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Role of HNLF Dispersion in Optimizing the Performance of an MTR

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Abstract— *we investigate numerically the interplay between dispersion and nonlinearity for optimizing the performance of an optical 2R regenerator based on self-phase modulation and spectral filtering at 40 GB/s. By considering the extent of improvement in the factor (related to level of noise reduction), we show that the ratio of accumulated dispersion to the maximum nonlinear phase shift can be used to predict the performance of regenerators making use of fiber with very different lengths, dispersions, and nonlinear parameters. Our results show that fiber dispersion plays an important role and needs to be properly optimized. In general, fibers with larger dispersion perform better but require higher input powers.*

Keywords: ASE, SPM, EDFA

I. INTRODUCTION

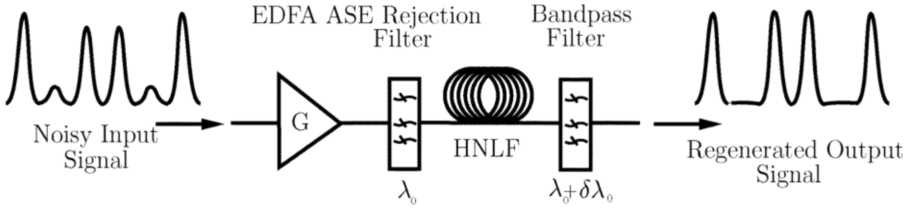
ALL-OPTICAL regeneration is a promising candidate for replacing optoelectronic regenerators that are currently employed in multichannel light wave systems operating at bit rates of 40 GB/s or more. At such high bit rates, the optical signal undergoes degradations through sources such as amplified spontaneous emission (ASE), chromatic dispersion, and various nonlinear effects. To restore the signal quality, some optical regenerators make use of a nonlinear process within a highly nonlinear fiber (HNLF) designed to enhance the nonlinear effects. Indeed, optical regenerators have been made making use of self-phase modulation (SPM), four-wave mixing, nonlinear optical loop mirrors, and two-pump parametric processes in HNLFs.

Among various regenerator configurations, the 2R regenerator based on SPM-based spectral broadening, followed by spectrally offset filtering, has received much attention owing to the ease of its implementation, scalability to high bit rates and multiple channels, and ease with which a retiming stage can be integrated with it to provide a 3R regenerator. Such regenerators are also known as the Mamyshev-type regenerator (MTR), and considerable work has been done to optimize their performance. Among other things, the impact of residual dispersion, ASE noise, and filter offset, and two-photon absorption has been thoroughly investigated, both theoretically and experimentally. Several studies have focused on the optimization of MTR parameters. Numerical simulations for MTRs have been used to deduce scaling rules and to show how its performance depends on device and signal parameters. In spite of these studies, much less attention has been paid to the role played by the HNLF dispersion in optimizing the regenerator performance. It has been commented that fiber dispersion affects the launched input power needed for optimum regeneration. It has also been claimed that high normal dispersion of the HNLF improves the regenerative capability of an MTR.

In this paper, we investigate numerically the role of the HNLF dispersion in optimizing the performance of an MTR. In particular, we show how the magnitude of fiber dispersion affects the shape of transfer function and the operating point of an MTR. In this paper after a brief discussion of the MTR principle and the simulation technique in Section II, in Section III the results on the scaling rule related to the dispersion and nonlinear parameters of the HNLF used to make the MTR are shown. Specifically, we calculated numerically the MTR transfer function and the extent of Q-factor improvement for specific MTR configuration. Further resilience of an MTR to dispersion variation is studied and the main results are summarized at the end.

II. DETAILS OF THE NUMERICAL SCHEME

The schematic of a single-stage MTR is



It employs a high-power erbium-doped fiber amplifier (EDFA) to boost the peak power of the incoming noisy signal to the power level that is high enough to cause spectral broadening through the SPM. The amplified signal is first passed through an ASE rejection filter that rejects the out-of-band ASE noise added by the high-power EDFA. The ASE filter is

