Report for the EGO Council Virgo+ Review Team

VIR-001A-08
January 8th, 2008

Abstract

The purpose of this document is to provide material for the review committee set up by the EGO council to look at Virgo+. After a general introduction which reminds the goal of Virgo+, this report first summarizes the status of the commissioning to describe our understanding of the noises sources, especially at low frequency. Then this report presents the Virgo+ upgrades with more emphasis on the most critical ones.

SUMMARY

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1 Introduction

1.1 Goal of Virgo+

Virgo+ has been initiated as an intermediate step between initial Virgo and Advanced Virgo . The main idea is to install modular and low cost upgrades, compared to what we expect for advanced Virgo. By using a modular approach, or in other words, by keeping the overall Virgo design, we expect to reduce the preparation and commissioning time required by these changes and to keep collecting data in the coming years.

It must be added that since the design sensitivity was not reached before the start of the first Virgo Science Run, the commissioning of the current detector is still ongoing in parallel with the preparation of the Virgo+ upgrades, and is playing an important role in the definition of the detector activities and in the selection of the Virgo+ upgrades.

1.2 Planning and definition of Virgo+

The Virgo detector has a sensitivity which makes it as one the best GW detectors (at high frequency) or even the best detector worldwide (at low frequency). It is therefore mandatory to exploit this detector to collect data for astrophysical searches and hopefully discovery.

At this time of the GW search, a network analysis of the collected data is important for the signal detection and therefore the data taking periods ("science runs") have to be synchronized with other major detectors, especially the LIGO instruments. Therefore, the choice of the data taking period is made in connection with the LSC and we **set as a primary goal to start the second Virgo Science Run (VSR2) at the same time as the start of the LIGO S6 run (i.e. spring 2009).** This choice is used to constrain the list of the Virgo+ upgrades to be installed for the start of VSR2. Upgrades which could not be ready on time were postponed or canceled. As an example, we have recently decided to keep our current payloads (mirror + reference mass + marionetta) for the start of VSR2 instead of going to a monolithic solution.

However, the duration and duty cycle of VSR2 are still open. Since not all of the possible upgrades will be installed at the beginning of VSR2, **we keep actively working on preparing the most rewarding upgrades in view of their installation during S6. This is especially true for the monolithic suspension** which could bring a significant sensitivity improvement, very attractive for the astrophysical point of view and also for the Advanced Virgo and Advanced LIGO preparation. To illustrate this potential the figure 1 present the sensitivity for different Virgo+ configurations compared to recent measured sensitivity curves (see more in the November 2007 Virgo report).

1.3 Organisation and management

Since the Virgo+ phase is just an evolution of the current detector, the standard organization of the collaboration is handling this phase. Namely the main decisions are made for the collaboration by the Virgo Steering Committee. The spokesperson is in charge of representing the Collaboration and acting on behalf of it in all relevant occasions. Different coordinators are appointed by the VSC to help the Spokesperson to manage the Virgo activities (see http://wwwcascina.virgo.infn.it/CollOrganization/organization/Virgo-Organization-last.pdf for the detailed list). The most involved coordinators for the Virgo+ preparation are the commissioning coordinator and the detector coordinator who prepared the two following sections of this report.
The commissioning activity is frequently reported and discussed during several kinds of meetings:

- Daily meetings in the control room for the ongoing activity

- Weekly meetings with remote participation of several Virgo groups
- Almost monthly meetings during the Virgo weeks with a large attendance of the collaboration and deeper discussion about the main orientations.

The preparation of the detector upgrades is also discussed during different meetings:

- Frequent topical meetings (like biweekly for the TCS preparation)
- Almost monthly meetings during the Virgo week with extensive discussions
- Two specific Virgo+ review meetings in 2007.

The "change request" procedure is used to define and track the evolution of the detectors changes (see http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/CRE/index.html).

Both coordinators are in close (daily) contact to elaborate and monitor the planning for the commissioning and for the installation or upgrade of detector parts. An almost weekly meeting of the main coordinators and spokesperson and EGO director is organized to coordinate the overall activity. In addition, a budget meeting is organized twice a month to monitor the expenses made by EGO for the Virgo upgrades. This is evolving and will be integrated in the coordinator meeting together with an easier access to the budget information.

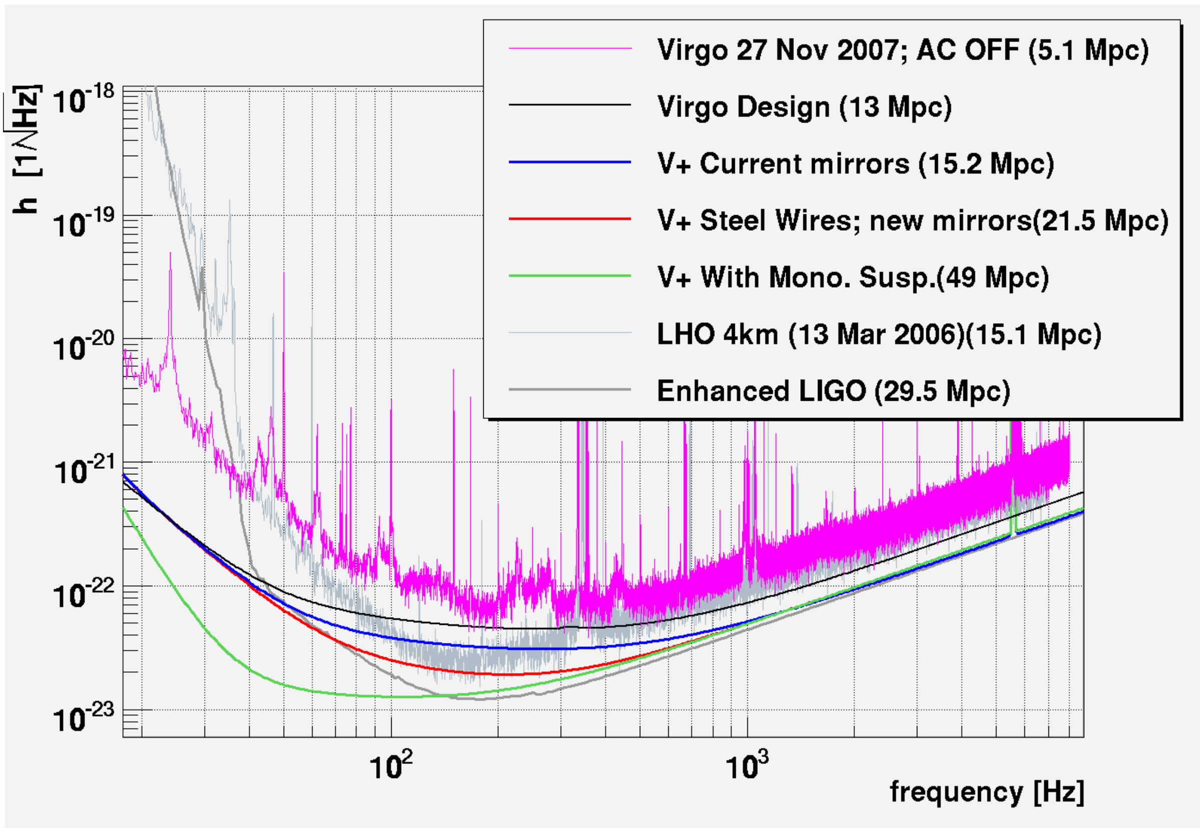

Figure 1 Different options for the Virgo+ mirror/payload choices. The V+ current mirror curve assumes that we can mitigate the possible effect of the Eddy current by means of caps on the magnet or by replacing the magnets. All the Virgo+ curves assume the new Thermal noise model ("Penn model"). The steel wires suspension curves assume a conservative number for the mirror internal noise (see footnotes on page 41 of the November Virgo report for details). Some technical noise based on an evaluation of the actuator noise have been added to the Virgo+ sensitivity. It should be underlined that these technical noises which are limiting the sensitivity at very low frequency are by definition not absolute noises. Their level may vary depending on many parameters like the exact configuration of the control system and therefore, their exact prediction is difficult..

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2 Commissioning plans until Virgo+ shutdown

Figure 2 shows a comparison of the sensitivity at the end of VSR1 and the best one reached since then. In the following, we summarize the progresses since the end of VSR1 and we give the plans until the Virgo+ shutdown.

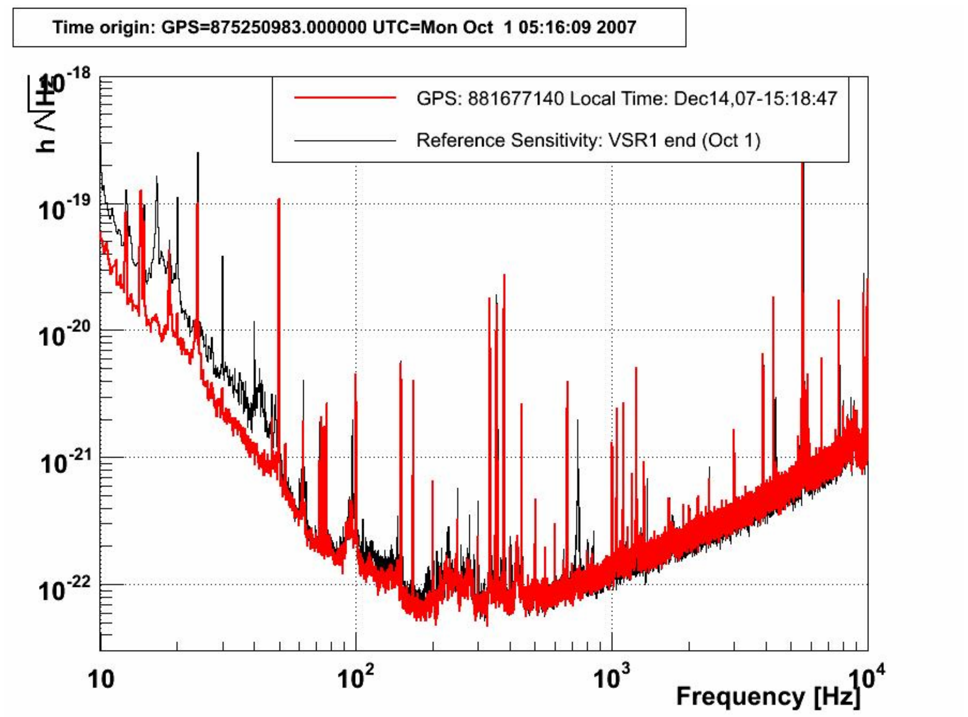

Figure 2: Comparison of the sensitivity at the end of VSR1 (Oct 1st) and after 3 months of commissioning (mid-December).

2.1 Progress since VSR1 end

The sensitivity improvements in the low frequency band since the end of VSR1 are:

2.1.1 Longitudinal control noises reduction:

The longitudinal control noises (control of the central cavity) have been well reduced thanks to the use of the signal at the second modulation frequency (8MHz) and improved sensing and driving strategies. The longitudinal noises are now well below the other known noises and close to the design sensitivity (within about a factor 2). The noise of these controls arise mainly from environmental noises which couple to the error signals (we suspect through beam jitter). Since the environmental noises have to be reduced (see below) we are quite confident that the longitudinal noises will be reduced consequently and should get below the nominal Virgo+ sensitivity.

Some resonances (around 17 and 47 Hz) of the marionetta were excited by the reallocation of the force. Some notches have been added to the control filters in order to reduce this effect. This is well visible on Figure 2.

2.1.2 Angular control noises reduction:

The angular control noises have also been reduced thanks to the use of more efficient filters, for both automatic alignment and local controls, and thanks to a better beam centring on the mirrors.

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The angular noise exceeds the Virgo+ design only below 20 Hz (see Figure 3). Filters can still be improved and the mirror centring has to be automated. The next improvement should be gained when the telescopes of the end benches will be changed (end of January): alignment signals are expected to be cleaner and the bandwidth of the loops should be increased aiming at a more stable beam pointing (and therefore centring on the end mirrors).

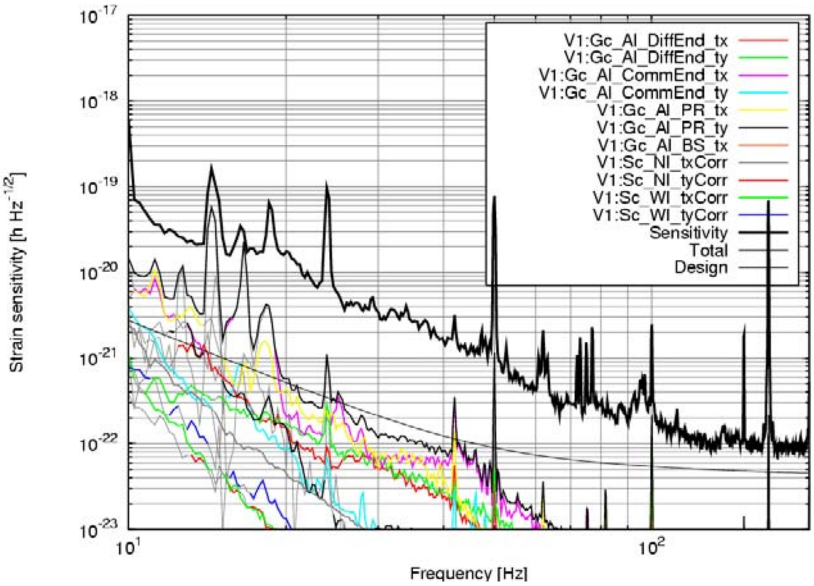

Figure 3 Angular noise budget

2.1.3 Diffused light by the end benches:

It was found that some light back-scattered by the end benches was responsible for a broadband noise below 60 Hz. A better dumping of parasitic beams has been performed and the situation is improved but this noise still shows up from time to time. Improvements are still on-going.
The new telescopes which will be installed on these benches (end January) should help to be less sensitive to these noises. The acoustic enclosure will also be improved (mid-January).

2.1.4 Diffused light at the detection port:

It is still not clear how the environmental noise couples to the dark fringe in the detection area. Investigations are going on. The possible paths are: some modulation or scattered light by the Brewster window, some light scattered by the suspended bench towards the tower walls and/or the Brewster link which then recombines to the dark fringe. Actions have started inside the detection tower to identify and dump spurious beams. Investigations are going on to understand if the light reflected/scattered by the suspended bench is a problem. It is also planned to install glass baffles on the tower wall and towards the Brewster link (January).

The Figure 4 shows the present noise budget when the coupling to environmental noises is at the lowest level

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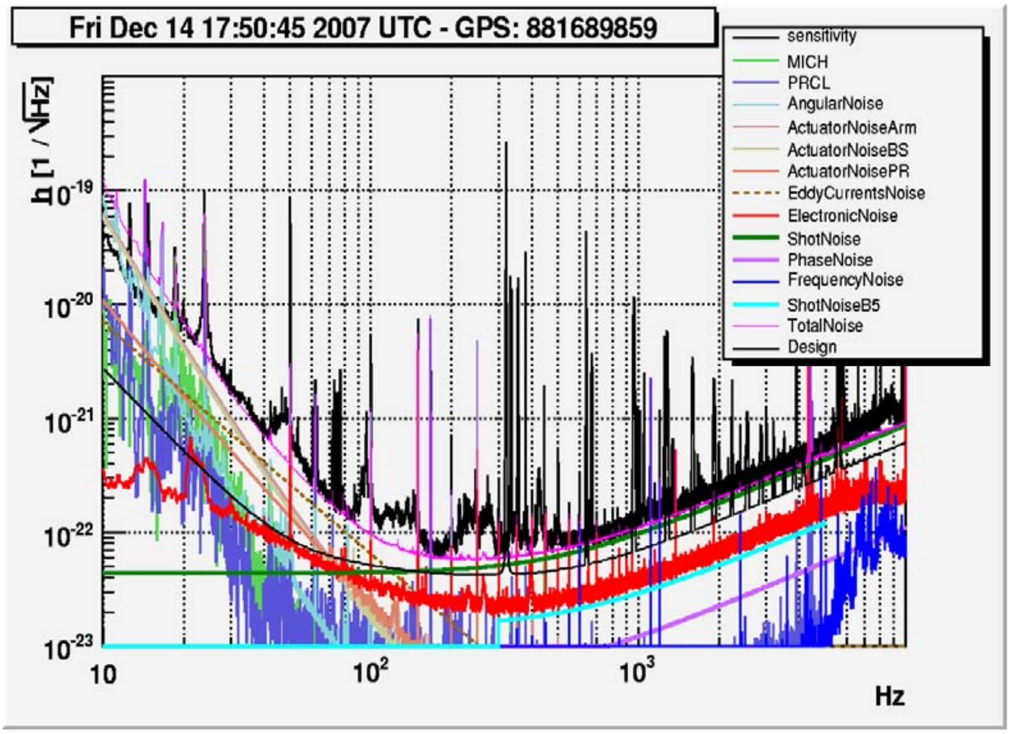

Figure 4 Virgo noise budget in December 2007

2.2 Plans for noise reduction until the Virgo+ shutdown

Other sources of noise have been identified and the work is starting in order to reduce them. This concerns the mirror actuator noise and the environmental noises.

