A Thermal Compensation System for the gravitational wave detector Virgo

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On behalf of the Virgo Collaboration

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Paris, Marcell Grosmann Meeting

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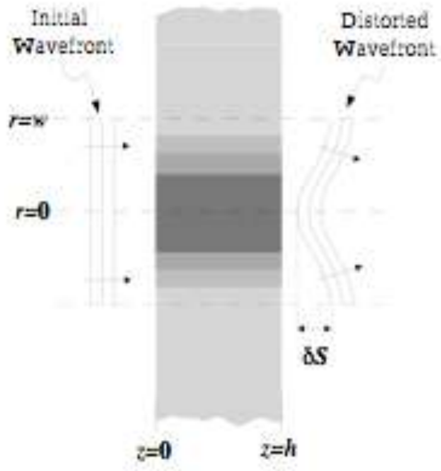
Thermal Lensing

Thermal Lensing has already been observed in the Virgo interferometer, but will get more critical in the advanced interferometers.



nonzero optical absorption in the substrate and coatings of the test masses

S0 = nh.

Distorsion of Optical Path Length

Thermooptic Effect,
(Thermoelastic Deformation, Elastooptic Effect)

The sideband mode size is critically dependent on the thermal lens.

The thermal lensing takes its source in the appearance of temperature gradients in the mirrors.

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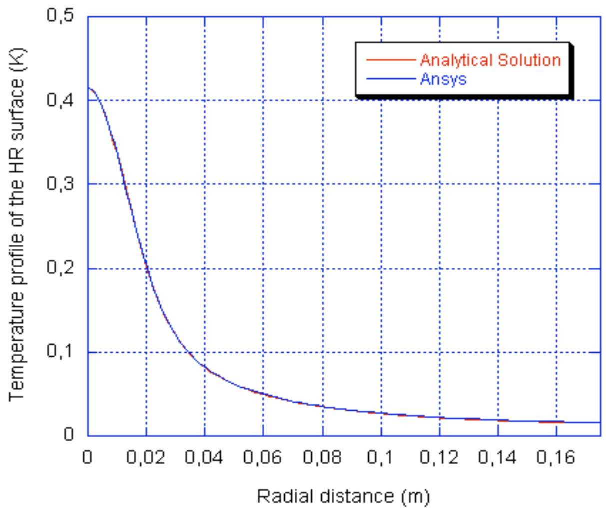
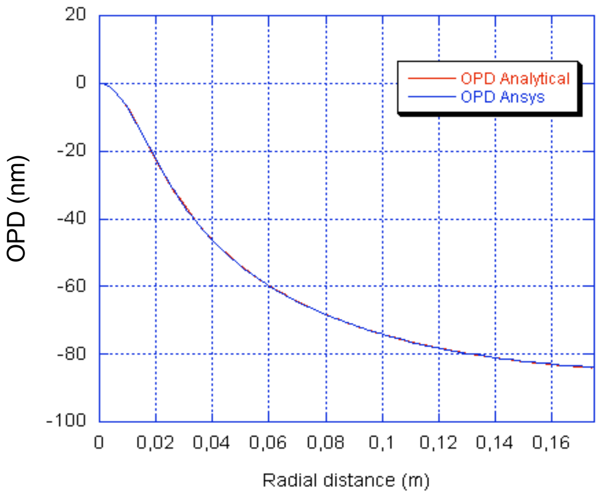
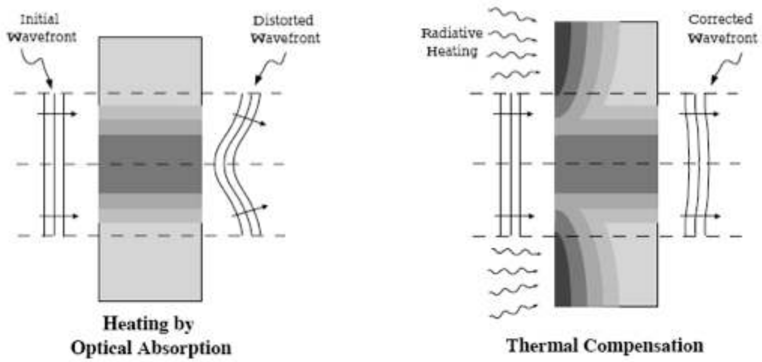
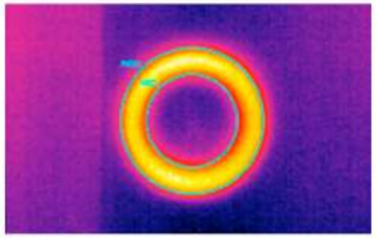
Thermal Compensation System: The Solution

Thermal Lens Profiles





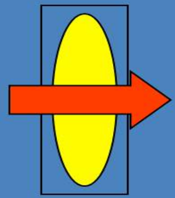




External beam must deposit a large amount of power in the substrate.