centred at the signal wavelength. The bandwidth of the filter is chosen to be wider than the signal bandwidth. Noise in the output signal is reduced when the signal spectrum, broadened nonlinearly inside the HNLF, is filtered by a bandpass filter. The filtered signal is injected into the HNLF, where it experiences SPM and its spectrum broadens considerably. The HNLF is characterized by its length, loss,dispersion, and the nonlinear parameter. The optical bandpass filter (OBPF) placed after the HNLF is offset from the signal wavelength by a certain amount so that it allows only a slice of the signal spectrum to pass through. The bandwidth of the output filter sets the output pulsewidth .The filtered signal is a cleaned-up version of the input with reduced noise, but it is offset from the original wavelength by a certain amount.
A parameter that plays a crucial role for the MTR operation is the maximum nonlinear phase shift occurring at the centre of the pulse where optical power peaks.
In the presence of dispersive effects, the spectral broadening inside an HNLF depends both on the nonlinear and dispersion parameters. Since nonlinear effects cannot be solved analytically in this case, we solve it numerically using the well-known split-step Fourier method. The nonlinear phase rotation method is used to estimate the required step size.
Our simulations are carried out for a 40 GB/s signal (in the form of a return-to-zero (RZ) bit stream) with the OptiSystem software (supplied by Optiwave). Fig. 2 shows the block diagram used for numerical simulations. The continuous-wave (CW) laser and the data encoder create the data in the form of a pseudorandom bit sequence consisting of 64 b. Each 1 b contains a Gaussian pulse with a full width at half maximum of 7.5 ps (a 30% duty cycle) at a carrier wavelength of 1550 nm.

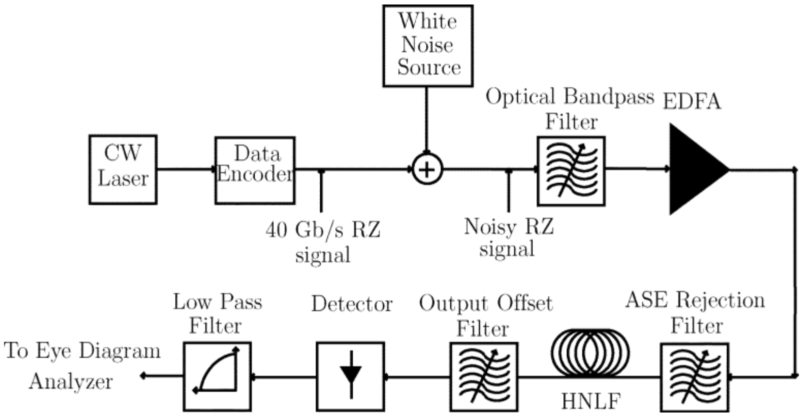


Fig. 2. Setup used for simulating numerically the operation of an MTR.

A white-noise source adds broadband noise to the incoming RZ signal to simulate the degradation of the Q factor associated with the bit stream. The bandwidth of the OBPF is adjusted to achieve the desired Q-factor degradation. This filter is a fourth-order super Gaussian filter with a bandwidth of 1.33 nm. The high-power EDFA has a noise figure of 5.5 dB. The ASE rejection filter shown in Fig. 2 is identical to the OBPF used before the EDFA, and its role is to suppress the ASE noise over the passband of the output offset filter, which selects a part of optical spectrum at the output of the HNLF. It is chosen to be a first-order Bessel filter with a spectral width of 0.47 nm and a spectral offset of 0.6 nm. The filtered optical bit stream is converted into an electrical bit stream using a detector, followed with a low-pass Bessel filter with a cut off frequency of 25 GHz. The resulting electrical signal is used to calculate the output Q factor.

III. ROLE OF DISPERSION

In this section, we analyse the performance of an MTR by considering the interplay between the dispersive and nonlinear effectstakingplace simultaneouslyinside the HNLF. In practice, the HNLF length can vary from a few meters to a few kilometres, depending on the fiber design and material used to fabricate the HNLF. In particular, the required length is much smaller for microstructured fibers because the nonlinear parameteris much larger for them.
In communication technology, "dispersion" is used to describe any process by which an electromagnetic signal propagating in a physical medium is degraded because the various wave components (*i.e.*, frequencies) of the signal have different propagation velocities within the physical medium. In an optical fiber, there are several significant dispersion effects, such as material dispersion, profile dispersion, and waveguide dispersion, that degrade the signal. In classical optics, *"dispersion"* is used to denote the wavelength dependence of refractive index in matter, (*dn/dλ*, where *n* is the refractive index and λ is the wavelength) caused by interactionbetween the matter and light.
We have found through extensive simulations that the combined effects of dispersion and nonlinearity on the MTR performance depend on the ratio between accumulated dispersion and maximum nonlinear phase shift.
The corresponding peak power P_0 of the 7.5-ps Gaussian input pulses varied from 0 to 3 W. The amount of noise added by the white-noise source was controlled to set the input value of the factor to 13. For each value ofP_{in}, we obtain the average output power at the exit of the MTR and also calculate the output factor.
The input average power was kept fixed at 320 mW, as one may expect, ΔQ changes when the dispersion of the HNLF deviates from its original value. However, we found that the Q factor can be improved even beyond the peak value if the dispersion is lower by about 10%.
It appears that there exists an optimum value of dispersion for a given value of the nonlinear parameter associated with an HNLF.

