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Determination of the laser power on the photosensors for the IMC instrumented baffle

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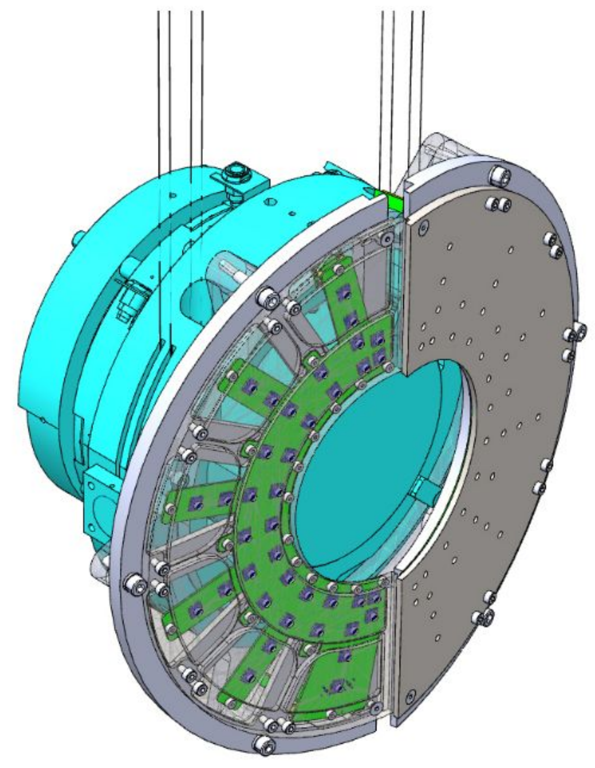
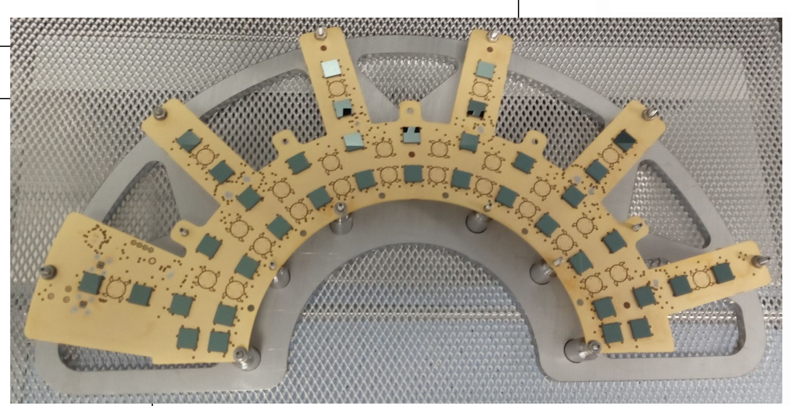
Outline

As part of the upgrade program, a new baffle with photosensors surrounding the end mirror (MC2) of the Input Mode Cleaner (IMC) has been installed at Virgo. This instrumented baffle is an innovative device to control and monitor the stray light inside the experiment, a persistent source of noise at interferometers (IFOs). It will serve as a demonstrator of the technology for its future implementation in the main arms of the IFO, surrounding the main mirrors. In order to determine the maximum energy a photodiode (PD) would be exposed to, we have considered four different scenarios the IMC could be in and simulated or computed analytically the maximum impinging power. All results are for a laser input power of 40W and an effective photosensitive area of the PD of 0.49 cm^2.

