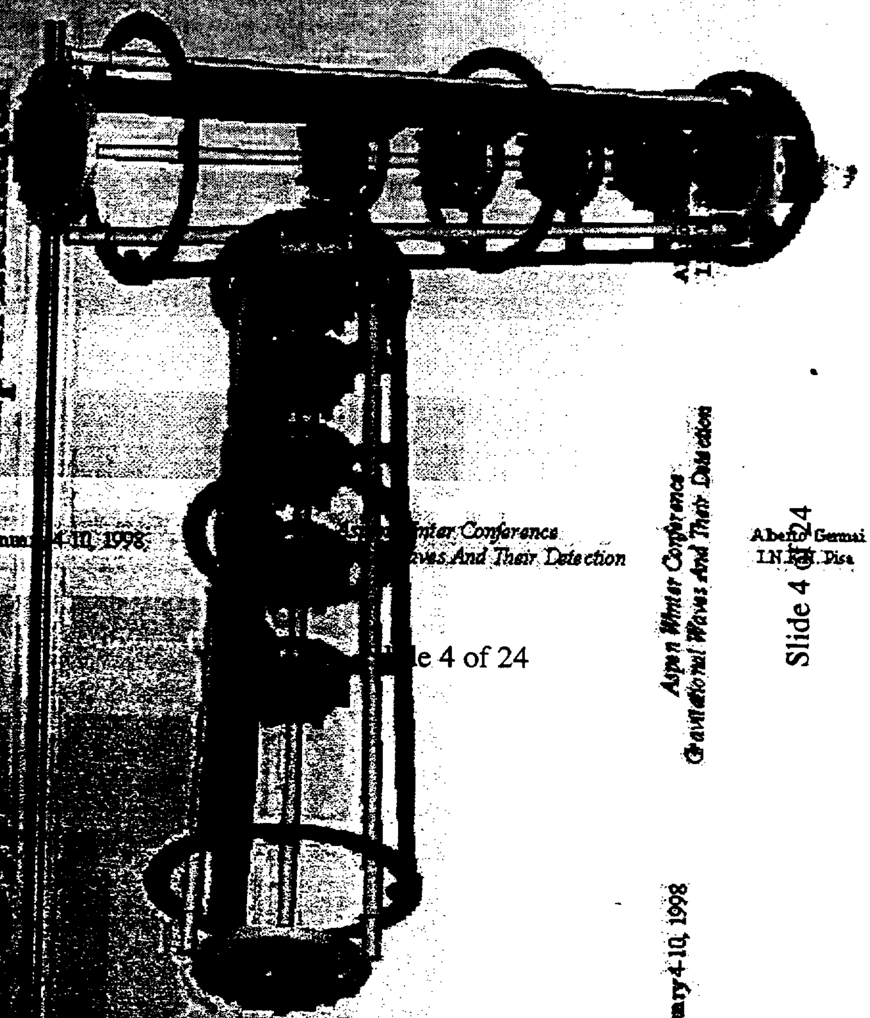
SuperAttenuator



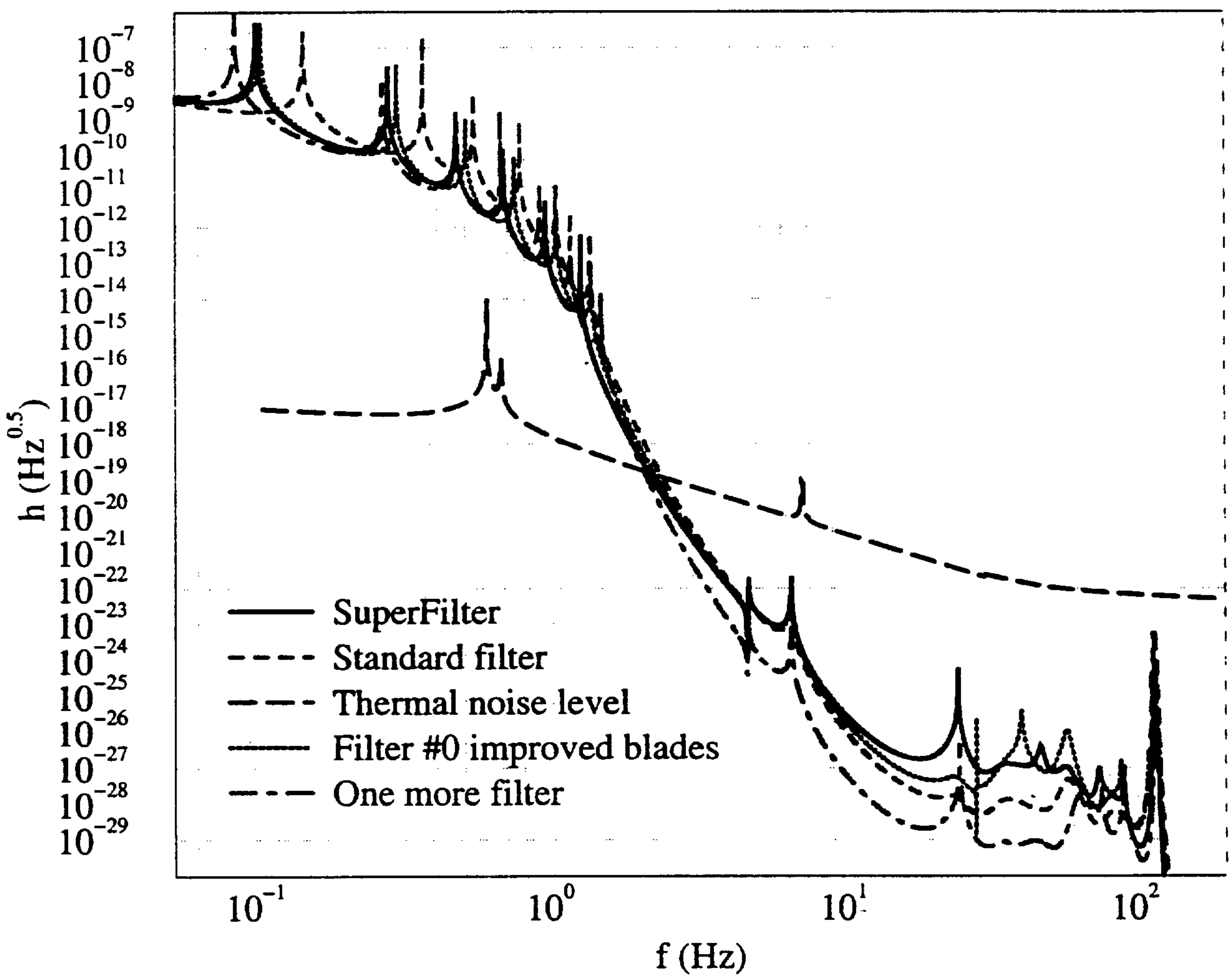
January 4-10, 1998

Aspen Winter Conference
Gravitational Waves And Their Detection

Alberto Gennai
I.N.F.N. Pisa

First Previous Next Last Index Home Text
SuperAttenuator
Aspen Winter Conference
Gravitational Waves And Their Detection
Slide 4 of 24
January 4-10, 1998

Rumore in h

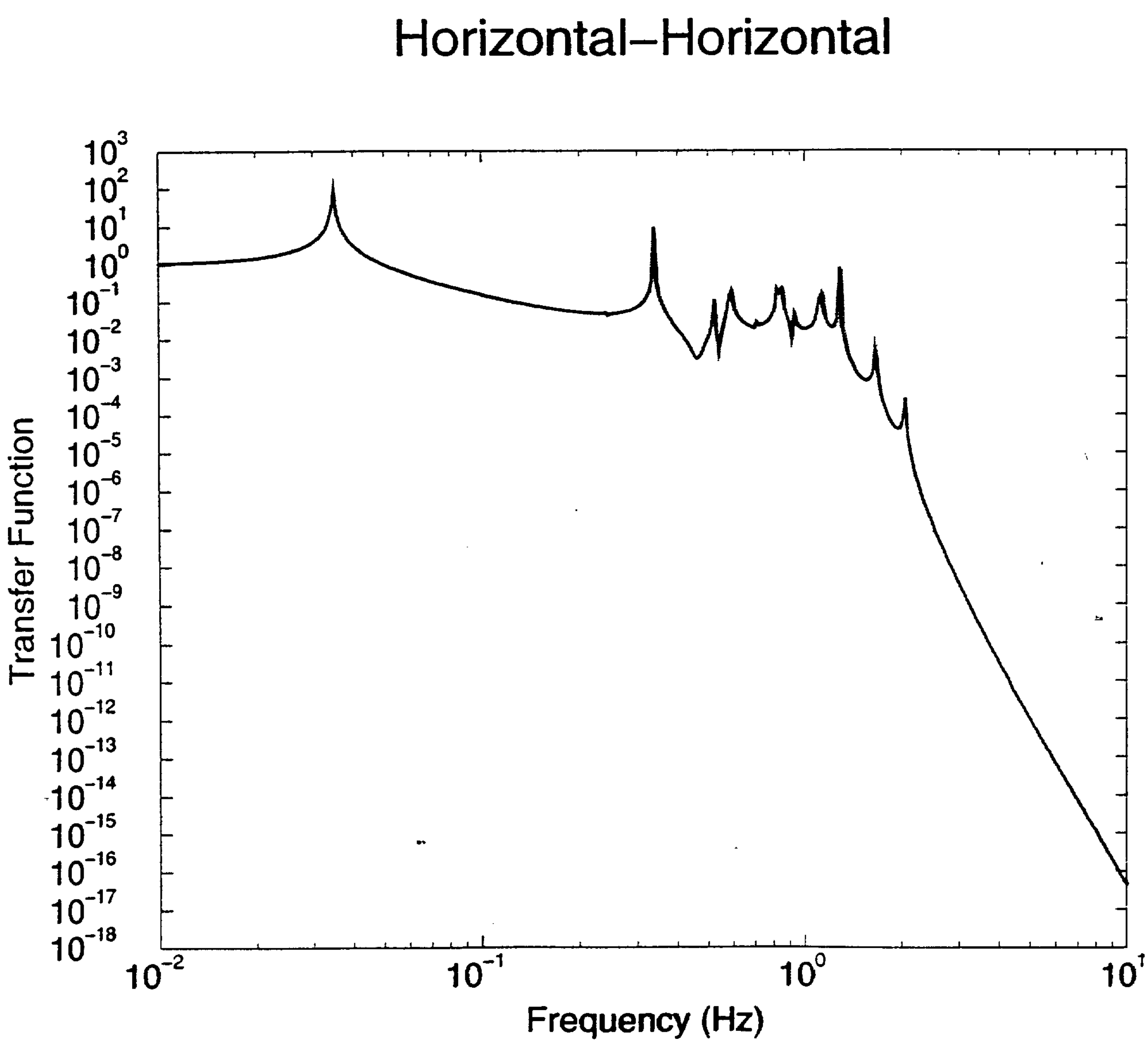


Tutte le soluzioni sono il livello di rumore termico atteso, ma è possibile che i livelli delle risonanze siano errati.

Ligo Suspension & Seismic Attenuation System

Riccardo DeSalvo

A collection of prejudices and obvious statements:



Horizontal–Horizontal
Transfer Function
Frequency (Hz)
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-2}
10^{-1}
10^{0}
10^{1}

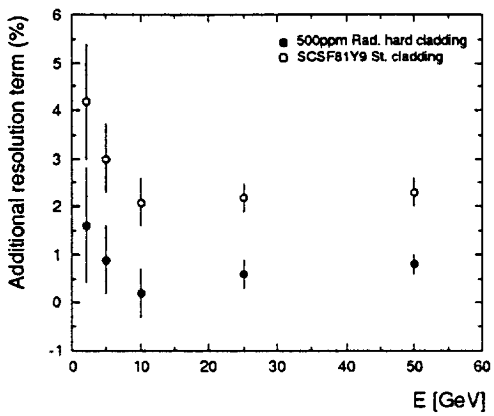


Figure 10. Additional constant term in the electromagnetic energy resolution for 3HF (500 ppm) fibres with radiation hard cladding (black dots) and for SCSF81 Y9 fibres with standard cladding (white dots), as a function of the incident electron energy.

to measure jet, single electron, single γ, W, Z cross-sections, and to search for top quark, high-mass ($m_H > 2m_W$) Higgs, or new IVBs. Coupled to the excellent hermeticity, the spaghetti calorimeter is also adequate to look for the production of new weakly interacting particles.

Due to its rather coarse electromagnetic resolution, the search for low-mass ($m_W < m_H < 2m_W$) Higgs in the most promising channel $H^0 \rightarrow \gamma\gamma$ will be somewhat more difficult with a spaghetti calorimeter than with an homogenous electromagnetic calorimeter, *e.g.* LXe or crystals with resolution $\sigma/E \sim 2\%/\sqrt{E}$. However, the capability of the spaghetti calorimeter to distinguish very nearby γ's may turn out to be a decisive advantage if the backgound from jets is higher than expected from present calculations. Moreover, the very small Moliere radius of the spaghetti calorimeter and its very fast signal reduce to a minimum the effects due to energy pile-up from different events and from different bunch crossings.

