

# ASC REF signals dependance on arm losses

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The purpose of this note is to check the ASC signal dependency on the arm losses. In particular, we expect to have a decrease in the ASC signal amplitude at the REFL port for a particular arm losses value. The results of this note have been obtained by Optickle simulations.

## 1 Introduction

The DRFPMI can be assimilated to a Fabry-Perot (FP) cavity for the reflected field  $\psi_{ref}$ . The input mirror of the FP cavity is the PR mirror and the output mirror is the rest of the interferometer, that has a complex reflectivity equivalency. This is illustrated in Fig.1 and Fig.2.

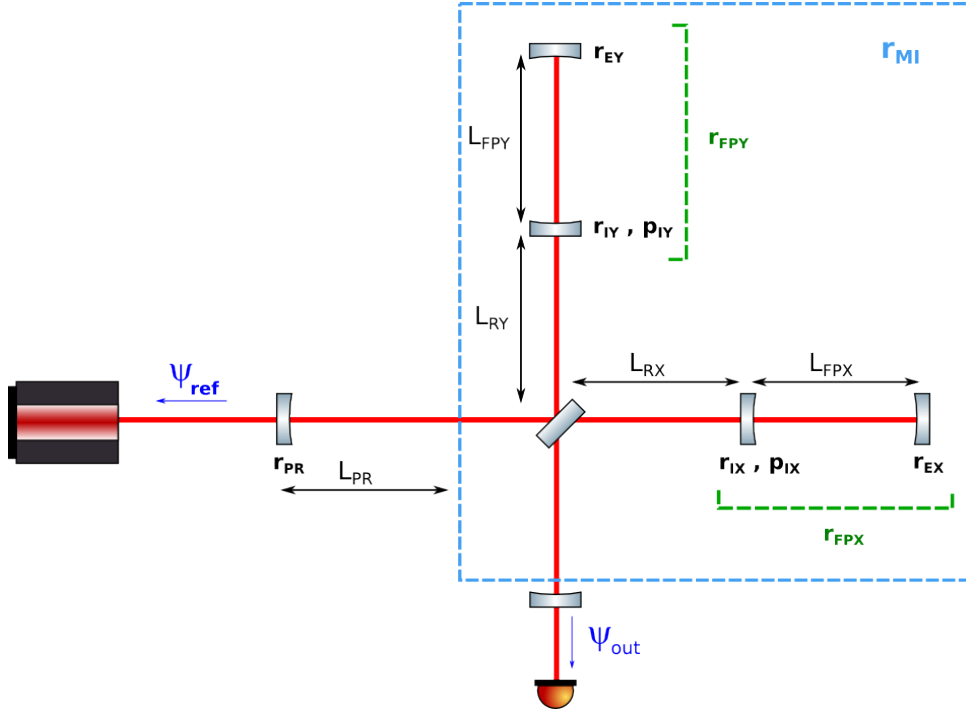


Figure 1: Scheme of the DRFPMI with the notations used in this document.

**Notations** For each optical component  $N$ , we define:

$$r_N^2 + t_N^2 + p_N = 1 \quad (1)$$

with  $r_N$  the reflectivity of the component,  $t_N$  its transmissivity and  $p_N$  the power losses. An incident field  $\psi_i$  is reflected and transmitted by the component with the following convention:

$$\psi_r = ir_N\psi_i \quad (2)$$

$$\psi_t = t_N\psi_i \quad (3)$$

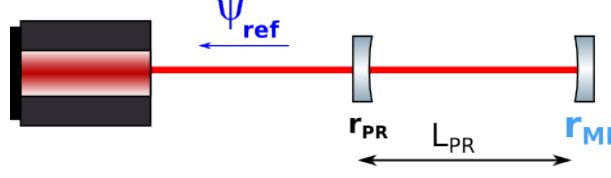


Figure 2: Fabry-Perot equivalency for the reflected field.

### 1.1 Interferometer description

**Arms** We assume that the arm lengths are identical with  $L_{FPX} = L_{FPY}$ . The reflectivity of each arm cavity is, at resonance:

$$r_{FPX} = \frac{r_{IX} - r_{EX}(1 - p_{IX})}{1 - r_{IX}r_{EX}} \quad (4)$$

$$r_{FPY} = \frac{r_{IY} - r_{EY}(1 - p_{IY})}{1 - r_{IY}r_{EY}} \quad (5)$$

**Central Michelson** The DRMI can now be seen as a Michelson interferometer whose the end mirrors have a reflectivity  $r_{FPX}$  and  $r_{FPY}$ . The reflectivity of the Michelson interferometer is expressed by, assuming a perfect beam splitter with  $r_{BS} = t_{BS} = \frac{1}{\sqrt{2}}$ :

$$r_{MI} = \frac{1}{2}(r_{FPX}e^{-2ikL_{RX}} - r_{FPY}e^{-2ikL_{RY}}) \quad (6)$$

The Michelson is set on the dark fringe for the anti-symmetric port. That means:

$$L_{RX} = L_0 + \delta L \quad (7)$$

$$L_{RY} = L_0 - \delta L \quad (8)$$

$$\delta L = \pm \frac{\pi}{4k} \quad (9)$$

and we do not need to take into account the signal recycling cavity for the carrier field. We then obtain:

$$r_{MI} = \frac{1}{2}(r_{FPX} + r_{FPY})e^{-2ikL_{RX}} \quad (10)$$

**Power recycling cavity** The field reflected by the resulting equivalent Fabry-Perot cavity can be expressed by:

$$\psi_{ref} = i \frac{r_{PR} + r_{MI}(1 - p_{PR})e^{-2ikL_{PR}}}{1 + r_{PR}r_{MI}e^{-2ikL_{PR}}} \psi_{in} \quad (11)$$

At resonance for the carrier beam, we have:

$$\psi_{ref} = i \frac{r_{PR} - r_{MI}(1 - p_{PR})}{1 - r_{PR}r_{MI}} \psi_{in} \quad (12)$$

## 1.2 Critical coupling

In a simple Fabry-Perot cavity, we have three coupling cases for the carrier beam:

- $r_i < r_e(1 - p_i)$  : the cavity is under-coupled.
- $r_i = r_e(1 - p_i)$  : the cavity is critically coupled. The power reflected by the cavity is null and the transmissivity is maximal.
- $r_i > r_e(1 - p_i)$  : the cavity is over-coupled.

