

# CAD model for co-propagating spatially multiplexed channels of same wavelength over standard multimode fibers

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## Abstract

Spatial Domain Multiplexing (SDM) is a novel technique that allows co-propagation of two or more optical communication channels of the same wavelengths over a single strand of optical fiber cable by maintaining spatial separation between the channels. Spatial multiplexer known as the beam combiner module (BCM) supports helical propagation of light to ensure spatial separation between the channels. It is inserted at the input end of the system. Spatial de-multiplexing is achieved by a unit named beam separator module (BSM). This unit is inserted at the receiving end of the system and it routes the optical energy from individual channels to dedicated receivers. Spatially multiplexed channels exhibit negligible crosstalk. The bandwidth of the fiber optic systems employing SDM technique increases by multiple folds. CAD model of a beam combiner module for a two channel system using commercially available simulation tools is presented here. Simulated beam profile of the output is compared to the experimental data.

**Keywords:** Multiplexing, Spatial Domain Multiplexing, Optical Fiber, CAD, Bandwidth.

## 1. INTRODUCTION

In a standard SDM [1,2] system two or more pigtailed single mode laser diodes operating at the same wavelength are used as input fibers to launch light into a standard multimode carrier fiber. The input fibers are aligned in a fashion that they launch light into the carrier fiber at different angles [3]. Light from each of these sources traverses the entire length of the fiber following helical path [4]. They do not interfere with each other and exit the fiber in the form of concentric circles [5] such that all SDM channels are confined to unique spatially allocated locations [6] inside the carrier fiber. The arrangement of the input fibers and their relative orientation with respect to the carrier fiber is strictly controlled with the help of Beam combiner Module (BCM) [4]. The CAD model for the BCM unit is composed of input fibers that are fused in a fashion that complies with the necessary requirements of constrained beam launching [7] into the carrier fiber. The CAD model of the BCM is designed using commercially available OptiBPM waveguide design software [8].

## 2. EXPERIMENTAL SETUP

Fig. 1 shows the block diagram of a SDM Beam Combiner Module (BCM). Two pigtailed laser sources are used to launch light into a carrier fiber at different angles. This arrangement of launching light from the two sources results in two spatially separated beams that do not interfere within each other and the output of such a system results in a spot and a ring when projected on a screen perpendicular to the axis of the fiber.

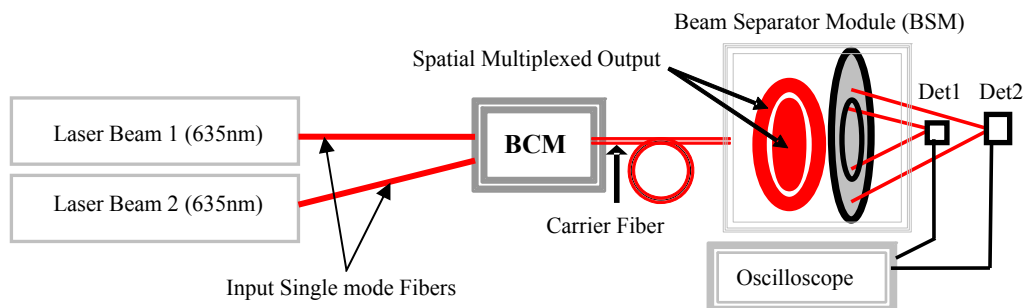


Fig. 1. Block diagram of a Beam Combiner in SDM system

Fig. 2(a) shows the experimental setup of BCM unit. Two pigtail laser sources with single mode fibers are used as input fibers to launch light into a single strand of 62.5/125 $\mu\text{m}$  standard multimode carrier fiber. The input fibers are tapered and the first fiber is aligned at two degree angle with reference to the carrier fiber. The second fiber is also tapered and aligned at 18 degrees with reference to the carrier fiber. Fig. 2(b) shows the simulated setup and propagation through the carrier fiber while 2(c) shows the CAD design layout of the BCM unit. Two dimensional and three dimensional beam propagation operation is then carried out using Optiwave design software and the output is compared with experimental data.

