Free-Space Optical Communication using Modulating Retro-Reflector

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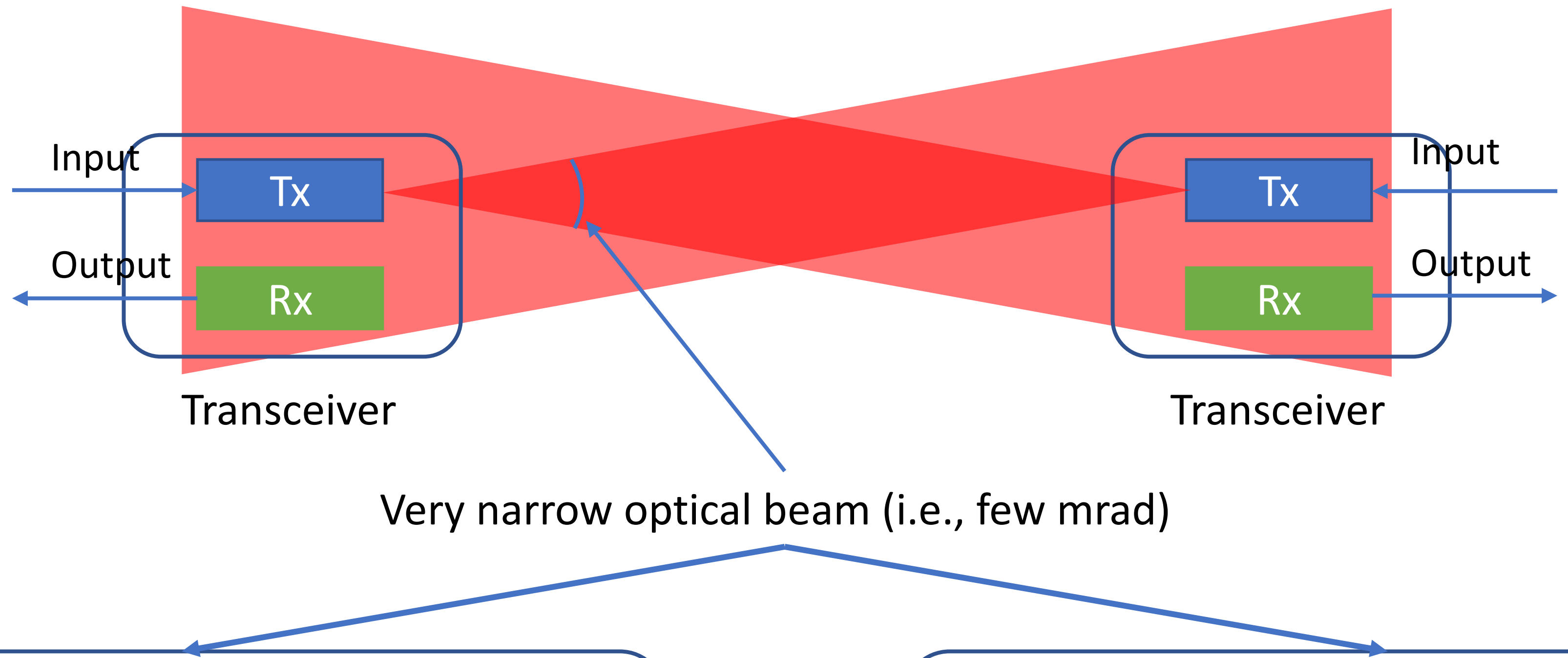
Outline

- Conventional Full Duplex FSO
- Modulating Retroreflectors (MRRs)
- Full Duplex MRR-FSO
- Research Proposals

