New Folder Name Fluctuation Measurements

LIGO PROJECT — Interoffice Memorandum

CALIFORNIA INSTITUTE OF TECHNOLOGY

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Subject: Preliminary results on laser beam fluctuation measurements

Attached is a preliminary report by A. Gillespie summarizing his work on evaluating spatial fluctuations of He-Ne and visible diode lasers. This is being circulated for your information but helpful observations or suggestions are always welcome.

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Beam Fluctuation Measurements for the HeNe and Diode Lasers

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Abstract

Measurements of both angular and lateral displacement noise were done for the Uniphase Model 1103P HeNe laser and the Laser Max Model LAS-200 Visible Diode laser. Radial spot size fluctuation measurements were also done for the HeNe; due to the eliptical beam shape of the collimated diode laser, no radial measurements were done with it.

Angular and Lateral Displacement Noise

Figure 1 shows a typical HeNe noise spectrum.[1] This spectrum was taken using a quadrant diode and taking the difference between the two halves with the beam centered on the diode. Above 50 Hz for a laser power of 0.6 mW., the noise was dominated by shot noise which was determined by shining a flashlight at the diode at the same intensity as the laser and measuring the noise. Shot noise could also be calculated by the formula $I(shot) = \sqrt{2eIB}$ where I is the current from the photodiode and B is the bandwidth. From 50 to 250 Hz electronics noise could also be significant if the laser power was lowered. The electronics noise was determined by blocking the laser and taking a noise spectrum. Below 40 Hz the noise level was clearly above both shot and electronics noise, even in a quiet environment late at night when mechanical and acoustic noise was minimal. This noise was taken to be the displacement noise.

Figure 2 shows a typical diode laser spectrum. Since the beam was elliptical, the x and the y axes were not the same. At no point did the noise levels reach shot or electronics noise, so all of the noise was assumed to be displacement noise.

Another possible source of noise was intensity noise. To check for it, noise spectra were taken with the laser centered on the photodiode, and then with the quad diode displaced slightly as measured by a voltage difference between the two halves. The level of intensity noise was expected to be in proportion to the voltage difference, with the noise canceling itself exactly when the difference was zero. The noise level was found to be unchanged up to a difference of 0.3 V and then to increase with the voltage. This led to the conclusion that other noise sources dominate the intensity noise below 0.3 V; since the voltage difference when the beam was centered was well below 0.1 V, intensity noise was not a significant factor in the displacement noise measurements.

The nature of the displacement noise was determined for the HeNe from the noise spectra by measuring the noise levels at different distances from the photodiode to the laser. The measurements were in $dBV/\sqrt{Hz}$, and they were converted into meters using a calibration done by displacing the photodiode a known amount and then measuring the resulting voltage change. Care was taken to be sure that those displacements were done in the region where the distance to voltage relationship was approximately linear. The resulting displacement noise, with the electronics and shot noise subtracted out in quadrature, was plotted as a function of the laser-photodiode distance. At large distances angular displacement noise was expected to dominate; at short distances lateral displacement noise

[1] Figure 1 is not an actual spectrum but rather a compilation of data. See me for

would dominate. The slope of that plot at large distances was therefore the angular displacement noise, and the level of the plot at short distance was the lateral displacement noise. An example of such a plot, done at 10 Hz is shown in figure 4. The fit of the lines to the points is not exceptional, so the uncertainty of the points is high. Below a distance of 0.81 m. the displacement noise was not consistently higher than the electronics noise, making the electronics noise, $4 \times 10^{-10} m/\sqrt{Hz}$, the upper limit for lateral displacement. From the graph the value for angular displacement noise was $8 \times 10^{-9} rad/\sqrt{Hz}$. Above 50 Hz such plots could not be done because the noise was dominated by shot and electronics noise; the corresponding upper limit for angular displacement was $2 \times 10^{-11} rad/\sqrt{Hz}$ and lateral displacement was $2 \times 10^{-11} m/\sqrt{Hz}$.