2.2.1 Actuators noise

When the coupling of the environmental noises is low (see Figure 4) the sensitivity seems to be limited by the mirror actuator noises below 40 Hz (dominated by DAC noise). The projection exceeds the measured sensitivity below 20 Hz due to the fact that the DAC (non-linear) noise has not been measured at this frequency but was extrapolated from 60 Hz down to 10 Hz. This noise has to be reduced by a factor 10 to be compliant with the Virgo+ design.
In order to further reduce this noise it is first needed to reduce the dynamic of the correction sent to the reference mass. The marionetta reallocation has been implemented at the Beam Splitter so that the gain of the coil driver can be now decreased by a factor 10. This has just been performed but it was not at the time of the noise budget shown in Figure 4.
Concerning the arms, the gain of the coil driver can also be decreased by a factor 8 but with a risk of saturation in case of bad weather. The force has therefore to be further reduced at the level of the reference mass. The strategy is not yet completely defined but there are several possibilities:

- split the force to more coils: now only 2 coils are used for each arm while 8 are available (4 at the end mirror and 4 at the input). No big difficulties are expected but it can be a lengthy work: all the coil drivers have to be well calibrated and the longitudinal controls and noise subtraction techniques will have to be retuned.
- more force could be reallocated to the marionetta by increasing the crossover frequency. It is not clear if this is feasible

The installation of the new coil drivers should start in January, as soon as the new boards are validated. These new boards include several low noise sections with decreasing gains down to a factor 16 with respect to now.

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With all these improvements it should be possible to reduce the actuator noise down to the Virgo+ design sensitivity.

2.2.2 Environmental noises:

Several sources of environmental noises have been identified:

- the electronic racks located inside the laser and detection laboratory are responsible for lines between 200Hz and 500Hz,
- the air conditioning inside the laser laboratory is responsible for noise at low frequency (below 30 Hz),
- the air conditioning of the central hall is responsible for a broadband structure around 30 Hz and lines at the pump harmonics (48, 96 and 144 Hz),
- the air conditioning of the DAQ room is responsible for a broadband noise up to 200 Hz,
- the air conditioning of the end buildings creates a broad band noise (up to ~100Hz).

The coupling of these noises to the dark fringe is also better understood:

- the noise inside to the laser lab (air conditioning systems and electronic racks) creates beam jitter either exciting the Beam Monitoring System resonances (PZT + mechanical mounts) or the optical table resonances,
- the noise inside the central hall couples through at the detection port likely through scattered light at the Brewster or inside the detection tower,
- the scattered light at the end benches couples to environmental noise present there.

The plans to reduce the couplings are:

- damp the vertical and horizontal resonances of the injection system optical benches (January-February);
- replace the BMS PZT with better ones (early January): the first resonance is at 580Hz instead of 145 Hz for the present setup and the mount is more rigid;
- improve the acoustic isolation at the end benches, protect the beam path from air flux and install better designed telescopes (no optics close to the beam waist).
- install large baffles to cover the detection tower wall (January) and place more baffles to hide the Brewster link from the optics located on the detection bench (as soon as baffles are available)
- replace the Brewster window with a cryogenic trap (February). The baffles should be installed before and additional tests will be done in order to improve as much as possible the understanding in this area.

The plans to reduce the noises are:

- move the electronic racks containing cooling fans away from the sensitive areas. This will be done during the may-june shutdown
- reduce the noise from the DAQ room: the air conditioning machine will be placed further away and an acoustic isolation will be installed in order to filter the noise of the racks (January-February)
- reduce the noise from the air conditioning in the laser lab: this system will be separated from the clean rooms and the air flux will be improved. A less powerful air conditioning will be needed when the racks will be moved. This will be done during the TCS installation or the may-june shutdown.
- Reduce the noise of the central hall air conditioning: this still has to be defined.

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All the efforts will be done in January and February for the reduction of environmental noises and actuator noises. When the Eddy current noise is met the magnets will be caped. The controls will then have to be retuned. The whole operation should therefore take about 1.5 week. It is important to perform this operation as soon as possible in order to know if it is effective and therefore if the reference mass has to be changed.

The thermal compensation system should be ready early in March. The installation should last 3 weeks. The time needed for its commissioning is difficult to estimate but should be at least one month. In parallel with this activity the noise hunting will go on.
Before the May-June shutdown it is planned to make a short commissioning data taking of one or two weeks.

1.3 Planning

The commissioning tentative planning is the following:

3-11/01: actuator noise reduction; new BMS PZT; diffused light mitigation in detection tower.

14-18/01: diffused light mitigation in detection tower; actuator noise reduction; in parallel: improve acoustic enclosures at end benches.

21/01-01/02: install new end benches (including protection of beam path and galvanometers for quadrant centring) and commission them (2 weeks);
in parallel: install acoustic isolation of DAQ room;

04/02-13/02: replacement of the Brewster link by a cryogenic trap (1 week) and check the effects on sensitivity (2 days); in parallel: damp the injection bench resonances;

14/02-22/02: cap the magnets (2 days) and retune the controls (1 week);
In parallel: displace the air conditioning machine of the DAQ room

25/02-29/02: noise investigations and reduction (to be defined depending on the result of previous tests/modifications);

03-21/03: install thermal compensation system. In parallel: improvement of the air conditioning system in the laser lab;

24/03-21/04: commission the TCS and go on with low frequency noise investigation;

21/04-2/05: commissioning run.

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3 The Virgo+ packages

Virgo+ project is currently composed by 2 major packages: "high power laser and compliant optics" and "new electronics". The first package is obviously driven by the aim to improve the sensitivity of the detector, meanwhile the second one is mainly driven by technical reasons (obsolescence of the hardware, higher reliability, larger flexibility), but some important improvement in terms noise performances could be expected also here (i.e. coil drivers, alignment electronics,..).

The high power package contains, first, the thermal compensation system, already needed to cope with the current laser power, because of a larger (respect to the design) absorption of the optics, the laser amplifier and the related injection optics replacement and optimization. The electronics package includes the coil drivers replacement (including the DAC update), the DAQ electronics replacement, the DSP replacement and the 4-Quadrant Front-End electronics renewal.

3.1 Overview of the "corollary" upgrades.

As requested, this review document is focused of few critical upgrades, but a series of other activities have been launched and their success is also important for the success of the global Virgo+ project. We defined here "corollary", to follow the logical approach of the reviewers, but it is hard to fully separate them from the "critical" ones.

3.1.1 Infrastructures

In parallel to the detector upgrade a huge activity of upgrading of the infrastructures has been launched to reach the Virgo sensitivity and to benefit of the possible detector noise reduction in the Virgo+ scenario. These activities have been mentioned in the commissioning part of this document because their success is fundamental to arrive to the nominal Virgo sensitivity. These activities are briefly:

- Reduction of the environmental noise produced by the DAQ room through
  - the renewal of the old air conditioning machine and its displacement in a location more distant and more acoustically isolated
  - the acoustic isolation of the DAQ room
  - possible displacement of part of the electronics in a different location (TBD)
  - part of this activity should be completed before March '08.
- Reduction of the environmental noise in the laser lab
  - Separation of the laser lab and clean rooms air conditioning systems
  - Improvement of the air conditioning outlet path in the laser lab
  - Displacement of part of the noisy electronics racks and of the laser chiller in a new isolated room
  - The first part of this activity will be performed in March and the second part in May.
- Detection lab
  - Displacement of part of the electronics in the adjacent L-shape-Lab (TBD)

About 80k€ are allocated for the defined activities; the man power is mainly supplied by EGO with the collaboration of the Detector and Commissioning coordinators.

3.1.2 Vacuum

Obviously the environmental noise couples to the dark fringe through the light scattered in the interferometer. As mentioned in the commissioning part of this document, a possible source of scattered light is the Brewster's window currently mounted between the signal recycling empty tower and the detection tower (DT). Since the simple removal of that window is unacceptable

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because of the huge contamination risk of the large optics caused by the larger level of hydrocarbons present in the DT vacuum respect to the central interferometer vacuum, a cryogenic trap system has been designed to block the contaminants flux from the DT. This cryo-trap will be realized in February and it will installed first for a test period, to understand the effective scattering role of the Brewster's window. In case of real improvement in the Virgo sensitivity this installation will became permanent with the addition of an external dewar to permit a better duty-cycle.
Other minor activities are the insertion of a bellows (and some dumping clamps) between the turbo-molecular pumps and the tower in the critical locations (like the DT).
The budget currently allocated for this section is about 60k€; the man power is mainly supplied by EGO with the support of INFN Pisa and the detector coordinator.

3.1.3 Electronics

The DAQ and control electronics upgrade is more deeply described in a dedicated section. Here we report about the remaining upgrades in the same package.
The current **DSP's** are often used at the limit of their capability both in terms of computational and memory load. A new generation of DSP's, having an increment of performances of about one order of magnitude are under realization. The design of the new multi-DSP boards has been completed (6 x 100 MHz ADSP211160N SHARC DSP (3.6 GigaFLOPS in single PMC Mezzanine)) and two prototype versions have been produced. The production for 50 devices has been placed, while the order for the carrier board manufacturing must be still placed. An installation plan must be still defined, but a pilot installation must be performed before the complete deployment to minimize the impact on the interferometer. The overall cost of this project, including the R&D is about 161k€, meanwhile the man power is mainly supplied by INFN Pisa and EGO.
The need of refurbish the spare parts of the **quadrant diode (QD) front end modules** used in the Virgo linear alignment triggered an additional upgrade activity. In fact, in addition to new spare modules production, some improvements in the performance has been requested for overcoming presently limitations, while maintaining full compatibility (interchange ability) with the existing modules. The desired improvements concern lower noise, higher possible incident light power (Virgo+ compatibility), lower DC offset (and resulting lower DC offset drifts), and changing the geometry from 'X' to '+' configuration. The concurrent request of higher power and lower noise, according to the Nikhef designers, can be satisfied only by producing two different modules optimized by each request. Since the angular alignment noise is still exceeding the Virgo nominal sensitivity at very low frequency, this activity could have an impact in the noise performance of the detector. The first prototype should be delivered in March, while the full production is expected for July. This activity is mainly performed by the Nikhef group (with the coordination of H.Heitmann) and the overall cost is on the Nikhef budget.

3.1.4 Detection bench upgrade

The detection photodiodes are a possible critical coupling point of the environmental noises with the dark fringe signal trough the scattered light. Moreover, in case of DC readout the B5 photodiode will probably be used for power stabilisation and has therefore to be isolated from environmental noises For this reason it has been decided to investigate the possibility to move these PHD in the suspended bench inside the detection tower. These photodiodes cannot work in vacuum and will be inserted in closed boxes (containing air) with a remote motorized system. A prototypal production of the components is started and the production of the full system is expected to be compatible with an installation during the May shutdown. This activity is realized by the LAPP group and the overall cost is about 30k€.

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3.2 Thermal compensation system - TCS

3.2.1 Description

Thermal lensing effect has already been observed in Virgo, through the reduction of the sidebands gain. This effect made it necessary to decrease the ITF input power from 10W to about 7.9W, about 20%. In Virgo+, the foreseen ITF input power will be of the order of 25W, about three times higher than present, making thermal lensing effect even more critical.

The thermal compensation has already been implemented by the LIGO Collaboration, through a system based on a 8 W CO_2 laser, whose profile is properly shaped by a mask. The power actually injected into the LIGO ITMs' is at most of the order of 100 mW. This value is due to the fact that the LIGO optics are pre-curved, so that they should reach the optimal radius of curvature at the operating beam power. For this reason, only a small correction is necessary to reach the optimal working point. This system has proven to be very effective.

The strategy delineated by the Virgo Collaboration for TCS installation is to proceed in sequential steps. A first phase will be to install a LIGO like TCS (in March), commission it and then to install the power stabilization components, during the Virgo+ installation shut-down (May-July 2008). See the planning section for more details.

In Virgo/Virgo+ cases the power needed to compensate the thermal lensing has been estimated to be higher than in the LIGO case. In order to make this calculation, a finite element model of the input mirrors and reference mass has been developed. A detailed characterization of the power absorbed by the input mirrors is necessary to properly choose the working parameters of the TCS. The power needed for the TCS depends on the heat absorbed by the mirrors (which is in turn determined by various parameters such as the losses of the coatings, the input power of the laser, the FP cavity finesse and the gain of the recycling cavity) and on the geometry of the mirrors and of the beam spot.

Because of the smaller beam waist and larger mirror size, already with the Virgo nominal mirror absorption, 0.4W are expected to be necessary to compensate the lensing induced by the beam. The absorptions of the Virgo input mirrors have been measured through the resonant mode technique and resulted to be between 3 (NI) and 7 (WI) times the nominal one; this absorption excess is unaffected by the cleaning attempt made the 29/11/2007, despite the fact that, after the cleaning procedure, the mirrors are better looking[1].

From the FEM thermal simulation, we found that to compensate the lensing effect it is necessary to apply onto the ITMs a heating pattern of proper shape. The simulations have been performed to study the effect of a laser based TCS, projecting an annular shape beam. In this case, we found that the power needed to compensate, impinging onto the ITMs, is of the order of 2 W for present Virgo and of the order of (1.5 – 13) W in Virgo+, depending on the losses of the coating and on the recycling factor. Given the high power that has to be shined onto the ITMs, we investigated the most efficient system to convert a Gaussian beam into an annulus. The Optical Imaging System (OIS) has been designed to use a single AXICON to shape the compensating beam.

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[1] Documentation relative to the cleaning attempt:

- Procedure: http://wwwcascina.virgo.infn.it/commissioning/weekly/2007/Dec2007/Cleaning%20-%20weekly%20meeting%204-12-07.ppt
- Movies: http://virgo.pg.infn.it/~punturo/index.html#2007
- Thermal transient (absence of) effect: http://wwwcascina.virgo.infn.it/commissioning/weekly/2007/Dec2007/Vajente_071204_ThermalTransient.ppt
- Absorption measurement: http://wwwcascina.virgo.infn.it/commissioning/weekly/2007/Dec2007/Absorption%20after%20Cleaning.ppt
- Phase camera 0 results: http://wwwcascina.virgo.infn.it/commissioning/weekly/2007/Dec2007/Phase%20Camera_0%20updates.ppt

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The OIS has been fully simulated with Zemax and the efficiency was found to be almost 100%. A 35W CO2 laser has been, anyhow, inserted in the optical design.

Given the high level of power to be injected onto the ITMs, it is essential to evaluate the displacement noise introduced by the TCS. These calculations have been performed. The noise depends on the power needed to compensate and on the power stability of the laser. Once again, it is seen that the losses of the coatings are indeed a crucial parameter since they determine both the overall power needed to compensate (and then eventually the costs) and the level of power stabilization required to make the TCS noise negligible. Results of the noise calculations suggest that, taking into account the measured relative intensity noise of the CO_2 laser presently used in LIGO, the TCS power stabilization is not required in the case of the present Virgo, but it will be necessary for Virgo+. The level of the required stabilization is $RIN \leq 3 \cdot 10^{-7}/\sqrt{Hz}$ @ 30Hz. The activity on the laser power stabilization will start at INFN Roma Tor Vergata Laboratories after the installation of the first phase TCS.

3.2.2 Status of the activities[2]

The design of the TCS system is completed. Almost all the components have been ordered and a detailed plan has been realized (see Figure 5). The first components should be delivered at the beginning of January, permitting the first tests, in the Roma Tor Vergata lab, about RIN of the CO2 laser. The second test to be performed at the end of January is the mirror movement system, followed by a full test of the optical imaging system (OIS). A complete test of the movement system will be performed in Cascina using the local infrastructures (hardware and software). The installation of the TCS system is expected at the end of February-beginning of March and should last for 3 weeks. Meanwhile the series of “macro-activities” needed to install the TCS is known (modification of the oven, installation of the optical tables, installation of the acoustic isolation, optics mounting, laser chiller positioning and connection,…), a detailed plan of the installation will be realized based on the experience accumulated in the tests in Roma TV. The TCS planning meeting, currently held every 2 weeks, will be, obviously, addressed to the installation and commissioning issue as soon as the March deadline will be approaching.
The design of the OIS is reported in the Figure 6.
In the Table 1 the list of collaborators involved in this activity is reported.
The budget invested in this activity is displayed in Figure 7 and accounts, currently, more than 180k€; the original expectation was strongly indeterminate, but after few iteration the total expected amount has been defined about 200k€. In the last period some saving has been performed and, unless some unexpected variation, the expenditure expected for 2007 should be completed, as shown in Figure 8, where it is clear the acceleration imposed to the project in the last weeks (thanks to an exceptional effort of the developing and coordination teams).
In the Table 2 the teams involved in the installation are reported. The main responsibility of the installation is of the Roma Tor Vergata group that should supply the needed man power, but, obviously, the interaction with the site infrastructures is so strong that a substantial support from the EGO electronic, software and infrastructures department is expected.

