



LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Arm Length Stabilization (ALS) Vertex Detection System

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1 Introduction

A key ingredient of the Arm Length Stabilization (ALS) system is the heterodyne detection of the two ALS 532 nm beams in the vertex, to generate ‘common’ and ‘differential’ mode error signals. The error signals originate from two Broad-Band Photodetectors (BBPD) on ISCT1:

- Common mode: heterodyning of the ALS X-arm beam with the frequency-doubled PSL beam; nominal beat frequency: 78.92 MHz
- Differential mode: heterodyning of the ALS X-arm and Y-arm beams; nominal beat frequency: 157.84 MHz

Each photodetector beat signal is detected with a Phase-Frequency Discriminator (PFD). The local oscillator, or frequency reference, for each PFD is a low-noise voltage-controlled oscillator (VCO). Additionally, the VCO is equipped with an analog servo so that a phase-locked loop (PLL) can be formed around the VCO and the PFD, locking the VCO frequency to the beat signal. This note describes the function and design of this detection scheme.

2 Design

A block diagram of the ALS Common Mode Detection is shown in Figure 1; the ALS Differential Mode Detection is shown in Figure 2.

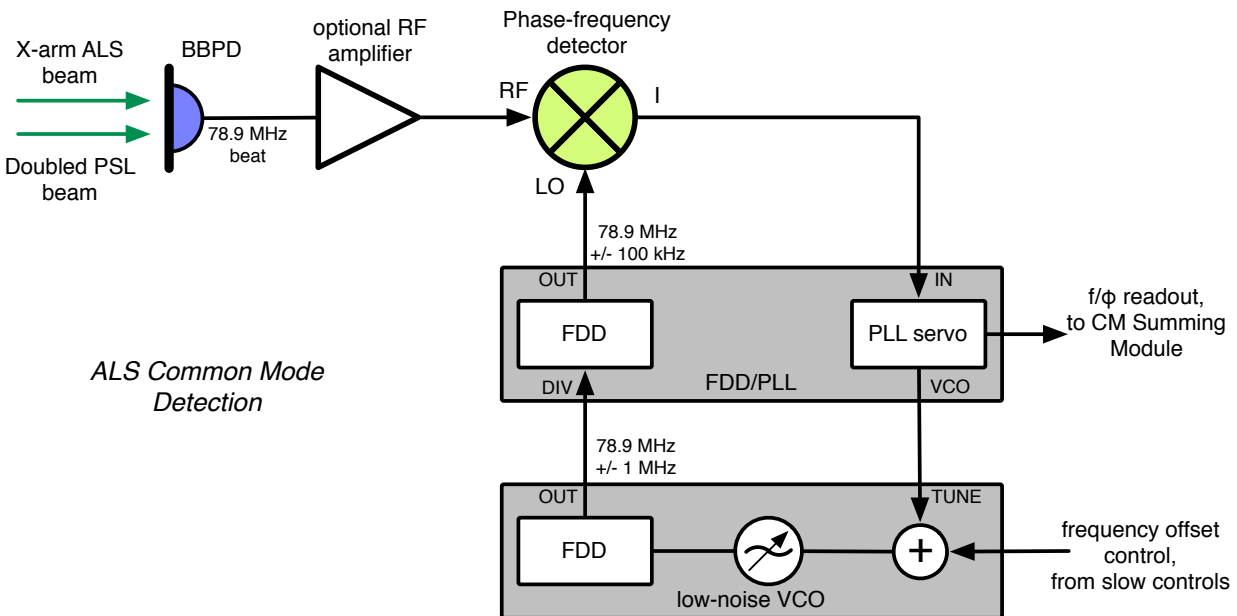


Figure 1. Block diagram of the ALS Common Mode Detection scheme. FDD: Frequency Difference Divider. Each FDD is fed with a 71 MHz reference signal (not shown). Though the X-arm beam is shown, the heterodyne detection could equally well be done with the Y-arm ALS beam.

