Laser Beam Couplers 60SMS-... for diode, gas and solid state lasers 370–2300 nm

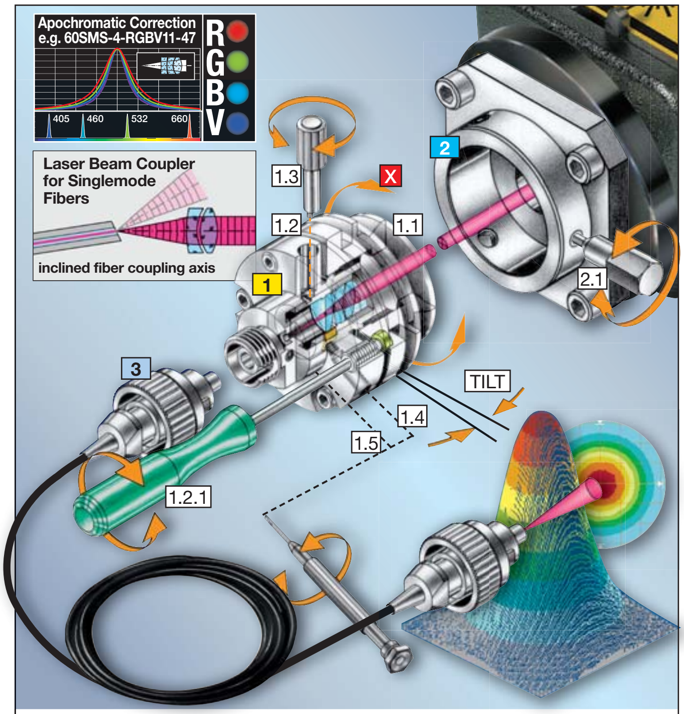
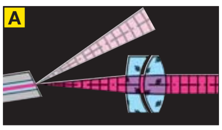


Figure 1: Fiber optics

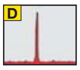
- 1 **Laser Beam Coupler 60SMS-...**
- 1.1 Tightly fitting cylinder with circular V-groove Ø 19.5 mm
- 1.2 Tilt adjustment with integrated adjustment and locking screws (hex screwdriver WS 1.5 - type 50HD-15 1.2.1).
- 1.3 Lens focussing mechanism (with eccentric key 60EX-4)
- 1.4 Lens locking (with screwdriver Ø 1.2 mm, type 9D-12)
- 1.5 Additional fixing of the fiber ferrule (with screwdriver Ø 1.2)
- 2 **Adapter flange 60A19.5-F** to connect laser beam source
- 2.1 Conical screws for system locking (with hex key WS1.5)
- 3 **Singlemode fiber with FC connector**
- X Adjustment of polarization axis

Inclined or coaxial fiber coupling axis

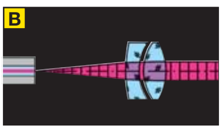
Singlemode fibers with 8°-inclined polish (APC) avoid back-reflected radiation into optical path and are used with Schäfter + Kirchhoff laser beam couplers that have an inclined coupling axis A. These inclined laser beam couplers ensure a coupling efficiency as high as those using a coaxial coupling axis with 0°-polish.



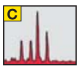
Inclined coupling axis, 8°-polish fiber



Suppression of back-reflection into the laser system. The laser spectrum does not change D.



Coaxial coupling axis, 0°-polish fiber



Some 8% of radiation is reflected back into the laser system and causes multimode emission C and optical noise.

Mismatched components

A fiber with 8°-polish mismatched with a coaxial laser beam coupler, or *vice versa*, a fiber with 0°-polish mismatched with an inclined laser beam coupler, reduces the coupling efficiency dramatically (by up to 50%) because of the geometric mismatch of the components.

Coupling efficiency

A coupling efficiency of >80% is achieved when coupling laser sources with rotationally symmetric beams of high quality ($M^2 < 1.05$).

Loss contributions are mainly through:

Transmission loss in the laser beam coupler .... ~ 1%
Imaging aberration, stray loss and beam distortion ($M^2 = 1$) .... ~ 8%
Fresnel reflection loss at fiber end faces....................................8%

This opto-mechanical device with integrated precision optics and mechanical fine adjustment elements provides efficient coupling of a collimated laser beam into a singlemode fiber or polarization maintaining fiber with MFD >2 µm.
The range covers 15 different coupling focal lengths and numerous AR coatings with each covering 300–1000 nm. The inclined fiber coupling axis of the type APC fiber connectors prevents back-reflection into the optical path. The performance features include:

