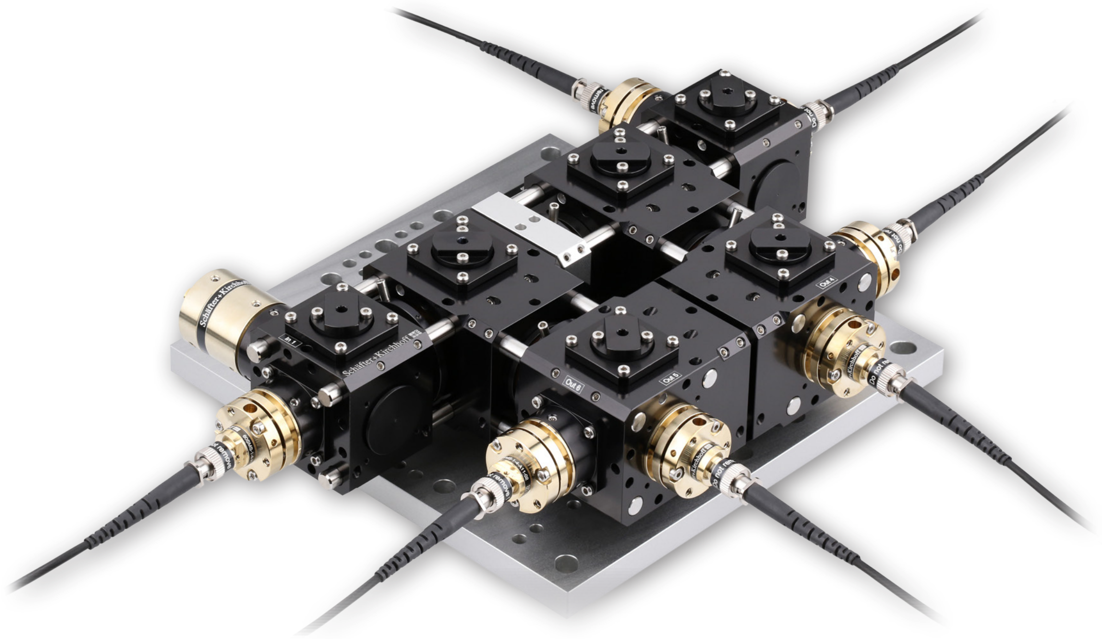
Thermal Stability Test of the Fiber Port Cluster 1-6



With the rise of quantum computing, the field of ultracold atomic and ion systems aims to move from laboratory experiments to robust applications suitable for different environments. This places higher demands on the thermal stability of the light distribution units used to prepare and manipulate the particles with multiple laser beams.

Here, we report on the output power and polarization stability of a fiber port cluster (FPC) with one input port and six output ports at a wavelength of 561 nm. The cluster is exposed to a temperature range from 20°C to 30°C in a climate chamber. In addition, a thermal stress test is performed by applying rapidly changing of thermal conditions between 10°C and 35°C.

All of the output ports have a stability of more than 90% of their maximum output power over the entire temperature range. This results in a power imbalance of less than ±2.5% for each output port pair.

The polarization extinction ratio (PER) is found to be well above 21 dB for all output ports and temperatures. In addition, the thermal stress test shows robust operation even under rapidly changing thermal conditions with no permanent drifts.

1. Fiber Port Cluster 1-6

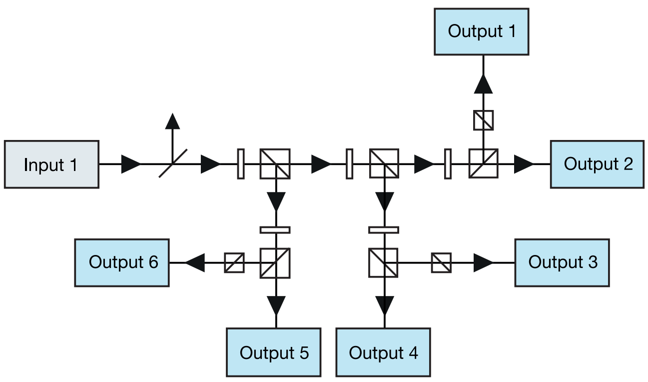


Figure 1:
Fiber Port Cluster scheme. The cluster distributes light from one input to six output ports. The input power is monitored by an integrated photo diode.

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The characterized FPC has one input port, where a 60SMS laser beam coupler (f‘ = 11 mm) collimates the incident beam to a diameter ($1/e^2$-level) of about 2 mm. The input power is monitored by an integrated photo diode (PD, Osram BPX61). After subsequent beam splitting, the laser light is distributed to six fiber coupler outputs (see Fig. 1). The output power of each port is monitored using a PD (Osram BPX61).

