Realistic simulations of lens-based fiber coupling components

Keywords
Fiber connector; coupling efficiency; tolerancing analysis; spherical microlenses.

Abstract
We perform a tolerance study of an angular and an inline fiber connector through optical simulations. Next, we assemble these connectors and measure experimentally the coupling efficiency. To obtain a better agreement between the experimental results and the simulation results, we measure the exact surface profiles of the microlenses and implement these real profiles in the simulation models.

1 Introduction

The continuous growth of interest for optical fiber technology is made possible thanks to the development and improvement of passive optical components and optical fibers [1]. Today, fiber coupling remains a bottleneck for improving the performance of data and telecommunication networks. Although optical fibers offer several advantages, their use in these networks is still restricted due to the required fiber positioning accuracy [2]. Indeed, optical fibers are very sensitive to spatial misalignments and deviations. Spherical microlenses can be integrated on top of a micro-hole array for collimating and refocusing the light beams at the emitting and receiving fiber array. We therefore study the design of two types of fiber coupling components that allow an easy integration in existing connector housings [3]. For an inline fiber connector (see figure 1), the light from one fiber ending is collimated by the first microlens and refocused by the second microlens to the other fiber ending.

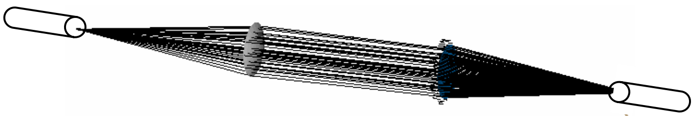

Figure 1: Inline fiber connector

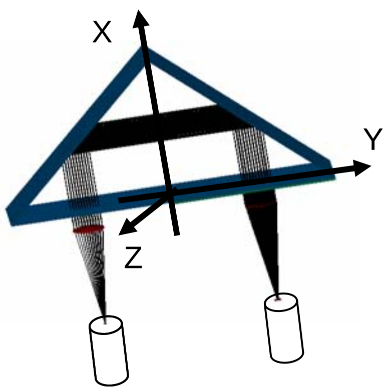

Figure 2: Angular fiber connector

The second type of fiber connector is an angular fiber connector where a microprism is used to bend the light over an angle of 180° [4] (see figure 2). In both connectors single-mode fibers are used. The most important requirement for fiber connectors is to yield a high coupling efficiency and a low back coupling reflection.

2 Tolerancing study of fiber connectors through simulations

The simulation model is implemented in ASAP[1] where we use the Gaussian beam propagation algorithm for the realistic simulation of the coherent optical field through the optical system. The optical field coming out the first fibre is represented as a multitude of Gaussian beams, which propagate through the optical system. The superposition of these propagated beams gives the resulting field at the exit fiber.
For both connector types the design starts with finding the optimal radius of curvature of the microlenses. We choose the optimal radius of curvature R at the point with the smallest coupling loss (e.g. inline connector: coupling loss of 0.04 dB if R=166 µm).
Then, we performed an elaborate sensitivity study for all kinds of misalignments. These simulations show which performance could be attained in the ideal situation (perfect spherical microlenses, without Fresnel reflection, without loss). Real fiber connectors should have a coupling loss less than 0.15 dB for an inline fiber connector and less than 0.6 dB for an angular fiber connector. Figure 3 shows the coupling loss as a function of the lateral prism misalignment for an angular fiber connector as an example of the sensitivity analysis.

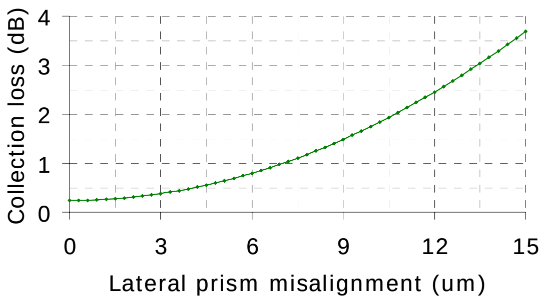

Figure 3: Coupling efficiency as a function of the lateral prism misalignment for the ideal angular fiber connector.

