Status of the VLTI-UT performances wrt vibrations

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ABSTRACT

The ESO Very Large Telescope Interferometer (VLTI) offers the unique access to the combination of the four 8-meter Unit Telescopes (UT) of Cerro Paranal. The quality of the scientific observations in interferometric mode is strongly related to the stability of the optical path difference (OPD) between the telescopes. Vibrations at the level of the telescopes and affecting the mirrors were shown to be an important source of perturbation for the OPD.

ESO has thus started an important effort on the UTs and VLTI to tackle this effect. Active controls based on accelerometers and phase measurements have been developed to provide real-time correction of the variation of OPD introduced by vibrations. Systematic studies and measurement of the sources of vibration (instruments, wind, telescope altitude, …) have been performed. Solutions to reduce the vibrations via design modification and/or new operation configurations are studied and implemented. To ensure good operational conditions, the levels of vibrations are regularly monitored to control any environmental change. This document will describe the modifications implemented and foreseen and give a status of the VLTI-UT vibrations evolution.

Keywords: Very Large Telescope Interferometer, Performances, Vibrations

1. INTRODUCTION

Interferometry is extremely sensitive to any OPD variation. The key to quality science is a controlled and stable OPD. Vibrations generate different motions and shape deformation on the telescope. In our case, only the resulting variations of piston are considered and corrected when introducing a visible effect. In general, the amplitude of measured movements (around 400nm RMS) due to vibrations is negligible in almost all non-interferometric instruments. On telescopes of important dimension like the UTs, the Eigen frequencies (Efreq) of the structure are low and as a consequence, movements are ample. Telescopes without any vibrations are unrealistics: as for any mechanical structures, vibrations will affect them. Nevertheless, it is possible during the design to focus on vibrations in order to avoid having strong Efreq on sensitive part like mirrors supports or/and to have those as high as possible. The UTs were not totally designed in that way, as requirements for interferometry were not specified well enough, and (at least at the beginning) most of instruments installed on different Nasmyth or Cassegrain were not either.

All telescopes are currently equipped with the Manhattan2 system (MN2), consisting of seven one-axis accelerometers (four on M1, one on M2, and 2 on M3). It allows a real-time correction of the OPD variations induced by vibrations on those 3 mirrors, by sending corrections directly to the VLTI delay lines. Most of the results and data presented in this document were obtained with this system.

The first step to study the vibrations is to characterize each UTs “signature”. As they are complex systems, with differences despite their common design, and as the way they are used is changing every night, having enough data for relevant statistics requires time.

The second step consists in identifying the sources. In principle, each perturbation seen in the signature of a UT has its source. And a single source can generate lots of perturbations, as shown in Figure 1.

The important number of potential vibrations contributors like operating telescopes system (control of the altitude, azimuth, …), the ‘non-controllable’ environment parameters (wind speed and direction, respective position of azimuth wrt wind direction, exposition to the wind, ...), instruments (each UTs can be and generally are equipped with 3 instruments), makes the identification complex. By playing in this parameter space, it is possible to limit the number of contributors. Moreover, unless the sources noise can be clearly heard, they can be hidden almost everywhere as will be presented in chapter 4.

