



CONTINUOUSLY SWEPT LASER-BASED FIBER BRAGG GRATING DATA ACQUISITION SYSTEM CAPABLE OF OPERATING IN EXTREME ENVIRONMENTS

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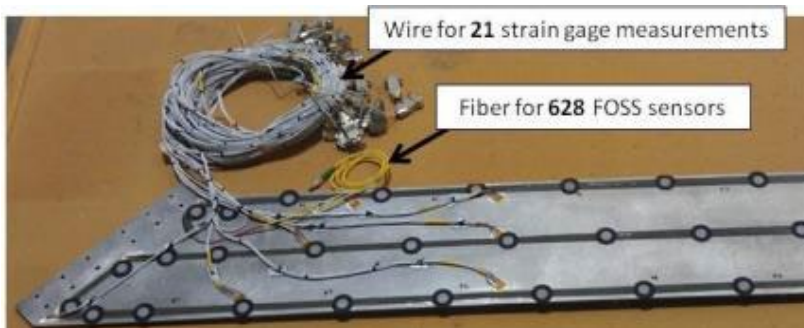


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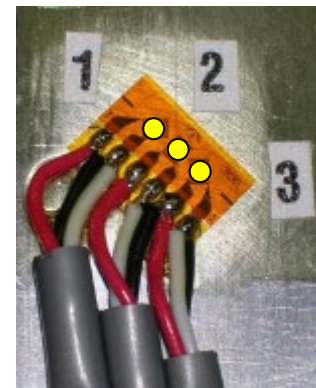
- Fiber Optics based sensors – how it works
 - Fiber Bragg Gratings (FBG)
 - Extrinsic Fabry-Perot Interferometer (EFPI)
- Fiber optics-based interrogator
 - WDM
- AFRC's WDM DAS technology implemented - Details
 - No moving parts
 - Environmentally tested
- Conclusion

Why Choose Fiber Optic Sensors over Resistive Gages?

One Of These Things (is Not Like The Others)



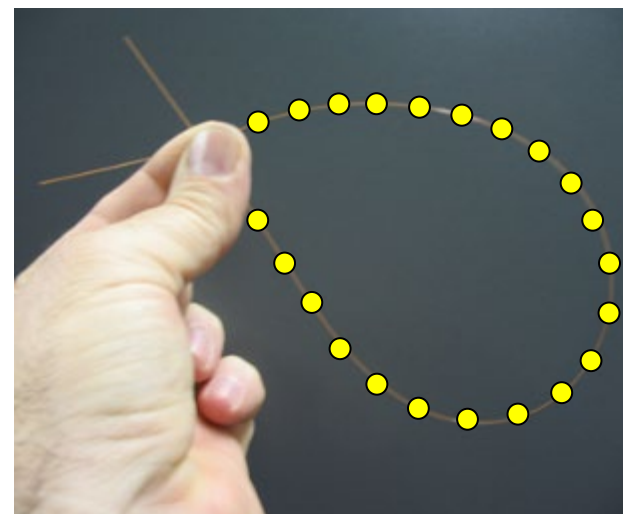
(Heavy)



(Big)



(Hard)



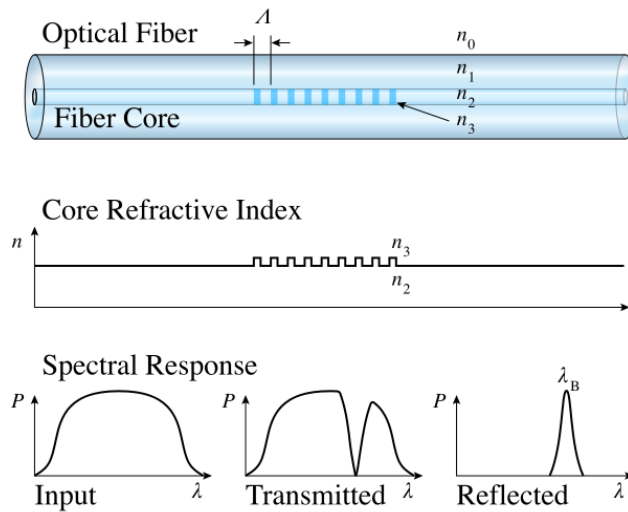
(Light, small, easy)

Fiber Bragg Grating (FBG) as sensor



Principle

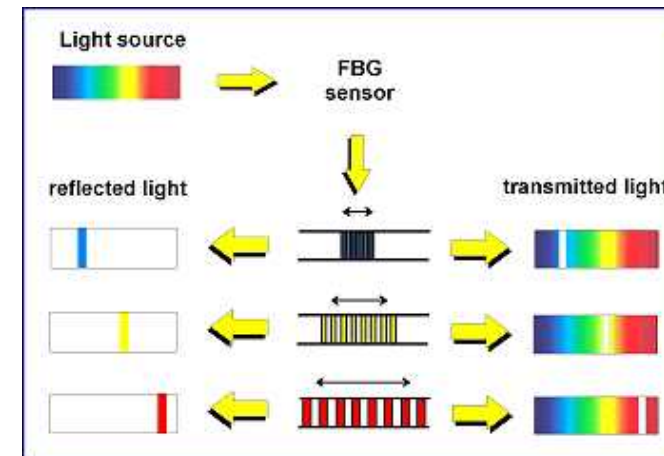
- Fiber Reflector that reflects a particular wavelength and transmit all others
- Bragg Wavelength: $\lambda_B = 2n_e \Lambda$



