DEVELOPMENT OF LASER INTERFEROMETER GRAVITY-WAVE DETECTORS, AND RELATED INVESTIGATIONS IN EXPERIMENTAL GRAVITY AND GRAVITATIONAL RADIATION

(R. W. P. DREVER)

(PAC 6 JAN 1997)

LIGO-G970018-00-R

TWO MAIN AREAS OUTLINED IN PROPOSAL

1) Extending Low Frequency Performance

- Coupled isolation systems
  - Coupled in position and tilt.
  - Use of magnetic levitation. ← LARGELY PASSIVE

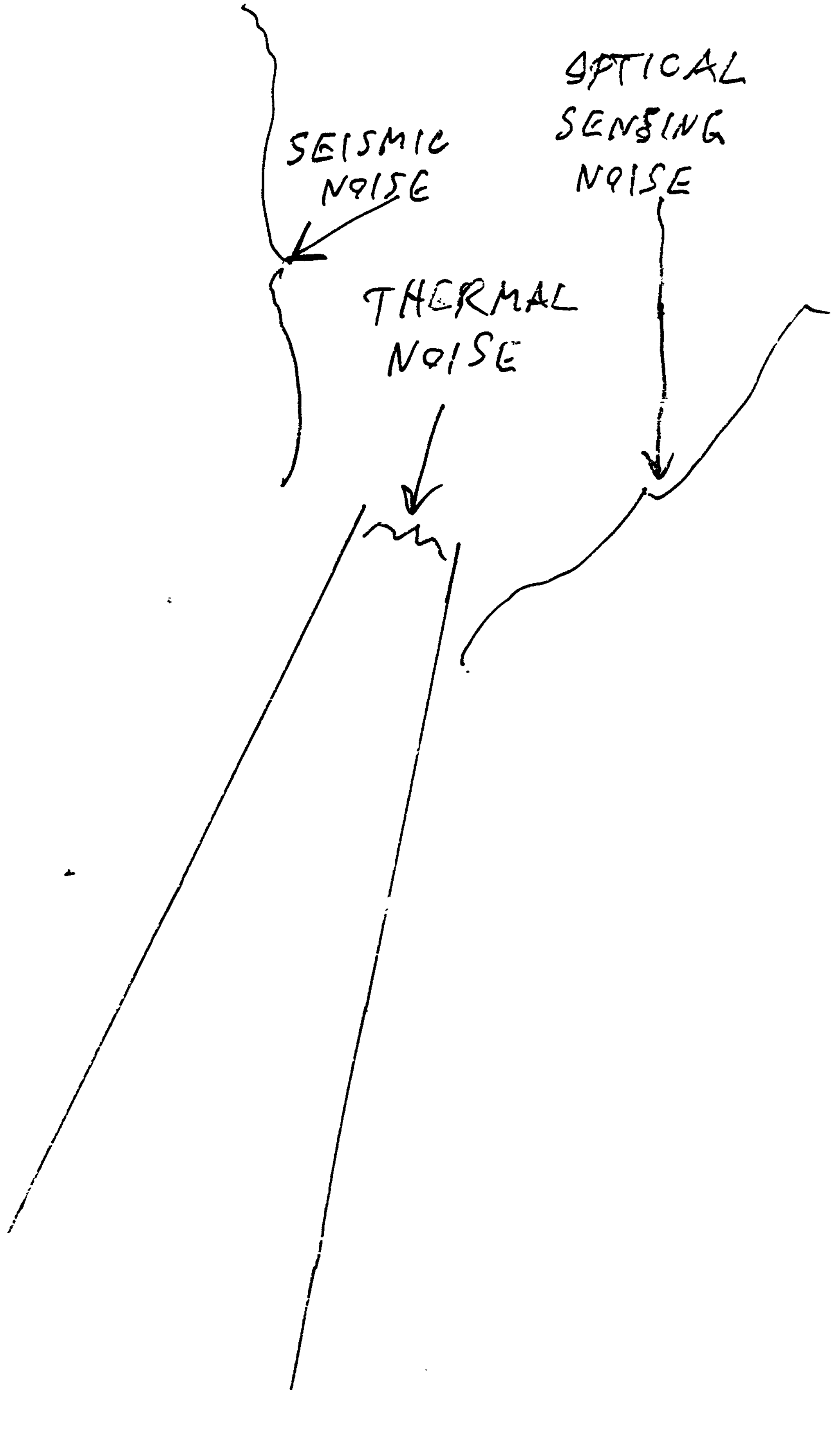
2) Extending High Frequency Performance

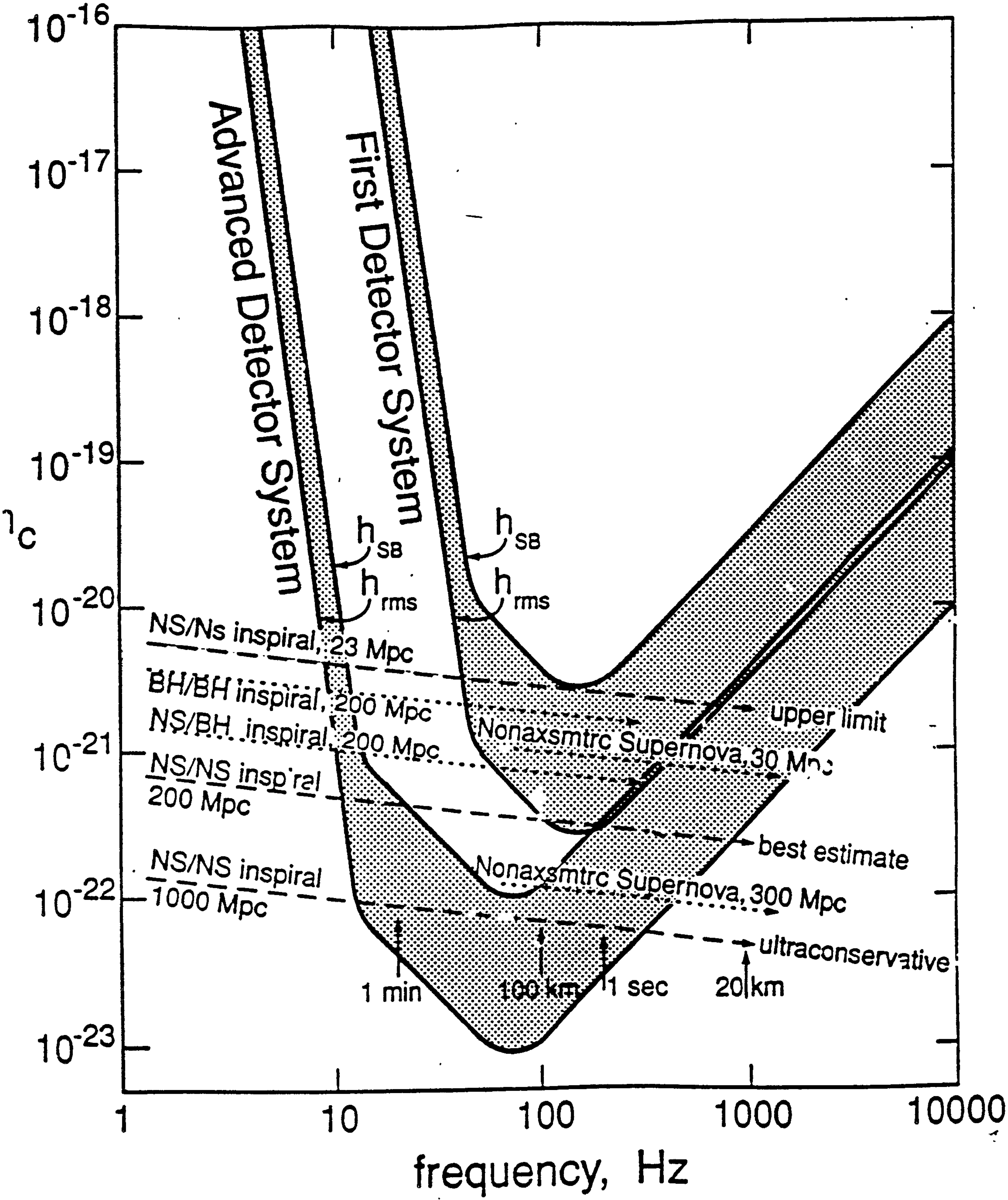
Use of diffractive optics – can allow higher light power –> reduce shot noise

- Reduces internal test mass thermal noise.

We concentrate on (1) initially, since in our situation this seems likely to give important results earlier.

THE MAIN SOURCES OF NOISE
WHICH LIMIT SENSITIVITY.





10-16
10-17
10-18
10-19
10-20
10-21
10-22
10-23
hc
Advanced Detector System
First Detector System
hSB
hrms
hSB
hrms
NS/Ns inspiral, 23 Mpc
BH/BH inspiral, 200 Mpc
NS/BH inspiral, 200 Mpc
NS/NS insp ral
200 Mpc
NS/NS inspiral
1000 Mpc
upper limit
Nonaxsmtrc Supernova, 30 Mpc
best estimate
Nonaxsmtrc Supernova, 300 Mpc
ultraconservative
1 min
100 km
1 sec
20 km
1
10
100
1000
10000
frequency, Hz

T4

PAC2

STANDARD SEISMIC ISOLATION – SPRING-MASS STAGES OF LOWEST CONVENIENT RESONANT FREQUENCY

ADVANTAGES of Using Magnetic Fields Instead of Metal or Rubber "Springs":

a) Avoid high-frequency paths through springs, etc.

b) Low resonant frequency obtainable in passive systems.

(Servo is only a stabilizer.)

c) Relatively simple – essentially passive.

d) Easy damping by eddy currents.

e) High vacuum compatible.

OBVIOUS DISADVANTAGES

a) Superconductors require reduced temp – inconvenient.

