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Effect of Mach Zehnder Residual Displacement Noise on the 40m Detuned RSE Interferometer

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ABSTRACT

The effect of the residual displacement noise existing in the Mach Zehnder (MZ) interferometer on the 40m Detuned Resonant Sideband Extraction (DRSE) interferometer is roughly estimated using the FINESSE simulation tool. The preliminary results suggest that we might have to suppress the current residual MZ noise further by increasing the servo gain of the MZ locking system in order to accomplish the aimed sensitivity of the 40m DRSE interferometer.

1. Introduction

Matt Evans pointed out in a 40m meeting that the residual displacement noise existing in the Mach Zehnder (MZ) interferometer, which is used to produce double modulation without producing the sidebands of the sidebands, might cause some serious excess noise for the Detuned Resonant Sideband Extraction (DRSE) interferometer. Here we show some preliminary simulation results for the effect of the MZ residual noise on the sensitivity of the 40m DRSE interferometer.

2. Mirror Motions in the Mach Zehnder Interferometer

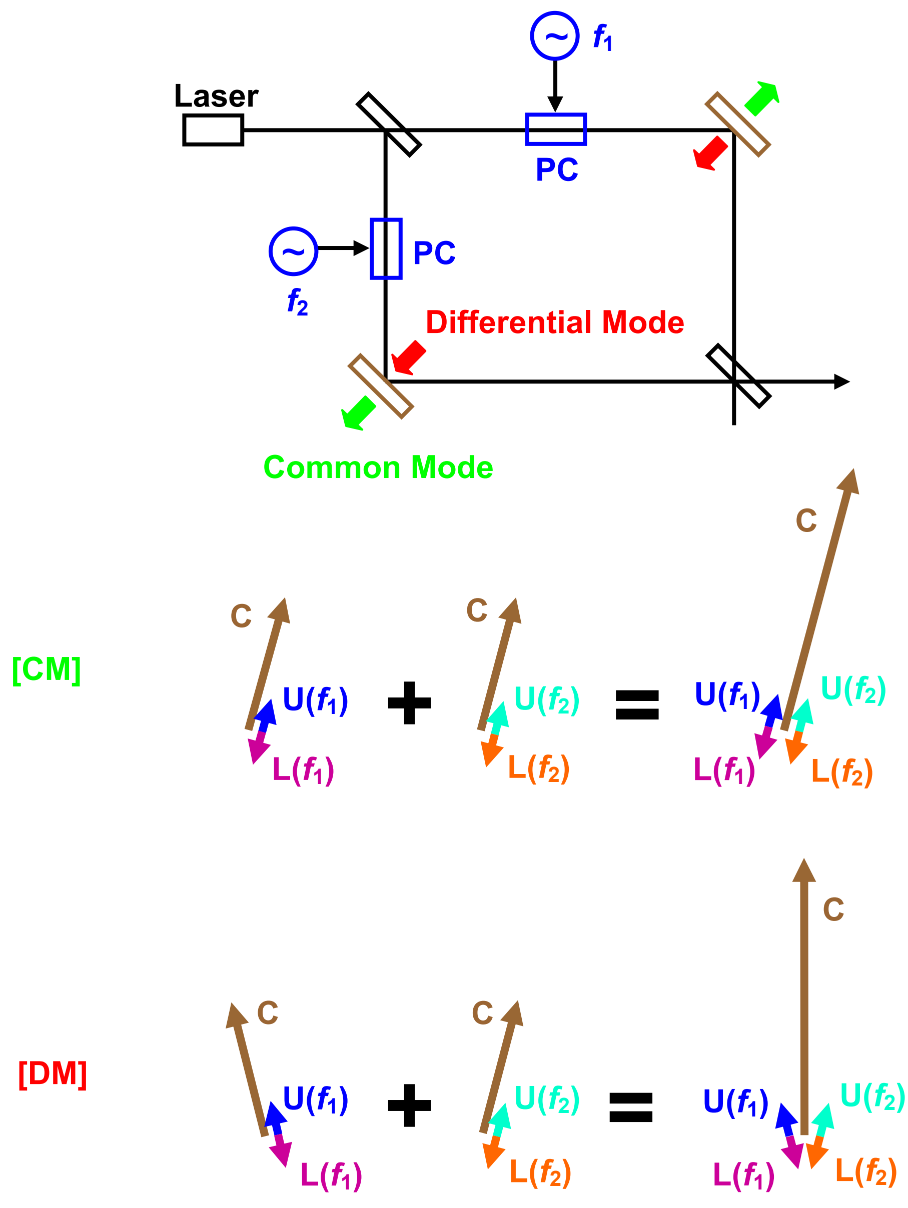

Fig. 1. Common mode and differential mode of the mirror motion in the MZ interferometer illustrated in the phasor diagram.

