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MEASURING LASER LINEWIDTH

APPLICATION NOTE

This application note covers the theory and importance of **laser linewidth measurements**, especially as they relate to low-linewidth lasers. Low linewidth lasers are important for use in systems such as coherent communications, fiber optic sensors, interferometric sensing and gas detection.

QP **Laser PXIe** Module

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This application note covers the theory and importance of laser linewidth measurements, especially as they relate to low-linewidth lasers. Low linewidth lasers are important for use in systems such as coherent communications, fiber optic sensors, interferometric sensing and gas detection. Typically, linewidths vary greatly depending on the type of laser; they can be as large as tens of nanometers for powerful broadband dye lasers down to as low as a few Hz for lasers employing ultra-stable reference cavities.

The linewidth of a laser is a measure of the full width at half maximum (FWHM) of the optical spectrum, and is typically given in terms of frequency; it is strongly related to the temporal coherence and is characterised by the coherence length/time of the laser. The finite linewidth of a continuous wave laser is due to the phase noise of the electric field and may occur as a form of continuous frequency drift, sudden phase jumps or a combination of both. Fundamentally, this phase noise is a combination of quantum noise and technical noise [1]; technical noise arises from sources such as vibrations, temperature fluctuations and power fluctuations.

Measurements of linewidths larger than ~10GHz can be easily achieved with standard diffraction type optical spectrum analysers, however for linewidths much lower than the resolution of these devices other methods must be employed. These methods usually involve mixing the laser under test with a reference laser and measuring the beat signal produced by this mixing on a high speed photodiode with an electrical spectrum analyser. The general principle is that the two uncorrelated optical fields interfere on the detector, causing the underlying phase noise of both lasers to be converted into intensity variations that can be displayed on an electrical spectrum analyser. The resulting electrical spectrum is the convolution of the reference laser's spectrum with that of the laser under test.

A common variation to this technique, called the delayed self-heterodyne method, offers a simple way to perform linewidth measurements without the need for a low linewidth reference laser. This method involves the mixing of the test laser with a delayed and frequency shifted replica of itself. The resulting interference signal is centred at the modulation frequency which was used to frequency shift the delayed replica. The detected electrical spectrum is the convolution of the optical spectrum of the test laser with itself. This resulting spectrum is always symmetric and thus cannot measure any asymmetries in the laser's optical spectrum. For Lorentzian shaped spectra the linewidth of the laser is simply half that of the FWHM of the measured interference signal.

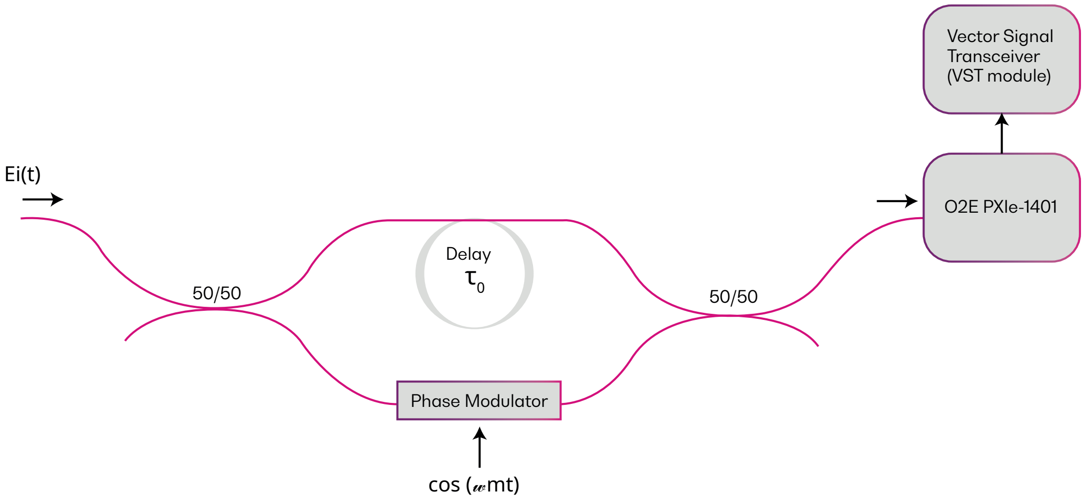
The measurement setup can be seen in **Figure 1**, where the electric field of our input laser is given by $\boldsymbol{E}_{\mathrm{i}}(\boldsymbol{t}) = \boldsymbol{E}_{\mathrm{i}}\boldsymbol{e}^{\mathrm{i}\phi(\boldsymbol{t})}$, which is assumed to have constant amplitude, , and a time varying phase, $\phi(\boldsymbol{t})$, So long as the delay, τ_0 is greater than the coherence length than the photodiode current, i(t), possess a component at the modulation frequency, (ω_{m}) that is proportional to the optical carrier spectrum convolved with itself.

$$i(t) \propto \frac{E_i^{\,2}}{4} + \left[\frac{E_i^{\,2}}{4} e^{i\Delta\phi(t)} + \frac{E_i^{\,2}}{4} e^{-i\Delta\phi(t)}\right]\cos(\omega_m t) + \frac{E_i^{\,2}}{4}\cos^2(\omega_m t)$$

Where $\Delta\phi(t) = \phi(t) - \phi(t - \tau_0)$

Figure 1:

Delayed self heterodyne measurement set up



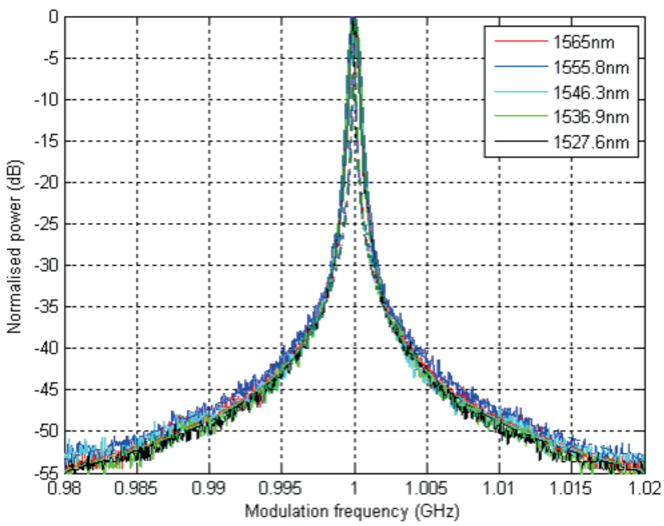
From the second term in the above equation, the linewidth of the laser can be recovered. One must ensure that the modulation frequency is sufficiently high so that the component at ω_m does not overlap with any signals centred at DC and also that the delay is longer than the coherence length.

An example measurement for an external cavity laser is shown in **Figure 2**; this displays the shifted beat signal at 1GHz for several different center wavelengths along with the Lorentzian fits that are used to calculate the linewidth of the laser. The Lorentzian fits are performed on the measured signal below -35dB from the peak. This is to ensure that the effects of the 1/f noise are removed from the measurement and an accurate estimate of the Lorentzian profile is measured. [2] The 1/f noise is responsible for the pseudoGaussian shape of the peak of the signal.

In practice the performance of a coherent optical communication system is dependant primarily on the white noise component, which exhibits the Lorentizan lineshape. As such the Lorentzian fits are performed as far from the peak frequency as possible, where the white noise component responsible for the lasers natural linewidth dominates. These Lorentzian fits in Figure 2 all return FWHM for the laser of below 25kHz for all wavelengths tested.

Figure 2:

Detected electrical spectra (solid lines) for several different wavelengths with their corresponding Lorentzian fits (dashed lines).



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