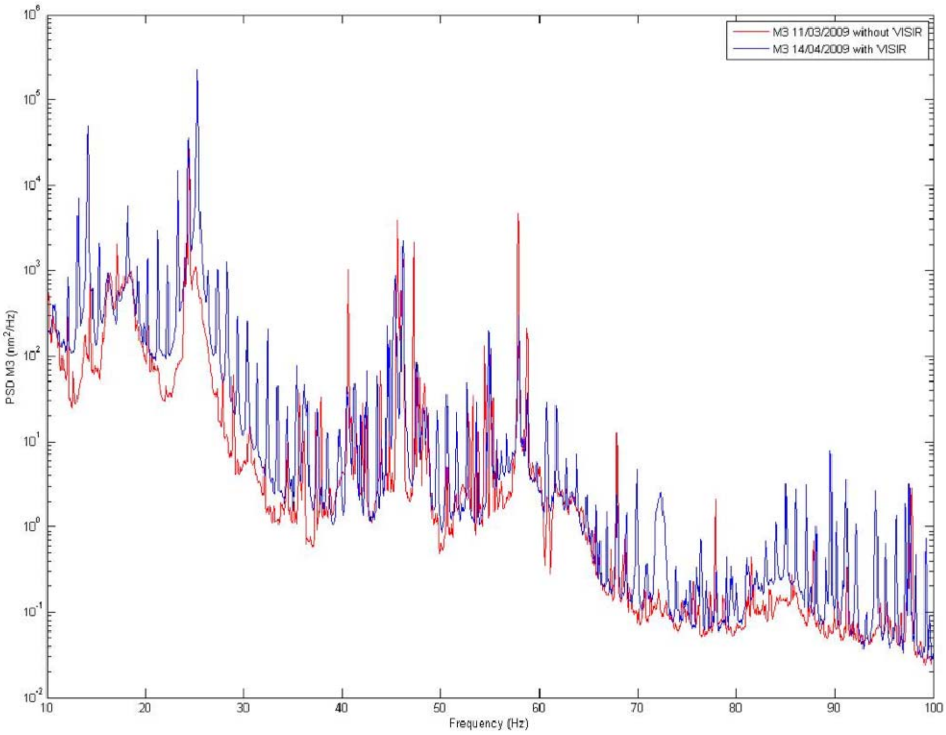


Figure 1: VISIR impact on the UT 'signature'.

Decreasing the vibrations, once the sources are identified, would come from damping or turning them off. Hardware, operation, and design modifications as well as active corrections are damping solutions that have been implemented.

2. MODES AND SOURCES

Each telescope has its own ambient conditions. In fact, instruments and associated electronics differ from one telescope to another. Moreover, the mass and fixation can be extremely different especially for instruments located at Nasmyth. A source located on one of the Nasmyth platform would not have the same impact as the same source located in an instrument attached to the Cassegrain.

The M3 mirror, due to its design, is the most Optical Path Length (OPL) sensible mirror on the optical path. Its first Efreq has important piston contribution at a quite low frequency (24Hz). Looking at this particular mirror only gives already a quite good understanding of the stability of the corresponding UT. As mentioned previously this mirror is equipped with 2 accelerometers (type B&K 4370), positioned such as to measure the piston contribution in each vibration mode and discard (part of) the tip-tilt contribution.

Figure 2 presents the M3 cumulative OPL of each UT. The modes at 14, 18, 24 and 46Hz are responsible for more than 80% of the produced OPL. The important difference of OPL between UT3 and UT1, UT2 and UT4 is due to the sources of excitation. In the UT1 and UT4 case, the excited frequencies are various (at 14 (only UT1), 18 and 24Hz); for UT2 a single source is present (24Hz). On UT3, at the beginning of 2009, no important source of vibrations could be seen. One can notice that the lowest level obtained for vibrations are on UT3 and is of 130nm RMS OPL.

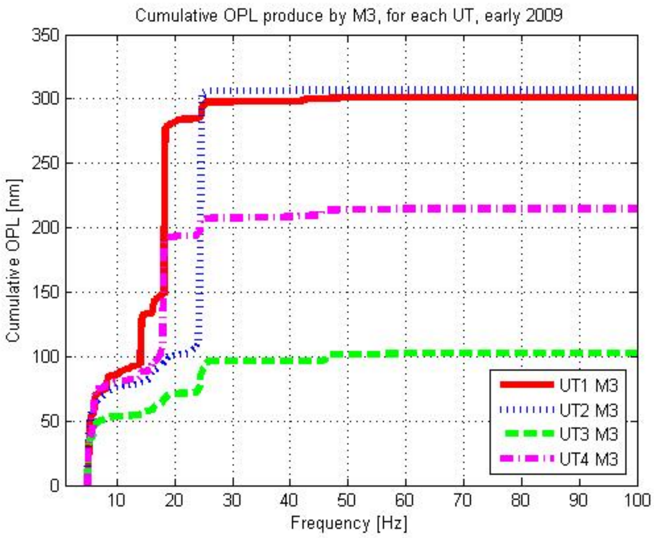


Figure 2: Typical M3 cumulative OPL between 02-03/2009; data taken at night during VLTI-UT observation.

3. INSTRUMENTS

Instruments were quickly identified as important vibrations contributors, especially those equipped with Closed-Cycle Cooler Heads (CCCH). Due to their necessary mechanical movements to produce cold, they transmit important excitation to the instruments structure and from there to the telescope. In order to determine the instruments impact on the telescopes, different measurement campaigns were realized. The following instruments were highlighted as 'sources': ISAAC, CRIRES, NACO, HAWK-I, VISIR. An important work have been performed by ESO during 2008 on the CCCH of CRIRES and HAWK-I, allowing to decrease by more than 90% the OPL produced by those instruments.