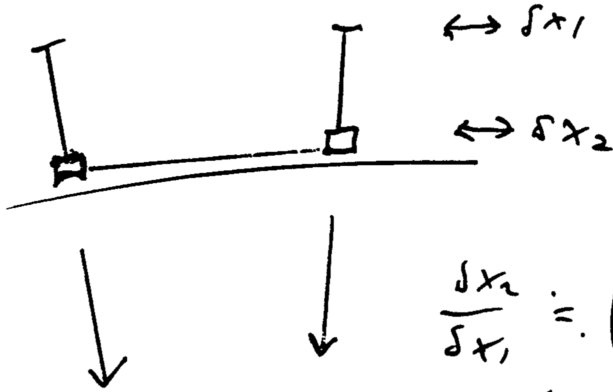
Plan to avoid them.

b) Permanent magnets unstable alone (Earnshaw's theorem).

- But can make stable by servo sytem

c) Must avoid response to outside field noise.

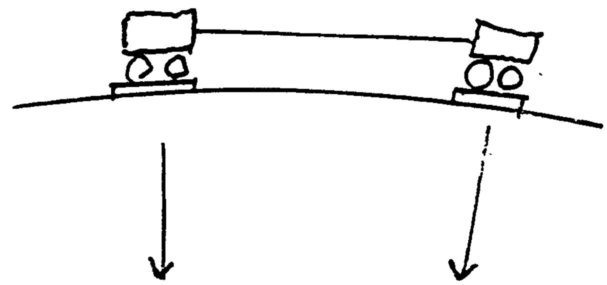
PENDULUM



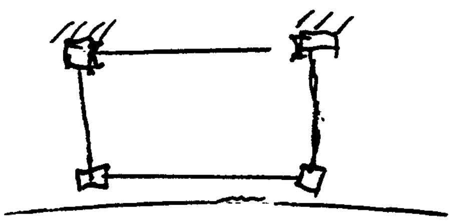
$$\frac{\delta x_2}{\delta x_1} \doteq \left(\frac{f_0}{f}\right)^2$$

for $f >> f_0$.

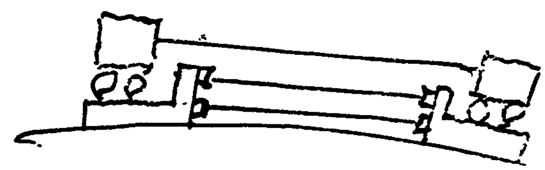
LONG-PERIOD
WEIGHTLESS, FRICTIONLESS WHEELS



MONITOR SUSPENSION POINTS



MONITOR RELATIVE TILTS

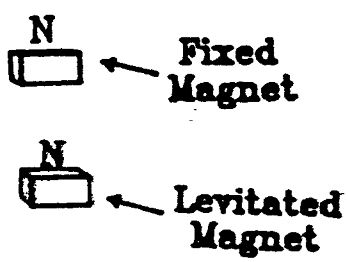


ALMOST ANY PASSIVE LONG-PERIOD SUSPENSION IS EQUIVALENT TO THIS.

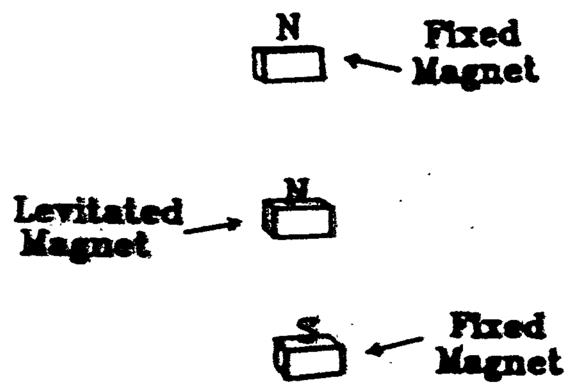
(INCLUDES GATE-TYPE SUSPENSION, X-PENDULUM, MAGNETIC SYSTEMS TO BE DESCRIBED)

MAGNETIC SUSPENSIONS PROPOSED CAN GIVE PRACTICAL WAY TO IMPLEMENT THIS.

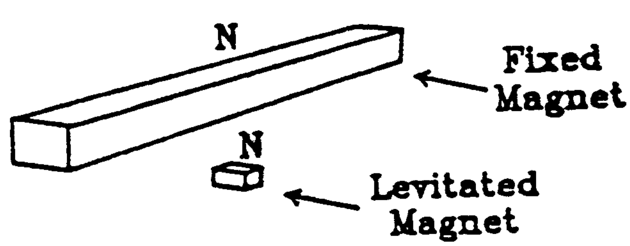
SOME MAGNET ARRANGEMENTS PROPOSED



(A) SIMPLE



(B) LONGER PERIODS THAN (A).
TRANSLATION-ROTATION COUPLING CAN GIVE INSTABILITY.



(C) INHERENT LONG PERIODS IN ONE DIRECTION.

ONE STAGE FOR A SEISMIC ISOLATION SYSTEM.

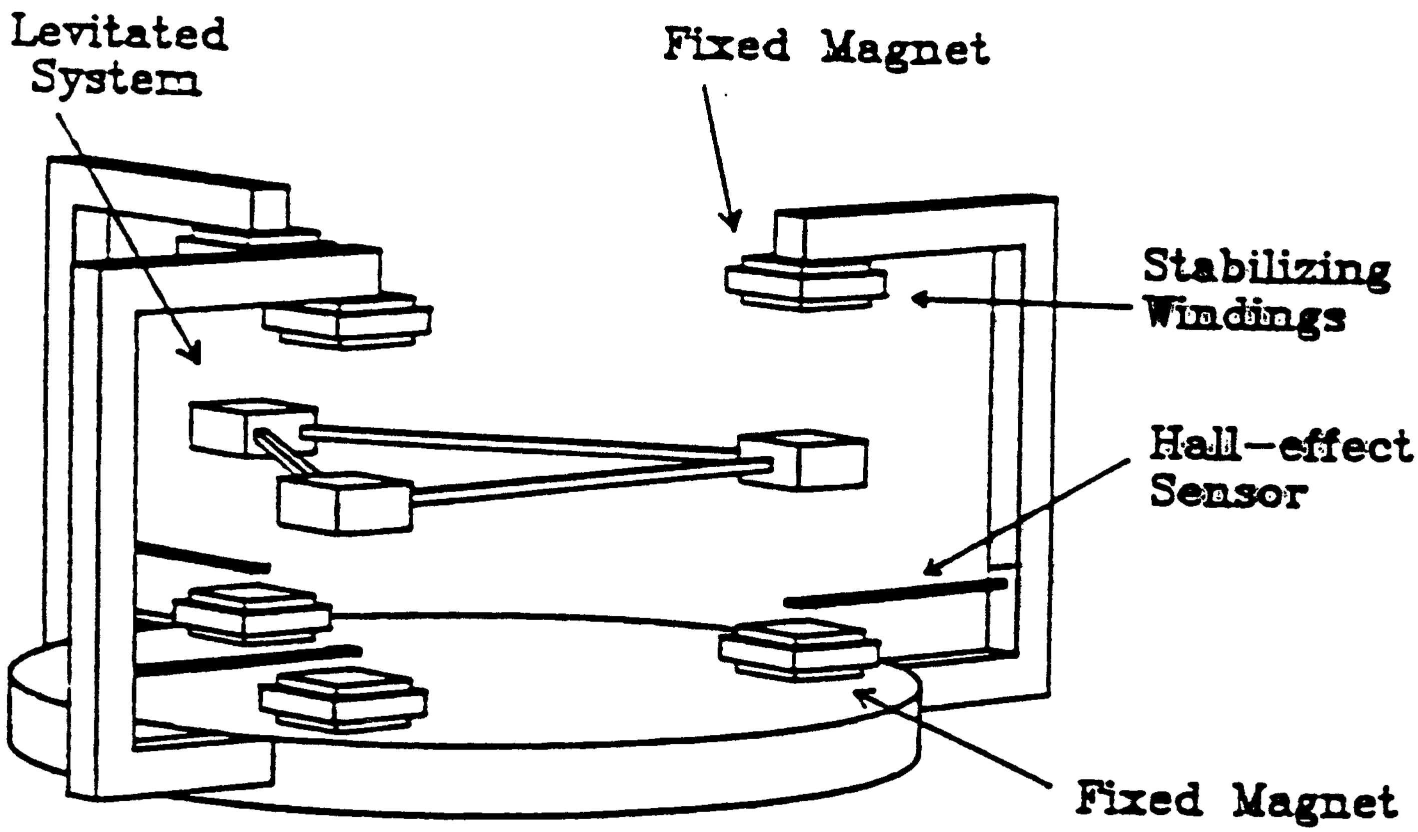


Fig. 8.

SMALL TEST SYSTEM :-

PAYLOAD 1 Kg

NATURAL PERIODS ;- HORIZONTAL 2 — 4 SEC.

