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SOUND REPRODUCTION AT THE ROYAL ALBERT HALL

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1. INTRODUCTION

Despite its undoubted appeal as a concert venue there are many aspects of this historic auditorium which give rise to considerable doubt as to its acoustic performance under certain conditions and types of programme.

Its volume, at 87,000 m^3 is considerably more than the more typically shaped hall, averaging 15,000 to 20,000 m^3. A reverberation time of 3s is double that of many venues and its capacity of 5100 makes it a daunting prospect, especially to the unaided solo artist.(1)

Both clarity and intelligibility have presented problems in the past and the management of the hall have established that such phenomena are very inconsistent, varying from seat to seat and tier by tier. Munro Associates were commissioned to investigate and to make recommendations as to the optimisation of electro acoustic systems which are installed by independent contractors on a regular basis. As the hall is used for many different activities, from boxing to blues music it would be inappropriate to recommend a fixed installation which could reproduce all types of programme material.

2. METHODOLOGY

One of the problems immediately encountered was the sheer busyness of the main auditorium. For this reason all the measurements were taken in the space of 3 hours on one day. In retrospect this was deemed advantageous because it ensured a high degree of correlation of the measured impulse responses.
The test source was a high quality, low directivity monitor speaker system with an extremely flat forward frequency response, from 40 Hz to 15 KHz. The calculated Directivty of the system, from 200 Hz to 5 KHz, is 2.5.

The system was placed stage centre at an elevation of 2 metres from the arena floor; in other words, in a typical performance position, angle upwards at 15 degrees.

All measurements were taken using a Maximum Length Sequence convolution to derive the analytical impulse response. An impulse length of over 4 seconds was used to eliminate time aliasing of the reverberant 'tail'. Averaging was used to eliminate background noise as a factor in determining direct to reverberant ratios.

3. TEST LOCATIONS

The following locations were chosen and can be found on Plan and Section A.

CODE AND FILE REFERENCE	LOCATION IN HALL
L4L	LEVEL 4. LEFT SIDE (facing stage)
L4 CB	LEVEL 4. CENTRE BACK (of hall)
L3 CB	LEVEL 3. CENTRE BACK
L2 CB	LEVEL 2. CENTRE BACK
L2. LF	LEVEL 2. LEFT FRONT
L1 LF	LEVEL 1. LEFT FRONT
L1 L	LEVEL 1. LEFT SIDE (widest point)
L1 CB	LEVEL 1. CENTRE BACK
OS RB	OUTER STALLS RIGHT BACK
OS R	OUTER STALLS RIGHT SIDE
OS C	OUTER STALLS CENTRE (arena rail)
RS R	REAR STALLS (arena rear)
RS C	REAR STALLS CENTRE (arena)
FS C	FRONT STALLS CENTRE (by stage)

The distance to the stage from each location can be seen from the impulse plots and varies from 10 metres to 40 metres. Each test was carried out under comparable conditions with the same source level and microphone orientation.

4. RESULTS

The measured impulse response plots are shown for comparison purposes in Appendix A.
It is obvious that there is a great deal of variation in the pattern of reflections with some virtually free from prominent specular reflections and some consisting of little else.
By post processing the impulse response, tables were generated to compare the values of Clarity (C80 & C50) at different frequency bands and also reverberation time and sound levels.
Clarity was found to vary from plus 8dB to minus 8dB at 500 Hz and the results are tabulated in Chart 2.
This implies that there is a considerable variation in articulation and intelligibility and this was verified by calculating Speech Transmission Indices for each location, using the MLSSA programme (2).
By making similar comparisons between C50 and C80 at 500 and 2KHz it can be seen, in Chart 6, that although there is good correlation where a strong direct sound occurs in the 500Hz band it is possible to obtain conflicting results in the presence of strong reflections, as in location 14.
However, on the whole, Charts 2 and 6 show good correlation.

6. INTELLIGIBILITY

By comparing the measured and calculated STI data for two 'good' locations, 1 and 4, with two 'poor' ones it was evident that an equivalent value of Articulation Loss of between 8% and 20% could be obtained for the auditorium.
This was compared with the theoretical values obtained using the modified Peutz- Patronis formula for % A Lcons.(3)
Chart RAH%alco shows the hypothetical effect of variations in acoustic absorption, source directivity Q and distance from the source D2.
The resulting %ALcons vary as one might expect but in making direct comparisons several factors emerge;

1. The theoretical % for location 4, which is at the front of the arena, 10 metres from the source on stage, is less that 2% but the measured result is 8%. As the MLSSA calculation is averaged across the frequency spectrum, this could be reasonable expected and % values in only the 500 and 2K would perhaps give better correlation.