- **For singlemode or PM fiber cables**
- **Inclined or coaxial coupling axis**
- **Integrated tilt and focussing adjustment**
- **A selection of 21 different coupling lenses,** partly achromatic or apochromatic
- **Sensitive alignment of the polarization axis** ensured by a circular V-groove with tightly fitting cylinder
- **Various fiber connector possibilities,** for fiber connectors type FC, ST or for extra-terrestrial applications with a DIN-AVIO connector, each with an inclined or coaxial coupling axis. F-SMA type connectors available with 0°, 5° or 8°-polish e.g. for SMA-905 High Power connectors
- **Nickel silver, steel or amagnetic titanium**
- **Carbide bearings** for the locking screws of the tilt adjustment guarantee a sensitive, repeatable, lateral setting of the focal position
- An additional **grub screw** locks the fiber ferrule, preventing any displacement or rotation
- Adapters for various laser types and for many optical bench systems

Material Options: Nickel Silver, Titanium and Steel

Standard laser beam couplers are made from nickel silver with a coefficient of thermal expansion of about 19.5×10^{-6}/K and have proven to be very stable. Schäfter+Kirchhoff now offers a range of materials for the laser beam coupler 60SMS with additional features:

Nickel Silver Laser Beam Couplers (Standard)

- Example **Order Code**: **60SMS-1-4-M5-33**

Steel Laser Beam Couplers 60SMS-...-SS with following additional features:

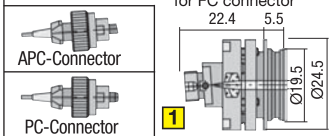
- low coefficient of expansion (similar to optical glass)
- high pointing stability
- Example **Order Code**: **60SMS-1-4-M5-33-SS**

Titanium Laser Beam Couplers 60SMS-...-Ti with the following additional features:

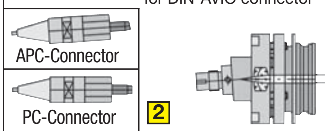
- low coefficient of expansion (similar to optical glass)
- amagnetic (relative material permeability near 1, for more details see page 69)
- low weight
- high pointing stability
- Example **Order Code**: **60SMS-1-4-M5-33-Ti**

Dimensions

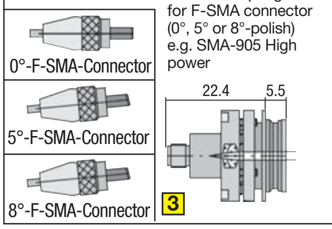
Laser beam coupler 60SMS-1-...
with inclined or coaxial fiber coupling axis for FC connector



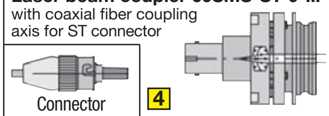
Laser beam coupler 60SMS-AVIO-...
with inclined or coaxial fiber coupling axis for DIN-AVIO connector



Laser beam coupler 60SMS-SMA-0-...
with coaxial or inclined fiber coupling axis for F-SMA connector (0°, 5° or 8°-polish) e.g. SMA-905 High power

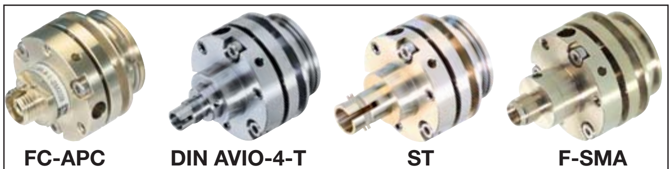


Laser beam coupler 60SMS-ST-0-...
with coaxial fiber coupling axis for ST connector



Other Configurations

for the Laser Beam Coupler 60SMS-... are available on request.
Please contact Schäfter+Kirchhoff.



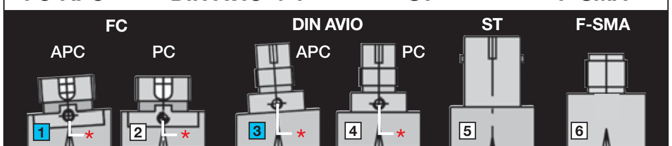


Figure 2: Typical fiber connections: 60SMS-... Laser Beam Couplers capable of accepting different types of fiber connector. Nos. 1 and 3 have an inclined coupling axis for accepting 8°-polish APC fiber connectors.
All laser beam couplers are optionally available in titanium.
* grub screw for additional fixing of the connector ferrule

Schäfter+Kirchhoff GmbH
Kieler Str. 212, 22525 Hamburg, Germany • Tel: +49 40 85 39 97-0 • Fax: +49 40 85 39 97-79 • info@SuKHamburg.de • www.SuKHamburg.com

Laser Beam Couplers 60SMS-... Lens Types and Order Codes

Lens types for Laser Beam Coupler 60SMS-...

The coupling lenses provided by **Schäfter+Kirchhoff** are corrected for spherical aberration and, thus, optimized for the diffraction-limited focussing of monochromatic laser radiation over a wide wavelength range. Three different kinds of optics are available, type M (laser monochromats, doublets), type A (aspheres) and type RGBV (apochromat). The focus position of type A and M optics varies with wavelength (more with aspheres than with monochromats) so that the laser beam coupler has to be refocussed after any changes to the wavelength.
Aspheres are designed for use with a single wavelength, while monochromats can also be used for two wavelengths over a limited range, in some cases, see Table 1, row 5.