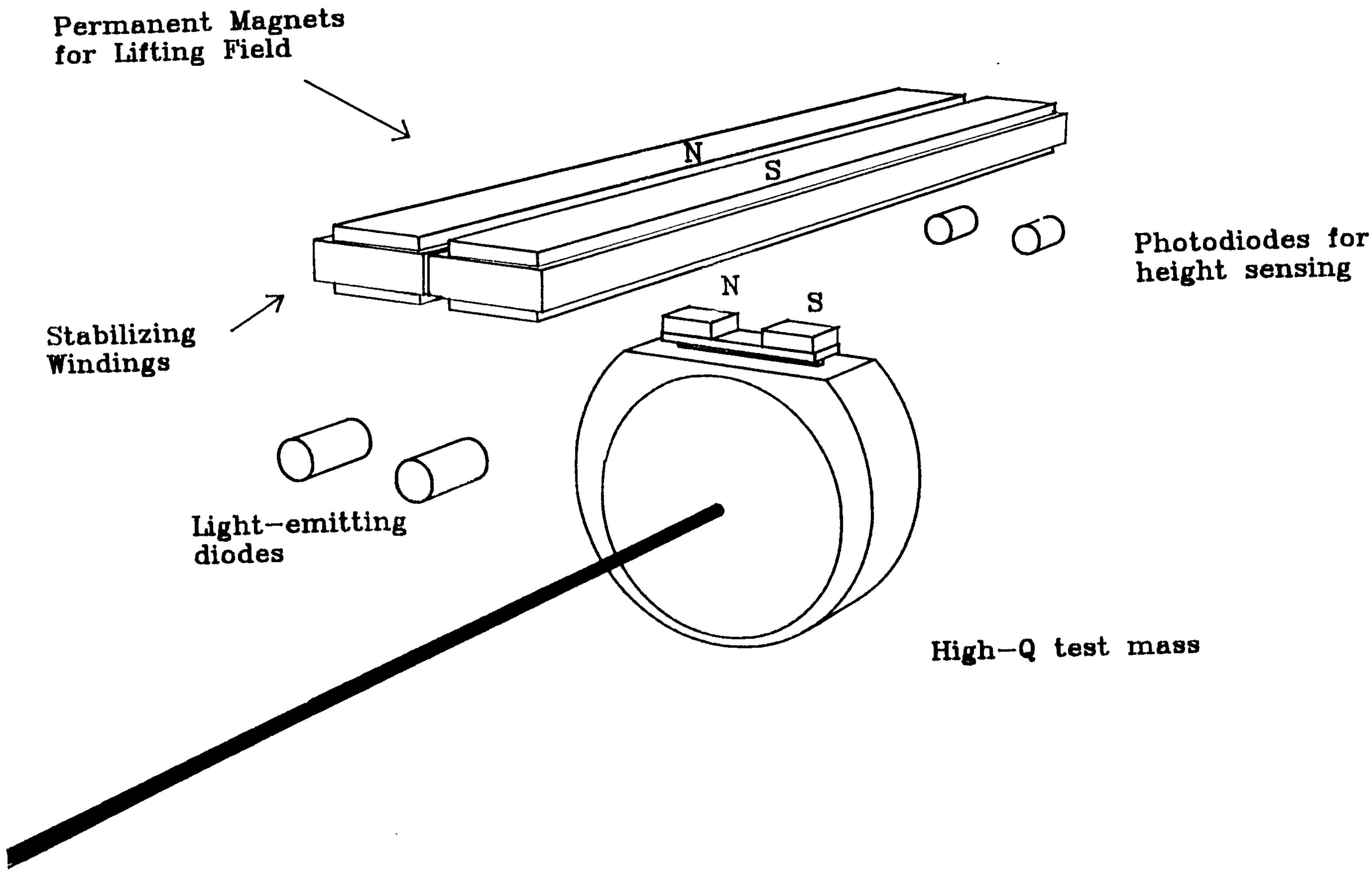
VERTICAL 0.5 SEC.

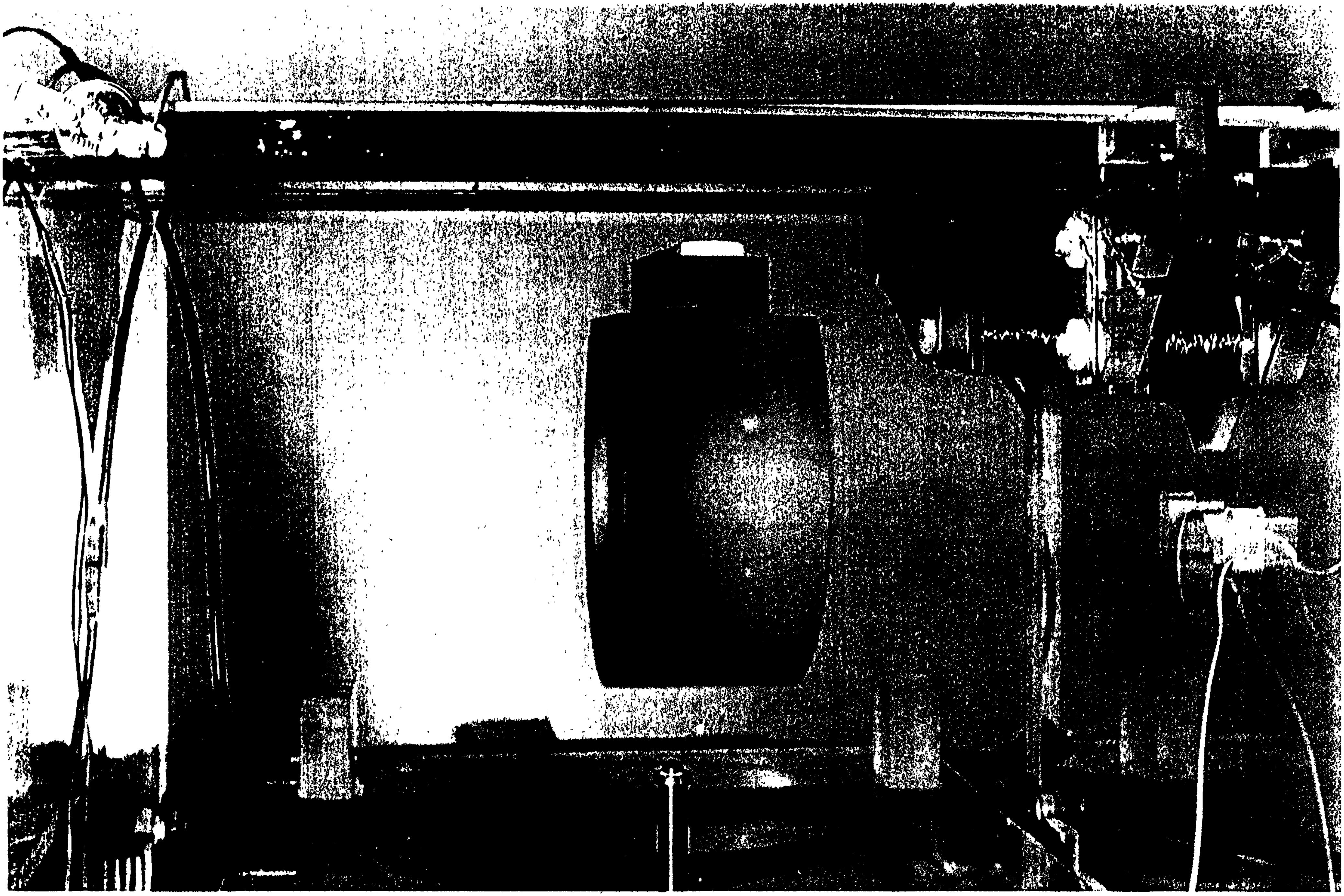
(CAN BE MADE LONGER BY TRIMMING FIELDS AND SERVO RESPONSE)

BUILT AND TESTED BY S. AUGST.

Magnetically Levitated Test Mass

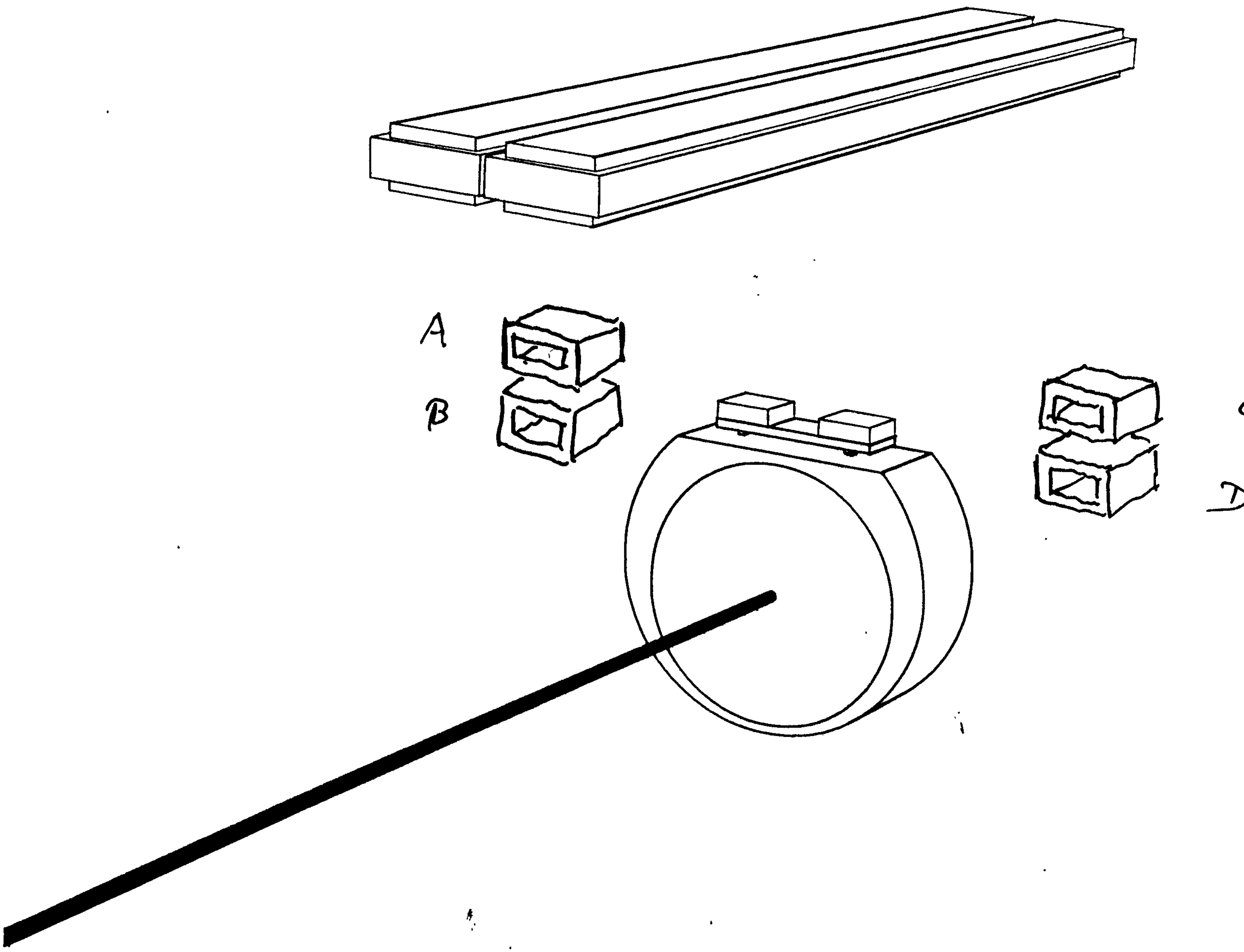
"QUADRUPOLE" VERSION – 2 MAGNETS ON MASS