2. The worst case of location 13 correlates extremely well with the spread sheet value giving an encouraging pointer to the way forward in calculating corrective measures for the auditorium.

7. CONCLUSIONS

It is clear from the plan view of the hall that most of the lateral energy radiating form the stage is refocussed, by means of elliptical geometry, at the opposite end of the auditorium.
This happens at each level but is noticeably severe in the outer rear stalls area.
Most of the upper levels enjoy a strong direct to reverberant energy ratio at the front and sides but all the rear sections suffer from negative D/R.

It can be seen from the spread sheet RAH%ALCO that a suitably directed sound system could increase intelligibility by a factor of 10, at 25 metres, when measured within the -3 dB coverage of the system. This may be the only improvement that is permitted, given the architectural protection that the hall enjoys.

All the data herein related to measurements in an empty hall with an RT60 of 3 seconds.
M. Barron stated (1) that the hall had been measured at 2.5 seconds when full.
This implies a total absorption of 47,000 Sabines empty and 56,000 full.
The difference is over 9000 Sabs which must be provided by 5,200 people including orchestra.
At 1.8 Sabs per person there must be some very large, well wrapped people at that concert.

8. REFERENCES

1. M. BARRON	AUDITORIUM ACOUSTICS	SPON 1993
2. D.RIFE	MTFM MEASUREMENT WITH MLS	JAES OCT 92
3. D&C DAVIS	SOUND SYSTEM ENGINEERING	SAMS 1987

