BNL-104119-2014-TECH

AGS.SN243;BNL-104119-2014-IR

SEB Slow Spill Servo System Measurement

S. Y. Zhang

September 1988

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

Notice: This technical note has been authored by employees of Brookhaven Science Associates, LLC under Contract No.DE-AC02-76CH00016 with the U.S. Department of Energy. The publisher by accepting the technical note for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this technical note, or allow others to do so, for United States Government purposes.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

September 20, 1988

AGS Studies Report Number 243

Date: May 16, 1988. Time: 0600-1100

Experimenters: S. Y. Zhang, A. Soukas, A. Feltman, J. Gabusi.

Reported by: S. Y. Zhang.

Subject:

SEB Slow Spill Servo System Measurement.

I. Introduction

The slow spill servo system at the AGS is designed for the purpose of maintaining a constant beam extraction during the SEB spill period. The feedback signal is taken from the extracted beam. It is then compared with the desired reference signal. The difference is used to drive the Siemens power supply in order to achieve an expected magnet current slope, which moves the AGS circulating beam radially outward for the extraction. The purpose of this measurement is to find the spill servo open loop transfer function, especially the time delay from the magnetic field slope to the beam extraction. The model obtained is useful in the spill servo system analysis, simulation and design.

II. Loop Components

In this section, we give the description through the proper transfer functions for each component in the spill servo loop. The schematic drawing is shown in Fig.1.

1) C10 SEC amplifier.

Let the current input to the C10 SEC amplifier be $I_{iC10}(s)$. Let the voltage output be $V_{C10}(s)$. We have

$$V_{C10}(s) = T_1(s) I_{iC10}(s), \tag{1}$$

where $T_1(s)$ is the transfer function of the amplifier.

$$T_1(s) = \frac{-100 \times 0.333 \times 10^6}{s + 0.333 \times 10^6}. \tag{2}$$

2) Spill Servo Regulator.

After a buffer with a gain 2.2, the beam signal is compared with the reference voltage V_{REFCBM}, which is from the L20CBM(circulating beam monitor) by an S/H device. The difference is then augmented by a computer controlled power supply signal, P/S, which ranges from 0V to -10V. The gain represented by P/S is denoted by G_{SSGAN}. The signal after an RC network is denoted by $V_{BUFF}(s)$. We have

$$V_{BUFF}(s) = T_2(s) \times (2.2 V_{C10}(s) - V_{REFCBM}). \tag{3}$$

where the spill servo regulator currently is

$$T_2(s) = G_{SSGAN} \times \frac{0.032s + 9.68}{s + 9.68} \tag{4}$$

3) Spill Signal Filter.

After a -0.63 buffer, the spill servo reference voltage $V_{SPILLREF}(s)$ is compared with $V_{BUFF}(s)$. The output of the comparator, after a -2 buffer and the spill signal filter, is then fed to the Siemens power supply, i.e. the B loop. This voltage is denoted by $V_{iSIEMENS}(s)$. We have

$$V_{iSIEMENS}(s) = T_3(s)\times(-2)\times(-0.63\,V_{SPILLREF}(s)+V_{BUFF}(s)). \tag{5}$$

with the spill signal filter

$$T_3(s) = \frac{-2{,}338}{s+6{,}865} \tag{6}$$

4) $\dot{B}$ Servo System.

From the measurement of the $\dot{B}$ servo system, we have obtained a third order linear model for the multiphase rectifier at the Siemens, which is

$$\begin{aligned} G_{RECT}(s) &= -60\times\left(\frac{4{,}500}{s+4{,}500}\right)^2\times\frac{13{,}500}{s+13{,}500} \\ &= \frac{-1.64E13}{s^3+22{,}500s^2+1.418E8s+2.734E11} \end{aligned} \tag{7}$$

This model well matches the system frequency behaviour from DC to about 200Hz, and therefore it can be used in the study of spill servo system. If we consider the phase delay network in the B servo loop

$$G_d(s) = \frac{42.55}{s+42.55}, \tag{8}$$

along with the DC gain adjustment in the loop, 5.3, and the feedback coefficient 0.01, then we can calculate the transfer function of the B servo system as

$$\begin{aligned} T_4(s) &= \frac{G_d(s)\times 5.3\times G_{RECT}(s)}{1-G_d(s)\times 5.3\times G_{RECT}(s)\times 0.01} \\ &= \frac{-3.7E15}{s^4+22{,}543s^3+1.427E8s^2+2.794E11s+4.862E13} \end{aligned} \tag{9}$$

The Bode Plot of the transfer function (9) shows that the $\dot{B}$ loop now has a DC gain 76, and a bandwidth 28Hz.

