LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
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LIGO- E040288-00-C 6/18/04

Installation of RFI Mitigated HEPI system at LLO

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This is an internal working note
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1 Overview

The purpose of this paper is to document the hardware, implementation, and philosophy used in the RFI mitigated installation of the HEPI subsystem at the LIGO Livingston Observatory. For a good background in LIGO RFI mitigation policies, please reference the LIGO document: EMC, Shielding and Grounding Retrofit Plan [1]. Hardware of note includes the selection of connectors, feedthroughs, enclosures, and cables that were used. The implementation that was used attempted to minimize ground loops while maximizing the occurrences of contiguous shielding. Both the hardware and the implementation are intended to act in concert to satisfy the overarching philosophy of RFI mitigation.

2 Philosophy

The philosophy employed in the installation of HEPI in LLO had two main tenets: the desire for RFI mitigation, and that any solution that we came up with had to be compatible with the installations and retrofits that were coming in the future. The desire to limit electro-magnetic interference necessitates limiting RFI absorption and also RFI transmission. There are many places where EMI can be absorbed in a system. The most notable places are in the cables, through an enclosure, and inside an enclosure from one part of a PCB to another. The transmission of noise can be reduced by physically separating known noise sources, using more quiet power supplies and components, and shielding noisy modules and devices.

2.1 Cable RFI Mitigation

There are three main paths through which cables contribute to electronic receipt of EM interference. First, the noise is induced in the wire as it winds along, due to incomplete shielding and/or wiring problems. Second, the noise is already on the wire from the source electronics, and it gets conducted through the enclosure onto the board. And last, an inappropriate grounding scheme could cause ground loops, which inject noise everywhere.

2.1.1 Induced noise reduction

Noise induced in a cable can be greatly reduced by both effective shielding, and by shipping all vulnerable signals differentially over twisted-pair wires. A properly grounded shield with a high percentage of coverage can go a long way to stop a cable from behaving like an antenna and picking up ambient noise. Shielding, however, is only half of the protection available to us. If a signal is shipped differentially over a twisted pair, any ambient noise is seen as common to the two wires. In a differential signal this common mode noise is not seen as differential noise, and the signal remains unchanged. Only noise that is seen differently between the two wires affects the signal at their output. For this to work well, true differential drivers and receivers must be employed on the two boards, and each twisted pair in the cable must carry the + and – line of the same signal. Care must be taken by the board designer to make sure the signal assignment matches the standard wire pairing in the cable.

2.1.2 Conducted noise reduction

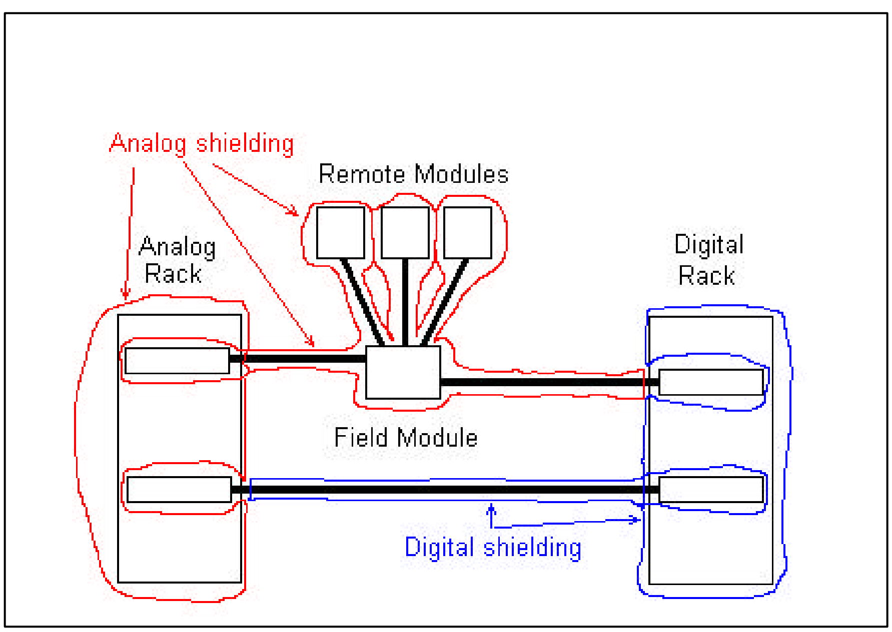
An effective method to reduce the noise transmitted into a circuit on a wire is to capacitively shunt it to the shield. The filtered feedthroughs that we employed in the HEPI installation shunt high-frequency noise to the enclosure with capacitive RFI filters. In this way noise on the wire, however it got there, is stopped from interacting with the circuitry inside the box.

