# POLARIZATION ATTRACTORS GENERATED BY MODE-LOCKED FIBER LASERS

Sergey SERGEYEV,[1*] Hani KBASHI[1]

[1]*Aston Institute of Photonic Technologies, Aston University, Aston Street, B4 7ET Birmingham,UK*
**s.sergeyev@aston.ac.uk*

Keywords: optics, polarization, mode-locked laser

Dissipative vector solitons (DVSs) in mode-locked fiber lasers take the form of trains of stabilized single or bunches of ultrashort pulses with the evolving pulse shape and state of polarization (SOP). The dynamics is driven by an interplay between the effects of gain/loss, dispersion, nonlinearity, and linear and circular in-cavity birefringence. Given the SOPs can be locked or evolving at different time scales, the SOPs' control and manipulation are important in the context of applications in metrology, high-speed fiber-optic communication and in trapping and manipulation of atoms and nanoparticles. The dynamics of vector solitons at a time interval from a few to thousands of cavity's round trips can be mapped by asymptotic states (attractors), e. g. fixed point, periodic, quasi-periodic, and chaotic trajectories on Poincare sphere. High signal-to-noise ratio (>60dB) measurement in the case of mode-locked lasers and application of a polarimeter, allows direct observation of attractors on Poincare sphere in terms of the normalized Stokes parameters.

In this abstract, we review our recent experimental and theoretical study of the single (fundamental and harmonic mode-locked) and multipulsed (bound state, soliton rain, breathers) solitons' polarization dynamics in Er-doped mode-locked fiber lasers [1]. To explain the emergence of different polarization attractors, we used a model of the phase-coupled oscillators taking the form of a generalized Adler equation [1, 2]:

$$\frac{d\Delta\phi}{dt} = \Delta\Omega + K_{NL}\sin^2(\Delta\phi) - K\sin(\Delta\phi - \alpha), \tag{1}$$

where the $\Delta\phi$ is the phase difference between the orthogonal linear states of polarization x and y, $\Delta\Omega$ is a frequencies shift that depends on the in-cavity birefringence; $\alpha$ is the phase shift proportional to the difference of the output powers $I_x$ - $I_y$ . Eq. (1) is accounting for coherent coupling of the polarization modes ($K$ coefficient) and coupling based on the Kerr effects ($K_{NL}$). Given the frequency difference $\Delta\Omega$, phase shift $\alpha$ and coupling coefficients K, $K_{NL}$ depend on the dynamics of the output powers $I_x$ and $I_y$, Eq. 1 presents a new class of coupled oscillators with the time-dependent coupling strength [1].

By tuning the coupling strength and the oscillators' frequency difference, it is possible to adjust the phase difference dynamics from the phase locking to different forms of the oscillations and chaotic phase slips [1]. As follows from Eq. (1), the synchronization ($d\Delta\phi/dt=0$) exists when $|\Delta\Omega|<|K|$ , e. g. continuous-wave mode-locking emerges. On the other hand, when $|\Delta\Omega|>|K|$ holds, the phase entrainment and chaotic phase difference slips appear which corresponds to different types of the oscillatory dynamics.

For the theoretical study of the adjustment of the polarization attractors caused by the soliton rain - small soliton pulses slowly drifting nearby the main pulse - and continuous wave lasing field in the laser cavity, we used a vector model of mode-locked fiber laser with an injected optical signal having evolving states of polarization [1]. We demonstrated that the mode-locked fiber laser is a heteroclinic system where the orthogonal states of polarization are quasi-equilibrium points [1]. The heteroclinic orbit takes the form of a trajectory periodically evolving between the orthogonal SOPs [1]. The heteroclinic system produces a large number of attractors which are located nearby the heteroclinic orbit connecting the quasi-equilibrium states. We demonstrated that the injected signal with the rotating state of polarization enables the selection of the polarization attractor corresponding to the specific multi-pulsing dynamics, e. g. breathing or soliton rain [1, 3].

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