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
ω = single mode fiber mode field diameter
λ = wavelength of light source

For example, if we wish to couple light into the F-SV fiber (ω = 4.3 um) from a HeNe laser with λ = 633nm, D = 1.2mm, we find that the focal length isf = 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 λ (mm)**	**Mode Field Diameter**	**0.5 mm**	**1 mm**	**2 mm**	**3 mm**	**0.5 mm**	**1 mm**	**2 mm**	**3 mm**
F-SA	488 514	3.3 3.4	M-60X	M-20X	M-10X	M-10X	2.65 2.60	5.31 5.19	10.62 10.39	15.93 15.98
F-SV	633 680	4.3 4.6	M-60X	M-20X	M-10X	M-10X	2.67 2.66	5.33 5.31	10.67 10.62	16.00 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 1550	4.5 7.5	M-60X	M-40X	M-20X	M-10X	1.80 1.90	3.60 3.80	7.21 7.60	10.81 11.40
F-SY	980 1064 1550	5.8 6.2 10.4	M-60X	M-40X M-40X M-20X	M-20X M-20X M-10X	M-10X	2.32 2.29 2.63	4.65 4.57 5.27	9.29 9.15 10.53	13.94 13.72 15.80
F-SMF-28	1310 1550	9.3	M-60X	M-20X M-40X	M-10X M-20X	M-10X M-10X	2.79 2.36	5.57 4.71	11.15 9.42	16.72 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 1550	6.7 7.5	M-60X	M-40X	M-20X	M-10X	2.01 1.90	4.01 3.80	8.03 7.60	12.04 11.40
F-SBD	1310 1550	6.7 7.5	M-60X	M-40X	M-20X	M-10X	2.01 1.90	4.01 3.80	8.03 7.60	12.04 11.40
F-SPA	488 514	3.6	M-60X	M-20X	M-10X		2.90 2.75	5.79 5.50	11.58 11.00	17.37 16.49
F-SPV	633-688	3.2	M-60X	M-40X	M-20X	M-10X	1.98 1.83	3.97 3.65	7.94 7.30	11.91 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 1550	6.6	M-60X	M-40X	M-20X	M-10X	1.99 1.67	3.99 3.34	7.97 6.69	11.96 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