LIGO Laboratory / LIGO Scientific Collaboration

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ROM estimate for LIGO EMI compliance upgrade

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of the LIGO Laboratory.

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Introduction

For estimating purposes I include both source mitigation and protection of susceptible equipment. Ideally we'd phase in source containment first and address susceptibility after evaluating results. We can do this to some degree, but it's all but guaranteed that shielding and ground rationalization of the signal electronics will be deemed necessary in the end. The generic concept is depicted schematically in Figure 1. Not all variants can be shown, but an example and context is offered for each major cost element described below. An attached spreadsheet details the unit cost and quantity per interferometer for each type of hardware.

I've exercised some judgment in choosing the hardware baseline, but have not extensively researched or optimized specs and pricing. Most quotes are actually single-unit list, so I do expect some relief in the form of discounts.

No allowance has been made for selling off existing non-compliant hardware. If ownership and procurement issues can be resolved we might recover significant credit for the power supplies, racks and VME crates we replace.

Radiated/conducted source mitigation

Separation of digital and analog electronics by rack

VME crates, digital I/O and clock functions will be segregated in isolated, RFI-gasketed containment racks. All I/O signals and power will enter and exit these racks via gasketed, RFI-suppression feedthroughs. Fibers will enter and exit through waveguide-type tubular vias.

The analog racks will get similar treatment, in this case to keep remaining ambient interference out. As a result I have priced out replacing all racks in the LVEA/VEA (other than vacuum equipment). Grounding for the analog racks will follow a hybrid HF/LF protocol (galvanic isolation to cut 60 Hz current paths, combined with capacitive bonding to establish a common RF groundplane).

EMI-shielded racks

I costed several options. "EMI Level R3" racks from Equipto Electronics are 400-series welded magnetic stainless with beryllium-copper fingerstock gaskets on all openings. This provides a galvanically and mechanically stable contact combination, but at very high cost (~$7.2k/rack). Equipto also has a 40% cheaper "FCC" rack series which uses carbon steel (with conductive paint on gasket surfaces) and conductive elastomer gaskets. The EMI performance looks similar up to 1 Ghz and degrades somewhat above that. However the contact integrity of the gasketing may be prone to decay with time and opening cycles; the literature targets limited life cycle commercial applications.

NRAO uses AMCO modular racks, which have passed their (evidently stringent) tests. They use cadmium-plated carbon steel with a replaceable Monel alloy metallic gasketing (apparently proprietary). This is a galvanically stable combination which can be field-maintained over the life of the rack, and is significantly cheaper initially.

Ventilation is with shielded AC blowers through aluminum honeycomb waveguide filter panels top and bottom. Cable I/O is via gasketed knockout subpanels in the base and roof. NRAO shared an AMCO price quote of $2,850 per rack for their preferred configuration; I doubled their cable access plates and cooling fans (to about 730 SCFM total), bringing their quote up to $3,523 each.

Power for the internal equipment will be routed through an EMI filter plenum in the base. Series EMI filters will be sized for the actual rack power loads. Digital racks will be bonded to the AC ground at this point, whereas analog racks will either route power through an isolation transformer (relying on a shared analog common for safety grounding) or else accept DC feeds from separate racks where the supplies are mounted. In either case I allowed $0.5k per rack for AC or DC power filtering equipment and miscellaneous hardware.

Elimination of switching power supplies

The existing Sorenson switchers, plus small switch-mode HV modules used for PD and PZT biasing will be replaced by low-noise linear pass regulated supplies. Rus and I priced out JQE-series low-noise linear-regulated supplies from Kepco. By our informal survey, no power form is currently drawing more than 250W, so none of the 1 kW Sorensons is fully used. As a result, while the Kepco linears require 3x as much rack volume per watt, sizing them for actual loads will actually reduce the net rack volume devoted to power supplies. The JQE supplies list for $824 each for 100 watt units (1/4 width 3U rack mount) and $1.43k for 250 watt (1/2 width 3U rack mount). Smaller MAT linear units will be used for photodiode and PD biases.

For LOS suspension drives, we priced Kepco ATE series 325 volt/800 mA linears. These are also half-width by 3U high. Eight per IFO are allocated to each corner station and two per end station.

EMI-compliant VME crates

Our Knurr powered crates turned out to be incompatible with EMI containment. We will replace them with MIL-style EMI containment VME crates. These generally feature finger-stock landing gaskets for card front panels, conductive finishes, a gasketed front shield, and shielded backplanes with knockout panels for gasketed I/O feedthroughs. Jay got a binding quote of $3.5k/unit from ELMA corp. for this type of crate, including integral power supply.

