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A New Dead Channel Monitor in the Virgo Detector Monitoring System

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Abstract

This paper discusses the design and implementation of a new Dead Channel Monitor in the Detector Monitoring System (DMS). The Dead Channel Monitor raises alerts if an environmental sensor has stopped functioning, for reasons such as being powered off or disconnected. The Dead Channel Monitor uses each sensor's rms signal to determine whether the sensor is working or not, for 48 fast sensors which include accelerometers, seismometers, microphones, magnetometers, and voltage and current meters. In order to use rms to distinguish between On and Off states for many of these sensors, a wiring change was necessary in order to reduce power-off noise. After completing the wiring changes, rms thresholds were set in the new Dead Channel flag in the DMS. The Dead Channel Monitor has been fully functional and working reliably for several weeks now.

1 Introduction

Dozens of environmental sensors at the Virgo interferometer (e.g. accelerometers, magnetometers, thermometers, etc.) monitor environmental noise conditions throughout the interferometer and its surroundings. The output of each sensor is processed as a separate *channel* of data. Environmental channels at Virgo are categorized into fast channels and slow channels. Fast channels include seismometers, accelerometers, magnetometers, microphones and power supply current and voltage monitors, which collect data at sample rates of $\sim$ 20kHz. Slow monitors process data at lower sample rates for sensors such as thermometers.

Understanding environmental conditions matters for several reasons. Environmental changes, such as seismic events can affect control loops in the optical cavities, producing misalignments or even unlocks. Furthermore, some environmental conditions are dangerous to the interferometer. For this reason, the Virgo Detector Monitoring System (DMS) [1] exists to raise alerts when certain sensors indicate a change beyond the acceptable operating conditions (e.g. an alert is raised if the temperature becomes too high).

The Detector Monitoring System is organized such that each condition to monitor is represented as a colored flag. The main flags are grouped according to seven divisions, one of which is the Environment. Each main flag can have groupings of subflags within it. When a flag's condition is not met, the flag turns from green to red. Each main flag is only green if all of its subflags are green.

This paper discusses the design and implementation of a new Dead Channel Monitor in the Detector Monitoring System. The Dead Channel Monitor has flags to raise alerts if an environmental sensor has stopped functioning, for reasons such as being powered off or disconnected. Among other reasons, this monitor is necessary because many of the environmental sensors have delicate power supplies, which can easily be accidentally shut off when work is done near them. The Dead Channel Monitor monitors 48 fast environmental channels, using each sensor's rms signal to determine whether the sensor is working or not.

For each channel, Virgo stores to disk many months of data sampled at 20MHz (exact sampling depends on the channel), known as fast data. To allow plotting over large amounts of time, the fast data is also down-sampled at 1 Hz. This down-sampled *trend data* is available with the mean, minimum, maximum, or rms of each second of fast data. At Virgo, the rms of a channel refers to the root mean square of the signal amplitude *after the mean signal has been subtracted*, i.e. the square root of the variance. This rms can equivalently be determined from integrating under the power spectral density (PSD) of a signal.

2 Preliminary Investigation

Use of sensor rms to set thresholds for the Dead Channel Monitor requires, of course, that the rms of a fully-functioning channel be significantly higher than the rms of a dead channel. At the start of this project, we discovered that this was not the case for many channels. Many channels had a power-off rms that approached or occasionally exceeded the typical power on values. The source of the problem lay in the connection from the sensors' power supplies' output to the analog-to-digital converters (ADC). The ADC inputs connect by means of three-pin lemos. The power supplies' outputs have BNC cables. In the original configuration, the BNC core and shield connected to lemo pins 1 and 2, while lemo pin 3 connected to nothing at all. This configuration works when an oscillating voltage (i.e. the environmental sensor signal) is applied across the BNC. When the sensor is powered off or disconnected, however, ground loops develop due to the fact that the power supply and the ADC are grounded to different grounds.

We tested a new configuration in which the third lemo pin shorts to the second [3], [4]. Thus lemo pin 1 connects to the BNC core while pins 2 and 3 both connect to BNC shield, with the effect of establishing a common ground for the system. For these tests, we disconnected the output of the channels from the analog to digital converter (ADC) and connected them to an Onosokki spectrum analyzer. Power-off noise dropped by several orders of magnitude in all three channels. After re-connecting to the ADC, we tested the original and the new wiring configurations (by means of a circuit switch box inserted before the ADC) and found that the new configuration reduces the power-off noise to near the Onosokki level. We replaced the cables for all the channels that had this problem in the Central Building and Mode Cleaner Building, and tested the power on and power off noise with the old and new cables for each sensor.