The input signal in the $\dot{B}$ system is the sum of $V_{iSIEMENS}(s)$ and V_{COMREF}, where V_{COMREF} is the computer controlled voltage reference, serving the purpose of Siemens output voltage set up. The output voltage is denoted as $V_{oSIEMENS}(s)$. Thus, we have

$$V_{oSIEMENS}(s) = T_4(s)(V_{iSIEMENS}(s)+V_{COMREF}) \tag{10}$$

5) Siemens Filter.

We denote the voltage output of the Siemens filter as $V_M(s)$, and let

$$V_M(s) = \tilde{T}_5(s)\,V_{oSIEMENS}(s). \tag{11}$$

where

$$\tilde{T}_5(s) = \frac{4E6s+1.143E9}{s^3+2{,}285.71s^2+4E6s+1.143E9}. \tag{12}$$

A simplified second order model for the filter can be found as

$$T_5(s) = \frac{3.334E6}{s^2+1,450s+3.334E6} \tag{13}$$

Later, we shall use the simplified model.

6) Magnet and Magnetic Field Slope.

Let the magnet current be $I_M(s)$. We have

$$I_M(s) = T_6(s)V_M(s) = \frac{1.54}{s+0.4}V_M(s). \tag{14}$$

The magnetic field slope is equivalent to the magnet current slope. There are two factors which are important as the magnet current slope is concerned. One is the voltage on the magnet, $V_M(s)$, and another is the initial magnet current, i.e. the magnet current at the starting moment of flatop. In the measurement, the sampling period was chosen at the middle of the flatop, therefore, the second factor, i.e. the initial condition of the magnet can be neglected. Therefore, the magnetic field slope can be described simply by multiplying a differential factor s to the magnet current

$$sI_M(s) = sT_6(s)V_M(s) = \frac{1.54s}{s+0.4}V_M(s) \tag{15}$$

7) Spill

The beam extraction is proportional to the magnetic field slope. Therefore, for the spill, we have

$$I_{iC10}(s) = \alpha e^{-t_d s} sI_M(s) = \alpha e^{-t_d s} sT_6(s)V_M(s) \tag{16}$$

Let

$$T_7(s) = \alpha e^{-t_d s} s, \tag{17}$$

where $e^{-t_d s}$ denotes the time delay factor of t_d seconds in the beam extraction, and α is the extraction coefficient, s representes the differential factor.

III. Measurement and Analysis

In the measurement, the AGS was operated at the SEB module. We had removed the output connection of the spill servo regulator $T_2(s)$. Thus, the spill servo loop was open. The sine waveform signals V_{TEST} were used as the input as shown in Fig.1 at the same position of the spill reference, i.e. $V_{SPILLREF}$. The output received in the measurement was from C10 T. P. i.e., the output of the 2.2 buffer after the C10 amplifier. The output amplitude and phase were measured by the HP3561A Spectrum Analizer, by 5-time averaging.

The sampling period was chosen at the middle of the flatop, and other technique employed is similar to that in the $\dot{B}$ servo loop measurement.

The measured data are listed in Table 1. Later, we measured the spill signal together with the Siemens' voltage output, i.e., the magnet voltage. The data are listed in Tables 2 and 3. The calculated spill transfer function data are also shown. Since the input signal passed through a buffer with the gain of -0.63, i.e., -4db, with 180 degree phase shift, and this buffer is not in the spill servo loop, we have excluded the factor by adding to all transfer function magnitude data by 4db, and adding to all phase by 180 degrees.

The data of the two measurements then have been summed, and plotted in Fig.2a and 2b, for the magnitude and phase, respectively.

In the measurement, we note that the spill servo regulator was not included. Also we note that since the sampling period is chosen at the middle of the flatop, the influence of the initial magnet current can be disregarded. Thus, for the measurement, the signal flow path can be decribed as

$$\overline{G}(s) = (-2)\times T_3(s)\times T_4(s)\times T_5(s)\times T_6(s)\times T_7(s)\times T_1(s)\times 2.2 \tag{18}$$

The corner frequency provided by the magnet, i.e. $T_6(s)$, is only 0.063Hz, while all data taken were from the frequencies higher than 5Hz, therefore the effect of the corner frequency due to the magnet is trivial. Thus, the denominator of $T_6(s)$ can be cancelled with the s in the numerator in $T_7(s)$. Also since the transfer function of the C10 amplifier $T_1(s)$ has a corner frequency at 5KHz, far away from the interested frequency band, it can be simplified by a constant, -100. Thus, we have the following transfer function for our measurement,

$$\begin{aligned} G(s) &= (-2)\times\frac{-2{,}338}{s+6{,}865}\times\frac{-3.7E15}{s^4+22{,}543s^3+1.427E8s^2+2.794E11s+4.862E13} \\ &\quad \times\frac{3.334E6}{s^2+1{,}450s+3.334E6}\times 1.54\times\alpha\times e^{-t_d s}\times(-100)\times 2.2 \\ &= \frac{1.954E28e^{-t_d s}\times\alpha}{s^7+30{,}858s^6+3.434E8s^5+1.788E12s^4+4.784E15s^3+7.384E18s^2+7.041E21s+1.113E24} \end{aligned} \tag{19}$$