Cabling and EMI feedthroughs

The current concept is to carry VME module I/O cables (mostly ribbons) down the crate front inside the shielded door and back underneath the card cage to a plenum included behind the backplane. They will terminate there on EMI filtered feedthrough connectors (e.g., Spectrum Control 700 series Pi-section) bolted into knockouts in the crate back panel. Fibers to/from the VME crate will pass through waveguide tubes. No unfiltered wire penetrations or open spaces will be allowed to breach the crate shields[1]. These short cables were assigned a WAG of $50 each with terminations (they might be recycled from existing cables, recut). The Spectrum Control 700 series feedthrough filters sell for $74 in 50-pin configuration from Newark, which is close to the average pin count.

From the crate back, a short fully shielded cable leads from each of these feedthroughs to a second similar EMI filter bulkhead connector, bolted into the rack top or side panel (procured pre-punched as part of the rack). From outside this bulkhead a second fully shielded multipin cable leads on to a comparable structure on the terminating rack. Each of these cables (internal and external) is estimated at $104 with terminations. This is the Newark price for a 15-foot DB-50M-DB-50F double-shielded (braid on foil) commercial computer cable. It is important that only cables with 360-degree terminated shields and conductive backshells are allowed in these applications; standardizing on a widely used commercial form, say 37 or 50-pin D subminiature, will save considerable labor in termination and QA.

Cable counts are estimated as follows: a limited sampling of EPICS, LSC, ASC, and DAQ VME crates gives an average of 8.5 active I/O cards per crate. Typically each card (Xycom 220, Xyom212, VMIC3113, VMIC4116) has one 37, 50, or 64-pin I/O connector (note that many pins are unused). CPU Ethernet, GPS and reflective memory fibers are accounted for by adding an extra "card" to the count and rounding up (i.e., 10 per crate).

Signal path protection

EMI-shielded racks

We'll need to replace the Knurr racks housing analog crates to achieve any significant shielding. This requires dealing with the cross-connects somehow, a controversial issue. For the moment we are costing the same rack as used for EMI containment in the digital world (above); these racks are from a modular system, so an arrangement could probably be devised for housing the existing cross-connects in a comparable geometry. A more radical proposal, to eliminate cross-connects entirely, is explored below.

EMI-shielded analog crates

Shielded crates like the above VME crates look like a good starting point. We can delete the VME power supplies, but should add something back in for a custom backplane and for isolated mounting provisions (crates will optionally float off rack ground). As another reference point, a shielded 13-slot VXI mainframe runs about the same cost ($3.8k with power supply from a "premium" vendor like Agilent). Efforts to shield

[1] Actually the GHz GPS antenna coax is problematical here; we may need to treat this one line specially.

individual boards (below) will increase their width such that some crates (ASC, DSC) will overflow, probably requiring an additional 3 analog crates per interferometer.

Analog module/board shielding

We are looking at adding a module shielding kit intended for prototype and one-off VXI modules. This will increase the width and depth of each analog card, but leaves backplane assignments and front panel layouts untouched. In some cases existing cards may be compatible with the kit with minor modifications, including an “extender” to increase the length; this may be compatible with the backplane isolation measures (below). The shield kit is $225 per board; add $50 for ancillary hardware modifications (assuming the original board itself can be saved).

An allowance is also included for retrofitting LOS and SOS 19” chassis boxes with EMI filters, insulated mounts and shielded backshell connectors.

Front-panel signal isolation

Differential driver/receiver pairs for Pentek ADC’s and DAC’s and DAQ ADC’s are already in the pipeline.

Analog backplane isolation

We will add an additional filter/isolation board in back of each current board. This will carry optical isolation, RFI feedthroughs and differential driver/receivers to galvanically and inductively isolate the analog board from EPICS and DAQ devices it communicates with through the backplane. These “buddy boards” will be simple, but will have to be custom-built for each type of board. My WAG is $300 per analog card for “buddy boards”. Note, however, that this will be engineering-intensive, so there may be significant hidden costs as well.

The Cross-Connects

One candidate solution to the large and uncontrolled RFI/EMI and ground loop cross section of the existing rack cross-connects is to try and eliminate them. In this scenario, point-to-point cabling would bring each VME I/O connector directly to a connector bulkhead on the corresponding analog Eurocard crates. End-use distribution would be done within the backplane plenum of the Eurocard crate using custom wiring to individual P1 and P2 pins (power forms will be dealt with this way) and/or some form of reconfigurable interconnect matrix (editorial note: nobody wants wire wrap so don’t ask!).