The laser light for the characterization is provided by a fiber-coupled Coherent Sapphire 561-20 CW laser. It is connected to a fiber-to-fiber coupler, that allows for attenuation of the input laser power. Here, an input power of 2 mW is used at a wavelength of 561 nm and guided to the fiber port cluster (FPC) using a polarization-maintaining fiber cable (type PMC-460Si-L) with end caps.

2. Thermal Cycling

In order to perform a thermal cycling test, the fiber port cluster is placed into a climate chamber (Binder KB 053), where the applied temperature is recorded by a temperature sensor. The chamber provides a thermal cycle between 20 °C and 30 °C as shown in Fig. 2 [A]. The temperature range is run in 2 °C increments with a hold time of more than one hour per step, allowing for thermalization of the cluster at that respective temperature. The applied temperature is ramped linearly in between these steps within 10 minutes.

In addition, the measured output powers (normalized to the maximum) for all six output ports is monitored as shown in Fig. 2 [B]-[D]. Each port shows a power oscillation driven by the incrementally changing chamber temperature with different amplitudes demonstrating a thermal stability of more than 90% of their maximum output power.

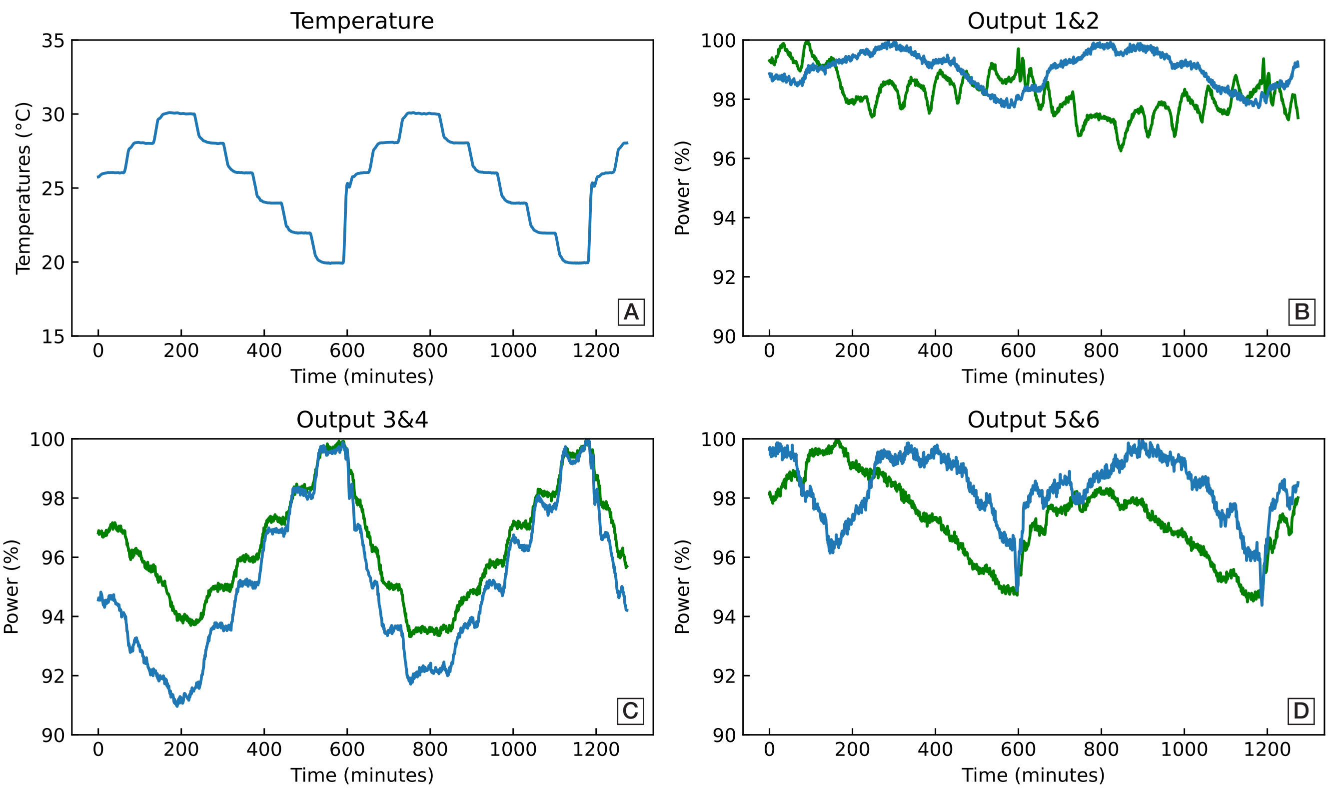

Figure 2: Thermal cycling
[A] Temporal temperature profile measured by a thermal couple in the heating climate chamber.
[B] - [D] Measured output power of the six output ports as a function of the cycling time. The even output numbers are given in green, the uneven ones in blue.

