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LIGO Interferometer Electronics EMC Requirements

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DRAFT FOR INTERNAL REVIEW AND COMMENT

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1 Introduction

This document summarizes standardized EMC requirements common to all LIGO interferometer electronics systems. They are to be considered a minimum framework for limiting unintended interaction between LIGO system components, and for mitigating interference from the ambient electromagnetic environment. Additional, more stringent requirements are expected to arise locally for certain interferometer systems, due to the extremely low signal levels and spurious signal intolerance intrinsic to the LIGO mission.

The requirements address measured properties of isolated equipment as well as standards for construction, component selection and interconnection. The latter categories are required because many interactions are not readily predictable from isolated testing, some interference mechanisms are nonlinear or parametric, and diagnostic capability for unforeseen problems is strongly affected by construction methods, irrespective of nominal unit performance.

Note on applicability:

As this document is released most initial LIGO system elements have already been installed and commissioned. The requirements herein are therefore intended to apply to new designs and future updates of fielded systems. A program to retrofit existing noncompliant equipment to meet these or comparable standards is proposed separately (see LIGO-E020350-08-R).

2 Commercial and MIL Standards

All LIGO digital electronics¹ shall conform to FCC Part 15, Subpart J regulations for radiated and conducted emissions from Class B computing devices.

In addition, LIGO analog and digital electronics shall conform to selected portions of MIL-STD-461E for both electromagnetic emission and susceptibility to ambient environment, specifically:

- CE 101 Low frequency conducted emissions*
- CE 102 MF-HF conducted emissions*
- CS 101 Conducted powerline susceptibility, 30Hz-10kHz
- CS 114 Conducted susceptibility to bulk cable injection
- RE 101 Radiated emissions, magnetic VLF
- RE 102 Radiated emissions, electric broadband*
- RS 101 Radiated susceptibility, magnetic VLF
- RS 103 Radiated susceptibility, electric broadband

These criteria and tests are to be augmented for specific LIGO applicability as described in Appendix 8.

¹ Defined by the FCC as those containing binary circuitry with clock rates in excess of 10 kHz

Subparts marked with * are also affected by the FCC Part 15 specification. Other things being equal, the prevailing restriction shall be the more stringent of these, except that available testing apparatus for compliance verification may offset this criterion for practical reasons. For example, many MIL emission tests require an EMI shielded chamber, whereas FCC tests may be conducted in open air.

3 DC Power Supplies

DC power supplies for custom LIGO circuitry shall be of the linear pass-regulated type. Switching regulators or pre-regulators are not permitted for LIGO instrumentation.

Power supplies shall be fully shielded and rack-mountable. Open-frame and benchtop supplies are not acceptable.

Where commercial or procured instruments contain embedded OEM switching supplies, these instruments shall be shielded and their connections filtered as specified for digital circuitry, described in Section 4 below.

4 Digital Circuit Shielding and Grounding

All digital circuits and subsystems shall be housed in shielded chassis enclosures.

Digital circuits, crates and subsystems shall be segregated in dedicated relay racks, physically separate from those housing analog and RF circuits.

Digital equipment rack enclosures shall be shielded to contain residual emissions. As configured for use, these racks shall attenuate plane wave fields by a minimum of 50 dB at frequencies between 100 kHz and 1 GHz. They shall attenuate magnetic fields by a minimum of 20 dB between 10 kHz and 1 MHz.

Cooling of equipment within racks shall be sufficient to maintain operating temperatures of all internal components and modules within safe operating areas under all anticipated load conditions.

Cooling fans shall not violate EMI limits applied herein, or acoustic limits specified in LIGO-T960083-A-E, *Derivation of CDS Rack Acoustic Noise Specifications*.

Digital circuit enclosures shall have conductive seam and panel treatments, conductive gasketing and connector panels consistent with broadband EMI containment.

VME crates, in particular, shall be provided with RFI-gasketed front panels and enclosed wiring plenums.

Digital circuit enclosures shall be provided with RFI-filtered power input connections suitable for the current and voltage form involved.

External connections to and from digital circuit chassis or crates shall employ fully shielded cables (Section 7).

Chassis cable penetrations shall employ filtered EMI feedthroughs with minimum rated attenuations as specified in Table 1.

<i>Frequency</i>	<i>Attenuation (see caption)</i>	<i>Comments</i>
1-3 MHz	10 dB min	Lamps/ballasts, etc.
3-10 MHz	24 dB min	Sample clock frequencies
10 MHz – 1 GHz	34 dB min	Broadband
$N * f_m \pm 10 \text{ kHz}$, $N=1, 2, 3$	50 dB min	24.5, 49.0, 73.5, 29.5, etc.

Table 1. Attenuation requirements for RFI feedthrough filters. Attenuation ratings are normalized to 50 ohm source and sink, although I/O lines may have unmatched and/or uncontrolled impedances. Bands around LIGO modulation frequencies f_m and harmonics are specifically identified.

Nonconducting signal penetrations, such as optical fibers, shall penetrate digital enclosure shields through cutoff waveguide vias having minimum length:diameter ratio of 10:1 (internal diameter to suit fiber and termination).

