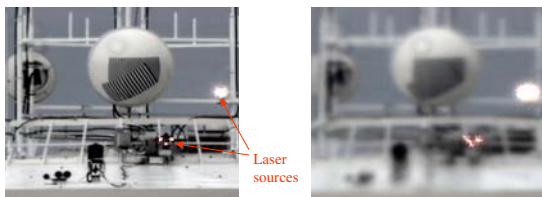


Wavefront Distortions from Atmospheric Turbulence

A light beam propagating through the atmosphere is subject to wavefront distortions by atmospheric turbulence due to air-density fluctuations; degradation of image quality or spreading of laser beams occurs.

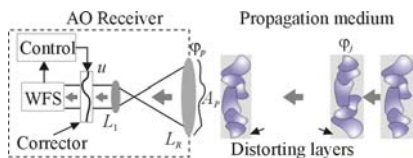


Imaging through 2.3km atmosphere under weak and strong turbulence conditions

Conventional Adaptive Optics

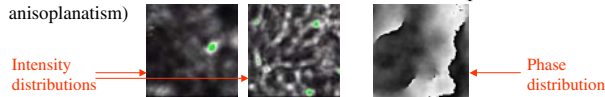
Compensation of atmospheric effects by

- measurement of wavefront slopes with a wavefront sensor (WFS)
- wavefront reconstruction
- phase conjugation with a wavefront corrector (e.g. a deformable mirror)



Problem: Doesn't work for many applications, esp. in case of an extended horizontal propagation path (e.g. free-space laser communication, horizontal imaging, or directed energy applications)

- Diffraction transform phase distortions into intensity fluctuations (scintillations) ⇒ wavefront slope measurements difficult
- Branch points and phase cuts in the wavefront are challenging for phase conjugation with a deformable mirror
- Wavefront measurements are difficult for extended beacons (partial coherence, anisoplanatism)



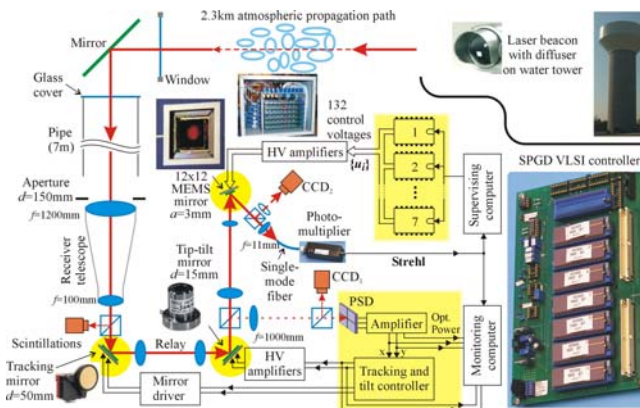
Stochastic Parallel Gradient Descent (SPGD) Adaptive Optics

- Wavefront correction without measuring the wavefront by blind optimization of a system performance metric J
- Definition of J depends on application (e.g. image quality, laser communication signal strength, irradiance at a target, etc.)
- Can work under strong scintillation conditions
- SPGD controller applies small perturbation signals $\{\delta u_j\}$ (stochastic with Bernoullie probability distribution) in parallel to all control channels and measures the resulting metric change δJ .
- Update rule for the control voltages u_j at iteration $(n+1)$:

$$u_j^{(n+1)} = u_j^{(n)} - \gamma \delta J^{(n)} \delta u_j$$

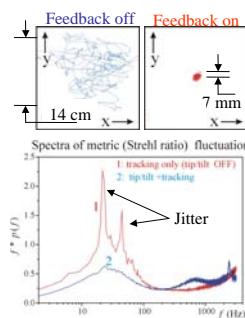
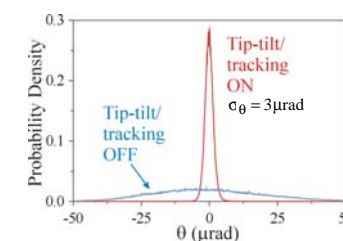
SPGD Adaptive Optics System Set-up