Figure 1 illustrates the results of the cable tests for an example sensor- the External Injection Bench Microphone. The red and purple curves show the similarity between the power on and power off noise with the original wiring. The cable change does not have a significant effect on the power-on noise; the purple and black curves are in fact barely distinguishable from each other in the plot. The power off noise, however, is reduced by several orders of magnitude with the new cable (compare green and red curves). With the new configuration, the power-off noise (green) approaches the ADC level. We performed similar tests with various combinations of disconnecting the sensors, or disconnecting the sensors' power supplies, or powering off the power supplies. We obtained similar results, and so for the remainder of this paper I will use 'off' to refer to the entire set possible powered off or unplugged scenarii, unless otherwise specified.

3 Establishment of the Dead Channel Monitor

Changing the wiring enables the use of rms as a discriminant between on and off states. Preliminary thresholds were set using trend rms data. The preliminary tests produced a plot similar to Figure 1 for each sensor. In this type of plot, the left-most point on the rms curves indicates the total rms of the signal (i.e. square root of the integral under the whole PSD). For most channels, the rms for On and Off states were separated by several orders of magnitude, and so preliminary thresholds were set by choosing a threshold one order of magnitude below the On rms. This threshold choice is still far above the power Off state but allows the On rms to fluctuate with changing noise conditions without setting false alarms. For channels with a smaller separation between On and Off rms, intermediate thresholds were chosen. After setting up the Dead Channel Monitor, tests for all the sensors verified that unplugging or powering off the sensors raises the desired alert and that false alarms are very rare during normal environmental conditions. The Dead Channel Monitor has been successfully operating as intended for the last several weeks.

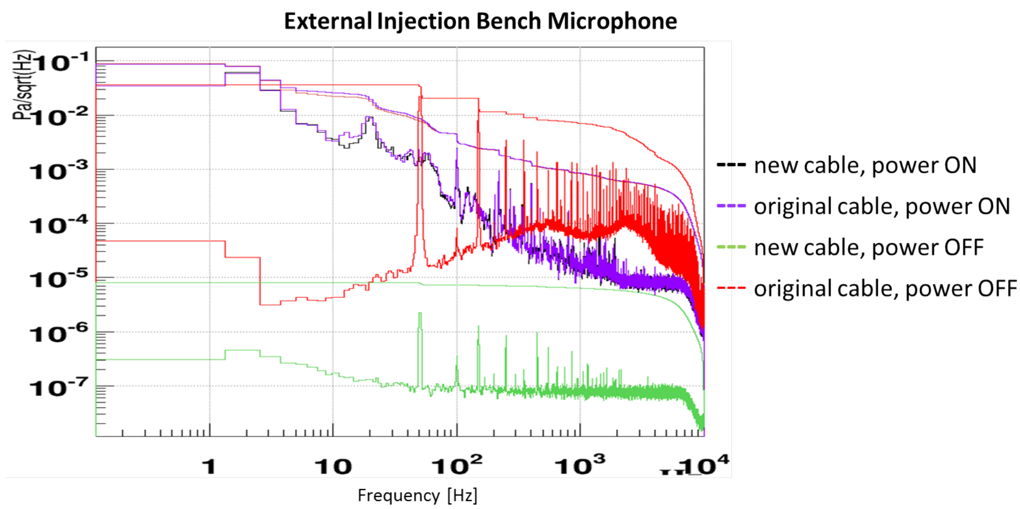

Figure 1: **Power Spectra and rms with new and old cables.** Each pair of curves shows the power spectra and cumulative rms (rms is displayed as the cumulative integral of the power spectrum, integrated from high to low frequencies) of a particular configuration (see legend).

3.1 Using Percentiles to Set thresholds

The empirically-set thresholds in the present system work, but a statistical characterization of the channels allows thresholds to be optimized in a different way. Computing the distribution of the trend rms over a 1 week period allows thresholds to be set by percentiles. The green curve in figure 2 shows the cumulative distribution of the power-On rms over a one-week period (the first week of June) for an example sensor (the central building west-oriented magnetometer). The red curve shows the distribution for a day when the sensor was off. Cumulative distributions enable the computation of percentile thresholds for each sensor. For example, we could choose to set a threshold such that the rms falls below the threshold 0.1% of the time that the sensor is powered on. This would ensure that false alarms are not only rare but also that we know precisely how rare they would be.

