Linewidth Measurements

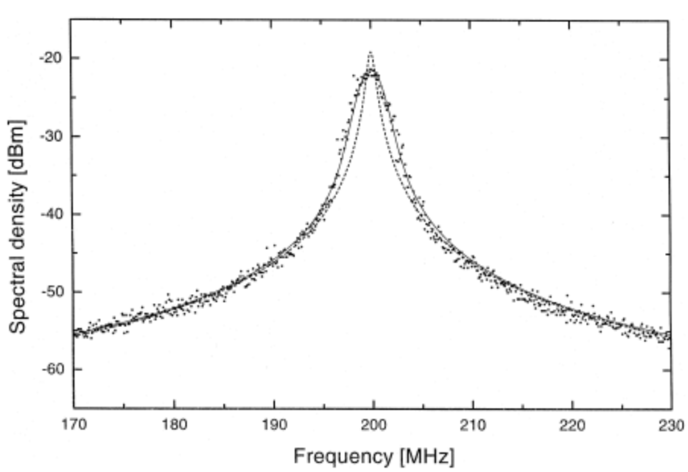
Laser linewidth measurements – Application Note

This application note is to address a common confusion in the measurement of linewidth on lasers (in general, and tunable lasers specifically). Some users expect to directly measure the Lorentzian linewidth measurement with a heterodyne or homodyne technique. However, they find a more Gaussian spectrum, due to the low-frequency noise (electronics and 1/f noise). We will explain the origin of this spectrum and how to derive the intrinsic linewidth from this spectrum.

Laser noise distributions

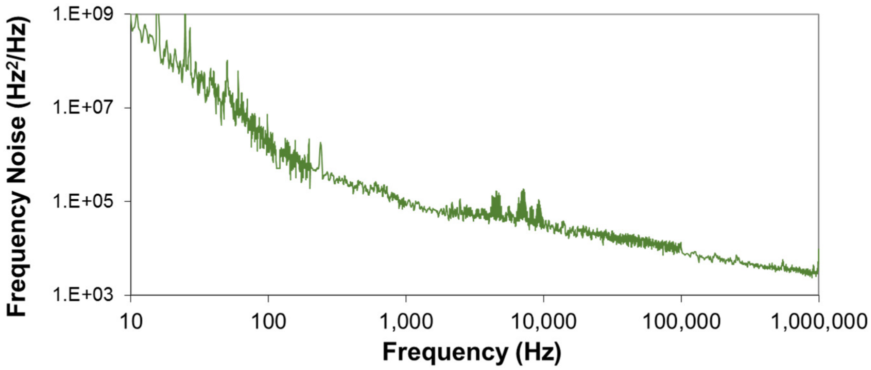
The noise characteristics of an ideal laser are described by a Lorentzian distribution (with a characteristic intrinsic linewidth). This is mostly a result of discrete electron-photon interaction within the laser cavity. However, most lasers are not ideal and couple in noise from their drive electronics and (firmware) control loops. Especially for complex laser systems (such as tunable lasers), multiple control loops will be working and parts will come with their own optimized electronics. The noise from these sources will add to the Lorentzian spectrum and will have a Gaussian distribution.

The article 'Laser linewidth measurements using self-homodyne detection with short delay', in Optics Communications 155 (1998) 180–186, provides a good description of this, with the below figure showing the Gaussian spectrum measured with the Lorentzian spectrum expected.



Origins of the phase noise

In the below figure it can be shown how this looks in the phase-noise characteristics of a laser. At higher frequencies the phase noise level goes to a plateau (~1,000 Hz^2/Hz). The intrinsic linewidth of the laser is described by a constant white noise at this level (from DC up to a resonance frequency >> 1 GHz). At lower frequencies, a 1/f noise fall off is seen and between 1 kHz and 1 MHz a couple of small peaks can be seen due to the electronics. This added noise (on top of the intrinsic linewidth noise) is resulting in the Gaussian spectrum.



Relevance to the user

From a use perspective, a user needs to determine if the lower frequency phase-noise matters for their application.

- Typically, the intrinsic linewidth is important for the coherence length, the distance over with a signal can be propagated and recombined with itself and still show interference effects. The low-frequency noise is irrelevant for this determination as the associated phenomenon occurs over a longer time period than the time it takes for the light to propagate over the coherence length.
- For coherent communication applications, the linewidth is important to reduce the phase variation over the duration of one or more bits (40ps per bit). Again, the low frequency signals are less important.
- The phase noise at lower frequency is important for signal to noise ratio in the measurements (especially with low power signals). It matters what the integration time of every individual measurement is. High-frequency noise is averaged out.

Deriving the intrinsic linewidth from your measurement

So for the user to determine the intrinsic linewidth, the spectral density versus frequency needs to be measured. Data down to 40dB below the peak needs to be ignored (around the peak the Gaussian spectrum dominates, but falls-off much faster than the Lorentzian spectrum, so below 40dB, the Lorentzian spectrum dominates). The Lorentzian fit is then made to the remaining sidelobes and the power in the Lorentzian peak needs to be equal to the power in the original spectrum (i.e. the height of the peak needs to be scaled relative to the height of the original peak).