It means that for some reflectivity values  $r_{MI}$ , the IFO becomes critically coupled and the power reflected  $P_{ref} = |\psi_{ref}|^2$  drops. This will happen when:

$$r_{PR} = r_{MI}(1 - p_{PR}) \quad (13)$$

In particular, for some losses in the input test masses, the power reflected can be minimal. What is the effect on the ASC REFL signals in this case?

## 2 IFO configuration for the simulation

**Rough computation** From the simple model and the parameters presented in Table 1, we can predict the approximate value of power losses creating the critical coupling. By applying these values in Eq.13 we find that  $p_{IX} = 125.5$  ppm creates the reflected power to be null. This simple computation is reported in a Matlab file to check the behavior of the reflected power as a function of the ITMX power losses (see Fig.3).

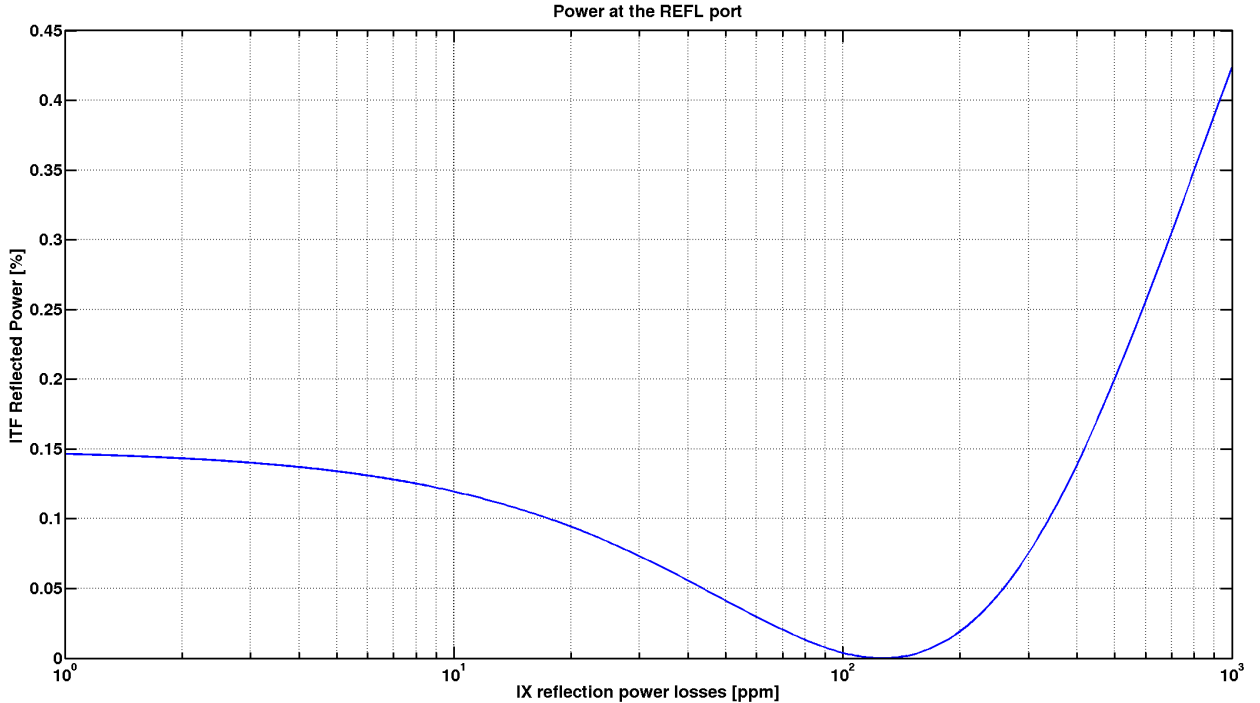


Figure 3: Power reflected by the IFO as a function of the ITMX power losses as predicted by the rough computation. The critical IFO is created for  $p_{IX}$  around 125 ppm.

**Optickle Simulation** With a full interferometer simulation, we check the value of ITMX power losses that creates a critically coupled IFO. We therefore assume that the only varying parameter is  $p_{IX}$ . The parameters used in the simulations are again reported in Table 1. The simulations are running with a PITCH excitation.

Optics $N$	Transmission ( $t_N^2$ )	Losses ( $p_N$ ) [ppm]
IX	0.0148	30
IY	0.0148	30
EX	$5 \cdot 10^{-6}$	30
EY	$5 \cdot 10^{-6}$	30
BS	0.5	37.5
PRM	0.03	37.5

Table 1: Configuration for the Optickle simulation

### 3 REFL Power dependency on ITMX losses

The fields reflected by the IFO are computed as a function of the losses in the ITMX mirror. We observe a drop for the carrier when  $p_{IX}$  is about 120 ppm (see Fig.4).

