EBERHARD KARLS
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Long-term Stable and Scalable Laser Beam Enhancement via Passive Injection Locking

Technology Description

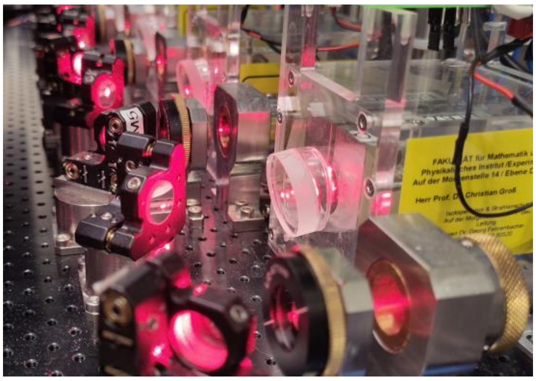

Figure 1: *Array of four injection locked slave lasers, picture taken in the Groß laboratory*

This innovative method transforms a single low-power laser source into multiple high-power, precision laser beams, increasing the laser capabilities by at least one order of magnitude. The process passively and permanently forces high-power laser diodes (slave lasers) to adopt the frequency of a weaker input laser (seed laser).

Key features are:

- Generation of multiple precise, high-power laser beams (> than 100 mW each) from a single weak laser source (appr. 5 mW)
- All generated beams coherent to each other and inheriting their spectrum from the seed laser

Innovation

The technology is based on optimal utilisation of passive stability and synchronized relocking, in contrast to previously published approaches that rely on active stabilisation. This enables:

- Scalability to many lasers, in a serial or parallel amplification chain
- Efficiency and cost-effectiveness by eliminating additional optical components
- Compatibility with many commercial laser diodes

Market Potential / IP Status

Passive injection locking combines simplicity, low maintenance and robustness for low power laser diode systems, offering a simpler and less costly alternative to active beam stabilization.

Priority application with the European Patent Office
Priority date 2024-10-29

Applications

- Optical communication: For generating multiple coherent laser beams in fibre optic networks
- Material processing: In industry, where multiple synchronised laser beams are necessary for complex processing operations
- Medical technology: For precise medical procedures or imaging techniques that require stable laser beams
- Research and development: In laboratories that need multiple, frequency-stable laser beams for various experiments, e.g. quantum technologies

Advantages

- Automated adjustment of system parameters through external trigger signal
- Generation of highly precise and stable laser beams
- Cost-effective utilisation of off-the-shelf microcontrollers per slave laser
- No additional expensive optical components necessary

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Proof of Concept

Functional Principles

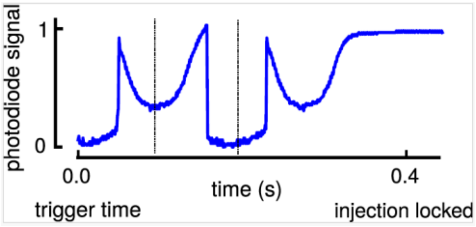

Figure 2: *Externally triggered auto-injection acquisition*

Figure description

Shown is the progression of monitored power during automatic injection acquisition. The slave laser controller is externally triggered at t=0. The current is ramped upwards until the time marked by the first vertical line. Afterwards the current is ramped downwards and the position of the discontinuity is recorded. Injection is acquired after another up-down ramp, which stops just before the discontinuity.
Stable injection is signalled by the constant value of the photodiode signal and has been confirmed by measurements of the laser's frequency spectrum.

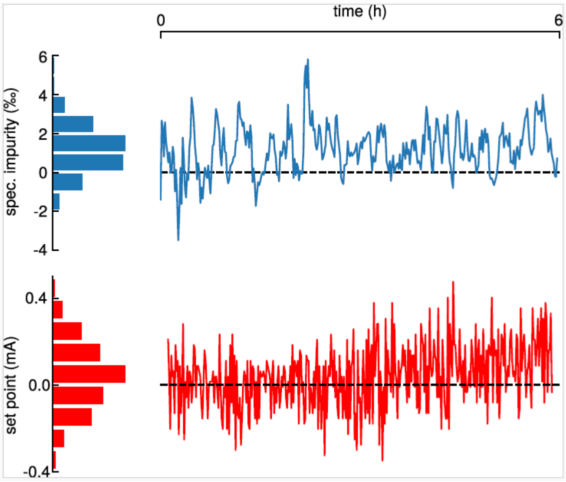

Figure 3: *Spectral purity measurement and set point tracking*

Figure description

Shown is the experimental data of the spectral purity of the injection locked slave laser. The slave laser is periodically triggered to reaquire injection. This causes the system to keep its injected state over very long times (practically infinite) as seen by the vanishingly small spectral impurity (upper plot). In reaction to environmental changes (such as temperature, humidity, air pressure, ...) the retriggering leads to a changing setpoint of the slave laser's laser current to keep the injected state. This behavior is visible over the last two hours, where an upward drift in the determined set point is observable.

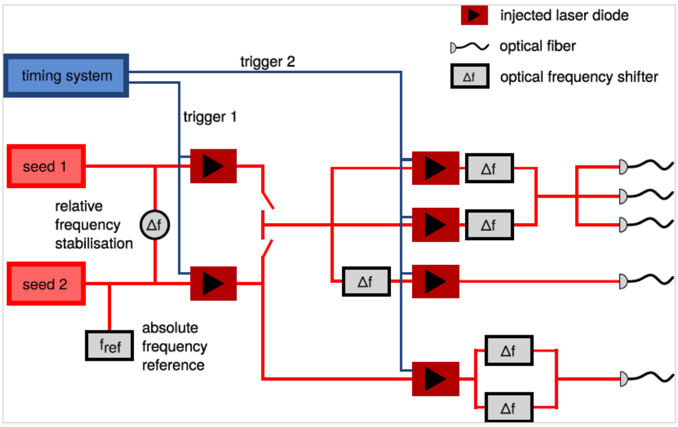

Figure 4: *Exemplary laser cooling system for atomic quantum technologies as in use in the Groß laboratory*

Figure description

Shown is the integration scheme for cooling application in a complex multi-layered laser system. Multiple spectrally narrow beams are generated with ~100mW power each. Thanks to the distributed amplification, different frequencies can be generated from few seed lasers. The technique is compatible with a serial (layered) system design as shown in this exemplary application. This system is in operation 24/7 in the Groß lab since more than a year. Sporadic failures are due to a loss of the absolute frequency reference of the seed laser, never due to a failure of the injection chain.

REFERENCES

❑ Kiesel, F., Karpov, K., Martino, A. de, Auch, J., & Gross, C. (2024). *Long-term stable laser injection locking for quasi-CW applications* (arXiv:2411.05392).