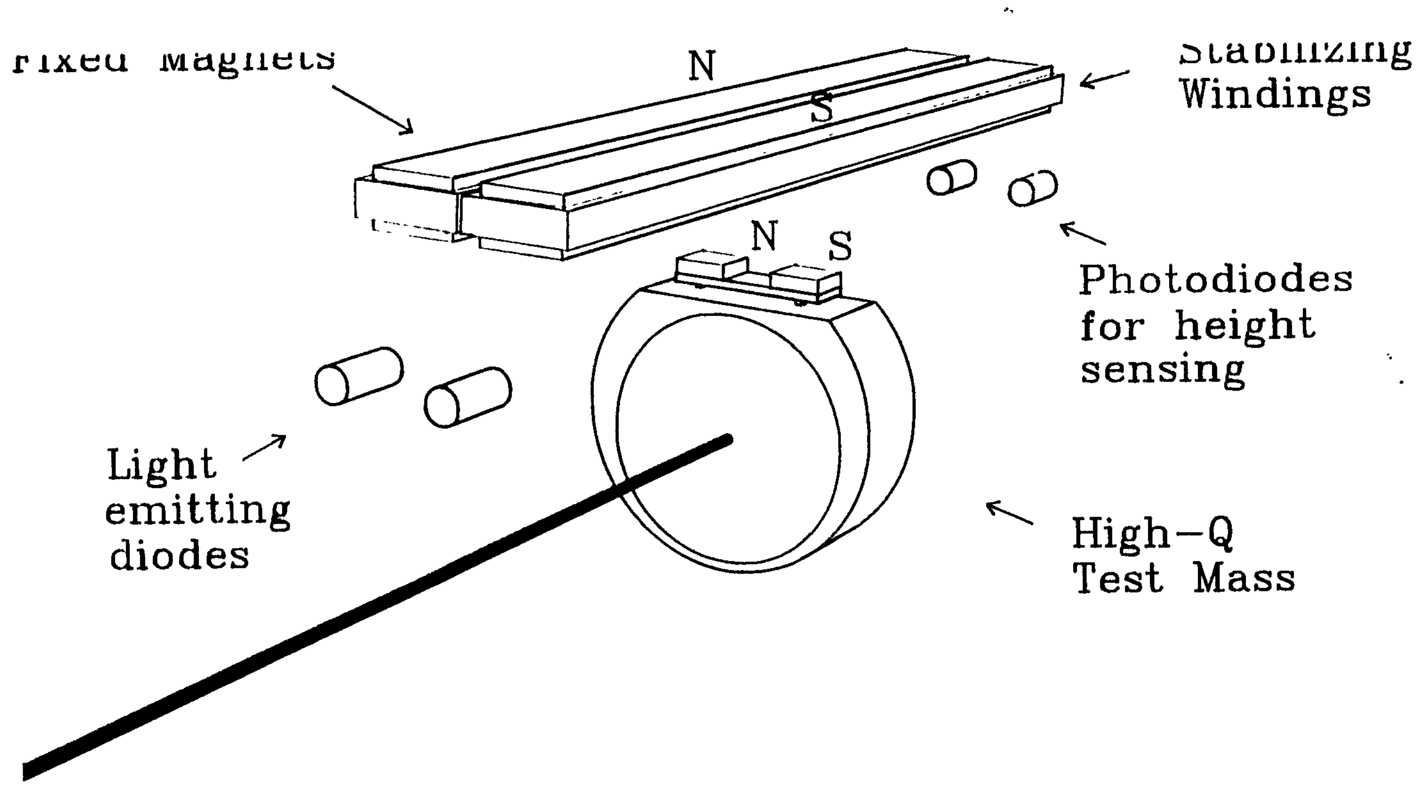
(E) - PAC 8

TEST MASS LEVITATION SYSTEM :— FINE CONTROL OF MIRROR ROTATION, TILT, AND LONGITUDINAL POSITION, BY AUXILIARY COILS A, B, C, D.



PAC 9

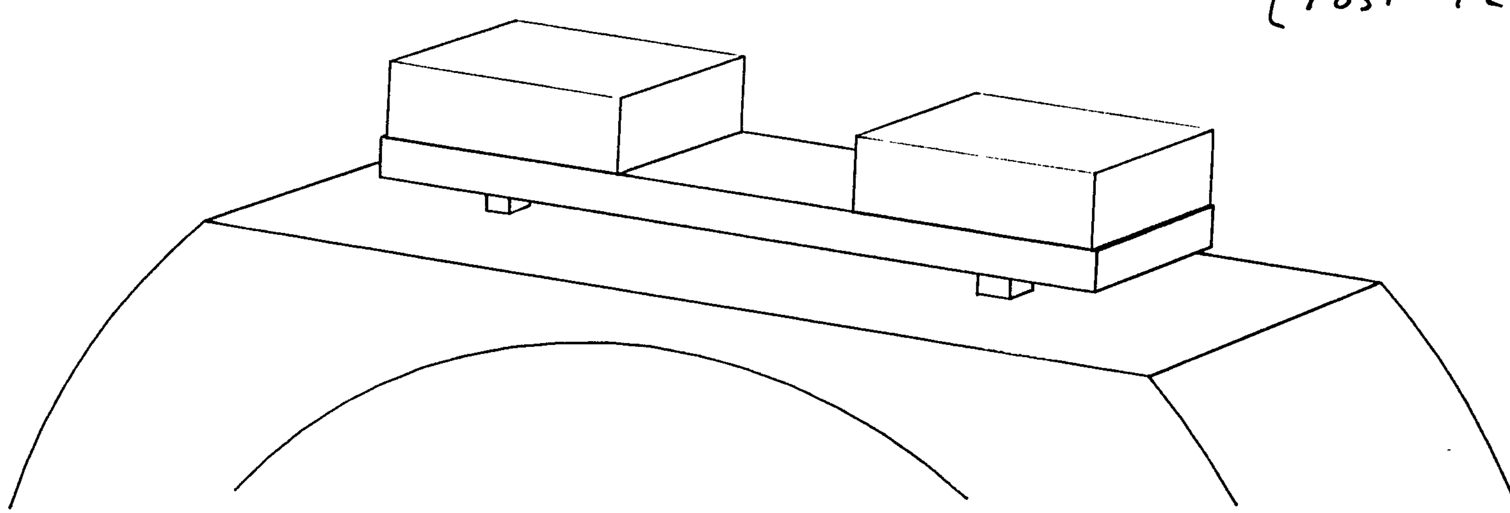
TIL



PAC 10

Enlarged view of top of Test Mass

(POST FLEXURE VERSION)



(15)

nsf5

EXPERIMENTAL FINDINGS
with 1-magnet and 2-magnet versions test mass systems

1) Natural period depends on non-uniformity of support magnet(s).

   Typical period   8 seconds –> 12 seconds

   with simple trim   –> 20 seconds

2) Relaxation Time (Horizontal mode)

   Typical in range 8 to 18 hours

   (under investigation – preliminary only)

   Typically longer with insulating magnets on mass (ceramic) than conducting (rare-earth) (by factor <2).

3) Stabilizing Power   << 1 mw

   Typical ~50 microwatts

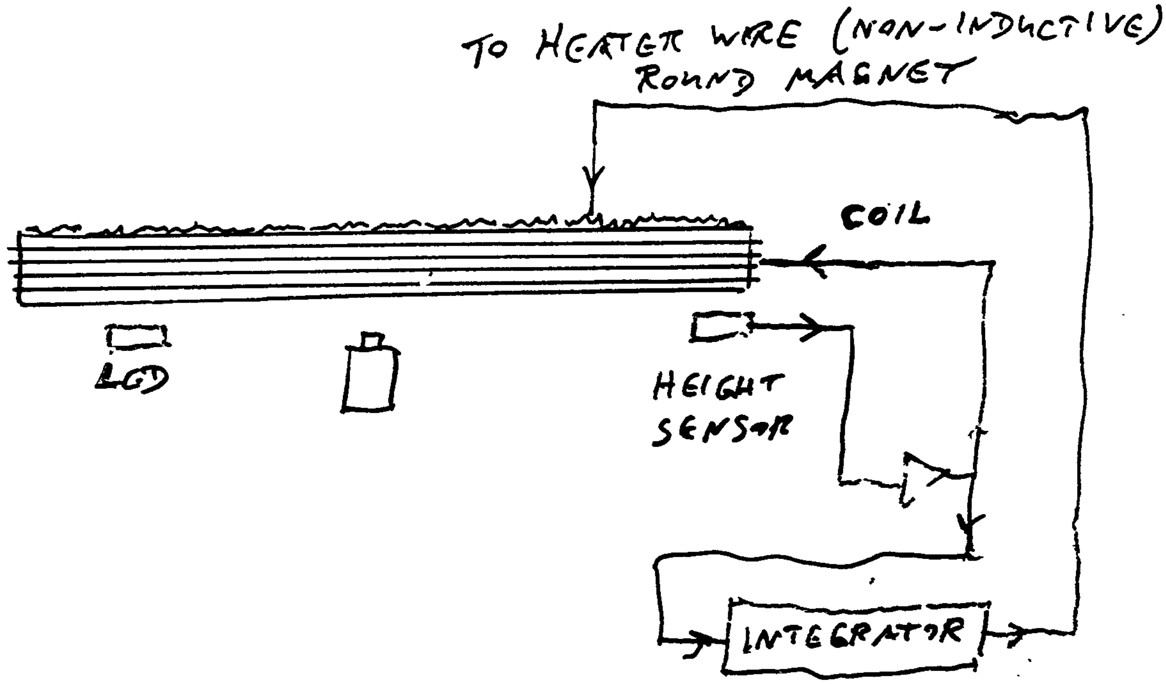
4) Permanent magnets have temp coefficient.

   Equilibrium height function of room temperature.

   Now using servo to control field via temperature.

5) Thermal Noise Plans

CONTROL OF MAGNETIC FIELD
VIA MAGNET TEMPERATURE.