Thermal Compensation System: The Solution

$$\gamma = \left\langle \Psi, e^{ikZ}\Psi \right\rangle$$

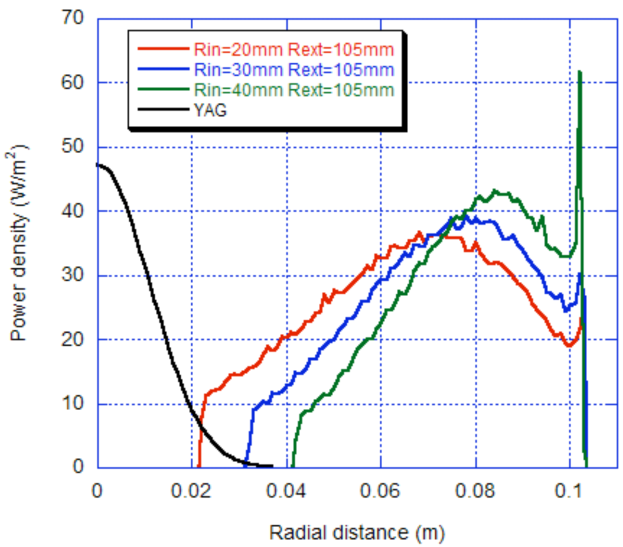


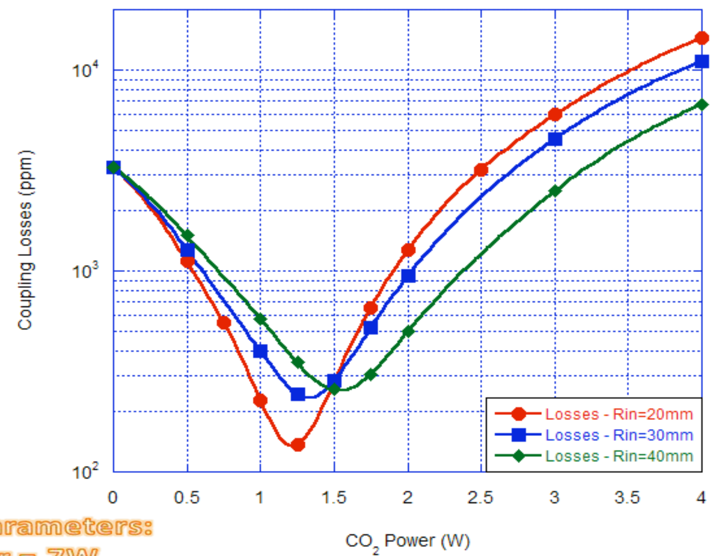
$\Psi \rightarrow \Psi' = e^{ikZ}\Psi$

$$\gamma = 2\pi \int_0^a e^{ikZ(r)} \left|\Psi(r)\right|^2 r dr$$

Losses : $L = 1 - \left|\gamma\right|^2$

From J.Y. Vinet,
Thermal Simulations Meeting, Cascina 1.10.08





Losses as a function of the power absorbed from the extra beam

Simulations parameters:
YAG power = 7W
Coating absorptions = 7.7 ppm

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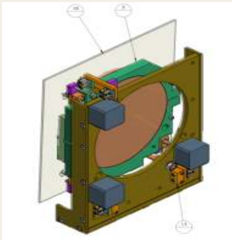
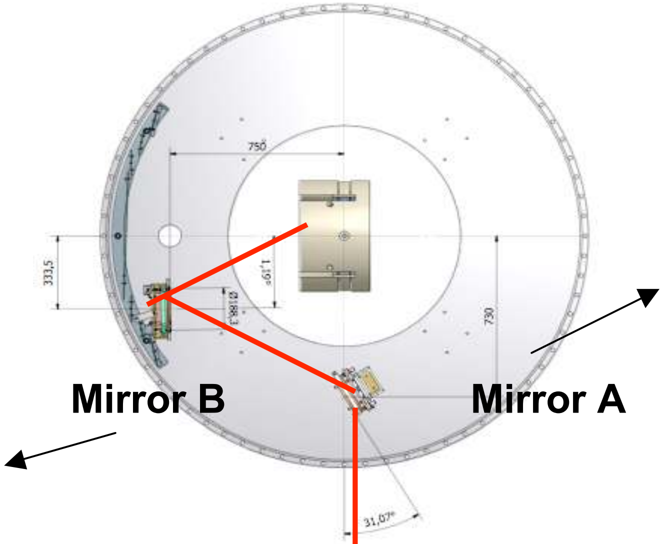
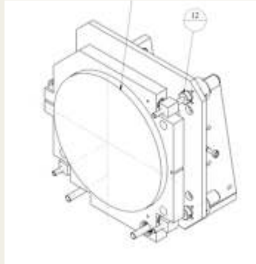
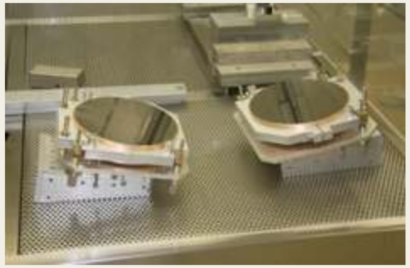
Thermal Compensation System: Hardware

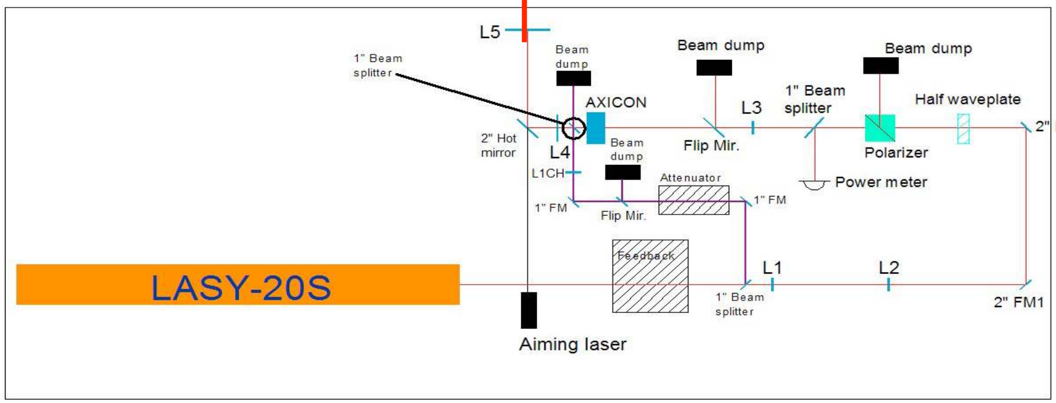
Since no viewport facing the ITM is available, Virgo+ TCS uses in-vacuum optics to steer the TCS beam onto the ITM high reflectivity face



