LIGO-G990079-29-M

Ambient and Diagnostic Magnetic Fields Measured inside of a BSC Vacuum Chamber at Hanford

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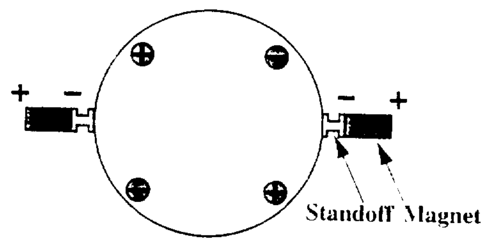
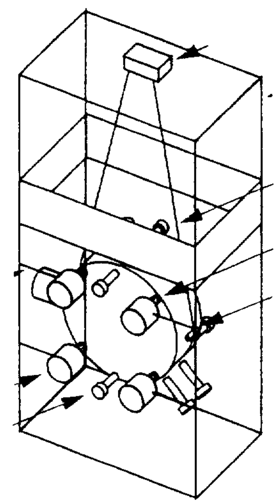
INTRODUCTION

Why measurements of ambient fields ?

- Magnets on the optics may couple optic motion to time-varying ambient magnetic fields.





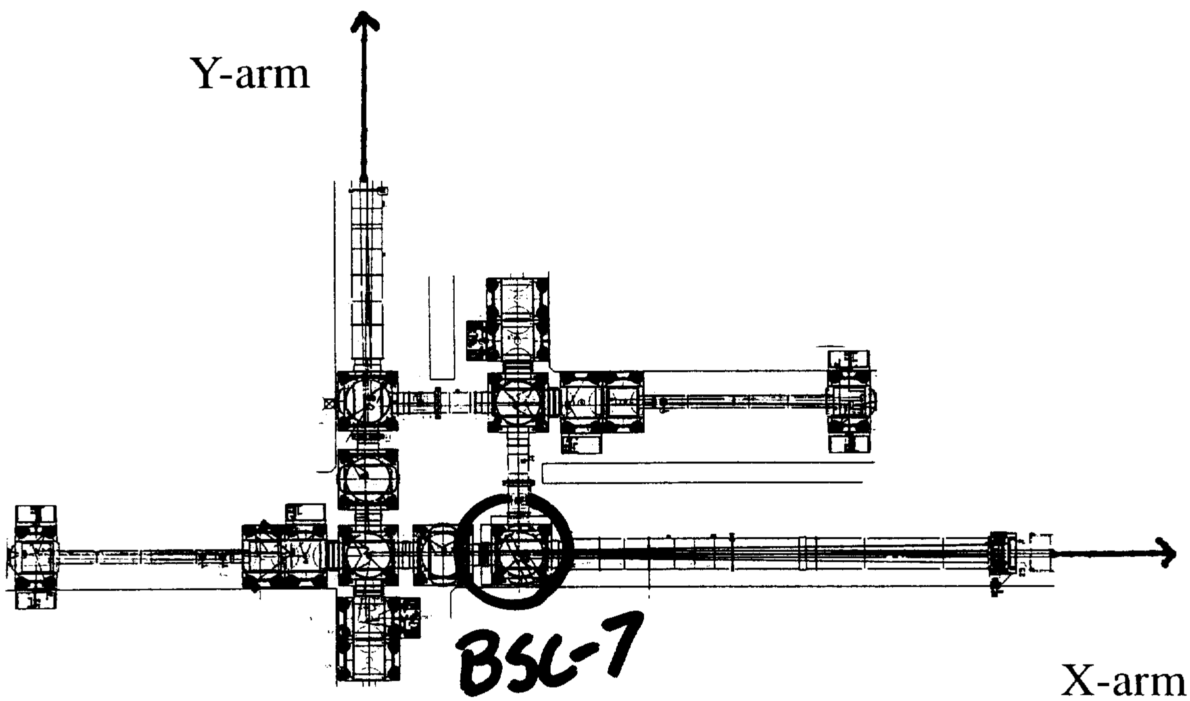
$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

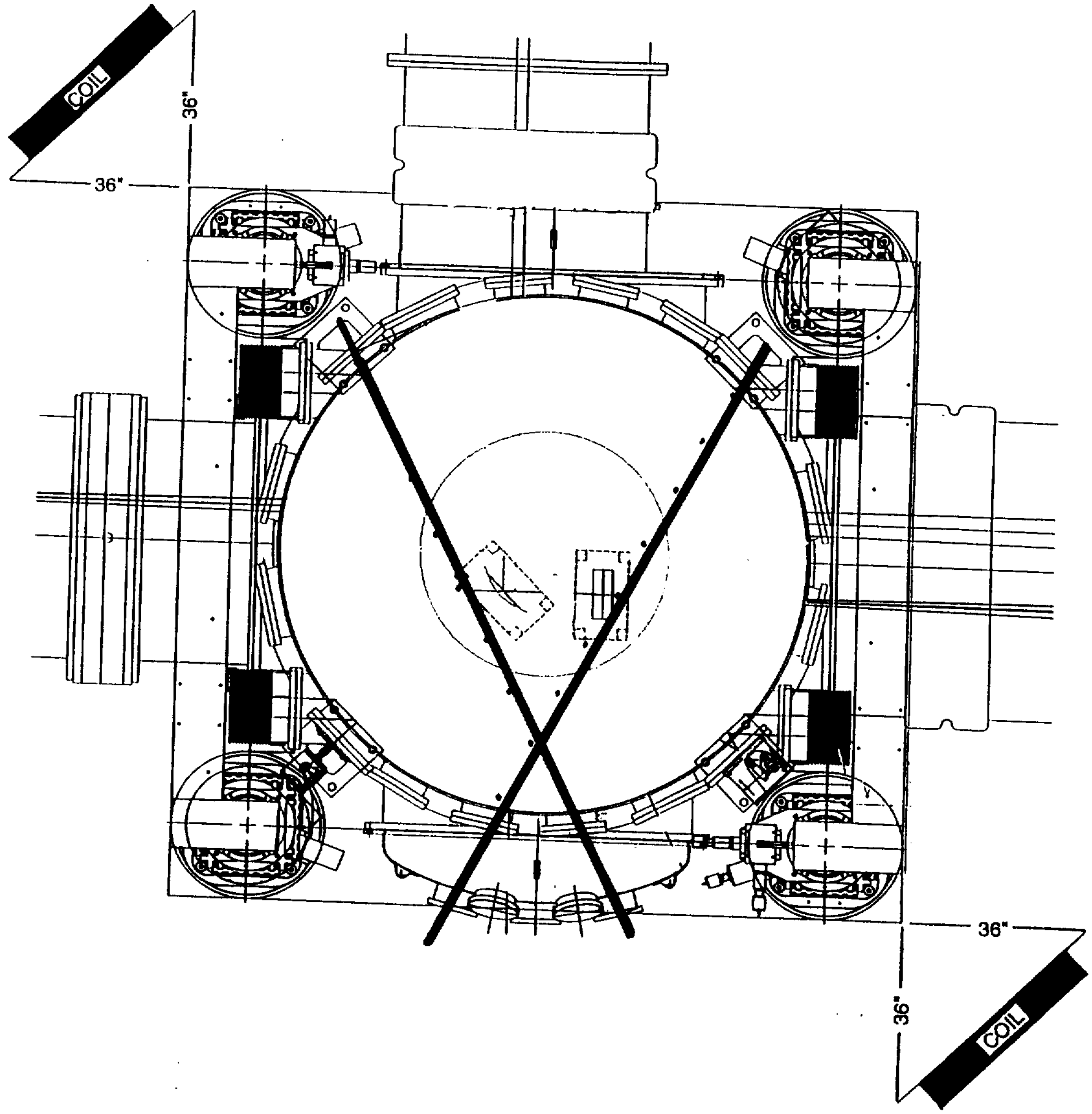
$$\vec{F} = (\vec{\mu} \cdot \vec{\nabla})\vec{B}$$