The motion of the two folding mirrors in the MZ interferometer (See Fig. 1) consists of two modes: the common mode and differential mode. The common-mode motion of the mirrors causes phase noise (thus frequency noise) of the light coming out of the MZ interferometer. This kind of noise would occur anyway even without the MZ interferometer, and the noise can be suppressed by the ordinary frequency stabilization system with the mode cleaner and then the common-mode arm length. Thus we do not deal with the common-mode motion in this report. On the other hand the differential-mode motion of the mirrors causes a relative phase variation between the carrier and the two sidebands. This is a new noise source that does not exist in the series-modulation configuration, and could be problematic. Of course the differential-mode motion of the mirrors is suppressed by the MZ locking system, thus we deal with the residual MZ noise to estimate to what extent the noise should be suppressed.

3. Direct Mechanism

In order to estimate the effect of the MZ residual motion on the 40m DRSE Interferometer we used the FINESSE simulation tool. As shown in Fig. 2, we calculated the transfer function from the MZ differential-mode motion to the demodulated output, V_{AP}, at the Asymmetric Port (AP) as well as the transfer function from the differential-mode arm length (L_-) to V_{AP}[1]. We then take the ratio of the two transfer functions to estimate the effect of the MZ residual motion in terms of L_-.

$$(\text{Effect of MZ motion in terms of } L_-)_{\text{Direct}} = \frac{(\text{Transfer Function from MZ motion to } V_{AP})}{(\text{Transfer Function from } L_- \text{ to } V_{AP})}$$

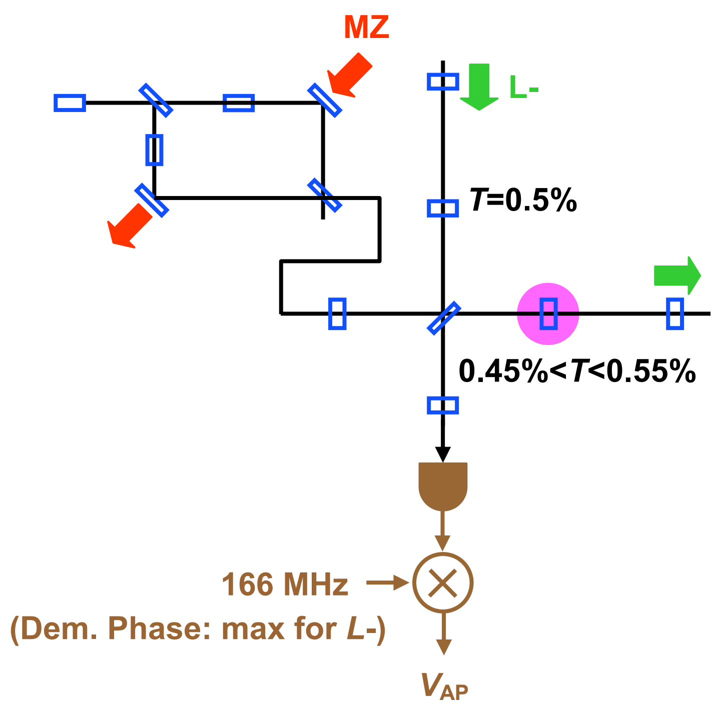

Fig. 2. Schematic diagram to estimate the effect of the MZ residual displacement noise with a direct mechanism.

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[1] In FINESSE the 'fsig' command should be used to shake the mirrors after the light is already phase-modulated at the RF frequency in order to phase-modulate both the carrier and the RF sidebands (thus to ensure the right result). This was pointed out by Rob Ward.

The simulation results are shown in Fig. 3 with the transmissivity, *T*, of one of the ITMs as a parameter. (*T* of the other ITM is fixed to be 0.5%.) It indicates that with a 10% error between *T* 's of the two ITMs the unit MZ motion corresponds to approximately 10^{-6} L_- motion. The results are qualitatively consistent with the intuitive understanding that the effect should be zero at DC when there is no imbalances in *T* (thus no carrier at AP), and that the effect is larger with the bigger imbalances.