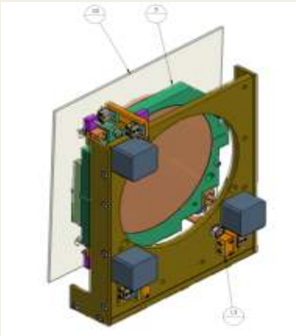


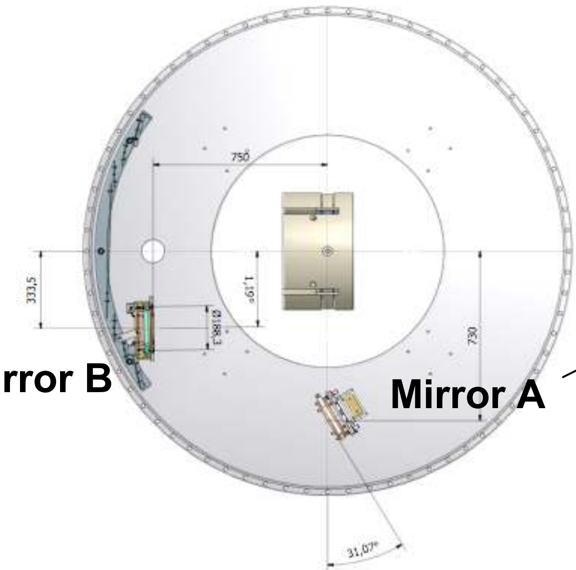


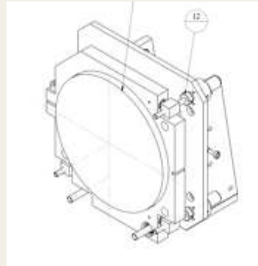


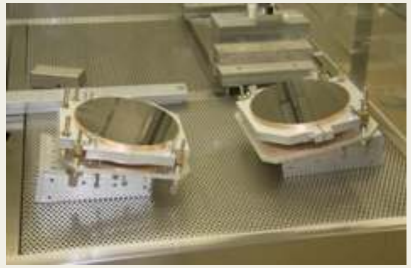


Thermal Compensation System: Hardware









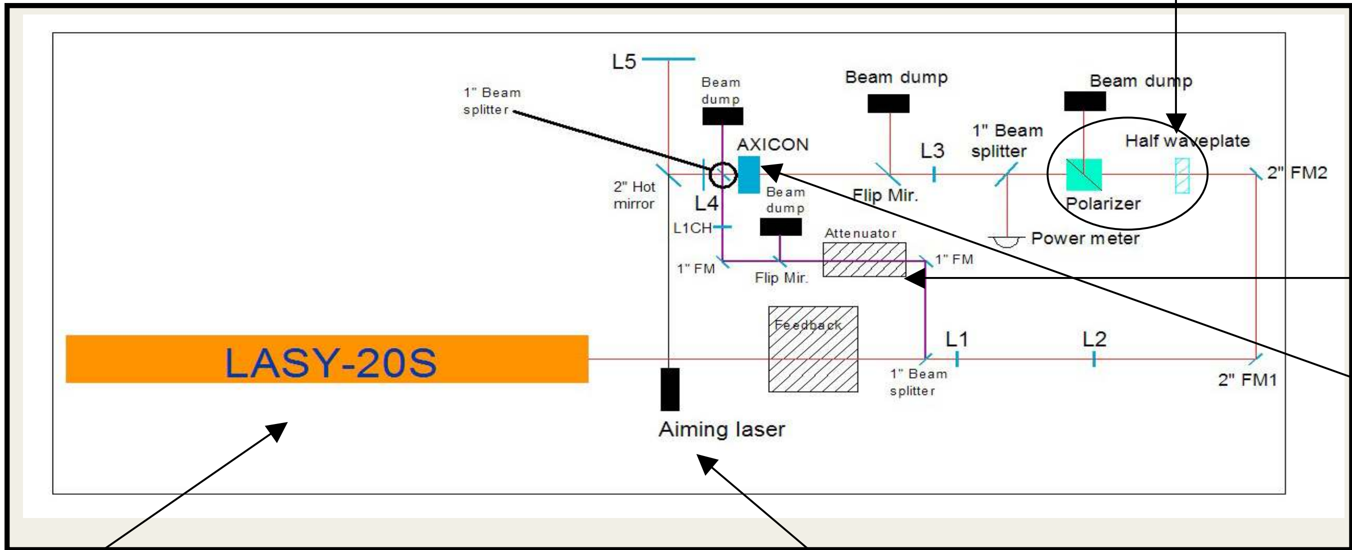
Mirror A is manually adjustable in all degrees of freedom

Mirror B is remotely adjustable
in all angular degrees of freedom.
Needed to align TCS beam onto ITM

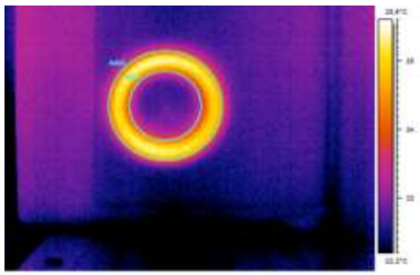
The support for Mirror B is covered with glass baffles to reduce any stray light noise

Thermal Compensation System: Hardware

Half wave plate and fixed polarizer are used for DC power control. The system does not deviate the beam impinging on the AXICON



Single AXICON used to convert a Gaussian beam into an annular beam. Size of the annulus hole can be set by moving L3