2.1 Output Power Stability

In order to obtain a detailed insight into the temperature dependence of the cluster's performance Fig.3 A - F shows the average relative output power as a function of chamber temperature. These are determined by binning the measured output powers for each temperature level.

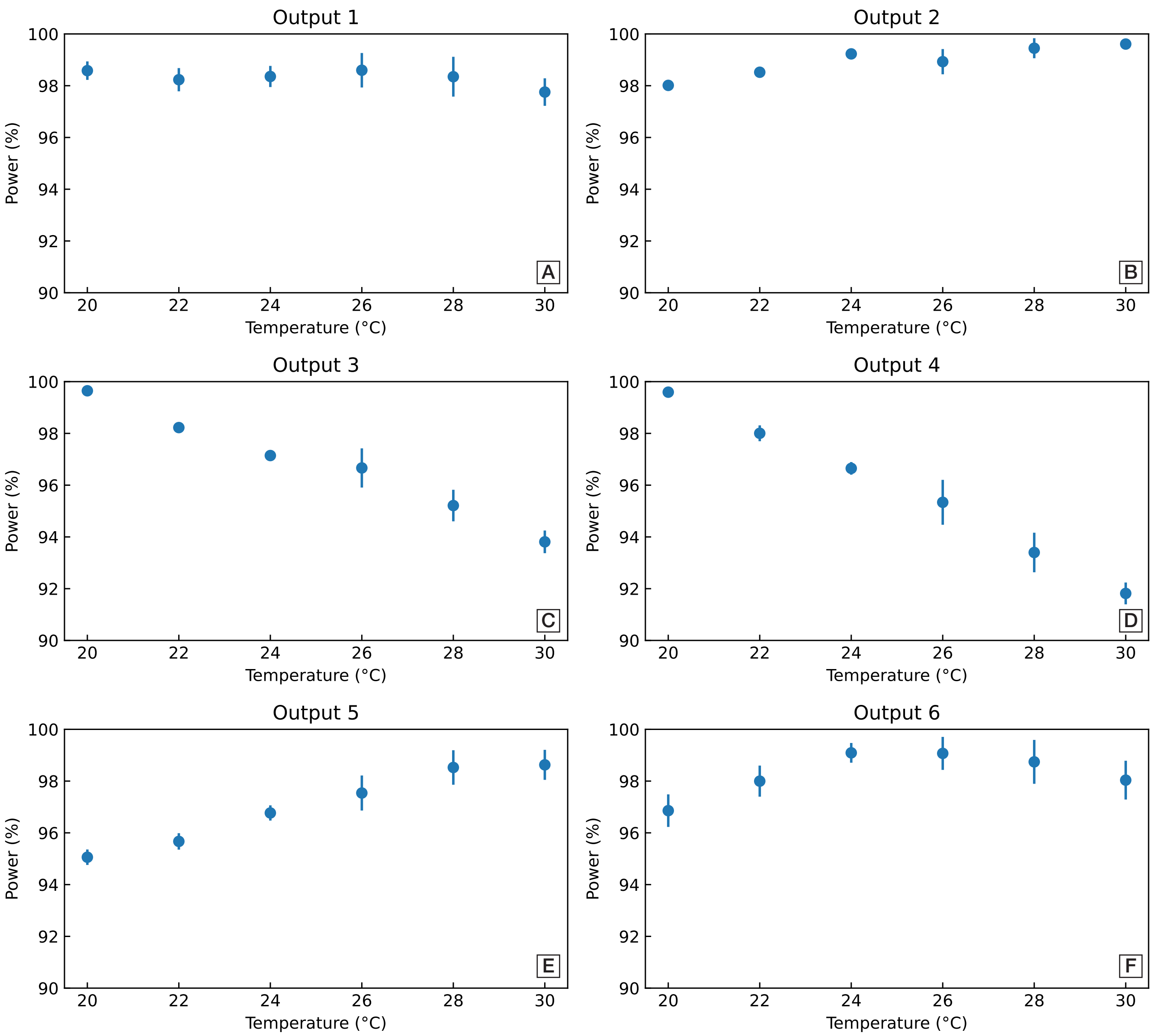

Figure 3:

Mean relative output powers P_i (normalized to the maximum) in dependence of the applied chamber temperature. The error bars denote the standard deviation.

