

Spatio-temporal observation of higher-order modulation instability in a recirculating fiber loop

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Modulation instability (MI) in fiber optics is a nonlinear process in which a monochromatic signal wave propagating along with a continuous pump wave initially experiences exponential growth, provided that its frequency detuning relative to the pump falls within the MI gain bandwidth [1]. This eventually leads to the formation of pulse trains with characteristic repetition rate. In practice, spectral noise surrounding the pump might itself be amplified by MI in the so-called “noise-induced” or “spontaneous” scenario and lead to the complete breakup of the wavefield. In this work, we report single-shot experimental observations of higher-order MI in a recirculating optical fiber loop system. This regime corresponds to the case where instability harmonics also fall in the MI gain bandwidth which result in a succession of pulse splitting in the spatio-temporal dynamics of the wave system [2]. We observe evidence of an interplay with the spontaneous MI that critically depends on the pump-signal frequency detuning.

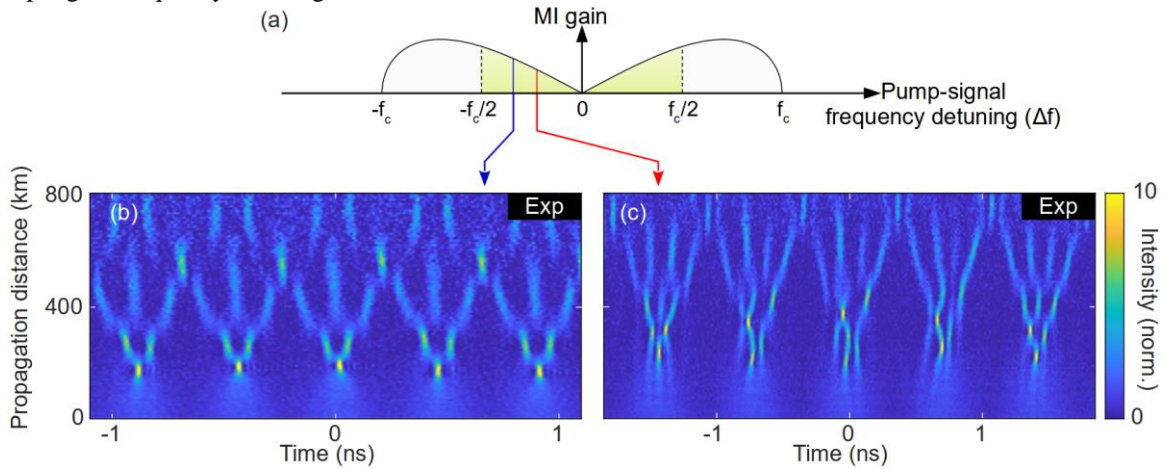


Fig. 1 (a) Sketch of the theoretical small signal MI gain spectrum. (b-c) Single-shot recordings of the spatio-temporal evolution of initially modulated wavefields for 2 pump-signal frequency detunings falling within the first half of the gain spectrum. $f_c \approx 12$ GHz, $\Delta f \approx 4$ GHz and 3 GHz in (b) and (c) respectively.

The experiment is performed in an 8km-long non-resonant recirculating fiber loop pumped by two spectrally narrow tunable lasers [3]. Roundtrip losses are compensated via distributed Raman amplification enabling propagation over hundreds of kilometers. Snapshot of the fast temporal dynamics of light intensity are recorded at every round-trip which allows the reconstruction in single-shot of spatio-temporal diagrams. Figure 1(b) shows such a diagram obtained for a pump-signal detuning of 4 GHz which is approximately a third of the MI gain frequency cut-off. The intensity humps of the initially modulated wavefield reaches a maximum compression point around 150 km after which it exhibits a deterministic pulse splitting sequence. Remarkably, around 550 km pulses on the sides of each humps seem to merge resulting in a pattern similar to the one at the maximum compression but out of phase. When decreasing the detuning to 3 GHz (i.e. increasing the period of the initial intensity modulation), the observed space-time evolution of intensity differs drastically as a consequence of the emergence of spontaneous MI [see Fig. 1(c)]. The breakup dynamics of each hump exhibits large variations especially during the first 400 km of propagation. It is however noteworthy that after 400 km, the wavefield somehow recovers an apparent degree of coherence. Realistic numerical simulations of the experiment indicate that the weak effective dissipation of the system eventually plays a significant role at such propagation distances.

This work sheds a new light on the well-known phenomenon of modulation instability in fiber optics system and improves our fundamental understanding of its mechanisms.

References

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