IV. OPTICAL SIMULATIONS

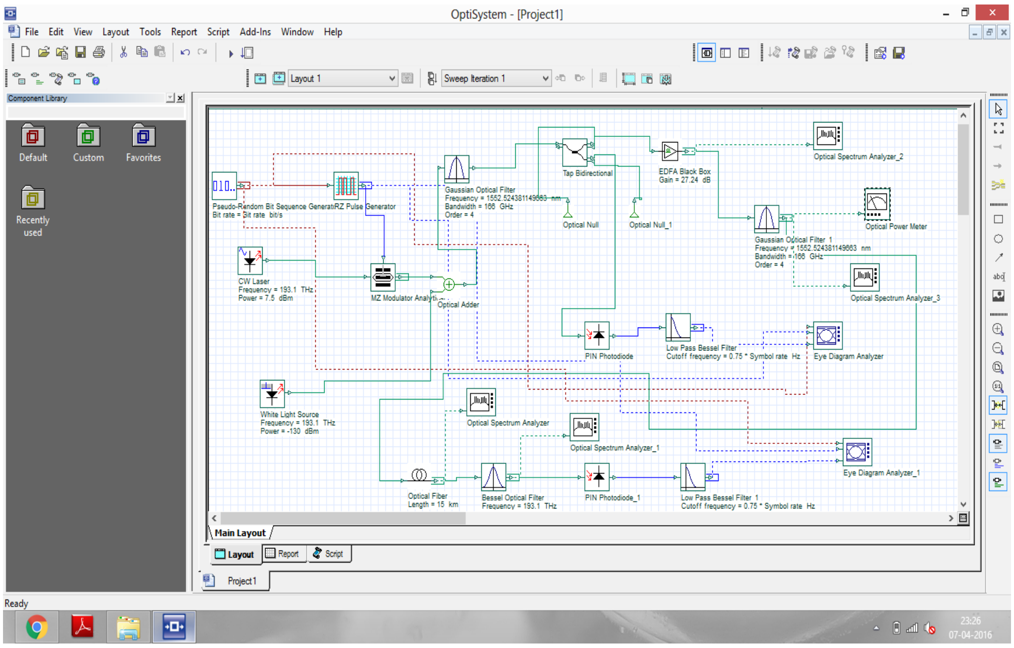


Fig: showing the simulation diagram using OptiSystem.

