STUDY OF LATERAL MISALIGNMENT TOLERANCE OF A SYMMETRIC FREE-SPACE OPTICAL LINK FOR INTRA INTERNATIONAL SPACE STATION COMMUNICATION

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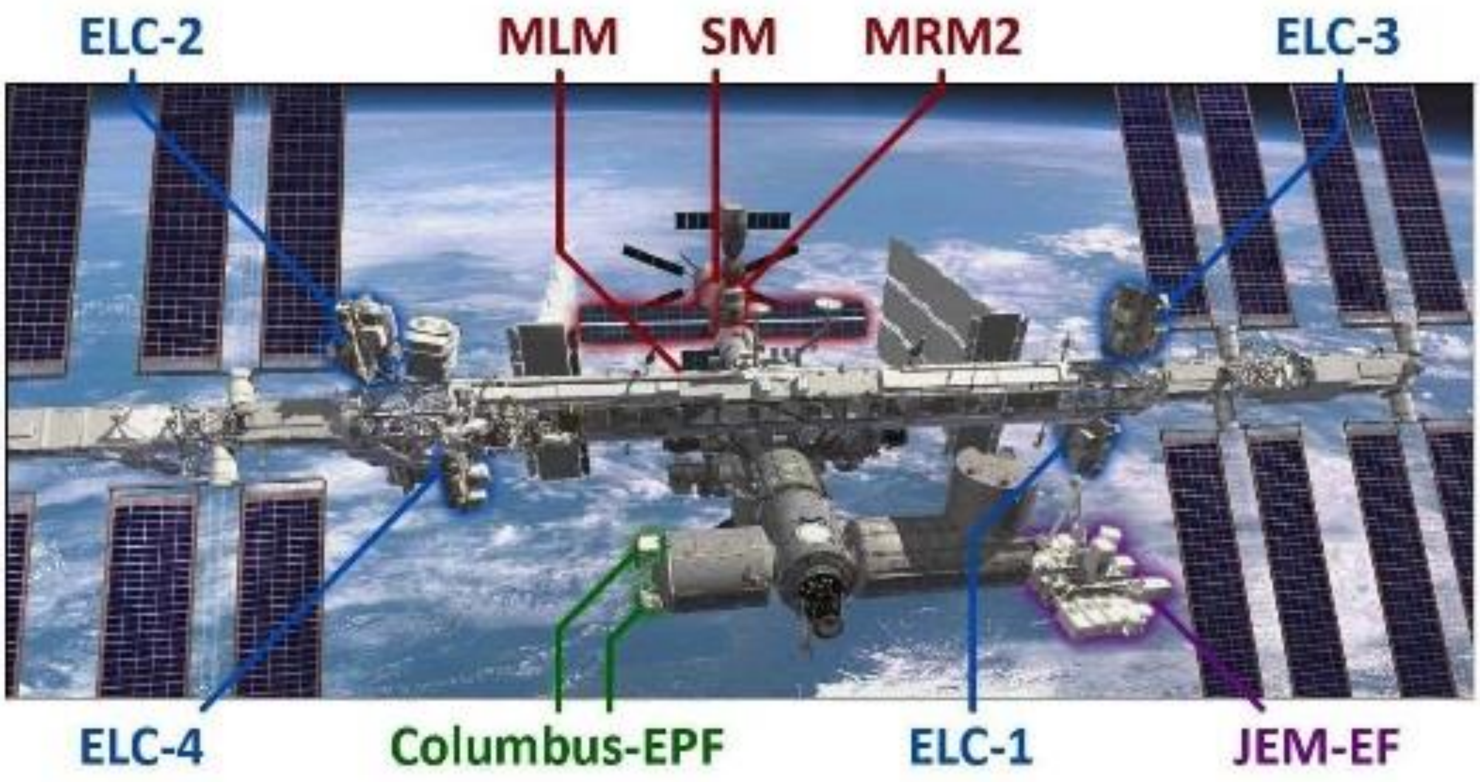
Motivation

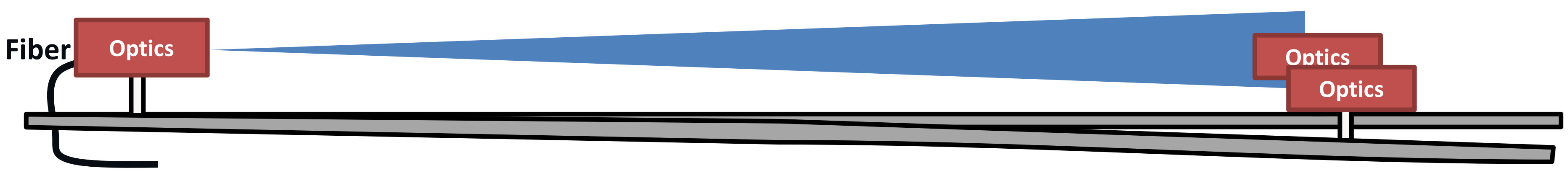
International Space Station (ISS) payloads sites have limited bus throughput (~10 Mb/s) restricting communicating large quantities of science data. Physical locations of exterior payload sites impose a physical barrier to routing cables.