Measuring Strain(ϵ) or Temperature (ΔT) via FBG sensor

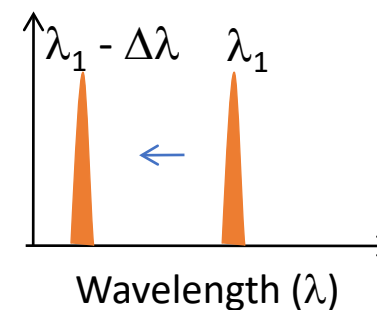
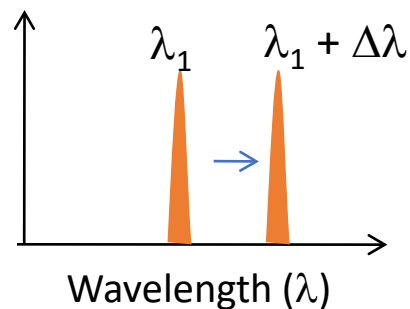
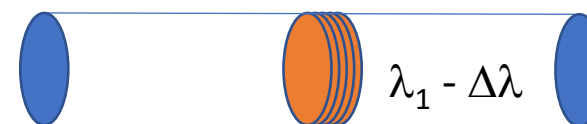
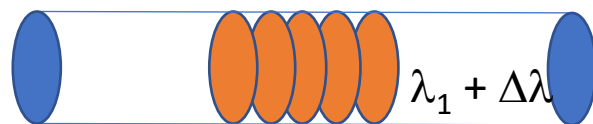
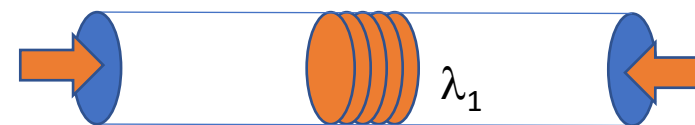
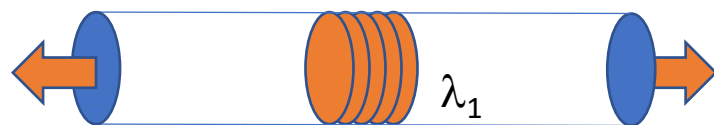
$$\frac{\Delta \lambda_B}{\lambda_B} = (1 - p_e)\epsilon + (\alpha_\Lambda + \alpha_n)\Delta T$$

- $\Delta \lambda_B$ = change in Bragg wavelength due to environmental change
- λ_B = Initial Bragg wavelength of FBG
- p_e = strain-optics coefficient
- α_Λ = Thermal expansion coefficient
- α_n = thermo-optic coefficient

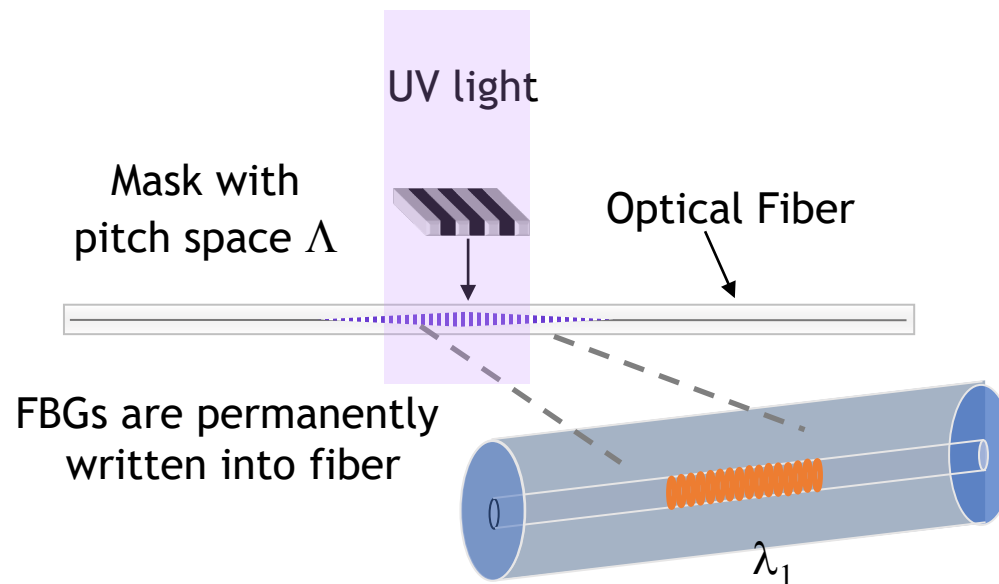


How do FBG sensors work?

- Like an accordion $\rightarrow$ change in Bragg Wavelength



How are these fiber sensors (FBG) fabricated?



- UV light is absorbed uniformly to the Ge-doped fiber core through phase mask
- The periodic index change results in grating (sensing) effect
- Each sensor acts as a miniature mirror that reflects light at a particular wavelength (λ)