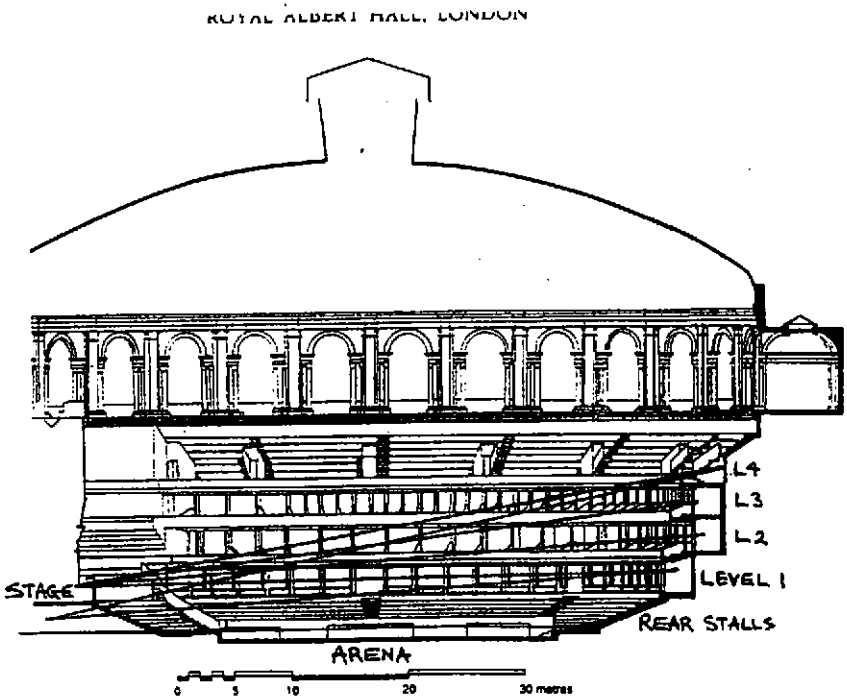
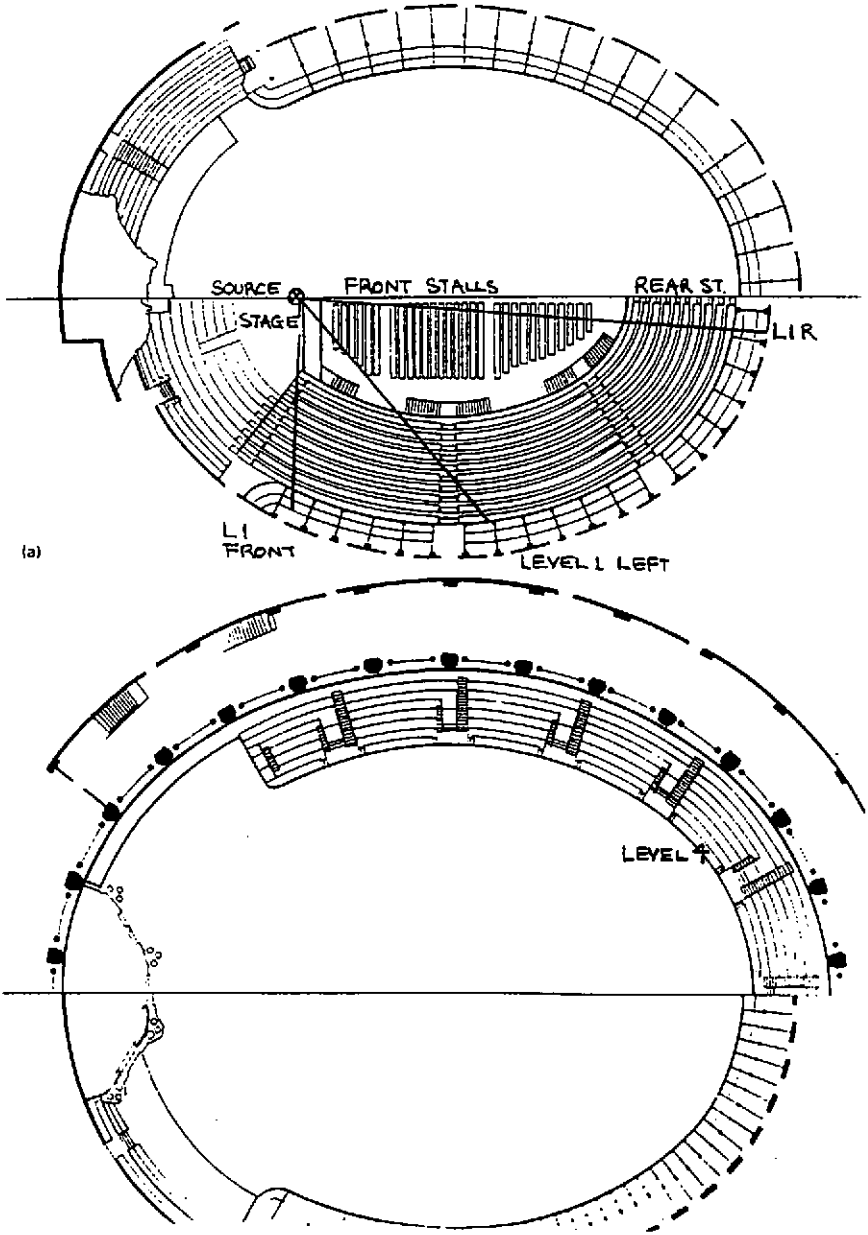
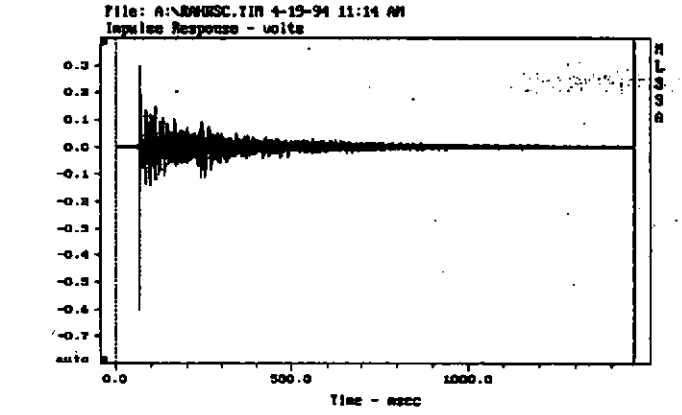


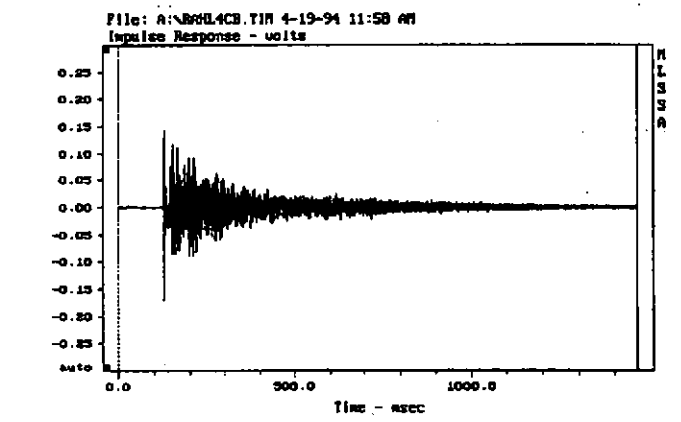
Figure 5.2 (a), (b) Plans and (c) long section of the Royal Albert Hall, London.


