BIT ERROR RATE PERFORMANCE OF A FREE SPACE OPTICAL LINK USING DOUBLE CLAD FIBERS

Joseph Sullivan

University of Oklahoma

Bryan Schoenholz and Sarah Tedder

NASA Glenn Research Center

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Introduction

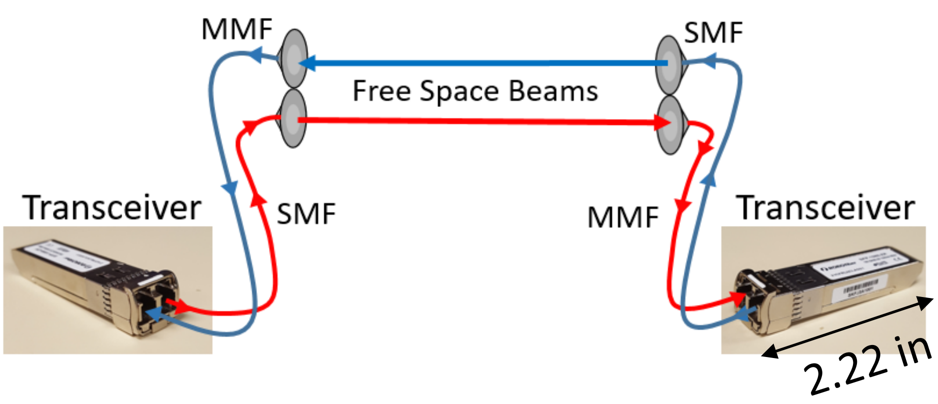
Objective

Determine bit error rate (BER) performance in a passively aligned free space optical link (FSOL) utilizing Double clad fibers (DCF) for transmitting and receiving, demonstrating the viability of a symmetric bidirectional FSOL using DCF.

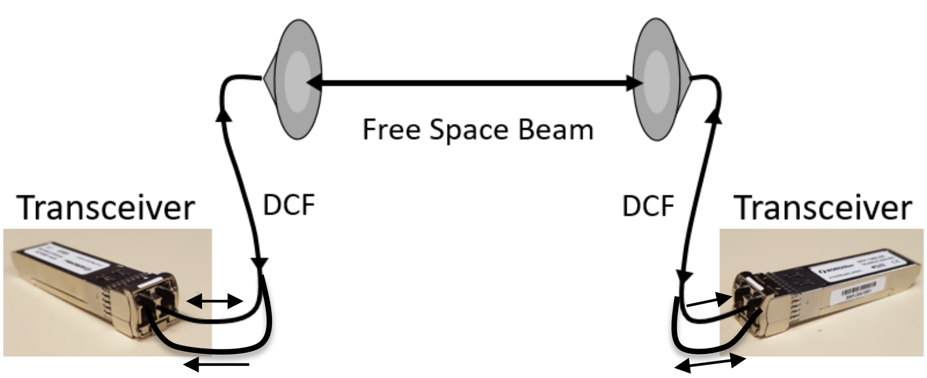
Background

Small form-factor pluggable (SFP) transceivers are a low cost, commercial off the shelf (COTS) implementation of a high data rate free space optical link (FSOL). Long range SFPs are designed for fiber optic systems using single mode fibers (SMF).

Typical Bi-directional FSOL



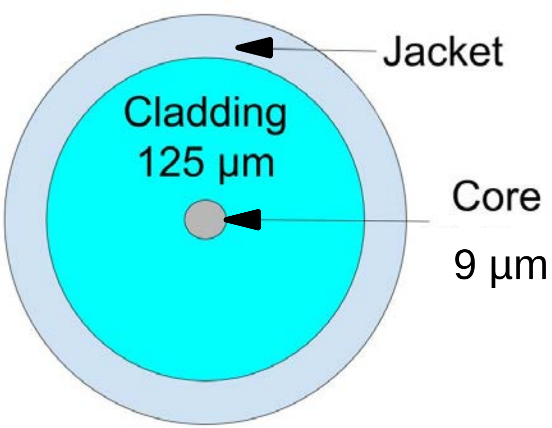
Bi-directional FSOL using DCF



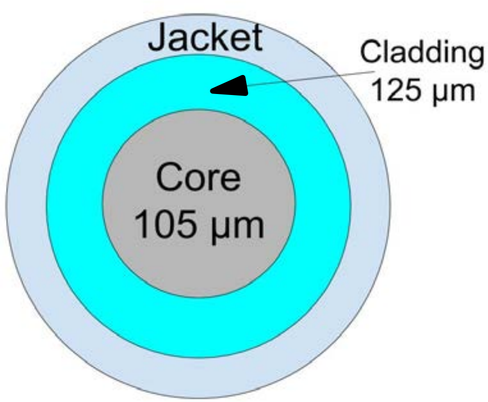
Background

Fibers

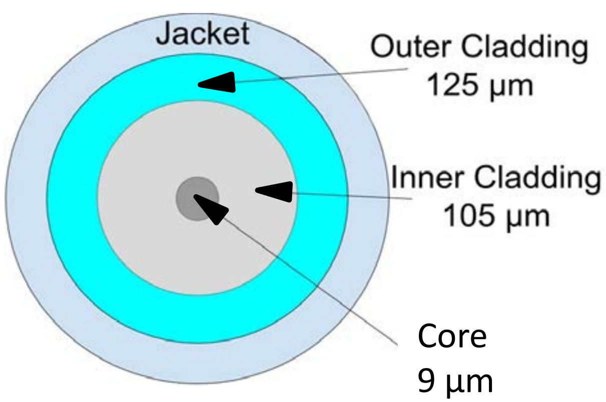
- Large core multi-mode receiving fibers (MMF) improve misalignment tolerance
- Using MMF to transmit causes power instability in laser beam
- Double clad fibers (DCF) can transmit a stable Gaussian beam through the single mode core and receive in the large inner cladding
- DCF enable a single bidirectional optical path with symmetric transmit and receive setups allowing for low size, weight, and power (SWaP)