Conventional Full Duplex FSO

- Two identical transceivers at both ends



Pros

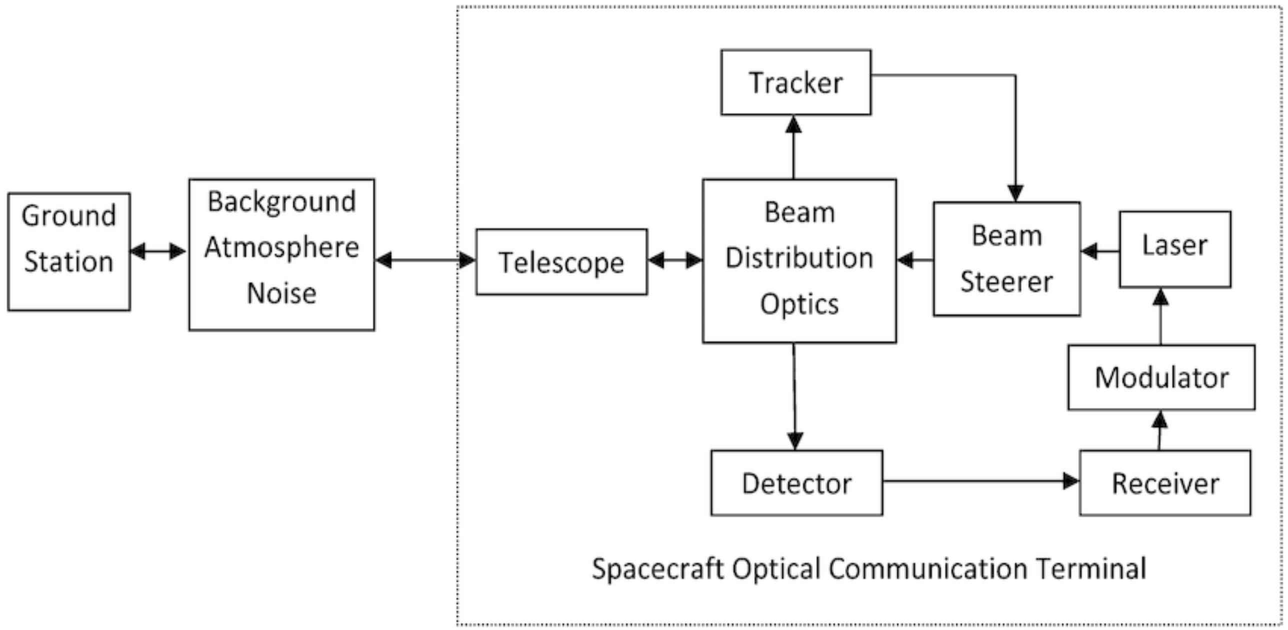
- Lower-power consumption
- Robust to electromagnetic interference
- Against eavesdropping

Cons

- Sophisticated pointing, acquisition, and tracking (PAT) systems

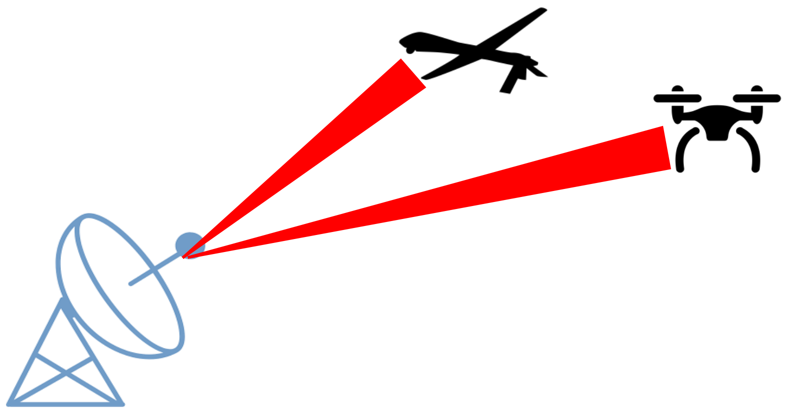
PAT Systems

- Avoid or reduce pointing error (e.g., due to platform vibration, the motion of mobile stations)
- 3 functions
  - Pointing the transmitter in the direction of the receiver
  - Acquiring the incoming light signal
  - Tracking the position of the remote terminal



