# Review of 12 m Mode Cleaner Task

Presented by Alex Abramovici, April 21 1995

LIGO people who contributed:

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Boude Moore
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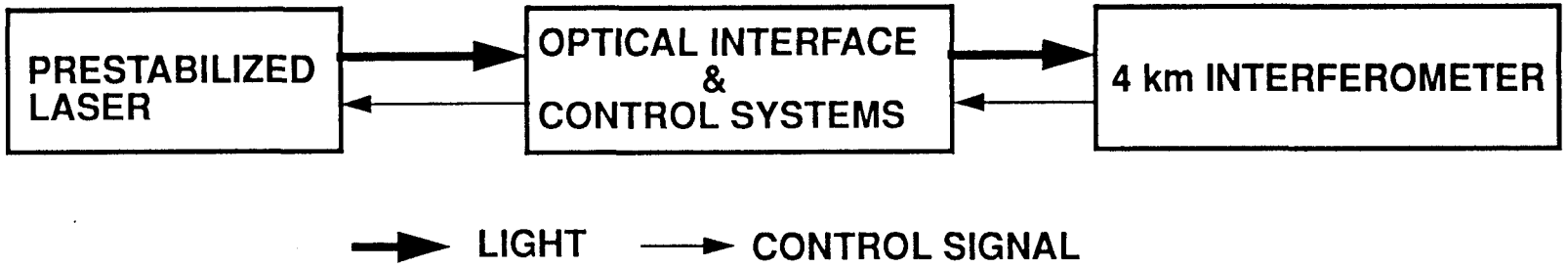
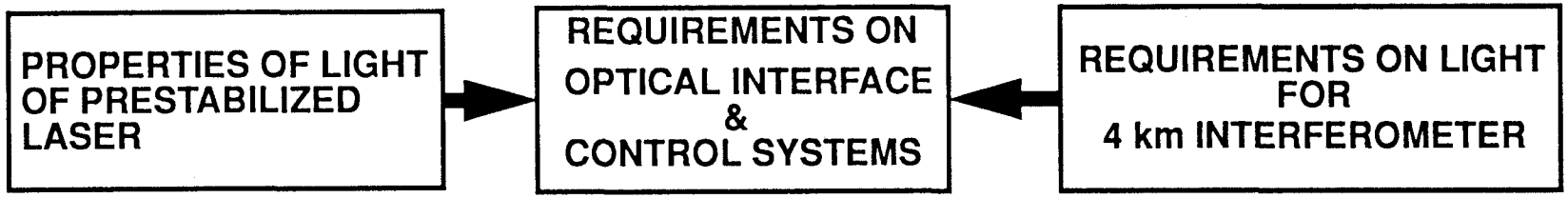
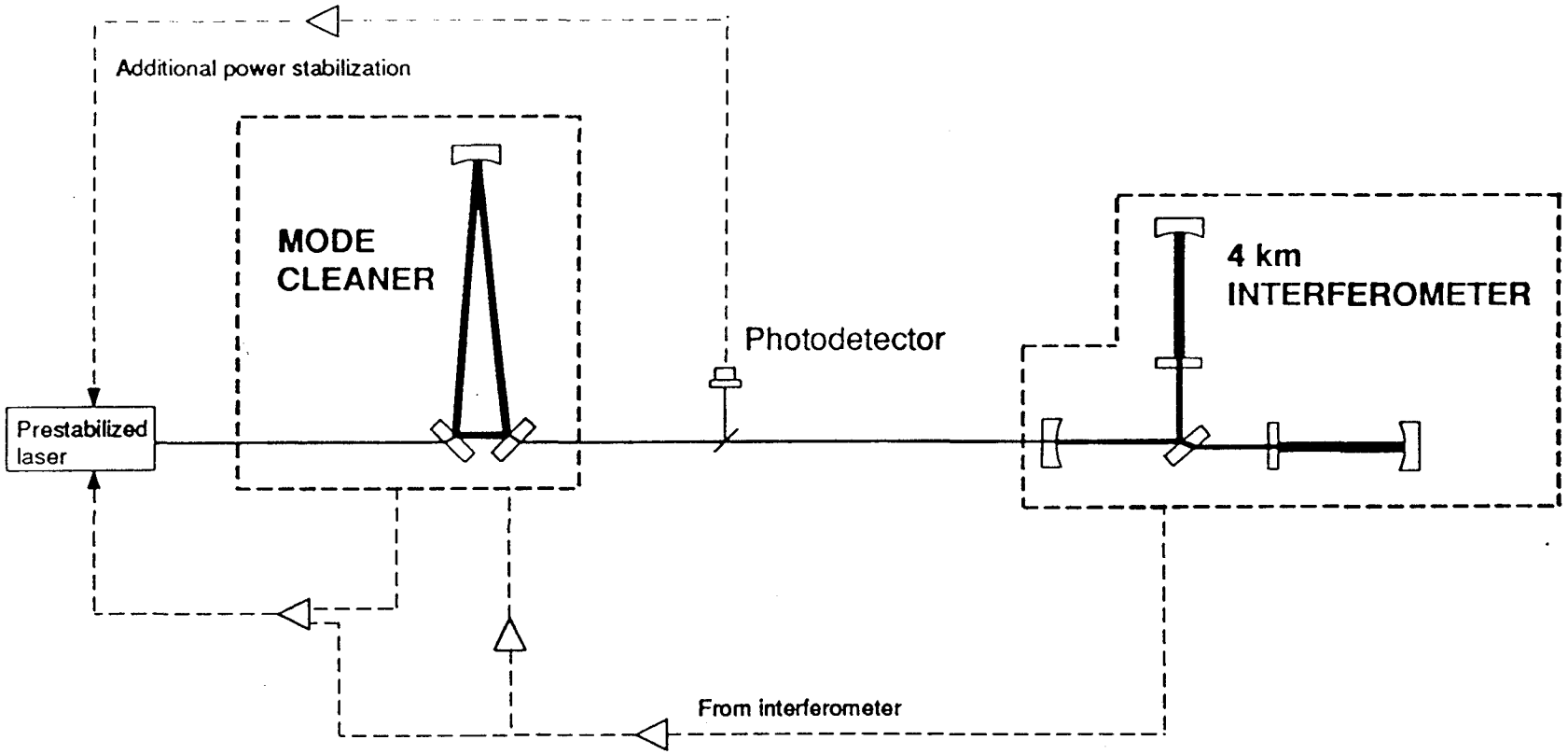



## REQUIREMENT FLOW CHART



# LIGO INPUT OPTICS



## Goals:

- **Primary**: design, build and test a prototype mode cleaner based on, and answering to LIGO requirements.
- **Secondary**: the prototype mode cleaner should be suitable for testing in the 40 m lab.

## Scope:

- Essential optical, mechanical, and feedback control characteristics of LIGO mode cleaner should be represented in the prototype.
- Mode cleaner testing to be carried out within the limitations imposed by the location of the lab and the existing equipment.
- Build the mode cleaner with minimum expense in the vacuum equipment area.
- Establish and adhere to vacuum cleanliness standards.

# Mode Cleaner Program Contents

- Systems Design

    1. Optical configuration
    2. Mirror parameters: transmission, shape, size
    3. Shot noise limit
    4. Seismic isolation requirements
    5. Feedback control system requirements:

        - Frequency servo
        - Mirror damping and pointing control servo

- Development of 2nd generation suspension and control system (OSEM control system) for mirrors, based on 40 m lab experience.
- Design and construction of new frequency servo, for locking the prestabilized laser to the mode cleaner.
- Design and construction of dedicated 3-layer, 20 kg/layer stacks, using mixed RTV-Viton spring configuration.
- Establishment of a vacuum cleanliness standard.
- Construction of a minimum cost vacuum system

# Mode Cleaner Design Requirements

1. Noise suppression, with prestabilized laser (at 100 Hz):

   • Frequency noise suppression factor: $1.4 \times 10^6$, when control signals originating with the 4 km interferometer are used

   • Beam jitter suppression factor: 75

   • Passive filtering in time domain: as high as possible

2. Power at interferometer input: >2 W

3. Minimum number of components after mode cleaner:

   • Ring cavity to avoid surfaces perpendicular to the beam

   • Ability to transmit 12 MHz phase modulation sidebands

4. Ability to withstand prevailing intensity levels

# Mode Cleaner Design Parameters

| | Parameter | Value |
|---|---|---|
| 1. | MC cavity | Ring-type, 3 mirrors |
| 2. | MC length | 12.165 m |
| 3. | I/O mirror transmission | 2,000 ppm |
| 4. | Mirror size | 3" DIA, 0.5" thick |
| 5. | Mirror curvatures | 17 m/Flat/Flat |
| 6. | Modulation frequency | 12.33 MHz |
| 7. | MC servo bandwidth | 500 kHz |
| 8. | Mirror pointing control | AC |
| 9. | Mirror damping at | Pendulum frequency |
| 10. | Seismic isolation requirement | For $10^{-18}$ Hz/Hz$^{1/2}$ at 100 Hz |

# Expected Mode Cleaner Performance

| | Performance indicator | Level |
|---|---|---|
| 1. | Shot noise limited frequency noise | $10^{-4}$ Hz/Hz$^{1/2}$ |
| 2. | Cavity pole | 4 kHz |
| 3. | Beam jitter suppression factor | ~800 |
| 4. | Input power before onset of heating effects | 3.3 W |
| 5. | Transmission | >65% |

