Magnetic noise of Vacuum rack components: measurement and distance constraints for Advanced Virgo.

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Introduction

We are well aware of the noise in hrec due to environmental magnetic fields coupling to the test mirror magnets [1,2]. Section 1 summarizes the maximum environmental B fields to which Advanced Virgo mirrors can be exposed, in order for the magnetic noise not to affect the AdV design sensitivity. Preliminary measurements we did with the Virgo interferometer indicated that vacuum racks are important sources of magnetic noise (eLog 21327). One of these measurement is illustrated in Figure 1 below. In Section 2 we describe measurements of the emitted B-field modulus at 1m distance from single components. In Section 3 we make a tentative extrapolation of measured B fields with distance and compare this to the set limits. We conclude giving indication for safe distance-from-towers location of the racks.

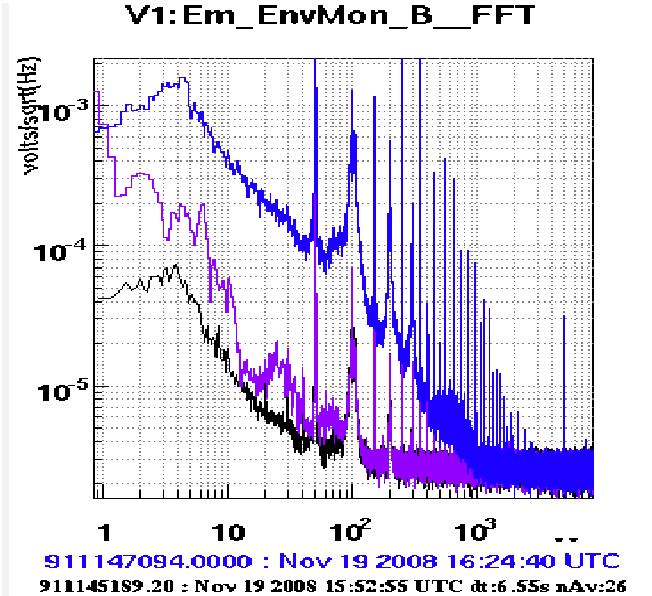

Figure 1: plot from eLog 21327. Measurement of magnetic field at 1m from SR vacuum rack: black= all rack OFF, blue=RACK ON, purple = only TCM on (powered separately on UPS). Vertical axis calibration: 1E-4 V corresponds to 1nT.

1. Magnetic noise limit for AdV

In note [3] we derived the maximum tolerable amplitude of environmental B field modulus in the AdV experimental areas. We recall that this is computed using the B to hrec transfer function measured for Virgo mirrors (far-field injection data from eLog 22108) and scaling it by a factor 5 as measured coupling reduction for the new payloads with dielectric RM (eLog 28260), assuming also the same mirror magnets strength. The maximum B spectral amplitude turns out to be 5pT computed over 1Hz bandwidth. This limit holds strictly for B spectral amplitudes between 0 and 50Hz. Here we make the following step further. The coupling TF between the B environmental field and hrec is measured to scale approximately as the cube of frequency[1]. On the other hand, starting from about 50Hz the AdV hrec sensitivity flattens (and then starts rising up above 500Hz). Thus, from frequencies of 50Hz and higher the 5pT limit on B is too requiring. We can scale this limit as the cube of frequency, that is to say: limit(f) = (5pT)*$(f/50)^3$, for f > 50Hz. The overall limit is summarized in Table 1 and the corresponding noise projection is illustrated in Figure 2. We stress that this limit already accounts for the shielding effect of towers "oven" plus vacuum chambers.

[1] A f^{-3} frequency dependence of the B field to hrec TF is measured (see for example 22108). Out of this, a factor f^{-2} arises when converting the mirror acceleration (due to magnetic force on mirror magnets) to mirror z displacement. We interpret the additional factor 1/f to be due to the low-pass filter action performed by the combination of the "oven" and the vacuum chamber starting from approximately 30Hz (see our measurements in [2] and [4]).

Frequency (Hz)	B field modulus amplitude (nT)
10-50Hz	5pT
100Hz	40pT
200Hz	300pT
600Hz	8nT
1000Hz	40nT

Table 1: maximum value of the magnetic field modulus in proximity of AdV test mirrors.

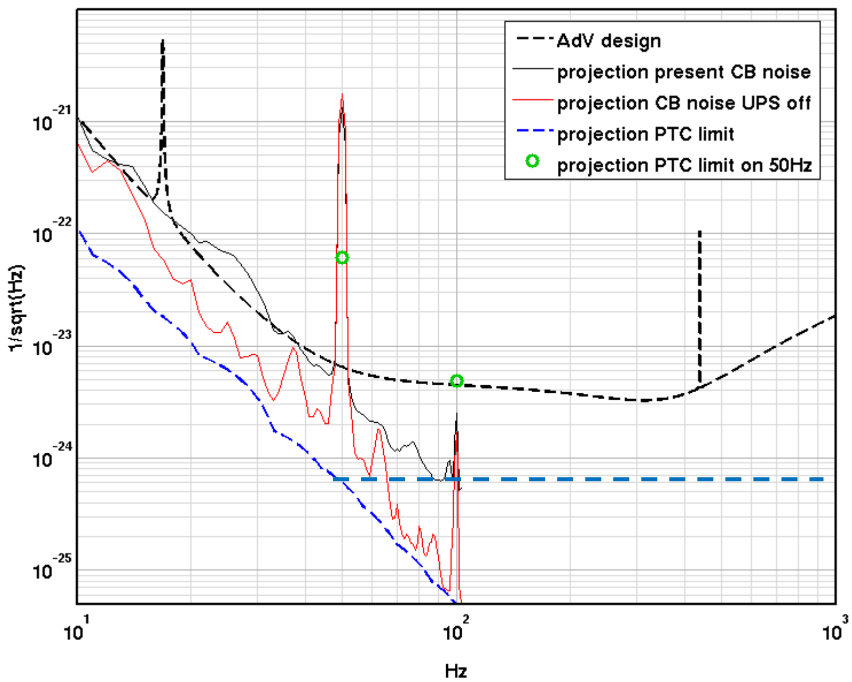

Figure 2. Taken from VIR-0135B-11. The dashed blue line depicts the hrec noise associated to a magnetic field at the AdV test masses which equals the limit values listed in Table 1.

2. Measurements

We examined the magnetic noise emissions of the following components of the vacuum rack:

- The rack Power Supply modulus,
- TCM, mod-1601 Pfeiffer (turbo-molecular pump controller),
- TPS, mod-200 Pfeiffer (turbo-molecupar pump controller),
- TPG, mod-256A Pfeiffer (sensors converter),

- VARIAN controller, three models: MULTIVAC (only modulus, no pump) MIDIVAC model and DUAL model (ionic pump controllers),

For test and reference purposes we also measured the noise emissions of:

- Turbo-molecular pump (model 1600 TMU),
- Scroll pump (Edwards, model ESDP 10). This is not the model in use in Virgo.

Figures 3 and 4 show the test setup at 1500N lab (Figure 3) and at 1200N (Figure 4). The measuring instrumentation consists of:

- One accelerometer, with vertical axis, piezoelectric (Bruel&Kjaer 4370 with charge amplifier 2635);
- One magnetic probe, tri-axial, fluxgate (http://www.stefan-mayer.com/FL3.htm), intrinsic noise 10 pT/sqrt(Hz) a 1 Hz, 5 pT/sqrt(Hz) at 10Hz and above.

Starting from the measured single-axis magnetic field components (B_x, B_y and B_z) we compute the magnetic field modulus: $B = \mathrm{sqrt}(B_x^2 + B_y^2 + B_z^2)$. This is the quantity we refer in the following as "magnetic noise" of the source.

Figure 3. Setup 1500N. Magnetometer and seismometer lay on the wooden test bench, and are both feed on battery power. Signals are read and FFT computed with the onosokki spectrum analyzer. The measured source barycenter (scroll pump in this picture) is at about 1m distance from the probes. The source device is deployed on one custom seismic isolator made of three 1cm^3 pieces of *sorbothane* rubber (http://sorbothane.com/) loaded with ≈15kg weight. The measured resonance frequency of this isolator is around 7Hz.