9 µm Single Mode Fiber

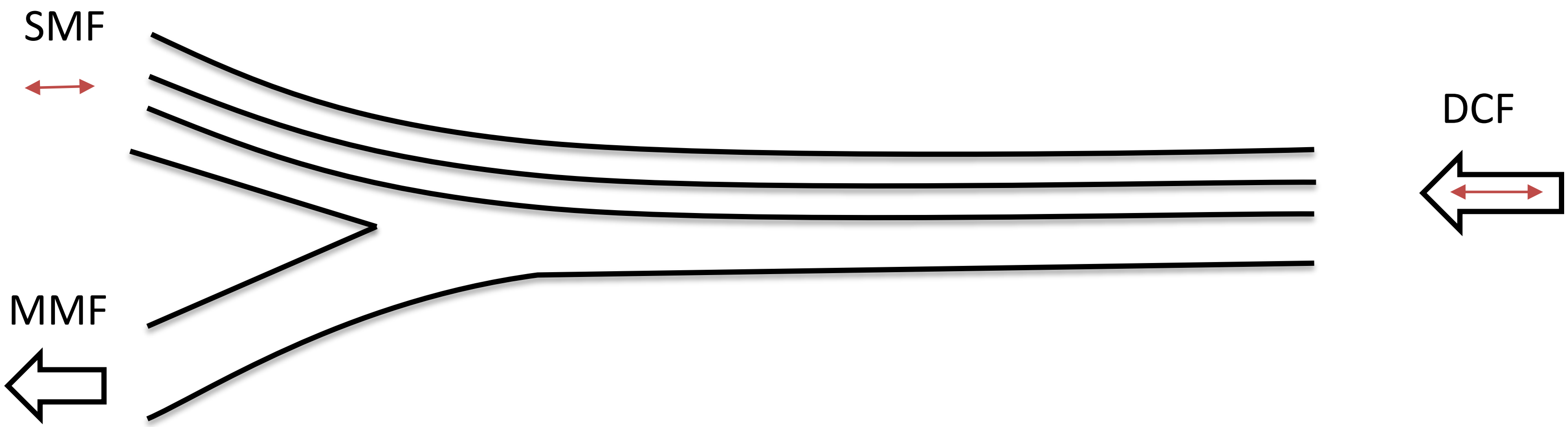


105 µm Multi Mode Fiber



9/105 µm Double Clad Fiber

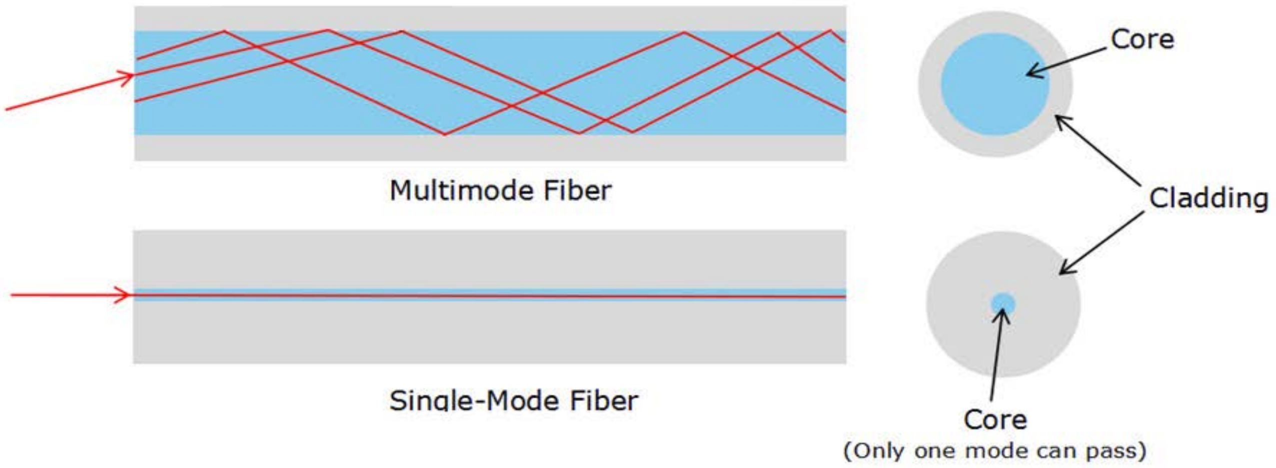
DCF Coupler



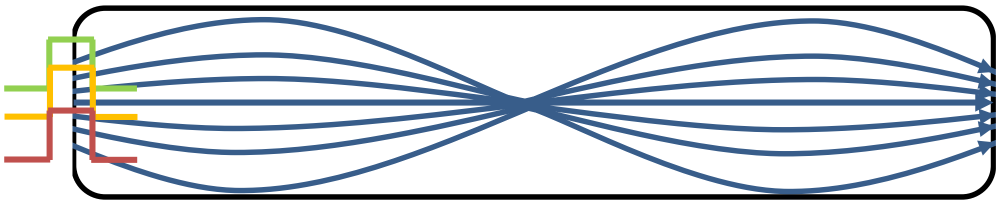
The DCF coupler separates the SM core signal from the MM inner cladding signal, enabling the separation of the transmitting signal from the received signal.

Modal Dispersion

Different modes arrive at the end of the fiber at differing times due to different path lengths



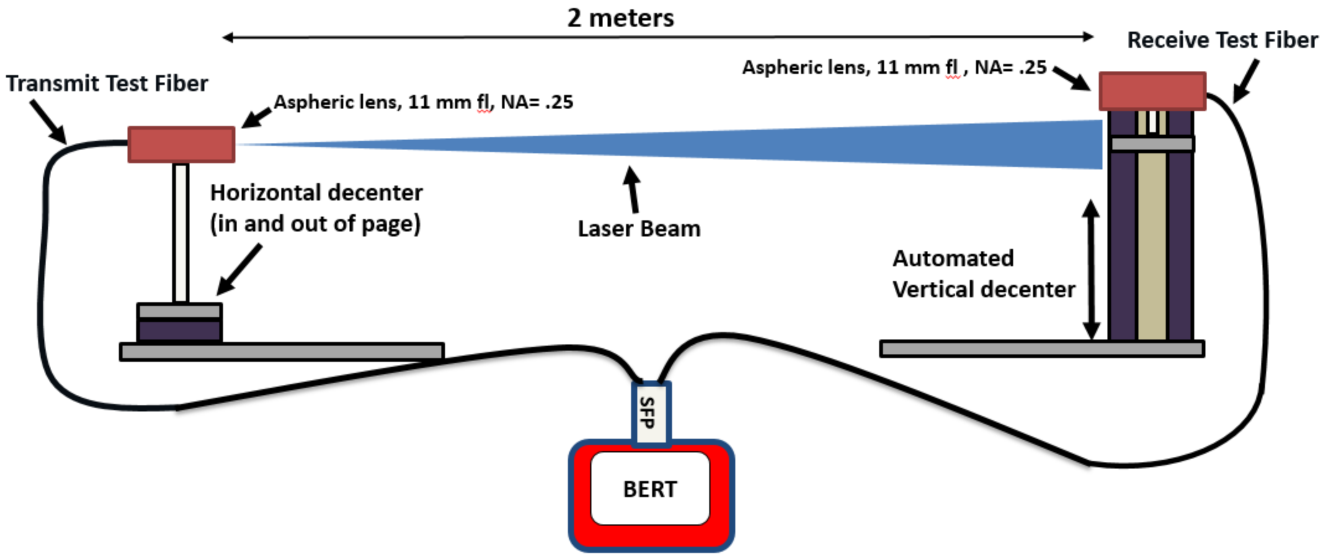
This differential mode delay (modal dispersion) causes increases in bit error rates



