LIGO Laboratory / LIGO Scientific Collaboration

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RFI Mitigation Review Board Report

R. Abbott, J. Acree, C. Beaudet, D. Coyne, J. Ford, J. Heefner, D. Hoyland, P. King, R. Lacasse, R. McCarthy, R. McCullough, V. Sandberg, G. Sanders, R. Weiss, R. Wooley, M. Zucker

Distribution of this document:
LIGO detector commissioning team

This is an internal working note
Of the LIGO Laboratory.

California Institute of Technology
LIGO Project – MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project – NW17-161
175 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 1970
Mail Stop S9-02
Richland WA 99352
Phone 509-372-8106
Fax 509-372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone 225-686-3100
Fax 225-686-7189

http://www.ligo.caltech.edu/

1. Overview

On 22 November 2002, the LIGO laboratory held a review of requirements and proposed mitigation actions for a RFI retrofit. The following summarizes the results of the review committee's findings and compares the results to the review panel charge (LIGO-M020420-00). The review panel consisted of members from LIGO Laboratory, National Radio Astronomy Observatory (NRAO), Los Alamos National Laboratory (LANL) and The University of Birmingham. A list is included below.

LIGO

Richard Abbott (Chair), Rainer Weiss, Gary Sanders, Richard McCarthy, Jay Heefner (Presenter), Rusyl Wooley, Mike Zucker (Presenter)

NRAO

John Ford, Jeff Acree, Carla Beaudet, Rick Lacasse, Randy McCullough

University of Birmingham

David Hoyland

LANL

Vern Sandberg

2. Comments and issues from the review

- 2.1. Richard Abbott
    - 2.1.1. A plan should be included to address grounding of the optical table that allows safety and signal grounding issues to co-exist
    - 2.1.2. The inability to see an improvement in measured EMI resistance for a given incremental change should not deter measurement checks using the interferometer if possible. This could avoid one fix creating another unforeseen problem.
- 2.2. Peter Fritschel
    - 2.2.1. Include recommendations for grounding cable trays
- 2.3. Dave Hoyland
    - 2.3.1. Offered to provide design overview guidelines for circuit board design
    - 2.3.2. Suggested the use of a portable shielding material the details of which he will send to LIGO
- 2.4. Randy McCullough
    - 2.4.1. 59.543 Hz NTSC standard frequency can easily be confused with 60 Hz
    - 2.4.2. Suggested the use of near field probes in assessing EMI issues. Offered to sent the relevant part numbers to LIGO
    - 2.4.3. Suggested the use of Spectrum Control in-line EMI filters for mixed signal cables
- 2.5. Carla Beaudet
    - 2.5.1. Emphasized the difficulty of implementing procedural EMI control. Just getting people to shut EMI tight doors is a problem
- 2.6. Vern Sandberg

2.6.1. Need to pay attention to separation of cables in bundles. Might need to use some sort of lossy material between cables

2.6.2. Mentioned the flexibility of building custom ADCs. Isolation between digital and analog portions can more readily be controlled

2.6.3. In response to a question from David Shoemaker (LIGO), Vern mentioned that he has shipped a VXI system recently that had excellent EMI resistance properties. It was in a 9u x 9u format that might be useful for LIGO to consider

2.6.4. Mentioned that he had quality issues that came up with Tyco Corp. mixed signal cabling products (coax and single conductors in one cable for example).

2.7. Rainer Weiss

2.7.1. Can a rule be made for no analog on backplanes? Initial committee consensus was that this was probably not desirable

3. Review panel comments formed after the review

3.1. Carla Beaudet

3.1.1. Clarified the purpose of using a reflective chamber is JUST to obtain a frequency list so you're not scratching your head trying to figure out what is ambient noise and what is EUT noise once you're out on the open site. In other words, it does not eliminate the need for open area testing, just simplifies it.

3.1.2. Extended Jeff Acree's invitation to use anechoic testing facility, as it does not see constant usage. Would mean LIGO must ship equipment and personnel out to do the test. The chamber will not be available in December, as a track for antenna testing is being installed. There are times when the chamber does get busy, so we may have to work out a test schedule.

3.2. Albert Lazzarini

3.2.1. One reason one might consider doing the initial EMI mitigation testing at LHO end (or mid) stations is that it does not take down the entire observatory, as it will in LLO.

3.2.2. Considerations for testing at one site versus another are; more LLO EEs per IFO than at LHO and when doing the LVEA it is best at LLO because there isn't another IFO to interfere.

3.3. Peter King

3.3.1. Consider the galvanic aspect of the nuts used to bolt the racks down

3.3.2. Cautioned against doing significant magnetic field susceptibility testing in the vicinity of the NPRO or other magnetically susceptible items.

