Fiber Port Cluster

Rugged, modular and fiber coupled beam splitting and combining units

by Anja Krischke, Michael Schulz, Christian Knothe and Ulrich Oechsner

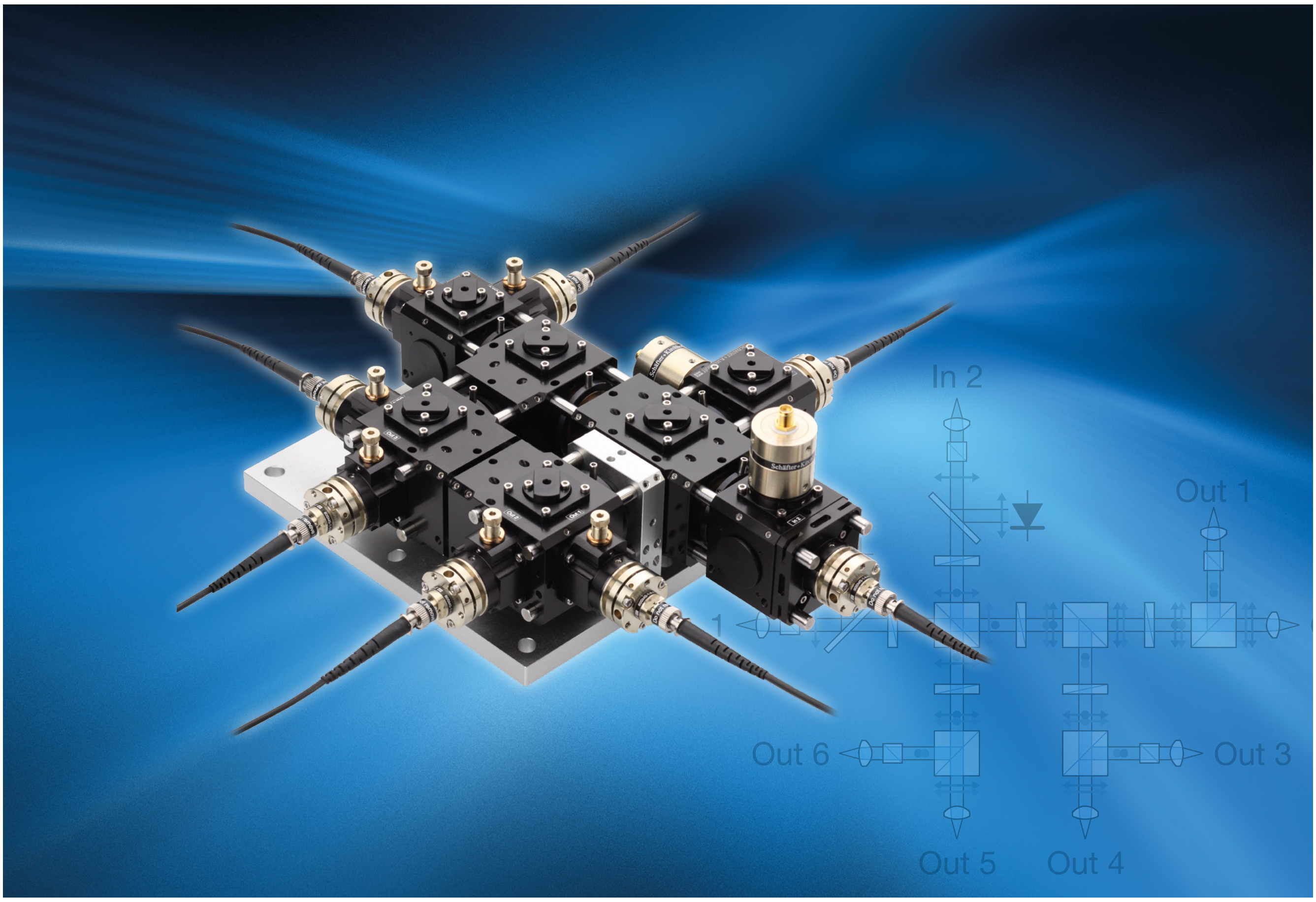

Fig. 1.
Fiber Port Cluster

A stabile measurement setup is fundamental for the success of an experiment, e.g. in quantum optics. A major cause of frustration and error is the need to continuously readjust opto-mechanical equipment because of their instabilities. By using fiber optics, both stability and convenience are significantly increased compared with standard breadboard setups. A fiber port cluster (Fig. 1), for example, can split the radiation from one or more light sources and distribute it on several polarization-maintaining output fibers with high efficiency. The assurance of stability in the opto-mechanics means that the full focus can be set on the experiment (and not the equipment).