RGBV Laser Beam Coupler 60SMS-1-4-RGBV11-47

Conventional lenses and optics exhibit chromatic aberration with a focal length dependent on wavelength (Fig. 3 A, B).
The coupling of combined polychromatic beams requires that chromatic aberration is corrected to the highest degree possible. For efficient coupling, all beams have to be focussed at the fiber end face onto a common point, as slight deviations lead to significant coupling losses. Any correction attempts using standard achromatic optics are really only suitable for just two different wavelengths.
To circumvent these problems, **Schäfter+Kirchhoff** has developed their own special apochromatically corrected optics for the efficient coupling of combined polychromatic beams (RGBV, C) in the spectral range of 400–660 nm.
For information on the fiber-coupled **Schäfter+Kirchhoff** RGBV laser beam combiners, see page 51.

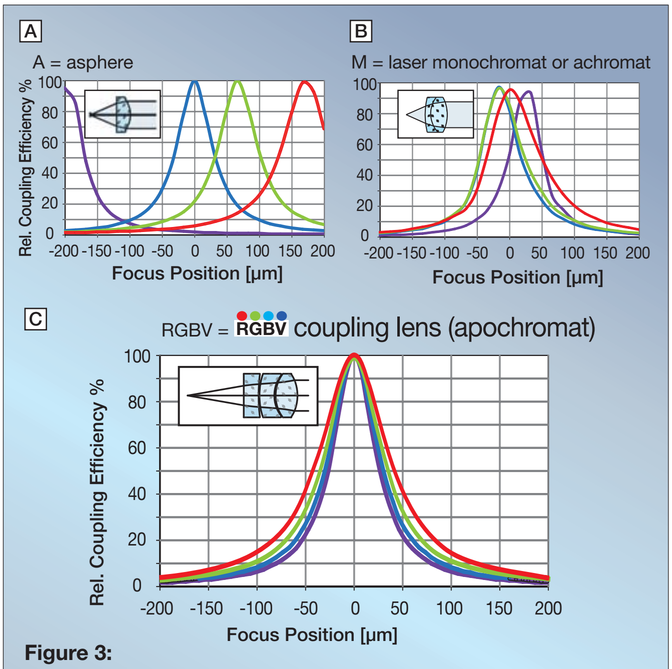


Figure 3:
Different types of lens for laser beam coupler 60SMS-...

Lenses offered for Laser Beam Coupler 60SMS-...

Table 1	Lens and beam parameters		**Laser Beam Coupler 60SMS-...**																				
row	curr. no.		1**	2**	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	Lens type		A1.5	A2	A2.7	A3.1	M3.1	M4	A4	A4.5S	M5	A6.2S	A7.5	A8	M8	A11	M11	RGBV11	M12	M12NIR	A15	M15	A18
2	Focal length f'		1.5	2	2.75	3.1	3.1	4	4	4.5	5.1	6.16	7.5	8	8.1	11	11	11	12	12	15.4	15	18.4
3	Numerical aperture NA		0.5	0.5	0.55	0.68	0.25	0.25	0.6	0.42	0.25	0.3	0.3	0.3	0.15	0.25	0.23	0.18	0.23	0.23	0.16	0.18	0.15
4	Clear aperture max. [mm]		1.5	2	3.6	5	1.7	2	5	3.7	2.5	3.7	4.5	4.9	2.5	5.5	5	4.0	5.5	5.5	5	5.5	5.5
5	Correction achromatic						x	x			x				x		x	RGBV		x		x	
Table 1.1			Input beam diameter [mm] (13.5% level)																				
6	Effective numerical aperture of the fiber NAe^2 (13.5 % level)	0.04	**	**	0.22	0.25	0.25	0.32	0.32	0.36	0.40	0.50	0.60	0.64	0.64	0.88	0.88	0.88	0.96	0.96	1.23	1.20	1.47
7		0.05	**	**	0.27	0.31	0.31	0.40	0.40	0.45	0.50	0.62	0.75	0.80	0.80	1.10	1.10	1.10	1.20	1.20	1.54	1.50	1.84
8		0.06	**	**	0.32	0.37	0.37	0.48	0.48	0.54	0.60	0.74	0.90	0.96	0.96	1.32	1.32	1.32	1.44	1.44	1.85	1.80	2.21
9		0.07	**	**	0.38	0.43	0,43	0.56	0.56	0.63	0.70	0.87	1.05	1.12	1.12	1.54	1.54	1.54	1.68	1.68	2.16	2.10	2.58
10		0.08	**	**	0.43	0.50	0.50	0.64	0.64	0.72	0.80	0.99	1.20	1.28	1.28	1.76	1.76	1.76	1.92	1.92	2.46	2.40	2.94
11		0.09	**	**	0.49	0.56	0.56	0.72	0.72	0.81	0.90	1.12	1.35	1.44	1.44	1.98	1.98	1.98	2.16	2.16	2.77	2.70	3.31
13	Multimode: nominal NA	0.22	0.66	0.88	1.19	1.36	1.36	1.76	1.76	1.98	2.20	2.73	3.30	3.52	-	4.84	4.84	-	5.28	5.28	-	-	-
Table 1.2	Spectral range		Code no. of AR coating																				
14	350 - 460 nm	52				52			52	52													
15	400 - 600 nm	01		01	01	01			01	01		01	01			01					01		01
16	600 - 1050 nm	02		02	02	02			02	02		02	02			02					02		02
17	1050 - 1550 nm	03	03	03	03	03			03	03		03	03			03					03		03
18	1300 - 1750 nm	45			45	45				45		45				45					45		45
19	1750 - 2150 nm	09				09				09		09	09			09					09		09
20	390 - 670 nm	33						33			33				33				33				
21	630 - 1080 nm	10									10				10				10	10			
22	980 - 1600 nm	08									08				08				08				
23	420 - 700 nm	26																				26	
24	750 - 1550 nm	37																				37	
25	400 - 670 nm	51					51											47					
26	460 - 740 nm	53													53								
27	520 - 830 nm	18															18						
28	650 - 1150 nm	07												07									
29	450 - 700 nm	04						04															
30	1750 - 3000 nm	64							64***							64***							