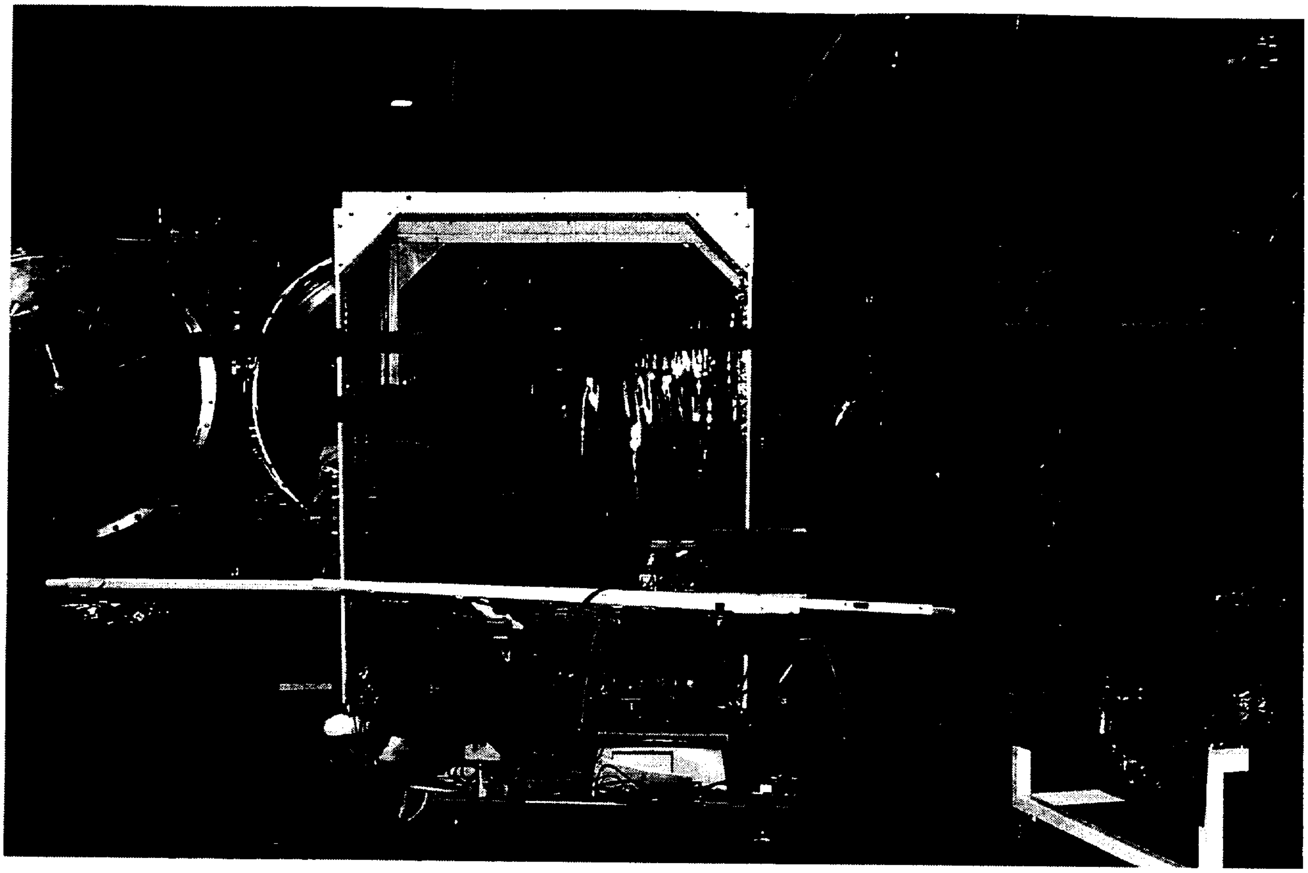
Why measurements of fields generated by external coils (diagnostic fields)?

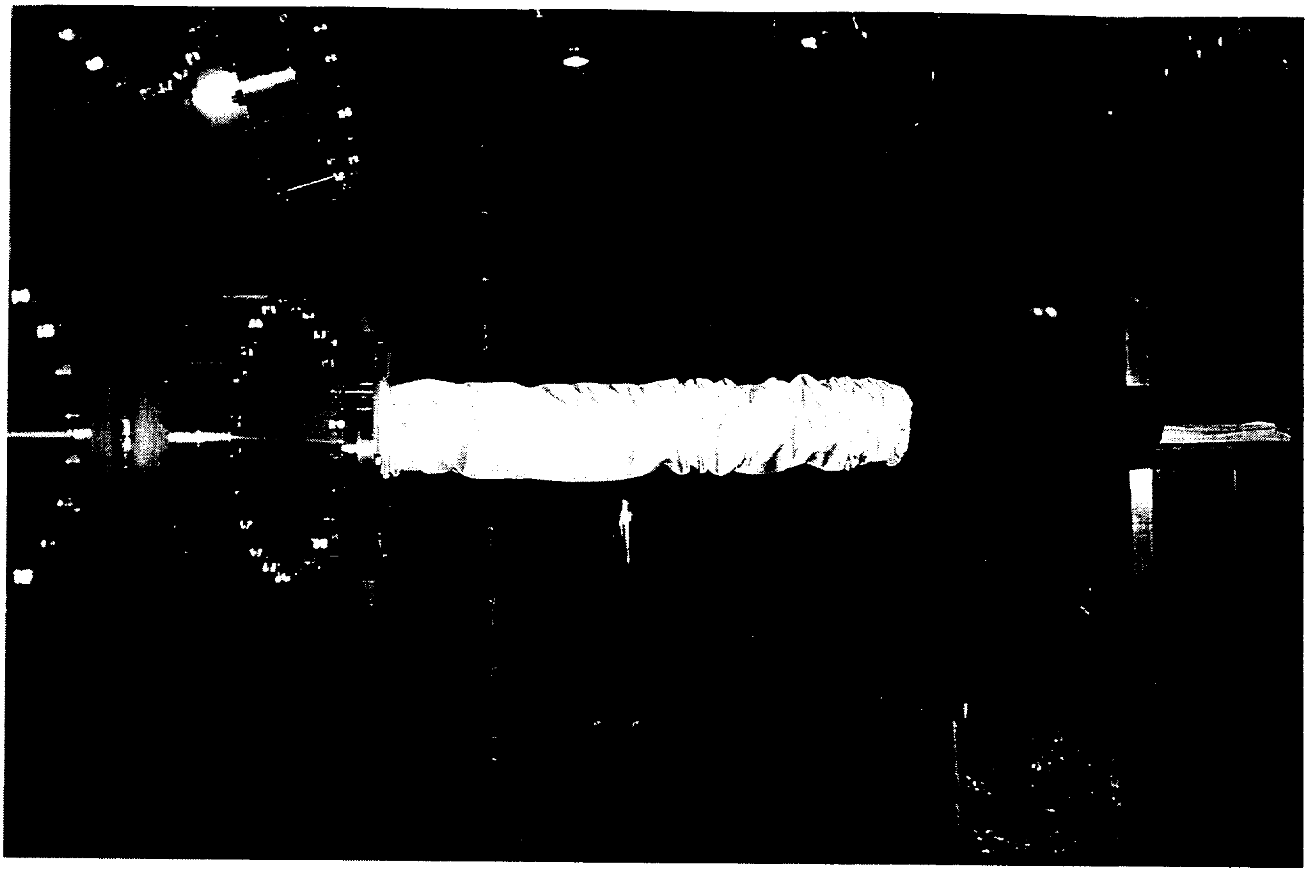
- Obtain approximate transfer function from outside to inside of chamber.

- Map out field from standardized coil position for future shaking of optics.


