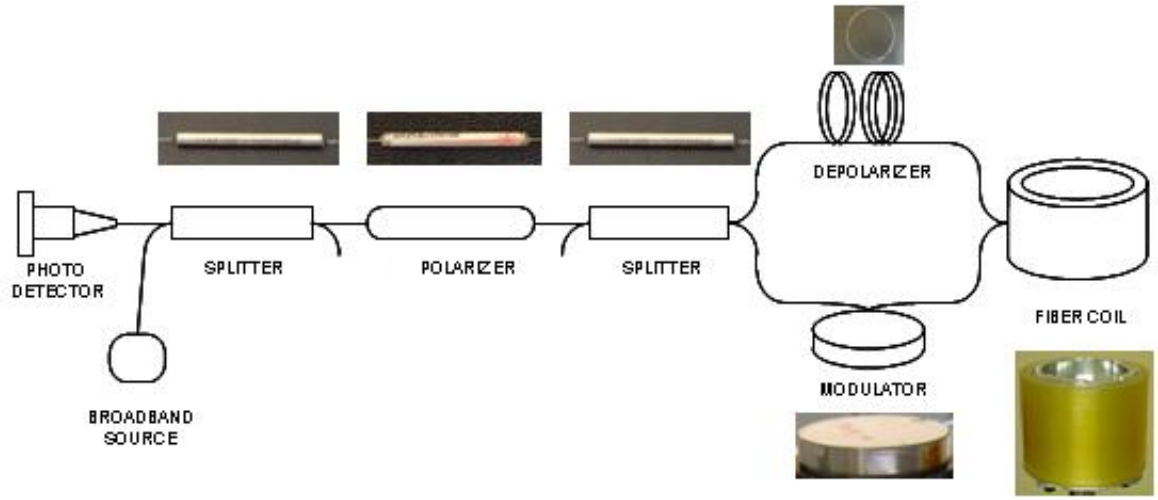
Technology – Background

- Generation 1 – Prototype FOG for LoS stabilization
  - Optical head ϕ 2.7in x h 2.0in (11.5in^3)
- Generation 2 – Small, robust, and flight worthy products
  - Optical head < ϕ 2.2in x h 1.4in (<5.3in^3)
  - Environmentally robust
  - Radiation resistant version for space application
- Generation 3 – Ultra compact sensor for small platforms
  - Short wavelength based gyro
  - Optical head << ϕ 2.2in x h 1.4in (<<5.3i



Technology – Background

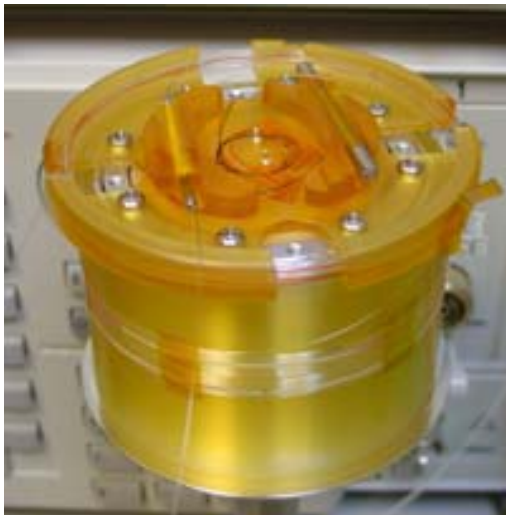
- Open loop architecture
- Novel all digital signal processing scheme
- Small diameter (130μm OD) fiber
- All fiber mostly COTS components
- Piezoelectric modulator (PZT)
  - Vacuum insensitivity
  - High reliability
  - Low cost

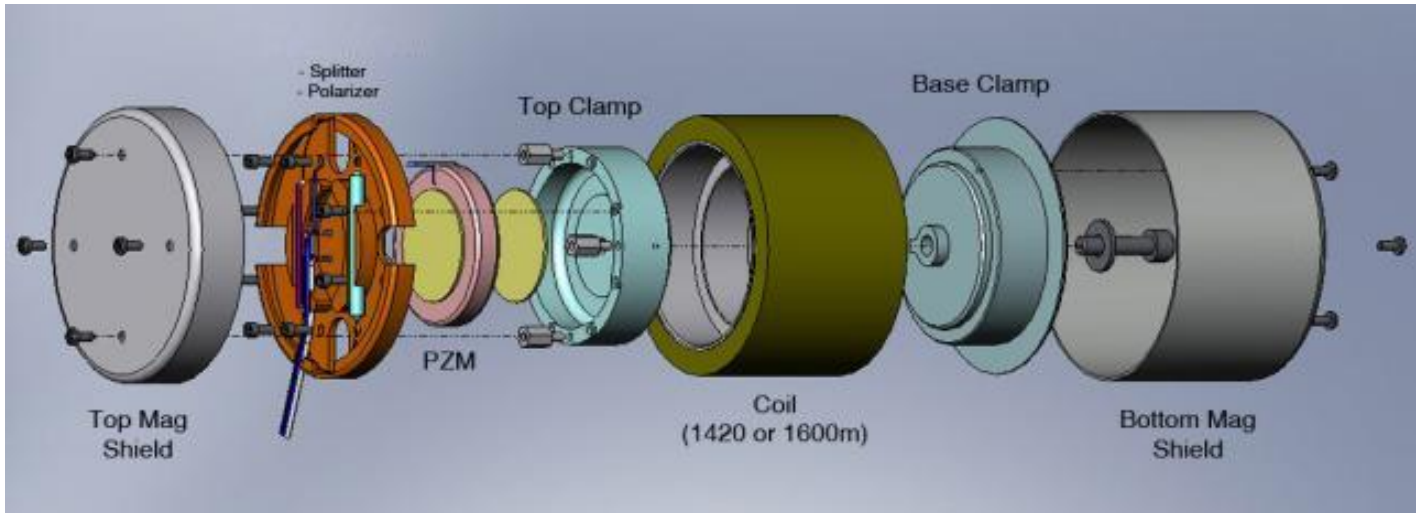


Technology – Introduction (Gen.1)

