TUNABLE PHASE-LOCKED DIODE LASERS FOR PRECISION SPECTROSCOPY*

L. D'Evelyn[a], L. Hollberg[a], R.W. Fox[a] and Z.B. Popovic[b]
[a] National Institute of Standards and Technology
325 Broadway
Boulder, CO 80303
[b] Department of Electrical and Computer Engineering
University of Colorado
Boulder, Colorado 80309-0425

Abstract

We have developed an electronic circuit for phase-locking extended-cavity diode lasers to a stable reference laser. The basic phase-lock operates with input frequencies between 5 MHz and 1.5 GHz and allows synthesizer tuning of the difference frequency between the lasers. An external mixing stage can be used for an arbitrary frequency offset.

As demonstrated in three recent publications[1-4] phase-locked diode laser sources are playing increasingly important roles in a number of applications. Some of the applications of phase and/or frequency locked lasers include: optical frequency synthesis and measurement, laser cooling and trapping of atoms, laser ranging and length measurements and coherent communications. The electronic system that we describe here also addresses some of these needs. In particular, our system is specifically designed for optical frequency synthesis and high resolution spectroscopy. For these applications we require precise frequency scans and locking of the frequency of extended-cavity diode lasers.

Basic operation of the phase-lock can be understood from the block diagram of the circuit as shown in Fig. 1. The beat note between two lasers is detected with a fast photodiode and input to the first mixing stage where it is combined with the LO input from a synthesizer. The output of this mixer is bandpass filtered, detected by an ECL phase/frequency detector, and then low pass filtered. The resulting error signal is then processed by the loop filter and fed back to the extended-cavity laser via two channels: one is a wide bandwidth channel (DC to ≈ 1MHz) to the laser's injection current, and the second channel goes to a PZT that controls the extended-cavity length, with a wide dynamic range and a lower bandwidth (DC to ≈2 kHz).

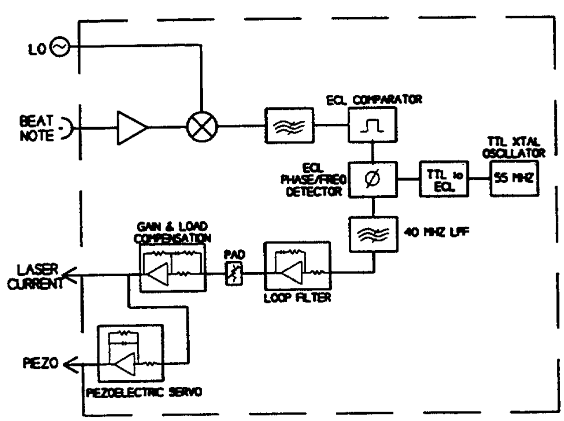

Fig. 1 Block diagram of circuit for phase locking extended-cavity diode lasers.

The design we have chosen was constrained, in part, by our desire to have a simple system that allows scans of the offset frequency over a range of at least 1.5 GHz with a resolution ≤1 Hz. The 1.5 GHz range was dictated by the 3 GHz free-spectral-range of the Fabry-Perot cavity that we use to lock the reference laser and our requirement of complete spectral coverage. The first mixing stage accepts inputs in the range between 5 MHz and 1.5 GHz, which, when supplied by a sweeping synthesizer, allows continuous tuning of the difference frequency between the two lasers. The phase/frequency detector is normally set to operate at a center frequency of ≈55 MHz which results in a capture range for input frequencies between 20 and 100 MHz.

The maximum tuning range of the frequency offset is not fundamentally limited, but is rather naturally set by the range of the sweeping synthesizer (LO). If larger offsets or broader scans are desired, high speed prescalers or additional microwave mixing stages can be used. For example, with special Schottky diodes it is possible to detect the beat note between near-IR diode lasers to frequencies higher than 400 GHz.[5]

The phase-lock circuit, as diagrammed in Fig. 1, has been fabricated on a single printed circuit board. The microwave and RF sections use a grounded coplanar-waveguide design with surface-mount components. High-speed integrated-circuit op-amps are used for loop filtering and to compensate the combined FM response of the current source and extended-cavity laser.

The locking system is now used in two experiments with different types of extended-cavity lasers. The first example is for high resolution spectroscopy of calcium and uses InGaAlP lasers operating at 657 nm.[6] In this system the reference laser is electronically locked to a high precision Fabry-Perot cavity and then the phase-lock circuit is used to control the frequency of a second extended cavity laser. The second example is for use in experiments on laser cooled Hg^+ and is done in collaboration with J.C. Bergquist of NIST. In this case a frequency offset of 47 GHz (from a microwave harmonic mixer input stage) is used and an AlGaAs laser (at 792 nm) is phase-locked to a $Ti:Al_2O_3$ laser. In both cases a servo-loop bandwidth of about 1 MHz results in stable phase-locks. Locking times of as long as 8 hours have been demonstrated.

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