# MIRROR SUSPENSION AND CONTROL

AA, 7 May 1991

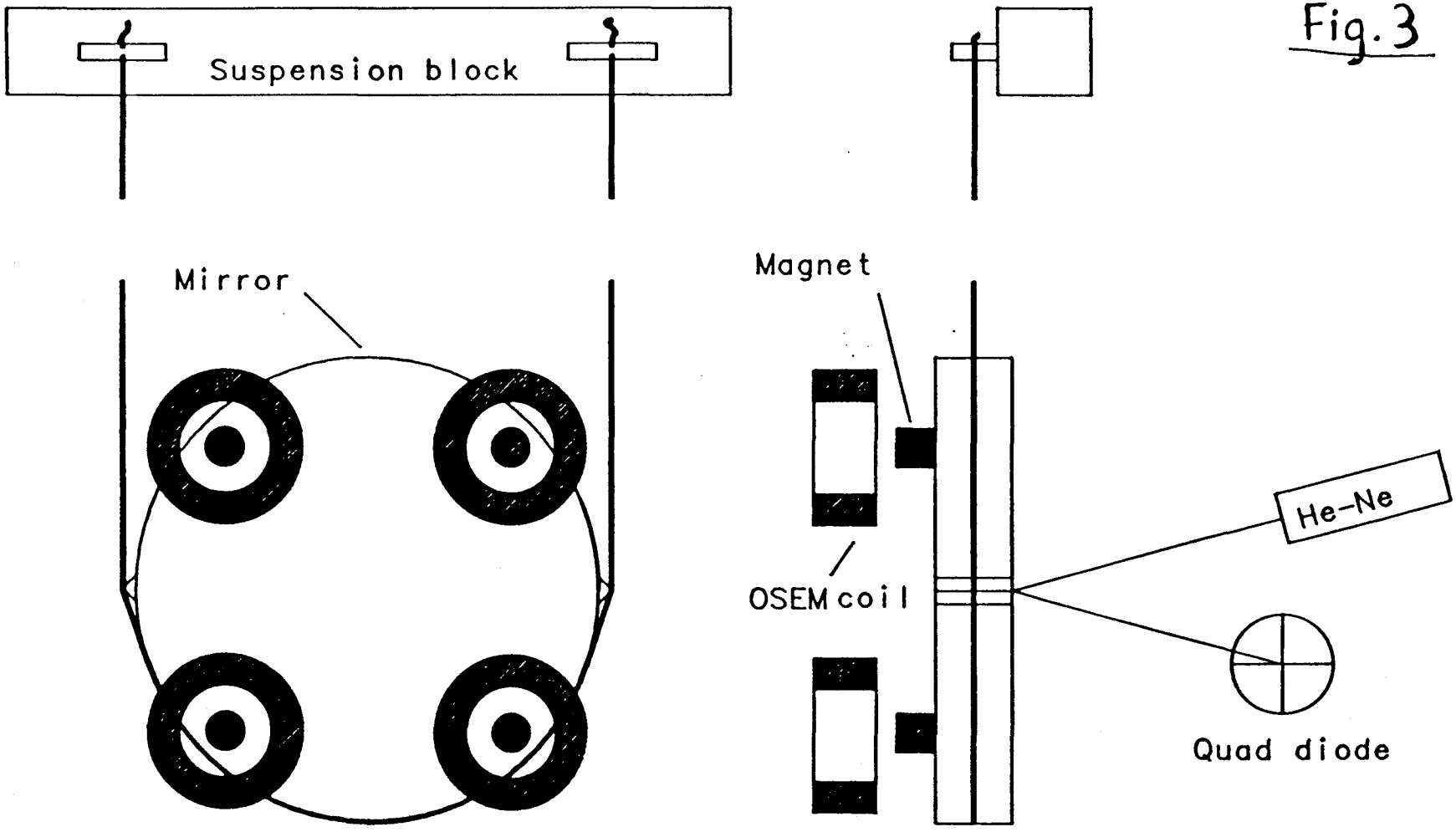
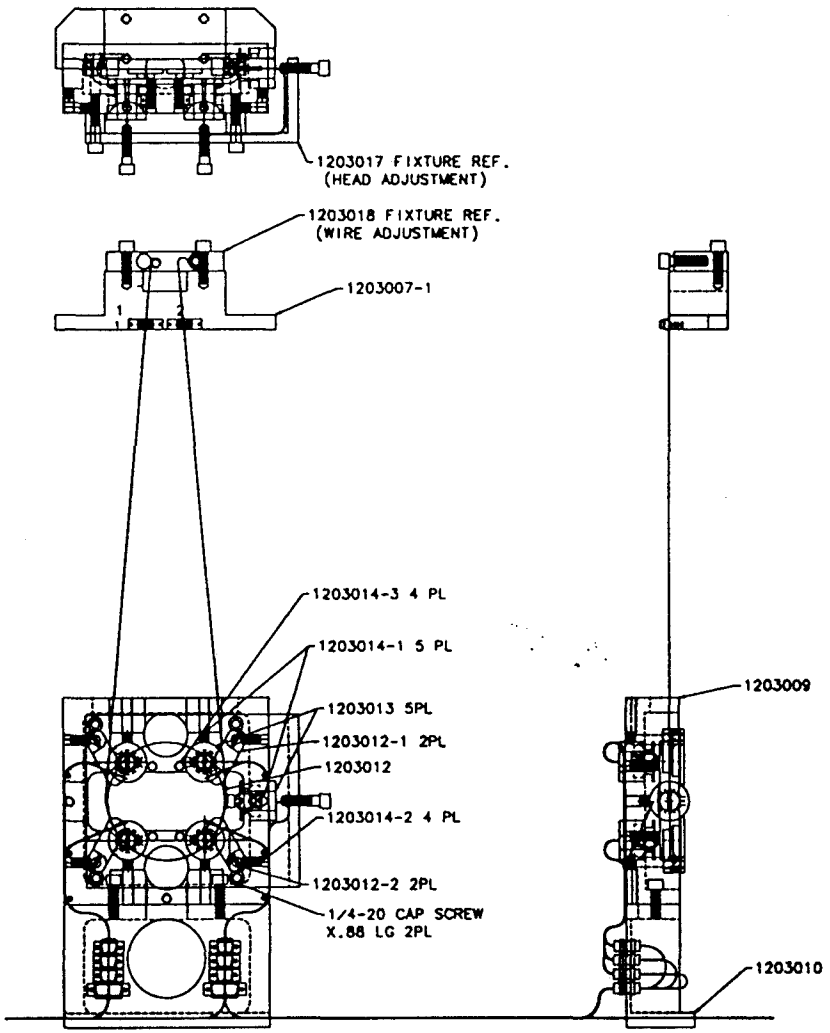



Fig. 3




LIGO PROJECT

OSEM ASSEMBLY
(WITH FIXTURES)

1203008

EDITION: 02-01-92

AA, 10 MAY 1991

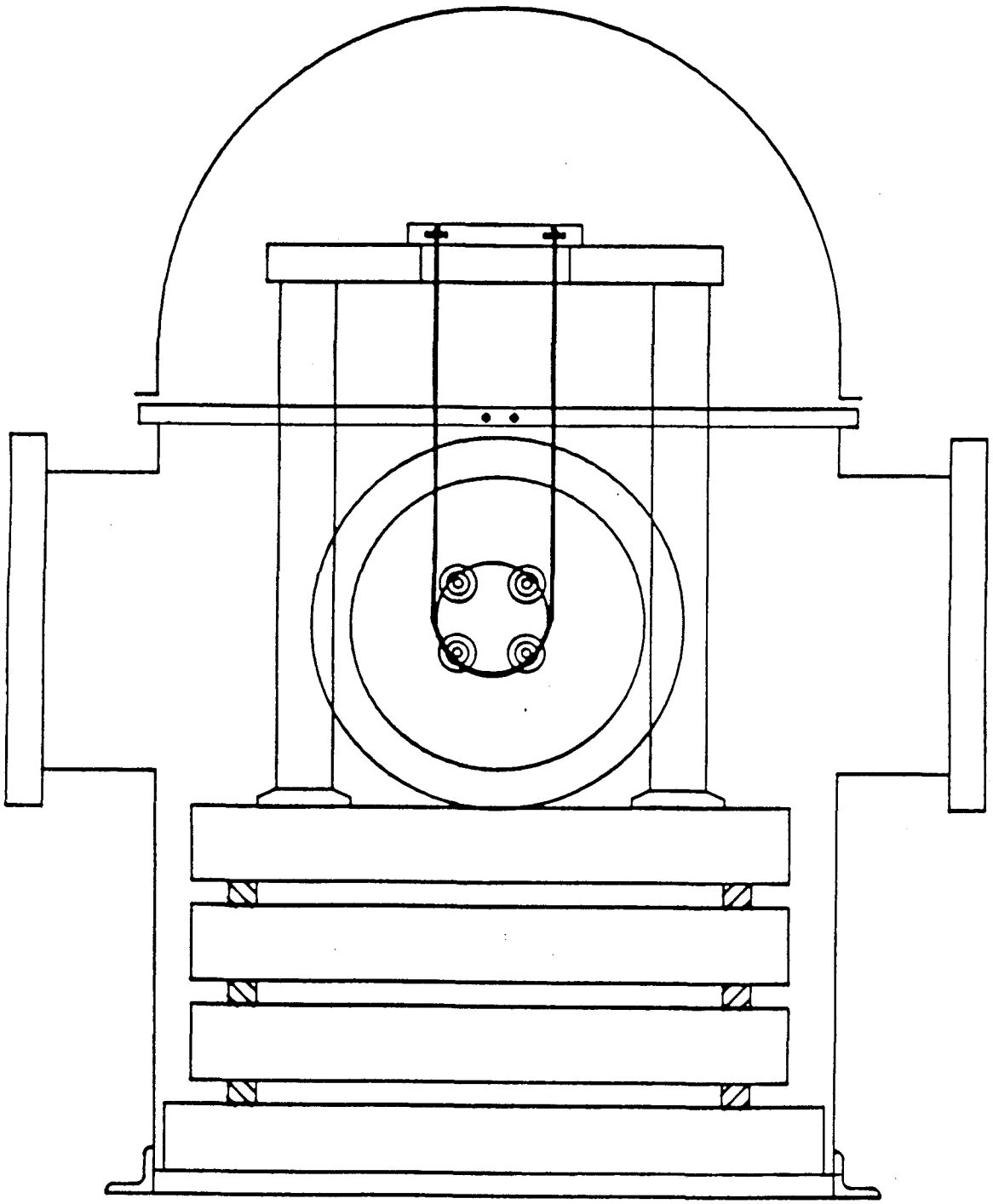
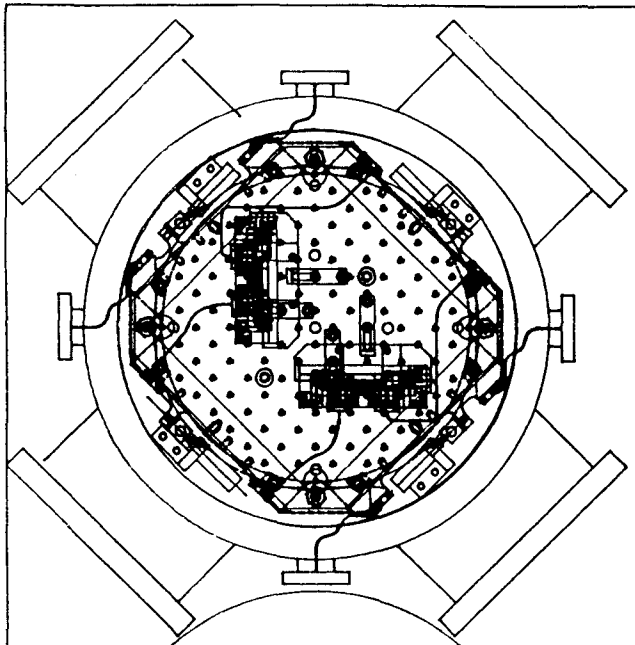
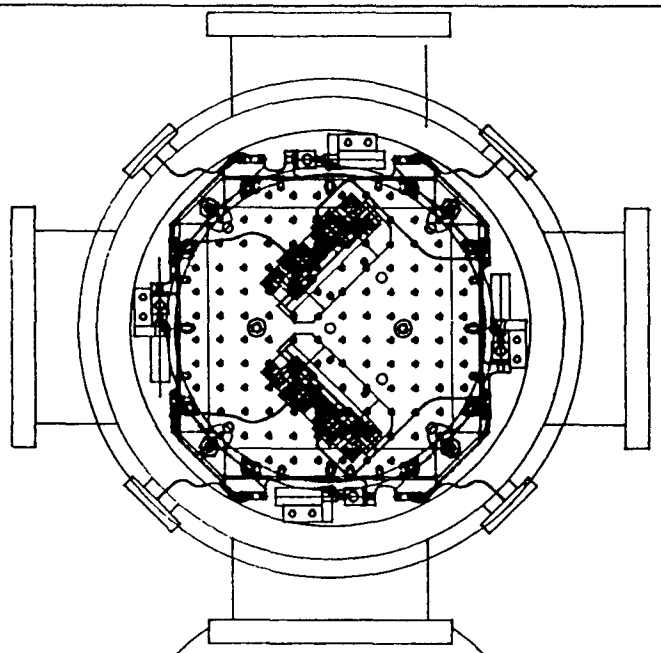
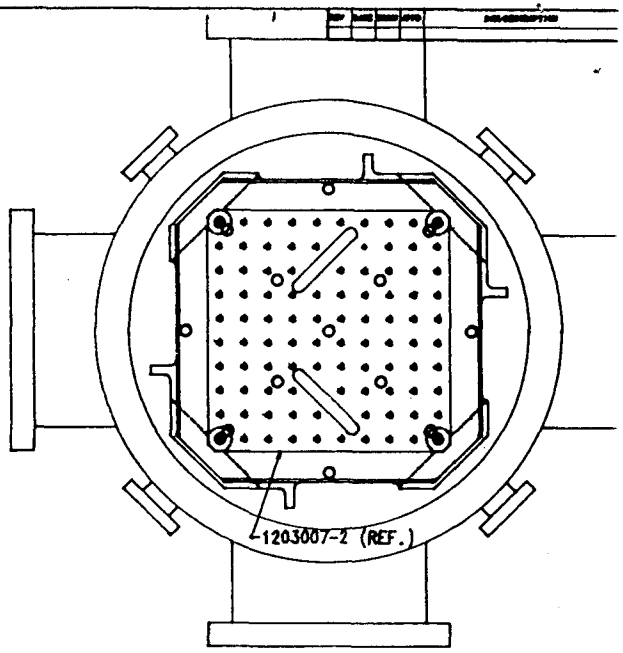