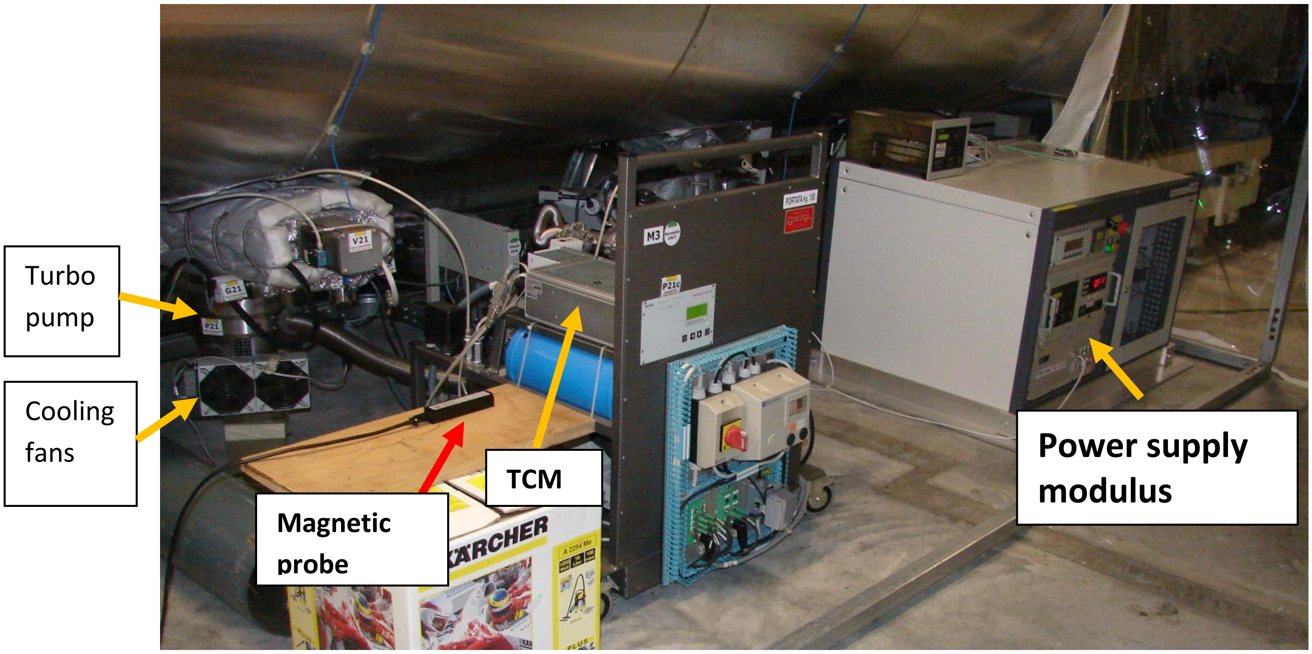

Figure 3. Setup at 1200N. Vacuum pumping station at 1200N along the Virgo N tube. The magnetic noise background is about 10 times larger than in the 1500N Lab. We measured the background noise approximately in the photographer position (i.e. about 5m from TMC and 7m from the power supply modulus, and 60cm from ground).

2.1 Test measurements with one Scroll Pump

We used one scroll pump to perform some preliminary checks.

2.1.1 Seismic noise decoupling

Aim of this first measurement is to check the effectiveness of the setup, and in particular to verify if the magnetic measurement is partly polluted with seismic noise. Examined sources emit magnetic noise (because of flowing currents) and seismic/acoustic noise essentially because of the cooling fans. In principle the magnetic probe, of flux-gate type, is sensitive to vibrations.
Figure 5 below, compares the test bench vibrations when the pump was switched off (yellow) and then turned on (blue), and after the addition of the seismic isolator between pump and the bench (red). The seismic isolator is described in Figure 3 caption.
The seismic isolator looks effective: Figure 5(top) shows seismic peaks (starting from the very first around 24Hz) reduce by at least a factor 4. Black dots in the figure indicate frequencies which have coherence greater than 0.5 with the magnetic sensor signal. Figure 5(bottom) shows the magnetic noise spectrum. We notice that, at seismically coherent frequencies, the magnetic noise does not decrease when the source is seismically isolated. Also, we notice several magnetic peaks exist (bottom Figure) which have no seismic counterpart in the top spectrum. We conclude that the magnetic measurement is not limited by bench vibration noise, wherever seismic noise is produced in association with magnetic noise, the magnetic probe results to measure the sole magnetic component of the noise.

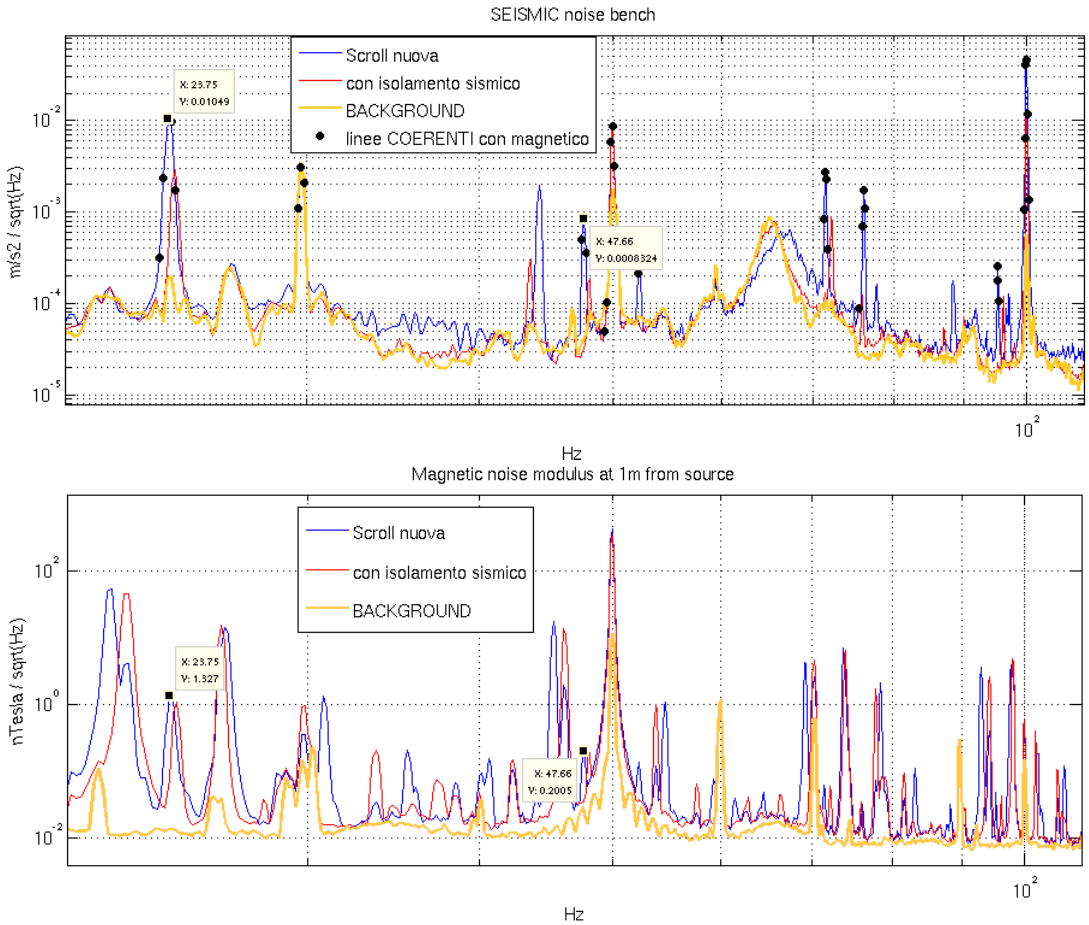

Figure 5: Scroll pump, test of magnetic versus seismic noise emissions and their measurement.

2.1.2 Powering the device with IPS or UPS

We know UPS generators produce a "dirty" electric power (eLog 25397). Comparative measurements of the EGO generators indicated that UPS voltage produce a broadband (0-1kHz) white voltage noise about ten times the noise level of the ENEL (aka "IPS") voltage, more precisely the amplitude of the noise depending on the type and size of the UPS generator (smaller UPS have less intense noise). When one electric device is powered on UPS we expect the white broadband magnetic noise component radiated by the device currents is proportionally more intense. Figure 6 shows magnetic field at 1 meter distance produced by the same scroll pump when powered on ENEL and when powered on the 1500N UPS line. Monochromatic peaks are not affected, but the broadband noise increases significantly.