BER Experimental Setup

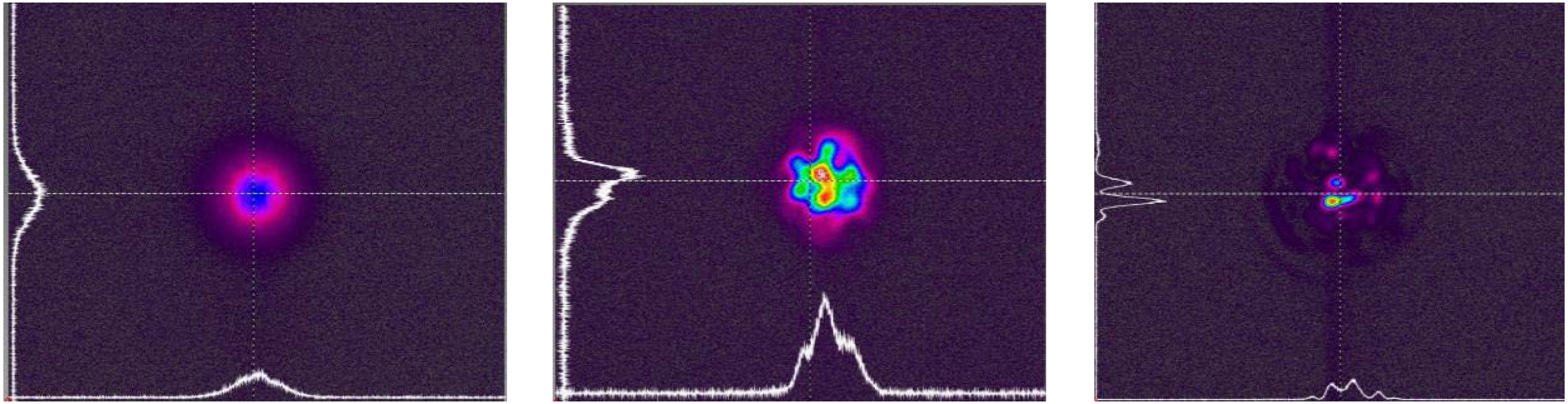
Methods

- Test combinations of single mode fibers (SMF), multi-mode fibers (MMF), and double clad fibers (DCF) in a FSOL setup at various divergence angles
- Tests will be run using vertical and horizontal misalignment



Fiber	Core Size (µm)	Graded or Step Index	Numerical Aperture
Single Mode Fiber (SMF)	9[a]	Graded	0.12[b]
Multimode Fiber (MMF)	105	Step	0.22
Double Clad Fiber (DCF)	9, 105	Step	0.12, 0.22
[a]Mode Field Diameter. [b]Not Given, Typical Reported			

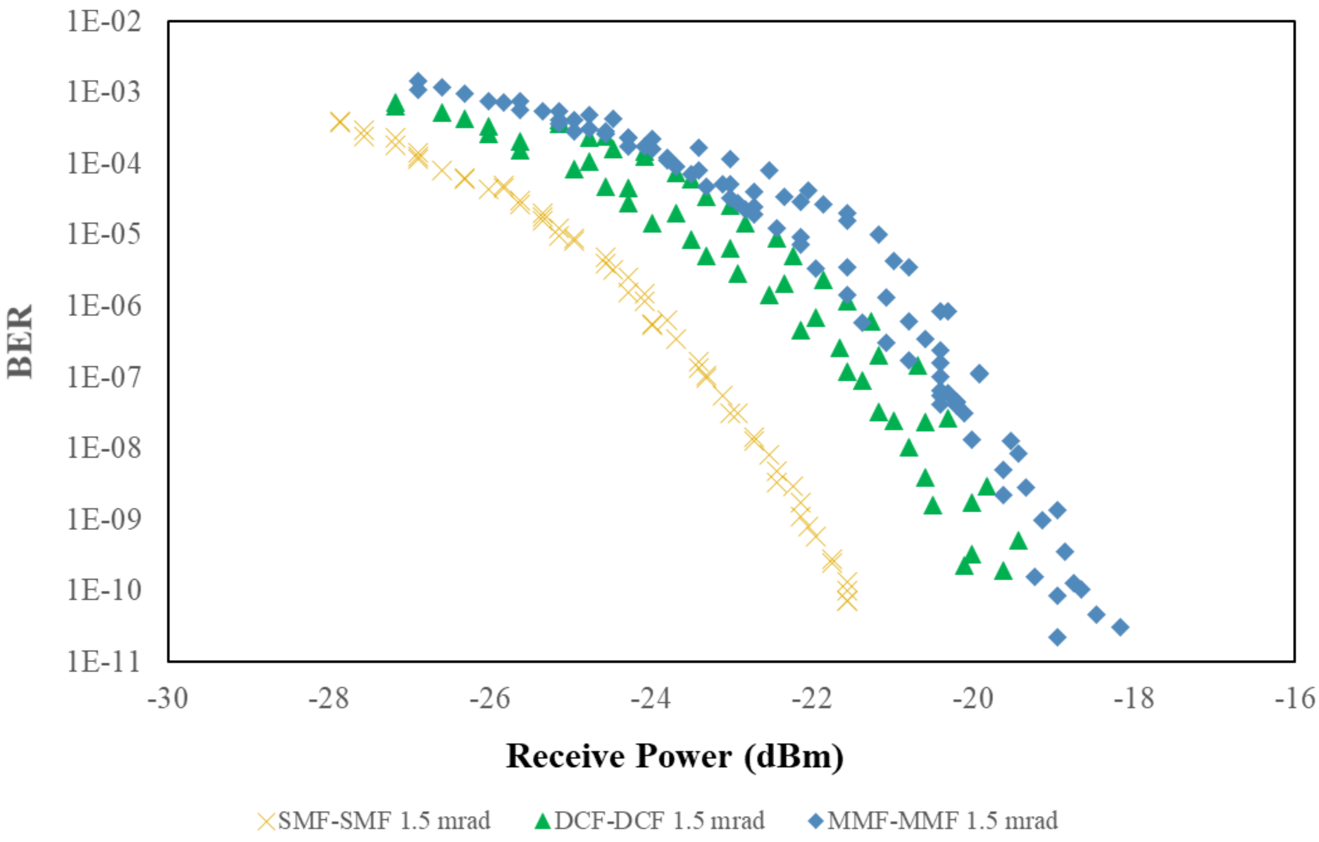
Transmit Fiber Profiles

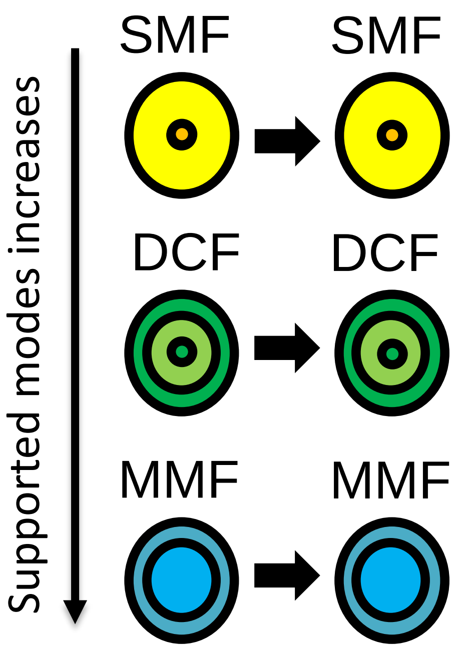


SMF DCF MMF

DCF as a transmitting fiber supports more modes than SMF, but fewer modes than MMF

