The handout for AdVirgo+ kat file

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Issue: 1
Date: May 31, 2022

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OMC real data	
Finesse	1100
FSR	834 MHz
T_{In}	0.285%
T_{Out}	0.285%
T_{HR1}	1.1ppm
T_{HR2}	1.3ppm
Throughout	$\approx 2\%$
Loss[1]	60ppm

Table 1: This table resume the OMC parameters measured in Cascina

Contents

1 Introduction

`Finesse` is a simulation program for interferometers. The user can build any kind of virtual interferometer. This is a handout for AdVirgo+ `KAT` file, Finesse input text file describing the interferometer in the form of components and connecting nodes. The purpose of this document is to review and motivate the parameters in the file, as well as to keep track of changes in the file.

1.1 IFO Matching

As from TDR (VIR–0128A–12), the required values for PR and SR radius of curvature (RoC) is 1430.0 m, both the PRC and the SRC are marginally stable for that value. The actual measured values for PRM and SRM are 1477.1 m (VIR-0029A-15) and 1443.35 m (VIR-0028A-15), respectively. In the `KAT` file the RoCs are set to the design value (1430.0 m) and the compensation plates (CP) focal length is such that the PRC and SRC are well matched to the arm cavities, even though this requires a divergent compensation plate (VIR-0629A-18).

Update December 7, 2021 - the focal length of the CPs have been further optimised to mode match the recycling cavities to the arm cavities.

1.2 The OMC modelling

The OMC simulated with Finesse for Ad.Virgo (Fig.**??**) used most of the measured values reported in LB 50572, and all the requirements reported in VIR-0535A-21. In table **??** are reported some of the OMC parameters measured in Cascina.

The *Loss* and the *Throughout* are derived from some measures made at LAPP (ref.person: Michal Was). The Finesse value was inferred in the following way:

starting from a theoretical FSR value of 834MHz, the Finesse value was raised until the tails of the Airy's curve (red line in Fig. **??**) matched the data plot. This lead to a measured Finesse of 1100. From this Finesse the transmissivities values of the Input and Output mirrors were inferred using the following approximation:

$$\mathcal{F} \approx \frac{\pi}{1 - r_1 r_2 r_3 r_4} \tag{1}$$

Where all the r are amplitude reflectivities. Here r_1 is taken equal to r_2; them refers respectively to the input and output mirrors. Following r_3 refers to the HR curved mirror and r_4 refers to the flat HR mirror. Setting $r_3 \approx 1$

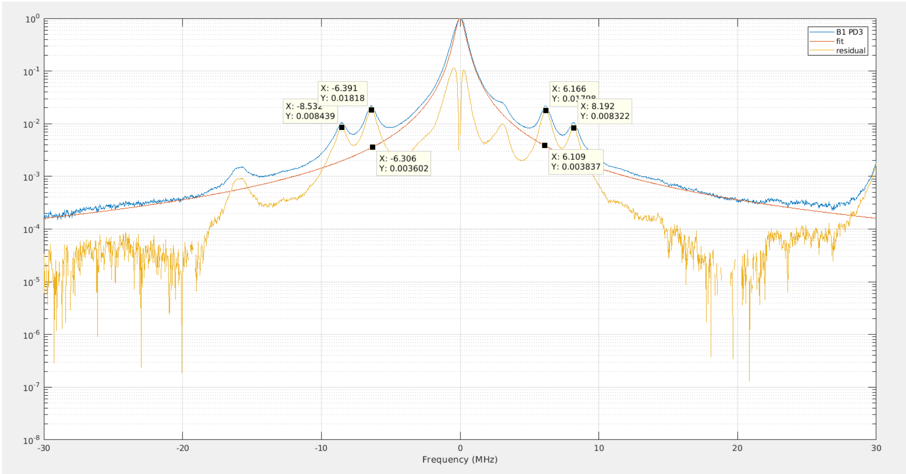

Figure 1: Matching tails between the Airy's curve and the real data plot.

OMC real data	
Finesse	1089.29
FSR	834.569 MHz
Throughout	0.979
Loss[2]	0.006

Table 2: This table shows the data measured on the real OMC

(ideal HR mirror) and $r_4 = 1 - L - t_4$, were L is the cavity round trip loss and t_4 is the amplitude transmissivity of the second HR mirror. Computing the formula we find the transmissivities in power mentioned in table**??**. The 60ppm round trip losses measured in the cavity come from various types of scattering and absorption in the coating and in the substrate of the cavity; it roughly match the measured throughput.
To insert this latter parameter in the simulation we place a fake T_4 coefficient on the BS indicated by $OMC1\_4$, this trasmittivity contains both round trip loss and the two real T coefficients from the two HR mirrors, the visual scheme of the trick is showed in Fig.**??** . More detailed info can be found in [add notebook link].
We running test on the OMC simulation file to see the match between the real data and the simulated one, the result is showed in table **??**. We have chosen to keep the round trip loss number round in the simulation, this lead to a little discrepancy between the measured Finesse and the simulated one. However that doesn't affect the overall work of the simulated OMC, if it will be required in future the Finesse values can be made equal.