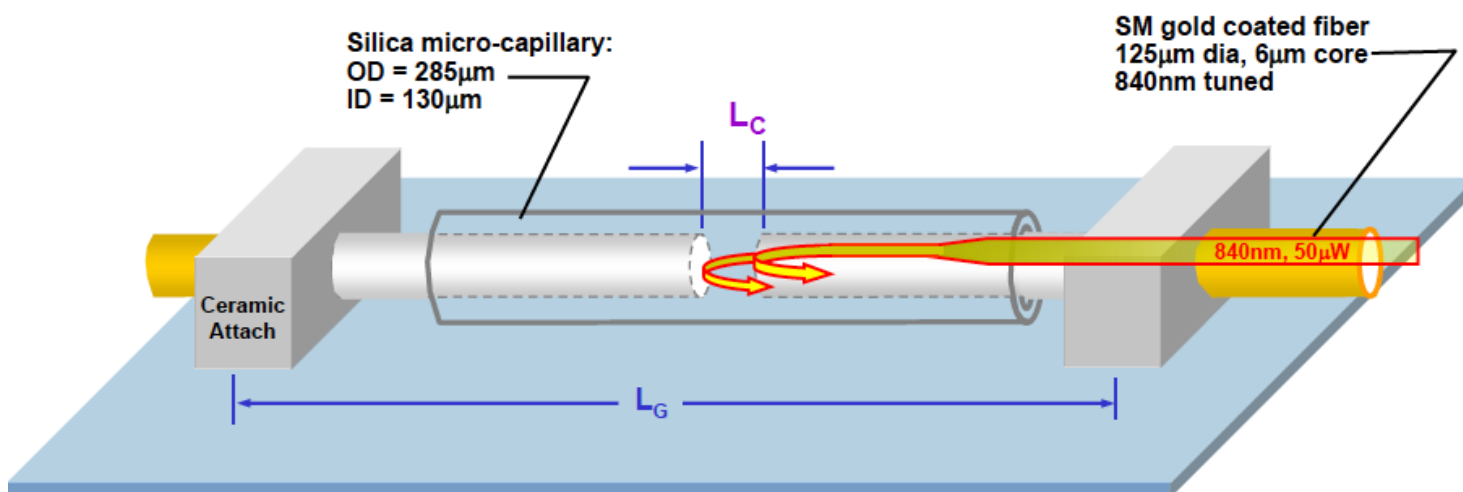
Extrinsic Fabry-Perot Interferometer (EFPI)

Sensors

Static Measurement (Max Op 1850°F)

Extrinsic Fabry-Perot Interferometer (EFPI)

Commercially Available



Strain = $\delta L_c / L_G$ (initial), where sensitivity = L_G

Apparent Strain (ξ_{app}) = $(\alpha_{sub} - \alpha_{fiber}) * \Delta T$

- EFPI are fabricated from bonding two separate fiber end
- Joined via a hollow-core extrinsic tubing, with a set gap-length, L_c , to create the path length difference

- Equation

$$I_r = |A_1 + A_2|^2 = A_1^2 + A_2^2 + 2A_1A_2\cos\Delta\phi$$

- By measuring the output phase change, gap length L_c and strain can be measured.



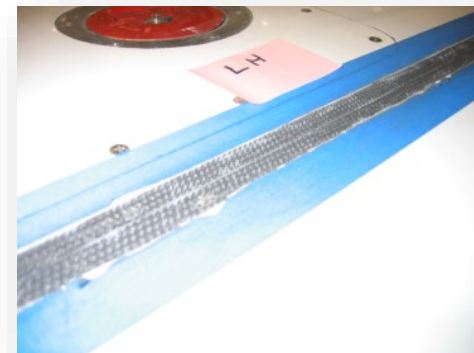
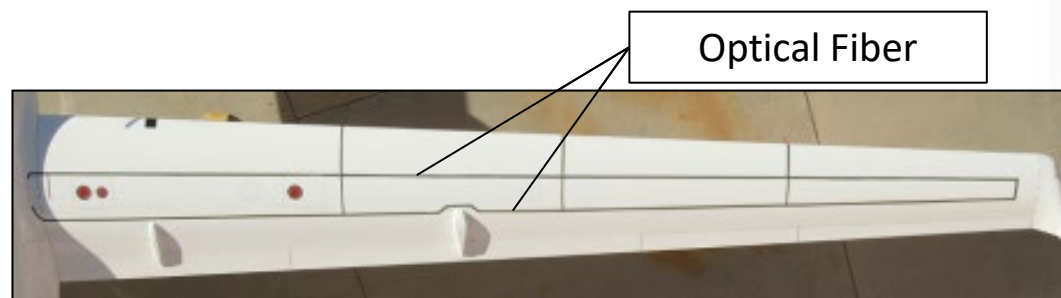
Fiber Bragg Grating Installation Advantages and Challenges – Aero Structures

Installation Advantages

- Greatly reduced installation time compared to conventional strain gages
 - 2 man-days for 40' fiber (1000 strain sensors for a continuous surface run)
 - Multiple sensors installed simultaneously
 - Same surface preparation and adhesives as conventional strain gages
 - Minimal time spent working on vehicle
 - All connectors can be added prior to installation, away from part
 - No soldering, No clamping pressure required
 - Circular cross-section eliminates possibility of trapping air between sensor and part (eliminates repeat installations)
- Can be installed with little or no impact to OML

