The Pure Photonics low-noise tunable laser product provide by design a 10kHz intrinsic linewidth (i.e. related to the laser physics) and low AM (RIN) and FM (phase) noise. Our claims have been verified experimentally by several labs and performance is consistent among devices.

This application note is to provide a more quantitative review of the AM and FM noise for a population of devices. Specifically, our measurement technology has advanced to the level that we can perform internal measurements of AM and FM noise up to a frequency of 1MHz (for FM, 15MHz for RIN) with good accuracy. These results are presented in this application note. Over time we will expand the measured population and provide updates to this application note.

This is revision C of this application note and contains an introduction to the measurements and data on a number of different units and configurations.
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2. Measurement Setup

The general challenge in noise measurements on lasers is both to keep the experiment clean/avoid external noises and to have a sufficient low noise floor, so that the signal can be detected.

As the control electronics for the ITLA tunable laser is contained onto an integrated PCB, and the external inputs to the laser are a DC power-supply only, the impact on the laser from external sources is limited. Proper care in the grounding and the avoidance of close-by radiation sources should eliminate most external influences. External sources such as shock and vibration cannot be completely avoided, but are known to have only a small impact on the laser. Ambient temperature variation typically has frequency components in the sub-Hz part, outside of our consideration. Hence we mount our tunable laser on a metal plate that is heatsinked and grounded to a bigger system. We use the PPEB200 evaluation board, with filtered DC power supplies for powering and controlling the laser. We know that noise on the -5.2V power supply can filter into the TEC circuit and noise on the +3.3V power supply will couple to the gain chip current. Care needs to be applied to avoid such noise.

All measurements are performed with firmware 8.0.9 and are in the whispermode (value 2 in register 0x90).

For detection of the power we are using a Thorlabs PDA10CS amplified detector. We use the 0dB amplification setting with 17MHz bandwidth. The output is routed to a 1 MOhm input resistance oscilloscope for monitoring the signal and to the 50 Ohm input of an ESA (HP3588A). The oscilloscope is disconnected during measurements to avoid residual noise. Active equipment in the optical path is avoided (e.g. attenuators) as these may add noise.

For FM noise measurements we convert the FM noise to AM noise with a filtering element. The filtering element has the transmission curve as shown below and we position the laser at the -3dB point. At this setpoint, a 2V signal will have a responsivity of approximately 0.01 V/MHz.
FM to AM filter characteristics

Operating point

Transmission (dB)

Frequency offset (MHz)
3. AM Noise (Relative Intensity Noise / RIN)

For the measurement of the AM noise, the optical signal is routed directly to the photodiode. The input power is adjusted through optical attenuation (no changes in the device setpoint) to achieve an output voltage from the photo-amplifier of 2V. This is monitored on the oscilloscope. After the optimization, the 1MOhm input of the oscilloscope is decoupled.

The ESA is configured with the highest possible sensitivity (-20dBm) and has an internally optimized resolution bandwidth. Averaging is set to 10x. The measurements are collected in Vrms units and converted to dBm/Hz values. The reference value (2V input) is 19dBm.

In the below figure the RIN measurements of a 16dBm optical input from device CRTNG2A00F is shown, along with the measurement with no optical signal. It can be seen that the difference between noise-level and signal at 16dBm is small and that there is a subtle response of the photo-amplifier that needs to be taken into account around 1MHz. With measurements this close to the noise level, we can only use the data as an upper bound of the noise. The real noise will be lower than these values. Naturally the noise level also provides a real bound on how deep we can measure.

![RIN measurements at 16dBm and noise floor](image)

Luckily, the RIN increases at lower output power levels and at power levels of 13, 10 and 7 dBm the RIN curve becomes more separated from the noise. This provides a good measure for the RIN performance and also allows more confidence in the RIN levels measured at 16dBm.
In the below graph the noise at 100kHz is plotted versus power. A clear dependence can be seen.
4. FM noise (phase noise)

For the FM noise measurement, we are converting the FM modulation, through a filter, into AM modulation. This converted optical signal is then detected by the photo-detector. To ensure alignment with the transmission curve, we first set the laser to a frequency 3 GHz away from the peak. We use the detected power at that setpoint as reference (0dB) and then change the frequency back until we have half of the power (-3dBm point). At that frequency setpoint we optimize the optical loss to obtain a 2V signal from the photo-amplifier.