`omc_t_in.png`

Figure 2: Visual representation of the losses used in the simulation.

2 Arms characterization

The arm lengths of the IFO are been measured with a FINESSE simulation, the full code is in Arms characterization.

The starting point was a discrepancy of the 56MHz sideband in the FSR scan, where the peacks were slightly shifted between the West and North arm results (VIR-53000).

Given the FSR of the carrier, in the FSR scan the 56MHz peacks have a frequency offset Δf of:

$$\begin{aligned} North\ arm &: 0.4528 \times FSR \\ West\ arm &: 0.4416 \times FSR\ . \end{aligned} \tag{2}$$

Knowing that:

$$f_{56MHz} = 56436993MHz \ \text{ and } \ FSR = \frac{c}{2L} \tag{3}$$

We can then compute the arm lengths in few simple steps.

For the North arm we have:

$$f = n \times FSR + \Delta f \tag{4}$$

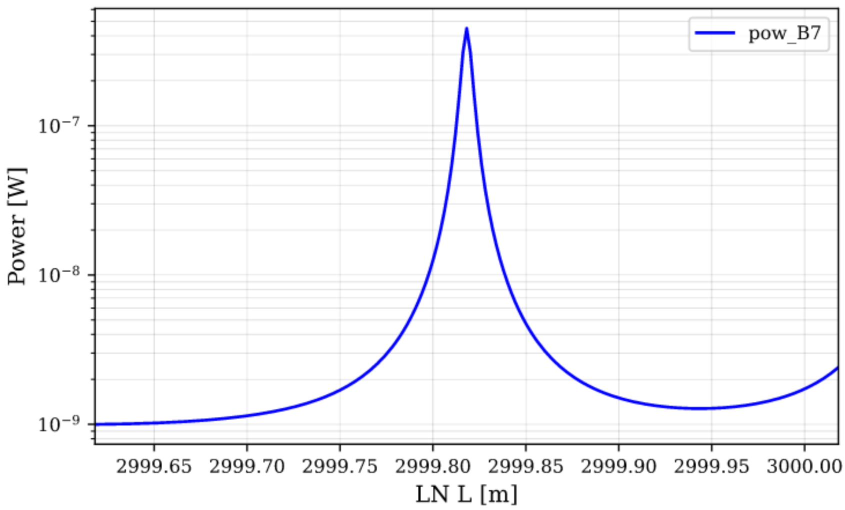

Figure 3: Simulation result of the North arm's measurement.

$$56436993MHz = n \times FSR + 0.4528 \times FSR \ . \tag{5}$$

The closest round number n that fit the equation is 1129, this lead to:

$$FSR = \frac{56436993MHz}{1129 + 0.4528} \ , \tag{6}$$

so we have:

$$MMTL_{North} = \frac{c}{2FSR} = 2999.818m \ . \tag{7}$$

The same procedure it's been done for the West Arms. It leads to $L_{West} = 2999.788$, VIR-1080A-21.

3 EOMs modulation depths

The EOMs installed in Ad.Virgo+ are phase modulators. Each of them requires an amplifier that gives power to the crystal that form the EOM; in order to create the phase shift in the side bands. For the one that produce the 56 MHz sideband the amplifier of 1 W was replaced by one of 2 W. This change lead to an electric signal ampitude of 0.12 dBm applied on the EOM, It can be monitorized using INJ_LNFS_AMPL1/2/3 channels. The corrisponding frequencies channels are INJ_LNFS_FREQ1/2/3. The change was made in order to increase the modulation depth from 0.16 rad to 0.25 rad, since the SNR value was too small to gain a good error signal (LB 38123).

4 Focal lengths optimisation for OMC's mode-matching

The new parameters for the OMC in Ad.Virgo+ provided some mode mismatch inside the Virgo kat script, specifically on the first beam splitter (OMC1_1) that compose the OMC cavity. The mode match in the rest of the cavity is provided by the command 'cav' that defines the cavity. To fix this problem it's been made a simulation to minimise the mode mismatch between OMC1_1 and the two lenses that serve to mode match it, MMT_L1 and MMT_L2. A 'mmd' detector is been used to simultaneously scan on the two focal lengths. We reached a mode mismatch $\sim 10^6$, this is enough to confirm that the OMC is in mode-match state, since at this point the variation on the focal lengths of the lenses is so negletable that is not manually possible anymore.