3.3.3. Consider the use of an FPGA based replacement to the current cross connect wiring harness.

3.4. Dave Hoyland

3.4.1. For EMC emissions testing/debugging, I have previously used an EMC chamber from a company called Global EMC (http://www.global-emc.co.uk/). They manufacture a portable EMC chamber manufactured from conductive material (cloth)(see attached glossy). I have not used their portable EMC chamber, the one I used was a permanent fixture - but manufactured from the same material. The shielding performance was really very good, and I used it for emissions and immunity testing to great effect for pre-compliance testing and self certification in order to CE mark product. Obviously with no anechoic lining you have to take a little more care interpreting the results, but I found that this was not too difficult - with careful test procedures we got verifiable results - i.e. we EMC debugged products then took them to a certified test house and confirmed the results - this is a lot cheaper than trying to debug at a test house (we get charged about £100/hour at these sort of facilities) This sort of chamber to me would seem ideal for your system - as you can take the chamber to the rack(s) you want to test rather the other way - I seem to remember that the chamber took a couple of hours to assemble

3.4.2. One further suggestion with respect to cabling - particularly power cables - if you make them twisted pairs it greatly reduces the magnetic field. This also reduces the inductance per unit length - which helps with signal integrity when applied to signal lines.

3.4.3. One point in your 020350-08-R document which is very important is mentioned on page 5 - the use of 360 degree continuous connection between screen and back-shell - This is vital to minimize the parasitic impedance between the screen and the enclosure - which will cause the screen to loose shielding effectiveness with increasing frequency

3.4.4. I have used filtered D connectors before to very good effect - you may want to consider gaskets between the connector and the enclosure though to avoid radiating slots.

3.4.5. In applications where you want to avoid low frequency ground loops, connecting screens via capacitor(s) seems to work reasonably well. I found 1-10nF works fine - don't use diodes!

3.5. Richard Abbott

3.5.1. Noticed Agilent 84115 EMC Evaluation system that is used from 9kHz to 1.5 GHz available used from Tucker for $14k. Received comments from committee members to watch out for the bandwidth of the receiver, as EMC equipment can sometimes be less flexible that regular laboratory analyzers.

3.5.2. The requirements document (LIGO-E020986-01-D) quotes MIL-STD-461E and FCC Part 15, Subpart J as governing limits to be used by LIGO. These documents are very thorough and applicable, but need to be reduced in scope for use at LIGO. For example, these documents have shielding performance requirements that extend to 40 GHz. A comprehensive requirement document will need to provide quantitative testing acceptance criteria that can be used in the field.

3.5.3. Suggest looking at in-the-rack active noise reduction electronics like Vicor's MicroRam Output Ripple Attenuation circuit (www.vicr.com/products/datasheets/ds_microram.pdf), which boast 40 dB of ripple rejection from 60 Hz to 1 MHz at up to 20 amps of supply current.

These could be on the receiving end of the DC power distribution system in each rack.

3.6. Vern Sandberg

3.6.1. Gave an endorsement of the Agilent EMC test equipment as well as a suggestion to look at counter surveillance technology as a potential source of EMC test equipment.

3.6.2. Has used ferrite-like sheets and tiles to reduce RFI from ~20 MHz and up. Supplied a list of manufacturers and excellent list of application notes which were forwarded to Mike Zucker for inclusion on his website.

3.6.3. Experience leads him to subscribe to the adage: All grounds are local; all signals require two wires.

3.6.4. Re: EMC Requirements E020966. The requirements and plans described in E020966 supersedes E960036-A, but does not replace it. E960036 was written to give guidance and recommendations for best practice at the time. E020966 describes a program on a real instrument with all its unique features, system, noise sources, shielding details, etc. The two documents should be used in concert, with E020966 updating E060036. In reading both again, I was pleased to discover how complete E960036 was. It's recommendations on handling signals, cable routing, and radiated and conductive noise transmission was clear, concise, and based on good science and engineering. The course of time has offered a few new tricks, which you clearly and elucidate in E020966. An example of an updated technique is the shielding of cables from common mode RF noise and pickup by the use of ferrite cores around the outside of coaxial lines at their entrance and egress points. Another is the use of advanced gasket materials that provide losses at RF and may be used to line door and other openings. (Unfortunately they only kick in above 30MHz. If I find a better gasket material I will send it on to you.)

3.6.5. Re: Design Requirements E020350 This is a very well thought out and up-to-date plan. Drawings can always be improved, but a good way to proceed would be to make improvements and corrections to a drawing base as you go. The goal being an "as built" that comes out along with the operating instrument. As with any real world system, the parts and instruments used will depend on availability and budget. What is called out in E020350 is excellent. I have concerns about the operation of some of the approaches, such as the termination illustrated in Fig. 5 on page 20. A test bench must be set up and used to evaluate these schemes before installation, but you already understand this need quite well.

3.6.6. When performing and installation and then evaluating the consequences, keep in mind the basic physics of electric and magnetic fields around the conductors your signals are traveling upon. The separation into conductive and radiative sources of noise will get mixed up in many of your situations, especially in the wiring plants in the back of the racks. Document E960966 gave some good guidelines in considering where and when to ground. Add some updates with ferrites and a bit of snooping with some field probes (coils, capacitive plates, short antennas, etc.) and you should make good progress. Use broadband techniques where possible and then focus in on identified areas with narrow band equipment. A good oscilloscope (old analog, e.g., Tek 585, or a new Tek DSO set to emulate an old analog scope) and a loop or wire connected to a ball or plate can work magic. (Take a look at some of the field probes the people in the weather community use to measure local electric fields or field gradients. You may get some ideas for guards and such to improve your measurements.)