BER vs Power Curve

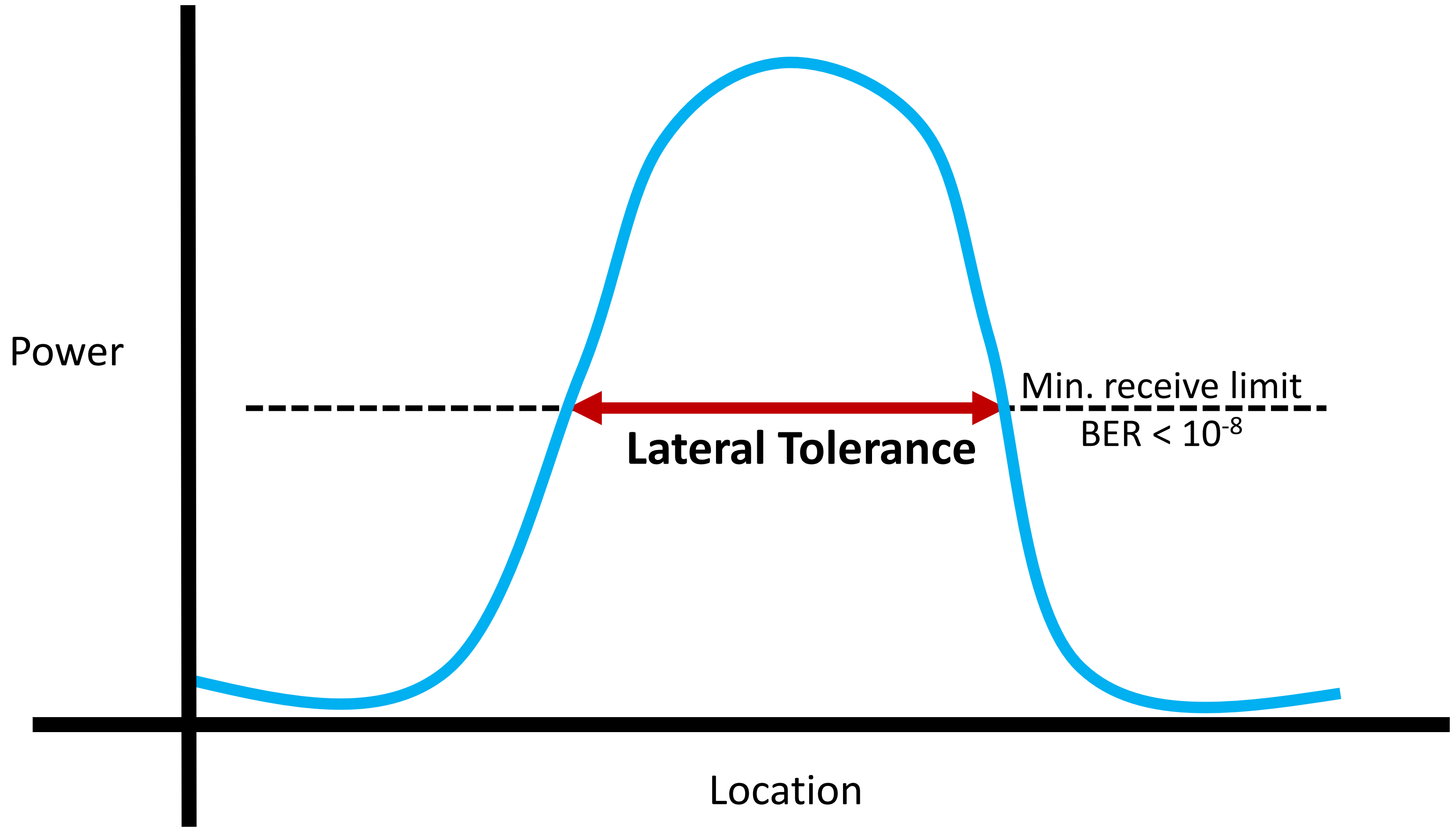




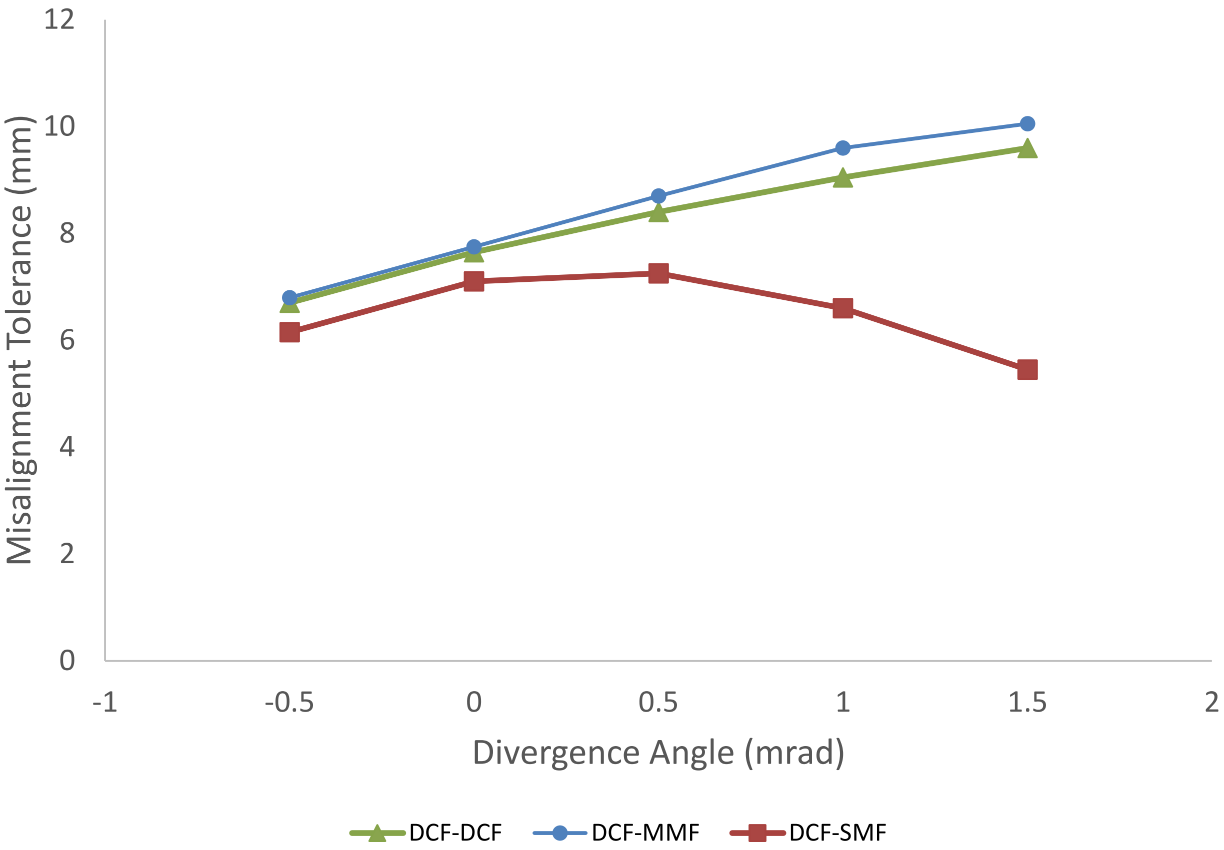
BER increases as number of modes supported by the system increases

