Nufern 50W fiber amplifier test – first part

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CHANGE RECORD

Version	Date	Section affected	Reason/ remarks
1.0	20/03/2013		First official release

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1. Introduction

In order to find another vendor of fiber amplifier, we have approached Nufern, a US company producing fibers and we have got a 2 weeks loan of their commercial 50W fiber amplifier. The product has been shipped to Nice for product demonstration: it is an engineering version (ie devoted for testing) of the commercial 50-Watt, polarization-maintaining (PM) fiber amplifier of the NuAMP product series. The operational input power of the Master laser is in the range of 50 to 200 mW, and the output is delivered through a 1.5 m-long PM fiber, which is spliced to a free space Faraday isolator. The reference number of the unit is NUA-1064-PD-005-C0.
Depending on the availability of the EOLITE prototype at the delivery time of end of 2013 (cf planning of AdV), the NuAMP 50 W is a potential candidate for fulfilling this request.
We present herewith the noise measurements and some preliminary conclusions based on these few days tests.
Unfortunately, a failure of the Innolight Master laser induces some damage in the fiber amplifier (see Section Master failure) and we have not undergone all the tests planned for the moment.

2. Experimental setup

The unit arrived on Mar. 6th 2013, and was scheduled to undergo two weeks of test at Artemis. The unit comprises a Yb doped fiber pumped by one or two laser diodes in order to amplify in a few hundred times any input signal coming from a Master laser. For the tests, we have mounted an experimental setup shown in **Figure 1**. An NPRO laser, identical to the one used in the Virgo+ operations, was borrowed from EGO and served as the Master laser. It is coupled into a 3 m-long PM fiber connected to the fibered input port of the amplifier. A fiber beam-splitter is inserted in order to monitor the master laser power during the tests.
The amplifier was cooled using a Virgo-like water chiller; the water temperature was set to 23 degrees Celsius.
The output of the amplifier was monitored with a quadrant photodiode for beam-jitter measurement, two photodiodes and a calorimeter for absolute power and relative intensity noise (RIN) measurements, as well as a Fabry-Perot cavity for spatial mode content measurement.