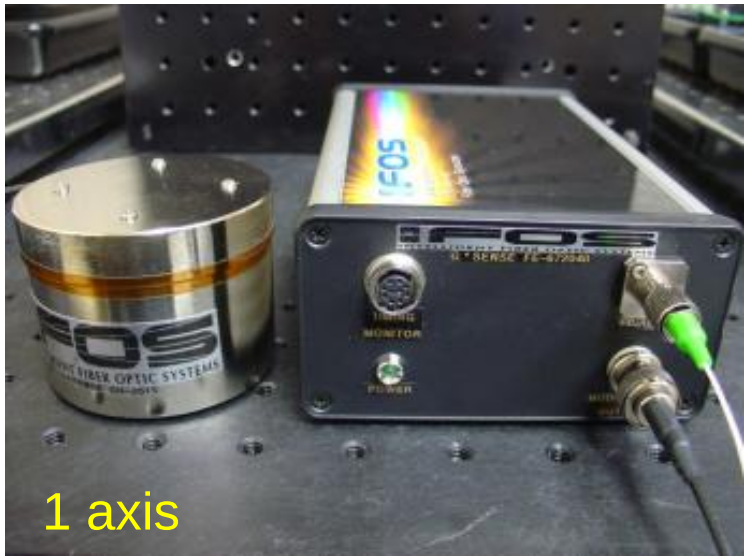
Rugged Gen.1 package

- Hub mounted coil
- Optical components mounted internally
- Mu metal for magnetic shielding
- Design for straightforward integration to minimize labor cost

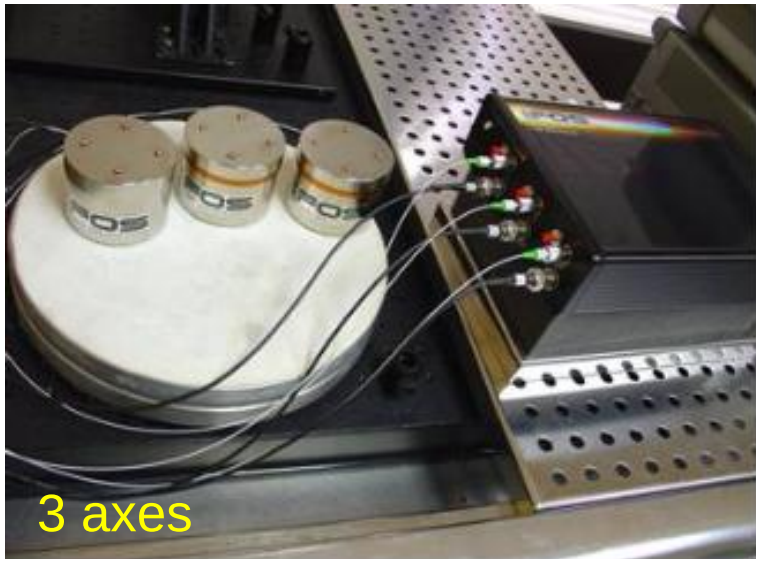




Technology – Introduction (Gen.1)

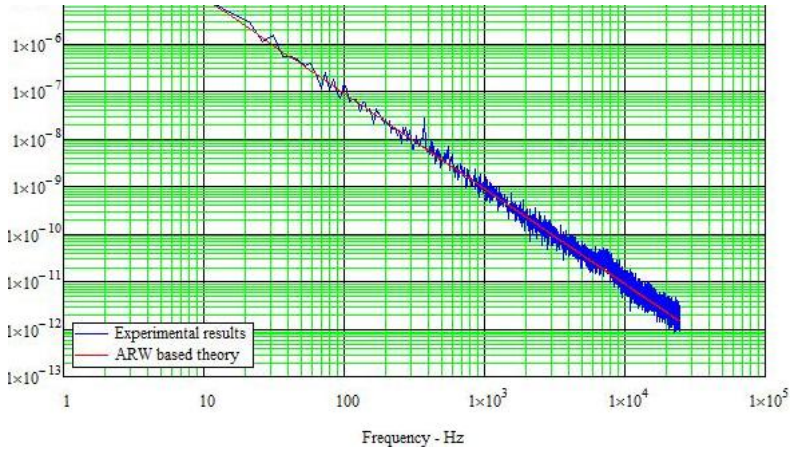


Gen.1
System



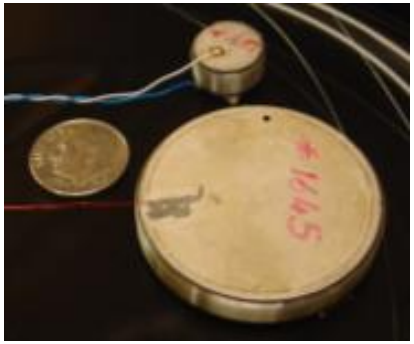
Technology – Introduction (Gen.1)

- Gen.1 prototype sensor (ϕ 2.7in x h 2in)
- Large sample and data rate – as high as the modulation frequency (e.g. 40kHz & depending on fiber coil length)
- Angle Random Walk (ARW) <<0.04°/√hr
- Bias stability <<1°/hr over 12 hours
- Extremely stable input axis alignment over temperature
- No measurable acceleration sensitivity
- No initial turn on transient



Technology – Introduction (Gen.2)

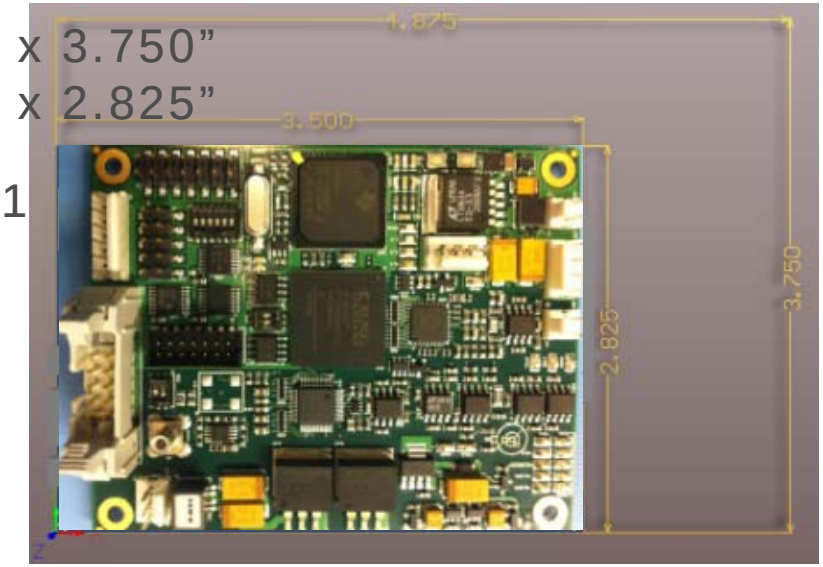
- Smaller Gen.2 sensor < ϕ 2.2in x h 1.4in (<5.3in^3)
- 1350m fiber coil
- Smaller phase modulator
- New smaller electronic boards
- Ruggedized for military environment
- Improved components and design (DFM)