CO_2 laser, temperature tuned. Maximum DC power ~25W

Cross-hair visible laser for alignment of TCS beam onto ITM

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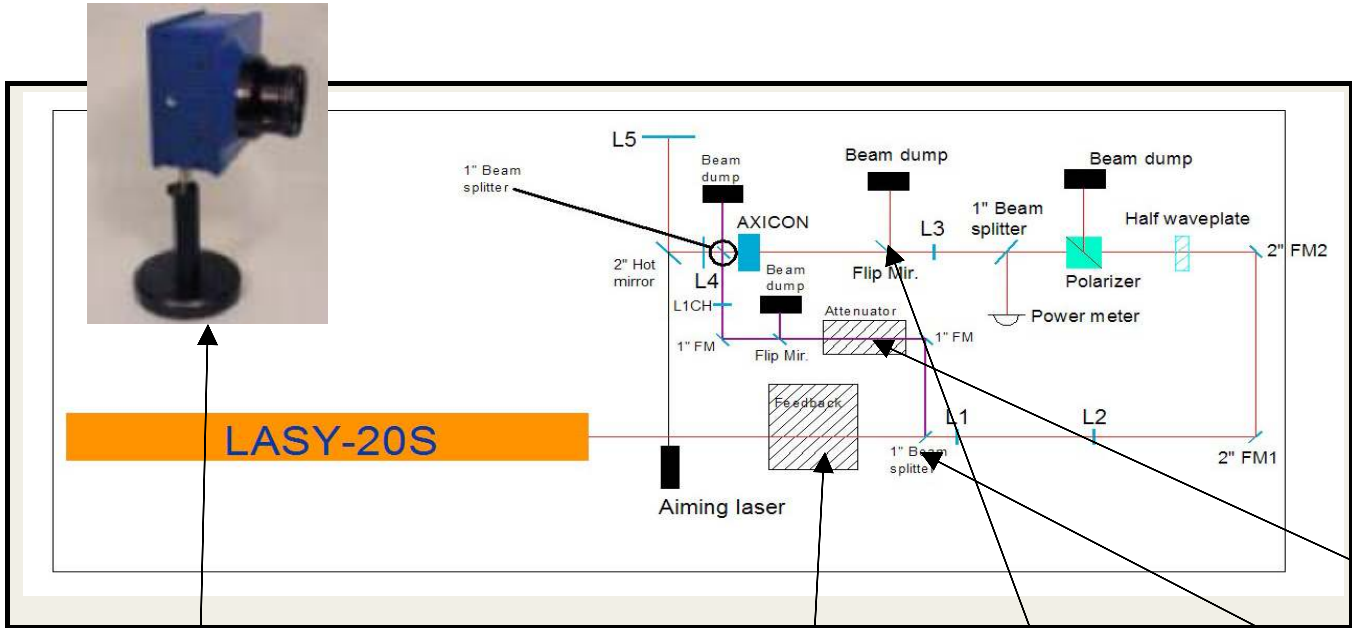
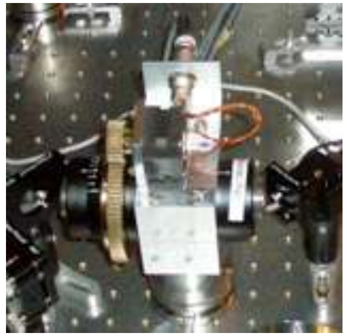
Thermal Compensation System: Hardware





Central heating beam DC power control is accomplished by rotating a pair of Brewster windows

The uniformity of the heating profiles is checked time by time by imaging the heated beam on a target and recording a thermal image.

Flip Mirror is used to switch on and off the TCS.

Central heating beam pick-up from first beam splitter.
This configuration allows CH and annular heating to be on at the same time