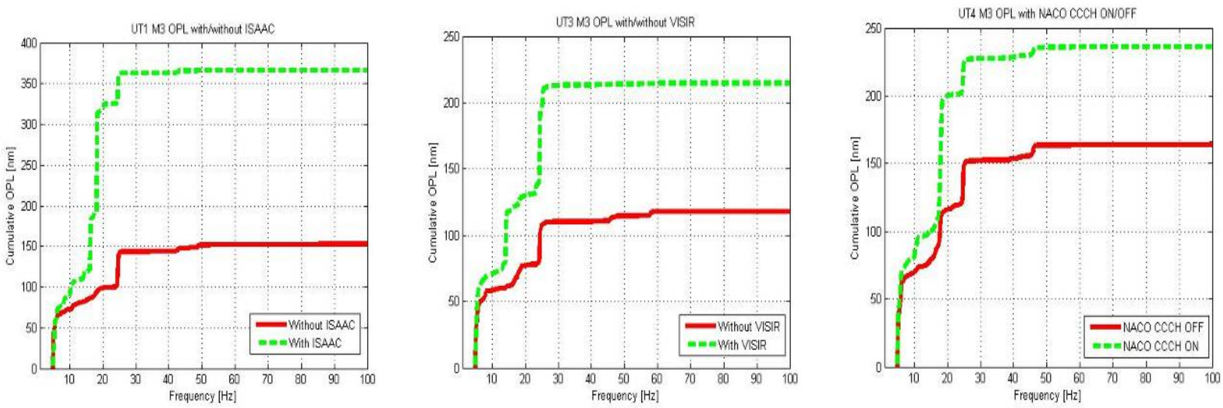


Figure 3: Left, ISAAC impact on M3 OPL; middle, VISIR impact on M3 OPL; right, NACO impact on M3 OPL

For a given UT, a reduction or increase of vibrations can be synonym of a change of instruments configuration, as for UT1 and UT3 in 2009. During august, ISAAC was dismounted from UT1 and installed on UT3. Few months before, VISIR had been installed on UT3. This resulted in a few months in an increase of the UT3 OPL RMS by a factor three; at the same time, the UT1 OPL RMS decreased.

As switching off the UT's instruments CCCH during interferometric runs would affect their stability, a light modification of operation has been found to decrease the vibrations produced by the instruments. By playing with the rotator position where the instruments are parked when in standby and thus playing with the gravity for CCCH, the vibrations can be decreased. Good results could be obtained with this solution, but this is not robust to CCCH maintenance and modification, and the position must be optimized each time a change of CCCH appears, every 2 years in nominal case. This optimization has allowed decreasing the OPL RMS by up to 25% on some instruments.

4. 'HIDDEN' SOURCES

The previous chapter showed that instruments could be the origin of vibrations. In the UT2 case, at first glance, instruments were not identified as noisy; nevertheless the level of OPL on this telescope was high. All the vibration-induced displacements affecting UT2 were at the frequency of 24Hz. After investigation, a membrane pump installed in an electronic cabinet was found to be the source. This pump has a working frequency of precisely 24Hz, i.e. right at the resonant frequency of the telescope and the M3 tower that were therefore strongly impacted.

Here, the level of OPL could be decreased by a factor of three after the installation of a simple damping system. It is interesting to notice here the impact of a small element, a membrane pump (with a mass of about 10kg and dimensions of 500x300x300mm), on one UT (with a mass of more than100 tons).

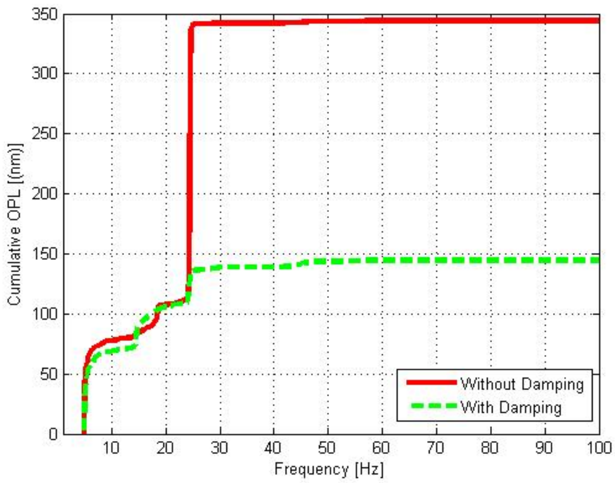


Figure 4: Damping of Oz-Poz pump realized at beginning of 2010, OPL over the 3 first mirrors.

