# Fiber Optics: How to Choose an Optic for Free Space Fiber Coupling

Among the essentials for obtaining optimal transmission through a fiber optic are having a good cleave and end polish, and, if free space coupling light into or out of the fiber, choosing the correct lens.

Choosing a coupling optic for a multi-mode fiber is relatively simple. Select an optic whose numerical aperture (NA) is closest to matching that of the fiber. This will result in a focused spot size from the light source that is comparable to the core size of the fiber and whose incident cone angle does not exceed the arcsine of the NA of the fiber, which will allow for maximum coupling efficiency.

For single mode fibers, selection of the appropriate coupling optic is a bit more complicated. In this case we need to determine the required focal length of the lens. From Gaussian optics, the equation[1] used for this is given by

$$f = D(\pi\omega / 4\lambda)$$

where,

$f$ = focal length of required coupling lens
$D$ = collimated beam diameter of light source entering the coupling lens
$\omega$ = single mode fiber mode field diameter
$\lambda$ = wavelength of light source

For example, if we wish to couple light into the F-SV fiber ($\omega$ = 4.3 um) from a HeNe laser with $\lambda$ = 633nm, D = 1.2nm, we find that the focal length is f = 6.4 mm. Looking at Newport Corporation's M-series objectives, we find that the objective with the closest matching focal length is the M-20X (f = 9mm). The next closest focal length is that of the M-40X (f = 4.5 mm).

So why was the M-20X chosen over the M-40X? The coupling efficiency depends upon the overlap integral of the Gaussian mode of the input laser beam and the nearly Gaussian fundamental mode of the fiber. This overlap integral is the same whether the input mode is the larger or the smaller of the two modes. The focal length of the M-20X is too large by a factor of 1.4, while the focal length of the M-40X too short by a factor of 0.7. In this example, it is close, but the M-20X will be the better fit for this application.

Below are tables indicating the fiber optic model and the best Newport match for M-series objectives used as coupling lenses. Note that you could also use standard spherical lenses or micro lenses, as long as they meet the NA or focal length requirements. Calculations assume a well collimated input beam.

1. O'Shea Donald C. 1985 *Elements of Modern Optical Design* (John Wiley & Sons, Inc) Chapter 7 General

## Single Mode Fibers::

| | | | Objective by Beam Diameter | | | | Required f by Beam Diameter | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Fiber Model** | **Operating $\lambda$ (mm)** | **Mode Field Diameter** | **0.5 mm** | **1 mm** | **2 mm** | **3 mm** | **0.5 mm** | **1 mm** | **2 mm** | **3 mm** |
| F-SA | 488 | 3.3 | M-60X | M-20X | M-10X | M-10X | 2.65 | 5.31 | 10.62 | 15.93 |
| | 514 | 3.4 | | | | | 2.60 | 5.19 | 10.39 | 15.98 |
| F-SV | 633 | 4.3 | M-60X | M-20X | M-10X | M-10X | 2.67 | 5.33 | 10.67 | 16.00 |
| | 680 | 4.6 | | | | | 2.66 | 5.31 | 10.62 | 15.93 |
| F-SE | 780 | 5.3 | M-60X | M-20X | M-10X | M-10X | 2.67 | 5.33 | 10.67 | 16.00 |
| F-SF | 830 | 5.6 | M-60X | M-20X | M-10X | M-10X | 2.65 | 5.30 | 10.59 | 15.89 |
| F-SC | 980 | 4.5 | M-60X | M-40X | M-20X | M-10X | 1.80 | 3.60 | 7.21 | 10.81 |
| | 1550 | 7.5 | | | | | 1.90 | 3.80 | 7.60 | 11.40 |
| F-SY | 980 | 5.8 | M-60X | M-40X | M-20X | M-10X | 2.32 | 4.65 | 9.29 | 13.94 |
| | 1064 | 6.2 | | M-40X | M-20X | | 2.29 | 4.57 | 9.15 | 13.72 |
| | 1550 | 10.4 | | M-20X | M-10X | | 2.63 | 5.27 | 10.53 | 15.80 |
| F-SMF-28 | 1310 | 9.3 | M-60X | M-20X | M-10X | M-10X | 2.79 | 5.57 | 11.15 | 16.72 |
| | 1550 | | | M-40X | M-20X | M-10X | 2.36 | 4.71 | 9.42 | 14.13 |
| F-SBA | 820 | 4.1 | M-60X | M-40X | M-20X | M-10X | 1.96 | 3.93 | 7.85 | 11.78 |
| F-SBB | 820 | 4.1 | M-60X | M-40X | M-20X | M-10X | 1.96 | 3.93 | 7.85 | 11.78 |
| F-SBC | 1310 | 6.7 | M-60X | M-40X | M-20X | M-10X | 2.01 | 4.01 | 8.03 | 12.04 |
| | 1550 | 7.5 | | | | | 1.90 | 3.80 | 7.60 | 11.40 |
| F-SBD | 1310 | 6.7 | M-60X | M-40X | M-20X | M-10X | 2.01 | 4.01 | 8.03 | 12.04 |
| | 1550 | 7.5 | | | | | 1.90 | 3.80 | 7.60 | 11.40 |
| F-SPA | 488 | 3.6 | M-60X | M-20X | M-10X | | 2.90 | 5.79 | 11.58 | 17.37 |
| | 514 | | | | | | 2.75 | 5.50 | 11.00 | 16.49 |
| F-SPV | 633-688 | 3.2 | M-60X | M-40X | M-20X | M-10X | 1.98 | 3.97 | 7.94 | 11.91 |
| | | | | | | | 1.83 | 3.65 | 7.30 | 10.95 |
| F-SPF | 830 | 4.2 | M-60X | M-40X | M-20X | M-10X | 1.99 | 3.97 | 7.94 | 11.92 |
| F-SPS | 1300 | 6.6 | M-60X | M-40X | M-20X | M-10X | 1.99 | 3.99 | 7.97 | 11.96 |
| | 1550 | | | | | | 1.67 | 3.34 | 6.69 | 10.03 |
| F-SPPC-13 | 1310 | 9.0 | M-60X | M-20X | M-10X | | 2.70 | 5.39 | 10.79 | 16.18 |
| F-SPPC-15 | 1550 | 10.5 | M-60X | M-20X | M-10X | M-10X | 2.66 | 5.32 | 10.64 | 15.95 |
| F-PM1300 | 1300 | 9.5 | M-60X | M-20X | M-10X | M-10X | 2.87 | 5.74 | 11.47 | 17.21 |
| F-PM1550 | 1550 | 10.5 | M-60X | M-20X | M-10X | M-10X | 2.66 | 5.32 | 10.64 | 15.95 |
| F-PM480 | 480 | 4.0 | M-40X | M-20X | M-10X | M-10X | 3.27 | 6.54 | 13.08 | 19.63 |
| F-PM630 | 630 | 4.5 | M-60X | M-20X | M-10X | M-10X | 2.8 | 5.61 | 11.21 | 16.82 |
| F-PM850 | 850 | 5.5 | M-60X | M-20X | M-10X | M-10X | 2.54 | 5.08 | 10.16 | 15.24 |
| F-PM980 | 980 | 6.6 | M-60X | M-20X | M-10X | M-10X | 2.64 | 5.29 | 10.57 | 15.86 |
| F-HB1500G | 1550 | 7.9 | M-60X | M-40X | M-20X | M-10X | 2.00 | 4.00 | 8.00 | 12.00 |
| F-PMF-RC-1550-B1 | 1550 | 7.8 | M-60X | M-40X | M-20X | M-10X | 1.98 | 3.95 | 7.90 | 11.85 |