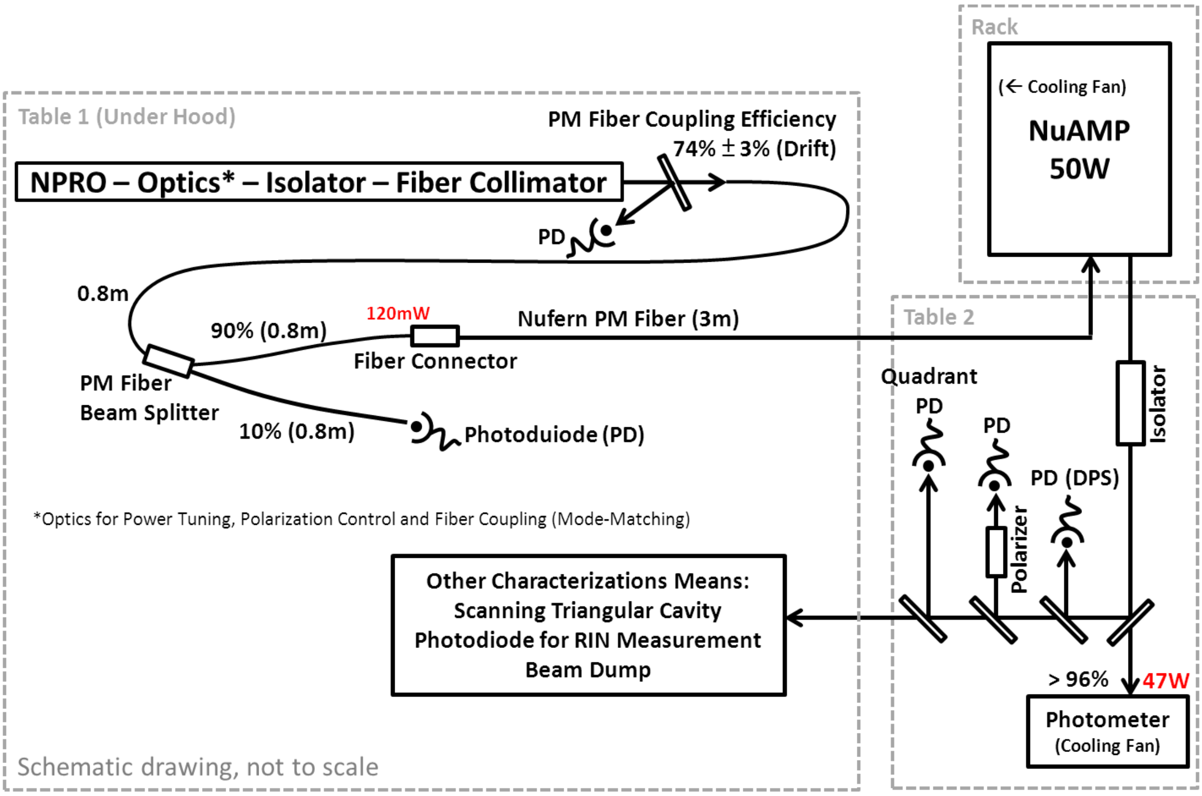

Figure 1: Schematic drawing of the experimental setup

1. Long term test on output power stability

At first start-up 49-Watt output power was obtained with 120 mW of input laser. Two continuous runs were conducted; the first lasted 62 hours and the second lasted 57 hours. During the first run a 4.5% continuous drop in output power was observed [**Figure 2**]. Following the response from Nufern regarding the power drop, the unit was turned off temporarily for some 15 minutes before the restart for the second run. No obvious recovery was observed. The second run was terminated on Mar. 18th owing to a stop of the master NPRO laser. A continuous drop in output power was also observed during the second run, but the rate was reduced to 1.5% [**Figure 2**]. The long term test has been done during 5 days.

- We have checked experimentally that the amplifier output power is independent of the input Master power. The output power of the amplifier oscillated around a more or less constant value even when up to 30% variation in the Master power was applied [**Figure 3**]. This clearly shows that input power fluctuations from the NPRO laser and the fiber-coupling optics do not match the long-term power drop observed.
- We have measured the temperature dependency of the amplifier output power, and observed that a 2-degrees-Celsius variation of the chiller leads to a 6% variation of the amplifier output power [**Figure 4**]. Since the chiller temperature was regulated within 0.2 degree Celsius peak-to-peak, the corresponding temperature fluctuation could not match the power drop observed. Moreover the time constant of temperature variation is few minutes rather than tens of hours.