Goal

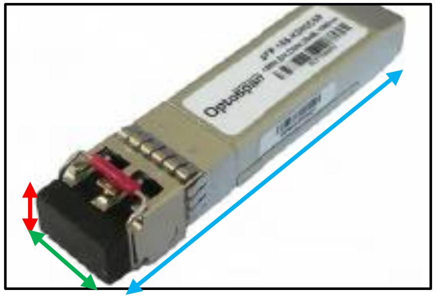
Enable transfer of science data at 1 Gbps from payload sites to main ISS cabin using a free space optical link.

- Minimum size, weight, and power (SWaP)
- Easily integrated into the existing ISS hardware (low complexity)
- Eye safe over entire optical path
- Allow for dynamic movement of transceivers caused by ISS flexure



Current Focus

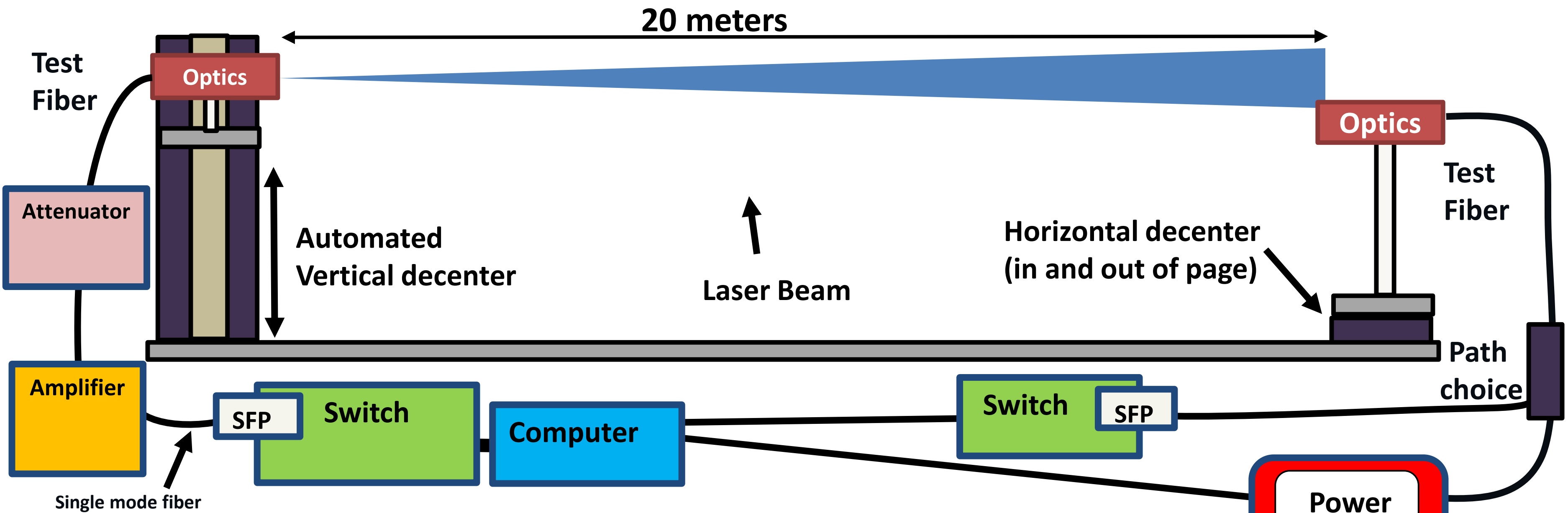
- Couple light into a transceiver over the predicted ISS lateral misalignment range (9 cm) for a 20 meter symmetrical link
  - No active pointing components (reduce SWaP and complexity)
  - Small form factor pluggable (SFP) transceivers
    - A high data rate with a low SWaP
    - Ease of integration: plugs directly into network switches
    - Low cost : Commonly used in terrestrial fiber networking links
    - Challenge: Small detectors decrease the tolerance to misalignment
- Studied lateral misalignment tolerance (decenter span) effects
  - Beam divergence
  - Type of SFP
  - Fiber type
  - Transmitted power