SOURCE
STAGE
FRONT STALLS
REAR ST.
L1R
L1
FRONT
LEVEL 1 LEFT
(a)
LEVEL 4



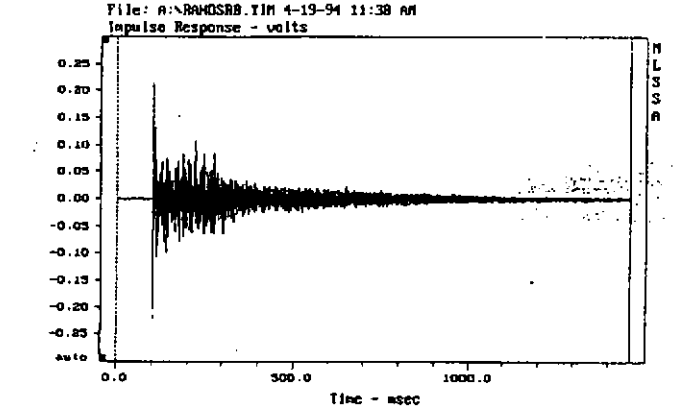
Comment: rear stalls centre canopy down

compare with canopy up.



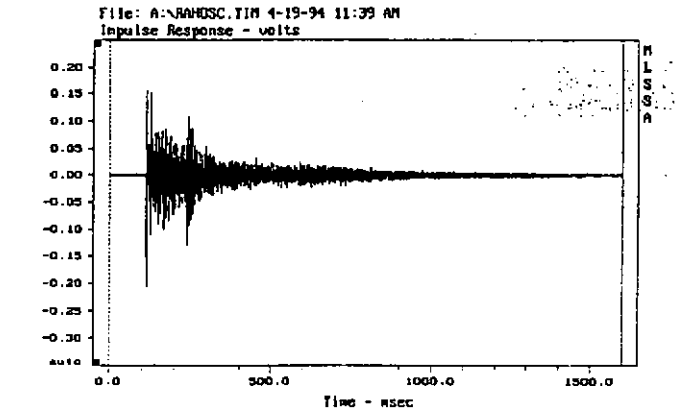
Comment: level 4 circle centre back canopy up