5 Baseband Analog Circuit Shielding and Grounding

All analog circuit modules, chassis and card crates shall be fully Faraday shielded.

Analog module, chassis, and card crate construction shall employ conductive surface finishes, redundant fastenings and gaskets to assure continuous panel contact.

Analog connectors and cables shall be fully shielded (Section 7).

Analog chassis, card cage, sensor, actuator, and rack designs shall be compatible with “single-point” grounding to block or contain magnetically induced ground currents.

Power, supervisory control and monitoring conductor penetrations shall employ RFI-blocking feedthrough connectors with properties listed in Table 1.

Analog signals passed between chassis or racks shall be transmitted differentially, with at least 60 dB of common mode rejection at frequencies below 1 kHz and at least 40 dB at frequencies below 10 kHz.

Analog equipment rack enclosures shall be shielded to exclude external electric and magnetic fields. As configured for use, racks shall attenuate plane wave fields by a minimum of 50 dB at frequencies between 100 kHz and 1 GHz. They shall attenuate magnetic fields by a minimum of 20 dB between 10 kHz and 1 MHz.

Cooling of equipment within racks shall be sufficient to maintain operating temperatures within safe operating areas. In addition, sensitive analog front and back end electronics

for which thermal (Johnson, transistor junction, etc.) noise is a significant performance constraint shall not be exposed to ambient air temperatures exceeding 40C.

Cooling fans shall not violate EMI limits applied herein, or acoustic limits specified in LIGO-T960083-A-E, *Derivation of CDS Rack Acoustic Noise Specifications*.

6 RF Circuit Shielding and Grounding

All RF circuit modules, chassis and crates shall be fully Faraday shielded.

Module, chassis and card crate construction shall employ conductive surface finishes, redundant fastenings, and conductive gaskets to assure continuous panel contact and circumferential connector grounding.

Power, supervisory control and monitoring conductor penetrations shall employ RFI-blocking feedthrough connectors with properties listed in Table 1. Additional attenuation may also be required at operating frequencies to comply with conducted and radiated emission limits established in Section 2.

RF equipment rack enclosures shall be shielded to exclude external electric and magnetic fields. As configured for use, racks shall attenuate plane wave fields by a minimum of 50 dB at frequencies between 100 kHz and 1 GHz. They shall attenuate magnetic fields by a minimum of 20 dB between 10 kHz and 1 MHz.

Cooling of equipment within racks shall be sufficient to maintain operating temperatures within safe operating areas. In addition, sensitive analog front and back end electronics for which thermal (Johnson, transistor junction, etc.) noise is a significant performance constraint shall not be exposed to ambient air temperatures exceeding 40C.

Cooling fans shall not violate EMI limits applied herein, or acoustic limits specified in LIGO-T960083-A-E, *Derivation of CDS Rack Acoustic Noise Specifications*.

7 Cabling standards

All external cabling and connector bodies shall be fully shielded.

Cables shall be externally insulated to prevent inadvertent ground contact with supports, cable trays or metallic structures.

Cables may only terminate at connectors mounted on approved shielded enclosures. Floating mid-run connectors (e.g., BNC “bunts” or barrels) are not permitted. Hard splices, if required, shall be shielded and insulated so as not to compromise the shielding and insulation properties of the parent cable.

Cable shields will make full, redundant circumferential contact with connector backshells to the extent permitted by ground loop considerations.

Connectors shall make redundant, fully circumferential shield contact with their mates.

Audio-band analog signals shall be transmitted by shielded, differential twisted pairs.

RF signals shall be transmitted by coaxial cable; where ground isolation is required, baluns, capacitive breaks or common-mode chokes will be employed to maintain shielding effectiveness without passing common or differential mode audio-frequency ground currents.

8 Appendix: LIGO-Specific Augmentations to MIL-STD-461E Procedures and Criteria

This section is currently under construction.

- 8.1 CE 101 Conducted Emissions, Power Leads, 30 Hz - 10 kHz**
- 8.2 CE 102 Conducted Emissions, Power Leads, 10 kHz - 10 MHz**
- 8.3 CS 101 Conducted Susceptibility, Power Leads, 30 Hz-150 kHz**
- 8.4 CS 114 Conducted Susceptibility, Bulk Cable Injection, 10 kHz - 200 MHz**
- 8.5 RE 101 Radiated Emissions, Magnetic Field, 30 Hz - 100 kHz**
- 8.6 RE 102 Radiated Emissions, Electric Field, 10 kHz - 18 GHz**
- 8.7 RS 101 Radiated Susceptibility, Magnetic Field, 30 Hz - 100 kHz**
- 8.8 RS 103 Radiated Susceptibility, Electric Field, 2 MHz - 40 GHz**

9 References

U.S. Department of Defense, *Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment*. DoD Interface Standard MIL-STD-461E (1999).

Federal Communications Commission, *FCC Methods of Measurement of Radio Noise Emissions from Computing Devices*. FCC/OST MP-4 (1983).

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