Accurate and Precise Characterization of Linear Optical Interferometers

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Why Characterization of Linear Optical Interferometers?

Background: Current Characterization Procedures

Accurate and Precise Characterization

Conclusion
Why Characterization of Linear Optical Interferometers?
Linear Optical Interferometer
Why Linear Optical Interferometers?

Theory

Linear optical quantum computation
BosonSampling
Optical quantum walk

Experiments

Better single-photon sources
Better detectors
Tunable photonic integrated circuits
Problem

The current procedures for characterizing multi-channel interferometers are inaccurate and imprecise.
Background: Current Characterization Procedures
Suitable for general CPTP channel.
Phase stability requirement.
\[ m \text{-channel process} \iff m^4 \text{ measurements on } m \text{ homodyne detectors, } m \text{-product coherent states.} \]
Super-stable tomography of any linear optical device

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Linear optical circuits of growing complexity are playing an increasing role in emerging photonic quantum technologies. Individual photonic devices are typically described by a unitary matrix containing amplitude and phase information, the characterisation of which is a key task. We present a constructive scheme to retrieve the unitary matrix describing an arbitrary linear optical device using data obtained from one-photon and two-photon ensembles. The scheme is stable on the arbitrarily increasable length scale of the photon packet and independent of photon loss at input and output ports of the device. We find a one-to-one correspondence between ideal data and unitary


Stable to photon-packet length scale
Inaccurate. No good estimator of precision.
Accurate and Precise Characterization
Characterization using One and Two Photons

\[ U = \begin{pmatrix}
\tau_{1,1} & \tau_{1,2} & \cdots & \tau_{1,m} \\
\tau_{2,1} & \tau_{2,2}e^{i\alpha_{2,2}} & \cdots & \tau_{2,m}e^{i\alpha_{2,m}} \\
\vdots & \vdots & \ddots & \vdots \\
\tau_{m,1} & \tau_{m,2}e^{i\alpha_{m,2}} & \cdots & \tau_{m,m}e^{i\alpha_{m,m}}
\end{pmatrix} \]
Accurate and Precise Characterization

Single-photon transmission rates → $\tau_{i,j}$
Accurate and Precise Characterization

Two-photon coincidence rates $\rightarrow \alpha_{i,j}$
Curve Fitting for Enhanced Precision

B

Coincident counts x 10^4 (s⁻¹)

Temporal delay (ps)

{1,4}

{1,5}

{1,6}

{1,2}

{1,3}
Curve Fitting for Enhanced Precision

\{1,4\}
Calibration against Mode Mismatch

\[ C_{\infty} \]

\[ \gamma = 0 \]

\[ \gamma = 0.8 \]

\[ \gamma = 1 \]
Bootstrapping for Meaningful Error Bars

\[ C(\tau) \]

\[ \tau \]

-0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08
Measure beamsplitter reflectivity using single-photon data.
Calibrate for mode-mismatch using beamsplitter of known reflectivity.
Measure reflectivity value of three beamsplitters obtained using different methods.
Our procedure gives correct answer wrt single photon data within error bars. Other methods do not.
Conclusion
Accurate, precise characterization of linear optics interferometers.

Experimental test of characterization procedure.