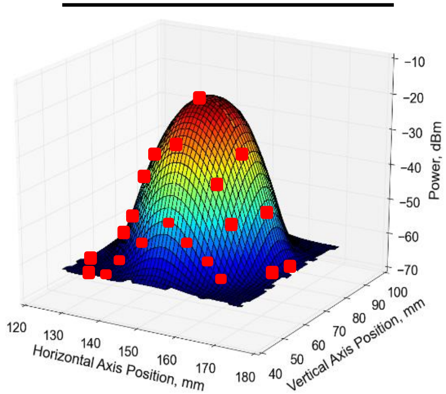
8.5 by13.4 by 56.5 mm

Experimental Setup

Simulates ELC site to ISS main cabin lateral movement (decenter), ~9 cm

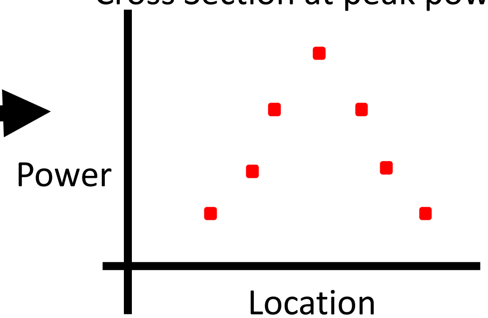


Data collection



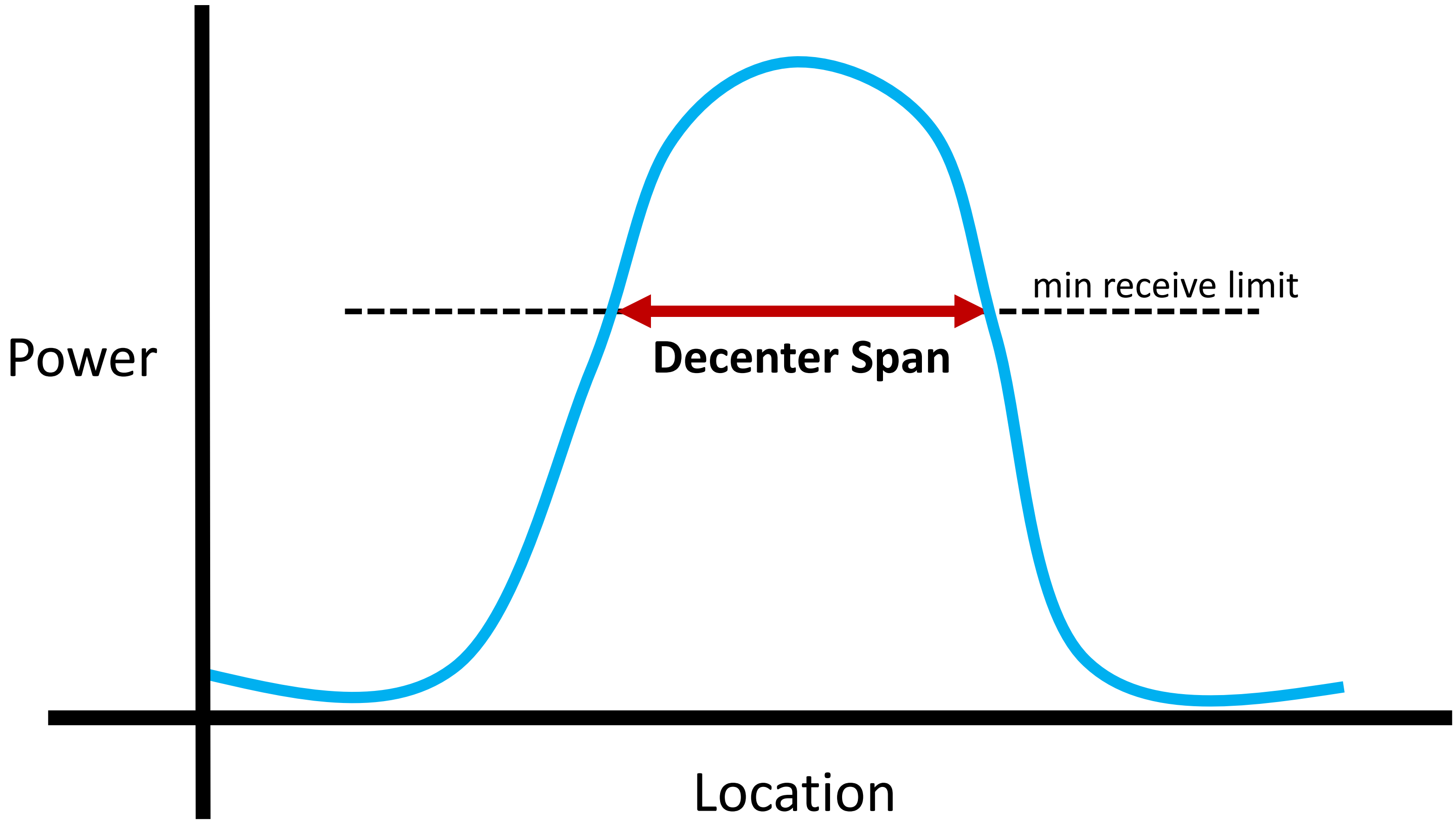
Data Analysis

Cross Section at peak power

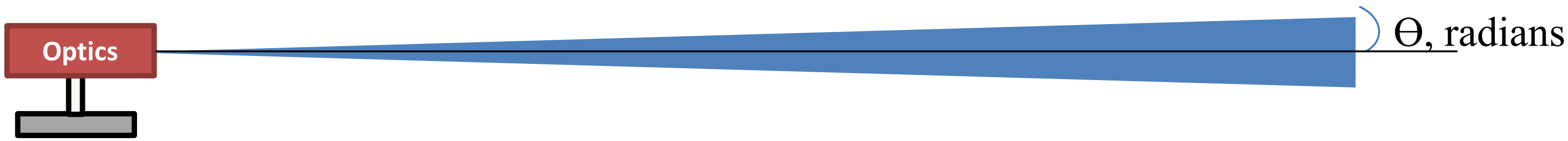


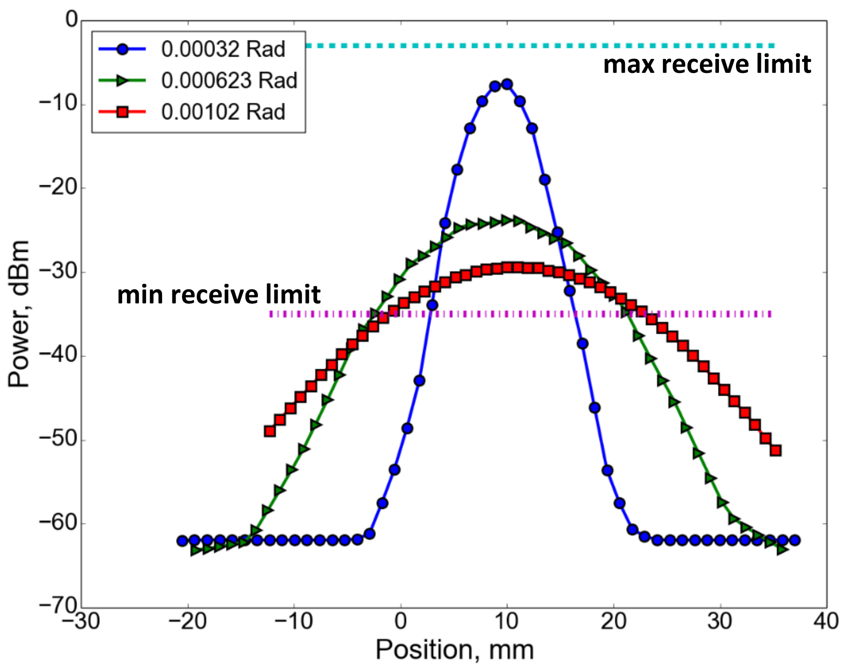
Data Analysis

