O4 CALIBRATION SCHEME

η_R = Opt. eff. $S(\omega)$ = SUS L3-L3 = L3-L3 NORM · 2 1Hz poles · L3 DC m/N

$\frac{2\cos\theta}{c}$ = N/W TX Y ρ_R = PD ct/W = PD A/W · TIA V/A · ADC ct/V · AA(A) GAIN

2 1Hz poles are intentionally left *out* of the front-end representation of S(w), as a form of whitening prior to data storage

(Optical Response * Overall Gain) Only

PCAL
CAL-PCALX_EXC
CAL-PCALX_EXC_OUT
CAL-PCALY_EXC
CAL-PCALY_EXC_OUT
"N/ct"
"susnorm"
"m_per_N"
TY PD N/ct
RY PD N/ct
TX PD N/ct
RX PD N/ct
CAL-PCALY_TX_PD_DQ
CAL-PCALY_RX_PD_DQ
CAL-PCALX_TX_PD_DQ
CAL-PCALX_RX_PD_DQ
PCAL Front-end Monitor Computation
Front-end compensation for N/ct is described further in T1800046 and P2000113
OFFLINE CORRECTION
Pcal Y TxPD (m)
Pcal Y RxPD (m)
Pcal X TxPD (m)
Pcal X RxPD (m)
Sensing Function
C
Rough mA/ct = 1000 mA/A · TIA GAIN · W GAIN · ADC ct/V
"HI F" response with super-nyquist poles
"LOW F" response with zeros or poles within Control Band
See LEGEND for further breakout of switchable configurations and expansion of LO F and HI F blocks
Optical response * Optical Gain
(Light travel time)
(Single pole correction)
Front end Compensation
Balance, linearization, and input matrix gains can be arbitrary (including signs), so DARM_IN1 units are "counts" (though not "just" ADC counts)
BALANCE MATRIX
LIN
INPUT MATRIX
Interferometric Response to Differential Arm Displacement
Photo-diode and Readout Response
Digital-to-Analog Signal Processing and Artifacts
Global Sensing And Control Front-end Control Computation
DARM LOOP
Actuation Function
A
Super Nyquist
Sub Nyquist
Within Control Band
EACH L1, L2, L3 OUTPUT PATH IS ACTUALLY FOUR CHANNELS EACH WITH THEIR OWN DAC CHANNEL AND ELECTRONICS PATH
Within control band, some electronic response is compensated digitally
FE Comp
Actuator Strength and Force-to-Displacement Response
Actuator Driver Response
Suspension Front-end Control Computation
Inter-computer communication
Control Filters
D
LSC-DARM_IN1
LSC-DARM_EXC
LSC-DARM_IN2
OUTPUT MATRIX
SUS-ETMY_L1_CAL_LINE_OUT_DQ
SUS-ETMY_L2_CAL_LINE_OUT_DQ
SUS-ETMY_L3_CAL_LINE_OUT_DQ
SUS-ETMY_L1_CAL_LINE_EXC
SUS-ETMY_L2_CAL_LINE_EXC
SUS-ETMY_L3_CAL_LINE_EXC
CAL-DARM_ERR_DBL_DQ
PARTIAL INVERSE SENSING
CAL-DELTAL_RESIDUAL_DBL_DQ
INV. C
CFTD PARTIAL INVERSE SENSING
CAL-CFTD_DELTAL_RESIDUAL_DBL_DQ
CFTD INV. C
f_cc CALCS
WHITE
CAL-DELTAL_EXTERNAL_DQ
L1 ACT.
L2 ACT.
L3 ACT.
7/0 DELAY
Thiran filter
(Thiran filter is used for non-integer—fractional—delays at LLO. At LHO, an integer number of clock cycles are used for the delay)
CAL-DELTAL_CTRL_DBL_DQ
ACTUATION
L1 N/ct
L2 N/ct
L3 N/ct
Assume ESD BIAS is fixed, so calibration of ESD L3 is fixed, and linearization algorithm LIN does not come in to play
CAL-CS
"Front-End"
"Real-Time"
Real-time Calibration Front-end Monitor Computation
CFTD OUTPUT
CFTD L1 ACT.
CAL-CFTD_DELTAL_CTRL_DBL_DQ
CAL-CFTD_DELTAL_EXTERNAL_DQ
CAL-DELTAL_CTRL_UIM_DBL_DQ
CAL-DELTAL_CTRL_PUM_DBL_DQ
CAL-DELTAL_CTRL_TST_DQ
CAL-CFTD_DELTAL_CTRL_UIM_DBL_DQ
CAL-CFTD_DELTAL_CTRL_PUM_DBL_DQ
CAL-CFTD_DELTAL_CTRL_TST_DBL_DQ
CFTD L1 ACT.