4-25-94 4:22 PM MLSSA: Time Domain



Comment: outer stalls right back

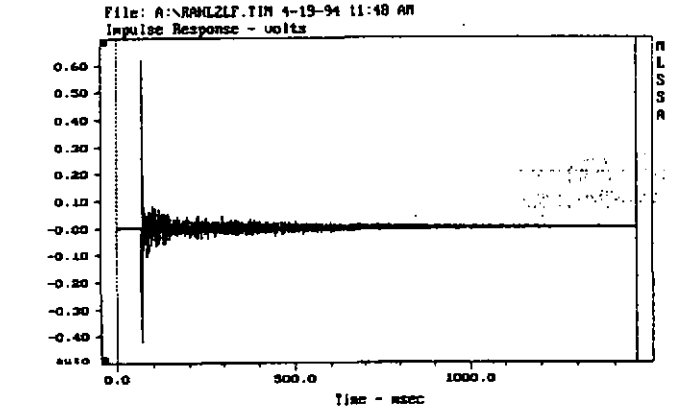
right rear stalls



Comment: outer stalls centre

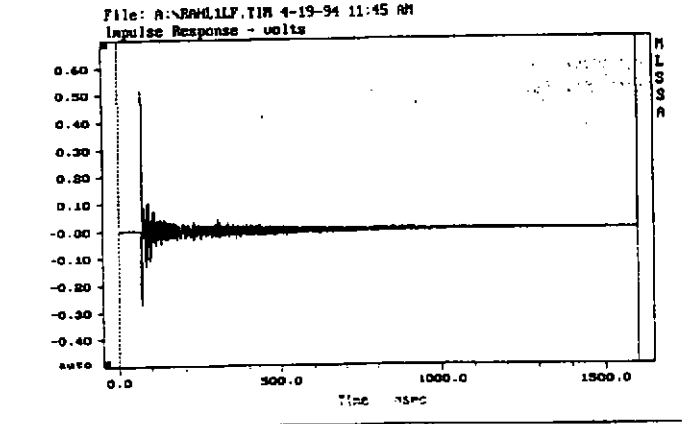
outer stalls. note multiple reflections

4-25-94 11:37 AM MLSSA: Time Domain



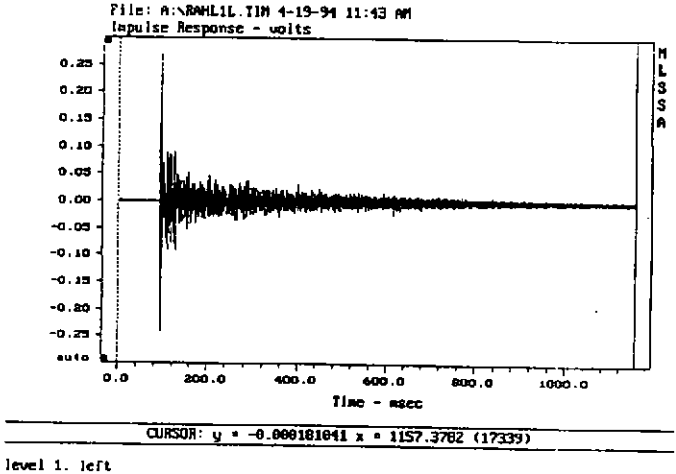
level 2 front, note better d/r

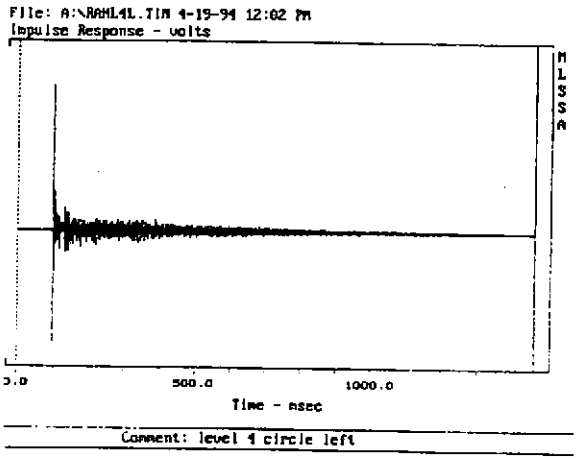
4-25-94 1:17 PM MLSSA: Time Domain



level 1 box, front left.

4-25-94 11:31 AM MLSSA: Time Domain


File: A:\RAHL1L.TIM 4-19-94 11:43 AM