Motivation to instrument baffles

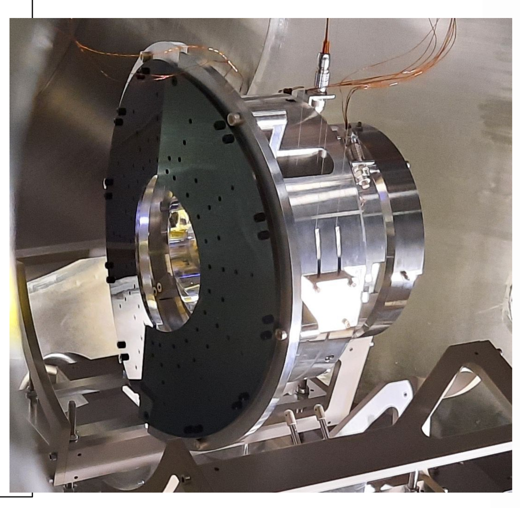
- Better understanding of the stray light (SL) distribution at low angles in the interferometer (IFO).
- More efficient pre-alignment and fine-tuning of the IFO parameters after shutdowns and during operations.
- Detection of excited higher order modes which lead to modified patterns in the SL detected by the baffles.
- Monitoring contamination on mirror surfaces that lead to low-angle scattering[1].