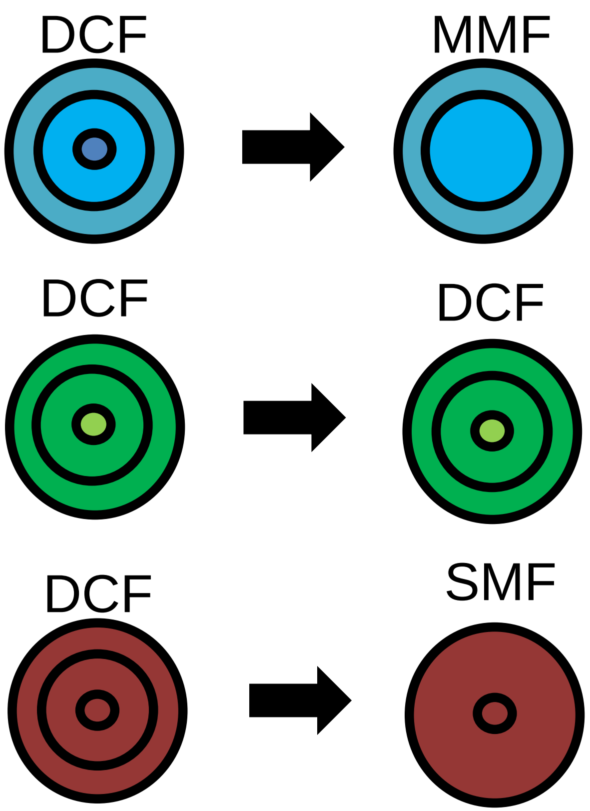
Definition of Misalignment Tolerance

Lateral misalignment tolerance (*Pointing Accuracy Tolerance*) = distance over which the BER is below 10^{-8}



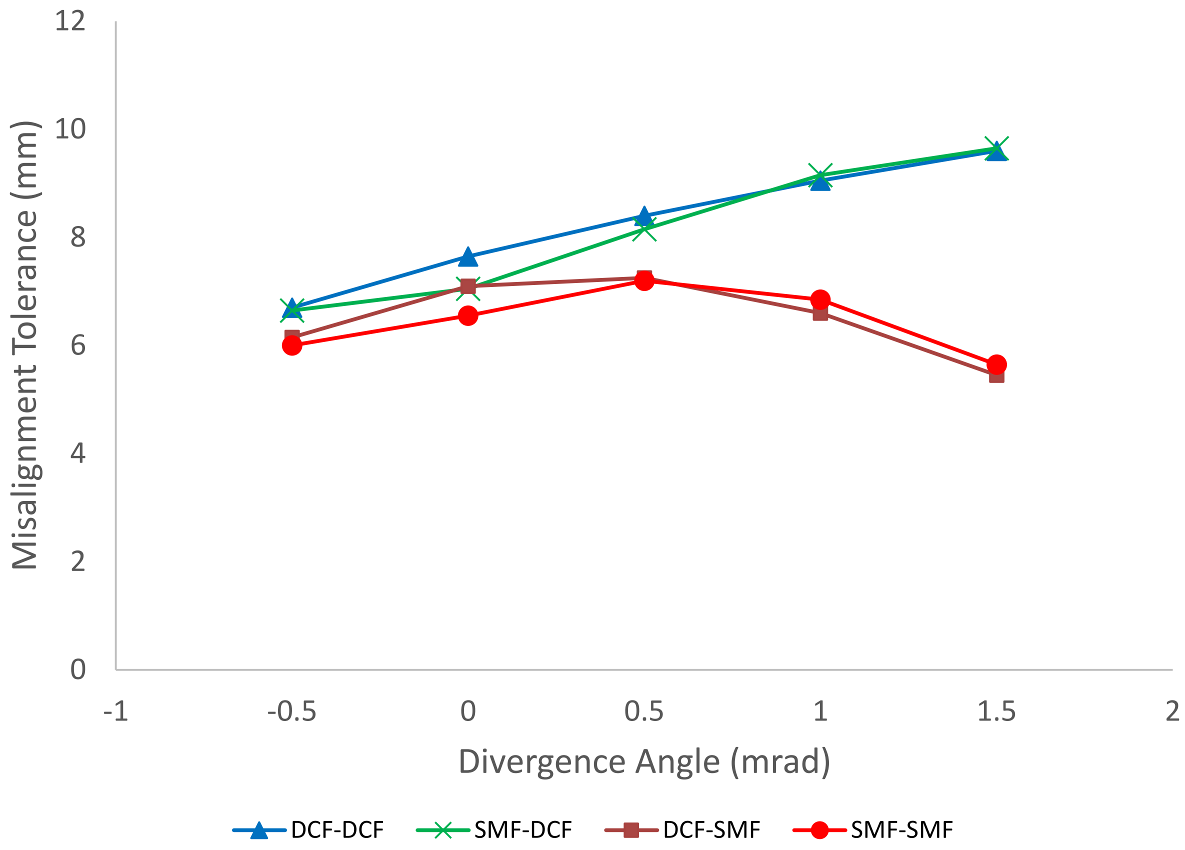
Receive Fiber Results

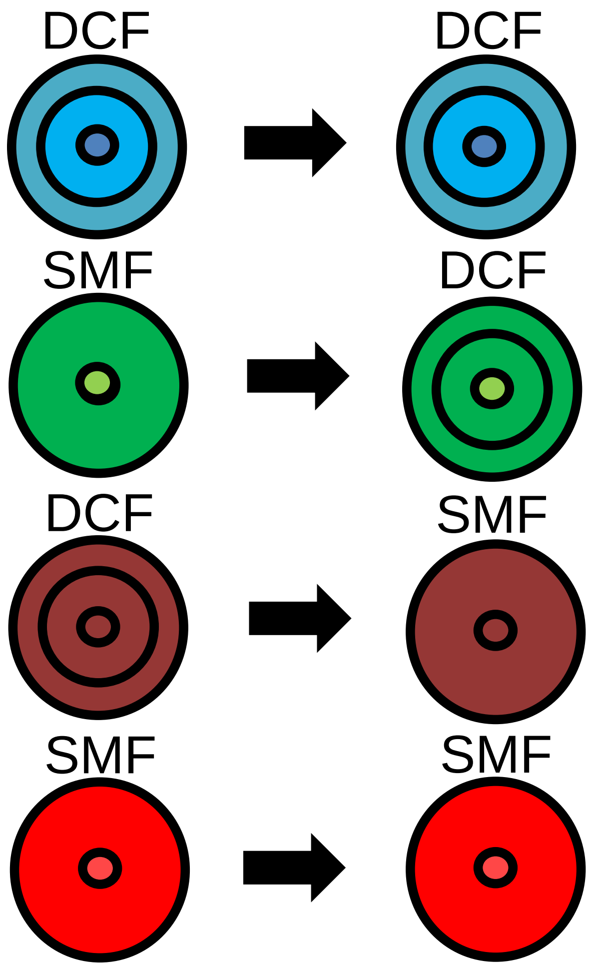




DCF and MMF perform similarly as a receiving fiber.