In operative conditions vacuum racks are powered on UPS. To get a better idea of the magnetic noise emitted by each rack device in operative conditions, in the following we measure and compare the magnetic noise emission when the device is powered on both IPS and UPS. We have to keep in mind that UPS generators used for our measurements (Riello model) are of smaller size and thus less noisy than for example the big UPS (MGE model) at CB. Thus, in the following whenever we evidence a white noise emission from a device, we apply to it a factor x10 scaling for a conservative evaluation of the AdV noise.

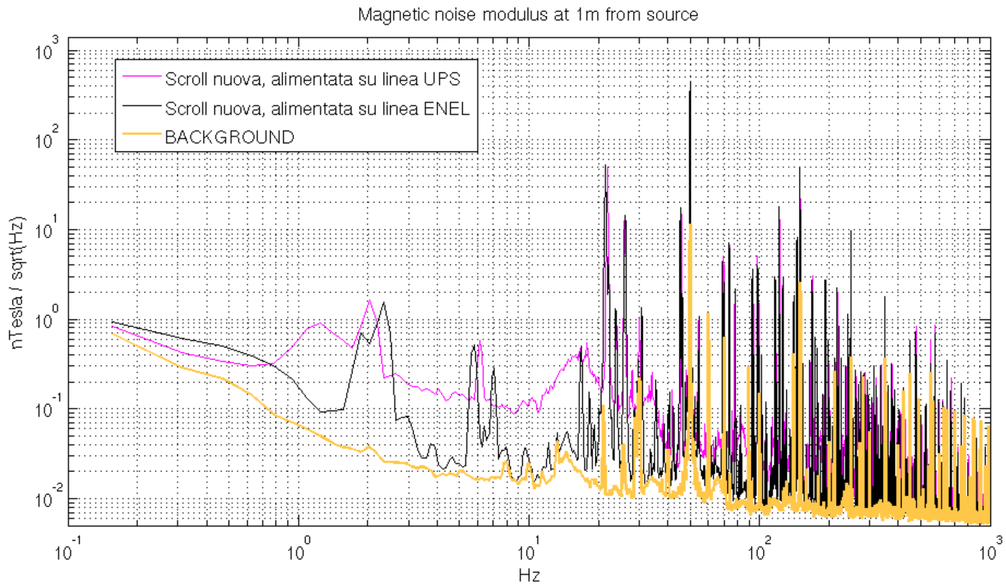

Figure 6. Scroll pump. Measured magnetic noise at 1m when the device is powered on UPS (magenta) or IPS (black) or off (yellow).

2.1.3 Magnetic noise decay with distance

Magnetic noise radiated from a source of geometrical size "d" models, at distances "r" larger than "d", as the field radiated by a magnetic dipole. The magnetic dipole field intensity is known to decay with a cubic power of the distance. Figure 7 below reports the measured B field intensity as function of distance from one TCM (see Section 2.7). The TCM largest size is d~0.5m. Thus our measurements, spanning from 0.25m to 1m, are not fully representative of the "far field" condition. In this measurement we find the amplitude of three lines, at 88Hz, 176Hz e 185Hz (Figure 14) attenuate with a distance power law "r^{A}", being "A" between 2 e 3. Note that we do not expect a frequency dependence of the decay law. The dispersion of the measurements should be explained as due to measurement uncertainty.

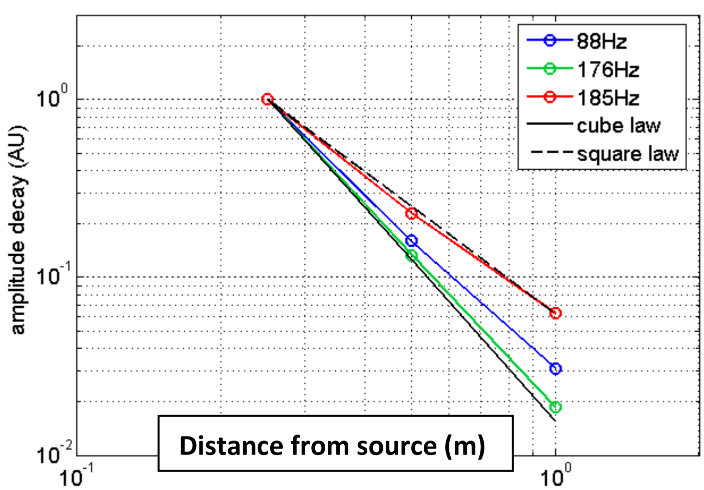

Figure 7. Measured decay of B field intensity when increasing distance from the source (one TMC modulus). The measurement is done for three different frequencies.

2.2 TPS 200, Pfeiffer

We do not detect any emitted noise at 1m distance (Figure 8: blue and yellow lines correspond to TPS on and off). We repeat measurements with the device rotated by 90deg around the vertical axis and around the horizontal axis and as well when UPS powered. The device does not emit also any audible noise or seismic noise (we deduce it has no active cooling device). As a check (to assure the device was actually working, in absence also of any led power indicator), we repeated the measurement with the magnetic probe very close to the device. This time a clear noise is detected as shown by light-blue and red curves (switching from IPS to UPS power lines).

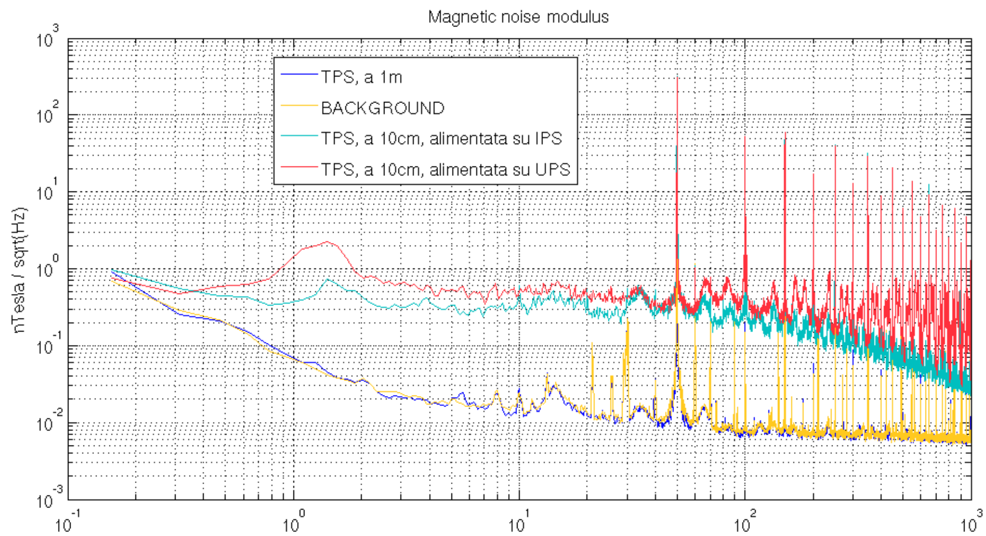

Figura 8. TPS, magnetic field noise at 1m distance (blue) and at much closer distance (light-blue and red). The red one corresponds to TPS powered on UPS.

2.3 TPG 256A, Pfeiffer

We do not detect magnetic noise exceeding the background at 1m (Figure 9). We repeat measurements with the device rotated by 90deg around the vertical (horizontal) axis and as well when UPS powered. Also well we do not detect any seismic noise emission, we hypothesize no active cooling is present.

