Laser frequency stabilization to water vapour absorption lines using direct- and offset-locking techniques

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Frequency stabilization is generally performed by using atomic or molecular absorption lines. However, it is sometimes necessary to lock a laser at a frequency located outside of any absorption peaks. In this case, an offset locking configuration is necessary, in which a so-called slave laser is locked at a given frequency difference with respect to a stabilized master laser.

1 Introduction

Frequency stabilization of a laser is generally performed by using atomic or molecular absorption lines (on-line) for locking directly on it. However, it is sometimes necessary to lock a laser at a frequency located outside any absorption peak (off-line). In this case, an offset locking configuration is necessary, in which a slave laser is locked at a given frequency difference with respect to a stabilized master laser.

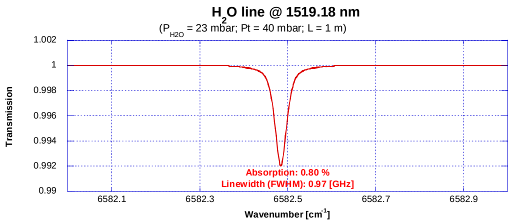

Figure 1 *Water vapour absorption line at 1519.18 nm for direct-locking technique by Wavelength Modulation Spectroscopy (WMS) [2].*

The first demonstration of stabilization on a water vapour absorption line was done with commercial telecommunications semiconductor lasers around 1519 nm. We stabilized one DFB laser directly on the water vapour absorption line at 1519.18 nm shown in the figure 1.

The main goal of this project aims to stabilize an off-line up to 20 GHz. We could stabilize slave laser on this off-line frequency by heterodyne detection (beating-technique) with the previously stabilized master laser. Further investigations on locking properties and different operating wavelengths will be done.

2 Experiment

The laser stabilization setup consists of two different stages, which are combined together. In the first part the light emitted by a modulated laser (the master laser in the figure 2) is injected into a 1 m long cell. This cell is filled with water vapour at a low total pressure of 30 Torr. At higher pressure the absorption lines are affected by the dominating pressure collision broadening effect (Lorentzian shape). For our purpose at 30 Torr a narrower water vapour absorption line with a Voigt shape is given for a precise stabilization.

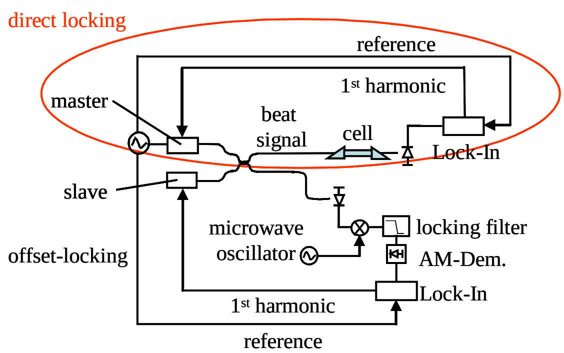

Figure 2 *Laser stabilization setup with combining of direct-locking (upper part) by WMS-technique and offset-locking with our new concept (the complete setup).*

The second part consists of the offset-locking of the non-stabilized slave laser on the already stabilized master laser.

2.1 Direct-locking by WMS

The direct-locking is based on the technique widely used in the Wavelength Modulation Spectroscopy (WMS), in which the zero-point of the first harmonic is used for the stabilization and the slope gives the direction of the correction for the drifting slave laser by Lock-In detection (see figure 3).

The modulation frequency $\Delta\nu$ for the laser has to be much smaller than the half-width of the chosen absorption profile ($\Delta\nu \ll \Delta\nu_{line}$). In the WMS the instantaneous laser frequency interacts with an absorption line and is converted into an intensity modulation.

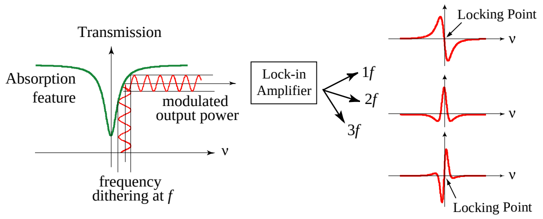

***Figure 3** Evaluation of the 1st harmonic on a molecular absorption line.*

The amplitude of the modulated current of the laser Δi is proportional to the amplitude of the modulation frequency $\Delta\nu$ and the modulation frequency normalized on the absorption line $m = \Delta\nu / \Delta\nu_{line}$ [1]. Thus the parameter were chosen for $\Delta\nu$ = 10kHz and for the Δi = 3mA.

