

COUPLING INTO MULTIMODE FIBERS

For fiber coupling, either the fiber couples type [60FC-A19.5](#) or the collimators of type [60FC](#) can be used. If a collimator is selected then it can be used for fiber-coupling by using it in reverse mode and placing it in an adjustable mirror mount (or other mechanics providing the same degrees of freedom). This gives all degrees of freedom to achieve a high coupling efficiency.

SELECTION OF COUPLING FOCAL LENGTH FOR A CIRCULAR BEAM EMITTED BY A POINT SOURCE

When using a multimode fiber, the coupling focal length is calculated from the beam diameter and the [nominal fiber NA](#)

$$f' = \frac{0.5 \cdot \varnothing_{beam}}{NA}$$

A coupling focal length too long can cause insufficient mode mixing, resulting in unwanted beam characteristics, while a focal length too short will reduce the coupling efficiency.

EFFECTS OF MODE MIXING ON THE BEAM PROFILE OF A FIBER COUPLED MULTIMODE FIBER

The beam profile exiting a multimode fiber is strongly dependent on how the light interacts within the fiber and is often very different from that of a single-mode fiber - it might even change with time and fiber position. For a good, symmetric, and "super-Gaussian" distribution of light exiting the multimode fiber (aside from laser speckle), it is important that mode mixing has occurred within the fiber or that multiple modes have been excited from the start when coupling in.

For example, if you couple light into the fiber from a single-mode laser source, only a few modes will be excited. If you then change the fiber position or touch the fiber, the ex-fiber beam profile can change rapidly over time because different modes are excited that may not have a symmetric, Gaussian-like output (e.g. donut modes).

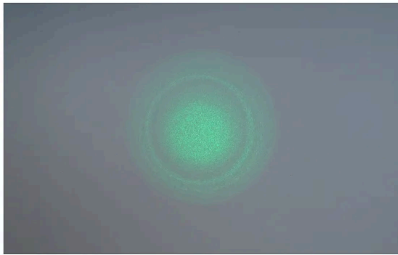
To avoid this, you can either make the multimode fiber longer (to increase mode mixing as it passes through the fiber) or coil the fiber with a smaller bend radius to increase mode mixing. You can also choose a smaller focal length to have a larger light cone when coupling into the fiber, which in turn excites more modes. Often a combination of these three strategies will result in a stable, "super-Gaussian" beam profile exiting the multimode fiber.



Good multimode beam profile

BEAM PROFILE WITH SUFFICIENT MODE MIXING

Stable beam profile exiting a multimode fiber with "super" Gaussian beam profile.



Multimode beam profile with unwanted ring structure

MULTIMODE BEAM PROFILE WITH BAD BEAM PROFILE

Insufficient mode mixing leads to an unstable beam profile, that might have ring structures and can change over time or when the fiber is touched or positioned differently.

COUPLING AN EXTENDED SOURCE INTO A MULTIMODE FIBER

THE BEAM PARAMETER PRODUCT (BPM) OF AN EXTENDED LIGHT SOURCE

When coupling the radiation of an extended source into a multimode fiber, there are principle limitations.

An extended source, e.g. a LED source or a plasma typically emits a beam from a large area and with a large angular spectrum. This beam characteristics (area x angle) is given by the so-called beam parameter product BPM or, more precisely, the étendue.

The multimode fiber however, (as every fiber type), only has a limited acceptance angle and core area (defined by the numerical aperture and the core diameter, respectively). Only light that is focused with the right angle (-> numerical aperture) and focus size (-> core diameter) is coupled into the fiber, everything else is not transmitted. The multimode fiber accepts beams with the corresponding BPM.

Every components has different BPMs it emits or accepts (source, optics, as well as fiber). In classical optics, this BPM is an invariant, which means that it is not possible to change the BPM of an optical system by means of optical imaging.

An extended source , e.g. a LED source or a plasma emits a beam that automatically has a large BPM as both the emitter area as well as the angular spectrum is large. This also means that you need to choose a fiber that accepts a large BPM (large NA, large core diameter) in order to couple as much light as possible into the fiber.

SO HOW DO I CHOOSE THE RIGHT COUPLING OPTIC?

It is unimportant, if you use an optics with a small focal length (smaller spot, wide angle) or a longer focal length (larger spot, smaller angle), as the main limitation is the non-changeable BPM and the ratio of BPM to the BPM accepted by the fiber.

This is as long as the optics fulfills the following criteria:

- It is coated with an AR-coating for the appropriate wavelength
- It has a numerical aperture larger than the one of the multimode fiber (otherwise more light is lost)

In other words: there is no optimum focal length when choosing the right coupling optics, the NA of the optics needs to be large enough.

Note: Single-mode fibers have a smaller NA and a smaller MFD. Maximum coupling efficiency is achieved for an ideal Gaussian beam ($M^2 = 1$, no astigmatism) when the convergence of the focused, circular beam equals the effective NAe^2 of the fiber. Then the laser spot on the fiber end face equals the mode field diameter MFD of the single mode fiber. Thus single-mode fibers accept a much smaller BPM compared to multimode fibers.

It is impossible to couple a significant amount of light emitted by an extended source into a single-mode fiber.

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