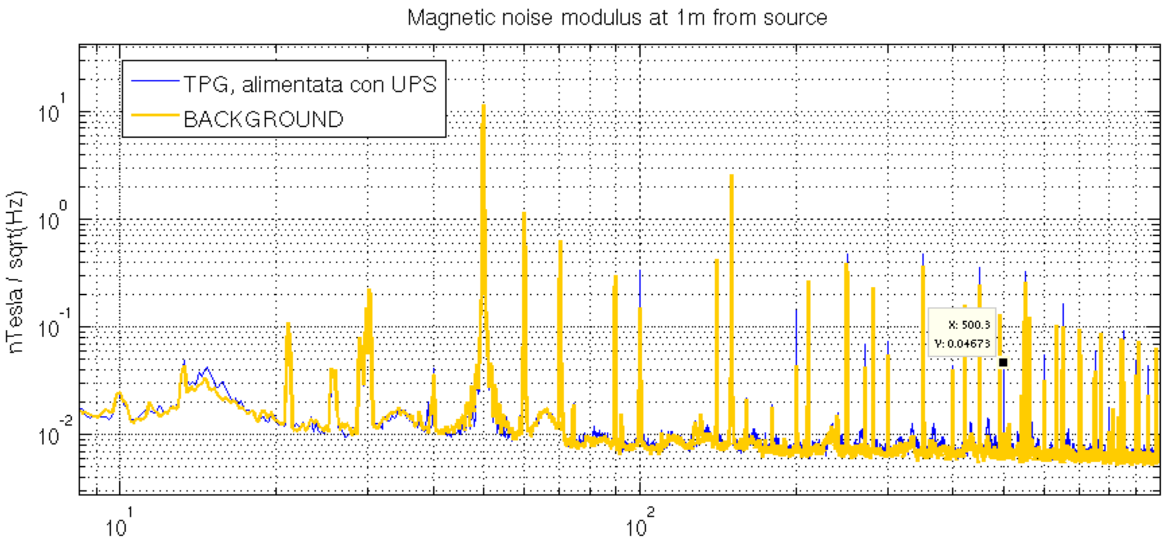

Figura 9. TPG.

2.4 VARIAN ion pump controllers

Ion pumps used to be off in Virgo but are to be kept operating for AdV. We tested three different models. The only missing magnetic datum is about the MULTIVAC model when connected to the ion pump.

2.4.1 VARIAN, model MULTIVAC EX929400

This is the model currently installed in most of VAC racks located in the experimental halls. We tested one of these at the 1500N Lab. It was operated standalone, i.e. without connecting it to the ion pump. Figure 10: we detect magnetic monochromatic noise emissions around 40Hz (and multiples), 130Hz, 201Hz and larger frequencies. Some of them (40Hz, 201Hz) are coherent with seismic noise (Figure 10,bottom) thus we suspect these might be associated to cooling fans (audible noise). We do not see appreciable noise increase when switching the device to the UPS power line.

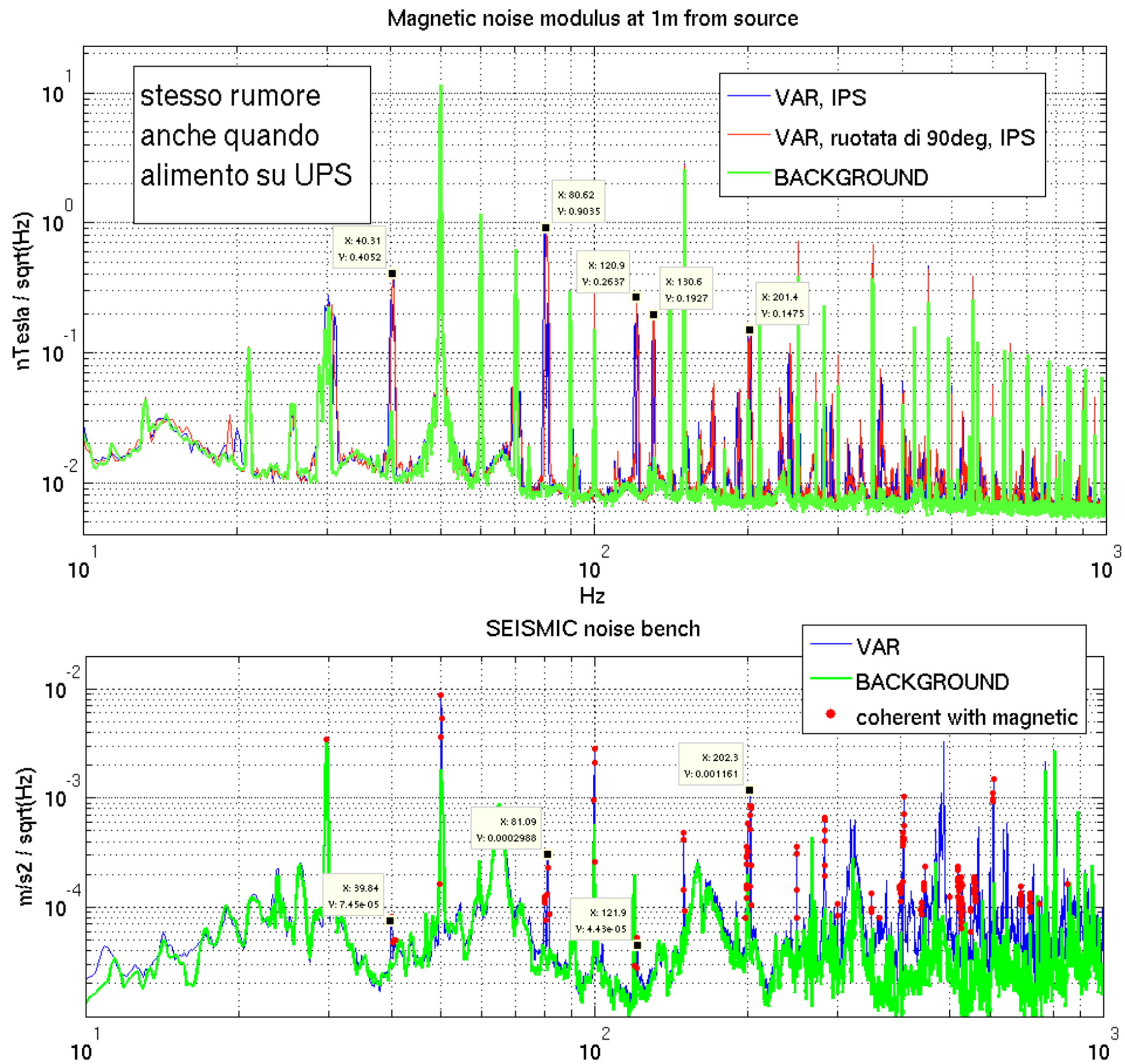

Figura 10. VARIAN, mod. MULTI-VAC (standalone, not connected to ion pump).

2.3.2 VARIAN, model MIDIVAC 929-5003

This module emits neither audible acoustic noise nor seismic noise, and we deduce it has no active cooling devices. When powered, but not connected to the ion pump, we also do not detect any magnetic noise emission at 1m. We connect it to the ion pump apparatus at 1500N Lab. The Varian display indicated a current flow of 8E-2 A. Figure 11 shows magnetic noise at 1m in this configuration. Peak noise is 1.1nT at 55Hz. To confirm the noise is emitted by the Varian and not by the pump, the magnetic probe is moved closer (about 0.5m) to the Varian: Figure 11(bottom) shows the noise increases.