Impulse Response - volts
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
auto
0.0
200.0
400.0
600.0
800.0
1000.0
Time - msec
MLSSA
CURSOR: y = -0.000181041 x = 1157.3782 (17339)
level 1. left
10-5-94 5:27 PM
MLSSA: Time Domain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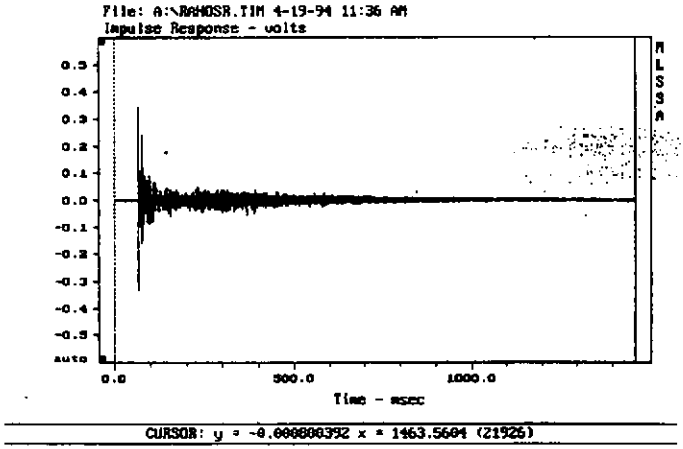
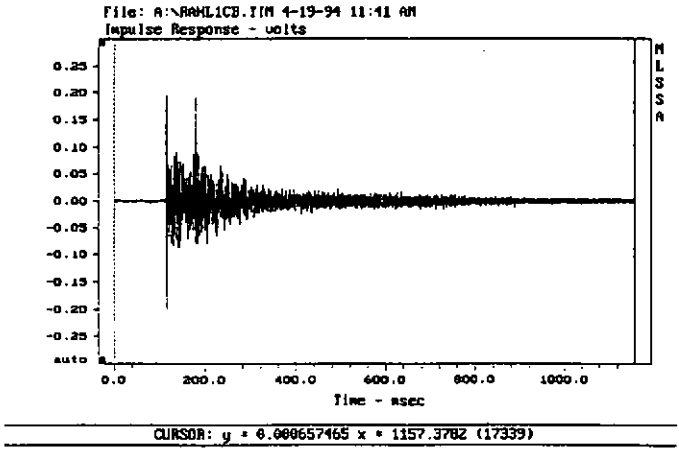
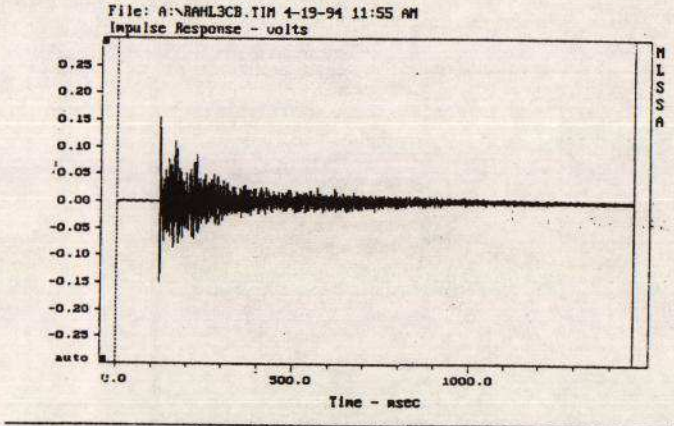
Impulse Response - volts
0.0
500.0
1000.0
Time - msec
MLSSA
Comment: level 4 circle left
PM
MLSSA: Time Domain



