# Spatio-temporal dynamics of a Composite Soliton regime in a Passively Mode Locked Fiber Laser

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Passively mode locked fiber lasers are conventionally used as sources of high quality stable ultrashort pulses. The pulse characteristics of such lasers can be completely characterized using techniques employing radio-frequency analyzers, autocorrelators, FROG etc. However these methods have limited applicability when it comes to more complex operational regimes – for example when the laser is partially mode locked, has a dispersive background, or is exhibiting intermittent behaviour. Here, we demonstrate how the method of spatio-temporal dynamics [1] can be used for the characterization of such complex mode-locked regimes in passively mode locked fiber lasers.

An Erbium gain based single-walled carbon nanotube (CNT) mode locked fiber laser equipped with a single polarization controller before the CNT is used in the current experiment. The cavity is 41 meters long, with average anomalous dispersion (0.781 ps/nm). Thus the laser can support soliton-like pulses. However, for certain orientations of the polarization controller, it also supports a unique regime wherein a noise like pulse and soliton molecule with distinctly different spectra coexist (Fig. 1(a), (b)). Intensity histograms reveal the existence of peak events (Fig. 1(c)), however the true nature of their origin is not clearly revealed by simple one dimensional time domain measurements.

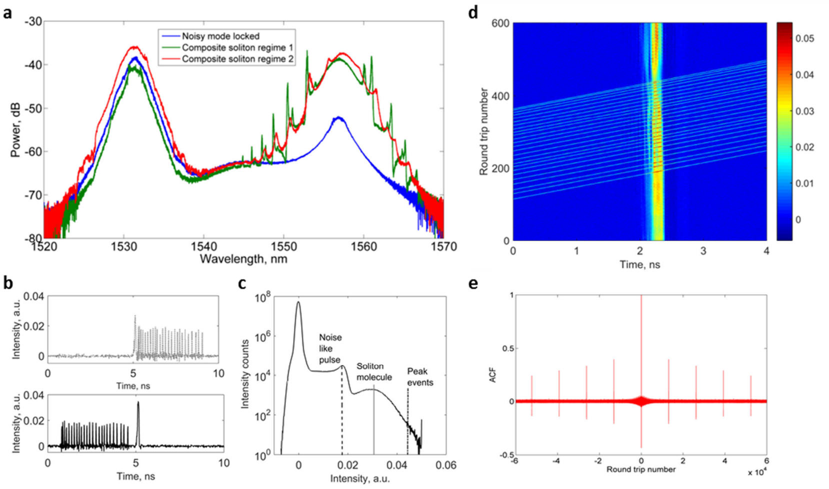


**Fig. 1** (a). Spectra observed for different orientations of the polarization controller. (b). Typically observed one-dimensional intensity dynamics. (c). Histogram of laser intensity, where the different peaks can be clearly attributed to the observed pulse complexes. (d). Spatio-temporal dynamics corresponding to regime 1 in (a). (d). Autocorrelation of dynamics calculated along slow-time evolution co-ordinate over 100000 round trips, which reveals the periodic nature of interaction between the pulse complexes.

Fig. 1(d) shows the equivalent spatio-temporal representation of the underlying dynamics. This representation is obtained directly from time domain intensity measurements (performed using a 33 GHz storage oscilloscope), where knowledge of the cavity round trip time allows one to move in the reference frame of one of the moving pulse complexes. Spatio-temporal dynamics clearly reveals the stable nature of the regime, wherein the difference in group velocities between the pulse complexes is also clearly visible. The stability of the regime and group velocity difference results in periodic intersections between the pulse complexes, which gives rise to the peak events observed in the intensity histogram. In this case, the occurrences of peak events can be predicted by simply calculating the autocorrelation function of intensity along the slow time co-ordinate (Fig. 1(e)).

To conclude, we have studied for the first time a composite soliton regime in a long passively mode locked laser using the method of spatio-temporal dynamics. The availability of a slow time evolution co-ordinate facilitates further analyses. The above method can be extended to more complex regimes of operation and can be used to characterize a broader spectrum of lasers.

## References

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