Limitations

- Occupy the majority of power consumption, weight, and size of the transceiver
  - Not suitable for limited payload platforms like drones, UAVs

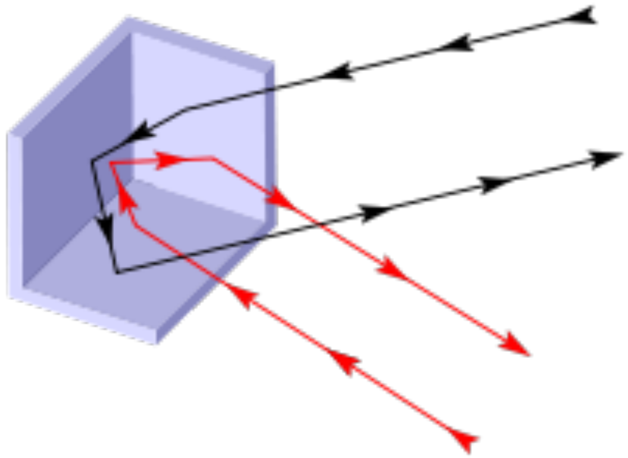


Drone, UAV-based FSO

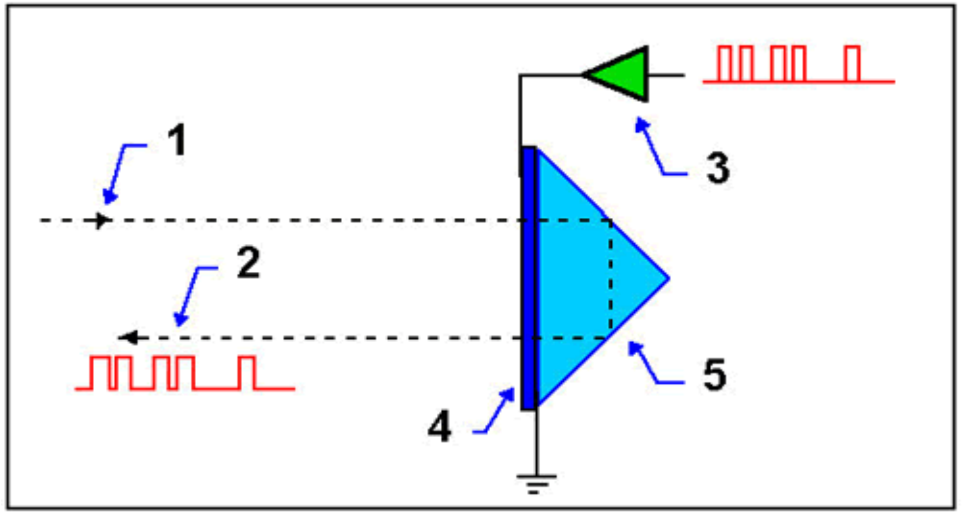
- Solutions: a passive transceiver that doesn't need a PAT system
  - A device that can
    - Modulate the incoming light beam
    - Reflect the modulated light beam back to the source

Modulating Retroreflectors (MRRs)

- A retroreflector is a device that reflects light back to its source
- A modulating retroreflector = a light modulator + a retroreflector



