*LIGO Laboratory / LIGO Scientific Collaboration*

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 ALS Laser Locking Library

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| **Library** |
| Title | ALSLaserLocking |
| Version | 2 |
| TwinCAT version | V2.11.0 |
| Name space |  |
| Author | Sheila Dwyer |
| Description | Autolocking for ALS PLL at end station. See following section for more details. |
| Error Code | 1 — Communications error (lost communication from corner PLC1 or cornerPLC2, or there is an error from the timing system)2 — Reference cavity transmission PD error4 — Reference cavity transmission below the limit (limit set in this autolocker)8 — Fiber launch PD (in the fiber distribution box, internal.DC) error16 — Fiber launch power below the limit (limit set in this autolocker)32 — Fiber trans PD error (the limits are enforced in the DC PD library for the local PDs)64 — Fiber trans PD limits not set, they need to be set correctly128 — Fiber rejected polarization PD error32768 — Fiber rejected PD limits not set256 — % of the fiber light that is in the wrong polarization is too large512 — Power transmitted by fiber in the correct polarization to interfere with ALS laser is too small1024 — ALS Laser IR power PD error65536 — ALS Laser IR power PD limits not set2048 — Phase Frequency Discriminator Error4096 — Beat note power too low8192 — Beat note out of range of frequency comparator131072 — ALS Laser Error262144 — AutoLocker Failed |
| Library Dependencies | ErrorHandler, SaveRestore, ReadADC, WriteDAC, ALSCommunication, ALSStateMachine, DCPower, Demodulator, CommonModeServo, ALSLaser |

**1. Library Description:**

This library includes an autolocker for the ALS end station lasers, as well as a function block called temperature controls taken from Alexa Staley’s ALSLaser library that implements a slow servo feeding back to the laser crystal temperature.

It implements the following equation, which results in a 1/f filter if TemperatureControls.PF is zero OR a 1/f response with a zero at Pf, which is intended to compensate for the thermal pole of the laser crystal:

$u\_{i}=u\_{i-1}+g×\left\{\begin{matrix}e\_{i}&h\leq 0\\ (e\_{i}-e\_{i-1})/h&h>0\end{matrix}\right.$ with

$g=πf\_{ugf}∆t$ and $h= πf\_{Pf}∆t$.

$∆t$: sampling interval,

$f\_{ugf}$: unity gain frequency of integrator,

$f\_{Pf}$: Knee frequency of proportional gain.

There is also a polarity switch that reverses the sign of the feedback, and an enum (TemperatureControls.ErrorSignal) which allows the user to choose what to use as an error signal: the options are the beat note frequency error measured by the frequency comparator (beat.frequency-beat.vcofrequency/2), the signal sent to the laser PZT calibrated in MHz, or the fast mon from the servo, also calibrated in MHz. There is also a reset that clears the integrator, and range limits for the output of the slow feedback.

The library also includes an error checking function block called locking conditions, which checks for a large number of error conditions that may prevent the PLL from locking, and sets the bit Logic.Conditions to FALSE if any of the locking conditions are not met.

The variable ‘locked’ is set to true if the common mode servo is not saturated and the beatnote is within tolerance.

A state diagram for the autolocker is below. The user can enable the autolocker so that it will run when the locking conditions are met, or force it so that it will disregard errors from the locking conditions function block. The user can also choose a polarity to lock the ALS laser above or below the PSL in frequency. This sets the polarity on the servo, the phase frequency discriminator, and the temperature feedback.



Figure : State diagram for PLL autolocking, transitional states in purple

 When the autolocker state machine begins running, it either passes to the PLLInitialize state if the pll is unlocked or to the PLLGainRamp state if it is locked.

The user can choose to skip initialization or to initialize the autolocker, in which case it begins by increasing the laser crystal temperature, waiting 30 seconds and determining based on the response of the beat note measured by the frequency comparator if the laser is above or below the PSL in frequency. If the laser is on the wrong side, or the autolocker cannot determine what side it is on, it goes to the failed state, and the user needs to manually tune the crystal temperature. Once the temperature is manually tuned the user can disengage the autolocker and re-engage it to begin the locking process.

