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1 IR PSL CDS CONCEPTUAL DESIGN DOCUMENT

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1 INTRODUCTION

This document describes the conceptual design of the IR PSL electronics to be implemented by the LIGO CDS Group. The design requirements are contained in LIGO document LIGO-T970115-00-C (Infrared) Pre-stabilized Laser (PSL) Electronics Design Requirements.

The IR PSL is built around a 10 watt IR Laser consisting of a model 126 master oscillator and 10 watt power amplifier built by Lightwave Electronics Corporation in Mountain View, California. The free running frequency and intensity noise specification for the IR PSL require a feedback control system to suppress these noise terms to the limits put forth in the design requirements.

The development of VME based servos, data acquisition and control constitutes the bulk of the IR PSL task. The specific categories for the conceptual design are broken up into the following subsystems: Laser Control and Monitoring, Frequency Stabilization Servo, Intensity Stabilization Servo, Pre-mode Cleaner and Personnel Safety System.

2 IR PSL SUBSYSTEMS

2.1. Control and Monitoring

2.1.1. Overview

The function of the Control and Monitoring System is to provide all the interface to the LIGO control system for each of the IR PSL subsystems. This includes links to data acquisition, operator control of adjustable features, system status monitoring and operator control screens.

The LIGO IR PSL will be a VME based solution using commercially available VME cards for monitoring and control to the extent possible. The five categories of VME interface consist of: Binary input, Binary output, Analog input, Analog output and a VME bus interface card.

In the following sections, the Laser Control and Monitoring links to each subsystem is specified and included in table format according to system. The signal names for each item correspond to features on the individual subsystem block diagrams.

2.1.2. Master Oscillator and 10 Watt Laser

2.1.2.1 Table 1: MOPA Analog Signals To Be Monitored shows A/D signals to VME.

Table 1: MOPA Analog Signals To Be Monitored

Name	*Description*	*Misc.*	*Range*	*Sample Rate*	*Qty*	*#Bits*
APM	Amplifier Power Mon.	No External Gnd Zout = 1K	0 to 10V, 8V Nominal		1	
OPM	Oscillator Power Mon	No External Gnd Zout = 1K	0 to 10V, 8V Nominal		1	
DPM	Individual Diode Power Mon	No External Gnd Zout = 1K	0 to 10V		8	
126PWR	Indicates status of +5V power supply on 126 laser	Zout = 100 ohms No external Gnd.	0 to 10V, +5V indicates there is power to 126 laser		1	
Dtmp	126 Diode Temp.	No External Gnd Zout = 10K	5 to -5V for 10C to 35C		1	
Ltmp	126 Laser Crystal Temp.	No External Gnd Zout = 10K	0 to 10V @ 10C/Volt		1	
Dmon	126 Diode Pump Mon.	No External Gnd Zout = 10K	0 to -10V Uncalibrated.		1	
Lmon	126 Power before launch into fiber	No External Gnd Zout = 10K	0 to 10V		1	
Cmon	126 Diode Current Mon.	No External Gnd Zout = 10K	0 to 10V @ 1V/A		1	

Table 1: MOPA Analog Signals To Be Monitored

Name	*Description*	*Misc.*	*Range*	*Sample Rate*	*Qty*	*#Bits*
DTEC	126 Diode TEC Voltage	No External Gnd Zout = 10K	+/- 10V, pos=cool, neg=heat -2.5<V<4.5 Zout = 10K		1	
LTEC	126 Crystal TEC Voltage	No External Gnd Zout = 10K	+/- 10V, pos=cool, neg=heat -2.5<V<4.5 Zout = 10K		1	
ADCM	Amplifier Diode Current Mon.	No External Gnd Zout = 1K	0 to 10V, 5 to 2.5V for 0 to 40A		1	
HTM	Head Temp Mon.	No External Gnd Zout = 1K	0 to 10V, 0 to 5V for 5 to 30C		1	
TSP	Head Temp Set Point	No External Gnd Zout = 1K	0 to 10V, 0 to 5V for 5 to 30C		1	

2.1.2.2 Table 2: DAC Signals for MOPA shows the required MOPA DAC signals.

Table 2: DAC Signals for MOPA

Name	*Description*	*Misc.*	*Range*	*Sample Rate*	*Qty*	*#Bits*
126CA	126 Laser Diode Current Adj.	No External Gnd Zin = 10K	+2 to -10V for +2% to -10%		1	
126SFA	126 Laser Slow Freq Actuator	No External Gnd Zin = 10K three poles @ 0.2Hz	+/-10V @ 4GHZ/Volt		1	
AMPCA	Amplifier DC Current Adjust	Differential Input. Zin = 10K, 2 Poles @ ~1 Hz.	+/- 10V		1	

2.1.2.3 Table 3: Laser Binary Status Indications shows the binary status signals to be monitored by a VME based binary input module.

Table 3: Laser Binary Status Indications

Name	*Description*	*Misc.*	*Qty*
FLTSTAT *	Combined fault status line. The exact cause is viewed from the front panel of the amplifier power supply.	Open drain, common return line with other items tagged with “*” High on fault. May have external GND.	1

Table 3: Laser Binary Status Indications

Name	*Description*	*Misc.*	*Qty*
INTLK *	Indication of the status of the safety interlock chain.	Open drain common return line with other items tagged with “*” High on fault. May have external GND.	1
SHSTAT *	Indication of the status of the shutter.	Open drain common return line with other items tagged with “*” High = OPEN. May have external GND.	1
126LASE *	Laser status indication.	High indicates 126 could be lasing. Alternating high, low indicates: 15 Sec pwr up delay or 126 laser fault. Open drain common return line with other items tagged with “*”	1

2.1.2.4 Table 4: MOPA Binary Control Signalsshows the binary control signals for the MOPA

Table 4: MOPA Binary Control Signals

Name	*Description*	*Misc.*	*Qty*
126NEAT *	Activates 126 Laser noise eater feature	Common return line with other items tagged with “*” May have external GND. Opto-isolated input. Supply current to enable.	1
126STBY *	Puts the laser in either Lase or Standby mode	Common return line with other items tagged with “*” May have external GND. Opto-isolated input. Supply current to enable.	1
SHCON *	Opens and closes the shutter for the laser.	Common return line with other items tagged with “*” May have external GND. Opto-isolated input. Supply current to open.	1
SBYCON *	Changes state of the laser from STANDBY to ON.	Common return line with other items tagged with “*” May have external GND. Opto-isolated input. Supply current to turn ON.	1