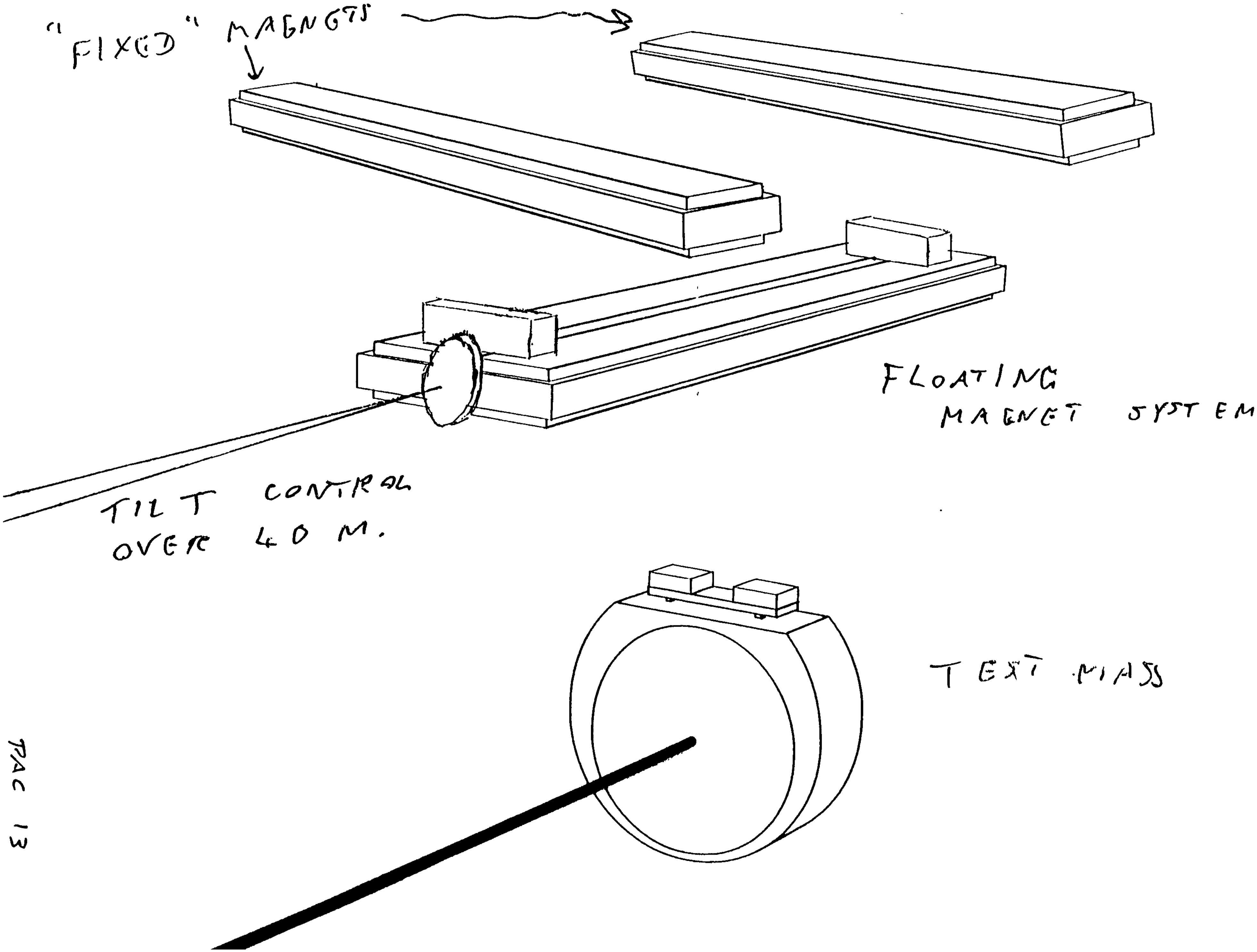


(INTEGRATE COIL VOLTAGE OVER MINUTES → TO DRIVE MEAN VALUE TO ZERO)