A retroreflector



A modulating retroreflector

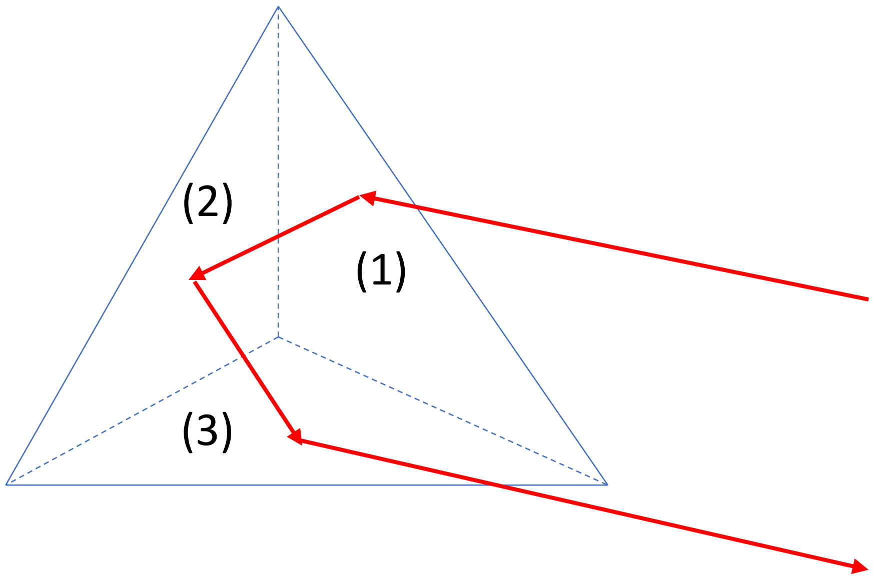
(1): incoming beam (2): retroreflected beam
(3): drive signal from the data source (4): light modulator
(5): retroreflector

Types

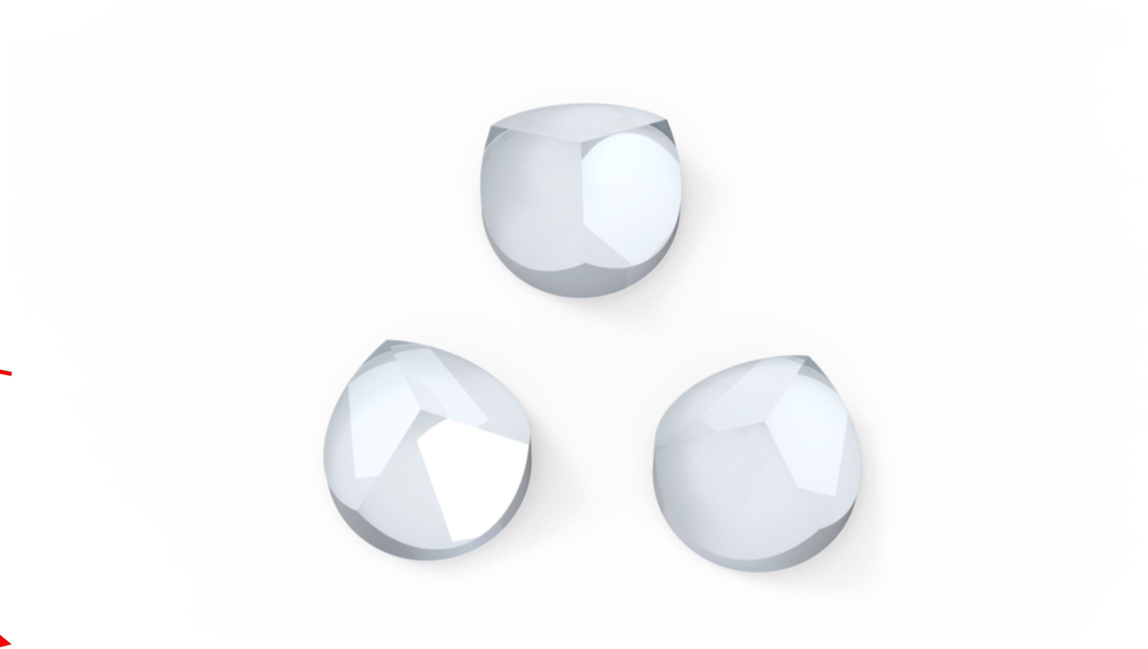
Retroreflectors	Light modulators
Corner cube reflectors (CCRs)	Liquid crystal (LC)
Cat's eye reflectors (CERs)	Micro-electromechanical system (MEMS)
	Multiple quantum well (MQW)
	Ferroelectric piezoelectric lead zirconate titanate (PZT) thin film