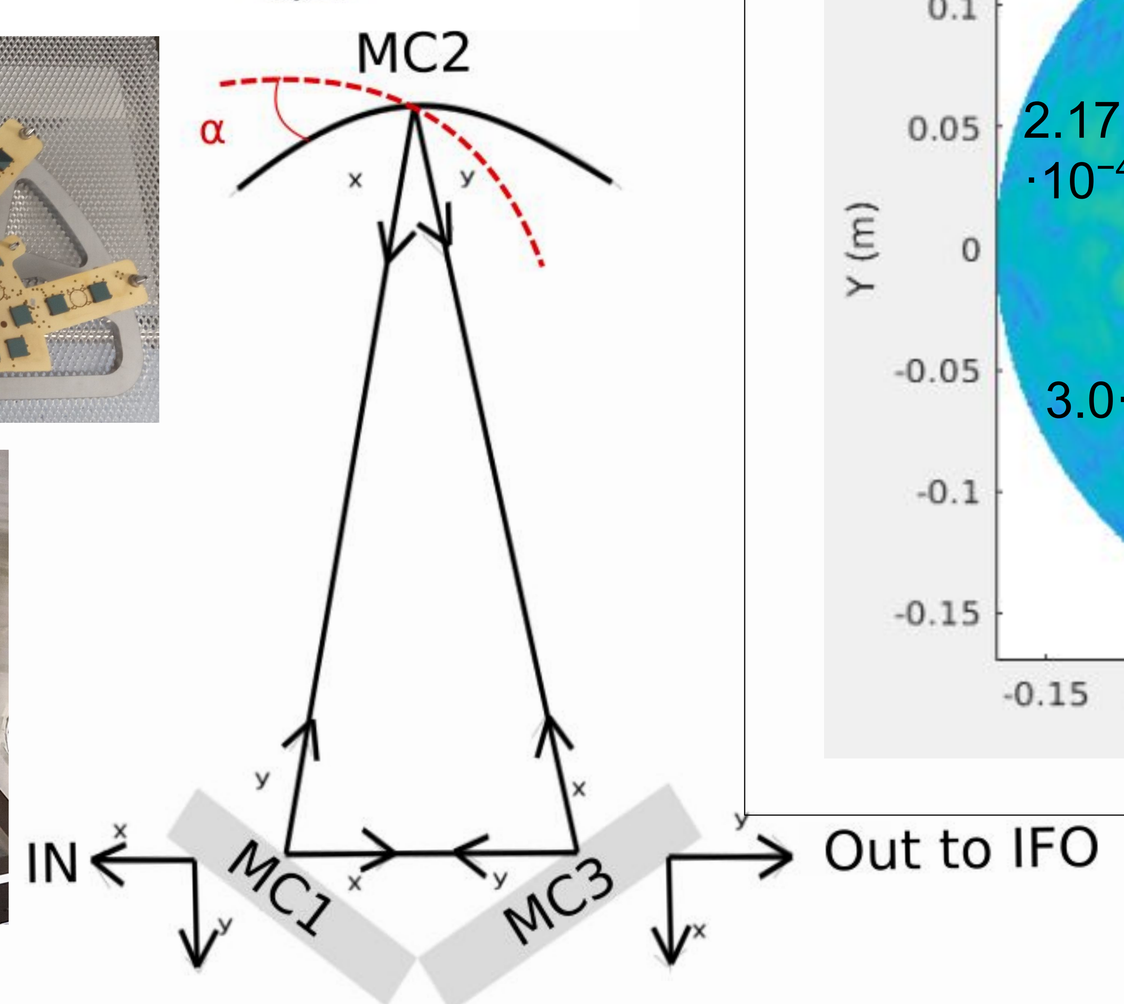




Simulation tool : Static Interferometer Simulation (SIS15) designed by H. Yamamoto[2,3]

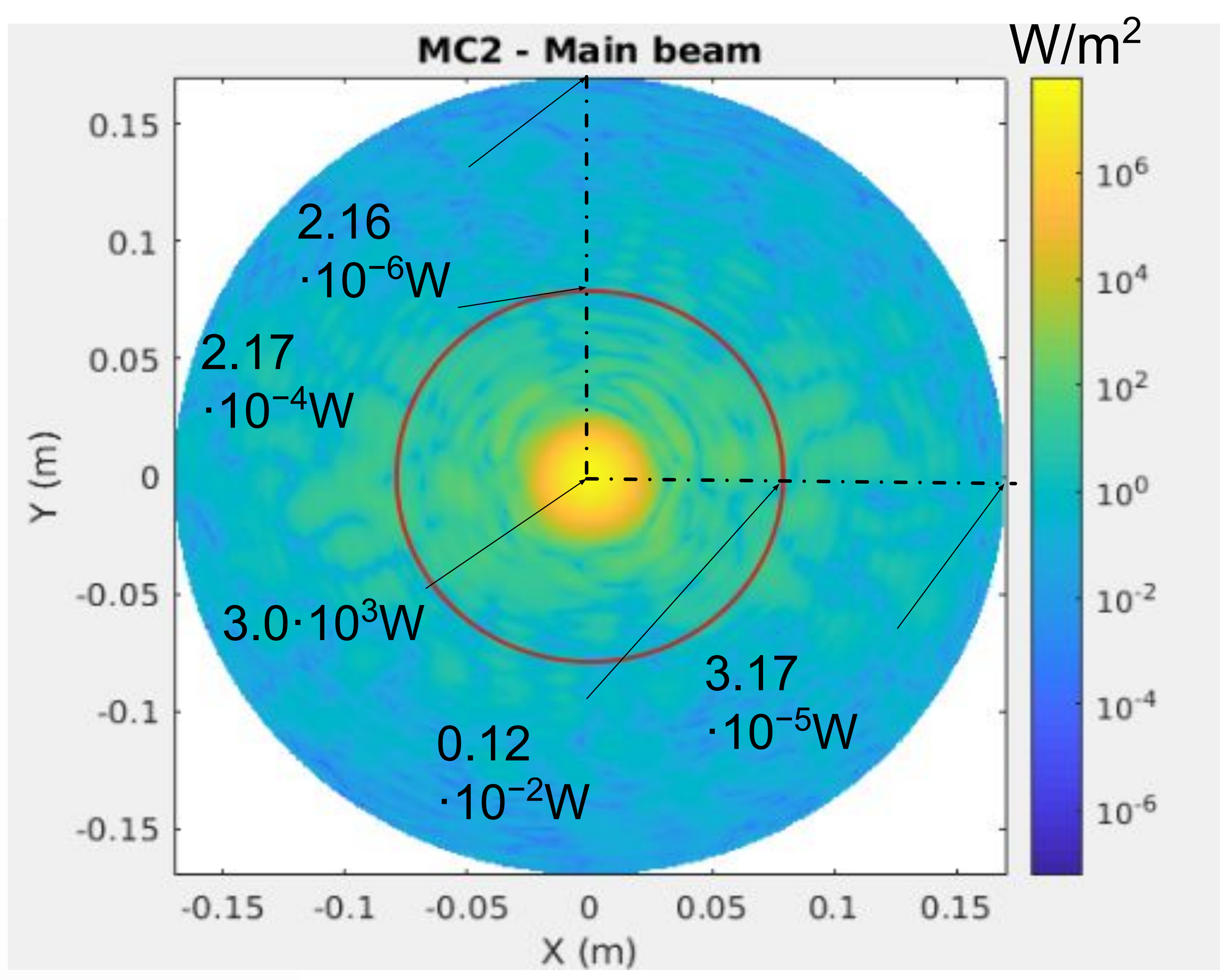
FFT based tool that computes the field propagation in any resonant cavity based on user-defined high-reflective profiles of the test masses (surface maps, taken and convoluted with paraxial diffraction kernel to find the power distribution at a certain location defined by the user[2]).