Table 1 - Virgo/EGO collaborators involved in the TCS production activities

Name	**Institution**	**Activities/role**
C. Bradaschia	INFN Pisa	Vacuum
E. Calloni	INFN Napoli	TCS Servo
F. Carbognani	EGO	Software
E. Coccia	INFN Roma Tor Vergata	Measurements analysis

[2] A detailed status report, task by task, is reported in the updated version of the 2nd Virgo+ internal review document: http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/Virgo+/EGOreviewJan08/Virgo+_TCS3.5.pdf
[3]

V. Dattilo	EGO	Vacuum cablino
M. Di Paolo Emilio	INFN Roma Tor Vergata	Laser power stabilization
V. Fafone	INFN Roma Tor Vergata	Coordinator, all
F. Frasconi	INFN Pisa	In-vacuum SM motion
E. Genin	EGO	OIS design
F. Gherardini	EGO	Vacuum cabling
P. La Penna	EGO	OIS design
Y. Minenkov	INFN Roma Tor Vergata	Experimental set up
F. Nocera	EGO	Drivers
A. Pasqualetti	EGO	Vacuum
F. Richard	EGO	Optical benches acoustic isolation
A. Rocchi	INFN Roma Tor Vergata	Coordinator, all
R. Simonetti	INFN Roma Tor Vergata	Technician, mechanics
R. Terenzi	INFN Roma Tor Vergata	Software, electronics
T. Zelenova	EGO	Technical drawings

Table 2 - TCS Installation teams

Name	Institution
Installation team	
M. Di Paolo Emilio	INFN Roma Tor Vergata
V. Fafone	INFN Roma Tor Vergata
Y. Minenkov	INFN Roma Tor Vergata
A. Rocchi	INFN Roma Tor Vergata
R. Simonetti	INFN Roma Tor Vergata
Technical support team	
V. Dattilo	EGO
EGO Sw Group	EGO
E. Genin	EGO
F. Gherardini	EGO
F. Nocera	EGO
A. Pasqualetti	EGO
F. Richard	EGO

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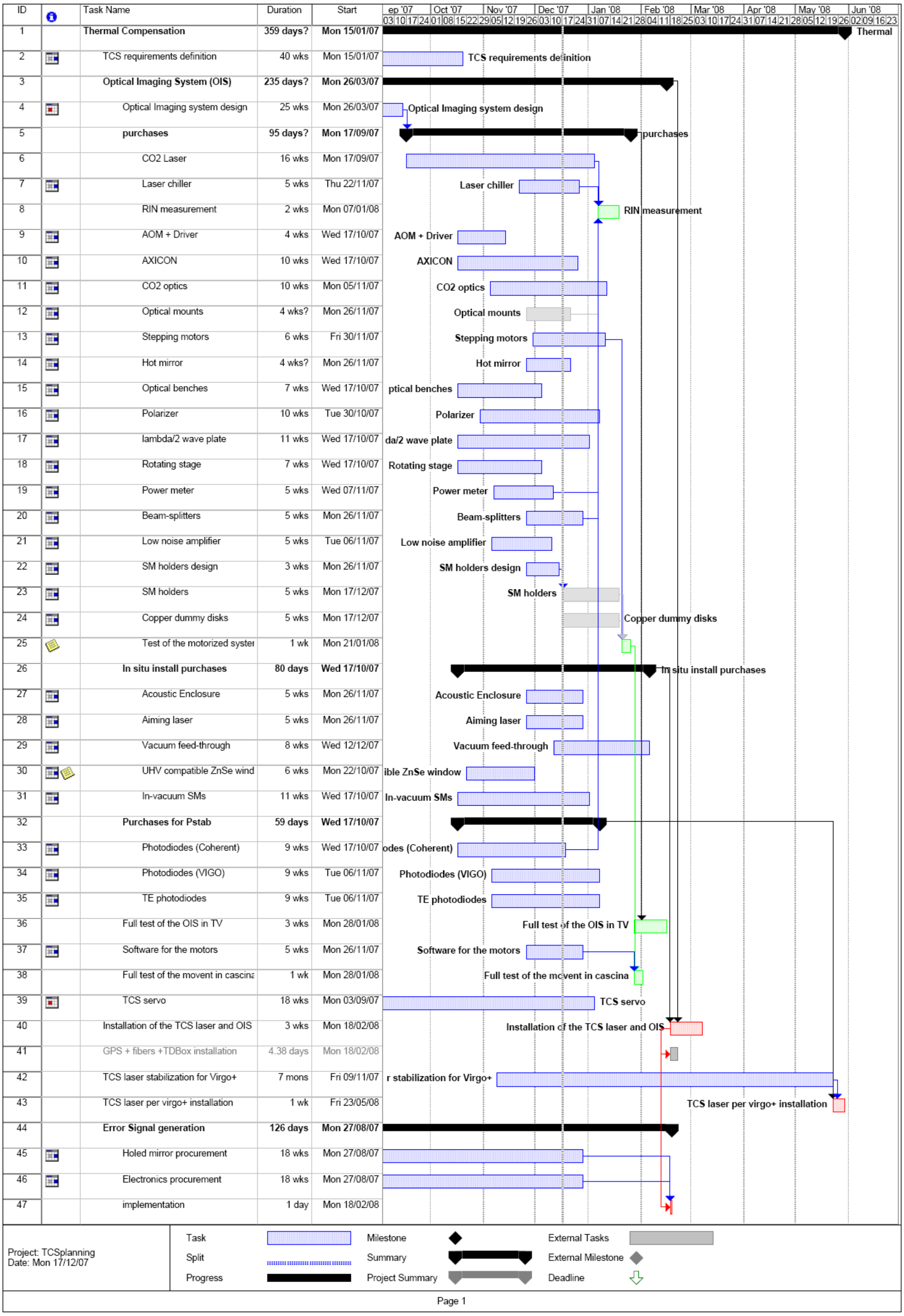

Figure 5 - TCS preparation plan; blue tasks are expected delivery times, grey are guessed delivery times, green activities are tests and red installation

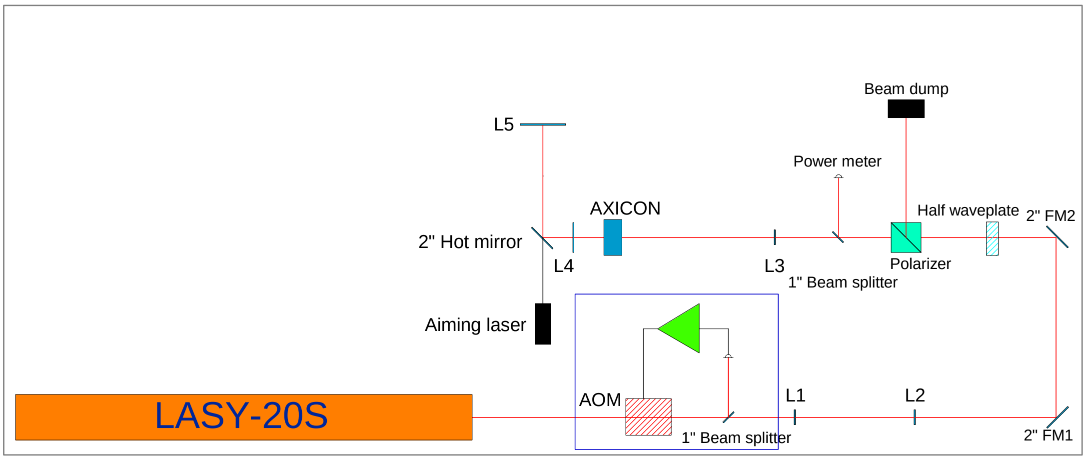

Figure 6 - Optical Imaging System (OIS) layout

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MaskExpenditures2007

VIRCHRQ: 011/2007 — Title: Thermal Compensation System

Responsible: A. Rocchi, V. Fafone

Status: OV

TotalBudget: € 200 000

2006Expenditures: € 0

2007Expenditures: € 68 000

2008Expenditures: € 0

SpentIn2007: € 180 925.69

Expenditures2007 Su

ID	EGOcode	VIRCHRQ	Date	Supplier	Note	Impegnato
82	OR-2007-31	011/2007	23/10/2007	Access Laser Company	CHRQ 011/2007 CO2 laser for TCS	€ 26 430.10
83	OR-2007-32	011/2007	23/10/2007	IntraAction Corp.	CHRQ 011/2007 AOM and driver for TCS CO2 laser power s	€ 8 629.57
85	IS-2007-770	011/2007	23/10/2007	LOT Oriel Group	CHRQ 011/2007 AXICON fot TCS	€ 5 455.20
86	IS-2007-771	011/2007	23/10/2007	LOT Oriel Group	CHRQ 011/2007 Half-wave plate for TSC laser power contro	€ 17 385.60
87	IS-2007-772	011/2007	23/10/2007	dB electronic Instruments srl	CHRQ 011/2007 optical benches for TCS	€ 7 080.00
88	OR-2007-34	011/2007	23/10/2007	Coherent Europe B.V.	CHRQ 011/2007 Room temperature photodiode from Cohere	€ 5 448.77
91	IS-2007-789	011/2007	23/10/2007	LOT Oriel Group	CHRQ 011/2007 In-vacuum steering mirrors for TCS	€ 9 076.80
92	IS-2007-769	011/2007	22/10/2007	MICOS Italia	CHRQ 011/2007 rotation stage for half wave plate for TCS la:	€ 5 738.45
107	IS-2007-827	011/2007	05/11/2007	LOT Oriel Group	CHRQ 011/2007 focusing lenses for TCS Optiac imaging sy	€ 11 577.60
108	IS-2007-837	011/2007	07/11/2007	ECOSILENT divisione della Ecos	CHRQ 011/2007 In a way to insulate acoustically the Therr	€ 18 456.00
109	OR-2007-39	011/2007	07/11/2007	VIGO-System Ldt	CHRQ 011/2007 Photodiodes from VIGO for TCS CO2 lasei	€ 24 307.20
110	IS-2007-836	011/2007	07/11/2007	PHOTO ANALYTICAL srl	CHRQ 011/2007 Low noise preamplifiers for TCS CO2 laser	€ 5 976.00
111	IS-2007-850	011/2007	09/11/2007	Coherent Europe B.V.	CHRQ 011/2007 Power meter for TCS laser power measure	€ 3 736.80
115	OR-2007-43	011/2007	23/11/2007	AMS Technologies AG.	CHRQ 011/2007 Chiller for TCS lasers	€ 5 034.00
116	IS-2007-898	011/2007	23/11/2007	LOT Oriel Group	CHRQ 011/2007 beamsplitters and folding mirrors for TCS O	€ 6 484.80
121	OR-2007-45	011/2007	28/11/2007	Arun Microelectronics Limited	CHRQ 011/2007 stepper motor for construction of TCS	€ 8 150.53
123	IS-2007-932	011/2007	30/11/2007	PROMEC srl	CHRQ 011/2007 deisgn and assembly of the in-vacuum stee	€ 5 400.00
125	OR-2007-47	011/2007	03/12/2007	ISP Optics Corp.	CHRQ 011/2007 Gold dichroic mirrors for TCS	€ 906.27
127	IS-2007-940	011/2007	05/12/2007	bdiscom srl	CHRQ 011/2007 Two vacuum flange to connect the in-vacuu	€ 4 728.00
130	IS-2007-957	011/2007	10/12/2007	ULO Optics Ltd	CHRQ 011/2007 Beam dumps for Thermal Compensation S)	€ 924.00

Record: 1 di 20

Record: 29 di 32

Figure 7- detailed budget for the TCS realization (2007 expenditures). The management of the 2007 expenditures is provisionally kept under control by the detector coordinator through an ad hoc software. In 2008 a better integration between change requests and EGO budget management will be implemented.

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Figure 8 - TCS expenditure curve. The purple curve represents the percentage of expenditure respect to the 2007 budget and the black curve respect to the total budget.

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3.3 Laser amplifier and high power compliant optics

The Virgo sensitivity is dominated, starting from few hundred Hertz by the shot noise. Obviously, the most direct way to reduce the high frequency noise is to increase the injected power. This is possible as far as the optics in the interferometer don't undergoes to an excessive thermal effects. Currently the most evident thermal effects are in the input mirrors of the long cavities, that are suffering a large thermal lensing effect, and in the Faraday rotator installed in the suspended input bench, that isolates the injection system (ISYS) from the large interferometer. The thermal lensing in the input mirrors is described in the TCS section and the Faraday Isolator (FI) effects will be hereafter described. High power laser don't require only the minimization of the scattered light, but also the reduction of the scattered light processes in the illuminated optics (hereafter described).

3.3.1 Laser amplifier

The laser amplifier has been delivered by Laser Zentrum Hannover to the Nice-OCA laboratories few months ago and a first commissioning activity has been performed to characterize the performances of this device and to define the last customizations to adapt it to the Virgo requirements . The detailed characterization of this device has been presented to the 2nd internal Virgo+ review (16-17 October 2007) and here are reported the major aspects[3].

In Figure 9 is reported the expected new layout of the laser bench; the amplifier will be installed after the current Virgo 20W slave laser.

In Table 3 is reported the amplification characteristics of the new laser amplifier; Comparing the last row of the table with the others is evident that, in order to limit the high order content of the beam, the best way to select the desired output power is to play with the slave laser pumping current; the slight contamination of the beam occurring with a smaller seed will be cured by the insertion of the new pre-mode cleaner (PMC).

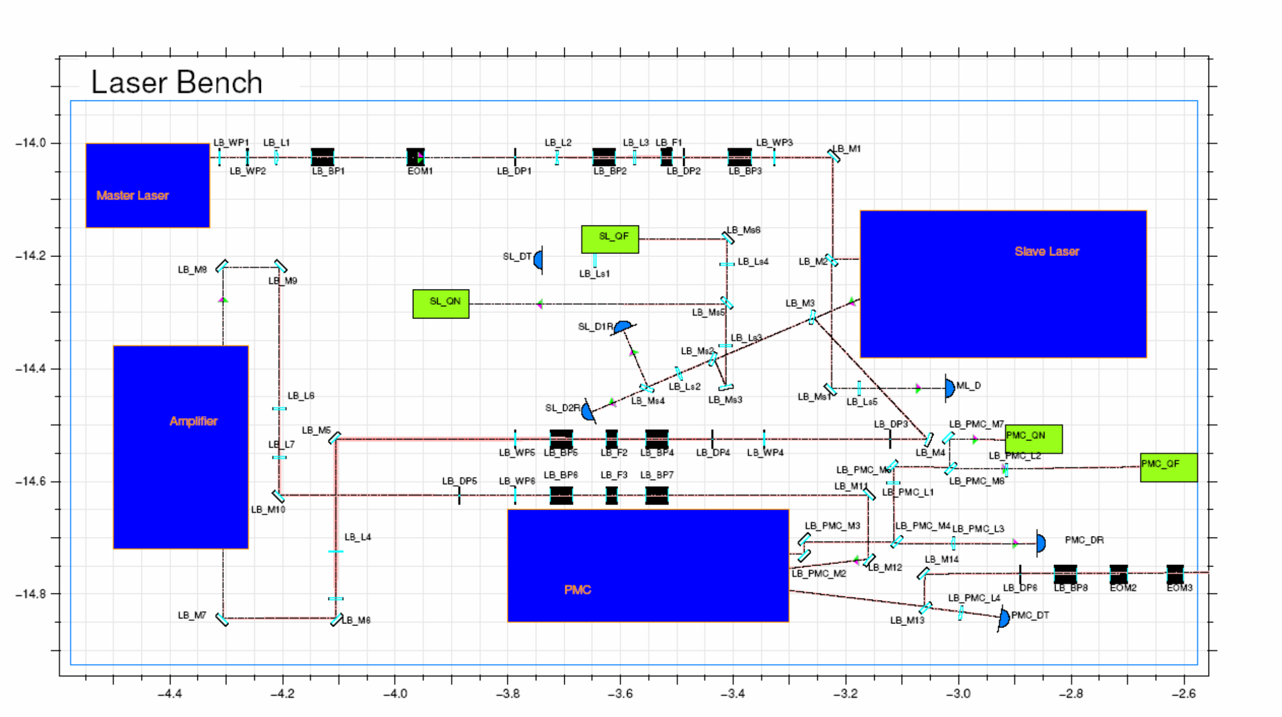

Figure 9 - Laser Bench implementation

[3] Additional information at the address: http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/Virgo+/EGOreviewJan08/Virgo+Review_Ampli50W_V+Jan2008Review.pdf

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Table 3 - Amplification factor

Seed	Amplifier Output	Gaussianity (% in TEM00)
Nominal amplifier pumping		
1W	24W	90%
10W	50W	93%
20W	65W	94%
72% reduced amplifier pumping		
20W	50W	73%

The estimation of the high frequency residual technical noise is reported in Figure 10; as described in the caption of the figure, the contribution of the residual technical noise of the amplifier at the modulation frequency could cause a reduction of the Virgo+ sensitivity of a 13% and this is expected to be cured by the insertion of the PMC in the laser path.
After the first phase of commissioning the amplifier has been upgraded by LZH, according to the indications given by ARTEMIS-OCA. The main intervention implemented are:

- new power supply (allows analog diode current control)
- crystal heat sinks will be thermally connected to the amplifier head (should reduce amplifier head heating due to residual pump light lost in the head)
- move water chiller away from amplifier (>10m, reduce acoustic noise)[4]
- pump diode power monitor (at amplifier crystals level)

The amplifier upgrade has been completed and now a second phase commissioning is started. As preliminary commissioning result could be stated that the new power supply, delivered by LZH, solved the low frequency excess of power noise (reported to the 2nd V+ review), as shown in Figure 11. The main activities of this second commissioning phase will be:

- power supplies current RIN/ pump diode RIN/ output RIN measurements
- pump monitor commissioning (check temperature immunity)
- long term test (check for possible misalignments)
- check compliancy with power stabilization present scheme
- check beam quality on PMC cavity

and they will start as soon as the PMC upgrade and commissioning will be completed (mid-January).
The man power involved in this activity is reported in Table 4.