** for multimode fibers only, *** IR chalcogenide lens

Order Options for laser beam couplers 60SMS-...

Laser Beam Couplers 60SMS-... 60SMS - 1 - 4 - M 5 - 33 **Order Code**

- 33: **AR coating,** see Table 1.2
- 5: **Lens focal length *f'*** in mm
- M: Lens type: A = aspheric (beam parameters Table 1); **M = laser monochromat or achromat**; RGBV = laser apochromat
- 4: **4 = inclined coupling axis**, e.g. Fig. 2 with APC connector (8°-polish); 0 = coaxial coupling axis, e.g. Fig. 2 with PC connector (0°-polish)
- 1: 1 = connector type FC (standard), see dimensions 1

Optional:
AVIO = DIN-AVIO connector, see dimensions 2
ST-0-... = ST connector, see dimensions 3
SMA-... = F-SMA connector, see dimensions 4

Option: Add **Ti** for titanium construction (amagnetic): Example Order Code **60SMS-1-4-M5-33-Ti**
Add **SS** for steel construction: Example Order Code **60SMS-1-4-M5-33-SS**

Schäfter+Kirchhoff GmbH
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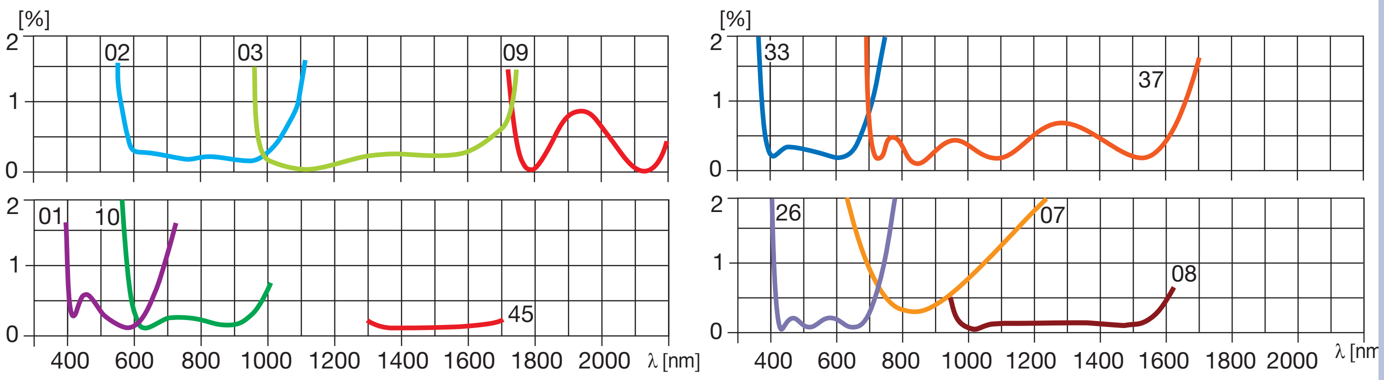
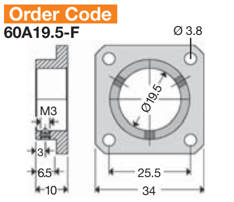
Anti-Reflective Coatings for Laser Beam Couplers 60SMS-... and Fiber Collimators 60FC-...