3 Experimental tolerancing study of fiber connectors

To verify our simulation results, we fabricated these microlenses by deep lithography with protons [5] and measured the coupling efficiency and tolerances in a dedicated experimental setup.
We coupled light with a center wavelength of 1550 nm and a spectral width of 40 nm into the entrance fiber and measured the coupling efficiency at the exit fiber. For the angular fiber connector, we found a coupling efficiency around 33% (4.8 dB).
We also made a practical tolerance study of certain parameters. The tolerance ranges for certain longitudinal and rotational parameters were measured experimentally by using a Hexapod six-axis parallel kinematics positioning robot, having an accuracy of 100 nm.

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[1] ASAP is available from Breault Research Organization, Inc, 6400 East Grant Road, Suite 350 Tucson, Arizona 85715.

Figure 4 shows the coupling loss as a function of the lateral movement of the prism for the angular fiber connector. When moving the prism in the plane parallel to the emitter-detector plane, we see that only the misalignment with respect to Y is important (this means the position with respect to the centerline of the prism) (see figure 2).

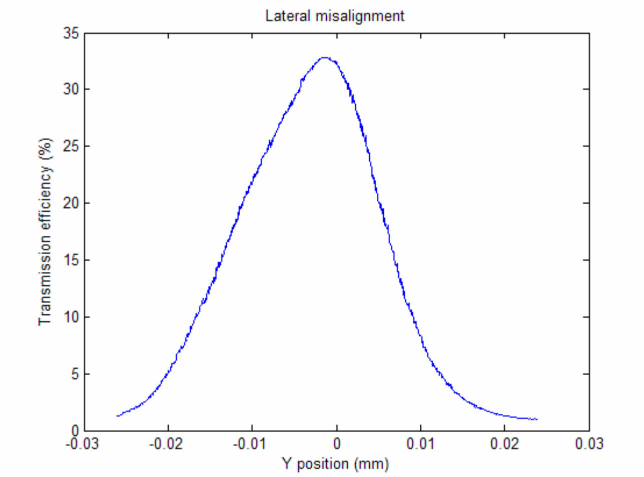

Figure 4: Coupling efficiency as a function of the lateral prism misalignment for the angular fiber connector.

4 Study of fiber connectors through simulations with real lens profiles

4.1 Implementation of lens profiles in the simulation setup

In order to have a better correspondence between measurements and simulations, we characterized the surface profiles of the microlenses with a Dektak stylus profiler and implemented these profiles in our simulations. This implementation is done through two different approaches. The first approach relies on fitting a polynomial surface through the sampling points. The most appropriate approach is to use a two-dimensional matrix of surface heights. ASAP creates then an explicit surface interpolated from the sampled data. Therefore this method gives more reliable results. However, if the surface is locally not smooth enough, ASAP gives paraxial-departure violations because the individual beams making up the optical field are no longer Gaussian. This can be solved by first denoising the data and to use the smoothened data in ASAP.

4.2 Simulation results

We performed a Gaussian averaging algorithm on the sampling points to reduce the noise, which comes from the measurement with the Dektak stylus profiler. The denoised surface is still a surface with small local variations which is the reason why we prefer to work with the beam propagation rather than the Gaussian beam propagation. We found a coupling efficiency around 37% for the inline fiber connector. If we want to use the Gaussian beam propagation method, we should use the second order fitting of the surface instead of the surface of sample points. This simulation showed a coupling efficiency of 53% for the inline fiber connector.

The surface profiles of the microlenses from the angular fiber connector (used for the experimental tolerancing study) were smoother. We used the Gaussian beam propagation method in combination with the second order fitting of these surfaces and found a

coupling efficiency of 75%. When using the surface interpolated from the sample points, we found a coupling efficiency of 50%.
The disagreement between simulations and experiments could be due to scatter or to the lens profiles themselves.

5 Conclusion

We studied two types of fiber connectors through simulations and experiments. We made a tolerancing analysis through simulations for the ideal connectors. Afterwards, we measured the coupling efficiency experimentally and found a coupling efficiency of 33% for the angular fiber connector. In order to have a better agreement between the measured efficiencies and the simulations, the lens surface profiles were measured with a Dektak stylus profiler. We incorporated these profiles in our simulation models following different approaches. The angular fiber connector was simulated using a second order fitting of the lens surface profiles. This simulation gave a coupling efficiency of 75%. We found a coupling efficiency of 50% when we used the sampled lens surface profiles with averaging.

References

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