A Comparative Study of Pulse Interactions in Optical Fiber Transmission Systems with Different Modulation Formats

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SUMMARY

One of the principal problems in the design of high-data rate optical fiber communications systems is the choice of the modulation format. The conventional non-return-to-zero (NRZ) format was the first format employed in optical fiber communications, and it remains the predominant modulation scheme at this time. The NRZ format has evolved into the chirped return-to-zero (CRZ) format, where both phase and amplitude modulation are used to improve the system performance. At the same time, there has been a considerable amount of work done to investigate the possibility of using classical solitons in optical fiber communications [1]. The classical soliton format eventually evolved into the dispersion-managed soliton (DMS) format. Classical and dispersion-managed solitons are similar in important respects. For example, the balance between chromatic dispersion and nonlinearity is the key condition for the existence of periodically stationary dispersion-managed solitons. By contrast, the CRZ pulse shape is not periodic and the pulse evolution is mostly determined by the dispersion. However, we find that with respect to nonlinear pulse interactions, the DMS and CRZ systems resemble each other and their behavior differs dramatically from that of classical soliton systems. We stress that in our work here, when we refer to a DMS system, we mean a periodically-stationary DMS system like in [2] rather than a quasilinear DMS system like in [3]. The quasilinear DMS systems resemble CRZ systems more than they resemble the periodically-stationary DMS systems [4]. We will demonstrate that in the DMS and CRZ systems, the performance degrades as the number of frequency channels increases, as opposed to classical soliton systems, where adding channels does not affect the performance.

In this work, we use a periodically stationary DMS system based on the system described in [2]. The chirped return-to-zero system is based on the system presented in [5]. The classical soliton system is constructed from a lossless fiber with an anomalous dispersion. All the systems are designed for a 10 Gbit/s data rate transmission. We use a 64-bit random pattern, which repeats periodically. To characterize the system performance, we use electrical eye diagrams obtained by squaring the electrical signal and then passing it through a fifth-order Bessel filter with an 8 GHz bandwidth. Figures 1a, 1b, and 1c correspond to the classical soliton, DMS, and CRZ systems respectively. The left, middle, and right parts of each subfigure show the eye of the central channel in systems with two, three, and five frequency channels respectively. The propagation distance in the classical soliton and DMS systems is 10,000 km, and it is 6,000 km in the CRZ system. We will show animations of the eye diagram evolution with distance. We find that in both the DMS and CRZ systems, the eye closes faster with three channels, and even faster with five. This behavior is consistent with a simple physical picture, in which four-wave mixing interactions increase because the number of sideband frequencies grows rapidly with the number of channels [6]. By contrast, we note that the eye closure does not change as the number of channels increases in the classical soliton system. This behavior is consistent with the fact that multiple collisions of classical solitons are a superposition of pairwise collisions [1].

We have also studied single collisions in systems where only one pulse per channel is launched. We will show animations to demonstrate the collision dynamics. When two classical solitons collide, we observe that the sidebands grow as the pulses approach each other, reach a maximum at the point in which the pulses completely overlap, and finally decay back to zero after the pulses separate. This

reabsorbtion of the sideband energy is one of the remarkable properties of classical solitons [7]. The behavior of the DMS as well as the CRZ system differs significantly. In both the DMS and CRZ systems, the sideband frequencies rise on average as the pulses move towards each other and do not decay after the collision. This key difference from the behavior of the classical solitons is caused by dispersion management and the presence of fiber loss and amplification. When we consider three-pulse collisions, the situation does not change with the classical solitons, because a collision of three pulses is a superposition of two-pulse collisions [1]. Thus, we find that the sideband energy is again reabsorbed after the collision. By contrast, in both the DMS and CRZ systems, we find that the sidebands do not decay and the effect of three-pulse interactions is stronger than the effect of two-pulse interactions.

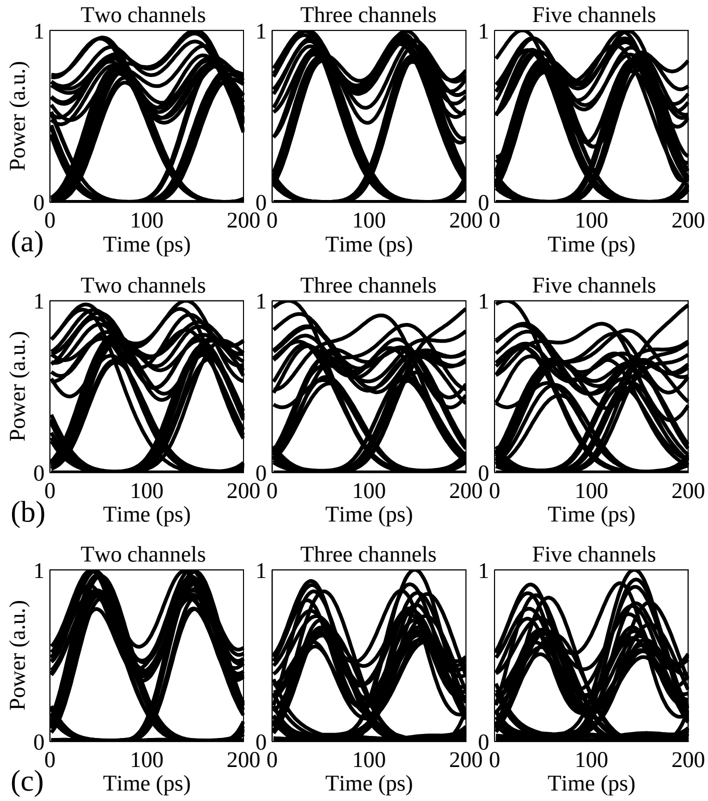

Fig. 1. Eye diagrams of the central channel in the (a) classical soliton, (b) DMS, and (c) CRZ systems at the end of the transmission line.

This behavior allows us to understand the performance of multichannel systems with bit streams in each channel. It is also consistent with a simple physical picture, in which the behavior of classical solitons is fully described by pairwise interactions. This is not true for the DMS and CRZ systems, which suffer increased degradation as the number of channels grows due to proliferation of four-wave mixing products. Even though the dispersion-managed solitons developed from classical solitons and have important properties in common with them, nonlinear interchannel interactions in DMS systems are quite different from those of classical solitons and resemble interactions in CRZ systems.

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