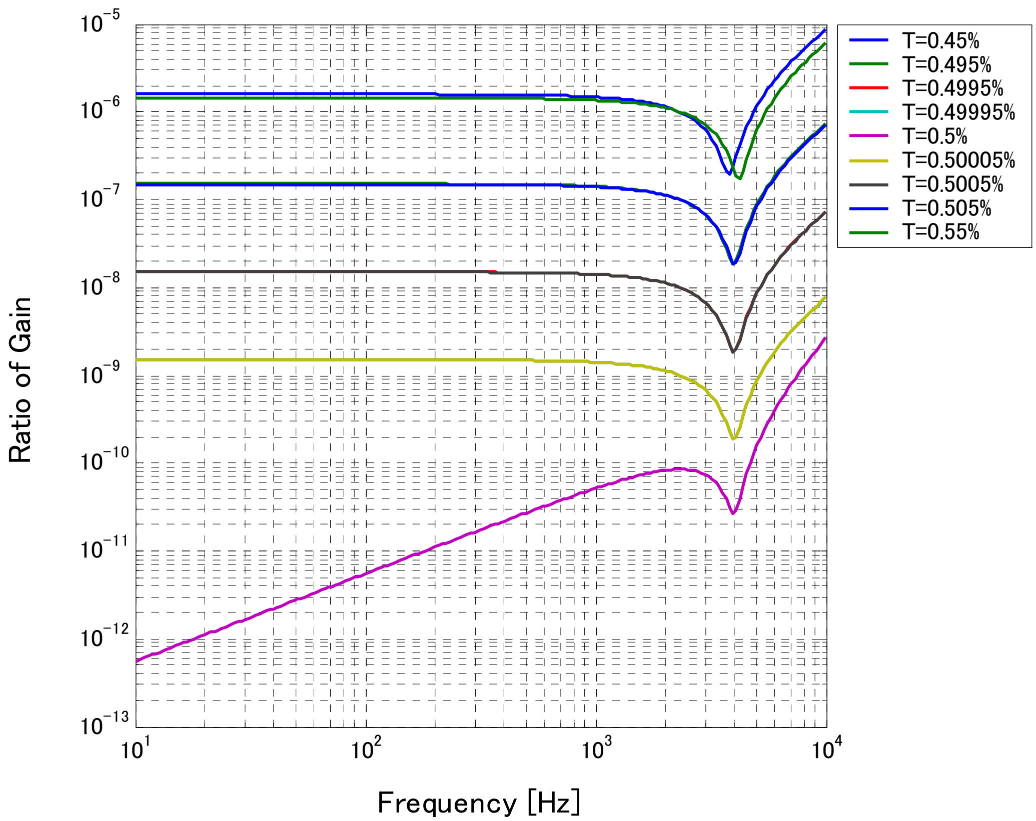

Fig. 3. Effect of the MZ residual motion in terms of L_- with a direct mechanism.

4. Mechanism via Frequency Stabilization System

Another mechanism which should be considered is the one via frequency stabilization system. The MZ residual motion appears in the demodulated signal, V_{SP}, at the Symmetric Port (SP), which is imposed on the frequency of the light by the frequency stabilization system[2]. This frequency variation of the light appears in the demodulated signal, V_{AP}, at AP and mimics the L_- signal. Therefore, the effect of the MZ residual noise in terms of L_- is the product of the imposition of the MZ motion on frequency of the light and the effect of the frequency variation in terms of L_-. In the actual simulation we used the motion of the steering mirror placed after the Mach Zehnder interferometer, which causes phase variation of the light (thus frequency variation of the light) instead of the frequency of the laser light[3]. Therefore the previous statement is replaced by the following one. The effect of the MZ residual noise in

[2] Here we assume that the frequency stabilization gain is so high that the MZ residual motion is completely imposed on the frequency of the light. Otherwise the effect of this noise will be smaller.

[3] Again this is because in FINESSE the "fsig" command should be used after the RF modulation to ensure the right results.

terms of L_- is the product of the imposition of the MZ motion on the motion of the steering mirror (SM) after MZ and the effect of the SM motion in terms of L_-.

$$(\text{Effect of MZ in terms of } L_-)_{\text{Freq.Stab.}}$$
$$= (\text{Imposition of MZ motion on SM motion}) \times (\text{Effect of SM motion in terms of } L_-)$$

The imposition of the MZ residual motion on the SM motion is calculated by dividing the transfer function from the MZ residual motion to V_{SP} by the transfer function from the SM motion to V_{SP} (See Fig. 4).

$$(\text{Imposition of the MZ motion on PN}) = \frac{(\text{Transfer Function from MZ to } V_{SP})}{(\text{Transfer Function from PN to } V_{SP})}$$