- High-resolution wavefront control with 132-control-channels MEMS mirror (piston type actuation) in combination with independently controlled tracking and fast tip/tilt correction system using piezoelectric actuated mirrors [1,2]
- VLSI SPGD controller: scalable analog VLSI system allows high iteration rates ($>10,000/s$) avoiding time-consuming D/A conversions [3]
- System installed at ARL's atmospheric laser optics testbed with 2.3km atmospheric propagation path [2,4]
- Uses laser sources with diffuser or multi-mode fiber coupled source as beacon (model for partial coherent beacon)



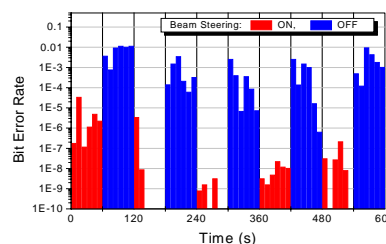
Mitigation of Atmospheric Distortions: Experimental Results

Compensation of tip/tilt distortions only:

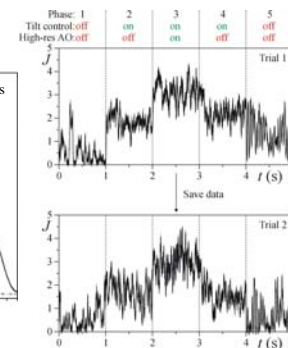
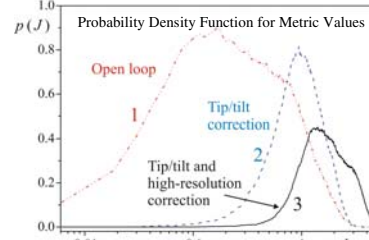


Beam steering applied to free-space optical communication over 2.3km

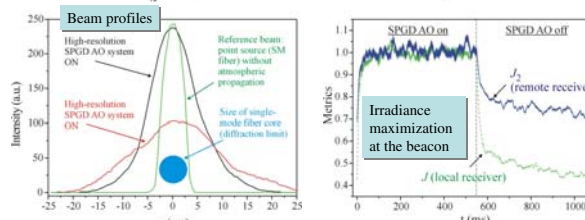
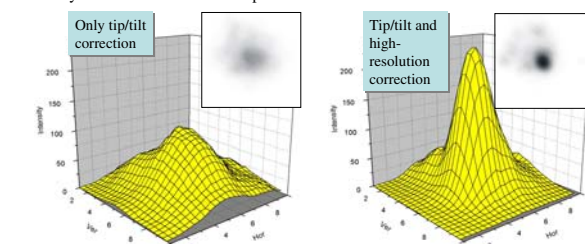
Optical power $P = 60\mu W$ from single-mode fiber source provides the same BER as 10mW laser diode with diffuser



Wavefront correction with low- and high-resolution systems:



Intensity distributions in the focal plane:



References

- [1] "Dynamic wave-front distortion compensation with a 134-control-channel submillisecond adaptive system," T. Weyrauch and M. A. Vorontsov, *Opt. Lett.* **27**, 751-753 (2002).
- [2] "Mitigation of atmospheric-turbulence effects over 2.4-km near-horizontal propagation path with 134 control-channel MEMS/VLSI adaptive transceiver system," T. Weyrauch and M. A. Vorontsov, *Proc. SPIE* **5162**, 1-13 (2003).
- [3] "Analog VLSI parallel stochastic optimization for adaptive optics," R. T. Edwards, M. Cohen, G. Cauwenberghs, M. Vorontsov, G. W. Carhart, in *Learning on Silicon*, G. Cauwenberghs and M. A. Bayoumi, eds. (Kluwer, Boston, 1999), pp. 359-382.
- [4] "Atmospheric laser optics testbed (A_LOT): atmospheric propagation characterization, beam control, and imaging results," M. A. Vorontsov, G. W. Carhart, M. Banta, T. Weyrauch, J. Gowens II, and J. C. Carrano, *Proc. SPIE* **5162**, 37-48 (2003).

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