# Fiber to Fiber Optic Switching

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**Abstract**

The use of fiber optic cables bringing the laser power from the laser to the work piece is today a standard procedure. The dream of having the laser beam from a wall plug has come closer. Fiber to fiber coupling and fiber to fiber switching is today a reality. Equipment has been installed handling multikilowatt mean power. This paper will present the experience with fiber to fiber coupling and switching and describe its impact on beam quality and power loss.

**Keywords:** Fiber Optics, Fiber to Fiber Coupling, Fiber to Fiber Switching, High Power.

## 1 Principle of Fiber to Fiber Coupling

The basic principle in Fiber to Fiber Coupling is simply to reimage the fiber end surface from the emitting fiber towards the receiving fiber. We note the two fibers as "Feeding Fiber" and "Process Fiber" respectively. The image system consists of two corrected optics giving a beam path according to **Fig. 1**. In the nominal situation with the beam collimated between the two optics, the image of the feeding fiber is magnified with a factor of $M= f_f/f_c$ onto the process fiber. The focal lengths $f_f$ and $f_c$ are the effective focal lengths of the focussing optics and the collimating optics respectively.

The Magnification factor M, does not only magnify the image size onto the process fiber, but also demagnify the incoming angle with the same amount.

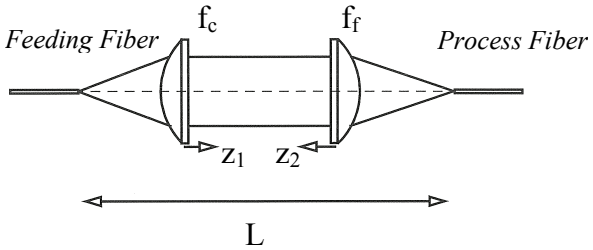


***Fig. 1:*** *Outline of a Fiber to Fiber Coupling unit.*

In case of Fiber to Fiber Switching, the switch is placed in the collimated beam path, to direct the beam into different fibers. A Fiber to Fiber Optic Switch is shown in **Fig. 2**.

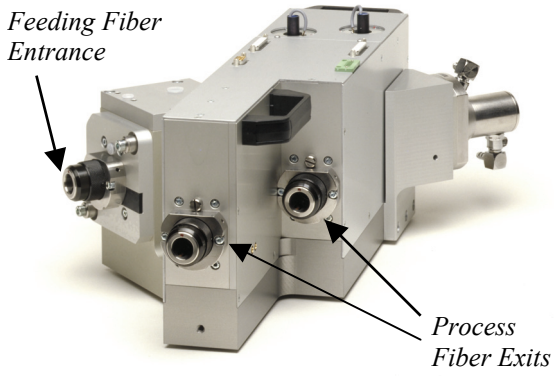


***Fig. 2:*** *A Fiber to Fiber Optic Switch with one Feeding Fiber input and two Process Fibers.*

## 2 Design of the Optical System

### 2.1 Lens design

The lens design should take care of a proper image quality, and a good optical performance at multi kilowatt power levels. The ability to stand high power levels limits the materials that can be used. We have in our investigation studied Fused Silica lens systems and Gradium optics. The drawback with the Fused Silica optics is the low refractive index, giving rise to aberrations if not multiple lens systems are used. In the case of Gradium the ability to stand high powers are somewhat less.

*Imaging quality*
Zeemax ray tracing software has calculated the performance of the optics.

*High Power performance*
Tests have been carried out at high mean power to investigate the focus shift introduced by the high power beam. In **Fig. 3**, a typical behaviour of the lens is shown. The laser has been running at low power, and a Primes Focus Monitor has measured the focal position. At a certain time the Power has been increased to 4 kW and the focal position is monitored. When steady state is reached, the power is set low again, and further focus position measurements are made until steady state has been obtained.