CFTD L2 ACT.
CFTD L3 ACT.
CAL-DARM_CTRL_DBL_DQ
GDS
"Low-Latency"
Low-latentecy Data Monitoring Tool (DMT) Computation
RESIDUAL INVERSE SENSING FILTER
Front-end incapable of compensating for these
Front-end does a poor job of these
Back to "in loop" error signal
Assume TIA and W LOW F front-end compensation and gain is good enough for low-latency…
1/K_C GDS
f_cc GDS
TD CC CORR
1/L
GDS-CALIB_STRAIN
RESIDUAL ACTUATION FILTERING
LOW F L1, L2, and L3 front-end compensation is good enough for low-latency…
RESIDUAL UIM FILTER
RESIDUAL PUM FILTER
RESIDUAL TST FILTER
Front-end incapable of compensating for these
Front-end does a poor job of these
Back to "in loop" control signal
f_cc DCS
FULL INVERSE SENSING FILTER
if we assume TIA and W LOW F front-end compensation is good… otherwise, back out front-end compensation and apply better here Also assume gain balancing is good…
1/K_C DCS
DCS
"Offline"
LDAS Cluster Computation
DCS-CALIB_STRAIN
if we assume and LOW F L1, L2, and L3 front-end compensation is good… otherwise, back out front-end compensation and apply better here
FULL ACTUATION FILTERING
UIM filter
PUM filter
TST filter
K_U DCS
K_P DCS
K_T DCS
Assume ESD BIAS is fixed, so calibration of ESD L3 is fixed, and linearization algorithm LIN does not come in to play
OVER GAIN = OPT GAIN · OUT LOSS · A OMCBS TRANS · PDA GAIN · TIA_A GAIN · W_A GAIN · AA(A) GAIN · ADC ct/V · A Rough mA/ct · LIN · INPUT MATRIX = units of counts / meter
GAIN RATIO = (B OMCBS REFL · PDB GAIN · TIA_B GAIN · W_B GAIN · AA(A) GAIN · B ADC ct/V · B Rough mA/ct · BALANCE MAT B) / (A OMCBS TRANS · PDA GAIN · TIA_A GAIN · W_A GAIN · AA(A) GAIN · A ADC ct/V · A Rough mA/ct · BALANCE MAT A)
C = (LSC-DARM_IN1 / CAL-PCALY_RX_PD_DQ) · ((1 + G) / 1) · 1 / (ARM SIGN · AA(A) HI F · AA(D) 64-16 · 2 1Hz poles)
LSC-DARM_IN2 / LSC-DARM_EXC = 1 / (1 + G)
MCMC Input for C
if we assume TIA and W LOW F front-end compensation, and gain balancing is good…
if we assume PCAL AA(A) and AA(D) response is identical to both channel's OMC AA(A) and AA(D) responses…
CAL-DARM_ERR_DBL_DQ = CAL 61 · LSC-DARM_IN1
1 / (1/C + AD)
No assumption here, these are identical
if we assume LOW F L3 front-end compensation is good…
Assume ESD BIAS is fixed, so calibration of ESD L3 is fixed, and linearization algorithm LIN does not come in to play
MCMC Input for A_T = ESD
ETMY_L3_EXC
TDCFs
Time Dependent Correction Factors
K_T
t = now
t = ref
if we assume LOW F L3 front-end compensation is good, linearization doesn't play a role because bias is fixed…
Generation of time dependent correction factors is further described in T1700106, including subtle differences between GDS/DCS computation and CAL-CS computation
C (t = now)
if we assume LOW F L1, L2, and L3 front-end compensation is good…
K_T CORR
K_P CORR
K_U CORR
K_C = |S|² / Re S
f_cc = −f₁ Re S / Im S

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LEGEND

1 Blocks with white lettering are inverse of its counterpart block with black letters and the same name
* Partial correction (when full correction is not possible)

