Measurement of Phase Noise of Offset Phase Lock Controlled by the D2-135

1. Introduction

The Vescent Photonics D2-135 Offset Phase Lock Servo can be used to create a phase lock between a master laser and a slave laser with a user-controlled frequency offset in the range of 250 MHz to >9.5 GHz[1]. In order to quantify the lock performance, a phase lock between two D2-100-DBR Distributed Bragg Reflector lasers was set up and interrogated. The phase noise power spectral density was measured by collecting the Fourier Transform of the error signal. Between 1 Hz and 100 kHz the phase noise Power Spectral Density (PSD) was measured to be less than 5 µrad/√Hz, and the integrated phase noise was measured to be less than 1.1 mrad over the same frequency range.

2. Experimental Setup

Two D2-100-DBR lasers operating around 780.24 nm were arranged as shown in Figure 1. Two D2-105 Laser Controllers provided temperature regulation and low-noise drive current for the two DBR lasers. The master laser (red) was “free running” in the sense that it was not frequency locked to a spectroscopic transition or other stabilization error signal. This places more stringent requirements on the D2-135 as the slave will have to track any drift or noise on the master laser.

The master & slave laser outputs were spatially overlapped in a D2-250 Heterodyne Module and injected into a multimode fiber. The resultant optically beating light was delivered to a D2-160 Beat Note Detector where the beat was converted into an electrical signal. This beat note was then passed to the D2-135 Offset Phase Lock Servo as the incoming error signal.

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[1] For locks with offsets greater than 10 GHz, please see “Extending the Offset Frequency Range of the D2-135 Offset Phase Lock Servo by “Indirect” Locking” (https://www.vescent.com/wp-content/uploads/2015/12/Sideband-Offset-Application-note.pdf)

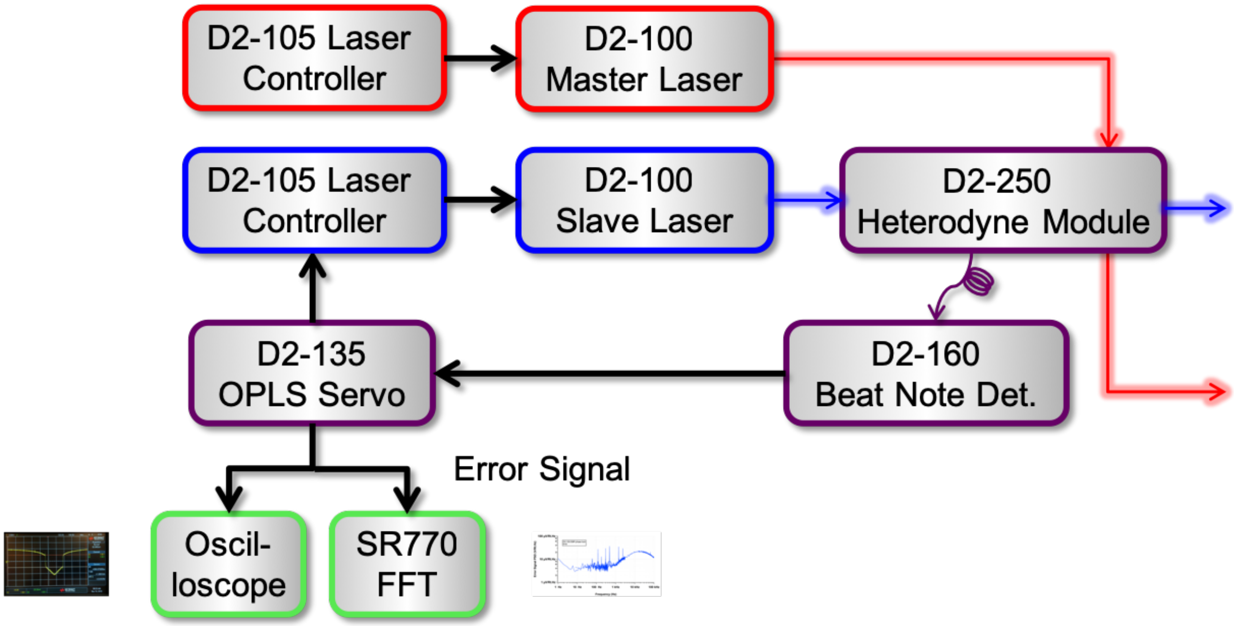

Figure 1. Setup for phase-locking one D2-100-DBR laser ("slave laser" in blue) to another D2-100-DBR laser ("master laser" in red).

