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EVALUATION OF DISPERSIVE WAVES IN SOLITON PULSES GENERATED FROM A MACH-ZEHNDER MODULATOR AND A SINGLE MODE FIBER

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Abstract: We evaluated dispersive wave energy included in a soliton pulse generated from a Mach-Zehnder modulator and a single mode fiber. When pulse repetition is 10 GHz, the minimum dispersive wave energy is only 0.23 % when the pulse width is 23 ps, and 3 % even when the pulse width is 13 ps.

Introduction

Electro-absorption modulators (EAM) are being used for generating optical soliton pulses with repetition rate of up to several tens GHz because of their integration capability with laser diodes, simple configuration, and stable operation. However, when the EAM pulse shaper is adopted in WDM soliton transmission systems, an EAM for every several channels are required due to wavelength dependence of EAM absorption. Recently, Veselka and Korotky proposed and demonstrated an optical soliton source using a Mach-Zehnder modulator (MZM) as chirped pulse shaper and a piece of single-mode fiber (SMF) for chirp compensation[1]. Comparing with a pulse source using an EAM, this pulse source has the advantages of low insertion loss and wavelength insensitivity although RF driving circuit is more complicated. In this paper, we evaluate dispersive wave energy included in the optical pulses generated by an MZM and SMF by means of the inverse scattering transform in order to qualify the pulse source for soliton transmission systems.

Calculation of dispersive wave energy

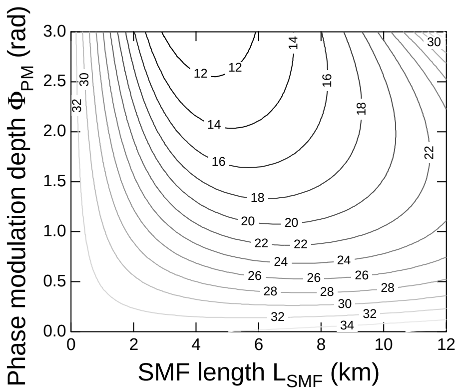
A dual-electrode MZM is driven by two RF signals with the angular frequencies of ω_m and $\omega_m/2$. The signal of $\omega_m/2$ is applied in anti-phase to each electrode for intensity modulation. The signal of ω_m is applied in in-phase to each electrode for phase modulation to create frequency chirping. The electric field of the output light of the MZM becomes

$$E_{\mathrm{MZMout}} = \cos\left(\frac{\pi}{2}\sin(\omega_m t/2)\right)\exp i(\Phi_{PM}\cos(\omega_m t)), \qquad (1)$$

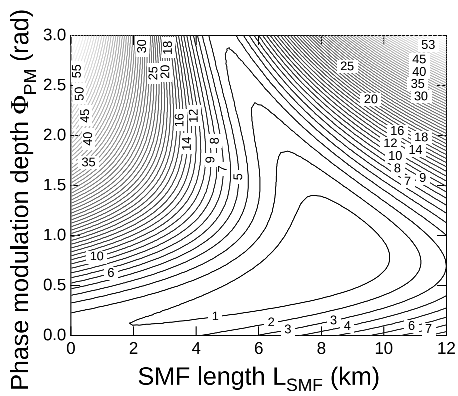
where Φ_{PM} is the phase modulation depth. We first solve a linear wave propagation equation numerically in order to obtain the electric field of the optical pulse after propagating in the SMF. We assume that the group velocity dispersion of the transmission line is constant and the system has no soliton control scheme. The amplitude of soliton included in the pulse is thus obtained by solving Dirac-type eigenvalue equations[2]. The dispersive wave energy E_D is obtained by subtracting the soliton energy from the total pulse energy[3]. Since E_D depends on pulse amplitude, we chose the pulse amplitude to minimize E_D. Finally we obtained dispersive wave energy ratio ε_D. The calculation was made with varying Φ_{PM} and the SMF length L_{SMF}.

Figure 1 (a) and (b) show the contour plots of the FWHM pulse width and ε_D versus L_{SMF} and Φ_{PM}. The minimum pulse width decreases as Φ_{PM} increases. Note that ε_D of less than a few percent is achievable in a fairly wide area as seen in Figure 1 (b).