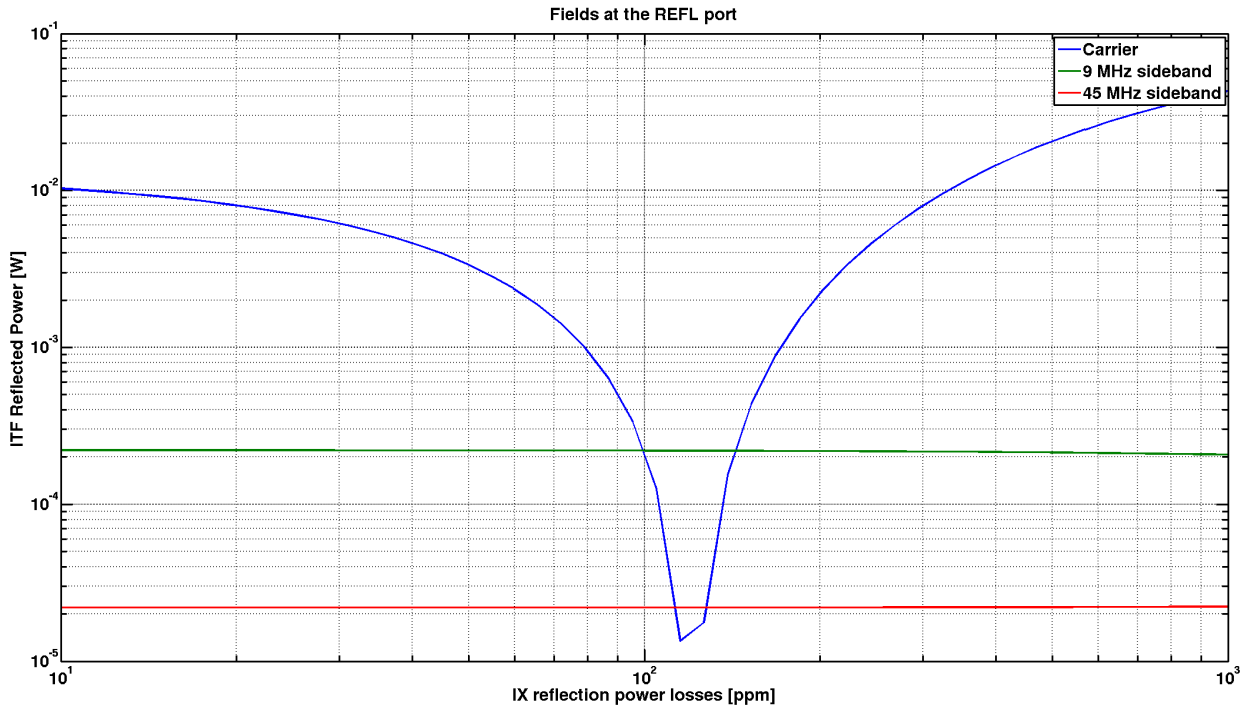


Figure 4: Power reflected by the IFO at different frequencies (Carrier, 9 MHz, 45 MHz).

### 4 WFS REFL signal dependency on ITMX losses

We now observe the effect on the ASC signals at the REFL port for three degrees of freedom (CHARD, PRC2 and IM4) and for the PITCH and YAW excitation. We compare the ASC signals for all the test mass in the two excitation modes. The results are presented in Fig. 5

and 6 for the 9 MHz demodulation. The signals are the same but with opposite signs for ETMY and ITMX. The amplitudes seen by the WFS for all the TMS are comparable.

To obtain the degrees of freedom, we combine the WFS signals according to (see alog 16254):

$$CHARD = REFL\_A\_9\_I + REFL\_B\_9\_I + REFL\_A\_45\_I \quad (14)$$

$$PRC2 = REFL\_A\_45\_I - 0.66REFL\_A\_9\_I \quad (15)$$

$$IM4 = REFL\_B\_9\_I - REFL\_A\_9\_I \quad (16)$$

The results are reported in Fig.7, 8, 9 for the Pitch excitation and in Fig.10, 11 and 12 for Yaw excitation. The black dot lines indicate  $p_{IX} = 120$  ppm.

#### 4.1 CHARD

The behavior is different for the Pitch and the Yaw excitation. With the actual combination of signals, we obtain that the CHARD signal becomes null for the ITMX loss being about 140 ppm and changes sign in Yaw excitation. It means that for this value of losses, the ASC signal disappears at the reflection port and we loose the information about the CHARD DOF.

#### 4.2 PRC2

The signal crosses zero for the ITMX loss being about 120 ppm and changes sign. It demonstrates the possibility to loose the ASC signals when the IFO is critically coupled.

#### 4.3 IM4

The sign of the signal is not affected by the ITMX losses. The IM4 DOF senses an angular motion before the critically coupled cavity. It is therefore expected that it will not change as a function of the internal power losses.

The signal increases as the power losses increase. This trend is observed for the 3 DOFs. It can be explained by the fact that the power reflected back by the ITF is higher as seen in Fig.4: the equivalent cavity is over-coupled.

#### 4.4 Signal Extinction

To check the power loss value corresponding to the extinction of the different signals, we plot them at the Gouy phase that corresponds to their maximum amplitude. We obtain the Fig.13 and Fig.14. To highlight the position of the minimum, the absolute value of the signals is represented. We confirm that the signals CHARD (Yaw) and PRC2 (both Pitch and Yaw) signals are close to zero for  $p_{IX} \simeq 140$  ppm and  $p_{IX} \simeq 123$  ppm respectively.

