PAM-4 Data Transmission using Modulation Instability Frequency Combs on a Kerr Microresonator platform

C. Shirpurkar[1,*], R. Bustos-Ramirez[1], P.J. Delfyett[1**]
[1]CREOL, The College of Optics and Photonics, University of Central Florida, USA

Corresponding Author:
C. Shirpurkar, CREOL
The College of Optics and Photonics, University of Central Florida,
Orlando, Florida, 32816, USA

Received: 4 May 2021; **Accepted:** 14 May 2021; **Published:** 18 May 2021

Citation: C. Shirpurka, R. Bustos-Ramirez, and P.J. Delfyett. PAM-4 Data Transmission using Modulation Instability Frequency Combs on a Kerr Microresonator platform 1 (2021): 08-11

Abstract

In this paper we investigate the dynamics and noise characteristics of modulation instability combs generated on a Kerr Microresonator platform and explore their potential application in optical communications with a multilevel pulse amplitude modulation-4 (PAM-4) modulation format.

Introduction

Optical frequency combs have provided a range of applications in a variety of different areas. Traditional frequency combs consist of electro-optic modulated frequency combs or mode-locked lasers. However, a new type of frequency comb generated on ultrahigh-Q microcavities has emerged in the past decade. These microcavities utilize the nonlinear four-wave mixing processes to generate a broadband frequency comb having a very low threshold power that scales with $1/Q^2$ [1]. They have been used in applications ranging from optical frequency synthesizers [2] to optical communications [3]. Kerr microresonators can support a variety of different intracavity spatiotemporal field patterns depending on the pump power and the effective detuning from the Kerr shifted cavity resonances. Modulation instability (MI) combs can emerge which range from coherent spectrally sparse Turing patterns to incoherent, spectrally dense, high-intensity noise chaotic combs. The ideal coherent frequency comb has perfectly equidistant comb lines and low noise is generated from the formation of Dissipative Kerr Solitons which exhibit a balance of gain, cavity loss, nonlinearity and dispersion. These solitons are ideal for many applications which require precise measurements of time or distance. However, generating and stabilizing these solitons requires optimization of frequency tuning techniques [4] due to the thermal behavior of the microcavity which often masks this quiet comb state.

We use a chip-integrated, 300 GHz free spectral range (FSR) silicon nitride Kerr frequency comb and explore the noise characteristics of the MI combs which avoid the challenge of optimized frequency tuning and can be obtained by pumping the cavity resonance at a fixed detuning. We identify the low noise comb lines in the MI comb and perform PAM-4 data transmission.

EXPERIMENTAL SETUP

(a) (b)

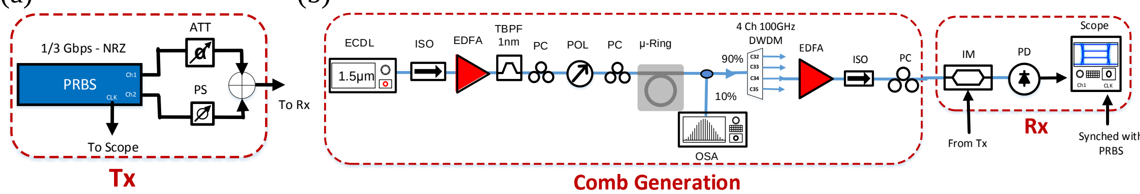
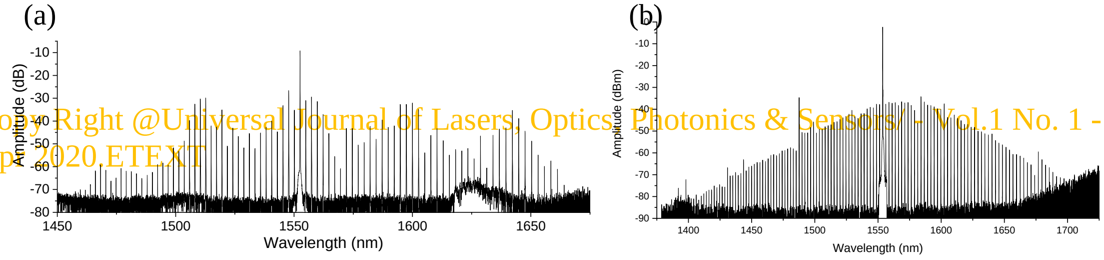