For all six outputs, the measured mean power is greater than 90% of the maximum output power for the entire range from 20 °C to 30 °C. The lowest value of 91.8% is reached for output port four at 30°C. Thus, the power deviation from the mean power is a variation of ±5% for all output ports, indicating robust and lossless operation of of the fiber port clusters in multiple thermal environments.

For various applications of the FPC, as for instance magneto-optical traps, which require 3 pairs of counterpropagating beams, a pairwise power balance is the critical measure for stable operation.

Fig. 4 A - C show the power ratios P_1 / P_2, P_3 / P_4 and P_5 / P_6 respectively. The maximum deviation in the output power for all output pairs is well below ±2.5% over the entire temperature range, which meets the requirements for a stable MOT performance.

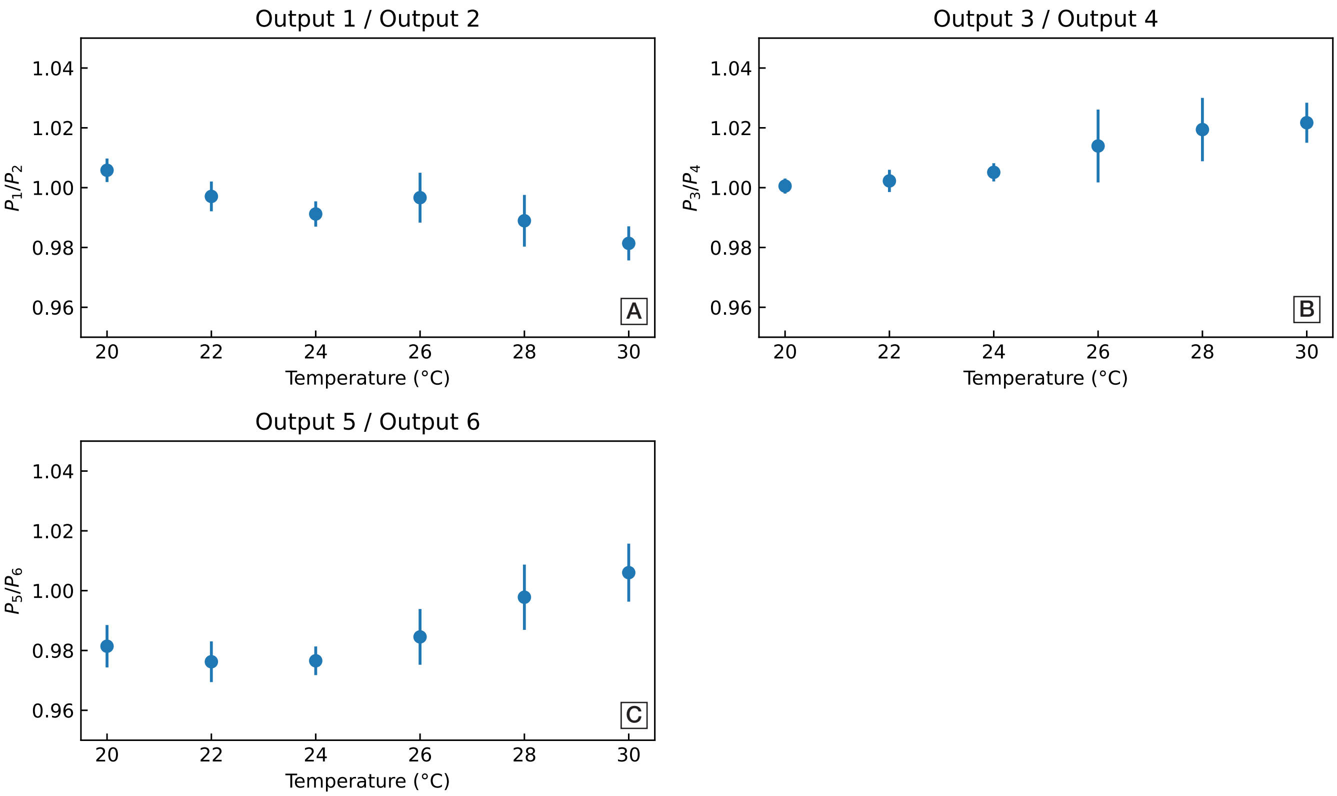

Figure 4:

Pairwise output power balance. The ratio of the output powers pairs P_1 / P_2, P_3 / P_4 and P_5 / P_6 are shown in dependence of the applied chamber temperature.