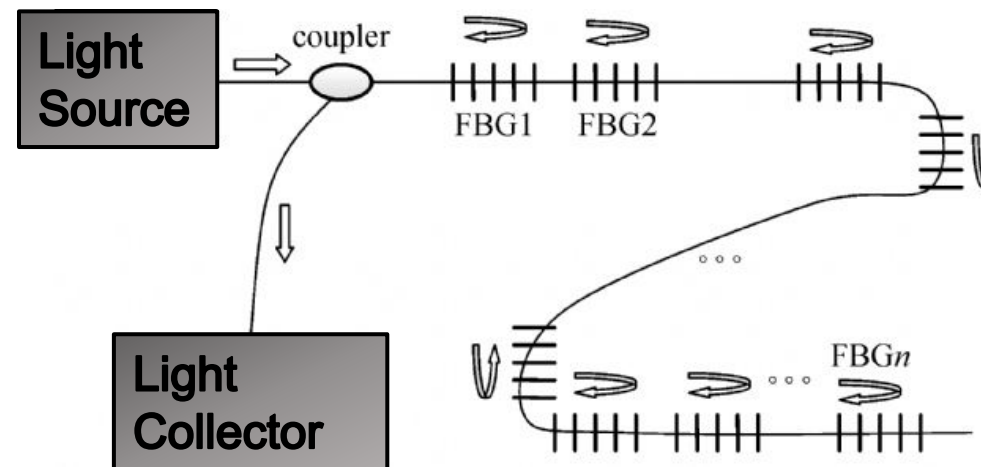
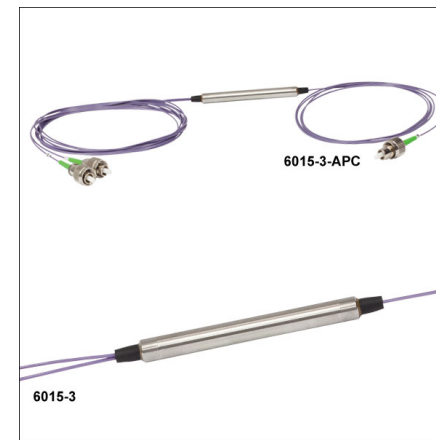
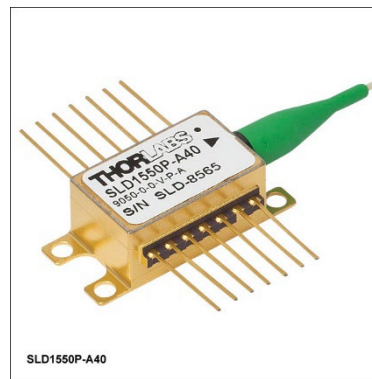
Installation Challenges

- Optical fiber more fragile than strain gages
- Some measurement locations not practical due to fiber minimum bend radius



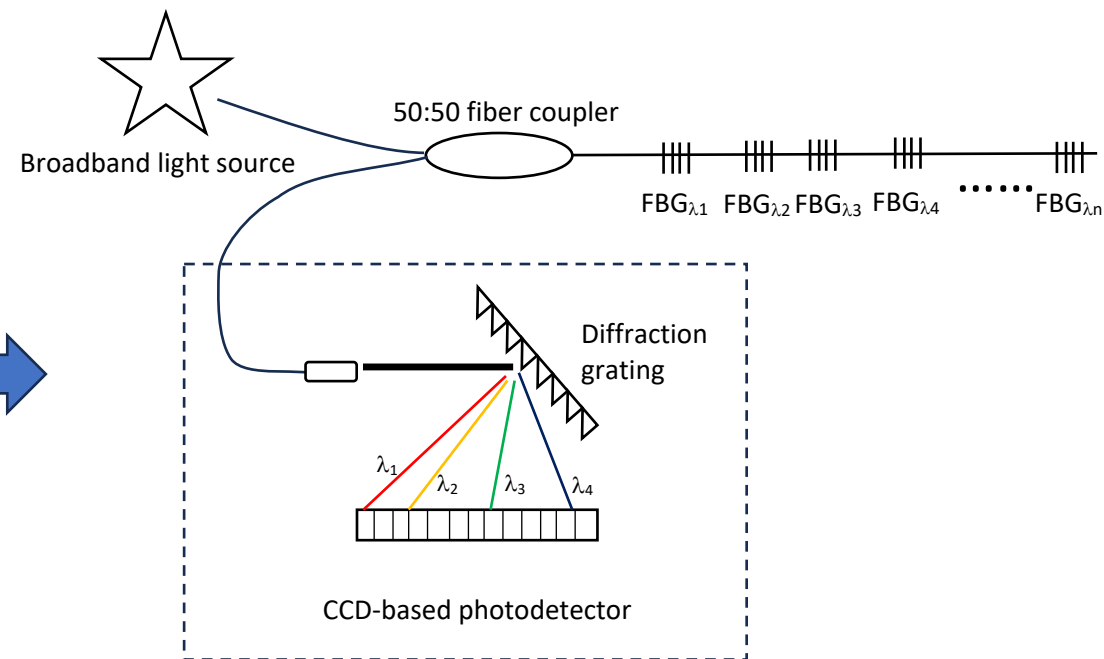
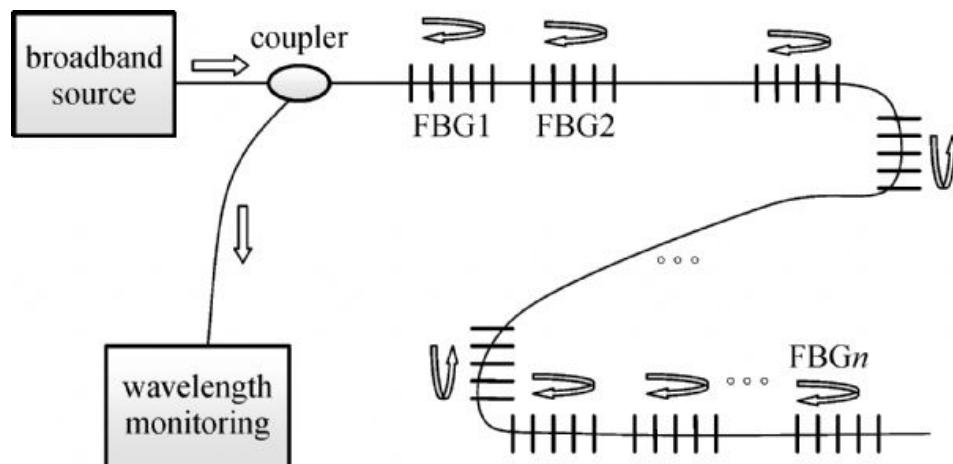
Typical Fiber sensing via Wavelength Division Multiplexing (WDM)