2.1.3. Frequency Stabilization

2.1.3.1 Table 5: Frequency Servo Analog Signals to VME shows the analog signals to be read by VME based A/D converter.

Table 5: Frequency Servo Analog Signals to VME

Name	*Description*	*Misc.*	*Range*	*Sample Rate*	*Qty*	*#Bits*
RFPDDC1	RF Photodiode DC out	TBD V/A	0 to 10V		1	
LODET1	Detected LO level.	Polynomial to describe level in dBm.	0 to 10V		1	
PCDET1	Detected PC drive level	Polynomial to describe level in dBm.	0 to 10V		1	
FSMIXER	Demodulating mixer output.		+/- 10V		1	
FASTACT	Input to the fast actuator		+/- 10V		1	
PCACT	Input to the PC actuator		+/- 10V		1	
SLOACT	Input to the slow actuator.		+/- 10V		1	
TRANSPD 1	Transmitted light photodiode		+/- 10V		1	
VCOMON	Drive signal to the 80 MHz VCO		0 to 24V		1	

Table 5: Frequency Servo Analog Signals to VME

Name	*Description*	*Misc.*	*Range*	*Sample Rate*	*Qty*	*#Bits*
VCODET	Detected RF output of the AOM driver amp.		0 to 10V		1	
TIDINPUT	Input to tidal actuator		+/- 10V		1	
TIDOUT	Drive to reference cavity heater.		+/- 10V		1	

2.1.3.2 Table 6: Frequency Servo VME Bus Interface Items shows the on board signal registers required to be accessed by the VME bus to control the necessary features of the board. This will be done by an umbilical from a VME bus interface card to the Eurocard crate that houses the IR PSL FSS card.

Table 6: Frequency Servo VME Bus Interface Items

Name	*Description*	*Misc.*	*Qty*
INOFFSET 1	Input offset adjust to trim out system DC offsets.	+/- 10 mV input offset trim	1
MGAIN	Overall gain adjust for fast and PC loops.	-10 to +30 dB gain adjustment about nominal in TBD dB increments.	1
FGAIN	Fast loop gain adjustment.	-10 to +30 dB gain adjustment about nominal in TBD dB increments.	1
PHCON1	Phase shifter adjustment for demodulating mixer.	0 to 360 degrees in ~0.1 degree increments	1
RFADJ1	Amplitude control for the 5W drive to the modulating PC.	0.5dB increments from 5W to cover a 20dB range	1

2.1.3.3 Table 7: FSS DAC Signals shows the DAC signals required for the IR PSL FSS

Table 7: FSS DAC Signals

Name	*Description*	*Misc.*	*Range*	*Sample Rate*	*Qty*	*#Bits*
SLODC	DC offset adjust of the slow actuator		+/- 10V for a +/- 1V change in slow actuator voltage.		1	
VCOPWR	DC voltage to control the RF drive to the AOM		0 to 10V		1	

2.1.3.4 Table 8: FSS Binary Inputs shows the binary inputs for the IR PSL FSS

Table 8: FSS Binary Inputs

Name	*Description*	*Misc.*	*Qty*
FSSW1	Input switch after demodulating mixer used to actuate FP1 test input.	High activates the FP1 test input.	1
FSSW2	Switch used to actuate the FP2 test input. This input is used for closed loop transfer function measurements.	High activates the FP2 test input.	1
VCOSW1	Switch to isolate frequency modulation test input (FP2)	High activates the FP2 test input	1

2.1.4. Intensity Stabilization

2.1.4.1 Table 9: ISS Signals to A/D shows the analog signals to be read by VME based A/

D converter.

Table 9: ISS Signals to A/D

Name	*Description*	*Misc.*	*Range*	*Sample Rate*	*Qty*	*#Bits*
PD1DC	DC output of PD after PMC		0 to 10V		1	
PD2DC	DC output of PD after MC		0 to 10V		1	
ISERR	Servo error point		+/- 10V		1	
ISACT	Input to AC power adjust actuator		+/- 10V		1	

2.1.4.2 Table 10: ISS DAC Inputs shows the DAC inputs to the ISS servo

Table 10: ISS DAC Inputs

Name	*Description*	*Misc.*	*Range*	*Sample Rate*	*Qty*	*#Bits*
ISGAIN	Gain adjust for ISS servo.	-10 to +30 dB about the nominal gain	0 to 10V		1	

2.1.4.3 Table 11: Binary Inputs to ISS shows the binary inputs to the ISS from VME.

Table 11: Binary Inputs to ISS

Name	*Description*	*Misc.*	*Qty*
ISSW1	Switch to select which photo-diode is used for intensity stabilization	High selects PD after PMC. Low selects PD after MC.	1
ISSW2	Switch to activate test input FP2	High activates FP2 test input.	1

2.1.5. Pre-mode Cleaner

2.1.5.1 Table 12: PMC A/D Signals shows the analog signals from the PMC to be read by a VME based A/D converter.

Table 12: PMC A/D Signals

Name	*Description*	*Misc.*	*Range*	*Sample Rate*	*Qty*	*#Bits*
RFPDDC2	DC output of the RF PD.		0 to 10V		1	
LODET2	Detected RF from the PMC mixer LO		0 to 10V		1	
PMCTLPD	Transmitted light photo-diode		0 to 10V		1	
PCDET2	Detected RF to the pockels cell.		0 to 10V		1	
PMCERR	PMC servo error point		+/- 10V		1	
PMCOUT	Drive signal to PMC actuator	Will have 10:1 voltage divider	+/- 10V		1	

2.1.5.2 Table 13: PMC DAC Signals shows the inputs to the PMC from a VME DAC.

Table 13: PMC DAC Signals

Name	*Description*	*Misc.*	*Range*	*Sample Rate*	*Qty*	*#Bits*
MGAIN2	PMC servo gain adjust	-10 to +30 dB about the nominal gain	0 to 10V		1	
INOFFSET 2	PMC servo input offset adjust	+/- TBD volts of offset correction	+/- 10V		1	

2.1.5.3 Table 14: Binary Inputs to the PMC servo shows the inputs to the PMC servo from a VME binary input module

Table 14: Binary Inputs to the PMC servo

Name	*Description*	*Misc.*	*Qty*
PMCSW1	Switch to activate FP1 test input.	This will open the servo loop. High activates the input.	1
PMCSW2	Switch to activate FP2 test input.	High activates the input.	1

2.1.5.4 Table 15: VME Bus Controlled PMC Items shows the on board signal registers required to be accessed by the VME bus to control the necessary features of the board. This will be done by an umbilical from a VME bus interface card to the Eurocard crate that houses the IR PSL PMC servo card.