SIGNAL
64 kHZ
16 kHZ
4 kHZ
2 kHZ
ANALOG
LIGHT

EXCITATION CHANNEL

READ-BACK CHANNEL

CORRECTED READOUT

	Filter / Delay	Inverse Filter / Advance	Expanded Definition GAIN * RESPONSE	
OPTICAL GAIN	OPT GAIN	OPT GAIN		GAIN ONLY
COUPLED-CAVITY POLE	CC POLE	CC POLE		RESPONSE ONLY
DETUNED SRC OPTICAL SPRING	SRC D2N	SRC D2N		RESPONSE ONLY
PHOTODIODE QUANTUM EFFICIENCY * RESPONSIVITY	PD A/W			GAIN ONLY
TRANSIMPEDANCE AMPLIFIER	TIA	TIA	TIA_A GAIN · TIA HighZ / TIA LowZ · TIA_A LOW F · TIA_A HI F	High or Low impedance ("Z") setting is manually switchable in hardware
OMC PD ANALOG WHITENING	W	W	W GAIN · W LO F 1 · W HI F 1 · W LO F 2 · W HI F 2 · W LO F 3 · W HI F 3	Each of three filter stages can be remotely switched ON or OFF in hardware
ANTI-ALIASING (ANALOG)	AA(A)	AA(A)	AA(A) HI F · AA(A) GAIN	
ANTI-ALIASING (DIGITAL)	AA(D) 64-16	AA (D) 64-16		RESPONSE ONLY Numbers indicate kHz of sampling rate, indicated as "from" rate - "to" rate
ANALOG or DIGITAL TIME DELAY or ADVANCE	TD µsec	TD µsec		RESPONSE ONLY
ANTI-IMAGING (ANALOG)	AI(A)	AI(A)	AI(A) GAIN · AI(A) HI F	
ANTI-IMAGING (DIGITAL)	AI(D) 2-16	AI(D) 2-16	AI(A) GAIN · AI(A) HI F	
COIL/ESD DRIVER	DRVR stage	DRVR stage	GAIN L1 · HI F L1 · MID F L1 · LOW F L1	
n STAGE LOCK FILTER	LF3 · LF2 · LF1			1 = UIM, 2 = PUM, 3 = TST
n STAGE DRIVE ALIGN FILTER	DA1 · DA2 · DA3			
LINEARIZATION OF QUADTRATIC ALGORITHMS (FOR ESD / OMC)	LIN			GAIN ONLY
ANTI-IMAGING (DIGITAL)	AI(D) 2-16	AI(D) 2-16		RESPONSE ONLY Numbers indicate kHz of sampling rate, indicated as "from" rate - "to" rate
ANALOG/DIGITAL CONVERTER	DAC V/ct	ADC ct/V		GAIN ONLY
ACTUATION COEFFICIENT	L1 N/ct · L2 N/ct · L3 N/ct			GAIN ONLY
FORCE-TO-LENGTH SUS RESP	SUS L1-L3 · SUS L2-L3 · SUS L3-L3 = $S(\omega)$			L1 = UIM, L2 = PUM, L3 = TST
FORCE-TO-LENGTH DC GAIN	L1 DC m/N · L2 DC m/N · L3 DC m/N			GAIN ONLY
NORMALIZED, WHITENED SUSPENSION FORCE-TO-LENGTH RESP	L3-L3 NORM = SUS L3-L3 / (2 1Hz Poles · L3 DC m/N)			RESPONSE ONLY
PCAL POWER TO FORCE TERM	N/W X = $\frac{2\cos\theta}{c}$			GAIN ONLY
PCAL OPTICAL EFFICIENCY TERM	Opt. eff. = η_R			GAIN ONLY
ACOUSTO-OPTIC MODULATOR	AOM			
OPTICAL FOLLOWER SERVO	OFS			
TIME DEPENDENT CORRECTION	K_U CALCS · K_P CALCS · K_T CALCS · 1/K_C CALSS · f_cc CALCS K_P GDS · K_U GDS · K_C GDS · 1/K_C GDS · f_cc GDS			Lower label indicates from what pipeline the TDCF comes. See Section 3 of T1700106
TIME DEPENDENT CORRECTION	TD CC CORR = $\frac{(1+if/f_{cc}(t=0))}{(1+if/f_{cc}(t))}$			
FOTON IIR FILTER WARPING	IIR WARP	IIR WARP		