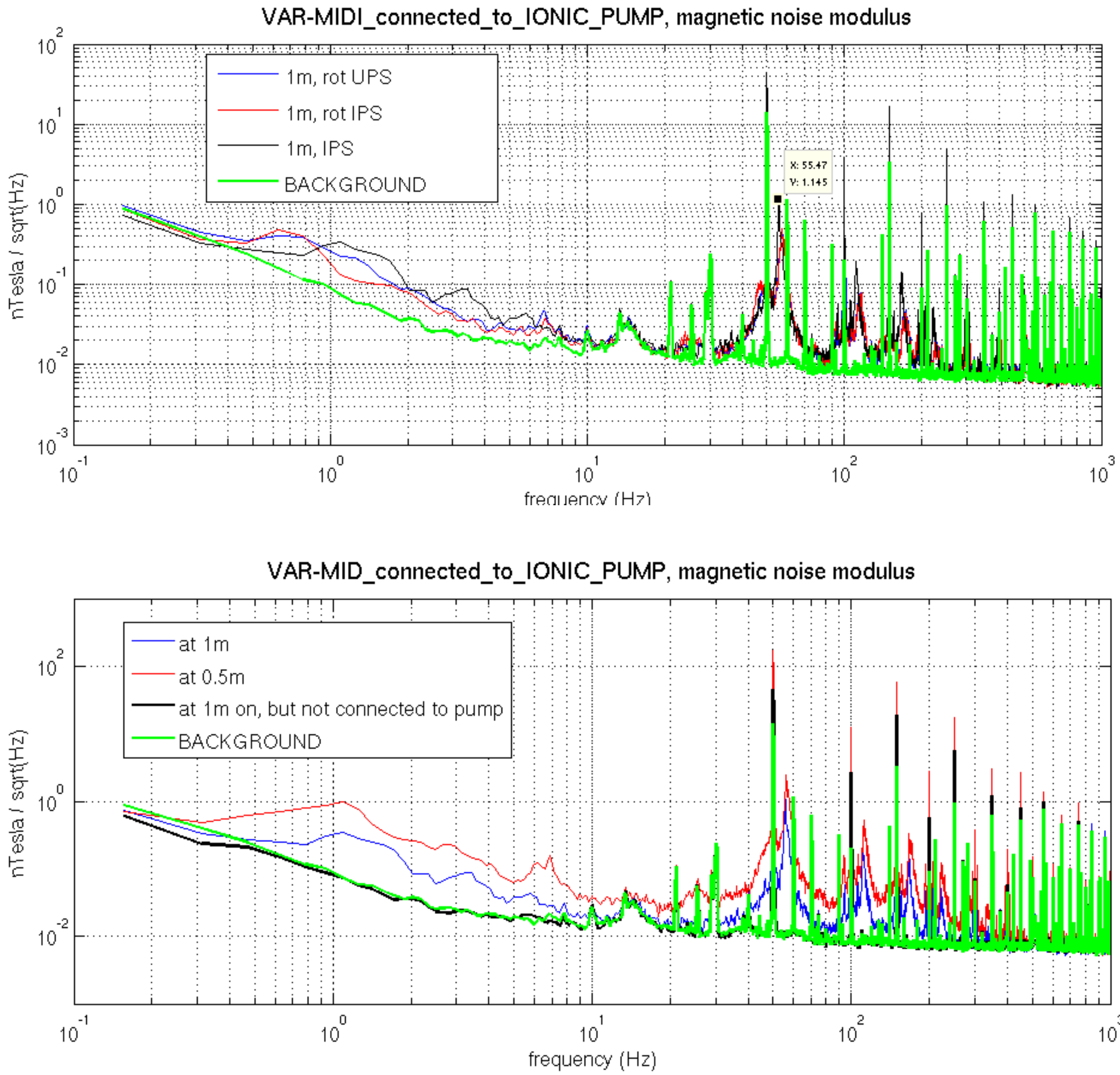

Figura 11. VARIAN-MIDI connected to ion pump. TOP: magnetic noise at 1m distance, BOTTOM: magnetic noise at two different distances.

2.3.3 VARIAN, model DUAL

This new model is going to replace the present MULTI-VAC model as soon as they go out-of-service. Such controller is already installed at the NE and one of CB racks. Cooling fans are present: we detect audible noise. We connected it to the ion pump apparatus at 1500N. Figure 12 shows measured magnetic noise at 1m. We do not see evidence of low frequency magnetic noise, neither of monochromatic lines as we might expect from cooling fans. Emitted noise consists in one broad peak between 500Hz e 2000Hz which appears when the pump is connected to the ion pump. Peak noise is 1.3nT at 1650Hz. The impact of this high frequency noise emission is going to be negligibly low (orders of magnitude below the limit) thus it is not considered further.

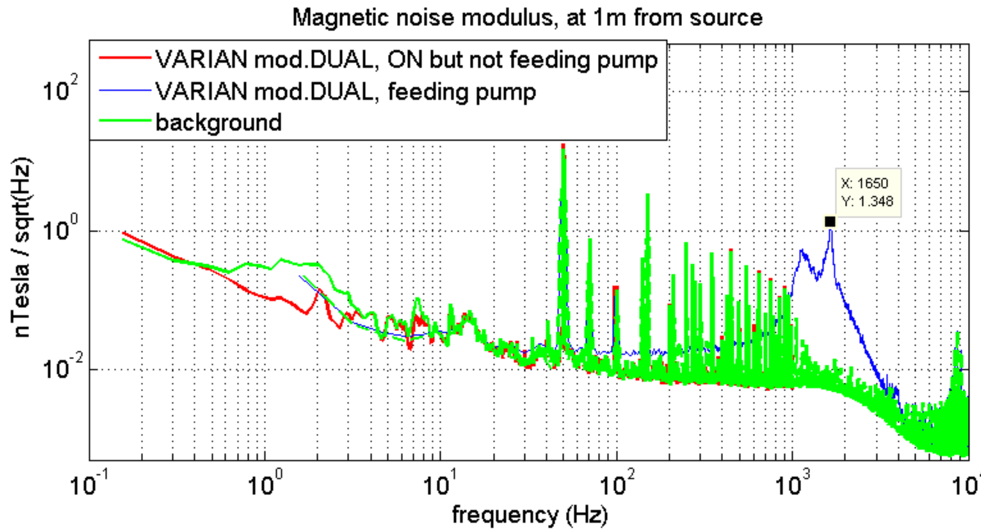

Figura 12. VARIAN-DUAL connected to ion pump.

2.5 TCM mod. 1601, turbo pump driver

2.5.1 TCM running standalone

At the 1500 lab test bench we measured one TCM module not connected to the turbo pump. As Figure 13 shows, we detect magnetic monochromatic lines around 80Hz and multiples likely associated to cooling fans. No significant variation when the device is rotated or powered on UPS.

2.5.2 TCM connected to pump

We measure a similar module (same model) in operation at the 1200N vacuum station (see picture in Figure 4). This module is connected to its turbo pump. Also, the module is powered on UPS. The magnetic background noise at 1200N (Figure 14, green line) is about 10 times larger than at the 1500N lab. We detect again the 80Hz and multiples structures, whose amplitude at 1m is comparable to the standalone measurement (Figure 13). Our measurement at 10Hz is compatible with the background noise, which is around 0.1nT (Figure 14). Thus, we cannot exclude the TCM emits a white noise of this amplitude. Accounting for a possible factor 5 multiplicative factor due to the dirtier CB UPS, we set for the TCM an upper limit white noise emission of 0.5nT at 10Hz. This value is compatible with the noise measured in eLog 21327 (the purple lines in Figure 1 give a B noise emission of about 0.3nT).

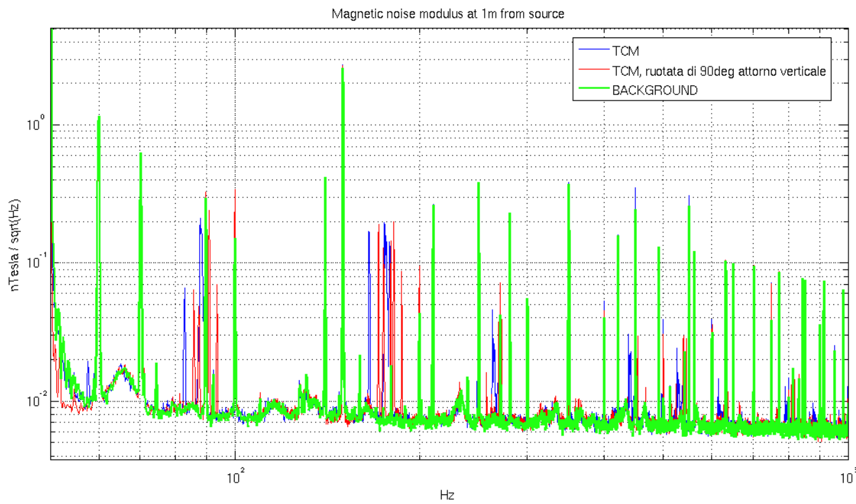

Figure 13. Magnetic noise at 1m from one TCM running standalone (switched on, but not connected to its turbo pump).

