



MICRO PHOTON DEVICES

PDM fiber adapter mounting notes

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Table of Contents

| | |
|------------------------------------|----------|
| 1. INTRODUCTION | 3 |
| 2. OPTICAL SYSTEM DESIGN | 3 |
| 3. IMPLEMENTATION EXAMPLES | 4 |
| 4. EXAMPLE 1 ASSEMBLY | 6 |
| 5. REFERENCES | 9 |
| 6. COPYRIGHT AND DISCLAIMER | 9 |

1. Introduction

In this document we will describe how to create simple fiber-optic optical focusing system for PDM single photon counters, by using Thorlabs components. The focusing system will not be as miniaturized, optimized and high performance as the one sold by MPD and described in [1] and it will not be cheaper too. The largest advantage will rely in the fact that it can be removed or reattached whenever it is needed.

In the next paragraphs, we will illustrate both the general criteria and guide lines to be used when designing it and few example in some specific cases. Indeed, the optical performance of the focusing system will rely heavily on the combination of SPAD active area, fiber core (or mode field diameter in case of single mode fibers) and the desired wavelength range.

Finally, it is recommended to use the examples included in this application note as guidelines for assembling a focusing system. Do not use them as a precise procedure to be followed. Indeed, for example, some of the trade-offs that were made, were due to the component's availability at the time this document was written and a consequence of considering only one supplier of lenses and optical components. If possible, we would also suggest to perform a system simulation before any purchase with proper tools like Zemax.

2. Optical system design

A fiber coupler adapter is a simple optical system composed by a fiber collimator, a focusing lens and a mechanical holder like the one shown in Figure 1. In order to correctly design the fiber mounting adapter, you have to consider several constraints. First of all, you have to define:

1. The desired fiber, i.e. fiber type, diameter or MFD, Numerical Aperture (NA);
2. The desired detector diameter;
3. The operating wavelength range;



Figure 1. PDM with Thorlabs lens-based collimator.

Once these quantities have been defined, you can follow the procedure in this paragraph to find out the best possible combination of lenses:

1. Calculate the needed magnification as $M = D_{\text{SPAD}} / D_{\text{fiber}}$. The optical magnification of your system, given by $f_{\text{lens}} / f_{\text{collimator}}$ should be lower than this value;
2. Among available collimators, select those with a NA at least equal to that of the desired fiber.
3. For each collimator found, pick up the focal length, and then calculate the needed focal length for the focusing lens as $f_{\text{lens}} = M * f_{\text{collimator}}$
4. Discard any collimator that yields to $f_{\text{lens}} \ll 10$ mm, since it would be difficult to mount such a short focal length lens (the absolute minimum working distance is 4 mm).
5. For each remaining collimator calculate the output beam size, given approximately by $D = 2 * NA * f_{\text{collimator}}$.
6. Among available lenses select those with focal length approximately equal to that calculated in 3 and clear aperture higher than that calculated in 5 (note that the mechanics reported in this AN works well with diameters of the lens $< 1/2''$)
7. Depending on your wavelength range, restrict your selection to aspheric lenses/collimator (single wavelength), achromatic lenses/collimator (broad range) or reflective collimator (mirror-based, very broad range). Note that the system requires a careful focusing of the lens to be done actively at a test wavelength, so performance at different wavelengths may be worse. Choosing a M factor much lower than the maximum allowed will greatly help archiving the desired performance on the whole wavelength range of interest.

Of course, it may not be possible to fulfill all the requirements with optical components commonly available in the market. For instance, you may be forced to use a collimator with suboptimal NA, or a lens with too small clear aperture. This will result in a vignetting of the beam and thus in a reduction of the coupling efficiency.

3. Implementation examples

Let's see thus few implementation examples employing Thorlabs components.

