MEMORANDUM

DATE:	Revision -01: September 20, 2005 (incorporating SUS/UK comments)
Rev-00 TO: Rev-01 FROM:	AL SUS Design Team: Stuart Aston, Dave Hoyland, Nick Lockerbie, Ken Strain
Rev-00 FROM: Rev-01 TO:	AL SUS/UK Electronics PDR Review Committee Ben Abbott, Rana Adhikari, Dennis Coyne, Peter Fritschel, Gabriela Gonzalez, Brian Lantz, Virginio Sannibale
SUBJECT:	Questions regarding the Advanced LIGO (AL) Suspensions (UK scope, SUS/UK) Electronics Preliminary Design Review (PDR)
Refer to:	LIGO-L050039-01

The committee's review of the SUS documentation, and the presentation on July 12th, has generated the following questions. We would like to convene a meeting with the SUS design team to follow up on these questions in the near future and before finalizing the committee's review report. The questions are organized in the following subsections:

1) General Electronics Requirements
2) OSEM head
3) OSEM emitter driver & photodiode amplifier
4) Coil drivers (2 styles)
5) Electrostatic drive amplifier
6) ICD

Documents reviewed are as follows:

- E050160-01, Interface Control Document (ICD): SUS/UK – SUS/US
- T050110-00, Electrostatic Driver Electronics Preliminary Design and Test Report
- T050111-00, OSEM Preliminary Design and Test Report
- T050112-00, Electronics Preliminary Design and Test Report
- D050270-00, Block Diagram (OSEM Electronics and Electrostatic Drive)
- D050269-00, Schematics
- T050122-00, Summary of Noise Calculations as Input to the UK Electronics PDR *[posted after the review]*
- T000053-03, SUS Subsystem Universal Design Requirements Document *[revision –03 includes more general electronics requirements]*

Presentations, available from the Birmingham Gravitation Group web site:

- G050318-00, AL SUS/US Quad Controls Conceptual Design
- Interface Control
- Electrostatic Driver Electronics Design
- OSEM Electronics Preliminary Design
- OSEM Design

1 General Electronics Requirements

A general issue raised by the committee is the need for LIGO to establish a better set of electronics design rules and guidelines for AL designs. The closest thing we have to that right now is the revision –03 of the Suspension Subsystem Universal Design Requirements Document (T000053-03) which includes a number of general electronics requirements. In addition, Rai Weiss and Rich Abbott have recently circulated notes regarding general good/robust electronics design practices, which have been included as an Appendix in this document. Although not yet formally adopted into the Generic Requirements document, E010613-01, it is our intent to incorporate these two sources for guidance (or text quite close to these two sources).

2 OSEM head

2.1 Sensor noise requirements

It's unclear where the sensor noise spectrum is actually specified. But in T050111 it says:

1-10 Hz: 3e-10 m/rtHz
> 10 Hz: 1e-10 m/rtHz

The 1-10 Hz band needs to have some power law spectrum, so it's consistent at 10 Hz. Also, there needs to be a spec for below 1 Hz; this matters, since some of the SUS eigenmodes that will be damped are below 1 Hz.

Comments (from K. Strain): Input to OSEM downselect document – target graph there evaluated with respect to the resulting RMS. See section 4.3 of T040110-01. The noise model is 1e-10 m/rt Hz white noise “plus” 1e-9/frequency m/rtHz (added in quadrature). This level was slightly above the worse case sensor noise at that time. Since then the sensor noise has been slightly improved. There have been no important changes to the suspension model since that was done.

2.2 PTFE Alternatives

Are there alternatives to PTFE in the areas this is used? Doesn't PTFE absorb water more readily than other insulators?

Preliminary answer (from D. Coyne): PTFE probably does absorb water more readily than polyimides, but the quantity use is so small compared to the LIGO water pumping capacity (and compared to other sources of water pickup in the LIGO vacuum system), that this does not seem to be a significant concern.

Comments (from S. Aston): Need to confirm that the only elevated temperatures experienced by the PTFE parts after installation, will be the non-operational in vacuum bake-out at 46^0C. We may wish to verify the functionality of the PTFE parts (e.g. interference fit of adjustment nuts) are not compromised by the elevated temperature. These tests can be conducted at Birmingham if deemed necessary.

2.3 Axial adjustment system.

Range is awfully large (1 cm) - is this needed? What about the mechanical rigidity of this assembly, supported by two somewhat long-and-skinny screws?

Comments (from S. Aston): The noise prototype OSEM axial adjustment range of approximately 10mm has been driven by the existing controls prototype (Hybrid OSEM) design. The Hybrid OSEM actually allows for >10mm (approximately 15mm) of axial adjustment.

It would be trivial to reduce the axial range of the noise prototype OSEM to that which is required. However, we need to know what range of ‘operating points’ we are likely to encounter and therefore tolerate for OSEMs situated in various suspended and non-suspended locations.

The overall mechanical rigidity of the assembly is maintained by the two screw fixings mentioned, but also by the additional support provided by the fit into the coil-former clamp. The effective section thickness of the coil-former clamp has been increased in recent designs, with the addition of protruding ‘guide’ features. These aid the OSEM axial adjustment and reduce the tendency of the coil-former assembly to jam/gall in the clamp. Fabrication and test of prototype units has enabled us to verify the rigidity and robustness of the adjustment assembly.

