MEMORANDUM

DATE:	August 23, 2005
TO:	AL SUS Design Team Stuart Aston, Dave Hoyland, Nick Lockerbie, Ken Strain
FROM:	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-L050039-00

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.

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.

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?

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?

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)

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?

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.

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.

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.

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.)

3.2 Origin/derivation of the 8 μV/rtHz

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

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.

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.

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.

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.

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).

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.

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.

5.2 Output Voltage 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.

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?

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?

6 Comments on OSEM Electronics (T050112)

1. block diagrams needed for circuits
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 ?
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?
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.
5. What's the calculated noise for the PM coil driver, in science mode?
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.
7. System status and state readback (per section 2.8.1.2 of the Universal SUS requirements, T000053-03) appears to be absent.

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.

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.

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.

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.