Title: Optical Transmission System Using Dual Solitons

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Abstract

A densely dispersion managed soliton (DDMS) [1] system design that alleviates the adverse effects of inter-pulse interaction and Gordon-Hauss timing jitter, is presented. This design is based on the judicious selection of dispersion map parameters using comprehensive computer simulation tools [2]. The design is made using commercially available non-zero dispersion shifted fibers (NZDSF) over 1000Km. Two waves were launched each having a data rate of 60Gb/s and a separation of 240Ghz, this providing a 120Gb/s system design over that distance.
Introduction

Soliton systems have lead to a quantum jump in the bit-rates in fiber optic system and maybe the next generation in fiber communications. The basis dispersion managed soliton (DMS) approach, in which the length of the dispersion map is greater than or equal to the amplifier spacing, has been successfully used to construct long-haul fiber optic systems with low bit-rates (10-40Gb/s) [3]. However the technique has not been highly successful for running higher bit-rate systems with multiple WDM bit streams. Since DMS fails to provide enough accumulated dispersion to properly manage the timing jitter caused by ASE noise and inter-pulse interaction, unacceptable inter-symbol interference (ISI) occurs as the propagation distance approaches or exceeds 500Km. Hence DMS systems degrade over distances above 500Km for high bit-rates [5, 6].

Richardson, et.al. [1] have proposed the DDMS scheme for propagating high bit-rate systems. Such systems have multiple dispersion maps between erbium-doped fiber amplifiers (EDFA0. Each dispersion map has a net positive dispersion over the spans between amplifiers. This helps mitigate the effects of the addition of ASE noise from the amplifiers and inter pulse interaction as well as four wave mixing. The success of DDMS systems has been demonstrated by several experiments. In 1999 paper, a 100Gb/s train of DMS has been achieved over a distance of 1000 km [7]. Another technique to achieve high data rate soliton systems that has been used recently is the Average Decreasing-Dispersion Dispersion Managed Soliton (A4DM) Systems. This technique involves the use of a repeating map with the average dispersion of the map decreasing with the distance. This leads to higher stability of the pulses. But the major drawback of such a
system is the complexity involved in constructing a system which has pieces of different fibers.

The approach we have followed is far simpler as compared to an A4DM system. We have attempted to use a single DDM map which is repeated over the amplifier span and has a positive net dispersion. We have tried to propagate two 60Gb/s soliton pulses each having a pulse width of 4.4 ps each at a channel spacing of 240 GHz centered around 193.1 THz in standard non-zero dispersion shifted fibers (NZDSF). This has been achieved with an amplifier span of 25Km. We have successfully demonstrated the propagation of highly stable pulses over a distance of 1000Km and to the best of our knowledge such a system has not been constructed previously.

Map Design and Setup

The above figure (see Figure 1) portrays the schematic representation of a dispersion map for a DDMS system [9]. The Dispersion map period is much smaller as compared to the amplifier spacing. The dispersion map is a solution to the non-linear schrödinger’s equation. A suitable dispersion map is the key to solving the problem of long distance dispersion managed propagation; our dispersion map was decided after

![Image of DDMS System](image)

**Figure 1.** DDMS System

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several trials of different maps. The 25km dispersion map which we used consists of repetitions of three fibers. A negative dispersion NZDSF with a dispersion of -2.60 ps/nm.Km with a core area of 55µm² for a distance of 7.5 Km, followed by positive dispersion NZDSF with a dispersion of 3.95 ps/nm.Km and core area of 55µm² for a distance 10Km. We have neglected the third order effects from the system by setting the third order group velocity dispersion (GVD) parameter to zero, and similarly setting the dispersion slope to a specific value, which is given by:

\[ Dispersion\_Slope = -2 \times Dispersion \times \frac{Frequency}{Speed\_of\_Light} \]  

(1)

This has been done keeping in view that a higher order mode compensator is commercially available. The higher order mode dispersion compensator module (HOM-DCM) is based on conversion of LP\(_{01}\) to LP\(_{02}\) to achieve high dispersion and dispersion slope values. A HOM of a dispersion slope of 1.35 ps/nm\(^2\) should be able to compensate for the 95% of dispersion slope through the graph. The use of a HOM increases the distance of propagation for over 300Km. The HOM-DCM should be placed after each amplifier span. An EDFA with an amplification of 10 dB is used to compensate for the 0.2 dB/Km fiber loss and a 300 GHz filter is inserted in the loop to remove the ASE noise inserted by the amplifier.
We have used Gaussian pulse transmitters, and each pulse is transmitting a pseudo random bit sequence with a length of 16 bits. The pulse width used is 4.39 ps, and these pulses are pre-chirped using a DSF fiber to compensate for the pulse broadening over the dispersion map. To compensate for the unaccounted losses due to HOM-DCM and polarization mode dispersion (PMD), we have considered a much higher value of the Q-factor and BER for our system.

The dispersion map used for our system provides for an excellent trade-off between the conventional fiber optic systems and high map density systems. The conventional systems with longer map length don’t offer the same stability to high bit-rate pulses. On the other hand, dense dispersion maps faces difficulty in implementing since it requires large number of various fiber pieces. Our system provides for a good degree of pulse stability along with a practically implementable dispersion map.
Results

Best values for the channel spacing and map strength were found by running a sweep of the channel spacing between 150 – 300 GHz, and the map density between 1–10 for our 1000 Km system. The goal was to run the sweep, analyze the resulting data, and to find the parameters which will give us the best Q-factor for the both channels of the system. Because we were multiplexing both channels and were sending the signal through the single fiber we had to find the one unique set of parameters which will give us good results for both channels. After running the sweep we concluded that the system was performing the best for both channels by using the channel spacing of 300 GHz which corresponds to an actual channel spacing of 240 GHz between the channels as specified in the setup and the map density of 1. This can be observed in Figure 4 and Figure 5 below.

Figure 4. Graphical representation of sweep results for Channel 1 (The best result is circled).
Figure 5. Graphical representation of sweep results for Channel 2 (The best result is circled).

The best set of parameters achieved by the Q-factor for channel 1 was 9.02 and 14.26 for channel 2. These two Q-factors relate to bit error rate (BER) of $9.45\times10^{-20}$ and $1.44\times10^{-46}$ respectively. The validity of the parameters can be observed in the eye diagrams of the output for both channels (see Figure 6).

Figure 6. Output eye diagrams for channel 1 and channel 2
We can notice that in our case the width of the eye opening which represents that the time interval over which the received signal can be sampled without any error is satisfactory, and also the height of an eye opening that shows the noise margin or immunity to noise is acceptable.

**Conclusion**

We have demonstrated that the DDMS technique can be effectively used to create a $2 \times 60$ Gb/s dual channel soliton transmission system with the use of NZDSF±. Through a careful design of a re-circulating 25 Km dispersion map, we have created a system $2 \times 60$ Gb/s soliton transmission system which operates well over the distance of 1000 Km with a pre-compensation fiber with Q factors of 9.02 and 14.26 for Channel 1 and Channel 2 respectively. This performance of our system is however severely limited by the PMD and TOD. However this system is an important step towards creating a transoceanic $2 \times 60$ Gb/s soliton system using dense dispersion management.
REFERENCES

[2] VPItransmission Maker™ WDM, Virtual Photonics, Inc., Landsberger Str.6, D80339, Germany.