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Digital LOS and SOS Control Systems For LIGO

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1 INTRODUCTION

1.1. Purpose

This document covers the design of digital Large Optic Suspension (LOS) and Small Optic Suspension (SOS) control systems that can be used as a replacement for the existing analog LOS and SOS controllers. This idea is being pursued as an alternative to replacing the existing design with an analog upgrade that incorporates all of the design changes, lessons learned and design/feature additions that are summarized in Section 2.3., Summary of Modifications and Additions to Existing System.

The document is intended to be a preliminary design, from which the final designs for the system can be obtained.

This document does not address the satellite amplifier design, but the design described is compatible with either the existing “DC” design or the “AC OSEM/coherent detection” design currently under development.

This document does not address a specific coil driver circuit design, but does assume that a circuit similar to that being designed in the current suspension upgrade is used.

In the original design an SOS controller was used to control MMT3 in the input optics chain. If the control for MMT3 is moved to the new digital LOS controls being developed for the LHO 4K IFO there can be a significant reduction in the requirements for the SOS controllers. Specifically the need for an ASC input that has a 35 Hz elliptic filter in it’s path can be eliminated. In addition, the need to connect the IFO ASC and LSC system to the other IO optics via either a digital or analog link can be eliminated.

1.2. Document Organization

This document is organized into the following sections.

Section 1- Introduction

Section 2- Statement of Requirements and Changes. This is a brief list of the original requirements and changes to the existing systems that have come about as a result of operational experience. These changes and additions can be seen as a second set of requirements.

Section 3- Servo Design. The design for a local damping servo for each degree of freedom is shown.

Section 4- Implementation. This section describes how the servo design shown in section 3 can be implemented to provide a fully integrated ASC, LSC and suspension control system for LIGO.

2 STATEMENT OF REQUIREMENTS AND CHANGES

2.1. LOS Requirements

The design requirements for the LOS control system are listed in LIGO document T960151-02. The key requirements are repeated below.

2.1.1. LOS Local Damping Transfer Function

The design of the LOS controller shall provide for "pseudo-critical" damping[1] of the optic in the local damping and control mode of operation.

2.1.2. LOS ASC Input to Actuator Coil Transfer Function

The gain from the ASC pitch or yaw input of the controller to the optic under control shall be 25μrad/Volt.

The shape of the output filter transfer function shall be a 35 Hz, forth order, 4 dB passband ripple 60 dB stopband attenuation elliptic low pass filter.

The input referred noise of the ASC inputs of the controller shall be less than $(1\mu V)/(\sqrt{Hz})$ for freq <40 Hz and less than $(80nV)/(\sqrt{Hz})$ for freq >40 Hz.

2.1.3. LOS LSC Input to Actuator Coil Transfer Function

The transfer function from the LSC input of the controller to the optic under control shall be 1.0μmeter/Volt at DC.

The shape of the transfer function shall include a pole at 1.0 Hz and a zero at 40 Hz with no other poles or zeros for freq < 10 KHz.

The input referred noise of the LSC input of the controller shall be less than $(1\mu V)/(\sqrt{Hz})$ for freq <40 Hz and less than $(80nV)/(\sqrt{Hz})$ for freq >40 Hz.

The length control input shall have three modes of operation that shall be selectable by the operator. The acquisition and locked modes are as defined in Table 2:

- Acquisition mode
- Locked mode
- Off Mode: LSC Input Disabled

1. Pseudo-critical damping: no bump in the transfer function of force to displacement with suitable gain.

2.1.4. LOS Dynamic Range and Input and Output Noise

For frequencies below 40 Hz the input referred noise of the controller shall be dominated by the LED/PD sensor noise. If the sensor noise is assumed to be $1x10^{-10}((m)/(\sqrt{Hz}))$ and the transimpedance of the photodiode amplifier is 20 KV/A, this would lead to:

$$v_{noise} \ll \left(1x10^{-10}\left(\frac{m}{\sqrt{Hz}}\right) \times 08\frac{\dot{A}}{m} \times 20K\frac{V}{A} = 160n\frac{V}{\sqrt{Hz}}\right)$$

Therefore, the input referred noise of the controller should be less than $16((nV)/(\sqrt{(Hz)}))$ for frequencies less than 40 Hz.

The dynamic range and output noise of the controller shall be as defined in Table 1 below.

Table 1: LOS Controller Dynamic Range and Output Noise

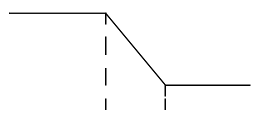
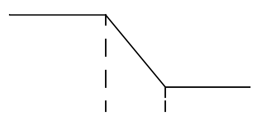
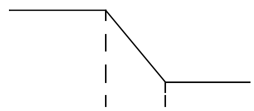
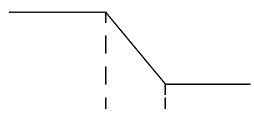
	Mode of Operation	*Dynamic Range*[a]	*Output Noise*[b]
Local Damping and Control	Local damping and control mode	20 $\mu m_{p\text{-}p}$ 	$5x10^{-20}\left(\frac{f}{40}\right)^{-2}(m/(\sqrt{Hz}))$ f > 40 Hz
ASC Pitch Input to Optic	All modes	500 $\mu rad_{p\text{-}p}$, 	$1x10^{-17}((rad)/(\sqrt{Hz}))$ f > 40 Hz

Table 1: LOS Controller Dynamic Range and Output Noise

	Mode of Operation	*Dynamic Range*[a]	*Output Noise*[b]
ASC Yaw Input to Optic	All modes	500 $\mu rad_{p\text{-}p}$,  1 Hz 40Hz	$1x10^{-17}((rad)/(\sqrt{Hz}))$ f > 40 Hz
LSC Input to Optic	LSC Acquire	>100 $\mu m_{p\text{-}p}$ Flat response	N/A
LSC Input to Optic	LSC Locked	20 $um_{p\text{-}p}$  1 Hz 40Hz	$5x10^{-20}\left(\frac{f}{40}\right)^{-2}(m/(\sqrt{Hz}))$ f > 40 Hz

a. Memo L960728-00-D, “Requirements of the LOS Suspension Driver”, S. Kawamura, outlines the dynamic range and noise requirements for the LOS controller and the trade-off that can be made between the number of actuator coil windings, the maximum output current drive and the output referred current noise.

b. It has been decided (4/1/98 meeting between Whitcomb, Heefner, Coyne, Shoemaker and ISC Group) that the number of turns on the sensor/actuator head should remain at the current number (~400). With the present coil driver design this implies that the noise requirements can not be met. The actual noise will be $\sim 9x10^{-20}\left(\frac{f}{40}\right)^{-2}(m/(\sqrt{Hz}))$. It, at some future date it is determined that the range requirements for the LOS can be relaxed, the existing circuitry could be modified to reduce the noise to the required numbers.

2.2. SOS Requirements

The design requirements for the SOS control system are listed in LIGO document T960151-02. The key requirements are repeated below.

2.2.1. Small Optic Suspension

2.2.1.1 SOS Local Damping Transfer Function

The design of the SOS controller shall provide for “pseudo-critical” damping of the optic in the local damping and control mode of operation.

The design shall provide for adjustment of each of the nominal gains +20/-40 dB in minimum 1 dB increments.

2.2.1.2 SOS ASC Input to Actuator Coil Transfer Function

The gain from the ASC pitch or yaw input of the controller to the optic under control shall be as shown in Table 2 below.

The shape of the output filter transfer function shall be a 35 Hz, forth order, 4 dB passband ripple 60 dB stopband attenuation elliptic low pass filter.

The input referred noise of the ASC inputs of the controller shall be less than $(1uV)/(\sqrt{Hz})$ for freq <40 Hz and less than $(80nV)/(\sqrt{Hz})$ for freq >40 Hz.

2.2.1.3 SOS LSC Input to Actuator Coil Transfer Function

The transfer function from the LSC input of the controller to the optic under control shall be as shown in Table 2 below.

Table 2: SOS LSC Input to Output Transfer Function

Optic	*LSC Transfer Function (at DC)*	*ASC Transfer Function (at DC)*
MMT1, MMT2 SM1, SM2	$(25um)/(Volt)$	$(1340urad)/(Volt)$
MMT3[a]	$(2um)/(Volt)$	$(25urad)/(Volt)$
MC1, MC2, MC3	$(1.4um)/(Volt)$	$(75urad)/(Volt)$

a. Note that the MMT3 requirements now apply to the LOS controller used to control MMT3.

The input referred noise of the LSC input of the controller shall be less than $(1uV)/(\sqrt{Hz})$ for freq <40 Hz and less than $(80nV)/(\sqrt{Hz})$ for freq >40 Hz.

The length control input shall have three modes of operation that shall be selectable by the operator. The modes are defined as:

- Acquisition mode
- Locked mode
- Off Mode

In the initial implementation of the SOS controller, the Acquire mode and Locked mode will be the same and as described in Table 2 and Table 3, but the design shall include provisions for incorporation of an Acquire mode similar to that described for the LOS controller.

2.2.1.4 SOS Dynamic Range and Input and Output Noise

For frequencies below 40 Hz the input referred noise of the controller shall be dominated by the LED/PD sensor noise. If the sensor noise is assumed to be $1x10^{-10}((m)/(\sqrt{Hz}))$ and the transimpedance of the photodiode amplifier is 20 KV/A, this would lead to:

$$v_{noise} \ll \left(1x10^{-10}\left(\frac{m}{\sqrt{Hz}}\right) \times 08\frac{\dot{A}}{m} \times 20K\frac{V}{A} = 160n\frac{V}{\sqrt{Hz}}\right)$$

Therefore, the input referred noise of the controller should be less than $16((nV)/(\sqrt{(Hz)}))$ for frequencies less than 40 Hz.

The dynamic range and output noise of the controller shall be as defined in Table 3 below.

Table 3: IOO Suspension Controller Noise and Dynamic Range Requirements

Optic	*Type of Controller*	*Dynamic Range Length and Angle*	*Noise*
MMT1, MMT2	SOS	500 um p-p 28 mrad p-p	$5x10^{-16}\left(\frac{f}{40}\right)^{-2}(m/(\sqrt{Hz}))$ f > 40 Hz
MC1, MC2, MC3	SOS	27 um p-p 1.5 mrad p-p	$3.8x10^{-18}\left(\frac{f}{40}\right)^{-2}(m/(\sqrt{Hz}))$ f > 40 Hz
SM1, SM2 (2Km IFO only)	SOS	500 um p-p 28 mrad p-p	$5x10^{-16}\left(\frac{f}{40}\right)^{-2}(m/(\sqrt{Hz}))$ f > 40 Hz
MMT3[a]	LOS	40 um p-p 1 mrad p-p	$5x10^{-16}\left(\frac{f}{40}\right)^{-2}(m/(\sqrt{Hz}))$ f > 40 Hz

a. MMT3 will be controlled by an LOS controller in this implementation

Note that all SOS controllers shall have a flat response for 0<freq.<10KHz.

2.3. Summary of Modifications and Additions to Existing System

The following is a summary of the requested changes and additions to existing design. It is in no way prioritized, but it has been discussed among the various users of the suspensions. This list is an updated copy of the list originally sent out by Mike Zucker on January 24, 2000. These changes and additions apply to both the LOS and SOS controllers.

2.3.1. User interface & operational convenience

1. Make pitch and yaw bias setpoints (i.e., output currents) independent of servo gain, servo enable/disable, and run/acquire setting.
2. Build EPICS facility for putting square step onto selected bias field for damping adjustment
3. Single button to simultaneously switch all coil outputs between RUN and ACQUIRE modes
4. Fix scanf (lock up) problems on VME CPU.