Y-arm
BSC-7
X-arm


COIL
36"
36"
36"
36"
COIL

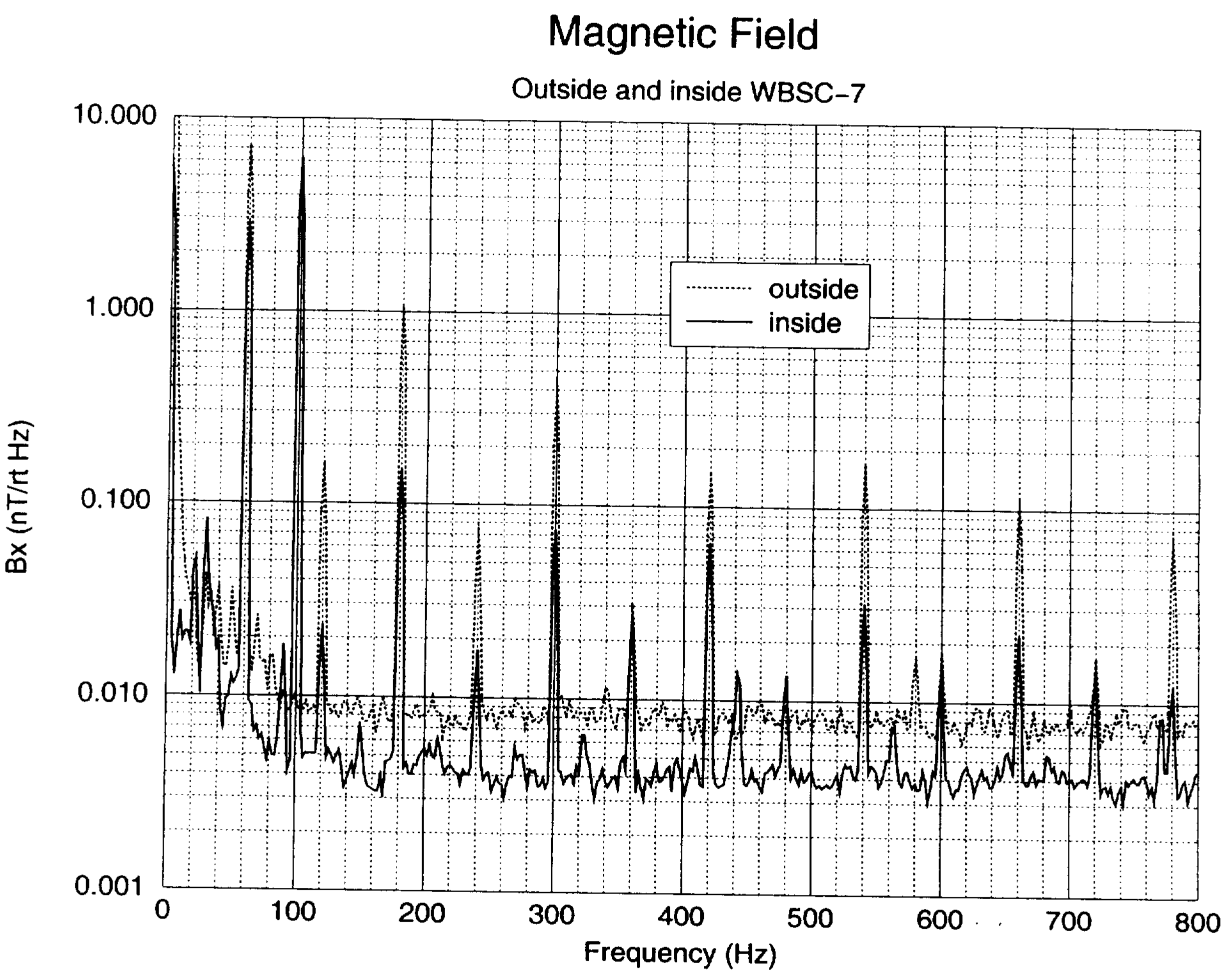




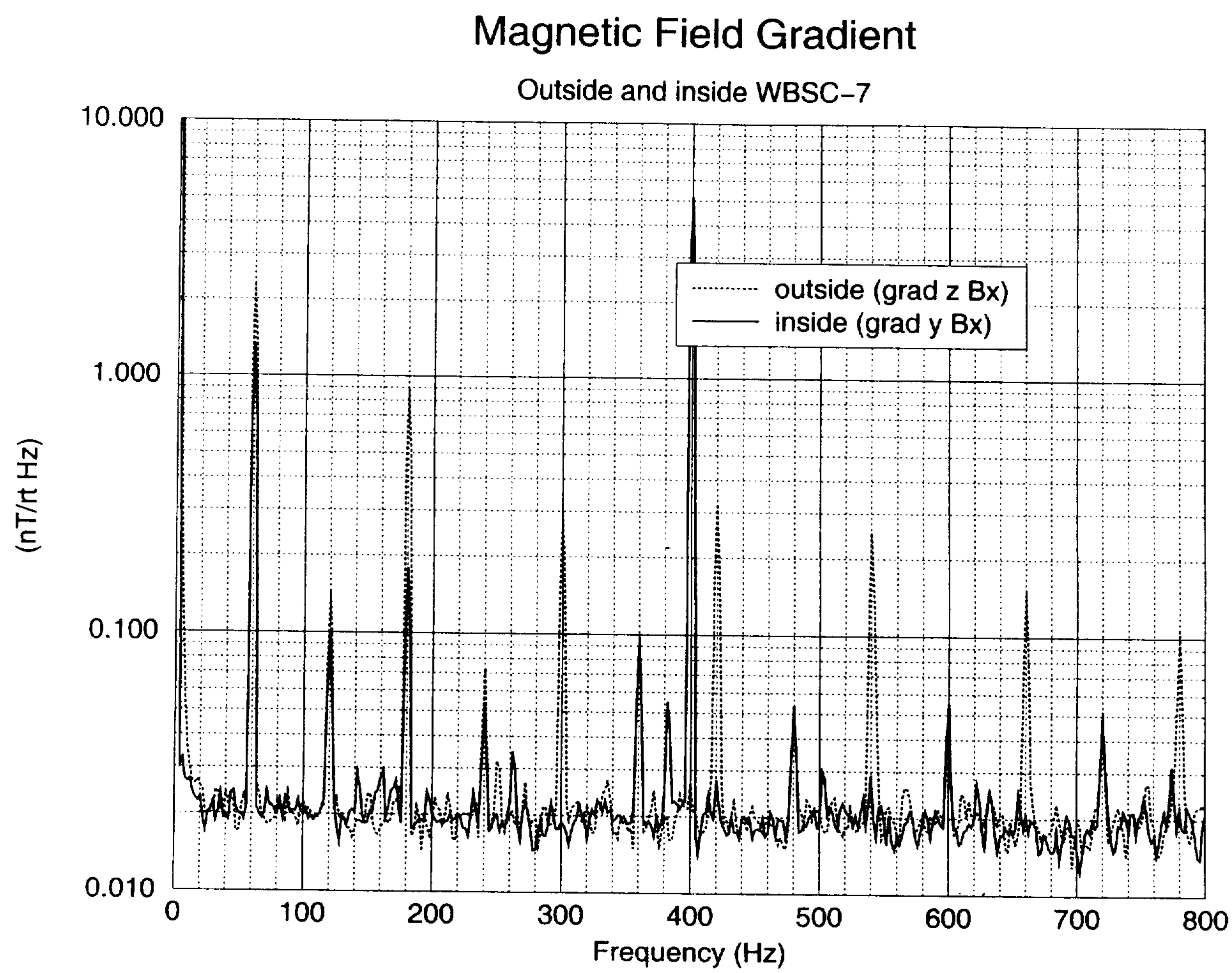
EXPERIMENTAL

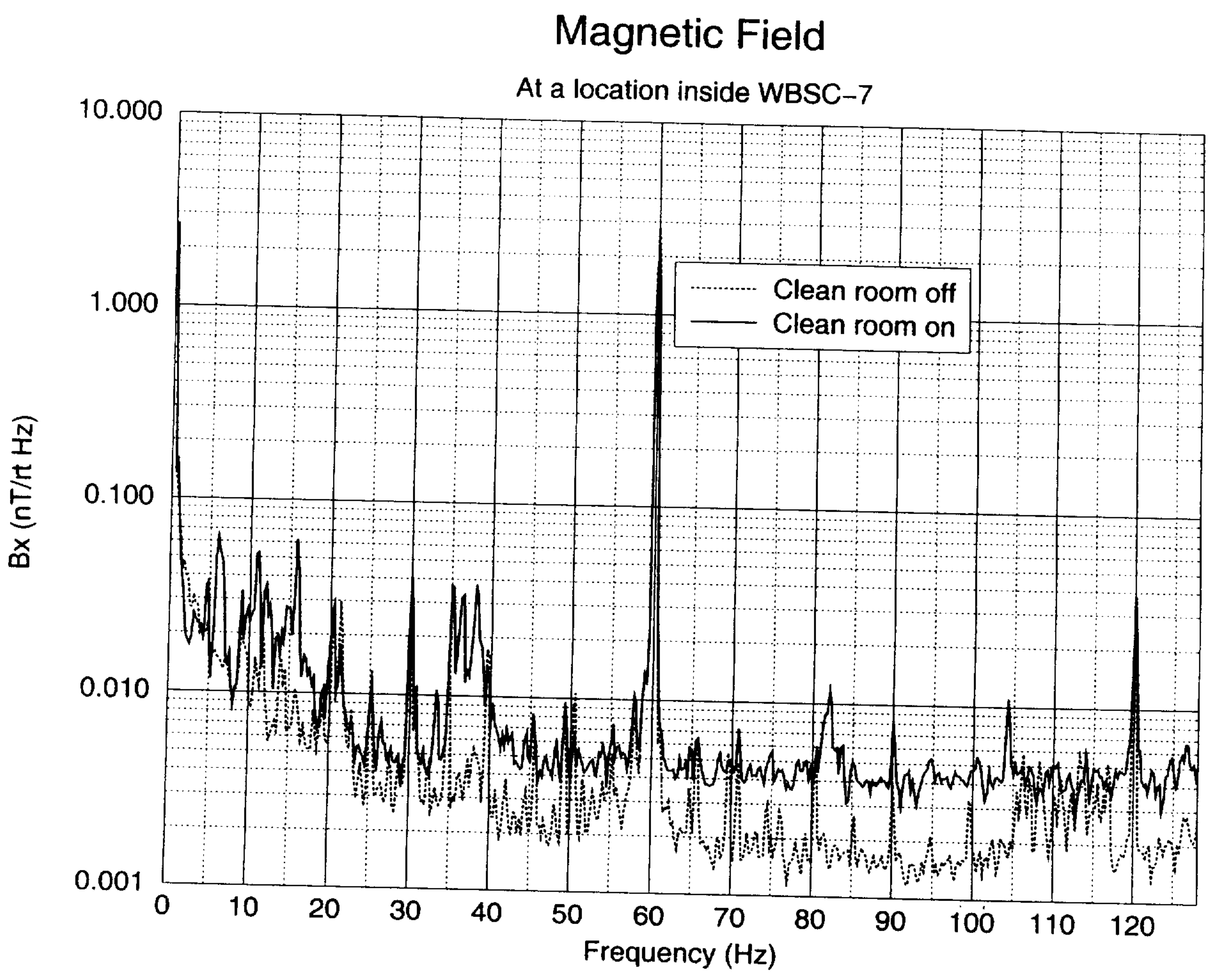
Equipment:

- Two Bartington MAG03 magnetometers. Signals subtracted for gradient measurements. Sensitivity: 3pT/sqrt Hz; 10 nT/mV
- Stanford SR560 preamps (3 nV/sqrt Hz input noise). A-B function used for gradient measurements.
- H. P. 35670A signal analyser (300 nV/sqrt Hz input noise).
- Two 1 m diameter, 10, 30, 60, 100 turn coils. Used in "pseudo-helmholtz" configurations to generate fairly uniform fields or field gradients in the chamber. Driven in series by a SRS DS345 function generator (10V p-p) or the HP 35670A (3V p-p) for swept sine measurements.
- Four inch A&M Composites filament wound, 610 resin, tube to minimize sag over 14' length
- Two sets of custom feed-through flanges. Type 1 to protect knife edges, type 2 for final positioning.