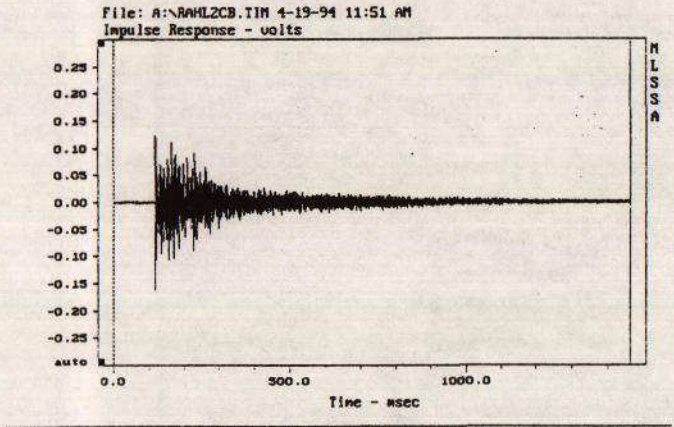


level 1, centre back, reflection at Ld = 63ms

10-5-94 5:14 PM MLSSA: Time Domain

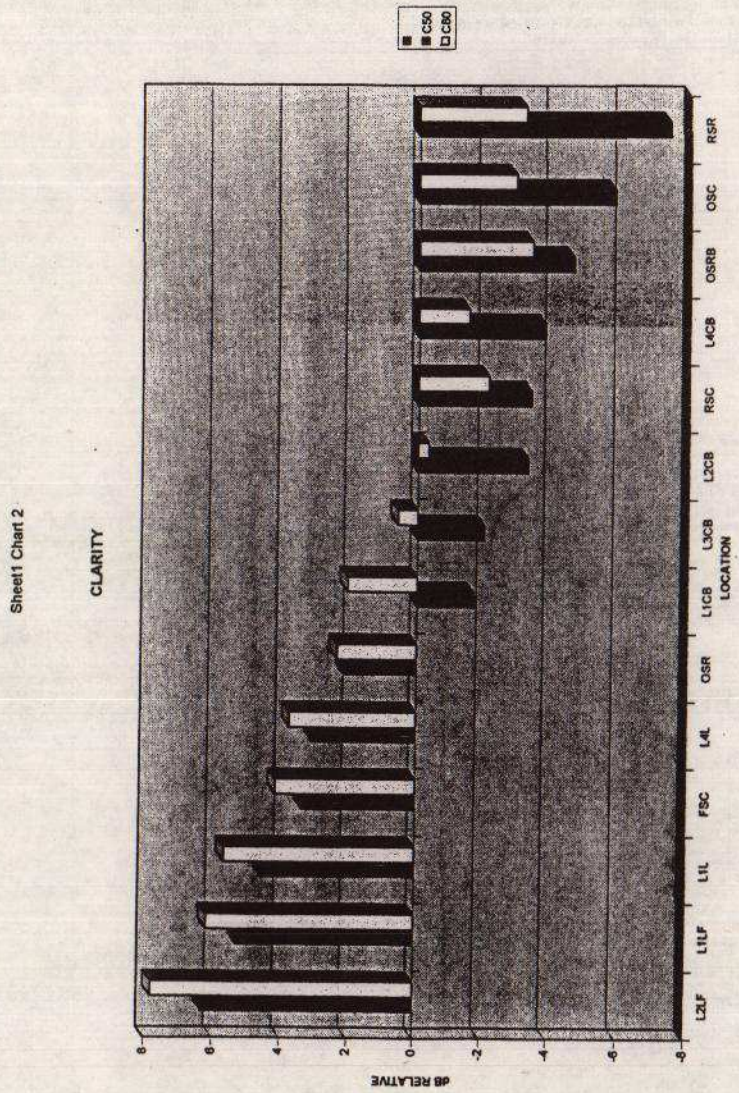


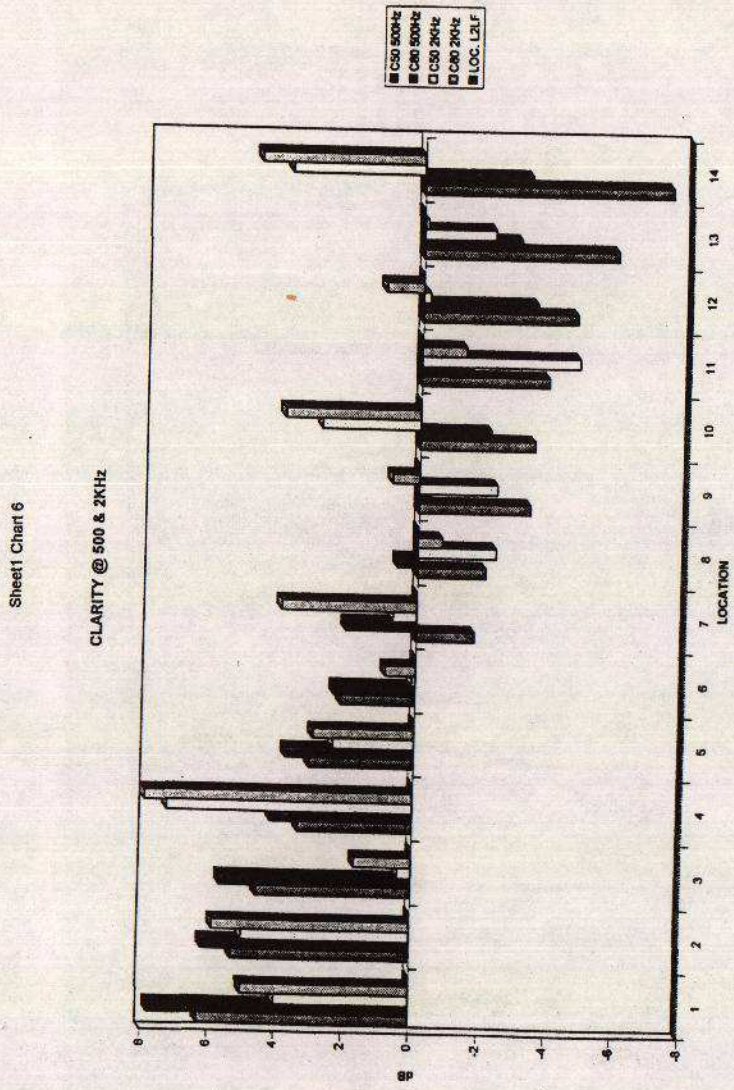
note earlu reflections

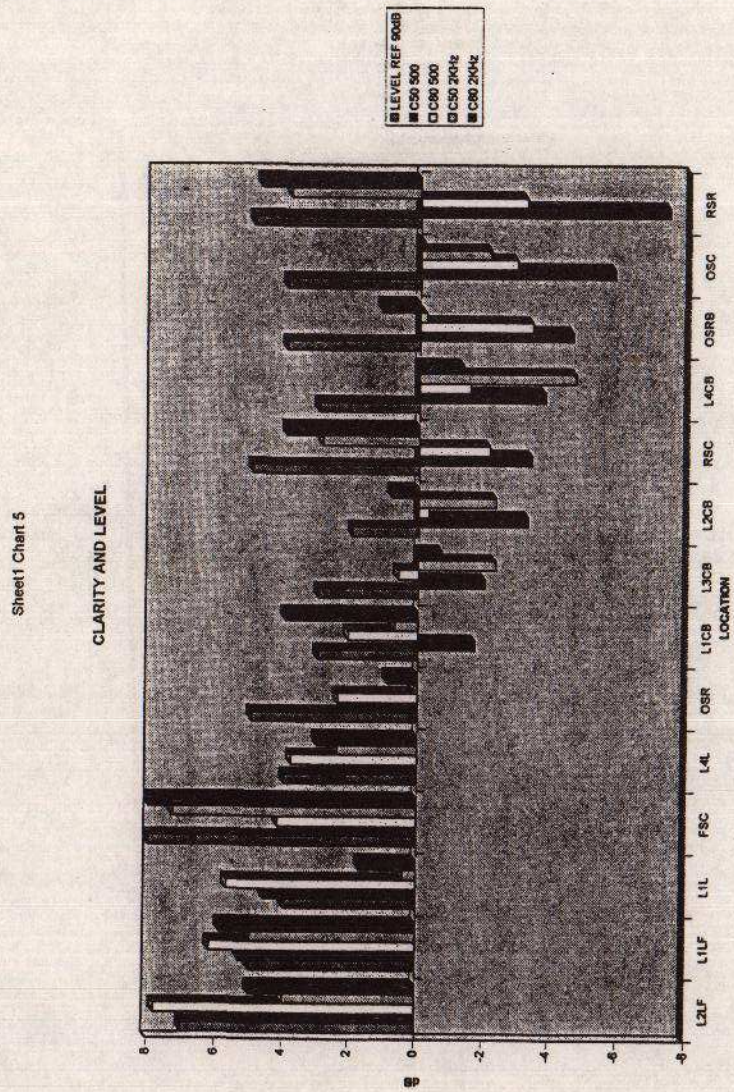


note reflections and compare with L1

4-25-94 1:03 PM MLSSA Time Domain


Sheet1 Chart 2
CLARITY
C50
C80
dB RELATIVE
8
6
4
2
0
-2
-4
-6
-8
L2LF
L1LF
L1L
FSC
L4L
OSR
L1CB
L3CB
L2CB
RSC
L4CB
OSRB
OSC
RSR
LOCATION


C50 500Hz
C80 500Hz
C50 2KHz
C80 2KHz
LOC. L2LF
Sheet1 Chart 6
CLARITY @ 500 & 2KHz
dB
LOCATION


Sheet1 Chart 5
CLARITY AND LEVEL
LEVEL REF 90dB
C50 500
C80 500
C50 2KHz
C80 2KHz
8
6
4
2
0
-2
-4
-6
-8
dB
L2LF
L1LF
L1L
FSC
L4L
OSR
L1CB
L3CB
L2CB
RSC
L4CB
OSRB
OSC
RSR
LOCATION

MTF Matrix (Uncalibrated)

Frequency-Hz	125	250	500	1000	2000	4000	8000
level dB-SPL	89.1	89.1	96.8	95.3	93.8	94.2	
m-correction	1.000	1.000	1.000	1.000	1.000	1.000	
0.63	0.787	0.747	0.900	0.797	0.848	0.932	