The same measurements were attempted with the diode laser, but the resulting correlation factors were very small. Instead noise levels were taken at both short (0.81 m.) and very long (24.0 m.) distances; the noise at the short range was assumed to be predominantly lateral, and at long range it was assumed to be angular, giving upper limits for each. (A similar test was not done with the HeNe because the beam was not as well collimated.) The resulting displacement noise was:

	lateral ($m/\sqrt{Hz}$)		angular ($rad/\sqrt{Hz}$)	
	10 Hz	1000 Hz	10 Hz	1000 Hz
x-axis	2×10^{-9}	2×10^{-11}	5×10^{-9}	2×10^{-11}
y-axis	8×10^{-9}	5×10^{-10}	7×10^{-9}	4×10^{-10}

Radial Spot Size Fluctuations of the HeNe

Figure 5 shows a plot of typical HeNe radial fluctuations. A lens was used to widen the HeNe beam and the bullseye photodiode was placed in arbitrary positions along the path with the only restriction being that the difference in voltage between the inner and the outer rings be less than 0.3 V to minimize the effects of intensity noise. From both the difference and the sum of the two rings' voltages, the diameter of the beam could be calculated. Then the noise, dw/w, could be calculated from the noise in the difference. It should be noted that the noise level of the difference was within a few dBV of the shot and electronic noise across the entire spectrum, so the values on the graph are upper limits and include a large portion of other noise.