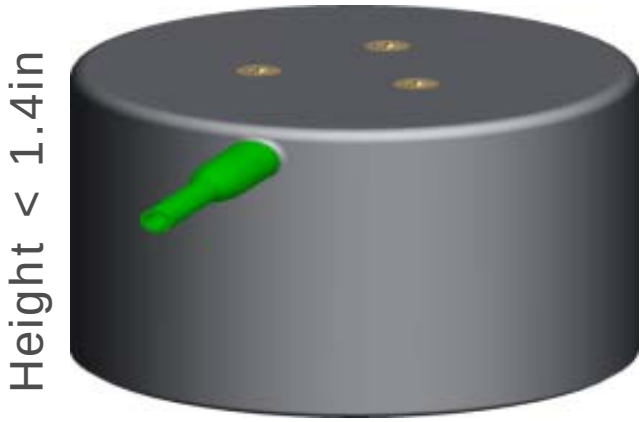
Smaller modulator

Gen.1 = 4.875” x 3.750”
Gen.2 = 3.500” x 2.825”

A=54% of Gen.1



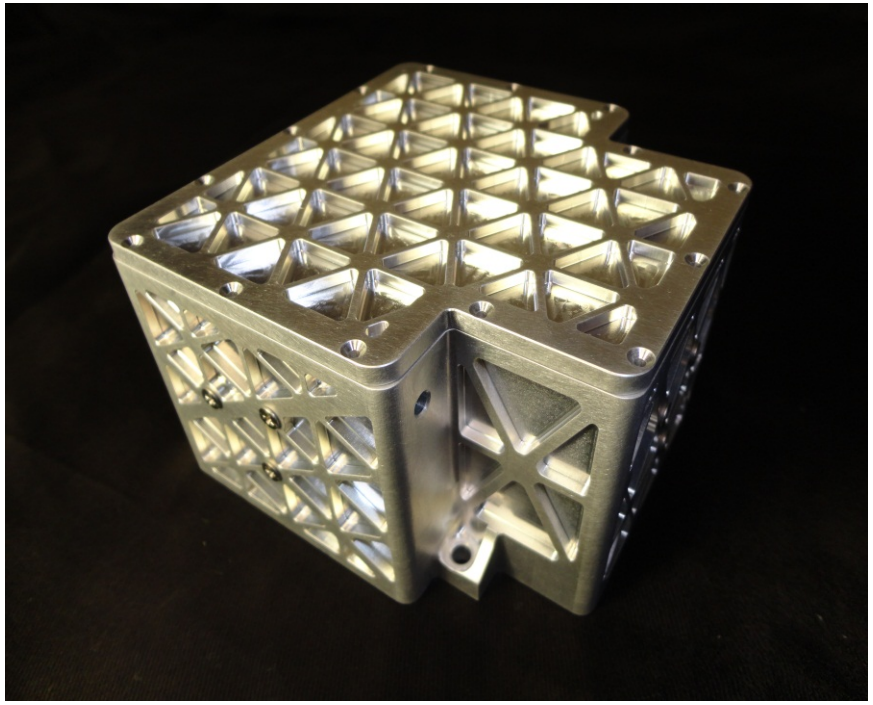
G.2 gyro



Diameter < 2.2in

Technology – Introduction (Gen.2)

- Gen.2 IRU (inertial reference unit) cluster
- Overall dimensions < 4” x 4” x 2.5” (<40in^3)
- First modal frequency >1kHz



Technology – NASA SWFOG Program

- FOG sensitivity is a function of three parameters
  - Fiber length (L)
  - Coil diameter (D)
  - Light Wavelength (λ)