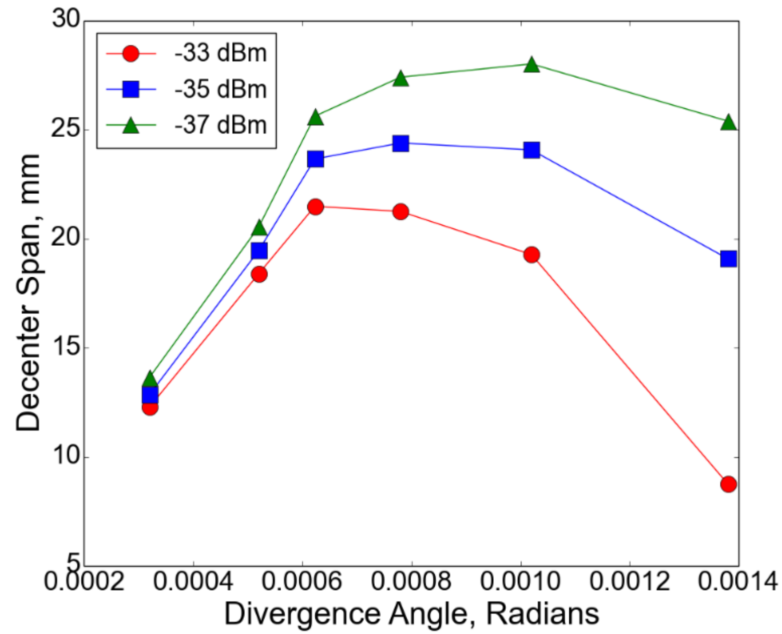
Decenter span = distance over which received power is above threshold for error-free link (*lateral misalignment tolerance*)



Beam Divergence





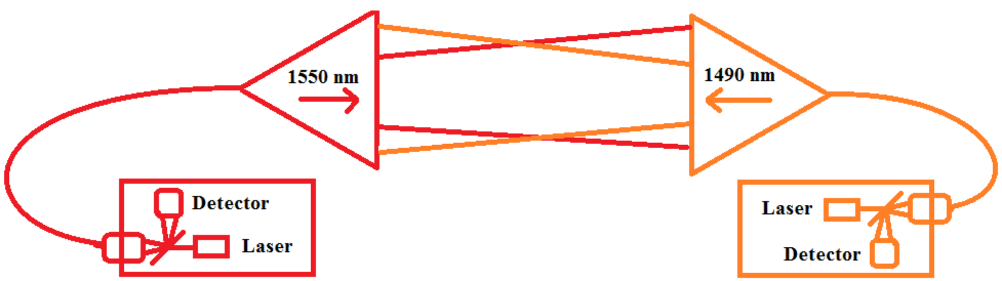


- There is an optimum divergence angle at which the decenter span is maximized which depends on
  - minimum and maximum receive limits of receiver
  - Shape of power distribution (Gaussian, flat-top, etc…)