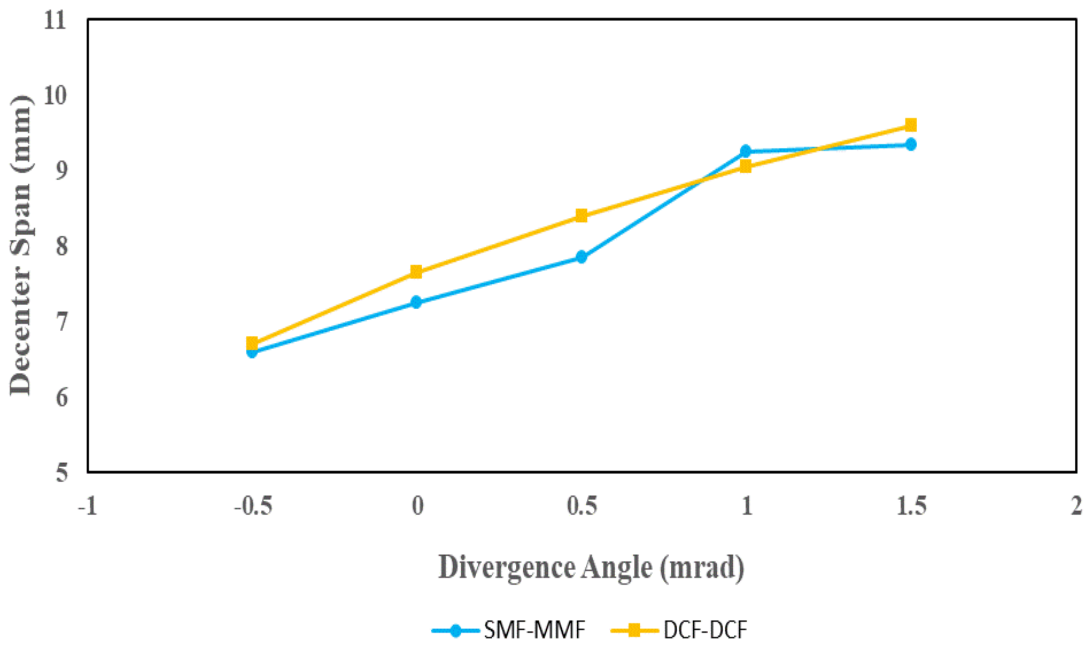
Transmit Fiber Results

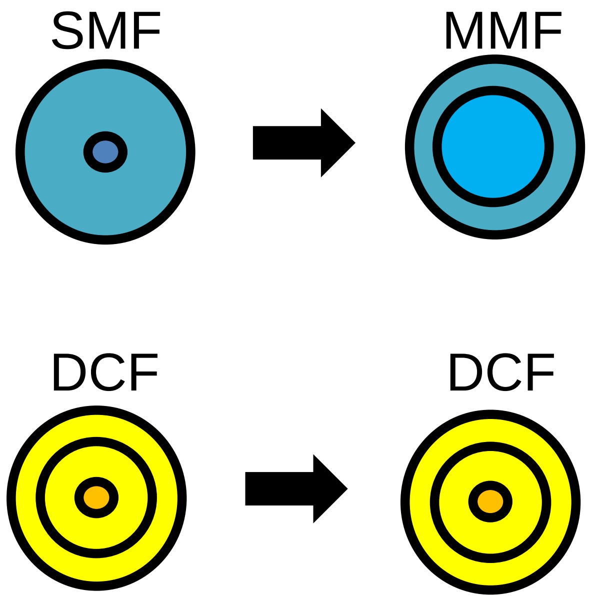




DCF and SMF have similar misalignment tolerance as transmitting fibers.

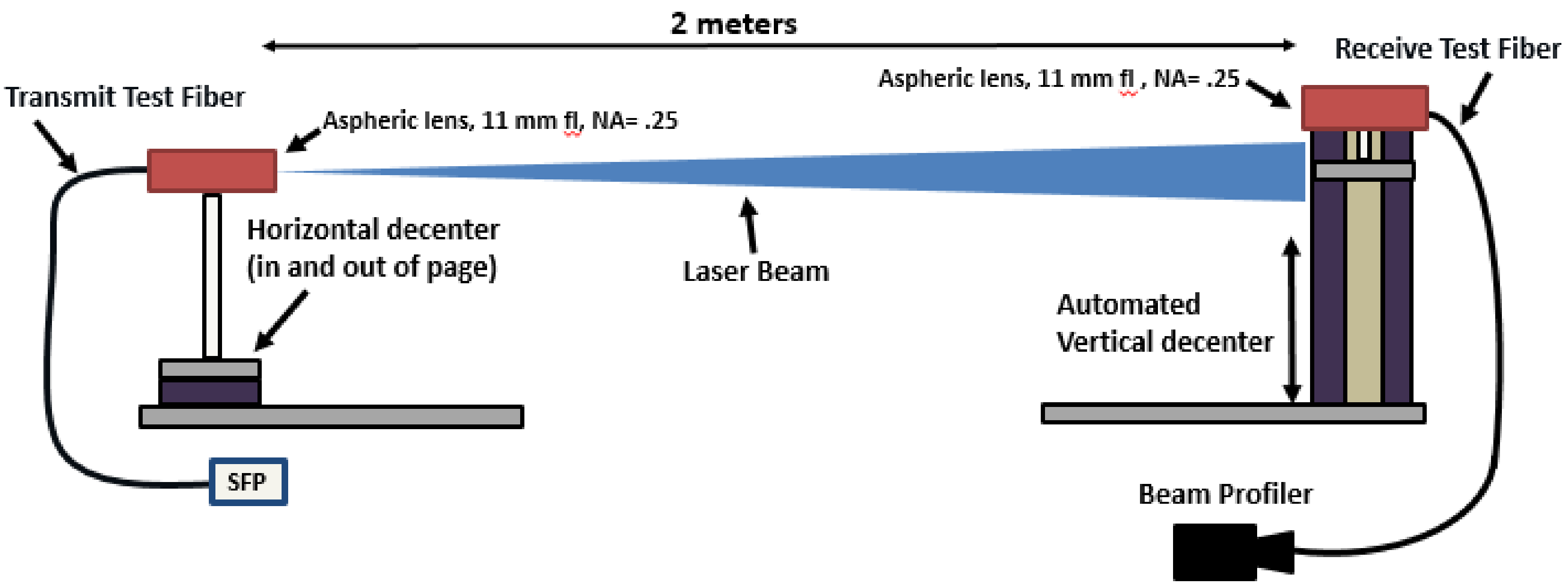
Transmit Fiber Results





DCF-DCF has a similar misalignment tolerance to SMF-MMF, a common solution, and enables a symmetric setup.