2.3 Grounding scheme

The grounding scheme used in the HEPI installation followed, as closely as was feasible, the recommendations found in the EMC paper cited above (which gives better detail than can be found herein). The custom cables were made with either one or both ends' datashell tied to the cable shield, as needed.

Sometimes shielding can be looked at as a contiguous envelope that begins at one enclosure where the cable shield is then tied. It then follows that shield to the enclosure of a remote box, which is floating from all other grounds (such as an optical table, or enclosure). Any cables emanating from this box should also continue the shield to the final unit. If, however, the destination of this signal is grounded at another point, say, another rack, the shield should stop just short of tying to its enclosure. This allows for maximal shielding without creating big ground loops. In passing through one crate, through a rack wall, through another rack wall, and into a module, there are 4 cables whose grounding needs to be carefully considered. Figure 1 shows the idea behind the contiguous shielding. Figure 2 shows the generic cable grounding and shielding scheme that was employed in HEPI. Notice that the shield of the first cable (1) is ungrounded. The next two cables (2 & 3, following the signal from left to right) are tied to the digital rack wall. The third cable, which travels from the Digital rack to the Analog rack, has its shield tied only at the Digital rack, not at the Analog rack side as well. This is because we didn't want to tie the two racks' grounds together through the cable shield. The shield on the next cable, inside the Analog rack, is then grounded at both ends.