- Clean "sock" to cover tube in chamber.



Magnetic Field
Outside and inside WBSC-7
10.000
1.000
0.100
0.010
0.001
Bx (nT/rt Hz)
outside
inside
0
100
200
300
400
500
600
700
800
Frequency (Hz)

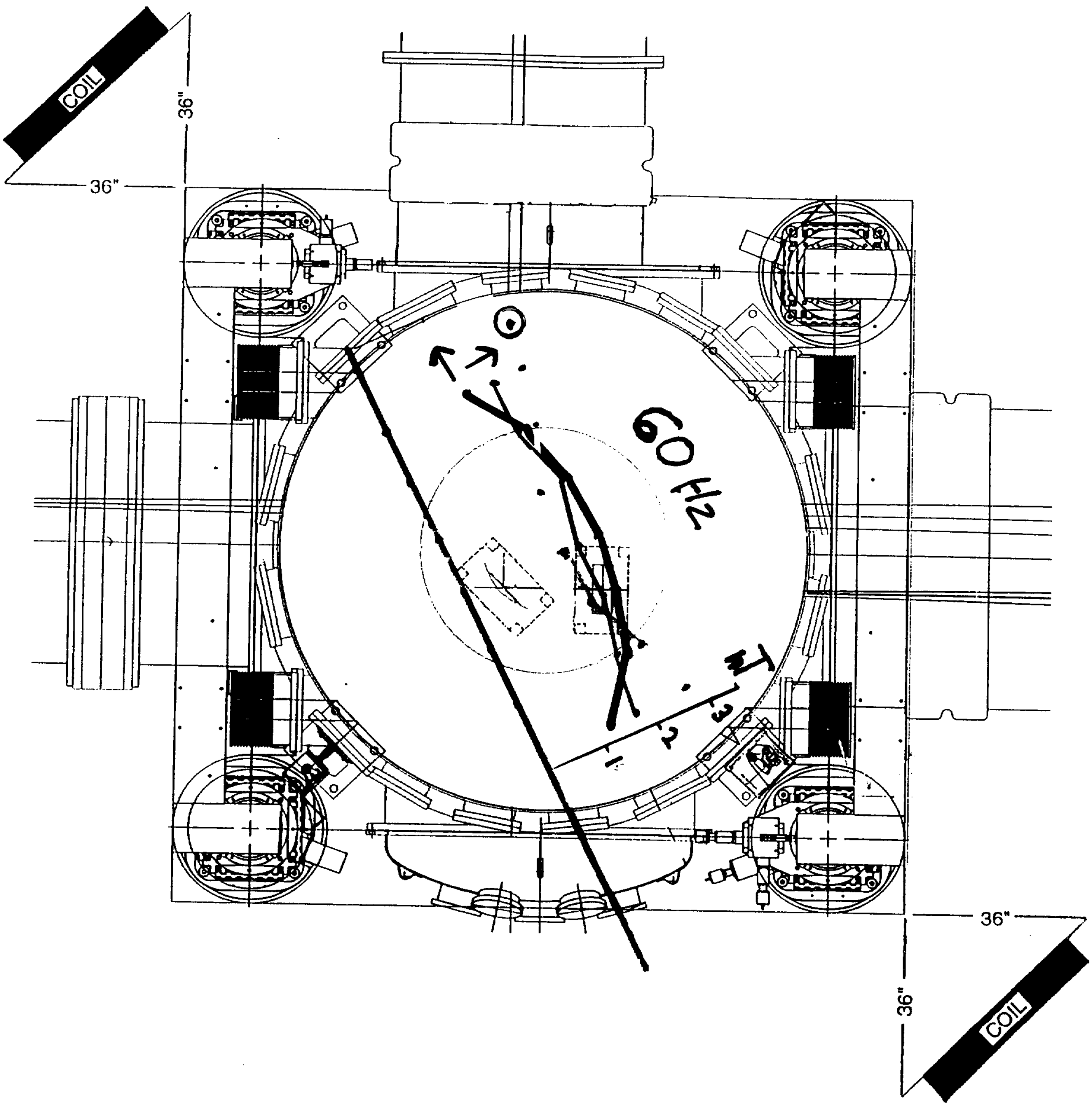

Magnetic Field Gradient
Outside and inside WBSC-7
10.000
1.000
0.100
0.010
(nT/rt Hz)
0
100
200
300
400
500
600
700
800
Frequency (Hz)
outside (grad z Bx)
inside (grad y Bx)


Magnetic Field
At a location inside WBSC-7
Clean room off
Clean room on
Bx (nT/rt Hz)
10.000
1.000
0.100
0.010
0.001
0
10
20
30
40
50
60
70
80
90
100
110
120
Frequency (Hz)

Instrument noise:
For gradient measurements, the lowest value obtained in repeated trials when the 2 magnetometers were placed as close together as possible - an upper limit. For field measurements, the lowest value obtained in repeated trials - also an upper limit.