Table 4 - Man power devoted to the commissioning phase 2 of the laser amplifier

Name	Institution	Activities/role
LZH	Laser Zentrum Hanover	Amplifier manufacturer
Cleva F.	OCA-CNRS	Commissioning responsible
Coulon J.P.	OCA-CNRS	Electronic

[4] was foreseen originally; will not be tested at Nice, but on site according to chosen configuration

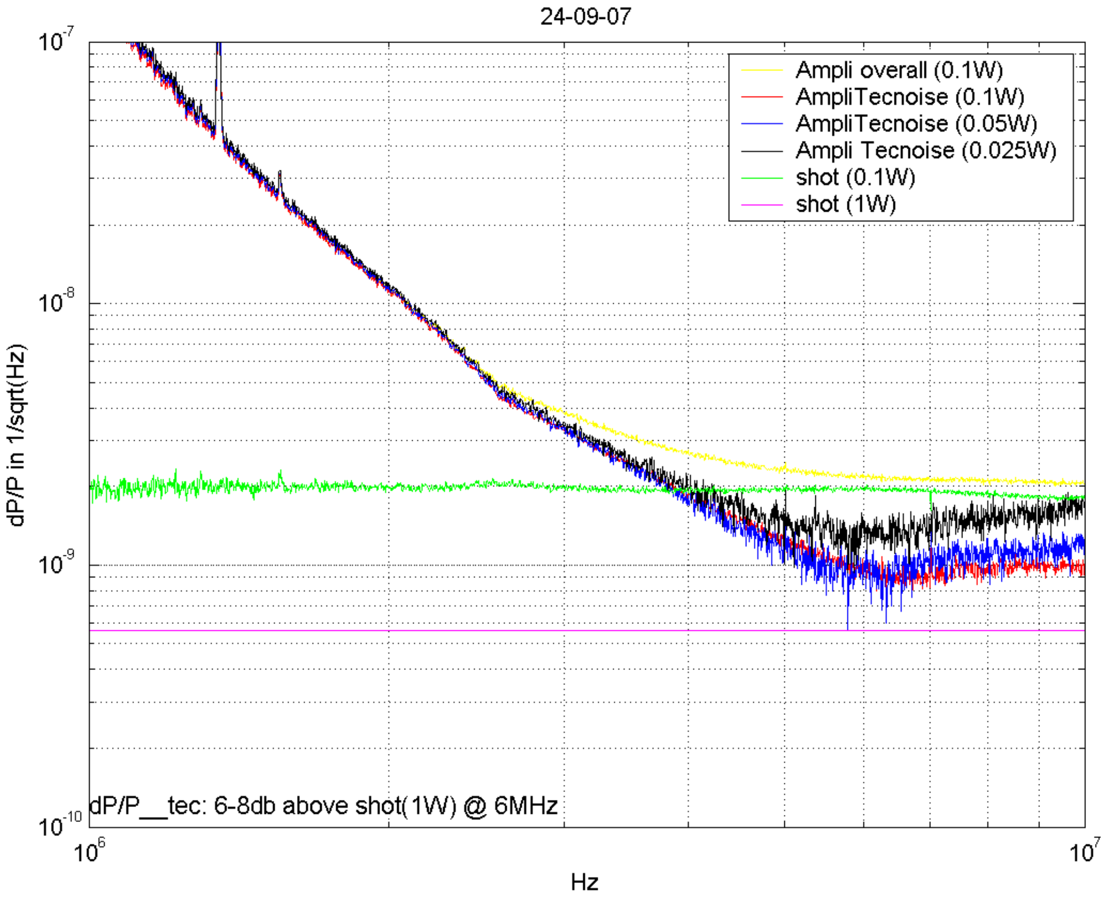

Figure 10 – Estimation of the amplifier technical noise at high frequency. Curves black/blue/red are amplifier technical noise for 25/50/100mW lightning the photodiode (overall noise from which shot and dark noise have been quadratically subtracted. `At 6MHz,` *the data are coherent for 50 and 100mW, meanwhile higher noise level for 25mW has been obtained (may be due to low S/N ratio). Using the curves with the higher lightening of the photodiode, a 13% reduction of the sensitivity is caused by the residual technical noise at 6MHz. .)*

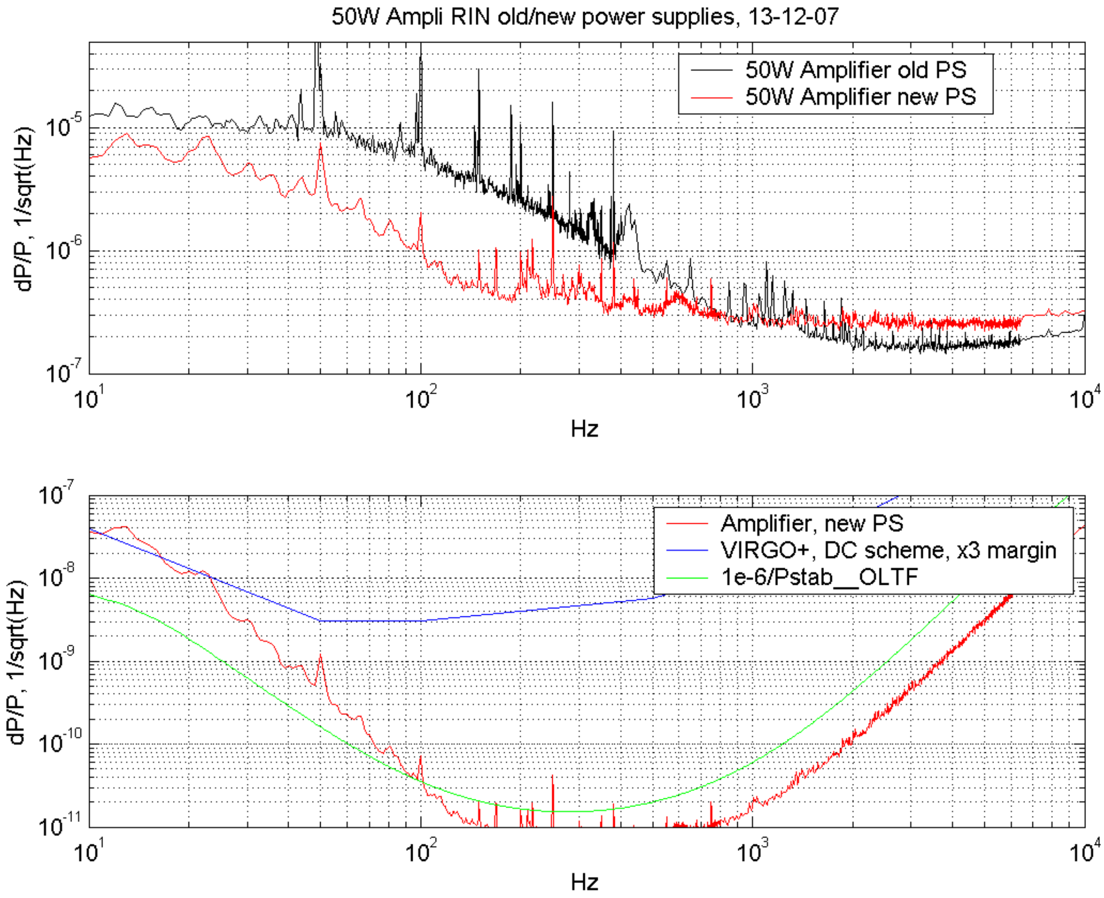

Figure 11 - Upper plot, we show amplifier RIN with new and old power supplies (red/blue plots); Lower plot, we show amplifier RIN divided by the VIRGO power stabilization Open Loop Transfer Function (red), and the inverse of VIRGO power stabilization OLTF times 1e-6 (green), Specifications for VIRGO+, assuming DC readout scheme, (most stringent spec. over among AC & DC schemes) are given in blue, with factor 3 margin[5].

3.3.2 Pre- Mode Cleaner (PMC)

The Pre Mode Cleaner is the Perot-Fabry ring cavity to be installed after VIRGO+ 50W amplifier. It has been initially foreseen to filter the possible laser technical RIN excess at 6.26MHz, and on the basis of 1W dark fringe.

Another interesting feature is to provide TEM00 mode to Input Mode Cleaner, this will ease the IMC alignment control since the useful Ward error signals will not be affected by possible spurious high order modes (may make quadrant centering a critical issue).

Although the new laser Amplifier has been demonstrated to not add any further beam jitter, the presence of the PMC could also slightly suppress extra beam jitter.

The performances of the PMC have been shown at the 2nd V+ review and the reader is invited to refer to the corresponding document (http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/Virgo+/2ndReviewDocuments/Virgo+

[5] Specifications are computed using parameter of VIR-NOT-LAP-1390-338.pdf document That is 35mW on dark fringe, VIRGO optical gain G = 5.2e9W/m, Loffset= 12e-12m; we applied a safety factor of 3.

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Review_PMC_V+Oct2007Review.pdf) for more details. The conclusion of that documents where that

- the PMC is compliant with the 50W laser amplifier
  - PMC can transmit 50W (assuming 57W at the input), the PMC transmissivity is then 88% (taking into account both PMC and amplifier high order mode mismatch)
  - The transmittivity can be increased by 2,6% by using proper PMC input mirror coatings (wrong AR coating of the PMC input mirror)
- A thermal drift of the PMC length has been measured: 2.4e-4 FSR/sec, where FSR is the PMC Free Spectral Range (1.1GHz). This drift has been found to be due to pickup prism mistuning.

The retuning of the pickup prism and the replacement of the wrong coated mirror have been performed in the last week before Christmas and the commissioning is restarted at the beginning of January

Table 5 - Man power involved in the upgrade of the PMC

Name	Institution	Activities/role
Cleva	OCA-ARTEMIS	Responsible for the project, design/assembly/test
Coulon	OCA- ARTEMIS	Electronics
Genin	EGO	Implementation (VIRGO site), Assembly/test
Pasqualetti	EGO	Vacuum aspect (VIRGO site)
Nocera	EGO	Cabling on site, electronic implementation (VIRGO site)
M. Ciardelli	EGO	Cleanliness aspects

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3.4 Laser Integration

The present set-up of the laser bench (LB) and part of the optics of the external injection bench (EIB) cannot remain the same when the 50 W will be installed: there are space reasons, and some new telescopes have to be installed on the LB in order to have good beam collimation on the amplifier and from the amplifier to the PMC. Some new components have to be added to send the beam to the amplifier. And the effect of an higher power on the optical components of the two external benches has to be checked. These reasons make it necessary to redesign part of the optical layout of the two external benches and to add (and purchase) new components.
A detailed description of the tasks belonging to this activity is reported in an updated version of the 2nd Virgo+ review document; here we report just a status report.
After the design (completed) of the new layout of the laser bench and of the external injection bench, the critical components in the benches have been investigated. In Table 6 the status of the critical components in the LB is reported, meanwhile for the EIB the transmittivity of several beam splitters has been re-considered according to the new power available and some superpolished mirror has been ordered (and it will be coated at LMA) to reduce the possible scattering
In Table 7 the man power involved in the laser integration "production" activity is reported.

Table 6 - Critical components in the laser bench

Faraday isolator between Slave laser and the amplifier	It will remain the present one (EOTech 8 mm aperture)

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Faraday isolator between the amplifier and the pre-mode cleaner	It should be not necessary, but a conclusive answer should come either from the analysis of the behaviour of the pre-mode cleaner and from the characterization of the amplifier (not yet finished). Needed low losses FI. Tests in progress (Isowave Faradays 5 mm aperture available)
Faraday isolator after the pre-mode cleaner	Needed for low losses. Test in progress (Isowave Faradays 5 mm aperture available)
EOM between the master laser and the slave laser	No change needed
6.26 and 22 MHz EOM	can withstand 50 W without damage
8MHz EOM	can withstand 50 W without damage
Polarizers in front and after every Faraday isolator	Brewster thin film polarizers. Superpolished substrates ordered to General Optics. The thin film polarizers will be made in Lyon
Waveplates	no problem is expected from the waveplates present on the LB. The presently used will be reused.
Telescopes	New telescopes have been designed for the slave-amplifier collimation (already tested in Nice) and for amplifier-PMC collimation, the telescope after the PMC to collimate the laser beam onto the IMC, has been checked, simulated, and its adaptability verified

Table 7 - Man power involved in the laser integration design and testing

Name	**Institution**	**Activities/role**
Paolo La Penna	EGO	coordinator, computation, testing
E. Genin	EGO	optical design, simulation, testing
F. Cleva	OCA-Nice	computation, testing
J. Marque	EGO	optics of the EIB

3.4.1 Installation

Although the PMC and some other activities (like shifting from the LB to the EIB the final telescope collimating onto the IMC) could be anticipated, it is our intention to implement all together during the May shutdown. The installation can be split in three tasks, where the PMC, the laser amplifier + related optics and the EIB are involved. The overall time needed is about 7 working weeks and the man power involved is reported in Table 8, but also a consistent support of the EGO electronics group is expected.

Table 8 - Man power involved in the laser integration activities

Name	Institution
E. Genin	EGO
F. Cleva	ARTEMIS
J. Marque	EGO
B. Canuel	EGO

3.5 Remote tuning of the Faraday Isolator in the suspended injection bench

The installation of a Faraday isolator between the IMC and the Power Recycling (PR) mirror was one of the main reasons for the design of a new SIB. Up to C7 the power had been attenuated by a factor 10 (and the input power into the ITF was also reduced by a factor 10), this leading to an

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attenuation of the beam reflected back inside the IMC by a factor 100. The Faraday isolator that was purchased was tested in air, yielding a maximum isolation factor larger than 10,000. Once installed on the SIB, after a final tuning and adjustment of the isolator when the SIB was still in air, the isolation was still better than 10,000. Once the SIB was put in vacuum, after fine beam alignment with respect to the Reference Cavity (RFC) and interferometer (ITF), the measured attenuation was something less than 1,000. We think that this is the result of a combination of misalignment and thermal effects. The latter could be different going from air to vacuum, due to the lower heat dissipation in this condition. Simulations give a convincing explanation of the degradation of the isolation factor as due to the coming from a heating of the TGG crystal, which changes this mainly changing the refraction index of the crystal itself. So, unless there is a significant unexpected contribution of thermally induced birefringence, this effect could in principle be corrected, if a in-vacuum tuning were possible.

Now, even if the present isolation is already ten times better than during C7 (but with ten times more power entering into the ITF), there is clearly some backreflection into the IMC, which is still measurable. Although it is still unclear if this level of backreflection can be an issue, the same simulation used to successfully explain the process, indicates that with the Virgo+ expected laser power the isolation factor will fall down to less than 100.

For this reason we are realizing a system that allows to perform a remote tuning of the isolation of the Faraday by rotating, with a motor, the mount of a $\lambda/2$ waveplate inserted between the input polarizer and the rotator itself. This will happen maybe at the expense of the light transmitted by the output polarizer of the Faraday isolator, which should be however negligible.

With this system we should be able to reach the maximum performances of the Faraday isolator as far as isolation is concerned, thus reducing the noise induced in the injection system by the PR backreflection.

It is not sure that there will be really the need for Faraday thermal lensing correction, even if it seems now likely. There will surely be thermal lensing, but it could be corrected acting on the parabolic telescope tuning. Simulations on this topic have shown that thermal effect should induce a mismatch of 5% on the ITF. It should be possible to compensate for this mismatch by using the parabolic telescope which allows to correct for a laser beam which induces up to 10% mismatching on the ITF.

In case, for correcting the thermally induced focal length in the TGG rod, it is planned to mount (later) after a compensative rod, made in DKDP. This element should correct the change in the focalization of the beam acting in the opposite way of the Faraday.

The details of this activity are reported in an updated version of the 2nd internal review report; here we can summarize that almost all the production tasks have been accomplished and no delays are expected.

