Robustness of Dual-Pump-Induced Ultrahigh Repetition Rate Pulse Trains Against Input Power Fluctuations

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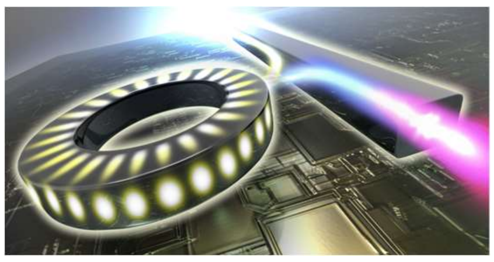
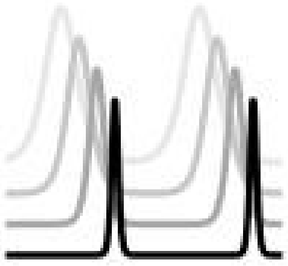
Introduction

- Pulse trains with THz scale repetition rates are needed for
  - ➢ Terahertz radiation generation [1]
  - ➢ Optical manipulation of molecules [2], etc.
- THz repetition rates are not achievable with electronics
- All-optical methods need to be used:





- Microring resonators [3,4]
- Robust, not widely tunable

- Reshaping a dual-pump [5]
- Tunable, possibly unstable

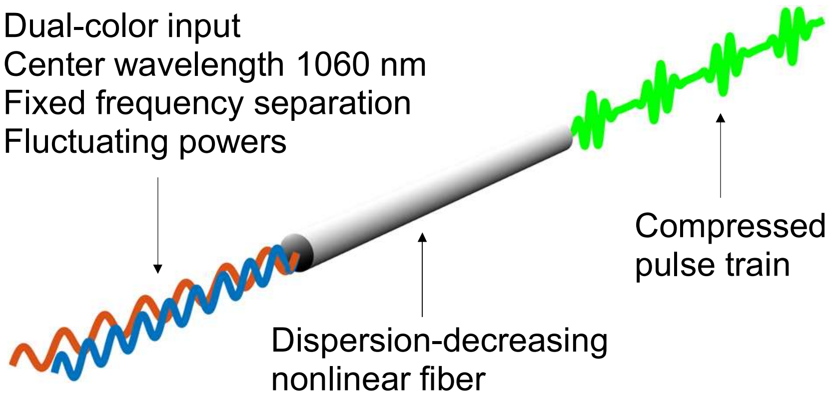
- Here we study the robustness of pulse trains generated through reshaping a dual-color pump in a dispersion-decreasing fiber in the presence of relative power fluctuations between the two pumps

Simulations

- Light propagation in single-mode fibers down to the few-cycle regime is accurately described by the generalized nonlinear Schrödinger equation (GNLSE) [6]:

$$\frac{\partial A(z,t)}{\partial z} = \sum_{k\geq 2}\frac{i^{k+1}}{k!}\beta_k\frac{\partial^k A(z,t)}{\partial T^k} + i\gamma\left(1 + i\tau_s\frac{\partial}{\partial T}\right) A(z,t)\int_{-\infty}^{\infty} R(T')|A(z,T-T')|^2 dT'$$

- 20 meters of tapered photonic crystal fiber
- Dispersion changes linearly from $\beta_2 = -8.56$ ps^2/km to 0
- Input: two CW beams centered around 1060 nm
  - ➢ Frequency separation varied in a controlled manner
  - ➢ Relative powers made to fluctuate randomly

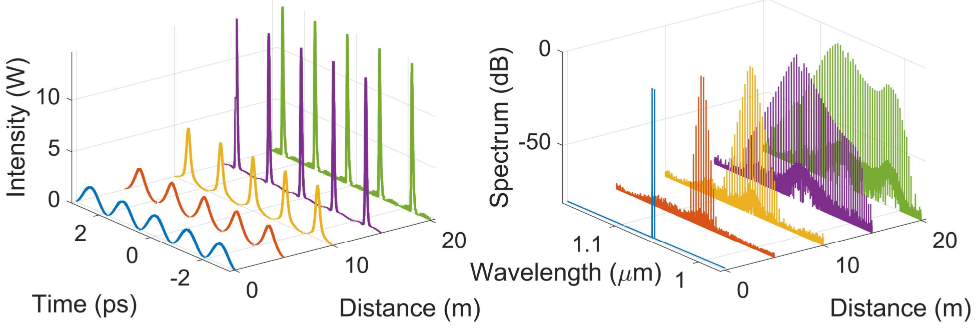


Dual-color input
Center wavelength 1060 nm
Fixed frequency separation
Fluctuating powers