When the laser is on the correct side, the autolocker passes to the PLLSearch state, and uses the temperature servo with the beat note measured by the frequency comparator as an error signal, with the common mode board feedback to the PZT disengaged. If the beat note error become less than beat.LockingRange the state machine passes to PLLacquire, or if 20 minutes pass without the beatnote coming into range the autolocker goes to the PLLfailed state.

In the PLLacquire state the common mode board feedsback to the laser PZT with low gain and the temperature servo continues to use the beatnote error as measured by the frequency comparator as an error signal. If the beat notes goes out of the locking range, the state returns to PLLSearch, if the PLL locks it passes to PLLRampGain.

In PLLRampGain the temperature servo error signal is switched to the PZT feedback, and the input gain of the common mode board is ramped at 1dB per second until it reaches the gain used for locking. If the PLL is locked at the locking gain for 1 second, the state transitions to PLLLocked,

It will stay in the locked state unless the PLL becomes unlocked for more than 1 second, in which case it passes to PLLaquire, or if the locking conditions are no longer met it will pass to disengaged.

**2. Example Usage:**

AlsEndFibrLockFB (

 FromCornerPLC1:=RecieveFromCornerPLC1,

 FromCornerPLC2:=RecieveFromCornerPLC2,

 ALSLaserLocking := Ifo.ALS.End.Fibr.Lock,

 ALSLaser:=Ifo.ALS.End.Laser.Head,

 Request := Request,

 ALSLaserLockingInit := AlsEndFibrLockInit,

 FiberTrans:=Ifo.ALS.End.Fibr.Trans.Dc,

 FiberRejected:=Ifo.ALS.End.Fibr.Rejected.Dc,

 LaserIR:=Ifo.ALS.End.Laser.Ir.Dc,

 Demod := Ifo.ALS.End.Fibr\_A.Demod,

 CommunicationsError:= Ifo.Sys.Communication.Y.Error,

 Servo := Ifo.ALS.End.Fibr.Servo);

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| **ALS Laser Locking Type**TYPE ALSLaserLockingEnum : (PLLDisengaged, PLLInitialize, PLLSearch, PLLAcquire, PLLRampGain, PLLLocked, PLLFailed)END\_TYPE; |
| Type Name | ALSLaserLockingEnum |
| Description | Specifies the state for the PLL |
| Definition | ENUM |
| Element | Name: PLLDisengagedDescription: The autolocker is disengaged |
| Element | Name: PLLInitializeDescription: Initialize the PLL autolocker |
| Element | Name: PLLSearchDescription: Searching for resonance |
| Element | Name: PLLAcquireDescription: PLL lock is acquired |
| Element | Name: PLLRampGainDescription: Increase the gain of the PLL Common Mode Board |
| Element | Name: PLLLockedDescription: PLL is locked |
| Element | Name: PLLFailedDescription: Autolocker has failed to lock the auxiliary laser |

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| **User Interface Type**TYPE ALSLaserLockingBeatNoteStruct :STRUCT RFMin: LREAL; Frequency: LREAL; VcoFrequency: LREAL; Tolerance: LREAL; LockingRange: LREAL; Low: LREAL; High: LREAL; Sign: BOOL; FrequencyError: LREAL; SmoothedFrequencyError: LREAL;END\_STRUCT;END\_TYPE; |
| Type Name | ALSLaserLockingBeatNoteStruct |
| Description | Structure used in the user interface type to control the autolocker  |
| Definition | STRUCT |
| Output Tag | Name: RFMinType: LREALDescription: Beat note threshold |
| Output Tag | Name: FrequencyType: LREALDescription: Beat note frequency |
| Output Tag | Name: VcoFrequencyType: LREALDescription: VCO frequency |
| Output Tag | Name: ToleranceType: LREALDescription: Beat note frequency tolerance |
| Output Tag | Name: LockingRangeType: LREALDescription: Frequency range for locking |
| Output Tag | Name: LowType: LREALDescription: Low cut-off for acquisition  |
| Output Tag | Name: HighType: LREALDescription: High cut-off for acquisition  |
| Input Tag | Name: SignType: BOOLDescription: Sign of laser frequency |
| Input Tag | Name: FrequencyErrorType: LREALDescription: Frequency error of beat note |
| Input Tag | Name: SmoothedFrequencyErrorType: LREALDescription: Frequency error of beat note smoothed |