**Multi Mode Fibers::**

| Fiber Model | Operating λ (nm) | Fiber NA | Objective | Objective NA | Objective CA (mm) |
|---|---|---|---|---|---|
| | | | | | |
| F-MSD | 850/1300 | 0.200 | M-10X | 0.25 | 7.5 |
| F-MFD | 850/1300 | 0.275 | M-10X | 0.25 | 7.5 |
| F-MLD | 850/1300 | 0.290 | M-10X | 0.25 | 7.5 |
| F-MSD-T | 850/1300 | 0.2 | M-10X | 0.25 | 7.5 |
| F-MFD-T | 850/1300 | 0.275 | M-10X | 0.25 | 7.5 |
| F-MLD-T | 850/1330 | 0.29 | M-10X | 0.25 | 7.5 |
| F-MBB | 500-1100 | 0.37 | M-20X | 0.40 | 7.5 |
| F-MBC | 500-1100 | 0.37 | M-20X | 0.40 | 6.0 |
| F-MSC | 500-1100 | 0.37 | M-20X | 0.40 | 6.0 |
| F-MBE | 500-1100 | 0.37 | M-20X | 0.40 | 6.0 |
| F-MCB-T | 250-1100 | 0.22 | M-10X | 0.25 | 7.5 |
| F-MCC-T | 250-1100 | 0.22 | M-10X | 0.25 | 7.5 |
| F-MTC | 500-2100 | 0.22 | M-10X | 0.25 | 7.5 |
| F-MFC | 500-2100 | 0.22 | M-10X | 0.25 | 7.5 |
| F-MSC | 500-1100 | 0.37 | M-20X | 0.40 | 6.0 |

**Objectives::**

| Model | Magnification | Numerical Aperture (NA) | Focal Length (mm) | Working Distance (mm) | Clear Aperture (mm) |
|---|---|---|---|---|---|
| | | | | | |
| M-5X | 5x | 0.10 | 25.4 | 13.0 | 6.0 |
| M-10X | 10x | 0.25 | 16.5 | 5.5 | 7.5 |
| M-20X | 20x | 0.40 | 9.0 | 1.7 | 6.0 |
| M-40X | 40x | 0.65 | 4.5 | 0.6 | 5.0 |
| M-60X | 60x | 0.85 | 2.9 | 0.3 | 4.5 |