Table 9 - Virgo collaborators involved in the FI remote tuning production tasks

Name	Institution	Activities/role
Eric Genin	EGO	Coordinator
Vincenzo Dattilo	EGO	Vacuum cabling
Flavio Nocera	EGO	Electronics implementation
Paolo La Penna	EGO	Coordinator
Daniel Sentenac	EGO	Software
Tatiana Zelenova	EGO	Mechanical design
Benjamin Canuel	EGO	Experimental tests, simulation and installation
Slim Hamdani	EGO	Simulation
Mario Favati	EGO	Mechanical pieces machining

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3.5.1 Installation

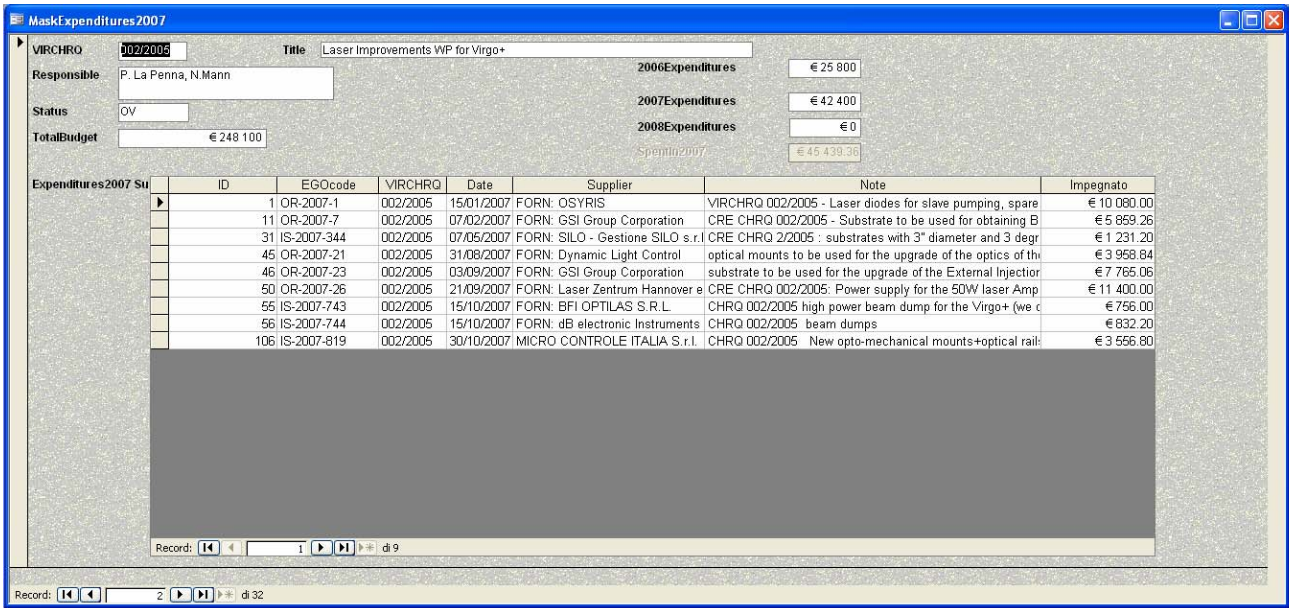
The list of collaborators that will be involved in the installation is reported in Table 10; this activity should be performed after a short commissioning of the laser amplifier integration task. The installation activity should be performed in a working week, but we are aware that the recovering from this intervention shows some difficulty (already encountered during the injection bench upgrade).

Table 10 - Virgo collaborators involved in the FI remote tuning installation.

Name	Institution
E. Genin	EGO
B. Canuel	EGO
P. Ruggi	EGO
F. Nocera	EGO
V. Dattilo	EGO
D. Sentenac	EGO

3.5.2 Budget and expenditures

The laser amplifier production and integration is costing about 250k€, the remote tuning of the FI is costing about 8k€, meanwhile the PMC upgrading (and not production, because it was already expected in Virgo) is costing about 15k€. As shown in Figure 13, the amplifier activity already started in 2005 and a dominant fraction of the expenditure (mainly the laser amplifier purchase) occurred in 2006. This supports the maturity of the activities.


MaskExpenditures2007

VIRCHRQ: 002/2005
Title: Laser Improvements WP for Virgo+
Responsible: P. La Penna, N.Mann
Status: OV
TotalBudget: € 248 100
2006Expenditures: € 25 800
2007Expenditures: € 42 400
2008Expenditures: € 0
SpentIn2007: € 45 439.36

Expenditures2007 Su

ID	EGOcode	VIRCHRQ	Date	Supplier	Note	Impegnato
1	OR-2007-1	002/2005	15/01/2007	FORN: OSYRIS	VIRCHRQ 002/2005 - Laser diodes for slave pumping, spare	€ 10 080.00
11	OR-2007-7	002/2005	07/02/2007	FORN: GSI Group Corporation	CRE CHRQ 002/2005 - Substrate to be used for obtaining B	€ 5 859.26
31	IS-2007-344	002/2005	07/05/2007	FORN: SILO - Gestione SILO s.r.l	CRE CHRQ 2/2005 : substrates with 3" diameter and 3 degr	€ 1 231.20
45	OR-2007-21	002/2005	31/08/2007	FORN: Dynamic Light Control	optical mounts to be used for the upgrade of the optics of th	€ 3 958.84
46	OR-2007-23	002/2005	03/09/2007	FORN: GSI Group Corporation	substrate to be used for the upgrade of the External Injectior	€ 7 765.06
50	OR-2007-26	002/2005	21/09/2007	FORN: Laser Zentrum Hannover e	CRE CHRQ 002/2005: Power supply for the 50W laser Amp	€ 11 400.00
55	IS-2007-743	002/2005	15/10/2007	FORN: BFI OPTILAS S.R.L.	CHRQ 002/2005 high power beam dump for the Virgo+ (we c	€ 756.00
56	IS-2007-744	002/2005	15/10/2007	FORN: dB electronic Instruments	CHRQ 002/2005 beam dumps	€ 832.20
106	IS-2007-819	002/2005	30/10/2007	MICRO CONTROLE ITALIA S.r.l.	CHRQ 002/2005 New opto-mechanical mounts+optical rail:	€ 3 556.80

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Figure 12 - detailed budget for the laser amplifier realization and integration (2007 expenditures)

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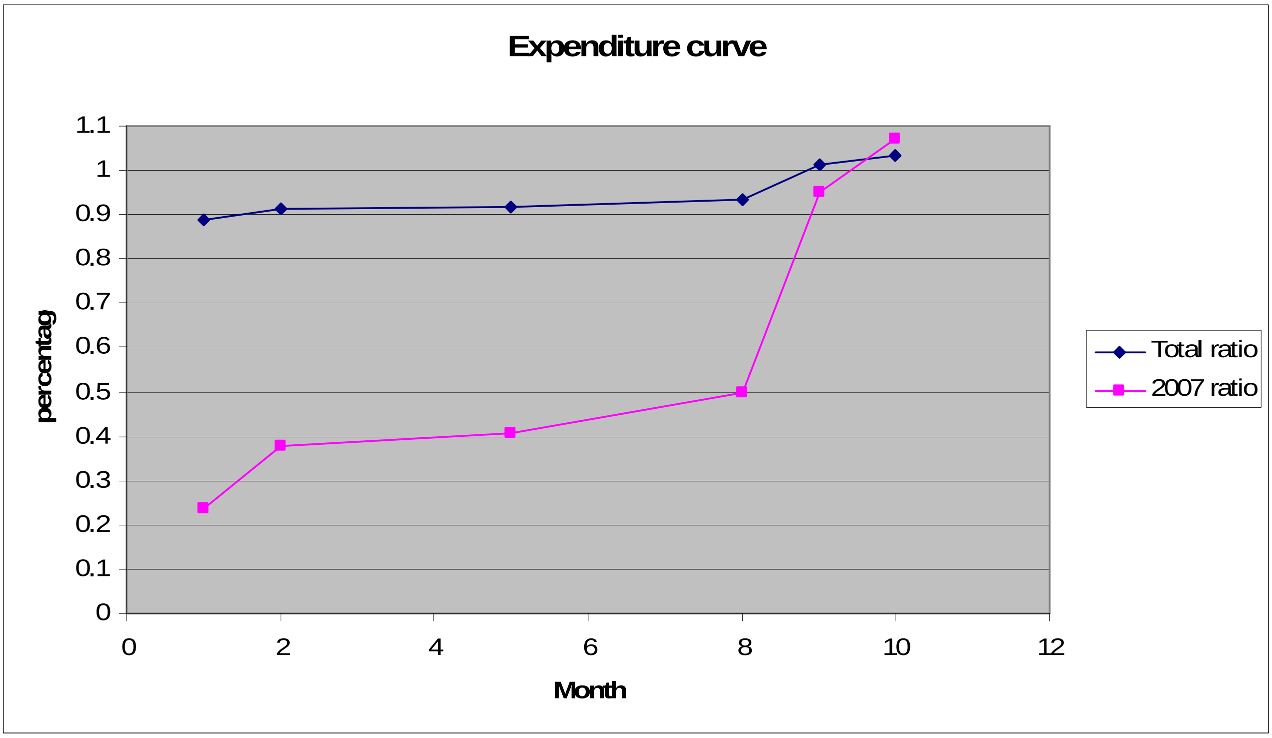

Figure 13 - Laser amplifier construction and integration expenditure curve. The purple curve represents the percentage of expenditure respect to the 2007 budget and the black curve respect to the total budget.

3.6 New end payload of the input mode cleaner (IMC)

The payload in the terminal tower of the triangular IMC is causing some problem to Virgo both from the optical and mechanical points of view. In fact we are suffering of a not negligible loss of the laser light injected in the interferometer: the power at the exit of the external injection bench (EIB) is about 12.5W, meanwhile the power injected in interferometer is about 8W (IMC transmittivity ~64%). The cause of this loss is not well identified, but we know that the substrate (and then the coating) of the end mirror of the IMC is of really poor quality, as reported in the minutes of the MC transport box opening:

- http://wwwcascina.virgo.infn.it/IBupgrade/StacPresOct2004/pv%20Mmc%20op-1.doc

and in the mirror characterization sheet:

- http://wwwcascina.virgo.infn.it/IBupgrade/StacPresOct2004/C03004-New-Concave-Mirror-MC.pdf

For this reason has been decided in the past to replace this mirror.

The current IMC end mirror is realized by a 80mm diameter, 31mm thickness substrate. Taking in account the density of the fused silica and the mass of all the components attached to the mirror (markers, magnets, spacers) the total MC mirror mass is about 360g. This so low mass causes many problems. First, radiation pressure effects are well visible; it has been shown (S.Hebri at the April 06 detector meeting: http://wwwcascina.virgo.infn.it/collmeetings/presentations/2006/2006-04/DetectorMeeting/hebri_det030406.ppt) that the light circulating in the MC acts as an elastic force changing the resonant frequency of the Tx and Ty modes of the MC mirror. It is true that the control instabilities, caused by this change, have been cured tuning the control filters at the effective resonant frequency, but this tuning depends on the circulating power.

As can be noted in Figure 14, the back face of the MC is really crowded: the markers and the magnets off-centre the centre of mass by (only) one millimetre, but, mainly, the markers and the coils can bump together. For this reason the coils have been displaced by few millimetres away the ideal Helmholtz position in the assembling phase.

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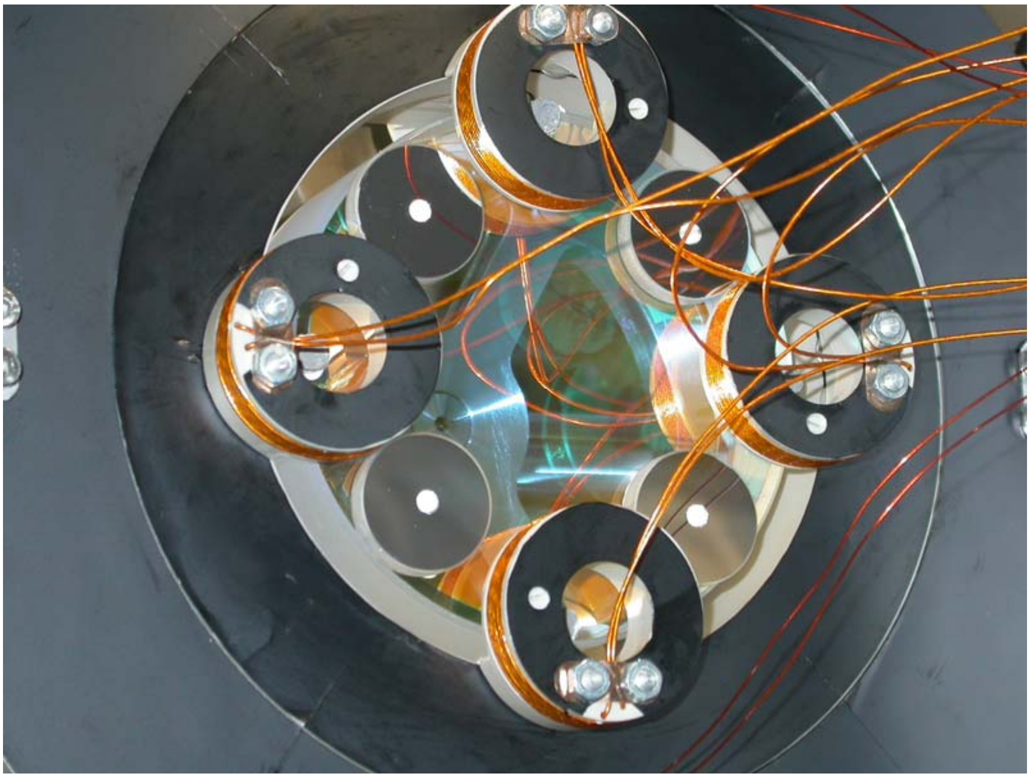

Figure 14- Back face of the IMC end mirror. The lack of space caused by the markers and by the coils is well evident. The large diameter coil wires are also well visible.

The low mass of the MC caused a design of the payload completely different from the standard Virgo mirrors. The clamping system is different and the suspension wires are 125µm diameter CuBe[6] wires, nominally having the lower violin mode at about 81Hz (well below the 330Hz expected for the standard large payloads).
The reference mass (RM) is made by a double ring: the inner one is made by peek and the outer one in stainless steel for a total mass of about 4.196Kg. This RM is suspended by two Virgo wires (200µm diameter, two loops configuration), but, since there are 6 coils in the RM, 12 copper wires, 0.6mm diameter each (0.4 Cu + 0.2 Kapton) connect the RM to the marionette, affecting dramatically the suspension stiffness. Furthermore, the transfer function measurement of the MC payload don't correspond to the analytical model (i.e. the first violin mode frequency is not found where it is expected) revealing a complex behaviour of the system and a poor modelling possibility[7].
After a designing phase and an optimization of the mirror geometry, taking in account the available substrates, a new mirror has been ordered, based in a sub-section of an available substrate in Herasil (Virgo end-mirror material). The new substrate requirements are reported in Table 11;

[6] The usual carbon steel (C85) cannot be used because the wires pass close to the magnets in the mirror.
[7] For more details see the change request VIRCHRQ003/2006: http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/CRE/virchrq0032006.html

Table 11 - New IMC end mirror requirements

Property		**Virgo Requirement**
Substrate		Herasil
Identification		LCMC# with # =1,2,3 (on side C)
Diameter		140±1 mm
Thickness		45±1 mm
Wedge		600±20 μrad (minimum thickness below)
Curvature	Side A	Flat
	Side B	R=180±2m ϕ 60 mm
Flatness R.M.S.	Side A	<40 nm ϕ 150 mm <15 nm ϕ 60 mm
	Side B	<8 nm ϕ150 mm <2 nm ϕ 60 mm
Roughness (RMS)	Side A	<0.1 nm
	Side B	<0.05 nm ϕ150 mm
Bevel	Side A	1.5 mm @ 45°
	Side B	1.5 mm @ 45°
Scratch/Dig	Side A	< 20/10
	Side B	< 10/5
OD FLAT (one on each side)		
Clean Area (mm)		X=+22.5/-22.5 & Y=+10/-10
Flatness (PV)		λ/10 wave
Roughness		For optical contacting

3.6.1 Mirror production

This activity has been delayed by a problem with the radius of curvature of the substrate. The first of the three polished substrates has been delivered by General Optics last October. The metrology made at LMA revealed that the radius of curvature of this substrate is 195 m instead of the requested 180 m ± 2m.
The possibility to correct the radius of curvature by adding a thick layer of silica coating on the back face of the mirror has been studied. The tests performed have shown that this technique does not allow getting the correction needed.
The measured mirror profile has been transmitted to the group of Nice and the performances of the mode cleaner cavity once this mirror will be mounted have been simulated. The main results are the following (see also the forthcoming note VIR-056B-07):

1. While the clipping of the beam on the end mirror decreases considerably, thanks to the larger coating, the increase of the cavity mode waist introduces a previously absent clipping at the level of the dihedron. As a consequence the cavity transmission decreases from 84% to 80%. It should be noted that both these numbers are considerably larger than the measured transmission of the present input mode cleaner (~65%).
2. The third order transverse mode gets closer to the resonance condition. As a consequence its transmission increases from $9\ 10^{-3}$ to $33\ 10^{-3}$. This mode, that is already the one having the larger transmission, becomes the one having the largest transmission by a great factor (for comparison the first order mode has a transmission of $2\ 10^{-3}$).