The low frequency range gain is easily calculated as

$$G = \frac{1.954E28\times\alpha}{1.113E24} = 17{,}551\alpha \tag{20}$$

which is (84.9+20logα)db. From the measured data, it is shown that the low frequency range gain is about 8.5db, thus, we may conclude that

$$20\log\alpha = 8.5db - 84.9db = -76.4db \tag{21}$$

i.e., the extraction coefficent defined in (16) is

$$\alpha = 0.00015 \tag{22}$$

In Fig.2a and 2b, we also show the Bode Plot by using the model in (19) by the continuous curves, which are plotted by using PC-MATLAB. The magnitude curve matches the experiment data closely. For the phase plot, we show 4 curves representing 0ms, 0.5ms, 1ms, and 2ms time delay, respectively. It seems that the time delay for the beam spill is very close to 1ms.

In Fig.3a and 3b, we show the Bode Plot for the differences between the $\dot{B}$ servo system output and the extracted beam. This time, no rectifier is included in the path. We use only the most significant dynamic model, i.e., the Siemens Filter, see (13), as the simulated model. The phase data are very close to the simulated curve with 1ms time delay.

We may also conclude that since the computer controlled spill gain G_{SSGAN} was very close to 1, therefore the SEB spill servo loop gain at the time of the measurement is about 8.5db, i.e. about 2.66. This is low.

Acknowledgement: We wish to thank S. Naase for the skilful technical support.

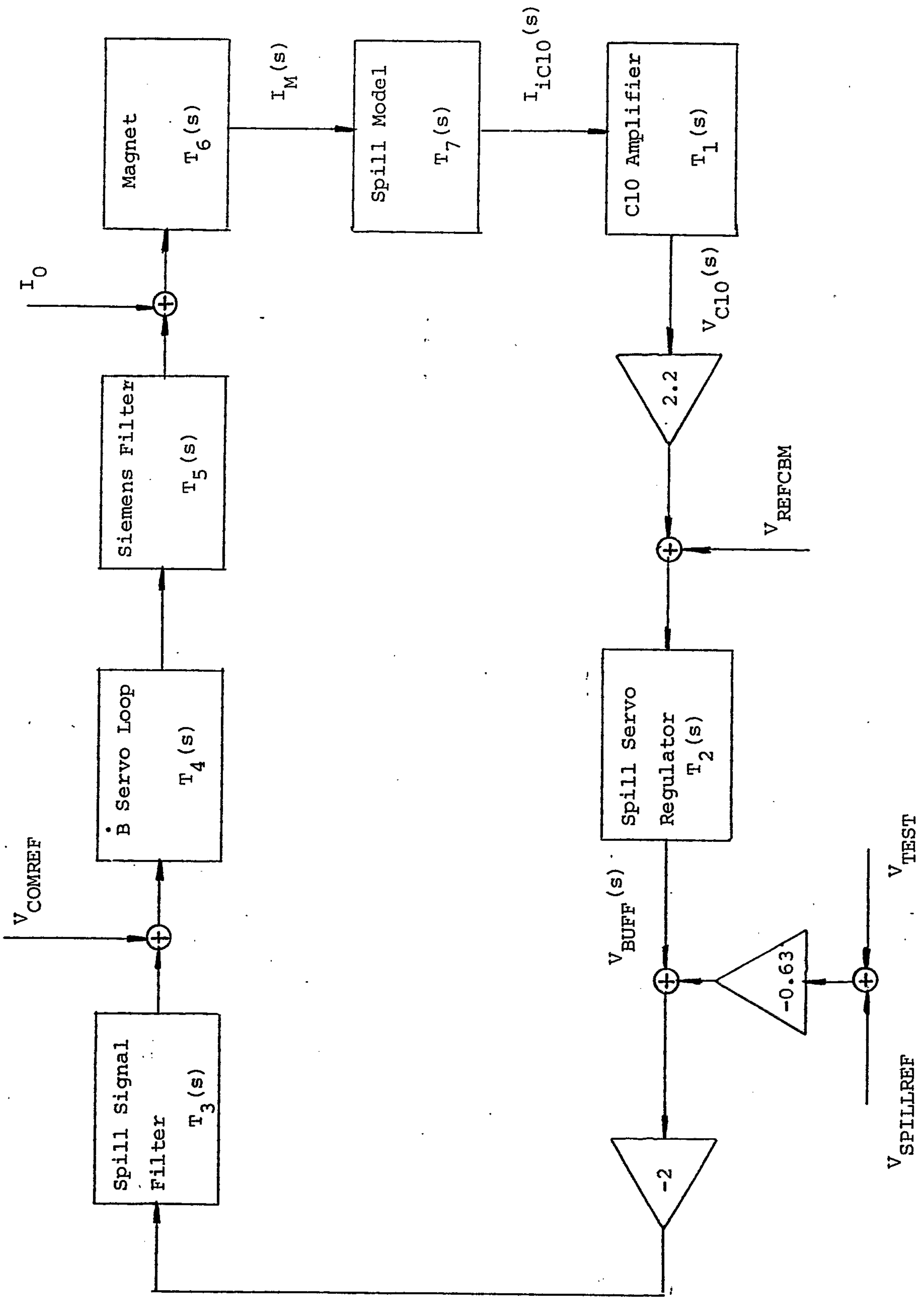
Magnet
$T_6(s)$
$I_M(s)$
Spill Model
$T_7(s)$
$I_{iC10}(s)$
C10 Amplifier
$T_1(s)$
I_0
$V_{C10}(s)$
2.2
Siemens Filter
$T_5(s)$
V_{REFCBM}
$\dot{B}$ Servo Loop
$T_4(s)$
Spill Servo Regulator
$T_2(s)$
V_{COMREF}
$V_{BUFF}(s)$
-0.63
V_{TEST}
Spill Signal Filter
$T_3(s)$
-2
$V_{SPILLREF}$