The effect of the SM motion in terms of L_- is calculated by dividing the transfer function from the SM motion to V_{AP} by the transfer function from L_- to V_{AP}.

$$(\text{Effect of SM motion in terms of } L_-) = \frac{(\text{Transfer Function from SM motion to } V_{AP})}{(\text{Transfer Function from } L_- \text{ to } V_{AP})}$$

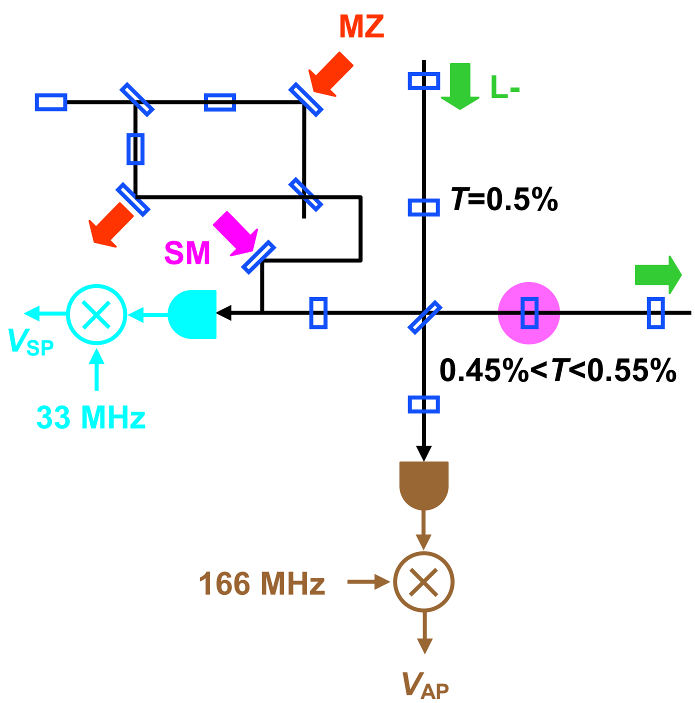

Fig. 4. Schematic diagram to estimate the effect of the MZ residual displacement noise with a mechanism via frequency stabilization.

The simulation results are shown in Fig. 5 with T of one of the ITMs as a parameter. (T of the other ITM is fixed to be 0.5%.) It indicates that with a 10% error between T 's of the two ITMs, the unit MZ motion causes approximately 10^{-7} L_- mimic motion. This is smaller than the effect with a direct mechanism.