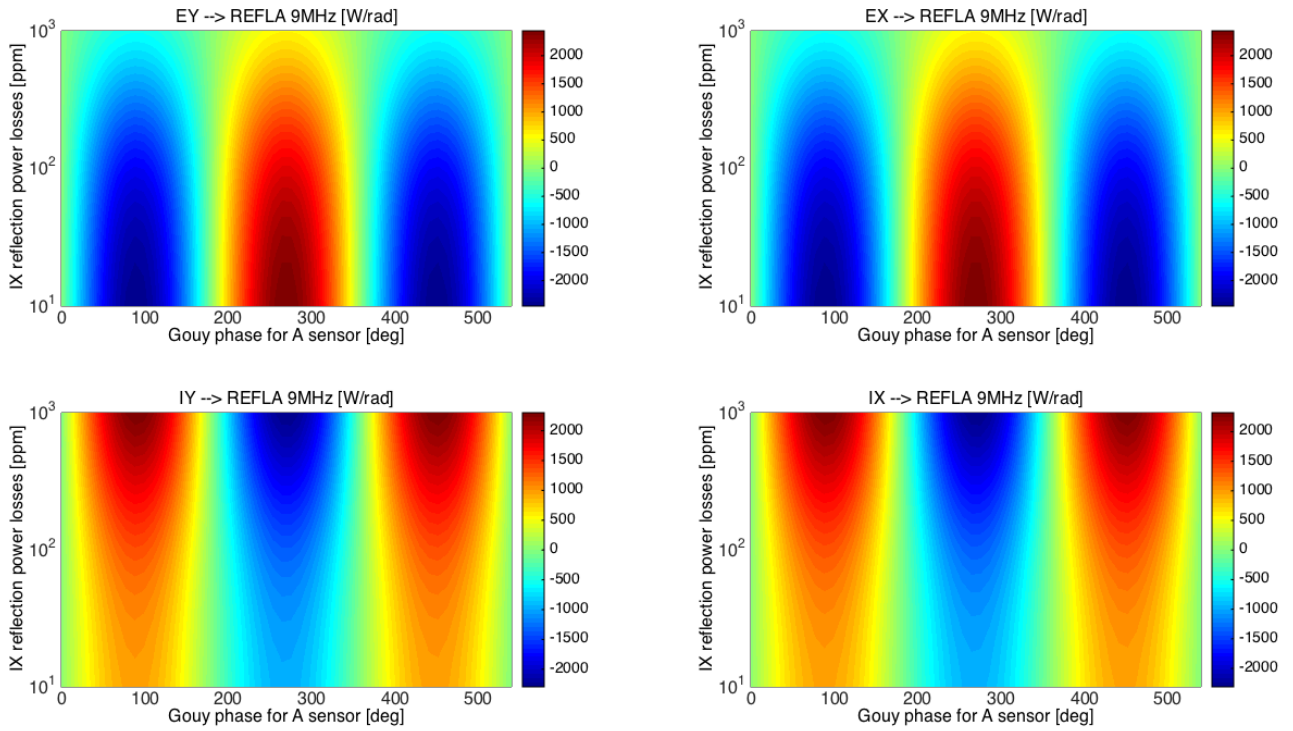


Figure 5: REFL 9 MHz as a function of ITMX losses and the Gouy phase sweep (Pitch excitation).

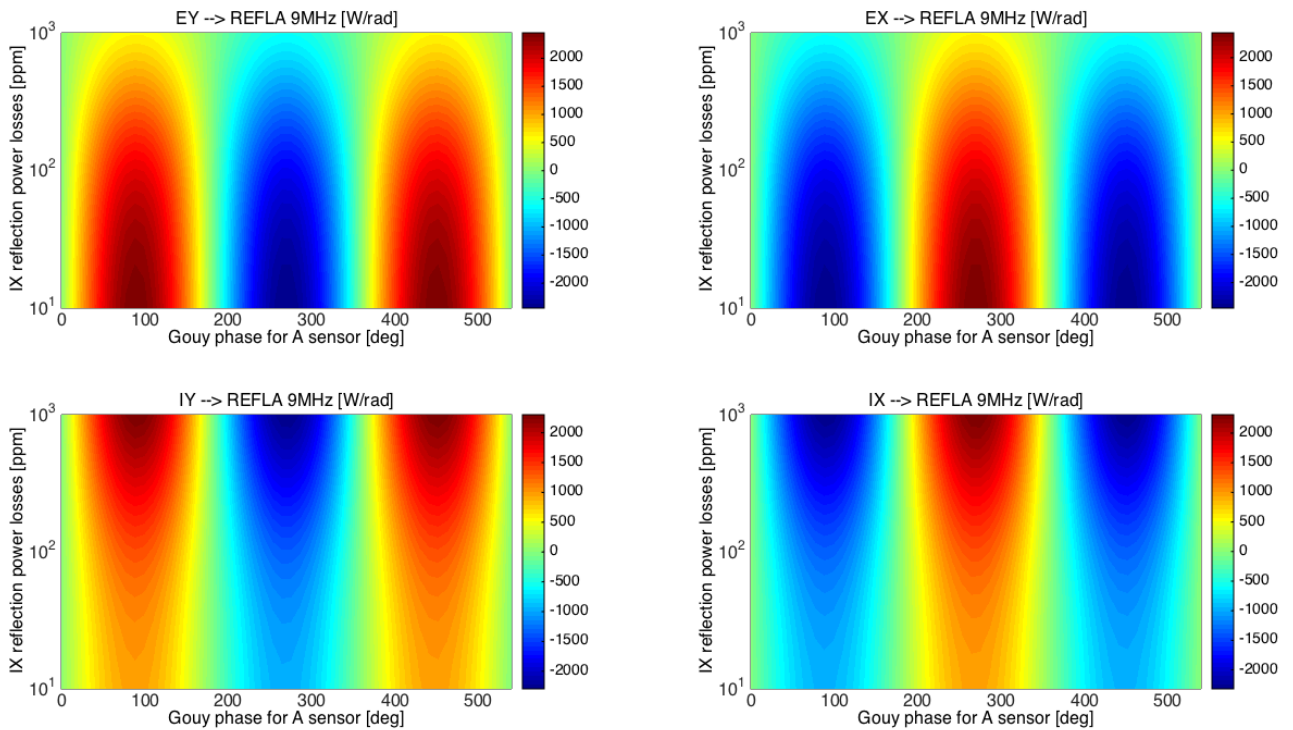


Figure 6: REFL 9 MHz as a function of ITMX losses and the Gouy phase sweep (Yaw excitation).