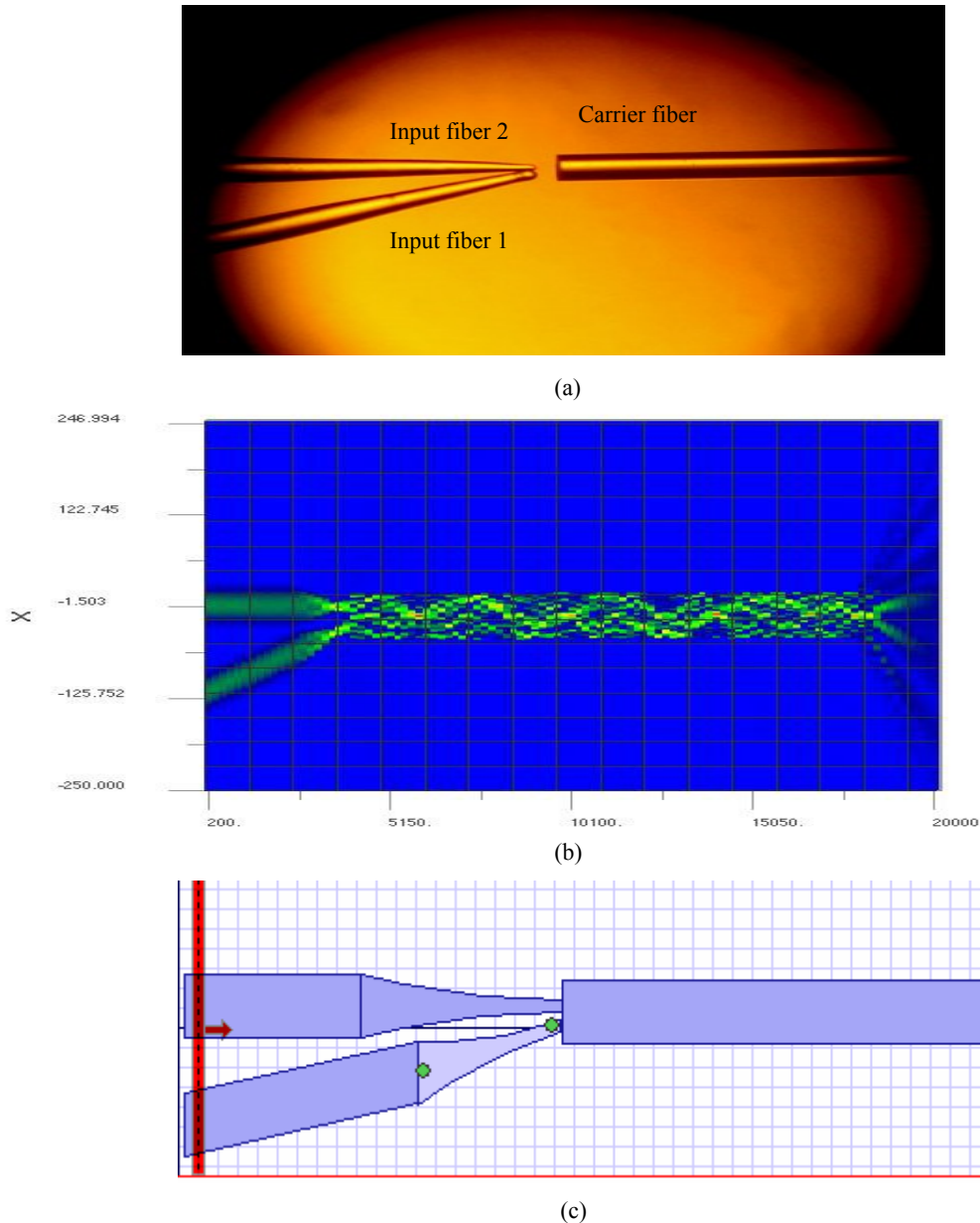


Fig. 2 (a) Experimental setup of Beam Combiner Module  
 (b) Simulated beam propagation through carrier fiber  
 (c) CAD layout of a Beam Combiner Module for SDM system

Fig 3 (a) and (b) show the simulated and experimental intensity plot of two spatially multiplexed output of the BCM. Inside the carrier fiber the two channels traverse the length of the fiber in a helical path, which causes the formation of the circular rings at the output. The intensity of helical beam approaches zero at the intersection of the two channels indicating that the two channels have negligible crosstalk between them. The trend of the results of the simulated BCM unit matches the real world data however the model is currently being refined to develop better correlation between the simulated and experimental results.