$$S \sim L \times D / \lambda$$

- Shorter wavelength enhances the sensitivity
  - S(650nm) / S(1550nm) ~ 2.4

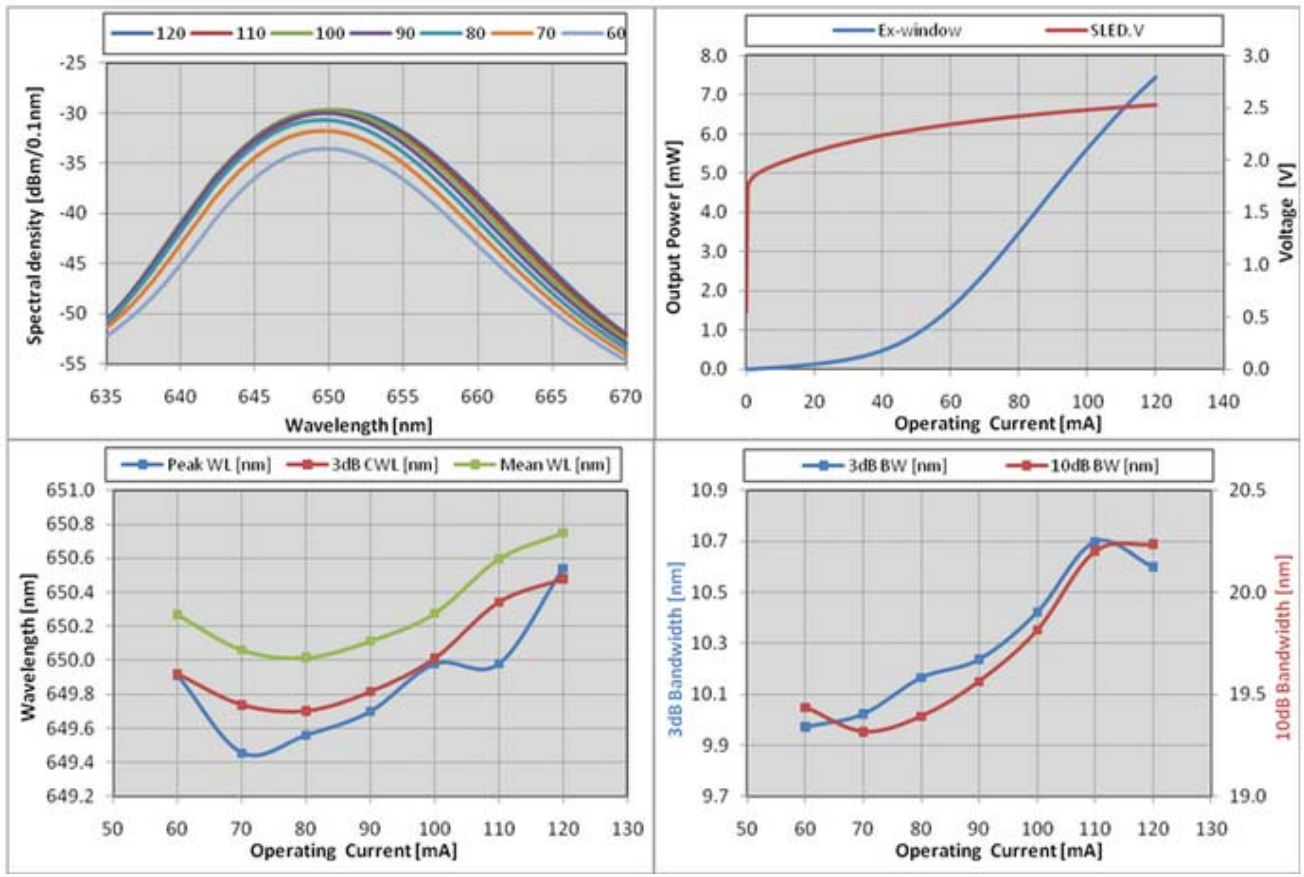
- Gen.2 : S ~ 41$m^2/\mu m$

Technology – NASA SWFOG Program

Parameter	Gen.2 gyro	Proposed SWFOG
Bias Drift Stability, short term, steady state temperature	<<1°/hr	<<1°/hr
Bandwidth/data rate	>10kHz	>10kHz
Angle Random Walk (ARW)	<<0.04°/√hr	<<0.04°/√hr
Survival temperature range	0 to 80°C	-50 to 80°C
Size (Sensor)	<5.3in^3	<<5.3in^3
Weight (Sensor)	<0.4lb	<0.4lb