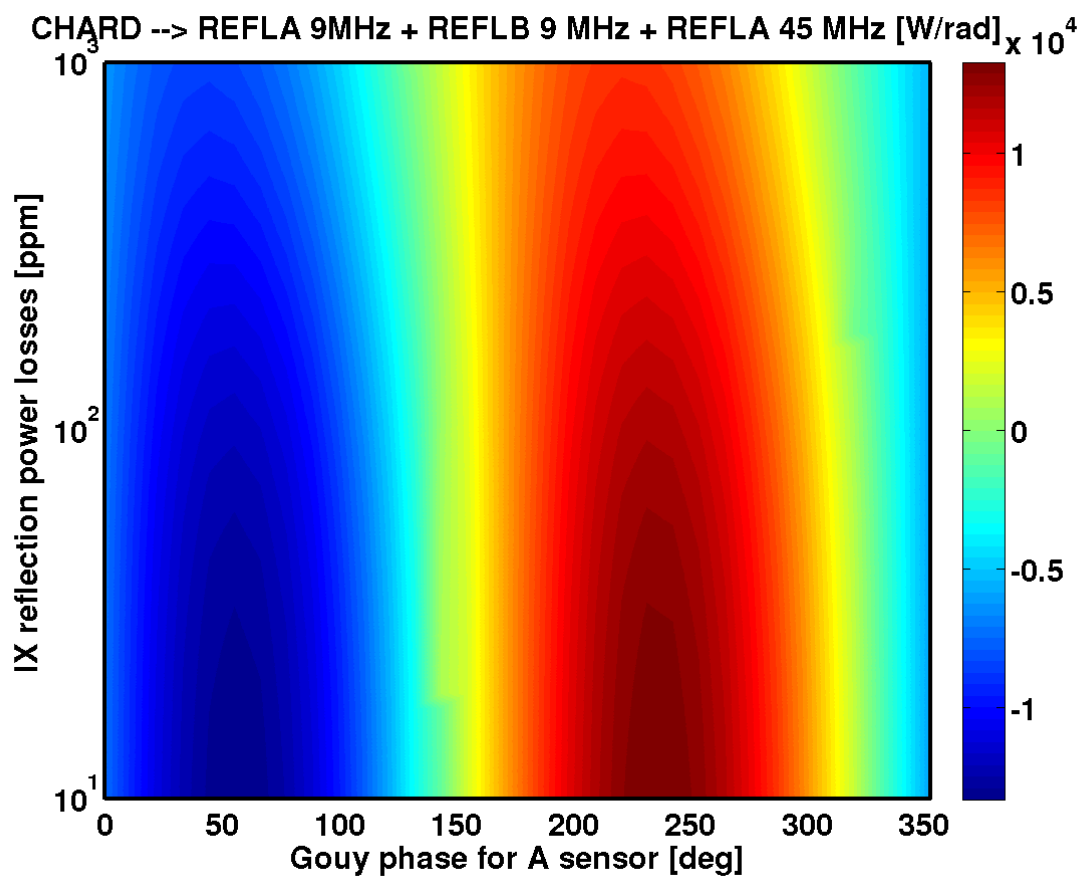


Figure 7: CHARD signal as a function of ITMX losses and Gouy phase sweep for Pitch excitation.

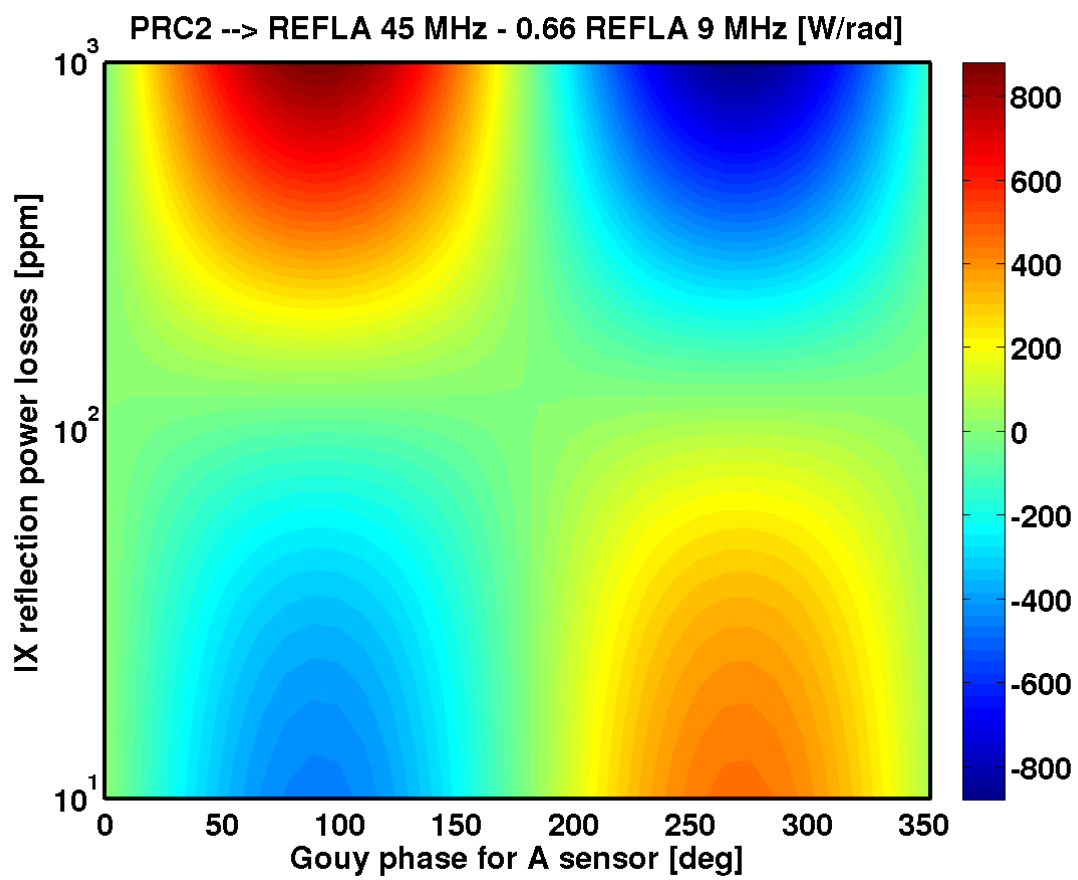


Figure 8: PRC2 signal as a function of ITMX losses and Gouy phase sweep for Pitch excitation.