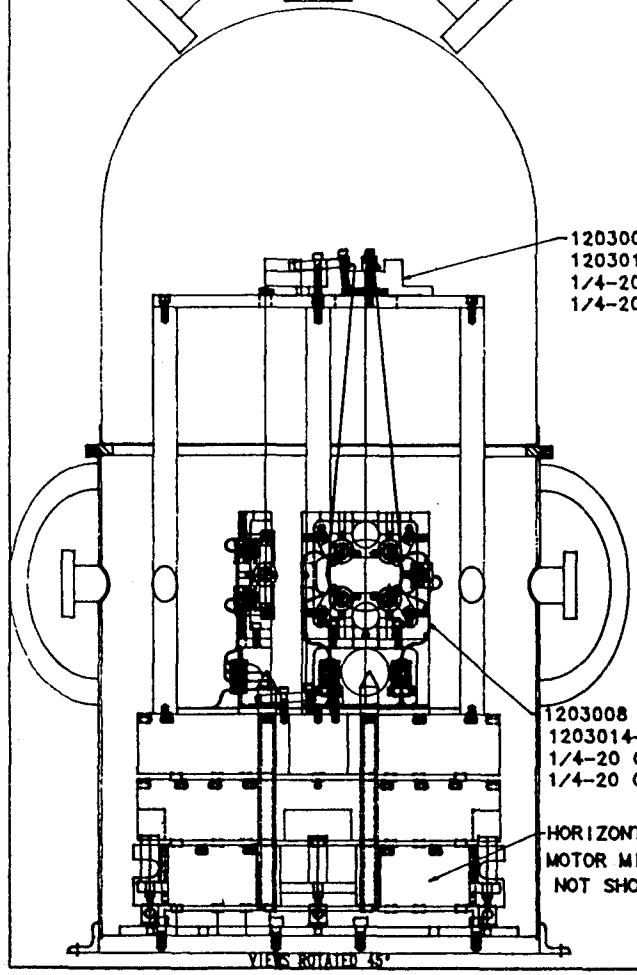
Fig. 6

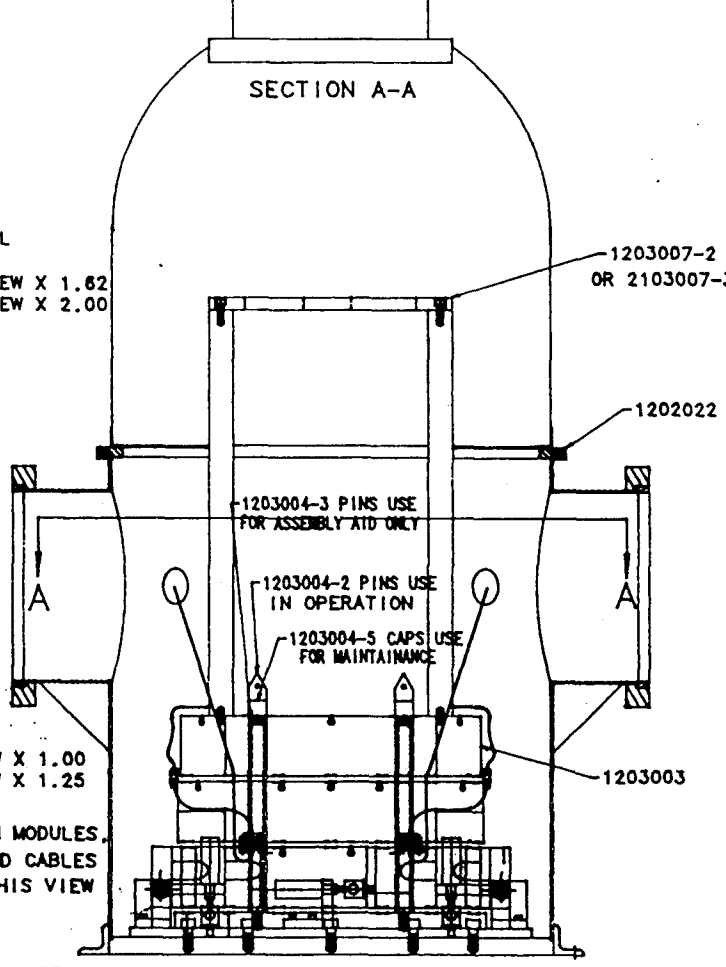


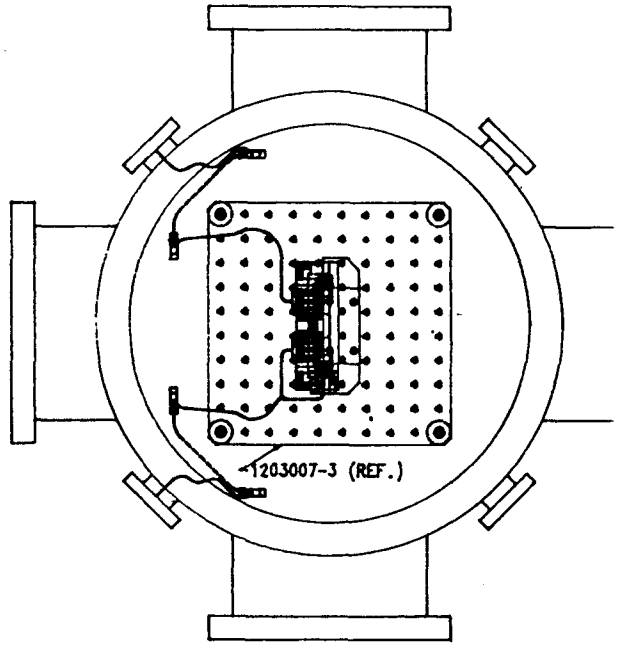


SECTION A-A




ALTERNATE CONFIGURATION

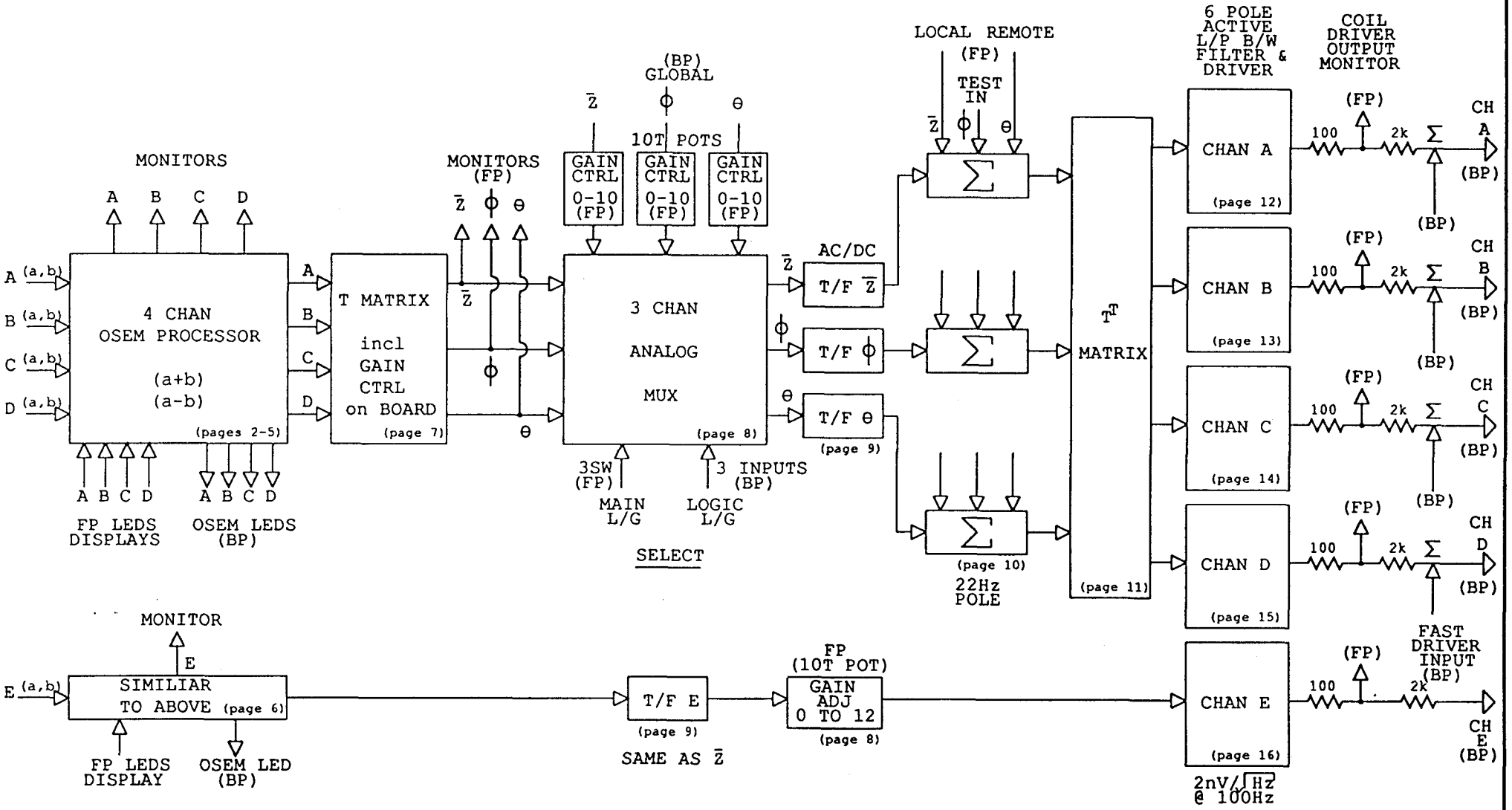
LIGO PROJEC

LONG MODE CLEANER TANK

1203000

EDITION: 01-30-92

11-23-92 JC

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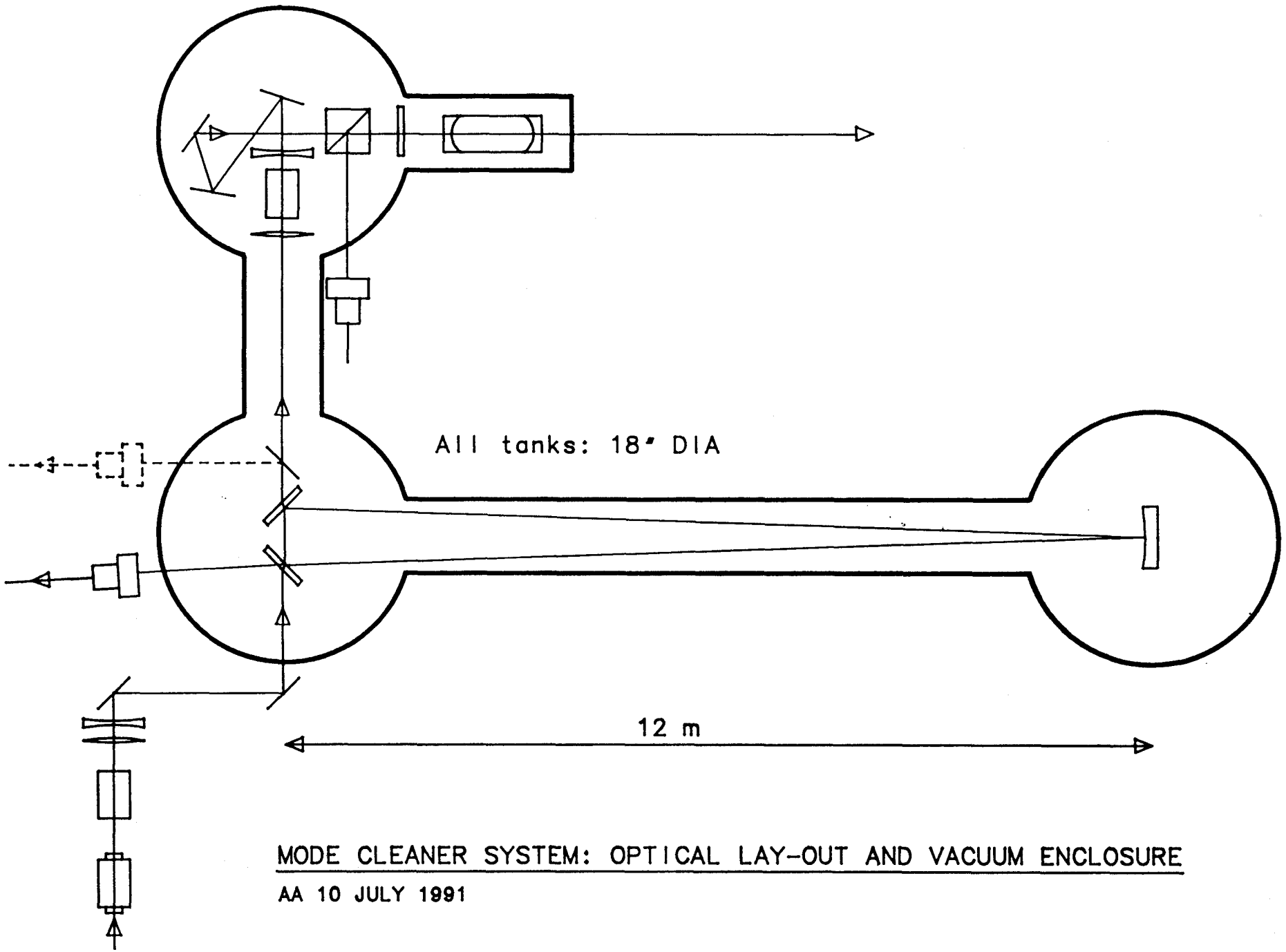
# LIGO PROJECT

| | | | |
|---|---|---|---|
| TITLE: OSEM CONTROLLER BLOCK DIAGRAM | | | |
| DRAWN: SANDEE 8/19/92 | | ENGINEER: | |
| CHECKED: | | APPROVED: | |
| DRAWING NUMBER: | SCALE: --- | PAGE: 1 OF 17 | REV: --- |