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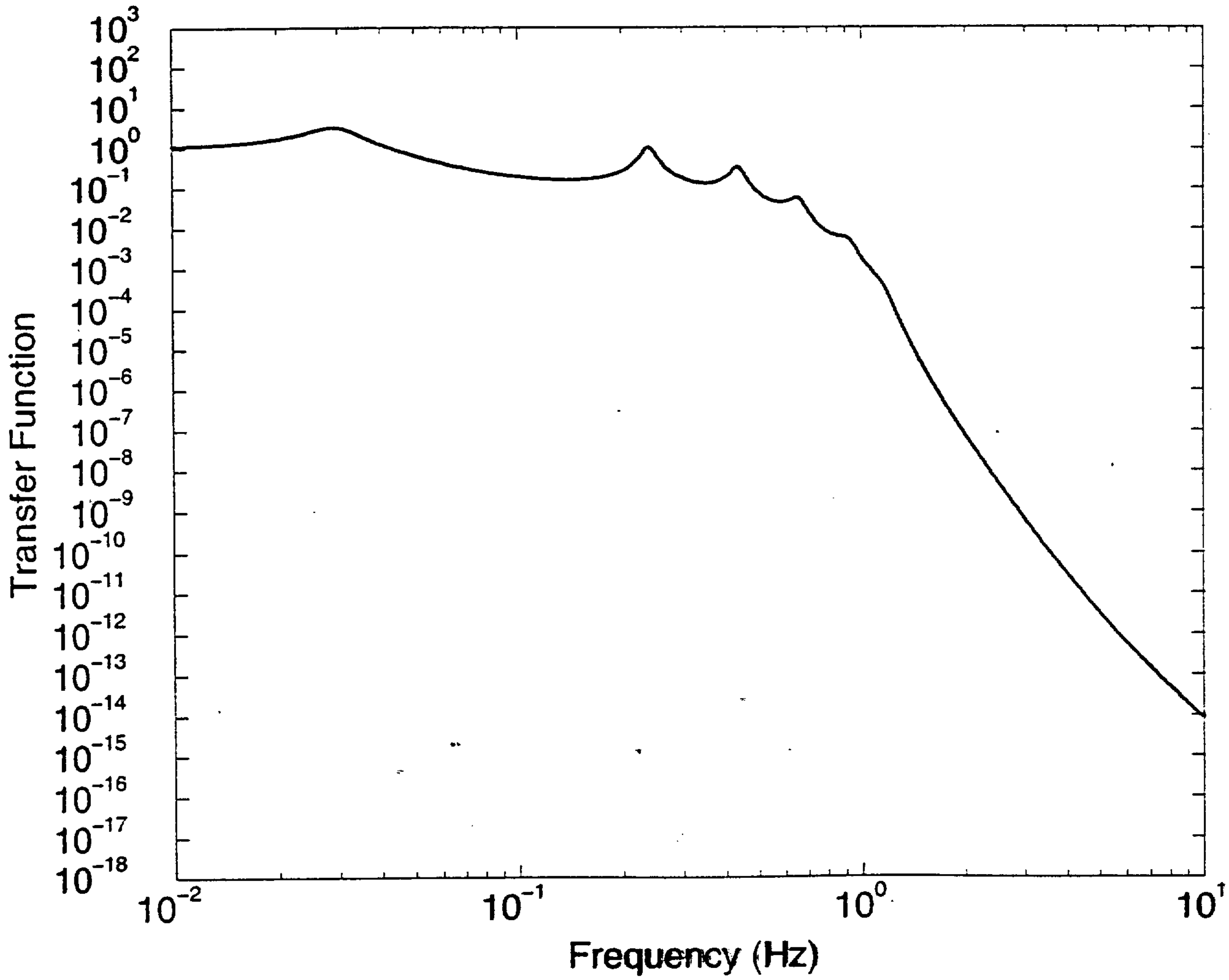
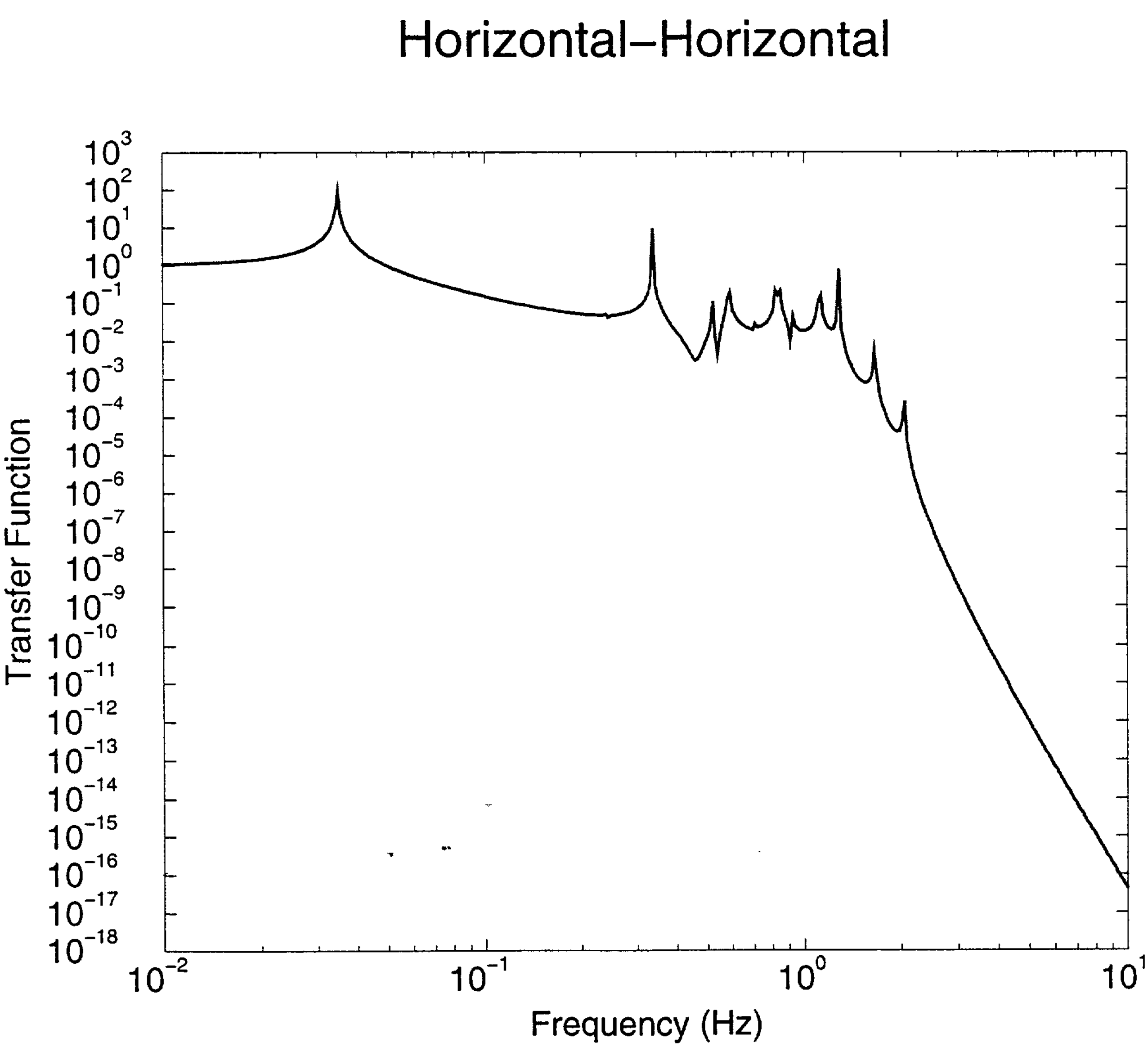
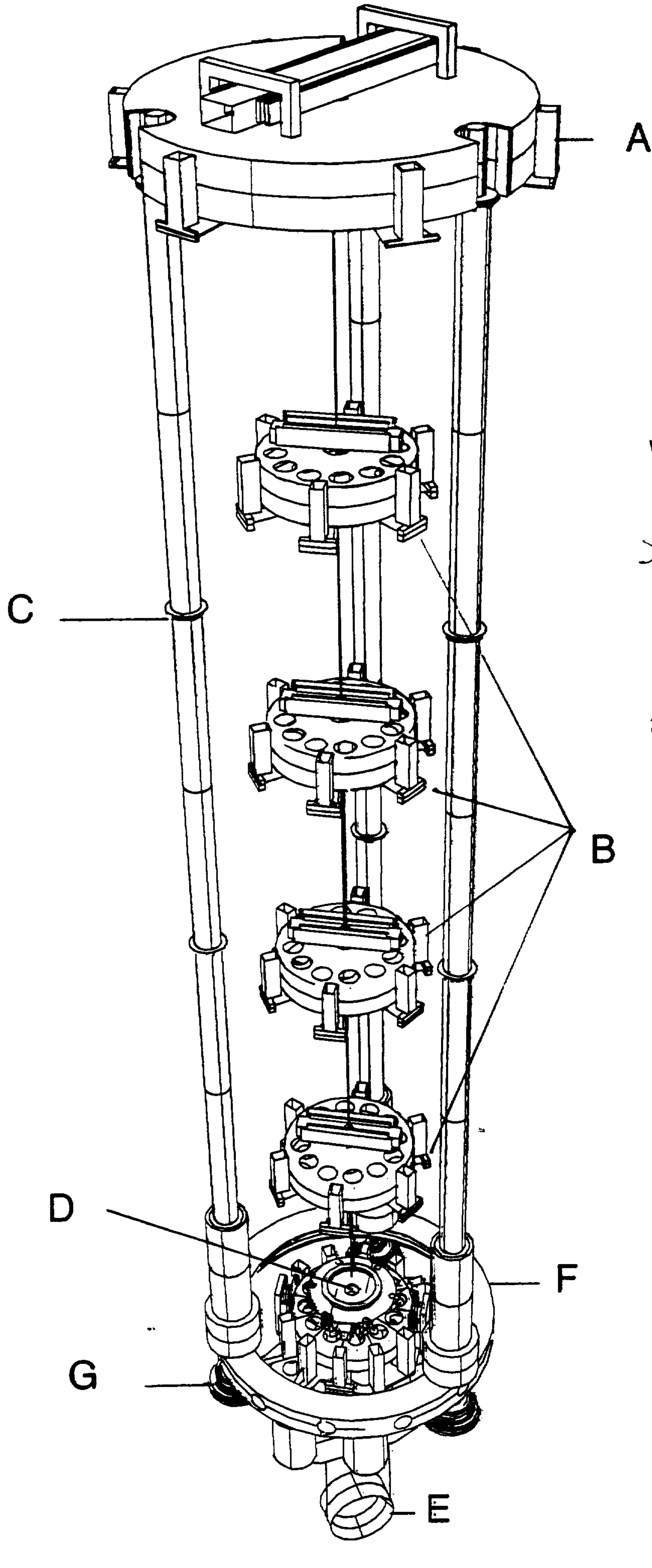
16. A. Contin *et al.*, Nucl. Instr. and Meth. A315 (1992) 344.
17. P. Liparulo, *Analisi strutturale di un calorimetro in piombo e fibre ottiche scintillanti proposto per le future esperienze al large hadron collider del CERN*, Doctoral thesis, Politecnico di Torino, Facolta' di Ingegneria

Vertical–Vertical





Horizontal–Horizontal
Transfer Function
Frequency (Hz)
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
10^-14
10^-15
10^-16
10^-17
10^-18
10^-2
10^-1
10^0
10^1