Fiber optics can serve as a defined interface between a laser source and the more sensitive environment of the experiment. A physical separation between these parts of the setup enables a mechanical and thermal decoupling, avoiding any negative mutual impacts.

Fiber port clusters are compact opto-mechanical units that split the radiation from one or more polarization-maintaining (PM) fibers into multiple output polarization-maintaining fiber cables with high efficiency and variable splitting ratio. The beam delivery system consists of compact, modular opto-mechanic units. The modularity ensures that almost any desired system can be assembled that is compact and sealed. Because of the polarization sensitive properties of the optical components within the fiber port cluster, PM fibers are used to transport the light to the cluster with defined linear polarization. The fibers used here have a polarization extinction ratio of more than 26 dB (measured at 780 nm).

For fiber port clusters with one input wavelength, radiation splitting is achieved by using a cascade of rotary half-wave plates in combination with polarization beam splitters. Integrated elements, such as photo diodes, allow insightful monitoring of the input powers. By use of the rotary half-wave plates, almost any desired splitting ratio can be realized. Standard configurations use 2, 3, 4, 6 or 8 output ports.

Schäfter+Kirchhoff can also offer fiber port clusters with two input ports for those applications, such as for a MOT at 780 nm (Fig. 2a). It is also possible to combine beams of different wavelengths at the input port of a fiber port cluster for the subsequent splitting of both components equally.

If using several inputs with multiple wavelengths, the wavelength difference between the input ports determines how the combination can be achieved. For two laser sources with a large wavelength difference, a dichroic beam combiner is used (Fig. 2b). If the wavelength difference is too small for dichroic beam combination, a polarization beam splitter and subsequent dichroic wave plates allow multiplexing. (Fig. 2c). Standard configurations with two input ports are available with 3, 4, 6 output ports.

For those occasions when the wavelength difference of the two lasers is too large for guiding in a common single-mode fiber, Schäfter+Kirchhoff have developed

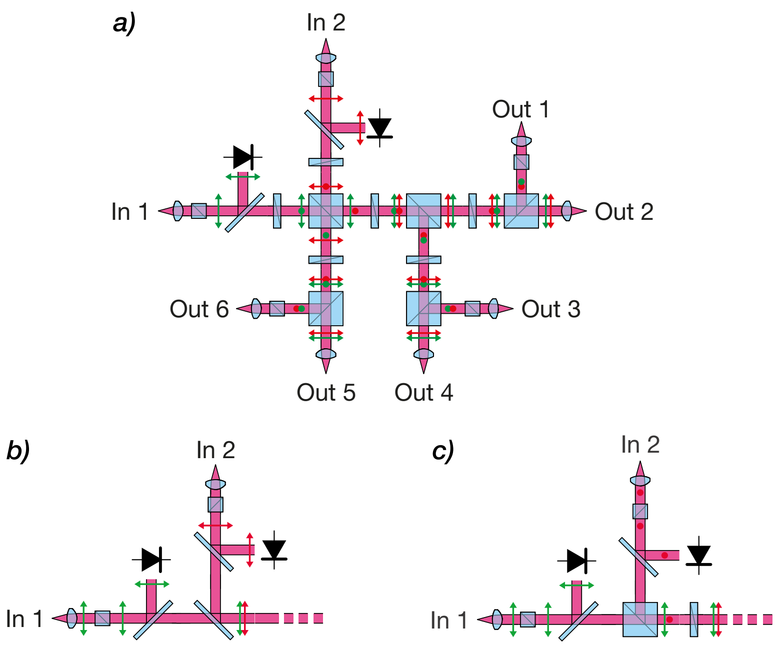

Fig. 2:

a) Optical scheme of a fiber port cluster 2-6. The arrows and the dots denote the state of polarization.