Fig. 1

SPILL SERVO MEASUREMENT 1

FREQ (Hz)	INPUT AMPL (db)	INPUT PHASE (Deg.)	OUTPUT AMPL (db)	OUTPUT PHASE (Deg.)	BODE AMPL (db)	BODE PHASE (Deg.)
5	-19.5	155	-15	-35	8.5	-10
10	-19.6	-34.1	-15.8	123	7.8	-22.9
20	-19.6	-24.8	-15.14	112.5	8.46	-42.7
30	-19.6	-27.4	-18	92.1	5.6	-60.5
40	-19.6	-18	-18.9	89.2	4.7	-72.8
50	-19.6	-25.7	-15.84	71	7.76	-83.3
55	-19.6	166.6	-16.63	-121.2	6.97	-107.8
60	-19.6	-20.9	-19.7	46.1	3.9	-113
65	-19.6	147.6	-17.75	-156.5	5.85	-124.1
70	-19.6	-15.6	-19.66	18.1	3.94	-146.3
80	-19.6	-24.9	-23.43	8.9	0.17	-146.2
88	-19.6	-17.9	-22.98	8.8	0.62	-153.3
97	-19.6	157.3	-24.53	-176	-0.93	-153.3
105	-19.6	152	-25.32	162.5	-1.72	-169.5
115	-19.61	144.5	-26.12	164.1	-2.51	-160.4
125	-19.6	-49	-27.4	-127.6	-3.8	-258.6
135	-19.61	150.1	-27.45	153.3	-3.84	-176.8
145	-19.6	107.3	-29.34	98.1	-5.74	-189.2
155	-19.6	161	-28.33	136.1	-4.73	-204.9
165	-19.63	-91.1	-30.6	-124.3	-6.97	-213.2
175	-19.63	-98.2	-30.65	-150	-7.02	-231.8
185	-19.63	-140.8	-30.82	159.3	-7.19	-239.9
195	-19.611	-152.8	-30.99	146	-7.38	-241.2
205	-19.16	148.5	-32.95	68.4	-9.79	-260.1
215	-19.16	165.3	-32.55	81.2	-9.39	-264.1
225	-19.16	159.1	-32.73	68	-9.57	-271.1
235	-19.16	-123.5	-33.97	145.4	-10.81	-271.1
245	-19.15	-147.5	-34.41	97.5	-11.26	-295
260	-19.16	-29.8	-36.22	-156.7	-13.06	-306.9
280	-19.16	-44.2	-35.59	168.4	-12.43	-327.4
288	-19.16	-24.6	-37.91	160.4	-14.75	-355
304	-19.16	-14.7	-41.62	-185.6	-18.46	-350.9
325	-19.16	-167.5	-41.13	0.4	-17.97	-372.1
375	-19.15	108.3	-46.81	-137.7	-23.66	-426
438	-19.16	173.2	-48.86	-70.7	-25.7	-423.9