2.3.2. Diagnostic features

1. Change coil test inputs into summing nodes (which can be disabled or enabled) to allow closed-loop test signal injection (see e. below, similar)
2. Add bias input for POS and SIDE to allow damping test
3. Put in 10x gain and filter on PIT and YAW monitors to improve resolution
4. Readback OSEM photodiode signals directly to EPICS channels
5. Move test inputs after servo enable and servo filtering for pos, pitch & yaw D.O.F.
6. Add ASC test inputs on the front panel

2.3.3. Basis transformation & diagonalization

1. Add side OSEM into sense and feedback matrices
2. Change ASC and LSC control inputs to differential for noise immunity

2.3.4. Servo dynamics

1. Introduce microseismic-frequency gain "bubble" into pitch (and yaw?) control transfer function to reduce RMS angle due to inertial coupling

2.3.5. Noise & dynamic reserve

1. Reevaluate coil driver range requirement in RUN and ACQUIRE modes
2. Check static misalignment corrections & do worst-case peak current analysis
3. Reevaluate closed-loop gain effect on current noise RTO
4. Change coil driver circuit to use straight resistor feedback
5. Add DC bucking current source to relieve low-noise driver from maintaining orientation biases (possible added HV supply?)
6. 80K TEC cooling on output resistors
7. Design a better readout for the DAQ coil current monitor

2.3.6. OSEM changes

1. Redo satellite amplifier with modulation/coherent detection scheme
2. Re-optimize coil turns count (if decision is made to replace OSEM heads)
3. Redo satellite for IR-immune OSEM design (if replace OSEM heads)

4. Include PD I/V buffer in OSEM head (if replace OSEM heads)

In addition to the changes and additions listed above, there is one major lesson that has been learned. Any design that is pursued must be versatile, modular and easy to relatively change. Many of the operational and maintenance problems associated with the current design are the result of the fixed design of the system.

3 SERVO DESIGN

Block diagrams of the proposed systems are shown in the figures below

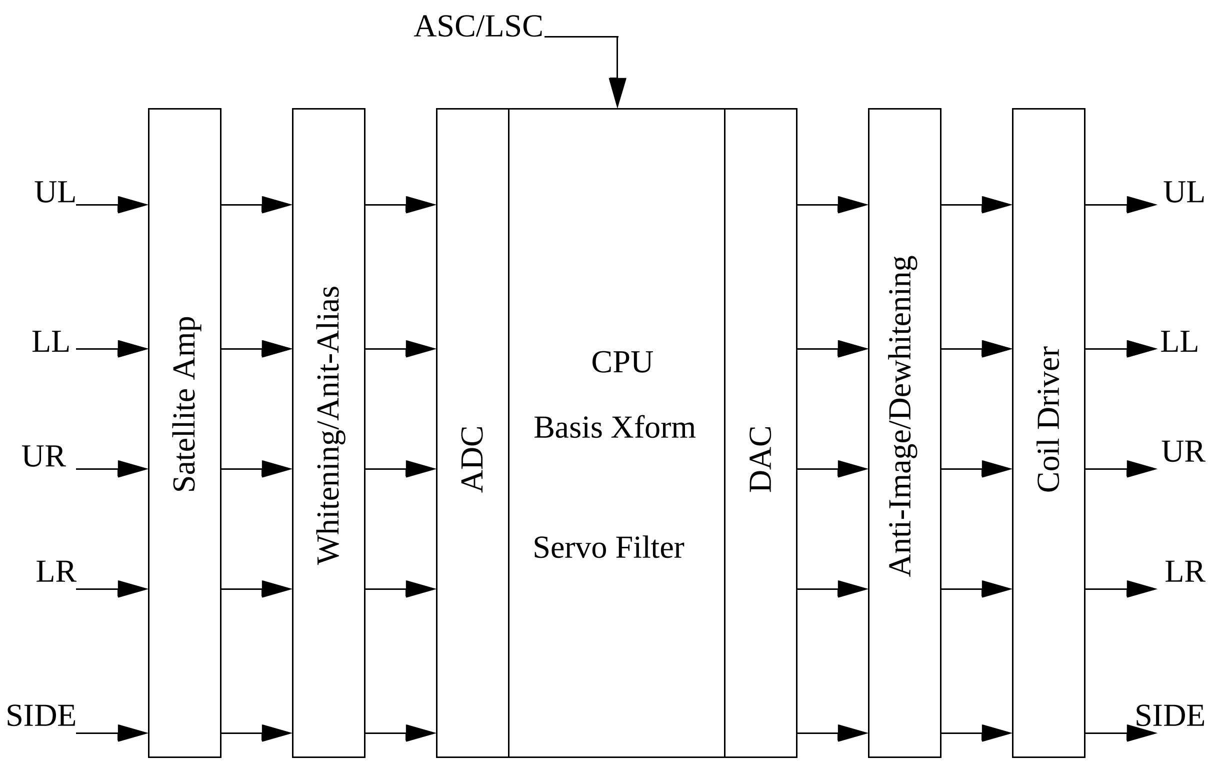


Figure 1: Block Diagram of Proposed LOS Controller

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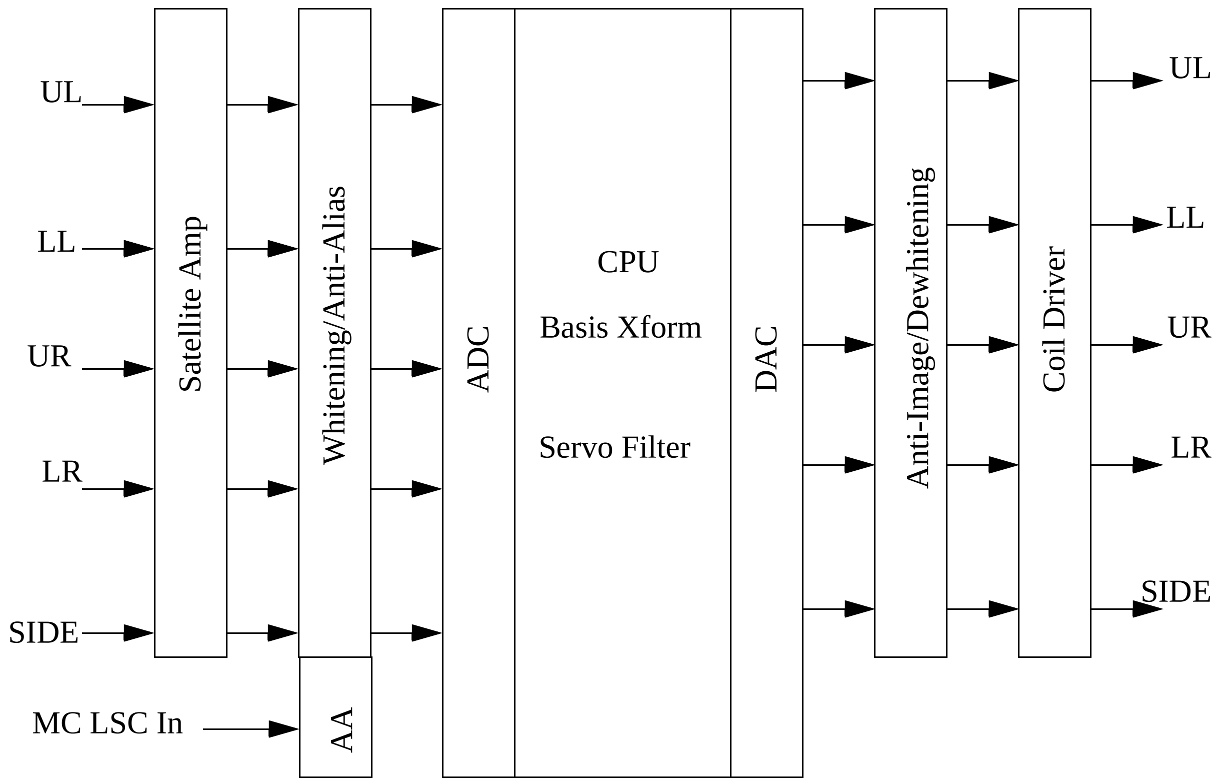

Figure 2: Block Diagram of Proposed SOS Controller

For the purposes of this document it is assumed that the satellite amplifier provides the LED bias, PD bias and PD amplification (gain = 20Kohm). Each section of the design is discussed below. As can be seen from the block diagrams the two systems are essentially the same in block diagram form with the exception that the SOS controls have an additional analog input from the mode cleaner length control system.

Another difference will be in the anti-image and dewhitening requirements for each of the controllers. These differences are described in the sections that follow.

3.1. LOS and SOS Suspension Sensor Signal Whitening

The input referred noise voltage of the both controller types must be less than $16((nV)/(\sqrt{(Hz)}))$ for frequencies greater than 40 Hz. The input referred noise voltage of the ADCs that are to be used in the design (ICS110-B1B) is on the order of $200((nV)/(\sqrt{(Hz)}))$. This implies that whitening filter should have a gain of ~10 at a frequency of 40 Hz. For this design a whitening filter with a zero at 3 Hz, poles at 30Hz and 100Hz and a DC gain of 0 dB has been chosen.

3.2. Mode Cleaner Length Control Signal Whitening (SOS only)

A plot of the mode cleaner length control signal voltage spectrum is shown in the figure below.

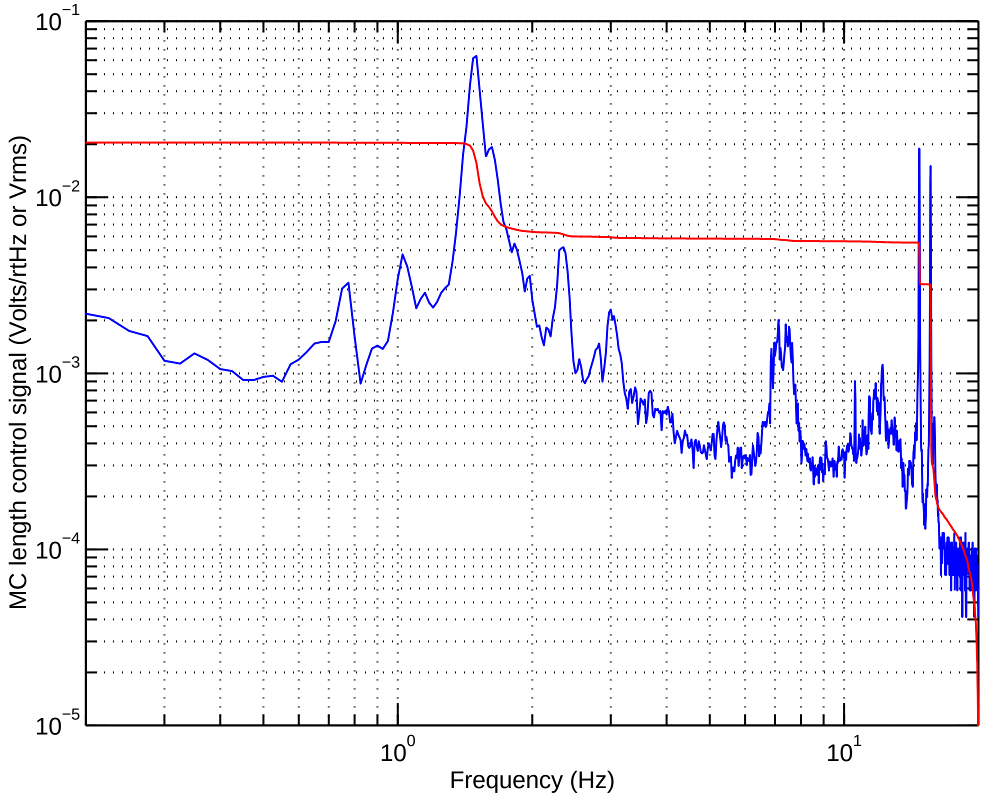

Figure 3: Mode Cleaner Length Control Signal Voltage Spectrum

As can be seen from the figure, the noise voltage for frequencies above ~15 Hz is approximately $10((mV)/(\sqrt{(Hz)}))$ and the integrated voltage (red curve) is approximately 20mV. The input referred noise voltage of the ADCs (ICS-110-B1B) is on the order of $200((nV)/(\sqrt{(Hz)}))$ and the input range of the ADC is +/- 1Volt. This implies that very little if any whitening will be needed for the mode cleaner length control signal.