- Excitation Source (light source)
 - Broadband LED based light source
 - Tunable Laser
- Fiber Sensors (FBG)
- Light Collector (Detector)
 - Detection Scheme (Optical Spectrum Analyzer)
 - Photodetector (A/D)



Current types of Commercial WDM system

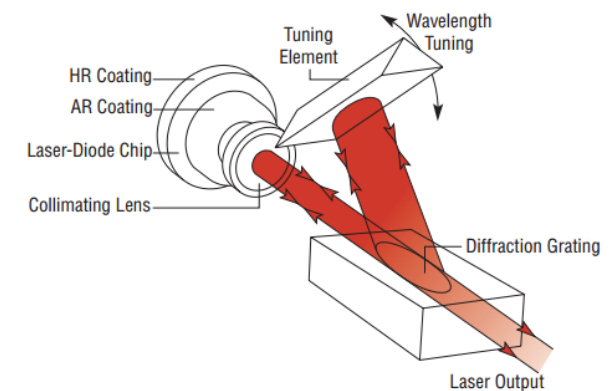
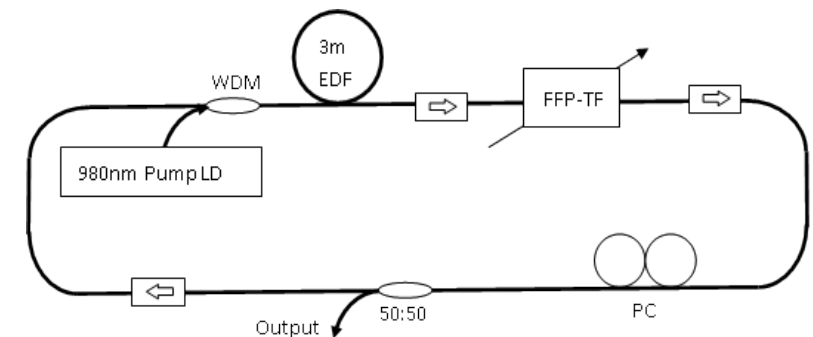
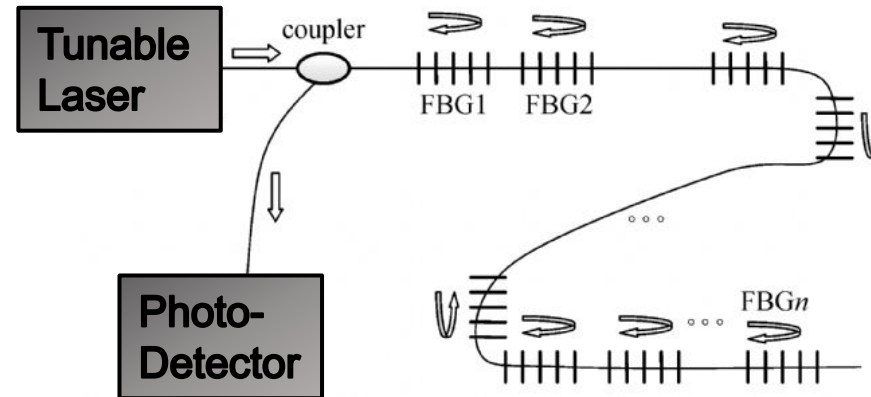
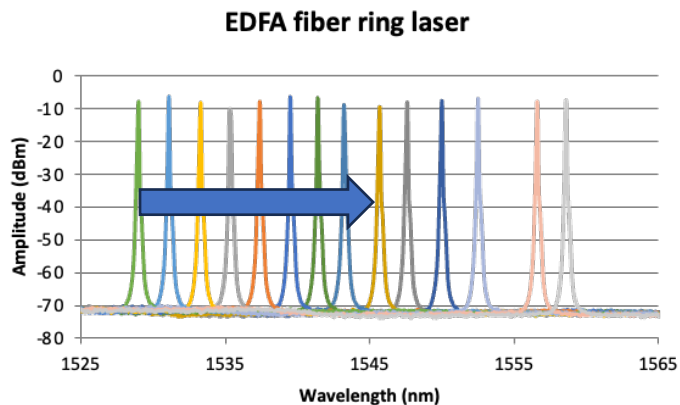
Broadband Light Source based



Bulk-optics based spectrum analyzer – alignment issues under avionics environment