Feedback for the laser stabilization

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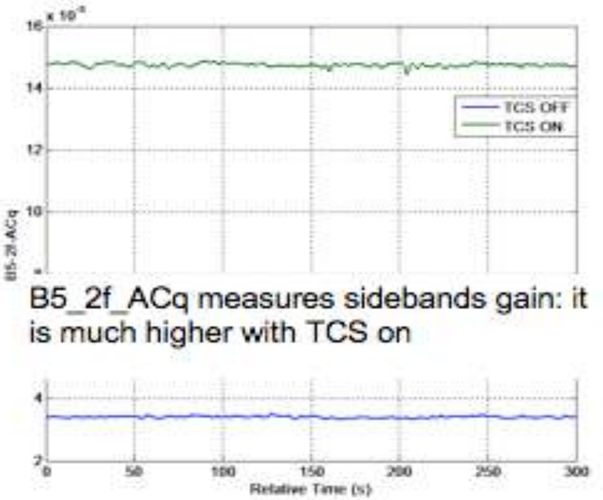
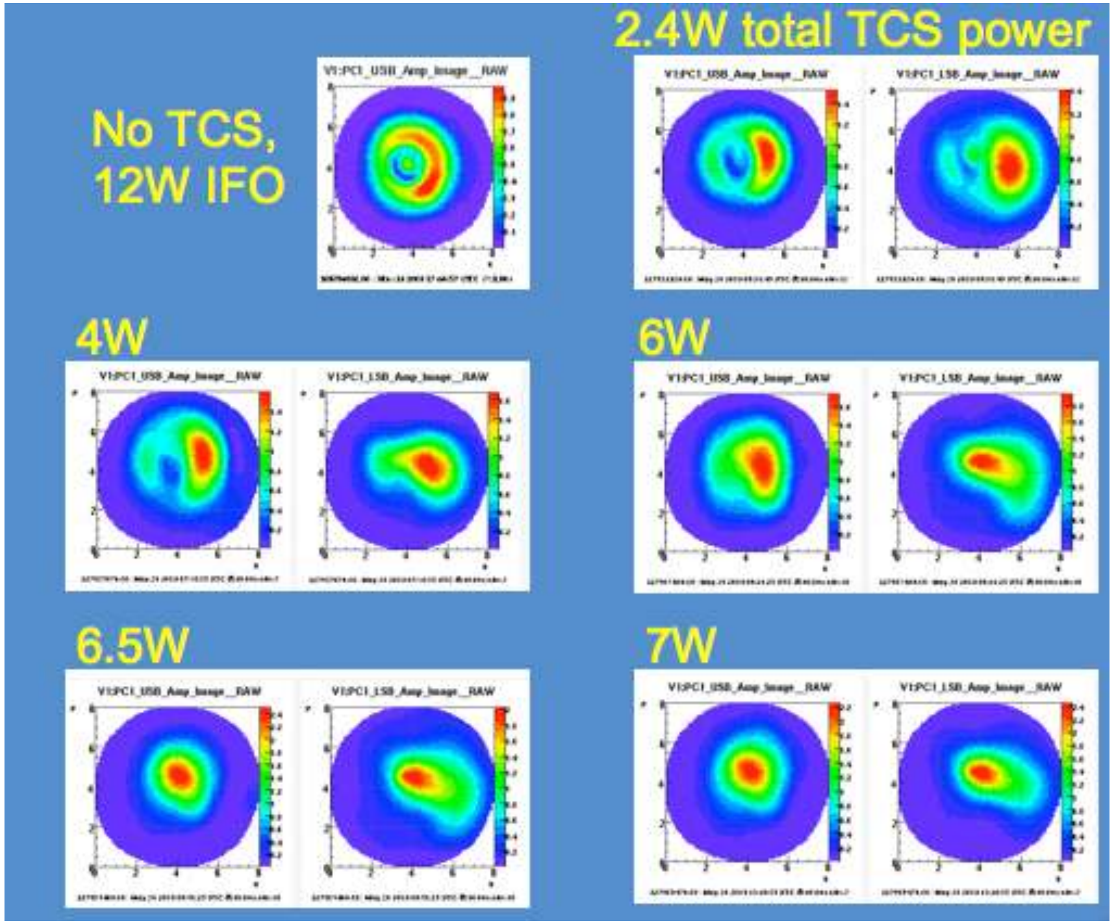
Thermal Compensation System: Performance

With 14.5W of IFO input power, TCS has been tested looking at the phase camera images to see the effects of compensation on the shape and position of the sidebands.
The optical gain of the ITF increases by about 50%. Same kind of test has been repeated with 17W of ITF input power.



B5_2f_ACq measures sidebands gain: it is much higher with TCS on



"The phase camera is a "high-resolution wave-front sensor that measures the complete spatial profile and phase of any frequency component of a beam."