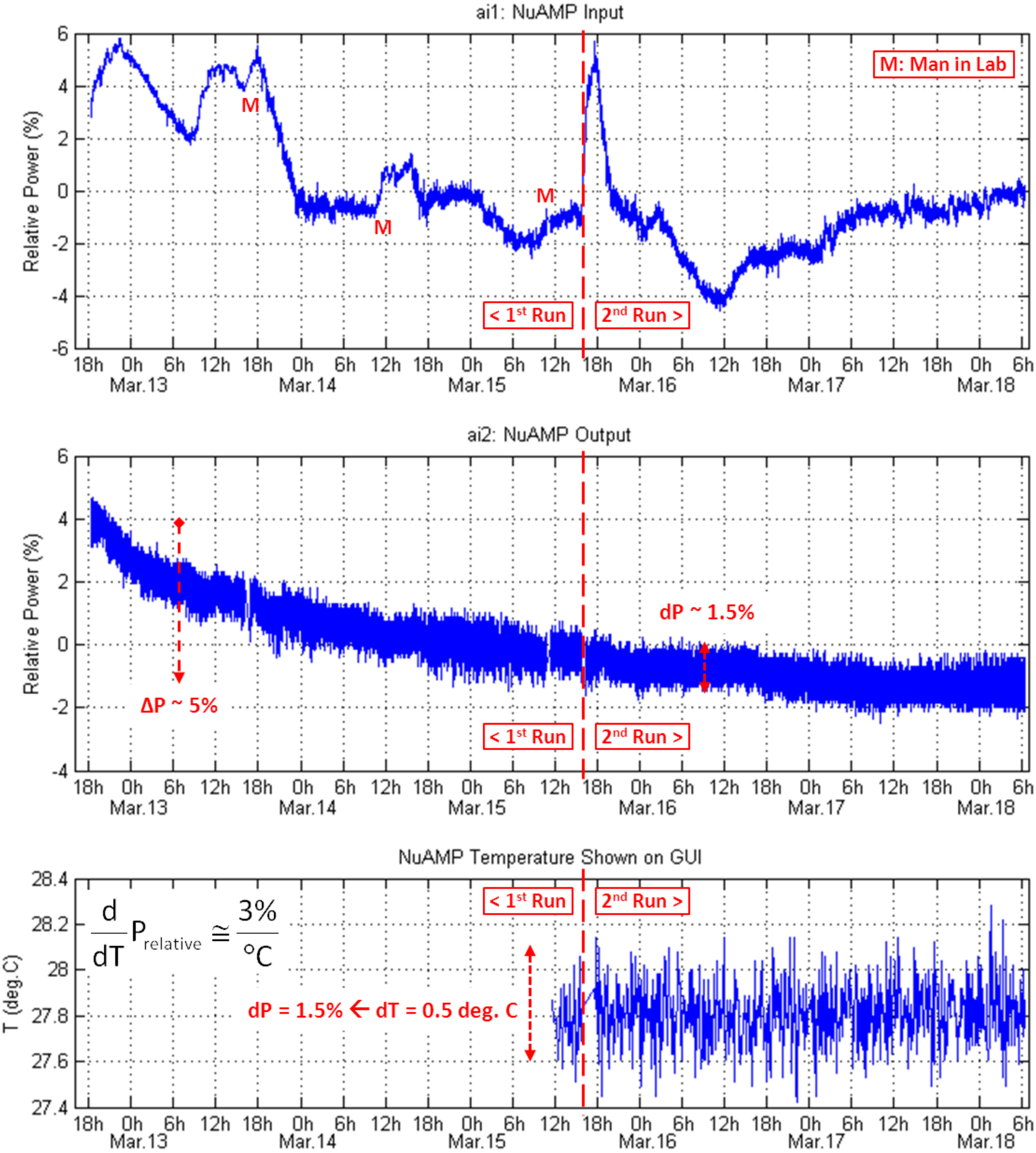

Figure 2: Amplifier input/output and temperature curves vs time. Top curve: Relative power fluctuations of the Master laser read on the input fiber beam-splitter 10% port; Middle curve: Relative output power fluctuations of the amplifier; Bottom curve: Temperature of the amplifier unit shown on its Nufern GUI. M, which is a human presence in the lab induces small perturbations in the relative power.

- In additional to the power drop, the amplifier output power also oscillated with a magnitude of 1.5% peak-to-peak [**Figure 2, Figure 3, Figure 4**]. This is very likely because of the temperature fluctuation of the amplifier itself, which is about 0.5 degree Celsius peak-to-peak [**Figure 2**] and corresponds to 1.5% of output power fluctuation.

Accordingly, the long term power drop is considered as an intrinsic property of the amplifier unit and the attached isolator.
Nufern has provided us some long term measurements made over 500 hours, where they have observed less than 3% drop over 1000 hours. Since the unit we received was dedicated for the isolator qualification, Nufern claimed that the power drop might come from the Faraday isolator spliced to the output fiber and is likely to be not relevant of standard units.