Fig. 1. (a) Transmission module of PAM-4 (b) Comb Generation using microrings and receiver module. ATT: Attenuator, PS: Phase Shifter, PC: Polarization Controller, POL: Polarizer, PD: Photodiode, IM: Intensity Modulator, TBPF: Tunable Bandpass Filter, EDFA: Erbium-Doped Fiber Amplifier, ISO: Isolator, ECDL: External Cavity Diode Laser, OSA: Optical Spectrum Analyzer, PRBS: Pseudo-random bit sequence, NRZ: Non-return to zero, DWDM: Dense Wavelength Division Multiplexing Blue lines are optical paths, Black lines are RF paths

Figure 1. shows the experimental setup of the microrings needed for generation of the modulation instability combs and the transmitter and receiver module. The transmitter module consists of a PRBS generator which outputs NRZ signals. These signals are split into two arms where one arm is delayed and attenuated by 6dB and then combined to create a PAM-4 signal. The comb generation setup consists of an ECDL which is used to pump the ring at 1553 nm. The polarizer and polarization controllers are used to ensure a TE polarization input as the micro rings are designed to only couple in TE polarized light. The tunable bandpass filter suppresses the amplified spontaneous emission from the EDFA. The comb output is then input into a commercially available 100 GHz dense WDM which separates the comb lines. We take one of these comb lines and modulate it from the PAM-4 signal out of the transmitter module. This modulated comb line is then photo detected and the eye diagram is viewed on a communications signal analyzer.

(a) (b)



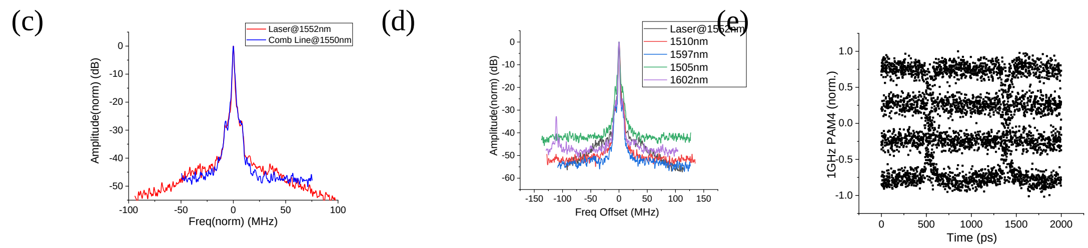


Fig. 2 a) MI Comb Generated b) Soliton Pattern Generated c) Comparison of line width of neighboring comb line of MI comb at 1550.4 nm with pump laser at 1552.83 nm d) More ‘quiet’ comb lines at various wavelengths of the MI Comb spectra e) Photodetected PAM-4 eye diagram – Freq. offset denotes the deviation from the center of the comb line/laser

Fig. 2a shows the MI Comb generated and it is quite clear that this comb does not show the characteristic hyperbolic secant comb envelope as expected when a soliton is generated as in Fig. 2b. However, we do find that certain lines near the peaks of the spectrum of the comb exhibit low noise lines as shown in Fig. 2c,d. These comb lines can be modulated and we do observe an eye diagram in Fig. 2e with clearly distinguishable rails. Performing an estimation of the BER give us a BER of around 10^{-2}. As expected, we observe a higher number of low-noise comb lines on the soliton (>80) as compared to the lines of the MI comb (>20). Further study into using soliton comb lines for PAM-4 data transmission would be our future work.

Conclusion

We have demonstrated PAM-4 modulation on one of the quiet comb lines of a MI comb. These MI combs can be accessed by slow tuning through the resonance (order of MHz/s).

Acknowledgements

This project was funded in part by the DARPA PIPES Program. The authors would also like to thank Dr. Scott Papp, Dr. Travis C. Briles and Dr. Su-Peng Yu at the National Institute of Standards & Technology (NIST) for providing the microrings used in the experiments and their support.

References

1) Kippenberg, T. J., S. M. Spillane, and K. J. Vahala. "Kerr-nonlinearity optical parametric oscillation in an ultrahigh-Q toroid microcavity." Physical review letters 93.8 (2004): 083904.
2) Spencer, Daryl T., et al. "An optical-frequency synthesizer using integrated photonics." Nature 557.7703 (2018): 81.

3) Marin-Palomo, Pablo, et al. "Microresonator-based solitons for massively parallel coherent optical communications." Nature 546.7657 (2017): 274
4) Stone, Jordan R., et al. "Thermal and nonlinear dissipative-soliton dynamics in Kerr-microresonator frequency combs." Physical review letters 121.6 (2018): 063902.