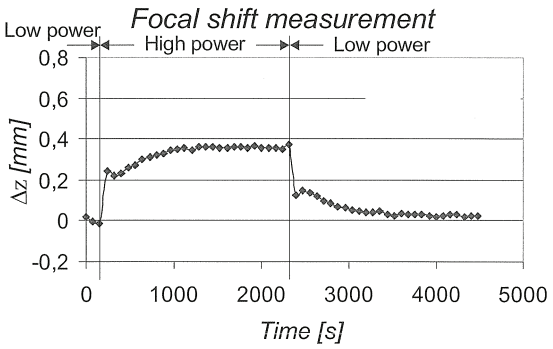


***Fig. 3:*** *Typical focal shift in optics for a 4 kW laser beam.*

Comparison between Gradium optics and corrected Fused Silica optics shows less focal shift for the Fused Silica optics. Typically the shift it is about one third for the Fused Silica optics, but we have seen cases where the difference is almost negligible. With the correct design, it is however always possible to get a better performance with the Fused Silica optics.

### 2.2 M-tuneable design

If we avoid having the distance between the fiber end surfaces, $L = 2*(f_c + f_f)$, we can tune the magnification factor M, by changing the position of the collimating lens, readjust the focussing lens to get the image onto the process fiber. This is shown in **Fig. 4**. The coordinates for the collimating and focussing lens $z_1 = 5$ and $z_2 = 5$ respectively, corresponds to the situation with a collimated beam between the lenses. In case we have an f50 / f60 combination we get a magnification factor of 1,2, which is shown in the figure. If we want to have a magnification factor M=1, we simply readjust the $z_1$ position to 2,5, and correspondingly readjust $z_2$ to approximately 8.

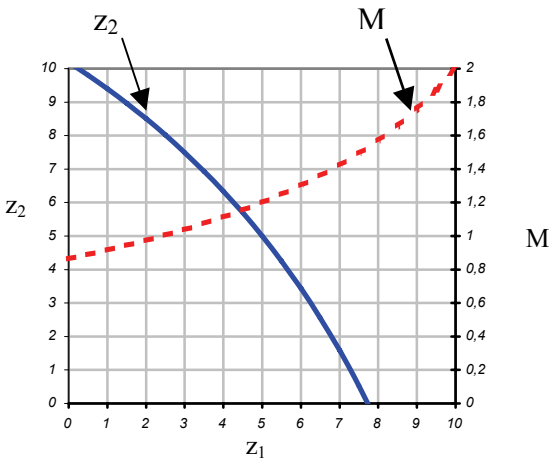


***Fig. 4:*** *Tuning of the Magnification factor*

The optics are basically calculated for the "collimated" case, and it is important to keep the imaging performance under control for the whole range of magnifications possible. In **Fig. 5**, the calculated blurr radius is presented as the RMS values from the Zeemax calculations. Basis for the calculations is an infinitely thin fiber imaged onto the process fiber.

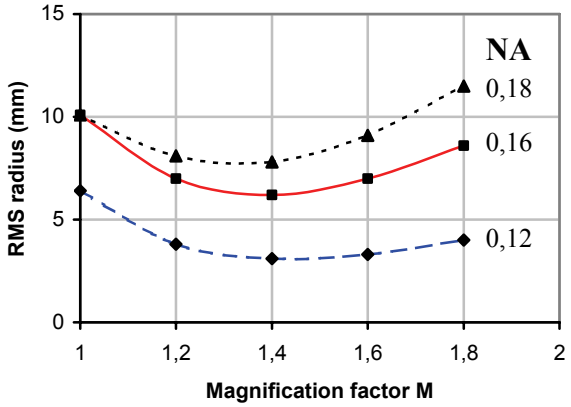


***Fig. 5:*** *Blurr radius as a function of Magnification factor, with Numerical aperture from the feeding fiber as parameter.*

## 3 Technical Performance

### 3.1 Experimental set up.

Two different sets of experiments have been carried out. One with a high power cw Nd-YAG-laser (Rofin Sinar DY044) and the other with a low power laser. In both cases, we have compared the performance of the feeding fiber and process fiber respectively. The outcoming beam has been measured with the identical equipment for both fibers. The set up for the measurements is shown in **Fig. 6**.