Meanwhile, it should be noted that Nufern guarantees against drifts of output power down to 3% over 1/2/3 years according to the warranty chosen by customers. Last, we have contacted two laboratories in Germany, Max-Planck Institute of Quantum Optics, Munich and Heidelberg University, to inquire about the reliability of such unit: the feedback was quite positive regarding the reliability, see below: e-mail discussion between Max-Planck Institute of Quantum Optics (MP) and F. Cleva (FC):
MP: “after fixing some bugs together with Nufern, the long term reliability now seems good. We have systems running for over a year now without a problem.”
FC: “Do you mean continuous running at full power?”
MP: “about 6-10 hours 5 days a week.”

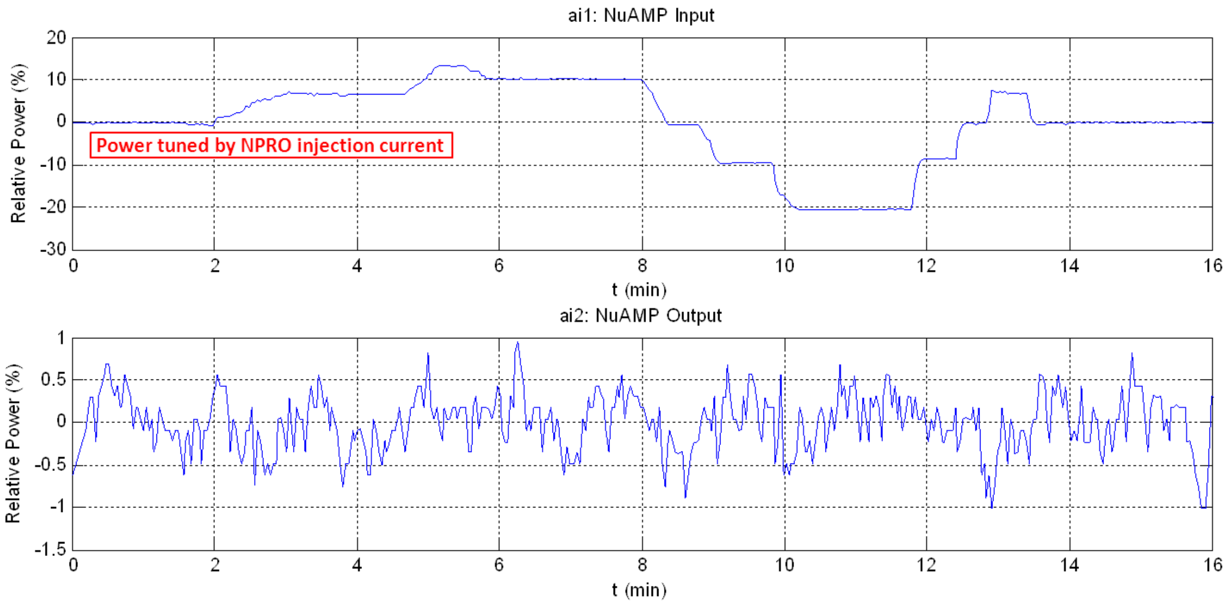

Figure 3: Input Master level (in)dependency of the amplifier output power. We changed in steps the Master power (upper plot) and measured the effect on the amplifier output power (lower plot) and observed no changes.

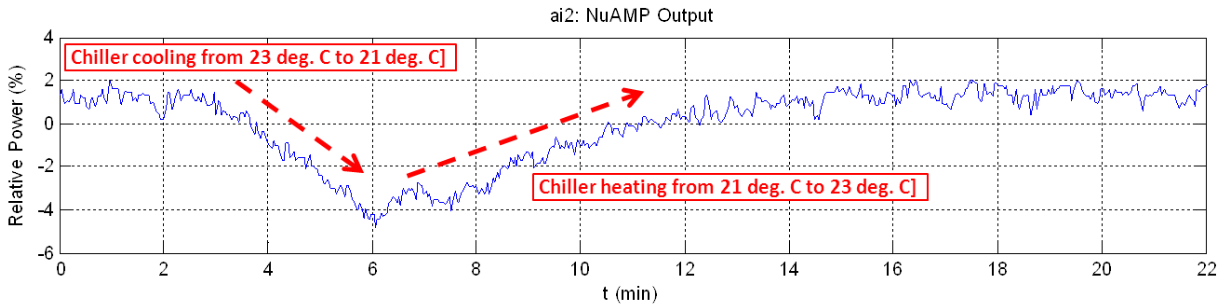

Figure 4: Temperature dependency of the amplifier output power. We changed the chiller temperature setting and measured its effect on the amplifier output power.