2.2 Output Polarization Maintenance

In addition to the output power, the polarization extinction ratio (PER) of the linearly polarized output laser light is crucial for various applications in quantum optics. For each temperature level, the PER value is measured for all six output ports using the Polarization Analyzer SK010PA-VIS by Schäfter+Kirchhoff.

The measured values are shown in Fig. 5 A - F. For each channel, the PER is well above 21 dB for all output ports within the full temperature range. The lowest value of 21.8 dB is reached for output port 2 at 30°C.

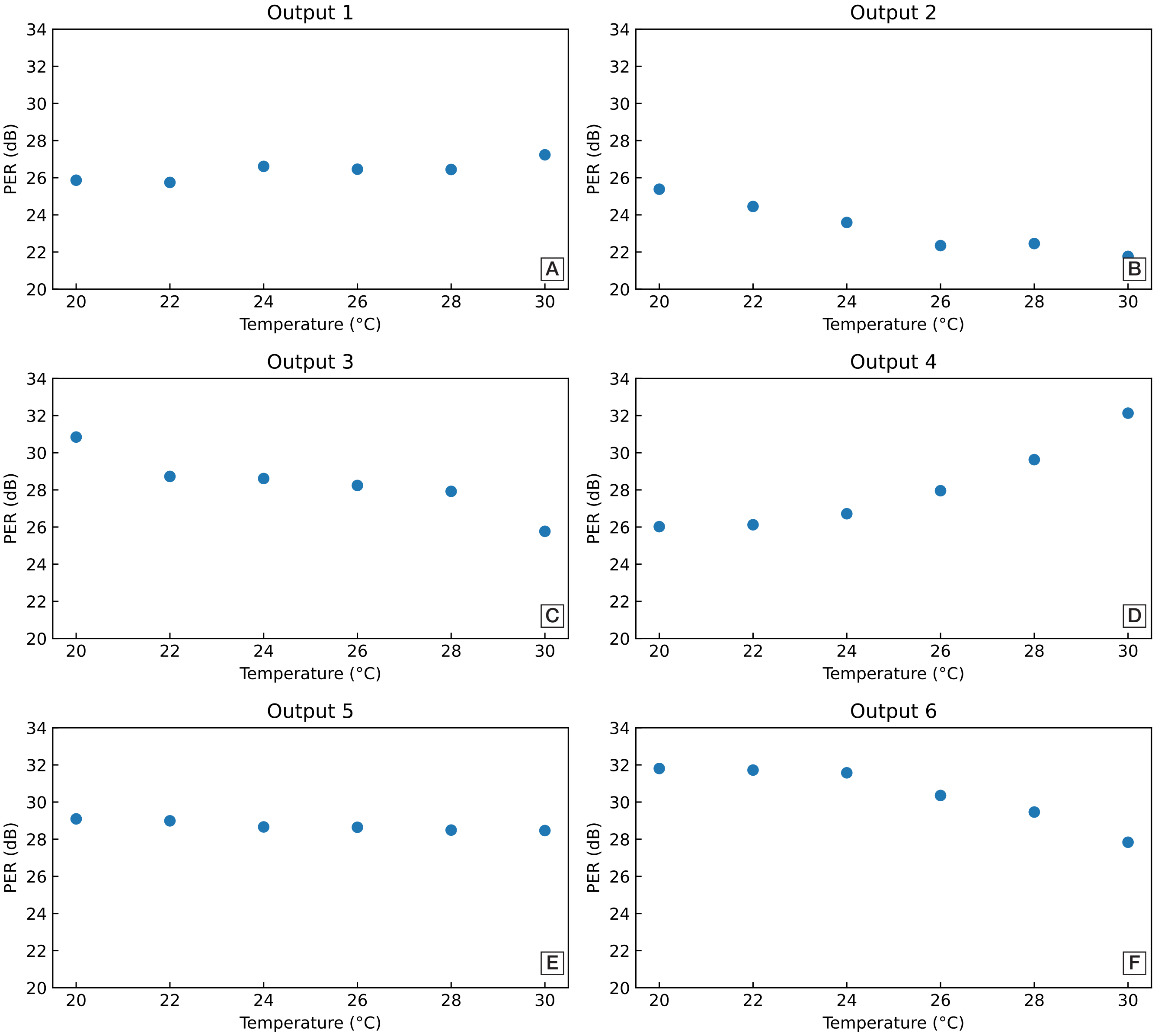

Figure 5:

Polarization extinction ratio (PER) in dependence of the applied chamber temperature for all six output ports.