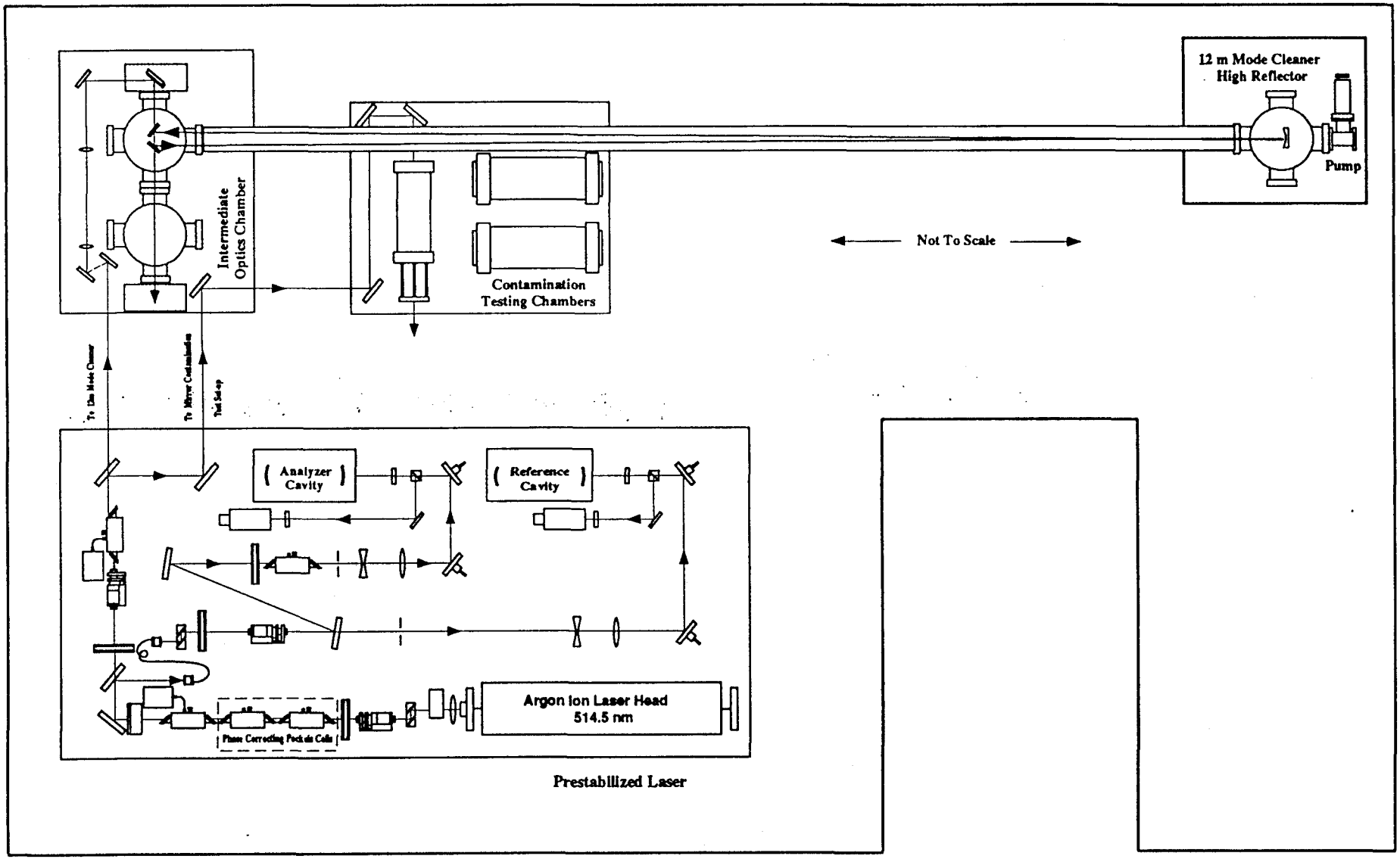



MODE CLEANER SYSTEM: OPTICAL LAY-OUT AND VACUUM ENCLOSURE

AA 10 JULY 1991

# Optics Lab: 12m Mode Cleaner Layout

Steven Elieson, 8 October 1993

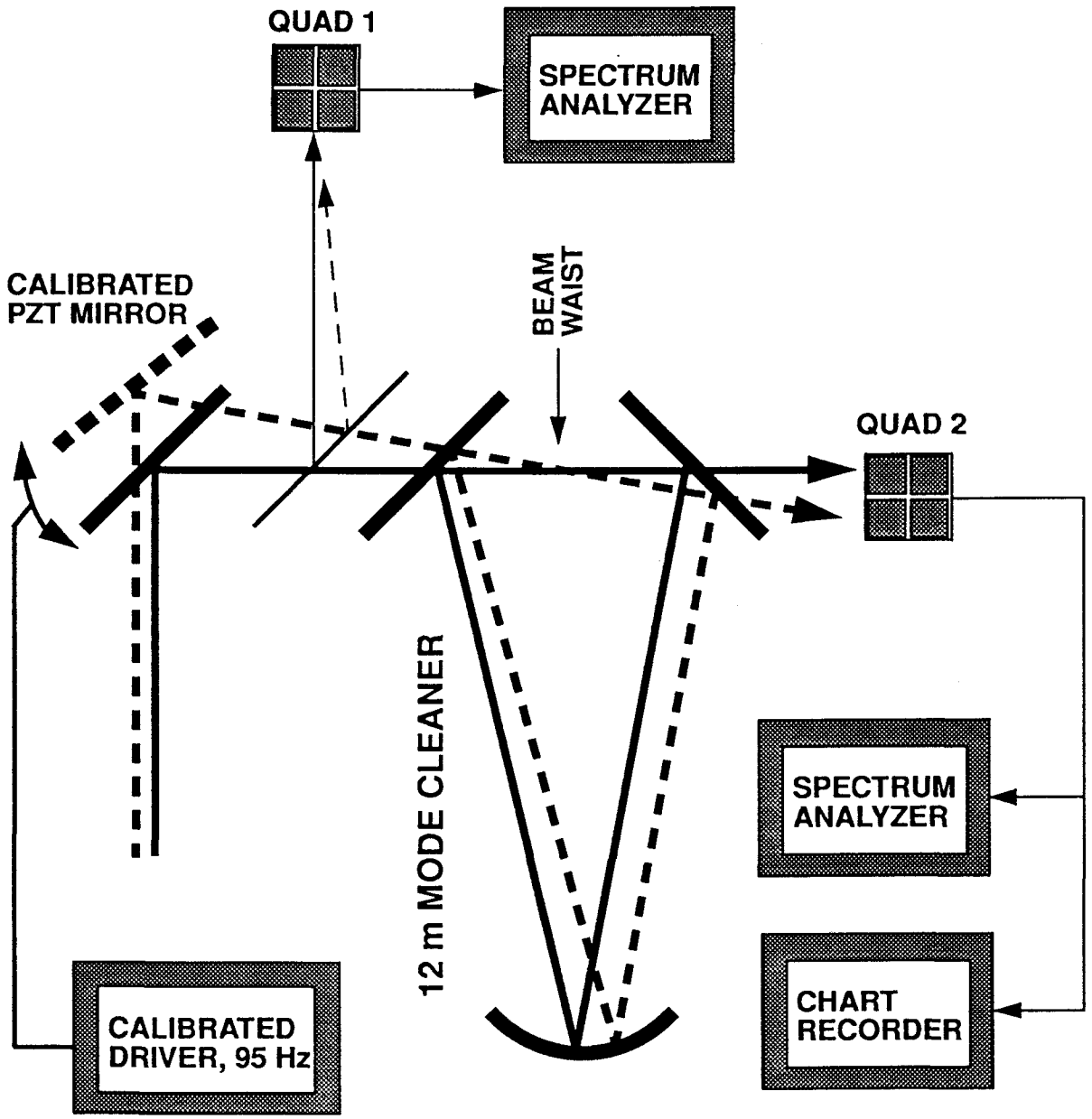


# Mode Cleaner: Originally Planned Tests

**Purpose of tests:** to verify that the mode cleaner performs and behaves as expected

1. Directional beam stability:
    - Drift
    - Beam jitter under 100 Hz
    - Beam jitter above 100 Hz
    - Beam jitter suppression
2. Power stability
3. RFAM with feedthrough modulation
4. Frequency noise after the mode cleaner
5. Backscattered light measurement
6. Polarization noise suppression
7. Beam jitter-to-phase noise conversion: if possible

# Beam Stability Test Arrangement

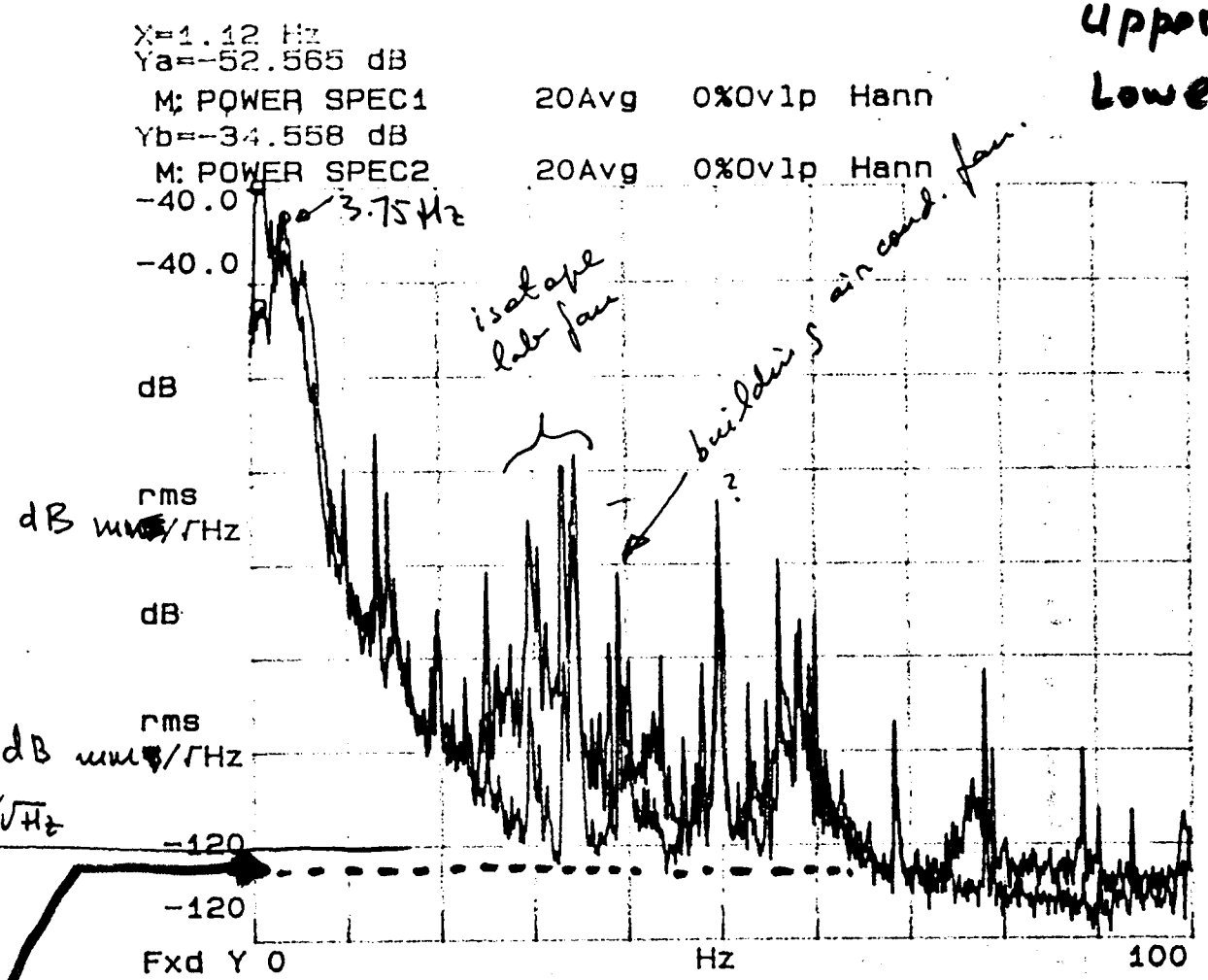


25-MARCH-95 17:25

# QUAD 2 Output (calibrated)

Calibration: 5V/mm, for both H and V

Upper: Blue: Horizontal
Lower: Red: Vertical.

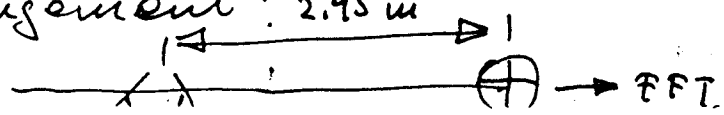



LIGO

Make cleaner gain
- Bypass on
- Boost on
- ⊕ 5½ o'clock.