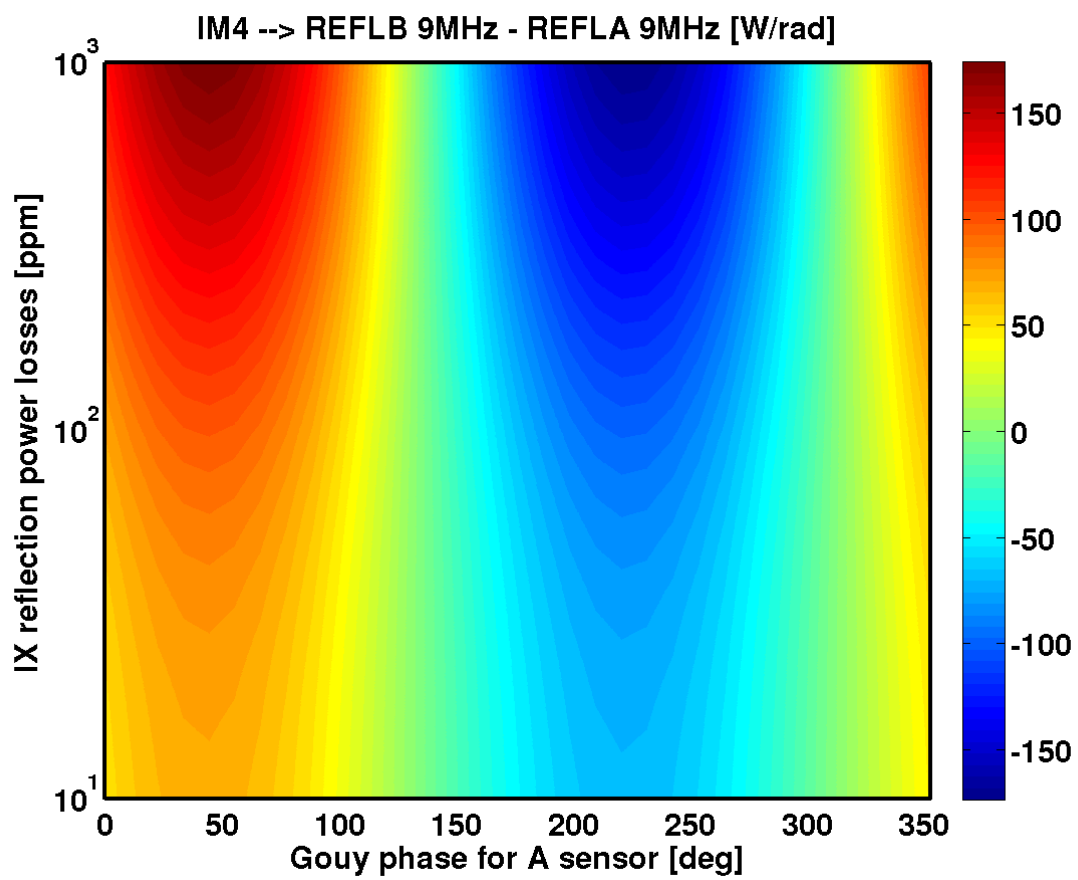


Figure 9: IM4 signal as a function of ITMX losses and Gouy phase sweep for Pitch excitation.

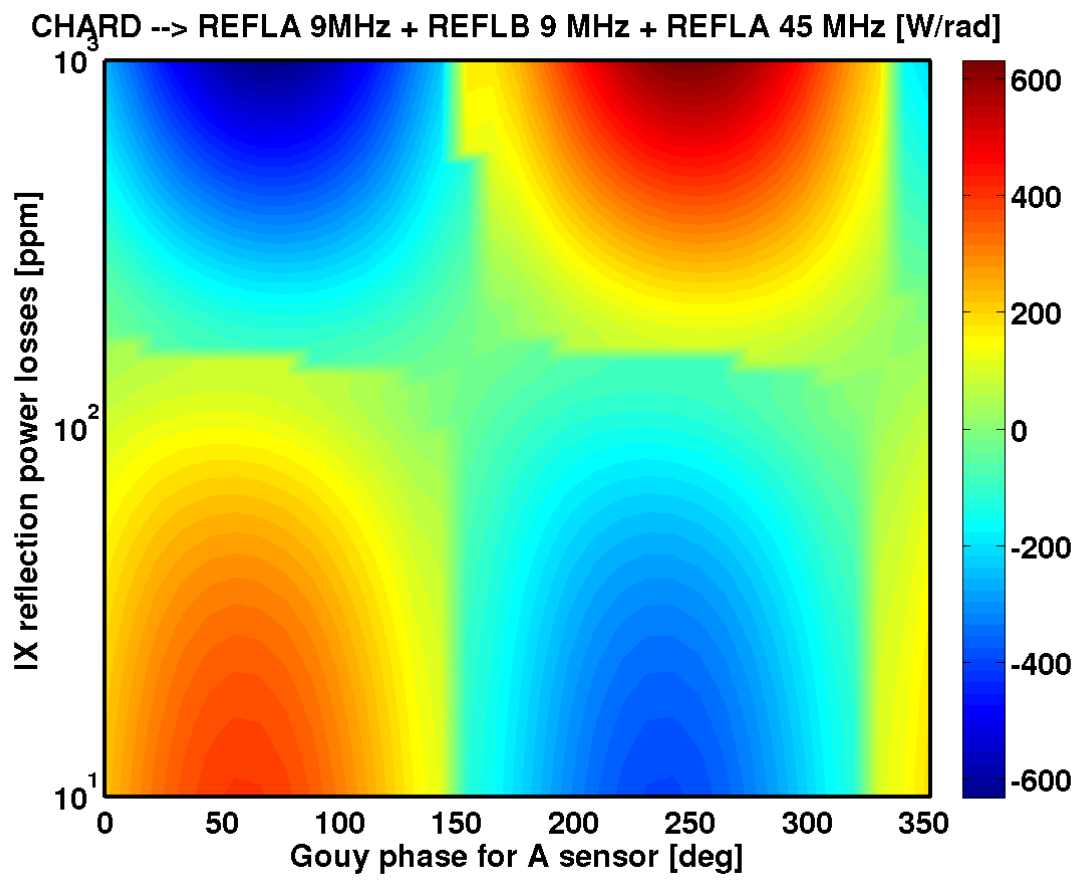


Figure 10: CHARD signal as a function of ITMX losses and Gouy phase sweep for Yaw excitation.