2.4 OSEM Cable Insulation

OSEM cable harness insulation is specified as Teflon -- why not use the polyimide (higher bake temperature and cleaner) insulated wire used for the coil?

Comments (from S. Aston): The Cooner (medical) wire has been previously selected, for use on the controls prototype and in initial LIGO, due to its UHV compatibility and its inherent low stiffness (multiple core construction). It can also be easily braided into twisted pairs, whilst maintaining excellent flexibility for cable harnessing and routing.

2.5 Magnetic coupling of packages

It's stated that the magnetic coupling force from the magnetic device packaging must be less than 5 mN. How/where is this number derived? Is this the only thing driving the large magnet/device separation? (ie, long flag)

Comments (from S. Aston): A maximum magnetic coupling of 5mN between the magnet and sensor devices was considered to be acceptable (given that the actuator can apply 50mN). Measurements of the coupling force were made and the coil-former geometry lengthened (axially) to accommodate i.e. the magnetic coupling is the only driver for the dimensions of the coil-former and hence length of the flag.

Comments (from K. Strain): One of the few problems with the new sensor design is that only (ferro) metal-encapsulated emitters deliver on performance. We must therefore separate the magnet and the sensor to limit interactions. The effects of this were analysed both in terms of static force and unwanted coupling. If the separation is increased to the point that the static force is less than 10% of the 50mN adjustment range, the coupling is also negligible. (Addendum 1 contains an excerpt from an email conversation concerning this issue).

2.6 Lateral to Longitudinal Coupling

LIGO OSEMs design is by nature are not very degree-of-freedom (DOF) selective, possibly leading to unwanted DOF coupling to the length (longitudinal) signal. In T050111-00-K, the picture of the final OSEM assembly looks as if the orientation of the mask and size of the flag are such that it will continue to be susceptible to lateral translation coupling into longitudinal. The imposed flag size and geometry limit design options, but some improvements are possible. The actual design shows a flag 3mm in diameter and a LED window 4.5mm tall. Making the flag significantly larger than window height will reduce the coupling with the two directions orthogonal to the OSEM sensitive direction. The cylindrical shape of the flag could be changed to minimize scattered light trapping within the cylindrical cavity of the OSEM head. Have any tests on the prototype OSEM head been done to determine the level of cross coupling to lateral motion of the flag? Has any testing or analysis been done to optimize the flag size or shape to eliminate this lateral motion coupling into the signal?

Comments (from S. Aston): No testing to determine the level of cross-coupling has taken place during the sensor design and implementation. However, a general design goal of the noise prototype was to reduce the cross-coupling effects compared to the controls prototype and initial LIGO OSEMs wherever possible. For example, the surface mount design utilized a lens integrated into the emitter package and 2mm diameter flag. Our noise prototype design incorporates an additional collimating lens and mask – to select only paraxial rays emitted by the IRLED (also reduces noise). As noted, we also make use of a larger 3mm diameter flag.

Measurements could be taken with the noise prototype design to determine the level of cross-coupling, if required. However, has the cross-coupling been previously determined for the Honeywell sensor configuration? We would anticipate that the noise prototype design presented would reduce any such effect.

Experiments with various flag geometries have been carried out during the “sensor study” by our collaborator Nick Lockerbie, at the University of Strathclyde. These measurements are outlined in document T040136-00. Addendum 2, shows alternative flag geometries under consideration (due to possible sensor and flag clearance concerns that have been raised by the US/SUS team). Note that, should any of the proposed alternative flag geometries be implemented, the flag will be required to be assembled/mounted in a known orientation. At present, it is uncertain if this approach will need to be taken. Further tolerance analysis should help justify the path forward.

2.7 New Vacuum Materials

There are some new materials that appear iffy from the vacuum standpoint: hysol epoxy; LCP - what is this? What do we think about this?

Preliminary answer (from D. Coyne): There are a few materials which have recently been **provisionally** qualified for vacuum use which have yet to be presented to the LIGO Vacuum

Review Board and be incorporated into the approved LIGO Vacuum Compatible Materials List, E960050-B. Hysol epoxy was qualified for use by SEI for use with the ADE capacitive displacement sensors. LCP is used in the GlenAir micro-D connectors.

2.8 EMI Shielded Cabling & ESD to Sensor Coupling

Has any calculations or testing been done to assure that the direct radiative coupling of the electrostatic drive to the sensing chain is tolerable? This may require some excellent shielding and good filters at least.

Comments (from K. Strain): Assuming AC drive to the ESD, pickup is likely to be significant but rather easily filtered from the low frequency senor signal, provided there is not too much IMD before the filtering. We should consider the likely IMD. A test could be done using an electrical mockup and adding a few mV of 16kHz while measuring 1 Hz noise.

Has there been any attempt to shield the traces on the flexible circuit board from EMI? Is there truly no way of getting cables that are both shielded and flexible enough to pass our specs? Having unshielded wire so close to the ES Driver might create pickup problems.

