STUDY OF LASER FREQUENCY STABILITY AND SPECTRAL PURITY

under the direction of

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I. STUDIES IN LASER FREQUENCY FLUCTUATIONS AND ABSOLUTE FREQUENCY STABILIZATION

A. QUANTUM PHASE NOISE IN HE-NE LASERS (R. Arrathoon)

1. Introduction

The achievement of extreme spectral purity in gas laser oscillators is a problem of practical importance in such areas as communications, interferometry and precision measurements in general. Under appropriate conditions, the output of a stable single-frequency laser may become essentially monochromatic; however, the resultant output will still have a measurable spectral width. This linewidth will be primarily determined by acoustic, seismic and thermal disturbances which perturb the optical cavity. There may also be perturbations within the plasma itself which can serve to substantially increase the linewidth of the laser. Taken together, these factors may be arbitrarily classified as "external" (or "environmental") disturbances. In addition to the external factors, the linewidth will be further increased by the presence of spontaneous emission or "quantum noise." If the effect of the external disturbances is eliminated, the ultimate spectral width will then be determined solely by quantum noise.

Ordinarily, the quantum-phase-noise-limited linewidth will be extremely narrow. For typical He-Ne lasers operating in the milliwatt region, theoretical linewidths of the order of a few tenths of a hertz are predicted. In practice, observed laser linewidths are considerably greater than this due to the presence of external disturbances. The quantum linewidth contribution may be radically enhanced by operation at extremely low power levels; moreover, with proper instrumentaion this contribution may be isolated from the external contribution. Measurements of spontaneous emission noise can then be made in spite of the presence of relatively large external noise contributions, as we report here.

2. Measurement Theory

The measurement of quantum phase noise in laser oscillators involves techniques similar to those used in accurate determinations of the total linewidth of a laser oscillator. These techniques ordinarily are based on an analysis of the rf beat note between two lasers which are heterodyned together. In the time domain, the heterodyne technique results in a form which contains the product of the two time signals. In the frequency domain, this corresponds to the convolution of the spectral characteristics of each individual laser.

Earlier work[1] determined that the lineshape of the beat signal was gaussian in nature. Since the convolution of two gaussians is also gaussian, the spectral characteristics of each of the lasers (assuming they are identical and independent) can be inferred from an analysis of the beat note. A quantum noise limited signal, however, will have a lineshape that is Lorentzian and the beat signal from two such lasers will again be Lorentzian. Practically, this indicates that the external linewidth contribution, which is gaussian in nature, far exceeds the spontaneous

[1] A.E.Siegman, B.Daino, and K.R.Manes, "Preliminary Measurements of Laser Short-Term Frequency Fluctuations," IEEE J.Quant. Electr. QE-3, 180 (May 1967).

emission linewidth contribution. Any measurement of quantum noise must then separate the effects of the two noise sources by utilizing the differing spectral characteristics of the two sources. The basic techniques for these measurements are presented in Appendi~~ces A and B.~~ Removed

3. Experimental Results

The results of our first experiments on quantum phase noise have now been published. The measurements were made over a somewhat limited range in power, for power levels in the low microwatt region. These results essentially verify the Schawlow-Townes relation, which is a fundamental formula for the quantum noise limited linewidth of a laser oscillator. The measurements utilized a 30 MHz FM discriminator and a high frequency sampling scope. More extended measurments with a 4.5 MHz discriminator have more recently been made over approximately two decades in laser power. These results are presented in Removed ~~Appendix B~~ together with a discussion of laser amplitude fluctuations that are necessary for a theoretical evaluation of the Schawlow-Townes relation.

B. PLASMA INDUCED PHASE NOISE IN HE-NE LASERS

1. Introduction

The effect of the external factors on the oscillator linewidth may be reduced by utilizing extremely stable optical cavities and by operating the laser in relatively noise free environments. Careful precautions along these lines have yielded spectral widths in the kilohertz range for 6328 Å He-Ne lasers. Beyond a certain point, however, more elaborate environmental precautions have not resulted in substantial reductions in the linewidth. Experimental evidence indicates that this residual broadening may be explained in terms of perturbations within the gas discharge.

2. Experimental Results

Modulation of the dc discharge current of one of our lasers was observed to produce substantial blue shifts of the lasing frequency with increasing current of the order of MHz/mA. At 6328 Å this shift was found to be essentially independent of position on the inhomogeneously broadened atomic line, implying that the shift was due to background changes in the dispersion of the media rather than to any pushing or pulling effects associated with the atomic transition itself. Further experimental evidence indicated the most probable mechanism to be the dispersive effects of the nearby neon 1s-2p upward transitions at 6334 Å and 6402 Å. These results have now been accepted for publication, and a reprint is Detached ~~attached~~ ~~as Appendix~~ C.

3. Conclusions

The magnitude of these effects suggests that the spectral width of 6328 Å lasers, presently thought to be limited by microphonic disturbances, may rather be due to plasma effects. If random plasma oscillations are present in the discharge, the use of rf excitation should have a tendency to reduce or eliminate these perturbations. Intrinsically, in the absence of other external effects, it appears that the 1.15 μ He-Ne transition will have a considerably narrower linewidth than the 6328 Å transition.

4. Future Analysis

Experimental evidence indicates that the frequency fluctuation mechanism involves variations in the neon 1s metastable population. This leads to the interesting problem of attempting to theoretically determine the neon 1s population density based only on such readily available information as the pressure, tube diameter, electron temperature and gas mixture. The resulting neon 1s population may then be used to calculate the expected effect of plasma perturbations on the oscillator. The basic solution to this problem has already been formulated and will shortly be concluded.