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| **User Interface Type**TYPE ALSLaserLockingFiberStruct :STRUCT LaunchLim: LREAL; PolarizationPercent: LREAL; PolLim: LREAL = 30; TransRightPol: LREAL; TransRightPolLim: LREAL;END\_STRUCT;END\_TYPE; |
| Type Name | ALSLaserLockingFiberStruct |
| Description | Structure used in the user interface type to control the fiber  |
| Definition | STRUCT |
| Input Tag | Name: LaunchLimType: LREALDescription: Lower limit for launched fiber power |
| Input Tag | Name: PolarizationPercentType: LREALDescription: Fiber trans in the wrong polarization |
| Input Tag | Name: PolLimType: LREALDescription: Limit for wrong polarization light |
| Output Tag | Name: TransRightPolType: LREALDescription: Fiber trans power in right polarization |
| Input Tag | Name: TransRightPolLimType: LREALDescription: Fiber trans power in right polarization limit |

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| **User Interface Type**TYPE ALSLaserLockingLogicStruct :STRUCT Conditions: BOOL; Enable: BOOL; Force: BOOL; On: BOOL; TemperatureForce: BOOL; TemperatureOn: BOOL; Polarity: BOOL; SkipInitialization: BOOL;END\_STRUCT;END\_TYPE; |
| Type Name | ALSLaserLockingLogicStruct |
| Description | Structure used in the user interface type to control the laser locking logic  |
| Definition | STRUCT |
| Output Tag | Name: ConditionsType: BOOLDescription: Pre-conditions for locking |
| Input Tag | Name: EnableType: BOOLDescription: Enable autolocker |
| Input Tag | Name: ForceType: BOOLDescription: Force autolocker on even if conditions are not met |
| Input Tag | Name: OnType: BOOLDescription: Autolocker on |
| Input Tag | Name: TemperatureForceType: BOOLDescription: Force autolocker on despite temperature |
| Input Tag | Name: TemperatureOnType: BOOLDescription: Slow servo on |
| Output Tag | Name: PolarityType: BOOLDescription: Polarity for ALS Laser PLL |
| Input Tag | Name: SkipInitializationType: BOOLDescription: Check laser on right size |

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| **User Interface Type**TYPE ALSLaserLockingStruct :STRUCT Error: ErrorStruct; State: ALSLaserLockingEnum; RefCavTransLim: LREAL; Fiber: ALSLaserLockingFIberStruct; Beat: ALSLaserLockingBeatNoteStruct; Logic: ALSLaserLockingLogicStruct; TemperatureControls: TemperatureControlsStruct; LockLosses: INT; ResetLockLosses: BOOL;END\_STRUCT;END\_TYPE; |
| Type Name | ALSLaserLockingStruct |
| Description | Structure used in the user interface type to control the laser locking |
| Definition | STRUCT |
| Input/Output Tag | Name: ErrorType: ErrorStructDescription: Calls error handler |
| Input/Output Tag | Name: StateType: ALSLaserLockingEnumDescription: Autolocker state |
| Input/Output Tag | Name: RefCavTransLimType: LREALDescription: Lower limit for reference cavity transmission |
| Input/Output Tag | Name: FiberType: ALSLaserLockingFiberStructDescription: Structure of limits and calculations for fiber transmission |
| Input/Output Tag | Name: BeatType: ALSLaserLockingBeatNoteStructDescription: Structure for achieving a beat note |
| Input/Output Tag | Name: LogicType: ALSLaserLockingLogicStructDescription: Structure for logic behind autolocker |
| Input/Output Tag | Name: TemperatureControlsType: TemperatureControlsStructDescription: Temperature controls structure |
| Output Tag | Name: LockLossesType: INTDescription: Counts the number of times lock has been lost |
| Input Tag | Name: ResetLockLossesType: BOOLDescription: Resets the lock loss counter |