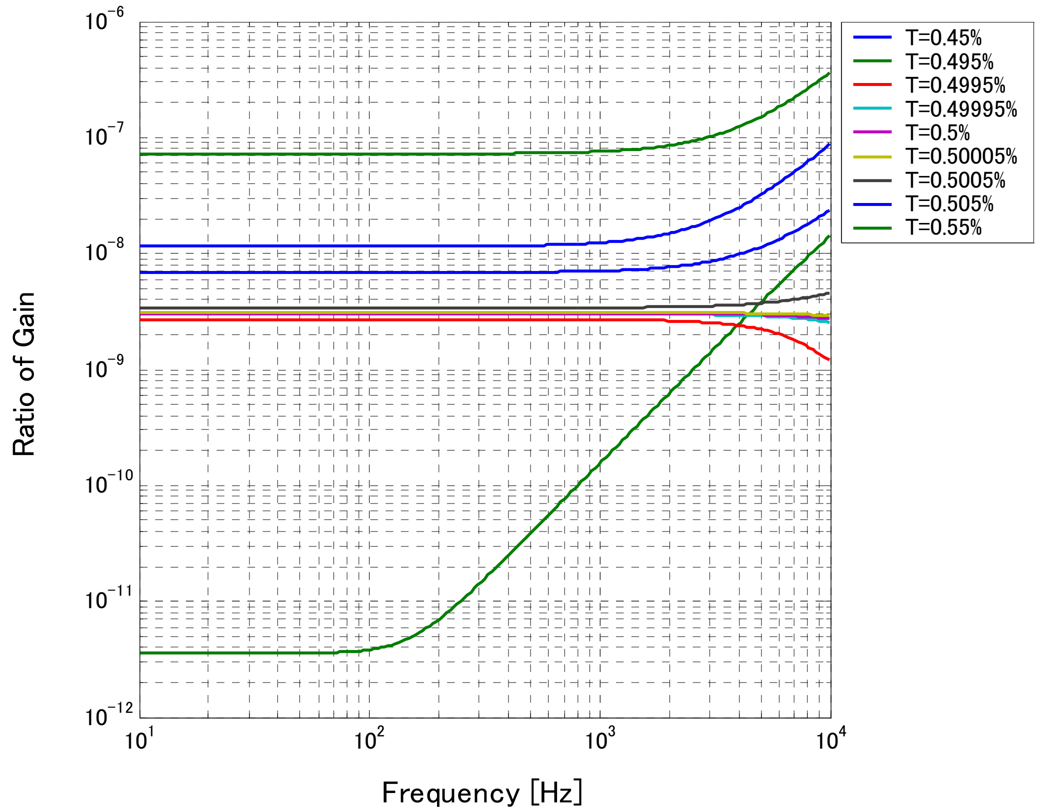

Fig. 5. Effect of the MZ residual noise in terms of L_- with a mechanism via frequency stabilization.

5. Measured MZ Residual Noise

The MZ residual noise was measured (See Fig. 6). It has a rugged structure and some peaks exceed 10^{-12} m/rHz. With an imbalance of *T* of 10%, this could produce 10^{-18} m/rHz, which is larger than the target sensitivity of the 40m DRSE interferometer.

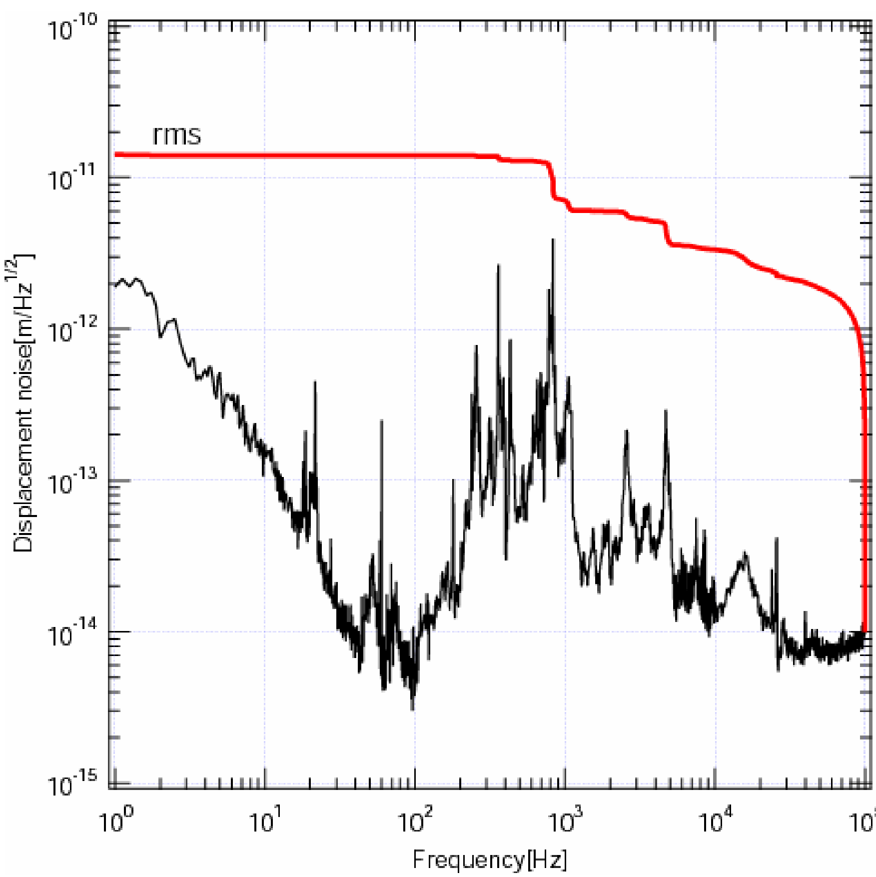

Fig. 6. Measured MZ residual noise.

6. Remedy

The MZ residual noise can be drastically and relatively easily improved by implementing a phase correcting Pockels cell to enhance the bandwidth of the servo system, thus to increase the loop gain. (Currently only a high-speed PZT is used as an actuator.)

7. More Investigations

Some more investigations are necessary to ensure that the MZ residual noise is not a fatal problem. Those include:

(1) Effect with various kinds of imbalances of the interferometer (e.g. Loss of the mirrors, etc.)
(2) Effect with various kinds of imperfections of the system (e.g. demodulation phase, etc.)
(3) Effect with a practical contrast defect
(4) Effect by the mode cleaner servo
(5) Effect by the control of the other degrees of freedoms
(6) Effect on the DC readout scheme