3.3. LOS Dewhitening

The DACs that have been chosen for this design (Pentek 6102 with the new low distortion option) have an approximate output noise of $(2\mu V)/(\sqrt{Hz})$. In order to meet the design requirements this noise must be attenuated by approximately 60 dB at 40 Hz. The dewhitening filter chosen is a design originally proposed by P. Fritschel[1] and later modified by J. Heefner. This design is referred to as the Universal Dewhitening Filter and it meets the requirements for all subsystems: ASC, LSC and Suspension. The poles and zeros for this filter are summarized in the table below:

Table 4: Universal Dewhitening Filter Poles and Zeros

Zeros	*Poles*
-26.7 +/- i46.4 Hz	-8.91 +/- i9.76 Hz[a]
-5.11 +/- i37.5 Hz	-4.67 +/- i8.10 Hz
-86.7 Hz	-5.77 Hz
-48.9 +/- i134 Hz	-611 +/- i1.68 KHz
-97.8 Hz	-1.22 KHz

a. These poles are different from those in D000074-00. The Q of the stage was lowered by a factor of 5 to make the circuit less susceptible to saturation.

3.4. SOS Dewhitening

The DACs that have been chosen for this design are the same Pentek 6102s that have be chosen for the LOS. In order to meet the design requirements this noise must be attenuated by approximately 60 dB at 40 Hz. This filter must also be compatible with the requirements for the mode cleaner length control system. The current mode cleaner length control servo module has a 5th order 30 Hz, elliptic low pass filter incorporated into the design. It is proposed that this filter be moved to the DAC output and the pole frequency changed to 26 Hz. This filter design is consistent with the noise reduction requirements of the DAC and phase requirements of the mode cleaner length control servo.

3.5. LOS and SOS Anti-Alias Filter

The anti-alias filter will be compatible with the 2048 Hz sample frequency of the Suspension system. For the purposes of the servo design the anti-alias filter can be ignored.

3.6. LOS and SOS Anti-Image Filter

An anti-image filter is required to attenuate images produced by the digitization process at the output. In the case of the a stand alone digital suspension system the anti-image board would be designed around an output sample frequency of 2048 Hz, but the LOS output sample rate for this design implementation will be the 16384 sample rate used by the LSC system. Therefore, the anti-image filter must be compatible with the suspension, ASC and LSC requirements. The design chosen for the LOS is a 5th order, 4 dB ripple, 60 dB stopband attenuation, 7570 Hz elliptic filter.

1. Reference LIGO Document D000074-00, "DAC Output Signal Conditioning: Dewhitening and Anti-Image Filter Design", P. Fritschel

This filter was chosen because it meets the requirements of all systems and has the added advantage of placing a zero at 16384 Hz.

There is no explicit anti-image filter in the SOS design. The 26 Hz dewhitening filter described Section 3.4. SOS Dewhitening will also serve as the anti-image filter for the SOS.

3.7. LOS Servo Design

The simulink models for the position, pitch and yaw degrees of freedom are shown in the figures below.