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| **User Interface Type**TYPE TemperatureControlsStruct :STRUCT On: BOOL; Enabled: BOOL; Run: BOOL; Reset: BOOL; Low: LREAL; High: LREAL; Range: BOOL; Ugf: LREAL; Pf: LREAL; Polarity: BOOL; ErrorSignal: TemperatureErrorSignalEnum;END\_STRUCT;END\_TYPE; |
| Type Name | TemperatureControlsStruct |
| Description | Structure used in the user interface type to control the laser temperature |
| Definition | STRUCT |
| Input Tag | Name: OnType: BOOLDescription: On/off button |
| Input Tag | Name: EnabledType: BOOLDescription: Controls enabled button  |
| Output Tag | Name: RunType: BOOLDescription: Temperature feedback running |
| Input Tag | Name: ResetType: BOOLDescription: Reset the integrator |
| Input Tag | Name: LowType: LREALDescription: Low control value in Hz |
| Input Tag | Name: HighType: LREALDescription: High control value in Hz |
| Input Tag | Name: RangeType: BOOLDescription: Controls range exceeded |
| Output Tag | Name: UgfType: LREALDescription: Unity gain frequency in Hz |
| Output Tag | Name: PfType: LREALDescription: Knee of proportional gain in Hz |
| Output Tag | Name: PolarityType: BOOLDescription: Polarity of slow feedback |
| Input/Output Tag | Name: ErrorSignalType: TemerpatureErrorSignalEnumDescription: Error signal for temperature feedback |

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| **ALS Laser Locking Type**TYPE TemperatureErrorSignalEnum : (PZTfrequency, BeatNoteError, SplitMon)END\_TYPE; |
| Type Name | TemperatureErrorSignalEnum |
| Description | Allows the user to specify what to use as an error signal for the temperature feedback  |
| Definition | ENUM |
| Element | Name: PZTFrequencyDescription: Laser PZT actuation |
| Element | Name: BeatNoteErrorDescription: Difference between the beat neat and half the VCO frequency |
| Element | Name: SplitMonDescription: Split mon of the common mode board which can be used when fast feedback is engaged |

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| **Function Block**TYPE ALSLaserLockingFB :VAR\_INPUT Request: SaveRestoreEnum; Demod: DemodulatorLscStruct; FromCornerPLC2: CornerPLC2toEndStruct; FromCornerPLC1: CornerPLC1toEndStruct; FiberTrans: DCPowerStruct; FiberRejected: DCPowerStruct; LaserIR: DCPowerStruct; Fibr\_A: DCPowerStruct; PDHServo: CommonModeStruct;END\_VAR;VAR\_IN\_OUT ALSLaser: ALSLaserStruct; ALSLaserLockingInit: ALSLaserLockingStruct; ALSLaserLocking: ALSLaserLockingStruct; Servo: CommonModeStruct;END\_VAR;END\_TYPE; |
| Type Name | ALSLaserLockingFB |
| Description | Function block for the autolocker |
| Definition | Function Block |
| Input Argument | Name: RequestType: SaveRestoreEnumDescription: Request save/restore/safemood or noop |
| Input Argument | Name: DemodType: DemodulatorLscStructDescription: User interfce structure |
| Input Argument | Name: FromCornerPLC2Type: CornerPLC2toEndStructDescription: Communication between corner PLC2 and end station |
| Input Argument | Name: FromCornerPLC1Type: CornerPLC2toEndStructDescription: Communication between corner PLC1 and end station |
| Input Argument | Name: FiberTransType: DCPowerStructDescription: PD monitoring total fiber transmission power |
| Input Argument | Name: FiberRejectedType: DCPower StructDescription: PD monitoring total fiber rejected power |
| Input Argument | Name: LaserIRType: DCPowerStructDescription: PD monitoring the ALS laser power in IR path |
| Input Argument | Name: Fibr\_AType: DCPowerStructDescription: DC output of broad band PD |
| Input Argument | Name: PDHServoType: CommonModeStructDescription: User interface structure |
| In/Out Argument | Name: ALSLaserType: ALSlaserStructDescription: User interface structure |
| In/Out Argument | Name: ALSLaserLockingInitType: AlsLaserLockingStructDescription: Save/restore variable in persistent memory |
| In/Out Argument | Name: ALSLaserLockingType: ALSLaserLockingStructDescription: User interface structure |
| In/Out Argument | Name: ServoType: CommonModeStructDescription: User interface structure |