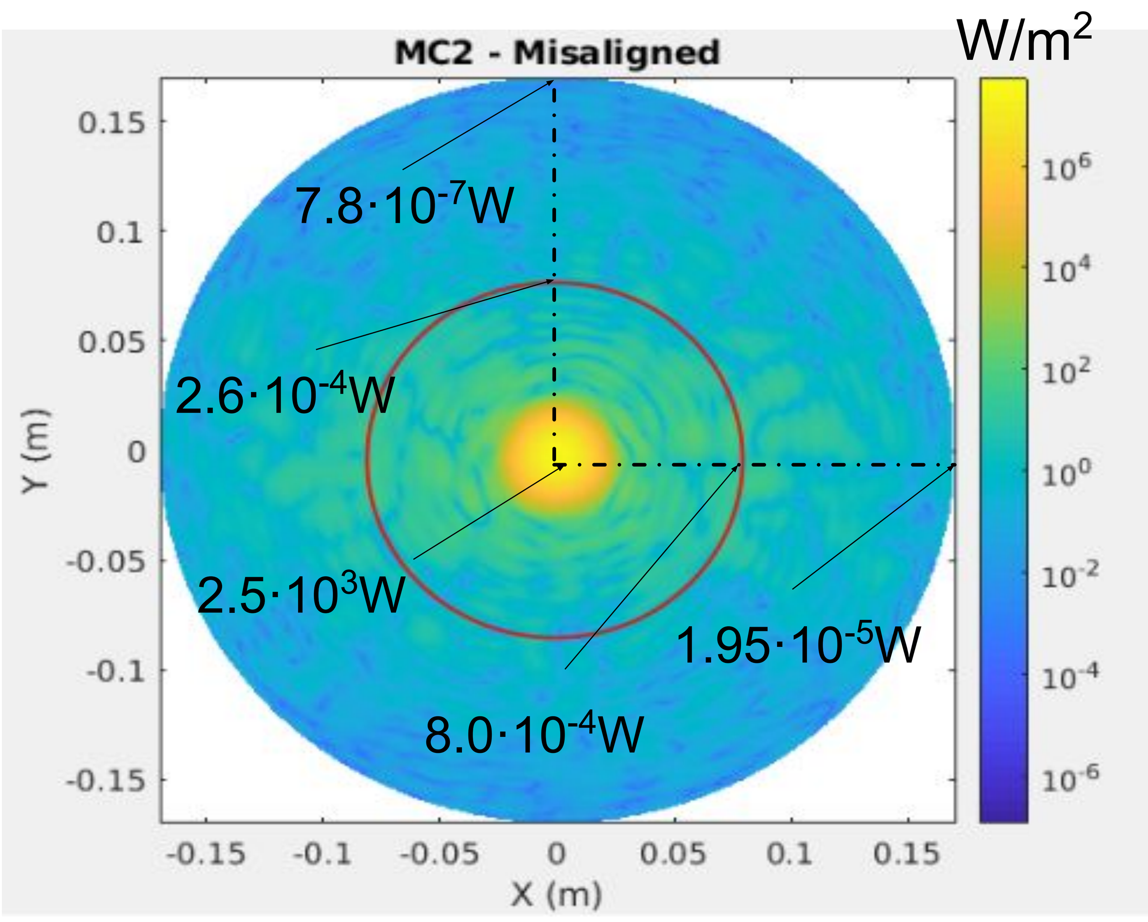
Scenario 1: Nominal conditions with aligned cavity in a steady state operation

