OPTICAL FREQUENCY DISCRIMINATOR

STABILIZATION OF A CONTINUOUS-WAVE LASER FOR REFERENCING DUAL-COMB SPECTROSCOPY

In this application note, we describe how the Optical Frequency Discriminator (OFD) can enable an easy stabilization of a continuous-wave laser to be used as an external reference for dual-comb spectroscopy.

Dual-comb spectroscopy (DCS) is a powerful spectroscopic technique allowing to access high-resolution and high-sensitivity broadband spectroscopy in short acquisition times for numerous applications such as greenhouse gas monitoring or two-photon spectroscopy as well as many others [1].

DCS experiments can be divided into three categories: free-running, mutually coherent and fully-referenced frequency combs. However, while going from free-running frequency combs to fully-referenced frequency combs can significantly improve the frequency resolution and accuracy as well as the signal-to-noise ratio, it also increases the complexity, size and cost of the experimental setup.

A recent example of a free-running dual-comb system showing the strength of this technique has been presented in [2]. In this work, the authors generated the required two frequency combs from the output of a single thin-disk laser oscillator. The suitability for free-running fast high-resolution DCS application was confirmed by detecting the absorption spectrum of acetylene as shown in Figure 1. An OFD-locked continuous-wave (cw) laser acted as external reference enabling the mapping of the detected radio-frequency spectra back into the optical domain. Their experimental setup is shown on Figure 1.

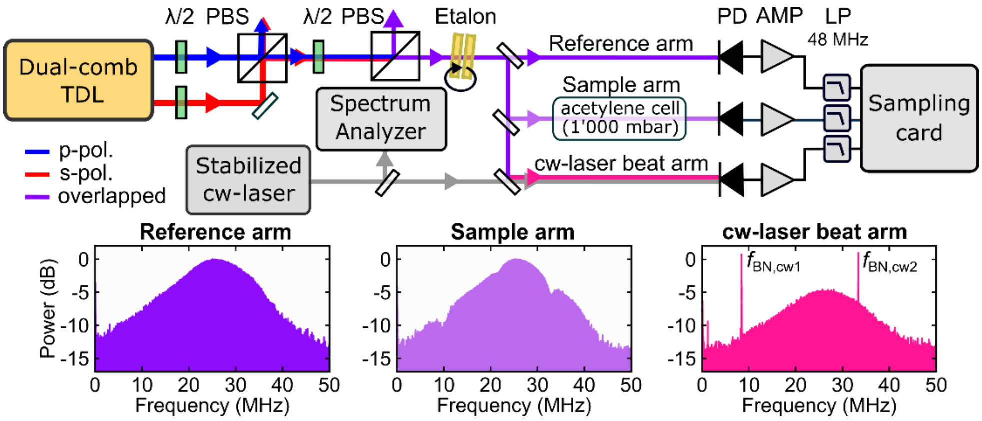

Figure 1: Experimental setup of the acetylene dual-comb spectroscopy and typical radio-frequency spectra of the corresponding detection arm. Reprinted with permission from [2].

OPTICAL DISCRIMINATION USING THE OFD

The reduction of the optical linewidth of a cw laser to ultralow level is typically done by stabilizing it to an ultralow thermal expansion (ULE) cavity with the Pound-Drever-Hall locking technique (see e.g. [3,4]). However, while this approach allows for ultra-stable sub-Hz-level optical linewidth (see e.g. [3–5]), ULE cavity are bulky, complex, and expensive and typically operate in a narrow spectral range. Additionally, many applications do not require such a stability level and a sub-kHz linewidth is often sufficient. The OFD is a simpler, affordable, and very robust system allowing to measure the optical frequency fluctuations of a cw laser and to stabilize it. In contrast to ULE cavity, the OFD can accommodate for a broad wavelength range optimized of the UV, visible, near- and mid-infrared spectral ranges. The cw laser optical frequency was stabilized using the OFD combined with an external servo controller as shown in Figure 2. Figure 3 compare the frequency noise power spectral density (PSD) of the cw laser in free-running operation and after its stabilization using the OFD. In locked operation, the optical linewidth of the cw laser is reduced from 200 kHz to 340 Hz (up to an integration time of 1 s, and limited by the noise-floor of the out-of-loop measurement system). The optical linewidth full width at half maximum was computed from the frequency noise spectrum by using the beta separation line method [6] with an integration down to 1 Hz.