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| **Function Block**TYPE LockingConidtionsFB :VAR\_INPUT CommunicationsError: ErrorStruct; Demod: DemodulatorLscStruct; FromCornerPLC2: CornerPLC2toEndStruct; FiberTrans: DCPowerStruct; FiberRejected: DCPowerStruct; LaserIR: DCPowerStruct; Fibr\_A: DCPowerStruct; Servo: CommonModeStruct; Laser: ALSLaserStruct;END\_VAR;VAR\_IN\_OUT ErrorHandler: ErrorHandlerFB; ALSLaserLocking: ALSLaserLockingStruct;END\_VAR;END\_TYPE; |
| Type Name | LockingConditionsFB |
| Description | Function block for the conditions of the autolocker |
| Definition | Function Block |
| Input Argument | Name: CommunicationsErrorType: ErrorStructDescription: Checks for a communications error |
| Input Argument | Name: DemodType: DemodulatorLscStructDescription: User interface structure |
| Input Argument | Name: FromCornerPLC2Type: CornerPLC2toEndStructDescription: Communication between corner PLC2 and end station |
| Input Argument | Name: FiberTransType: DCPowerStructDescription: PD monitoring total fiber transmission power |
| Input Argument | Name: FiberRejectedType: DCPower StructDescription: PD monitoring total fiber rejected power |
| Input Argument | Name: LaserIRType: DCPowerStructDescription: PD monitoring the ALS laser power in IR path |
| Input Argument | Name: Fibr\_AType: DCPowerStructDescription: DC output of broad band PD |
| Input Argument | Name: ServoType: CommonModeStructDescription: User interace structure |
| Input Argument | Name: LaserType: ALSlaserStructDescription: User interface structure |
| In/Out Argument | Name: ALSLaserLockingType: ALSLaserLockingStructDescription: User interface structure |
| In/Out Argument | Name: ErrorHandlerType: ErrorHandlerFBDescription: Calls error handler FB |

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| **Function Block**TYPE PfLoopFB :VAR\_INPUT Input: LREAL; Auto: BOOL; Polarity: BOOL;END\_VAR;VAR\_IN\_OUT Reset: BOOL; Ratio: LREAL; PropConst: LREAL; IntConst: LREAL;END\_VAR;VAR\_OUTPUT Output: LREAL; Error: BOOL; Message: STRING:END\_VAR;END\_TYPE; |
| Type Name | PFLoopFB |
| Description | This object represents a simple PI Loop |
| Definition | Function Block |
| Input Argument | Name: InputType: LREALDescription: Main input variable |
| Input Argument | Name: AutoType: BOOLDescription: Default values flag |
| Input Argument | Name: PolarityType: BOOLDescription: Polarity flaf |
| In/out Argument | Name: ResetType: BOOLDescription: Reset flag |
| In/out Argument | Name: RatioType: LREALDescription: Manual entry for P/I mixing ratio |
| In/out Argument | Name: PropConstType: LREALDescription: Manual entry for proportionality constant |
| In/out Argument | Name: IntConstType: LREALDescription: Manual entry for integration constant |
| Output Argument | Name: OutputType: LREALDescription: Main output variable |
| Output Argument | Name: ErrorType: BOOLDescription: Error flag |
| Output Argument | Name: MessageType: STRINGDescription: Information message out |

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| **Function Block**TYPE TemperatureControlsFB :VAR\_INPUT Request: SaveRestoreEnum; FromCornerPLC1: CornerPLC1toEndStruct; Servo: CommonModeStruct;END\_VAR;VAR\_IN\_OUT ALSLaser: ALSLaserStruct; ALSLaserLocking: ALSLaserLockingStruct;END\_VAR;END\_TYPE; |
| Type Name | TemperatureControlsFB |
| Description | Function block for temperature readback |
| Definition | Function Block |
| Input Argument | Name: RequestType: SaveRestoreEnumDescription: Request save/restore/safemood or noop |
| Input Argument | Name: FromCornerPLC1Type: CornerPLC1toEndStructDescription: Communication from corner PLC1 to end station |
| Input Argument | Name: ServoType: CommonModeStructDescription: User interface type |
| In/out Argument | Name: ALSLaserType: ALSLaserStructDescription: User interface type |
| In/out Argument | Name: ALSLaserLockingType: ALSLaserLockingStructDescription: User interface type |