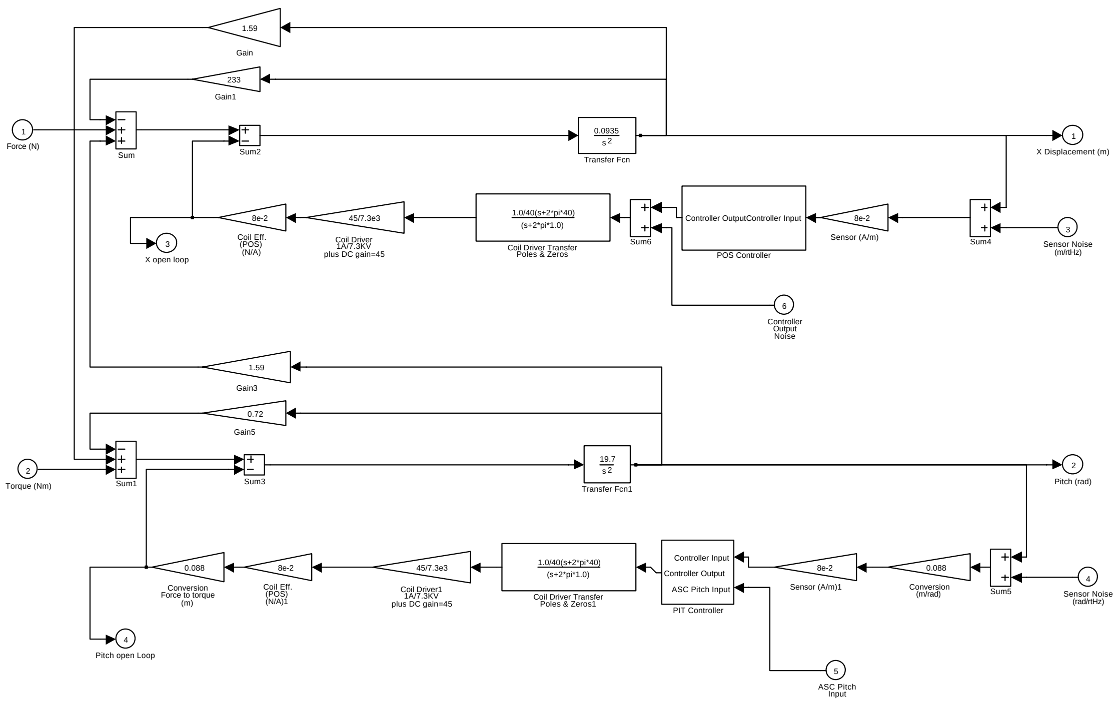

Figure 4: LOS Position and Pitch Servo Model

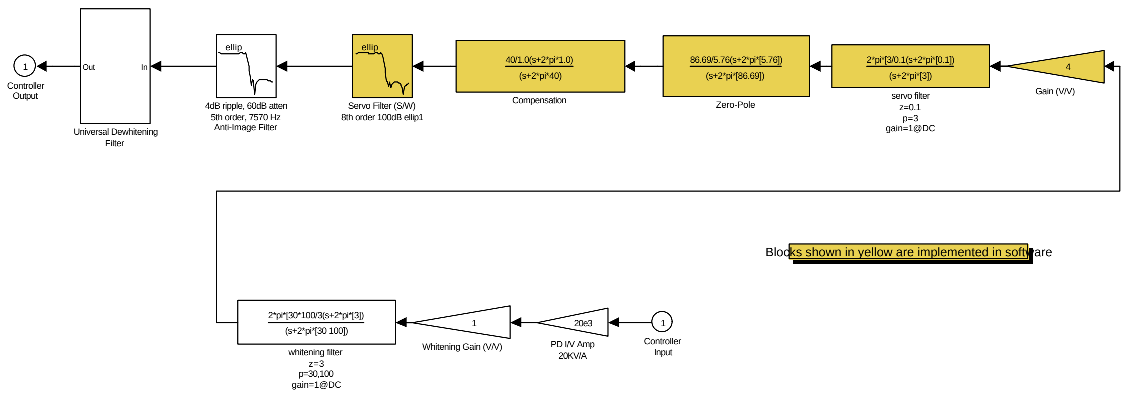

Figure 5: LOS Position Controller

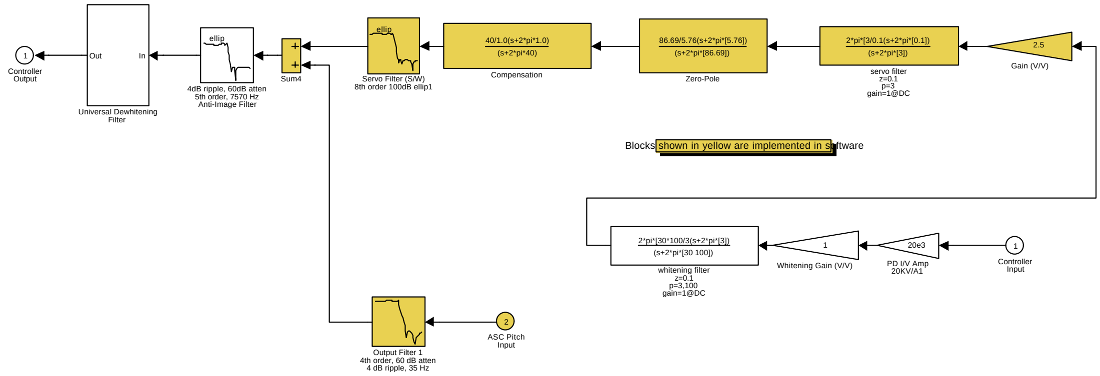

Figure 6: LOS Pitch Controller

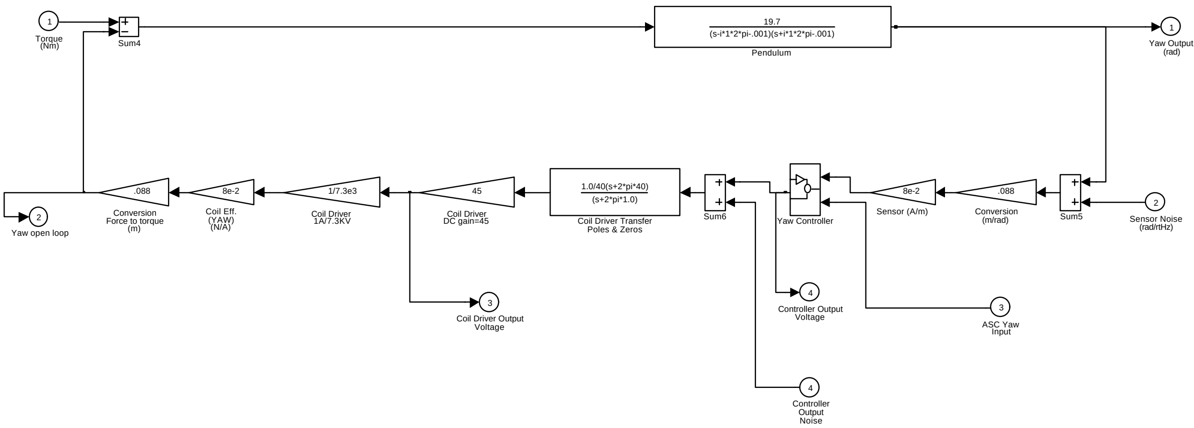

Figure 7: LOS Yaw Model

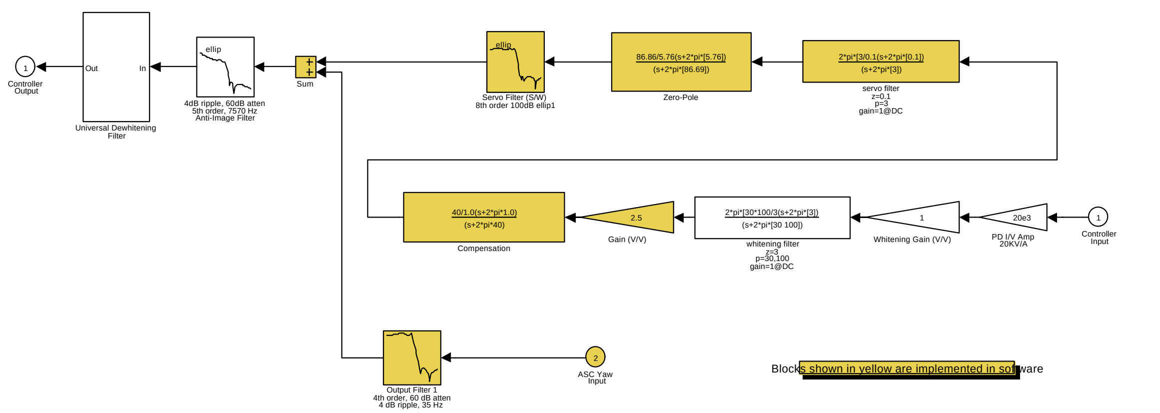

Figure 8: LOS Yaw Controller

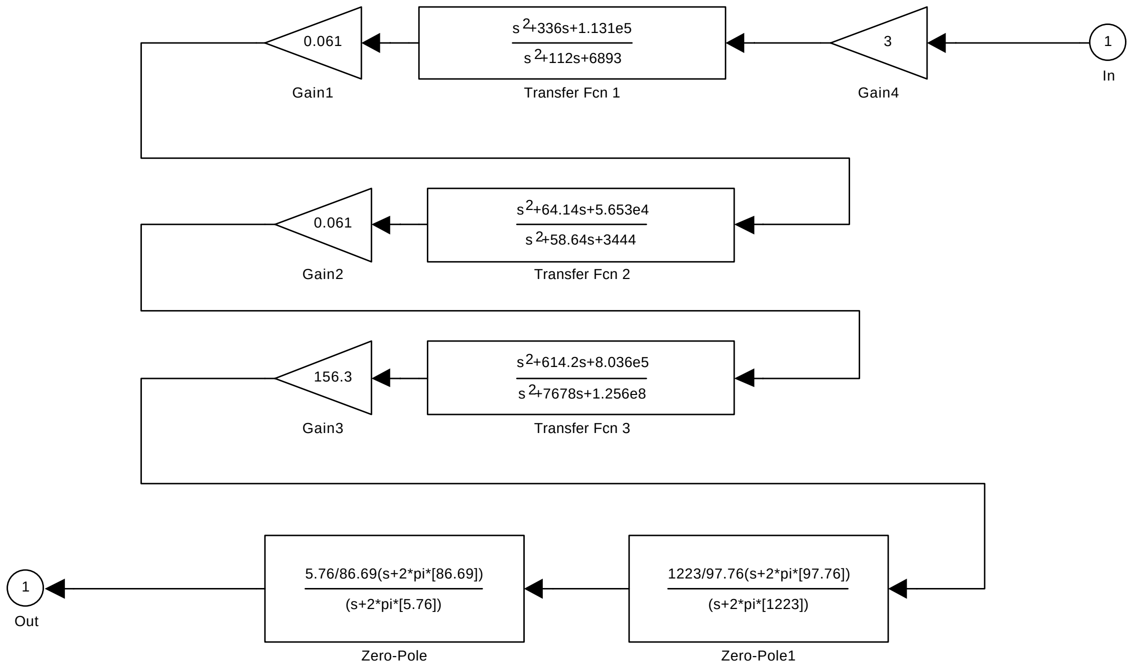

Figure 9: Universal Dewhitening Filter Used for LOS Position, Pitch and Yaw Degrees of Fredom

For the purposes of the modelling it has been assumed that each degree of freedom (position, pitch, yaw and side) has been obtained by a yet to be determined basis transformation of the PD readbacks. In the current system this transform is given by:

$$POS = K1 \bullet UL + K2 \bullet LL + K3 \bullet UR + K4 \bullet LR$$

$$PIT = K5 \bullet UL - K6 \bullet LL + K7 \bullet UR - K8 \bullet LR$$

$$YAW = K9 \bullet UL + K10 \bullet LL - K11 \bullet UR - K12 \bullet LR$$

and the side degree of freedom is separate. Any new system would have a similar transformation, although some interest has been expressed in adding the side channel into each calculation and having the ability to invert the sign of any of the gain coefficients or to add frequency dependency to the coefficients. These capabilities, while adding some complexity to the implementation, do not affect the design presented here. It should be noted that adding this capability to an analog design would be extremely difficult to implement.

Similar statements can be made for the output basis transformation. The output basis transform equations for the current design are:

$$UL = C1 \bullet POS_{out} + C2 \bullet PIT_{out} + C3 \bullet YAW_{out}$$
$$LL = C4 \bullet POS_{out} - C5 \bullet PIT_{out} + C6 \bullet YAW_{out}$$
$$UR = C7 \bullet POS_{out} + C8 \bullet PIT_{out} - C9 \bullet YAW_{out}$$
$$UL = C10 \bullet POS_{out} - C11 \bullet PIT_{out} - C12 \bullet YAW_{out}$$

where,

$$POS_{out} = LSC_{in} + POS_{in}$$
$$PIT_{out} = ASC_{pit} + PIT_{in}$$
$$YAW_{out} = ASC_{yaw} + YAW_{in}$$

POS_{in} , PIT_{in} and YAW_{in} are the values calculated by the local damping servo, and LSC_{in} , ASC_{pit} , ASC_{yaw} are the values from the interferometer length and alignment servos, respectively.

The figures below show the nichols plots for the position and pitch degrees of freedom.

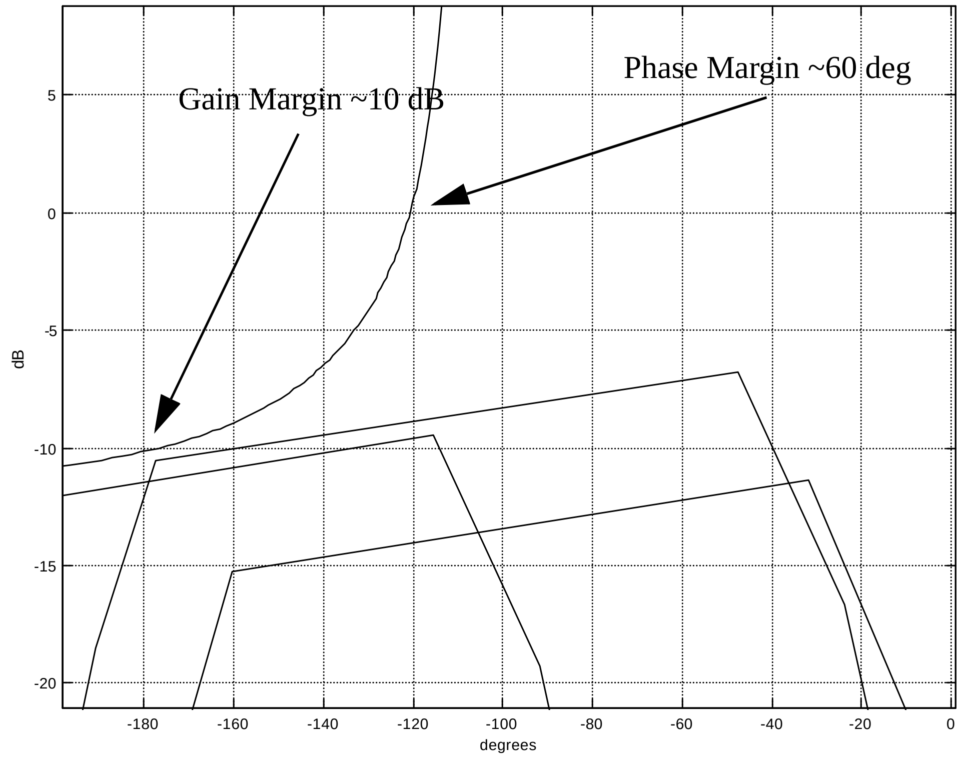

Figure 10: Nichols Plot for LOS Position Degree of Freedom

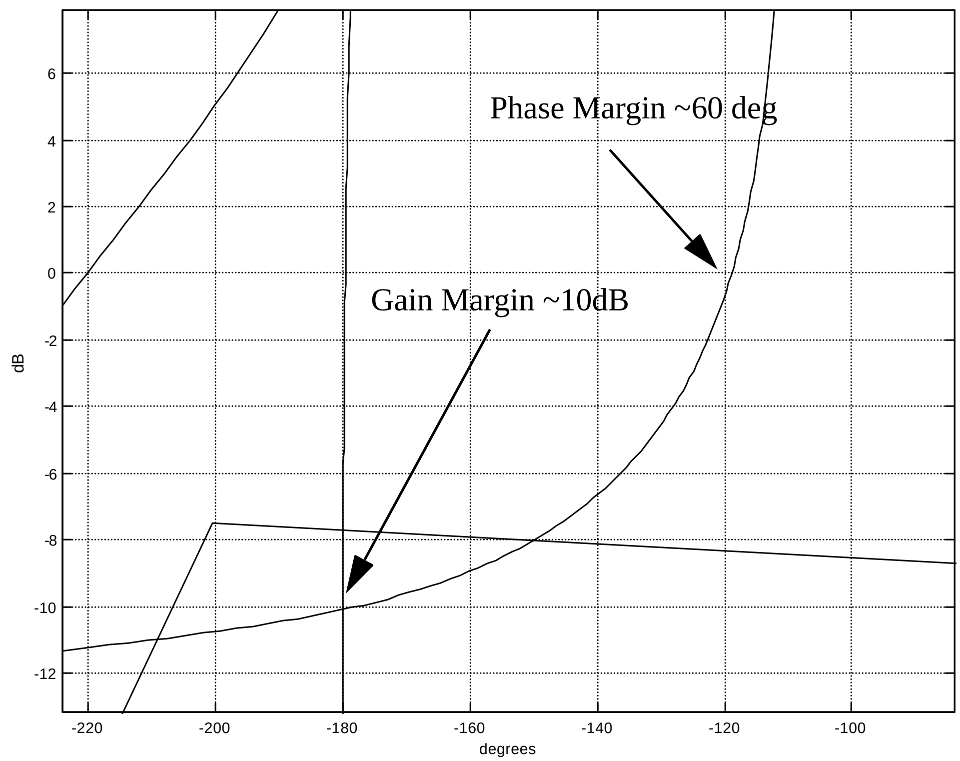

Figure 11: Nichols Plot for LOS Pitch Degree of Freedom

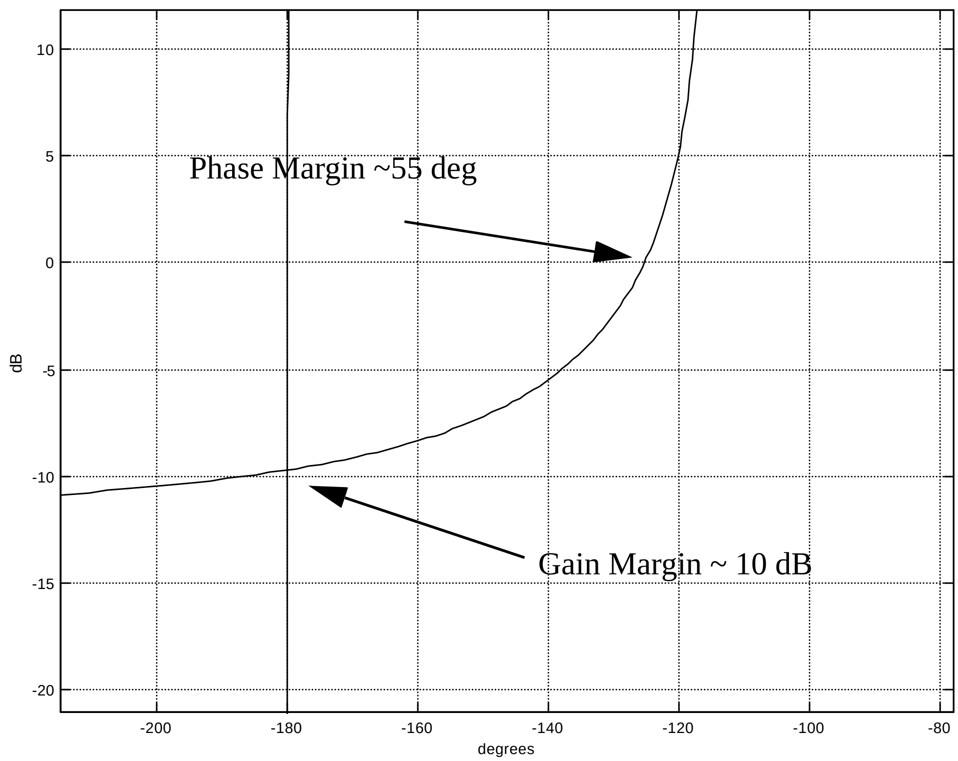

Figure 12: Nichols Plot for LOS Yaw Degree of Freedom

As can be seen from the simulink models for the controllers an 8th order, 30Hz, 4 dB ripple, 100 dB attenuation elliptic filter has been used to attenuate the local sensor noise for frequencies greater than 40 Hz. This filter is implemented in software and is similar in complexity to those used in the current ASC design. In addition to this filter the software contains three compensation stages, one for the coil driver, one for servo stability and one for the lower frequency pole and zero in the dewhitening filter. These compensation stages have a zeros at 0.1, 1 and 5.76 Hz and poles at 3, 40 and 86.69 Hz. Note that the coil driver compensation stage must be switched in and out as the coil driver is switched from acquire mode (no filter) to detection mode (filter).