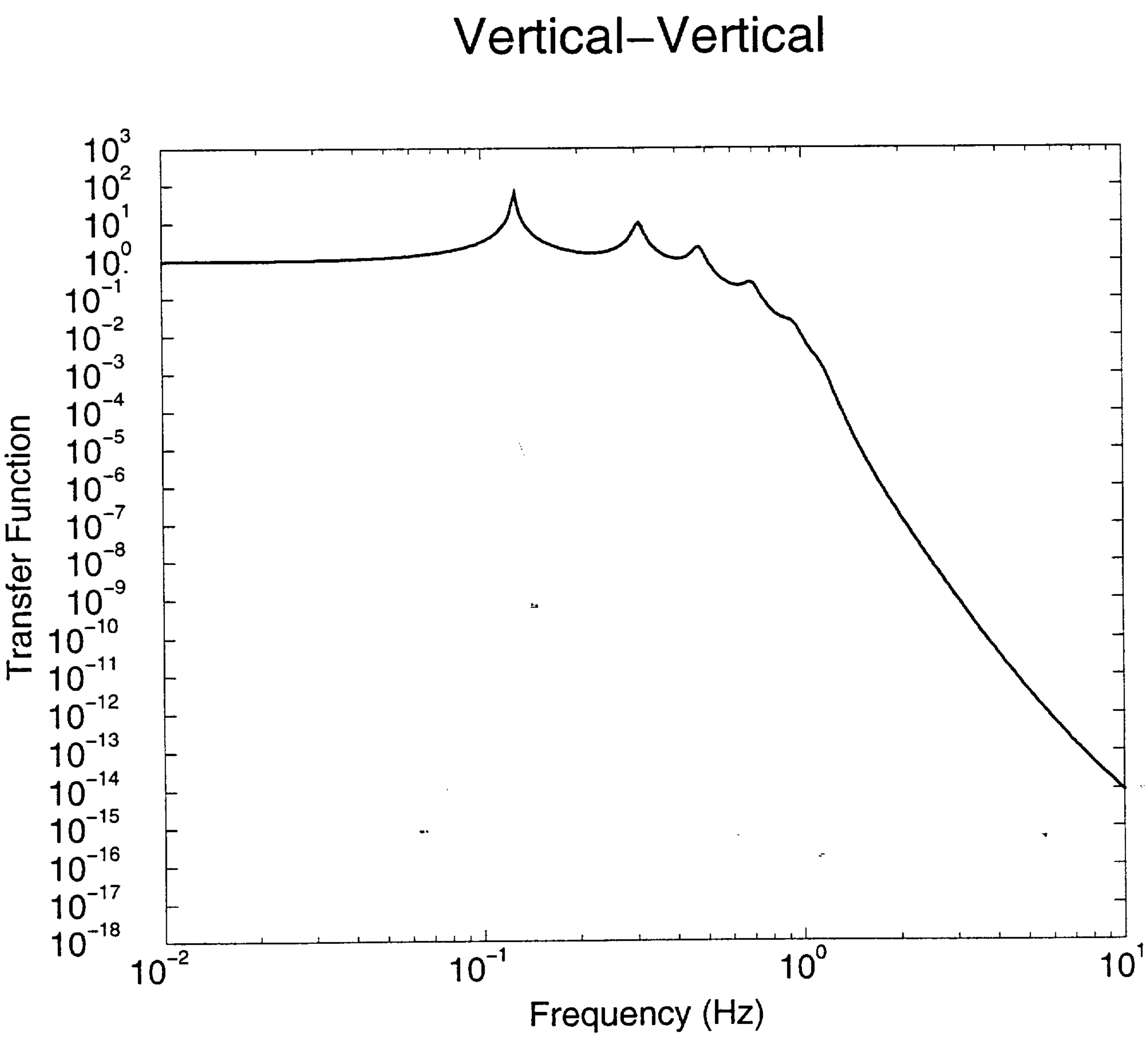


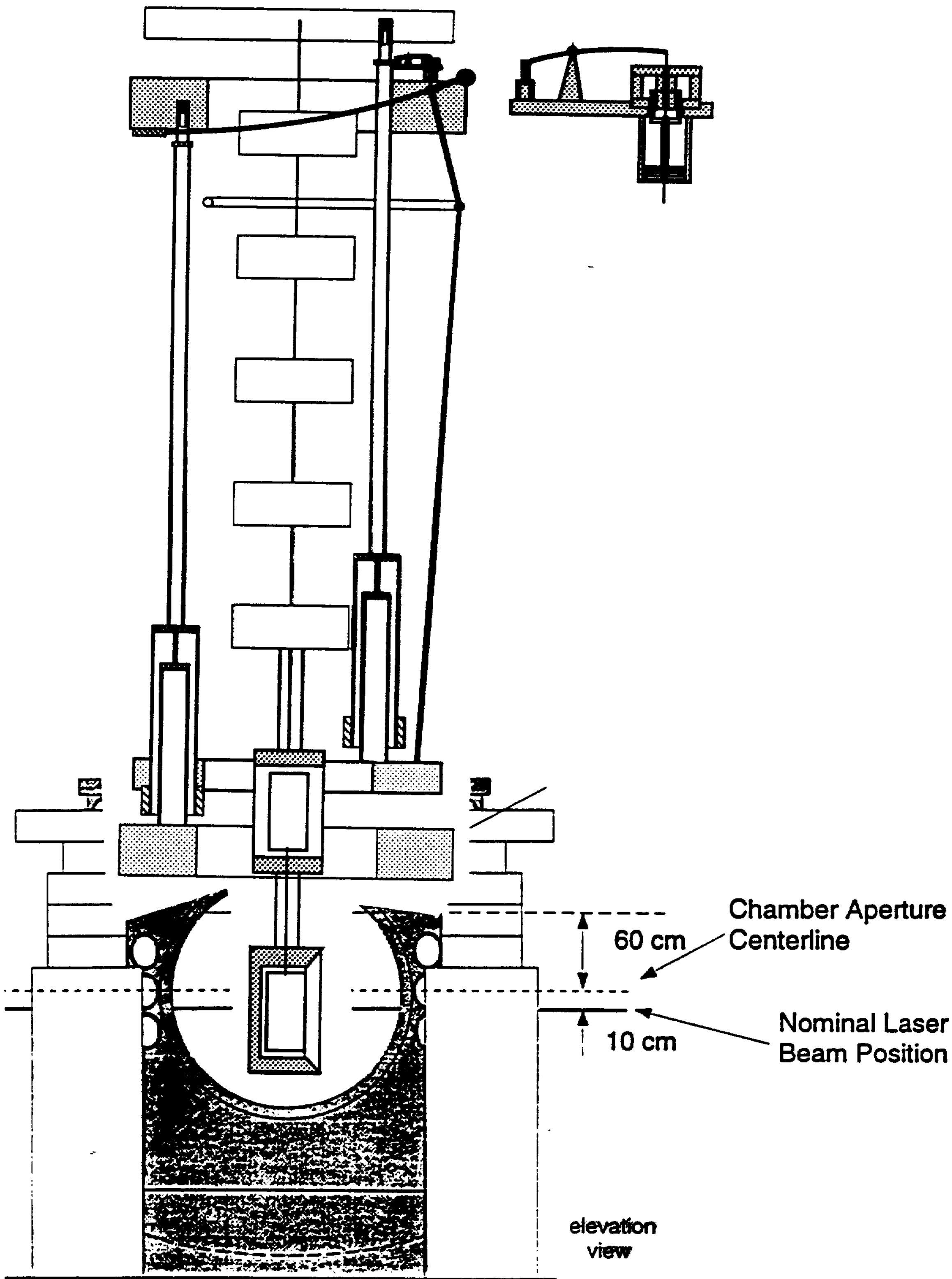
V-1

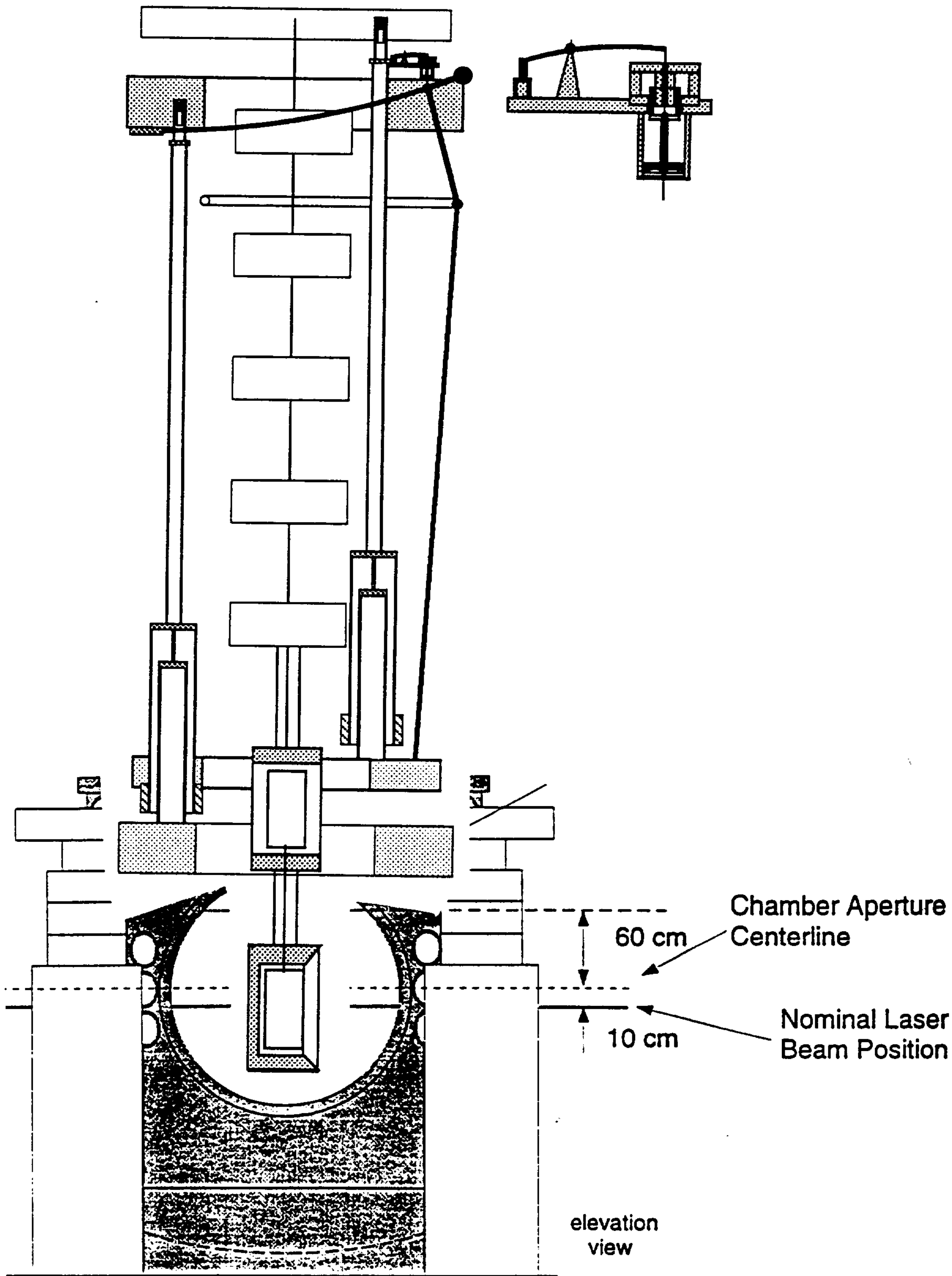
SOLUTION

6 → 5 m.

5 → 4 FILT.


Vertical–Vertical
Transfer Function
Frequency (Hz)
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-2}
10^{-1}
10^{0}
10^{1}


Chamber Aperture
Centerline
60 cm
Nominal Laser
Beam Position
10 cm
elevation
view

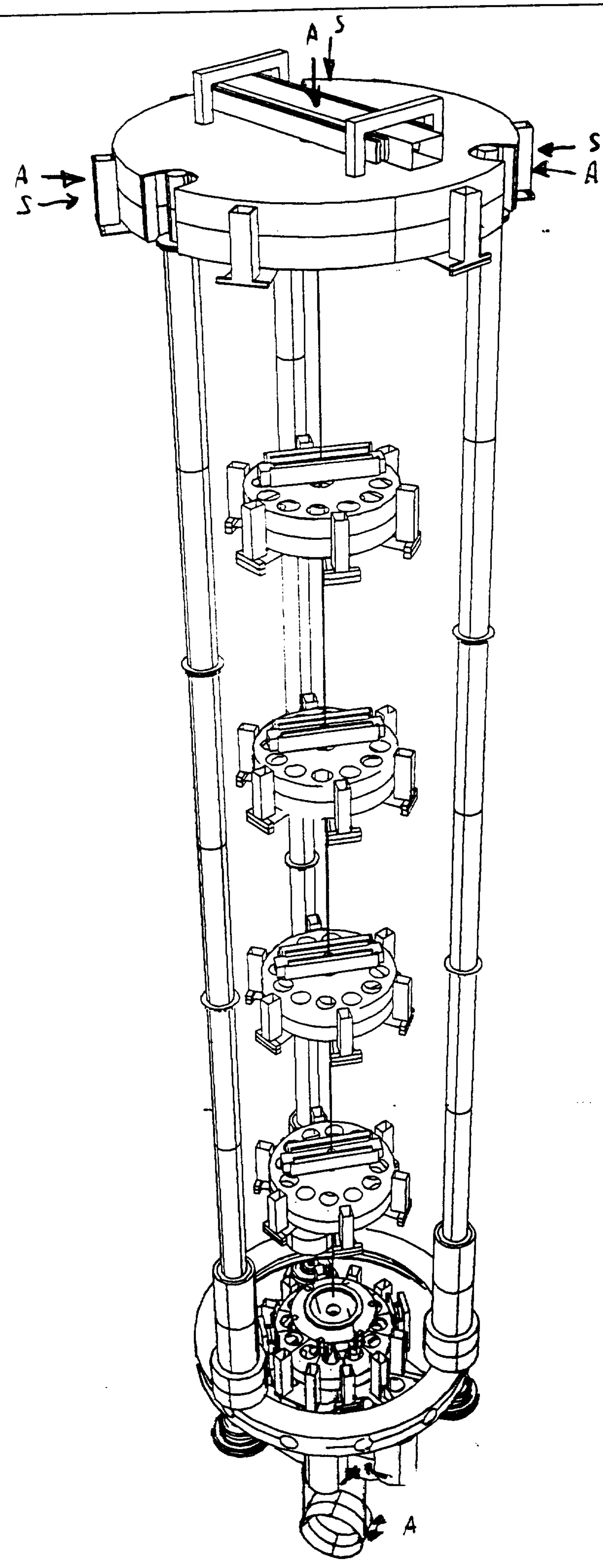

Chamber Aperture
Centerline
60 cm
Nominal Laser
Beam Position
10 cm
elevation
view

A suspension system provides:

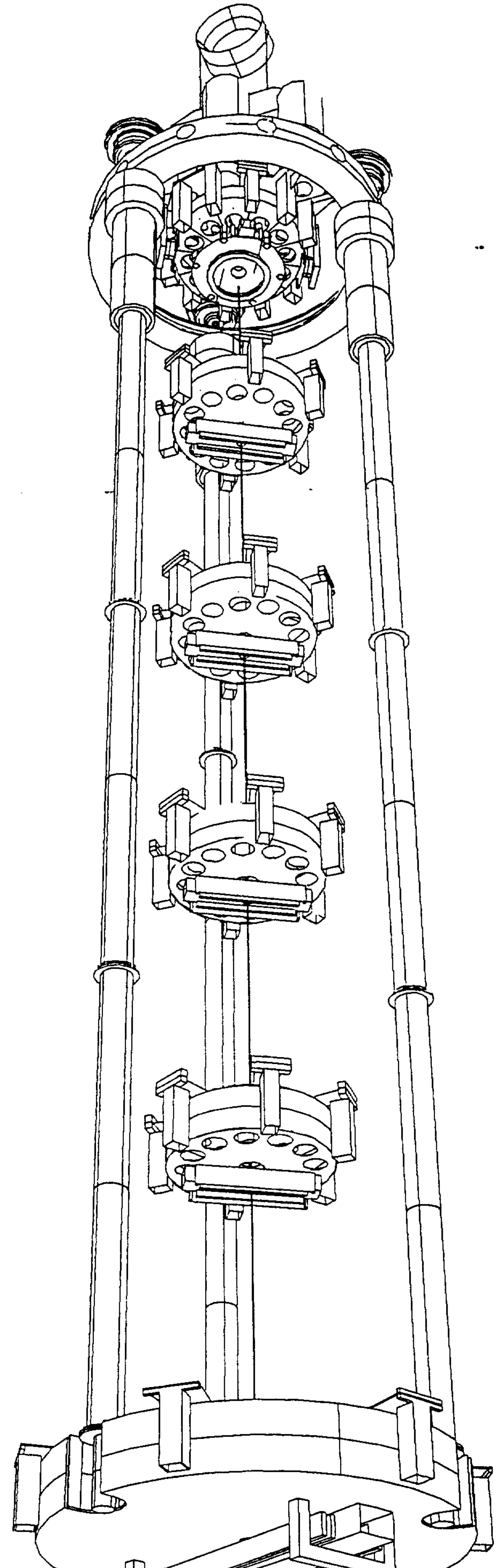
- 1) Seismic isolation
- 2) Interferometer locking feed back forces
- 3) Positioning actuation
- 4) Internal modes damping