b) Input group for combining of two wavelengths with a dichroic beam combiner (with two power monitors).

c) Scheme of combining of two wavelengths by means of a polarization beam combiner followed by a dichroic wave plate. Input group with two power monitors.

special fiber collimators with an integrated dichroic beam combiner that have two separate input connections for the two sources. Fiber collimators with an integrated quarter-wave plate can then be used to transform the linear output radiation into circularly polarized light for use in, for example, magneto-optical traps

The high stability and ruggedness of standard fiber port clusters has been proven in very harsh environments including zero-G experiments, either on an airplane performing parabolic flights [1] or even using a drop tower [2]. The cluster is shipped prealigned and fully assembled.

Stable fiber coupling even at short wavelengths

A fundamental component of a fiber port cluster is the laser beam coupler, which is the input into the opto-mechanic unit collimating the input radiation and, finally, couples the radiation back into the polarization–maintaining fibers. The basis of the stability of the total fiber port cluster is the stability of the laser beam coupler.

When coupling back into the polarization-maintaining fibers, the laser beam couplers produce a diffraction-limited spot that matches the mode field diameter and the numerical aperture of the fiber. It is only when this condition is met that fiber coupling with high coupling efficiencies of up to 80% are achieved. The mode field of a fiber is wavelength dependent and inversely proportional to the numerical aperture NA. Typical mode field diameters range from 3 µm (405 nm, NA 0.12) to 5 µm (780 nm, NA 0.12).

This nominal NA specification corresponds to the Gaussian angle distribution at a 1 – 5 % level, but in most cases, this is either not a measured value, the nominal NA is given with a large bandwidth or the level on which the NA was measured is not given or inaccurate. Schäfter+Kirchhoff defines an effective fiber NA_{e^2} which corresponds to the divergence of the power distribution emitted by the fiber taken at the $1/e^2$-level of the Gaussian angle distribution and measures this value for each fiber batch and for a number of wavelengths. Accurate measurements of the effective fiber numerical NA_{e^2} provide the basis for choosing the most appropriate coupling and collimating optics [3].

The required pointing stability of the laser beam coupler when coupling a free beam into a polarization-maintaining fiber can be visualized with an example: For a focal length of 5 mm, an angular misalignment of the coupler of a mere 0.2 mrad (0.01°)

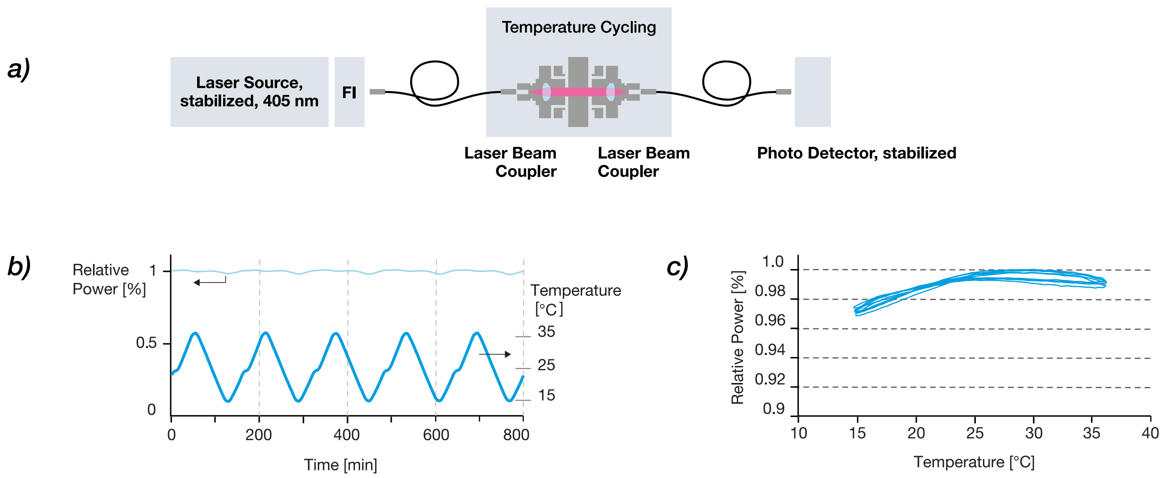

Fig. 3:

a) 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.