Table 15: VME Bus Controlled PMC Items

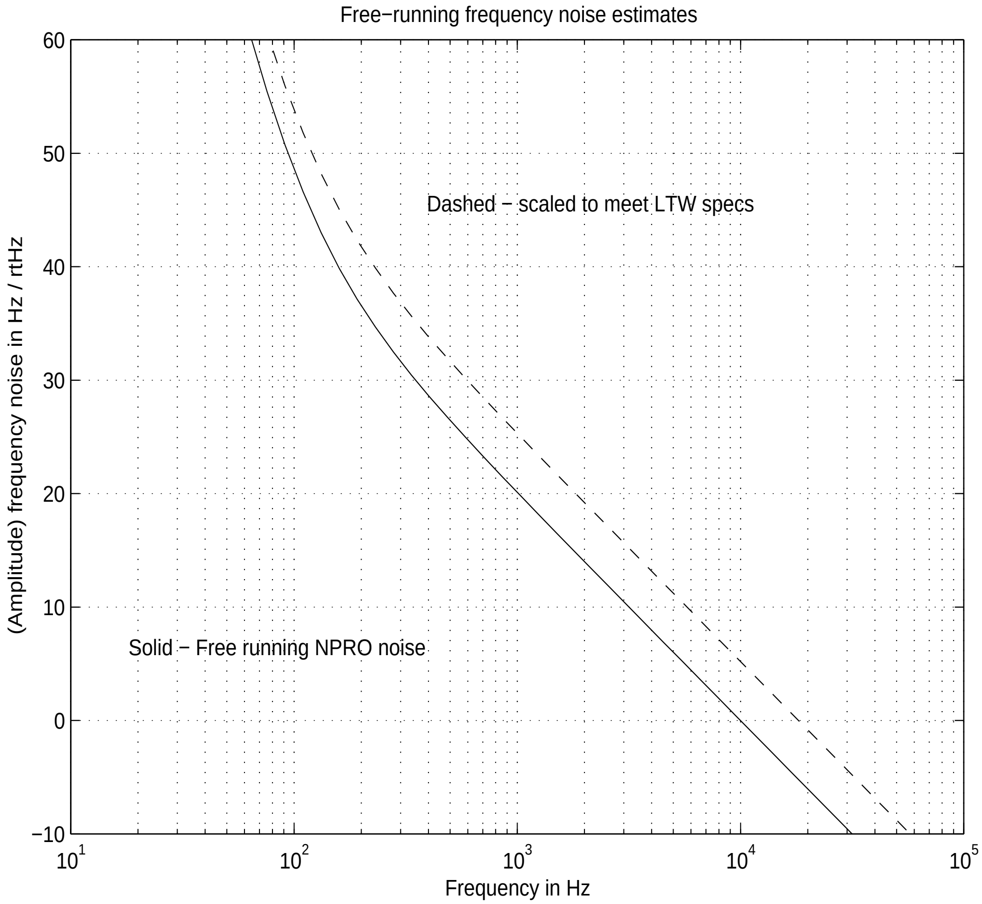
Name	*Description*	*Misc.*	*Qty*
PHCON2	Phase shifter control for the PMC modulation	0 to 360 degrees in 0.5 degree steps	1

2.2. Frequency Stabilization Servo

2.2.1. Overview

A schematic representation of the overall control system topology is shown in Figure 2: IR PSL Frequency Servo. The frequency of the Lightwave 10 watt laser is compared to the resonant frequency of the reference cavity using the standard reflection locking technique. An error signal is generated that is proportional to the deviation of the laser frequency from the reference cavity resonant frequency. This error signal is applied to three actuators that cover the range of frequencies from DC to about 600 kHz. The actuators are labeled Fast, PC and Slow. The fast actuator is a piezo crystal, the slow actuator is a thermal actuator and the PC is a pockels cell. Figure 1: 126 Free Running Frequency Noise shows the free running frequency noise of the Model 126 Lightwave laser as measured at Caltech, and a superimposed curve shows the required free running frequency noise limits for the 10 watt Lightwave laser.