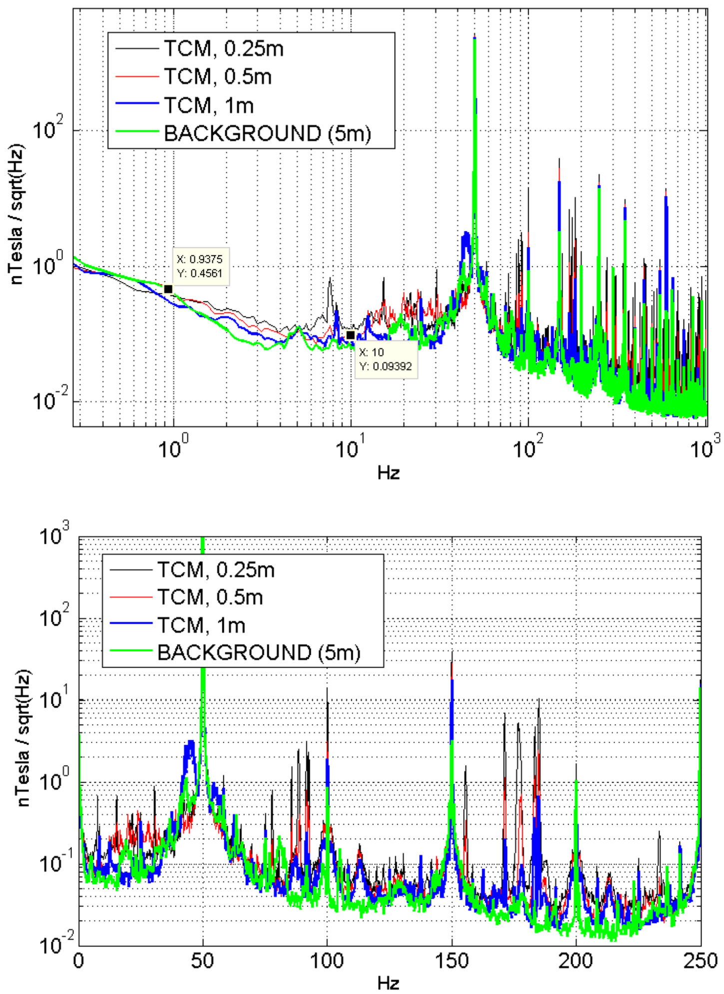

Figure 14. Magnetic noise of one TCM connected to its turbo pump.

2.6 Turbo pump

This device is measured at the 1200N vacuum station (see Figure 4). We could not find a suited location for the probe at 1m distance, so we took measurements at 0.5m and 0.2m distance from the turbo-molecular vacuum pump (Figure 15). We check the magnetic noise contribution of the cooling fans (Figure 16). The sole relevant magnetic noise from the pump is a narrow line at 600Hz (pump rotation frequency), its RMS amplitude is 70nT measured at 0.5m from the pump. Magnetic noise from the fans consists of 50Hz harmonics, 33Hz and 42Hz. Their RMS amplitude is less equal to 5nT at 20cm distance.

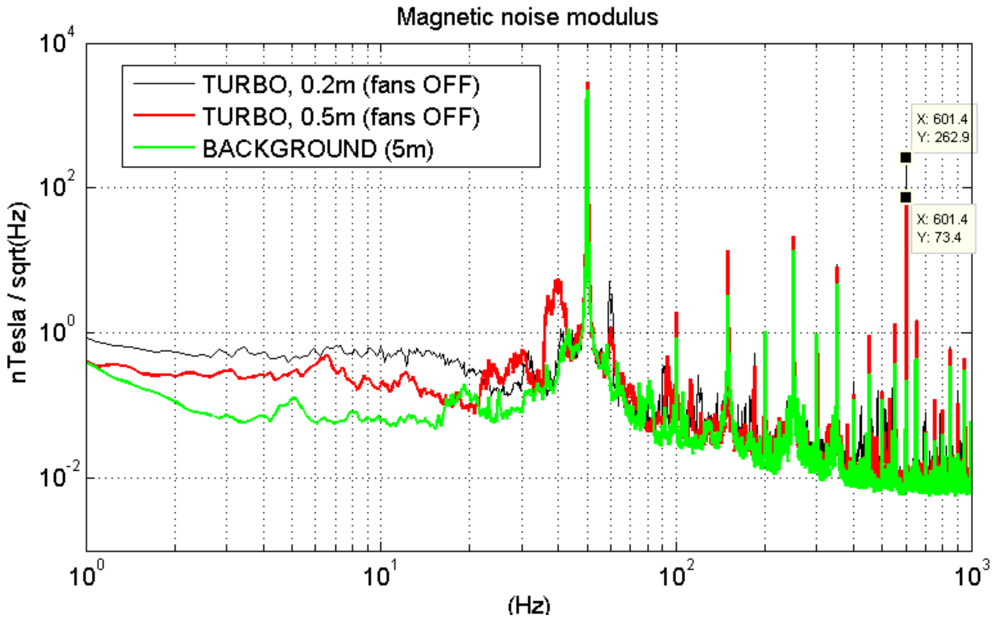

Figure 15. Turbo pump 1600 TMU: measured at 0.2m and 0.5m. Cooling fans off.

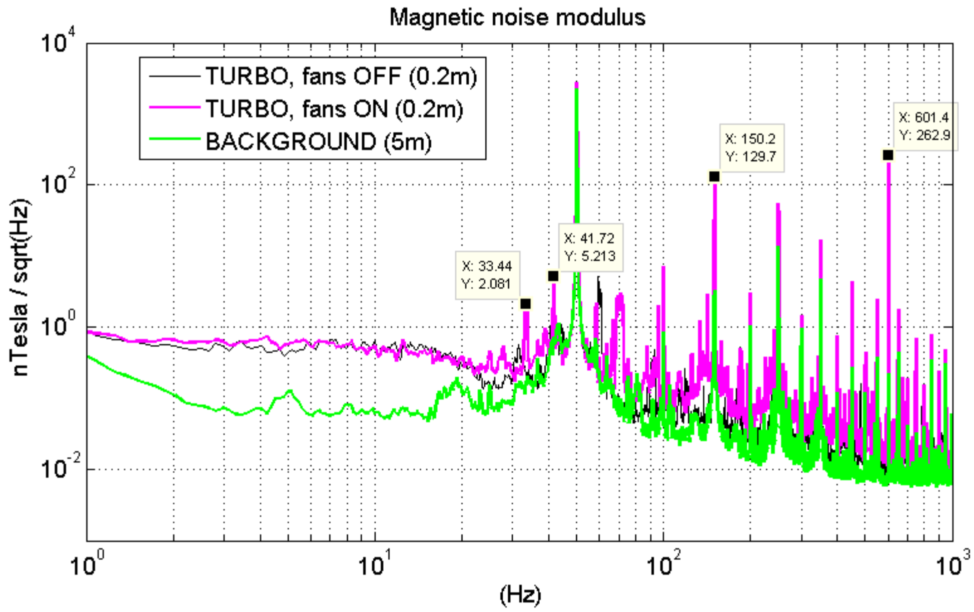

Figure 16. Magnetic noise from the cooling fans of the Turbo pump. Measurement at 0.2m distance.

2.7 Power supply modulus

This module provides power to the various vacuum rack devices. It should contain essentially AC to DC power transformers, however we do not know in detail its composition. Here we measured its noise emission as a whole. However, as stated in the conclusions, we think useful to inspect the module content to possibly find out if there is some major emitter, and in case perform further measurement of magnetic noise emission of single components.

We measured magnetic noise at 1m from the power supply module located at the 1200N vacuum station (see Figure 4). Figure 16 shows the measured field intensity with respect to the background. We find the module emission spectrum consists essentially of: (1) a white noise which is quite intense from 1Hz up to 200Hz: RMS amplitude (at 1m) is up to 1nT; (2) an intense 100Hz (10nT) and 50Hz harmonics (100nT). This noise seems roughly compatible (although white noise is about 5 times less intense) with the noise measured in the switch off tests of SR vacuum rack in eLog 21327 and reproduced in Figure 1. The missing “factor 5” might be explained with the larger white noise from the UPS generator which powers CB racks.

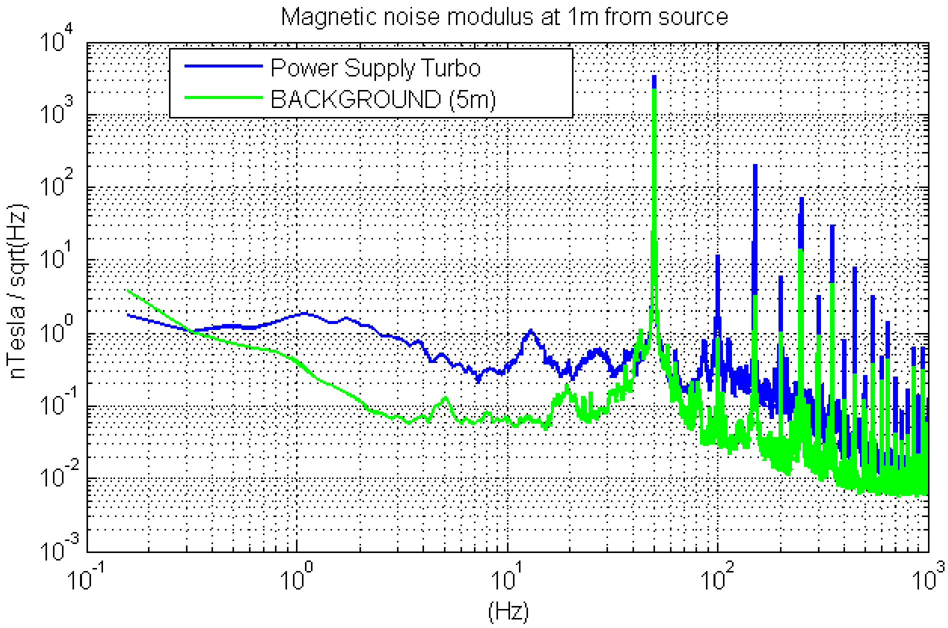

Figure 16. Magnetic noise at 1m from one Power supply modulus.

