The Ultimate DWDM Format in Fiber - True Bit-Parallel Solitons on WDM Beams

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Abstract

Whether true solitons can exist on WDM beams (and in what form) is a question that is generally unknown. This paper will discuss an answer to this question and a demonstration of the bit-parallel WDM transmission.

Summary

In general there are two distinct ways of transmitting data bytes under the WDM format in a single fiber: (a) The serial format (the traditional way) - Bit streams representing bytes are line-up in a serial manner and launched on a single wavelength beam. Under the WDM scheme, multiple beams of different wavelengths, each carrying its own data load, can propagate simultaneously in a single mode fiber. Each different wavelength beam represents a single channel and each channel is independent of the other channels. Any interaction between pulses on different wavelength beams is to be minimized. (b) The parallel format (the bit-parallel way) - Bits representing each byte are time-aligned in a parallel manner. These parallel time-aligned bits are launched simultaneously on multiple different wavelength beams. These beams are sent through a single mode fiber. Unlike the serial case, these copropagating pulses on different wavelength beams must retain their time alignment with each other.

For many high performance computing environments [1] or high volume internet connections, the input parallel electrical pulses must first be converted into a series of single electrical pulses which are then launched on different optical wavelength beams into a single-mode fiber. This is the traditional serial WDM format. For ultra-high data rate, this parallel-to-serial-and-serial-to-parallel electronic bottleneck may occur. Under the alternative bit-parallel WDM format, no parallel-to-serial conversion of the input electrical signal is necessary, parallel pulses are launched simultaneously on different wavelength beams. This provides a powerful motive for our quest for the bit-parallel WDM scheme.

Another powerful motive is to learn whether true solitons can exist in a WDM environment. Because, if this scenario exists, it can represent the ultimate DWDM case. Furthermore, the inherent difference between the serial WDM case and the bit-parallel WDM case - one demands the avoidance of pulse interaction between neighboring beams while the other demands the intimate pulse interaction between neighboring beams - may indicate that true WDM solitons can only exist in one case and not the other.

The fundamental equations governing M numbers of co-propagating waves in a nonlinear fiber including the linear group-velocity dispersion (GVD) effect, the nonlinear self-phase modulation (SPM) effect and the nonlinear cross-phase modulation (CPM) effect are the coupled nonlinear Schrodinger equations [2]. We have been able to solve these equations numerically. In the following we shall discuss the existence of WDM solitons and the experimental results on a two beam bit-parallel WDM propagation in a single-mode fiber.

A. <u>Existence of optical WDM solitons</u>

We shall discuss our recent discovery [3] that temporal solitons can exist on WDM beams in a single fiber under appropriate conditions. Simple analytic expression for the initial fundamental optical solitons on wavelength division multiplexed (WDM) beams in a nonlinear fiber has been found. For an ideal fiber with no loss and uniform group velocity dispersion (GVD) in the anomalous GVD region, the initial form is $(1 + 2(M-1))^{-1/2}$ sech(t), where M is the number of WDM beams and t is the normalized time. Computer simulation shows that these initial pulses on WDM beams in this fiber will propagate undistorted without change in their shapes for arbitrarily long distances. Discovery of the existence of solitons on WDM beams means that the ultimate DWDM format in a single fiber must take this form.

B. <u>Laboratory demonstration of a two-beam bit-parallel WDM format</u>

Two beams from two laser diodes whose wavelengths are 1530 nm and 1545 nm, are modulated by nano-second size pulses. These beams are coupled simultaneously into a Corning DS fiber. These nano second size pulses were well aligned at the entrance of the fiber link. The spool of Corning DS fiber used for our experimental link was 25.2 km long. From the output, we can readily measure the shift or the walkoff between these pulses - it was 200 ps or 6 ps/km. It is noted that the experimentally measured walkoff of 200 ps for this two wavelength BP-WDM demonstration is well within the allowable setup and hold time for the standard ECL logic which is 350 ps for a bit period of 1 ns.

This experiment shows that nanosecond size pulses on two BP-WDM beams at 1530nm and at 1545 nm can be successfully transmitted through a 25.2 km long Corning DS fiber with acceptable walkoff which is well within the allowable setup and hold time of standard ECL logic circuits. The maximum walkoff between any beams located within the wavelength range of 1530nm and 1560 nm is 200 ps. This result implies that 30 bit-parallel beams spaced 1 nm apart from 1530 nm to 1560 nm, each carrying 1 Gbits/sec signal, can be sent through a 25.2 km Corning DS fiber at an information rate of 30 Gbits/sec. This means that the speed-distance product for this link is about 94 Gbytes/sec-km [4]. (Another way of achieving bit-parallel WDM transmission was recently carried out by the Ipswich group [5] using dispersion managed fibers. There, bit-skew may be corrected by the use of alternate sections of high positive and negative dispersion fibers.)

References

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