Reproducibility:
Fractional uncertainty for seven tests: x axis: 0.023; y axis 0.069; z axis 0.004

Relative calibration for the two magnetometers:
x axis: 1.057; y axis: 0.993; z axis: 1.002



COIL
36"
36"
60 Hz
1
2
3
36"
36"
COIL

Estimations of displacement noise:
(after D. Coyne)

Displacement from force on unbalanced magnets in a B field gradient:

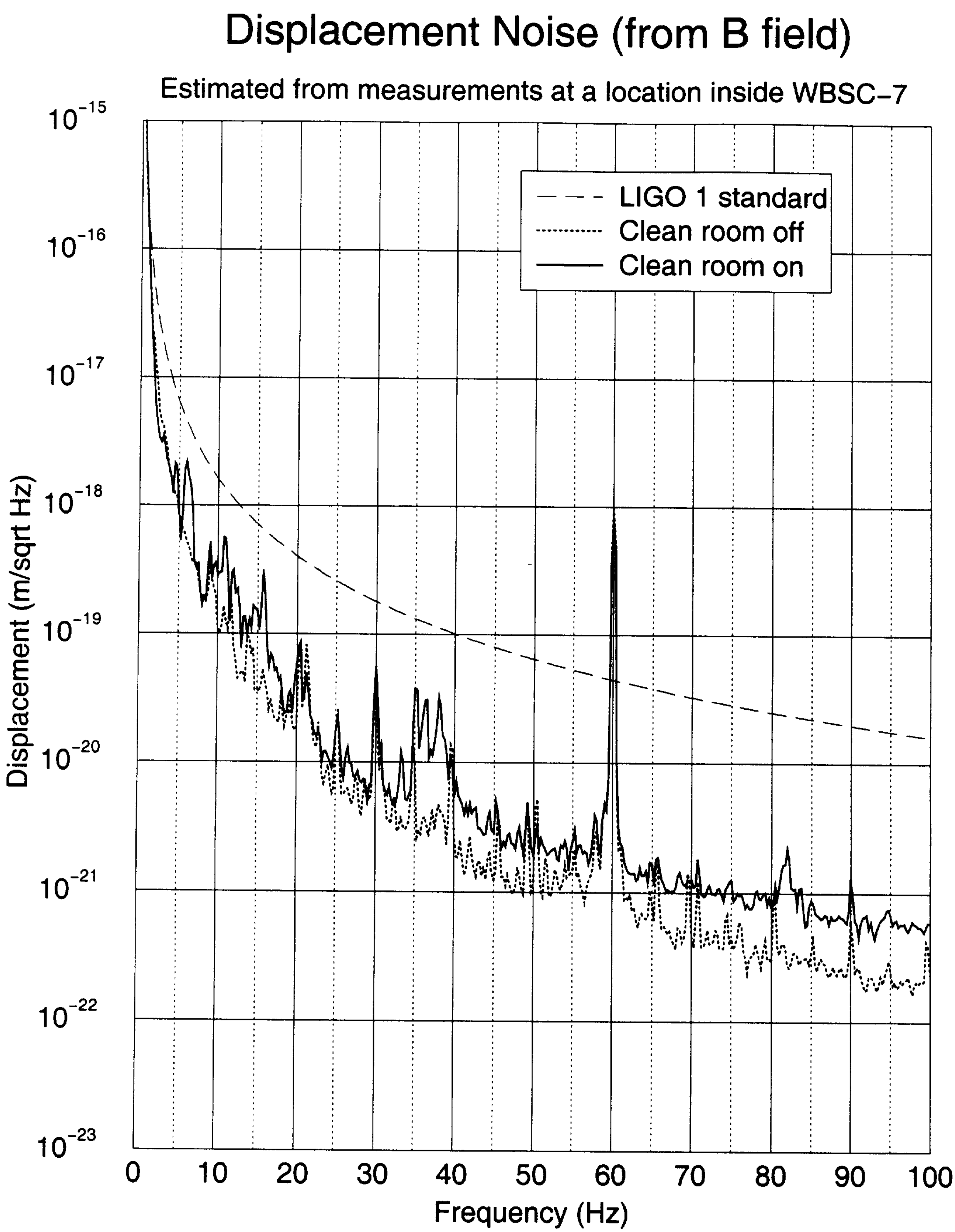
$$\tilde{x} = \frac{u\mu_x}{m\omega^2}\frac{dB_x}{dx}$$

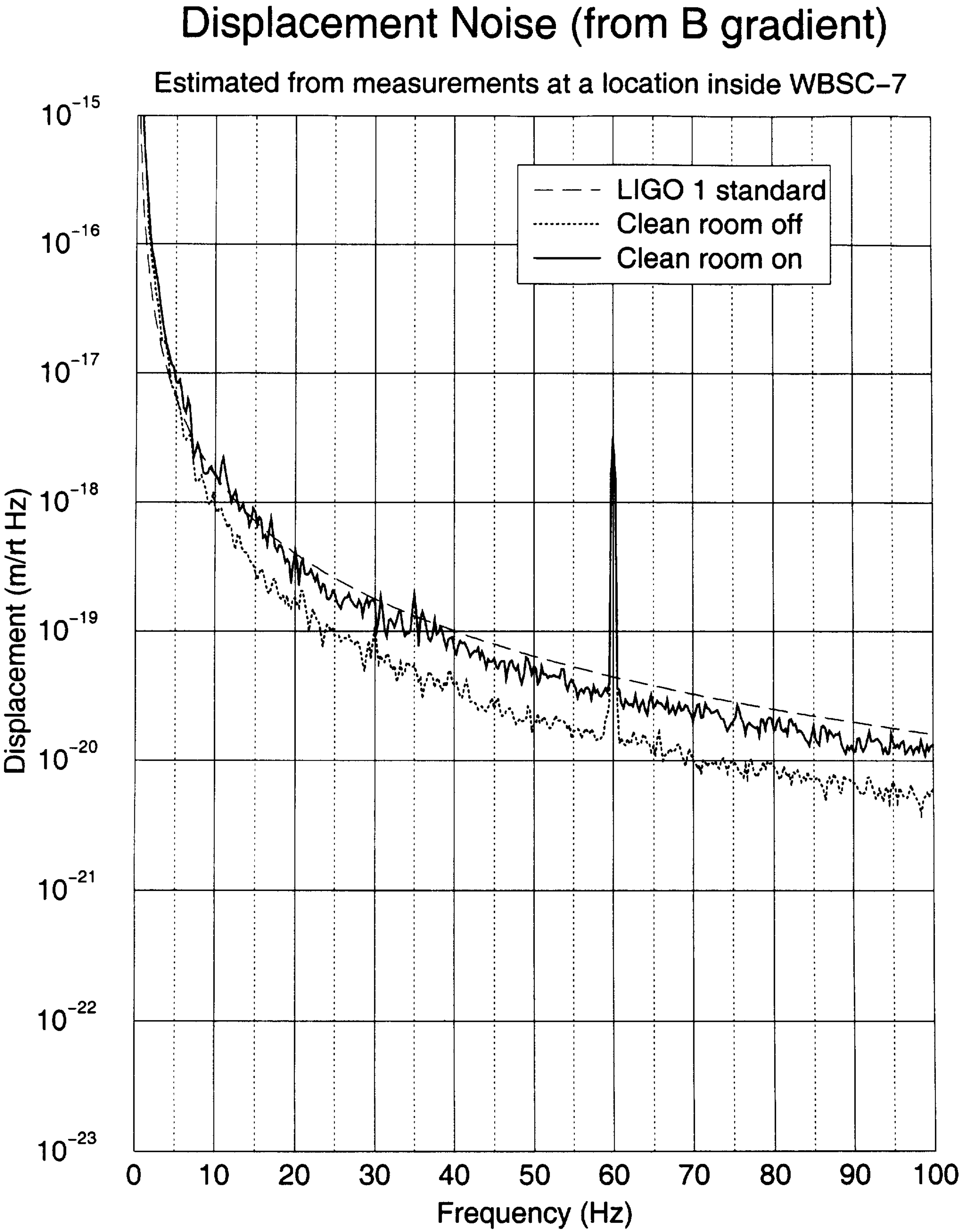
Where *u* is the effective fractional imbalance in the dipole moments of paired magnets (0.02 from quality control + 0.25 from our measured variation in the B gradient over the distance between paired magnets); μ is the magnetic dipole moment (0.0107 A m**2); and *m* is the mass (10 kg).