2. Master laser failure led to amplifier breakdown

After 120 hours (5 days and ½) of operation the Master laser switched off for some unknown reason (the laser driver was plugged in to an uninterruptible power supply) without any failure. The NuAMP 50W unit came with a protection against the absence of input signal and shuts down the pumping diodes as fast as possible to avoid any Q-switch behaviour of the amplifier that might destroy the fiber facets. When the master stopped, the amplifier went on safety mode triggered by the "Back Reflection" (BR) level which monitors the amount of light back-reflected to the amplifier. After checking that no optical part of the amplifier has been damaged, we were unable to restart it again as of the BR level has been set itself above some safety threshold. Even a cold restart from scratch of the amplifier was not able to reset such safety level, whatever the presence or absence of the input master signal.
Nufern has then suspected a damage of the BR probe, and proposed to retrieve the unit for repair and they would send it back again to us for further tests. After agreements, the unit was shipped back to Nufern on Mar. 20th.

3. Relative intensity noise (RIN)

Figure 5 shows the Nufern RIN from DC to 100 kHz with a 1/F slope. If we compare it to the RIN level of the Eolite rod fiber at 55W displayed in the TDR (see TDR, §3.6.2.1, page 105, figure 3.5, recalled here in **figure 5bis**), we can see that it is comparable or even better above 500 Hz then we can confirm that it is fully managed by our power stabilization loop.