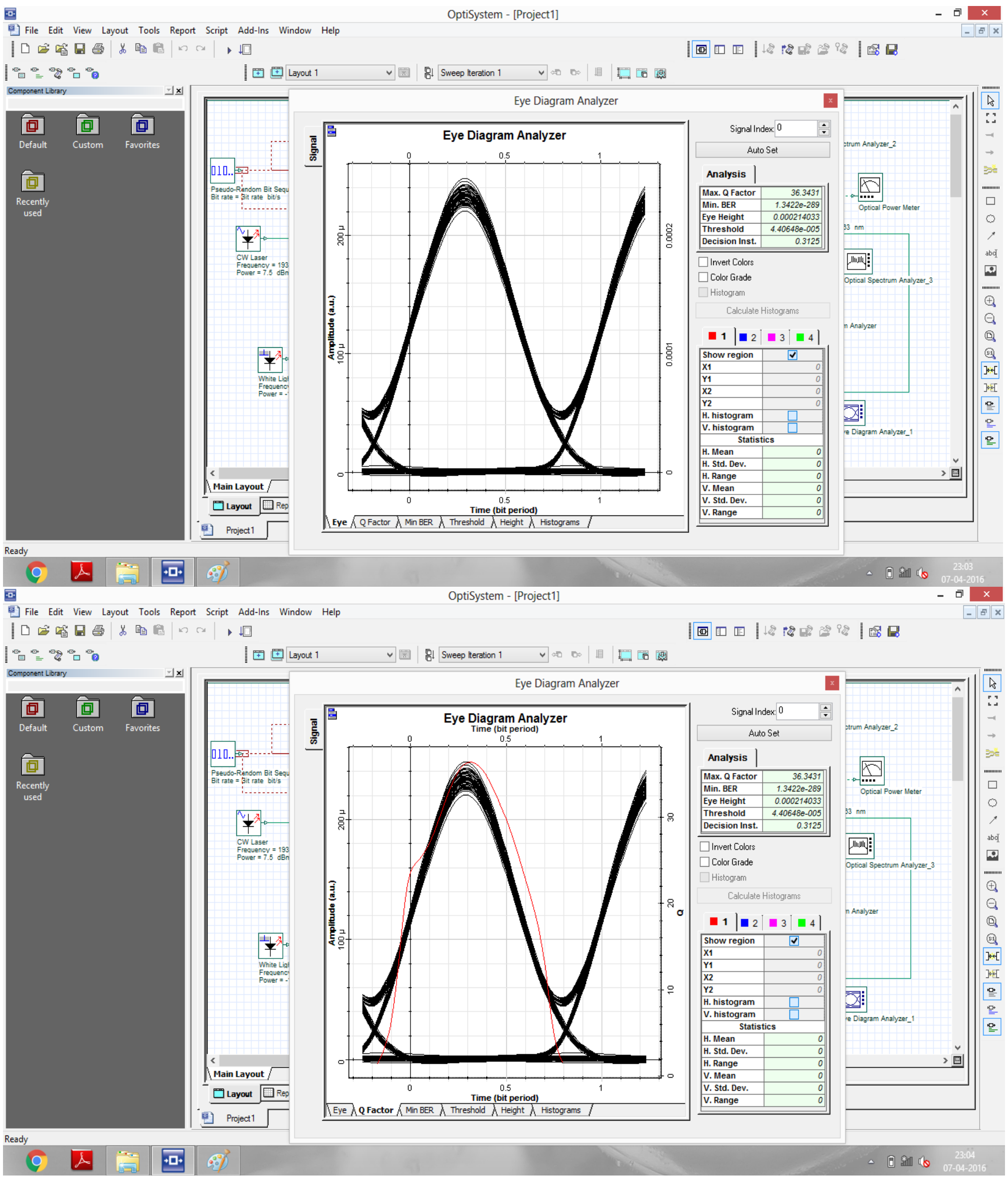


Fig: Showing the results for the eye diagram and Q factor for input and output peak power.

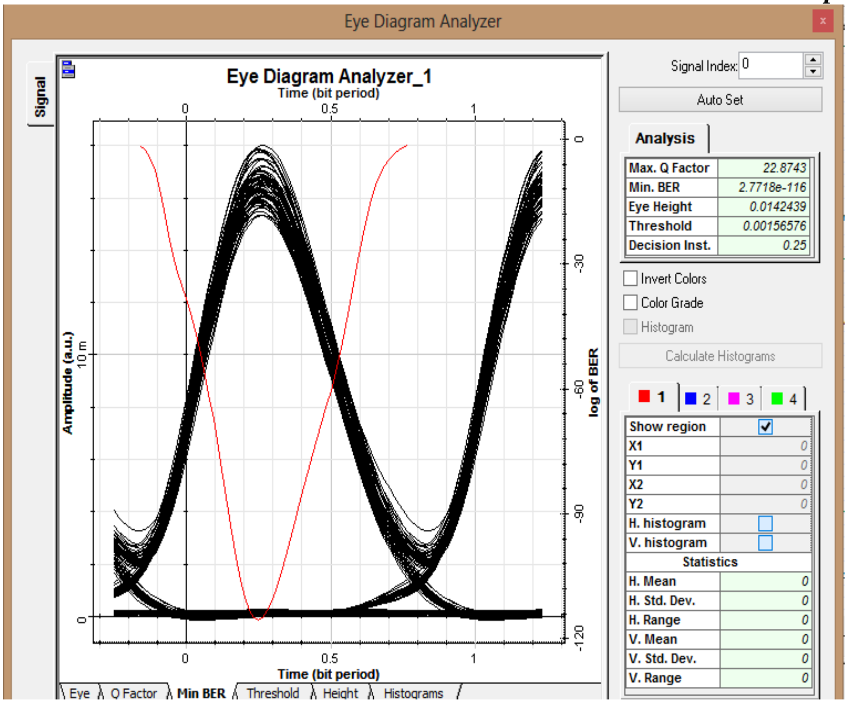


Fig: Showing the MIN BER obtained.

V. CONCLUSION

We have studied numerically the role of fiber dispersion in improving the regenerative capability of an MTR operating at 40 GB/s by studying several different MTR configurations. The focus of this work was on the impact of interplay between the dispersive and nonlinear effects that occur simultaneously inside the HNLF used to make the MTR. By considering the extent of improvement in the Q factor (related to level of noise reduction in the 40Gb/s bit stream), we concluded that a single scaled parameter$\mathcal{S}$, and representing the ratio of accumulated dispersion to the maximum nonlinear phase shift, can be used to predict the performance of MTR making use of fibers with very different lengths, dispersion, and nonlinear parameters. Our results show that fiber dispersion playsan importantrole and needstobe optimizedinpractice. Ingeneral,MTRs with larger fiber dispersion perform better but require higher input powers.

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