Note: Gain was increased beyond the point where it makes a difference. Thus, spectrum represents beam motion rather than intensity fluct. due to poor lock.

Arrangement: 2.95 m

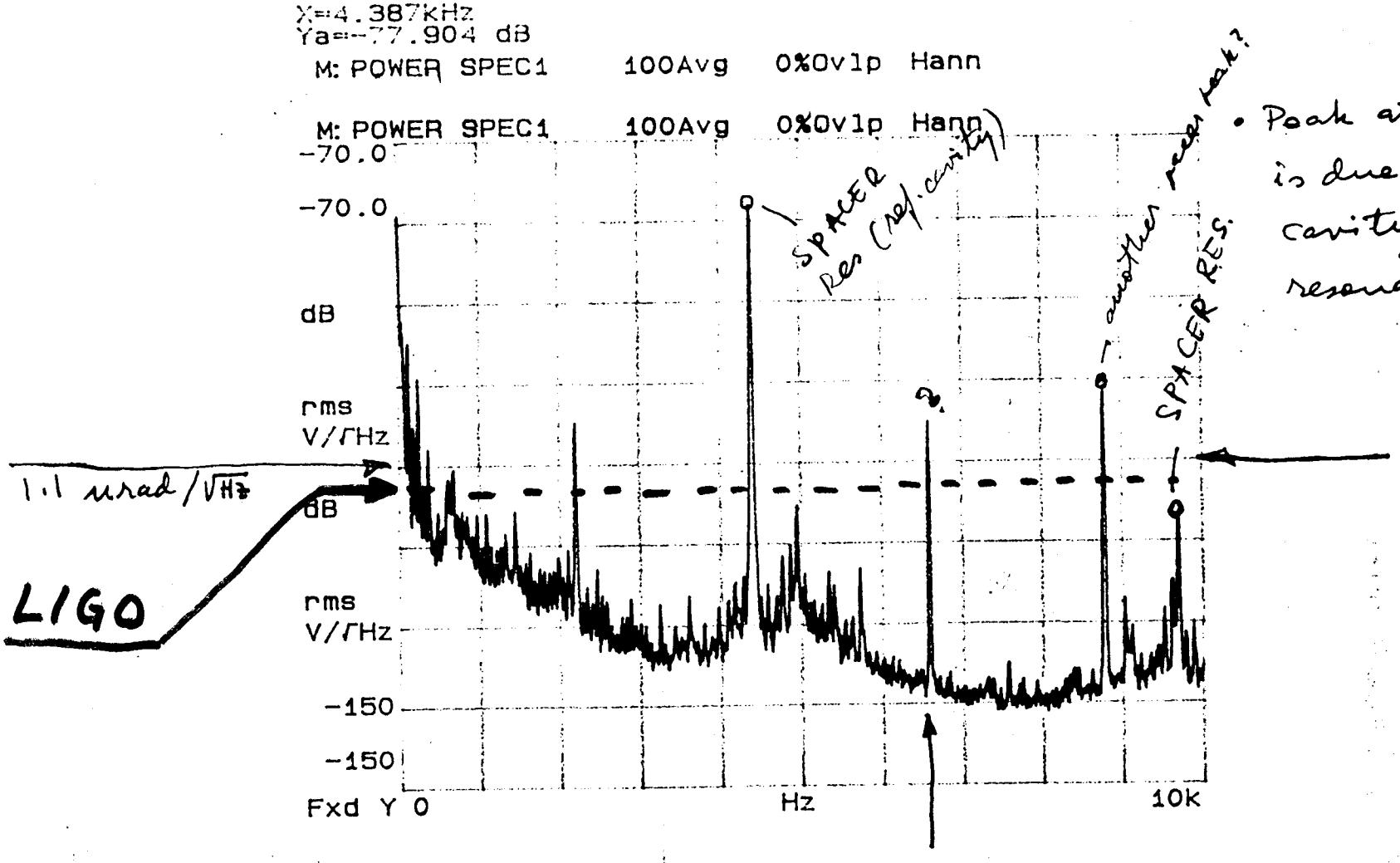



- Peaks: 1.12 Hz: insufficiently damped MC mirror

25-MARCH-95 18:20 Same as 18:00, for 10 kHz freq. Span

# Calibrated QUAD Output

- Blue: horizontal
- Red: Vertical.




- Peak at 4.387 kHz is due to a 1st cavity spacer resonance.

# Summary of Beam Stability Test Results

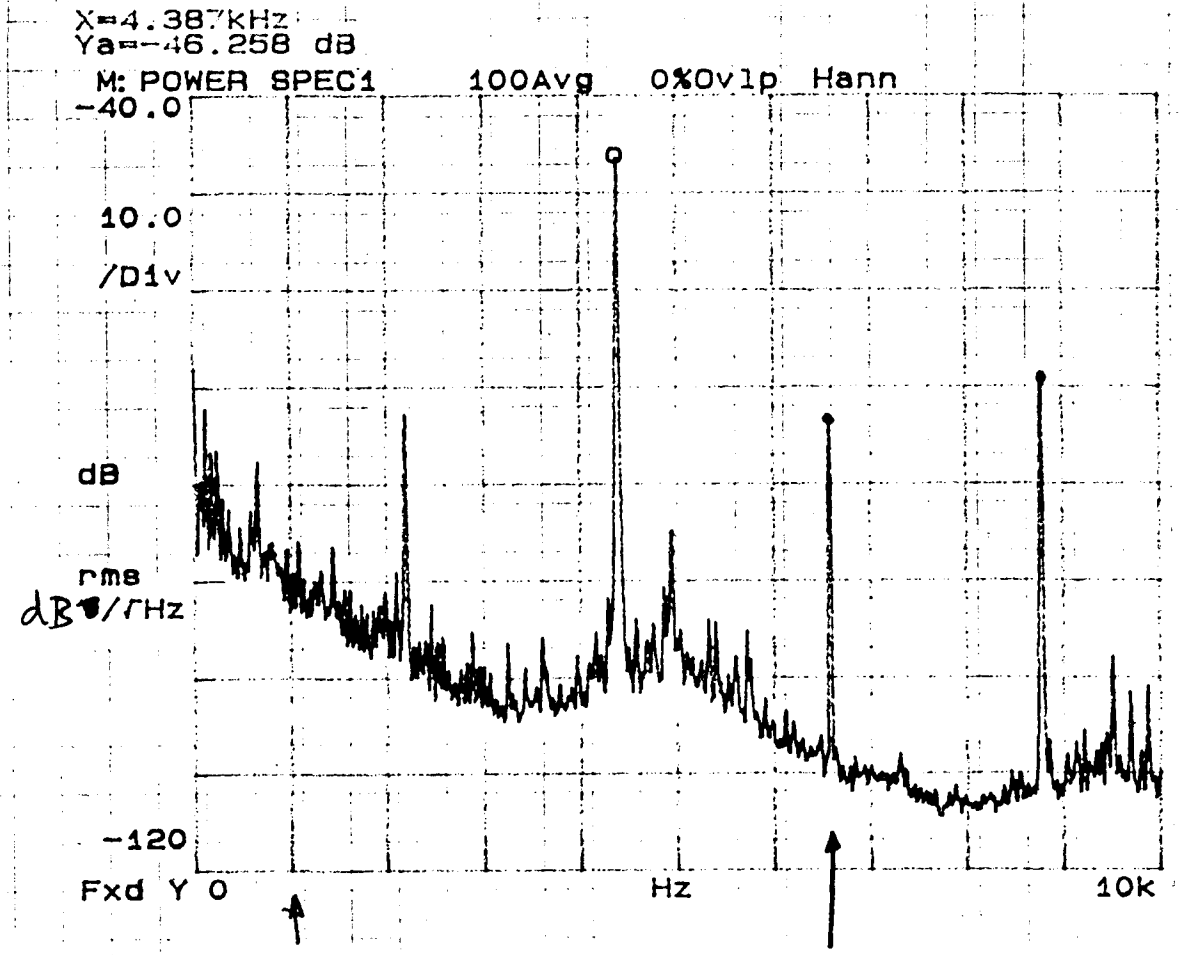
1. Drift, over a 17 hour timespan, starting at 5:30 p.m.:
   - Horizontal: 0.12 mm (3 m away from beam waist), or 41 μrad
   - Vertical: 0.06 mm (3 m away from beam waist), or 20 μrad
   - Corresponding $TEM_{01}$ tilt amplitude: $\varepsilon = 0.37$
2. Beam jitter at mode cleaner output:
   - 2 mrad/$Hz^{1/2}$, at 3.5 Hz
   - ~1nrad/$Hz^{1/2}$, except for peaks, below 100 Hz
   - < 0.3 nrad/$Hz^{1/2}$ (intensity noise limited measurement) above 100 Hz
3. Input beam jitter suppression: 840 calculated, $640 \pm 220$ measured

**Comments:**

- Beam jitter and beam jitter suppression are OK
- Drift is high and active compensation will be necessary

Intensity noise (relative units)
on QUAD 2 (SUM output).