Current types of Commercial WDM system

Tunable Laser based



Mechanical tunable laser based – stability issues under avionics environment

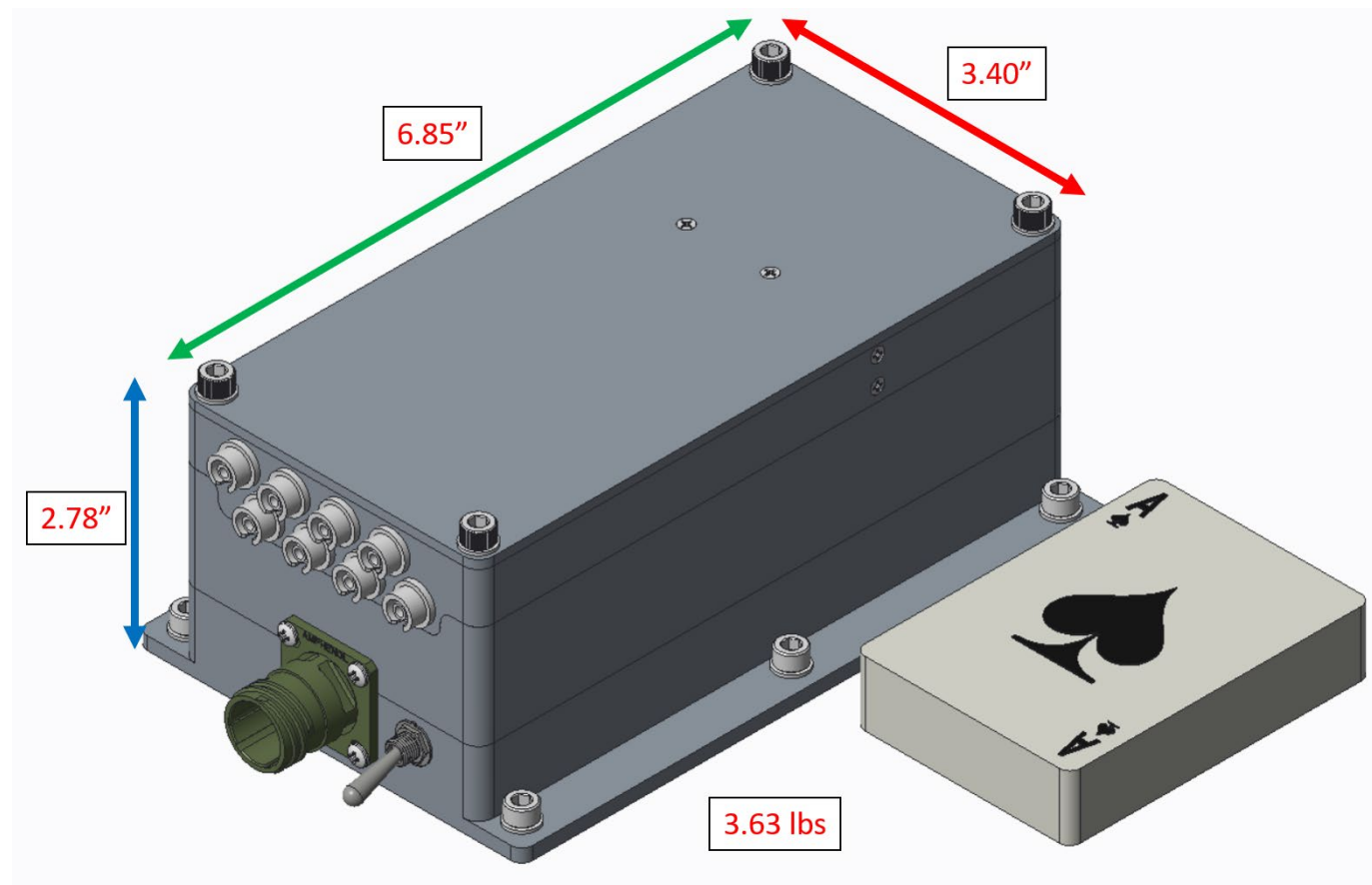
A modified Littman-Metcalf configuration.



NASA AFRC – Novel WDM Data Acquisition System (DAS) for ruggedized environment

Custom-built WDM DAS

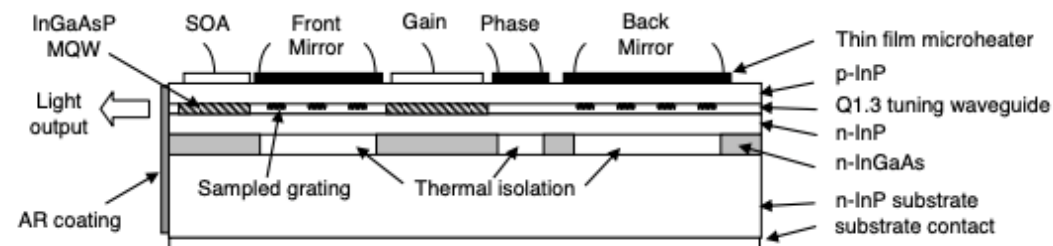
- Powered by tunable Laser based with no moving parts
- C-band with 40nm bandwidth
- 4 optical channel acquired simultaneously
- Tuning every 4pm – 50Hz sweep speed
 - Up to 500Hz if tuned every 40pm
- Dimension: 6.8" x 4.5" x 2.8"
- Weight : 3.5 lbs