Displacement from torque on unbalanced magnets in a B field:

$$\tilde{x} = \frac{Du\mu B}{I\omega^2}$$

Where *D* is the allowable offset of the beam from the optic center (0.001 m); *u* is 0.02(quality control) + 0.20 (from the measured variation in B); and *I* is the moment of inertia of the optic (0.0474 kg m**2).


Displacement Noise (from B field)
Estimated from measurements at a location inside WBSC-7
LIGO 1 standard
Clean room off
Clean room on
Displacement (m/sqrt Hz)
Frequency (Hz)
10^-15
10^-16
10^-17
10^-18
10^-19
10^-20
10^-21
10^-22
10^-23
0
10
20
30
40
50
60
70
80
90
100

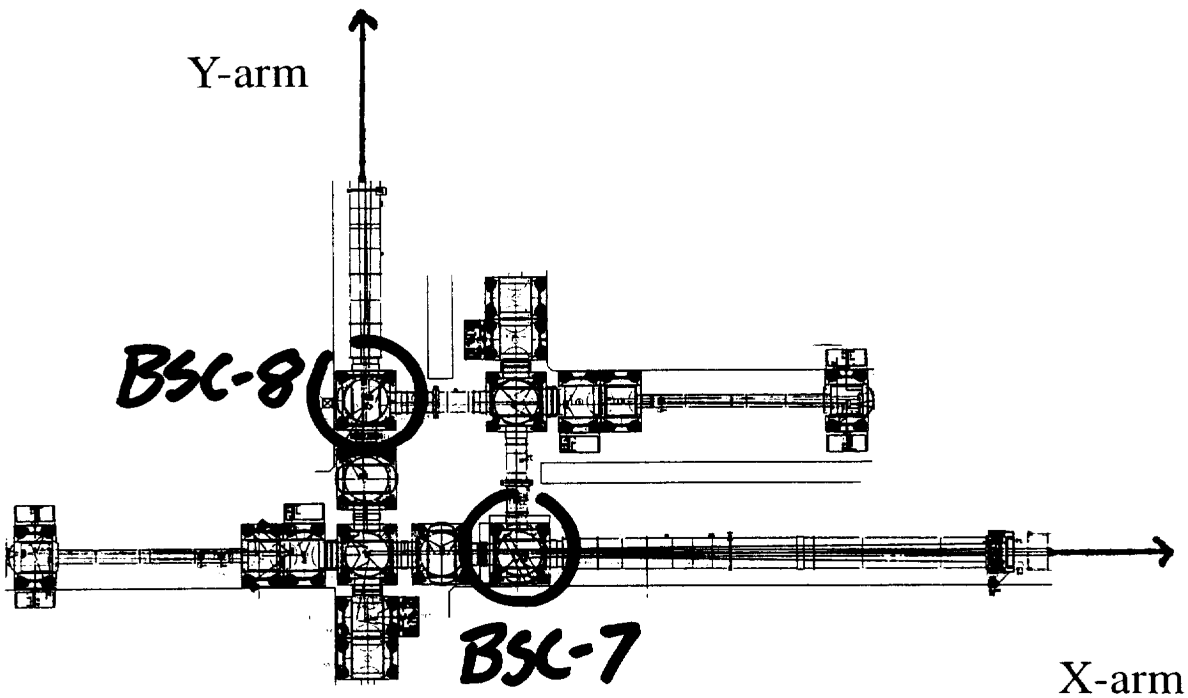

Displacement Noise (from B gradient)
Estimated from measurements at a location inside WBSC−7
LIGO 1 standard
Clean room off
Clean room on
Displacement (m/rt Hz)
Frequency (Hz)
10^−15
10^−16
10^−17
10^−18
10^−19
10^−20
10^−21
10^−22
10^−23
0
10
20
30
40
50
60
70
80
90
100

Ambient magnetic fields in WBSC-7 & 8

Location	(nT)rms at 60 Hz	noise (pT/ sqrt Hz)rms at 50 Hz	n	instrument noise (pT/ sqrt Hz) at 50 Hz
7 locations in WBSC-7; 5/30/99	3.73 ± 0.22	9.6 ± 1.4	7	≤ 2.6
3 locations in WBSC-8; 3/2/99	1.64 ± 0.21	10˜	4	≤ 2.6

Ambient B field gradients in WBSC-7

Location	(nT/m)rms at 60 Hz	noise (pT/m sqrt Hz)rms at 50 Hz	n	instrument noise (pT/m sqrt Hz) at 50 Hz
7 locations in WBSC-7; 5/29/99	2.31 ± 0.92	≥ 9 ± 2 ≤ 20	7	≤ 11


Y-arm
BSC-8
BSC-7
X-arm

External ambient magnetic fields

Location	(nT)rms at 60 Hz	noise (pT/ sqrt Hz)rms at 50 Hz	n	ref.
Around WBSC-7; 5/27-31/99	10.8 ± 3.7	22.7 ± 8.4	12	
7 locations around WBSC-8; 3/3/99	4.4 ± 1.2	15	7	
same 7 3/8/99	5.5 ± 2.4		7	
same 7 3/11/99	5.0 ± 2.1		7	
Louisiana LVEA; 2/20/99; Bx only	70	100	1	Johnson et. all
Louisiana Y-end;1/ 7/99; Bx only	2.5	< 1	1	Johnson et. all
Hanford LVEA; 1/ 7,8/98	9.6	100	1	Savage & Weiss
Hanford X-end; 1/ 7,8/98	17.5	170	1	Savage & Weiss
LIGO 40m 1996		< 60	?	Kuhnert

External ambient magnetic field gradients

Location	(nT/m)rms at 60 Hz	noise (pT/m sqrt Hz)rms at 50 Hz	n	ref.
Around WBSC-7; 5/27-31/99	4.2 ± 3.4	22.9 ± 11.9	7	
Louisiana LVEA; 2/20/99; Bx only	10	50	1	Johnson et. all
Louisiana Y-end;1/7/99; Bx only	0.8	< 5	1	Johnson et. all