Figure 1: 126 Free Running Frequency Noise



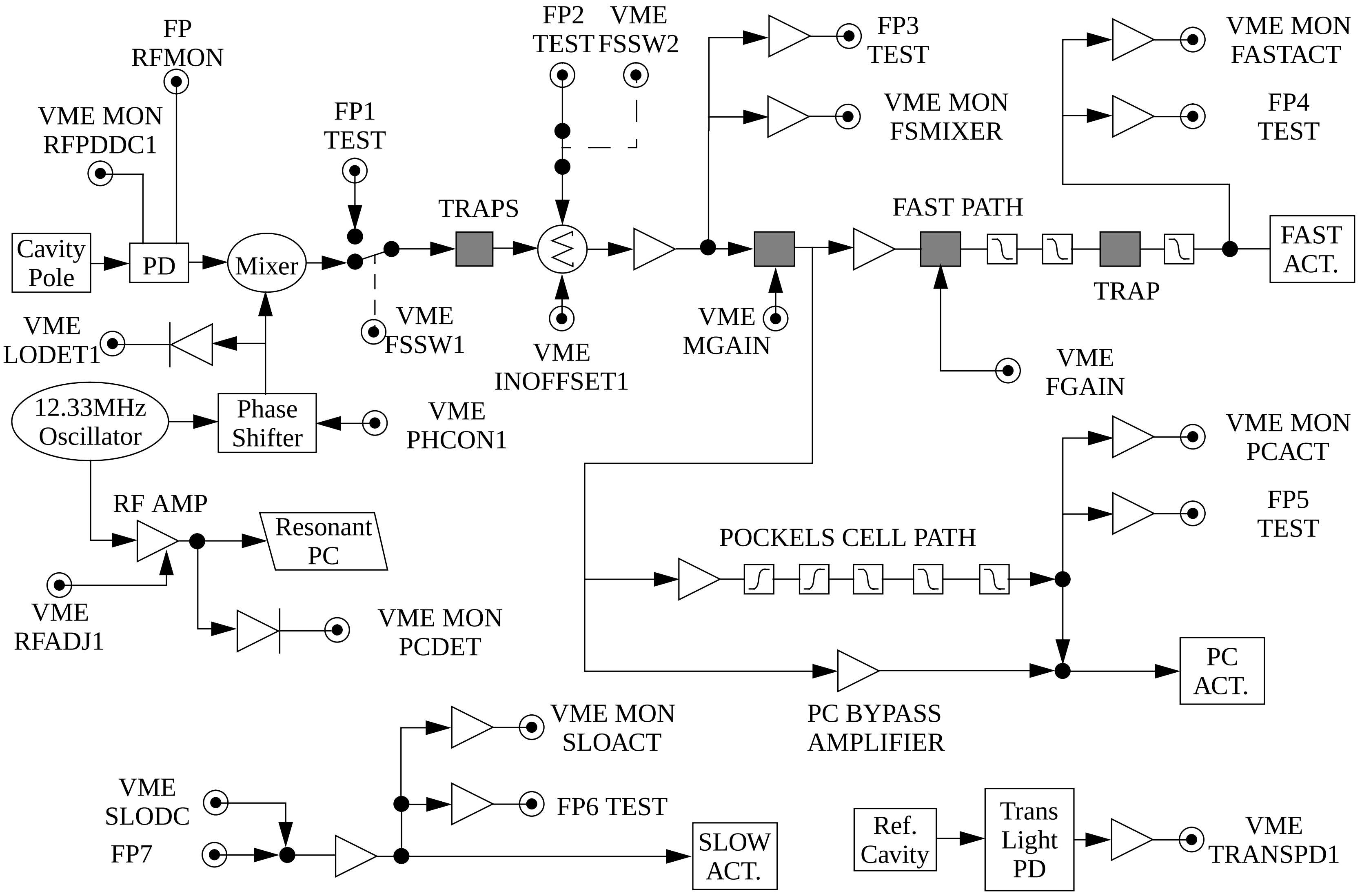


Figure 2: IR PSL Frequency Servo

2.2.2. Frequency Detector

The frequency detector portion of the servo is implemented by RF photodiode and RF mixer combination. The pole associated with the reference cavity is also included in the frequency detector response. RF traps are required to remove the RF components at the demodulating mixer output. The resultant design is as follows:

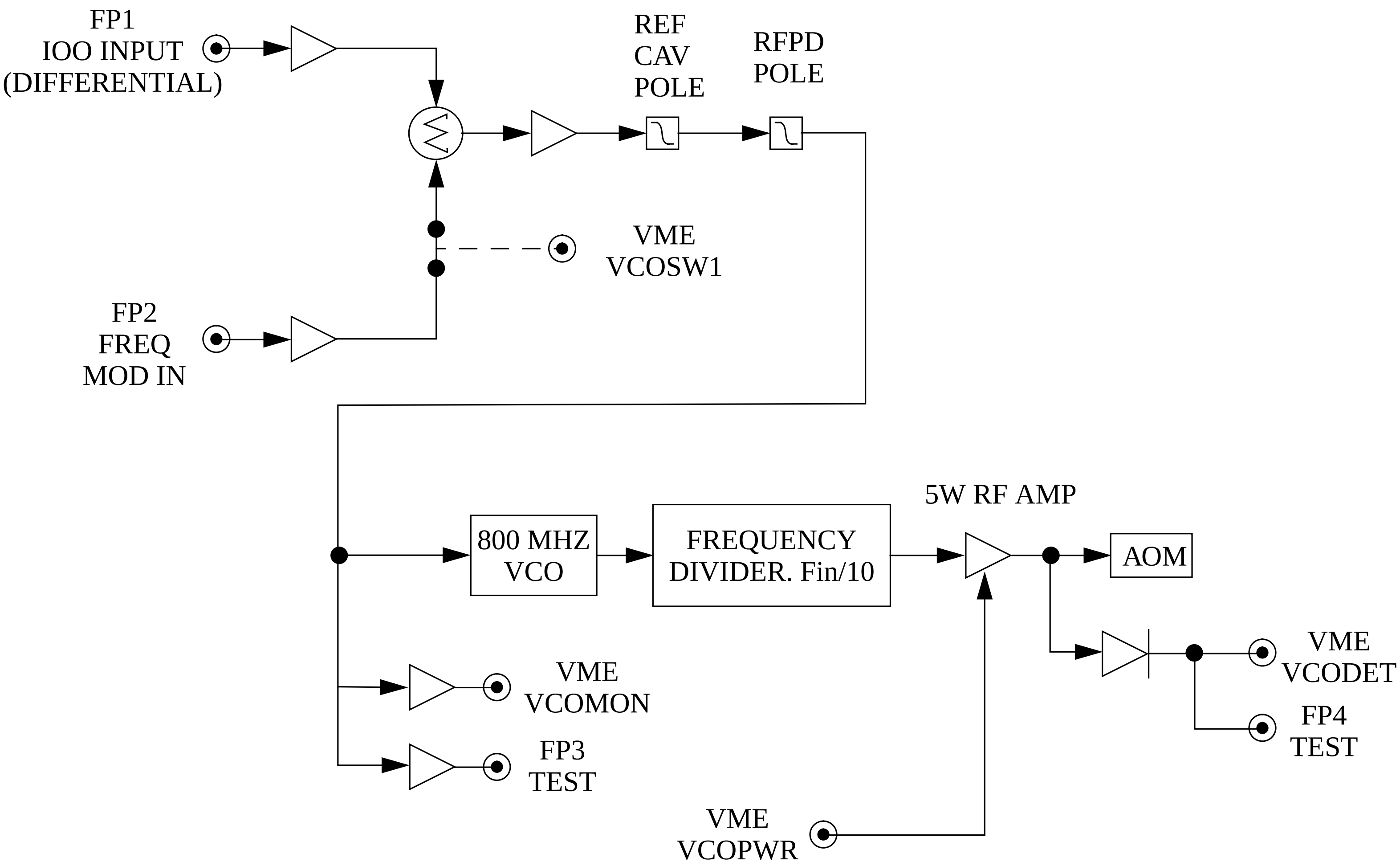
- Nominal Frequency Detector Gain - 1 volt / 6.7 kHz
- Photodiode Pole - 770 kHz corresponding to a quality factor of 8.
- Reference Cavity Pole - 37 kHz.
- Demodulating RF Mixer: Mini Circuits Inc. RAY-3 Level 23 Mixer (23 dBm LO Drive)
- RF Trap frequencies: Modulation frequency and first two harmonics.

2.2.3. Frequency Shifter (AOM)

The actuator as shown schematically in Figure 3: 80 MHz VCO and AOM Driver serves as the wideband actuator necessary for further reduction in frequency noise by more stable frequency references from the IOO. A second function of this actuator is to supply a point for injecting frequency modulation for diagnostic purposes. This is predominantly an AC actuator as the DC term is addressed by a length servo on the MC. The features of this actuator are as follows:

- **VCO Phase Noise:** The single sideband phase noise as measured in a 1 Hz bandwidth shall be less than -83 dBC at 100 Hz frequency offset from the carrier. The phase noise shall fall off at 1/F for frequencies greater than 100 Hz. Expected results are -130 dBC at 100 kHz frequency offset.
- **VCO Center Frequency**: 80 MHz +/- 1 MHz
- **VCO Adjustment Range:** +/- 5 MHz from the center frequency.
- **Input Voltage to VCO From IOO:** +/- 5 VDC full scale. This will be a differential input for noise immunity and shall be flat in amplitude response to within 2 dB up to 100 kHz, and have less than 20 degrees phase lag at 100 kHz.
- **Frequency Diagnostic Input:** An input is provided for frequency modulation of the PSL. The gain of this input is 1 volt/MHz with a 100 kHz bandwidth. A test switch is provided to isolate this input while it is not in use.
- **Reference cavity pole:** In order to provide a flat actuator for the IOO, the effects of the components in the feedback path of the frequency stabilization must be nulled. The pole at 35 kHz is for the reference cavity. The RF photodiode pole is at 770 kHz and probably will not be significant.
- **Monitoring Points:** As indicated in Figure 3: 80 MHz VCO and AOM Driver, there shall be local and remote monitoring capability for the drive to the VCO and the detected output of the 5 watt RF amplifier.
- **Adjustability:** The output drive level of the 5 watt RF amplifier will be remotely adjustable from the operator screens over a range of power from 1 watt to 5 watts in a continuous fashion.