Table 1

SPILL SERVO MEASUREMENT 2

FREQ (Hz)	INPUT AMPL (db)	INPUT PHASE (Deg.)	OUTPUT AMPL (db)	OUTPUT PHASE (Deg.)	BODE AMPL (db)	BODE PHASE (Deg.)
105	-19.21	153.5	-24.72	-178.6	-1.51	-152.1
135	-19.21	156.8	-27.3	162.1	-4.09	-174.7
155	-19.21	180.8	-28.63	161.7	-5.42	-199.1
215	-19.27	-130.2	-32.58	153.2	-9.31	-256.6
260	-19.46	130	-35.26	2.8	-11.8	-307.2
325	-13.73	185.1	-36.16	-29.8	-18.43	-394.9
395	-13.73	162.2	-41.05	-99.8	-23.32	-442
438	-3	37.4	-35.86	142	-28.86	-435.4
510	-0.32	-39.2	-44.3	-13.8	-39.98	-514.6
560	-0.24	0.5	-50.42	-5.5	-46.18	-546
624	6.16	-113.3	-49.13	-102.4	-51.29	-529.1
686	8.09	113.1	-55.11	14	-59.2	-639.1

Table 2

SIEMENS MEASUREMENT

FREQ (Hz)	INPUT AMPL (db)	INPUT PHASE (Deg.)	OUTPUT AMPL (db)	OUTPUT PHASE (Deg.)	BODE AMPL (db)	BODE PHASE (Deg.)
105	-19.21	153.5	-24.72	-178.6	-30.2	-90.8
135	-19.21	156.8	-27.3	162.1	-32.73	-91.8
155	-19.21	180.8	-28.63	161.7	-33.19	-107.8
215	-19.27	-130.2	-32.58	153.2	-35.5	-121.9
260	-19.46	130	-35.26	2.8	-39.05	-134
325	-13.73	185.1	-36.16	-29.8	-41.08	-155.3
395	-13.73	162.2	-41.05	-99.8	-43.72	-177.5
438	-3	37.4	-35.86	142	-46.05	-180.2
510	-0.32	-39.2	-44.3	-13.8	-50.82	-198.6
560	-0.24	0.5	-50.42	-5.5	-53.53	-202.2
624	6.16	-113.3	-49.13	-102.4	-58.49	-203.9
686	8.09	113.1	-55.11	14	-64.79	-253.1

Table 3

FROM SIEMENS TO SPILL

FREQ (Hz)	BODE AMPL (db)	BODE PHASE (Deg.)
105	-31.31	-61.3
135	-31.36	-82.9
155	-32.23	-91.3
215	-33.81	-143.7
260	-32.75	-173.2
325	-37.35	-239.6
395	-39.6	-264.5
438	-42.81	-255.2
510	-49.16	-316
560	-52.65	-343.8
624	-52.8	-325.2
686	-54.41	-386