Compressed
pulse train

Dispersion-decreasing
nonlinear fiber

- Example simulation (below), 800 GHz frequency separation, beams of equal power (1 W each)
- Temporal profile (left) and spectra (right) at various propagation distances
- Beating input signal turns into a pulse train in the fiber

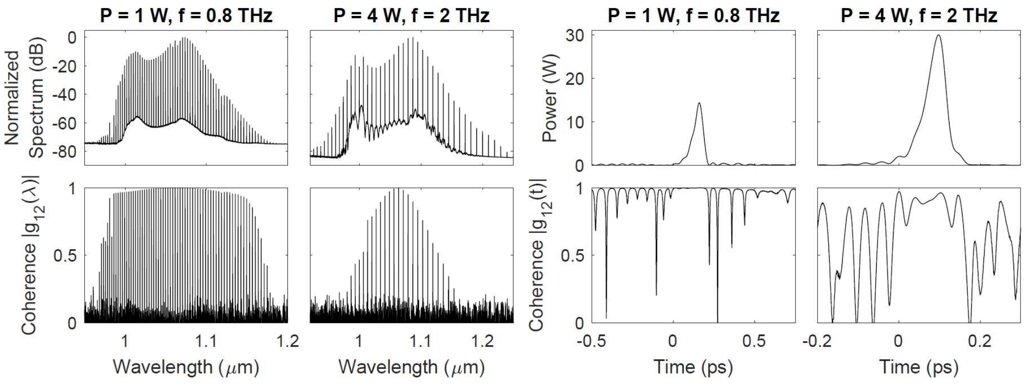


- Two frequency separations studied in detail: 800 GHz & 2 THz
- Relative power between the CW beams normally distributed around unity with a standard deviation of 5%
  - ➢ Power fluctuations are pessimistic, much larger than most commercial lasers
- Shot-to-shot fluctuations characterized using mutual degree of coherence $|g_{12}|$ (angle brackets denote ensemble average):

$$g_{12}(u) = \frac{\langle E_1^*(u)E_2(u)\rangle}{\sqrt{\langle|E_1(u)|^2\rangle\langle|E_2(u)|^2\rangle}},$$

where the variable *u* can be either time or wavelength

Results



Temporal (left) and spectral (right) profiles and mutual degrees of coherence for 800 GHz and 2 THz input frequency separations. The average power levels were 1 W and 4 W, respectively, chosen such that each beat period can reshape into a single fundamental soliton. The temporal traces on the right show a single beat period. The ensembles for both frequency separations consist of 200 simulations.

- Both frequency separations lead to the generation of pulse trains that manifest as frequency combs in the spectral domain
- Wherever there is optical power, there is coherence
  - ➢ In spite of the pessimistic 5% relative power fluctuations
- Pump wavelength remains the most coherent
- For 800 GHz initial frequency separation, soliton self-frequency shift is slower and hence the coherence remains better for the red part of the spectrum

Conclusions

- Robust pulse trains can be generated by dual-color pumping a dispersion-decreasing fiber
- Repetition rate dictated by pump frequency separation
- The simulations indicate this technique is surprisingly stable against input power fluctuations
- Power fluctuations have zero effect on the coherence properties near the pump wavelength
- Soliton self-frequency shift is a main coherence degradation mechanism and only an issue for higher frequency separations

Bibliography

1. **Y. Liu, S.-G. Park, and A. M. Weiner, Opt. Lett. 21(21), 1762–1764 (1996)**
2. **A. M. Weiner, *et al.*, Science 247(4948), 1317–1319 (1990)**
3. **T. E. Drake, *et al.*, Phys. Rev. X 9, 031023 (2019)**
4. **P. Xing, *et al.*, ACS Photonics 6(5), 1162 (2019)**
5. **S. Pitois, J. Fatome, and G. Millot, Opt. Lett. 27(19), 1729 (2002)**
6. **T. Brabec and F. Krausz, Phys. Rev. Lett. 78, 3282 (1997)**