The telescopes that are affected by important sources of vibrations are very sensitive to telescope conditions. Just following the changes of altitude, the OPL RMS can be multiplied by a factor of up to 1.8. Figure 4 thus does not show all the gain obtained when a source is damped. Not only the OPL RMS was reduced, but also the changes of the OPL RMS with the telescope parameters.

5. DESIGN OPTIMIZATION

The first 3 mirrors are linked to the main heavy structure allowing the altitude and azimuth movements. Modifying their support design is of course not an option, but those mirrors are only part of the 'vibrating mirrors', the most 'unstable' part.

The M4 to M8 mirrors are only linked to the azimuth (and thus boundaries conditions are different). Each mirror would be subject to different excitation and has different Efreq. Studying M4 to M8 is also another way to find sources, especially those that are not affecting M1 to M3. On Figure 5, the 70Hz peak was found to originate from a compressor; its identification was not possible with the first three mirrors.

Due to their support design, masses, position on the telescope, the mirrors M4, M5 and M6 can be non-negligible contributors. It is already proven that noisy instruments in Nasmyth A have a significant impact on M4 vibrations. M5 is also showing an 'important' OPL contribution. Due to the difficult access to the M6, located inside the telescope structure, it is not easy to measure the exact vibrations on the mirrors, and thus the vibrations affecting them are still unknown.

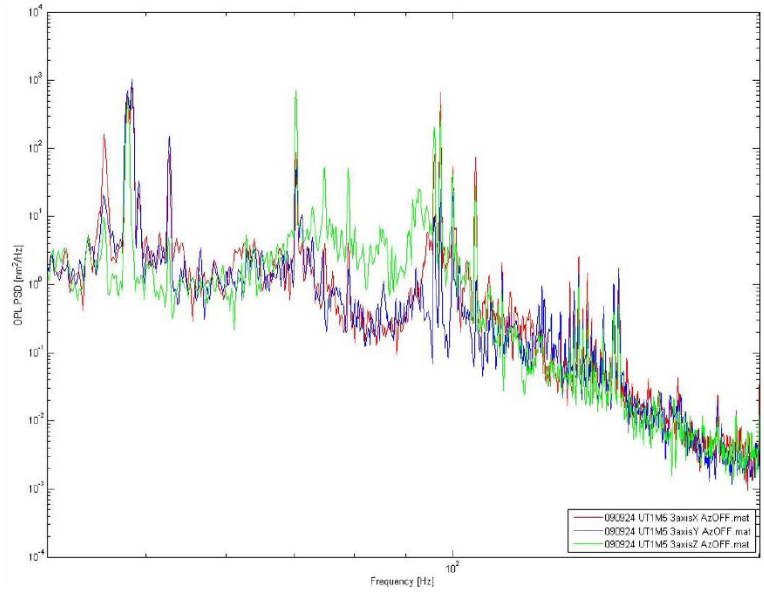
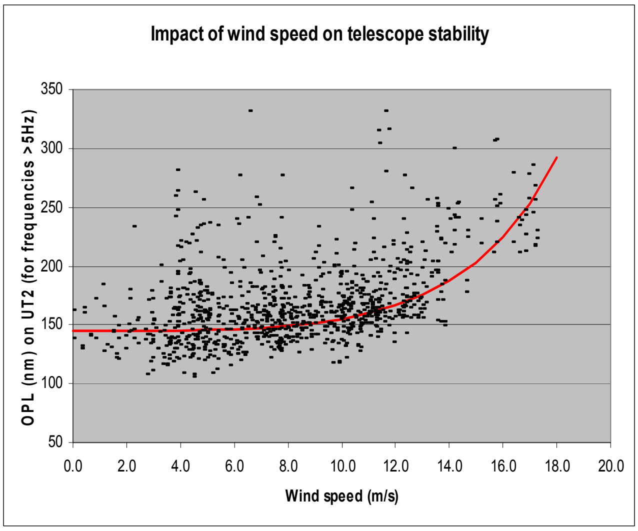


Figure 5: UT1 M5, 3 axis.