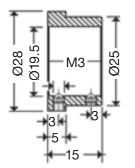
The lenses in table 1 (page 10) and tables 1–19 (pages 35 – 49) can be ordered with the following AR-coatings (selection):

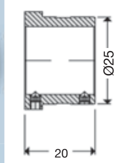


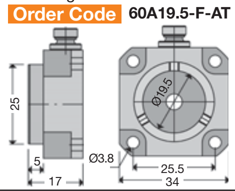
Adapters and Tools for Laser Beam Coupler 60SMS-...

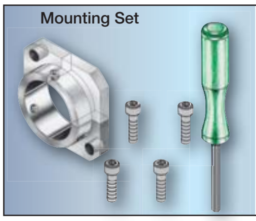
Descriptions and technical drawings are available from www.SuKHamburg.com


Adapter **Order Code**
60A19.5-F



Adapter **Order Code**
19.5 AM25


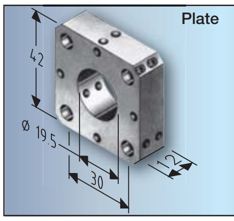

Adapter **Order Code**
19.5 AM25-L



Adapter with integrated attenuator
Order Code **60A19.5-F-AT**



Mounting Set

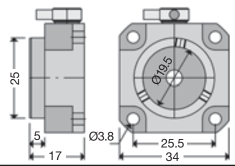
Order Code
60A19.5-F-MS
Mounting set for 60A19.5-F-...
and HeNe laser
4 pcs. screws 4-40 x 3/8"
(similar to DIN 912),
washers and hex key 3/32

Set is supplied without adapter



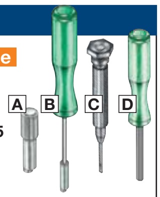
Plate

Order Code
48MC-MP-19.5
For Ø 19.5 mm
components,
compatible with
the microbench
system

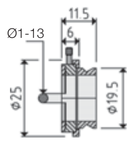

Adapter with integrated shutter
Order Code **60A19.5-F-S**


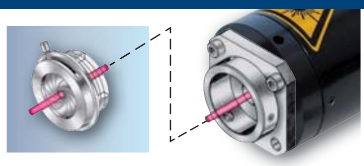
Tools for assembly and adjustment

	Order Code
A **Eccentric key**	
(no. 1–16)	**60EX-4**
(no. 17–21)	**60EX-5**
as an alternative:	
B **Eccentric key** with long handle	
(no. 1–16)	**60EX-4-L**
(no. 17–21)	**60EX-5-L**
C **Screwdriver**	
Ø1.2 mm	**9D-12**
D **Hex screwdriver**	
SW Ø 1.5 mm	**50HD-15**



Iris Diaphragm





For adjustment details of laser beam coupler 60SMS-..., see page 13.

Order Code
13BL1-13

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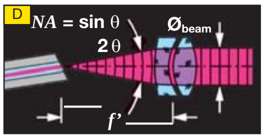
Fundamentals: Laser Beam Couplers

Selection of lens focal length

Optimum coupling efficiency is reached when the beam diameter of the incoming beam is equal to one of the beam diameters listed in Table 1.1. Maximum coupling efficiency is achieved for an ideal Gaussian beam (M^2 = 1, no astigmatism) when the convergence of the focused beam equals the effective NAe^2 of the fiber D. Then the laser spot on the fiber end face equals the mode field diameter *MFD* of the single mode fiber. Except for an 8% loss from Fresnel reflection at the entrance into and exit from the fiber, an ideal Gaussian beam is transported completely.



For a specified effective fiber NAe^2 the optimum focal length of the laser beam coupler at a given beam diameter $Ø_{beam}$ (defined at its 1/e² level) is given by

$$f' = 0.5 \cdot Ø_{beam} / NAe^2. \qquad (1)$$

If the effective NAe^2 of the fiber is not known, then the optimum focal length f' can be calculated from the nominal numerical aperture *NA* by

$$f' = F_{NA} \cdot Ø_{beam} / NA. \qquad (2)$$

The nominal fiber *NA* corresponds to the Gaussian angle distribution at a 1% - 5 % level requiring the factor F_{NA} to correct for the different definitions of the NA.

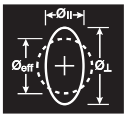
Level	F_{NA}
1 %	0.76
3 %	0.66
5 %	0.61

Example: Beam diameter: $Ø_{beam}$ = 1.0 mm
Effective numerical aperture of fiber: NAe^2 = 0.08
focal length: f' = 0.5·1.0 mm / 0.08 = 6.25 mm
Therefore, select e.g. lens A6.2S with f' = 6.2 mm

Numerical Aperture NA

The numerical aperture *NA* of the optics is defined by its clear aperture. The NAe^2 of a singlemode fiber is given at its 1/e² level.
The *NA* of the coupling optics must be larger than the declared NAe^2 of the fiber. Otherwise the beam is truncated by the optics and the fiber coupling efficiency is reduced.