3.8. SOS Servo Design

The simulink models for the position, pitch and yaw degrees of freedom are shown in the figures below.

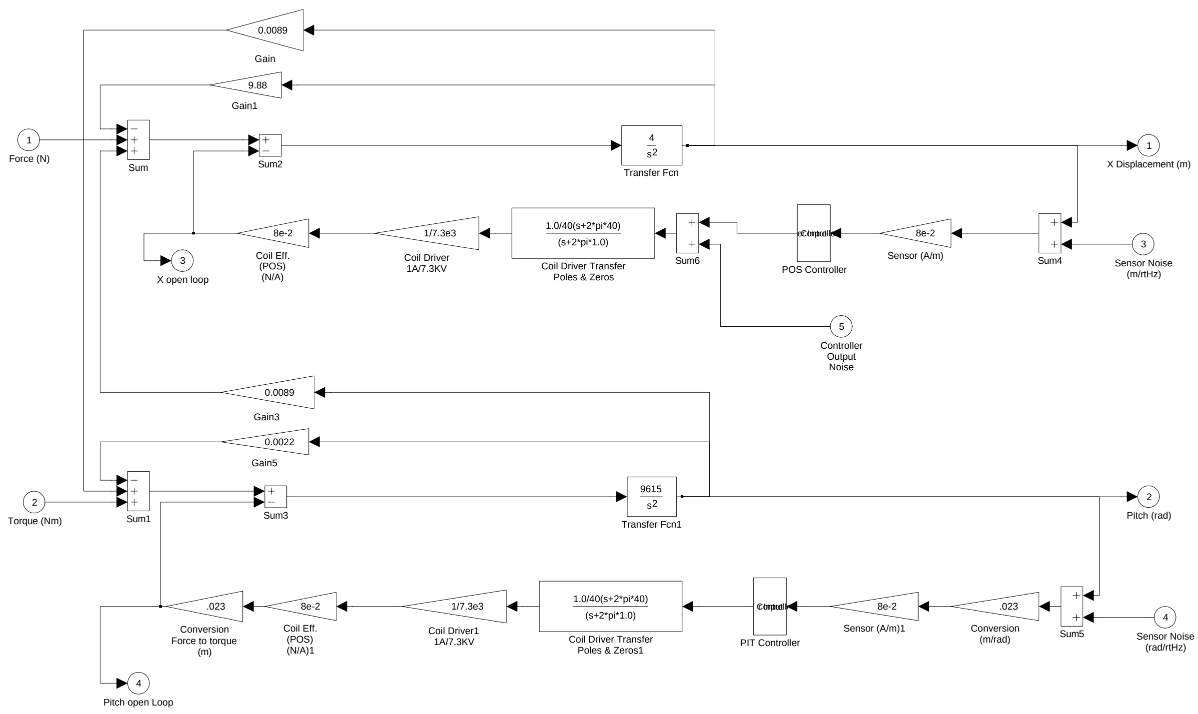

Figure 13: SOS Position and Pitch Servo Model

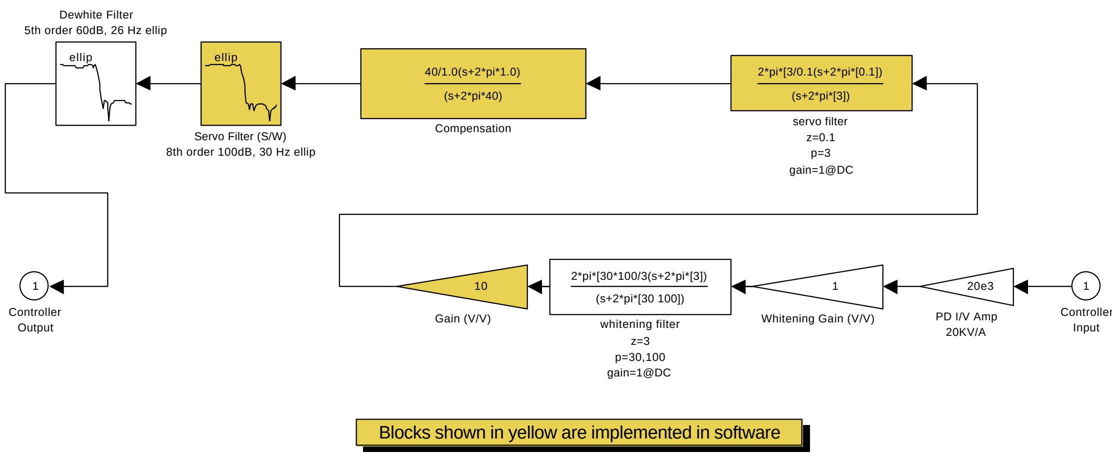

Figure 14: SOS Position Controller

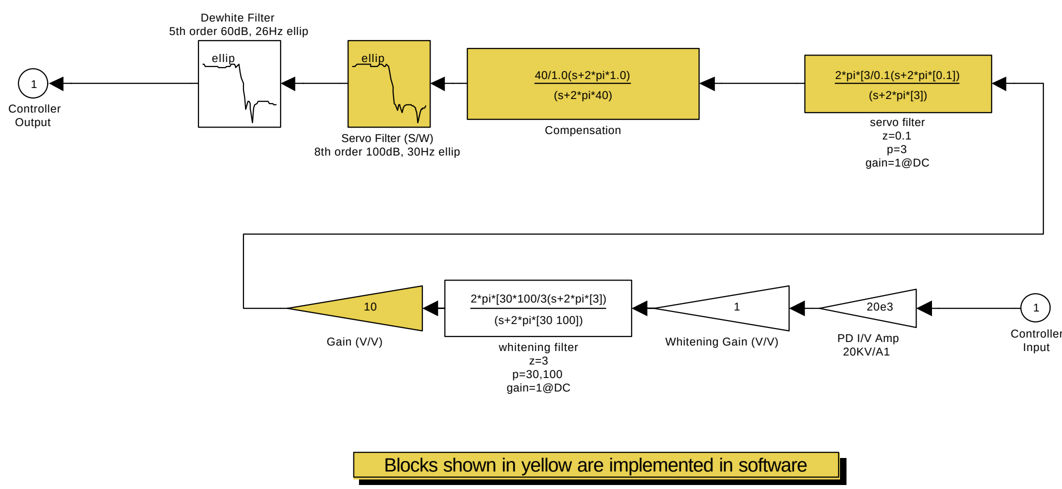

Figure 15: SOS Pitch Controller

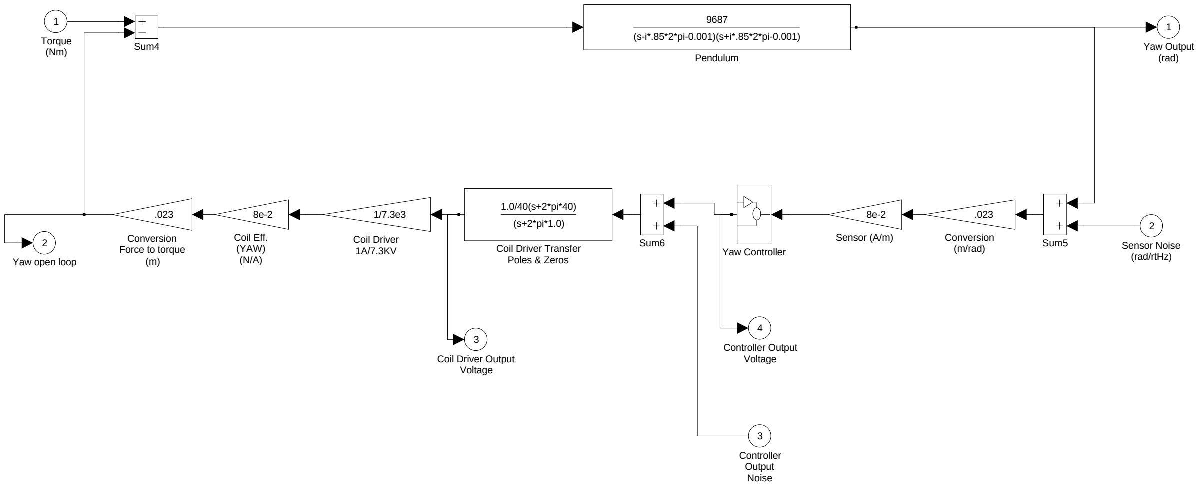

Figure 16: SOS Yaw Model

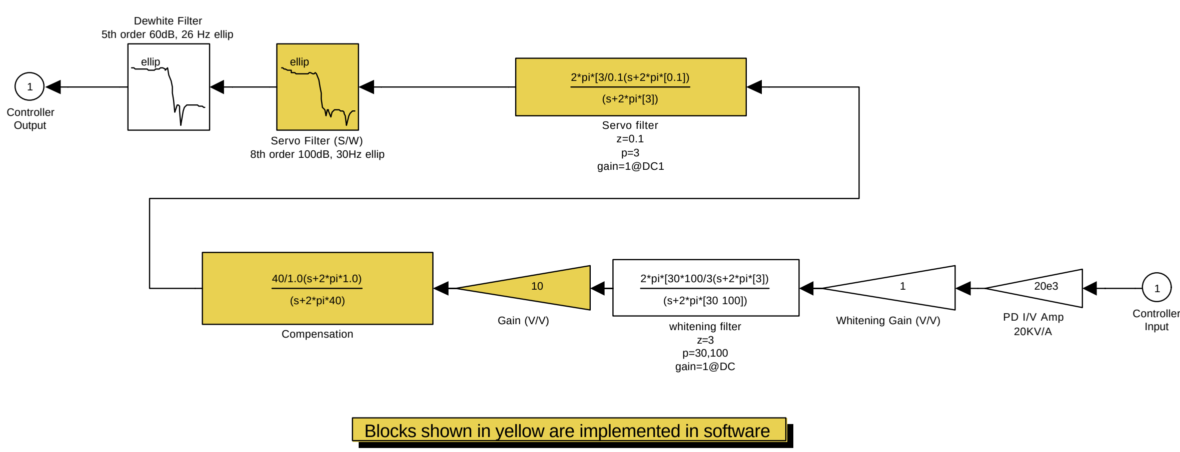

Figure 17: SOS Yaw Controller

For the purposes of the modelling it has been assumed that each degree of freedom (position, pitch, yaw and side) has been obtained by a yet to be determined basis transformation of the PD readbacks. In the current system this transform is given by:

$$POS_{in} = K1 \bullet UL + K2 \bullet LL + K3 \bullet UR + K4 \bullet LR$$

$$PIT_{in} = K5 \bullet UL - K6 \bullet LL + K7 \bullet UR - K8 \bullet LR$$

$$YAW_{in} = K9 \bullet UL + K10 \bullet LL - K11 \bullet UR - K12 \bullet LR$$

and the side degree of freedom is separate. Any new system would have a similar transformation, although some interest has been expressed in adding the side channel into each calculation and having the ability to invert the sign of any of the gain coefficients or to add frequency dependency to the coefficients. These capabilities, while adding some complexity to the implementation, do not affect the design presented here. It should be noted that adding this capability to an analog design would be extremely difficult to implement.

