# Laser Beam Analysis, Propagation, and Spatial Shaping Techniques

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The propagation and focusing properties of real laser beams are greatly influenced by beam shape, phase distortions, degree of coherence, and aperture truncation effects. The ability to understand, predict, and correct these real-world effects is essential in optical engineering. This short course develops the analytical tools for measuring and quantifying the important characteristics of a real laser beam, allowing the optical engineer to calculate the performance of the beam in a given optical system. In addition, the intensity, phase, and polarization of laser beams can often be engineered to enhance system performance. The course explores a wide variety of engineering approaches to beam optimization using intuitive design methods coupled with a rigorous mathematical treatment of fundamental limits.

The course starts with a basic and highly descriptive discussion of the propagation characteristics of coherent light from an ideal laser. Simple analytical formulae are developed to calculate the properties of this ideal Gaussian beam in a complex optical system. These concepts are extended to higher-order coherent fields, including Hermite Gaussian beams, beams with top-hat intensity shapes and ñnon-diffractingò beams. Finally, the propagation characteristics of coherent light arrays are described mathematically. A set of simple analytical equations is derived to predict the focusing ability of complex coherent light distributions, where the effects of beam intensity and phase distribution can immediately be discerned.

Laser beam characterization methods such as $M^2$, Strehl ratio, and TDL are reviewed. Incoherent and partially coherent light distributions are investigated, and the focusing limits dictated by the radiance theorem are developed. Simple expressions for estimating the effects of laser aberrations and coherence on beam focusing and propagation are reviewed. Coupling of light into single and multi-mode fibers, as well as far-field light concentration limits are explored as real-world examples. The concept of étendue is introduced as an engineering tool to optimize optical design, and simple analytical approaches are presented to estimate the effects of spatial beam shape and phase aberrations on beam concentration of incoherent light.

The course ends with a description of various beam shaping techniques. Intensity beam shaping methods are described for applications where the phase at the target is unimportant. Next, methods for shaping the complex light amplitude in the near- and far-field are developed. Polarization methods including cylindrical vector beams are reviewed. Finally, several intra-cavity beam shaping methods are shown that engineer the intensity and phase of the light inside a laser resonator and improve laser performance.