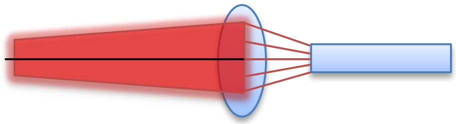
Launch Condition Experimental Setup

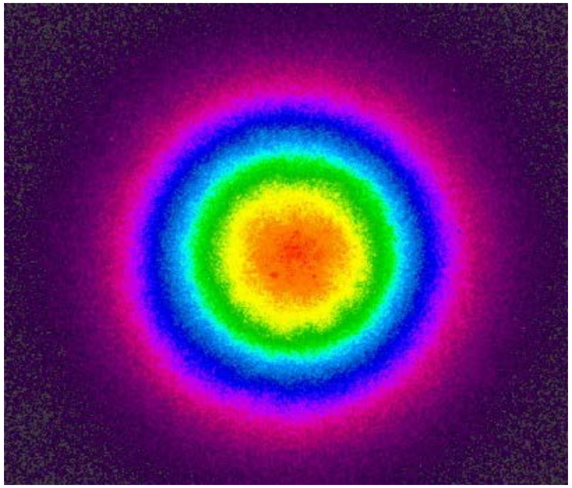


Beam Profiler was integrated into the setup to investigate the receive fiber launch conditions.

Single Mode Fiber Rx Profile

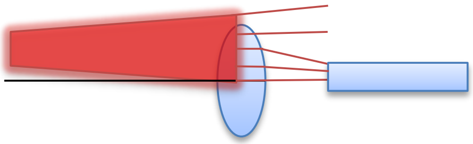
Centered

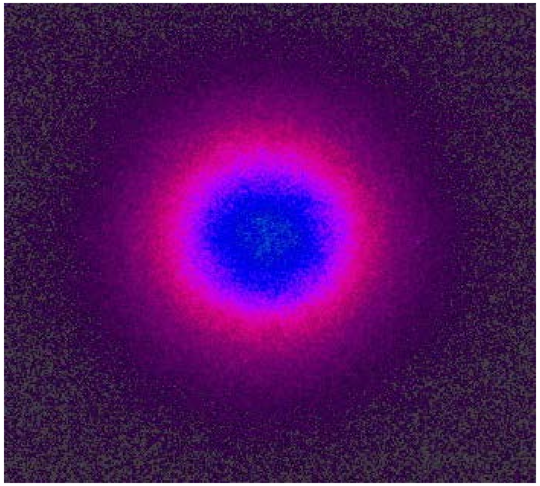




SMF – Centered

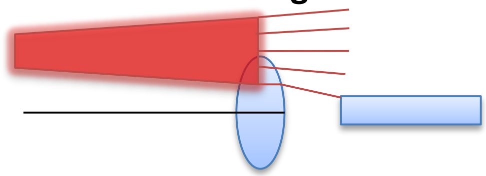
Slight misalignment

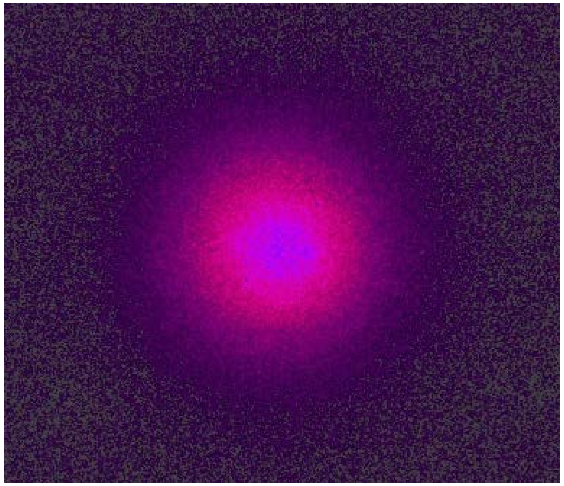




SMF – 2 mm decentered

Extreme misalignment



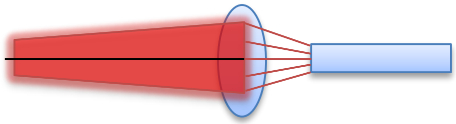


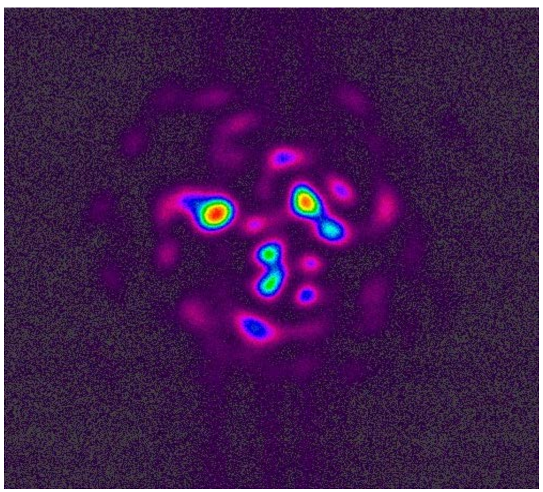
SMF – 4 mm decentered

Power profile doesn't change as misalignment increases only a decrease in power is observed