Table 4

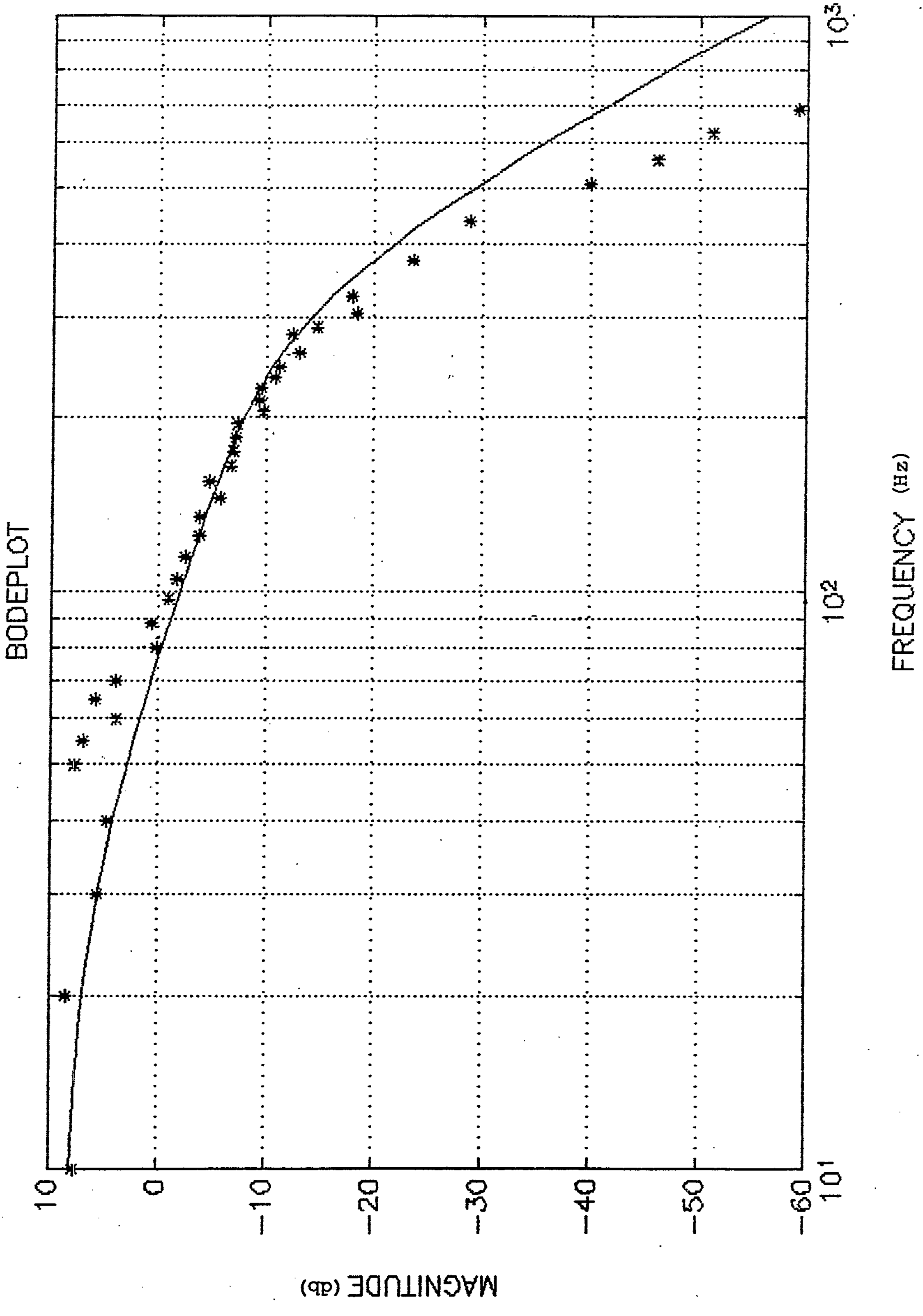
BODEPLOT
MAGNITUDE (db)
FREQUENCY (Hz)
10
0
−10
−20
−30
−40
−50
−60
10^1
10^2
10^3

Fig. 2A