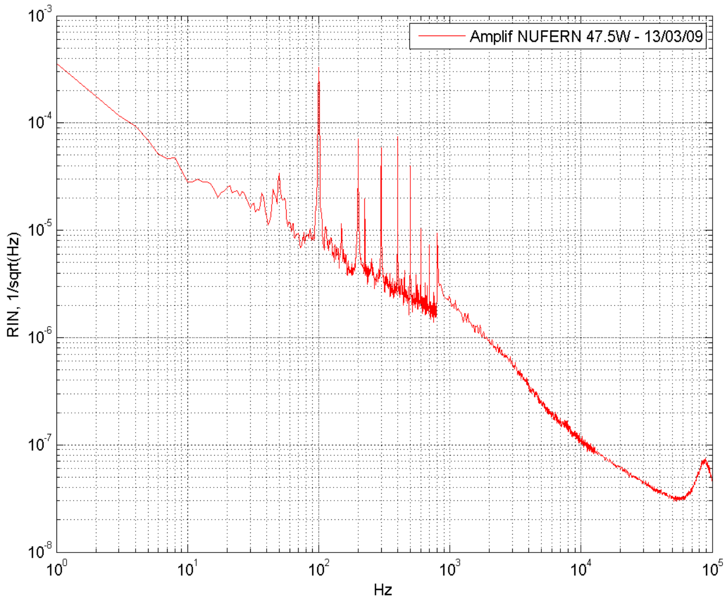

*Figure **5**: RIN at 48W output power, low frequency*

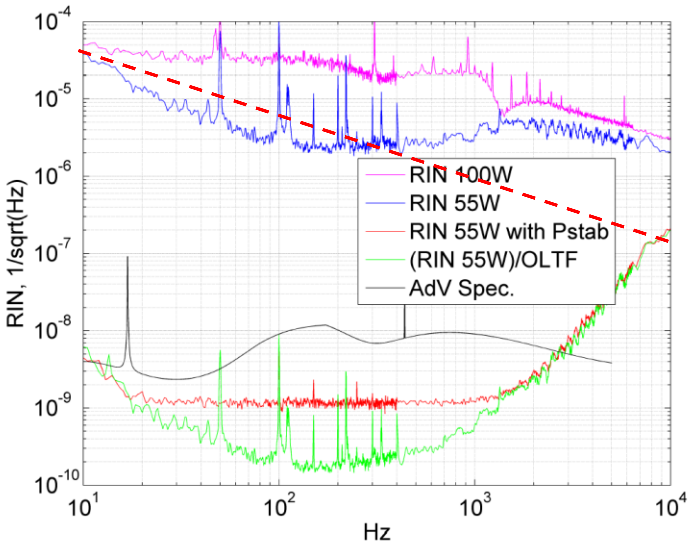

Figure 3.5: The magenta curve is the RIN of 100 W HP amplifier. Blue curve: RIN of the 55 W amplifier. Red curve: RIN of the 55 W amplifier after stabilization. Green curve: 55 W RIN divided by the open loop transfer function of the servo loop. Black curve: AdV specification.

*Figure **5bis** : RIN specifications and performances of the Eolite fiber rod amplifier as presented in the TDR. The red dashed line gives the level of the present 50W Nufern amplifier for comparison .*

Figure 6 shows the RIN above 100 kHz. At the RF frequencies of a few MHz, the noise shows 3 orders of magnitude more than what is requested. So far we had no time to investigate this feature further. Such a noise was not observed with the Virgo+ solid state laser and amplifiers (20W and 60W), nor the rod fiber amplifier prototype of EOLITE we tested in January, 2010 (50W). On the other hand, we have already observed such feature with the previous 100W Nufern amplifier prototype we tested in 2009, but with a rather smaller amplitude (2e-7/sqrt(Hz) @ 6MHz).
Several solutions could be considered to overcome this situation:

1) If the extra noise comes from amplified spontaneous emission (ASE) beatings, using therefore some ASE filtering could improve things.
2) On the other hand we can filter that RF noise by using a combination of 2 pre-mode-cleaners (PMCs) in series, each providing more than 1/sqrt(1000) attenuation factor at 6MHz. It means a cavity pole of 190kHz, assuming a finesse of 2000 and a half length of 20cm; this implies 286kW in the cavities (for 180W incident power), and 73MW/cm^2 flux on the mirrors.
3) Another elegant solution could be to act on the Master input power (through a fibered amplitude modulator) at 6MHz, relying on the fact that the amplifier is not fast enough to attenuate the input 6MHz perturbation. We would then complete some fast power stabilization.

The options 1 and 3 can be tested as soon as we get the amplifier back after repair.