Similar statements can be made for the output basis transformation. The output basis transform equations for the current design are:

$$UL = C1 \bullet (LSC + POS_{out}) + C2 \bullet PIT_{out} + C3 \bullet YAW_{out}$$

$$LL = C4 \bullet (LSC + POS_{out}) - C5 \bullet PIT_{out} + C6 \bullet YAW_{out}$$

$$UR = C7 \bullet (LSC + POS_{out}) + C8 \bullet PIT_{out} - C9 \bullet YAW_{out}$$

$$UL = C10 \bullet (LSC + POS_{out}) - C11 \bullet PIT_{out} - C12 \bullet YAW_{out}$$

where POS_{out}, PIT_{out} and YAW_{out} are the values calculated by the local damping servo and LSC is the input signal from the mode cleaner length control system.

The figures below show the nichols plots for the position and pitch degrees of freedom.

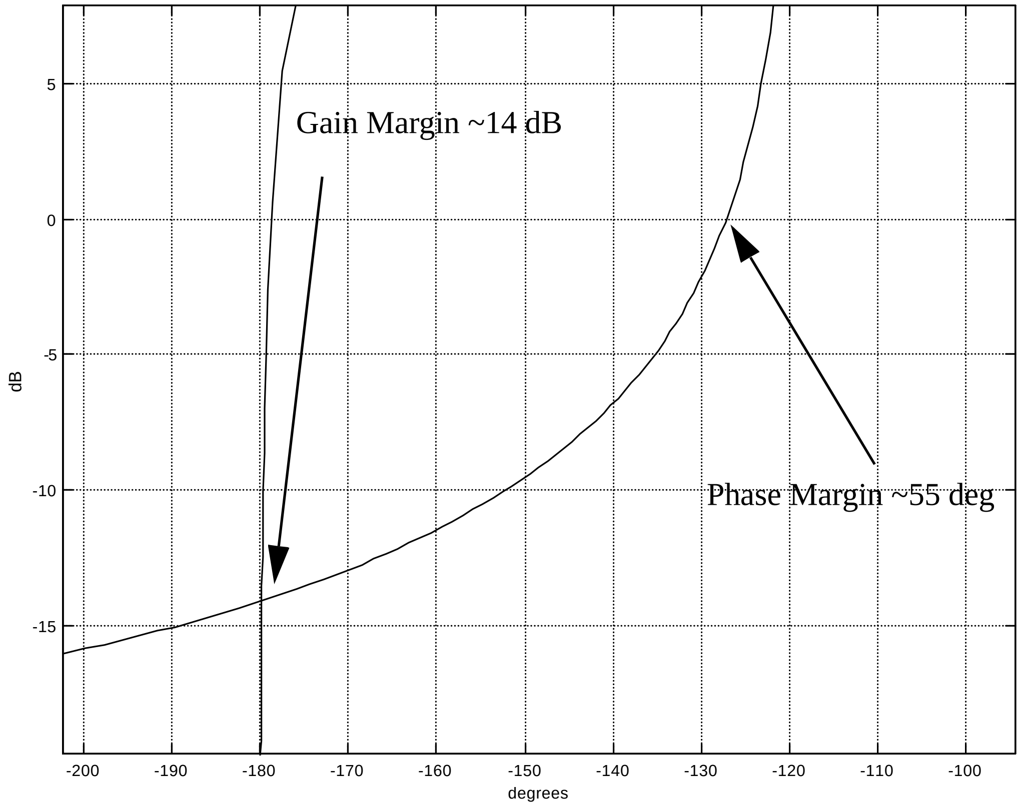

Figure 18: Nichols Plot for SOS Position Degree of Freedom

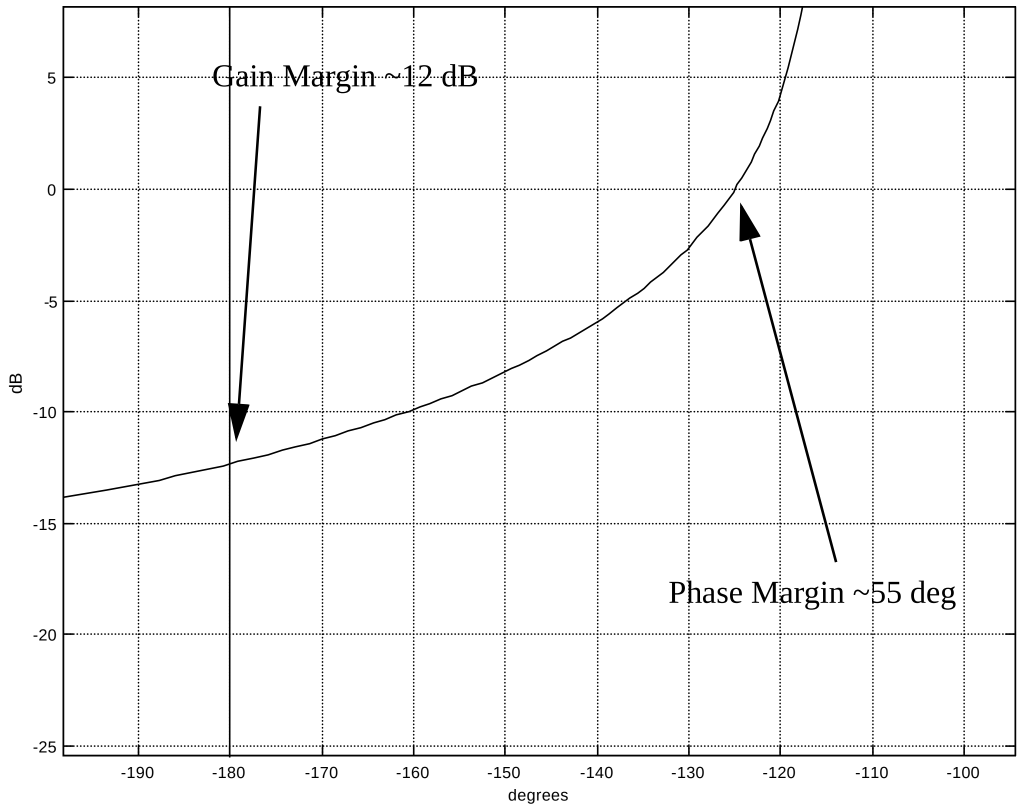

Figure 19: Nichols Plot for SOS Pitch Degree of Freedom

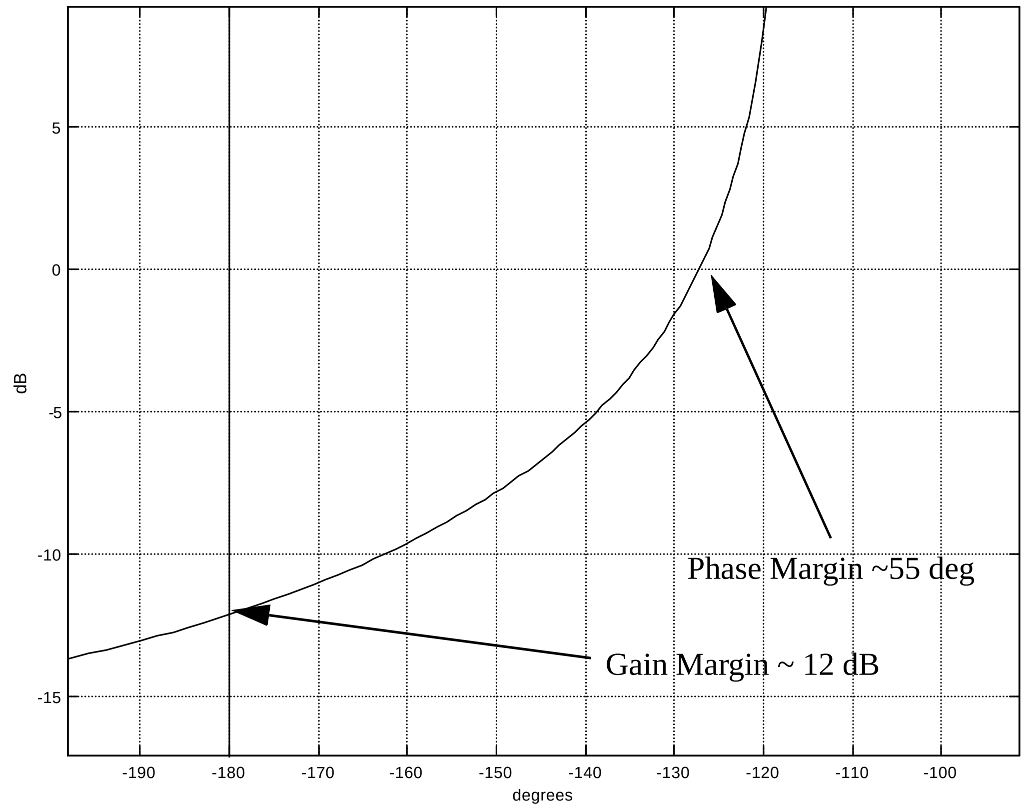

Figure 20: Nichols Plot for SOS Yaw Degree of Freedom

As can be seen from the simulink models for the controllers an 8th order, 30Hz, 4 dB ripple, 100 dB attenuation elliptic filter has been used to attenuate the local sensor noise for frequencies greater than 40 Hz. There is also a servo filter with a zero at 0.1Hz and pole at 3 Hz. These filters are implemented in software and are similar in complexity to those used in the current ASC design. In addition to these filters the software contains a compensation stage for the coil driver. This compensation stage has a zero at 1 Hz and a pole at 40 Hz. This compensation stage must be switched in and out as the coil driver is switched from acquire mode (no filter) to detection mode (filter).