5 Coating and substrate diameters for Ad.Virgo+, Phase I

We report here the tables of the designed values with the coating and substrate diameters used in Ad.Virgo+, Phase I (Ref $VIR - 0128A - 12$). To stay updated with the most recent changes, you can see the Virgo wiki.

	Input Mirror IM	End Mirror EM	Beam Splitter BS	Compensation Plates CP	Power Recycling Mirror PRM	Signal Recycling Mirror PRM	Pick Off Plate POP
Incident angle	0°	0°	45°	0°	0°	0°	6°
Coating diameter Surface 1	340 mm	340 mm	530 mm	340 mm	340 mm	340 mm	340 mm
Coating diameter Surface 2	340 mm	340 mm	530 mm	340 mm	340 mm	340 mm	340 mm
Coating Surface 1	HR T = 1.4%	HR T = 1 ppm	R=T= 50% +/- 0.5%	AR R <100 ppm	HR T = 5 %	HR T = 20 %	R = 300 ppm +/- 100 ppm
Coating Surface 2	AR R ≈ 300 ppm (TBC) (*)	AR R < 100 ppm (TBC)	AR R <100 ppm	AR R <100 ppm	AR R <100 ppm	AR R <100 ppm	AR R <100 ppm
Coating absorption Surface 1	< 1 ppm	< 0.5 ppm	< 2 ppm	-	< 2 ppm	< 2 ppm	-
Scattering Surface 1	<10 ppm	<10 ppm	<10 ppm	<10 ppm	<10 ppm	<10 ppm	<10 ppm
RMS Flatness Surface 1	0.5 nm RMS ∅ 150 mm	0.5 nm RMS ∅ 150 mm	< 2 nm RMS ∅ 250 mm	< 2 nm RMS ∅ 150 mm	< 2 nm RMS ∅150 mm	< 2 nm RMS ∅150 mm	<3 nm RMS (TBC) ∅ 150 mm
RMS Flatness Surface 2	< 2 nm RMS ∅ 150 mm	< 5 nm RMS ∅ 150 mm	< 2 nm RMS ∅ 250 mm	< 2 nm RMS ∅ 150 mm	< 2 nm RMS ∅150 mm	< 2 nm RMS ∅150 mm	<40 nm RMS (TBC) ∅ 150 mm

Figure 4: A summary of the coatings main features of the Ad.Virgo+ (Phase I) mirrors at 1064 nm.

	Input Mirror IM	End Mirror EM	Beam Splitter BS	Compensation Plates CP	Power Recycling Mirror PR	Signal Recycling Mirror SR	Pick Off Plate POP
Number of parts	4	4	3	4	3	3	3
Fused Silica Nature	Suprasil 3002	Suprasil 312	Suprasil 3001	Suprasil 312 SV	Suprasil 312 SV	Suprasil 312	Suprasil 312 SV
Diameter	350 mm	350 mm	550 mm	350 mm	350 mm	350 mm	350 mm
Thickness	200 mm	200 mm	65 mm	35 mm	100 mm	100 mm	35 mm
Bulk Absorption	<0.3 ppm/cm	typical 3 ppm/cm ≤ 5 ppm/cm	<0.3 ppm/cm	<1 ppm/cm	typical 3 ppm/cm ≤ 5 ppm/cm	typical 3 ppm/cm ≤ 5 ppm/cm	<1 ppm/cm
Index homogeneity	$\leq 5\ 10^{-7}$ PV in central 100 mm	$\leq 3\ 10^{-6}$ PV in central 200 mm	$\leq 5\ 10^{-7}$ PV in central 100 mm	$\leq 3\ 10^{-6}$ PV in central 200 mm	$\leq 3\ 10^{-6}$ PV in central 200 mm	$\leq 3\ 10^{-6}$ PV in central 200 mm	$\leq 3\ 10^{-6}$ PV in central 200 mm

PV : Peak to Valley

Figure 5: Specifications of the bulk substrates for the Ad.Virgo+ (Phase I) mirrors.

6 Behavior of beam parameters in the PRC

This section illustrates the behavior of the beam parameter in the PRC when defining the cavity as ”short” or ”long” by including or excluding the arms.

The following plots were generated using a simplified model of the three mirror coupled cavity including the PRC and one of the arm cavities.