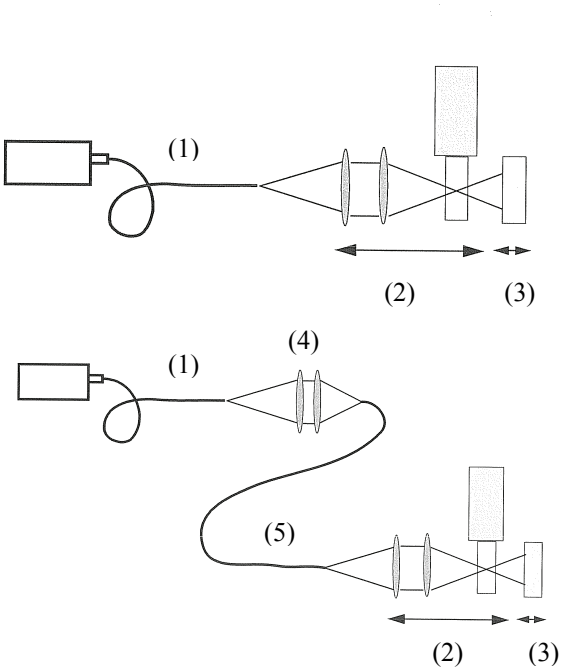


***Fig. 6:*** *Experimental set up for Feeding Fiber and Process Fiber respectively.*

*(1) Feeding Fiber*

*(2) BPP Measuring Equipment*

*(3) Power Measuring*

*(4) Fiber to Fiber Coupling*

*(5) Process Fiber*

The BPP (Beam Parameter Product) measurement equipments have been a Primes Focus Monitor for the high power measurements and a Nanoscan head from Photon Inc for the low power measurements. The optics used in the two cases is given in table 1. In all cases well-corrected optics has been used. In the high power case only fused silica optics was used.

**Table 1**

| | Coll. optics | Foc. optics |
|---|---|---|
| Low Power | f =60 mm | f =400 mm |
| High Power | f = 120 mm | f = 160 mm |

An Ophir power meter was used in the high power measurements. In the low power case the power measurement was carried out directly by the Nanoscan unit.

For the high power measurements a Rofin Sinar DY 044 was used, while we for the low power measurements used a diode laser with the same wavelength as for the Nd-YAG-laser.

The fibers used were all QBH Fibers from Optoskand. The fibers themselves cause losses in the order of 1-2%.

### 3.2 Measurement procedure

First the performance of the Feeding Fiber was measured. The parameters monitored were transmitted power and Beam Parameter Product. The measurements have then been carried out in an identical way for the process fiber, and the results are compared for different Magnification settings of the Fiber to Fiber Switch.

The Fiber to Fiber Optic Switch used in the experiments has been a standard Optoskand Fiber to Fiber Optic Switch with a collimating optics f 50, and a focusing optics f 60.

Three different combinations have been tested. They are given in table 2.

**Table 2**

| | Feeding Fiber | Process fiber | Power |
|---|---|---|---|
| Test 1 | 100 µm | 150 µm | Low |
| Test 2 | 300 µm | 400 µm | High |
| Test 3 | 400 µm | 600 µm | High |

*The Feeding Fiber*

The performance of the Feeding Fibers with the lasers used for the experiments is presented in table 3. It can be noted that we are running the fibers with the DY044, with larger numerical aperture, than normal, to stress the performance of the Fiber to Fiber Optic Switch. This can be seen by the high value of the beam parameter product from the Feeding Fiber.

**Table 3**

| Fiber | Core (µm) | BPP (mm*mrad) |
|---|---|---|
| Test 1 | 100 | 4,2 |
| Test 2 | 300 | 14,9 |
| Test 3 | 400 | 19,5 |

*The Process Fiber*

The performance of the beam after the Process Fiber is measured in the same way as for the Feeding Fiber. The BPP and the Power transmission is compared with the data for the Feeding Fiber and are presented in **Fig. 7** – **Fig. 9**.