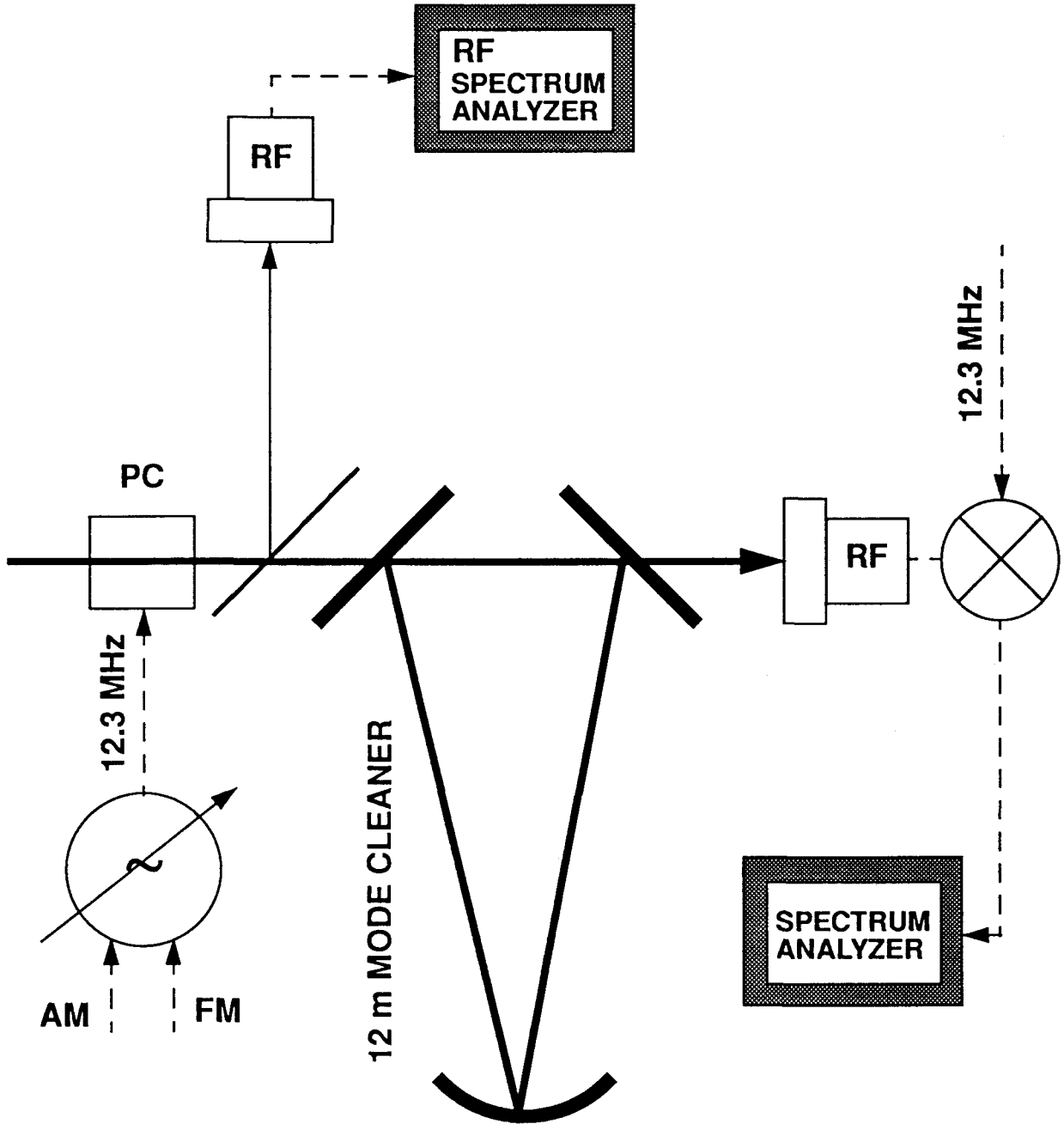
DC level: 3.4V




$\frac{\delta I}{I}$

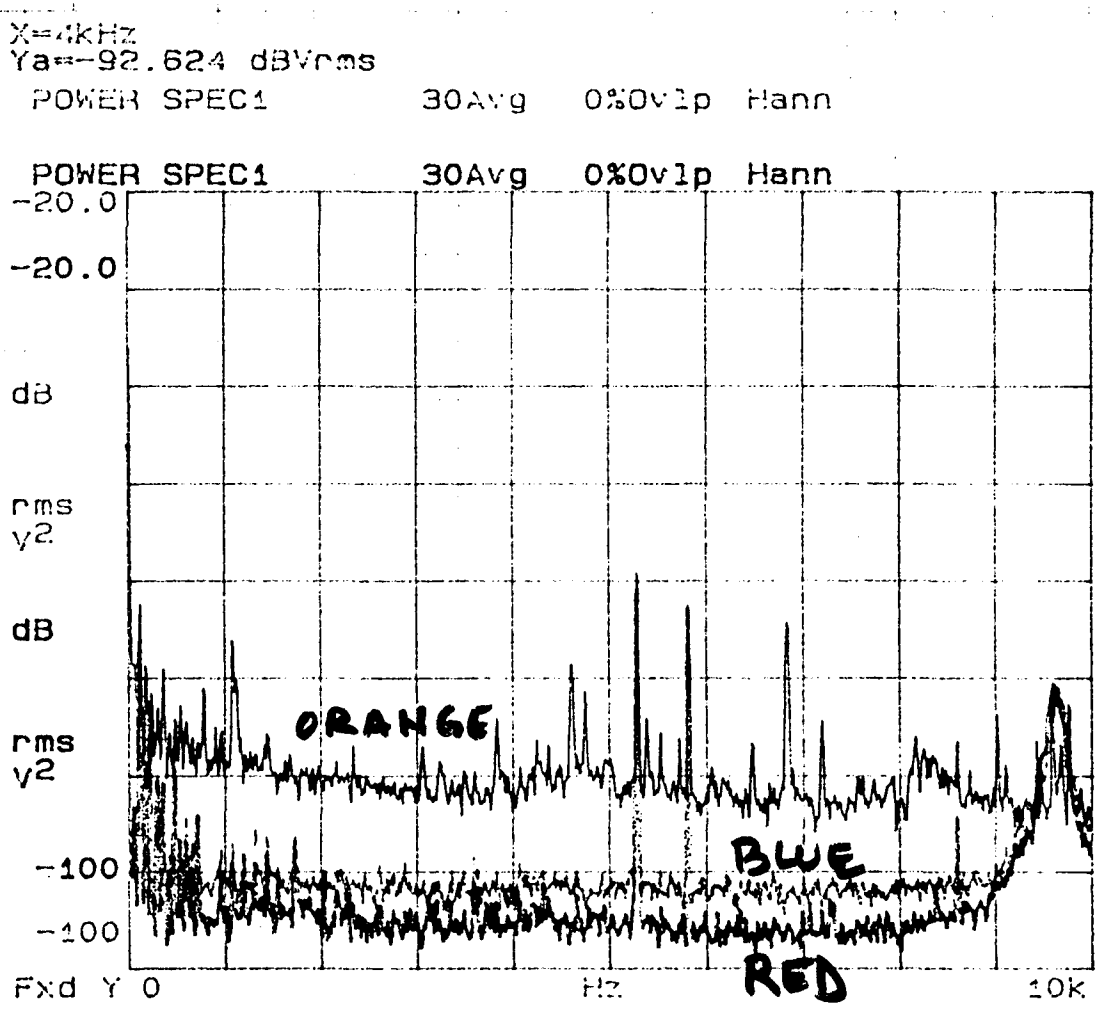
For LIGO, this needs to be suppressed x300

# RFAM Test Arrangement



25-Feb-95 , 17:15 — Analyzer diode demodulated RF output

Comments & arrangement: Same as 17:00




- range: RFAM, same as red trace at 17:00
- blue: shot noise, 200 mV flash light.
- red: dark noise.
  - Laser off

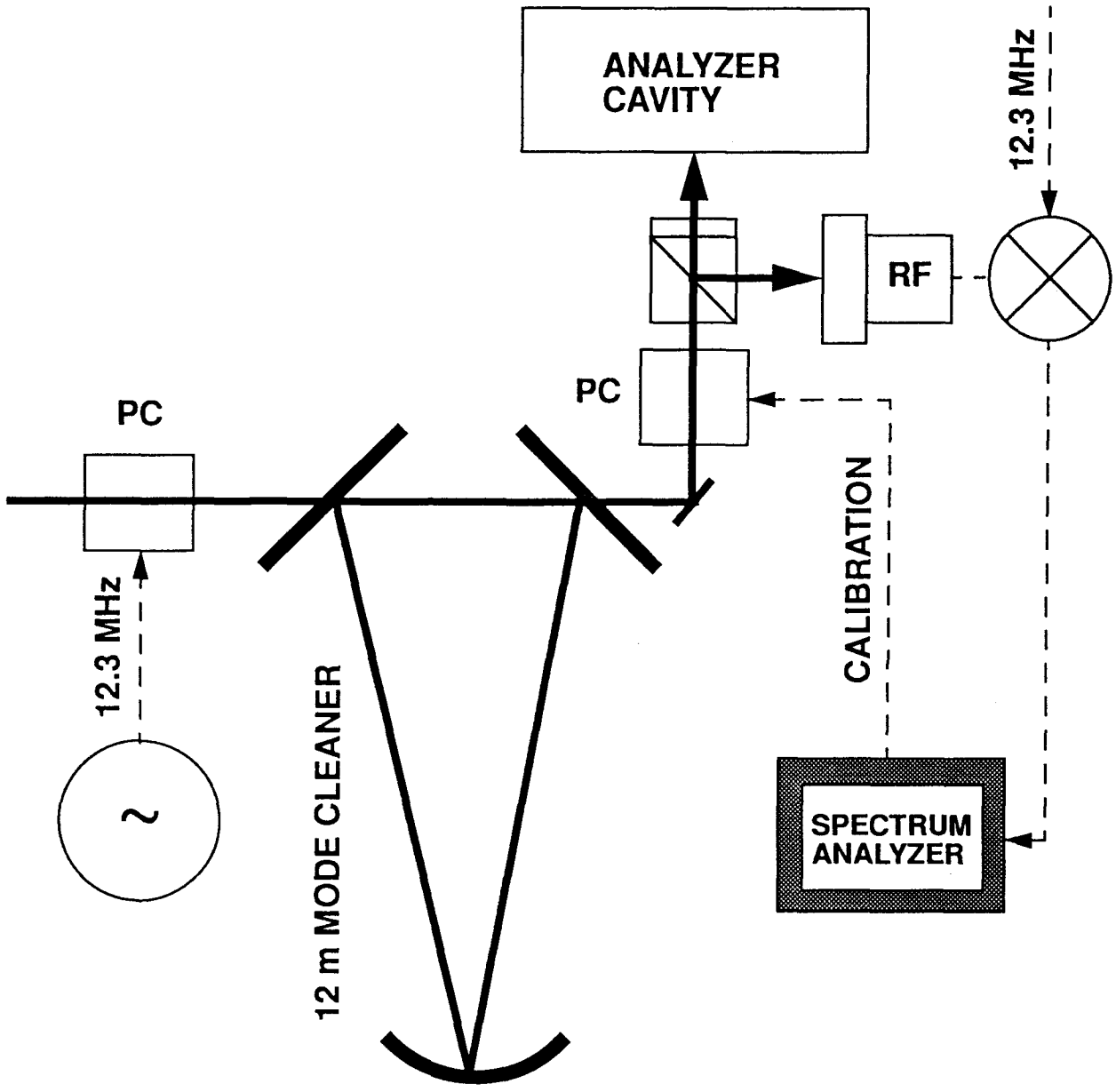
# Summary of RFAM Test Results

1. The level of RFAM was sensitive to:
   - The exact value of the ~12 MHz modulation frequency. Change by 50 Hz led to >10 dB increase in RFAM.
   - Gain in the mode cleaner servo. Nominal gain was sufficient.
   - RF pick-up in the RF photodetector.
2. Measured RFAM was 10 dB above shot noise (16 mW)
3. Injecting AM and FM into the ~12 MHz signal, the following levels were found equivalent with shot noise at 16 mW:
   - AM: -107 dBc/$Hz^{1/2}$
   - FM: -102 dBc/$Hz^{1/2}$

**Comments:**

- The excess RFAM noise is not understood
- The local oscillator used in these measurements (SRS-DS345) is adequate for the 40 m interferometer, but probably not for LIGO