Selection of coupling diameter for an elliptical laser beam



In order to find the best coupling focal length in case of an elliptical beam use in eq. 1 or 2 the effective beam diameter $Ø_{eff}$ which is calculated from the small and the large diameters $Ø_{\parallel}$ and $Ø_{\perp}$ of the collimated elliptical laser beam:

$$Ø_{eff} = \sqrt{Ø_{\parallel} \cdot Ø_{\perp}}$$

For methods to increase the coupling efficiencies of elliptical laser diode beam sources, see page 51.

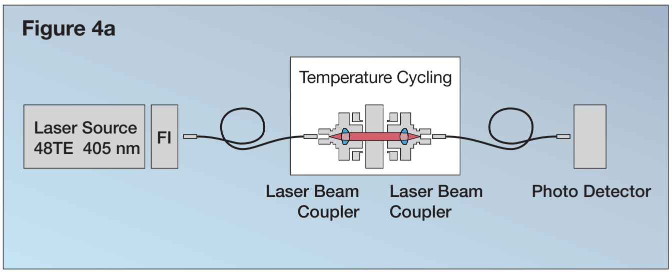
** Multimode fiber

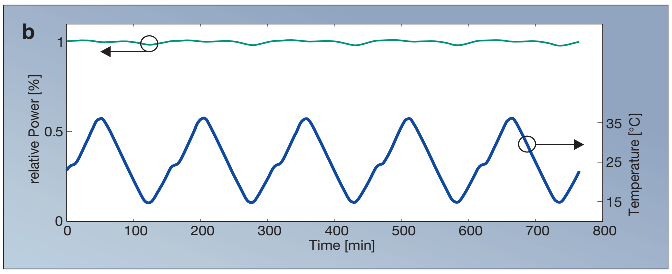
When using a multimode fiber, the coupling focal length is calculated from the beam diameter and the fiber NAe^2:

$$f' = 0.5 \cdot Ø_{beam} / NAe^2.$$

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

Long term Stability of the Laser Beam Coupler





The high stability of fiber-coupling using a laser beam coupler is demonstrated in temperature-stability tests using different focal lengths and wavelengths. The test setup is depicted in Fig. 4a.

The light emitted by the temperature-stabilized laser diode beam source 48TE (with integrated Faraday isolator FI) is guided to the test setup using a polarization-maintaining fiber, collimated by laser beam coupler, and then coupled back into a polarization-maintaining fiber using a second laser beam coupler, with both placed 12 mm apart. The recoupled power is monitored using a photo detector. The coupling setup is placed on a thermo-controlled plate, to vary the temperature between 15 °C and 35 °C in successive cycles with a rate of 0.5 °C per minute. The temperature of the coupling system is monitored by a temperature sensor placed on one of the two laser beam couplers.

In order to minimize any temperature impact on the measurement equipment, the laser source as well as the photo detector and the data logger are all placed on a thermo-controlled plate at a constant temperature of 25 °C.

Fig 4b shows the typical results of the relative transmitted power over 5 measurement cycles using a focal length of 4.5 mm and a wavelength of 405 nm. The power is normalized with respect to the mean power acquired over all measurement cycles. The power deviation from the mean power is ±1.5 %.

The repetitive pattern in the relative power caused by the temperature cycling is demonstrated more clearly in Fig. 4c, in which the relative power (normalized to the maximum) is plotted against the temperature of the laser beam couplers. In this case the maximum coupling efficiency is reached a little above 25 °C and it decreases faster towards lower temperatures than higher temperatures, with the smallest slope near the requested operating point (25 °C).

The respective power curves for each measurement cycle are almost coincident and the power variation at points with equal temperatures is <1 %, which demonstrates the reproducibility of the pointing stability during temperature cycling and the long-term stability of the fiber-coupling.

The maximum deviation with respect to the maximum power here is 3 %.

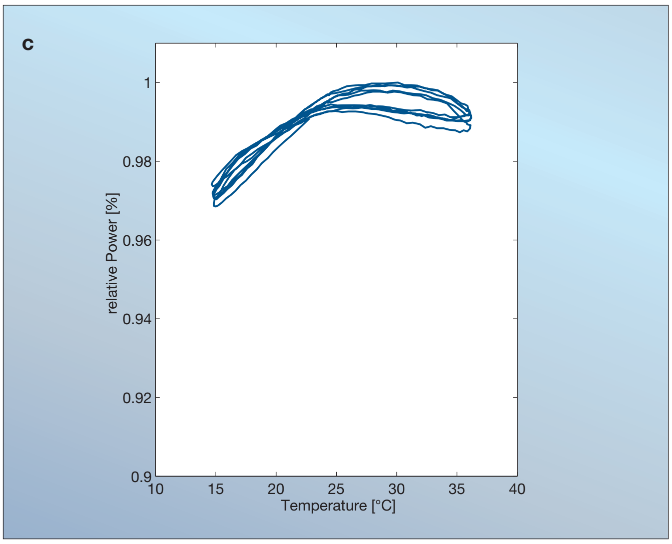


Figure 4:
Test setup for measuring the stability of two laser beam couplers (f = 4.5 mm, λ = 405 nm) during successive temperature cycling between 15 °C and 35 °C (a). The relative power (normalized with respect to the max power) (b) shows a repetitive pattern following the temperature (below) and has a maximum deviation of ±1.5 %.
The relative power curves (c) (normalized with respect to the maximum power) are almost coincident and confirm the high reproducibility of the pointing stability during temperature cycling. The maximum deviation is only 3 %.