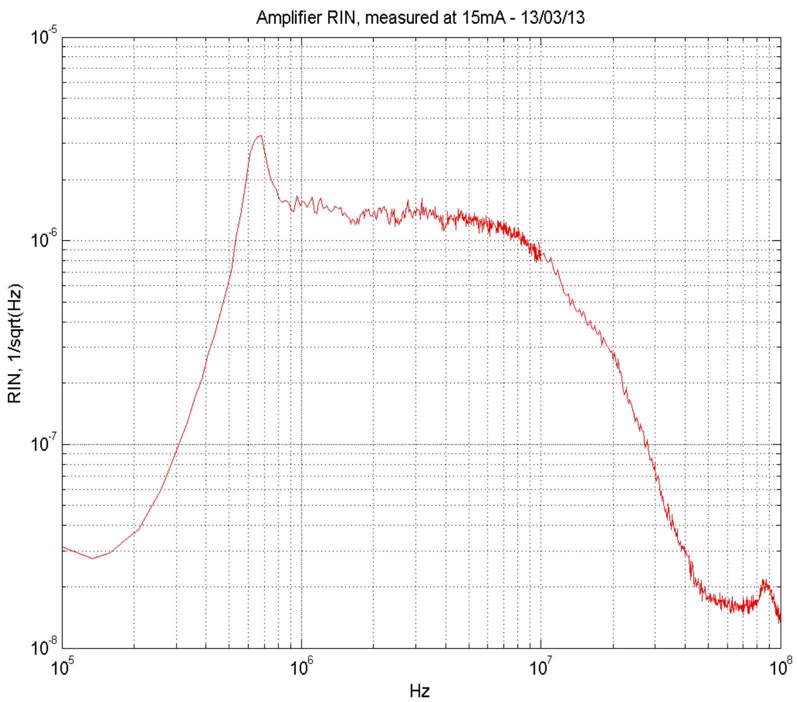

*Figure **6**: RIN at 48W output power, high frequency The peak near 700 kHz refers to the Master laser oscillation relaxation. The shot noise limited RIN at 0.1A is 1.79e-9/sqrt(Hz).*

4. Beam jitter and drifts

Figure 7 and **Figure 8** give the angular beam-jitter (BJ) measured 1.28m away from the amplifier output. No attempt has been made yet to measure the BJ shift.

The measured BJ match the AdVirgo specifications (see TDR p109, figure 3.8), and hence, from that specific point of view, one single PMC would be enough. Moreover, part of the noise in the range from 100 Hz to 1 kHz comes from the fan used to cool down the calorimeter we use for the overall power measurement. Therefore the amplifier intrinsic BJ noise should be lower by a factor 2 in this region than what is displayed herewith.

Figure 9 displays the beam drift at 1.28m from the fiber output. We guess the large vertical drift (350 um) comes from some tilt drift. So far we don't know whether it comes from the spliced output Faraday isolator of from some thermalisation of the test bench. On March the 15th, at 16 o' clock we proceed with a centering of the quadrants photodiode position, which explains the large gap on the vertical direction. Assuming the drift comes from a beam tilt one has to compare the associated tilt (273urad) with the beam divergence (1513urad).

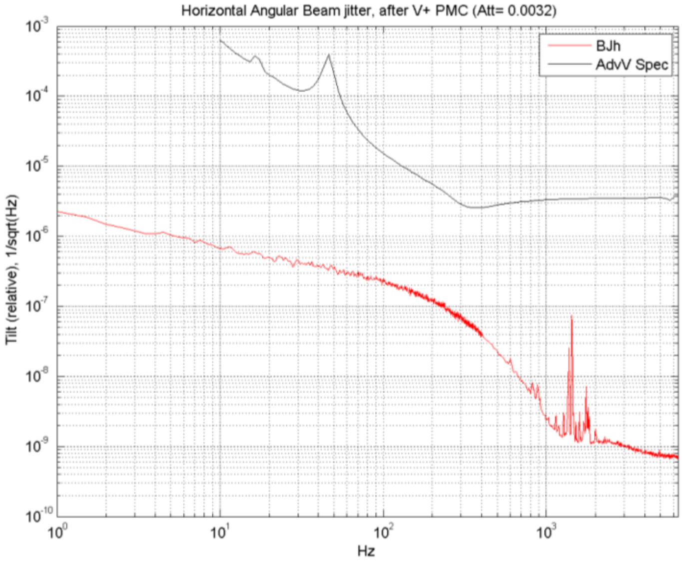

*Figure **7**: Horizontal angular beam jitter together with the AdVirgo specifications at IMC input (after PMC). The red curve is the BJ measured at the amplifier output and multiplied by the Virgo+ like PMC attenuation factor (1/312). Beam-jitter is overestimated since part of the noise from 100 Hz to 1 kHz comes from the fan of the calorimeter used to measure the output power.*