NASA AFRC – Novel WDM Data Acquisition System (DAS) for ruggedized environment

Custom-built WDM DAS

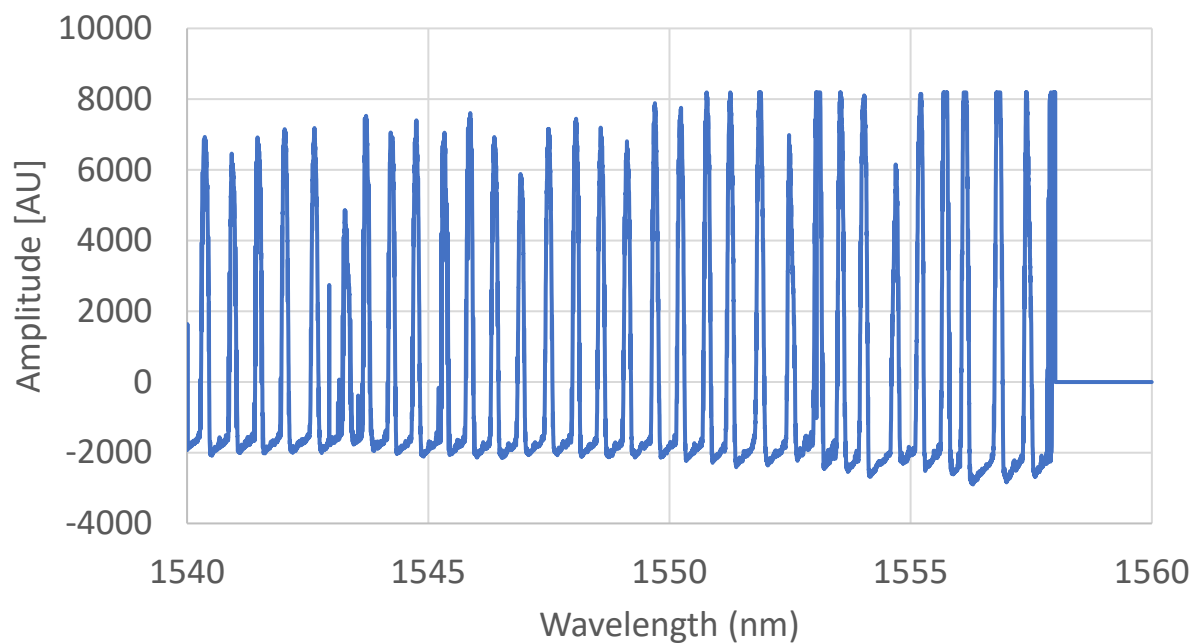
- Laser is based on sampled grating Distributed Bragg Reflector (SG-DBG)
- Laser output wavelength is tuned by changing injection current on
 - Front Bragg mirror
 - Back Bragg mirror
 - Phase section
- No mechanical moving parts