After its integration and first measurements of vibrations levels, the M4 support design had been modified to increase the first Efreq, resulting in decreasing the mirror displacement amplitude. After a dedicated campaign of measurements on M5 revealing its OPL contribution, the same kind of modification as done on M4 has been foreseen for this mirror. M5 can contribute up to 120nm RMS, and its contribution to OPL variations is not corrected by the MN2 system. A new design for the mechanical support of M5 should be installed in all UT (after preliminary tests to prove its efficiency) by end of 2010. The goal is to stiffen the mirror support structure. The design has been chosen in order not to require any disassembling of the existing structure and thus avoid having to go for a major re-alignment of the Coudé optical train. Due to this constraint, the new design is not fully optimized regarding the increase of the Efreq, but shall still bring a significant gain.

6. EXTERNAL CONDITIONS

The impact of the wind on the telescopes is currently being studied. First results show an important loss of performances when the wind speed (WSP) is higher than 10-12m.s^{-1}. Figure 6 presents examples of the wind impact on the telescopes. The left figure shows the direct influence of the wind speed on the OPL level. Wind stronger than 10m.s^{-1} is creating a quite important displacement that can surpass the OPL created by vibrations (for wind above 15 m.s^{-1}).



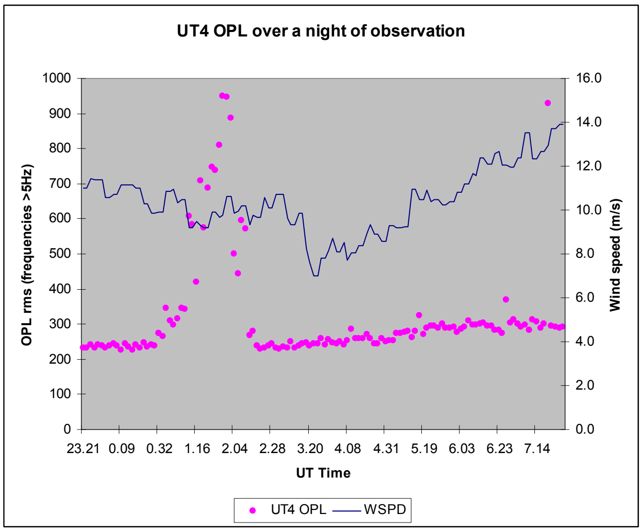


Figure 6: Wind impact on telescope OPL; left: data from more than 12 different VLTI-UT nights on UT2; right: UT4 OPL during the night of 25/05/2010.

Restrictions with regards to the pointing direction apply when the WSP is higher than $12m.s^{-1}$ (telescopes cannot point any object in the 180deg angle centered on wind direction (WDIR)), and the telescopes are closed if the wind exceeds $18m.s^{-1}$.

If it is still authorized to point an object in same direction than WDIR when the WSP is lower than $12m.s^{-1}$, this is not advisable, as presented in Figure 6 (right, UT4 measurement). Between 00h30 and 02h15, the telescope was facing the wind, resulting in an increase of the 'usual' OPL by a factor of 3.

Without entering deeper into details, the important parameters wrt the wind are the wind speed, and the direction vs the pointing direction of the telescope. The telescope azimuth and altitude, together with the wind direction will determine the surface of the telescope exposed to wind and therefore the level of OPD fluctuations.

7. SCIENCE AND VIBRATIONS

The precision of the measure of visibility with an interferometric instrument is linked to the stability of the OPL in the optical path during the integration time. For Amber in K or H band, the impact of the OPD fluctuations can be important. In K band, an OPD RMS bigger than 400nm (~λ/5) during a define DIT would result in an important degradation of the visibility, and an important jitter in visibility would be seen. This is illustrated on Figure 7.