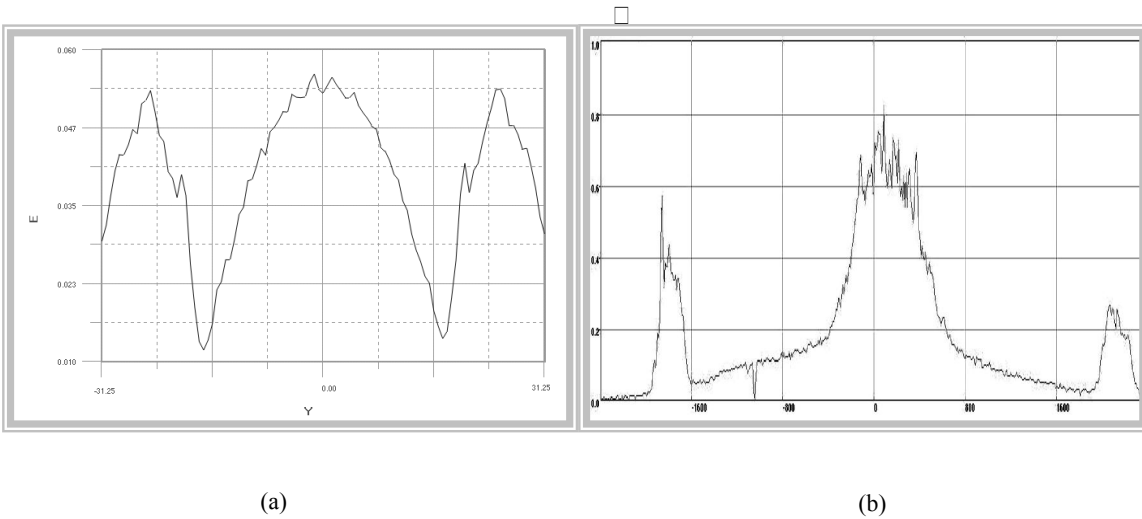


Fig. 3(a) Simulated 2-D intensity plot of two spatially multiplexed output channels  
 (b) Experimental 2-D intensity plot of two spatially multiplexed output channels as seen by a CCD camera

Fig. 4 (a) shows the simulated 2-D screen projection on a plane perpendicular to the axis of propagation. The experimental 2-D screen projection is presented in Fig. 4(b) while Fig. 4(c) shows the same view as seen by a CCD camera.

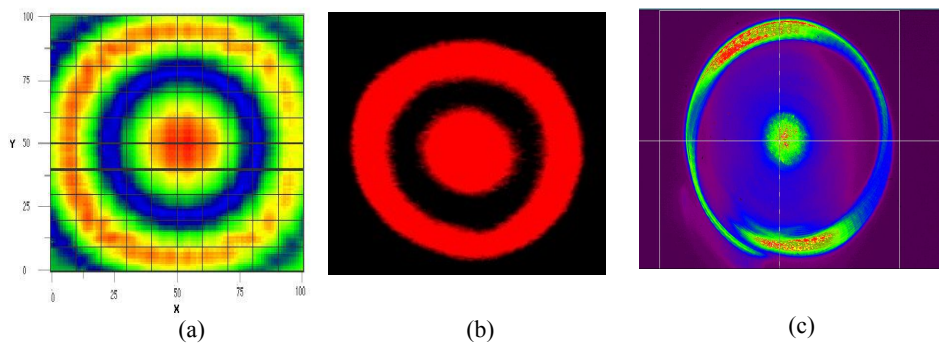


Fig. 4(a) Simulated 2-D Beam Profile perpendicular to direction of propagation  
 (b) Experimental 2-D Beam Profile perpendicular to direction of propagation  
 (c) Experimental 2-D Beam Profile captured using a CCD camera

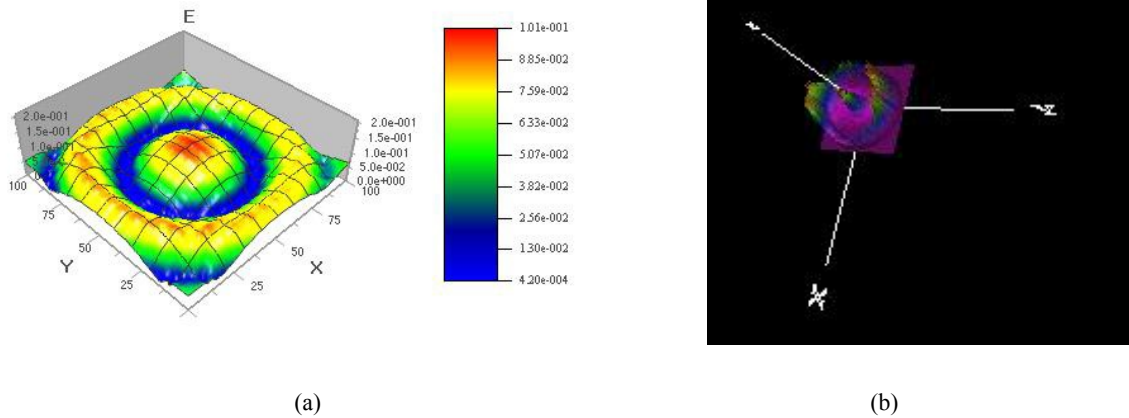


Fig. 5 (a) Simulated 3-D profile of two SDM channels  
 (b) Experimental 3-D profile of two SDM channels captured by CCD camera

The 3-D beam profile for two channel SDM system is shown in Fig. 5. Fig 5(a) presents the simulated 3-D profile generated from CAD whereas Fig 5(b) presents the experimentally generated 3-D beam profile acquired with the help of a CCD camera. The energy densities [9] of the two channels are confined to different spatial locations and the two channels do not interfere with each other. As a result this novel multiplexing method can be applied to increase the bandwidth of optical fibers many times over. Despite reasonable similarities between the simulated model and experimental data there are discrepancies in the dimensions of the energy density of the central spot. Therefore the CAD model is currently being refined and we plan to report the results from the refined CAD model in the near future.