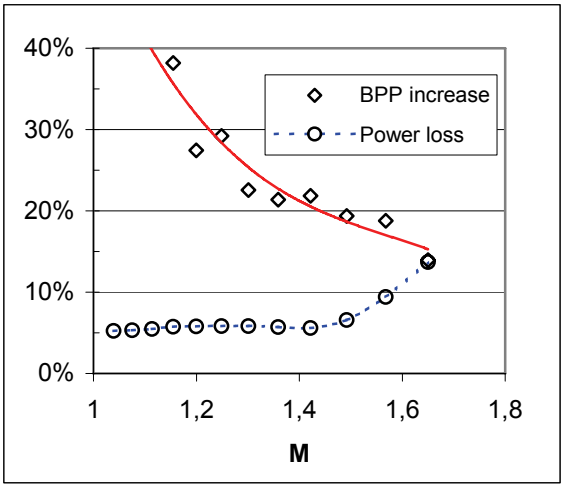


***Fig. 7:*** *BPP increase, and Power loss in Fiber to Fiber Switching with a 100 µm Feeding Fiber and a 150 µm Process Fiber.*

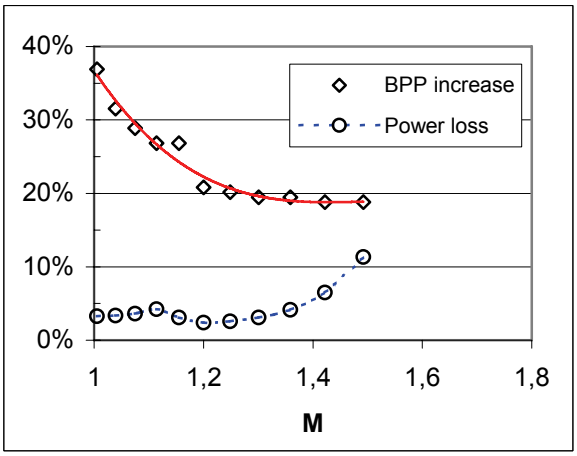


***Fig. 8:*** *BPP increase, and Power loss in Fiber to Fiber Switching with a 300 µm Feeding Fiber and a 400 µm Process Fiber.*

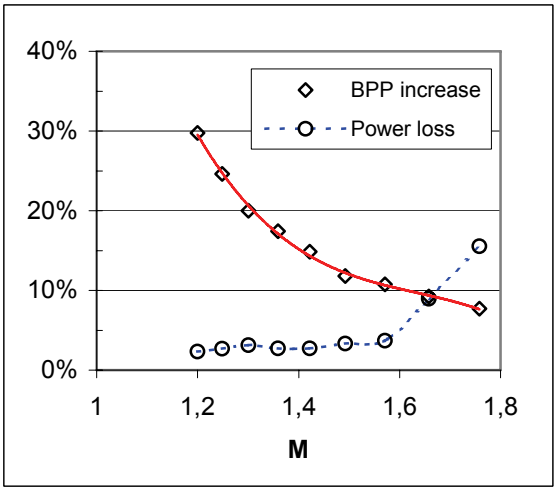


***Fig. 9:*** *BPP increase, and Power loss in Fiber to Fiber Switching with a 400 µm Feeding Fiber and a 600 µm Process Fiber.*

## 4 Comments and Discussion

The results from the measurements shows that we can run a Fiber to Fiber Coupling (or Switching) with a total Power loss of less than 5% and an increase of the Beam Parameter Product in the order of 10-20%, depending on fiber configuration. In industrial applications, we should go for a somewhat smaller magnification, just to ensure we have enough margins to change fibers plug and play. The impact on the beam parameter product is low.

The fiber itself contributes with about 1-2% of the total loss in the system.

The behaviour follows the expectations. Smaller magnification leads to a larger incoupling angle with an increase of the BPP as result. A detailed investigation of the Magnification scale implies a shift in the scale with about 0,1. This is simply a systematic measurement error from the calibration of the unit and tolerances in the focal length of the optical components.

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