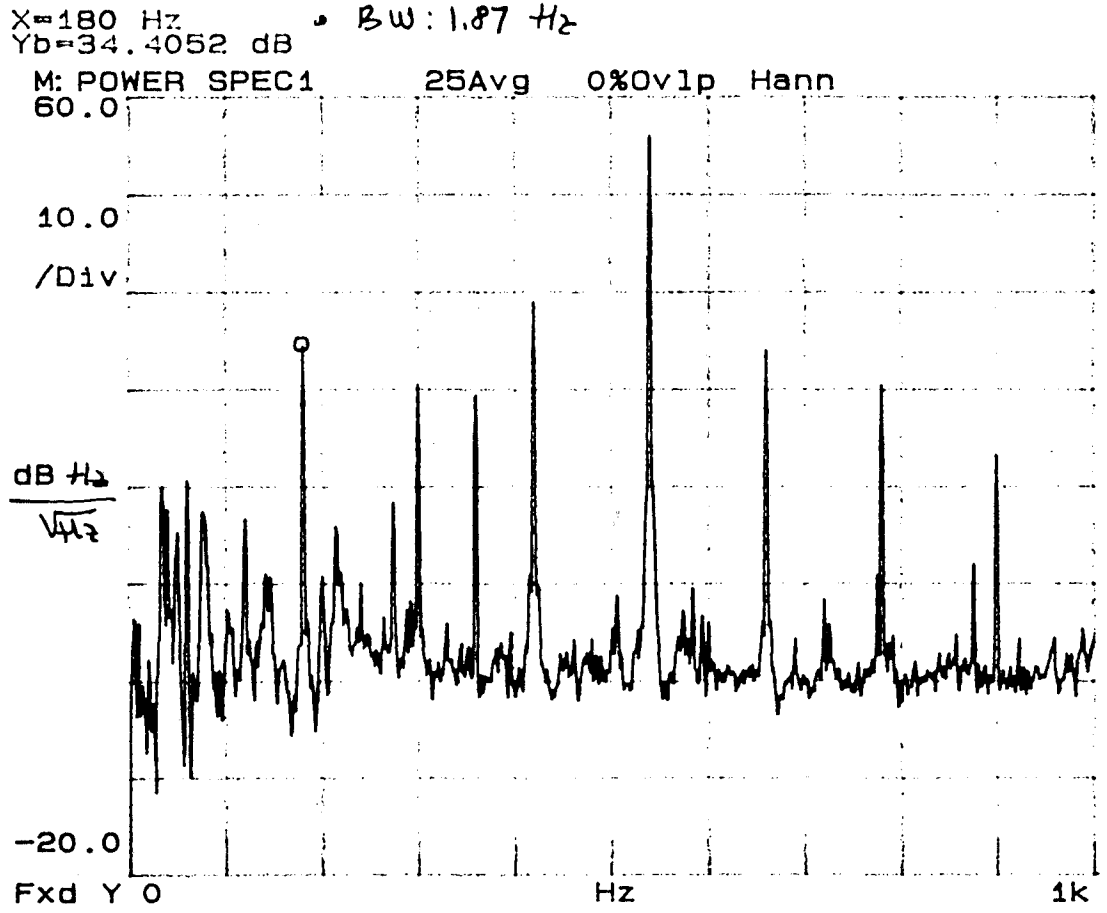
# Frequency Noise Test Arrangement




Result: Measurement limited by analyzer cavity noise

## calculated frequency noise spectrum

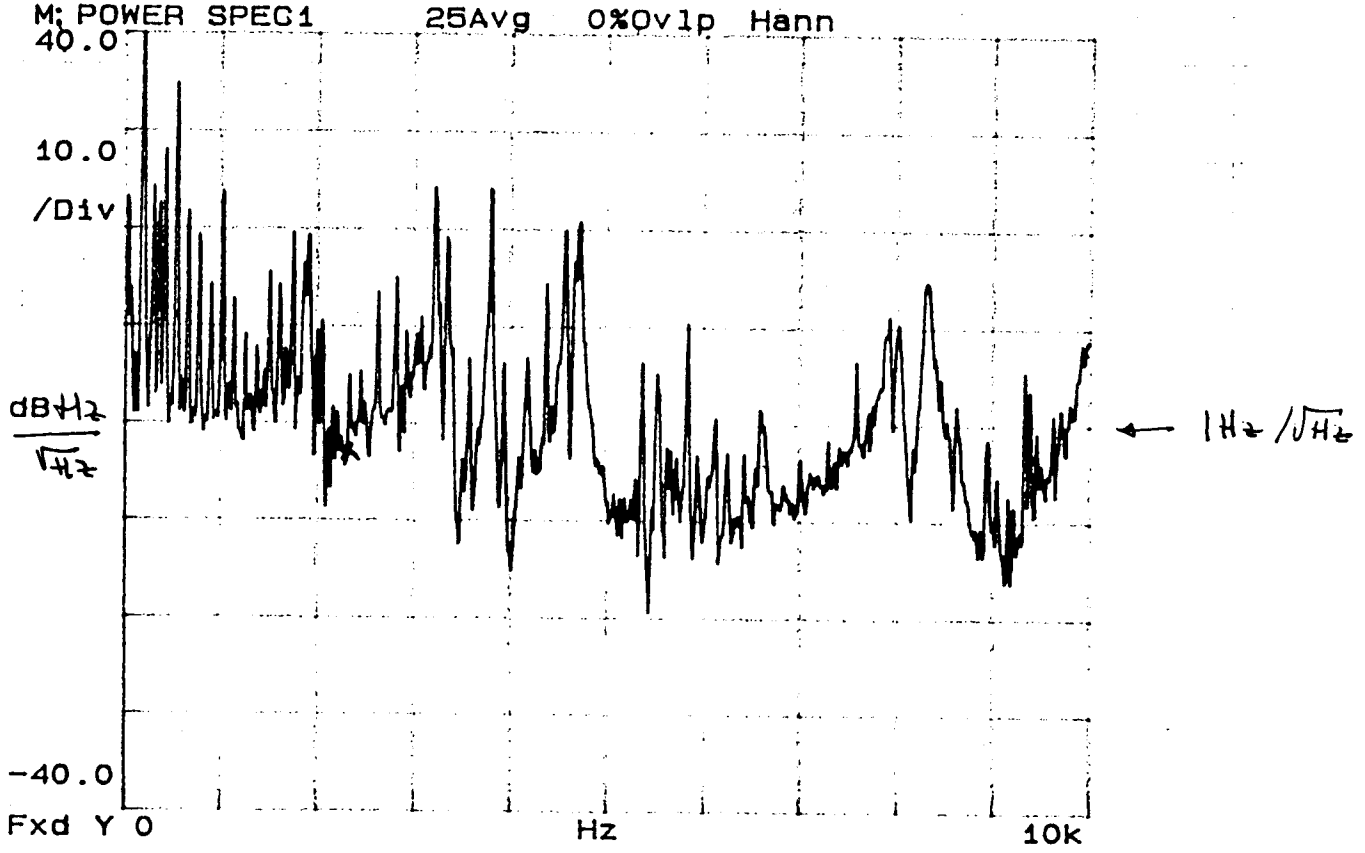
- measured after mode cleaner w. analyser cavity
- Set-up as on plot from 13-March, 21:45, except analyser servo (see changes on p 18 w. Gain: 49/10)
- Data: as of plot from 20:50
- Calibration signal: 100 V r.m.s.
- BW: 1.87 Hz



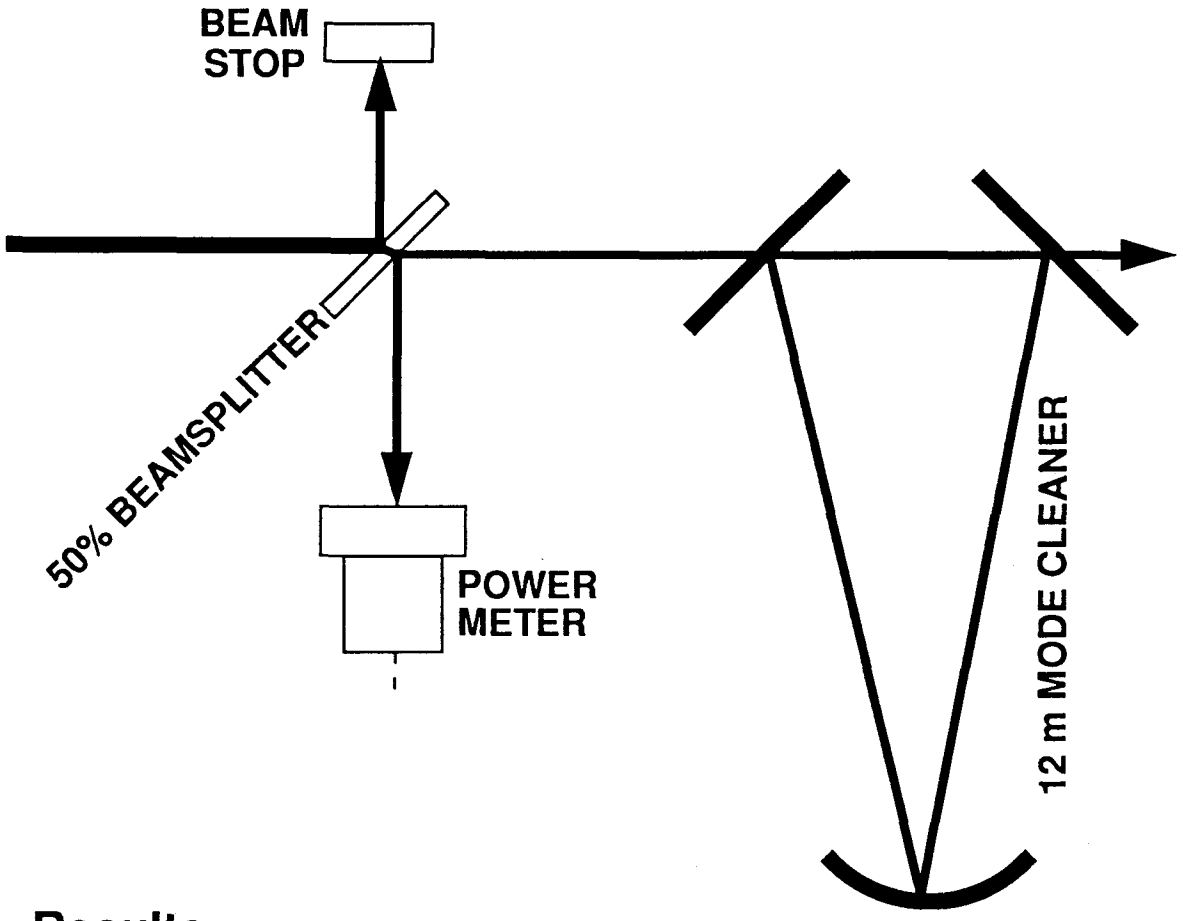

Calibration good above 50 Hz.

1 Hz/√Hz

- Measured after mode cleaner, w. analyser cavity
- Data: as of plot from 21:30
- Calibration signal: 100 V rms
- BW: 18.7 Hz
- Calibration good above 50 Hz



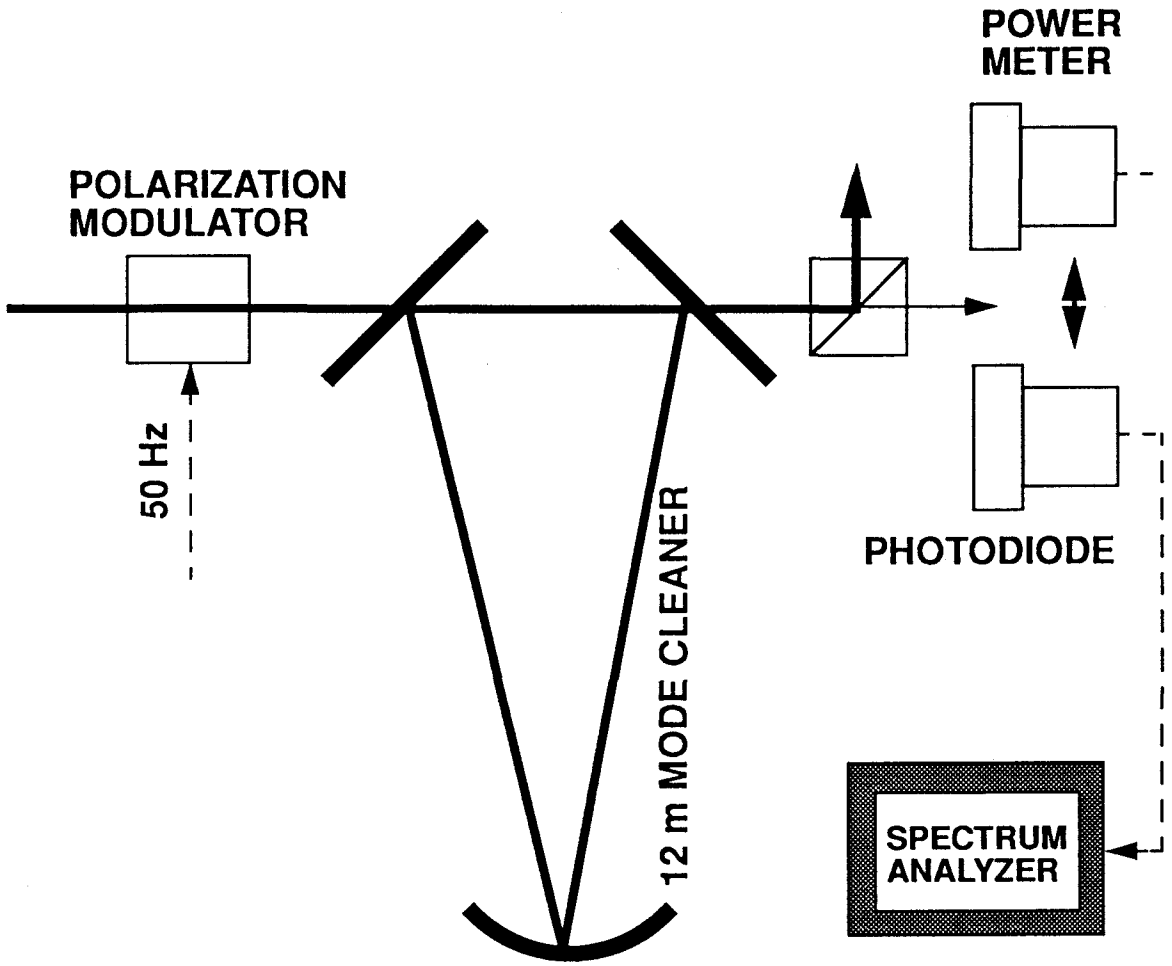
# Backscattered Light Test Arrangement




## Results

- Measured upper limit on backscattering: $2.6 \times 10^{-6}$
  - Experiment limited by light scattered off beamsplitter
  - Calculated value: $1.5 \times 10^{-6}$

# "Wrong" Polarization Suppression Test Arrangement



# Summary of Polarization Measurements

- Measured "wrong" polarization rejection factor: 30-60
- Calculated value: ~$10^6$
- Possible cause of discrepancy:
  - Presence of high order transverse modes in the input beam, coupling to resonances in the orthogonal polarization, at frequencies near the resonance for the "right" polarization which passes the main beam. The data contain some clues that this might explain the observations.
  - Birefringence of mirror coatings
  - Birefringence of vacuum system windows

## Comment

Polarization fluctuations in the input beam to the mode cleaner were measured and found to be below the level where they would affect LIGO interferometer sensitivity. Thus, even the low rejection factor measured is sufficient.