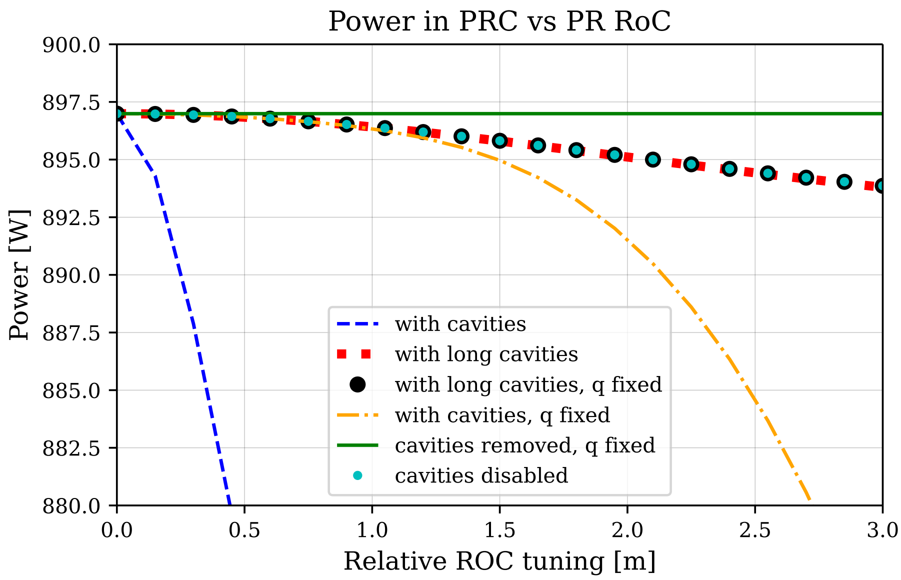

Figure 6: An overview of the behavior of the beam parameter seen through the power in the PRC.

7 Pre-tuning SRCL

Placeholder.

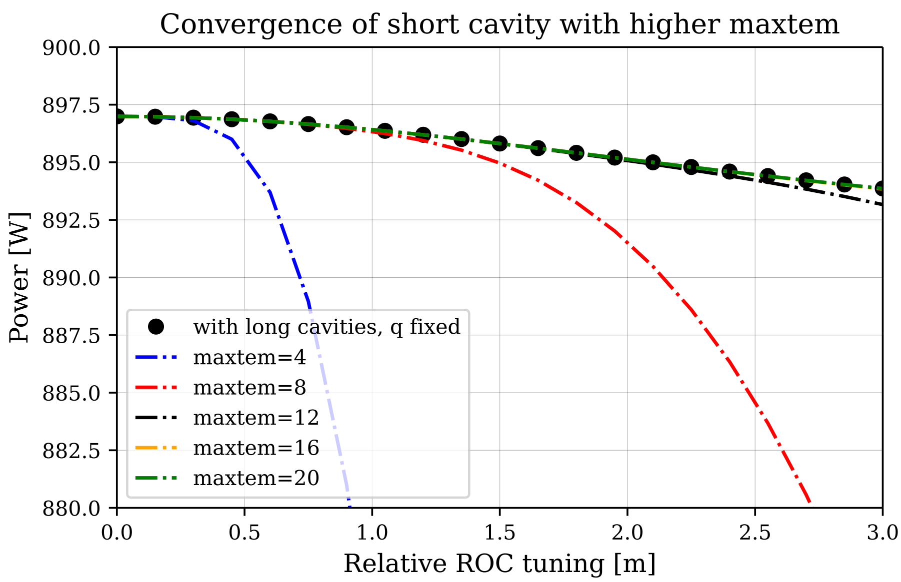

Figure 7: The short cavity with fixed q converges to the long cavity with increased maxtem.