The IMC cavity is locked and the laser beam hits the center of the end mirror.
Power light in the PDs placed in the end mirror and baffles ranges from $2.16\cdot10^{-6}$W to $3.0\cdot10^{3}$W (see figure below).



Scenario 2: Misaligned cavity (with respect to the MC2 nominal position) in a steady state operation

The IMC cavity is locked though the laser beam is not aligned (α=10 µrad of misalignment in this example).
Power light in the PDs placed in the end mirror and baffles ranges from $7.8\cdot10^{-7}$W to $2.5\cdot10^{3}$W (see figure).



Scenario 3 : Misaligned cavity out of resonance

The cavity does not resonate for a complete misalignment (α > 35 µrad). The total power inside the IMC cavity is computed in terms of the transmissivity of MC1 ($T_{in} = 2.5\cdot10^{-3}$) and the reflectivity of MC3 ($R_{out}=1$) as the product: $I_{in}\cdot T_{in}\cdot R_{out}$, where I_{in} denotes the input intensity. For a beam size of 0.01 m at the MC2, $I_{in}= 5.09\cdot10^{5}$ W/m^2, leading to a circulating power of $1.27\cdot10^{3}$ W/m^2. Then, the maximum exposure of a PD would become $6.19\cdot10^{-2}$ W.

Scenario 4: Transient noise, mechanical drift

Sudden misalignment of the cavity leading to a mechanical drift. The total energy stored in the cavity in nominal conditions can be expressed as $E_{TOT}=P_{in}\cdot g\cdot\tau$, where P_{in} is the input power, g is the gain of the cavity, defined in terms of the finesse (F) as $g = 2F/\pi$, and τ is the decay time of the cavity, computed as $\tau = 2\pi F/FSR$, where FSR denotes the IMC free spectral range. For F = 1005 and FSR = $1.04\cdot10^{6}$ Hz, leading to values g ~ 640, τ = 153 µs, and E_{TOT} = 3.91 J. Considering a time response of the payload and suspension systems of 10ms and assuming a Gaussian beam, a PD could be exposed to 126 W, during 10 ms. However, experiences obtained in Virgo indicate that the quoted simulated maximum power of 126 W should be regarded as a very conservative upper limit.

Summary/Outlook

In the first three scenarios studied, the dose received by the photosensors (with a power dissipation of up to about 50 mW) would not compromise their performance. However, in extreme cases, such as that in scenario 4, the dose could be potentially large. This motivates the already planned tests with powerful lasers to determine the performance of the sensors. We are currently taking data from the instrumented baffles to compare it with these results.

[1]A.Chiummo et al. "AdV+: IMC payload and instrumented baffles @VW". In: VIR-0435A-19 (2019).
[2]H.Yamamoto. "SIS15, FOG inside, Manual". In: LIGO-T1300942-v2 (2001).
[3]H.Yamamoto. "Stationary Interferometer Simulation Manual". In: LIGO-T070039-v8 (2013).
[4]J. Wenxuan, A. Effler, and V. Frolov. "Physical and statistical analysis of scatter in Fabry-P. Arm Cavity of Advanced LIGO". In: LIGO-T1800224-v0 (2018)
[5]A. Romero, Ll. M. Mir, M. Martínez, A. Alloca , A. Chiummo and H. Yamamoto. "Determination of the maximum impinging power into the photodiodes of the IMC instrumented baffle". In: VIR-1175A-19 (2020)