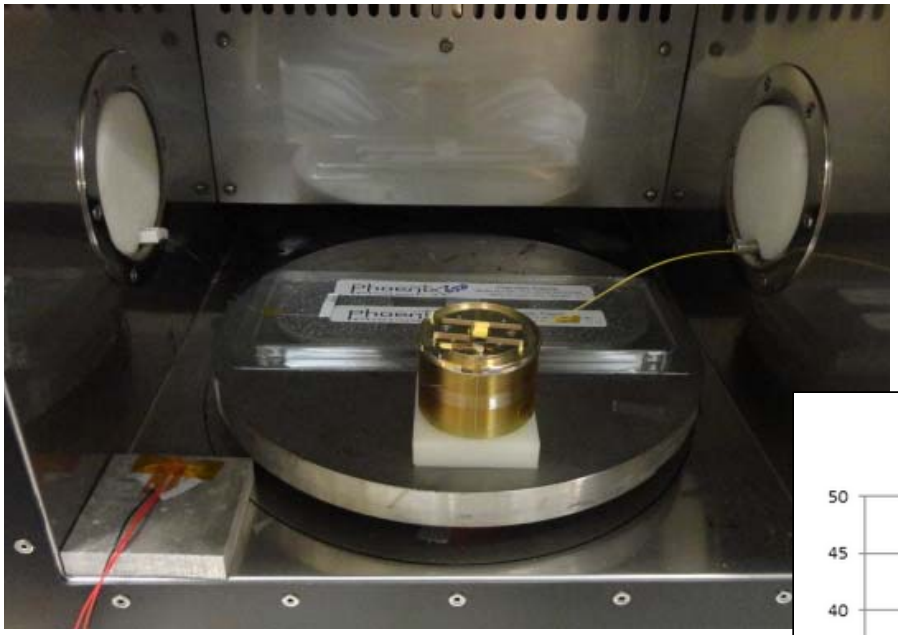
Technology – NASA SWFOG Program

Uncooled SW SLD with pigtailed fiber

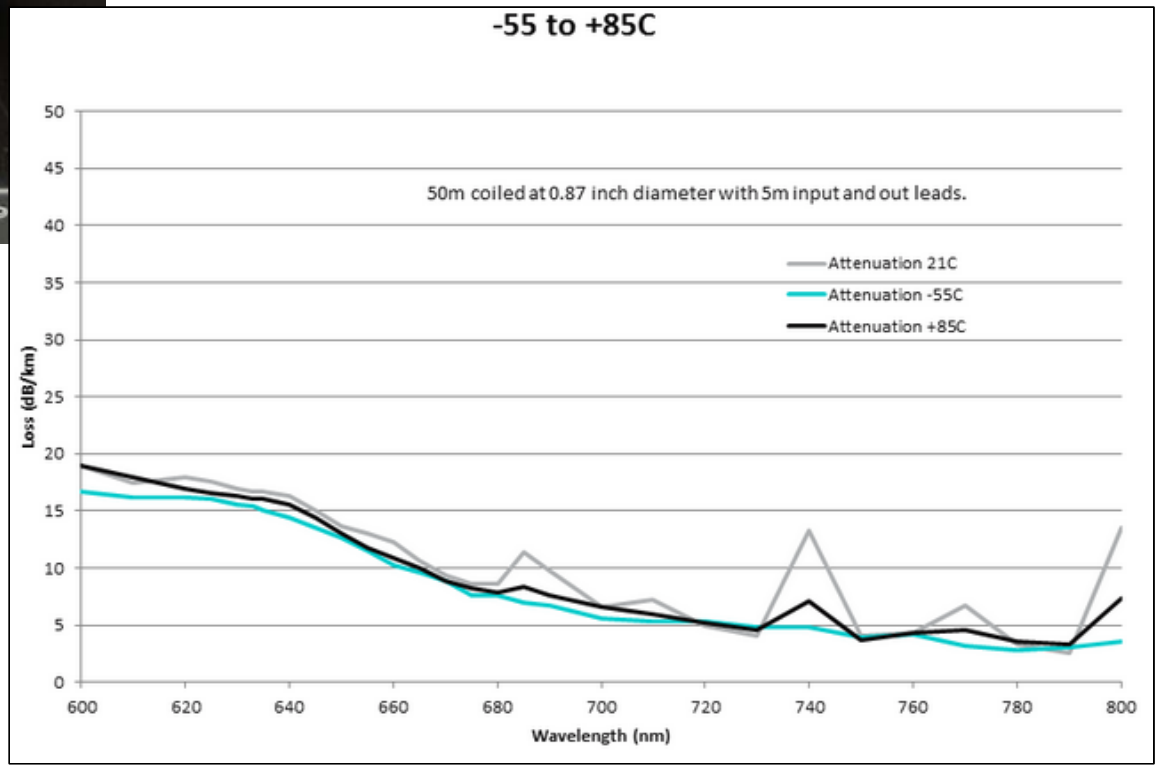


Source characterization

Technology – NASA SWFOG Program



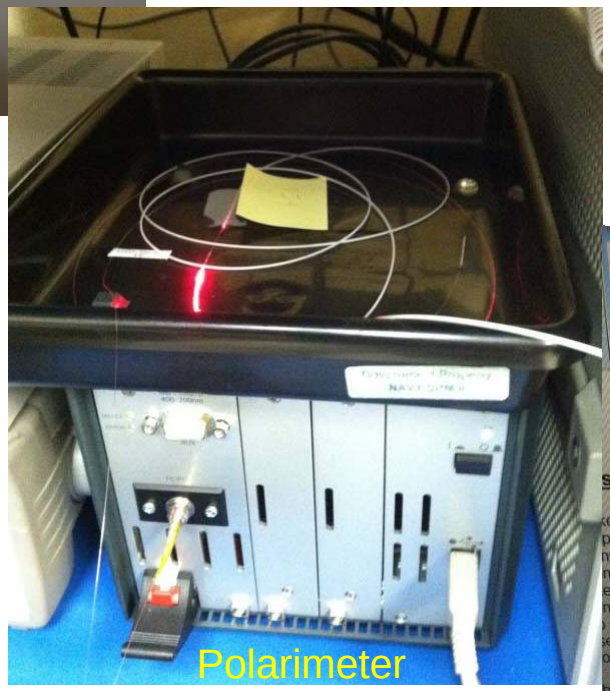
Main SW fiber coil
(>1300m navigation grade capability)

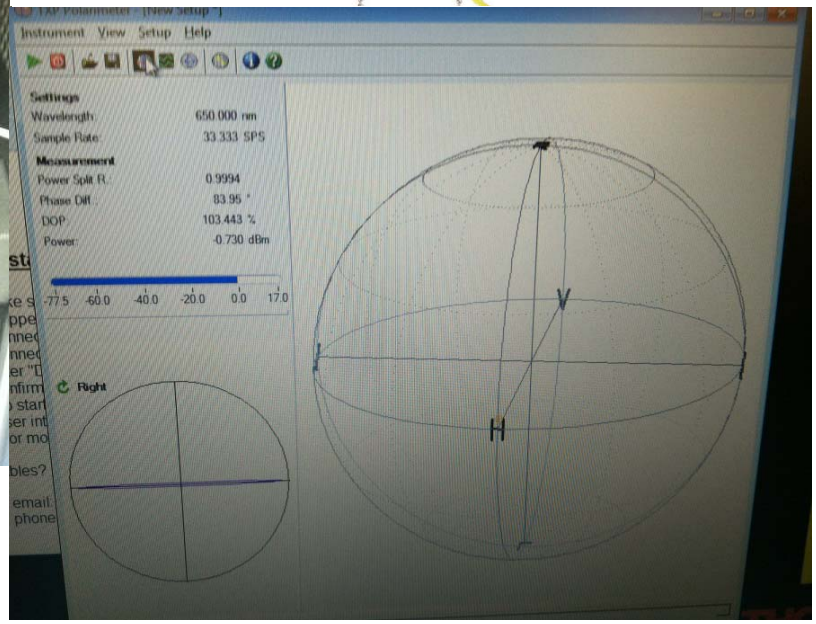


Fiber characterization

Technology – NASA SWFOG Program

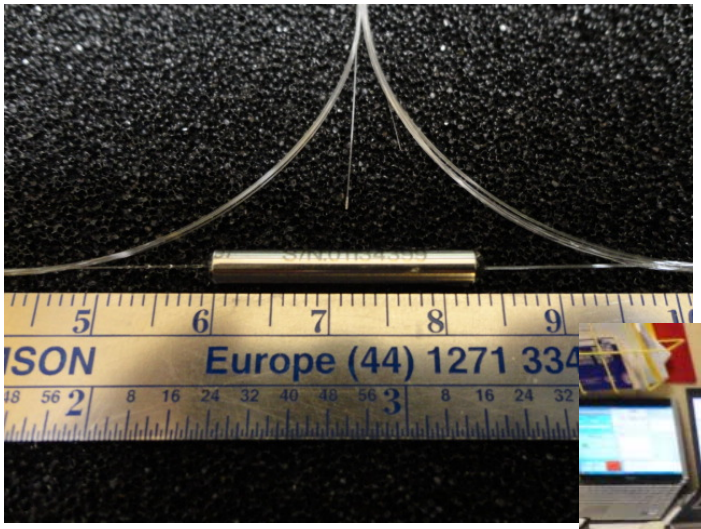
Miniaturized SW polarizer



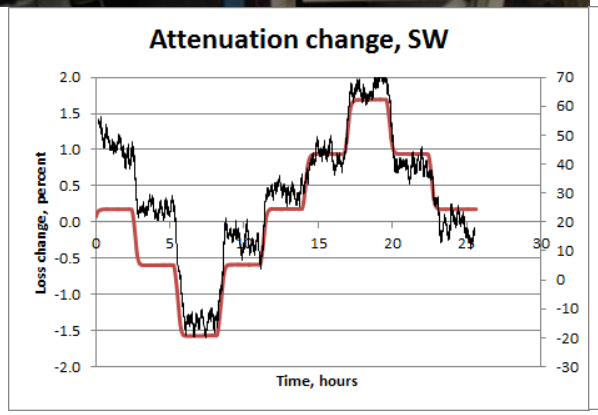


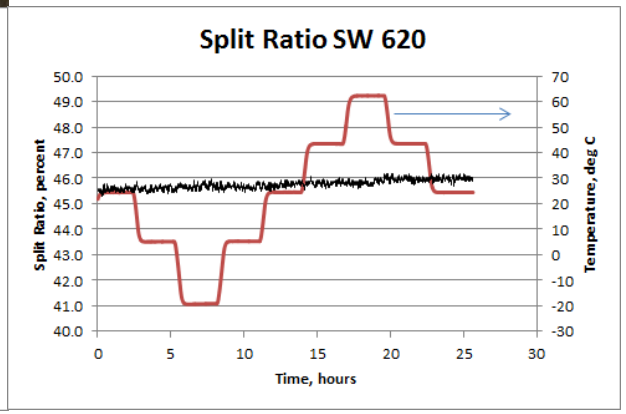
Polarizer characterization (>35dB is tough)

