Turbulence mitigation without AO

How can we compensate turbulence with an MPLC? A Focus on pointing error

David ALLIOUX
Product manager
Cailabs, a deep-tech company
Develop, manufacture & sell innovative optical components

Unique technology (MPLC) and expertise in beam shaping

45 employees (18 PhDs)

19 patent families

16.6 M€ ++ raised

References:

SAFRAN  tellabs®  KDDI  NOKIA  Amplitude
Placing Cailabs
Tailored beam shaping is photonics’ next disruption enabler

Beyond the usual properties …

Power  Wavelength  Polarization  Phase

… we control the shape of the light

Multi-Mode Fiber
Leadership in complex beam shaping
Telecom and beyond

MPLC technology

- **CANUNDA**
  - Improve laser material processing

- **AROONA**
  - Future-proof fiber infrastructure of LANs

- **PROTEUS**
  - Invent the optical networks of the future

- **TILBA**
  - Ensure the reliability of LaserCom

Cailabs inside
- Integrate tailored optical solutions

References:
- **Amplitude**
- **tellabs**
- **KDDI**
- **NEC**
- **SAFRAN**
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References:
- NEC
- KDDI
- NEC
- Safran
How do we operate LaserCom? Improving multiple sides of optical links

**Space - Space**
Compensate pointing error

**Space - Ground**
Mitigate atmospheric turbulence

**Ground - Space**
Combine powerful sources for feeder links
How do we operate LaserCom?
Improving multiple sides of optical links

- **Space - Space**
  - Compensate pointing error

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  - Mitigate atmospheric turbulence

- **Ground - Space**
  - Combine powerful sources for feeder links
MPLC for LaserCom

State-of-the-art beam shaping and spatial multiplexing
Multi-Plane Light Conversion (MPLC)
Take-home message

- Derived from quantum optics at French Kastler Brossel Lab
- Complex beam shaping through succession of spatial phase profiles
- Passive optical beam shaping with no intrinsic loss nor moving elements

Morizur & al. JOSA A 2010; US PATENT
Multi-Plane Light Conversion
A spatial multiplexer in a small box
Multi-Plane Light Conversion
Flexible and versatile beam shaping

Mono-mode transform

Multi-mode transform
Mitigating turbulence with an MPLC

How to do adaptative optics with a passive component?
Space-to-ground: mitigating turbulence at reception
Atmospheric turbulence deteriorates LaserCom links

Effects of turbulences:
- Beam spreading – Defocusing
- Beam wander - Tilt
- Scintillation

Impact on LaserCom:
- Less persistent link (milliseconds fades)
- Lower throughput (higher BER)
Space-to-ground: mitigating turbulence at reception
Existing solutions: adaptative optics

Drawbacks:
- Are expensive
- Need feedback loop
- Display moving elements

Mitigating turbulence and pointing errors
A similar function with a different approach

**ADAPTATIVE OPTICS**
- Cartesian basis
  \[ \sum A(x, y)e^{i\psi(x, y)} \]
- Deformable mirrors

**SPATIAL DEMUX**
- Mode basis
  \[ \sum \alpha_{n,m}HG_{n,m}e^{i\psi_{n,m}} \]
- MPLC

**Example Equation**
\[ x \sum A(x, y)e^{i\psi(x, y)} \]

**Example Image**
- Diagram of ADAPTATIVE OPTICS and SPATIAL DEMUX with examples of deformable mirrors and MPLC components.
Space-to-ground: mitigating turbulence at reception
Decomposing the incident beam

- Collect more incident light
- Modal diversity
- WDM compatible
- Passive component

By Cailabs
Space-to-ground: mitigating turbulence at reception
A photonic integrated chip to recombine the outputs

➢ On chip optical recombining
➢ One single SMF output
➢ Plug and play optical receiver to mitigate atmospheric turbulence
Space-to-ground: mitigating turbulence at reception
Experimental results: x5 increased reception

LEO-to-ground communication

✓ **10 Gb/s over 400 km**
Simulation of LEO-to-ground link

✓ **Up to x5 (+7 dB) coupling efficiency**
in 5% worst cases of strong turbulence

✓ **Passive optical component**
No use moving parts

References:
Playing with the modes

Focus on the pointing error
Mitigating pointing errors
Hypothesis

Input

• Super-Gaussian beam (3rd order)

• 25 mm pupils

• Plane phase

• Free space input
Results with HG modes
Small beam waist

MPLC with 2.5 µm waist

MPLC with 3.75 µm waist
Results with HG modes
Large waist

MPLC with 5 µm waist

MPLC with 7.5 µm waist
Results with HG modes
Finding the good compromise

2 possible compromise:

• Large angle compensation with moderate collection efficiency:
  **Blue** and **orange** curve

• Low angle compensation with very high efficiency:
  **Green**, **red** and **violet** curves
Built a custom MPLC

An SVD approach
Optimal approach
What is it?

Problem:
- >200 PSFs
  - Collect them with an MPLC with 3 to 45 modes.

What is the best collection mode bases?
1D depointing: +/- 72 arcsec
Optimal bases

Intensity mode profiles

>90% collection
1D depointing: +/- 180 arcsec
Optimal bases

Intensity mode profiles

>90% collection
2D depointing: +/-36 arcsec
Select the best modes for pointing error compensation

Modes close to LG modes

>90% collection
Conclusion and Roadmap

Improves Lasercom at the reception:
- Pointing errors
- Turbulence mitigation

Improves Lasercom at the emission:
- Coherent combining
- Potential for precompensation

Roadmap

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019</td>
<td>Ground station Field test</td>
</tr>
<tr>
<td></td>
<td>Silicon Photonic Chip</td>
</tr>
<tr>
<td>2020</td>
<td>Commercial Turbulence mitigation</td>
</tr>
<tr>
<td></td>
<td>Aircraft LaserCom Network</td>
</tr>
<tr>
<td>&gt;2024</td>
<td></td>
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Thank you for your attention

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