While point 1 could be a matter of discussion, the effect of point 2 is considered too dangerous. For this reason the mirror cannot be accepted.

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It should be noted that this is not the first time that General Optics provides a mirror with the bad radius of curvature. Already last spring a smaller mode cleaner mirror had been provided by GO having a radius of curvature of 165 m instead of the requested 180 m. In that case the mirror turned out to be acceptable and was accepted. This small mirror has been used to cross check the metrology at LMA. The mirror has been sent to LIGO, SESO and SOLEIL. This three different teams measure the ROC to be respectively 168 m, 164 m and 165 m, thus confirming the measurement made at LMA.
In order to discuss these results a meeting was organized with General Optics and the results obtained were presented. At the end of the meeting General Optics agreed to cross check its metrology apparatus. A few weeks later they informed LMA that they had found a problem in their metrology. On the basis of this result General Optics has accepted to re-polish the first substrate.
Moreover the two other substrates, that had already been polished but not delivered, are being re-polished as well. The first of these two should leave General Optics by the end of the year. We have good hopes to have it delivered at LMA by mid January. Once the mirror will be delivered, there is about one month that is required to coat the mirror. If the delivery date is maintained it should be possible to start the mirror preparation at LMA on mid-February.

3.6.2 Payload design and production

The new mirror geometry and mass and the more stringent requirements in terms of controllability of the payload forced to redesign the reference mass (**RM**) and the marionette. The RM new specifications are reported in the following list:

- Mass up from 4 kg to 13 kg
- Steel wires 0.2 mm diam.
  - Thermal treatment (1 week at 150 °C with weight in N2 atmosphere)
- Coils
  - resized to 50 mm; good for 0.5 mm adjustment.
  - max. force: 33 mN at 100 mA.
  - 5 Ohm, --> 60 mW
  - expect 1 mK/s.
  - working point of magnet: 10 mm from centre of coil

In Figure 15 the new RM is drawn on its assembling frame.
The position of the mirror can be adjusted, when the payload is integrated in the short super-attenuator, through a displacement mechanism (**gear box**). This is already true for the current mirror and will be implemented in the new payload extending the displacement range from the current ±30 mm up to ±65mm.

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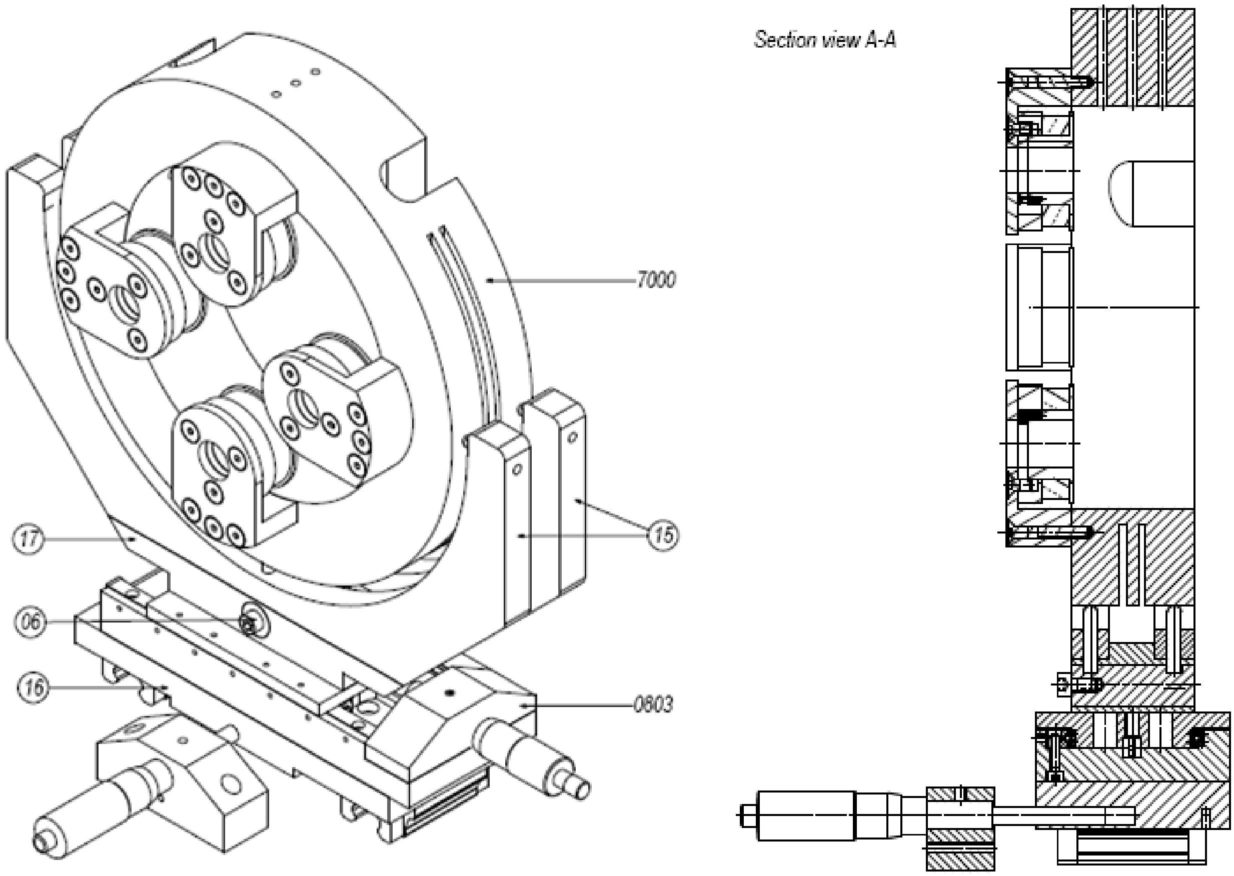

Figure 15 - The new reference mass (RM) of the IMC end mirror. The RM is drawn on its assembling frame.

To optimize the installation time it has been decided to realize a new marionette. In fact, the previously described modification of the payload requires a consistent modification of the current marionette, that should be, after the dismounting, updated in an external mechanical workshop. To avoid this dead time a new marionette, as much as possible similar to the current one[8] has been designed in Nikhef.
Finally, a not negligible tooling for installation must be produced and tested in clean room.

3.6.3 Status of the activities

The status of the mirror production has been already discussed; if GO solved its production problem, the first substrate should be delivered to LMA in the middle of January and in a month should be ready to be prepared for the first assembling phase (magnet and marker glueing). This phase should be concluded in less than one month and the mirror should be available before the end of March.
The RM is under machining (Roma 1) and should be ready at the beginning of January. The gear box has been machined (Roma 1) and it should be ready for the beginning of January.
Although the machining of the marionette is started in Nikhef in November, the last part of the design has been frozen the 15th of December and the production should be completed in January. The installation tooling (Nikhef) are under production and should be completed in January.

[8] The geometry and mass of the marionette must be adapted to the new payload, attempting to minimize the increase of load that the super-attenuator should sustain.

3.6.4 Man power and budget

The list of collaborators involved in the IMC production activity is reported in Table 12, meanwhile the budget dedicated to the mechanical components production is about 36 k€ (roughly 6 k€ EGO and 30k€ Nikhef). The EGO expenditure (the support to the Roma 1 activities) occurred in 2006 as well as the expenditures for the substrate production (about 30k€ for the polishing of all the substrates).

Table 12 - Collaborators involved in the IMC upgrade

Name	**Institution**	**Activities/role**
Jo van den Brand	Nikhef	Coordination
Michele Punturo	Perugia	Wires, detector coordination
Paola Puppo	Roma 1	Reference mass
Henrich Heitmann	CNRS-Nice	Commissioning
Raffaele Flaminio	LMA-Lyon	Substrate procurement
Ettore Majorana	Roma 1	Markers
Laurent Pinard	LMA-Lyon	Metrology
Christophe Michel	LMA-Lyon	Coating
Thomas Bauer	Nikhef	Design and follow-up
Franz Mul	Nikhef	Production and assembly
Mikael Laval	CNRS-Nice	Optical modeling

3.6.5 Installation

According to the planning, all the components, but the real mirror, should be available for the end of January. A series of mounting trials will be performed in the Nikhef clean room to define the assembling procedures. The IMC end payload will be dismounted (3 working days) in parallel to the laser amplifier installation and subsequently the new payload will be installed (2 weeks) to be commissioned as soon as the laser will be operative. To minimize the exposure of the new mirror to the contaminants, the super-attenuator tuning will be realized with a dummy payload. This activity could increase the installation time of a couple of weeks.

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3.7 New control and DAQ electronics

The replacement of many components of the control and DAQ electronics is driven by several motivations:

- obsolescence of the components
- reduction of electromagnetic noise
- provide a fast access to an absolute GPS time stamp to all the front end electronics
- reduction of the noise level of the ADC readout and (possible) increase of the readout rate
- increasing of the control loop phase margin and the computing power

This activity has been subdivided in 6 tasks and here is reported briefly the status of each of them. For a more detailed description of the tasks and of the technical content the reader could refer to the documentation reported in Table 15.

3.7.1 Production Task 1: Atomic GPS receiver

Short description:
Selection, procurement and test of the Atomic GPS receiver
Status of the task:
One GPS receiver is available and tested. The two additional Atomic GPS receivers have been ordered. We foresee to receive these 2 devices on January 2008.

3.7.2 Production Task 2: Timing distribution board

Short description
This is the design, test and production of the timing distribution boxes (TDBox) and the procurement of the fibres and cables needed to distribute to clock signal to all TOLM, ADC, and possibly DAC modules.
Status of the task:
The production of the TDBs is complete; all the boxes have been delivered at LAPP the December18. The reception tests will start in January 2008

3.7.3 Production Task 3: MUX/DeMUX board

Short description
This is the design, test and production of the Mux/DeMux board. This board is a router for the optical links between TOLM and ADC boards.
Status of the task:
The MUX/deMUX prototype has been successfully tested. All the components have been ordered. All the PCB are produced and the cabling will start in January 2008

3.7.4 Production Task 4: ADC board

Short description
This is the design, test and production of the new ADC board.
This is a 16 ADC channel board to be used for photodiode readout and monitoring of the various Virgo components. It has an optical fibre connection to the PC+TOLM driving it.

Status of the task:
The first prototype of the board has been produced (see figure). The first tests are positive and the noise level seems to be close to the one observed in the ADC standalone evaluation board.
All the elements of the board have been tested; a second prototype is under production.
Characterization of the signal conditioning mezzanines is in progress.
The ADC production remains the critical element for the delivering.

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3.7.5 Production Task 5: TOLM

Short description

This is the board which hosts the optical link connections and the timing elements. Two kinds of boards will be produced. The main difference is their format: PMC format for DSP or RIO usage and PCI format for PC usage.

Status of the task:

Several TOLM-PMC exist and are routinely used for the software and hardware tests of the Mux/DeMux, ADC or PC.

The design of the TOLM-PCI is complete. The prototype has been produced and it's currently under tests. Then, the production could start as well as a preparation/production of an updated version for the TOLM-PMC.

3.7.6 Production Task 6: Software

Short description

This task covers the software needed to run the system. This includes:

- The Real-time PC selection
- The real time front end for the ADC data collection for the longitudinal and angular photodiode readout, environment monitoring (known as Pr, Qa, Lr,…)
- The framework for the interferometer control. This is the evolution of the GC software. This means the infrastructure to collect, compute and send the data at the main frequency of the loop. The computing part of the system will involve basic algorithm (like filters as available in the current Pr software) plus the possibility to add more complex algorithms. The coding of new algorithms or the maintenance of the algorithm configurations is not included in this task.
- The slow control for the detection system (Pi, MC, Lo, Vb…)
- The Gx software upgrade
- All the DAQ usual software, detector monitoring, automation software.

Status of the task:

It has been checked (ref. [18, 19]) that it is possible to run the main ITF loop with the current signal and algorithm complexity up to 40kHz. This fulfils with some margin the needs of the locking group (10kHz frequency; more computing).

The selection of the real-time PCs has been done [23]. The ordering is performed and the PCs will be delivered in February 2008

The current activity is to develop the code for this main loop, for the data collection (new protocol on the fibres) and to interface some of the existing software running on RIO to the new system (not everything will be convert on the same day).

This will continue until (and after) the deployment of the hardware.

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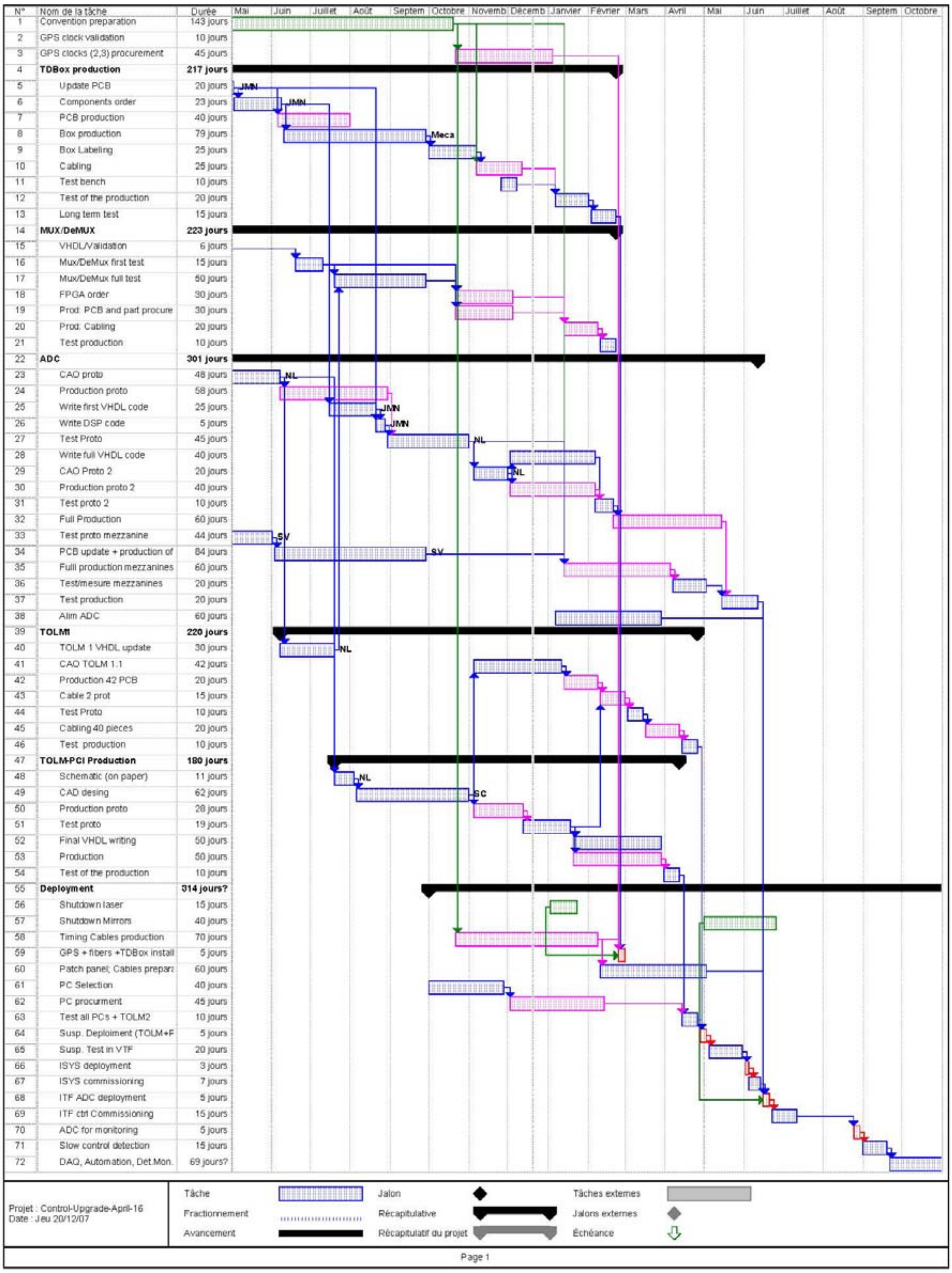
Table 13 - Production planning



3.7.7 *Remarks on the planning:*

- This planning is focus on the construction of the real time components of the system. Other "satellite task" like the upgrade of the DAQ workstations are needed but not included in this planning, since it is not on the critical path.

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- The first installation of some timing components will be in parallel of the existing system.

3.7.8 Installation activities description

The document [22] describes the new topology based on the *MUX/DEMUX* networks for the Interferometer controls and the Input system controls. The new topology has been validated by the commissioning groups.

Related to this document a description of the possible racks, crates and boards deployments has been made as a draft[24]. The goal of this draft is to prepare the cabling activities and to checks the availability of the hardware (racks and crates).