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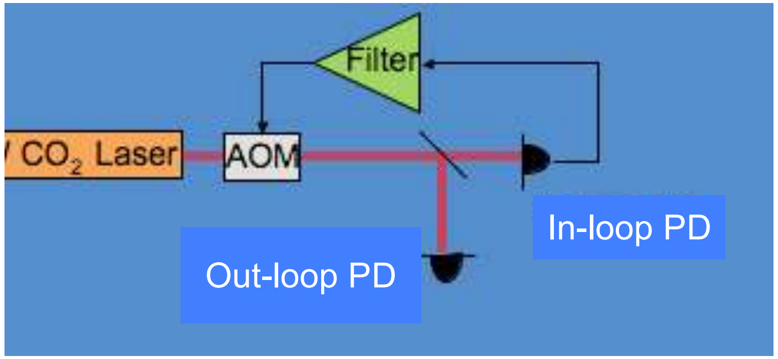
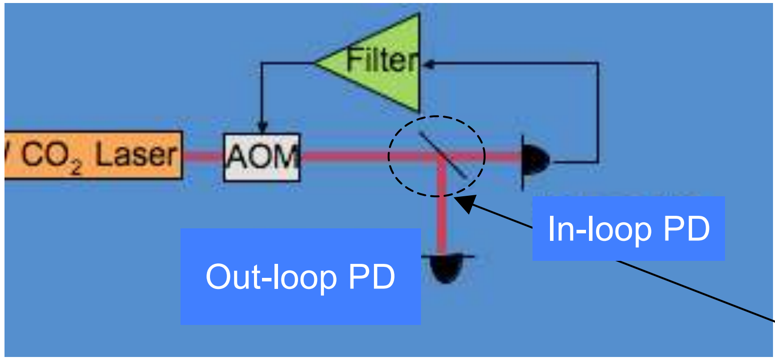
Thermal Compensation System: Power Stabilization

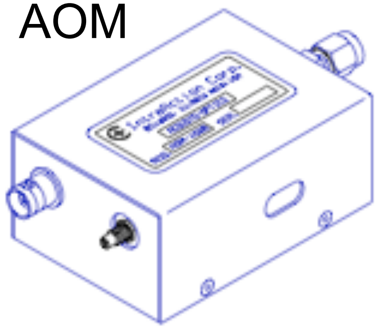
Virgo + sensitivity is such that CO2 Laser intensity noise could be a limiting factor.
At present, stable ITF operations requires 3 W of TCS power for 17 W for input power.
In these conditions some TCS noise starts to show up in the dark fringe, as expected by calculations.
If TCS power is increased to reach the “aberration free” ITF, CO2 noise will appear in the dark fringe spectrum limiting the Virgo+ sensitivity.

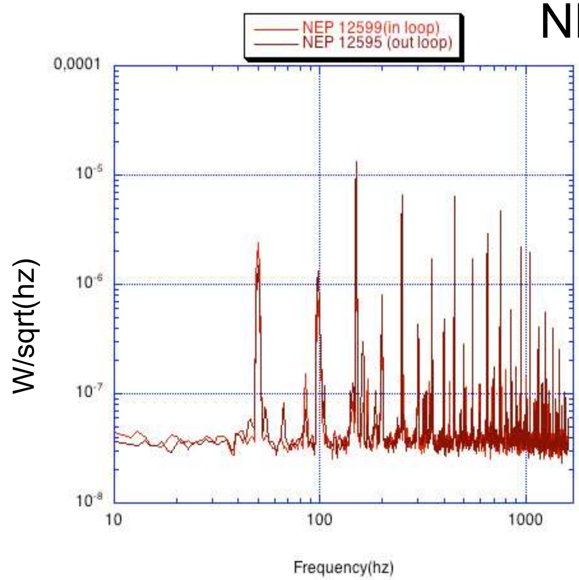
In Roma Tor Vergata Laboratories, a laser intensity stabilization circuit has been developed and tested.



