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Proposal for Recombination and Recycling Experiments with Unbalanced Interferometers

M. Regehr, F. Raab, and S. Whitcomb

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1 Introduction

One of the open questions concerning the design of a recombined, recycled interferometer is the method of modulation to be used. In an interferometer with identical arms, destructive interference at the antisymmetric port for the laser light (carrier) implies that there will also be destructive interference for any modulation sidebands added to the laser light before the light enters the interferometer. Such sidebands are necessary to achieve shot-noise limited detection of the light from the antisymmetric port when the interferomenter is distorted by a gravitational wave. A proposed solution is to make the two arms of the interferometer different, either by making one of the cavities longer than the other (the "unbalanced cavity" scheme) or by placing one of the cavities farther from the beamsplitter than the other (the "unbalanced Michelson" scheme). The unbalance in length, either in a cavity or in the Michelson interferometer, is arranged to be a half-integral number of the laser light wavelength, so that the carrier light still interferes destructively at the anti-symmetric port of the interferometer. The sidebands produced by the modulation, however, in general no longer interfere destructively at the anti-symmetric port since their wavelength is different.

To operate a recombined, recycled interferometer, it is necessary to control the positions of the cavity mirrors, the beamsplitter, and the recycling mirror in order to simultaneously maintain arm cavity resonance, recycling cavity resonance, and a dark fringe at the antisymmetric port. Signals corresponding to the four degrees of freedom in which the interferometer can deviate from resonance can in principle be derived in both schemes by sampling the light at several points in the interferometer, demodulating the corresponding photocurrents, and taking appropriate linear combinations of the demodulator outputs. Several uncertainties remain about the feasibility of this approach, most of which, it is hoped, will be adequately addressed by the proposed series of table-top experiments.

2 Numerical Modelling

A computer program has been written which calculates the effect on the demodulated signals of low-frequency (well below the lowest characteristic frequency of the interferometer) deviations from resonance. Another program calculates the shot noise to be expected at each output. Work on a program which simulates the response of the servo system, and on a program capable of calculating the general high-frequency behaviour of the interferometer, has been initiated and will continue. The low-frequency model predicts that all of the demodulator outputs will be much more sensitive to the lengths of the arm cavities than to the lengths in the recycling cavity. To control the mirrors affecting the recycling cavity lengths, such as the beamsplitter and the recycling mirror, one will have to extract signals depending mostly on the lengths in the recycling cavity by taking linear combinations of the signals from several points in the interferometer. Some simple analysis shows that inaccuracies in obtaining these linear combinations might result in servo instability.

3 Objectives of Experiments

The experimental objectives (derived in consultation with the ICD Modulation and Topology Group) are:

- Verification of the predictions of the low-frequency model, including sensitivity of the demodulator outputs to mirror motions and including light levels and modulation levels within the interferometer,
- Verification of the predictions of a high-frequency model which should be producing results concurrently,
- Verification of the predictions of a servo-system model still to be completed, including ability to suppress disturbances, the propagation of disturbances to different parts of the system, and the sensitivity to variations of parameters in the system (such as the coefficients in the linear combinations of demodulator outputs),

- Evaluation of the proposed method of lock-acquisition,
- Verification that there are no important and currently overlooked difficulties with the proposed schemes, or resolution of any such difficulties as they are found.

4 Experiments

The experimental plan consists of three phases. The initial phase will relate to evaluation of components and environmental factors affecting the fixed mass interferometer experiments. The second phase will experimentally evaluate an unbalanced Michelson configuration. A third phase to experimentally evaluate an unbalanced cavity configuration will follow, pending review of the unbalanced Michelson configuration results.

In the first phase, two cavities will be set up on a table, the laser frequency will be locked to one cavity and the second cavity will be locked to the laser frequency. The actuator controlling the length of the second cavity will be a two-layer piezo stack. The discrimant indicating the deviation from resonance of the second cavity will be derived in two different ways: by RF-reflection locking, and by dithering the cavity length at about 70 kHz and demodulating the transmitted light at the same frequency. The purpose of this first phase is to determine whether the piezo stack has sufficient range to compensate for whatever disturbances within the lab may be affecting the lengths of the two cavities differently, to verify that the transmitted-light discriminant performs as expected, and to measure the rate of increase of the mirror losses (the mirrors will be exposed to the air in one of the cleaner rooms of the OTF).