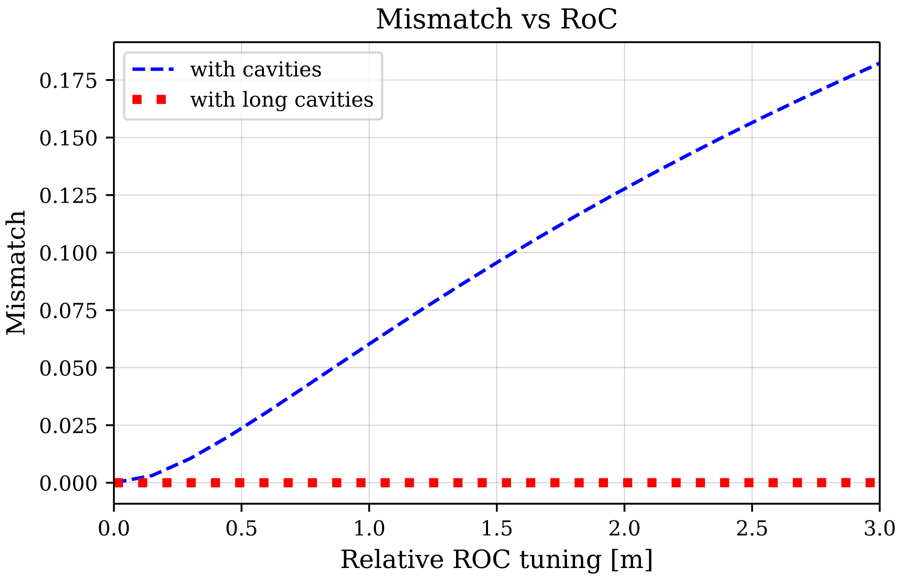

Figure 8: The short cavity has a mismatch at the ITM whereas the long cavity does not.

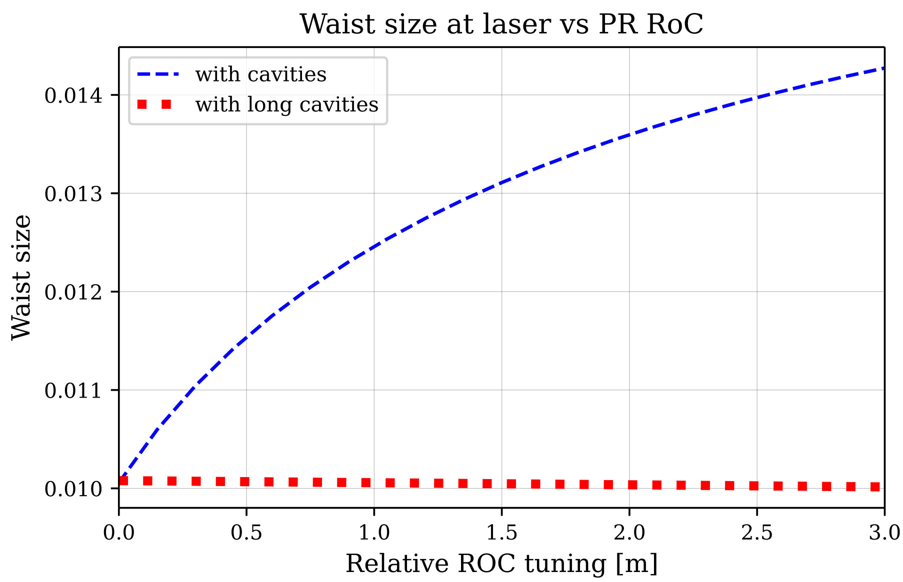

Figure 9: The waist size at the laser varies greatly when defining the short cavity.

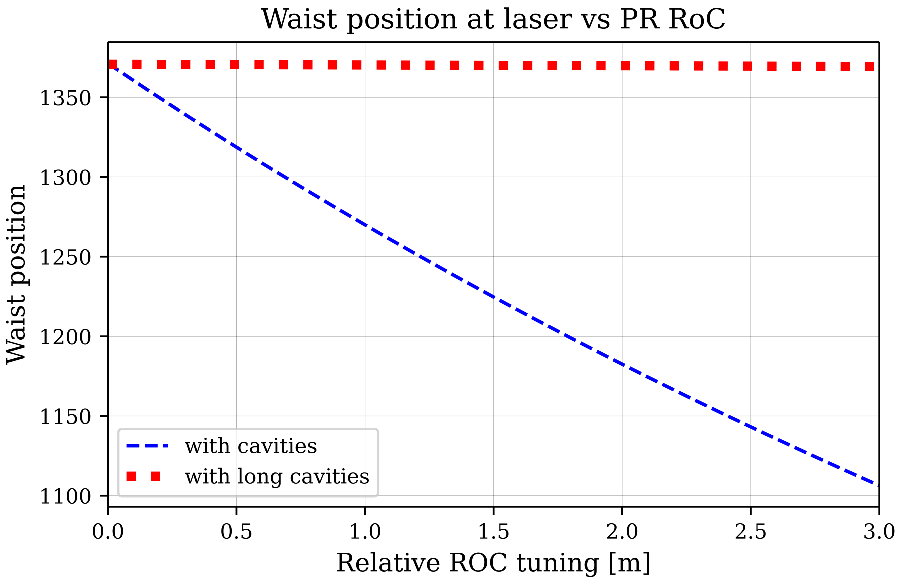

Figure 10: The waist position at the laser varies greatly when defining the short cavity.