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3. Thermal Stress Test

As quantum technologies move from the lab to the field, fiber port clusters also need to be robust against rapidly changing thermal conditions, such as those found in server rooms or laser racks without temperature stabilisation. In addition, such conditions may occur during shipment of the typically fully assembled and adjusted systems.

In order to measure the robustness of the fiber port cluster to rapidly changing thermal environment a thermal stress test is performed. Therefore, a second cycle with faster temperature variations is applied. Here, the chamber temperature is cycled between 10 °C and 35 °C with a cycle time of approximately 130 minutes. This corresponds to a maximum temperature change rate of 0.5 °C/min, which inhibits thermalization and leads to various temperature gradients within the cluster. The measured temperature profile is shown in Fig. 6 A.

In addition, the measured output powers (normalized to the maximum) are depicted in Fig. 6 B - E for all six output ports. Each port shows a power oscillation driven by the periodicity of the rapidly changing chamber temperature with different amplitudes.

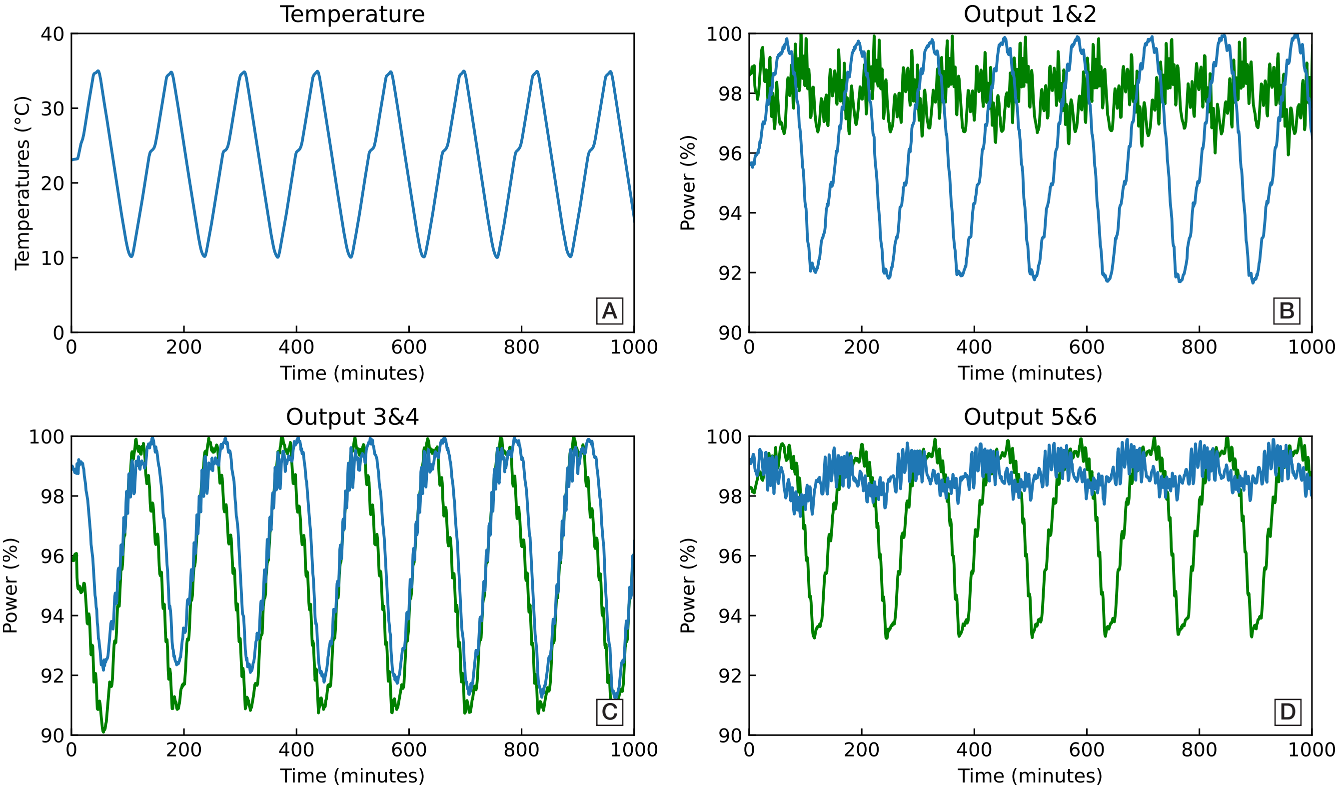

Figure 6:

Thermal cycling. A Temporal temperature profile measured by a thermal couple in the heating climate chamber. B - D Measured output power of the six output ports as a function of the cycling time.