3.6.7. Tests: My above comments slopped over into the test area, so continuing on: You will need a good assortment of low frequency hardware/software and RF tools. When doing scans remember to look not only at power, which is what comes out of a spectrum analyzer, but synchronously demodulated signals as well. You have a variety of sync signals available; although to decide which ones are appropriate will require some thought, perhaps based on some spectrum analyzer power scans. You can use RF receivers (shortwave receivers such as the ICOM R-75 are inexpensive tools and have good sensitivities at the .1 microvolt level) that have sync locks or IF oscillator inputs. Or, you can use lock-in amps and some simple diode-ring mixers (Mini-Circuits for example) with a MAR-6 front end. The point is, with synchronous detection you can focus on identified noise sources and drill down into the noise (~60dB, 80dB, ... ?). The problems you will be left with after you find and remove the "standards identified problems" will be in an interesting class. They should be treated as research projects in their own right.

3.6.8. Implementation: Your ROM plan (E020285) and resource allocation (viewgraphs) look to be well thought out and balanced against the budget limitations. Starting with a rack, a set of power supplies, and a cabling design is a good start and should be mocked up in a lab, then moved to the floor. I like you plan, but caution that its implementation will be controlled by external elements outside of science and engineering.

3.6.9. Careful thought and planning for a graded approach that co-exists with the science runs and gets to "useful" limits quickly must be of highest priority. This could be considered as a patch or retrofit and leave a negative impression in the community. (I offer these comments as a friend and someone who sincerely wants this instrument to be a success!!) This impression can be countered by keeping to a scientific approach to hunting down and removing noise. Your program looks very good from this viewpoint. I have collected many odds and ends that do not seem to belong to any coherent scheme. I will save them for another email or a phone call, since many need to be discussed as to their "implementability". Some are notes to suppliers; others are notes on noise or pick-up problems as seen by other workers.

3.6.10. The summaries of our comments during the review and in post-review emails appear to be accurate enough. You folks have lots of work to do, so do not worry too much about editing.

3.6.11. I'll leave with a story. (Gary Sanders should remember this one.) We were chasing down a ground loop one morning at "test channel" at LAMPF 20 years ago when somebody had the idea to measure the EMF induced in a wire threaded around a cable tray that was running overhead. We found, after some estimates of coupling, area, etc., that the cable tray was being used as power return and had several hundred amps flowing in it! This current was generating a large enough magnetic field to corrupt the photomultipliers connected to some scintillation counters. You might want to start by sensing (with a field clamp ammeter or similar tool) the currents flowing in the site infrastructure.

3.7. Randy McCullough

3.7.1. Supplied the source of EMC measurement probes

3.7.1.1. Manufacturer is ETS-EMCO, part number is Model 7405, and a battery-powered pre-amp is a worthwhile addition.

4. **Conformance to review board charge** (Refer to LIGO-T020098-00-D, RFI Mitigation Review Board Charge).

4.1. Requirements

4.1.1. Are requirements complete?

4.1.1.1. As previously mentioned in this document, the governing documents (FCC and MIL-STD) should be distilled to be in line with LIGO RFI needs

4.1.2. Are proposed requirement values appropriate?

4.1.2.1. In some cases, the mechanisms for RFI coupling are not well understood in the LIGO interferometer. This leads to a type of educated guess that form part of the quantitative requirement limits. With these limits, the requirements are probably as refined as possible at the present time.

4.1.3. Do the requirements supercede or are they complimentary to the original LIGO EMI control plan (LIGO-E960036-A)?

4.1.3.1. The proposed requirements compliment, but don't seem to supercede the original EMI control plan.

4.2. Design

4.2.1. Is the design (LIGO-E20350) consistent with the requirements?

4.2.1.1. Largely yes. There are design details that still require thought such as the cross connect issues, but overall, the framework is excellent

4.2.2. Is the design (LIGO-E20350) sufficiently developed to proceed with the planned end station testing?

4.2.2.1. This task assumes that the material purchases have been made (EMC test equipment, linear supplies, etc.).

4.2.2.2. Before any significant changes are made, the plan calls for baseline EMC surveys. This is prudent and should be formalized with a written plan to ensure fair and adequate assessment of results.

4.3. Tests

4.3.1. Are the planned tests sufficient, and is there a sound basis for the evaluation of the effectiveness?

4.3.1.1. As mentioned previously, formal test procedures should be agreed upon prior to making significant changes.

4.3.1.2. Techniques will need to be developed specific to the LIGO installations to evaluate RFI mitigation results. This implies a directed test and learning program, the plan for which is yet to be developed.

4.4. Implementation

4.4.1. Is the incremental approach form implementation sensible and are there sufficient milestones for test and evaluation to reduce the risk of installing inadequate measures?

4.4.1.1. The incremental approach seems sensible

4.4.1.2. Provided a comprehensive set of procedures exists for assessing each increment of the implementation, the proposed milestones based on section 4.2.3 of LIGO-E020350-08-R seem adequate.