Type of SFP

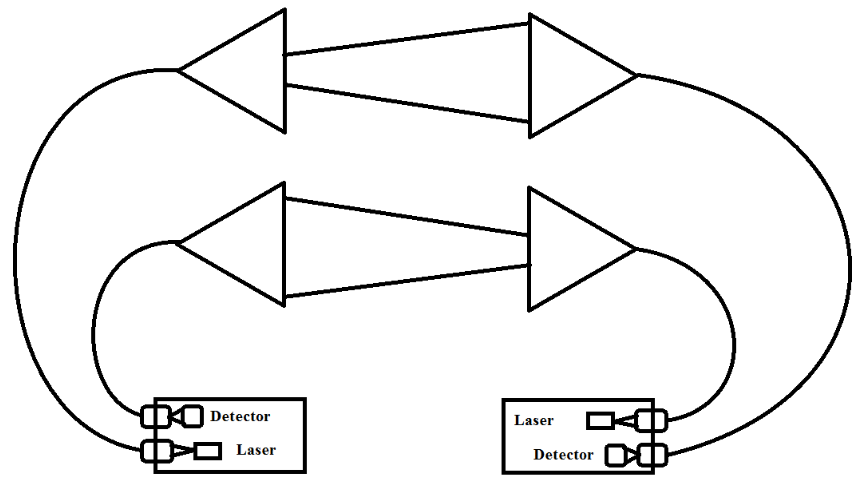
Single fiber bidirectional (BiDi)

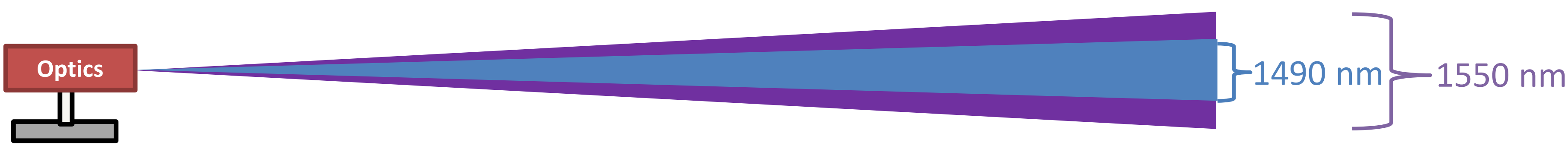
- Reduce the amount of optics needed for two way communication
- Requires symmetric system



Duplex

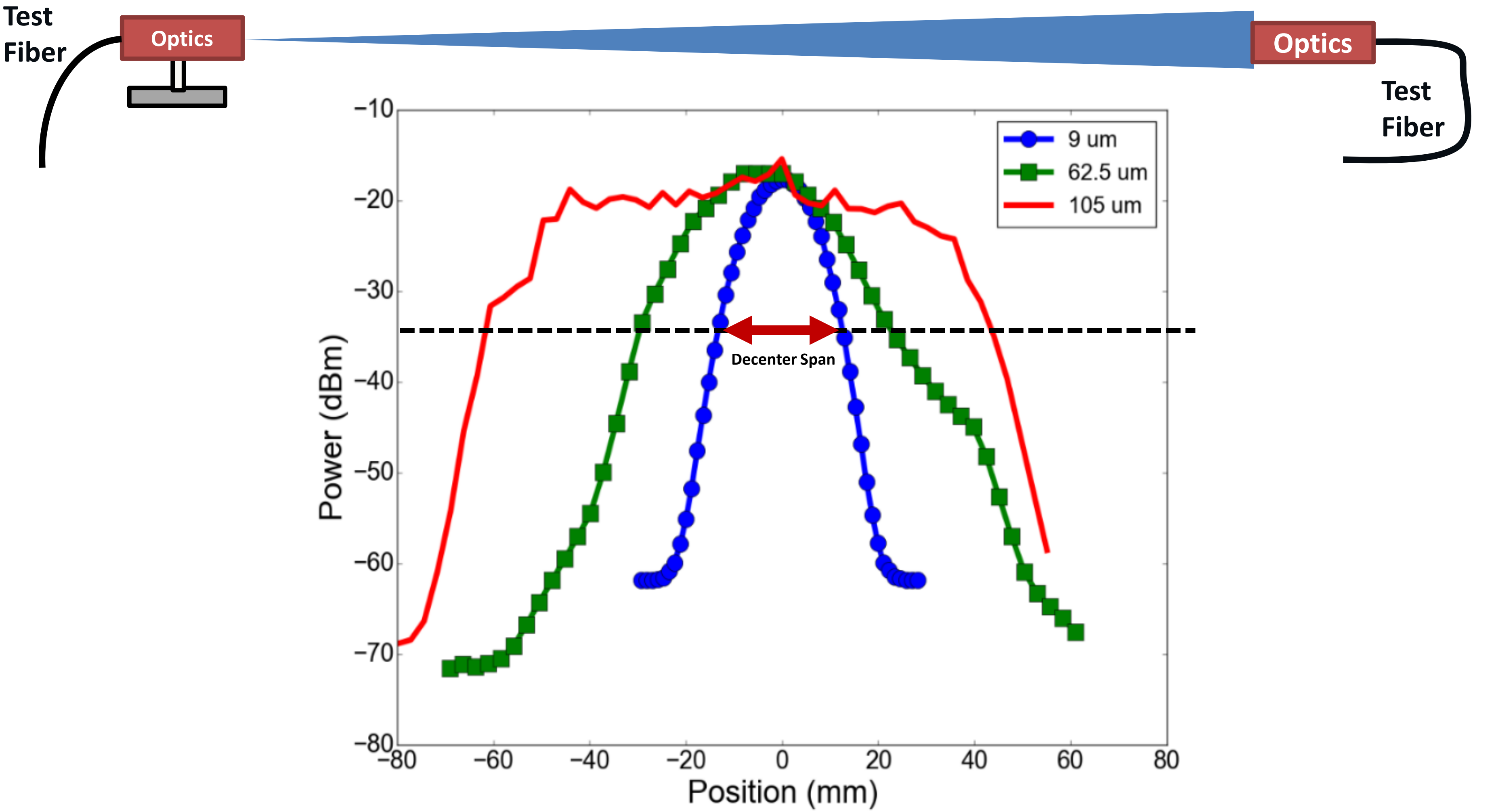
- Double the amount of transmit and receive optics