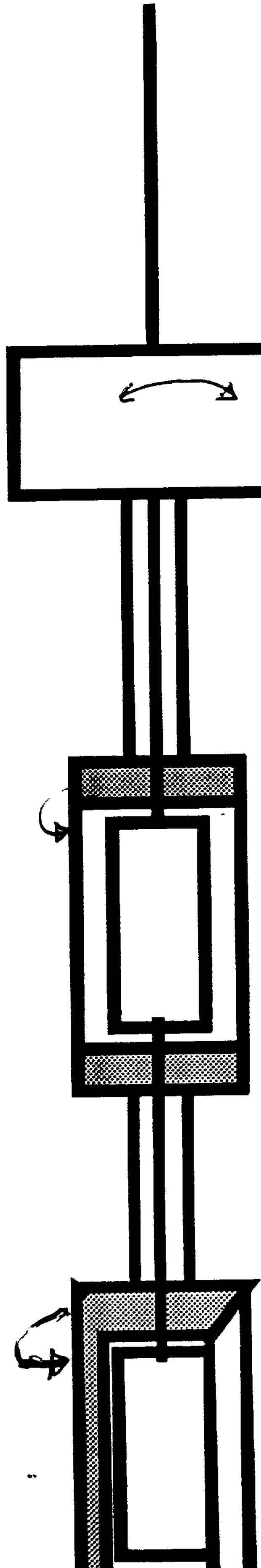
1) Seismic Isolation

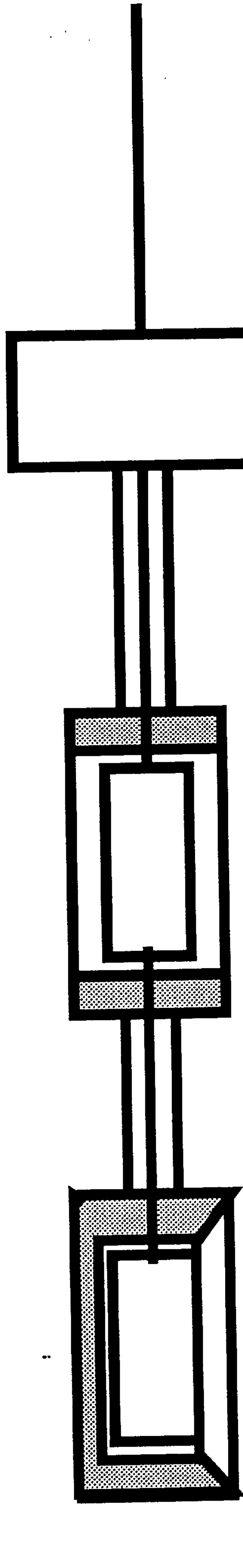
- a) Active — Top of chain
- b) Passive — Middle of chain
- c) Passive attenuation
  + locking actuation — Bottom of chain



A
S
S
A
A
S
A



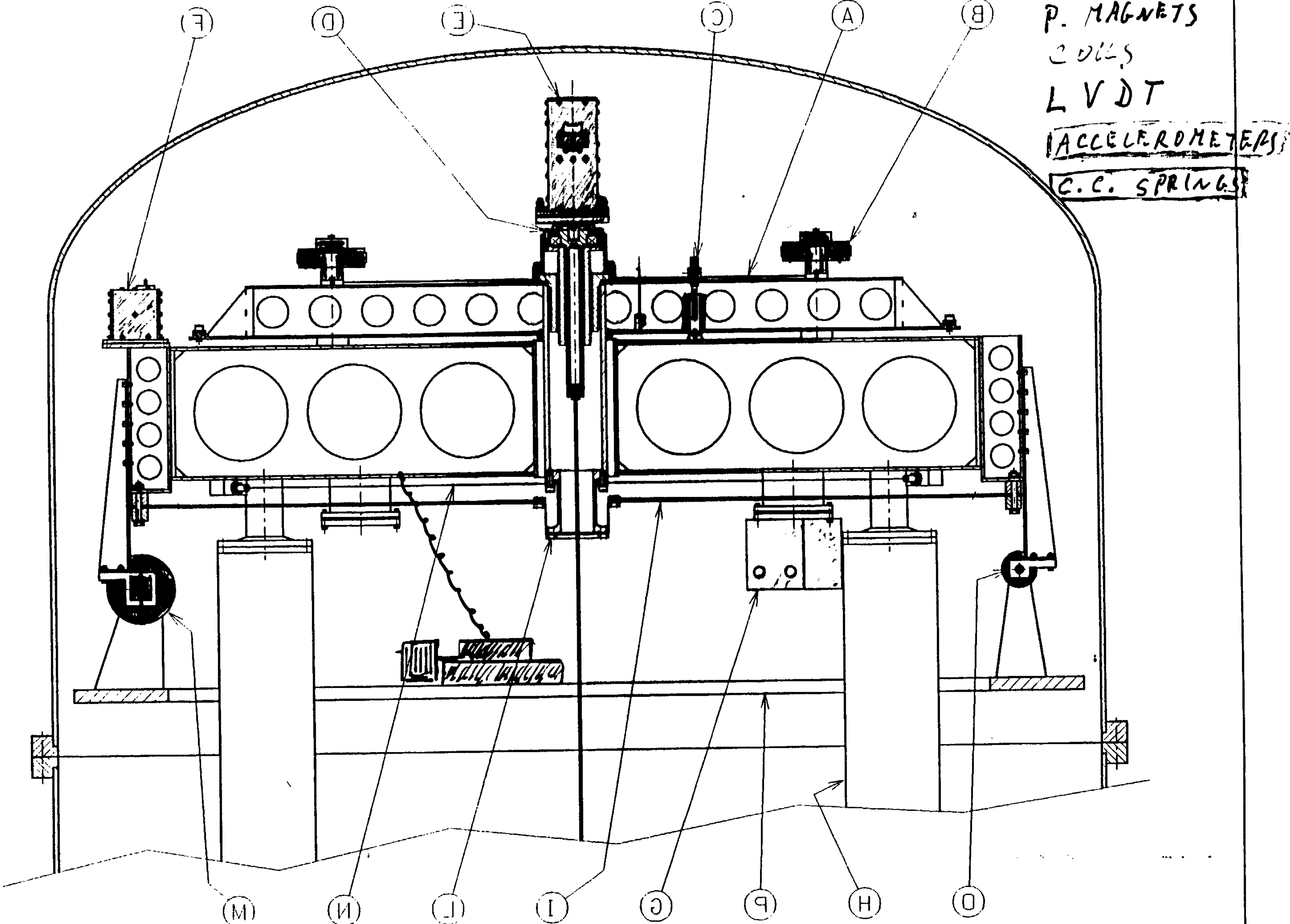


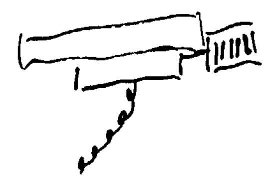


3) *Positioning actuation*

- *From top of chain*
- *Only flexural movements*
- *Soft (low frequency) mechanics*
- *Mechanical DC forces*
- *Electro magnetic dynamic forces*

FIGURA F/ ATTUAT.

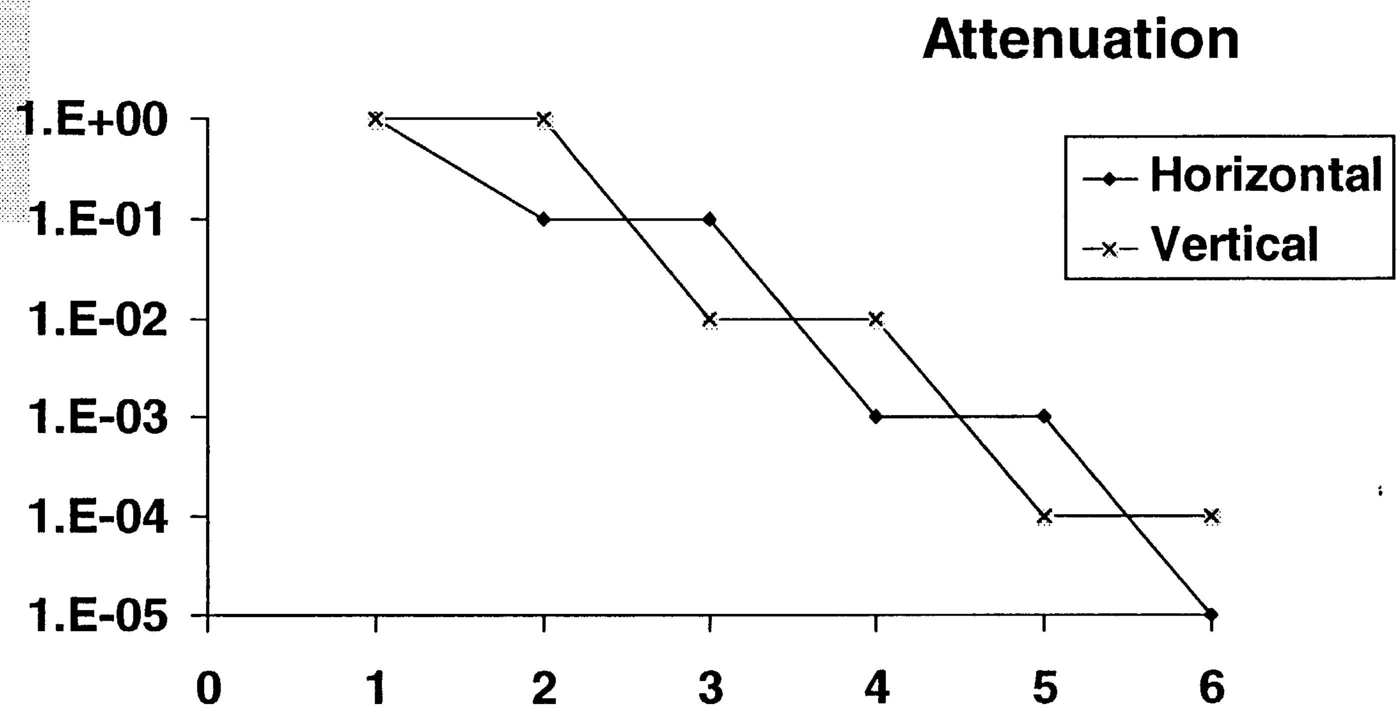

F
D
E
C
A
B
P. MAGNETS
COILS
LVDT
ACCELEROMETERS
C.C. SPRINGS
M
N
L
I
G
P
H
O



Limits of Isolation Measures

- *Difficult to isolate horizontal from vertical modes to better than few %.*
- *Need to attenuate progressively all degrees of freedom (d.o.f.)*
- *Conservative rule:*
  - *alternate vertical and horizontal stages*
  - *< 100 x attenuation in each stage*

Attenuation in different d.o.f. must never lag by more than 100



Attenuation in different d.o.f. must never lag by more than 100

- *Limit even more true for active damping*
- *Can turn around with software corrections on and from all d.o.f.*
- *(DSP control, multiple in-multiple out)*
- *must not push too far*
- *If x100 achievable passively*

  => go passively

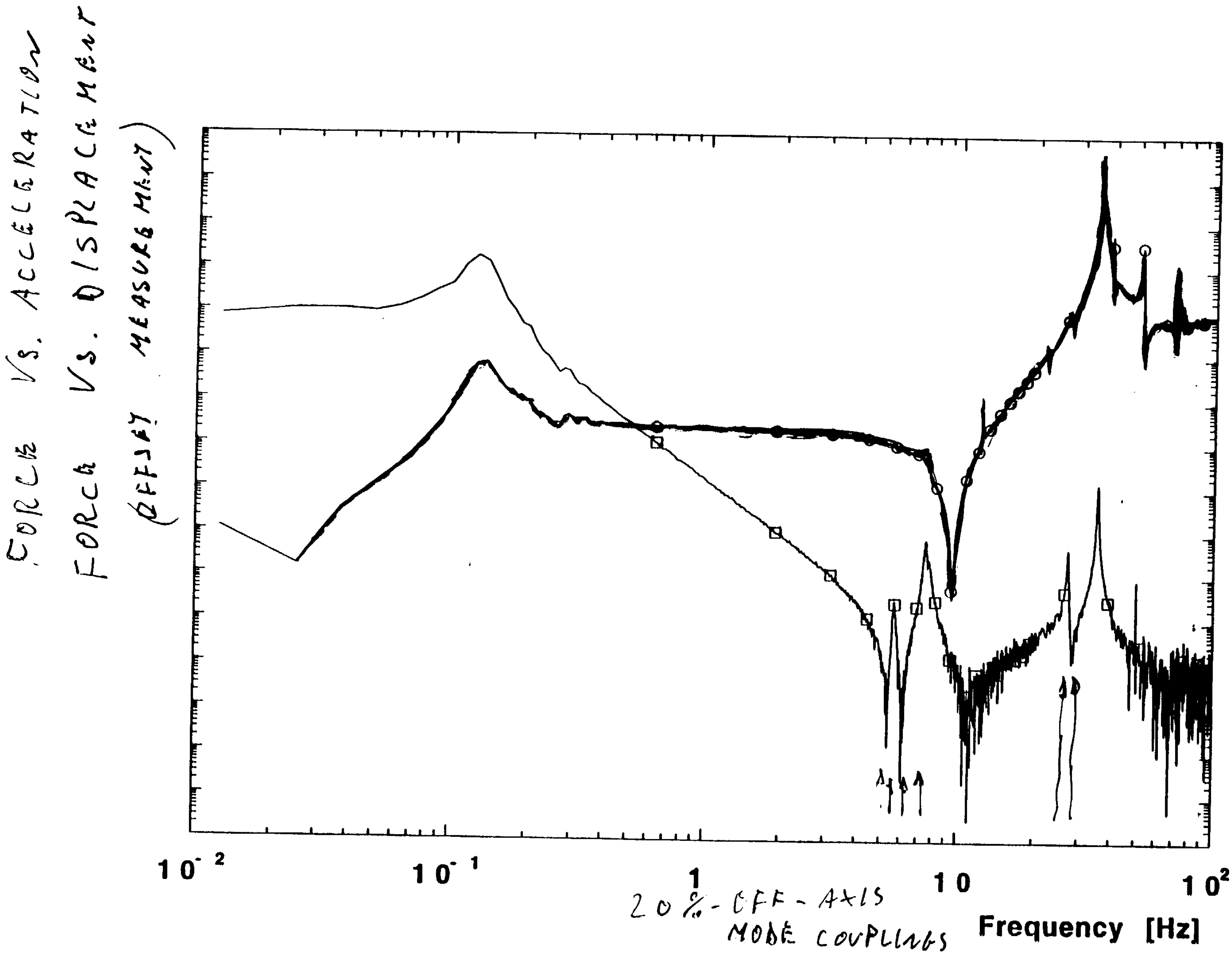
4) Internal modes damping

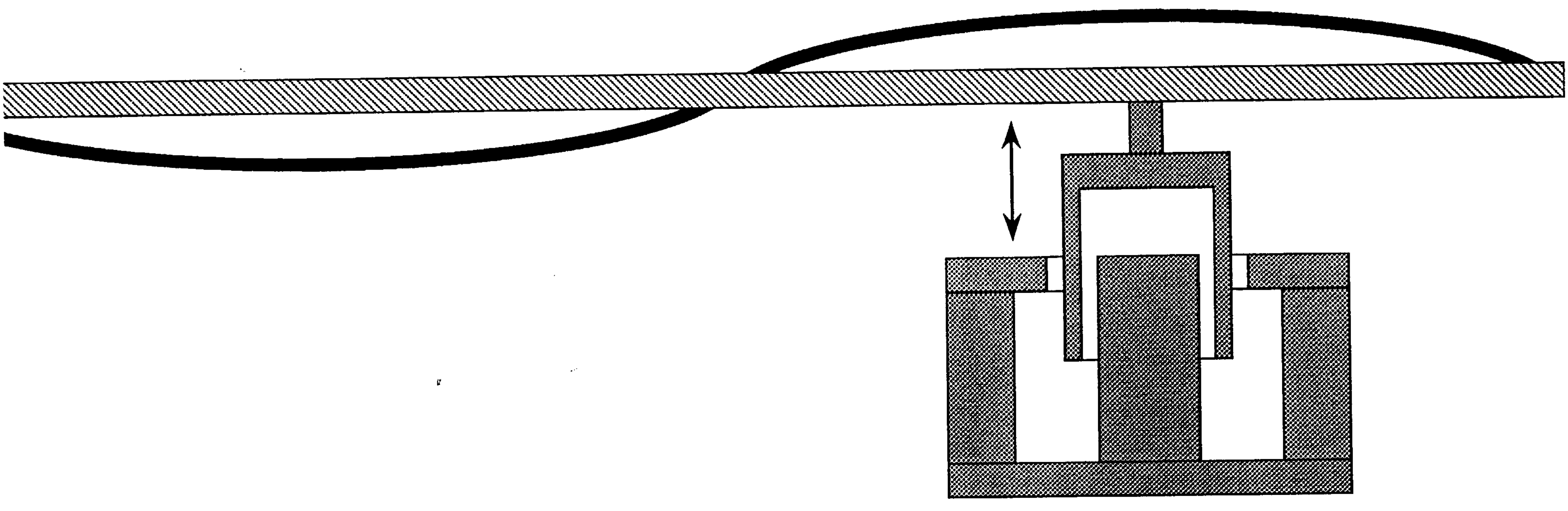
- *Based on accelerometer and LVDT signals*
- *Electromagnetic actuators*
- *DSP gain structure to follow resonances*