Figure 3: 80 MHz VCO and AOM Driver



2.2.4. Frequency Servo Tidal Actuator

Figure 4: Tidal Actuator shows the conceptual block diagram for this system. This actuator controls the temperature of the PSL reference cavity for large frequency corrections from the IOO.

2.2.5. Frequency Servo Actuators

2.2.5.1 Slow Actuator

- **Gain:** 4 GHz/Volt
- **Frequency Response:** 3 poles at 0.2 Hz
- **Operating Range (No mode hopping):** +/- 1 volt

2.2.5.2 Fast Laser PZT Actuator

- **Gain:** 4 MHz/Volt
- **Operating Range:** +/- 50 V
- **Frequency Response:** Flat within 1 dB to 100 kHz. There are known resonances in this actuator at about 250 kHz.

2.2.5.3 Pockels Cell Actuator

- **Manufacturer:** New Focus Inc. Santa Clara Ca.
- **Model:** 4004-D electro-optic modulator.
- **Gain:** 15 mrad/Volt with a corresponding frequency shift of 450 Hz/Volt.
- **Operating Range:** +/- 200 volts, corresponding to a +/- 90 kHz frequency shift at 30 kHz.

2.2.6. Frequency Servo Dynamic Range

The FSS must provide sufficient dynamic range for frequency correction to suppress frequency errors to the level required by *Prestabilized Laser Design Requirements*, LIGO T950030-03-D.

2.2.7. Frequency Servo Input Referred Electronics Noise

The IR PSL input referred noise requirement at the output of the frequency detection mixer should be a factor of 10 less than the suppressed frequency noise which for the purpose of simplicity shall be stated as 0.01 Hz/rtHz. With the assumed frequency detector gain of 1 volt/ 6.67 kHz, this gives an equivalent input referred noise of 1.5 E-6 volts/ rtHz, a factor of 1/10 of which is 150 nV/ rt Hz. This is sufficiently trivial where an additional factor of 10 is readily available and confirmed from the past design. This result gives the following working number:

- **Input Referred Noise** - 15 nV/ rtHz maximum

2.2.8. Frequency Servo Cross-over Frequency

The Fast loop gain crosses over with the Pockels Cell loop gain at 10 kHz. This is relatively arbitrary but driven by dynamic range constraints in the Pockels Cell path and resonances in the fast piezo actuator.

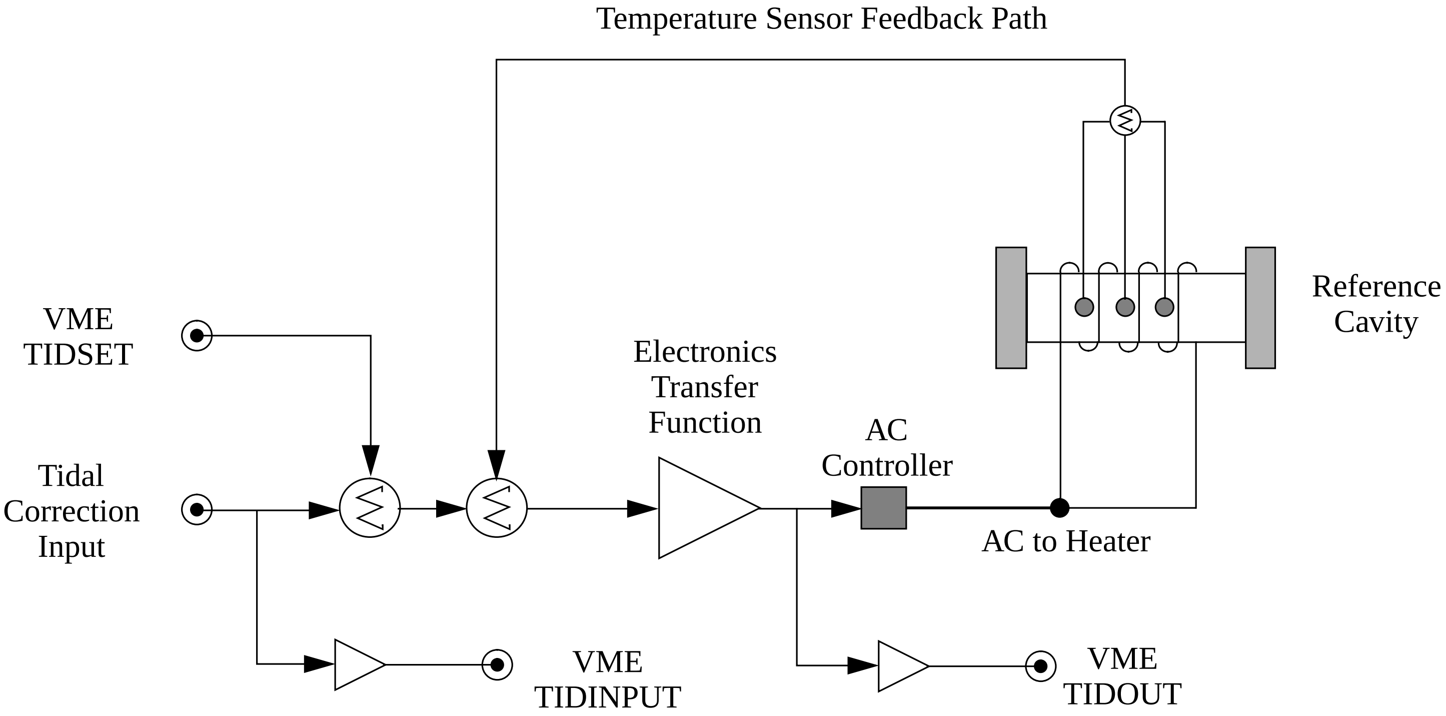


Figure 4: Tidal Actuator

2.2.9. Frequency Servo Unity Gain Frequency

The required level of noise suppression in the 40 Hz to 10 kHz band of frequencies results in a unity gain frequency of between 500 kHz to 800 kHz.