Comments (from S. Aston): No attempt has (yet) been made to use any shielding for the prototype flexi-circuits. However, options are available to shield the traces if required.

2.9 Actuator Geometry

The actuator geometry can be improved by using topologies that reduce the effect of motion along unwanted degrees of freedom. One example of such geometry is the racetrack coil within a twin-gap magnetic yoke, used in LIGO-SAS and TAMA-SAS, which are essentially modified versions of a loudspeaker (see for example "Constant force actuator for gravitational wave detector's seismic attentuation systems (SAS)", P010026-A). Using these geometries one can easily keep the actuator strength and reduce the magnetic field strength of the permanent magnet. The other advantage is the reduction of the force produced by ferromagnetic materials in the PD case, the LED case et cetera. Moreover, the magnetic force field are much more confined reducing even more such unwanted forces. Such topologies increase the actuator linearity versus alignment and therefore more important, increases tolerances in the alignment. Another marginal advantage is that the actuator+sensor will be smaller and shorter.

Preliminary answer (from D. Coyne): The actuator geometry might well be improved by switching to the topology cited. However, this would entail a basic redesign of the OSEM head and it's interface in the quadruple and triple pendulum suspension designs, i.e. this would invalidate the conceptual design that was pursued. Such a radical change would only be warranted at this point (preliminary design) if the current design could not meet requirements; this does not appear to be the case.

Comments (from K. Strain): We design all magnetic actuators to work at the maximum of the force. Actuators not at the top stage are to have a rather flat field gradient and minimise coupling. T050122-00 discusses some of this in outline, but the magnetic design is not yet done in detail.

The local control actuators are designed for larger force, but will still be operated at the maximum, for the coils proposed, and 10mm long magnets, the force is flat to ~1% up to more ~ 1mm away from the operating point. The sensor range is much less than that, so operating within sensor range implies operating in the correct field range. Our rough calculations were checked against Mark Barton's Mathematica model for magnet design, but the designs are not finalised and this has not been written up in detail (part of the mechanical design).

3 OSEM sensor electronics

3.1 Need block diagrams.

Every subsection in T050112 that is titled 'Circuit Description' should also contain a block diagram of the circuit, in accordance with Drawing Requirements, E030350-A, section 3.3.2. (Well actually it says that block diagrams at the module/board level are optional. However it is good practice and highly encouraged.)

Comments (from D. Hoyland): Bock diagrams can be added, but I think this should wait until we have a clear idea of scope of the diagnostic circuitry to be added. Diagnostic issues will be discussed with Jay Heefner during his visit in October, and diagrams can be created thereafter.

3.2 Origin/derivation of the 8 μV/rtHz

What is the origin of the 8 μV/rtHz number?

Comments (from D. Hoyland): This figure simply relates the measurement noise requirement for the sensor (m/rtHz) to the noise content of the sensor electronics output using the OSEM sensor and electronics transfer functions (at 10Hz). So the origin and derivation is as follows:
The references given to the figures below are the relevant section of E050160-01 (The SUS-US/ SUS-UK ICD)
The required measurement limit is 3E-10m/rtHz. (Section 1.1.2.2.6)
The required OSEM sensing range is 0.7mm pk-pk(Section 1.1.1.2.2)
The required Electronics output is 20v pk-pk (10V/0V-> 0V/10V) (Section 1.1.2.2.2.2)

System gain is therefore 28571V/m
The required measurement limit at 10Hz referred to the electronics output is therefore 8uV/rtHz (actual figure 8.57uV/rtHz)

3.3 Output Voltage Noise Spectrum

We need plots of the modeled voltage noise spectrums to better determine what whitening is necessary to read the sensors.

Comments (from D. Hoyland): Currently our specification for noise is only at 1 frequency (10Hz) and therefore noise performance was derived by hand calculation. What do you actually want us to provide here. I could develop models in something like SPICE, however I would want to verify them against actual measurements, therefore I would suggest that we provide noise curves which are derived from numerical fits to the experimental data (ie the model would consist effectively of a noise function defined in terms of poles and zeros). Such issues will be discussed with Jay Heefner during his visit in October, and models will then be created as necessary.

3.4 LED Balancing

The issue of balancing the optical outputs from each LED emitter can be addressed by buying a bunch of these things and hand picking enough to last until eternity with a simple biasing and detector fixture - unless they are prohibitively expensive. This would result in better symmetry in terms of individual currents through diodes.

Comments (from D. Hoyland): This is a fine solution if we were making 10, but the actual figure is closer to 1000. This approach is far more robust and repeatable than the solution you suggest because the devises are optimized in-situ (i.e. in their final operating position & orientation in the OSEM). This would not be the case if they were screened in a test jig prior to being installed into the OSEM. The approach should produce OSEMs whose spread of outputs over all units is better than ±10% (tighter if required) – so you do not sacrifice too much dynamic range on the emitter/detector tolerance. Also, the approach naturally provides some compensation of the emitter output intensity vs temperature coefficient.

