CWDM Mux/Demux Passive Optical Interconnect

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Abstract: A novel concept for integrating the mux/demux functionality of coarse wavelength division multiplexing (CWDM) into passive fiber optic connectors via expanded beam ferrules is presented, including optical modeling and preliminary empirical results.

1. Introduction

Wavelength division multiplexing (WDM) offers an effective method of increasing fiber optic bandwidth by combining optical signals of different wavelengths into one optical fiber. The current WDM market is estimated to be worth over $10 billion, while increasing at a CAGR of greater than 10% through 2023 [1]. Network architectures utilizing WDM schemes typically use mux/demux discrete devices as common building blocks in cassette style distribution boxes, with single fiber connectors on a front panel that consume valuable rack space. WDM systems typically aim to pack as much data as possible onto the fewest possible optical fibers. Massive data pipes make perfect sense in the immediate region around switch chips that will soon be routing 50Tb/sec of data. However, bandwidth requirements decrease significantly as the data environment shifts from the core switch to the top of rack switch and finally to the individual compute and memory servers. This paper presents a novel expanded beam ferrule with integrated mux/demux capabilities, providing a compact, low cost, low insertion loss, solution that enables efficient and low cost bandwidth scaling to match local fabric requirements.

A coarse wave division multiplexing (CWDM) ferrule has previously been developed and produced for use in optically pluggable mid-board transceiver applications [2]. By utilizing the same ferrule in this design, existing manufacturing and development cost of the CWDM ferrule can be leveraged. Furthermore, to reduce the traditional mux/demux device costs, both ferrules in the design are injection molded and utilize low cost fiber termination by laser cleaving instead of polishing. Space required for the mux/demux is reduced from cassette-size to the size of a multi-fiber optical ferrule.

2. Design Concept

The system design is comprised of two lensed ferrules consisting of a CWDM ferrule and an expanded beam ferrule, as shown in Figure 1. The CWDM ferrule assembly is an injection molded plastic ferrule with an installed wavelength filter block that performs the mux and demux function. The terminated ferrule assembly contains a single row of 50 micron core conventional multimode fiber. The filter is a glass substrate with four discrete wavelength specific bandpass filters and is anti-reflection coated to reduce multi-path reflections. The CWDM ferrule/filter assembly functions as an optical bounce cavity, as shown in Figure 1b, where the light walks through the ferrule cavity reflected by the ferrule lenses and filter block until it hits a wavelength matched bandpass filter that allows it to exit to be coupled into the expanded beam ferrule.

The expanded beam ferrule contains four rows of similar multimode fiber arrays, each of which can carry one wavelength signal. When operating in the mux mode, the CWDM ferrule and filter combine the four wavelengths from each row of lenses exiting the expanded beam ferrule and couple them into a single multimode fiber. The ferrule/filter assembly performs the reciprocal function in the demux mode, separating the four optical signals by wavelength and directing them to the individual rows of the expanded beam ferrule. The CWDM ferrule can accommodate up to 16 fibers on a 250 micron pitch and the expanded beam ferrule can accommodate 4 rows of fibers with up to 16 fibers per row for a total of 64 fibers. The two ferrules are passively aligned with the use of molded guide pins and holes. The expanded beam ferrule has an array of wavelength insensitive lenses that expand the light before coupling to the CWDM ferrule. Due to larger spot diameter of the expanded beam ferrule, the ferrules are less sensitive to debris and lateral alignment errors. By passively performing the mux/demux operations on the fiber ribbon arrays, traditional multi-fiber fiber optic connectors and cables can be used throughout the rest of the system architecture in conjunction with this design to simplify high density cabling.

The filter is passively aligned and bonded into a precision molded pocket in the CWDM ferrule using a UV curable epoxy. The filter is installed during the ferrule termination process when the fiber is installed in a process similar to conventional lensed ferrule product [2]. Therefore, the CWDM ferrule is wavelength agnostic; if a different wavelength scheme is desired for a specific system architecture, a different filter can easily be installed during the cable build.

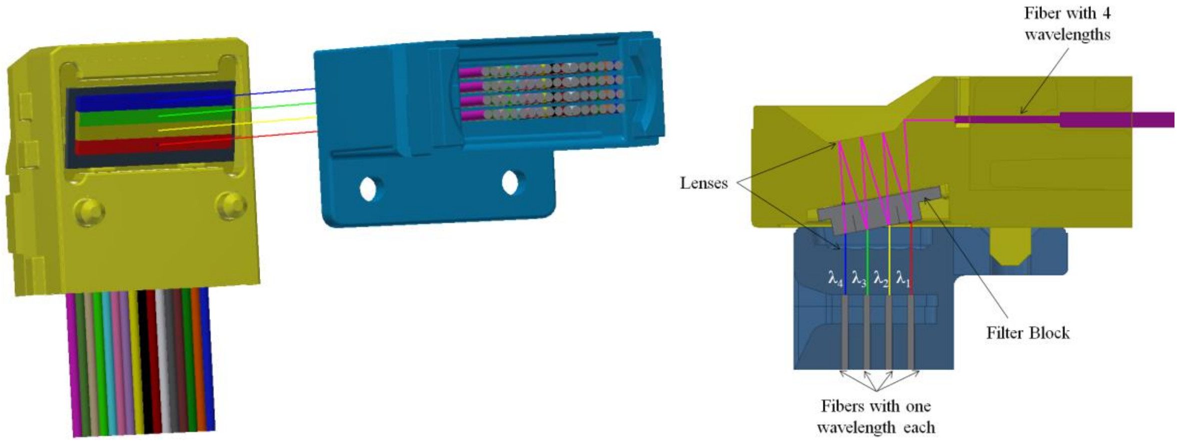

Figure 1. (a) Perspective view of the ferrules (b) cross-section view of the beam path.