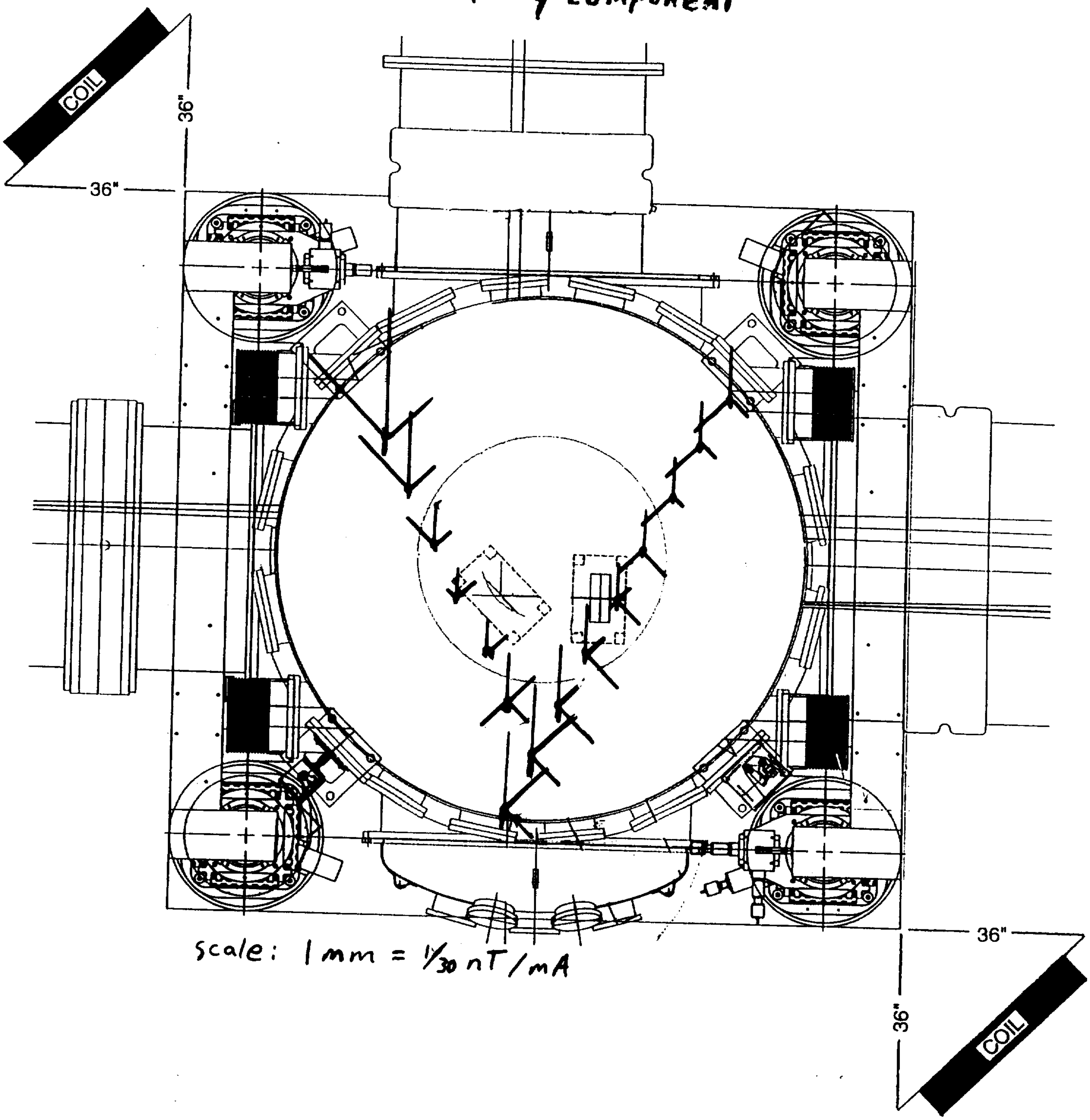
f = 3Hz

Total B-field

z component

x component

y component



scale: 1 mm = 1/30 nT/mA

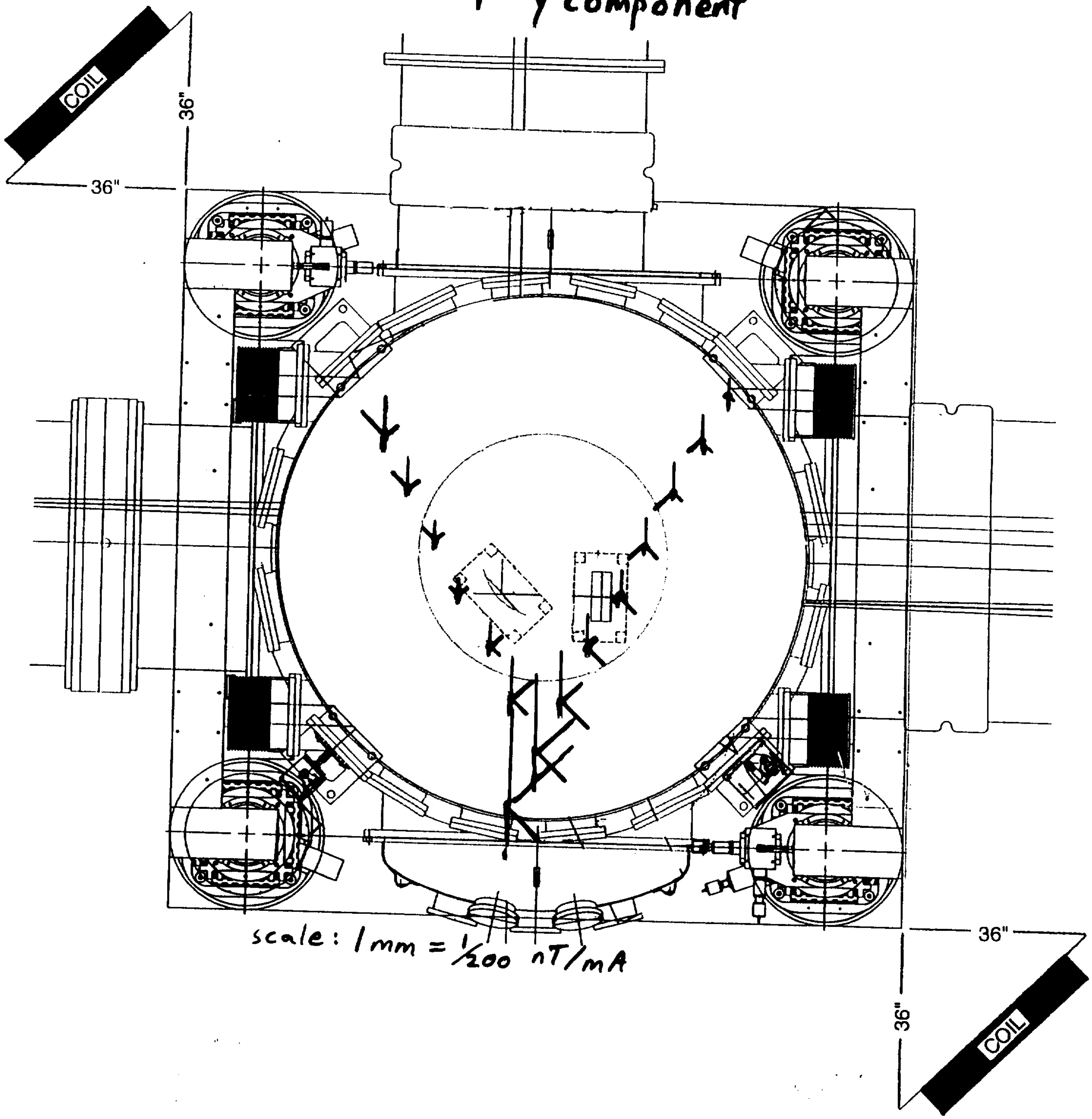
f = 400 Hz

| Total B-field

↖ z component

↙ x component

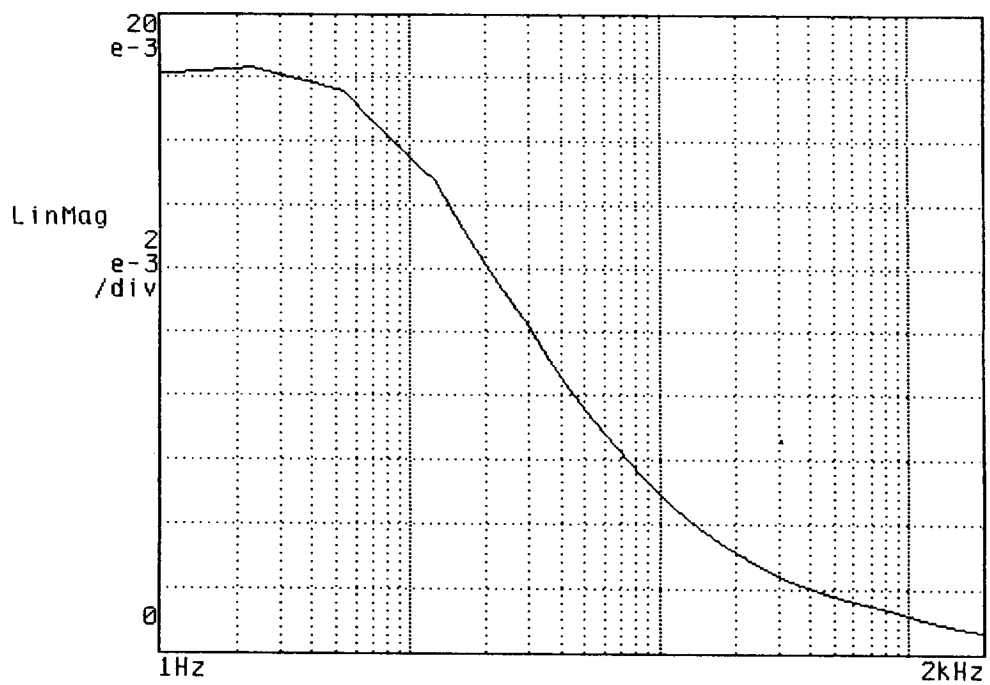
↑ y component



scale: 1 mm = 1/200 nT/mA

An approximate transfer function?

