Interface Control Document for the ISC sub-system

Preface

This is a draft of the ICD for the LCGT-ISC sub-system.

Sub-System Definition

The role of the Interferometer Sensing and Control (ISC) sub-system is to keep the interferometer at its optimal operation point and extract the gravitational wave signal with low noise. This sub-system can be functionally broken into two parts: Sensing and Control.

Sensing

In order to control the interferometer, we have to know the state of the interferometer. Sensing part of this sub-system defines the methods to extract information about the state of the interferometer. We sort the degrees of freedom (DOFs) of an interferometer into three categories.

Length Sensing

The word "length" here means the distances between the mirrors. In addition to the geometric lengths, a change in the laser frequency also appears as an apparent change in the lengths for an interferometer. Therefore, the laser frequency is counted as a length here. There are 5 length DOFs to be controlled for a Dual-Recycled Fabry-Perot Michelson Interferometer (DRFPMI).

Name	Notation	Description
Michelson (MICH)	l-	Differential change of the Michelson arm lengths
Power Recycling Cavity Length (PRCL)	l+	Length of the power recycling cavity
Signal Recycling Cavity Length (SRCL)	ls	Length of the signal recycling cavity
Differential Arm Length (DARM)	L-	Differential change of the arm cavity lengths
Common Arm Length (CARM)	L+	Common change of the arm cavity lengths

Out of those DOFs, MICH, PRCL and SRCL are called "central part", "short DOFs" or "スモール系". DARM and CARM are called "arm DOFs", "long DOFs" or "ラージ系". CARM is often regarded as being equivalent to the laser frequency variation. DARM contains the gravitational wave signal, so it is the most important DOF.

Alignment Sensing

In order for a laser beam to properly resonate inside the interferometer, the beam and the mirrors of the interferometer must be aligned well. Alignment sensing is a mechanism to monitor errors in the alignment. A mirror has three rotational degrees of freedom, out of which only two (pitch and yaw) are important for an interferometer. For each of pitch and yaw, there are 6 alignment DOFs in an interferometer.

Name	Description
Common Stable (CS)	

Common Unstable (CU)	
Differential Stable (DS)	
Differential Unstable (DU)	
Power Recycling Mirror (PRM)	
Signal Recycling Mirror (SRM)	

CS, CU, DS, DU are the DOFs of the arms in the Sidles-Sigg basis [ref].

Auxiliary Signals

There are other signals which may have to be monitored (and possibly corrected for by feedbacks) during the operation of an interferometer.

Name	Description
Thermal lensing	Heat deposited on the mirrors by the laser beam can create a lensing effect. This lens mainly manifests itself as a mismatch of the spatial modes between the recombined beams at the dark port.
AS_I	If we use RF readout for the DARM, we may have to monitor the I-phase signal of the AS-port PD, which does not contain any GW signal but comes from junk light at the AS-port. AS-I could saturate the AS-PD in RF and reduce the dynamic range for the GW signal channel (AS-Q). If so, we can feedback the AS-I into the AS-PD current to cancel it.
SPOB	SPOB is Sideband Picked Off at Beam-splitter. The light picked off inside the PRC is demodulated at twice the frequency of the sidebands to serve as a measure of the sideband power in the PRC.

Control

Once the information about the state of the interferometer is obtained, we feedback the information to keep the interferometer at the optimal operation point. Feedback has to be strong enough to keep the error signals in linear regions so that up-conversion and other noises related to the non-linearity are well suppressed.

The control part consists of two successive components: Filtering and Actuation.

Filtering

Type	Description	Related Subsystems
Digital	Most of the ISC feedback filters will be implemented as digital filters.	Digital
Analog	Analog electronics are used where a wide feedback bandwidth is required.This will be the case mainly for the laser stabilization loops i.e. the frequency and intensity stabilization servos.	IFO support

Actuator

Actuators change the state of an interferometer.

Name	Description	Related Subsystems
Suspension actuators	These actuators move the mirrors. This is the realm of the suspension sub-system.ISC group will set requirements for the suspension actuators	Suspension
Laser actuators	Laser intensity and frequency has to be controllable with a high bandwidth.	IOO

Thermal	If necessary, the thermal deformations of the mirrors have to be compensated by some way, such as illuminating the mirrors with CO2 lasers.	IFO Support

Requirements

The requirements for the ISC system ultimately come from the target sensitivity. Again the requirements for the ISC subsystem are divided into Sensing and Control.

Requirements for Sensing

DARM	The DARM sensing noise should be below the target sensitivity.
Other DOFs	The noises in the DOFs other than DARM affect the sensitivity through feedback. The sensing noises should be small enough to allow descent feedback gains for the auxiliary loops.

Requirements for Control

DARM	DARM actuator noise directly appears in the DARM noise spectrum. This has to be kept below the target sensitivity.
Other DOFs	Actuator noises in the DOFs other than DARM appear in the DARM signal through various couplings. The couplings have to be modeled and estimated to set the requirements for the actuator noises.

Interface with Other Sub-Systems

The ISC sub-system is realized by connecting hardware components provided by other sub-systems. So establishing good interface with the related sub-systems is imperative. Since the ISC requirements are set directly from the target sensitivity, ISC sets the requirements for other sub-systems in most cases.

Issues	Description	Numbers	Related Subsystems	Consensus
Laser Power			IOO	
Laser Frequency Noise			IOO	
Laser Frequency Control			IOO	
Laser Intensity Noise			IOO	
Laser Intensity Control			IOO	
Modulation			IOOl	
Input Mode Clearner			IOO	
Output Mode Cleaner			IOO	
Seismic RMS			Suspension	
Mirror actuators			Suspension	

Mirror Loss			Mirror	
Mirror Transmittance			Mirror	
Mirror Coating			Mirror	
Folding RCs			IOO, Mirror, Suspension, Vacuum	
Vacuum Layout	Optical layout of the interferometer determines the layout of the vacuum tubes and chambers.		Vacuum	
Vacuum Pressure			Vacuum	
PD	Requirements for power handling, quantum efficiency, noise, bandwidth etc		IOO	
Analog Electronics Standards			IFO support	