4 Coil drivers (two styles)

4.1 Derivation of Requirements

We have lots of questions about the origins of many of the numbers, and problems with the way requirements have been derived. There is much reference in T050112 to G010086, which are some viewgraphs on the control hierarchy that Peter Fritschel made 4 years ago. This was a fine start, but it needs to be revisited, with the current suspension model. (For example, in G010086, it looks like a different pendulum model is being used than the high Q quad transfer functions that Norna Robertson has been showing.)

The first thing we need to do is to agree on and document the actuation requirements for each stage:

- control range vs. frequency for each stage, for both
- acquisition mode and science mode
- allowed noise spectrum for each stage

Then we can come up with an input signal range and noise level for the coil drivers. The coil driver design would then need to connect these input specs with the above range & noise specs.

Comments (from K. Strain): Refer to T050122-00. The suspension model does not have a version control system in place. But I am always most careful to get the latest version from Norna, and compare. Many effects are only subtly different and the results you point to above are not applicable to our present work (as Norna has pointed out in an email). Note too that I reviewed G010086 to see if it was still applicable, and concluded that, until we see E2E results regarding acquisition it is a very good basis for this planning in terms of Global control actuator strength. A few details of the suspensions lead to the minor changes mentioned in T050122-00. The uncertainty remains large and we have thus CONSEVATIVELY designed for low noise, high actuation forces etc. wherever possible. (e.g. refer question on penultimate mass global control below).

T050122-00-K mentions low pass filtering (1 Hz poles) in the coil drivers in order to filter out DAC noise (at some assumed level). This is not the correct way to set the transfer functions, and it's not clear that we can tolerate these poles. According to the SUS/US Conceptual Electronics Design talk (G050318-00) the dewhitening is to be handled by the US SUS electronics team. If that's true then the suspension coil drivers and ESDs should only be filtering out the dewhitening board output noise. In general there shouldn't be any filtering at the back end which is just a low pass since it probably means the digital inverse makes the DAC spectrum non-white. We should probably give the actuator designers estimates of the output noise of the dewhitening board. Probably 15 V op-amps and output noise of 5 nV/rHz is a good estimate.

In any case, if the digital/analog switching has to be coordinated as in LIGO-1, we might as well have what we've always wanted: several small steps of attenuation rather than one large filter at the coil driver end. Smaller transients are always better.

Comments (from D. Hoyland): The work to date has I agree been based on some assumptions of the noise in the drive signal to the actuator electronics. This is because no clearly defined figures exist yet. So really the design so far is a ‘starting point’. It’s really up to ADLIGO US team to firm up on their requirements. Also this is the first mention of ‘small steps of attenuation rather than one large filter’ – Is this a requirement? If so can we have some more details please? Such issues will be discussed with Jay Heefner during his visit in October, so we should be able to get some agreement in principle as to the way forward.

Comments (from K. Strain): There seems to have been a gap in communication over the whitening issue. At the start I had assumed that all whitening would indeed be a US responsibility but we were (correctly, I now think) encouraged to look at whether it would be better to whiten in the satellite modules, especially if they were distant from the DAC/whitening. The choice of poles was thoughtful. It is to a first approximation what is needed to match the dynamic range of signal to the DAC output. OF COURSE it would be better if we could do that part of the design in an integrated fashion, it would allow trimming of the whitening. I don't think it is wise to throw away the possibility of some gentle whitening at the final stage, just as a matter of principle. Can we do that in a timely fashion? If so lets do it.

4.2 Penultimate Stage Driver Voltage Range

We're dubious that the +/-70V is really needed for the penultimate stage driver. This seems to be a result of the large output current and large source impedance that is being designed for, neither of which appears to be well motivated. (see also comment 6.4 below).

Comments (from K. Strain): *6.4 below explains that it is 140V.* The arguments for this follow closely those that lead to a similar solution for the LIGO test mass OSEMS. There is a short note showing that, if we want to keep the *approximate* range suggested in G010086 (which is felt to be about right given what we know – see T050122-00) we must have a high impedance output to avoid too much damping. see T050043-00.

4.3 Output Voltage Noise Spectrum

We need plots of the modeled voltage noise spectrums to better determine what whitening is necessary to drive the actuator.

Comments (from D. Hoyland): Our current specification for noise is only at 1 frequency and again, noise performance was derived by hand calculation. Therefore the comments of section 3.3 apply.

5 Electrostatic Drive Amplifier

5.1 Output Voltage Noise Spectrum

We need plots of the modeled voltage noise spectrums to better determine what whitening is necessary to drive the actuator.

Comments (from N. Lockerbie): Using the present OP-27E auxiliary op-amp in the high-voltage amplifier of the ES Driver, the output voltage noise spectrum below 12.5 Hz varied with frequency f as f ^beta, where beta = -0.48 +/- 0.07. From approximately 20 Hz to 25 kHz the noise spectrum was flat to within +/- 1 dB, with three superimposed sharp noise peaks at 50 Hz (+26 dB), 60 Hz (+4dB), and 100 Hz (+3 dB), due to mains and external instrumentation interference.

It is possible that the OP-27E may be changed to the other op-amp that has performed well in tests so far, the AD743.