The combined effect of required symmetry and the lower refraction of 1490 nm light reduces the decenter span of the Bidi by ~7% over 20 meters

Fiber Core Size

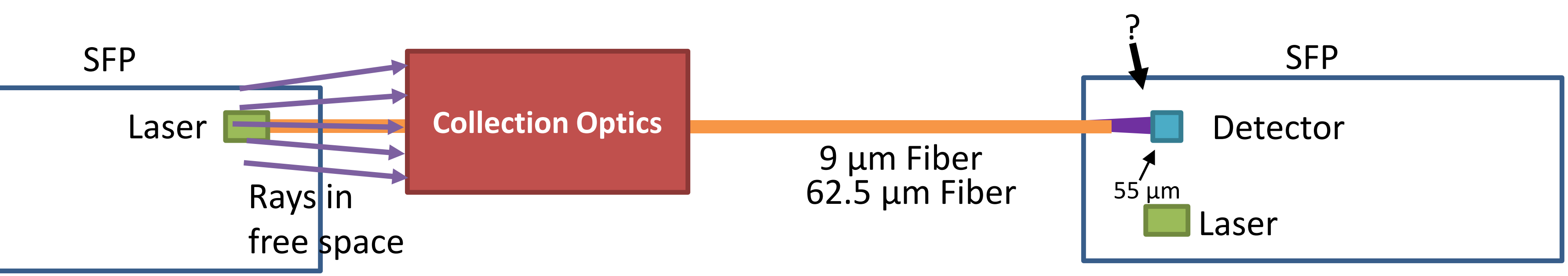


Increased core size changes shape of power distribution and increases decenter span

Fiber Core Size

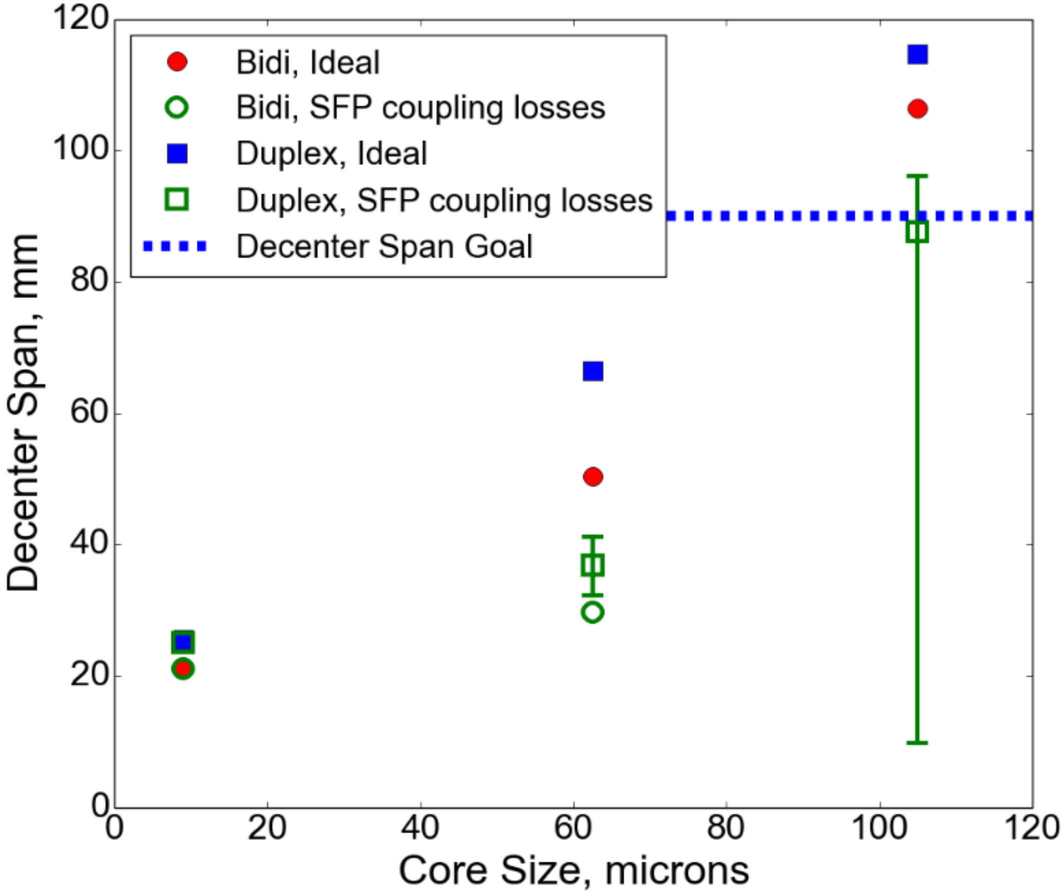
- 62.5 and 105 µm core sizes caused losses internal to SFP
  - Core diameters > detector diameter (55 µm) → overfill
  - Additional internal losses occur when light is coupled from free space
    - Cause: a change in transmission out of fiber
      - Modal → hits/misses on detector?
      - Increased divergence angle at fiber exit → increased detector overfill?