FIGURE
RES. + FB

A possible technical solution

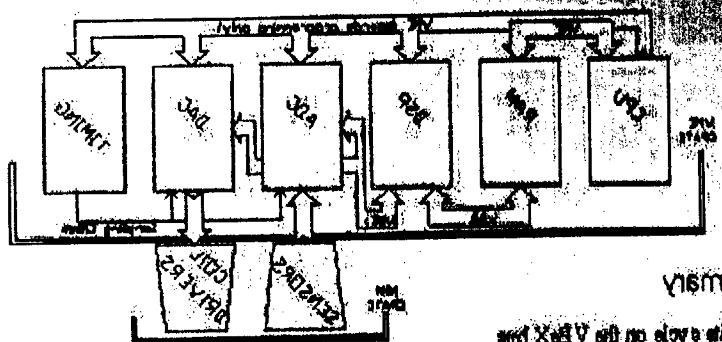
- Vertical attenuation steps between each horizontal one
- Warning: Final double pendulum is only horizontal
  - Require more vertical attenuation towards bottom of chain


FORCE Vs. ACCELERATION
FORCE Vs. DISPLACEMENT
(OFFSET MEASUREMENT)
10⁻²
10⁻¹
1
10
10²
20%-OFF-AXIS
MODE COUPLINGS
Frequency [Hz]



VIRGO Suspension Control

Hardware Architecture



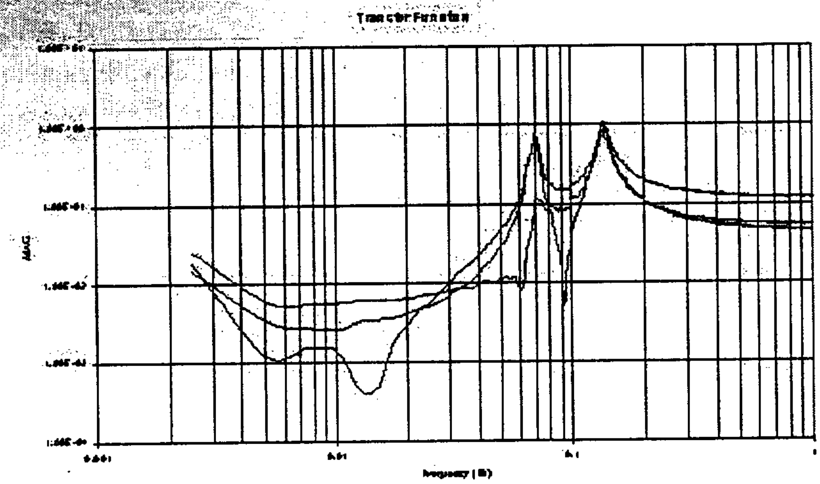
Timing Summary

600 to 800 ns	6 channels read/write cycle on the VBsX bus
1 to 2 us	Read/write cycle on the RAM board (VSB Block Transfer)
5 us	ADC's conversion time
1.2 us	DAC's conversion time

About 40 us available for DSP operations (800 instruction - about 200 poles and 200 zeros) with a sampling rate of 20 kHz (single sample delay between input and output).

Inertial Damping

- Inverted Pendulum TF



1-a) Active seismic isolation

- Active feed back systems stop
- at r.m.s. sensitivity of sensors

and

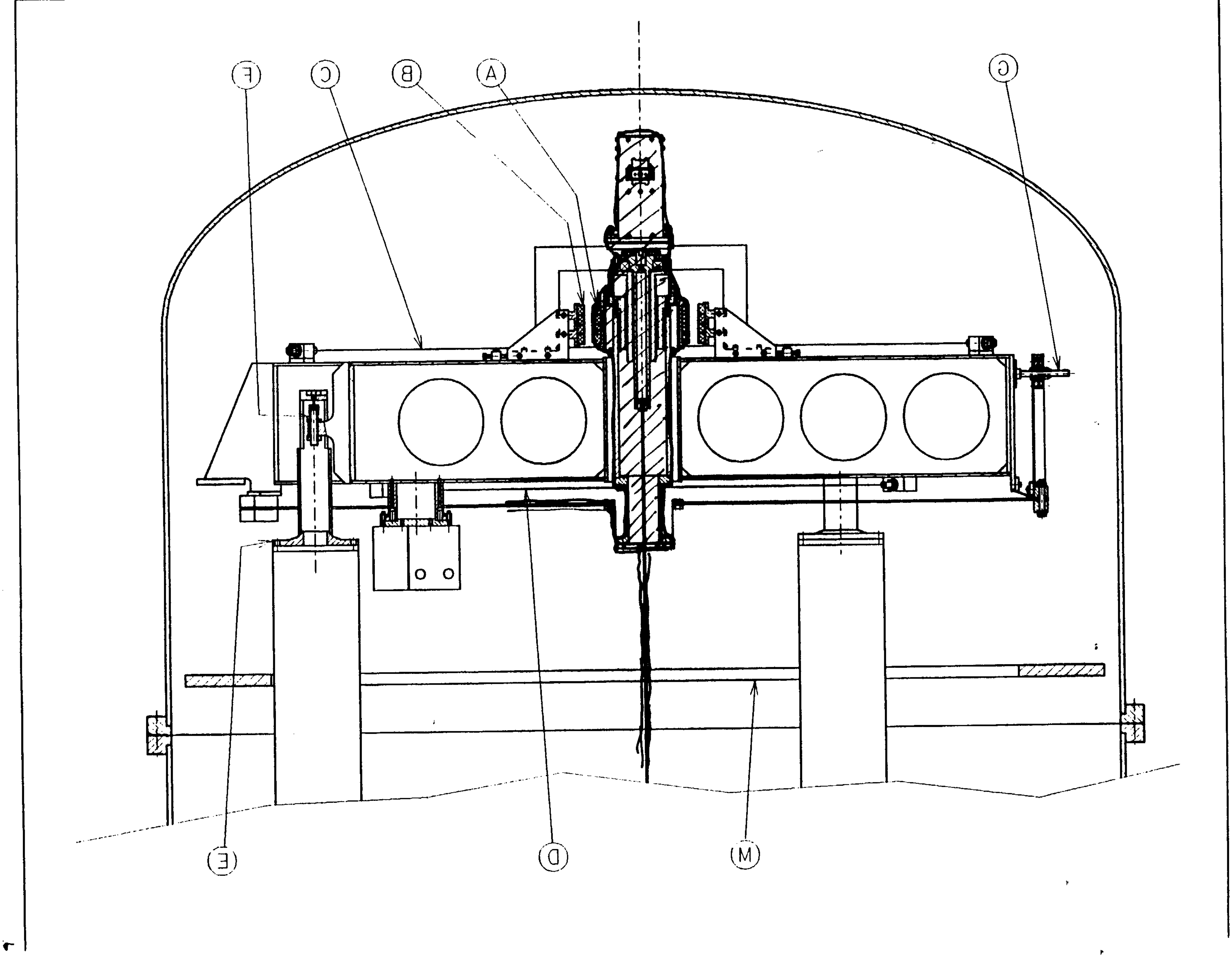
- at their systematic limit

1-a) Active seismic isolation

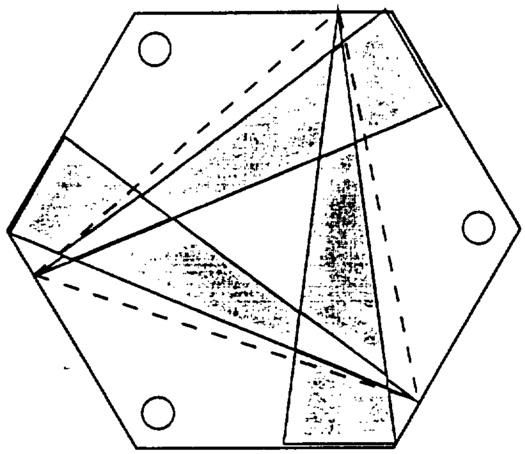
- *Top stages ideal for active attenuation*
- *1) need positioning actuators anyhow*
- *2) seismic signal still strong*
  - *=> sensors still sensitive*
- *3) their systematics filtered by the the chain's passive elements*

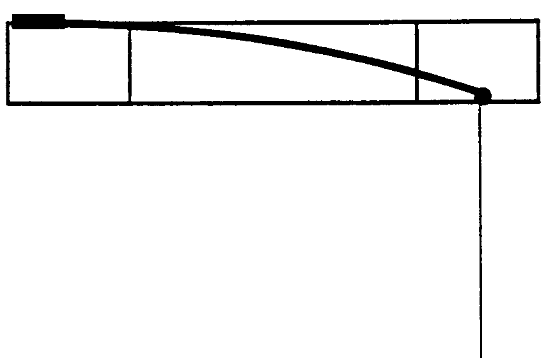
Top stages

- *interest to have ultra soft mechanics*
- *1) attenuation $1/(f-f_0)^{-2}$ starts early*
- *2) soft actuation*
  - *=>low power consumption*
  - *=>low noise injection*
- *3) residual motion reduction*


F
C
B
A
G
E
D
M

suspension of top stage





all blades are
2 m long
.5 m wide
1.2 GPa max load:

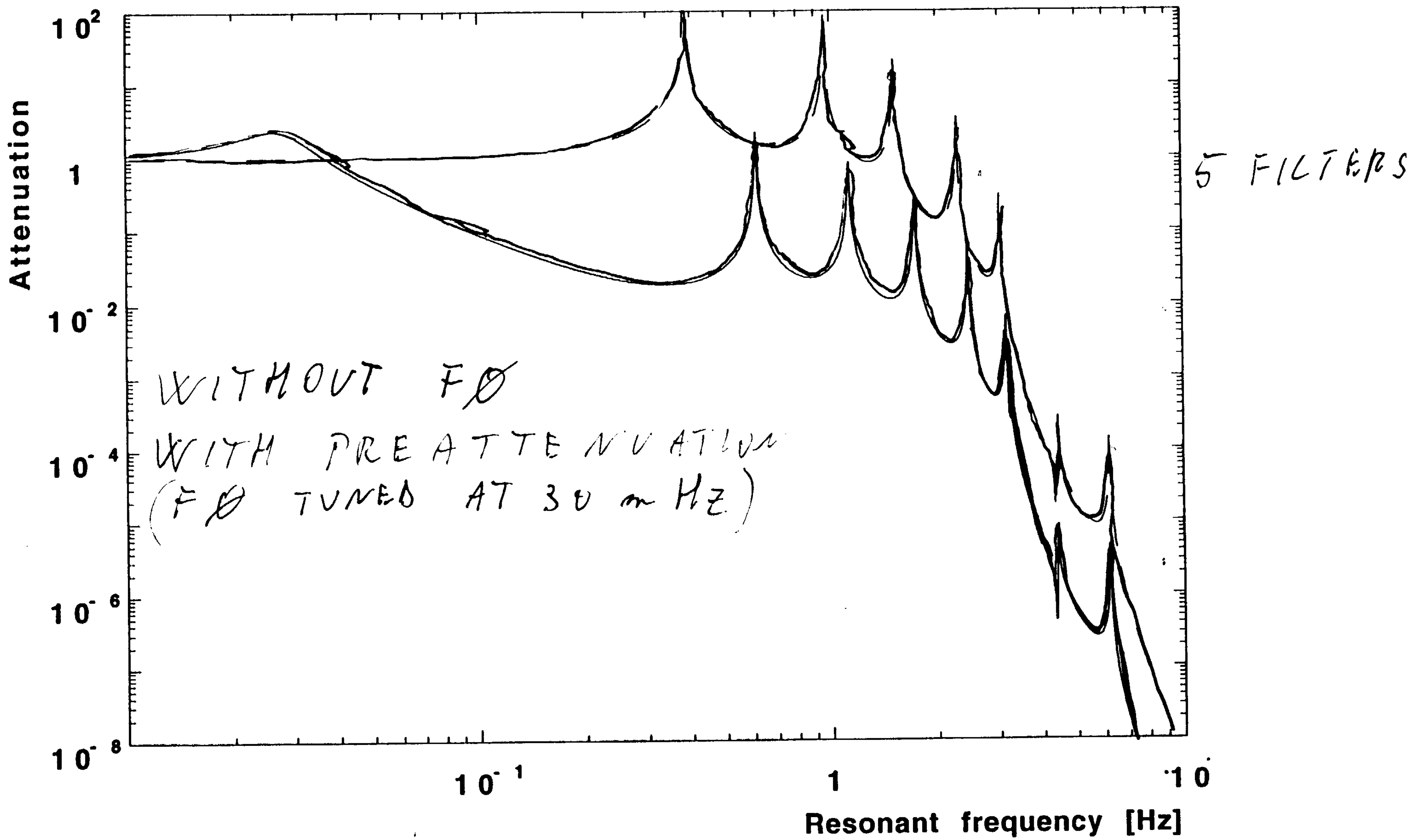
5 mm thick
hold 127 Kg
with fo = .219 Hz
to hold 1.5 tons
12 blades in stacks of 4
k =242 N/m / blade
k =2906 N/m