2.2.10. Frequency Servo Phase Margins

A minimum phase margin of 45 degrees will be employed for the fast/pockels cell cross-over and the servo unity gain frequency. It is also a design goal to have the slope of the phase be such that the design be forgiving of variations in critical frequencies (unity gain and cross-over).

The results of the conceptual design show that this requirement should be readily achievable and an effort will be made to provide additional phase margin where it is possible.

2.2.11. Frequency Servo Open Loop Gain Profile

The shape and magnitude of the open loop gain profile is dictated by the level of free running frequency noise suppression required. The minimum required gain at several frequencies of interest is shown in table 9 below.

Table 16: FSS Gain Profile

Frequency (Hz)	*Min. Gain (dB)*	*Suppressed noise limit*
DC	83	1/10 Reference cavity linewidth.
100	73	0.1 Hz/ rtHz
1K	66	0.01 Hz/ rtHz
10K	46	0.01 Hz/ rtHz

2.3. Intensity Stabilization Servo

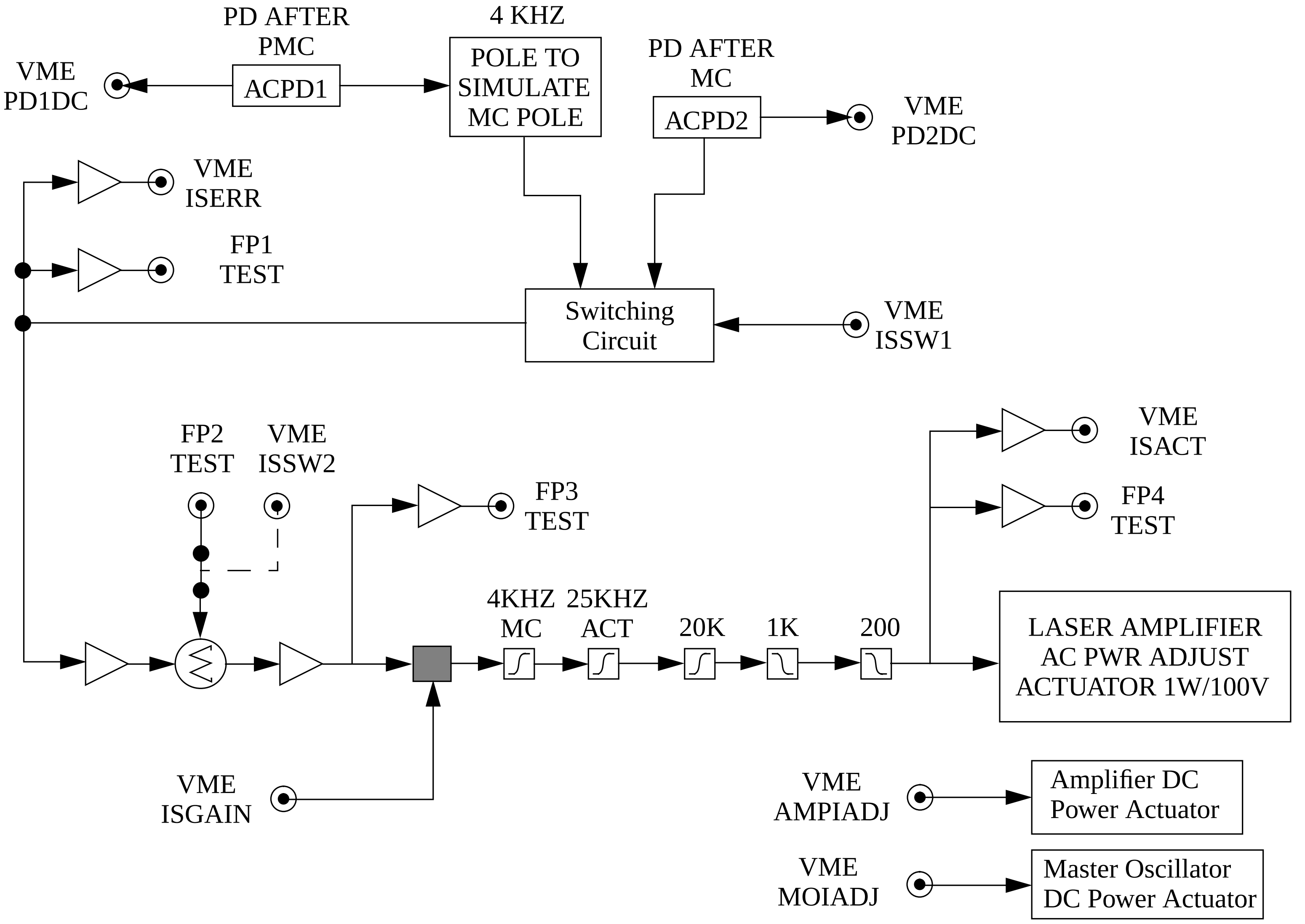
2.3.1. Overview

A schematic representation of the Intensity Stabilization Servo is shown in Figure 5: IR PSL Intensity Servo

By specification the laser intensity stability as supplied by the manufacturer is sufficient to maintain the output power constant to within 1%. For long term monotonic drifts in intensity there are provisions for computer controlled power adjustments on the Master Oscillator and the Amplifier that can provide periodic “tweaks” in the output of the laser/amplifier.

Active intensity noise suppression by closed loop servo is only required at frequencies from 40 Hz to 10 kHz. The absence of need to regulate intensity at DC allows for an AC coupled servo that simplifies the system design.

Figure 5: IR PSL Intensity Servo



2.3.2. Photo-diode

The conceptual design shown in Figure 5: IR PSL Intensity Servo shows the use of an AC coupled photo-detector. A similar detector was used in the previous IR PSL design and this design will be largely copied for this version. Information gained from experience with photo-diodes at MIT will be used to the extent applicable.

2.3.2.1 Photo-diode Incident Power.

A level of 1e-8/ rtHz in residual relative intensity fluctuation corresponds to the shot noise limit for 3.2 mA of photo-current. Assuming a quantum efficiency of 50% for the photo-diode this requires a minimum of about 7 mW of photo-detected light. The actual requirement for residual RIN is 1e-7/ rtHz. Due to the benefits of an RIN of 1e-8/ rtHz a value of 10 mW minimum is chosen for the design. Using the more stringent RIN figure does not impact the overall design at this phase, but allows room for improvements at a later time.

2.3.2.2 Photo-diode Poles and Zeros.

The AC coupling of the photo-diode results in a zero at DC and an assumed pole at 3 Hz for reasonable values of load resistance and coupling capacitance. A 50 uF coupling capacitance into 1 kohm is the nominal circuit.