Few concerns about the installation:

- There is no need to perform the full installation at the same time
- Some installation activities are anticipated like the TDB deployments, the real-time PC and Mux/Demux deployment
- The ADC installation can be split and performed subsystem by subsystem: Injection system, longitudinal and angular controls, Detection slow control

A temporary solution mixing some old and new electronic is also possible with few software upgrades; this could permit to interlace the other installations with this one.

Table 14 - Man power involved in this activity

Name	Institution
Annecy team (A. Masserot, N. Letendre, S. Vilalte…)	Annecy
D. Sentenac, F. Nocera	EGO

3.7.9 Budget and expenditures

The development of the DAQ electronics is performed by the Annecy group mainly through a convention contract (still to be activated) with EGO . The full cost of the activity is about 390k€ and about 58 have been already spent directly by EGO in October 2007 (GPS) and December 2007 (control PCs).

Table 15 - DAQ & control electronics reference documentation

1. New control and DAQ electronic; Change request
2. The Virgo DAQ System ; RTAI proceedings, May 2003 (Overview of the control/DAQ system)
3. Consequence of the jitter noise on ADC readout; D. Tombolato; VIR-NOT-LAP-1390-274 (3/08/04)
4. Control System Upgrade of the VIRGO interferometer. Timing Interface & Optical Links; O. Chautemps, et al. VIR-NOT-LAP-1390-278 (11/08/04)
5. Proposal for the Timing & Optical Links Mezzanine (TOLM); O. Chautemps, et al. VIR-NOT-LAP-1390-279 (11/08/04)
6. Preliminary Timing system interface requirements; O. Chautemps, et al. VIR-NOT-LAP-1390-280 (11/08/04)
7. Connectors pin-out of the TOLM ver1.0 prototype; N. Letendre, O. Chautemps; VIR-NOT-LAP-1390-281 (14/09/04)
8. MUX/DEMUX optical card specifications; N. Letendre, VIR-NOT-LAP-1390-321 (15/03/06)

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9. TOLM Boundary Scan Board specifications, N. Letendre VIR-NOT-LAP-1390-322 (05/04/06)
10. New timing distribution system for Virgo: prospect for a full system from the market; S. Karkar. June 9, 2006, VIR-NOT-LAP-1390-323
11. EGO R&D program R&D, Final report for the Electronic Upgrade; Part I (Timing; TOLM, ADC; Analog Electronic) June 2006
12. ADC tests for the general purpose acquisition board, VIR-NOT-LAP-1390-329 (October 25, 2006)
13. EGO R&D program; Final report. R&D for the Electronic Upgrade; Part I (Timing; TOLM, ADC; Analogue Electronic) LAPP Annecy (June 2006)
14. R&D for the Electronic Upgrade; Part I; Presentation during the STAC June 2006 meeting.
15. New control and DAQ electronic Architecture and cost estimate, November 2007
16. ADC Board: Analogue input stage; Presentation during the Advanced Virgo WG4 meeting, November 21, 2006
17. ADC Board; ADC choice; Presentation during the Advanced Virgo WG4 meeting, November 21, 2006
18. Characterization of RTAI/ Linux real-time performance on i386 hardware for the Virgo control loops, VIR-NOT-LAP-1390-335, (Jan 16, 2007)
19. PC server Realtime Performances with RTAI-Linux , Presentation during the Advanced Virgo WG4 meeting, January 24, 2007
20. Proposal for the Online architecture based on the new digital electronics with PC and DSP; Presentation during the Advanced Virgo WG4 meeting, January 24, 2007
21. News from Annecy Virgo+ electronic developments; Presentation during the Advanced Virgo WG4 meeting, January 24, 2007
22. Virgo+ Control and DAQ Electronic Deployment VIR-022C-07
23. Selection Tests for the Virgo+ Control and DAQ Real-time PC VIR-052A-07
24. Virgo+ Control and DAQ Electronic Cabling VIR-053A-07

3.8 Actuation noise mitigation and coil drivers

As mentioned in the commissioning part of this report, the noise introduced by actuators controlling suspended mirrors position could be one of the dominant noise sources at low frequency. For this reason, an upgrade activity is started well before the definition of the Virgo+ project and currently is arriving to the completion of the first installation phases (of the two expected). Because of its importance in the definition of the low frequency performances of the Virgo detector a short description of this subject is hereafter reported.

3.8.1 Actuation noise

Mirrors positioning requires a huge dynamical range for compensating tidal strain (in the order of 10^{-4} m rms for long cavities) without affecting the goal sensitivity (in the order of 10^{-18} m/sqrt(Hz) at 10 Hz for initial Virgo, 10^{-19} or even better in the next future). Moreover, the only lock acquisition technique up to now validated in Virgo foresees to stop mirrors motion with a large force pulse, force pulse that makes the dynamical range even larger. In order to deal with such a wide dynamical range, mirror position is set acting on three different stages of the Virgo Superattenuators (refer to Figure 16): 1) Filter Zero, 2) Marionette 3) Mirror (from recoil mass). Such splitting of forces is named in Virgo “Hierarchical Control”. The concept at the basis of this methodology is that larger displacements are at low frequency and we can take advantage from the mechanical filtering introduced by the Superattenuator chain using larger forces (and higher noise) on Filter Zero. Correction signal low frequency components are therefore sent to Filter Zero, mid frequency components are sent to

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Marionette while only the high frequency (> 10 Hz) part of the control signal is applied on the Mirror.

Used actuators are contactless magnet-coil pairs. The hierarchical control strategy works fine in the linear regime but during lock acquisition we need to apply large force pulses directly on the mirror. A pulse is a wideband signal and we cannot apply the hierarchical control since it would excite too many modes in the Superattenuator as it can be easily understood looking at the comparison between the transfer functions from force applied on Mirror (green plot) and on Marionette (blue plot) and the mirror position. This implies the need of a very large dynamical range for the amplifier driving the coils connected to the recoil mass.

Neglecting the noise due to direct coupling of external fields with magnets (or with a charged mirror in case of electrostatic actuators), we can assume that actuation noise is dominated by the noise of the driving electronics: digital to analog converter (DAC) and coil driver. The DAC in use in Virgo is a 20bit (nominal) with a 10V maximum output and a noise floor of about 200 nV/sqrt(Hz). In some measurements, it has shown a possible increase of the noise at low frequency when driven with with white noise filtered with 7th order lowpass filter[9]. Such non-linear noise increment was estimated to be about a factor 4 around 100 Hz. State of the art converter allows a noise floor of about 100 nV/sqrt(Hz) and hardly in the next 10 years we can hope to gain more than another factor 2. Under these conditions, the only way to reduce the actuation noise is shifting down the DAC dynamic inserting resistors in series with coils[10]. In this way the same noise voltage produces a smaller current and therefore a smaller force on mirror.

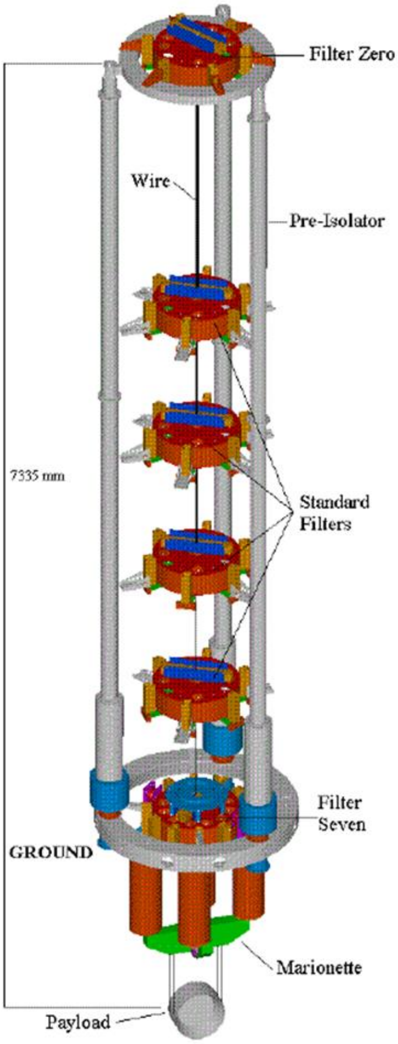

Figure 16- The Virgo Super-attunuator

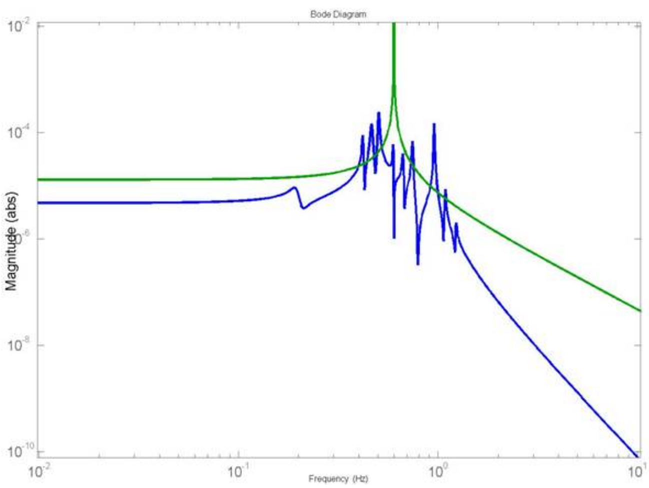

Figure 17-RM-to-mirror transfer function (green curve) and marionette-to-mirror (blue line)

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[9] Mimic the Virgo longitudinal control signal.

[10] But, in parallel, an investigation activity, devoted to the selection of a commercial DAC having the best performances in the frequency regime of interest for Virgo is progressing.

3.8.2 *Coil drivers*

A new coil driver was designed using two distinct sections: one high power section for lock acquisition and one low noise section for linear regime. The two sections are driven by two independent digital to analog converter channels. The new coil driver can supply up to 2 A during the lock acquisition phase with an arbitrary low output current noise thanks to the possibility to change during operation the value of a resistor inserted in series with the coil..
The version of the new coil driver is hosting three distinct sections. The following picture shows a functional block diagram for one Coil Driver channel. For each magnet-coil actuator pair, two analog inputs are available. Due to the high dynamics of the current flowing into the coil, also the monitoring section is split in two parts: Coarse (High Power) and Fine (Low Noise).

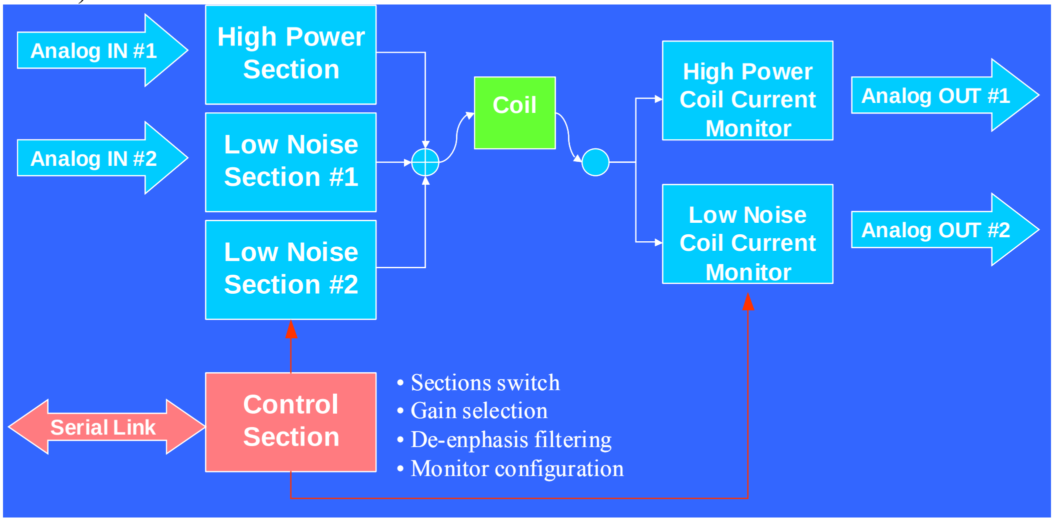

Figure 18- New coil drivers design

For each actuator three distinct sections are available (one High Power plus two Low Noise). The High Power section is a transconductive amplifier able to supply up to 2 A into the coil while the two Low Noise sections are voltage amplifiers with resistor in series with the coil. Each of the two low noise sections can be used with two different values of series resistors for a total of 4 distinct low noise modes (plus the high power one).
A prototype version of the new coil driver, with a single low noise section and without the possibility to change the series resistor during operation, was implemented modifying existing coil drivers and was installed in Virgo starting from the end of 2004 and successfully operated up to today.
The first 4 boards of the new version (ACDV-07-P2) of the coil drivers, 2 channels per board, were recently delivered (December 2007, see Figure 19) and will be soon installed.
The Figure 20 and the Figure 21 show some measurements of the transfer function in high power and low noise mode (with a 100 ohm resistive load, actual coils can be modelled with a 60 ohm resistor in series with a 3 mH inductor). The second plot is for the 4 distinct low noise modes, respectively with a series resistor of 6 kOhm, 24 kOhm, 48 kOhm and

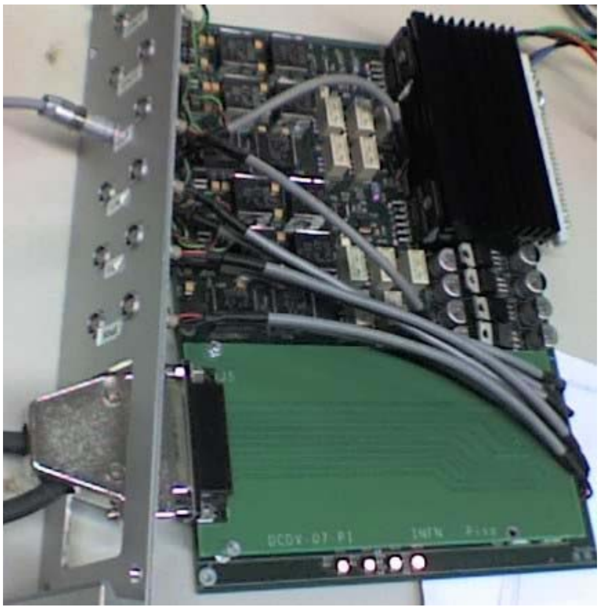

Figure 19- the new coil driver board

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96 kOhm. The non-flat response due to the de-emphasis filters installed in the coil driver