5.2 Output Force Noise Spectrum

It would be good to have explicitly the output force noise spectrum of the ESD driver and the peak-peak available force as a function of frequency. This is so that we know what reserve is available for lock acquisition, narrow line features, etc.

Comments (from ALUK Electronics Meeting): Thus far we have only outline requirements and, therefore, designs for global control actuation. We are in the process of reviewing the whole picture and intend to release a document in the near future. We intend to control the ESD strength, up to a maximum set by the voltage, area of TM available, and gap, by providing a very flexible design (double bias electrodes, flexible driving, and two levels of gain in the drive amplifiers - both with very high dynamic range). Any modifications to adjust maximum force will be very minor, unless 900V differential is insufficient for TM feedback - and there is no way to know that until E2E modeling is completed. This does not prevent us from proceeding with the design of whitening filters etc. for science mode, as the shape of the spectrum of feedback force in science mode (a trivial update of G010086) is calculable, and all noise requirements are already defined. In science mode the ESD will be operated such that it is very weak, though it can be somewhat stronger than the proposed photon drive due to its larger dynamic range (~20dB). A much larger peak force (perhaps of order 0.1mN) is required for acquisition, and this requirement remains essentially unknown *a definite risk* until E2E modeling or another approach to simulating acquisition and TM/PM feedback hierarchy gives an answer.

5.3 Two Electrode Patterns

It appears that two distinct sets of electrode patterns are used, presumably one for longitudinal (cavity length) bias and the other for pitch and yaw, and perhaps dynamic length, control. Do we really need two different electrode patterns?

Comments (from ALUK Electronics Meeting): This will also be clarified in the above document (See item 5.2 comments).

Comments (from K. Strain): Two patterns is an awkward description – there is provision for longitudinal, pitch and yaw adjustment with two strengths of actuation 40dB apart. It is a conservative approach that leads us to have about 120dB adjustability of the peak force – this is almost certainly more than required, but the benefit is that for small expense (20%) now we can avoid renewing the complete system later. The only risk is that the highest force is not sufficient.

5.4 Safety

What are the considerations being given to safety regarding the electrostatic drive system. With the capability for 500V, 100mA drives, there exists the real potential for death. Are normal vacuum feedthrough connectors sufficient? What if someone unplugs the system hot?

Comments (from D. Hoyland): The units produces thus far are prototypes. There are lots of features missing, such as diagnostics and safety. Safety interlocks etc need to be agreed.

Comments (from K. Strain): One of the reasons we wish to limit the voltage on the ESD to <500V with respect to ground is the difficulty in finding feedthrough connectors for higher voltages. The feedthroughs are, however, not a UK responsibility. Outside the vacuum we propose to use SHV as previously recommended for voltages >120V (see IDC)."

Comments (from ALUK Electronics Meeting): Safety issues, such as those noted above, may be resolved via instigating / changing procedures. For example, in this case it is unlikely that the ESD will require to be powered up outside of the vacuum. Therefore, it should be straight-forward to ensure that there is no HV until the ESD in vacuum.

6 Comments on OSEM Electronics (T050112)

1. block diagrams needed for circuits

Comments (from D. Hoyland): OK – when the full scope of the circuitry is defined (incl diagnostics etc). These issues will be discussed with Jay Heefner during his visit in October, and diagrams can be created thereafter.

2. Output noise in section 4.3.4: why is the measured noise of 38 pA/rtHz so different (smaller) than the predicted noise of 66 pA/rtHz?

Comments (from D. Hoyland): Firstly for reasons stated above, the initial noise calculations were done by hand. This sort of 'simplified' analysis (as oppose to something done with a circuit simulator) can be a somewhat conservative. Possible reasons for the discrepancy are:-

i) The Op-amp used in the output stage (which dominates the response) was somewhat quieter than specified on the data sheet

ii) The Op-amp input noise actually has some (unspecified) common mode component, which originates in the common bias circuitry associated with the input stage. This means that by balancing the impedance seen by the inputs (not just resistance) you can effectively reduce or eliminate that component.
Hand calculations assume the noise is completely differential mode.

3. What is the switching time of the solid state relays? Fig 6 seems to indicate it is about 30 msec, which is pretty long. Is this correct? Is it the same for all units, and the same every time?

Comments (from D. Hoyland): SSR switching time is typically 2.6mS (on) and 0.5mS (off) (data sheet values). The figures mentioned above are slightly misleading, because the drive circuit rather being logic was a SPST switch, and there is several uF capacitance across the device terminals (forming a low pass filter with the input drive resistor) which is actually holding the device on for a while after the switch is opened.

4. PM coil driver: the claim is that the output range is +/-150 ma, with a source impedance of 1 kohm. This seems to imply a voltage range of +/- 150 V at least, yet only +/-70 V is planned.

Comments (from D. Hoyland): No – I think I used ±70V to test the prototype as it was the highest voltage supply I could find. Actual rack power supply requirements are given in section 1.1.2.2.1.2 of E050160-01.

5. What's the calculated noise for the PM coil driver, in science mode?

Comments (from D. Hoyland): The electronics noise calculated for the PM output was ≈25pA/rtHz. Measured noise was 9pA/rtHz

6. We don't see any mention of applied actuator drive readbacks. As a minimum we should have a low noise readback of the test mass actuator and the penultimate mass actuator. This feature would add another wire/channel to the ICD diagram to get the data into the DAQ.