The even output numbers are given in green, the uneven ones in blue.

3.1 Output Power Stability

Figure 7 A - F shows the relative output power as a function of the chamber temperature. For each heating cycle all couplers show reproducible power curves with a maximum deviation of 2 % for each point of the trajectory, which demonstrates the absence of thermally-induced remanent drifts. The visible hysteresis reveals the operation out of thermal equilibrum.

For all six outputs, the measured power is greater than 90% of the maximum output for the entire range from 10 °C to 35 °C. The power deviation from the mean power is ±5% for all output ports.

Even after a number of cycles, the change in power is not permanent, but the initial values are reached again for each temperature respectively.

This shows a robust usability of the fiber port clusters even under rapidly changing thermal conditions.

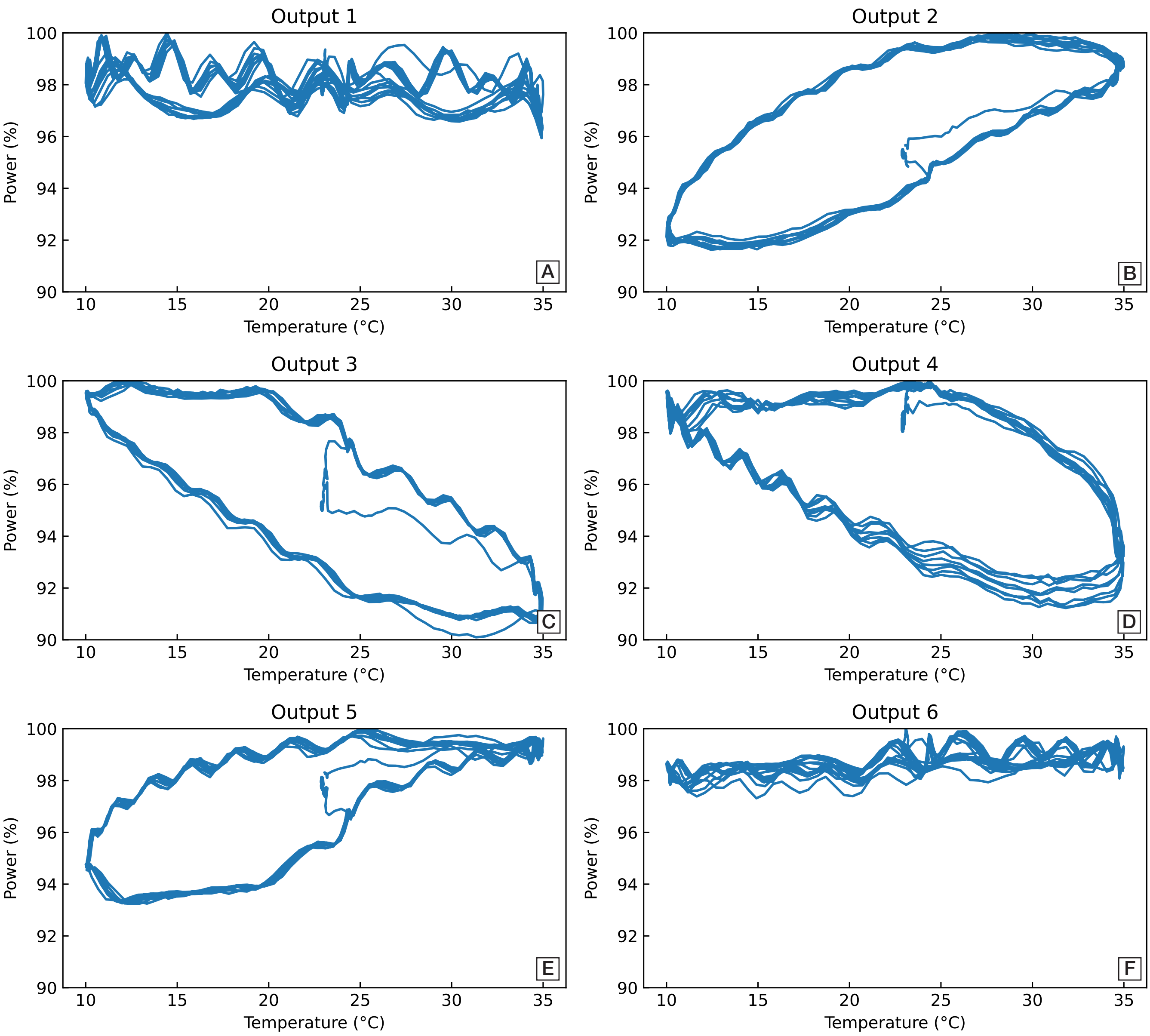

Figure 7:

Relative output powers P_i (normalized to the maximum) in dependence of the applied chamber temperature during the temperature cycles shown in Fig.6.