To evaluate the stability of this system a multi-pass cell of 20m length was added to the existing 1m-cell in the setup. The laser light was split and passed separately through both cells. For each cell the first harmonic was evaluated and the 20m cell signal was used as reference owing to its strong total absorption. As shown in figure 4. The free running laser can drift within 425 MHz and the stabilized laser by WMS is around 58 MHz.

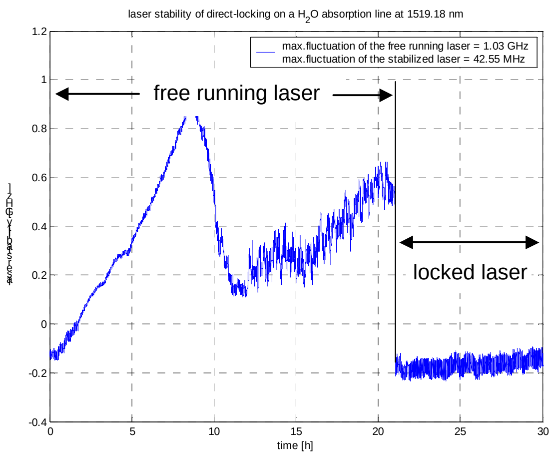

***Figure 4** Stability of the WMS-technique on the 1519.18nm-H2O absorption line.*

2.2 Offset-locking

The Lock-In principle is also used for the offset-locking technique. But instead of locking on a molecular absorption line, an electrical low-pass filter with a cut-off frequency of 200 MHz was used for the error signal (see figure 6). Filter drifts can be neglected by locking on zero Hz. The beat frequency resulting from combining master and slave light waves corresponds to the frequency distance between both lasers. After the detection by a photodetector the high beat frequency up to 18.95GHz is converted down using a mixer. After the low-pass locking filter and AM-demodulation the Lock-In detection sets the locking point to frequency zero.

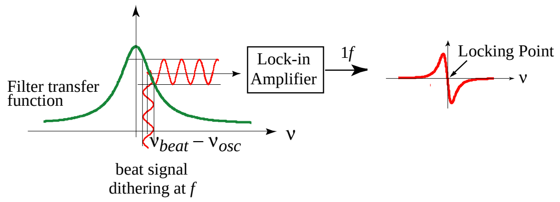

***Figure 5** Evaluation of the first harmonic on an electrical low-pass filter with Lock-In detection.*

So that the frequency difference between the two lasers exactly corresponds to the microwave generator frequency (see in figure 2).

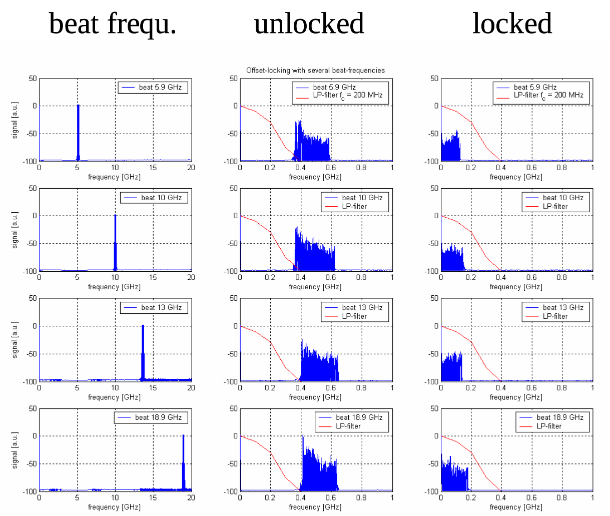

***Figure 6** The locking range for the offset-locking from 5GHz up to 18.95GHz, which is related to the bandwidth of the mixer.*

3 Discussion

We have shown that in combination with the WMS-technique and an offset-locking on any water vapour absorption line is possible at least up to 18.95 GHz. We are confident that such a technique can be straight forwardly used in any spectral region. The locking range can be easily increased by using a broadband mixer and higher microwave oscillator. And a multi-stage configuration could broaden the locking range.

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Literatur

[1] S. Schilt et. al.: „Wavelength modulation spectroscopy: combined frequency and intensity laser modulation“ in *Applied Optics / Vol.42, No. 33 / 20.Nov.2003*

[2] HITRAN database, http://badc.nerc.ac.uk