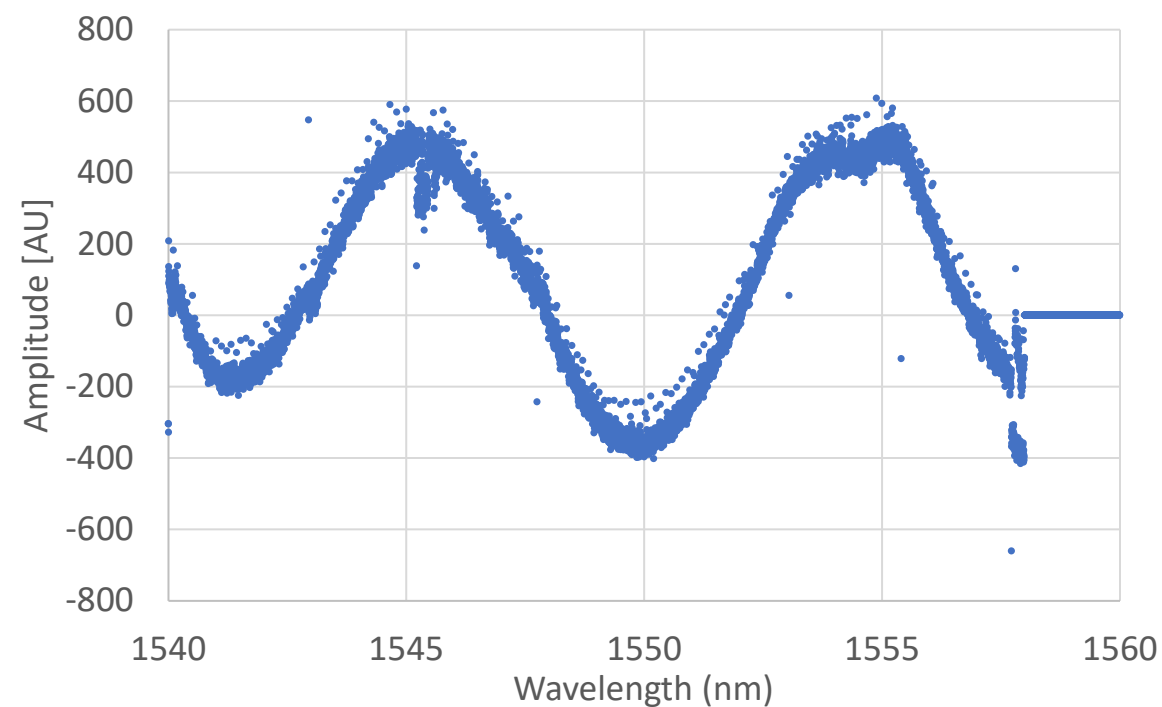


Data

FBG – Multiple FBGs reflections captured



EFPI – Phase data captured



Ruggedization Testing



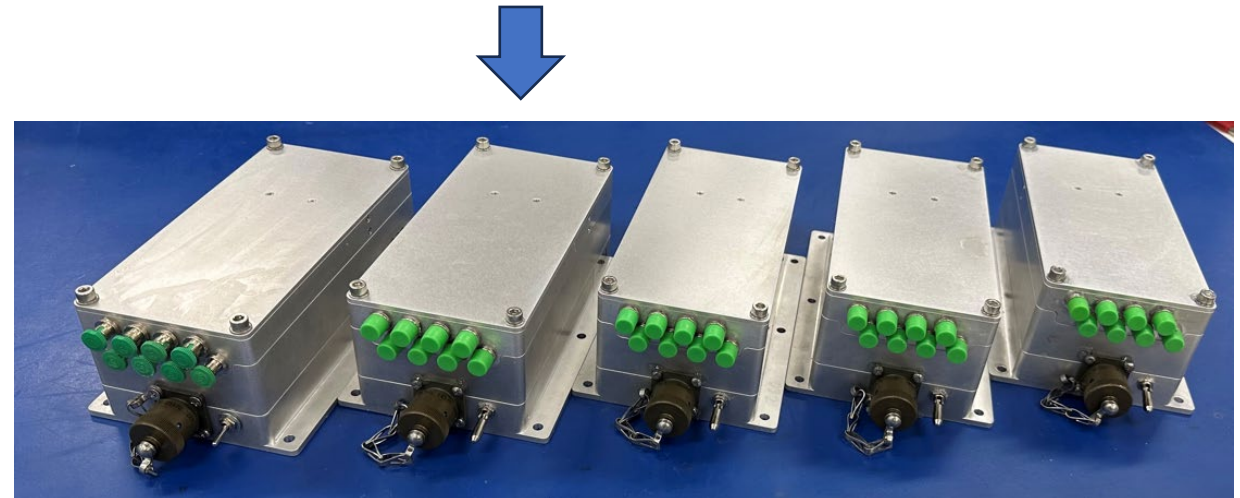
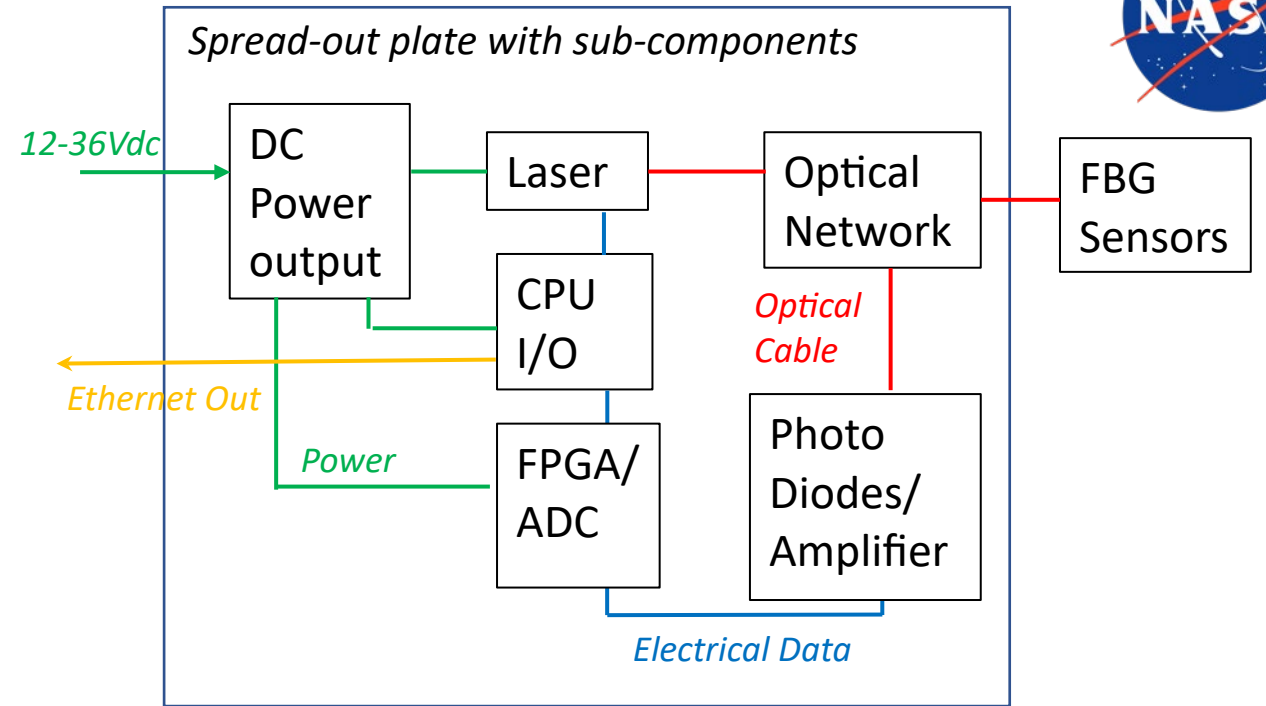
- Component level testing (2022) as well as system level testing (2023) has been completed
- Random Vibration (x,y,z axes)
 - 5.3 GRMS at 10 minutes
 - 6.3 GRMS at 10 minutes
 - 8.9 GRMS at 1 minute
 - System functional throughout
 - No drifting on sensors peaks
- Thermal Chamber testing
 - 60 minutes of dwell time
 - Operational testing from -40°F to 122°F
 - After cold soak at -70°F for 60 min.
 - After hot soak at 185°F





Conclusion

- A novel WDM DAS is developed at NASA AFRC
 - No moving part inside
 - Crawl-Walk-Run approach
 - Prototype proven in component level (2022)
 - System level testing completed (2023)
 - Flight testing planned (2024)
- Live demonstration of WDM DAS is available at NASA booth at ITC.



Back Up



WDM Trade – off : Bandwidth vs # of gratings



- Advantage

- Sensors can be ~km away from interrogator
- Simple Measurement – No Frequency Modulation needed
- Commercially Available
- High Sampling Speed Available (~MHz)

- Disadvantage

- Location of each FBG sensor matters
- Each sensors contains an unique wavelength
- Limited # of sensors can one channel
 - Aliasing effect - When 2 sensors intersects one another

