

Calculating Phase Noise from the D2-135

Q: What is the phase-noise on my laser beat-note going to look like when locked with the D2-135 Offset Phase Lock Servo (OPLS)?

A: There are a lot of factors that affect the final lock performance of the D2-135. Like frequency noise, phase noise is measured in terms of a noise density — or noise within a frequency band: dBc/Hz. The “Hz” tells us the width of the frequency band is 1 Hz. The “c” in dBc is for “carrier” as dBc is the ratio of the power of the phase noise relative to the carrier. The density of noise will depend on the frequency and generally falls into three distinct regimes, which we refer to as the High-Frequency Regime, the Gain-Limited Regime, and the Noise-Limited Regime:

1. **High-Frequency Regime:** The closed-loop bandwidth when using the D2-135 will depend on numerous factors, but often the primary factor is the frequency response of your laser. We’ve measured loop bandwidths as high as 3 MHz with the D2-135. For frequencies above your loop bandwidth, the D2-135 will not contribute to laser frequency noise; i.e., your phase noise at these frequencies is whatever your phase noise is on your lasers to begin with.
2. **Gain-Limited Regime:** This is where the frequency noise is limited by the performance of the D2-135’s servo loop. The phase noise is reduced by $\sim 1/G$ where G is the loop gain. If the loop bandwidth is 100 kHz with a simple integrator response, then phase noise at 10kHz will be reduced by a factor of 10 and phase noise at 100 Hz will be reduced by 1,000. Please note that in most situations, the output of the D2-135 adjusts as laser’s frequency, not phase, giving rise to an additional integrator in the feedback loop.
3. **Noise-Limited Regime:** At lower frequencies, the servo gain increases and the phase-noise decreases until eventually the servo hits a phase-noise floor, whereby the phase noise will remain constant with respect to frequency. The phase noise floor is typically set by either the D2-135’s noise floor, or the phase-noise on the frequency reference. To determine the phase-noise floor, one must calculate both and use the larger number. The phase-noise floor of the D2-135 is given by the formula:

$$D2-135 \text{ Phase – Noise Floor (dBc/Hz)} = -213 + 20\text{Log}(N) + 10 \text{Log}(F_{REF}(\text{Hz})),$$

where N is the divider setting (8, 16, 32 or 64) and F_{REF} is Reference Frequency. The value of -213 dBc/Hz accounts for the noise floor on the phase detector and the other terms including the multiplying effect of the frequency division and the effect of frequency of the information update rate. Whenever possible, use a lower N and a

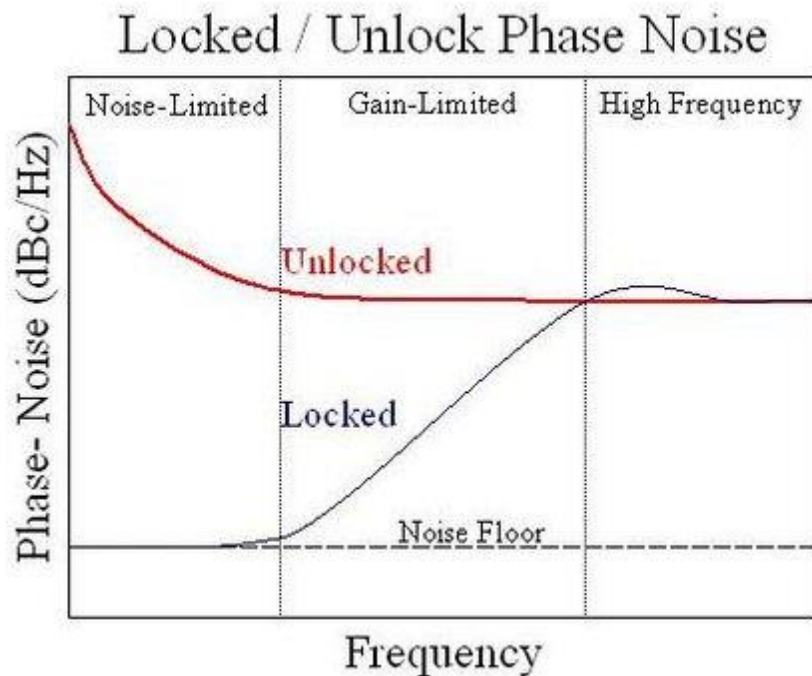
higher F_{REF} as this will lower your noise floor¹. As an example, say you want to lock to an offset of 4 GHz. You set $N=32$ and use the internal VCO reference (high mode) and tune the VCO until the Reference Frequency is 125 MHz ($125 \text{ MHz} * 32 = 4 \text{ GHz}$). Your noise limit is

$$-213 + 20 * \text{Log}(32) + 10 * \text{Log}(125e6) = -102 \text{ dBc/Hz}.$$

The noise floor from the VCO is the VCO's own noise floor multiplied by N as the phase-noise on the reference gets multiplied up to the beat note frequency by the OPLS,

$$\text{VCO Phase - Noise Floor} = \text{VCO Phase - Noise} + 20\text{Log}(N).$$

In our example, the phase-noise of the VCO is multiplied by 32 (30 dB) because of the N divider setting. Once both the VCO Phase-Noise Floor and the D2-135 Phase-Noise Floor has been calculated, use the larger value (or technically add them, but usually one term is much smaller than the other and can be ignored).



¹⁾ For ultra-high precision phase locks, such as needed in optical clocks, you may not want a divider (i.e. $N=1$). The D2-135 minimum divider value is 8. If a lower divider value would benefit you, please contact Vescent.