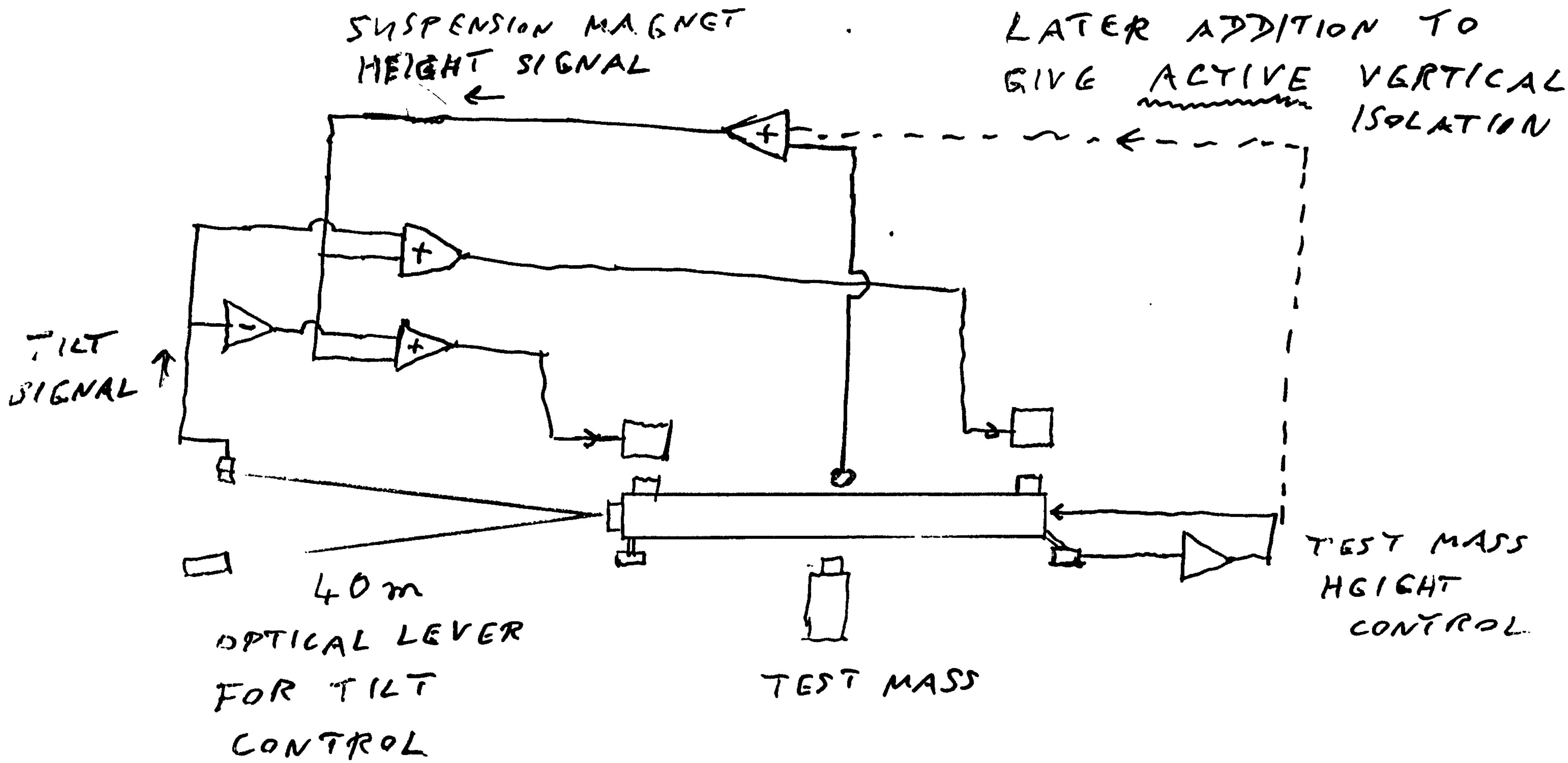
2 EFFECTS:-

① KEEPS COIL POWER << 1 mW

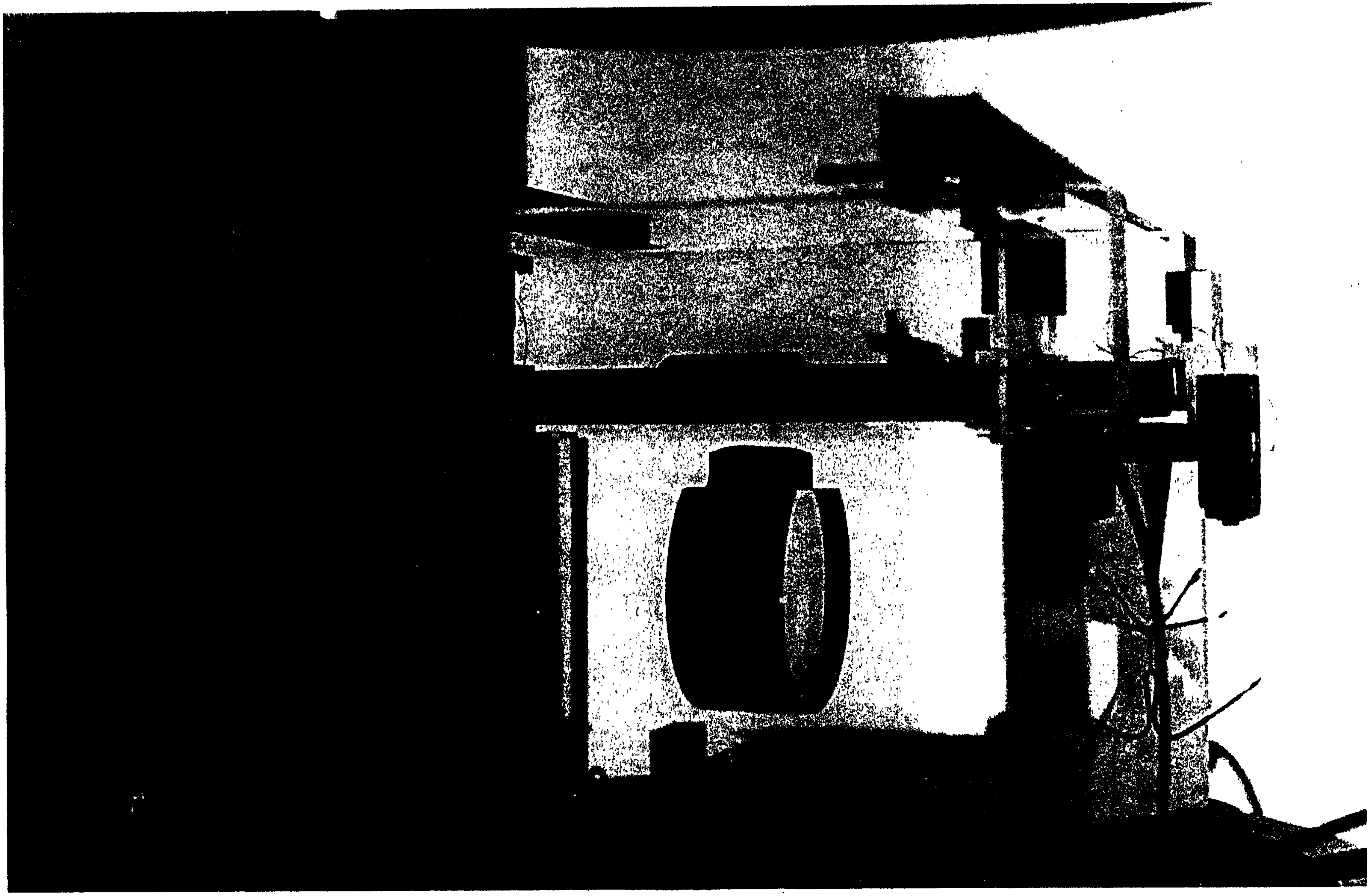
② KEEPS HEIGHT OF TEST MASS CONSTANT INDEPENDANT OF AMBIENT TEMPERATURE


"FIXED" MAGNETS
FLOATING
MAGNET SYSTEM
TILT CONTROL
OVER 40 M.
TEXT MASS

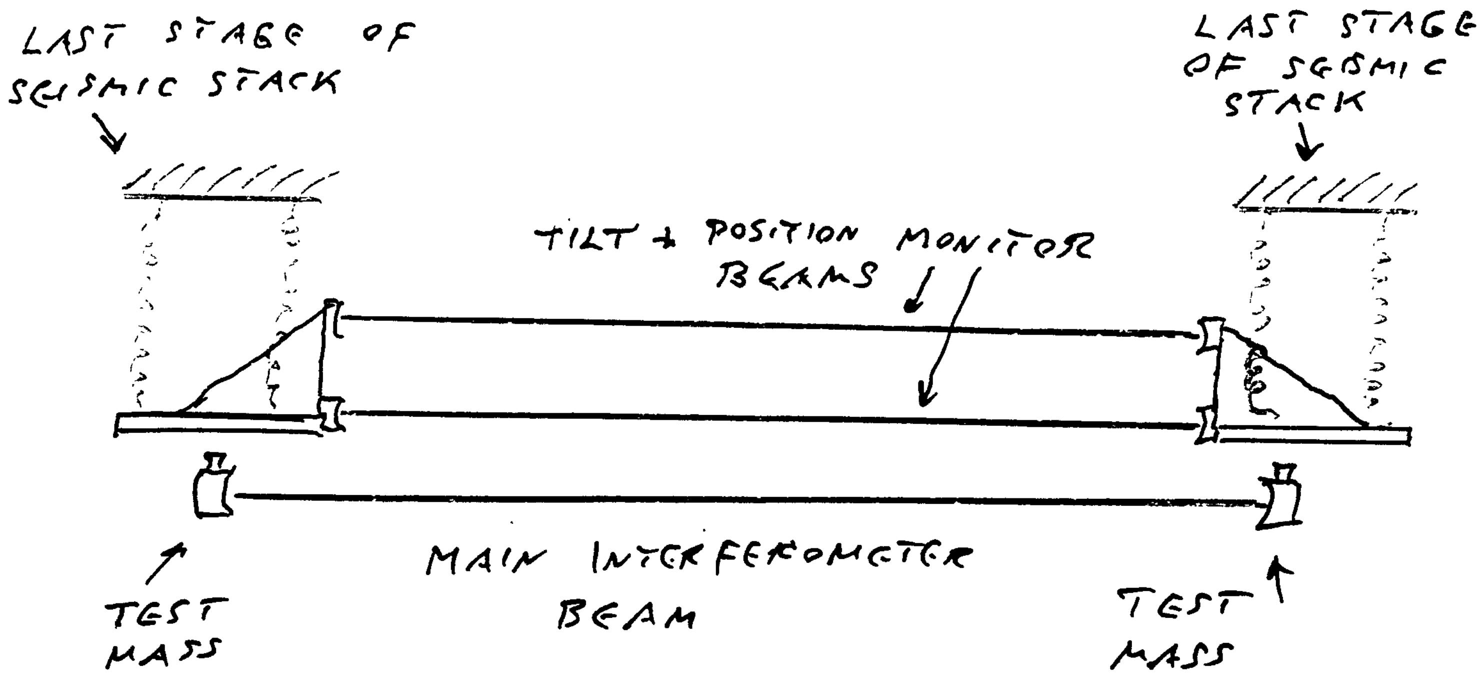
SUSPENSION SYSTEM LEVITATED FROM ISOLATION STAGE



(UNDER CONSTRUCTION NOW.)



PAC 15.



TILT-COUPLED SUSPENSIONS — MAGNETIC LEVITATION EXAMPLE.

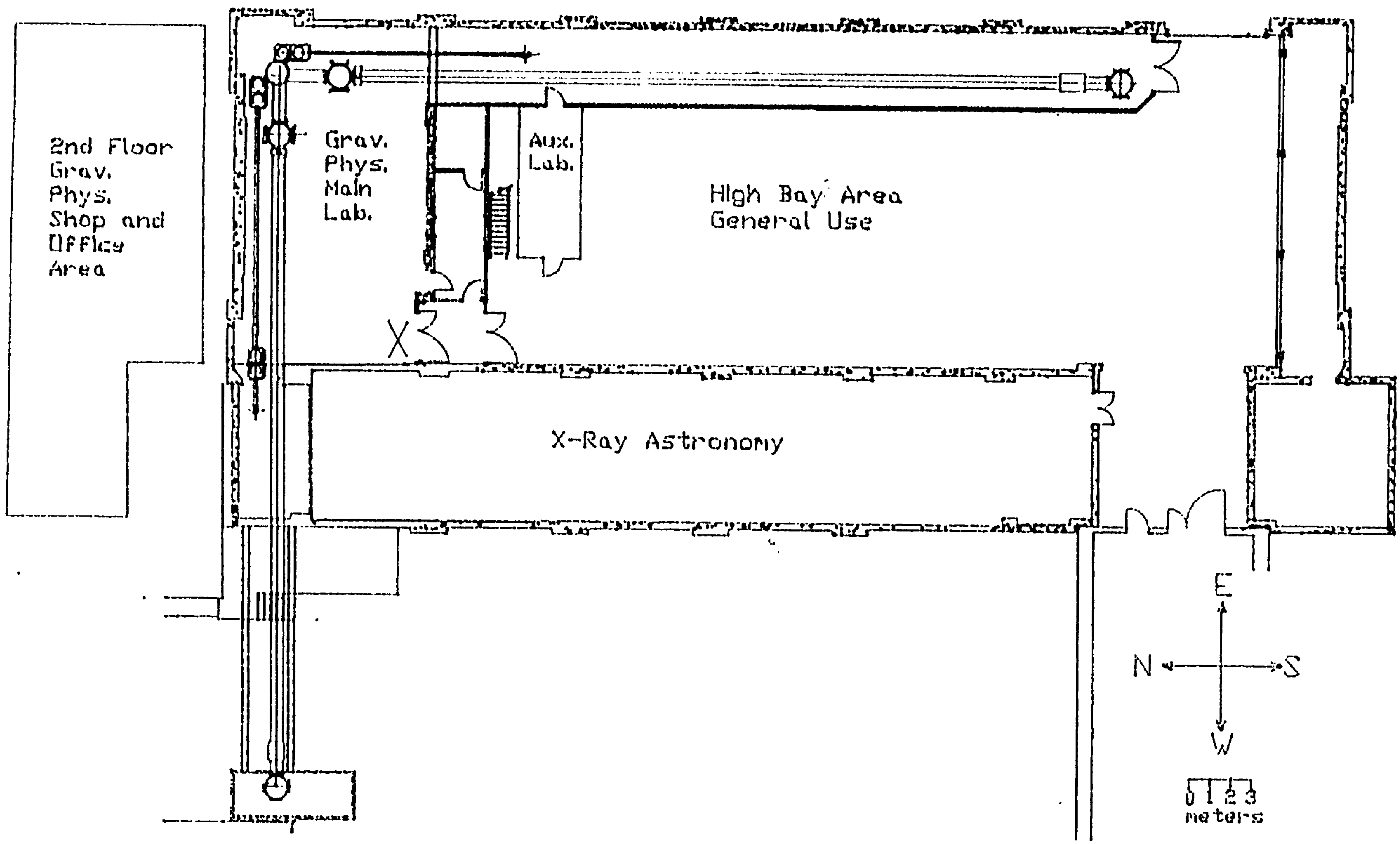


Fig. 16. Simplified layout of new laboratories and facilities planned for this project.