Comments (from D. Hoyland): No diagnostic readbacks have been added to the design. Precisely what readbacks you want/require, and their format still has to be discussed. This is one of the agenda items for Jay Heefners visit in October.

7. System status and state readback (per section 2.8.1.2 of the Universal SUS requirements, T000053-03) appears to be absent.

Comments (from D. Hoyland): See item 6 comments.

7 Interface Control Document (ICD), E050160-01

7.1 Pinout Assignments

The statement in E050160-01, page 10: "Note: Probably want a much different pairing than standard/typical, or revise the pin-out assignments?" is unclear. The pinout has the coil wires separated by one pair from the rest of the signals. This seems fine; though note that with the Cooner Wire Co. wire, this separation may make no difference to how close these pairs are in the body of the cable.

Preliminary answer (from D. Coyne): The note will be revised.

Comments (from S. Aston): The pin-outs will be re-assigned, to be consistent with the controls prototype Hybrid OSEMs. Mark Barton is to provide the definitive pin-outs shortly.

7.2 OSEM Interface Location

Why is it not anticipated to mount the OSEM interface modules at the level of the feedthroughs? If there is appropriate mounting hardware, this may be beneficial from the standpoint of cable lengths of small signals. (E050160-01, page 12)

Preliminary answer (from D. Coyne): If the OSEM interface modules are mounted at the level of the feedthroughs, service and troubleshooting of these units is made considerably more difficult. In addition there is little available mounting area/volume to accommodate these units at the elevation of the electrical feedthroughs on the BSC vacuum chamber. There does not currently appear to be strong or compelling performance considerations that require reduction of a few meters in cable length. This is the current baseline. If further testing or analysis proves otherwise, then these units can in principle be mounted near the electrical vacuum feedthroughs and support for their cooling, mounting, and power can be routed to this elevation (e.g. the SEI capacitive position sensors are to be mounted adjacent to these electrical feedthroughs).

7.3 OSEM Interface Box

On the bottom of page 12, when referring to "OSEM Interface Box", does this include the "satellite module" as well? Is there a plan to put these into racks? It doesn't seem like this based on the block diagram on page 5.

Comments (from D. Hoyland): I believe the diagram on page 5 needs updating. The Analogue electronics will be split such that the sensitive photodiode signals are processed (trans-impedance amplifier and line driver) in a satellite box. The coil drivers will come from an analogue rack – see block diagram D050270-00-K for clarification.

Appendix: Some Further General Electronics Guidance

The following design guidance will be incorporated into the overarching system-level, the Generic Requirements document, E010613-01 and the subsidiary Suspension Subsystem Universal Design Requirements Document (T000053-03) document.

Comments (from D.Hoyland): It would be extremely useful if the documents and technical notes which we should be using to produce the OSEMs and Electronics designs were compiled into an Appendix or even a specific section of the relevant ICD – even including things like guidelines/procedures for drawing release etc - To avoid us (UK) missing something simply because we were unaware that a document exists or a problem was experienced and was subsequently solved.

TO: People worrying about Advanced LIGO Electronics and Control Systems
CONCERNING: Some advice for the future (and maybe even now)

FROM: Rich Abbott, July 12, 2005 *(excerpted and paraphrased by D. Coyne)*
Lessons learned from initial LIGO on electronics design robustness:

1. I would suggest all connections have integral strain relief.
2. We should consider the real issues of the environments at our observatories (lightening etc.) so far as ruggedness of electronics to external damage.
3. We should anticipate the loss of a single supply to HV amplifiers, and design sequencing into the electronics to prevent damage.
4. We should avoid situations where we are subject to reverse polarity power damage, as - despite our best intentions - we usually hook up a few things backwards.
5. In general, we should give some thought to which cables come in through the front of a chassis and which come in through the rear panel, it may seem like minutia, but it impacts reliability and usability in the long run.

The list like this goes on and on …

FROM: R. Weiss, July 25, 2005
As we get the interferometer working at the noise levels required for initial LIGO it is becoming evident that the stability and reliability of the circuitry is becoming more and more important. The recent events with lightning strikes and momentary power outages at Livingston bring this home. We are still trying to recover the best noise performance we have had after about a month since the lightning strike and associated power outage. Why is this proving so difficult and time consuming?

There are several reasons:

1) The fact that the state of systems is misinterpreted by looking at the MEDM screens is one of the most significant problems we have. We have complained about this often. A command is given either by the operator or inadvertently by a transient, however, the system being commanded does not respond or is in a state other than the expected one. Imagine the situation after an uncontrolled power failure; one simply does not know what information on the MEDM can be trusted. The real state of gain settings, shutter closures, filter settings is not known, *it is simply a nightmare*. People have stopped complaining about this situation, those who are frustrated by it do not operate the instrument while those who have experience know at least some of the commands that need to be given to reset crucial parameters. In this situation, the technique of providing a sample MEDM screen, designed to show the nominal settings when operating, is not necessarily useful. The only successful mechanism, exercised by many of the operators, is to toggle every command. *Feedback to show the current state of the system is urgently needed*.