The different curves exhibit a small oscillation with a period of approximately 2 °C. This can essentially be attributed to a temperature dependence of the retardance of the wave plates. Rather than a loss, such oscillations represent a redistribution of power between the various output ports. This is in accordance to the constant total power in Fig. 8 given by the sum over all output powers.

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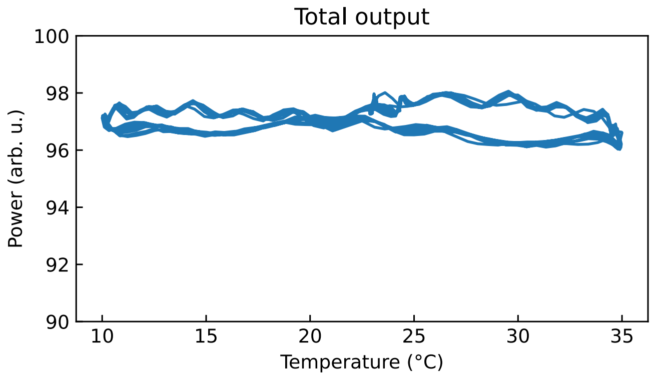
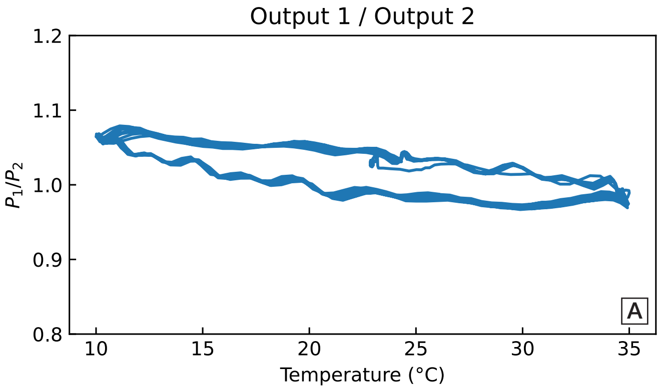


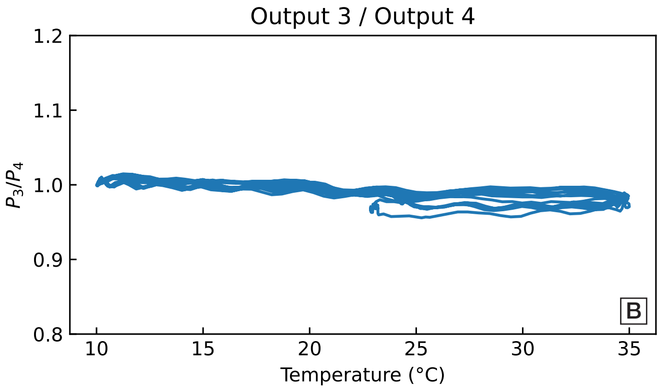
Figure 8:

Sum of the six output powers normalized to the sum of the maximum output powers of all six outputs.

3.2 Output Balance

As for the incremental measurement, Fig. 9 A - C shows the power ratios for the thermal stress test P_1 / P_2, P_3 / P_4 and P_5 / P_6 respectively. The maximum deviation in the output power for all output pairs is well below ± 8% for the entire stress test.





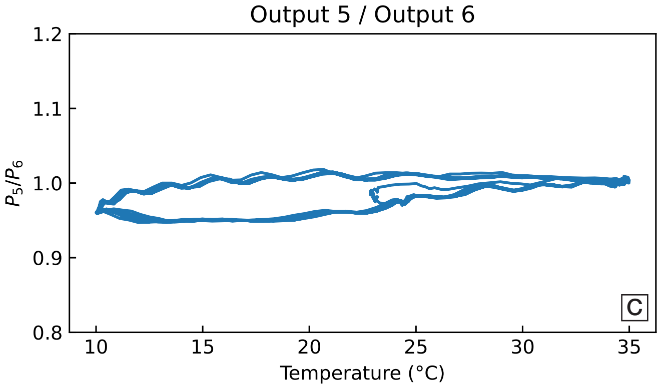


Figure 9:

Pairwise output power balance. The ratio of the output powers pairs P_1 / P_2, P_3 / P_4 and P_5 / P_6 are shown in dependence of the applied chamber temperature.

Contact

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