Power off distributions were calculated for the sensors for which an Off period was available. For this statistical characterization, we would ideally have an rms distribution over a week when the sensor was off and a week when the sensor was on. Since the sensors are in use, however, long off-periods are not generally available. In this project, power on statistics can be computed for all sensors and power off statistics are computed where possible.

Figures 3 and 4 display the same distributions as figure 2 in the form of normalized histograms, also for the central building west magnetomter. If the sensor detected pure, stationary Gaussian noise, we would expect the rms to follow a Rayleigh distribution [2]. Clearly it does not, even for the power-off state. Note that not only are the distributions not Rayleigh, but have multiple peaks. This behaviour of this magnetometer is typical of many sensors.

Since the noise is not stationary, setting thresholds by statistical theory would require different methods. Since the power-on and power-off distributions are separated by several orders of magnitude, however, the empirically-determined thresholds work well. Furthermore, we use a persitency requirement to further minimize false alarms without missing serious events. The Dead Channel Monitor main flag in the DMS turns red when a subflag has been below its set threshold for a full hour. The color of the subflag, however, always reflects the current state of the channel. This persistency requirement on the main flag ensures that brief events do not raise false alarms.

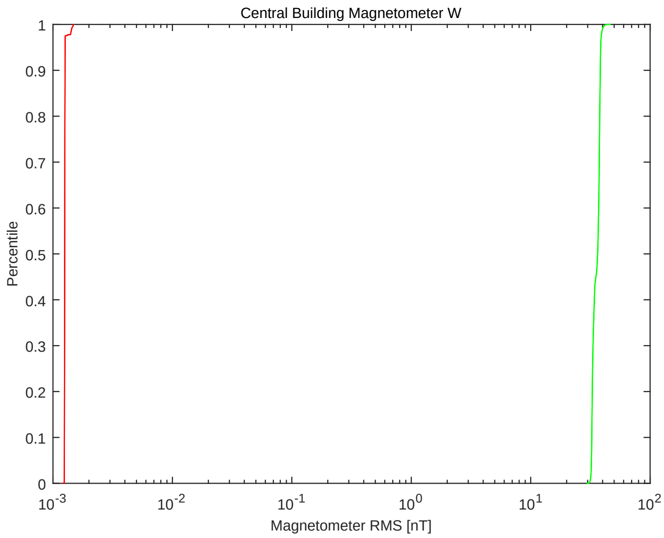

Figure 2: **Cumulative distributions of rms for an example magnetometer.** The green curve shows the distribution of rms over a one week period when the magnetometer was on. The red curve shows the distribution of rms for a day that it was off. Note that the distributions are well-separated even on a logarithmic scale.

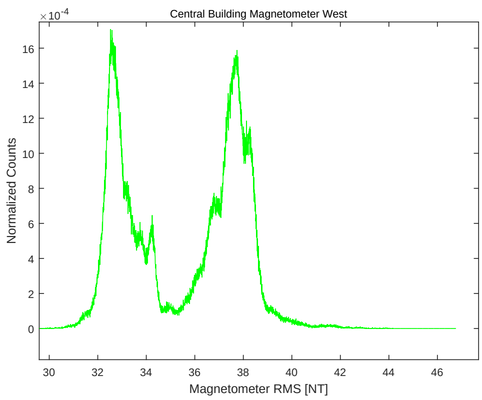

Figure 3: **Binned, normalized distribution of Power-ON RMS for Central Building Magnetometer West**. This distribution was computed for a week of rms trend data.

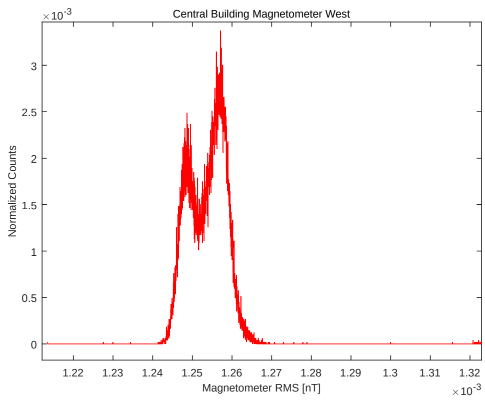

Figure 4: **Binned, normalized distribution of Power-OFF RMS for Central Building Magnetometer West**. This distribution was computed for a day of rms trend data. Note that the distribution is not Rayleigh distributed.