b) The relative power (normalized with respect to the mean power) shows a repetitive pattern following the temperature (below) and has a maximum deviation of ±1.5%.

c) The relative power curves (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%.

would result in a lateral displacement between the laser spot and the mode field of the fiber of 1 μm. A displacement of 0.4 μm alone at λ = 400 nm and NA 0.12 is enough to decrease coupling efficiency by as much as 10%. Thus, for high coupling efficiencies and long-term stability, a sub-micron precision and pointing stability of the coupling optics is required, especially in the blue range.

In order to demonstrate the stability of the laser beam coupler, temperature-stability test are performed using different focal lengths and wavelengths. The laser beam couplers are made from standard nickel silver. The test setup is depicted in Fig. 3a. The light emitted by a temperature-stabilized laser diode beam source is guided to the experiment via a polarization-maintaining fiber, collimated by a laser beam coupler and then coupled back into a polarization-maintaining fiber with a second laser beam coupler. Both couplers are placed at the opposing ends of a multicube element, about 12 mm apart. The power guided through the test setup is monitored using a photo detector. In order to minimize any temperature impact on the measurement equipment, the laser source, the photo detector and the data logger are all placed on a thermo-controlled plate holding a constant temperature of 25°C. The coupling system itself is placed on another thermo-controlled plate. The temperature of the coupling system is monitored by placing a temperature sensor on one of the laser beam couplers. This thermo-controlled plate is used to vary the temperature of the coupling system between 15°C and 35 °C in successive cycles with a rate of 0.5°C/ minute.

Fig 3b shows typical results of the relative power that is transmitted through the system using a focal length of 4.5 mm and a wavelength of 405 nm over 5 measurement cycles. The power is normalized with respect to the mean power acquired over all measurement cycles for a total measurement time of about 800 min. The deviation from the mean power is ±1.5 %. The repeating pattern in the relative power arising from the temperature cycling is demonstrated more clearly in Fig. 3c, in which the relative power (this time normalized to the maximum) is plotted against the temperature of the laser beam couplers.

A maximum coupling efficiency is reached a little above 25°C that decreases towards 15°C, but less so at higher temperatures, with a small slope near the required operating point (25°C). The relative power curves for each measurement cycle are almost located on top of each other and the power variation at points with equal temperatures is <1 %, which shows the reproducibility of the pointing stability during temperature cycling and the long-term stability. Maximum deviation with respect to the maximum power here is 3%.

Conclusion

Fiber optics can significantly increase the stability and convenience of measurement setups. Fiber port clusters are compact modular units that can be used to split radiation into multiple polarization-maintaining fibers. Large breadboard setups can be replaced by stable, compact, transportable, sealed fiber-optic systems. The stability of any fiber port cluster is dependent on the stability of the laser beam couplers used for collimation at the input and for coupling the radiation into the output PM fibers. Power stability during temperature cycling with a typical maximum deviation of 3% is achieved in a test setup for a focal length of 4.5 mm at 405 nm. This high stability is fundamental for the successful use of fiber-optic equipment.

The high stability and ruggedness of standard fiber port clusters has been proven in very harsh environments. The cluster is shipped prealigned and fully assembled.

References

[1] G. Varoquaux et al. I.C.E., An ultra-cold atom source for long-baseline interferometric inertial sensors in reduced gravity, arXiv: 0705.2922 (2007)

[2] T. Könemann et al., A freely falling magneto-optical trap drop tower experiment, Applied Physics B: Lasers and Optics 89 (4), 431 (2007)

[3] Schäfter+Kirchhoff GmbH, Fiber Coupling to Polarization-Maintaining Fibers and Collimation, https://www.sukhamburg.com/support/technotes/fiberoptics/coupling/couplingsm/art_fibercouplingnae2.html