3. Comparison with magnetic noise limit

Table 2 below summarizes, for each device, our best estimate of the B field spectral noise intensity (in nT) at 1m. We take as representative the amplitude of the "most crucial" spectral noise (chosen to be the lowest in frequency), and Table 2 lists both the spectral noise amplitude and frequency.

Device	Frequency [Hz]	Magnetic field modulus amplitude [nT] at 1m distance
TPG (*,+)	10Hz	≤ 0.2
TPS (*,+)	10Hz	≤ 0.2
TCM	90Hz	0.25
TCM	10-50Hz	0.3 (measured in 21327, Figure1)
Power supply modulus	10-50Hz	5 (measured in 21327, Figure1)
VARIAN-MULTI (standalone)	40Hz	0.4
VARIAN-all models (*,+)	10-50 Hz	≤ 0.2
TURBO pump	600Hz	70

Table 2: summary of magnetic noise from racks components. In some cases (*) **the measured noise is increased by a safety factor 10 to account for a dirtier UPS in the CB**. In some cases (+) the most conservative limit is set by the background noise we measured at 10-50Hz.

Figure 17 below shows the extrapolation of the noise amplitude measured at 1m to farther distances from the source, and compares it to the set noise limit from Table 1. In Figure 17 we considered both the case magnetic noise decays with the cube of distance, or with the distance squared: this second being the most conservative case. For each device, the intercept between the noise decay line and the noise limit sets the safe distance of the device from any suspended payload mirror. Thus, we derive the following minimum safe distance for each single vacuum rack component, in parenthesis is reported the most conservative choice (assuming square distance decay):

- Power Supply modulus: at least 10m (conservative: 25m) (in Figure 17.A)
- TPS e TPG: at least 3m (conservative: 5m) (Figure 17.B)
- VARIAN mod. DUAL and MIDI: at least 3m (conservative: 5m) (Figure 17.C)
- VARIAN mod. MIDI: at least 4m (conservative: 6m) (Figure 17.C)
- TCM: at least 3m (conservative: 5m) (Figure 17.D)
- Turbo pump: at least 2m (conservative: 4m) (Figure 17.E)
- Turbo cooling fans: at least 3m (conservative: 5m) (Figure 17.E)

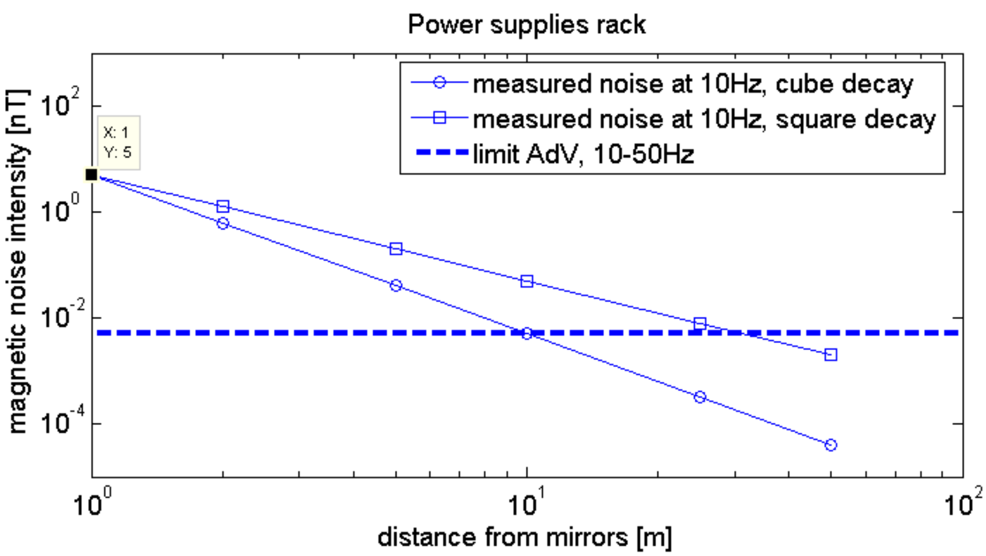

Figure 17.A Magnetic noise produced by the rack Power Supply section at increasing distances from it assuming a cubic (circles) or a square (squares) law, compared with the set limit (dashed line).

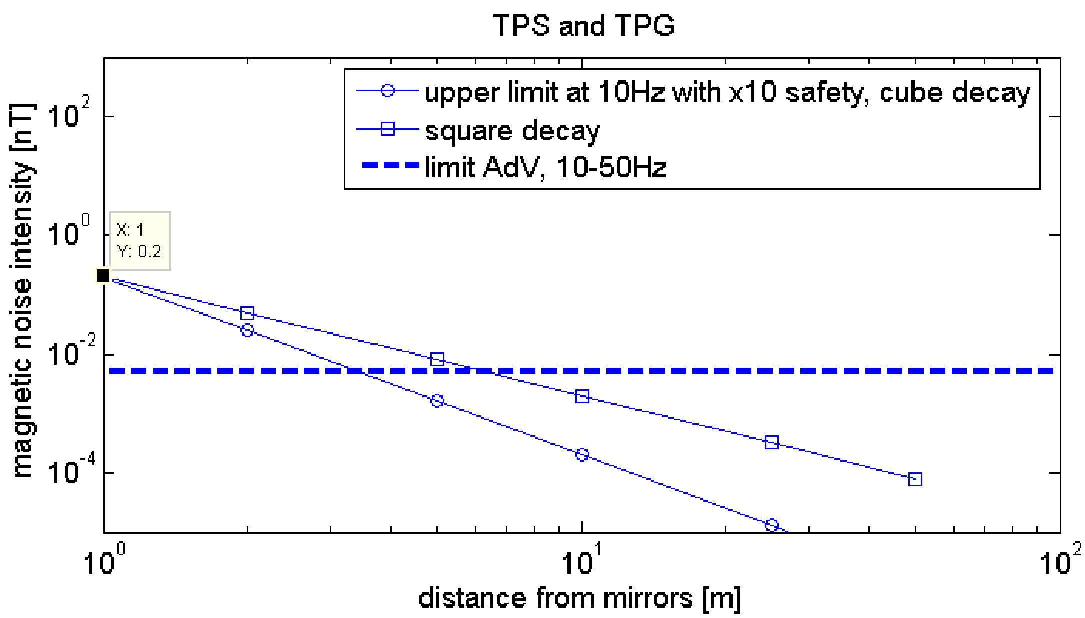

Figure 17.B Magnetic noise produced by TPS and TPG devices at increasing distances from them assuming a cubic (circles) or a square (squares) law, compared with the set limit (dashed line).