Within the D2-135, the error signal is divided down by 8 and mixed with a reference frequency generated by the internal VCO of the D2-135. This mixed-down signal is processed by a Phase-Frequency Detector (PFD). Therefore, the error signal far from the lock point is proportional to the frequency difference between the beat note and the reference frequency. When the magnitude of the phase difference is $<\pi$ rad, the error signal becomes proportional to this difference in phase. A benefit of this is the lock capture range is expanded to almost the entire sweep range of the servo making it very easy to initiate a lock. A typical unlocked error signal is shown in Figure 2.

The DC error signal from the D2-135 was then sent to an oscilloscope and an FFT analyzer to measure the power spectral density. The conversion factor of the PFD from observed Voltage to radians of phase is (2π rad)/4 V.

Figure 2. Oscilloscope trace showing the unlocked error signal. The regions on the trace with the largest slope are where the PFD is performing as a phase detector.

The phase error can be related to the measured incoming error signal voltage using the following equation

$$\theta_{rad} = \frac{V_{error}}{N} * \frac{2\pi}{4\ \mathrm{V}} \qquad \text{Equation 1}$$

where N is the division factor used on the D2-135. The corner frequency settings of the D2-135 loop filter servo were set to: f_{I} = 8 kHz, f_{D} = 32 kHz, and f_{HF} = OFF. The internal divider was set to N = 8. The internal VCO was used for the reference tone at 83 MHz. Therefore, the actual offset between master and slave was 83 MHz x 8 = 664 MHz.

3. Results

The PSD of the error signal voltage from the locked D2-135 is shown in Figure 3. This signal is proportional to the PSD of the phase noise as shown in Equation 1.