Figure 1



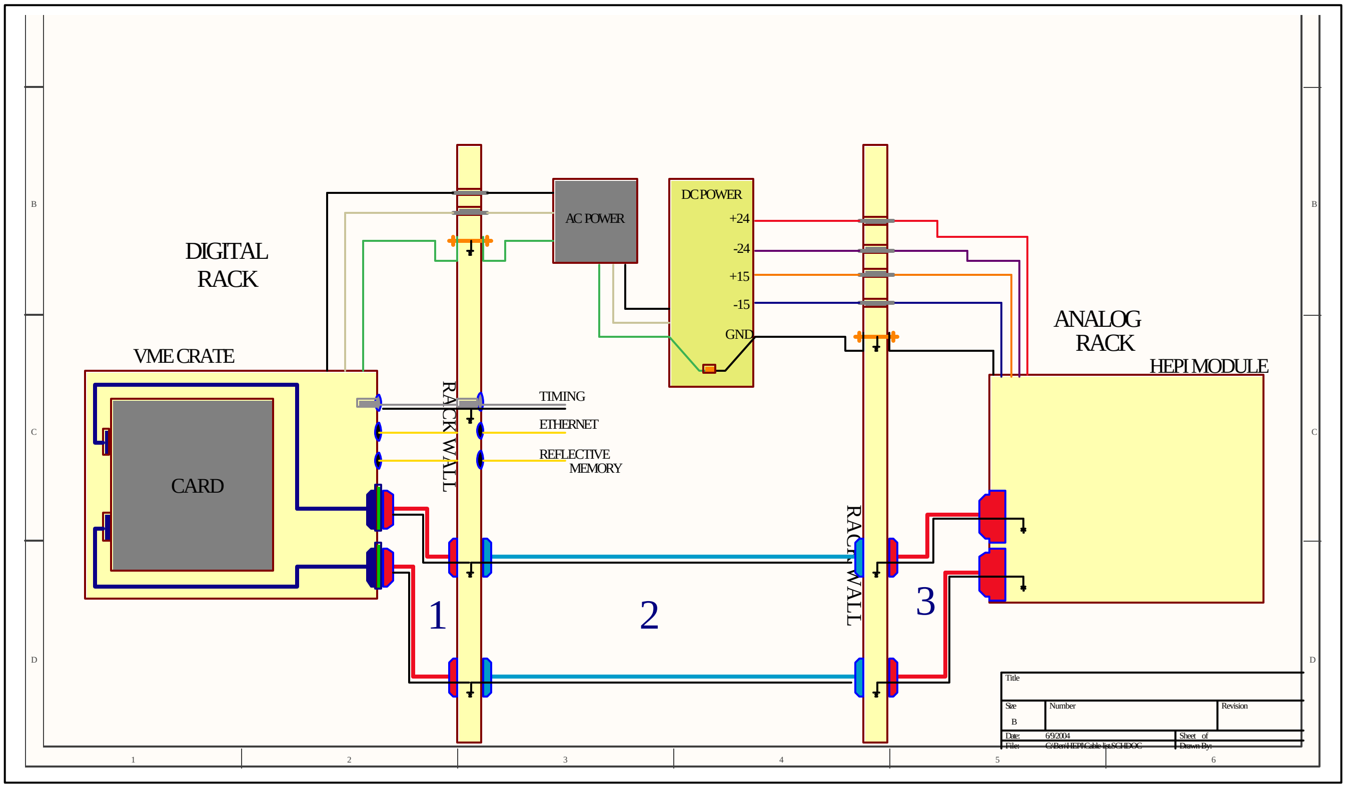


Figure 2

3 Hardware

3.1 Connectors and Feedthroughs

There are four types of connectors that were used in the HEPI installation at LLO. The first were RFI filtered connectors purchased from CONEC [2]. The second kind was the non-filtered cable-end connectors bought from CONEC to mate to the specialized filtered ones. The third type were LEMO [3] connectors that were used to distribute the timing signals. The last ones were fiber optic connectors that distributed both the reflective memory system, and the fast Ethernet.

3.1.1 Filtered Connectors and Feedthroughs

Several types and sizes of filtered connectors were used, but all were some variety of the D-subminiature form factor, and most had a shunt capacitance of 1300pF. We used 9, 15, and 50-pin right-angled, PCB mount connectors in the modules. To penetrate the rack and crate walls, feedthroughs of the same pin count were used. To get DC power into the racks we used three-pin power feedthroughs. These feedthroughs were rated at 20A, and had the same outline as a regular 15-pin connector. In order to keep the 15V separate from the 24V, we used different genders of the same connector. The CONEC catalog has a section for making your own part numbers for these connectors, and this can be useful when a specific trait needs to be changed. For example, the part number 242 A 17660 has certain parts that have meanings, and can be altered to suit a particular need. The "24" in the beginning means that it belongs to the filtered D-subminiature connector family. The following "2" dictates that it is a socket (F) connector of standard voltage rating (DWV of 300VDC). The “A” is a measure of gold flash thickness that dictates how many mating cycles the connector is rated for (50). A rating of “J” means that the connector is good for >500 cycles. The “1766” is the serial number dictating the number of pins, the pin size and spacing, and the capacitance value of the RFI cap. Lastly, the trailing “0 X” simply signifies that it is a standard part. The part numbers of the filtered connectors that we most commonly used in the HEPI Installation are presented in Table 1 below.