Thermal Compensation System: Power Stabilization







-HgCdTe Photo-Detectors from VIGO Systems equipped with low noise pre.amp

- Acousto-Optic Modulator

- Filter Signal Recovery 5113 pre-amp

- CO2 Laser 25 W

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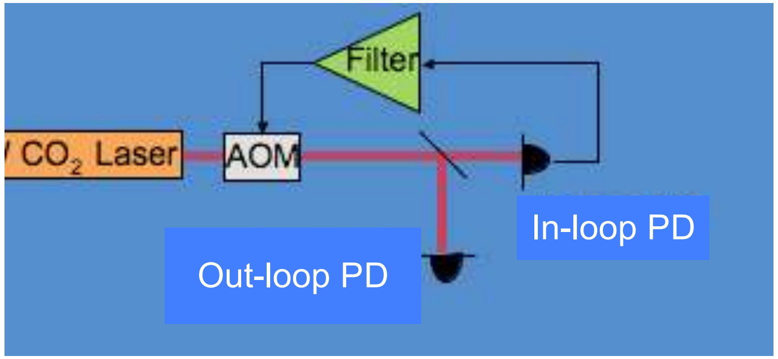
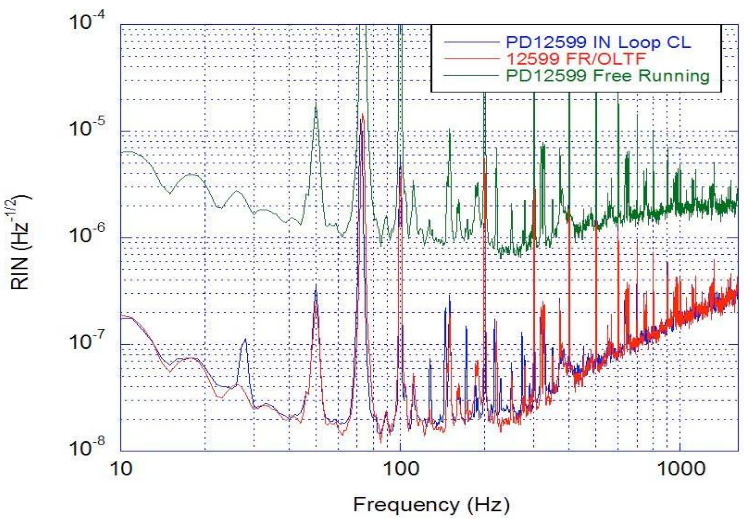
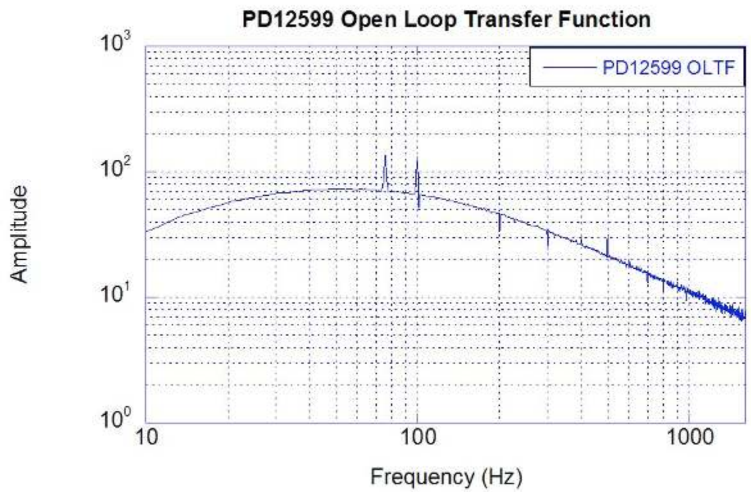
Thermal Compensation System: Power Stabilization



RIN in
close loop





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Conclusion

- TCS has been installed in Virgo in May 2008

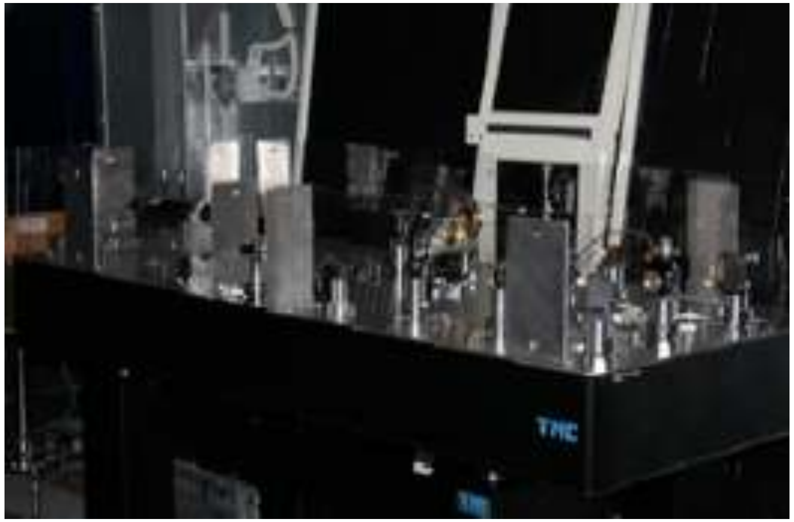
- From Oct 2008 till now, the commissioning of the ITF with higher input power has been carried on, in parallel with the TCS commissioning.

- The system allows to recover an “aberration free” ITF

- Laser Power Stabilization has been developed. At present it allows a decrease of the relative intensity noise from 10^{-6} /√Hz to $4*10^{-7}$/√Hz.

- Further tests are ongoing.

A TCS bench (NI)



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