2.3.2.3 Photo-diode Transimpedance

A value of 1 kohm was chosen as the photo-diode transimpedance as a reasonable compromise between the lower noise limited constraint and the upper power supply limited voltage.

2.3.3. Power Adjust Actuator

The power adjustment actuator for the IR PSL Servo is supplied with the MOPA. The specifications for the actuator are:

- AC Power Adjust Actuator - 1W/ 100 volts

The power adjust actuator frequency response is specified for no poles <25 kHz and second pole >100 kHz. This response is not yet well known and as such it sets an upper limit for a reliable unity gain frequency in the intensity servo.

2.3.4. Intensity Servo Electronics

2.3.4.1 Modulation Capability

AC intensity modulation could be applied to the FP2 test input as shown in Figure 5: IR PSL Intensity Servo provided the amount of modulation is relatively small. For step changes in intensity over a wider dynamic range and frequencies down to DC, an AOM after the PMC and a motorized half wave plate with polarizer could be used. These systems are still being conceptualized pending exact modulation requirements for the IR PSL.

2.3.4.2 Input Referred Noise

The servo amplifier input referred noise will be 10 nV / rtHz maximum. This is a factor of 4 less than the 40 nV/ rtHz resulting from the shot noise current to voltage transformation in the photodiode.

2.3.4.3 Intensity Servo Gain Profile

Table 17: Intensity Servo Gain Parameters shows the minimum gain required to meet the suppressed RIN requirements. The values taken from the Lightwave Corp. brassboard laser test results are a best estimation based on the assumption that the line frequency related intensity variations are suppressed to 10 dB better than the target specification. The baseline measured RIN neglecting line frequency components is 20 dB less than the target specification of -100 dB/ rtHz for frequencies less than 10 kHz down to about 200 Hz. At 100 Hz the brassboard results are about 10 dB better than the target specification.

The higher than needed actual servo gain figures reflect the need to suppress residual line frequency related RIN components and provide the ability for possible reduction in suppressed RIN to levels beyond 1e-7 while not compromising robustness. Not shown in this design is the effect of the pole determined by the laser physics related to the lifetime of the upper lasing level in the Nd:YAG crystal as this is not yet well quantified.

Table 17: Intensity Servo Gain Parameters

Frequency (Hz)	*Free Running RIN from Lightwave Brassboard results (dB/Hz RIN)*	*Required RIN (dB/Hz)*	*Minimum Gain (dB)*	*Actual Servo Gain (dB)*
100	-110	-140	30	75
200	-120	-140	20	73
1k	-120	-140	20	60
7k	-130	-140	10	30
10k	-130	-134	6	25

2.3.4.4 Intensity Servo Unity Gain Frequency

The conceptual design shown in figure TBD has a unity gain frequency of 60 kHz. This is driven by a desire to roll off the servo before entering an unpredictable regime associated with the actuator.

2.3.4.5 Intensity Servo Built In Test Features

The intensity servo design shown in figure TBD has as part of the design several built in test features. Those features are as follows:

- **Unity Gain Buffer** - Used in conjunction with FP2 test input and FP3 test output, this buffer is for measuring the closed loop transfer function of the servo. VME controlled switch ISSW2 in series with FP2 isolates the test input while it is not in use.
- **Monitoring Points** - VME and front panel (FP) monitoring points are placed at the DC output of both photo-diodes, the servo error point and the actuator input.

2.3.4.6 Intensity Servo Gain Adjust

The gain of the intensity servo is remotely adjustable over a range of 40 dB (+10 to -30 about the nominal servo gain) through the VME controlled variable gain interface.

2.3.4.7 Intensity Servo Photodiode Switch

AVME controlled switch is provided to select between two photo-diodes. The photo-diode after the PMC is used while the MC is not on line and a pole is added to this path to simulate the response of the MC.

2.4. Pre-mode Cleaner (PMC)

2.4.1. Overview

A schematic representation of the Pre-mode cleaner Servo is shown in Figure 6: PMC Servo.

An error signal is generated using the reflection locking technique in a manner identical to the frequency stabilization servo. This error signal is ultimately used to change the length of the PMC cavity such that the resonant frequency of the PMC tracks the frequency of the incoming light from the PSL laser. At the time of writing, the exact free running noise spectrum of the PMC cavity is not well known. The conceptual design is based on reasonable estimates of PMC free running frequency noise.

2.4.2. PMC Servo Dynamic Range

Due to the lack of an exact free running frequency noise spectrum for the PMC an exact analysis of the servo dynamic range is not possible. There is however an estimate of the temperature sensitivity of the PMC of 1e-6/ degree C. Assuming an ambient temperature change of +/- 2 degrees C, a frequency change of 600 MHz would result. A worst case DC scenario includes the temperature effects on the PMC, worst case locking offset of half a FSR and PSL maximum reference cavity tidal adjust actuator excursion. All these factors add up as shown in Table 18: PMC DC Dynamic Range Factors to yield 1005 MHz or 134 volts maximum excursion on the PMC PZT. This is within the design goal of +/- 150 VDC actuation range for the design. Additional range could be afforded by thermal control of the aluminum spacer in the PMC cavity.

Table 18: PMC DC Dynamic Range Factors

Item	*Worst Case Frequency Contribution (MHz)*
+2 degrees C change in ambient temperature.	600 MHZ
One half PMC FRS lock offset.	375 MHz
Full scale input to PSL tidal actuator.	30 MHz