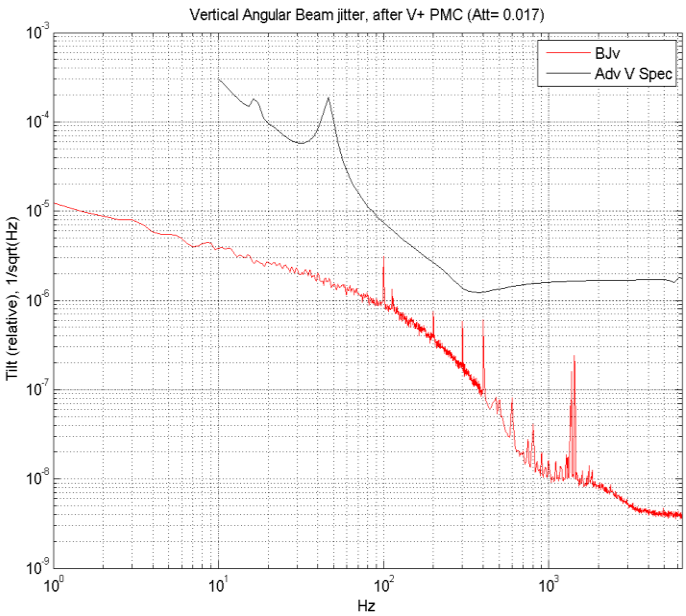

*Figure **8**: Vertical angular beam jitter together with the AdVirgo specifications at IMC input (after PMC). The red curve is the BJ measured at the amplifier output and multiplied by the Virgo+ like PMC attenuation factor (1/59). Beam-jitter is overestimated since part of the noise from 100 Hz to 1 kHz comes from the fan of the calorimeter used to measure the output power.*

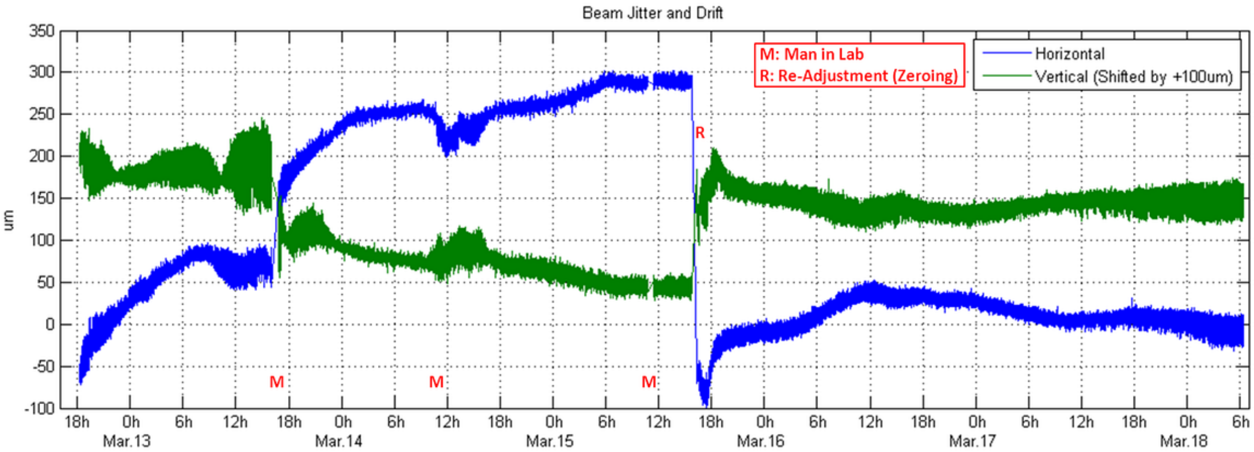

*Figure **9** Beam jitter and drift after the amplifier*

5. Conclusion

These first tests have been conducted with a Nufern amplifier (demonstration model) during 120 hours. We can give some preliminary conclusion about the noises, which are manageable with the usual controls, passive for beam jitters, active for RIN. High frequency RIN deserves a deeper understanding in relation with the manufacturer and probably an extra servo or an extra PMC to kill the noise at the 6 MHz modulation frequency. As far as long-term tests are concerned, the 120 hours of operation are not enough as we have not reached the Nufern guarantee of 3% power drop after 1000 h.

The impossible restart and power drop we have encountered with this demo unit is actually linked to that specific engineering unit and should be corrected.

Up to now none of the performances we have measured have excluded Nufern as a possible amplifier option for the end of 2013 and we expect the return of the unit to conduct further tests in the lab.