Example 1 : wavelength 780 nm +/- 20 nm; multimode (MM), step index (SI) fiber with 105 μm core diameter and NA = 0.1; PDM module with 50 μm SPAD diameter. In this case the required magnification would be 0.48 and thus a possible solution would be to use the following components:

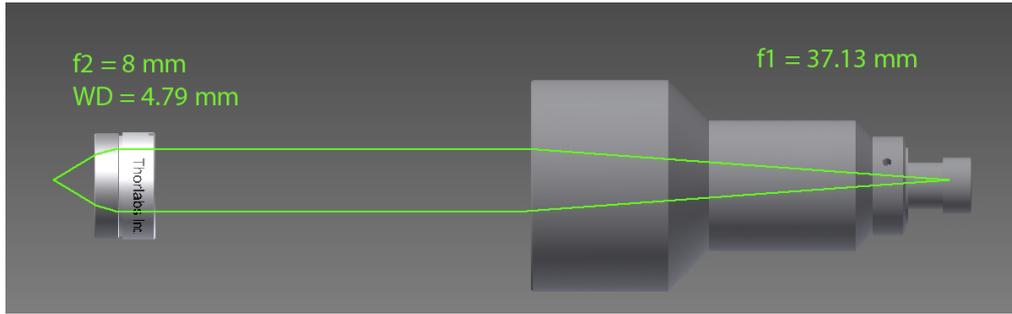


Figure 2. Suggested optical system for coupling a MM SI 105µm core fiber to a 50 µm SPAD at 780 nm.

- a. Collimator: F810FC-780 (f=36mm, NA=0.25)
- b. Focusing Lens: Lens A-240TM-B (f=8mm, D_{lens}=9mm)

This would give a beam size of $D = 2 \cdot 0.1 \cdot 36 = 7.2$ mm and an actual $M = 0.22$. This system would also have a maximum NA of 0.125 in order to avoid any vignetting. The optical system is shown in Figure 2. An example of a lens-based collimator is shown in Figure 1.

Example 2: broadband wavelength range (450 nm – 850 nm); multimode (MM), step index fiber with 105 µm core diameter and NA = 0.22; PDM module with 100 µm SPAD diameter.

In this case the required magnification would be 0.95 and thus a possible solution would be to use the following components:

- a. Collimator: RC04FC-P01 (f=15mm, NA=0.36)
- b. Focusing Lens: Lens AC080-010-A-ML (f=10mm, D_{lens}=8mm)

This would give a beam size $D = 2 \cdot 0.275 \cdot 15 = 6.6$ mm and an actual $M = 0.67$. This system would also have a maximum NA of 0.267 in order to avoid any vignetting. The broadband wavelength range is achieved through the use of achromatic lenses and, above all, the reflective collimator instead of the lens one. An example of reflective collimator is shown in Figure 6.

Example 3: broadband wavelength range (450 nm – 850 nm); multimode (MM), graded index (GI) fiber with 62.5 µm core diameter and NA = 0.275; PDM module with 50 µm SPAD diameter.

In this case the required magnification would be 0.8 and thus a possible solution would be to use the following components:

- a. Collimator: RC04FC-P01 (f=15mm, NA=0.36)
- b. Lens: Lens AC080-010-A-ML (f=10mm, D_{lens}=8mm)

This would give a beam size $D = 2 * 0.275 * 15 = 8.25$ mm and an actual $M = 0.67$. This system would also have a maximum NA of 0.267 (small vignetting). As the actual beam size is larger than the lens diameter this system will have surely a loss due to vignetting. The broadband wavelength range is achieved through the use of achromatic lenses and, above all, the reflective collimator instead of the lens one.

4. Example 1 assembly

Example 1 is designed for 780 nm and for coupling a MM SI fiber with 105 μm core diameter and $\text{NA} = 0.1$ with a 50 μm diameter. It is built around a lens-based collimator and an aspheric lens. In order to build the full assembly, the remaining parts to be purchased are: a xyz stage for Thorlabs cage 30 mm into which inserting the lens to be aligned; a collimator holder for the cage system; a PDM mechanical adaptor that will have the holes for the cage rods; 4 rods for holding the various components. The complete part list is shown in Table 1 while the actual assembly of such system is shown in Figure 1 and in Figure 3.