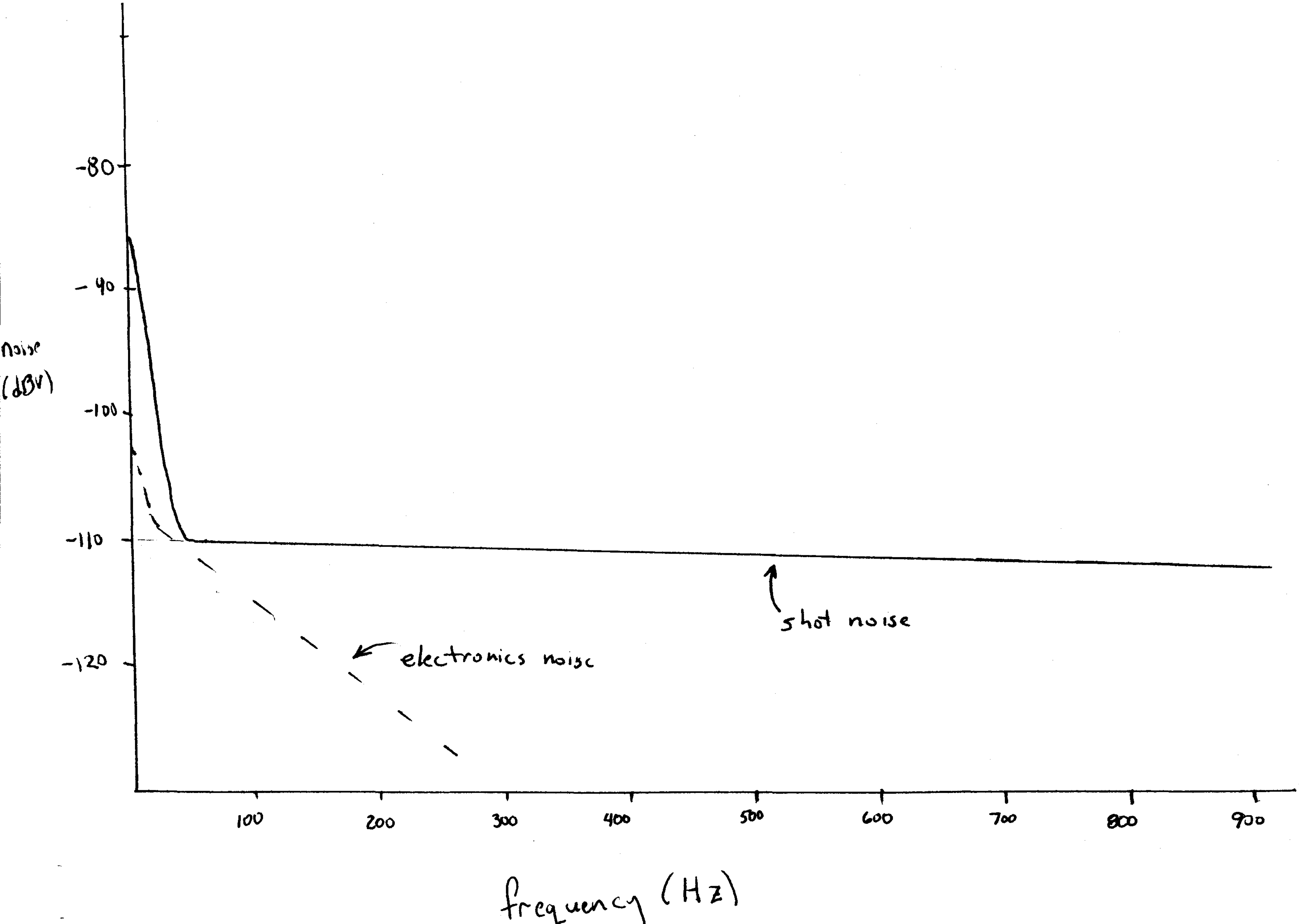
The Argon Laser

The next step is to examine beam fluctuations of the Argon laser and to determine how these are transformed into phase and frequency noise in the mode cleaner. Previous displacement noise measurements for the Argon laser have been a lateral noise of $1.6 \times 10^{-8} m/\sqrt{Hz}$ and an angular noise of $3 \times 10^{-9} rad/\sqrt{Hz}$.[2] The corresponding frequency noise in the current frequency stabilization loop, which uses a mode cleaner with mirrors of radii of curvature of 50 cm., transmittances of 1000 ppm, and a mirror separation of 94 cm., would be $3 \times 10^{-8} Hz/\sqrt{Hz}$.

[2] Alex, "Laser Beam Wiggle Equivalent with Frequency Noise Measured After the Mode Cleaner" 8 Aug 1989

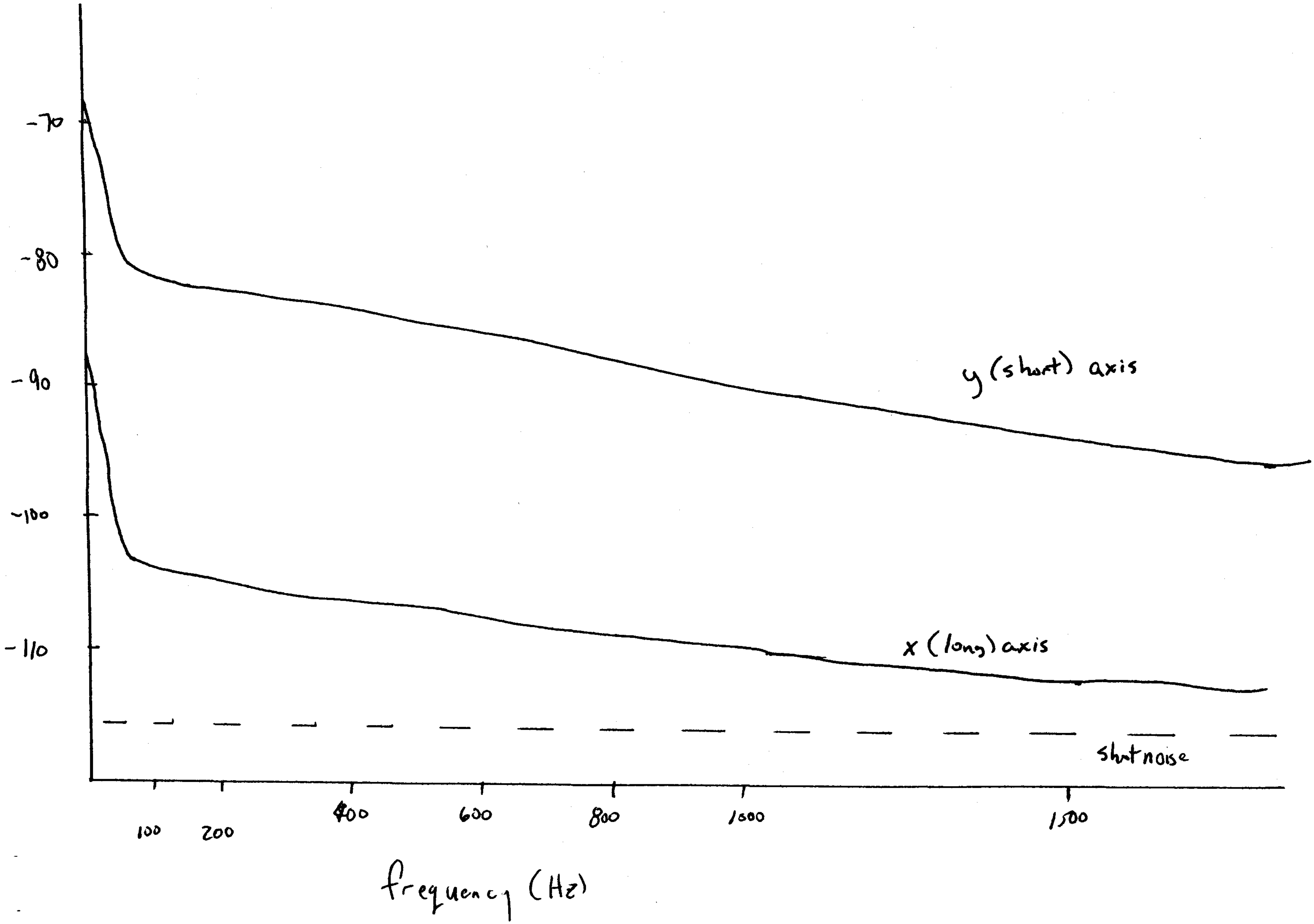
(Fig 1)