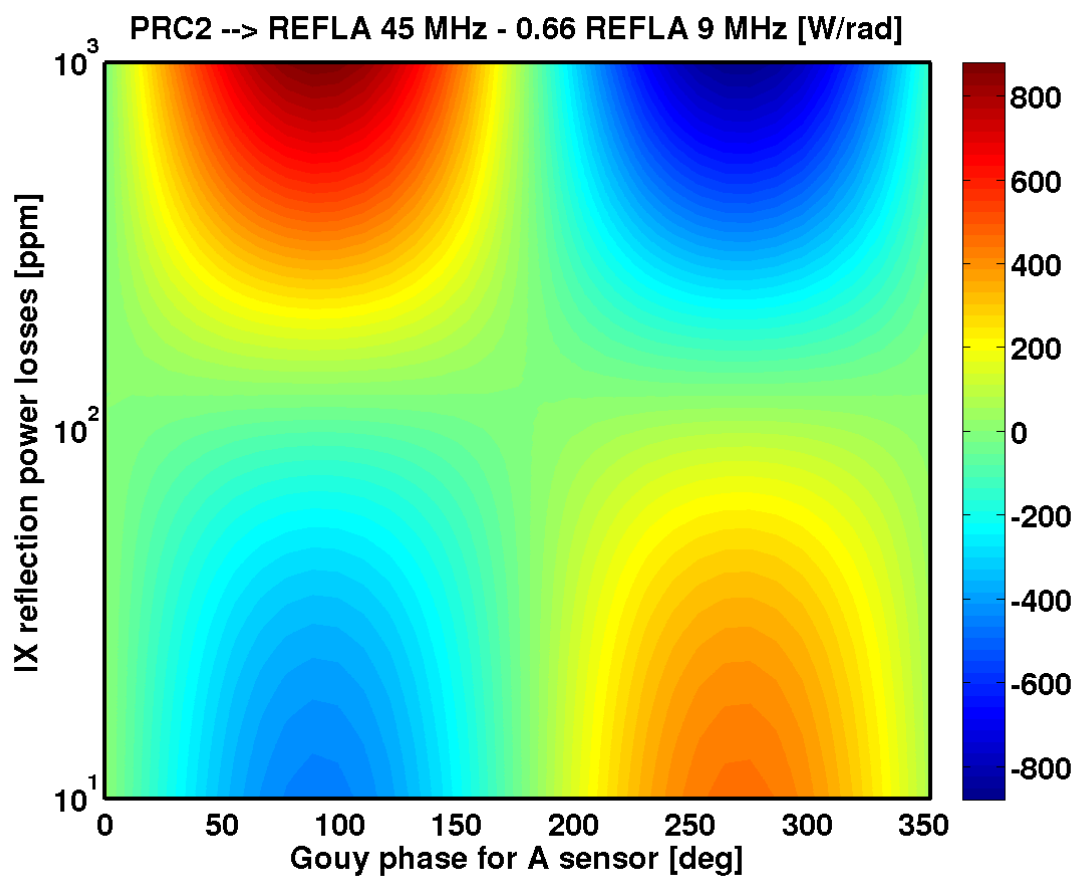


Figure 11: PRC2 signal as a function of ITMX losses and Gouy phase sweep for Yaw excitation.

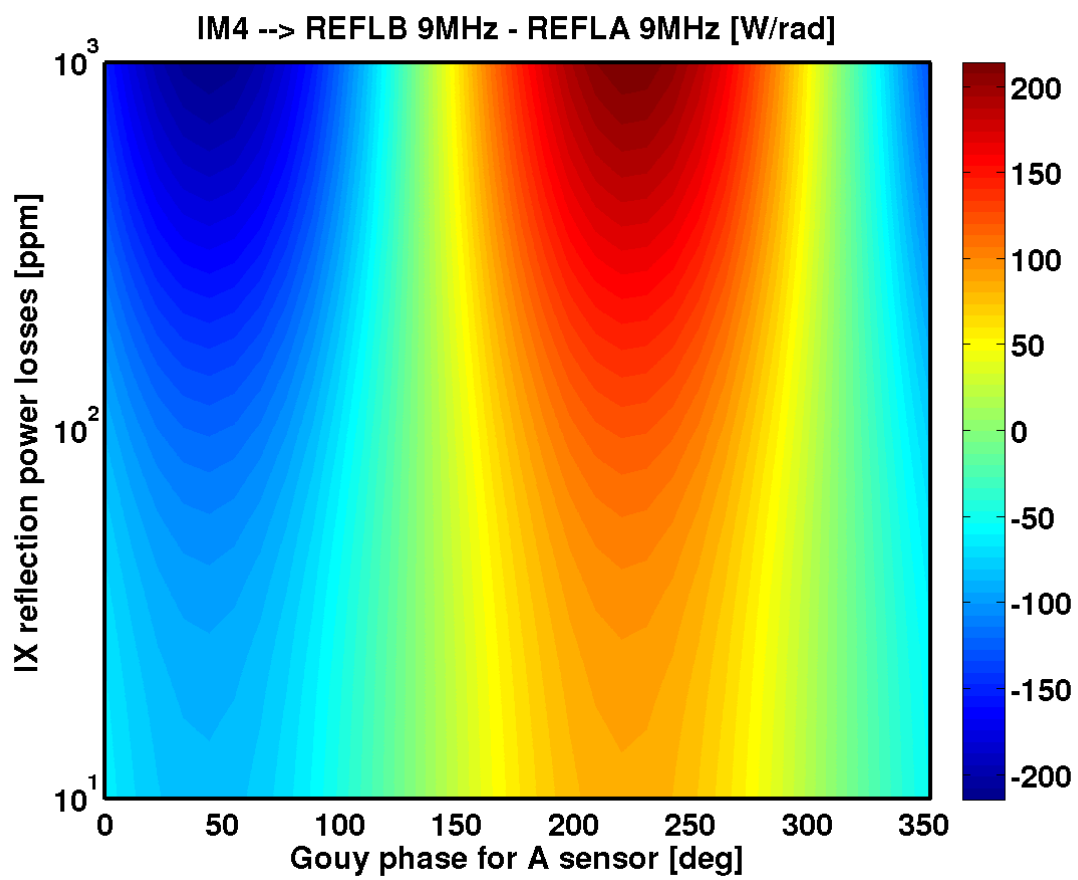


Figure 12: IM4 signal as a function of ITMX losses and Gouy phase sweep for Yaw excitation.