Technology – NASA SWFOG Program



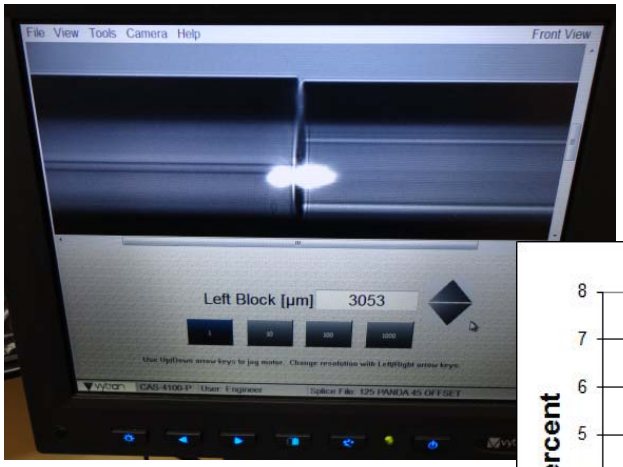
Miniaturized SW splitter



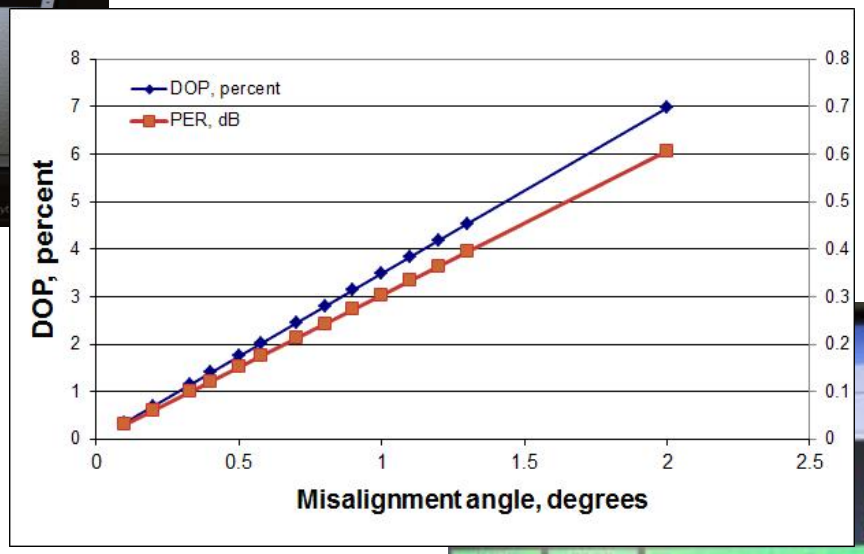


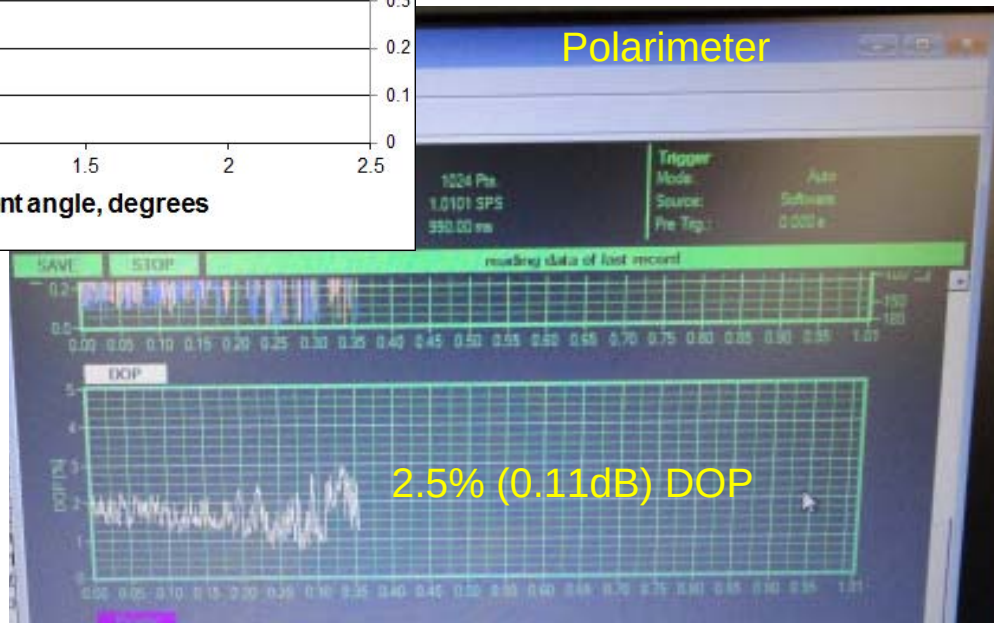
Splitter characterization

Technology – NASA SWFOG Program



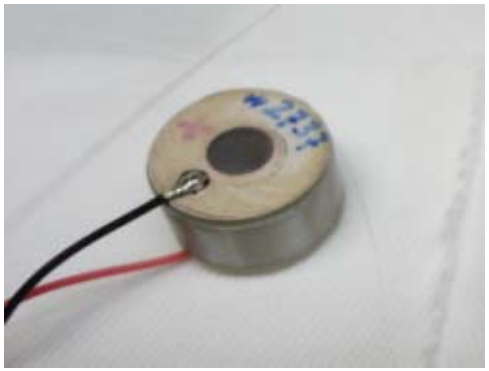
SW depolarizer fabrication (45°between SW PMF)