Core Size (µm)	Total Losses (dBm)	Losses from Detector Overfill	Losses from Free Space
62.5	7-9	1-2	6-7
105	~10	~6	~4



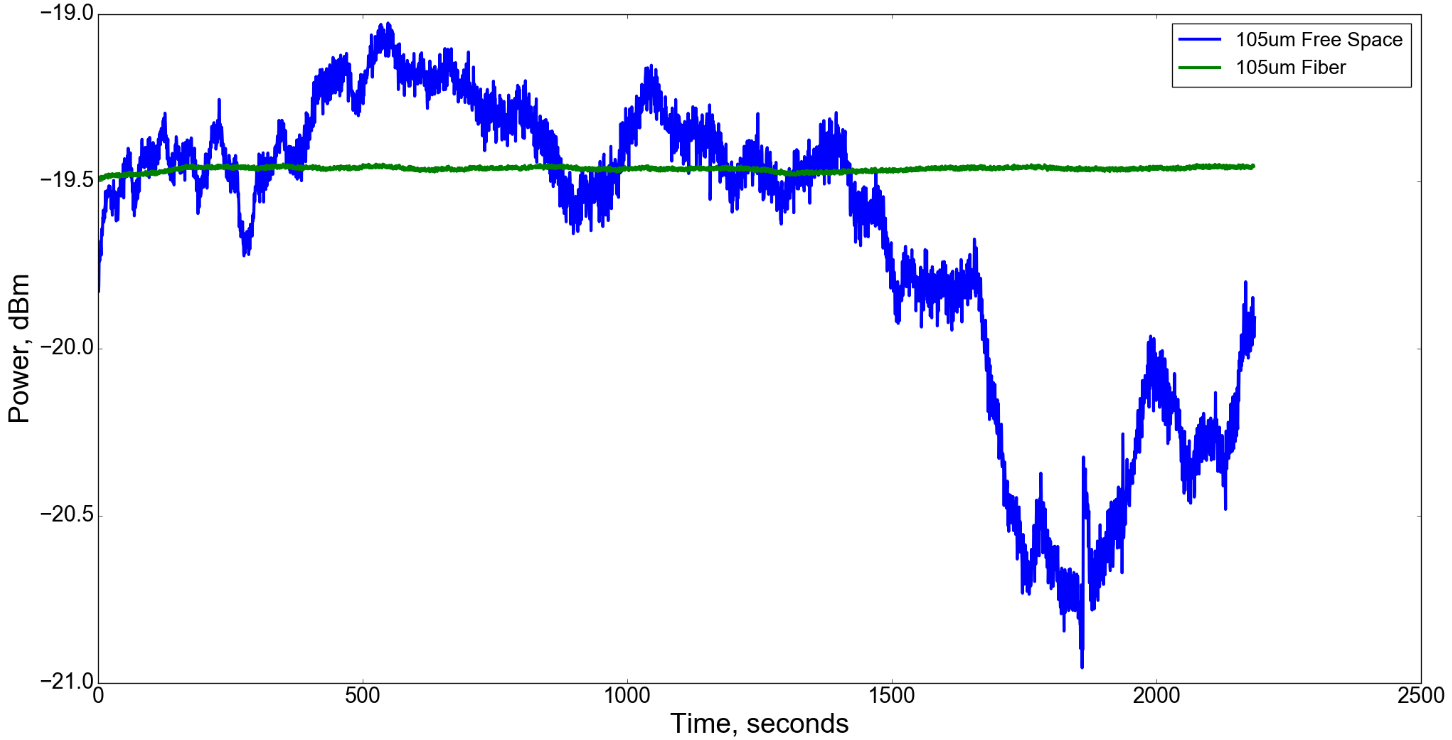
Fiber Core Size

- Ideal= no coupling losses
- Error bars= power drift



Decenter Span goal could be reached if some internal coupling losses were recovered