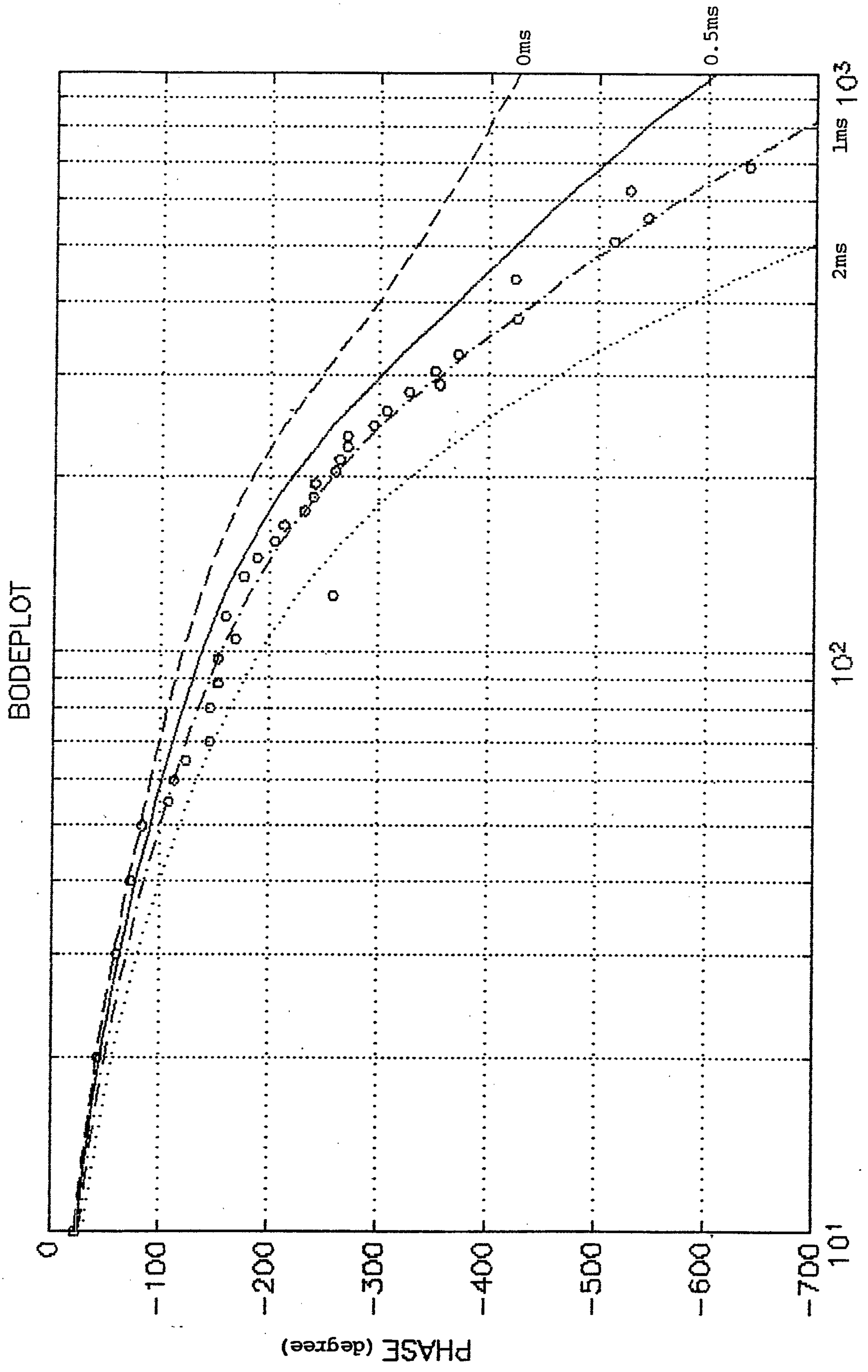
BODEPLOT
PHASE (degree)
FREQUENCY (Hz)
0
-100
-200
-300
-400
-500
-600
-700
10^1
10^2
10^3
0ms
0.5ms
1ms
2ms