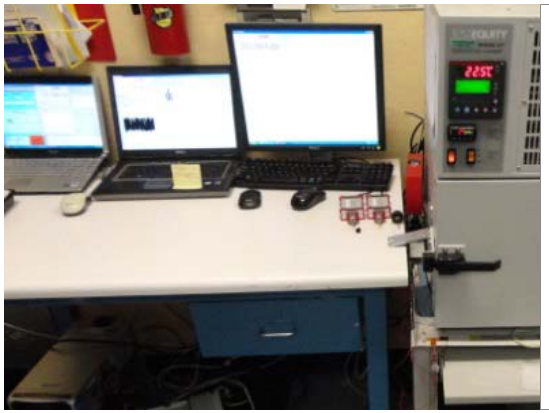


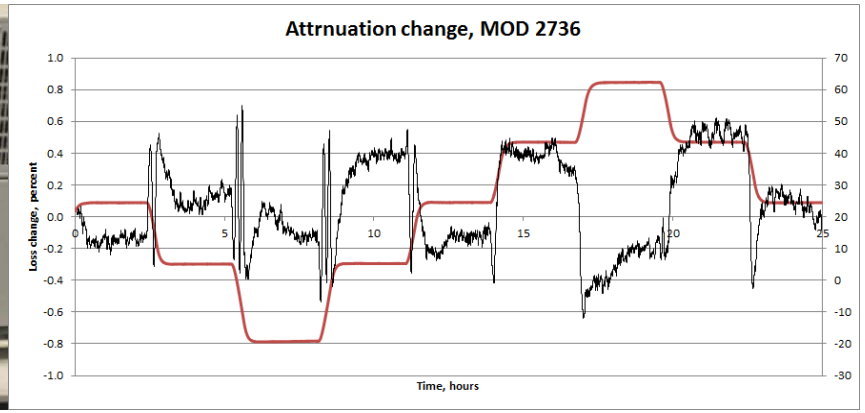
Depolarizer characterization

Technology – NASA SWFOG Program

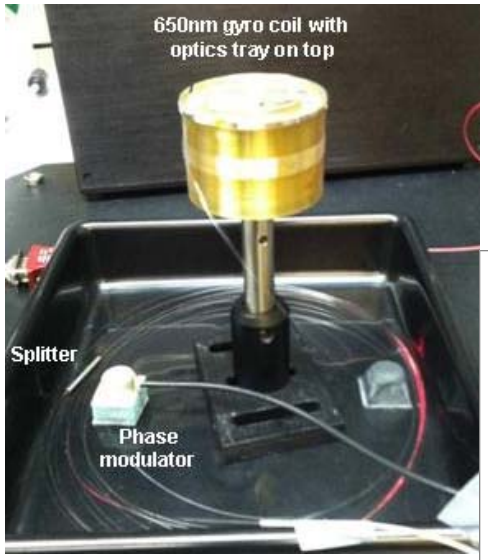


SW piezo modulator (ϕ 0.5”)

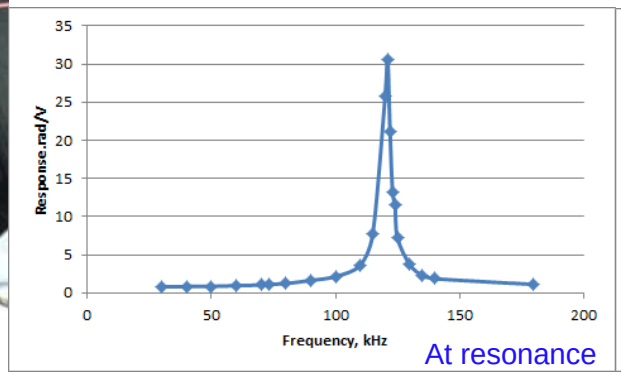




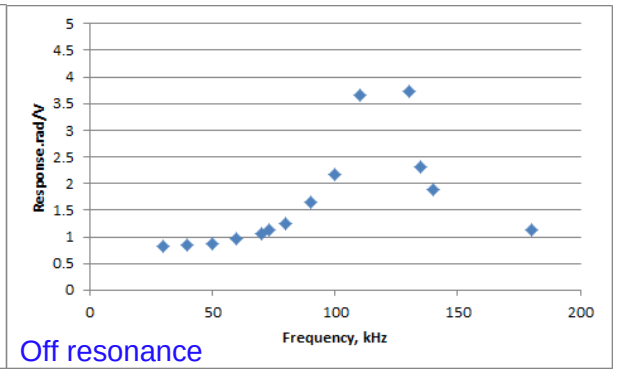
< ±0.5% over temperature



0.6V/rad @ 650nm (vs 1.2V/rad @ 1550nm)



At resonance



Off resonance

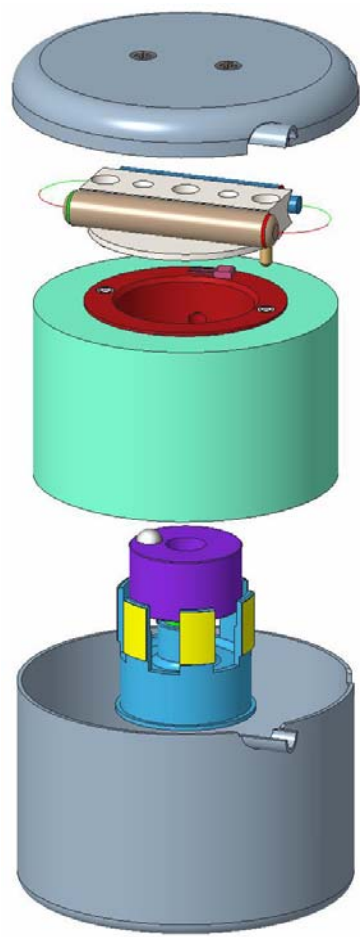
Modulator characterization

Technology – NASA SWFOG Program

Gen.3 gyro head package

Components subassembly

Modulator

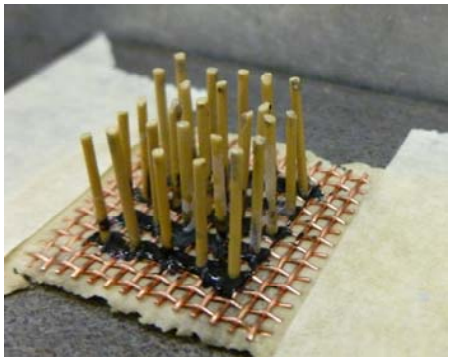
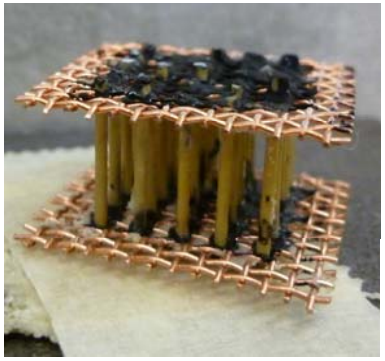


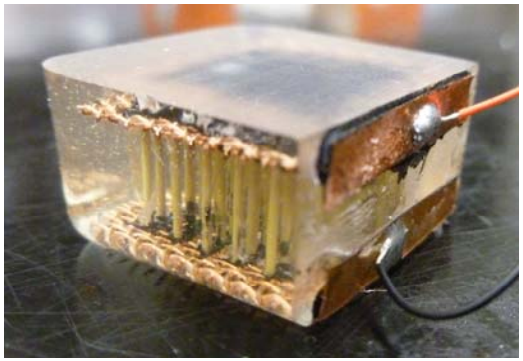
Lid

Coil (update per S tradeoffs)

Housing

Technology – NASA SWFOG Program (UAH)