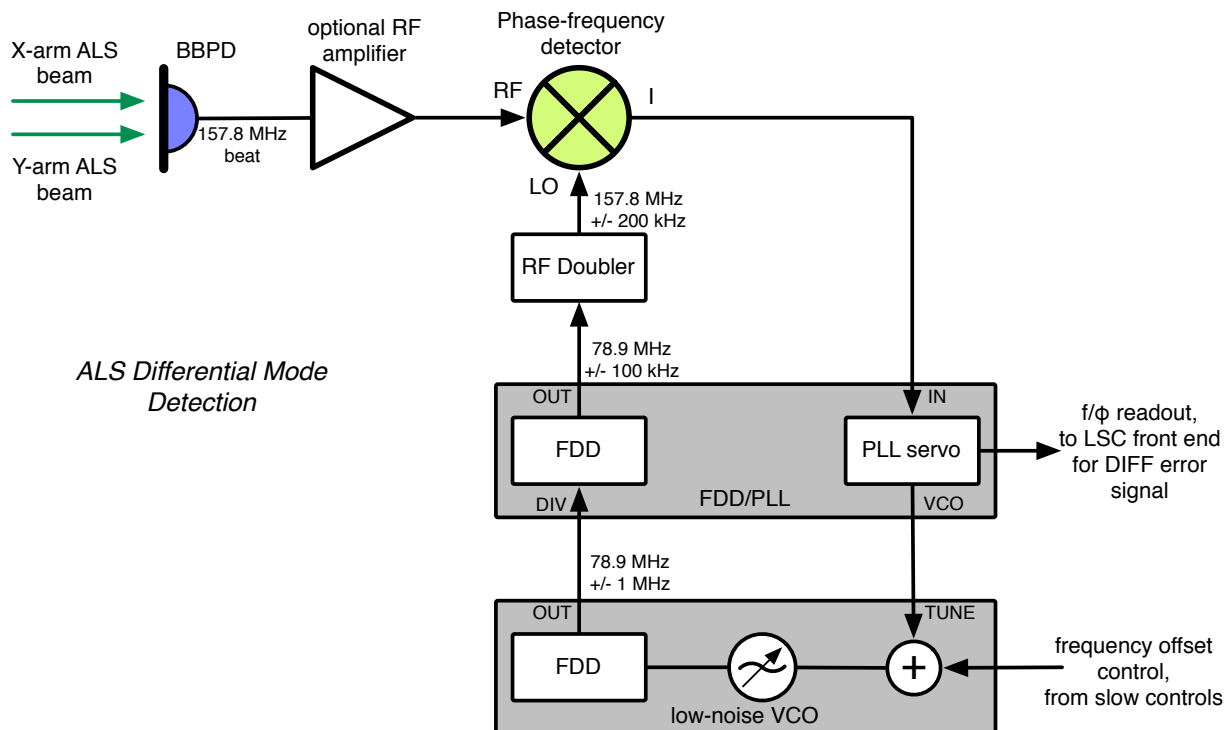


Figure 2. Block diagram of the ALS Differential Mode Detection scheme. See LIGO-T1300833 for the nominal ALS RF frequencies.

2.1 Function of the Phase-locked loop

In principle the output of the phase-frequency discriminator can provide the error signal for the ALS Common and Differential modes. However, when the signals go outside the phase mode of the PFD, the output flips between high and low. This was found to be unusable for CM control, as the transitions would kick the IMC (input mode cleaner) out of lock.

Instead, a wide-band electronic loop is wrapped around the PFD and VCO, keeping the PFD always in phase detection mode. The ALS error signal (Common and Differential) is then taken from the control signal of the PLL, which is proportional to the relevant frequency difference in a continuous fashion.

2.2 Component descriptions

BBPD. This is the custom aLIGO broadband photodetector, [LIGO-E1200428](#). From L1 (April 2014), typical signal levels are:

- ALS COMM. X-arm beam: 30 uW; doubled PSL beam: 80 uW; beat signal at output: -22 dBm.
- ALS DIFF. X-arm beam: 30 uW; Y-arm beam: 60 uW; beat signal at output: -27 dBm

Phase/frequency detector. [LIGO-E1200114](#). A digital phase/frequency discriminator is used as the phase detector for the PLL. Compared to an analog mixer, it has the advantage that it produces an output with the correct sign even if the two input frequencies are not equal to each other. This means the PLL will always lock, even with initially unequal frequencies.

Low-noise VCO. [LIGO-E1200120](#). The standard aLIGO 80 MHz VCO has a frequency tuning range of 2 MHz. This is more than enough, as it corresponds to 50 free-spectral-ranges of an arm cavity. On the other hand the stability of the output frequency is measured to be 16 Hz-rms (10^3 sec time scale), which is greater than the target ALS stability of 10 Hz. Therefore a second frequency-difference divider is used to reduce both the noise and the range.

Frequency-difference divider (FDD). [LIGO-T0900138](#). The second FDD (in the FDD/PLL block) is implemented to improve the VCO frequency stability. This is a divide-by-10 FDD, so it reduces the frequency noise and the tuning range by 10x. The measured stability of the output frequency is 2 Hz-rms (10^3 sec time scale).

PLL servo. [LIGO-E1300728](#). This is an analog servo amplifier contained in the same chassis as the second FDD. It contains a variable gain amplifier and multiple selectable filter stages. It is designed to accommodate a PLL bandwidth up to ~ 100 kHz, though typically the PLL is run with a unity gain of a few tens of kilohertz. The PLL open loop shape is: $1/f$ below 1.6 Hz; $1/f^2$ between 1.6 Hz and 17 kHz; $1/f$ above 17 kHz. The **f/ ϕ readout** of the PLL servo board is a tap-off of the output sent to the VCO tuning input, though with additional selectable compensation filters. See [LIGO-D1300945](#) for a block diagram of the PLL board.

RF doubler. [LIGO-E1200117](#). The beat frequency between the X-arm and Y-arm ALS beams is 157.8 MHz, so the output of the second FDD is sent through an RF frequency doubler before it is sent to the PFD.

RF amplifier. If needed an RF amplifier (Mini-Circuits) can be used between the BBPD and the PFD.

Frequency offset control. A main feature of the ALS system is the ability to control the frequency difference between the PSL and ALS beams, and thereby control the PSL frequency relative to the 1064 nm resonance of the arm cavities. This is done by adding an offset to the Common Mode VCO tuning input, summed in with the control signal coming from the PLL. Through the action of the PLL servo, this offset shows up on the **f/ ϕ readout** of the PLL board, and it is this signal that is used as the CM error signal. The Differential Mode VCO also allows frequency offset control if desired.

3 Related documents

This document describes only a portion of the ALS system. The overall ALS design is found in [LIGO-T0900144](#). Other documents that are closely related to this one:

[LIGO-T1300883](#), *Nominal ALS Frequencies*

[LIGO-T1000555](#), *Adv LIGO Arm Length Stabilization – Vertex Layout Overview*