In the below figures the measured Vrms values are again converted in dBm/Hz values. This allows comparison to the RIN values. As the AM noise will remain on the signal during the FM to AM conversion, the measured AM signal is a combination of the original RIN signal and the converted FM/AM signal. As a result, the noise floor of this measurement technique is both the RIN of the device and the detection limit of the ESA. At 16dBm, the signal becomes noise limited at about 3MHz, at 7dBm this condition is already reached at 100Hz.

Combining the results at different power levels into one graph, shows that the FM noise plots are all within a decade at different power levels. Cleaning up the graph at the left by removing the parts of the curves that are noise limited provides a bit better visibility. Showing that the FM noise level increases slightly at higher power levels. Regardless this is a small effect.
As we have calibrated the response curve of the filter, we can convert the Vrms values into a phase noise plot. Phase noise is commonly expressed as Hz^2/Hz or as mrad/Hz (normalized to 1m fiber). The Hz^2/Hz measurement is shown below for different power levels. The Hz^2/Hz measurement can be converted to a mrad/Hz measurement. Both measurements are shown next to one another in the below graphs.

We see minimal correlation between phase noise level and output power. If anything a slight increase of phase noise is observed at higher output powers.
5. Intrinsic Linewidth

Though we are not able to make these measurements at the GHz frequency range, to allow direct determination of the intrinsic linewidth, we are able to extrapolate the phase noise curves from 1MHz to 1GHz. At 1GHz we would need to be below 1000 Hz^2/Hz to meet a 10kHz linewidth. Based on our extrapolations, this is met.
6. Whispermode versus Standard Telecom Mode

Below measurements are shown of the device at 10dBm with the whispermode enabled and with the standard telecom mode. It clearly can be seen that the whispermode removes the dither elements in the spectrum at 888Hz and multiples. It also can be seen that the noise level below 100Hz (firmware related) is seriously reduced. At higher frequencies there is no difference. The FM measurement for the telecom mode is measured with reduced sensitivity (10dBm vs. -20dBm) on the ESA to prevent overload.

Naturally, for communications applications, the noise at low frequency is inconsequential. However, for sensing and T&M applications, low noise over the measurement time is critical.
7. RIN Stability
To investigate the stability of the RIN-level over time, the filter frequency of the ESA was fixed at 100kHz (RBW 580Hz) and the power level was measured for 300 seconds. The below graphs (on unit CRTNFBS003) show excellent stability over such a time-period.
8. Low RIN Option (LR)

On PPCL200 and PPCL300 an optimization on the circuitry and calibration can be achieved to dramatically reduce the RIN levels between 10kHz and 10MHz. RIN can be reduced to the noise level of our measurement method with this technique. Results are very consistent from unit to unit.

As a by-product, the phase noise is also further reduced by this method.

RIN (before / after)

![RIN plots]

Phase Noise (before / after)

![Phase Noise plots]

As per the discussion in section 5 the phase noise drops down to 1,000 Hz^2/Hz, which as a Lorentzian linewidth distribution would correspond to an intrinsic linewidth of <5kHz.
9. Long Term Stability
Standard dither mode (blue line frequency / power; red line ambient temperature)

Whisper mode (FW 8.0.9B, blue line frequency / power; red line ambient temperature)

The **No Drift** calibration option for the tunable laser will provide a device tailored compensation for ambient temperature and will result in lower variation of output power and frequency over ambient temperature and time.
10. Device Comparison

We are including measurements on several devices to provide a reference on consistency of the measured values and limited device to device variability.

**CRTNG2300F**

![Graph of RIN level at 100kHz versus device power for CRTNG2300F](image1)

![Graph of phase noise (Hz/Hz) for CRTNG2300F](image2)

**CRTNG2A00R**

![Graph of RIN level at 100kHz versus device power for CRTNG2A00R](image3)

![Graph of phase noise (Hz/Hz) for CRTNG2A00R](image4)

**CRTNG23004**

![Graph of RIN level at 100kHz versus device power for CRTNG23004](image5)

![Graph of phase noise (Hz/Hz) for CRTNG23004](image6)

**CRTNFBS003**

![Graph of RIN level at 100kHz versus device power for CRTNFBS003](image7)

![Graph of phase noise (Hz/Hz) for CRTNFBS003](image8)
CRTNG61004

CRTNG61009

CRTNG6100H

CRTNG6100A
CRTNG6100E

CRTNG6100K (PPCL550 module)