In the second phase, a recycled unbalanced-Michelson interferometer, with 6 m arm cavities and a 6 m recycling cavity will be constructed. The laser frequency will still be stabilized by locking it to a 3 m reference cavity on the same table as the interferometer. The interferometer will initially be locked using dithering of the cavity end mirrors, the beamsplitter and the recycling mirror, and monitoring of the cavity transmitted light, the light reflected from the recycling mirror, and the light at the antisymmetric port. The laser light will be phase modulated and the linear combinations of RF demodulator outputs tuned to obtain signals that depend only on the parameters which they will be controlling. Finally the control of the interferometer will be switched over to the RF detection system. The experiments to be performed with this system include:

- Measurement of the sensitivity of the demodulator outputs to low- and high- frequency motion of the mirrors for several different amounts of arm-unbalance

- Testing of the sensitivity of the control system to small changes in the linear combinations of the demodulator outputs

- Measurement of the closed-loop-gain matrix by summing in a disturbance at some point and measuring its suppression and its propagation to other parts of the system

- Measurement of interferometer contrast and cavity visibility

- Measurement of light levels and modulation levels within the interferometer

Figure 1 shows the proposed layout of optical components for phase 1 and Figure 2 shows the proposed servo topology using the RF detection system.

The third phase consists of the construction and characterization of recycled unbalanced cavity interferometer, with 12 m arm cavities and a 12 m recycling cavity. All of the steps of the second phase will be repeated for this other configuration. The main expected difference in the operation of this configuration is that it will probably be necessary to introduce a second phase modulation to the laser light at another modulation frequency to be able to extract the relevant signals from the interferometer, because with the single 12 MHz modulation, all of the demodulator outputs are highly insensitive to motion of the recycling mirror. Figure 3 shows the proposed layout of optical components for phase 2.

5 Update: Current Status

As of this revision of this proposal, phase 1 has been terminated and phase 2 is in progress. The piezo stacks have been found to have adequate range and the transmitted light discrimant performs as expected. A clean-air-purged table cover has been installed to reduce the previously large effect of dust and air currents on the resonant cavities. Evaluation of the rate of increase of mirror losses has been postponed. The hardware for phase 2 is now virtually complete.

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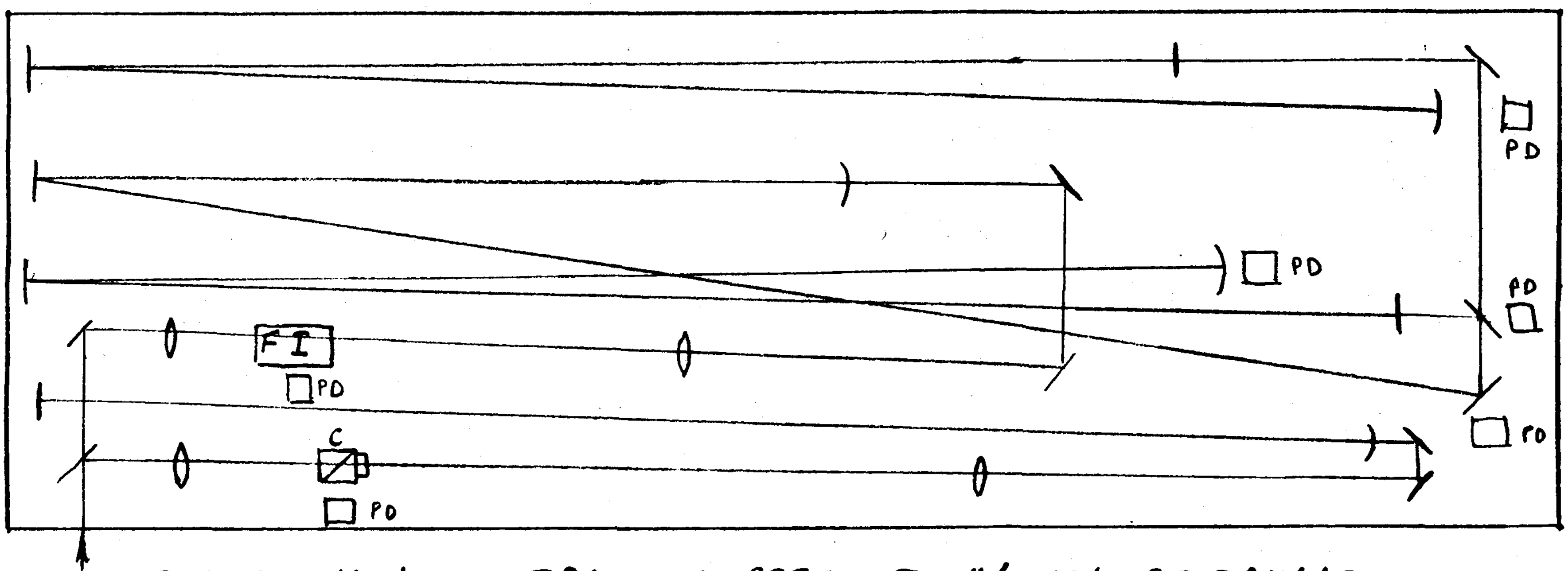
FIGURE 1: OPTICAL LAYOUT, PHASE 2