Corner Cube Reflectors (CCRs)

- Three mutually perpendicular, intersecting flat surfaces



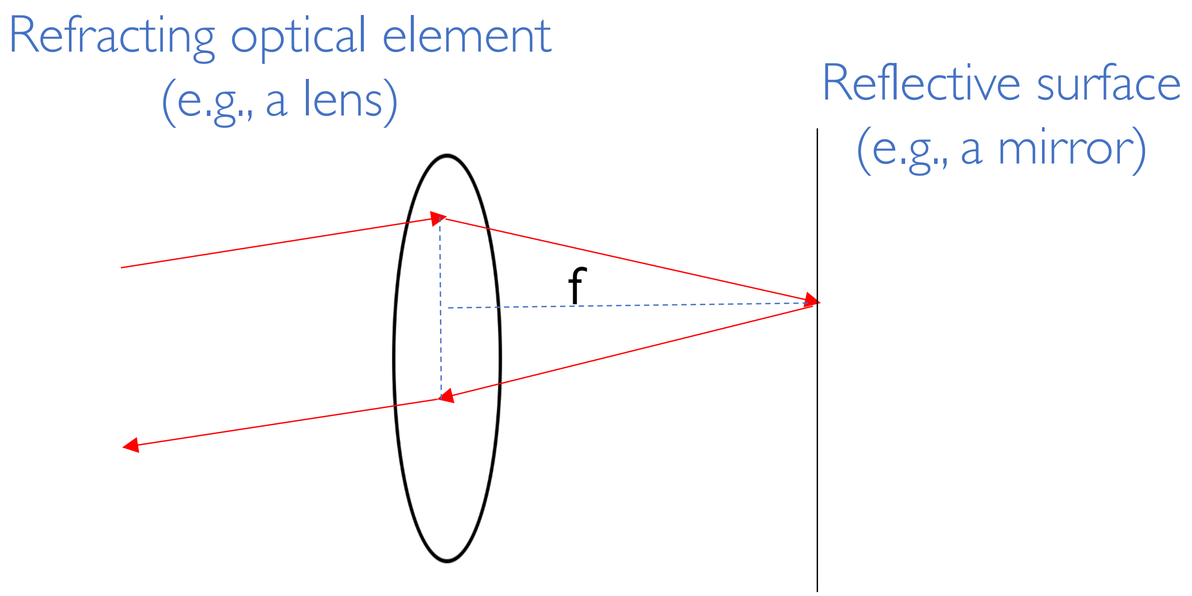
Working principle



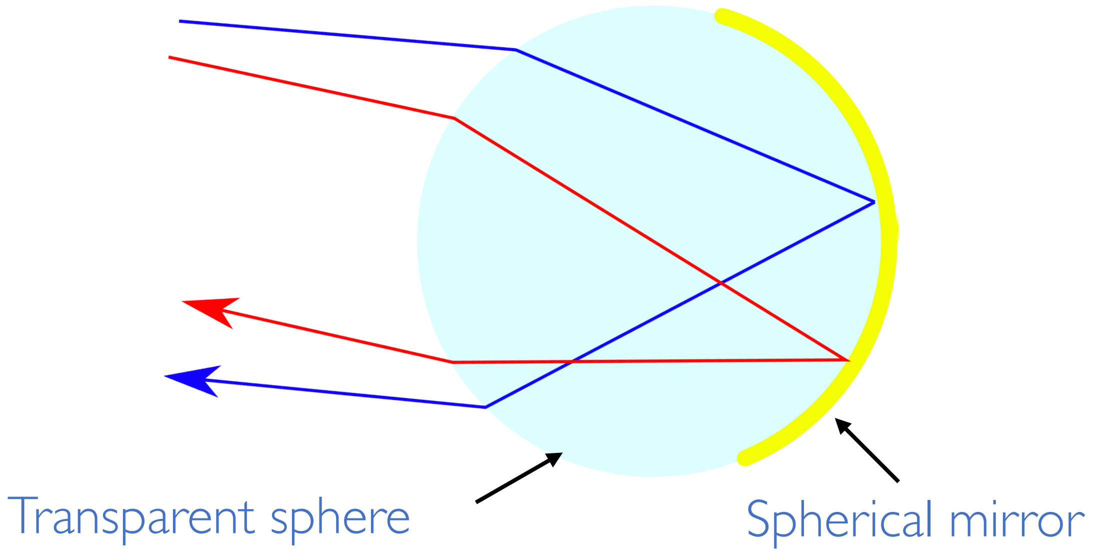
CCRs

Cat's Eye Reflectors (CERs)

➢ A refracting optical element with a reflective surface
  - The reflective surface is place at the focal surface of the refractive element



