Quantum-Noise–Limited Interferometry

High-precision interferometric measurements (e.g. gravitational-wave detectors, cavity-length stabilization) are fundamentally limited by quantum shot noise and radiation-pressure back-action. Injecting squeezed vacuum into the interferometer's unused port reduces fluctuations in the pertinent quadrature, thereby lowering the noise floor. Caves (1981) showed that a squeeze parameter r yields a noise reduction factor of e^{-r} in the shot-noise-dominated regime. Modern large-scale detectors (GEO600, Advanced LIGO) routinely employ >3 dB of injected squeezing to improve strain sensitivity below the standard quantum limit .

Phase-Sensitive Amplification

Conventional, phase-insensitive amplifiers must add at least half a quantum of noise per quadrature. In contrast, a **phase-sensitive parametric amplifier** based on a $\chi^{(2)}$ or $\chi^{(3)}$ nonlinearity can amplify one quadrature without excess added noise by locking to the squeezed quadrature.

Optical Communication Channels

Yuen and Shapiro (1978) first proposed encoding information in a squeezed-quadrature field to surpass the classical Shannon limit imposed by coherent-state (shot-noise) channels. By modulating the squeezed quadrature and homodyning at the receiver, one can achieve a signal-to-noise ratio increased by a factor e^{2r} over a coherent-state channel for the same mean photon number . While fiber losses limit realizable gains, recent experiments with pulsed squeezed light and low-loss dispersion-managed fibers have demonstrated quantum advantage in noise-limited links.

Optical Waveguide Taps and Quantum-Limited Routing

Shapiro (1980) showed that tapping an optical waveguide with a squeezed-state probe can extract a portion of the signal with arbitrarily low back-action when the probe is squeezed in the appropriate quadrature. This **optical waveguide tap** enables non-invasive monitoring of guided signals over multikilometer networks without intermediate optical amplifiers, offering a route to quantum-enhanced data buses and sensing arrays .

Continuous-Variable Quantum Information and Metrology

Two-mode squeezed states serve as a primary resource for continuous-variable entanglement, which underpins protocols in quantum teleportation, key distribution, and cluster-state computing. The degree of entanglement scales directly with the squeeze parameter r, enabling high-fidelity information processing. In quantum metrology, injecting squeezed probes into sensing interferometers achieves phase-estimation sensitivity $\Delta\varphi \propto \frac{e^{-r}}{\sqrt{N}}$, surpassing the standard quantum limit by a factor e^{-r} for N average photons. Reviews by Braunstein & van Loock (2005) and Weedbrook **et al.** (2012) provide comprehensive treatments of these protocols and experimental realizations .