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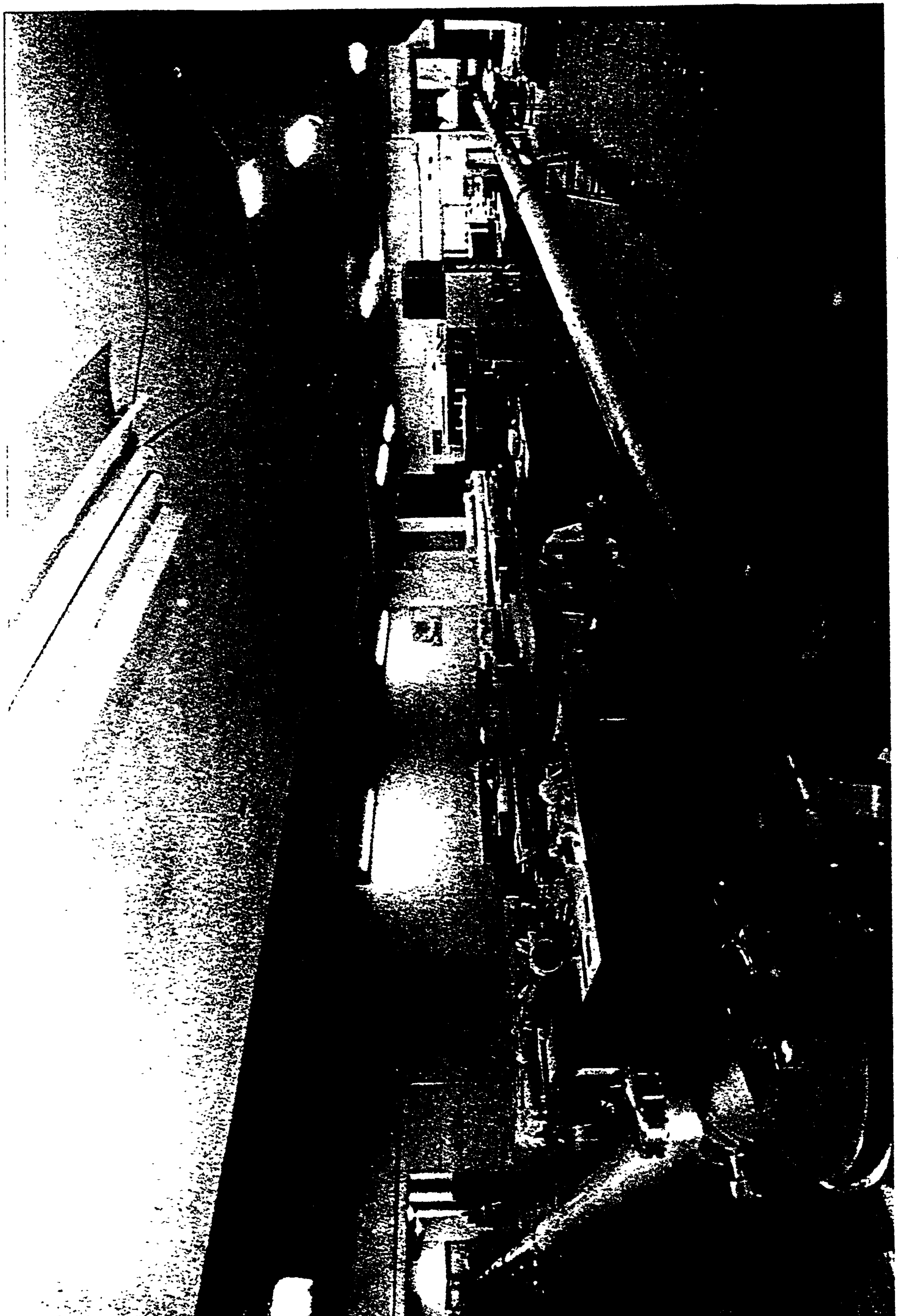

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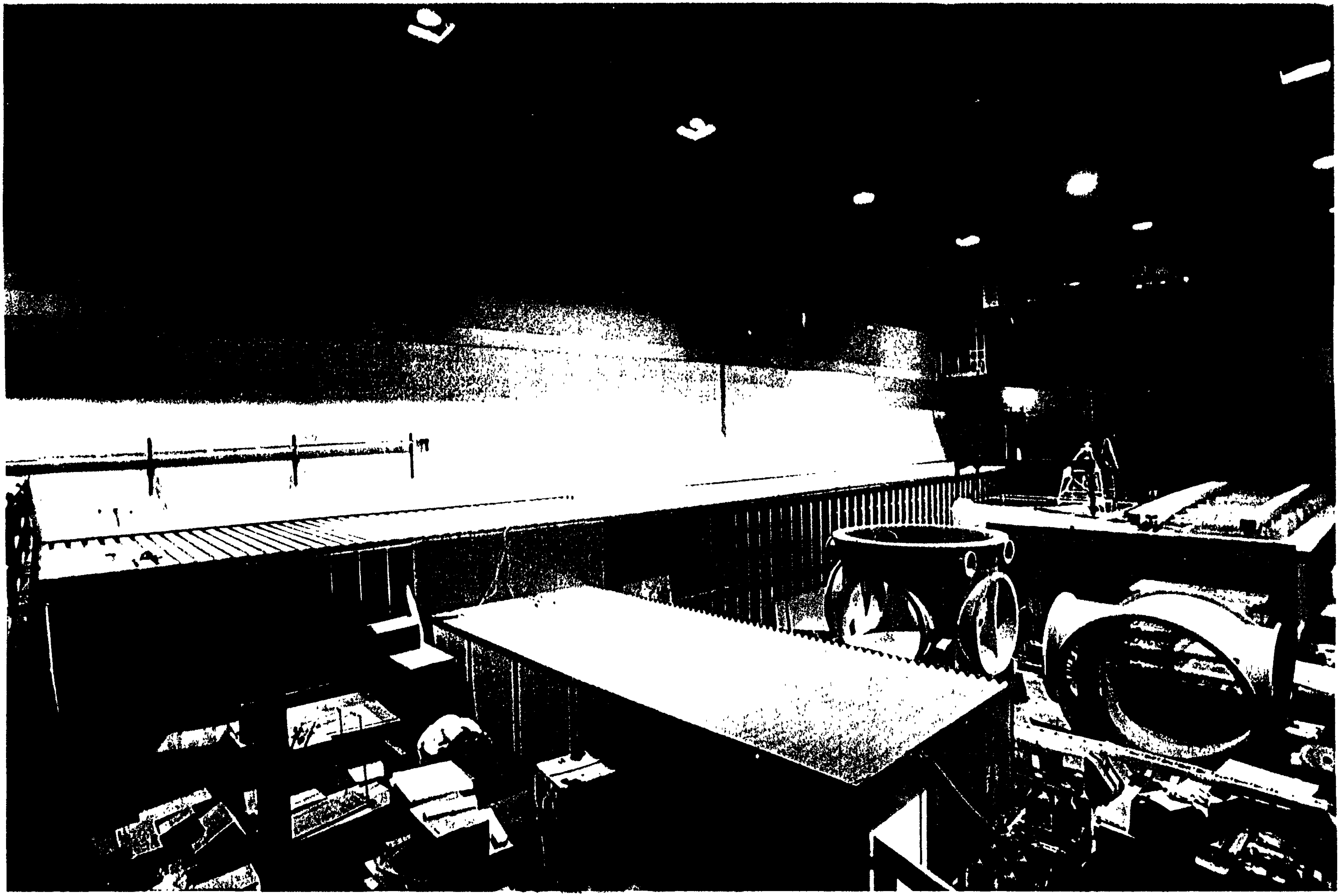
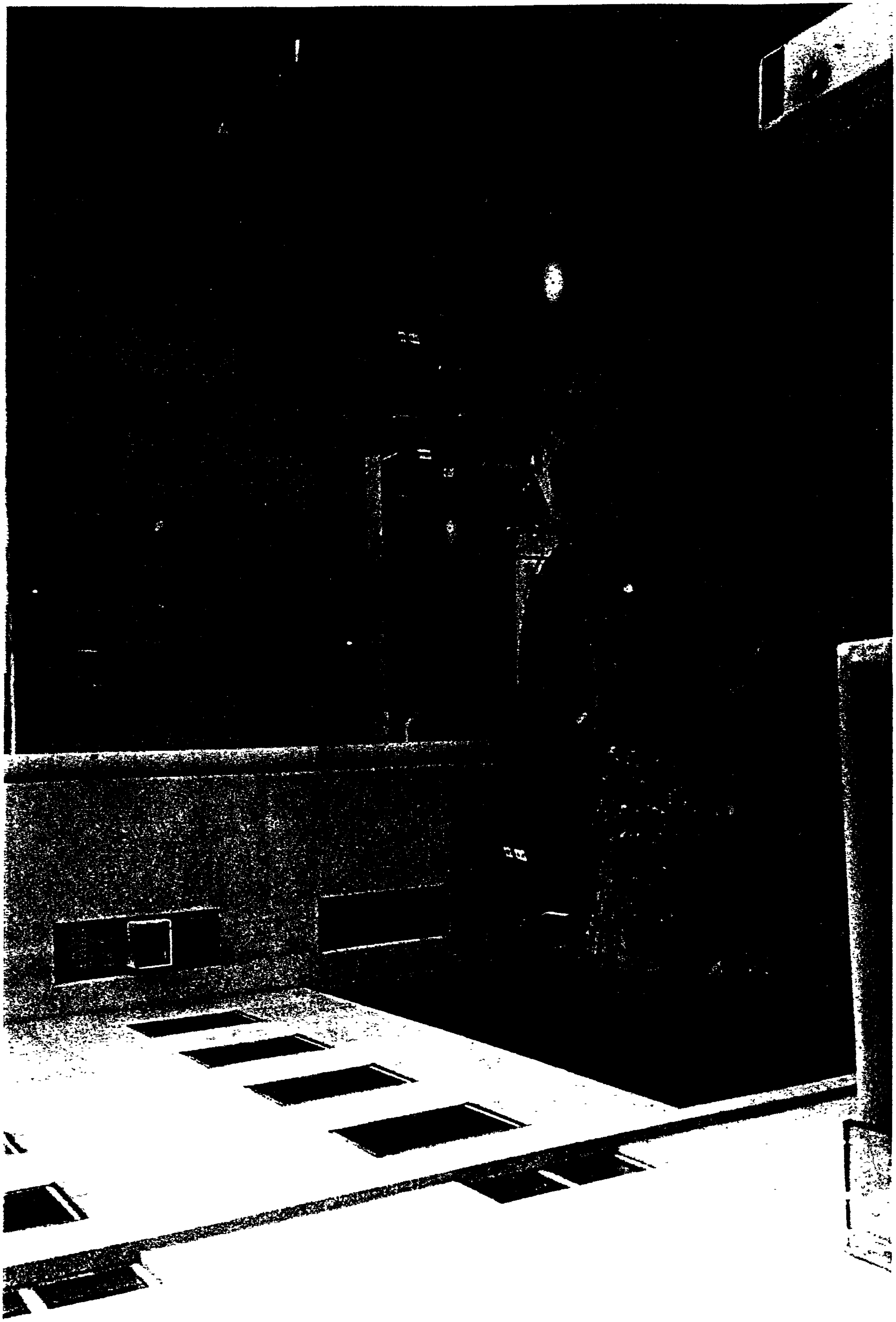
PAC 18

(20)



PAC 19

PAC 19



PAC 20

INITIAL EXPERIMENTAL PLAN

Low Frequency Interferometers

1. Assemble and begin testing levitated test mass suspension — dummy masses.

2. Extend to 2 levitated stages.

3. Duplicate, make first differential measurements with simple interferometer (low frequencies).

4. Build up 2-arm system to improve sensitivity of tests.

5. Extend interferometer to multi-bounce system to allow higher frequency tests.

6. Develop high-performance system for sensitive noise studies.

When practicable (~ Step 4), set upper limit to gravity gradient background.

