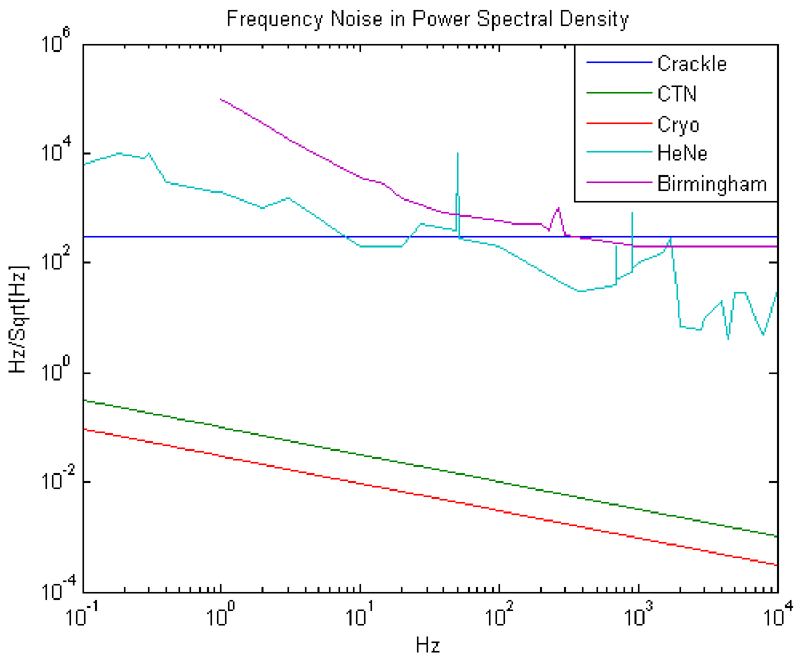
1 Noise

1.1 Noise Requirements

In order to create a useful ECDL, it must be capable of meeting the noise requirements of the experiment it is being used for. Thus, we need see the noise levels of the possible experiments we could perform with our ECDL and determine which experiment we will use. We collect the noise power spectral density (PSD) of several different experiments being performed at LIGO as well as comparing to an ECDL built by the Birmingham group. Note that the HeNe data is after frequency stabilization, and the actual data has significantly higher noise levels.



Based on the possible experiments we could perform, we settle on using the crackle experiment since it has the highest noise requirement and will therefore be the easiest standard to meet.

1.2 Estimated Noise of Proposed Setup

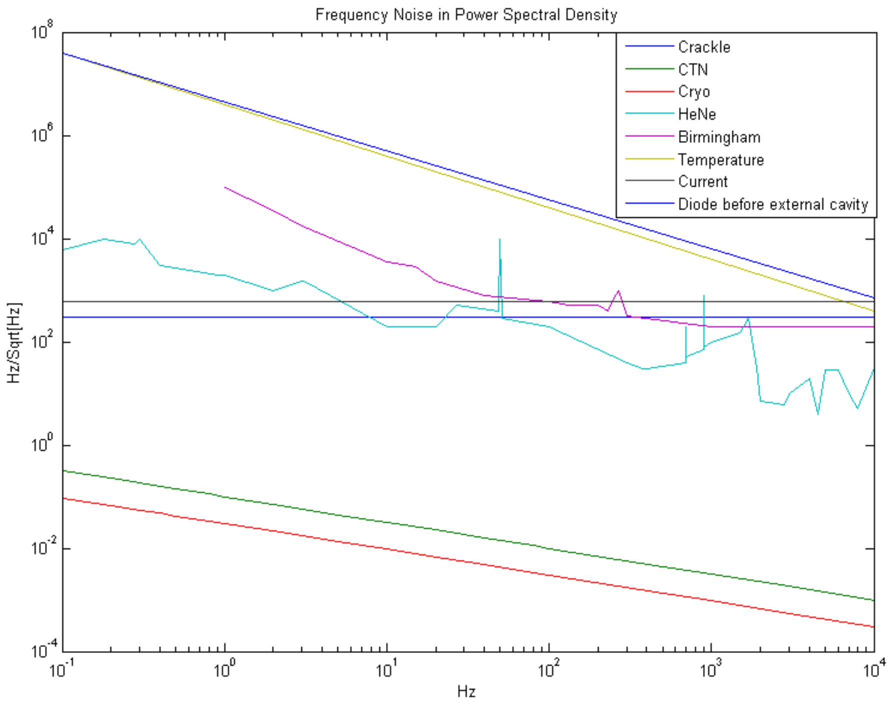
First, we need to determine the intrinsic noise of the diode laser (and thus its predicted linewidth). We consider two sources of noise in this analysis:

1. Noise from current: We plan to use the D2-105 laser controller from Vescent Photonics (which is based on the Libbrecht and Hall design). This has a PSD noise of 200 pA/ $\sqrt{Hz}$. The oscillation frequency of

a GaAs laser changes due to current fluctuations at 3 GHz/mA. We conclude that the noise from current fluctuations is $6 * 10^2$ Hz/$\sqrt{Hz}$.

2. Noise from temperature: We plan to use the TEC built into the laser diode mount from Thorlabs HLD001. We will have some intrinsic noise from the laser, of about $2 * 10^{-4}/f$ K/$\sqrt{Hz}$. The oscillation frequency of a GaAs laser changes due to temperature fluctuations at about 20 GHz/K. We conclude that the noise from temperature fluctuations is $4 * 10^6/f$ Hz/$\sqrt{Hz}$.

The noise in PSD adds in quadrature; that is, $S = \sqrt{S_1 + S_2}$, so the total noise will be $S(f) = \frac{\sqrt{3.6*10^5 f^2 + 1.6*10^{13}}}{f} Hz/\sqrt{Hz}$.



This gives us the level of noise across all frequencies. In order to determine how this translates to linewidth, we need to estimate a bandwidth of the noise (if we were to imagine taking frequencies up to infinity, how far would we see significant noise?). If we take the bandwidth of our noise to be 1 GHz, this translates to a linewidth of

$$(\Delta\nu)^2 = \int_0^\infty S(f)\, df \approx \int_\epsilon^{10^9} S(f)\, df$$

so the linewidth we find is $\Delta\nu \approx 7.7 * 10^5 Hz$ before passing through the external cavity.

Next, to estimate the factor by which the noise is reduced, we need to estimate parameter X (from Saito paper). l_1 is the length of the laser cavity, l_2 is the length of the external cavity, S is the scattering matrix for the laser, and Γ_1 and Γ_2 are the complex amplitude reflection coefficients. From Saito,

$$X = \frac{\tau_1}{\tau_2}|S_{12}S_{21}\Gamma_2/S_{11}| = \frac{\tau_1}{\tau_2}(\frac{R_{eff}}{R_2})^{1/2}$$

where $\tau_1 = \frac{2l_1}{c_1}$, $\tau_2 = \frac{2l_2}{/}c_0$, R_{eff} is the effective reflectivity of the external grating, and R_2 is the laser diode reflectivity. Simplifying, we find

$$X = n\frac{l_2}{l_1}(\frac{R_{eff}}{R_2})^{1/2}$$

. $l_1 = 0.0015m$ for the Thorlabs 200 mW diode M9-A64-0200, $R_{eff} = 0.002$ based on the efficiency of the Thorlabs 1200 grooves/mm 1 μm diffraction grating GR25-1210, $R_2 = 0.85$ based on estimates from the Saliba paper, and $n = 3.5$ for GaAs.

If we take the external cavity to be about 10 cm (0.1 m) as a starting point, we get X = 11 for this setup (note that making the external cavity longer increases X which would decrease the linewidth more... this can be done using a lens to focus the beam if we do not want to actually make a very long cavity).

From Saito, we have that

$$\Delta\nu^E = \frac{\Delta\nu}{(1+X)^2}$$

so using this external cavity, we predict a linewidth of $\Delta\nu^E = 5.3kHz$. Recall we used a bandwidth of 1 GHz so this translates to a final noise in PSD of about 0.03 $Hz/\sqrt{Hz}$.

Our requirement for the crackle experiment is 300 $Hz/\sqrt{Hz}$ (or $\Delta\nu = 5.5 * 10^5 Hz$) so this should be sufficient to meet our requirements.

Other items we may need to order:

- Adapter for mounting the diffraction grating on a mirror mount. Based on the size of the diffraction grating we chose, we should order Thorlabs KGM40 if we do not already have a mount in the lab.

- Piezo actuator to stabilize the external cavity?