2) Circuits are intolerant to aberrant conditions. This sounds vague but is at the heart of a set of problems. Some of the circuits have saturation states (clamped states) which would not normally occur if the power is brought up uniformly, others are intolerant to the sudden application of the full power or the lack of simultaneity in bringing up the positive and negative supplies. A good example of this is the tendency of some circuits to break into oscillation for special turn on conditions and remain oscillating unless the power is turned off. Some of the circuits do this when there is a momentary power failure which brings on a condition for the oscillation to turn on and no way to stop the oscillation unless the power is removed and then reapplied in a controlled way.

3) The capability of voltage transients to destroy the noise performance of the circuit but not its gross function. There are many examples of this in our circuitry. The input stage of an op amp is made noisy by a voltage transient but unfortunately keeps functioning approximately well enough to escape detection in the troubleshooting. This is one of the most insidious problems now when we are fighting to keep the noise at the specification.

4) The thermal design is marginal so that an additional loading of a circuit by a follow on circuit not functioning correctly will cause the feeder circuit to fail by overheating. There are some examples of this in our system. Normally, one would design circuitry to be short circuit tolerant or protected.

All of the above phenomena can be avoided by decent circuit design coupled with a testing program that actually tries the various possible imperfect turn on and turn off conditions. One could specify that no circuit used on LIGO should fail the following tests:

1) The circuit needs to perform under all conditions of power turn on and off. The entire parameter space of power supply voltage needs to be investigated for clamped states.

2) The circuit cannot be allowed to oscillate under any conditions of applied power.

3) The inputs and outputs of the circuits need to be protected from voltage transients and be able to withstand shorts.

4) The circuits need to function to their specifications for a range of power supply voltages that could be encountered at the sites. In the end this may only be manageable with local regulation on each board.

The above is rudimentary. More subtle but just as necessary are the need to establish circuit architectures that can protect circuitry under noisy electromagnetic field environments (such as lightning transients). This is the first line of defense against RFI and cross coupling. *The standard means of approaching such a requirement is to assert in order of importance that*:

1) All signal lines between remote locations (not in the same Faraday cage) need to be differential with a minimum common mode rejection specified and tested as function of frequency. The balanced leads need to be twisted to reduce coupling to external time varying magnetic fields. The shields need to be part of the Faraday cages and should not carry time varying currents.
2) Command lines need to be shielded. The open ribbon cables we are now using for both signal and command lines are not suitable.
3) Power supply lines may also need to be shielded (not sure of this, although it would prudent to do so**).**

In principle **2)** and **3)** could be satisfied by the RFI mitigation we have started at LLO. One could imagine that the RF feedthroughs should reduce the lightning induced time varying fields to levels that can be tolerated by the circuits. Need to consult some experts about this.

Addendum 1. *(E-mail correspondence with Ken Strain regarding Magnetic Coupling)*

N.B. Refer to figure 14 (section 4.1) of the OSEM Preliminary Design document (T050111-00) for the magnetic coupling measurements taken at Birmingham.

From: "k.strain" k.strain@physics.gla.ac.uk
Subject: Magnet & Sensor Coupling
Date: 16 February 2004 14:56

Dear All,

I have measured the magnetic force between 2 emitters and the worst case magnet configuration.

The magnets were two of our 10mm dia by 5 mm thick Nd:Fe:B magnets back to back. Distance coordinate measured from the front surface. This is the strongest magnet proposed (as far as I am aware). The magnet was placed on electronic scales (which did not seem to be affected by the magnetic field) and the DUT brought down towards the magnet to reveal the magnetic force. The force (f) was plotted over distance (x) from the magnet face to roughly the centre of the DUT. Orientation effects were of order 25% and measurement error was less than that. For both devices the force/distance result was a power law very close to f \propto x^{-3} in the range of x from 5 to 50 mm.

