Locking Lasers with Large FM Noise to High Q Cavities

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Abstract: We directly lock a diode laser with 1MHz of frequency noise to an optical cavity with a 3.5kHz linewidth. This is the narrowest linewidth used for directly locking a ≈1MHz laser.

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1. Introduction, Results, and Discussion

Lasers stabilized to passive high Q cavities are among the most stable oscillators and serve as the flywheel oscillators for optical frequency clocks[1]. These lasers often have free-running linewidths that are much greater than linewidth of the high Q cavity. When the relative frequency noise between the laser and the cavity is large, the laser frequency can sweep over the cavity resonance more quickly than the time it takes for light to build up in the cavity[2,3]. This produces severe distortions of the usual Pound-Drever-Hall error signal, suggesting that lock acquisition is not possible with an analog servo[4]. This issue has often been avoided by using a pre-stabilization cavity with a moderate finesse and linewidth[1].

A series of papers have demonstrated locking of external-cavity diode lasers to successively narrower cavity resonances, as narrow as 14 kHz[5,6]. Here we lock an external-cavity diode laser to a cavity with a linewidth of 3.5 kHz with an analog servo. Our cavity resonance is a factor of four narrower, leading to error signal distortions that are 16 times larger. We show that we can acquire lock when the laser frequency noise is greater than 1MHz.

Experimentally and theoretically, we show that the response of the error signal decreases reasonably slowly for frequency noise with very large frequency modulation (fm) depths (Fig. 1(a)). For high frequency noise, it is well known that the cavity response has a $\pi/2$ phase lag, corresponding to detecting the phase of the laser field[7]. In Fig. 1(b) we show that, for large laser fm noise at high frequencies, the phase of the error signal is bounded near zero and, surprisingly, oscillates between a phase lag of $\pi/2$ and a phase lead of $\pi/2$.

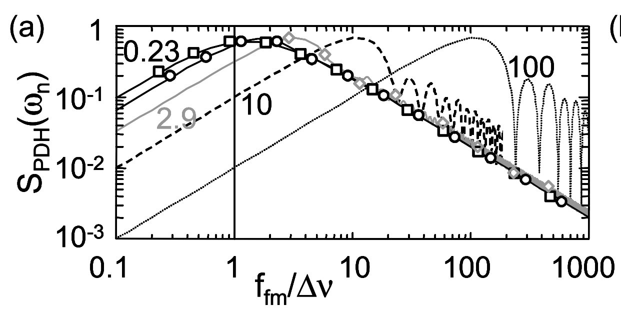

Fig. 1. The response (a) and phase (b) of the cavity-lock error signal S_{PDH} at the noise frequency $f_n=\omega_n/2\pi$ as a function of noise depth f_{fm} and $\beta_n= f_{fm}/f_n$ for $f_n/\Delta\nu$= 0.23, 1.15, 2.9, 10, and 100. Data are squares (circles, diamonds) for $f_n/\Delta\nu$= 0.23 (1.15, 2.9). The response falls as $1/f_{fm}$ for large fm depth. For $f_n>\Delta\nu$, the phase oscillates between a phase lag and a phase lead for $\beta_n>2$.

Our results show that one can use pre-stabilization cavities with much higher Q's to reduce the frequency and amplitude noise of the transmitted light at audio and radio frequencies. Thus, cavity transmission, and not the laser linewidth, limits the maximum finesse. Current mirrors offer a finesse greater than 10^5 with 50% transmission.

2. References

[1] B. C. Young, F. C. Cruz, W. M. Itano, and J. C. Bergquist, "Visible Lasers with Subhertz Linewidths," Phys. Rev. Lett. **82**, 3799-3802 (1999).
[2] J. Camp, L. Sievers, R. Bork, and J. Heefner, "Guided lock acquisition in a suspended Fabry–Perot cavity," Opt. Lett. **20**, 2463-2465 (1995).
[3] M. J. Lawrence *et al.*, "Dynamic response of a Fabry–Perot interferometer, " JOSA B **16**, 523-532 (1999).
[4] H. Rohde *et al.*, "Optical decay from a Fabry-Perot cavity faster than the decay time," JOSA B **19**, 1425-1429 (2002).
[5] A. Schoof, J. Grünert, S. Ritter, and A. Hemmerich, "Reducing the linewidth of a diode laser below 30 Hz by stabilization to a reference cavity with a finesse above 10^5", Opt. Lett. **26**, 1562-1564 (2001).
[6] C. W. Oates, F. Bondu, R. Fox, and L. Hollberg, "A diode-laser optical frequency standard based on laser-cooled Ca atoms: Sub-kilohertz spectroscopy by optical shelving detection", Eur. Phys. J. D **7**, 449-460 (1999).
[7] R. W. P. Drever *et al.*, ''Laser phase and frequency stabilization using an optical resonator,'' Appl. Phys. B **31**, 97-105 (1983).