In order to determine the system performance of the CAD based system, the CAD model is imported into commercially available OptiSystem [10] software to simulate an optical communication link. This simulation provides optical communication link parameters such as attenuation, dispersion and bit error rate. The OptiSystem layout is shown in Fig. 6.

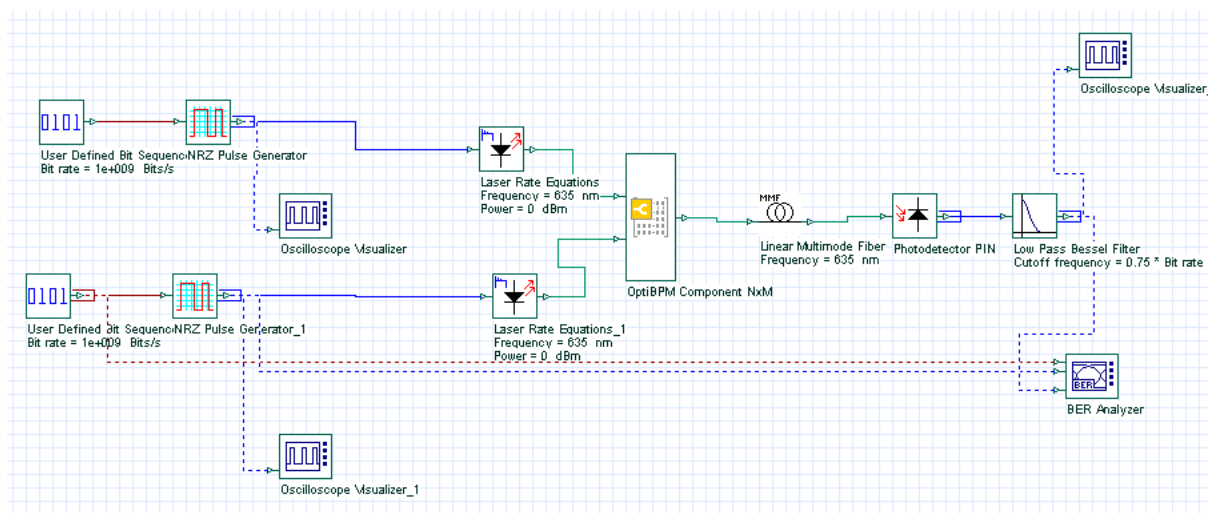


Fig. 6. Layout of two channel SDM system designed in OptiSystem

Two 635 nm laser sources are connected to the two inputs and the laser sources are modulated independent of each other using external modulating sources. The NRZ square pulses transmitted over the center channel and the outer channel of the BCM are spatially multiplexed through the simulated BCM design. The output of the two channels show no discernable cross talk after propagating a distance of one kilometer inside the carrier fiber as seen by the oscilloscope trace in Fig. 7.

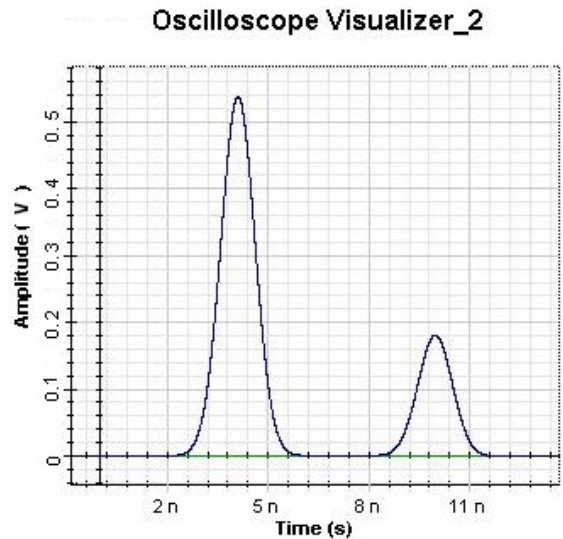


Fig. 7. Oscilloscope view of two-channel multiplexed over a single multimode fiber in a SDM system

### 3. CONCLUSION

CAD model of a beam combiner module for a two channel SDM system is presented. The results from the simulated system reasonably match the results obtained from the experimental setup. The CAD model is currently being refined to develop better agreement between the simulated and experimental versions. This CAD model was also successfully integrated into commercially available optical link design software, which will lead to rapid and inexpensive development of the SDM systems.

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