3. Optical Modeling

An optical model of the proposed system was built in Zemax to study the expected performance and sensitivity of the system. The model uses the components identified in Figure 1, creates a multimode encircled flux launch condition inside mux fiber, and simulates the propagation through the CDWM ferrule, filter block, expanded beam ferrule, and coupling back into the demuxed optical fibers. Since the CWDM ferrule and filter block have already been previously designed, optimized, and fabricated [2], optimization in the current model focused on the expanded beam ferrule, which maximized optical coupling by adjusting the expanded beam lens prescription and position with respect to the CWDM ferrule. Optimized model results indicate the nominal system can couple light between the two sets of fibers with a theoretical mean loss of 0.6dB.

4. Prototype Test Results

In order to validate the concept, existing components were used to create the first prototype of the system. Unlike the components shown in figure 1b, the two existing ferrules are not designed to be mated directly to each other. Therefore, an adapter plate was 3D printed to align the two sets of guide pins and holes, thereby producing optical alignment between the ferrules. The current expanded beam ferrule is designed to function in mated pairs, and therefore the lens prescription and focal point are not optimized for coupling into the CWDM ferrule. A variant of the optical model was created that incorporates both the current non-optimized expanded beam ferrule lens prescription and measured data from the 3D printed adapter plate in order to make the optical model as predictive of the prototype test as possible. Combining typical performance data for the CWDM ferrule with the revised optical model indicates that coupling loss of about 2.05dB should be achieved between the CWDM ferrule and expanded beam ferrule with the printed adapter place.

Two different wavelength signals, 1015nm and 1065nm, were coupled into eight channels of the CWDM ferrule fiber array. Inside the CWDM ferrule, each wavelength was passively separated by the filter block into distinct paths and coupled into the individual fibers of the expanded beam connector, which had been connected to the CWDM ferrule via the 3D printed adapter plate (Figure 2). The power exiting the expanded beam ferrule fiber arrays was measured to compare to the initial launch power and establish system insertion loss. Average insertion loss was 1.6dB, with the majority of the channels under 1.5dB. The prototype performance was limited by the resolution of the 3D printed adapter plate, which did not have the same alignment precision as the molded ferrule components. Figure 3 shows the measured insertion loss for both 1015nm and 1065nm through the mux/demux system. In addition, the 2.05dB predicted insertion loss for the prototype system is shown on the chart, as is the expected mean performance for a fully optimized and molded ferrule system. The predicted 2.05dB loss was slightly higher than the measured loss due to conservative assumptions in the optical model of each ferrule lens prescription with respect to the adapter plate, and corresponding coupling efficiency.

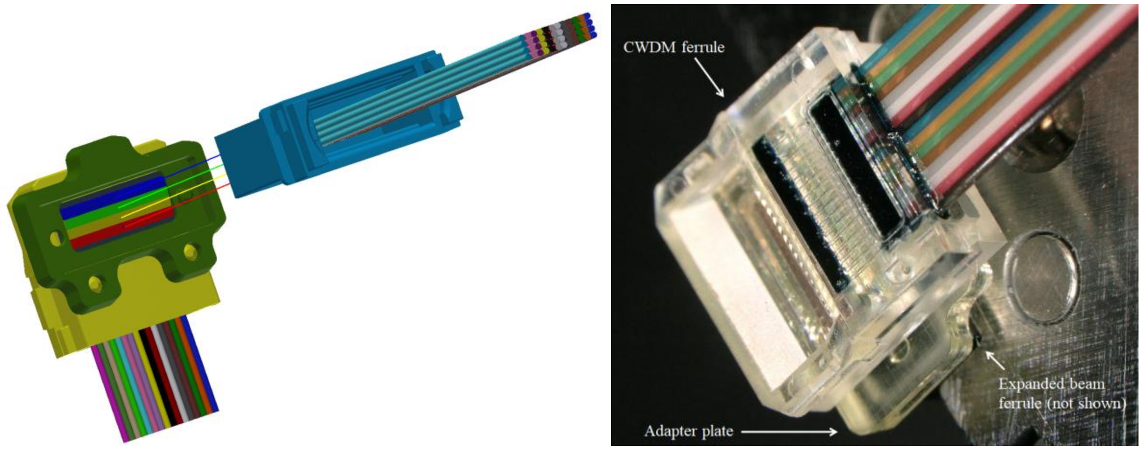

Figure 2. Prototype CWDM ferrule and expanded beam ferrule, with 3D printed adapter plate to couple components together.

Figure 3. Measured and theoretical insertion loss performance for the prototype two wavelength WDM system.

5. Summary

A novel compact, fully passive CWDM connector system has been proposed to provide mux/demux wavelength capabilities. The system uses low cost expanded beam fiber optic ferrules to provide wavelength mux/demux capabilities in traditional multimode fiber arrays in a compact, debris insensitive solution.

Using existing components, two wavelength demultiplexing has been successfully demonstrated simultaneously on eight fiber arrays with an average insertion loss of 1.6dB. Optical modeling of the optimized system demonstrated that an average loss of 0.6 dB, regardless of wavelength, should be achievable.

6. References

[1] https://www.globenewswire.com/news-release/2018/04/11/1468618/0/en/Global-Wavelength-Division-Multiplexer-Market-Will-Reach-USD-28-43-Billion-by-2023-Zion-Market-Research.html, accessed October 18, 2019.

[2] P. Rosenberg, et al., "CWDM transceiver for mid-board optics", Proc. SPIE 10109, Optical Interconnects XVII, 101090B (February 2017).

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