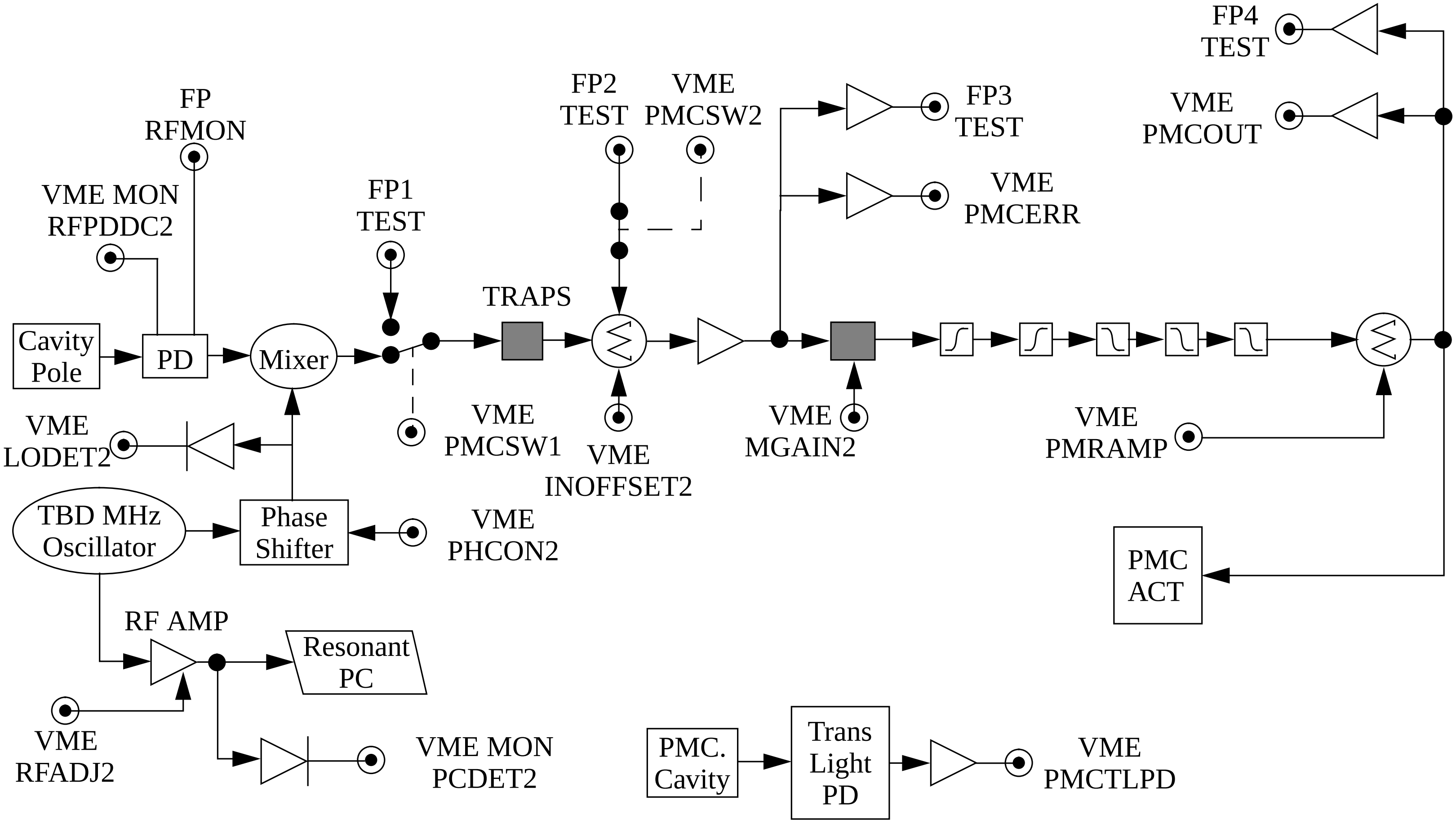


Figure 6: PMC Servo

2.4.3. PMC Actuator

The actuator for the PMC is Polytec PI, P-306 Tubular PZT Stack Actuator. The specified gain of this actuator is 5e-6 m/ 1000 volts. The first mechanical resonance of the actuator is at roughly 4 kHz. This resonance creates the need for a servo unity gain frequency of less than 1 kHz. In terms of frequency the gain of the PMC actuator is found below along with several other useful constants.

- PMC Actuator: 7.5 MHz/ volt
- Operating Voltage Limits: +250 to -1000 volts
- Capacitance: 90 nF +/- 20%

2.4.4. PMC Frequency Detector

The frequency detector portion of the servo is implemented by an RF photodiode and RF mixer combination yielding the familiar frequency discriminant. Traps are required after the mixer to remove the RF components from the demodulated output. The resultant design is as follows:

- Nominal Frequency Detector Gain - 1 volt / 120 kHz
- RF Photodiode Pole - 770 kHz corresponding to a quality factor of 8.
- Demodulating RF Mixer: Mini Circuits Inc. RAY-3 Level 23 Mixer (23 dBm LO Drive)
- RF Traps: At the fundamental modulation frequency and first two harmonics.

2.4.5. PMC Servo Input Referred Noise

In order to meet the PMC frequency noise requirements the input referred noise figure of the PMC servo is less than 830 nV/ rtHz for frequencies between 40 Hz to 1 kHz and less than 83 nV/ rtHz for frequencies between 1 kHz to 10 kHz. Given the trivial nature of these noise terms the input referred noise for the conceptual design will be less than 20 nV/ rtHz

2.4.6. PMC Servo Unity Gain Frequency

The dominant factor for setting the loop shape for the PMC is the need to have sufficient gain at DC to address the ambient temperature drifts. An upper limit for the bandwidth of the PMC servo is dictated by the presence of a first mechanical resonance in the PZT actuator at 4 kHz. As the suppression of free running frequency noise is not a limiting factor the unity gain frequency is:

- PMC Servo Unity Gain Frequency: 600 Hz

2.4.7. PMC Servo Gain Profile

Table 19: PMC Servo Gain Profile shows the proposed loop shape.

Table 19: PMC Servo Gain Profile

Frequency (Hz)	*Free Running PMC Noise*	*PSL Required Frequency Noise (Hz/rtHz)*	*PMC Required Frequency Noise (Hz/rtHz)*	*Minimum Gain (dB)*	*Actual Servo Gain (dB)*
DC	600 MHz	16.5 kHz		91	90
40	4000 Hz	1	4.1e4	-20	88
100	200 Hz	0.1	1.65e3	-18	56
1k	20 Hz	0.01	16.5	1.2	Less than unity.
10k	2	0.01	1.65	1.2	Less than unity.

2.5. Personnel Safety System

2.5.1. Overview

The class of laser used in the LIGO IR PSL requires two levels of protection for personnel in the vicinity of the laser. The first and most simple level of protection is afforded by the administrative requirement to wear appropriate safety glasses while in the LVEA. For a second method of protection there has to be a system in place to guard against inadvertent exposure to the beam.

2.5.2. Optics Table Enclosure

An enclosure is to be installed around the optics table to completely contain all but the desired light from the laser. This enclosure will have sliding sides to allow access to the components on the table. The side accessways will each have a micro-switch interlock to monitor the integrity of the enclosure. All of the micro-switches are in series such that any one will cause a fault.

2.5.3. Laser Interlock

On the laser supplied from Lightwave Inc. there is an interlock consisting of a 2 pin 0.156 inch spacing male connector. In order enable lasing, this connector must be shorted together. The conceptual design for the optics table laser interlock uses this feature to shut off the laser if an access door is opened during laser operations. A local keyswitch bypass of this interlock is provided on the exterior of the enclosure to allow operations with the laser on. The use of this interlock must be regulated by administrative procedure.

The status of the laser interlock is provided to VME as a binary status bit.

2.5.4. Emergency Shutdown

In the vicinity of the PSL optics table there will be a kill switch to disable the laser in the event of a perceived hazard. A similar switch will exist in the control room.