Schäfter+Kirchhoff GmbH
Kieler Str. 212, 22525 Hamburg, Germany • Tel: +49 40 85 39 97-0 • Fax: +49 40 85 39 97-79 • info@SuKHamburg.de • www.SuKHamburg.com

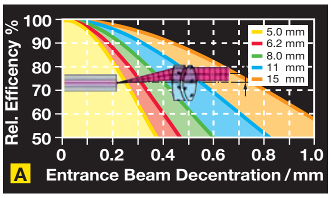
Laser Beam Coupler 60SMS-...
Assembly and adjustment

For efficient beam coupling, the choice of the coupling optics is made according to the diameter of the incoming beam and the numerical aperture of the coupled fiber. The precision adjustment mechanism is then used for the precise placement of the laser spot on the transmitted mode field of the fiber end face and – with polarization-maintaining fibers – for orientation of the polarization-maintaining axis of the fiber so that it is fully parallel with the polarization plane of the incoming radiation.

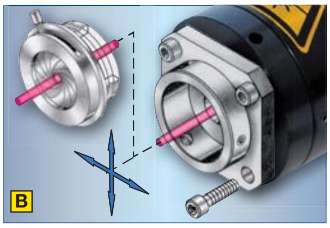
Four steps for perfect alignment:

1. Center the laser beam coupler with the laser beam propagation axis 1 by using the adapter 60A19.5-F (or similar).
2. Move the mode field of the fiber laterally within the laser focus area using the tilt adjustment 2.
3. Alter the preset factory-setting of the focal plane 3 (only needed for a wavelength different from specification or when beam splitting is experienced).
4. Rotate the laser beam coupler to align the polarization-maintaining axes (only PM-fibers) 4.

Centering of laser beam coupler with the propagation axis 1



Coupling efficiencies with f' 5–15 m lenses for uncentered parallel beams



A beam displaced laterally from the optical axis causes it to be focussed onto the fiber center, but with inclined propagation in relation to the fiber end-face, and parts of the beam exceed the acceptance angle of the fiber A.

The asymmetric propagation causes lens aberrations such as coma and astigmatism to appear. These are removed by centering the axes of the laser beam and the coupling optics using adapter 60A19.5-F.

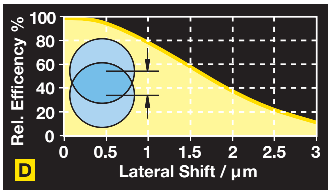
The laser beam coupler is simply replaced by an aperture (e.g. 13BL1-13) B. The aperture diameter should be close to the 1/e^2 level of the laser beam. This allows the transmitted power to be maximized by adjusting the adapter position concentrically (using the deliberately oversized mounting holes) while measuring the laser power.

The centering precision required is of the order of tenths of a millimeter and, with a longer focal length lens, manual adjustment is perfectly adequate and quickly performed A.

Lateral adjustment of the mode field and laser spot 2

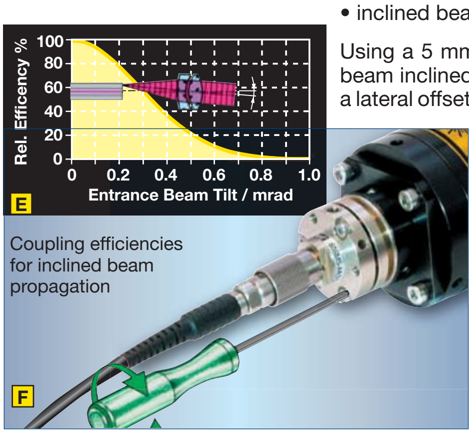
Lateral displacement of the laser beam focus from the mode field of the fiber arises because of:

- production tolerances in the centering of the coupling lens and/or the centering of the fiber core in the fiber ferrule. With a mode field or spot diameter of 2–5 µm, the required precision is in the sub-micron range D,



Coupling efficiencies for laser spots laterally displaced from the fiber mode field

- inclined beam propagation E.