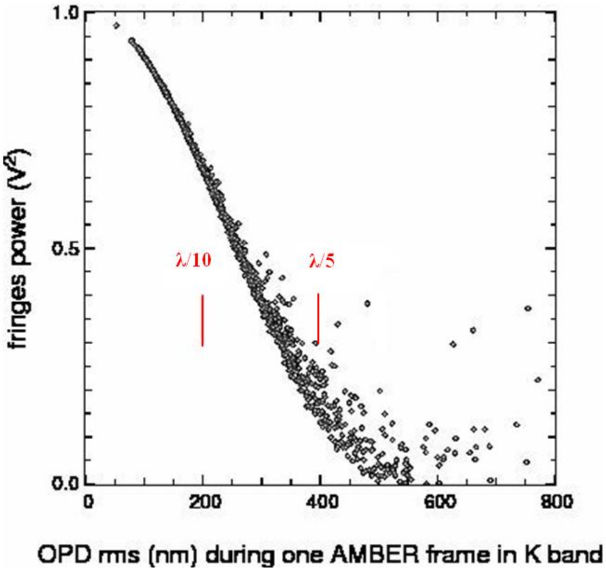


Figure 7: AMBER visibility function of OPD RMS, valid for 25ms DIT.

Analysis of numerous AMBER data has shown that a RMS of OPD of λ/5 was the limit for which you still have a peak distribution for visibility (AMBER case in K-band).

It is currently possible at Paranal, with the best baseline (UT1-UT2 working in nominal conditions) and under fairly good conditions (here especially with quite long coherence time, with seeing~0.8-1 arcsec and tau0~5-6ms), to integrate during more than 500ms with AMBER without exceeded the λ/5 value on OPD RMS. For baselines with only one 'stable' telescope (UT1-UT3, UT1-UT4, UT2-UT3, UT2-UT4), and under the same kind of conditions, the limitation on the DIT of AMBER would go down to 50ms. The limit for the worst baseline (UT3-UT4), under the same conditions, is 25ms.

For the previous cases, the only difference between the baselines is the amount of vibrations that is affecting them. The UT1-UT2 baseline could still be optimized. In fact the OPD measured by the FINITO fringe sensor was between 320 and 350 nm RMS for an exposure time of 50ms. There are almost no differences between an exposure time of 50ms and 500ms for this baseline. This is showing that the major part of OPD is produced by frequencies higher than 20Hz and therefore mainly by vibrations. Nevertheless, this baseline reaches quite encouraging and interesting performances level (under good conditions).

8. CONCLUSIONS

We present here the past and actual levels of vibrations of the UTs. An important amount of work has been done to reduce and control the telescopes vibrations. Two UTs have already reached quite stable levels, but will still benefit from further optimizations. Except for UT2, which has no specifically noisy instruments, the vibration level of the UTs have to be carefully monitored and verified after each intervention on instruments (especially noisy one) as they could result in important changes.

	UT1	UT2	UT3	UT4
OPL RMS* 2008 (nm)	>1000	300-450	240-280	>900
OPL RMS* 2009 (nm)	380-400	300-450	130-160	280-320
OPL RMS* 2010 (nm)	170-190	150-170	220-240	280-320

OPL RMS*: This is limited to the 3 first mirrors of the telescopes.

Table 1: UTs vibrations level status

The following optimizations are foreseen in the next months:

- Installation of the M5 stiffener.
- Optimization of the UT4 rotator. First results showed we can expect to obtain the same OPL level as UT3.

- The damping of UT1 compressor has been done recently. The results shall be confirmed soon.
- Vibration Tracking Algorithm (VTK) is being optimized in order to couple with highest resonances modes of baselines[1].
- More generally, electronics cabinets could be sources of vibrations, and a complete study of each cabinet (especially those on Nasmyth platforms) will soon be conducted. In fact on all OPD spectrum measured by FINITO, the contribution of modes in the 45-50Hz range are consequent. This is typically fans frequency.

In the current configuration, the UT OPL limit is around 100nm RMS for the telescope alone, without taking wind into account. Some vital elements of the telescope, like the hydraulic bearing system (which supply the high pressure oil to the altitude and azimuth axis) or the control of altitude and azimuth, are responsible for those vibrations. It can thus not be expected after the work done on other sources of vibrations to go below 100nm. Part of this OPL would still be corrected by MN2 and VTK. But this level would already be compatible with accurate interferometry measurements.

After the installation of the optimizations mentioned above, and thanks to the experience and knowledge that has been gained at Paranal, the objective would be to determine a realistic vibration spectrum showing the limit of acceptable vibrations for new UT instruments, in order to limit the instruments pollution and to offer UTs reliable performances.

REFERENCES

[1] Di Lieto, N., Haguenauer, P., Sahlmann, J., Vasisht, G., ‘Adaptive vibration cancellation on large telescopes for stellar interferometry’, Proc. SPIE 7013, 70130H (2008).