Working principle



CERs

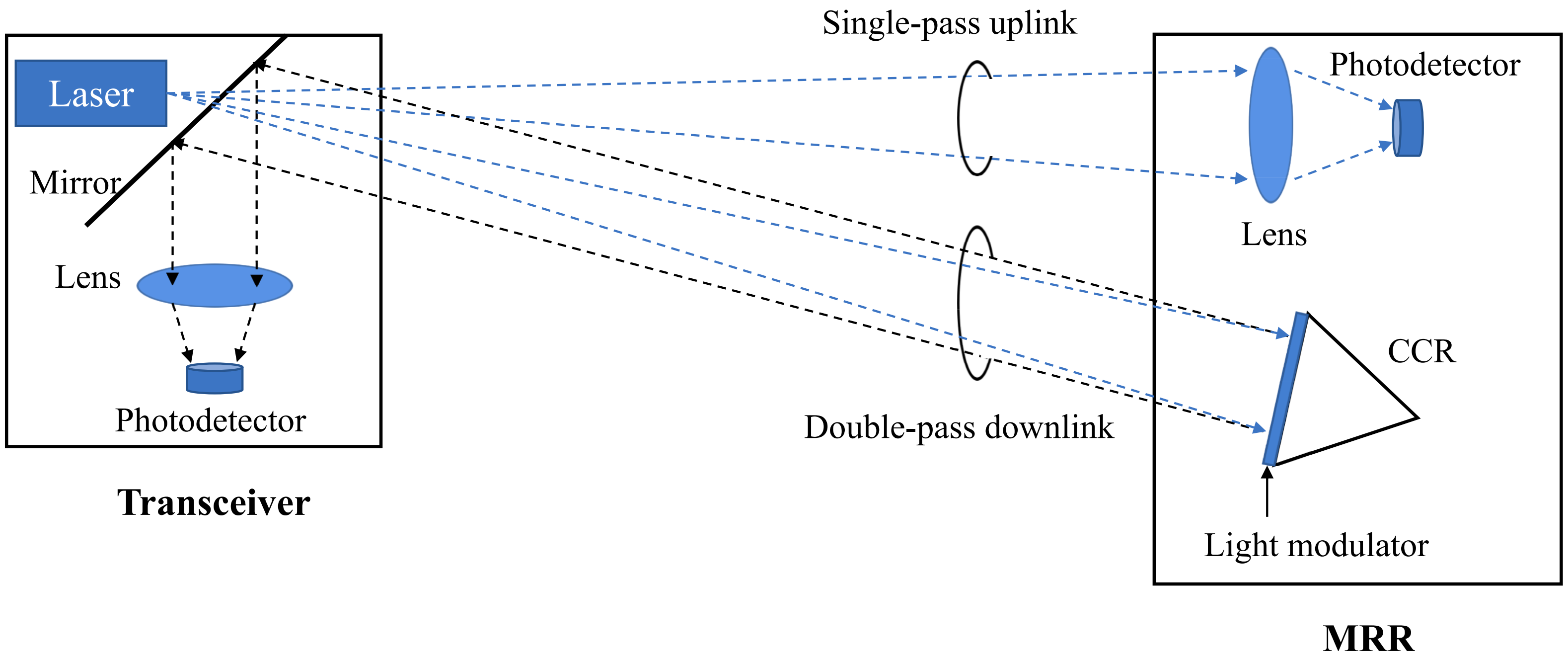
CCRs vs. CERs

	Range	**Data rate**	**Size & Complexity**
CCRs	Few km (usually less than 5km)	Few Mb/s (e.g., 5 Mb/s [1])	Small & low
CERs	Longer (e.g., up to 7 km [2])	Few tens Mb/s (e.g., 45 Mb/s [2])	Big & high

[1] P. G. Goetz et al., "Modulating retro-reflector lasercom systems for small unmanned vehicles," *IEEE J. Sel. Areas Commun.*, vol. 30, no. 5, pp. 986–992, Jun. 2012.

[2] W. S. Rabinovich, et al., "45 Mbps cat's eye modulating retro-reflectors," *Optical Engineering*, vol. 46, no. 10, 104001, 2007.

Full Duplex MRR-FSO



- **Uplink**: conventional FSO link
- **Downlink**: double-pass FSO link
  - Incoming beam (i.e., forward channel) from the transceiver + reflected beam (i.e., backward channel) from the MRR
  - Modeled as the product of two (possibly correlated) random variables

Research on MRR-FSO

	References	Notes
Theory	1. A. M. Scott, K. D. Ridley, "Calculations of bit error rates for retroreflective laser communications systems in the presence of atmospheric turbulence," *Proc. SPIE*, vol. 5614, pp. 31-42, Dec. 2004.	Bit-error rate, outage probability, and average capacity • Forward and backward channels are independent gamma-gamma (G-G) RVs.
	2. X. Li et al. "Probability density function of turbulence fading in MRR free space optical link and its applications in MRR free space optical communications," *IET Communications*, vol. 11, no. 16, pp. 2476-2481, Nov. 2017.	