Fig. 2B

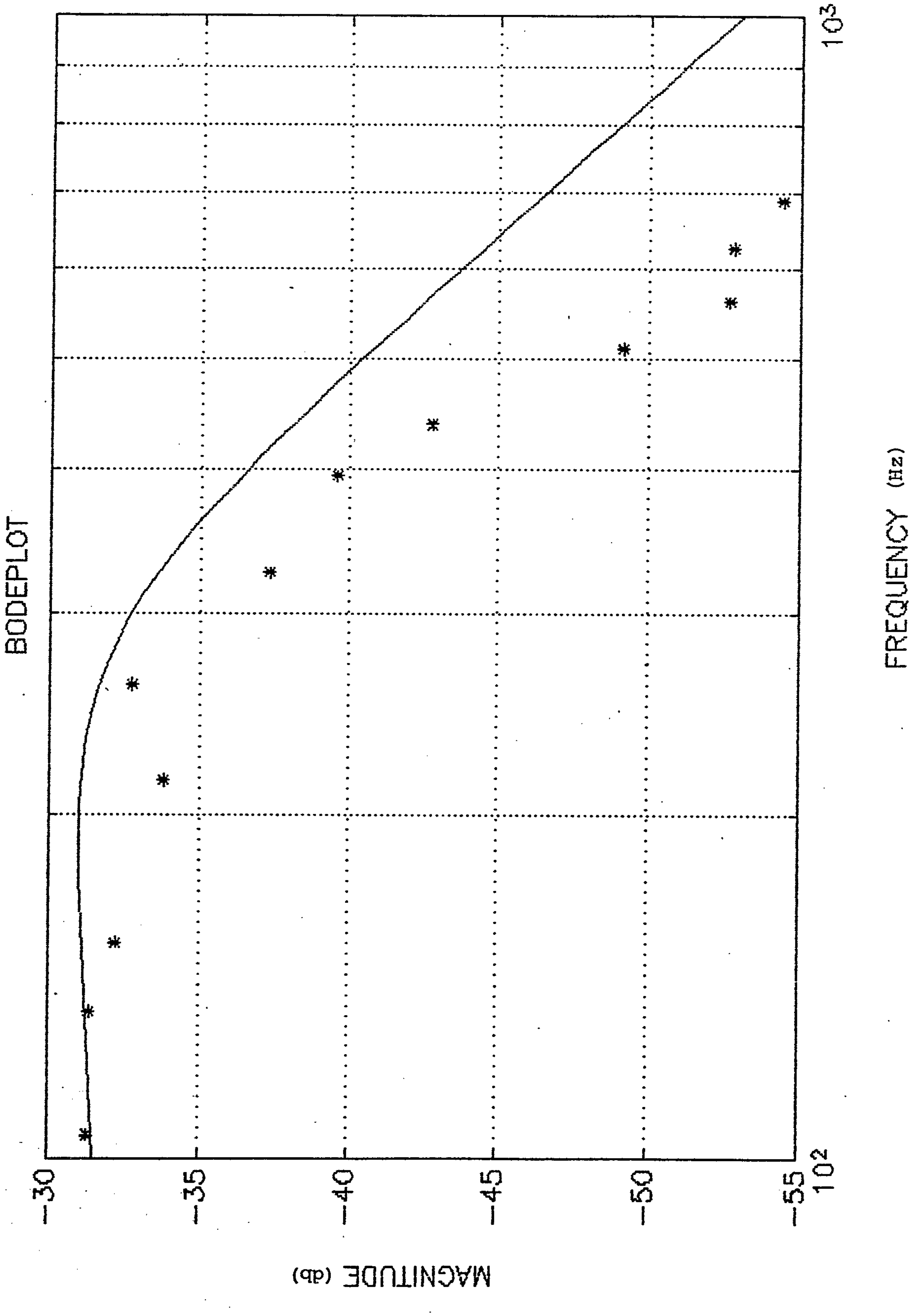

Fig. 3A

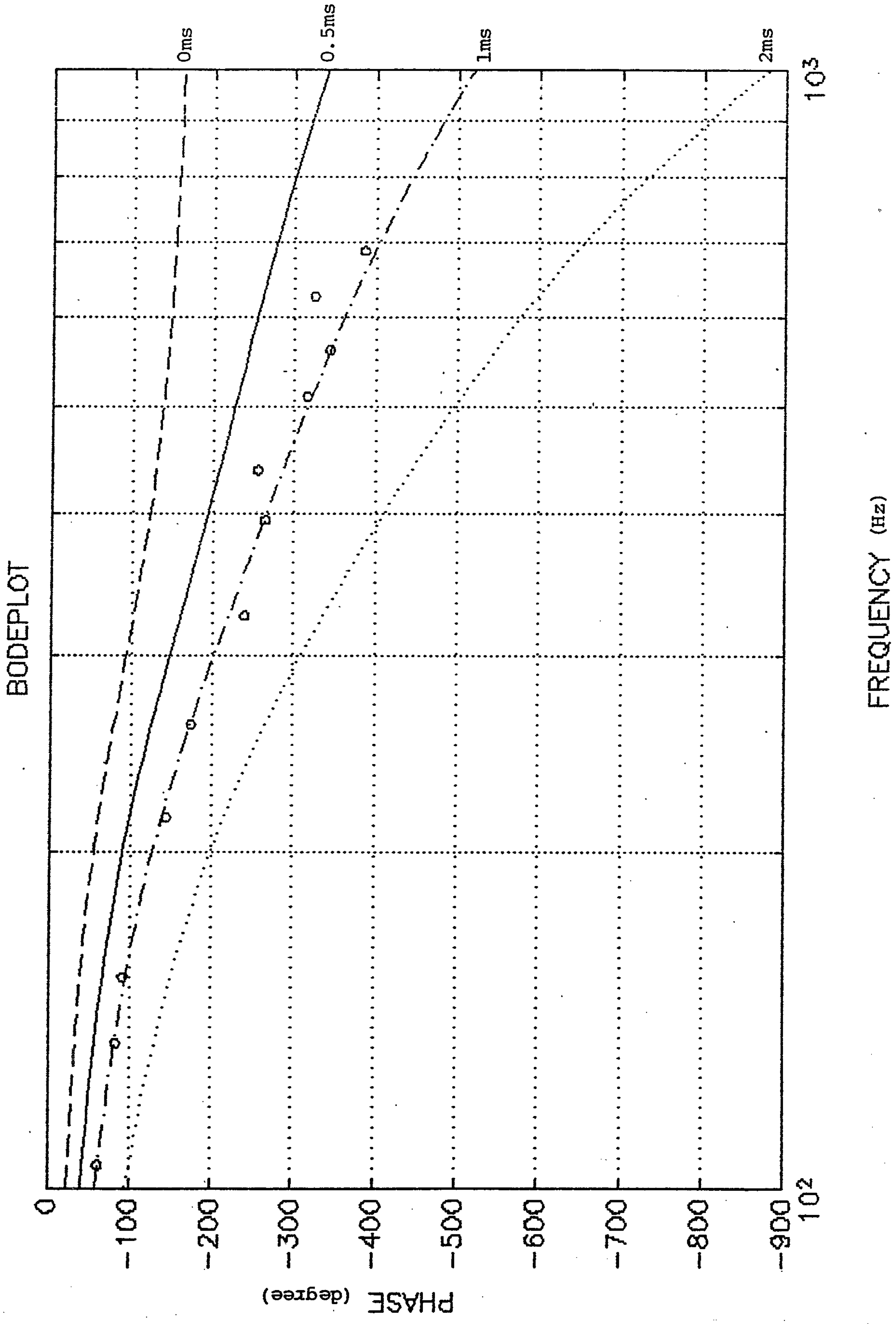
BODEPLOT
0ms
0.5ms
1ms
2ms
PHASE (degree)
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
10^2
10^3
FREQUENCY (Hz)

Fig. 3B