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Performance Evaluation of Fiber-Converged Free-Space Optical Systems in Emulated Atmospheric Turbulence

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Abstract. Free-space optical (FSO) systems that interface directly with optical fibers offer enhanced flexibility and compatibility with modern fiber-optic transceivers, but their performance is strongly influenced by atmospheric turbulence and fiber-coupling efficiency. In this work, a custom-developed atmospheric chamber is presented for controlled and repeatable emulation of turbulence with real-time estimation of the refractive-index structure parameter. Using fiber-coupled FSO modules, the recorded optical power fluctuations were measured for single-mode (SMF) and multimode fiber (MMF) coupling under identical turbulence conditions spanning $C_n^2 \approx 10^{-16}$ to 10^{-11} m$^{-2/3}$. Experimental results show that strong turbulence causes severe power scintillations for SMF coupling (standard deviation ≈ 5.16 dB), while MMF coupling remains highly stable (standard deviation ≈ 0.08 dB). These findings demonstrate the strong resilience of MMF coupling to turbulence-induced wavefront distortions and validate the atmospheric chamber as an effective and repeatable platform for investigating turbulence effects in fiber-converged FSO systems, providing practical insights for system design and performance optimization.

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