Typical HeNe Noise Spectrum



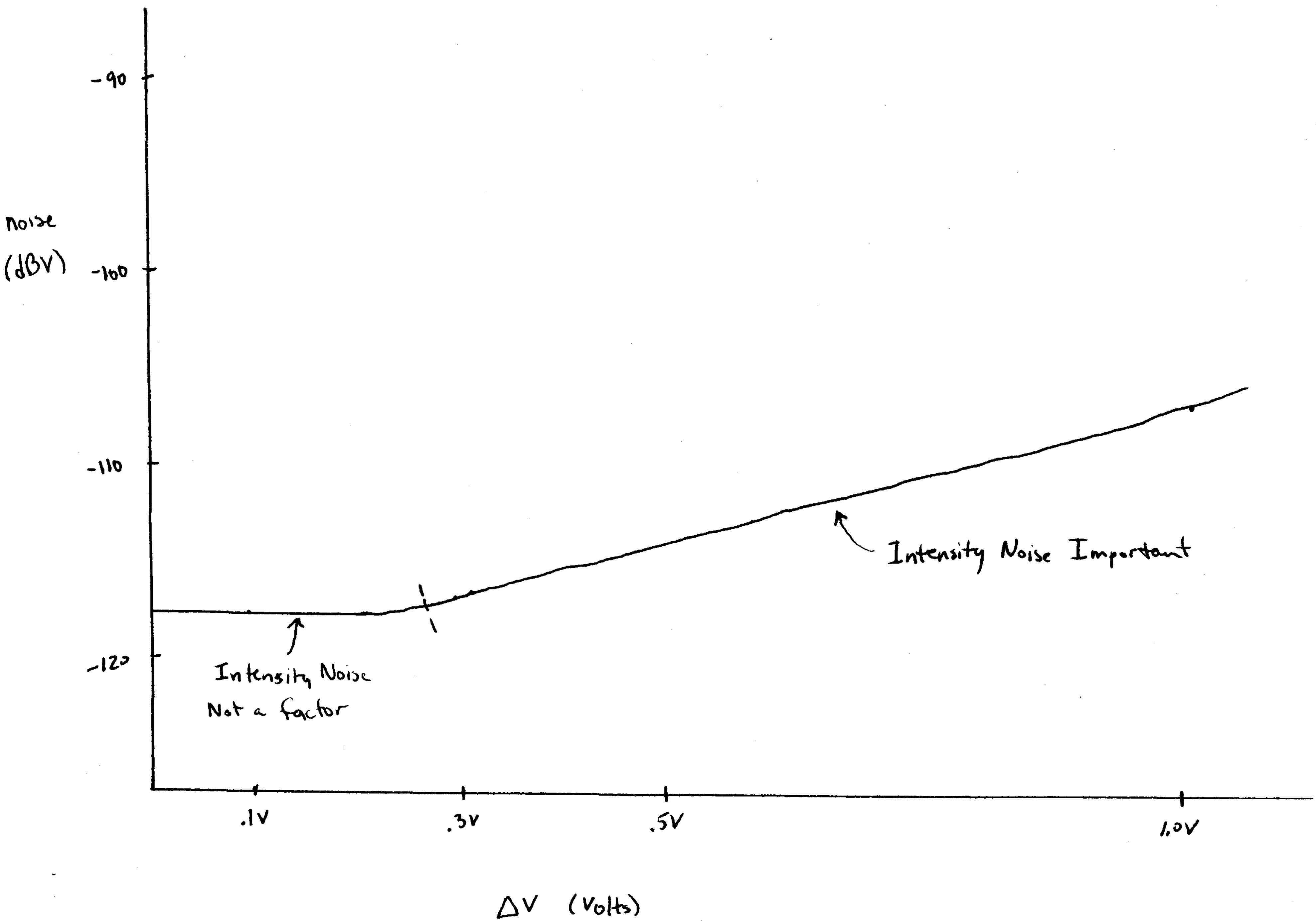
(Fig 2)