4 IMPLEMENTATION

The figures below are block diagrams of the proposed LOS and SOS control systems

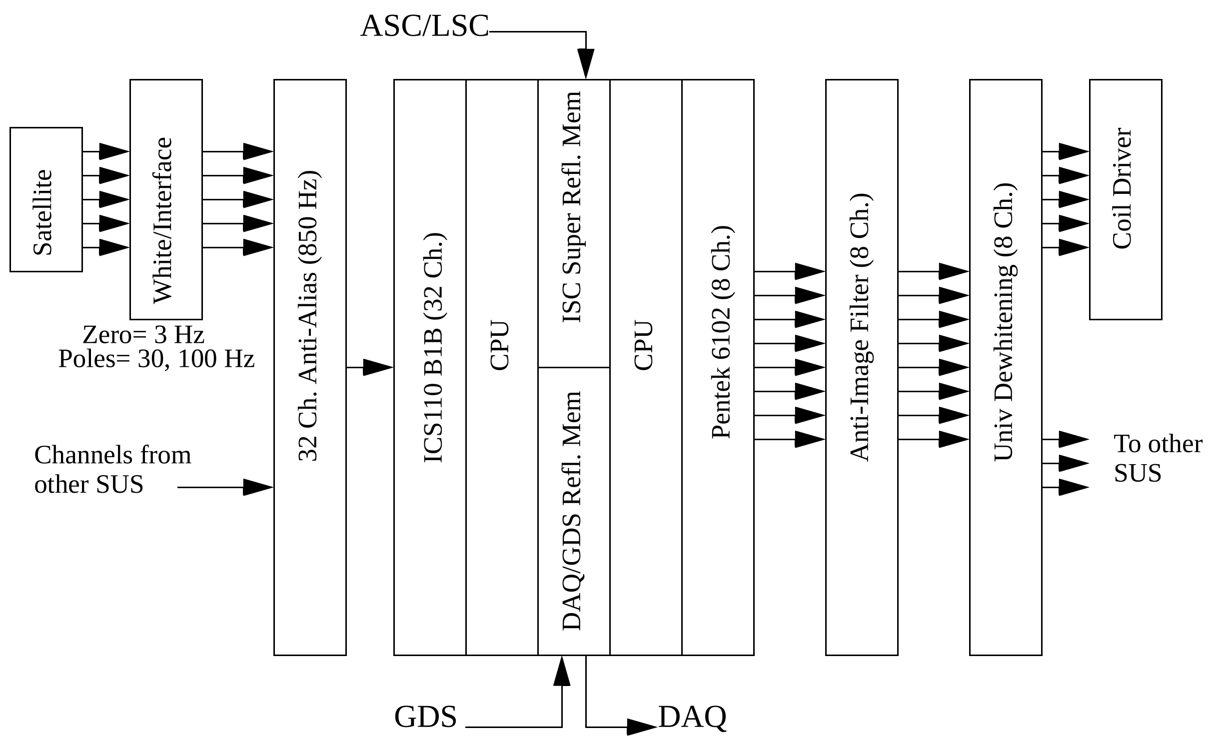

Figure 21: ASC, LSC, SUS LOS System Block Diagram

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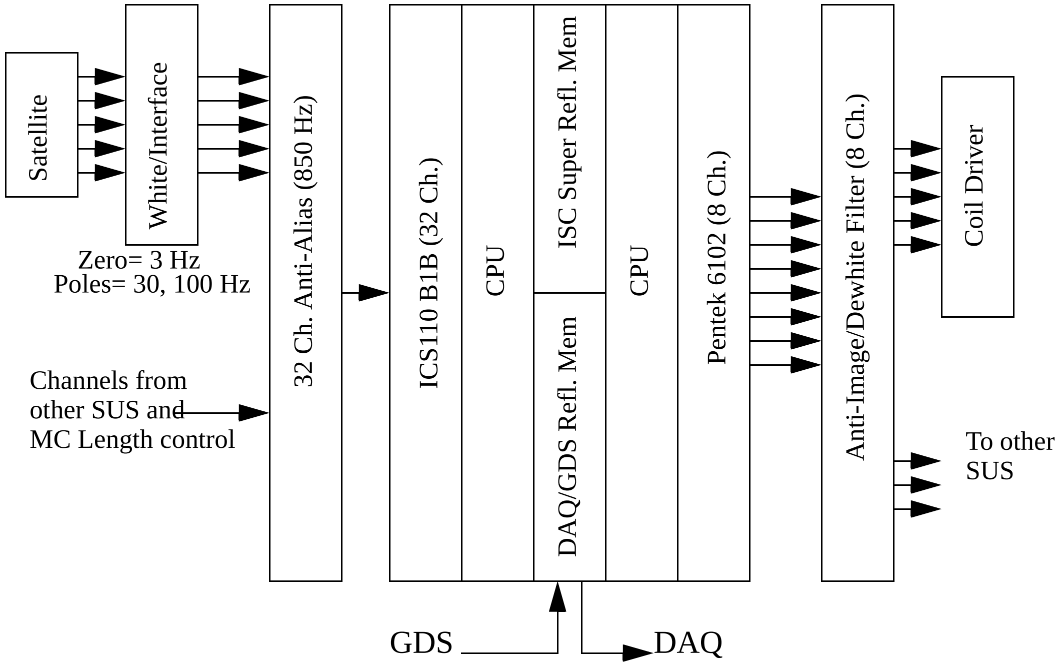

Figure 22: ASC, LSC, SUS SOS System Block Diagram

For the sake of simplicity only a single suspension system is shown for each type of controller. As can be seen from the figures and the descriptions in the servo design section of this document, the systems are very similar. The similarities and differences are described in the sections that follow.

4.1. LOS and SOS SUS Whitening/Interface Board

The SUS whitening and interface board will be a 5 channel eurocard module that implements the whitening filter shown in the figure above. The board will have front panel monitors for the "raw PD" signals. It is envisioned that these monitors can be used in the field for observing PD voltages during optic installation and debug. The interface to the Anti-Alias board will be via 4 pin LEMO connections.

4.2. 32 Channel Anti-Alias Board (LOS and SOS)

The current DAQ 32 channel Anti-Alias chassis will be used. The cutoff frequency for the filter will be 850 Hz, 8th order elliptic low pass filter. In the 2K IFO corner station there are 6 optics to be controlled, therefore 30 channels of the chassis will be stuffed. The input connectors are 4 pin LEMO (two channels per connector), but 8 of the channels are set up to be one input per connector. For the mid and end stations and the 4K IFOs only the necessary channels of the chassis will be stuffed with filters.

4.3. 8 Channel LOS Anti-Image Filter Board

The LOS Anti-Image Filter board will be an 8 channel eurocard module. The anti-image filter is a fifth order, 4 dB ripple, 60 dB stopband attenuation, 7570 Hz elliptic low pass filter. This frequency has been chosen to put the first zero at 16384 Hz and also provide the attenuation necessary in the stopband. The input connector will be 40 pin IDC that matches the output connector of the Pentek 6102. The output connector will be a 10 pin IDC that matches the input connector of the Universal Dewhitening Board. The module will have an input connector for an external clock that can be used by the Pentek 6102. The module also has LEMO output connectors for each channel. These outputs can be used as monitors or as outputs if the board is used without the Universal Dewhitening Filter.

4.4. Universal Dewhitening Board (LOS only)

The universal dewhitening board will be an 4 channel eurocard module with two pin LEMOs as the output connectors on the front panel. The input connector for the module will be 16 or 20 pin IDC. The module will implement the poles and zeros shown in Table 4.

4.5. LOS SUS and ASC Upsampling and Interpolation

The output clock rate for the system will be the 16384 Hz clock used by the LSC. The clock used for the SUS and ASC systems is 2048. It is currently envisioned that the interpolation filter for upsampling the SUS and ASC signals prior to combining them with the LSC signals can be a simple 3 tap FIR filter or a second order IIR filter. The actual design of the filter is TBD.

4.6. 8 Channel SOS Anti-Image/Dewhitening Filter Board

The SOS Anti-Image/Dewhitening Filter board will be an 8 channel eurocard module. The anti-image filter is a fifth order, 4 dB ripple, 60 dB stopband attenuation, 26 Hz elliptic low pass filter. The input connector will be 40 pin IDC that matches the output connector of the Pentek 6102. The output connectors will be SMA or LEMO coax connectors. The module will have an input connector for an external clock that can be used by the Pentek 6102.

4.7. VME Systems

The digital implementation of the suspension controls will make use of existing VME crates which interface to the present analog system, however the eight MVME162 processors and ADC/DAC modules will no longer be used. In their place will be five 850MHz Pentium III processors, ICS110B ADC modules, and Pentek DAC modules.

4.7.1. Small Optics Suspension Controller (SOSC) Architecture.

The layout for the SOS controller is shown in the following figure. This is to be a single VME crate with I/O modules as shown. The servo software acquisition and output rate will be 2048Hz. The ADC and DAC, however, will be clocked at 16384Hz to reduce pipeline delays.

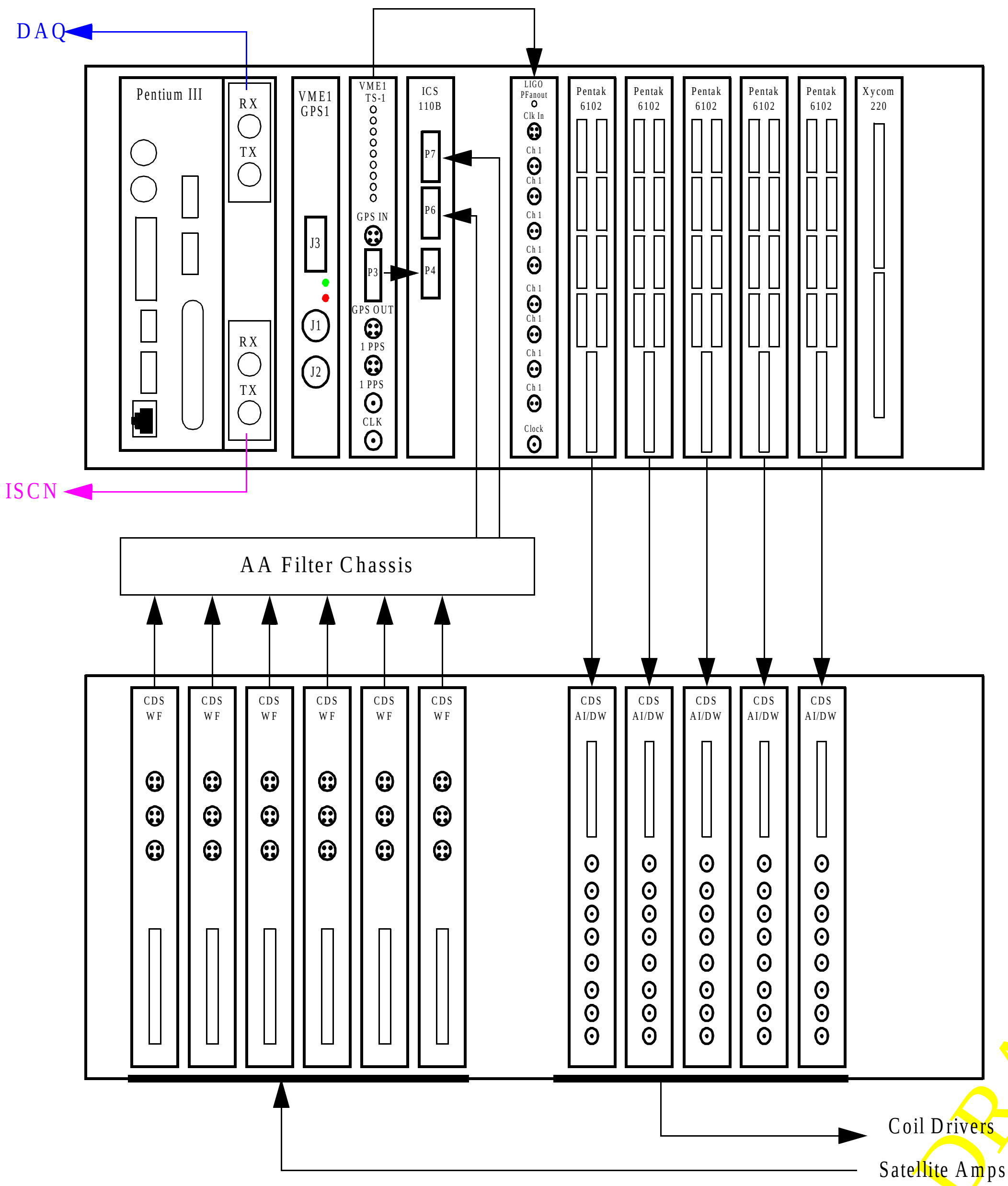

Figure 23: SOS Controller VME and Eurocard Layout

4.7.2. LVEA Large Optic Suspension Controller (LOSC)

The LVEA LOSC is similar in design to the SOSC, but, due to higher performance requirements, employs two CPU in a split backplane VME crate, as shown in the following figure. The CPU in the right half of the crate reads in the sensor signals and performs the coil damping calculations at 2048Hz. The left hand CPU takes input from this CPU, along with the ASC pitch and yaw signals and the LSC signals, performs ASC and SUS control signal upsampling, calculates the final coil outputs and sends these signals via the DAC units to the AI/DW eurocard modules. The servo update rate of this unit is 16384Hz.