7 mm thick
with fo = .259 Hz
to hold 1.5 tons
6 blades in stacks of 2
k =664 N/m / blade
k =3987 N/m

10 mm thick
with fo = .309 Hz
to hold 1.5 tons
3 simple blades
k =1937 N/m / blade
k =5812 N/m

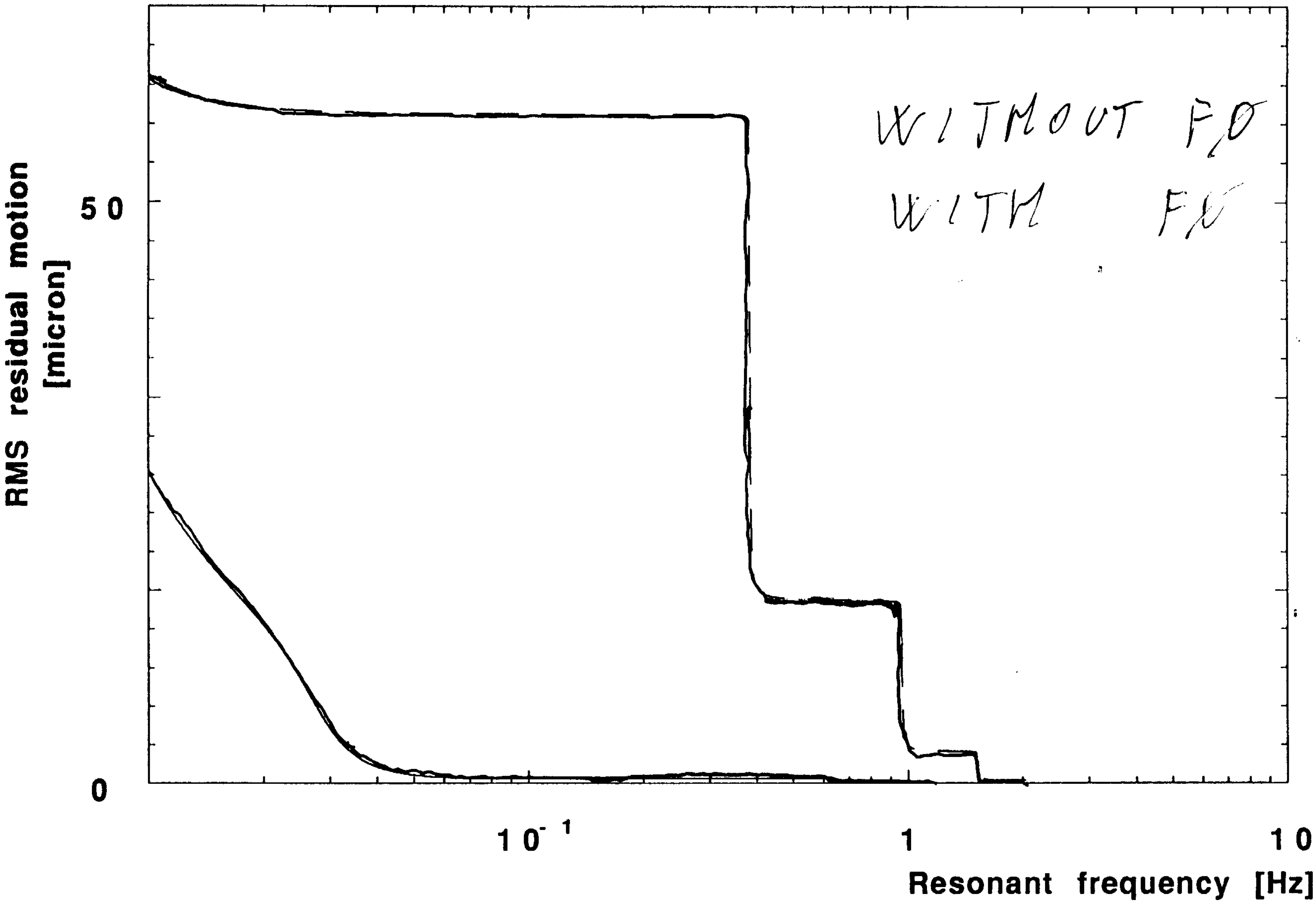
VIRGO VERTICAL TRANSFER FUNCTION

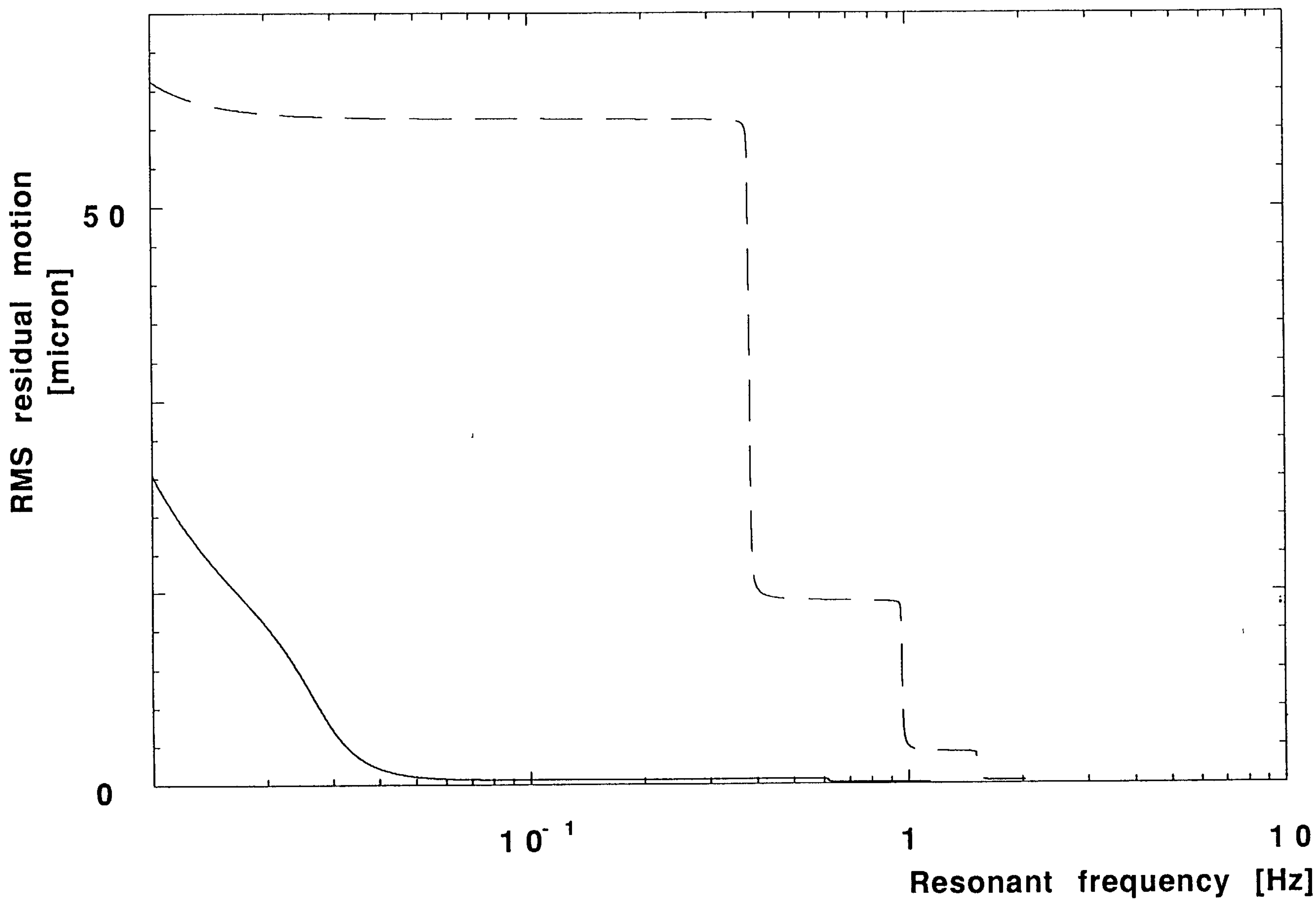
figure 2 top



MIRROR VERTICAL RESIDUAL MOTION

EXCITATION $\frac{10^{-6}}{f^2}$ m




RMS residual motion
[micron]
5 0
0
1 0^{-1}
1
1 0
Resonant frequency [Hz]

ACTIVITY REPORT

28/11/94 21:09

TOTAL TIME TX = 02:05' RX = 00:24'

NO.	DATE/TIME	TIME	DISTANT STATION ID	MODE	PAGES	BOX	RESULT	S.CODE
057	22/11 22:48	02'28"	+49 40 89983092	RX	004		NO	39C2
058	23/11 08:43	00'31"	CERN/TELEPHONE-T	RX	002		OK	0000
060	23/11 09:45	00'49"	91172545459	TX	000/001		NO	41A0
059	23/11 09:48	00'00"	0091172544533	TX	000/001		STOP	1080
061	23/11 09:50	00'27"	32 2 2962239	TX	001/001		OK	0000
062	23/11 09:52	00'00"	003222962239	TX	000/001		STOP	1080
063	23/11 11:15	07'57"	39 40 3756258	TX	006/006		OK	0000
064	23/11 13:49	01'24"	0734 352604	RX	003		OK	0000
065	23/11 14:45	05'46"	31 5908 13510	TX	010/010		OK	0000
066	23/11 15:56	15'03"	051 249847	TX	024/024		OK	0000
068	23/11 16:41	01'36"	88106292	RX	005		OK	0000
067	23/11 16:45	00'44"	41 1 730 15 02	TX	001/001		OK	0000
069	24/11 10:17	00'44"	41 21 644 4490	RX	001		OK	0000
070	24/11 11:40	01'19"		TX	002/002		OK	0000
071	24/11 11:49	00'38"	31 5908 13510	TX	002/002		OK	0000
072	24/11 11:56	00'36"	+49 40 3296923	TX	002/002		OK	0000
073	24/11 15:15	00'00"	0091172544533	TX	000/001		BUSY	14C2
074	24/11 15:18	00'45"	91172545459	TX	000/001		NO	41A0
075	24/11 15:45	01'03"	0051 14 772905	RX	002		OK	0000
076	24/11 15:57	00'34"	88106292	TX	001/001		OK	0000
077	24/11 16:07	00'32"	+33 1 69333002	TX	001/001		OK	0000
078	24/11 16:16	01'08"	39 81 2394508	RX	003		OK	0000
079	25/11 06:22	00'40"	91172545459	RX	001		OK	0000
080	25/11 08:59	00'37"	3825919	RX	001		OK	0000
081	25/11 10:25	00'30"	81332776631	TX	001/001		OK	0000
082	25/11 12:13	00'00"	003388106615	TX	000/001		STOP	1080
083	25/11 12:15	00'39"	+3388106234	TX	001/001		OK	0000
084	25/11 13:13	00'26"	41 21 644 4490	RX	001		OK	0000
085	25/11 13:17	00'47"	0051 14 772905	TX	001/001		OK	0000
086	25/11 13:49	02'02"	022 344 40 93	TX	003/003		OK	0000
087	25/11 14:01	02'02"	041 215757	RX	003		OK	0000
088	25/11 15:35	00'55"	41 22 7676900	RX	002		OK	0000
089	25/11 16:34	02'08"	+49 6206 59543	TX	003/004		NO	41A0
090	25/11 18:02	05'05"	039 2 76013379	TX	006/006		OK	0000
091	28/11 08:25	01'39"	+43 1 5447589	TX	003/003		OK	0000
093	28/11 11:42		0018187953951	TX			S_JAM	9087
092	28/11 11:41	22'55"	15708196	TX	041/041		OK	0000
094	28/11 12:11	13'09"	15708196	TX	029/029		OK	0000
095	28/11 13:59	17'41"	31 5908 13510	TX	032/032		OK	0000
096	28/11 14:20	01'24"	41227679060	RX	003		OK	0000
097	28/11 14:47	01'09"	051 249847	TX	003/003		OK	0000
098	28/11 15:38	00'33"	+49 211 4397462	RX	001		OK	0000
099	28/11 16:47	04'09"	011 6699579	RX	009		OK	39A0
100	28/11 16:52	00'27"	011 6699579	RX	001		OK	0000
101	28/11 16:55	00'56"	0865272400	RX	001		OK	0000
102	28/11 17:01	05'01"	39 81 2394508	TX	012/012		OK	0000
103	28/11 17:14	01'00"		RX	001		OK	0000
104	28/11 17:34	17'37"	31 5908 13510	TX	032/032		OK	0000
105	28/11 19:39	01'21"	0039805442470	RX	003		OK	0000
108	28/11 21:08	00'50"	4048949081	RX	003		OK	0000

VERTICAL ACTUATION POWER REQUIREMENTS
(750 Kg. LOAD)