Typical Laser Diode Noise Spectrum



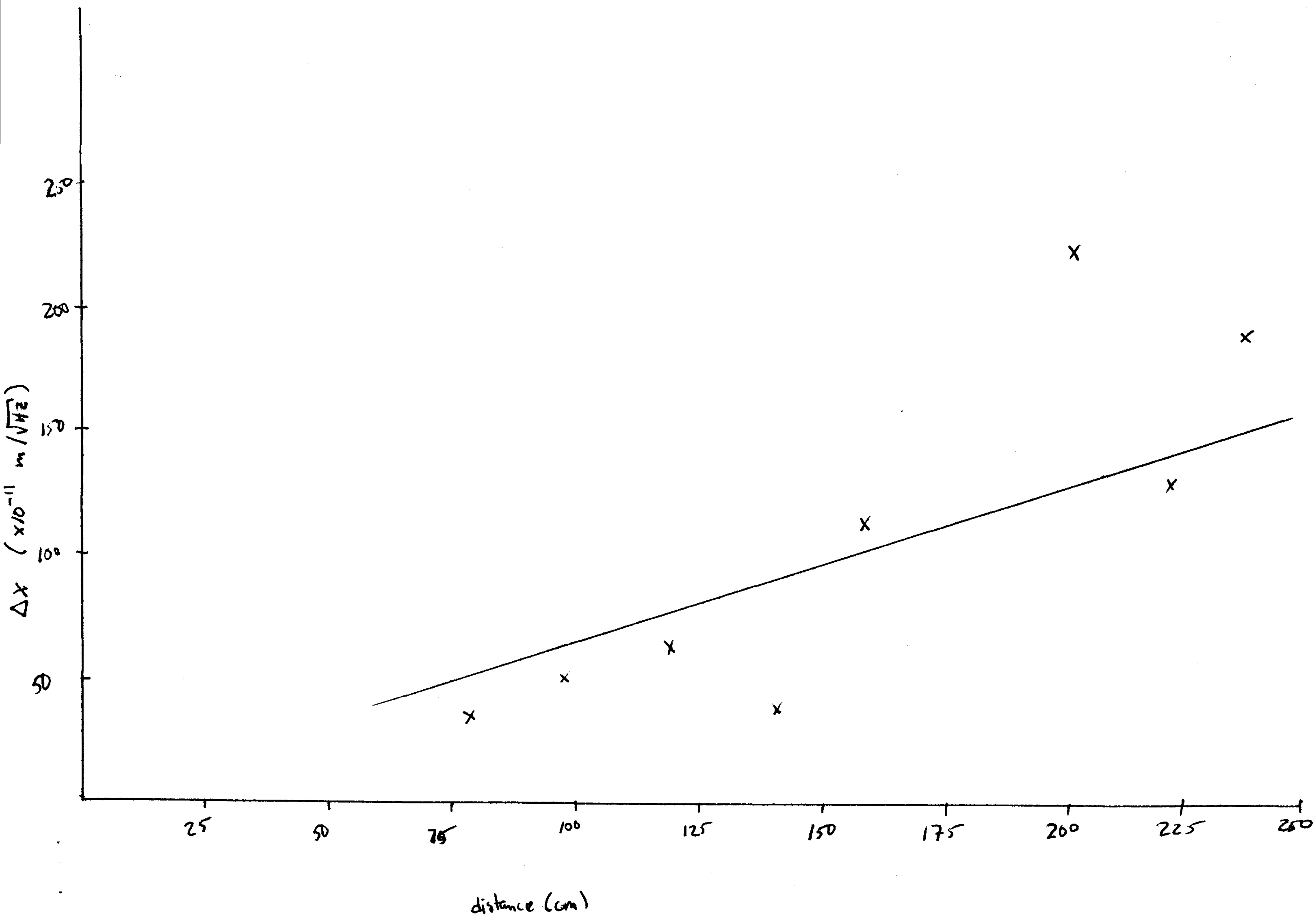
(Fig 3)

Typical HeNe Intensity Noise



(Fig 4)

Plot of Noise v. Distance of HeNe at 10 Hz



(Fig 5)

Typical HeNe Radial Fluctuations