SCALE 16:1 FRAME REPRESENTS 4'x12' RECTANGLE

LEGEND

☐ PD	PHOTODIODE
C	CIRCULATOR
FI	FARADAY ISOLATOR

FIGURE 2: Servo Topology (Phase 2)

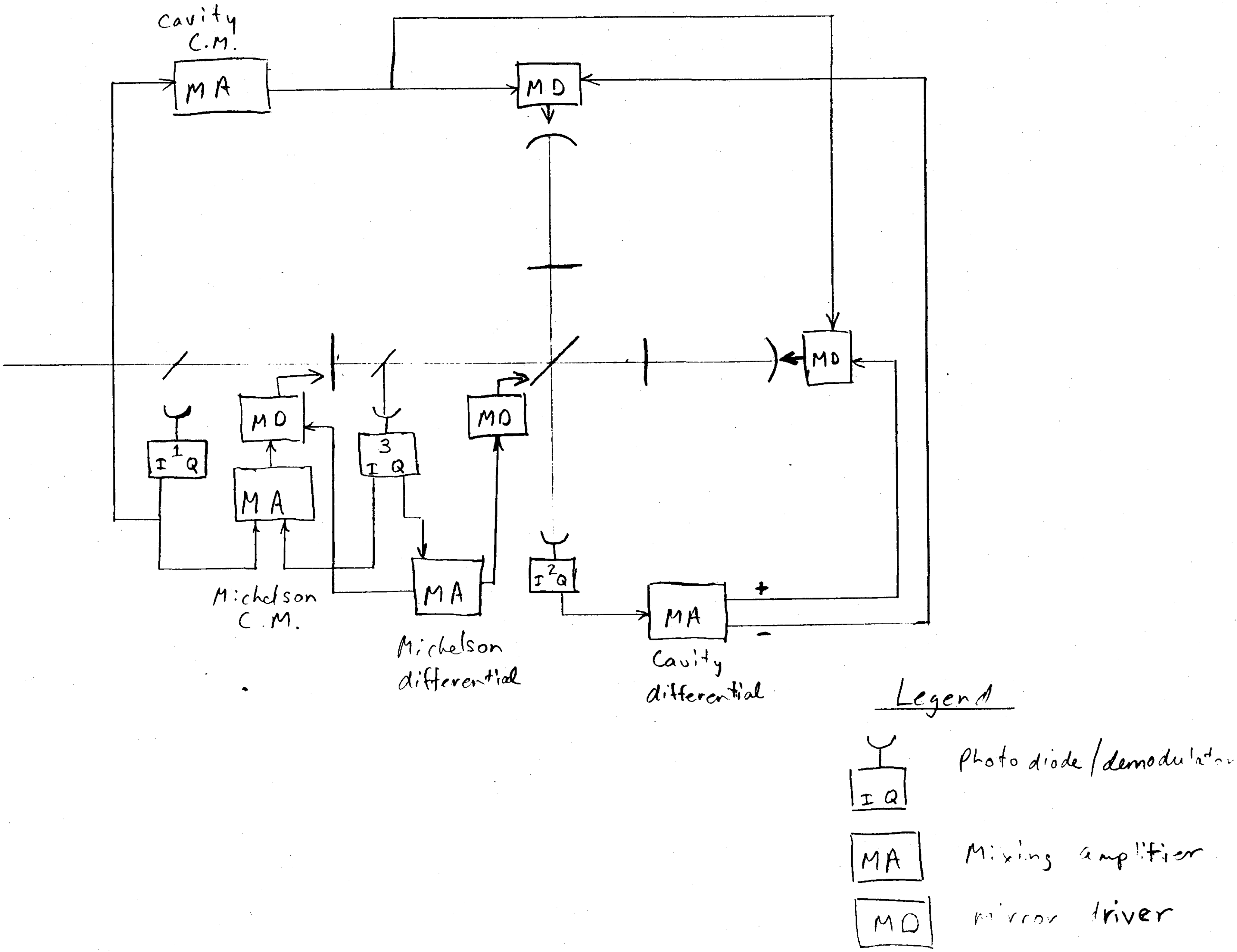
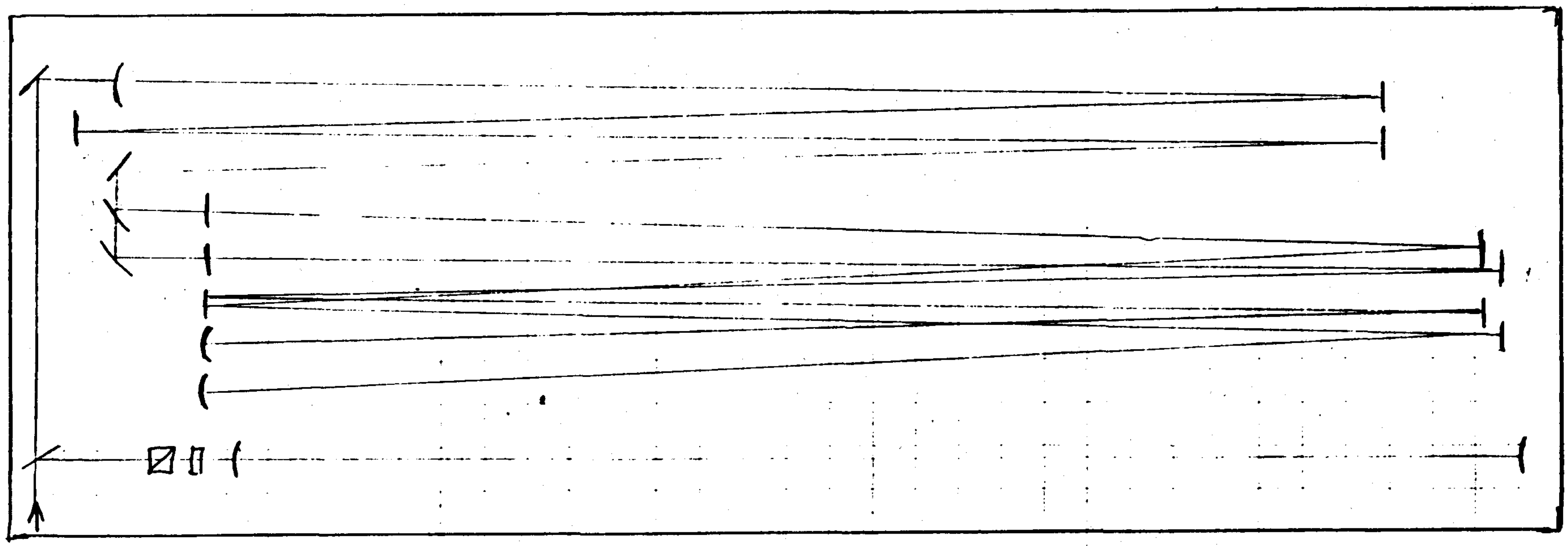


FIGURE 3 : OPTICAL LAYOUT, PHASE 3



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