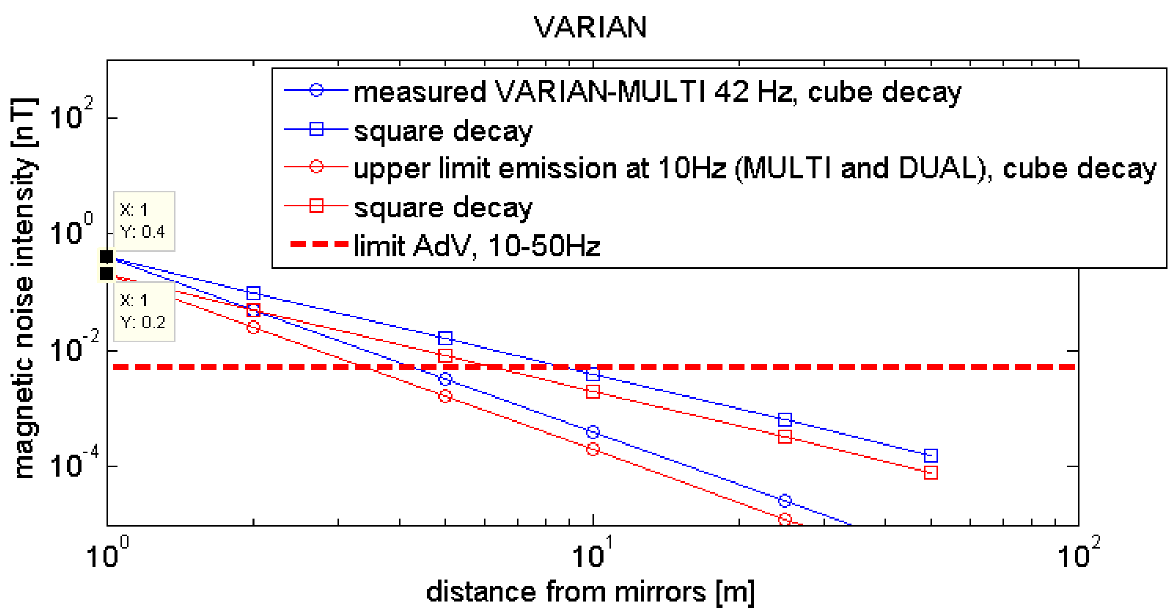

Figure 17.C Magnetic noise produced by VARIAN devices at increasing distances from them assuming a cubic (circles) or a square (squares) law, compared with the set limit (dashed line). Blue lines refer to the noise emitted at 42Hz, Red lines refer to the noise emission at 10Hz.

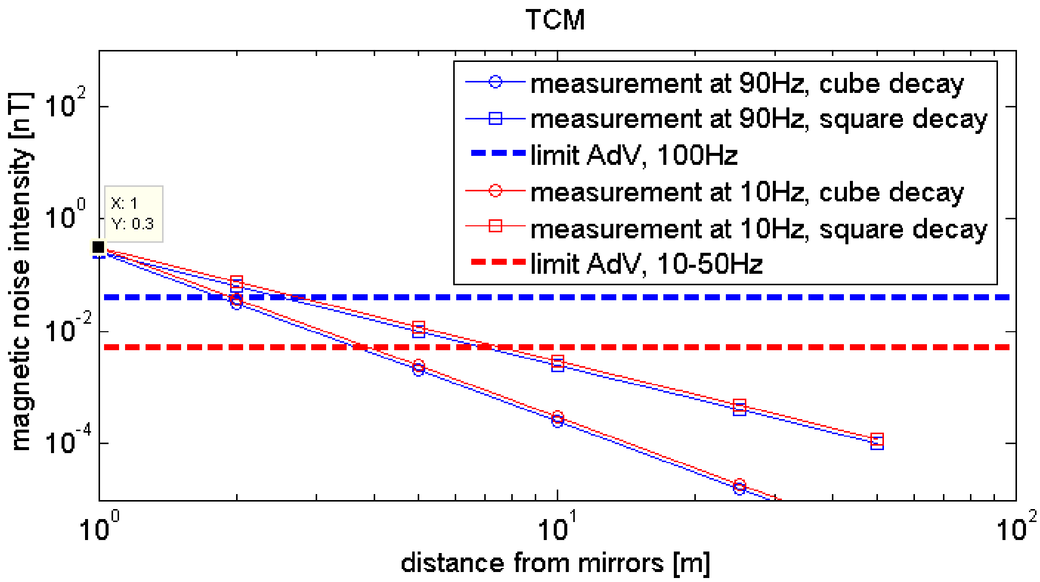

Figure 17.D Magnetic noise produced by the TCM-1601 device at increasing distances from it assuming a cubic (circles) or a square (squares) law, compared with the set limit (dashed line). Blue lines refer to the noise produced at 90Hz, Red lines refer to noise produced at 10Hz.

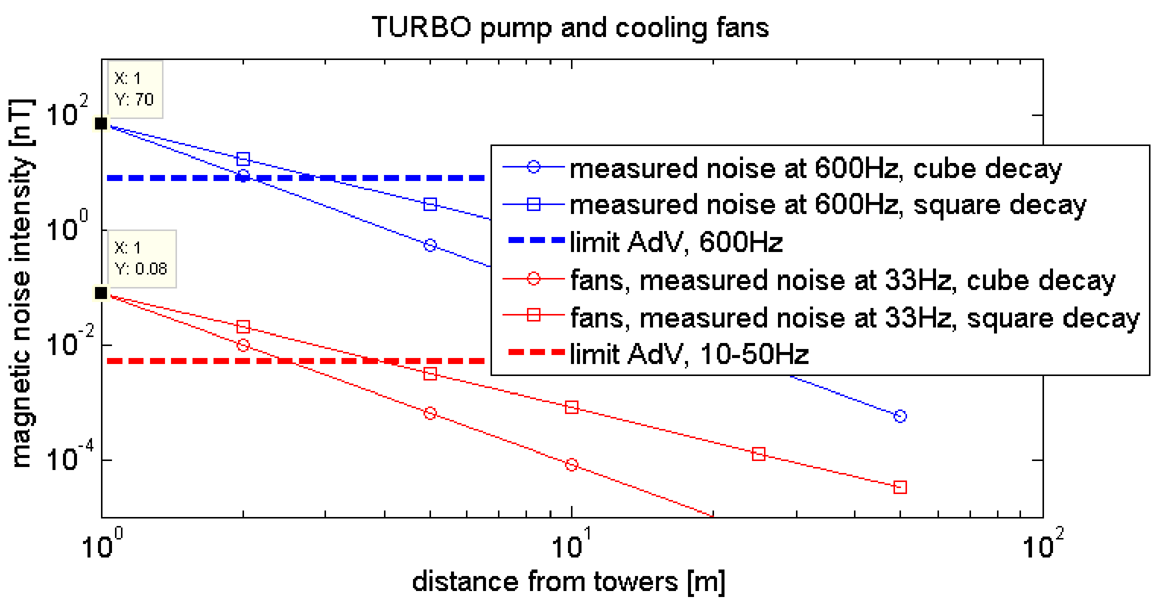

Figure 17.E Magnetic noise produced by the Turbo pump (blue) and its cooling fans (red) at increasing distances from them assuming a cubic (circles) or a square (squares) law, compared with the set limit (dashed lines).

4. Conclusions

We conclude by setting location requirement for the vacuum racks in advanced Virgo. These requirements (below) derive from the following assumptions: (1) seismic and acoustic noise emissions from the rack cooling fans are cured (i.e. adopting silent fans, and seismically isolating the rack) and therefore do not pose themselves constraints of the Vacuum racks position; (2) AdV adopts the same mirror magnets configuration as Virgo (same magnet strength); (3)

Our measurements give the following indications about the (re)-location of AdV vacuum rack components:

- The magnetic noise emission of most rack components (**VARIAN, TPS, TPG, and TMC**) is not critical, requiring a safe distance from the tower payloads of about 5meters. Essentially the present rack locations satisfy this requirement.
- **Turbo pump**: the main magnetic emission from the turbo pump (600Hz line) is acceptable at 2-3m from the mirror. A more accurate measurement of the low frequency (0-50Hz) emissions shall be attempted, since the present measurement was limited in this frequency region by a bit too large residual noise. Ad-hoc magnetic shields can be possibly adopted, this has to be investigated.
- **Turbo cooling fans**, as they are to be kept close to the tower (i.e. 2m from mirrors), require some further attention. This means a more accurate measurement. Lower emission fans or possibly ad-hoc magnetic shields need to be investigated.
- The magnetic noise emission of the rack **Power Supply module** could be critical for AdV and requires some attention. We foresees two possibilities:

1) All the modules are moved to a new location which is at least 15m far from any tower. For practical reasons this could be the same location for all the modules, although not necessarily.
2) Replace these modules with ones emitting at least 5 times less magnetic noise.

An inspection of the content of the module might reveal if some easy-cure is feasible, for example if E-I core type transformers are used, their noise emission might be significantly reduced by replacing them with equivalent toroidal core type of transformers which have less exterior dispersed fields.

References

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[3] I.Fiori, F.Paoletti, B.Swinkels, VIR-0135B-11, and references therein.

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