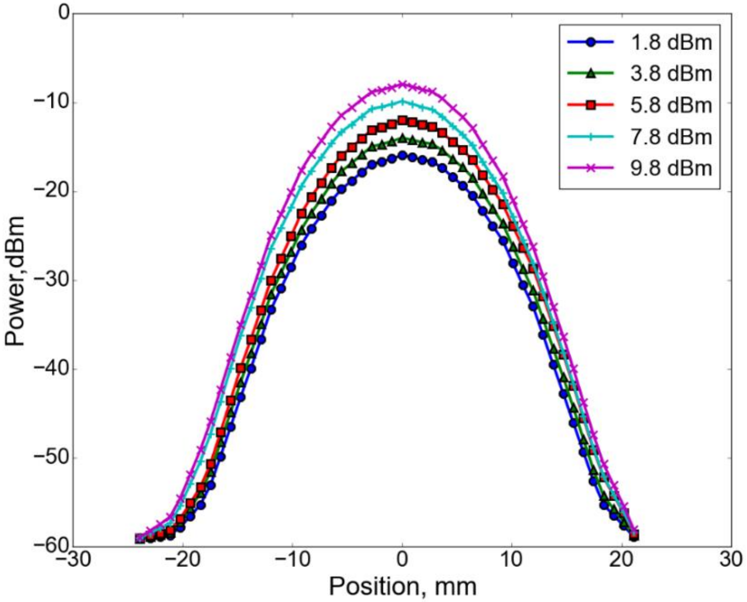
Drift in Power



Receive Cable Core Size, µm	Peak to Peak Power Swing, dBm	Standard Deviation, dBm
105	4.475	0.733

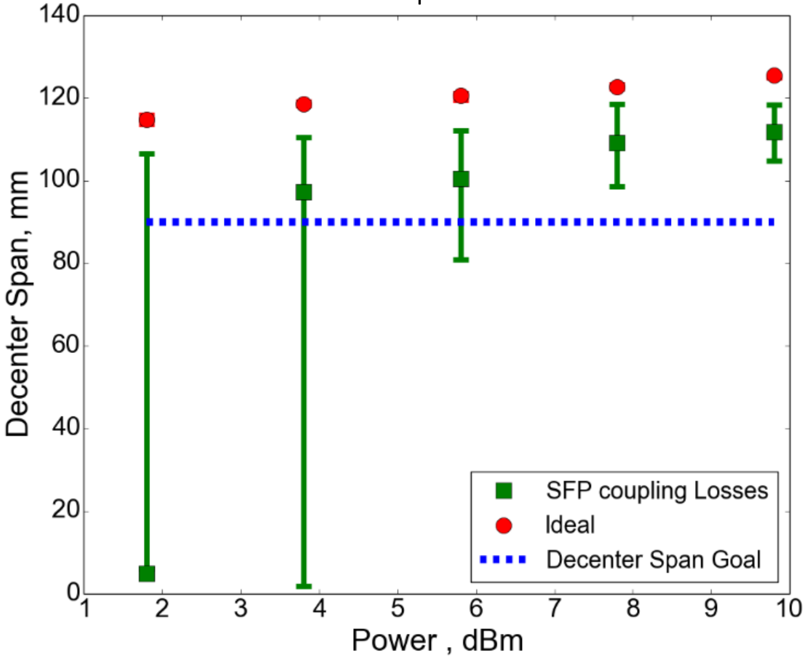
Transmitted Power

Single mode fiber



105 µm fiber

Error bars= power drift



- Decenter span goal reached at 7.8 dBm with 105 µm core fiber.
- Ways to increase power of link:
  - Customize SFP → increase cost of SFP
  - Use Duplex SFP with amplifier → increase SWaP
- Eye safe < 9.8 dBm

Conclusion

- Data taken to understand the effect of type of fiber, SFP type, and transmitted power on the decenter span of a 20 meter symmetric FSOL
- Findings:
  - Increasing core size, power, the lowest minimum receive limit → increased decenter span
  - Losses internal to the SFP was increased by free-space coupling compared to fiber-only coupling
  - Using 105 µm fibers, Duplex SFPs, and a pair of amplifiers creates a decenter span that can tolerate the lateral 9 cm misalignment expected on the ISS.

Future Work

- Investigate more efficient methods of coupling light into the SFP detector
  - Eliminate need for amplifier or custom SFP
  - Allow further improvements to SWaP and cost
- Bit error rate performance
  - Degradation may occur from modal dispersion in the 105 µm fiber
- Study angular misalignment tolerance

Acknowledgments

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