Coils were driven by a frequency swept sine wave from the signal analyzer. We measured the ratio of the voltage from the magnetometer in the chamber to a voltage across a resistor in series with the generating coils:



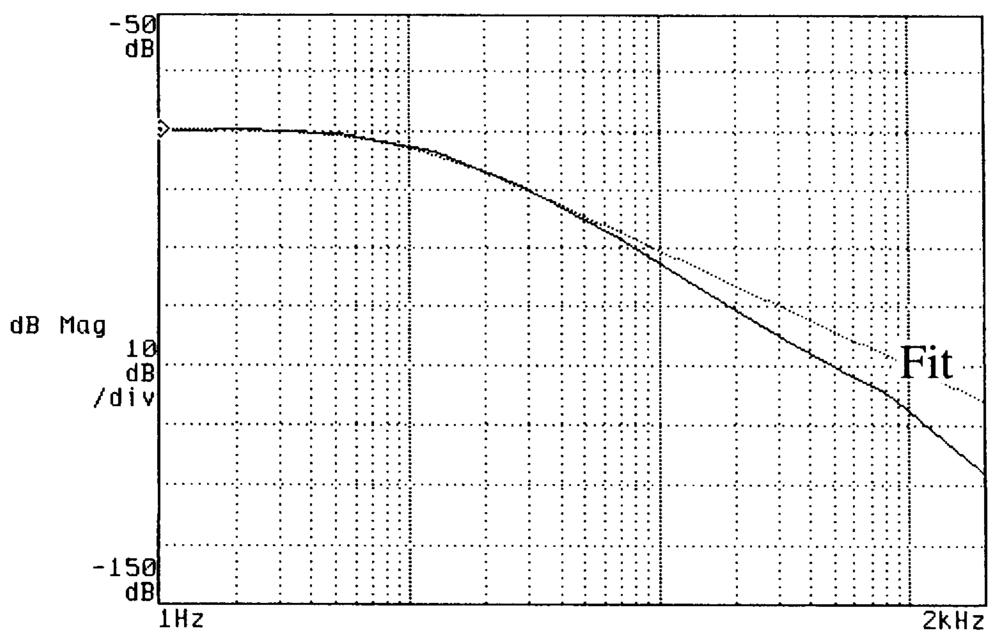
Position B9

<u>What would we expect?</u>

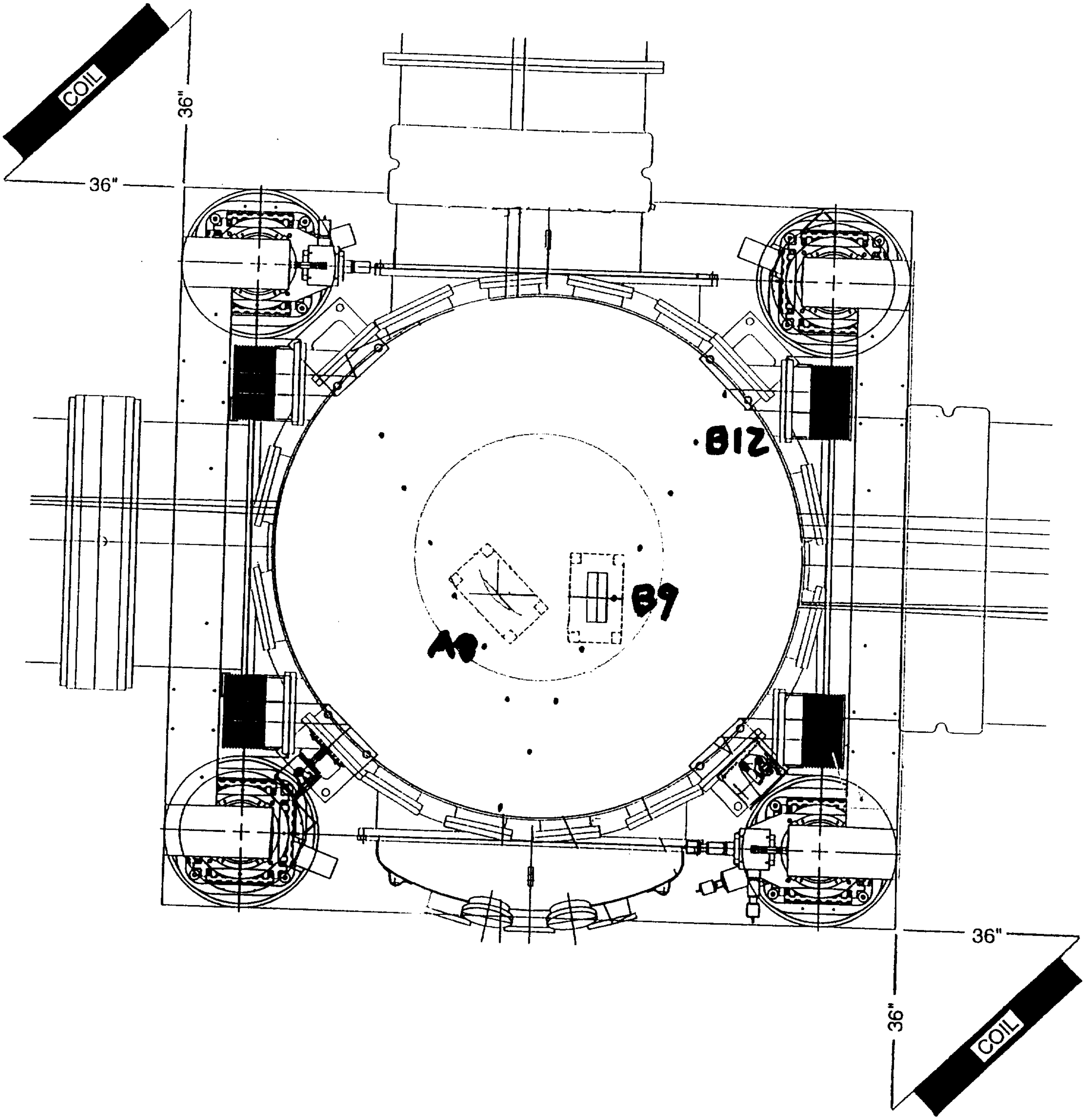
If the wall of the BSC is imagined to be a planar circuit in a normal magnetic field generated by the coils, we would expect to see :

$$\left|\frac{B}{Icoil}\right|_{rms} \propto \frac{1}{\sqrt{1 + a\omega^2}}$$

This functional dependence is in rough agreement with what we measured.



Position B9
Data squared for 1 pole fit; fit: 20 Hz corner


COIL
36"
36"
B12
B9
A8
36"
36"
COIL

How well does this approximate transfer function generalize?

At 60 Hz the measured ratio (B/Icoil) was about 0.3 of that at 1 Hz. Assuming no attenuation at 1 Hz, we would expect 60 Hz fields to be attenuated by about 0.3.

Location	Inside nT at 60 Hz	n	Outside nT at 60 Hz	n	ratio
WBSC-7	3.73+/-0.22	7	10.8 +/-3.75	12	0.35
WBSC-8 (door open)	1.64+/-0.21	4	4.41 +/-1.23	7	0.37

SUMMARY

- The 60 Hz ambient magnetic fields in the Hanford LVEA, with most non-essential equipment off, were within a factor of 2 or 3 of **5nT** for a series of measurements over several months. The 60 Hz gradients were about **5nT/m**.
- The field noise at 50 Hz was about **20 pT/sqrt Hz**. The gradient noise was about **20 pT/m sqrt Hz**.
- Fields from the generating coils were mapped.
- A transfer function for magnetic fields from outside to inside of the BSC chambers:

$$\frac{Bin}{Bout} \cong \frac{1}{\sqrt{1+(f/20)^2}}$$

- seemed to work fairly well for fields generated by our coils and for ambient 60 Hz fields.
- Displacement noise due to fields inside of the BSC, without the optic suspension structures in place, were below LIGO 1 requirements.
- Measurements of the gradients produced by eddy currents in optic suspension structures are planned.

Note 1, Linda Turner, 08/17/99 08:34:19 PM
LIGO-G990079-29-M