First Endless Optical Polarization and Phase Tracker

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Application areas for simultaneous polarization & phase control/tracking

- If phase difference of controlled polarization and its orthogonal is also controlled, then the whole normalized Stokes vector space will be stabilized.

- For the BB84 protocol of quantum communication, 0°/90° and 45°/-45° linear polarizations must be preserved.

- Phased arrays require polarization control & absolute phase control in each tap or channel.
Control principle with 3 degrees-of-freedom

Not only 1 polarization $C_1$ is to be transformed into $S_1$ but simulataneously a 2nd, „semi-orthogonal“ polarization $C_2$ into $S_2$.

To achieve this, the phase shift between $C_1$ and its orthogonal polarization $-C_1$ must be controlled in addition to the polarization transformation of $C_1$.

Solution: By rotation about $R$, $C_1$ is turned via $a$ into $S_1$ and $C_2$ via $a'$ into $S_2$.

Conventional, not sufficient: $b...e$ also turn $C_1$ into $S_1$, but $C_2$ is transformed into $P_b...P_e$, hence anywhere on the $S_2$-$S_3$ great circle.
Setup for polarization & phase control (3 degrees-of-freedom)

- Lasers: $f$ [THz]
  - 193.8: 0° (control)
  - 194.0: 45° (control)
  - 193.9: variable (probe)

- Polarization scrambler Novoptel EPS1000
- LiNbO$_3$ polarization transformer
- FPGA-based controller
- PBS + photodiodes
- DEMUX
- Polarimeter

- 2 „semi-orthogonal“ control signals required
- 2 feedback signals: Signal intensities behind 2 polarizers

![Graphs]

- Feedback signal without control
- Feedback signal with control switched on
Complementary cumulative distribution function $1-F(\text{RIE})$ of relative intensity error ($\text{RIE}$) for different scrambling speeds.

- No light
- $\text{RIE0°}$, 0.1 krad/s
- $\text{RIE0°}$, 20 krad/s
- $\text{RIE45°}$, 0.1 krad/s
- $\text{RIE45°}$, 20 krad/s

Polarization and phase tracking at 0.1 krad/s and 20 krad/s.

$\text{RIE45°}$, 0.1 krad/s, 45° control signal polarization intentionally misaligned.

50 MS/s polarimeter.
Poincaré sphere displays of probe signal, set to 6 polarizations on normalized Stokes space axes

Conventional polarization control

Polarization & phase control, 0.1 krad/s

Polarization & phase control, 20 krad/s

As per $1-F(RIE)$:

max mean errors [rad] of $0^\circ$ control signal

0.08 rad

0.04 rad

0.12 rad

0.06 rad
Discussion, Conclusion

- Portation and preservation of Stokes space from transmitter to receiver
- Polarization & phase reliably stabilized even at 20 krad/s polarization scrambling:
  0.12 rad max, 0.06 rad mean error
- Errors at low scrambling speed:
  0.08 rad max, 0.04 rad mean
- Probe polarization error at low scrambling speed dominated by PMD (25 fs + 30 fs $\Rightarrow$ up to 0.035 rad)

Applications
  - Phased arrays with polarization & absolute phase control
  - BB84 protocol of quantum communication