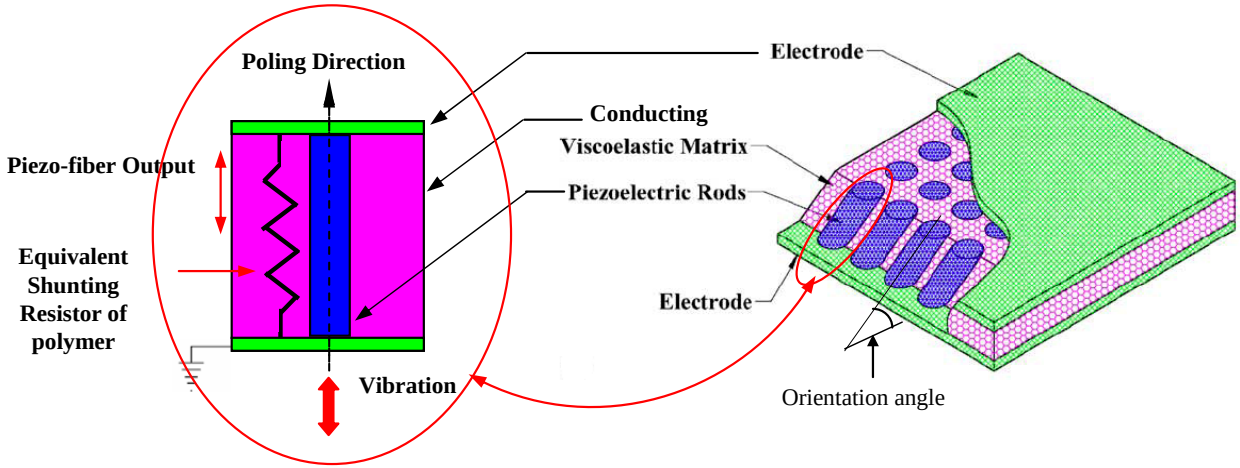





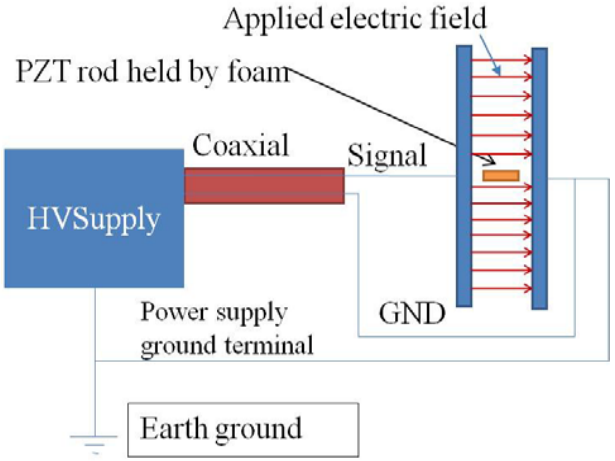
UAH (Profs. Gang Wang, Ken Zuo, & team) tasked with active damping solution – an innovative conducting polymer / piezoelectric composite (CPPC) consisting of piezoceramic fibers and a conductive polymer matrix, designed to achieve damping augmentation for vibration and shock reduction

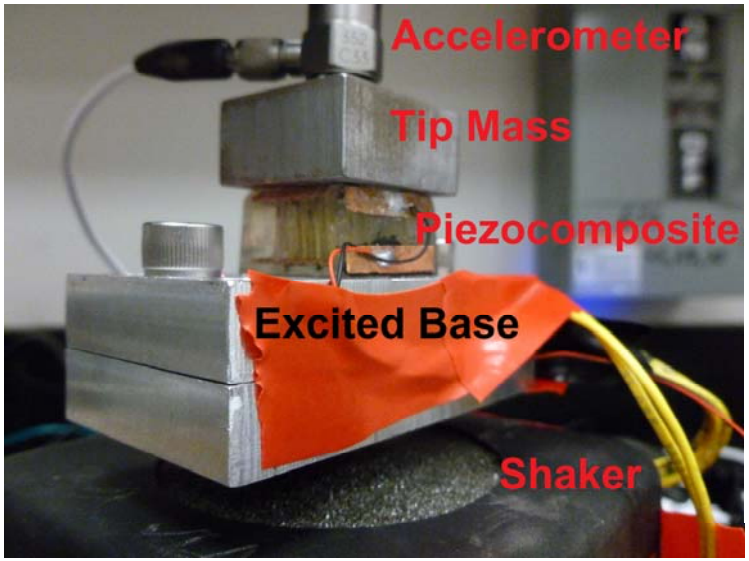
Technology – NASA SWFOG Program (UAH)

Concept



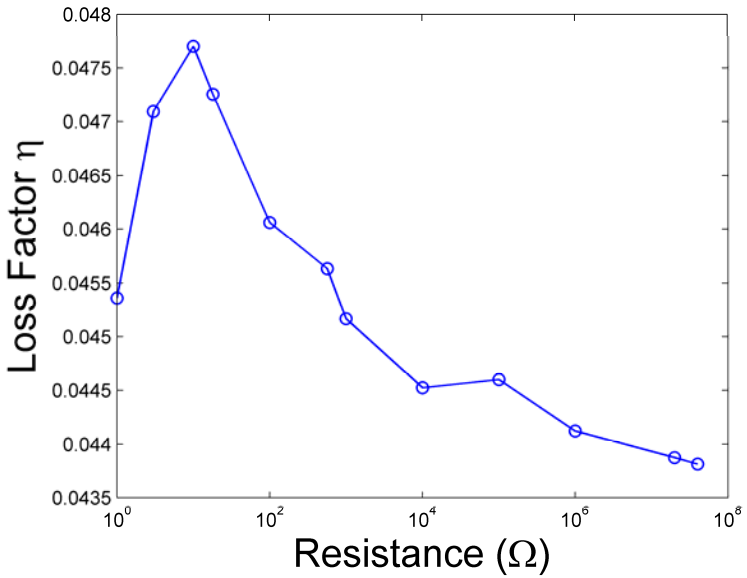
PZT rod poling





CPPC sample testing

Damping performance



Current Development Status of Technology

Status:

- Completing gyro components evaluation and selection
- Preparing for gyro integration & system debug
- Completing prototype damping material development
- Finalizing electronics development path for miniature boards

For commercial readiness:

- Conclude SW components development cycles
- Setup primary & backup component vendor agreements
- Freeze SW component specifications and fabrication docs
- Finalize SW component & system testing infrastructure
- Develop production metrics (BOM CAR ECO EDD FA QA QC R&T SOP…)

Investment & Applications

ROM cost to advance technology:

- P2E 500K / Infrastructure 1.5M / Transition 2M

Investment worthiness:

- Innovative cutting edge technology enabling pointing & navigation of craft and systems that are otherwise too small to host high accuracy inertial guidance devices

Application examples:

- Microsat / Aerostat systems / Antenna pointing
- MAV / UAV / Mortar & missile guidance
- MWD (measurement while drilling)

Summary of Key Points

Core technical competencies:

- Fiber optic sensing solutions
- Gyro development and integration
- ITAR compliant

Manufacturing & facility capabilities

- 10,000ft^2 area
- Photonics R&D facilities
- Pilot production only (outsource production)

Contacts

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