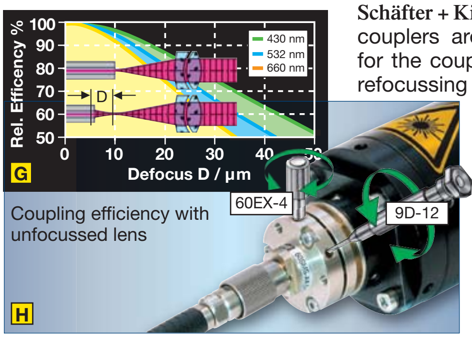


Coupling efficiencies for inclined beam propagation

Using a 5 mm focal length lens, a beam inclined by 1 mrad results in a lateral offset of 5 µm – completely missing the mode field. By using the tilt mechanism of the laser beam coupler, the mode field of the fiber is then placed very precisely onto the laser focus area. Cyclical tightening and release F of the three radially arranged adjustment screws maximize the coupled beam power. The final position is locked by the adjacent grub screws, which have carbide bearings.

Focussing 3

The positioning accuracy in the coaxial direction is less critical than for the lateral directions. From the depth of field of the laser focus (Rayleigh range), a decrease in coupling efficiency of a few percent occurs even with a displacement of only a few microns G.



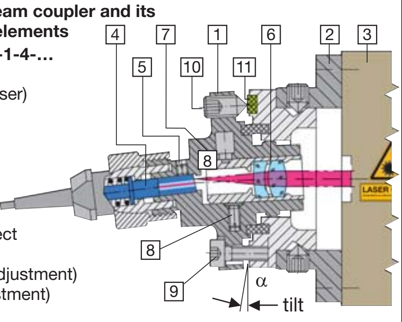
Coupling efficiency with unfocussed lens

Schäfter+Kirchhoff laser beam couplers are supplied adjusted for the coupled wavelength and refocussing is not necessary for a highly collimated laser beam.

Refocussing can be done, however, by releasing the two lens-locking screws (accessible via small holes) using screwdriver 9D-12 H. Use the eccentric key 60EX-4 to relocate the focal plane, before tightening the locking screws again.

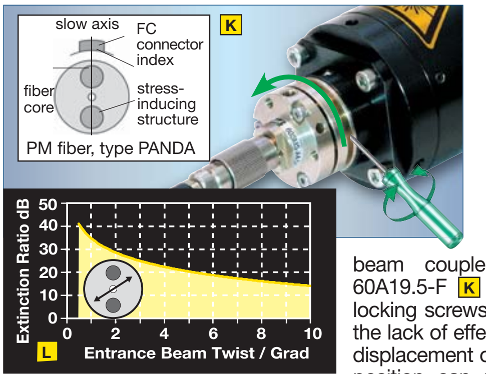
I Cross-section of a laser beam coupler and its functional and adjustable elements

1 Laser beam coupler **60SMS-1-4-...**
2 Adapter **60A19.5-F**
3 Laser beam source (HeNe laser)
4 Singlemode fiber cable with FC-APC connector
5 Grub screws for fixing the fiber ferrule position
6 Coupling lens
7 Lens focussing mechanism
8 Locking screws for the indirect fixing of the coupling lens
9 Adjustment screws (3 x tilt adjustment)
10 Locking screws (3 x tilt adjustment)
11 Carbide bearings (3 x)



Orientation of the polarization axis 4

Polarization-maintaining singlemode fibers guide radiation in the two orthogonal planes of oscillation (fast and slow), independently. When linearly polarized radiation is not orientated exactly with one of the fiber axes, the radiation is split across the fast and slow propagation speeds and recombines at the fiber end as elliptically polarized radiation; the linear state of polarization is lost L.

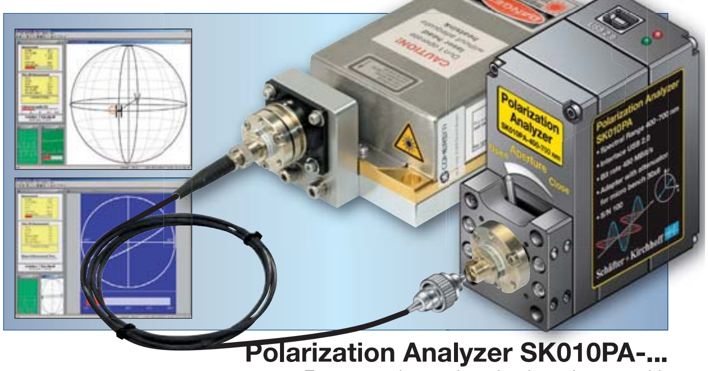


Extinction ratio for polarization axis twisted in respect of the slow and fast axes of the fiber

The polarization state of a fiber can be influenced by bending, vibration and temperature.

A linear and stable state of polarization is obtained by rotating the laser beam coupler in the adapter 60A19.5-F K (after releasing the locking screws), and confirmed by the lack of effect of gentle physical displacement of the fiber. This new position can now be locked by retightening the screws.

The SK010PA-... polarization analyzer was specifically developed for analysis of the state of polarization at the fiber end. The analyzer evaluates the extinction ratio and immediately displays the results of any adjustments made to the polarization.



Polarization Analyzer SK010PA-...

For measuring and testing laser beams with polarization-maintaining singlemode fibers, see page 71

Schäfter+Kirchhoff GmbH
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