Part description	**CONEC part #**
50-pin EMI Panel Mount Feedthrough	243 A 10140 X
50-pin EMI PCB Male Connector	241 A 24190 X
50-pin EMI PCB Female Connector	242 A 24090 X
15-pin EMI Panel Mount Feedthrough	243 A 10060 X
15-pin EMI PCB Male Connector	241 A 16070 X
15-pin EMI PCB Female Connector	242 A 17670 X
9-pin EMI Panel Mount Feedthrough	243 C 10050 X
9-pin EMI PCB Male Connector	241 C 16060 X
9-pin EMI PCB Female Connector	242 C 17660 X
2 pole, keyed (F) power connector (misc. DC +12, +36 etc.)	2W2CSC05S42A30X
2 pole, keyed (M) power connector (misc. DC +12, +36 etc.)	2W2CPC05S42A30X
3-pin Right Angled PCB Mount (M) Power Connector 100nF	3W3SPC28S56K40X
3-pin Right Angled PCB Mount (F) Power Connector 100nF	3W3SSC28S56K40X
3-pin straight, filtered (F) (+/- 5VDC)	3W3SSC05S42A30X
3-pin straight, filtered (M) (+/- 5VDC)	3W3SPC05S42A30X
3-pin keyed, filtered (F) (+/- 150VDC)	3W3CSC05S42A30X
3-pin keyed, filtered (M) (+/- 150VDC)	3W3CPC05S42A30X
5-pin straight, filtered (F) (+/- 15VDC, +/- 24VDC)	5W5SSC05S42A30X
5-pin straight, filtered (M) (+/- 15VDC, +/- 24VDC)	5W5SPC05S42A30X

Table 1.

Gaskets need to be used to ensure the RF seal around the connectors as they pass through a rack wall or module panel. The appropriate gaskets for these connectors are available from Newark [4]. Their Newark part numbers are: 51F3688 for the 50-pin connector, 51F3660 for the 15-pin, and 51F3699 for the 9-pin one.

3.1.2 Non-Filtered CONEC Connectors

There were several connectors that had to be bought from CONEC to connect with their filtered ones. These connectors are the cable-end connectors that allow mating with the panel feedthrough power connectors, or the PCB right-angled type.

Part description	CONEC part #
2-pin, keyed, un-filtered (F) cable-end crimp	2W2CSCXXS42A10X
2-pin, keyed, un-filtered (M) cable-end crimp	2W2CPCXXS42A10X
3-pin, straight, un-filtered (F) cable-end solder cup	3003WSCM42A10X
3-pin, straight, un-filtered (M) cable-end solder cup	3003WPCM42A10X
3-pin, straight, un-filtered (F) cable-end crimp	3W3SSCXXS42A10X
3-pin, straight, un-filtered (F) cable-end crimp	3W3SPCXXS42A10X
3-pin, keyed, un-filtered (F) cable-end crimp	3W3CSCXXS42A10X
3-pin, keyed, un-filtered (F) cable-end crimp	3W3CPCXXS42A10X
5-pin, straight, un-filtered (F) cable-end crimp	5W5SSCXXS42A10X
5-pin, straight, un-filtered (F) cable-end crimp	5W5SPCXXS42A10X

3.1.3 LEMO Connectors and Feedthroughs

The only LEMO connectors we used were the two-pin cable-end male connectors (FGG.0B.302.clad52), and the associated panel-mount connector (EGG.0B.302.CLL).

3.1.4 Fiber Optic connectors

Since fiber optics neither absorb nor radiate EMI radiation, the connectors used need only be selected by considering their size. Any would work, in principle, but the smaller varieties need a smaller hole through the panel, and therefore are less of an RFI risk (see implementation section for more details). We used the ST type connector on the HEPI system. This connector is already commonly used in LIGO, so should not present any compatibility problems with existing hardware. For the Ethernet connection, we used a Startech [5] 10/MBPS RJ45 To Fiber converter to translate the electronic signal to fiber, and back again. That way, the Ethernet signal run could not be at risk to external RFI.

3.2 Enclosures

There were four types of enclosures that we used for the HEPI installation. The first two types were both bought from OKW Enclosures Inc. USA [6]. The first was a 19" rack mount variety, and the second was a field box assembly. While they offer some protection from RFI, they could benefit from gasketing around some of their seams in units that are especially vulnerable to interference. The boxes are both anodized aluminum, and structurally robust in their construction. The part numbers for the 19" rack-mounted boxes are: M5910035 for the 1U box, M5920035 for the 2U box, and M5930035 for the 3U model. The boxes on the tables are from the uniCASES line of OKW, and should be selected based on the size enclosure needed. All of the front panels for these enclosures were custom milled for us by Front Panel Express [7]. The third type of enclosure used was the 19” RFI rack. These racks we ultimately decided to standardize on were manufactured by Knurr [8], and provide a good deal of RFI shielding for the crates inside. The number for the Marshalling racks is: MR33894 CAL TECH 19” MIRACLE RACK, 600D, EMC. The Control racks were Part# CALEMC4101 CAL TECH 19” MIRACLE RACK 41U/800W/800D EMC W/ #MR34521 fan set. The last enclosure is the RFI VME crate made by Dawn[9]. This new crate houses the VME modules inside the rack. Any cable penetrations through the racks and crates were done through custom-milled panels, again made by Front Panel Express. The information on these racks is as follows:

FULL BACKPLANE:

8U(H) x 22"(D) 19" Rackmount VME64 Chassis, with:

- 3.5" recessed 6U160 Card Cage
  1101.10 Inject/Eject Rails with EMI gaskets
- Standard 21 Slot, VME64 Monolithic J1/J2 Backplane:

(Dawn BP part number: 06-1003052-1224)

J1 = 3 row, 96 pin, DIN, 5mm-tail connectors
J2 = 3 row, 96 pin, DIN, 13mm-tail connectors, w/shrouds
On Board Termination, With Noise Filtration Capacitors
Automatic BUSGRANT/IACK jumpering

- 600W Power Supply (Dawn part number: 50-1010498, or equivalent)
  Providing: Input: 85-264VAC, Frequency: 47-440Hz

Peak Listed (+5V@120A, +12V@10A and -12V@4A)

- Threaded 1/4-20 ground stud on rear of chassis
- 1U x 17" front panel for LED's
- Hinged easily removable front door, w/6ea., #6 captive thumbscrews

Stiffener added for improved stability of front door

- With rounded phosphor-bronze strip, or a conductive elastomer EMI gasket
  (on all door to chassis connections)
- Rear blank I/O panel
- Improved Top and bottom cable passages (Increase cutout by 25% in the bottom air deflector to allow for more convenient cable pass-through)
- Three (3) rear mounted (front to rear air flow) 150cfm DC fans, with improved air inlet filter
- Alodine finish on aluminum(conductive)
- Inner dimension decreased from 17.180” to 16.980” (no effect on backplane mounting)
- Fully Assembled, Tested, and Ready for Use

Dawn Part Number: 11-1012099-07

(cont.)

SPLIT BACKPLANE:

8U(H) x 22"(D) 19" Rackmount VME64X Chassis, with:

- 3.5" recessed 6U160 Card Cage
  1101.10 Inject/Eject Rails with EMI gaskets
- Dual, 10 Slot, VME64 Monolithic J1/J2 Backplanes:

(Dawn BP part number: 06-1003041-1224)

J1 = 3 row, 96 pin, DIN, 5mm-tail connectors
J2 = 3 row, 96 pin, DIN, 13mm-tail connectors, w/shrouds
On Board Termination, With Noise Filtration Capacitors
Automatic BUSGRANT/IACK jumpering

- 600W Power Supply (Dawn part number: 50-1010498, or equivalent)
Providing: Input: 85-264VAC, Frequency: 47-440Hz
Peak Listed (+5V@120A, +12V@17A and -12V@10A)
- Threaded 1/4-20 ground stud on rear of chassis
- 1U x 17" front panel for LED's
- Hinged easily removable front door, w/6ea., #6 captive thumbscrews
Stiffener added for improved stability of front door
- With rounded phosphor-bronze strip, or a conductive elastomer EMI gasket
(on all door to chassis connections)
- Rear blank I/O panel
- Alodine finish on aluminum(conductive)
- Improved Top and bottom cable passages(Increase cutout by 25% in the bottom air deflector to allow for more convenient cable pass-through)
- Three (3) rear mounted (front to rear air flow) 150cfm DC fans with improved air inlet filter
- Inner dimension decreased from 17.180” to 16.980” (no effect on backplane mounting)
- Fully Assembled, Tested, and Ready for Use
Dawn Part Number: 11-1012099-08

3.3 Cables

All of the cables that were used in the HEPI installation have an overall foil shield, and are twisted pair. Some are Belden Spectra strip cable. This type was used for mass-term field cabling and the majority of the cables, which were manufactured by Wilco Wire [10]. The custom cables came in two varieties: straight through pinned rolled ribbon, and custom pinned twisted-pair cable. The rolled ribbon was specified to be Belden Spectra-strip, and the other cable for the ICS110B was just to be twister-pair, overall shielded. The ICS110B cable was made by Positronic Industries [11] because they make the 44-pin connectors that are on the ICS modules.

