Spectral Function Modulation based on Nonlinear Fourier Transform

Siyu Liu[1], Luning Wang[1], Chenyang Li[1], Jindong Wang[2], and Guangqiang He[1,*]

[1]*State Key Laboratory of Advanced Optical Communication Systems and Networks, Electronic Engineering Department, Shanghai Jiao Tong University, Shanghai 200240, China*

[2]*Guangdong Provincial Key Laboratory of Quantum Engineering and Quantum Materials, South China Normal University, Guangzhou 510006, China*

[*]*gqhe@sjtu.edu.cn*

Abstract: We propose a spectral modulation method using Nonlinear Fourier Transform based on eigenvalue on the nonlinear discrete spectrum.

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It is generally believed that optical fiber nonlinearity is a fundamental factor of channel spectral efficiency and capacity limit in the fiber communication systems. The nonlinearity of optical fiber can be modeled by the nonlinear Schrödinger equation (NLSE) in propagation [1]. NLSE can be solved by inverse scatting transform (IST) which includes Nonlinear Fourier Transform (NFT) and Inverse Nonlinear Fourier Transform (INFT) [2–4]. These two processes are mainly based on the general idea of the eigenvalue communication. The eigenvalue is invariable during the propagation in optical fiber [5]. For the nonlinear propagation in the optical fiber , the NLSE [1] is expressed by Eq.(1)

$$i\frac{\partial q}{\partial Z}+\frac{1}{2}\frac{\partial^2 q}{\partial T^2}+|q|^2q=0. \tag{1}$$

Here q is complex envelope of electric signal, Z is the distance of optical fiber propagation, t is the time comoving with envelope velocity.

We propose an optimized modulation method using given eigenvalue on the nonlinear discrete spectrum based on the NLSE theory and eigenvalue communication.

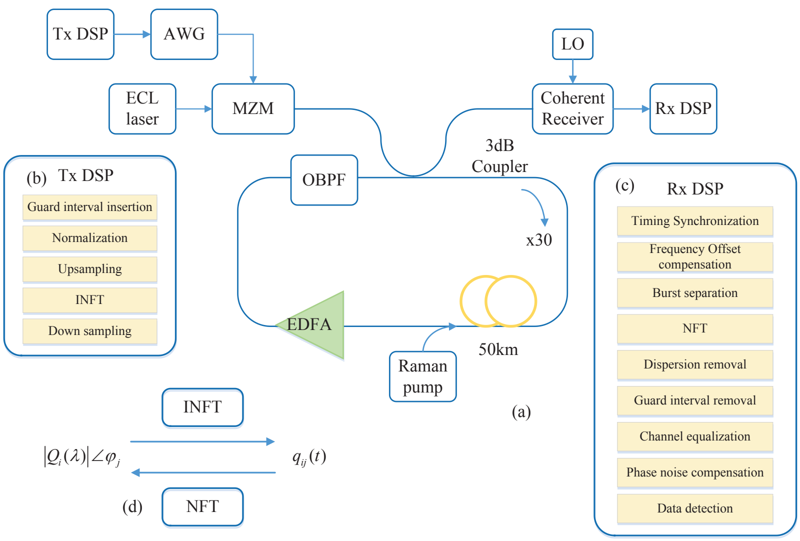

Fig. 1. (a) NFDM transmission system based on Spectral Function Modulation; (b) Block diagram of the Tx DSP; (c) Block diagram of the Rx DSP; (d) Correspondence of electrical pulse time domain waveform and non-linear frequency on the discrete spectrum.

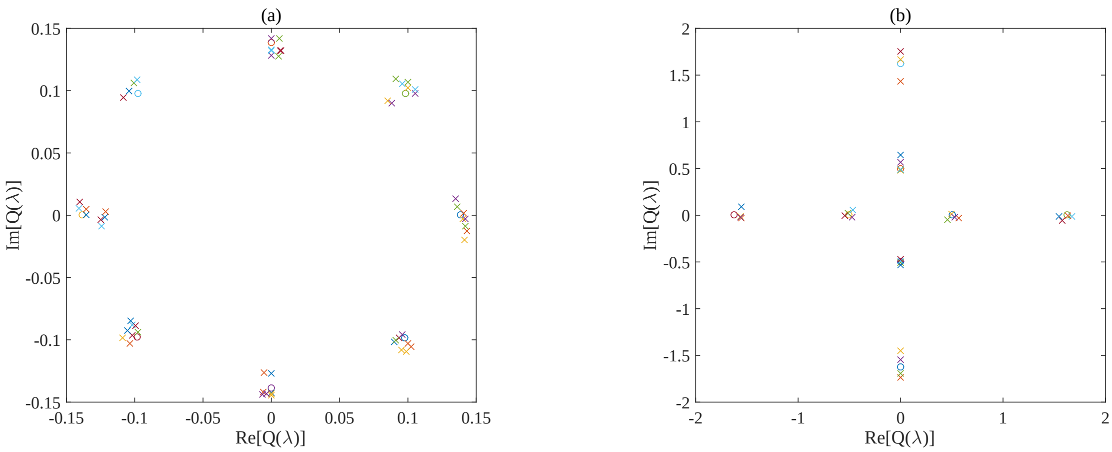

Fig. 2. Constellations of spectral modulation (SNR=20). The circles stand for the input signal while the crosses stand for the output signal.

Fig. 1 shows the NFDM transmission system based on Spectral Function Modulation. The amplitude modulation and phase modulation can be achieved at the same time on the nonlinear discrete spectrum by our system. Data is transformed to electrical pulses through the Tx DSP block and the Arbitrary Waveform Generator (AWG) in the time domain. These electrical pulses have the same eigenvalue, but differ in amplitude and phase on the nonlinear discrete spectrum. The electrical pulses are transformed to optical signal and loaded on the optical fiber of 50km * 30span by MZM. Distributed Raman amplifiers are used in the optical fiber since NFT is based on the integrability of the NLSE, while EDFA is used to compensate the residual losses in each span. Out-of-band noise is eliminated by an optical band pass filter (OBPF) to improve the signal-to-noise ratio (SNR) at the end of each span. After the propagation in the optical fiber, the optical signal and the local oscillator enter the coherent receiver to proceed coherent demodulation. Then electrical signal recovers to the original signal in Rx DSP block and decodes to binary sequence. NFT converts time domain signal into nonlinear frequency domain and removes the dispersion and nonlinearity. We observe the constellation of the recovery signal on discrete spectrum obtained by NFT.

Fig. 2(a) shows the constellation of 8PSK using phase modulation, while Fig. 2(b) shows the constellation of 8QAM using a combination of phase modulation and amplitude modulation. Two spectral function amplitudes are adopted, which can form 8 diverse signals, indicating three bits. When a signal is obtained after nonlinearity removal, we check its spectral phase and amplitude to make the final decision. Using the above method, dual-multiplexing can be realized.

In conclusion, Nonlinear Fourier Transform removes the dispersion and nonlinearity of the optical fiber. Phase modulation and amplitude modulation can be achieved by changing the phase and amplitude of spectrum. We propose two means of spectral modulation, and both means can recover the signal effectively.

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