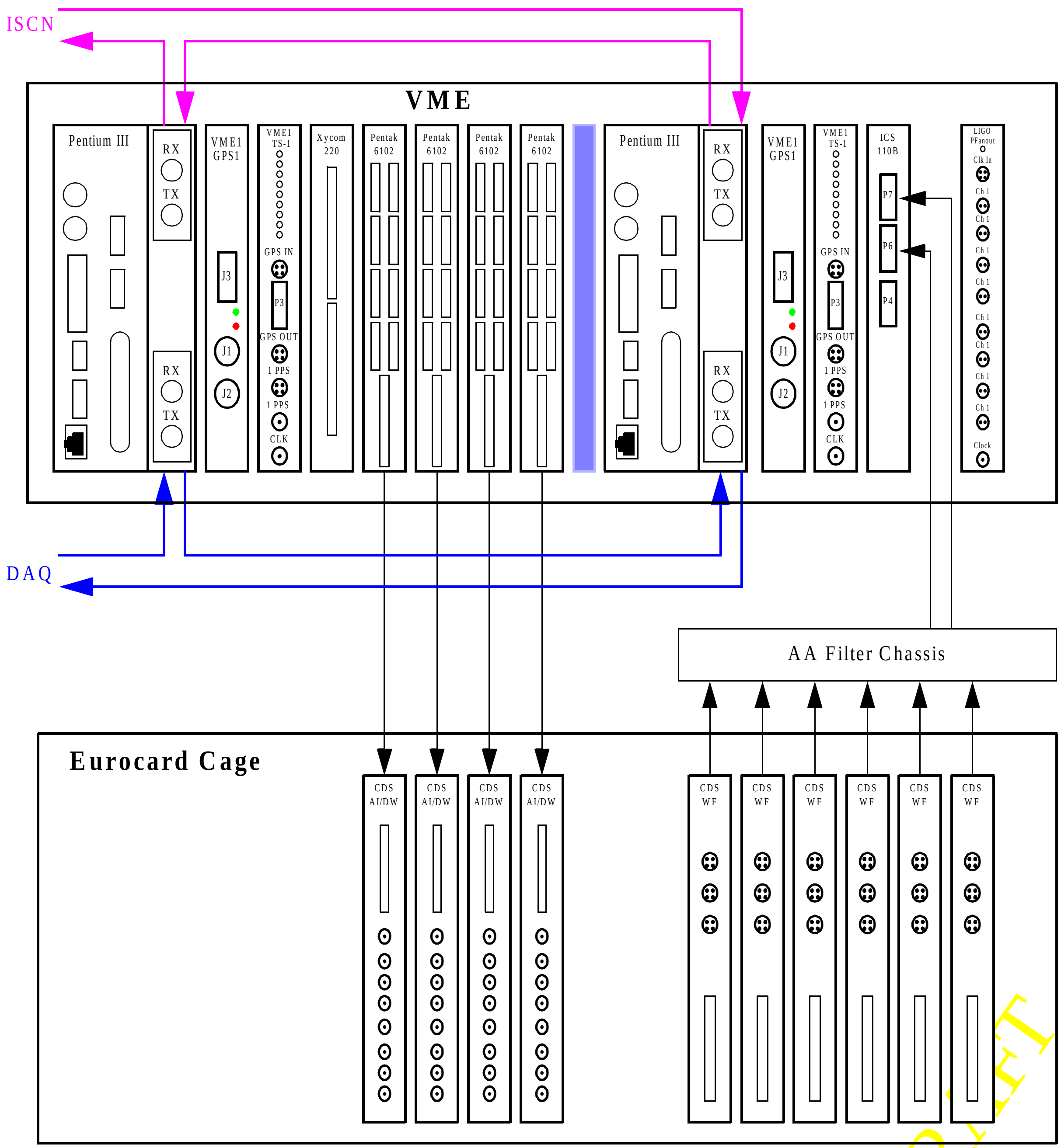

Figure 24: LVEA LOS Controller

4.7.3. End Station LOS Controls

The end station LOS controller will expand upon the existing ISC controller. Again, a split back-plane VME crate will be used, with the right half the reading in the sensor signals and performing the damping calculations at 2048Hz.

The existing modules in the left half will now perform the final controller calculations at 16384Hz and output control signals directly to the suspension coils instead of ASC/LSC signals to the present analog controller.

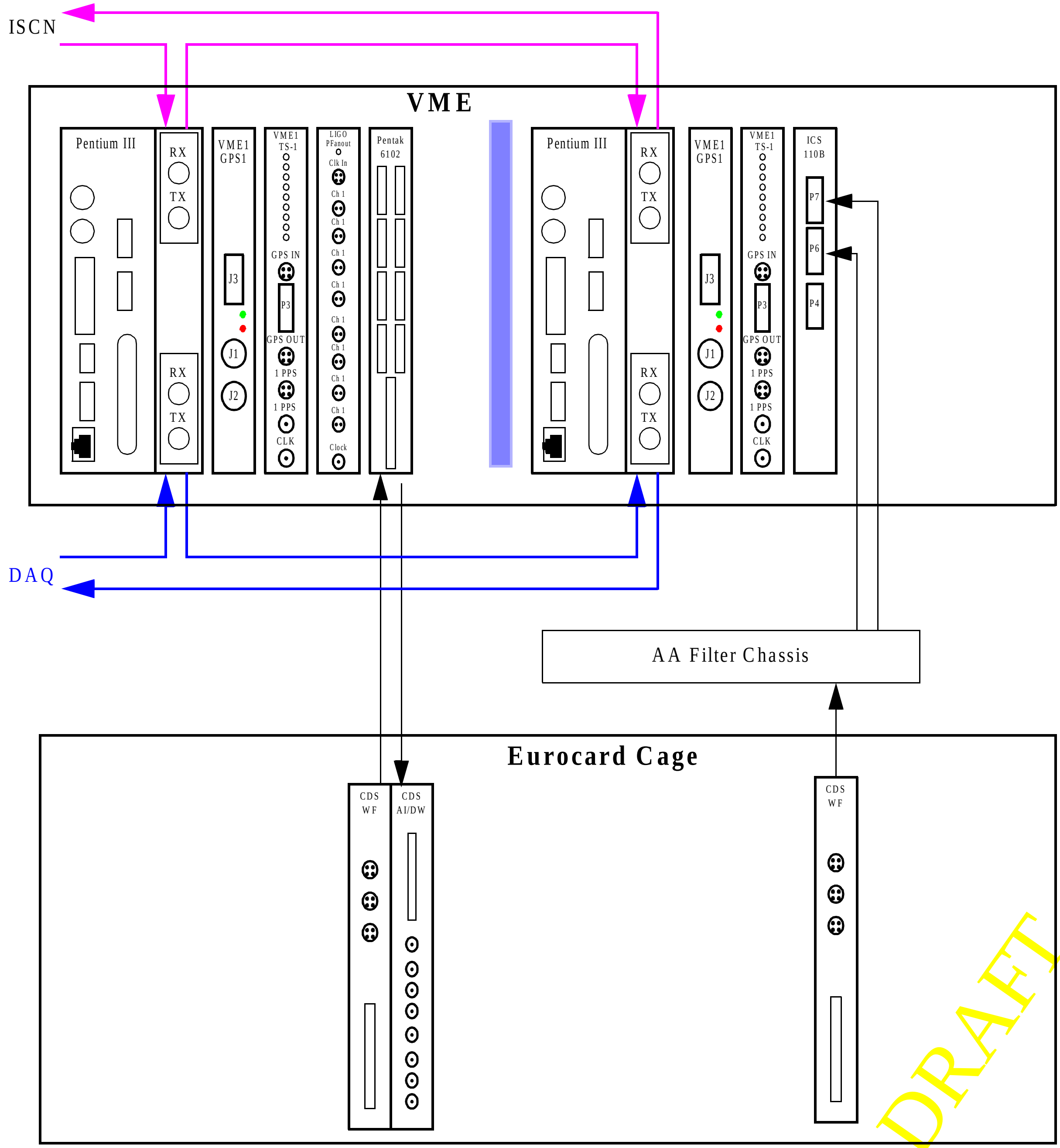

Figure 25: End Station LOS Controller

4.8. Digital Control Networks

The digital implementation will require tight integration with the existing digital ASC and LSC systems. These systems will now provide a digital signal to the suspension controllers instead of the present analog signals. To accommodate this, these systems will be interconnected on real-time reflected memory networks, as shown in the following figure. Each reflected memory network has a speed of 266Mb/sec and memory allocation of 64MBytes at each node.

4.8.1. Data Acquisition Network (DAQN)

An additional network will be added to the DAQ system to accommodate acquisition of suspension signals. This network will be an extension of the existing ISC supervisor network, shown in blue in the following figure. As such, it will provide the dual function of DAQ and passing operator control and monitoring information between and ASC, LSC and SUS controllers and the CDS network via the ISC Supervisor processor.

4.8.2. Interferometer Sensing and Control Networks (ISCN)

The two existing networks which interconnect the ASC and LSC front end controllers with the end stations will be expanded to include the digital LOS controllers and coil drivers. These networks are shown in red and green in the following figure. The only data carried on these networks are essential control signals to the LOS coil drivers and QPD data from the end stations back to the ASC and LSC controllers.

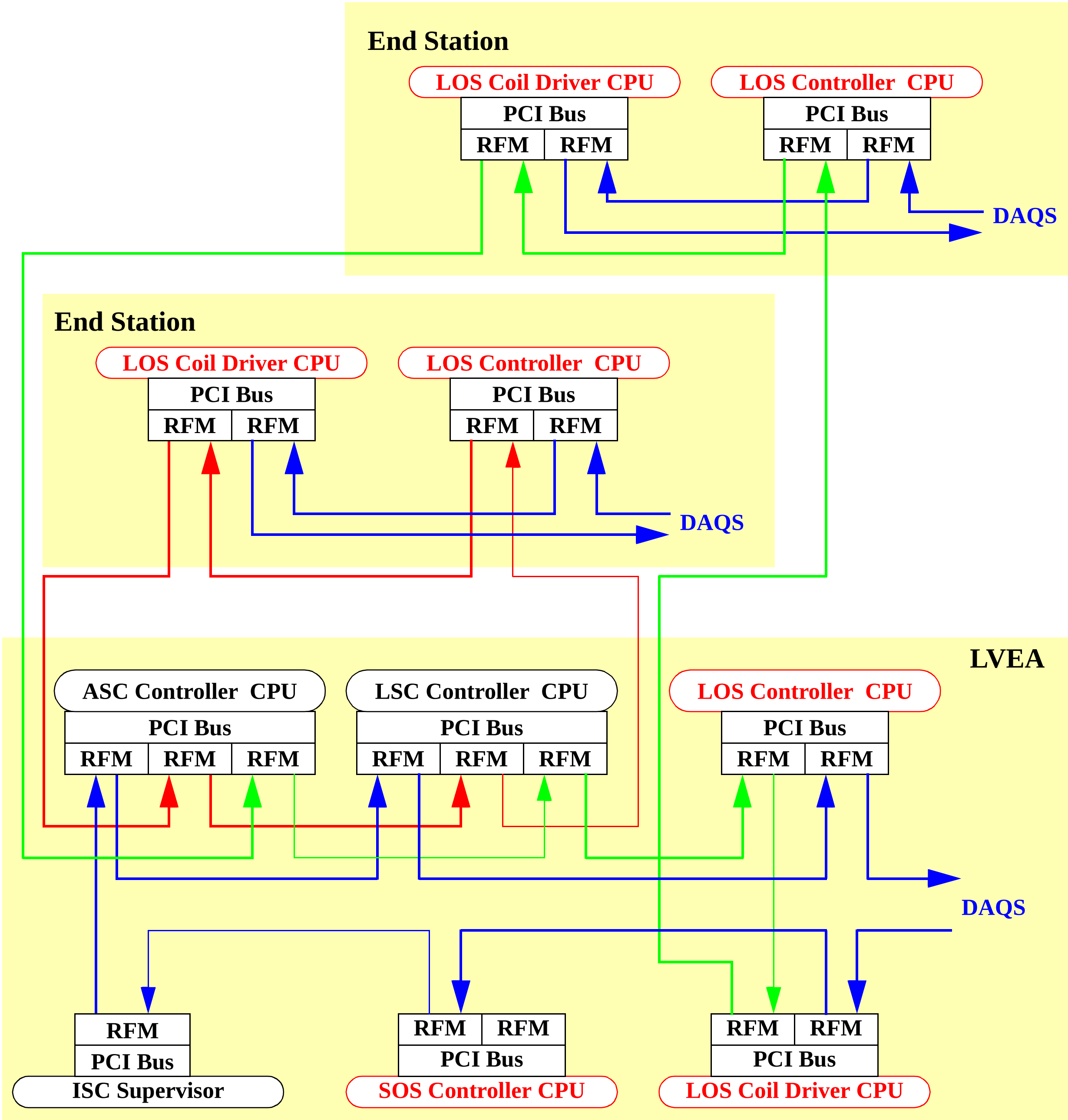

Figure 26: ISC and SUS Digital Control Networks