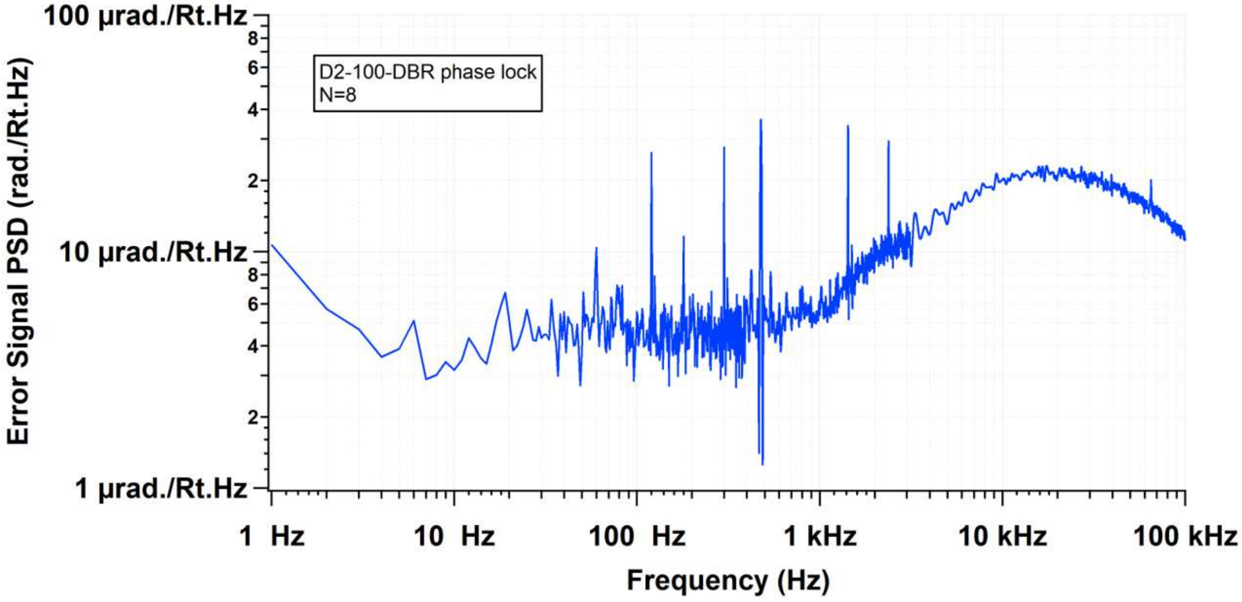

Figure 3. Error signal PSD (V/√Hz) versus frequency (Hz). Data was recorded over multiple resolution bandwidths.

The data from Figure 3 was multiplied by the conversion factor in Equation 1 and the results are shown in Figure 4. Additionally, the integrated phase noise was calculated (shown on the right axis of Figure 4) by the following equation

$$Integrated\ Phase\ Noise = \sqrt{\int_{f_{HI}}^{f_{LOW}} (Phase\ Noise\ PSD)^2\, df} \qquad \text{Equation 2}$$

where f_{HI} and f_{LOW} are the highest and lowest spectral frequencies of interest on the phase noise PSD.

The phase noise PSD was measured to be below 5 µrad/√Hz between 1 Hz and 100 kHz. The integrated phase noise was measured to be less than 1.1 mrad when integrated from 100 kHz down to 1 Hz.

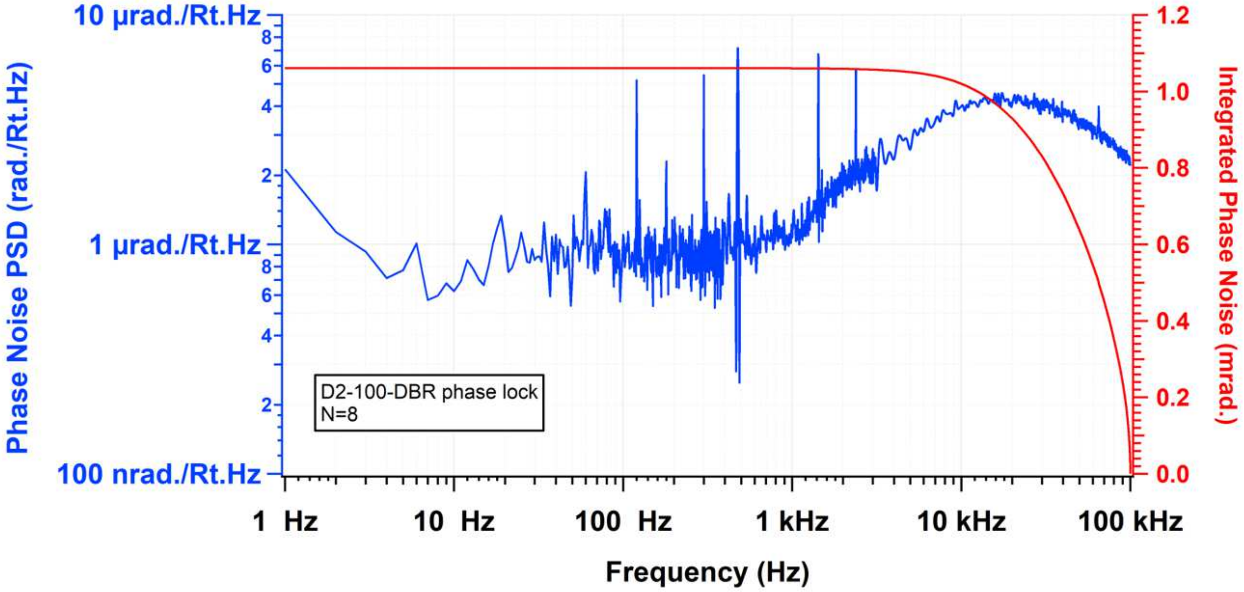

Figure 4. Left (blue): Phase poise PSD (rad/√Hz) versus frequency (Hz). Right (red): Integrated phase noise (rad) versus frequency (Hz). The integration was performed from high frequency to low frequency.

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