To see if this is really feasible one needs to analyze the full mapping of VME-to-Eurocard connections, especially “forks” by which one VME module serves multiple analog crates. One also needs to run through the scenario of accommodating changes to an analog module or subsystem down the road. For now, I am costing this way because it is reasonably definite and easy to cost. In essence, the RFI feedthroughs and standard

DB-50 cabling proposed for the digital crates/racks are mirrored in the analog crates/racks, up to the bulkhead feedthrough at the rear of the crate.

Analog "Remote Outposts"

Bundling and shielding of LSC, WFS and QPD detector head cables will require some investment in shield materials and connectors. Comparable measures are expected for dealing with the SOS/LOS drive cabling and satellite module connections. For now these costs are a WAG pending some design work.

Testing facilities and equipment

On-site testing is required to verify shield integrity and compliance for each type of assembly. An outdoor test range will be set up at each observatory site with power supply, RF spectrum analyzer, excitation and receiver antennas, and support equipment. Pending further definition I am estimating an expenditure of $50k per site, to be augmented by standing stock test equipment already on hand.

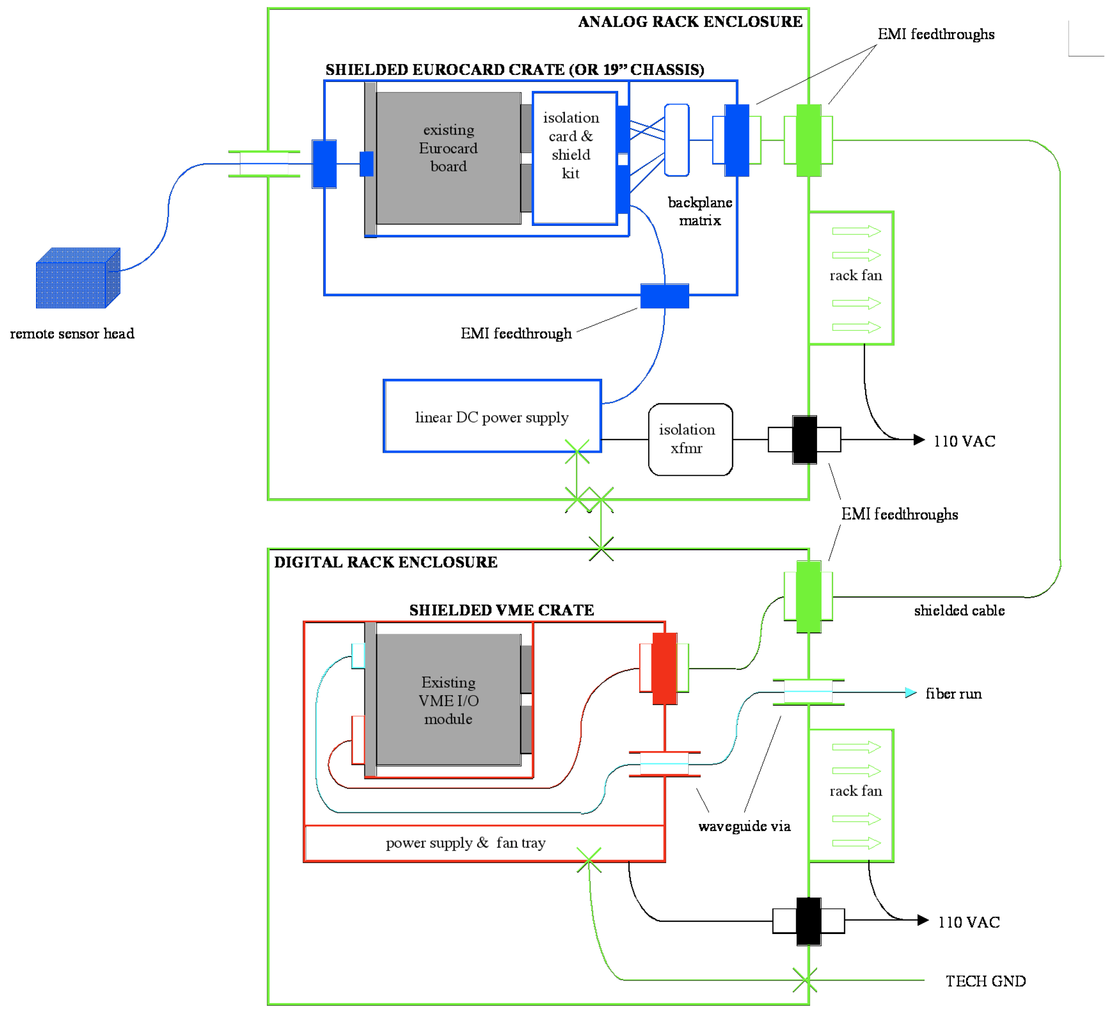

Figure 1 Schematic of enclosure shielding and repackaging concept adopted for costing exercise.