Figure 1: Contour plots of (a) pulse width and (b) dispersive wave energy ratio ε_D versus Φ_{PM} and L_{SMF}.



(a) pulse width (ps)



(b) dispersive wave ratio (%)

Figure 2 shows the minimum ε_D versus Φ_{PM}. The pulse width when ε_D is minimum is also plotted. The minimum ε_D of 0.13 % where the pulse width is 23 ps is much smaller than the calculate value for the soliton source using an EAM[(4)]. Figure 3 shows the minimum ε_D versus pulse width. When pulse width is < 23 ps, minimum ε_D increases as the pulse width decreases but remains approximately 3 % when the pulse width is 13 ps. This fact is an advantage over the soliton source using an EAM because the intrinsic loss of this pulse source is only 3 dB and does not depend on the pulse width. Figure 4 (a) and (b) show the (a) waveform and (b) instantaneous frequency shift of the output pulse when ε_D is 1 %, where the pulse width is 18.2 ps. The instantaneous frequency at center portion of the pulse is close to zero. The pulse shape is close to Gaussian rather than $\mathrm{sec}^2 T$.

Figure 2: Minimum ε_D versus Φ_{PM}. The pulse width when ε_D is minimum is also plotted.

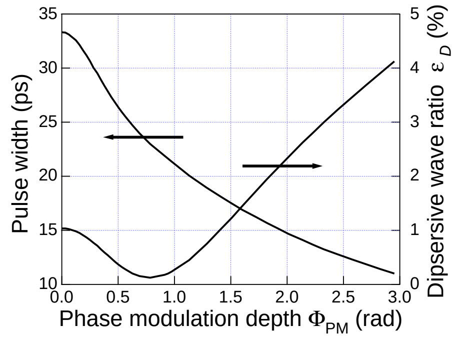


Figure 3: Minimum ε_D versus pulse width.

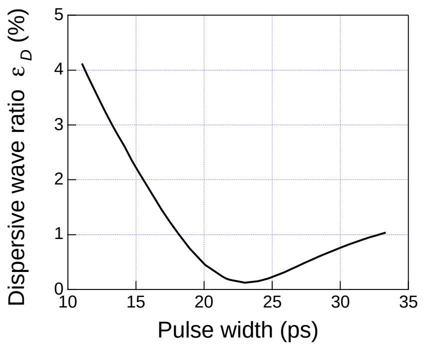
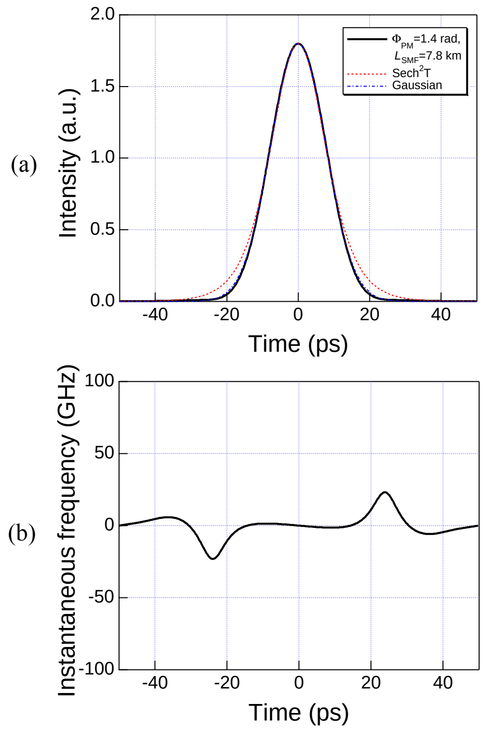


Figure 4: The (a) waveform and (b) instantaneous frequency shift of the output pulse when ε_D is 1 %.



Conclusion

In conclusion, we numerically evaluated dispersive wave energy included in the optical pulses generated by an MZM and an SMF. When pulse repetition rate is 10 GHz, we found that the minimum dispersive wave energy is only 0.23 % when the pulse width is 23 ps, and 3 % even when the pulse width is 13 ps. Features of low dispersive wave energy, low intrinsic loss and wavelength independent operation make this pulse source almost ideal for multi-wavelength WDM soliton transmission systems.

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