Table 1. *Components' List for assembling a focusing system coupling a MM SI fibre with 105 μm core diameter, and NA=0.1 to a PDM with a 50 μm SPAD and using Thorlabs and MPD components.*

| Component | Model |
|---------------------------|---------------------|
| Collimator | F810FC-780 |
| Collimator to SM1 Adapter | AD15F |
| SM1 to Cage Adapter | CP02/M |
| Rods (4X) | ER4E |
| xyz stage | CXYZ05/M |
| Lens | A240TM-B |
| PDM to 30 mm cage adaptor | \$MAC024 (from MPD) |

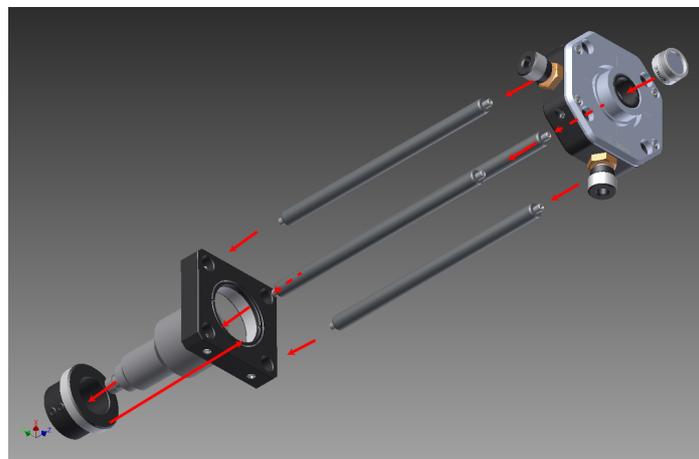


Figure 3. *3D mounting assembly of a fiber coupler using a lens-based collimator and a focusing lens.*

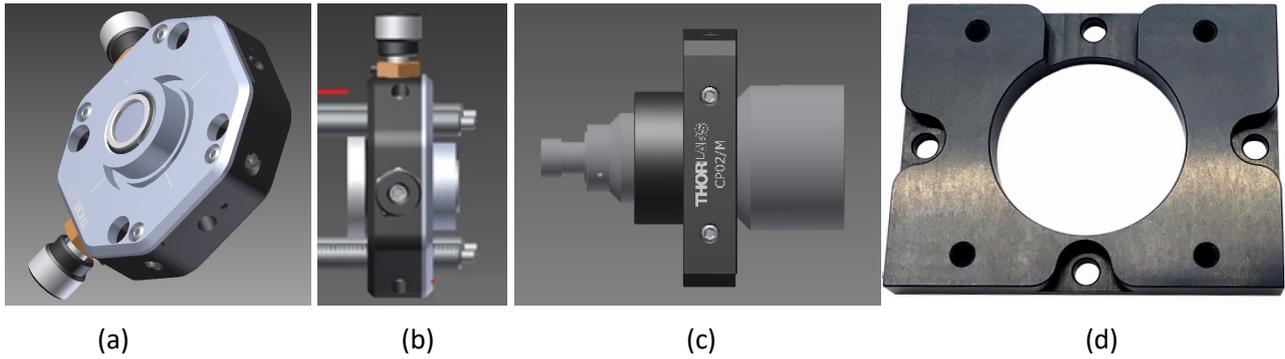


Figure 4. *XYZ-stage showing the attached lens position (a), xyz-stage inserted in the rods (b), collimator coupled to a 30mm cage adapter (c) and MPD 30 mm cage adapter (d).*

The optical setup is mounted as shown in Figure 3. First the retaining ring, inside CXYZ05/M, is screwed to the bottom of the xyz-stage. Then the A-240TM-B is inserted in the CXYZ05/M. The flat part of the lens should be kept external respect to the three stage as shown in Figure 3 and in Figure 4 (a). The retaining ring is used as a lens support. Now the lens should be glued in place while being very careful not create any tilt of the lens respect to optical axis. The lens can be hold in place, for example, by using a second retaining ring or similar Thorlabs component, avoiding thus the glue. Anyway, in the latter case the “real” lens would be slightly inside the xyz stage internal hole, causing a reduction of the actual lens working distance.

At this step, the rods (ER4E) should be screwed in the PDM cage adaptor \$MAC024, shown in Figure 4 (d), and then the CXYZ05/M should be inserted in the rods by pushing it towards the PDM and stopping at a distance of 4 mm from the adaptor (see Figure 4 (c)). At this point the xyz stage should be locked. Of course, the side with the lens should be facing the SPAD detector. The goal now is to insert the AD15F in the CP-02/M and locking it and then to insert the F810FC-780 in the AD15F and to lock it too. Finally, the obtained sub-assembly, shown in Figure 4 (c), should be inserted in the bars (ER4E) while locking it.