# Suggested Additional Work

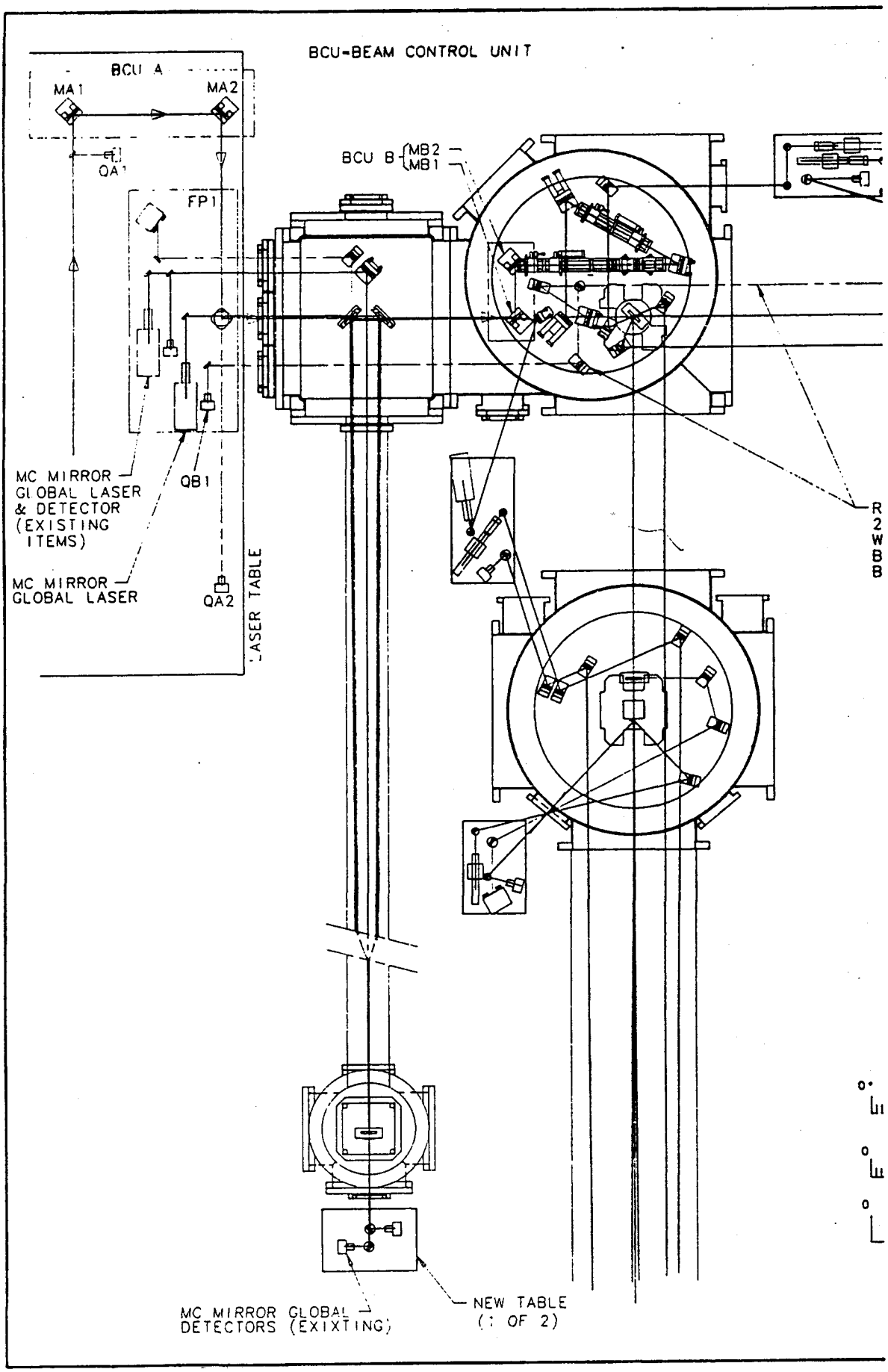
- Generate a beam control unit (BCU) to address beam pointing drift at mode cleaner output
- Implement mode cleaner length control servo, needed for installation in 40 m lab, while the instrument is still in West Bridge subbasement
- Investigate cause of excess RFAM after the mode cleaner

**Note:** topics ordered by perceived priority

# Next Step: Moving the Mode Cleaner to the 40 m Lab

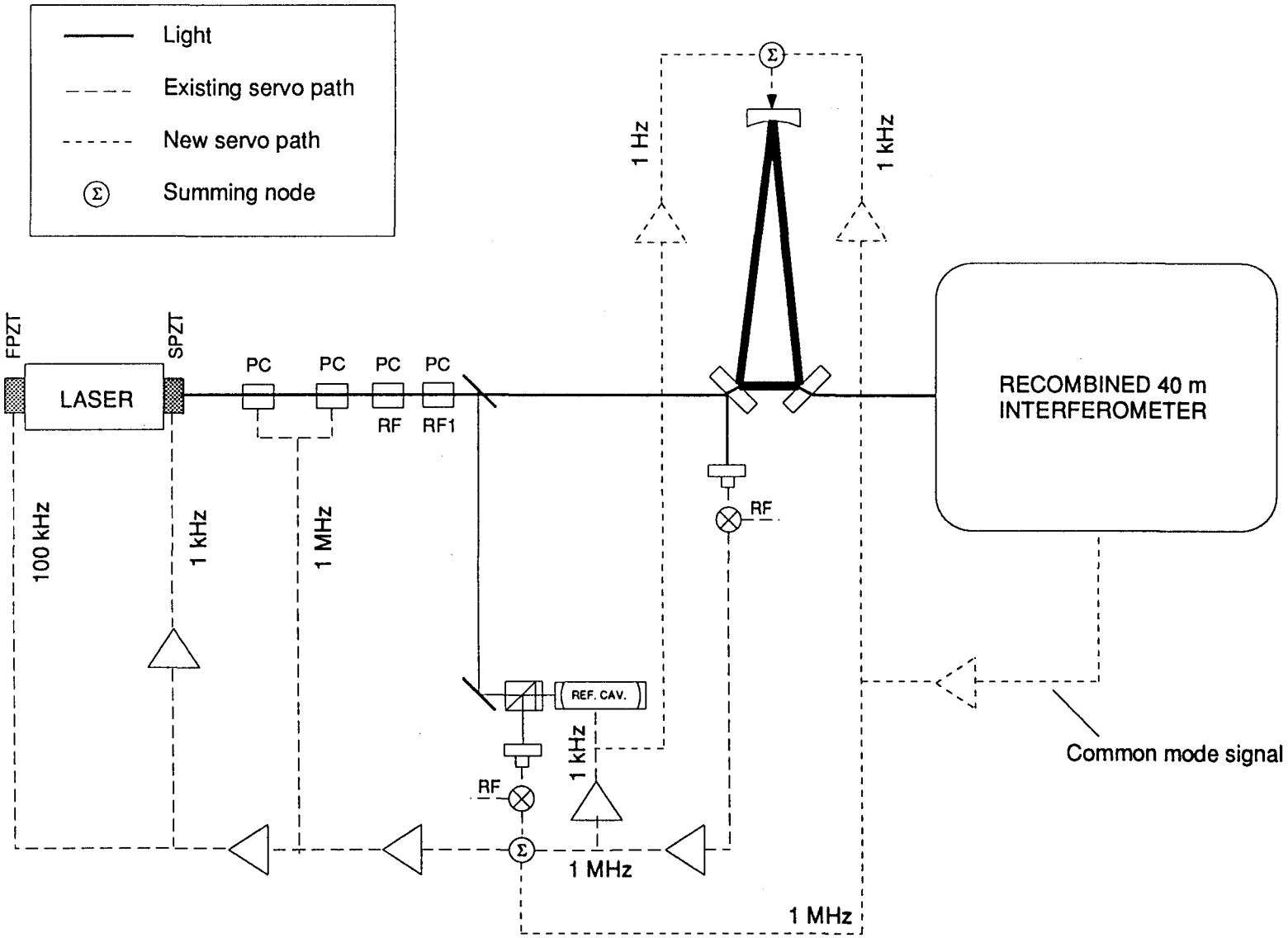
## Ingredients

- Mark II vacuum system reconfiguration
  1. New 18" tank, with external drift compensator arrangement
  2. New stack for one of the existing side chambers, including external drift compensator arrangement
  3. Logistics of implementing the vacuum system configuration change
- Development of additional feedback control paths
- Development of a Beam Control Unit, to ensure beam pointing stability after the mode cleaner (TBDone)
- Transfer of the mode cleaner from West Bridge to the 40 m lab. Projected to start by early July 1995.
- Reconfiguration of the rest of the Mk II input optics
- System shake-down. Projected to be completed late October 1995.

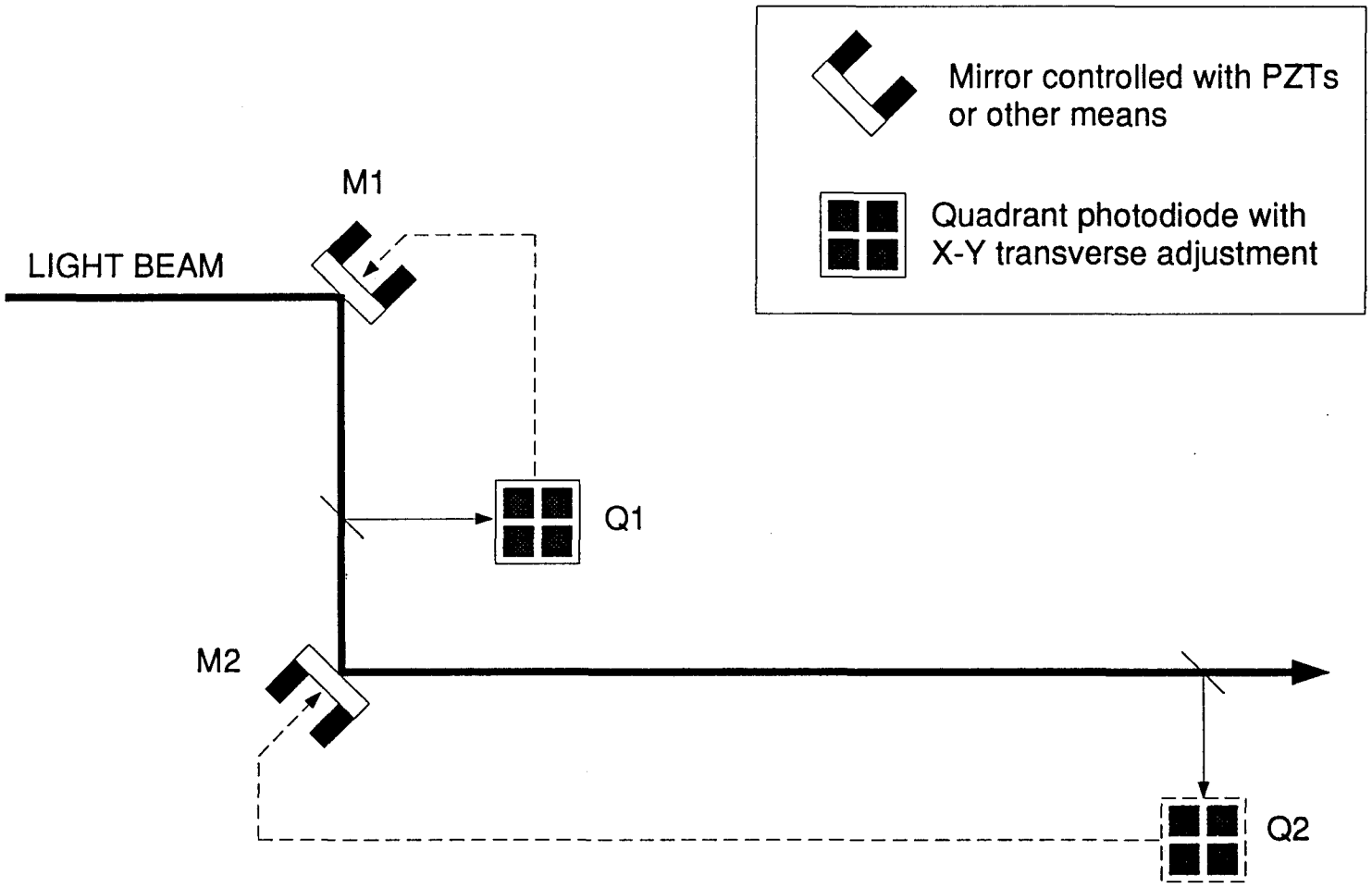

BCU-BEAM CONTROL UNIT
BCU A
MA1
MA2
QA1
FP1
BCU B
MB2
MB1
MC MIRROR GLOBAL LASER & DETECTOR (EXISTING ITEMS)
QB1
MC MIRROR GLOBAL LASER
QA2
LASER TABLE
R2WBB
MC MIRROR GLOBAL DETECTORS (EXIXTING)
NEW TABLE (1 OF 2)

# 40 m SYSTEM WITH 12 m MODE CLEANER: PARTIAL SERVO DIAGRAM

Alex Abramovici, 12-09-94



# LAY-OUT OF BEAM CONTROL UNIT (BCU)



# Mode Cleaner Transfer to the 40 m Lab: Status

- Mode cleaner tests: complete
- design of parts: 95% complete
- Fabrication of parts, including new 18": vacuum tank: expected to be complete by May 10 1995
- Additional feedback control system paths development: amplifiers built, available
- Planning for transfer to 40 m lab: TBDone