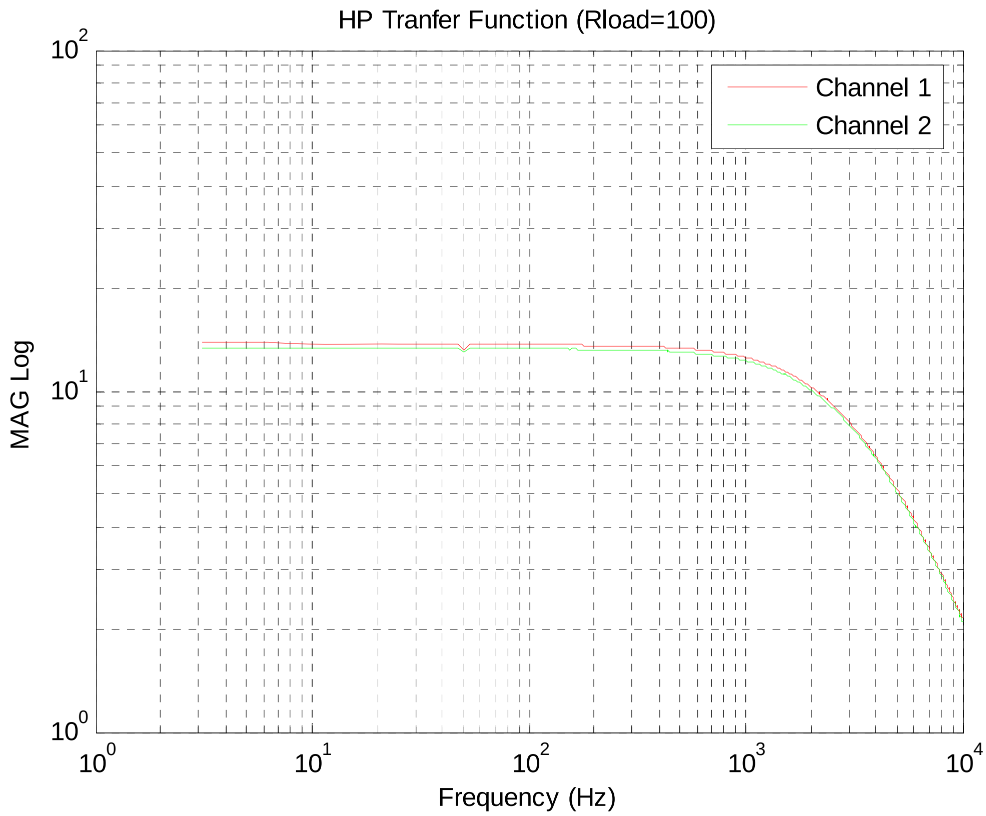

Figure 20 - Transfer function in high power mode

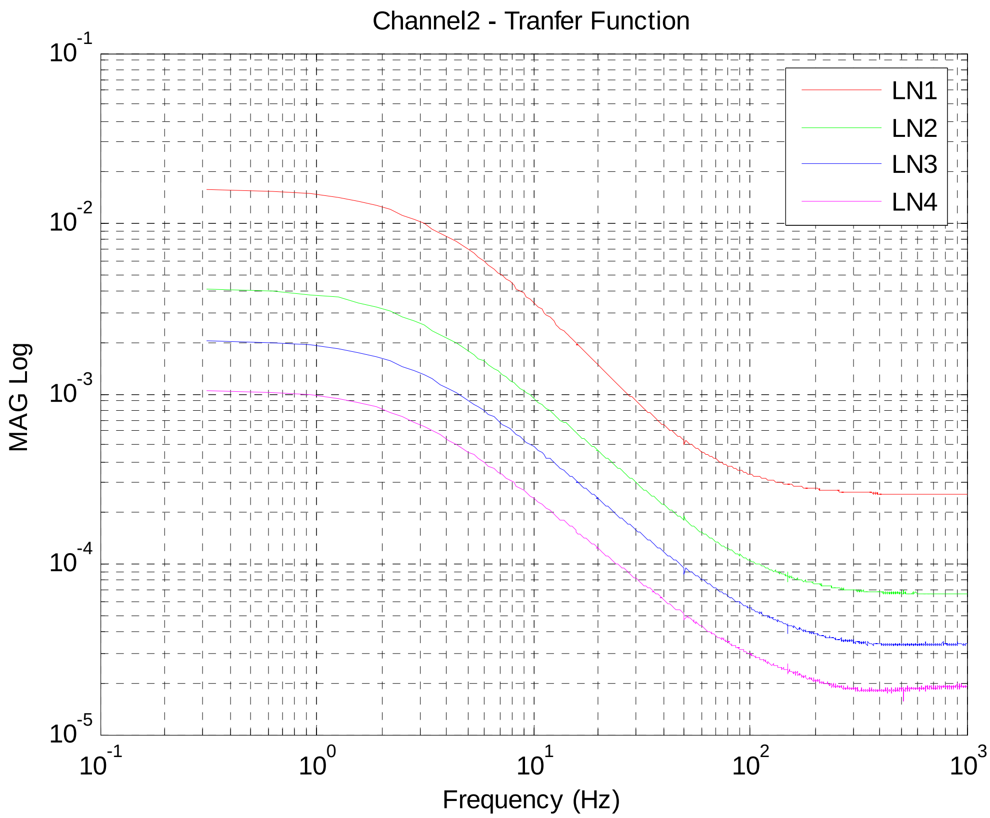

Figure 21 - transfer function in low noise mode

The plot in Figure 22 shows a preliminary measurement of the output noise when the coil driver is in lownoise 1 mode (6 kOhm) series resistor. Clearly the measurement can be used only to set an upper limit to the noise since it is completely dominated by the noise of the spectrum analyzer (about 20 nV/sqrt(Hz)).

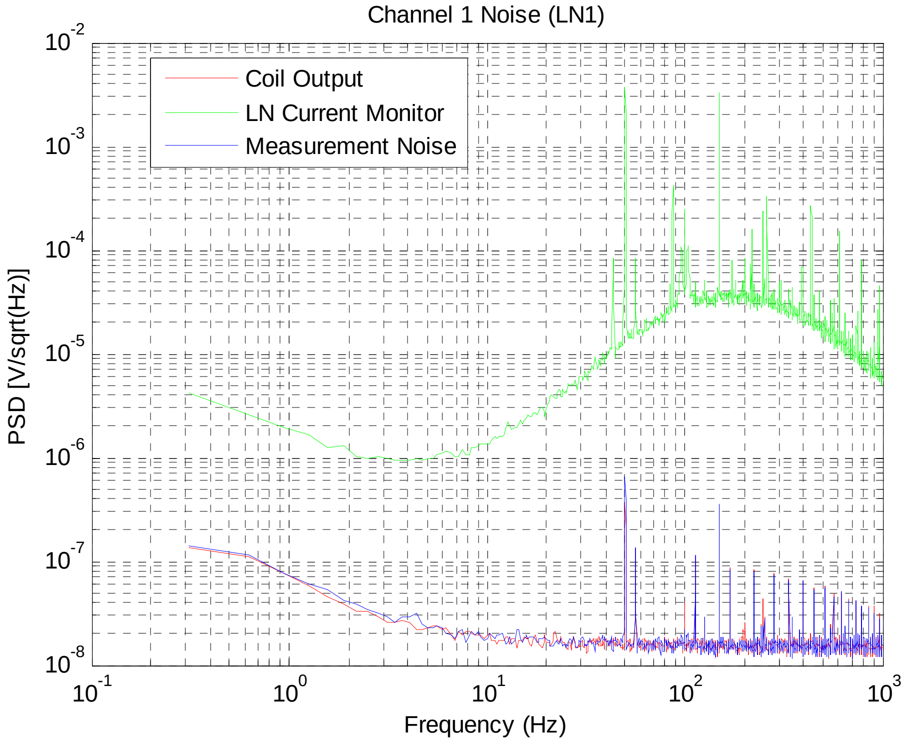

Figure 22 - Preliminary measurement of the output noise when the coil driver is in lownoise 1 mode (6 kOhm) series resistor

3.8.3 *Production and installation plan*

Today (December 2007), we have 4 devices ready for a total of 8 coils. Production of additional boards will start after validation and will require about 1 month. Installation plan foresees the installation of one new coil driver at North End terminal tower at the beginning of January 2008. A second coil driver will be installed at West End terminal tower as soon as the first one will be validated from the operation point of view. With this first installation (2 coil drivers), actuation noise in Virgo can be reduced by a factor up to 8. Following installations will start as soon as production will be available and accordingly with other Virgo activities. This should complete the first phase of the installation, where the coil drivers themselves are replaced. These coil drivers can host directly an embedded DAC and the second phase of this activity of actuation noise reduction foresee the finding and installation of a DAC able to further reduce the actuation noise. This was expected to be realized in May-June, after the DSP deployment, but is still matter of investigation.

Table 16 - Virgo collaborators involved in the Coil drivers activity

Name	**Institution**	**Activities/role**
A. Gennai	INFN	Coordination, design
D. Passuello	INFN	Coordination, design
C. Magazzu	INFN	Breadboards development, DCDV
M. Errante	INFN	Thesis – DCDV
R. Cavalieri	EGO	Components procurement, assembly, installation

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F. Paoletti	EGO	Desing, assembly, installation
G. Scandurra	EGO	Fellowship, DCDV firmware

3.8.4 Costs and expenditures

The total cost of the coil drivers development and realization is about of 112 k€[11], almost completely committed in the last 12 months. Few k€ should still be spent for the realization of the new (better looking) panels and for some minor changes in the boards layout requiring new films.

3.9 Postponed upgrades

Two important upgrade activities have been postponed/delayed for different reasons.

3.9.1 Change of the modulation frequency

At the last Virgo+ review, a large discussion has been dedicated to the possibility to jump from the Anderson frequency to the Nominal modulation frequency[12]. This action is driven by a large simulation effort that shown the presence of bi-stabilities of the locking point of the interferometer in presence of large power absorption in the Virgo optics and correspondent thermal lensing. Additional motivations to this action are given by

1. the dependence, in the Anderson's configuration, of the optimal power recycling cavity length respect to the main cavities finesse
2. the coupling, in the Anderson's configuration, between the PRCL and MICH degrees of freedom that make difficult the definition of the best locking point and then the minimization of the longitudinal control noises.

The change of the modulation from the Anderson's frequency to the Nominal frequency requires the adjustment of the power recycling and IMC cavities length. Although the infrastructures of Virgo already foresee the possibility of a tower displacement, the adjustment of the IMC length by about one meter has an heavy impact in terms of implementation and recovery time, since it requires about one month of activity, the realization of and additional vacuum pipe section and, surely, a large commissioning effort. Furthermore, the decision, in the Virgo+ baseline framework, to postpone the Virgo main mirrors replacement, because of the delaying of the monolithic suspension installation, nulls the first additional motivation (see previous list) for the change of the modulation frequency[13]. The second point in the previous list is, instead, suppressed by the fact that, thanks to the excellent work of the locking team, the longitudinal control noise don't limit anymore the current detector sensitivity and other sources are currently responsible of the excess of noise at low frequency[14].

Hence, the more solid motivation for the modulation frequency change is the interaction with the thermal lensing induced by the laser power absorption excess. Despite our expectation and despite the better look of the mirror, the cleaning attempt of the mirror don't resulted in a

[11] 34k€ are still pending for the digital (DCDV) part

[12] See http://wwwcascina.virgo.infn.it/collmeetings/DMwebpages/Virgo+/2ndReviewDocuments/Marque-Anderson-Review2.pdf and http://wwwcascina.virgo.infn.it/collmeetings/presentations/2007/2007-10/Virgo+2ndReview/Marque_161007_Frequencymodulationchange_VirgoPlusReview.ppt for more details

[13] Keeping the same mirrors the finesse will not change anymore from 50 to 150, as expected with the new Virgo+ main mirrors.

[14] In effect, longitudinal control noises are expected to be still larger, at very low frequency, of the nominal Virgo sensitivity (see http://wwwcascina.virgo.infn.it/collmeetings/presentations/2007/2007-11/Commissioning/Vajente_071126_Locking.ppt) and further commissioning activities are expected.

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lower power absorption and in a lower thermal transient during the lock. This strictly relates our possibility to increase the injected laser power to the correct performing of the TCS apparatus.
Our decision, taken at the November Detector meeting, is to insert, if needed, the implementation of the Nominal modulation frequency in the monolithic suspension time-slot, when the change of the cavity finesse will require an adjustment of the power recycling cavity length. Obviously, if the TCS system don't fulfil the requirements, this decision must be reviewed. This will be understood in March 2008, but meanwhile the simulation and solution design effort will be kept alive, considering also the minimal option of a small displacement away from the Anderson's frequency.

3.9.2 Monolithic suspensions

The monolithic suspension activity encountered many technical difficulties in the realization of a reliable clamping system at the mirror level. The so-called ears demonstrated to be a fragile rupture point and any suspension of a complete payload failed after a short period of time. A first design of the ears has been currently completed and the assembling test, using good quality components, will be performed in the next weeks (as soon as the components will be delivered), but this is only the first step in the validation procedure. Further assembling and control tests, already expected in the past weeks, must be still performed and this forced to postpone the realization of the monolithic suspension to a future scenario to be defined (possibly in the late 2009-2010 timeslot). Meanwhile, the design activity of the suspension system (ears and fibers) has been restarted to obtain a more advanced solution that should solve the reliability (and cleanliness) problem of the current design.

3.9.3 New mirrors

The replacement of the Virgo mirrors with all Suprasil, high reflectivity coating (F=150) test masses has been included in the monolithic suspension framework. Although the input mirror substrates are available, the end mirror substrates suffered the same ROC problem reported for the IMC end mirror substrate and the blanks are still at General Optics for their re-polishing. As soon as the mirrors will be available[15], an assembling activity could start to attach, in clean room, the needed components:

1. magnets,
2. markers
3. ears-or-spacers.

The first two steps are in common with both the monolithic and standard steel wire suspension scenario and require about 3 weeks per mirror[16] of activity in clean room. The last step is specific for each scenario and it requires about 3 weeks per mirror in the standard suspension scenario (really more in the monolithic suspension framework and, also, the development of a new assembling box).
The effective need of the new mirrors even without the monolithic suspension could be caused by few facts:

1. The eddy current noise is limiting the Virgo sensitivity and the mitigation attempt, through the capping of the magnets with ferro-magnetic hats, failed
    a. If the replacement of the magnets in tower with less intense one is impossible, the only solution will be to replace the current Aluminium reference masses (RM) with new RM made by a material having a lower electrical conductivity. A design of new RM made in stainless steel, fully compatible with the standard

[15] Middle March for the input mirrors, later for the end mirrors.
[16] Mirrors can be prepared in parallel. In the past we prepared up to 2 mirror in parallel, but having enough space in clean room and enough assembling boxes all the mirrors, if it is needed, can be prepared in parallel.

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steel suspension (including the current marionette) is ready. The decision point for this scenario is expected at the end of February and it should be compatible with the possibility to replace the payloads in May.

2. Failure of the TCS system to compensate the full Virgo+ laser power with the current excess of absorption.
    a. A first understanding of this scenario could be obtained after the installation of the TCS system in March (but jut up to 10W of power after the IMC). Any payload replacement decision, set after the first commissioning of the TCS, will start to be incompatible with the shutdown in May (unless a certain delay is accepted).
    b. The final scenario should be available after the full operability of the laser amplifier, but, obviously, this requires a complete redefinition of the global commissioning activities.

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4 Virgo+ commissioning

4.1 Injection system

The commissioning of the new injection system will be done in the following steps:

1- new laser bench commissioning;
2- retuning of the mode cleaner mirror local controls;
3- alignment and matching of the beam on the mode cleaner and the mode cleaner cavity locking;
4- alignment of the beam into the ITF and matching to the long cavities;

Then the ITF will be relocked (with the thermal compensation) with an input power equal to that reached before the shutdown. The ITF will be relocked in low noise and the noise budget will be checked to make sure the injection system is performing well.

4.2 New electronics

In parallel with the injection system commissioning the new control electronics and software will be installed and tested (mainly communication issues). The present electronics will remain in place in order to restart the control of the ITF with the present electronics and software. Once the ITF will be relocked the new electronics will progressively be put in operation:

1- the new Photodiode Readout and Global Control systems will be put in operation keeping the old ADC and suspension control;
2- the photodiodes ADC will be replaced with the new ones;
3- the new suspension electronics will be put in operation;
4- the injection system control electronics will be replaced;

After each step all the controls will be closed before going on.

4.3 Thermal compensation

Then the commissioning of the thermal compensation system will go on while increasing the laser power up to the nominal value. This could be performed in parallel with the commissioning of the new electronics as it should be independent.

4.4 Noise hunting

The noise hunting activity will go on in parallel with all other activities as soon as the ITF is relocked in low noise.

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5 Manpower Statistic

This section reports on the summary of the Virgo Manpower. This is a compilation of the 2007 Memorandum of Agreement between the groups and the collaboration. This detailed information is available in the Virgo codifier (https://pub3.ego-gw.it/codifier/). The MoAs, and therefore the following tables are covering the period October 1 2007 to September 30th 2008.

Since part of the collaboration members have teaching duties, this could reduce a little bit their research time. This factor is difficult to estimate and fluctuate from person to person. The first table has been built assuming a 75% effective time for research for persons with teaching duty. The get an idea of this effect on the number of FTEs, a second table has been build assuming a 100% time available for research.

Group	Persons	FTP	Student	Authors	FTE	V	V+	AdV	DA	Other
Annecy	18	11	0	12	14,6	3,1	8,2	0,3	3,1	0,0
Artemis	14	5	2	12	10,2	1,4	2,8	3,0	3,0	0,0
Firenze	10	6	2	10	8,2	1,8	1,5	3,5	1,5	0,8
Genoa	8	0	1	3	2,7	0,4	0,8	1,5	0,0	0,0
LMA/ESPCI	12	0	1	8	4,6	0,4	2,5	1,6	0,1	0,0
Napoli	15	1	4	10	7,0	1,8	0,1	2,7	2,5	2,0
NIKHEF	7	0	1	4	3,6	0,5	1,3	0,0	1,8	0,0
Orsay	7	5	0	8	5,6	0,7	0,0	1,5	3,4	0,0
Padova-Trento	4	0	0	4	1,9	0,2	0,0	0,0	1,7	0,0
Perugia	10	2	2	9	3,5	0,5	1,0	1,1	1,0	3,2
Pisa	24	6	7	22	14,4	2,6	2,5	4,1	5,3	4,4
Roma I	16	7	2	9	11,4	1,0	2,7	2,9	4,7	0,0
Roma II	10	0	2	8	6,6	0,0	2,7	2,1	1,8	0,0
Total	**155**	**43**	**24**	**119**	**94,1**	**14,2**	**26,0**	**24,1**	**29,8**	**10,3**
EGO	32	25	0	21	28,1	18,1	6,2	1,9	1,9	
Total	**187**	**68**	**24**	**140**	**122,2**	**32,3**	**32,2**	**26,0**	**31,7**	**10,3**

Table of the manpower dedicated to Virgo, assuming that persons with university duties are spending 75% of their time on their research activities.

Remarks:

- FTP is the number of person (including the one with teaching duties) who are working full time on Virgo, excluding the students (who usually are 100% on Virgo).
- The V column quotes the FTE spend on the current Virgo detectors (commissioning activities, services activities,…)
- The V+ column quotes the FTE working of the preparation of the Virgo+ upgrades.
- The AdV column quotes the FTE working on the preparation of the Advanced Virgo, (baseline and possible options)
- DA is for data analysis
- The column “other” includes activities that are not part of the Virgo/V+ or Advanced program (like the cryogenic activities), but are listed as Virgo contribution in the institution list. These activities are not included in the total FTE which is just the sum of the V, V+, AdV and DA columns.

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