4 Implementation

There are several things that should be done to get the most out of the RFI hardware chosen. Special attention must be paid to appropriate grounding of the cables to the datashells, and the connectors to the boards and boxes. A new schematic part should be made in Protel that has two extra pins that are connected to ground. These pins should then correspond to the two pins on the mounting brackets in the PCB part. Without doing this, the filtration is rendered invalid. Also, all cables that pass through enclosure walls should be treated in such a way as to protect the RFI integrity of the enclosure. Signal cables should go through a panel-mounted feedthrough that is grounded to the enclosure wall. These and all module connectors should have the appropriate gasket between them and the panel to which they are attached. Some physical modification of the gaskets may need to be performed depending on whether the connector is being mounted from the front or the back of the panel. Any other entrance into the rack should be done with a hole that acts as a waveguide with suitable cutoff frequency. A ½-inch hole has a low-enough cutoff frequency, and leaves enough room to get the Ethernet and reflective memory fibers through.

In order to make our solution as applicable as possible, we took some steps to use generic parts that might be most widely useful. For example, the panels that hold the feedthroughs in the rack wall were made into generic 9-pin, 15-pin or 50-pin panels, instead of making a specific panel for each application. In this way, we could make panels that are interchangeable with other systems, and we wouldn't have to redo a panel if the wiring scheme changed. Any holes in the panels that are not used should be covered with an appropriate sized blank with a gasket underneath. Also, we chose three standard connector types. By using 9, 15 and 50-pin connectors exclusively, we minimized the number of different connectors bought. We also made the custom cables much more interchangeable, and cut down on the number of spares needed. Whether you are connecting to a 50-pin 3113, a 40-pin Pentek, or a 44-pin ICS110B, all of the feedthroughs on the rack walls, and all of the cables between the module and the VME crate feedthrough are all 50-pin types. This makes for a more interchangeable system that can be reconfigured with ease. Only the cable inside the VME crate itself has the correct interfacing connector on the VME card end.

5 Improvements

Now that the HEPI installation is coming to a close, we can look back and see that, while our efforts will suffice there, room for improvement exists. In the 24V power connectors, for example, we used a female connector on the board. This means that the connector on the cable needs to be male, and 24V could be exposed on protruding pins of the male cable connector. This could result in a highly unlikely, yet possible short on the power line. A better option is to use a special connector offered by CONEC that has both genders on it. They sell connectors that have two female pins that flank a male pin in the middle. The female pins could be used to carry the voltages, and the male pin could carry GND. This way there is much less possibility of electrical mishap, but at the same time, it's still not possible to mix the 15V with the 24V connector.

Another place that could bear further speculation are the boxes and rack modules used. As they stand, they offer some RFI protection, but could do more. Discussions with OKW have revealed their willingness to develop a new line of enclosures that is more RFI compliant. Further discussions with them may produce a more enticing enclosure for us to use.

6 Resources

1. *EMC, Shielding and Grounding Retrofit Plan* M.Zucker, J. Heefner LIGO-E020350-08-R
2. CONEC inc.- http://www.conec.com 919-460-8800
3. LEMO USA - http://www.lemousa.com 707-578-8811
4. Newark - www.newark.com 1-800-4-NEWARK
5. Startech – www.startech.com 1-800-265-1844
6. OKW Enclosures - http://www.okwenclosures.com/index.html (800) 965 9872
7. Front Panel Express - http://www.frontpanelexpress.com (206) 768-0602
8. Knurr - http://www.knurr.com/index0.htm (805) 526 - 7733
9. Dawn VME Products - http://www.dawnvme.com (510) 657-4444
10. Wilco Wire – http://www.wilcowire.com (510) 249-9000
11. Positronic Industries - http://www.connectpositronic.com 800-641-4054