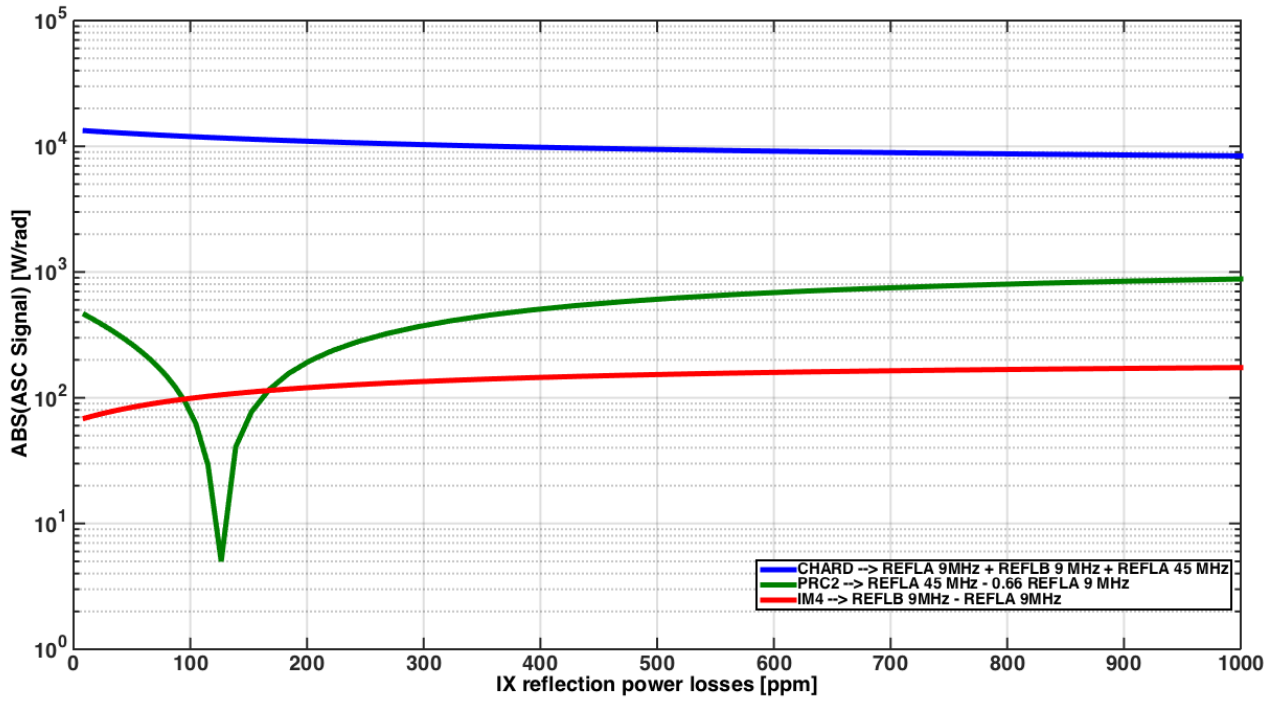


Figure 13: Absolute value of the ASC signals as a function of the power losses in ITMX at the Gouy phase that corresponds to their maximum amplitude (Pitch excitation).

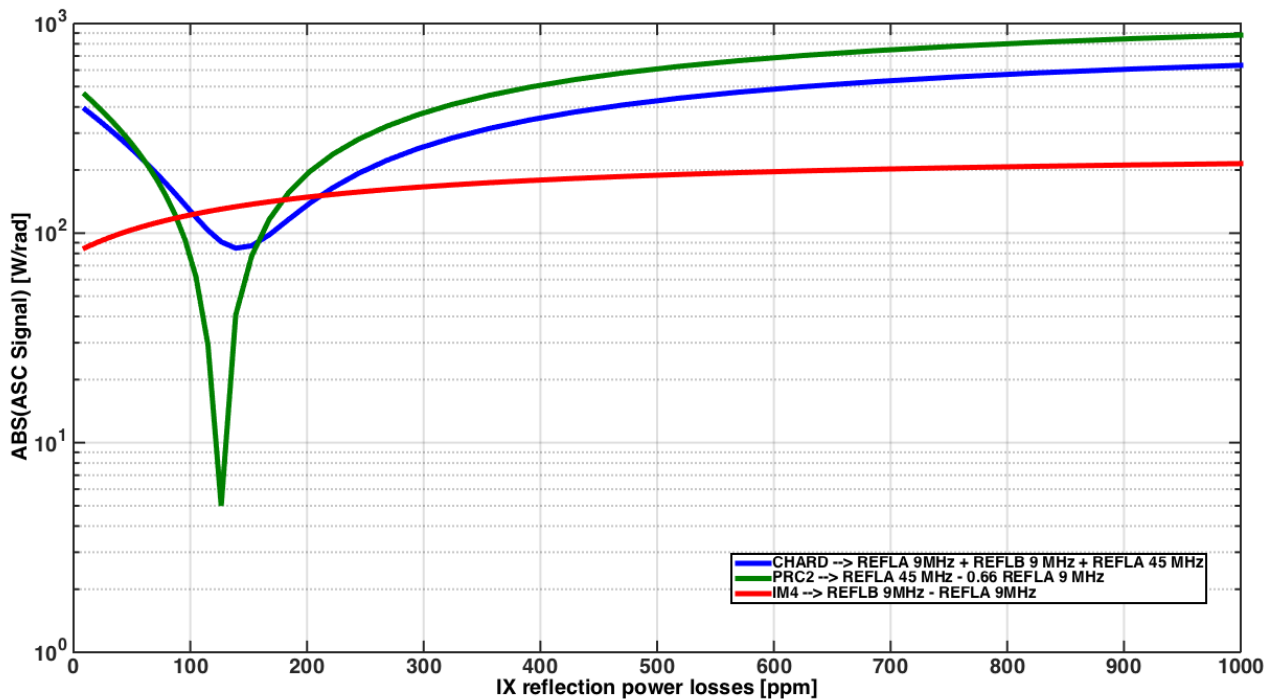


Figure 14: Absolute value of the ASC signals as a function of the power losses in ITMX at the Gouy phase that corresponds to their maximum amplitude (Yaw excitation).