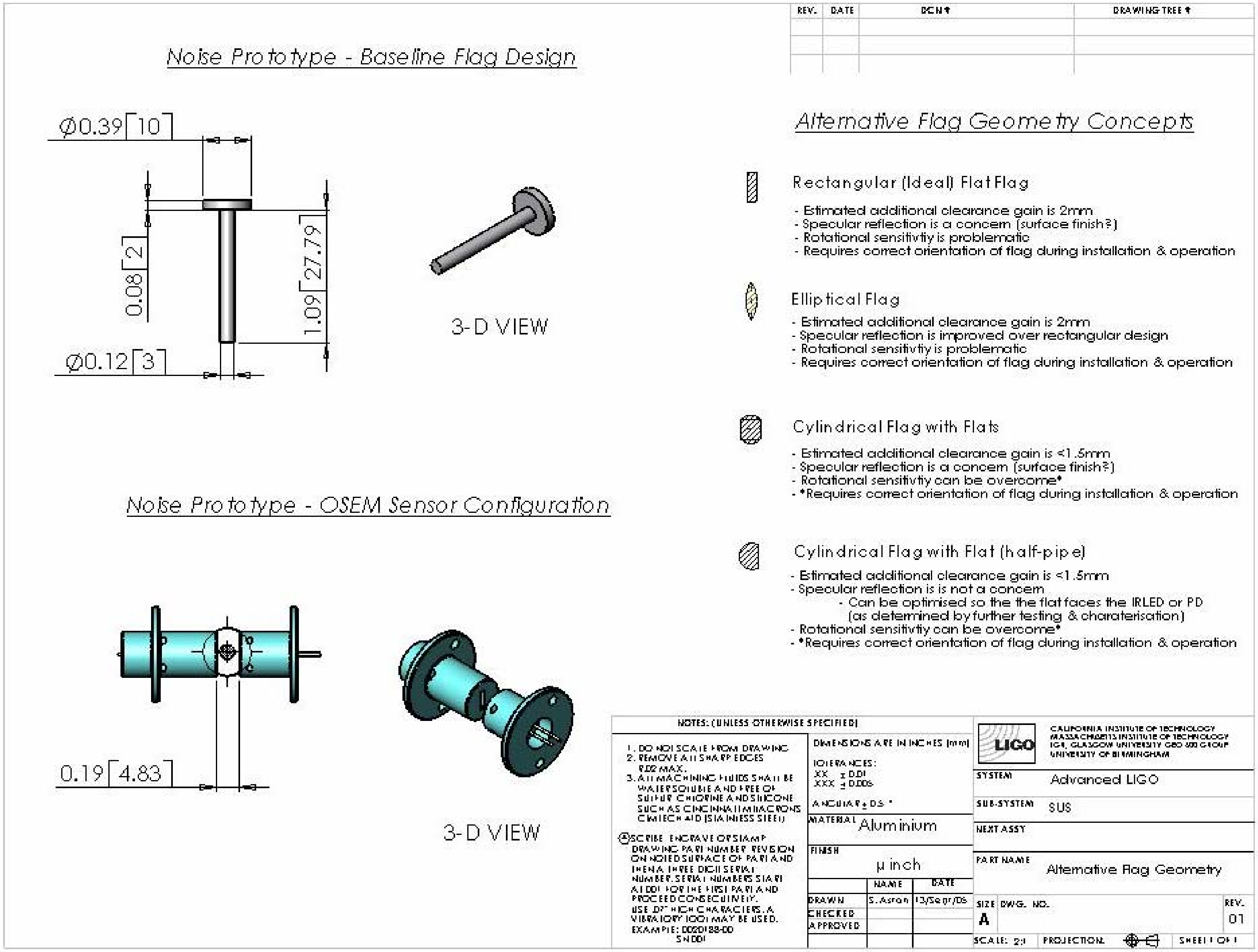
The values of force at a spacing of 10 mm were 40 mN for 0D50L and 25 mN for SFH-480 (TO-18).

I'm not sure what allowance for static force we can make, but the typical stiffness of a suspension is around 500N/m (for the QUADs) so something much less than 50 mN might be OK. The MC mirrors are much lighter and we'd need to ensure at least a few cm spacing from magnet to LED. Perhaps we need to ask Norna for guidance on max static force.

I don't think we have a worry with isolation short circuiting, but the full calculation can be done by differentiating the numbers I've provided

Cheers,
Ken

Addendum 2. *(OSEM Flag Geometry Options)*



Alternative Flag Geometry Concepts

Rectangular (Ideal) Flat Flag
- Estimated additional clearance gain is 2mm
- Specular reflection is a concern (surface finish?)
- Rotational sensitivtiy is problematic
- Requires correct orientation of flag during installation & operation

Elliptical Flag
- Estimated additional clearance gain is 2mm
- Specular reflection is improved over rectangular design
- Rotational sensitivtiy is problematic
- Requires correct orientation of flag during installation & operation

Cylindrical Flag with Flats
- Estimated additional clearance gain is <1.5mm
- Specular reflection is a concern (surface finish?)
- Rotational sensitivtiy can be overcome*
- *Requires correct orientation of flag during installation & operation

Cylindrical Flag with Flat (half-pipe)
- Estimated additional clearance gain is <1.5mm
- Specular reflection is is not a concern
    - Can be optimised so the the flat faces the IRLED or PD (as determined by further testing & charaterisation)
- Rotational sensitivtiy can be overcome*
- *Requires correct orientation of flag during installation & operation

NOTES: (UNLESS OTHERWISE SPECIFIED)

1. DO NOT SCALE FROM DRAWING
2. REMOVE ALL SHARP EDGES R.02 MAX.
3. ALL MACHINING FLUIDS SHALL BE WATER SOLUBLE AND FREE OF SULFUR CHLORINE AND SILICONE SUCH AS CINCINNATI MILACRONS CIMTECH 410 (STAINLESS STEEL)

④ SCRIBE, ENGRAVE OR STAMP DRAWING PART NUMBER, REVISION ON NOTED SURFACE OF PART AND THEN A THREE DIGIT SERIAL NUMBER. SERIAL NUMBERS START AT 001 FOR THE FIRST PART AND PROCEED CONSECUTIVELY. USE .07" HIGH CHARACTERS. A VIBRATORY TOOL MAY BE USED. EXAMPLE: D020188-00 SN001