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Broadband Entanglement over Fiber: PMD Metrics and Mitigation

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Transmission of entangled photons through optical fiber underpins quantum key distribution (QKD), quantum computing, and the quantum internet. However, polarization mode dispersion (PMD) remains a key obstacle to distributing polarization-entangled photons over deployed fiber, especially for broadband sources where wavelength-dependent polarization rotation accumulates into measurement errors.

Using an intuitive graphical approach on the Poincaré sphere, we derive a closed-form expression that links qubit infidelity to the channel's differential group delay (DGD) and source spectrum, yielding a simple engineering rule for setting filters and link budgets. We validate the framework with O-band experiments and QKD trials over tens of kilometers of deployed fiber, observing that first-order theory predicts a near-parabolic dependence of infidelity on bandwidth.

We then extend the model beyond first-order PMD. Our recent results show that higher-order PMD can partially average polarization errors, thereby mitigating infidelity relative to first-order predictions.

Finally, we propose practical mitigation strategies: (i) selecting fiber spans with PMD parameters optimized to limit PMD-induced errors; (ii) choosing measurement bases that minimize the average error; and (iii) employing non-local PMD compensation, in which a polarization transformation in one arm of an entangled-photon link counteracts distortions accumulated in the other. Together, these results recast PMD from a hard limit into a tunable parameter for robust, broadband, fiber-based quantum communications.

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