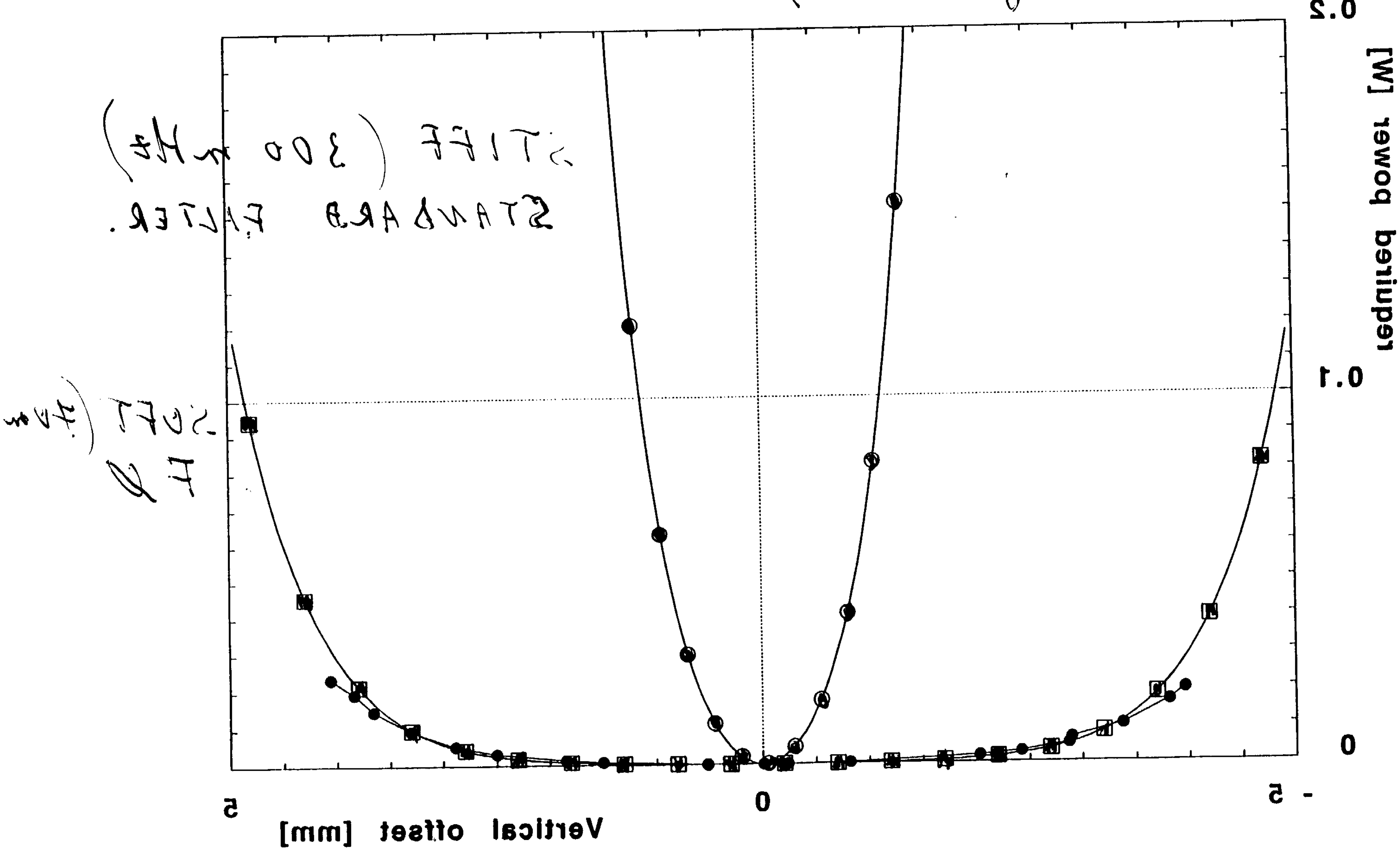
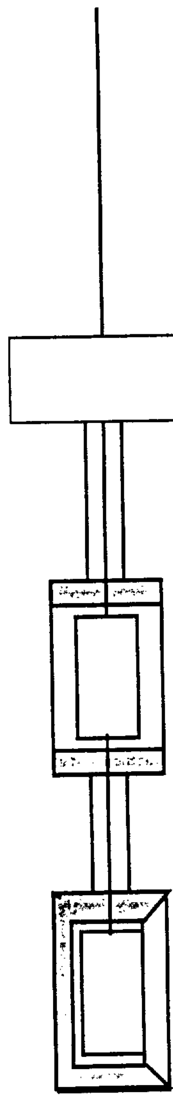
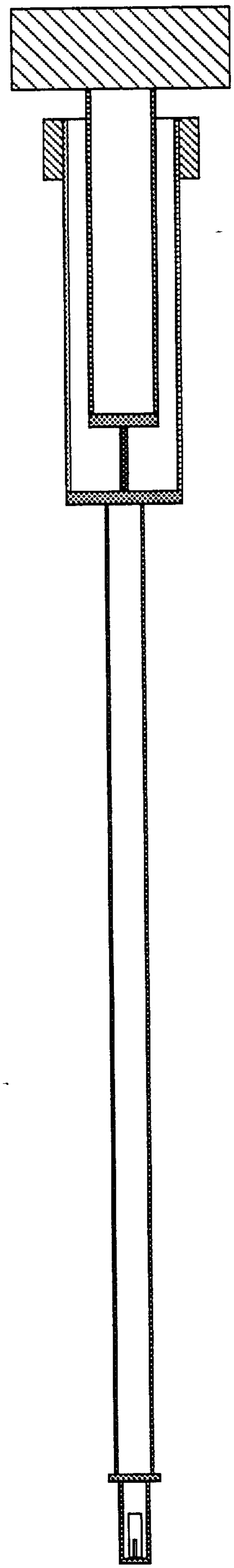
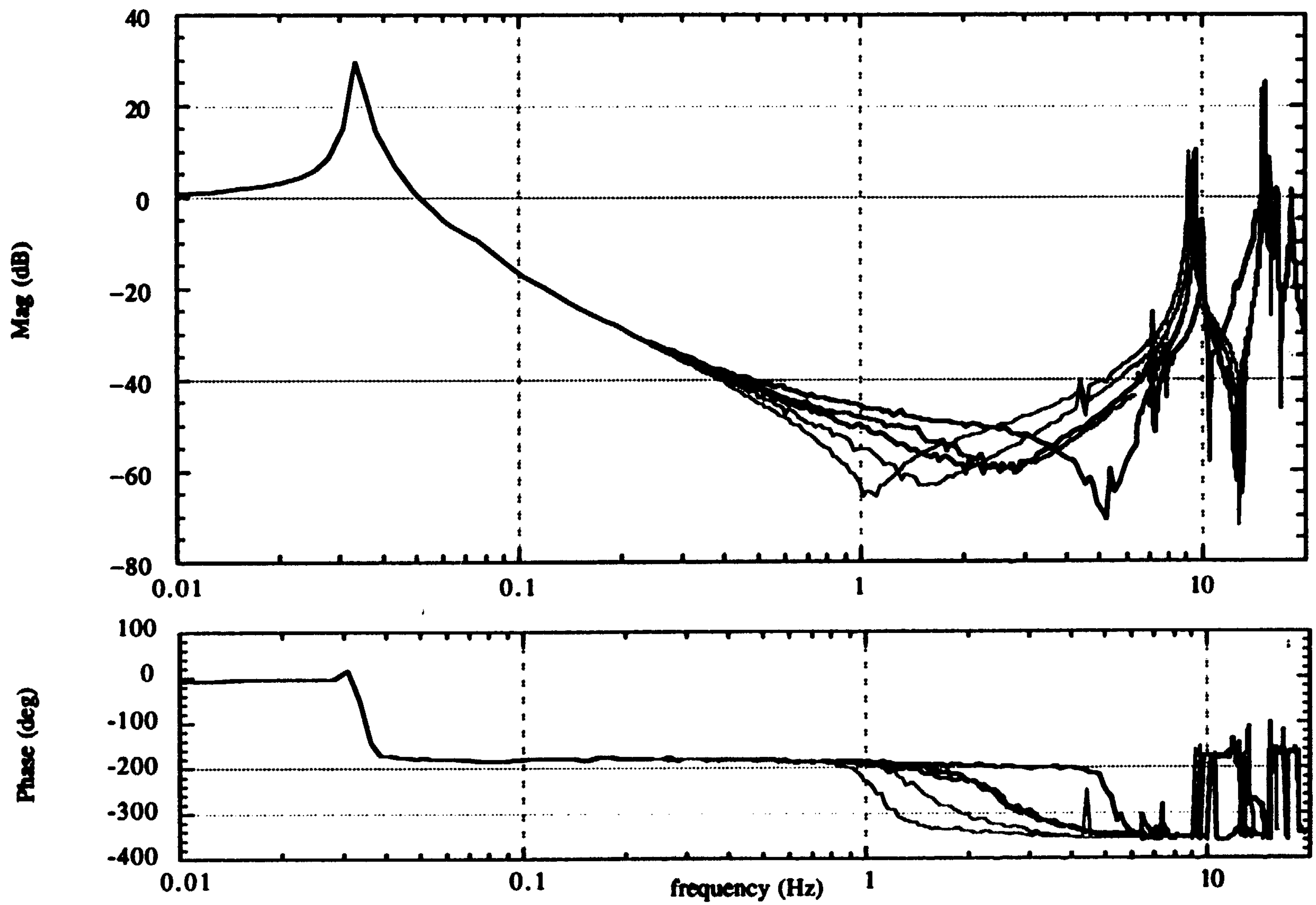


figure 9





Inverted Pendulum Transfer Function



Giovanni Losurdo - Scuola Normale Superiore & INFN

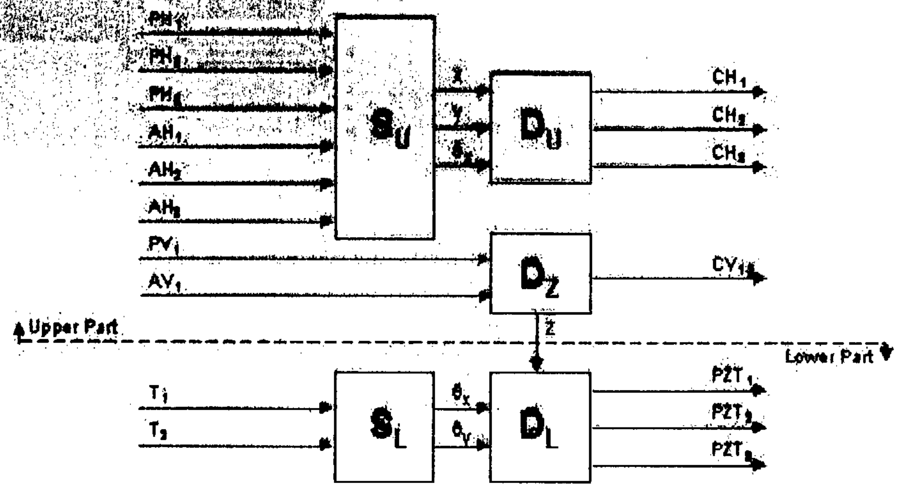
```
  {
   return(GX->r4y);
  }

double GX_dx(void)
  {
   return(GX->dx);
  }

double GX_dy(void)
  {
   return(GX->dy);
  }
double GX_dz(void)
  {
   return(GX->dz);
  }

double GX_dtx(void)
  {
   return(GX->dtx);
  }

double GX_dty(void)
  {
   return(GX->dty);
  }

double GX_dtz(void)
  {
   return(GX->dtz);
  }
```

Active top stages

- Interest to separate d.o.f.
- Feed back loops simpler
  - leave DSP capabilities for complex resonances
- Corrections for crossed d.o.f. are small perturbations (linear)

VIRGO Suspension Control

- Damping Strategy



Inertial Damping

- State-Space Description

$$\begin{cases} \dot{x} = Ax + Bu \\ y = (S_A \cdot A + S_T)x + (S_A \cdot B)u \end{cases} \quad A = \begin{bmatrix} 0 & I \\ A_M & A_D \end{bmatrix} \quad \begin{aligned} B &= [0 \quad B_x] \\ S_A &= [0 \quad S_a] \\ S_T &= [S_t \quad 0] \end{aligned}$$

- **Transfer Function Matrix**

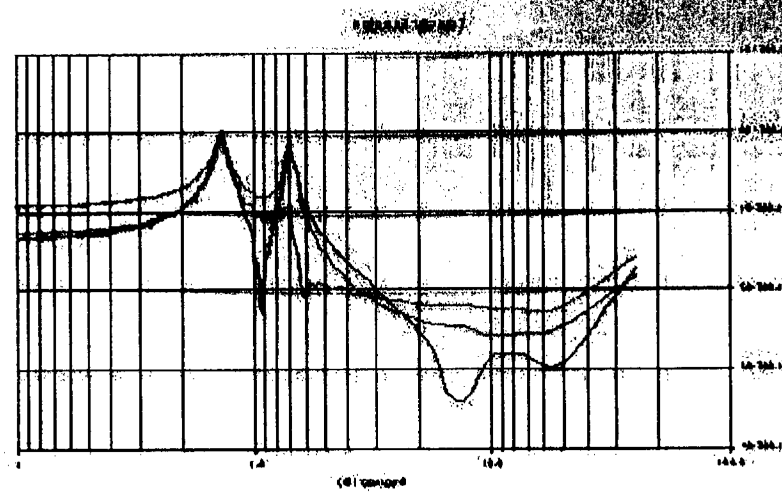
$$\boxed{G(s) = S_a \cdot H(s) \cdot B_x}$$

$$H(s) = diag(h_1, h_2, h_3)$$

$$\begin{aligned} H(s) = {} & A_M \cdot (s^2 \cdot I - s \cdot A_D - A_M)^{-1} + \\ & + S_a^{-1} \cdot S_t \cdot (s^2 \cdot I - s \cdot A_D - A_M)^{-1} + \\ & + s \cdot A_D \cdot (s^2 \cdot I - s \cdot A_D - A_M)^{-1} + I \end{aligned}$$