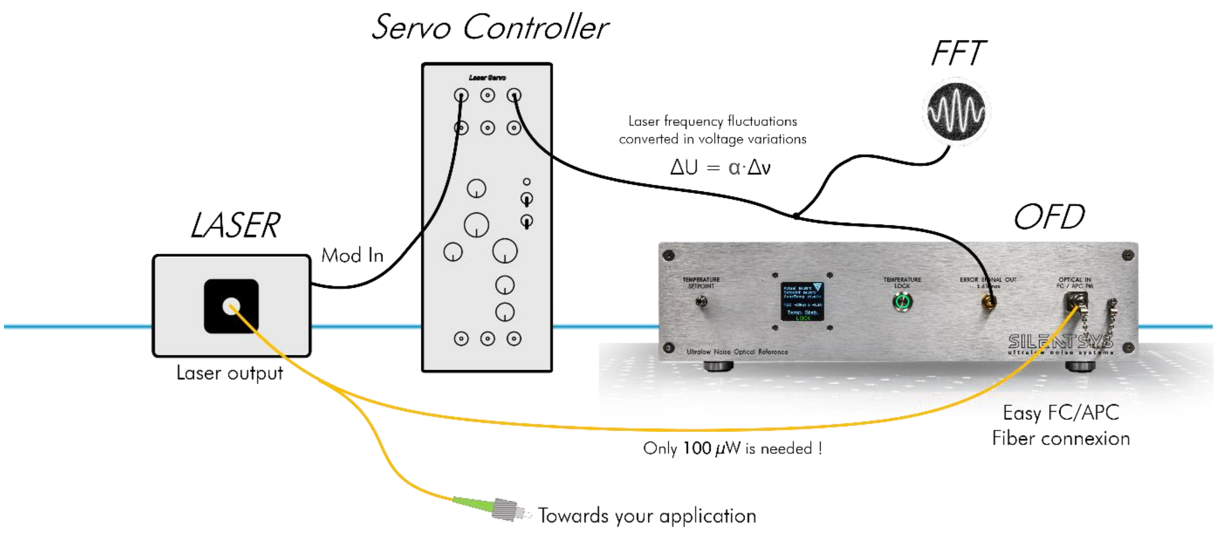

Figure 2: Experimental setup of a laser stabilization using SILENTSYS OFD.

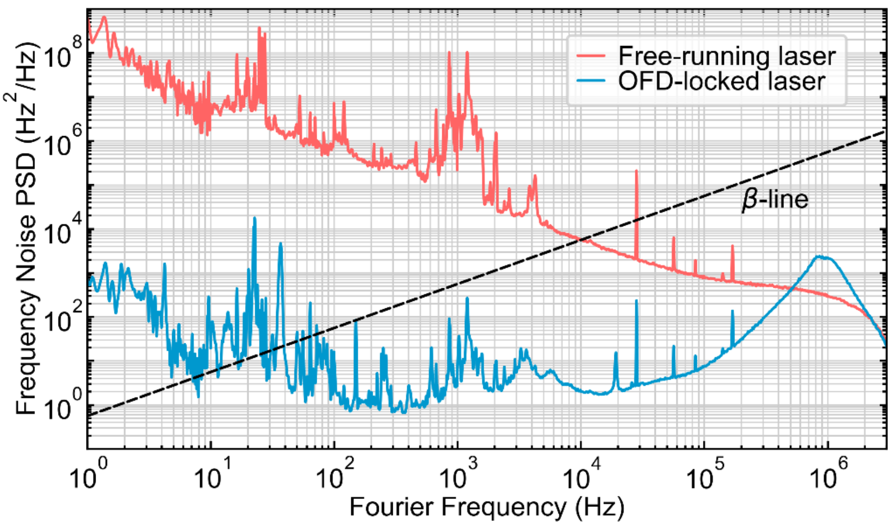

Figure 3: Comparison of the frequency noise power spectral density (PSD) of the cw laser free-running and after stabilization using the OFD(or in free-running and ODF-locked operation).

CONCLUSION

The OFD is an affordable and plug-&-play device for anyone required to stabilize a laser to a Hz-level linewidth. In this example, the OFD was optimized for the 1-µm wavelength range. Besides its simplicity of utilization, the OFD is a very versatile solution which can be adapted to specific customer needs to stabilize of a cw laser from the UV to the MIR spectral range. The next version of the OFD will feature an integrated servo controller to provide an even simpler and more compact all-in-one laser-stabilization solution.

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REFERENCES

1. I. Coddington, N. Newbury, and W. Swann, "Dual-comb spectroscopy," Optica **3**, 414–426 (2016).
2. N. Modsching, J. Drs, P. Brochard, J. Fischer, S. Schilt, V. J. Wittwer, and T. Südmeyer, "High-power dual-comb thin-disk laser oscillator for fast high-resolution spectroscopy," Opt. Express **29**, 15104–15113 (2021).
3. C. Salomon, D. Hils, and J. L. Hall, "Laser stabilization at the millihertz level," J. Opt. Soc. Am. B, JOSAB **5**, 1576–1587 (1988).
4. C. Hagemann, C. Grebing, C. Lisdat, S. Falke, T. Legero, U. Sterr, F. Riehle, M. J. Martin, and J. Ye, "Ultrastable laser with average fractional frequency drift rate below 5×10^{-19}/s," Opt. Lett. **39**, 5102 (2014).
5. D. G. Matei, T. Legero, S. Häfner, C. Grebing, R. Weyrich, W. Zhang, L. Sonderhouse, J. M. Robinson, J. Ye, F. Riehle, and U. Sterr, "1.5 µm Lasers with Sub-10 mHz Linewidth," Physical Review Letters **118**, 263202 (2017).
6. G. Di Domenico, S. Schilt, and P. Thomann, "Simple approach to the relation between laser frequency noise and laser line shape," Appl. Opt. **49**, 4801–4807 (2010).

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