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## Measuring Small-Beam MFD: Overcoming the Challenges

Small beams are used in many critical applications, such as such as fiber optic coupling efficiency, defect scanning, optical design, and optical fabrication process control. Yet often, they are not directly profiled because determining the size of the beam emerging from a waveguide or fiber — often referred to as the mode field diameter (MFD) — is difficult. While obtaining good beam profiling data on beams under 10 μm has its challenges, they can be overcome with near-field profiling and far-field profiling.

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Test & Measurement

### Measuring Small-Beam MFD Overcoming the Challenges

Small beams are used in many critical applications yet often they are not directly profiled. While obtaining good beam profiling data on beams under 10 μm has its challenges, they can be overcome with proven techniques.

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**P**rofilng beams under 10 μm in size is one of the more challenging beam profiling applications. There are numerous reasons for this, including the very small size. Most plane arrays commonly used to beam profile have grid dimensions of 7 to 10 μm, which are no larger to reasonably profile these small beams without magnification. Further complicating these measurements are the high-contrast precision of the beam profiling apparatus, as well as the beam's high divergence and rapid expansion.

These issues cause many organizations to “fit MFD” via projects involving small beam sizes. Instead of using data from direct beam measurements, users typically rely on indirect methods and estimates, theoretical models, or the expectation that the vendor's data actually reflects reality. Accurate beam size measurements at these sizes are critical in applications such as fiber optic coupling efficiency, defect scanning, optical design and optical fabrication process control.

While measuring a beam under 10 μm is more difficult than measuring a beam of 1 to 2 mm, reliable profiles of these small beams can be obtained in a straightforward manner. Two techniques commonly used are near-field profiling and far-field profiling. Near-field profiling comes at a cost, as it involves imaging the light at an evanescent plane at the “near-field” of the beam waist. Far-field profiling is counter-intuitive, as the beam is analyzed at a great distance from the beam waist to determine its size. This type of profiling can be more advantageous than direct near-field methods.

**Where is the near field and how is it profiled?**

The near-field of a laser beam is the region around its beam waist, or focus. For small beams, a near-field profiler consists of a microscope objective lens to image and magnify the beam at its focus; the resulting image is captured with a beam profiler. In most cases, a CCD beam profiler is used, but it is also possible to use scanning aperture profilers. An important consideration in near-field profiling is the mechanical precision of positioning the apparatus, as the beam size measurements are sensitive to small imperfections in the image plane. We can understand the mechanical positioning constraints from the following beam propagation equation:

$$D_2^2 = D_1^2 + \lambda^2 \frac{L^2}{D_1^2}$$

where  $D_1$  is the beam size at location  $z$  along the optical path,  $D_2$  is the beam size relative to the microscope, and  $L$  is the far-field beam divergence in radians. For a diffraction-limited beam, this becomes:

$$D_2^2 = D_1^2 + \lambda^2 \frac{L^2}{D_1^2}$$

To determine precisely how the measurement plane needs to be established to measure a 5-μm beam within 2 percent accuracy for a beam at visible wavelengths, we use this equation to calculate it in the range of 5 to 7 μm. This means the entire apparatus must be positioned to this accuracy, relative to the focal point, to achieve a reasonably accurate beam size, and the depth of focus of the microscope objective lens must also be equally precise (Figure 1). Mechanical positioning equipment and microscope objectives that meet the required parameters are readily available.

**Figure 1.** A C-mount near-field profiler adapter assembly is commonly used in beam measurements.

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