Multi-Mode Fiber Rx Profile

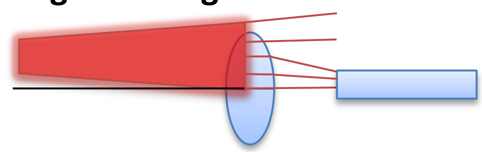
Centered

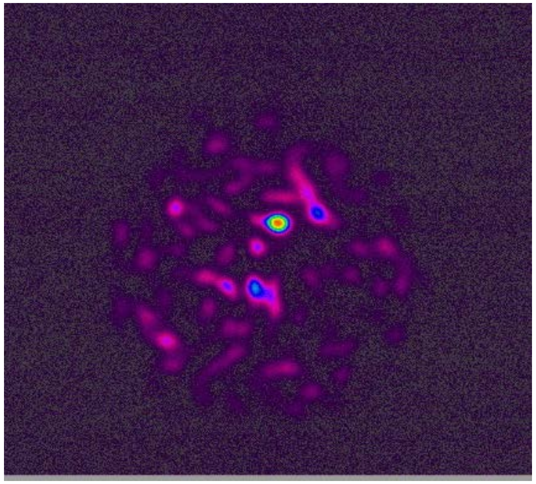




MMF – Centered

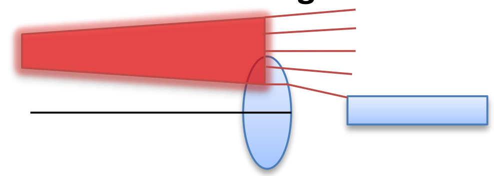
Slight misalignment

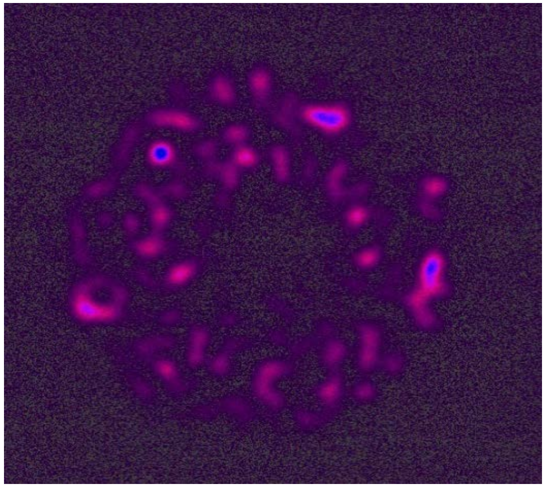




MMF – 3 mm decentered

Extreme misalignment





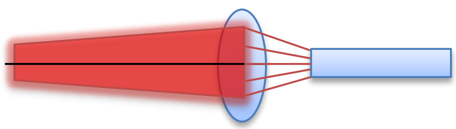
MMF – 5 mm decentered

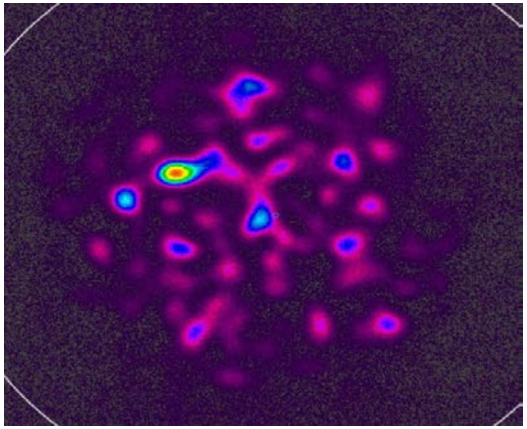
Rx Power: -28.73 dBm

Power moves outward radially as misalignment increases until skew rays dominate

Double Clad Fiber Rx Profile

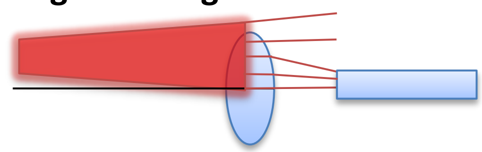
Centered

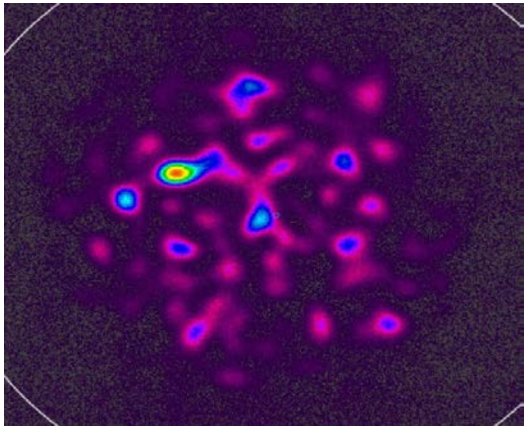




DCF – Centered

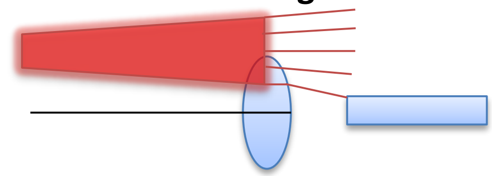
Slight misalignment

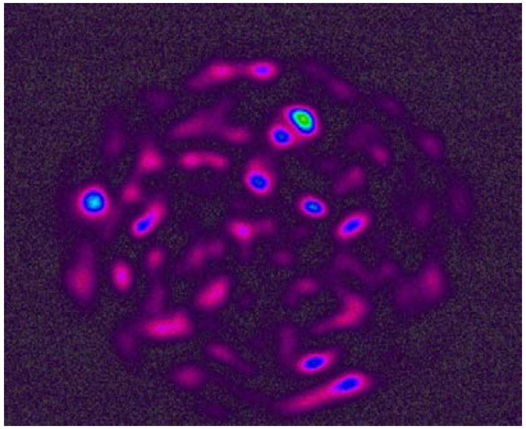




DCF – 3 mm decentered

Extreme misalignment





DCF – 5 mm decentered

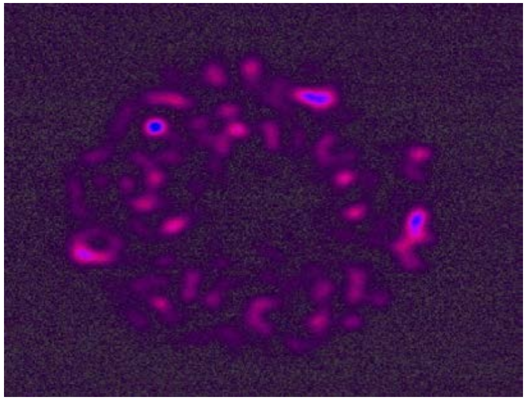
Rx Power: -26.75 dBm

No skew rays observed in the DCF for same conditions

Conclusion

Summary

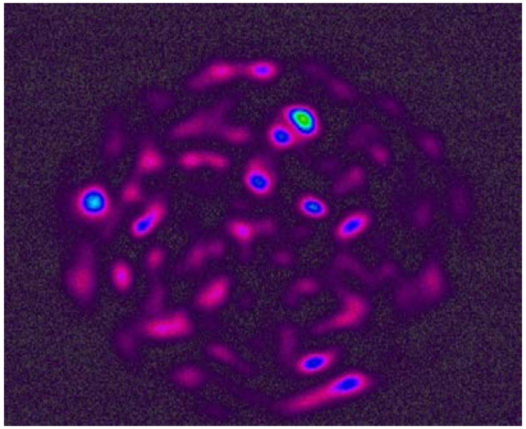
- Findings demonstrate the viability of a low-SWaP, bidirectional, symmetric FSOL utilizing DCF to transmit and receive.
- The BER misalignment performance of the DCF was comparable to the SMF while transmitting, and to the MMF while receiving.
- Skew rays were observed in the MMF, but not in the DCF, resulting in receive power losses.



MMF – 5 mm decentered

Future Work

- Quantify the effect of skew rays on the BER performance
- Determine if/when skew rays are present in DCF using higher transmit power
- Setup and test a symmetric duplex FSOL using DCF.



DCF – 5mm decentered

Acknowledgements

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