	3. G. Yang et al. "Performance analysis of full duplex modulating retro-reflector free-space optical communications over single and double gamma-gamma fading channels," *IEEE Trans. Commun.*, vol. 66, no. 8, pp. 3597-3609, Mar. 2018.	Forward and backward channels are correlated G-G RVs. • Approximately model as an $\alpha-\mu$ RV
Experiment	1. P. G. Goetz et al., "Multiple quantum well based modulating retroreflectors for inter- and intra-spacecraft communication," *Proc. SPIE*, vol. 6308, p. 63080A, Aug. 2006. 2. P. G. Goetz et al., "Modulating retro-reflector lasercom systems at the naval research laboratory," in *Proc. IEEE Military Commun. Conf.*, pp. 1601–1606, 2010 3. P. G. Goetz et al., "Modulating retro-reflector lasercom systems for small unmanned vehicles," *IEEE J. Sel. Areas Commun.*, vol. 30, no. 5, pp. 986–992, Jun. 2012. 4. B. Neuner, III, and B. M. Pascoguin, "Wavelength optimization via retroreflection for underwater free-space optical communication," *Proc. SPIE*, vol. 9467, p. 946724, May 2015	Illustrate the feasibility of MRR-FSO systems

Research Proposals

Statistical model of the double-pass channel

$\alpha - \mu$ approximation

- Parameters of the approximating $\alpha - \mu$ RV are obtained numerically → does not give much insight into the effect of turbulence and channel correlation on the system performance

Alternative mathematical models

- Approximated by a G-G RV whose parameters can be obtained in closed-form
- Exact statistical distribution (already known for the product of two independent G-G RVs)

Effect of pointing error

- Almost inevitable due to the mobile's hovering and vibration.
- once pointing error happens in the forward link, the backward one should also be suffered from it

THANK YOU FOR YOUR LISTENING