3.2 Percentile Spectra

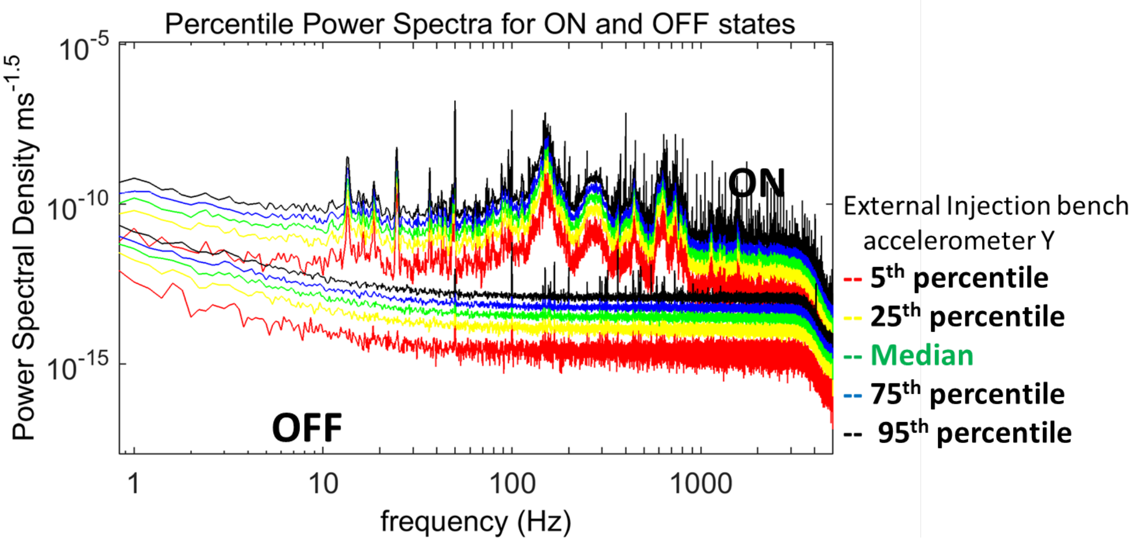

Figure 5: **Percentile Power Spectra for an Example Accelerometer.** Each set of percentile spectra is calculated from the power spectra of 100 successive 5-second intervals. The lower set of spectra is from a time when the sensor was off and the upper set of spectra is from a time when the sensor was on.

Percentile power spectra give a more detailed characterization of the sensor noise. Percentile spectra describe the statistical distribution of power at each frequency bin. Figure 5 shows the percentile power spectra for an example sensor, the External Injection Bench vertically-oriented accelerometer. The spectra were produced by computing the Power Spectral Density (PSD) of 100 successive 5-second intervals and then computing the cumulative distribution for the power in each frequency bin. Percentile spectra are then produced by plotting a given percentile at each frequency bin. Figure 5 displays the 5th percentile, 25th percentile, median, 75th percentile, and 95th percentile for the On and Off states of the example accelerometer.

4 Conclusions

The Dead Channel Monitor in its present configuration has been working for several weeks. During this time, various events that involved the unexpected powering-off or unplugging of sensors (e.g. near-by work accidentally disturbed power supplies and a magnetometer was temporarily relocated for a different project) have tested the Dead Channel Monitor and shown that it is reliable. The dead channel monitor currently monitors 48 fast sensors (accelerometers, microphones, magnetometers, seismometers, etc.). The Dead Channel Monitor appears as one of the main flags under the Enviromental category in the DMS. Under the Dead Channel Main flag, the 48 subflags are grouped according to the location of their channel's ADC. The groups are: Electrical Engineering (EE) Room, Data Aquisition (DAQ) Room, Mode Cleaner Building (MCB), West End Building (WEB), and North End Building (NEB). In the future, the Dead Channel Monitor could be expanded to include slow-monitor channels such as thermometers.

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[4] Virgo logbook entry `https://tds.ego-gw.it/itf/osl_virgo/index.php?callRep=32431` 3