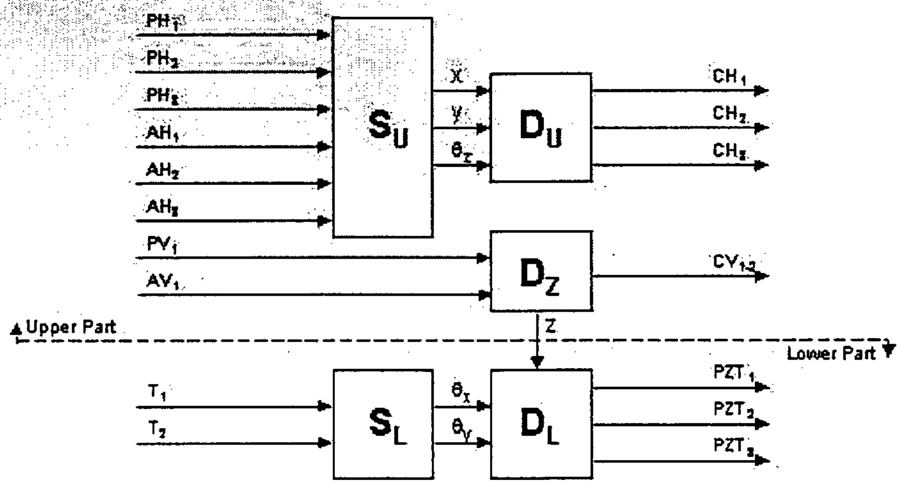
Inertial Damping

Inverted Pendulum TF



VIRGO Suspension Control

- Damping Strategy



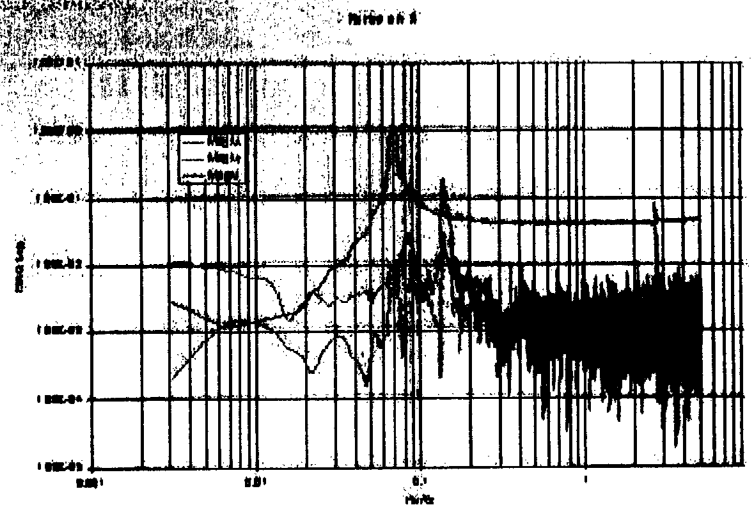
January 4-10, 1998

Aspen Winter Conference
Gravitational Waves And Their Detection

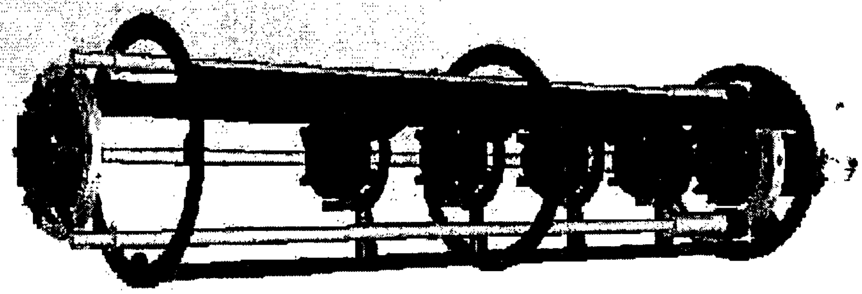
Alberto Gennai
I.N.F.N. Pisa

Inertial Damping

- Force on X



SuperAttenuator



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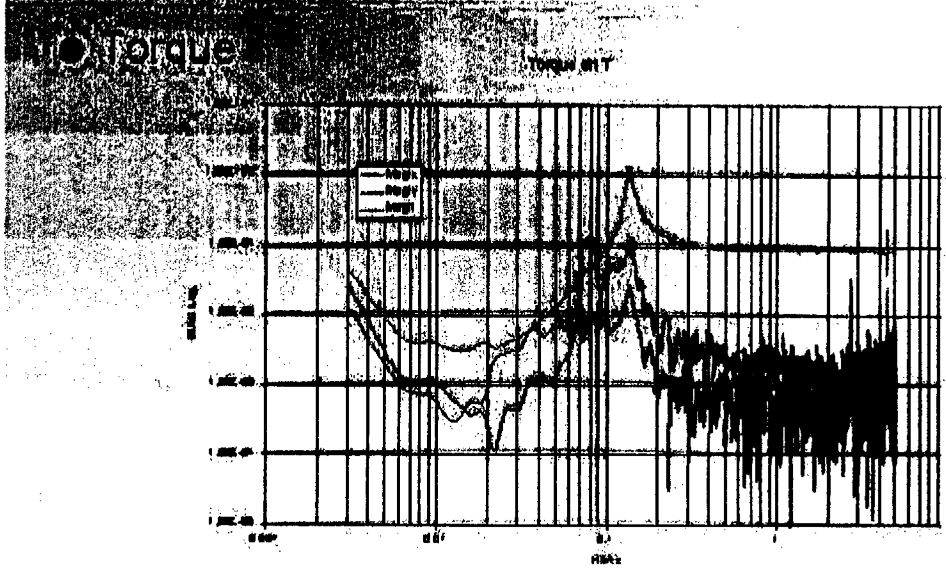
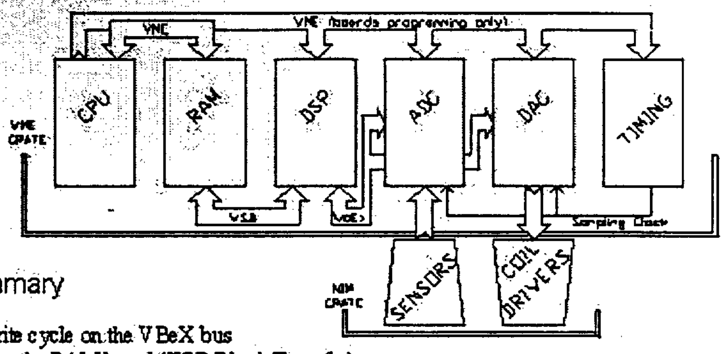
Inertial Damping



VIRGO Suspension Control

• Hardware Architecture



Timing Summary

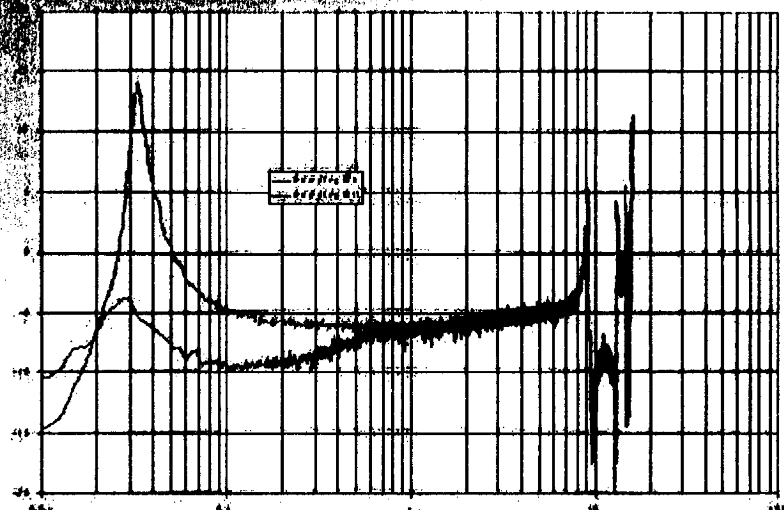
600 to 800 ns	6 channels read/write cycle on the VBeX bus
1 to 2 us	Read/write cycle on the RAM board (VSB Block Transfer).
5 us	ADCs conversion time..
1.2 us	DACs conversion time.

About 40 us available for DSP operations (800 instruction - about 200 poles and 200 zeros) with a sampling rate of 20 kHz (single sample delay between input and output).

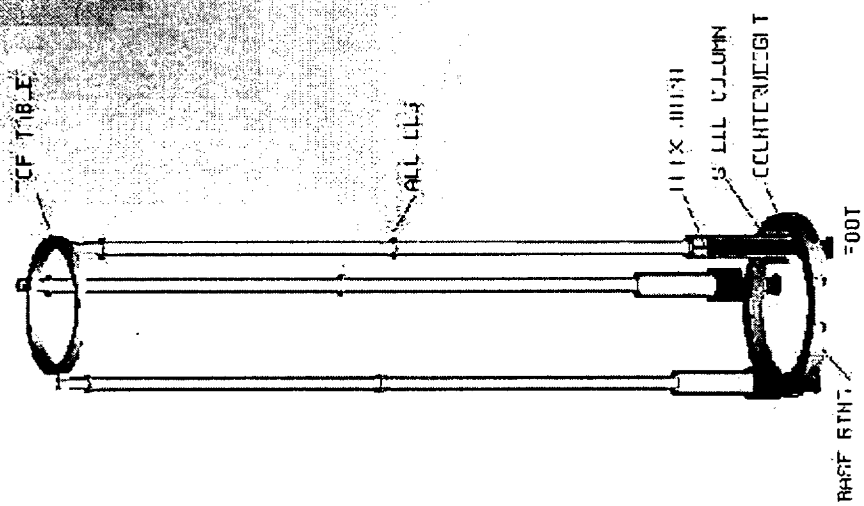
Alberto Gennai
I.N.F.N. Pisa

Inertial Damping

Closed Loop Transfer Function: X



Inverted Pendulum



Data Signal Processor controls

- <u>*DSP is a vital requirement*</u>
- *large systems have many resonances*
- *feed back loop <u>MUST</u> adapt to mechanics*
- *not enough a priori knowledge of mechanical pitfalls*
  - *=> need added flexibility for evolutive system*
- *all actuators freq. range between mHz and KHz*
  - *=> D.S.P. at their best*
  - *=> analog feed back difficult at mHz*

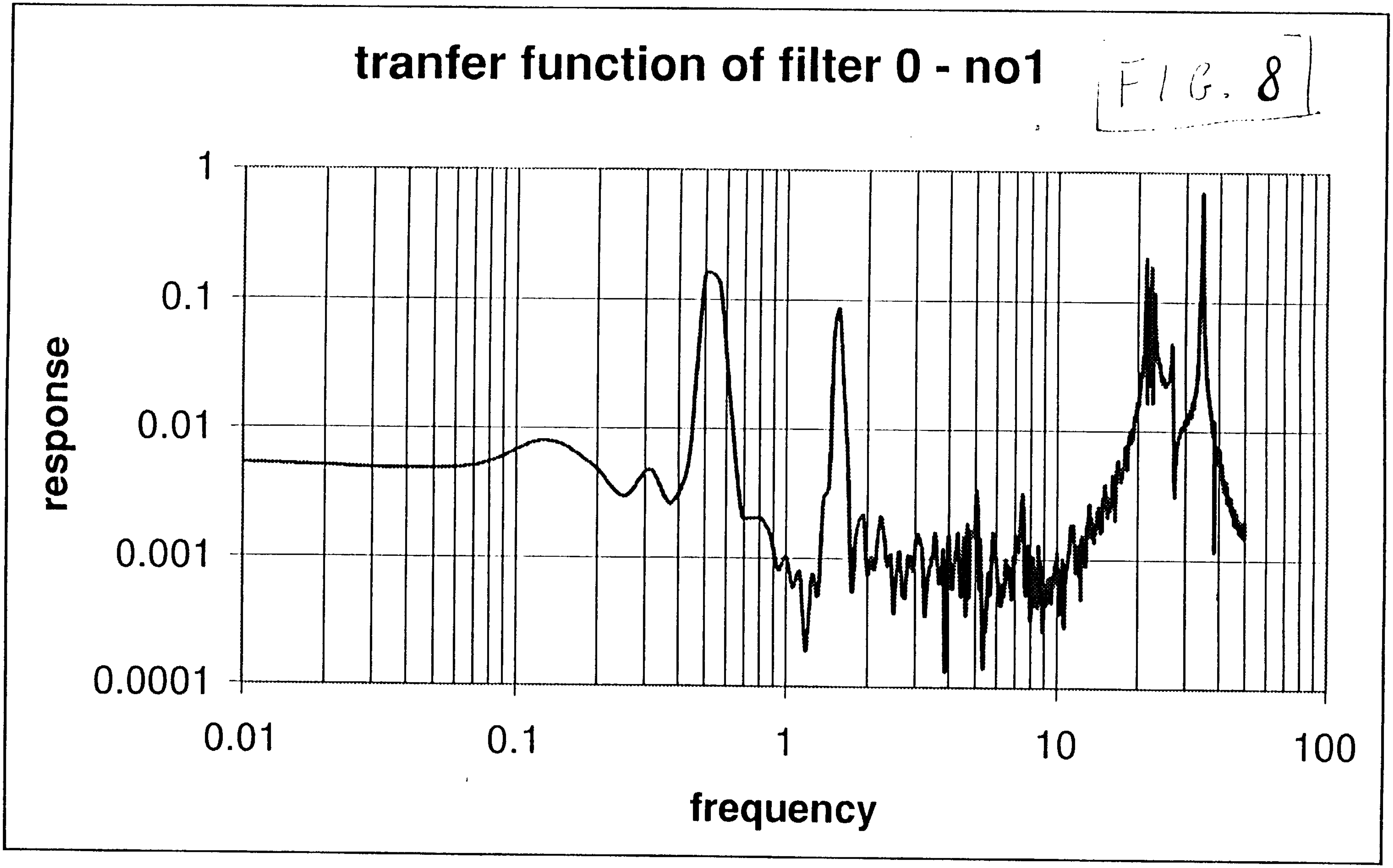

tranfer function of filter 0 - no1
response
1
0.1
0.01
0.001
0.0001
0.01
0.1
1
10
100
frequency

FIG. 8

Bottom of Chains

Interferometer locking feed back actuation

- *1) higher frequencies*
- *2) lower forces (still need no standing forces to avoid power dissipation and noise injection)*
- *3)10^{-18} 10^{-12} m for last active stage*
  - *limited by signal mixer*
- *4)10^{-12} 10^{-x} m for 2nd last active stage*
  - *10^{-x}quietness os S.A chain residual motion*

Bottom of Chains

Interferometer locking feed back actuation

- 4) Actuation from recoil masses
- 5) Standing forces nulling mechanisms (tilting locally or movements at higher stages)
- 6) Highest possible Q (thermal noise)

Quietness of S.A. chains

- *a) Σ   residual motions*
- *b) Σ   occasional forces*
- *a) attenuation from lowest possible frequency and damped resonances*
  - *active isolation helps*
- *b) small releases from mechanical systems (example cables)*

Example of small energy releases

- *force necessary to move 1 pendulum, 5 m tall, 500 Kg by 1 nm.*
- $F = mg\theta = 5000\ (1\ 10^{-9} / 5) = 10^{-6}$ N
- $E = 1/2\ F x = 10^{-15}$ J $= 10^{4}$ eV
- *Cables that are far from the axis of suspension can easily do that*
  - *Eliminate cabling, Marconi project*

Suspension Isolation Task Group

- Physicist (general)
- Physicist (general)
- Physicist (general)
- Physicist (software)
- Engineer (mech.)
- Engineer (electr.)
- Engineer (electr.)
- Engineer (vacuum)

- Gen. logic
- Actuators/sensors
- Integration
- Simulation
- Mech. Design
- DSP
- Wireless
- Compatibility

Prototyping needs

- *Will use every possible cm in height*
  - *double crane beam in site*
- *Test hall with similar Ligo height*
- *Interested and competent group locally*

Past experience in Virgo

- *prototyping of each component*
  - *conception and design 6-8 mo.*
  - *construction 4 mo.*
  - *testing 4 mo.*
  - *production of final product*
- *capitalize on Virgo experience*
- *only 2-3 new components to prototype for Ligo*

Experience of other experiments.

- Geo
  - small but vigorous
- Aciga
  - starting but lots of thought and tests
- Common development and testing
  - to collect the best idea
  - to reduce doubled developments

Note 1, Linda Turner, 04/20/98 04:33:11 PM
LIGO-G980049-18-M