Diffractive Optics Interferometer

- Fit in when system is good enough (~ Step 5).

OVERALL AIM:

To explore and develop wider-range interferometers as rapidly as build up of personnel and equipment allows.

Eventually expected to lead to significant advances in gravity-wave research.

Diffractive-Coupled Interferometers

- proposed new technique aimed at improved power-handling capability and thermal noise.

Basic Concept: Couple light into and out of cavities and interferometer arms by diffraction grating pattern on mirrors of tes masses or beamsplitters

- to divide wavefront by diffraction instead of transmission

Possible Advantages: No need to pass light through test masses or beamsplitters, so -

1. Can select materials for high Q , and if needed good thermal conductivity / expansion properties
   - without any transparancy constraint

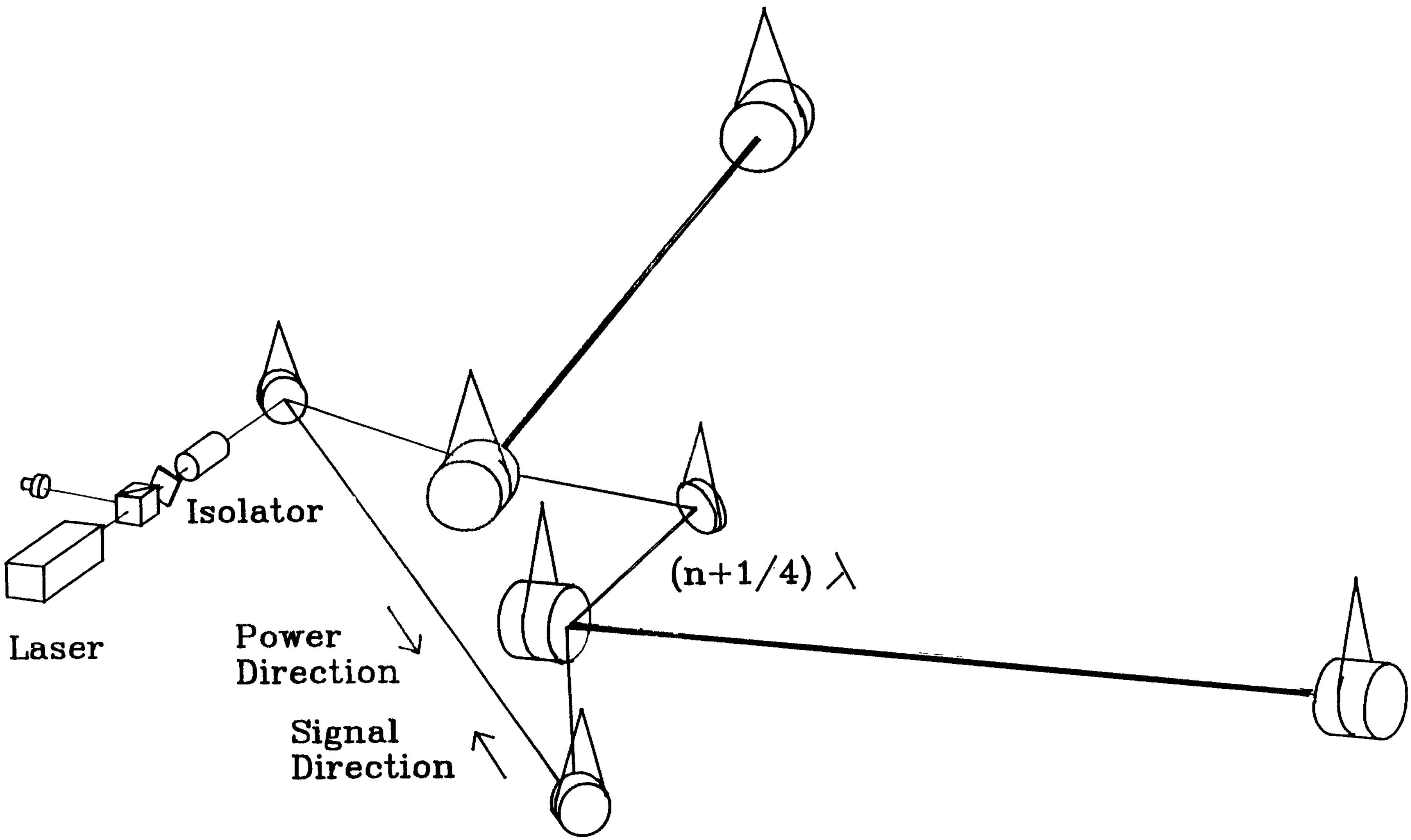
2. Thermal lensing eliminated , leaving thermal expansion as the only thermal effect - so higher light power is practicable

3. Power dissipation reduced, as transmission losses eliminated
   - reduces thermal distortions further

4. Reduction in power dissipation makes cryogenic test masses more practicable
   - improving possibility of getting higher Q than at room temperature, and possibility of further reduction in thermal noise.

PAC 22 (SKIPPED)

PAC 23 (SKIPPED)



(Diagram shows main beams only)

DIFFRT1
5/8/?4 RD

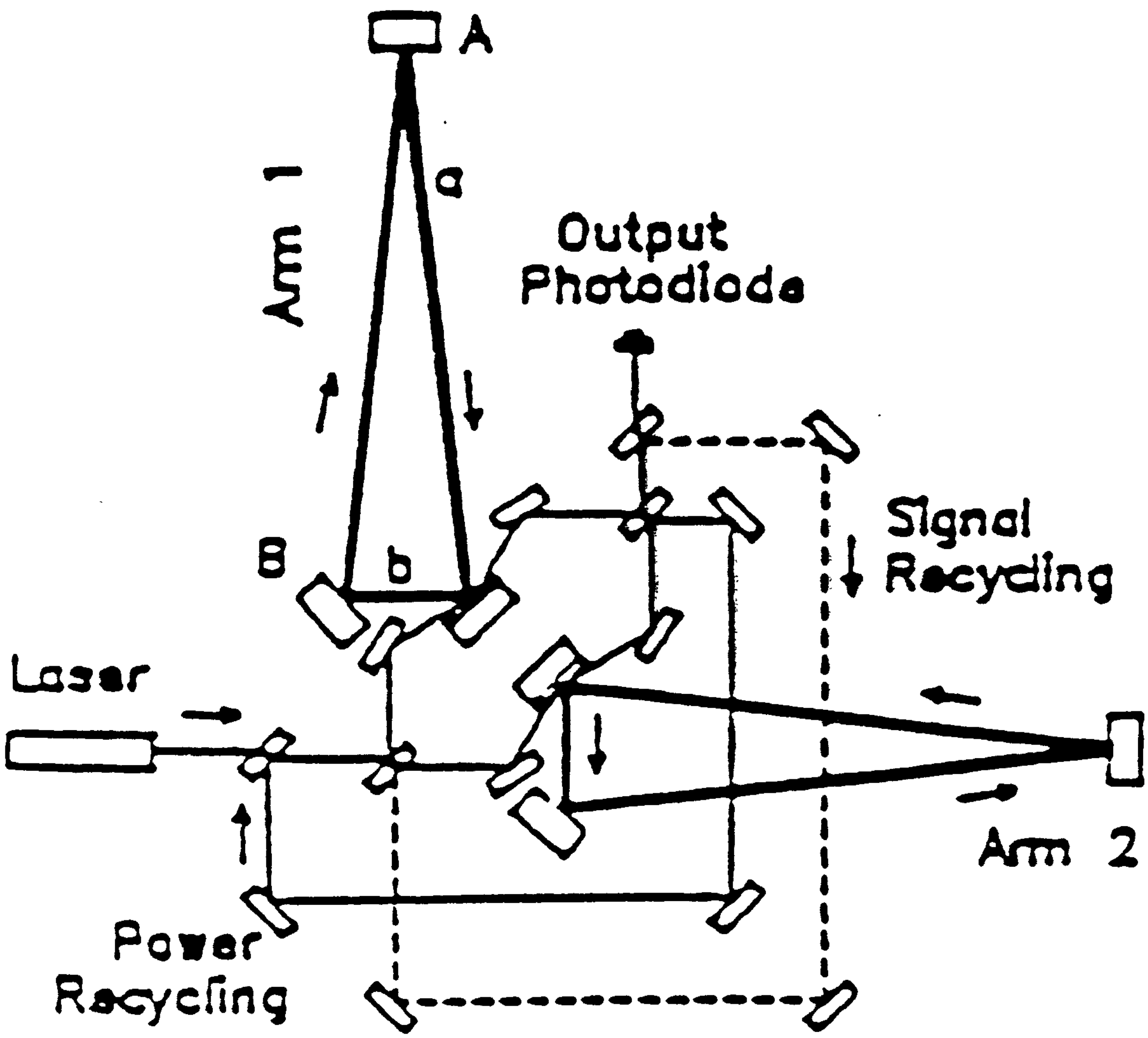


Fig.13.

PAC 25 (SKIPPED)