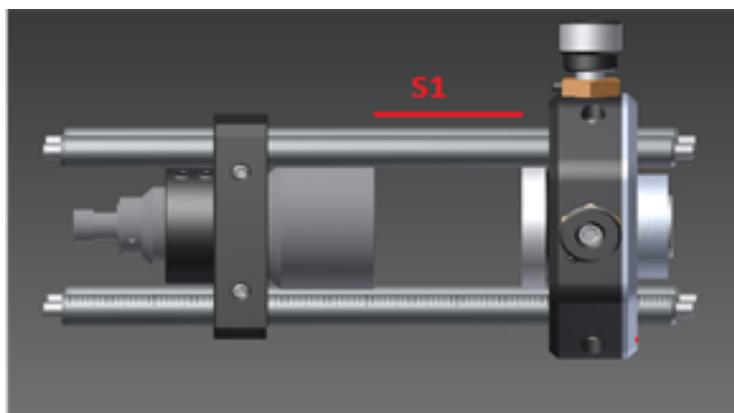


Figure 5. *Fiber coupler assembly showing the distance that should be kept between the collimator and the xyz stage in order to easily adjust Z without touching the lens of the collimator.*

A distance S_1 , shown in Figure 5, between the subassembly and the xyz stage should be left in order to be able to access the rotating gear that moves the Z axis without touching (smearing) the collimator exposed lens. As a rule of thumb let's start with $s_1 = 3$ cm and modify it only if needed.

The procedure for maximizing the coupling efficiency is now the following:

1. Move XY axes to maximize the counts.
2. Decrease the Z distance.
3. Move again XY axes to maximize the counts.
4. If you achieve higher counts than the previous step, repeat from step 2. If the counts are lower, increase the Z distance and repeat from step 3. If a maximum has been reached, since changing the Z distance reduces the counts, move to step 5.
5. Verify the plateau moving the XY axis.
6. The beam is focused!

Once the beam is focused, hold the XY axis by locking screws. During the locking operation, the beam may shift from the achieved optimal focusing position. Do not lock completely the three stage in one step to have the possibility to adjust the shift moving the XY axis:

1. Tighten the locking screw of one axis until the focus shift (look when the counts decrease)
2. Adjust the XY position to achieve the max count (if the screw is not completely tightened the XY axis can be moved). Do not move Z axis.
3. Repeat step 1-2 changing the axis until the axes are completely locked.

Finally, the same system assembled with a reflector collimator, is shown in Figure 6. It is worth noting an advantage of such assembly: since it is possible to screw a mini tube (from Thorlabs) in the collimator (see the tube between the xyz-stage and the collimator, it is possible to reduce the amount of stray light going to the detector without the use of black cover, which is anyway always recommended.

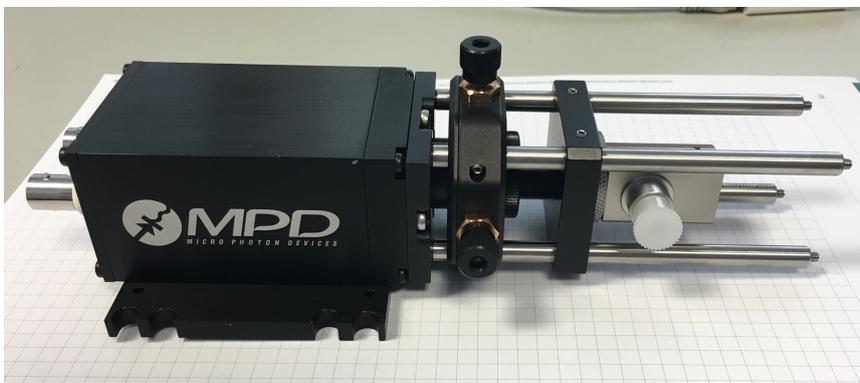


Figure 6. PDM with Thorlabs reflective collimator.

5. References

- [1] Mahnkopf, S., A. Giudice, D. Demmer, T. Haslett, and G. Simmerle. "Optoelectronic Packaging of Single Photon Avalanche Diodes." edited by Alexei L. Glebov and Paul O. Leisher, 100850C. San Francisco, California, United States, 2017. <https://doi.org/10.1117/12.2255556>.

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