0.80	0.723	0.667	0.878	0.740	0.803	0.906	
1.00	0.664	0.591	0.858	0.690	0.761	0.878	
1.25	0.620	0.533	0.841	0.651	0.724	0.850	
1.60	0.595	0.503	0.826	0.626	0.695	0.822	
2.00	0.566	0.489	0.815	0.620	0.683	0.804	
2.50	0.503	0.463	0.802	0.614	0.677	0.792	
3.15	0.470	0.439	0.780	0.605	0.662	0.782	
4.00	0.436	0.447	0.757	0.596	0.645	0.768	
5.00	0.511	0.380	0.715	0.577	0.615	0.743	
6.30	0.427	0.328	0.673	0.566	0.590	0.720	
8.00	0.393	0.291	0.627	0.537	0.570	0.693	
10.00	0.391	0.243	0.593	0.507	0.518	0.659	
12.50	0.481	0.223	0.573	0.538	0.533	0.661	
octave TI	0.526	0.471	0.679	0.573	0.605	0.701	

STI value= 0.512 (0.623 modified) ALcons= 10.6% Rating= FAIR

LEVEL 2. LEFT FRONT MLSSA: ST

MTF Matrix (Uncalibrated)

Frequency-Hz	125	250	500	1000	2000	4000	8000
level dB-SPL	95.0	94.2	98.2	99.1	100.4	102.3	
m-correction	1.000	1.000	1.000	1.000	1.000	1.000	
0.63	0.881	0.835	0.809	0.828	0.911	0.973	
0.80	0.844	0.786	0.756	0.774	0.883	0.962	
1.00	0.811	0.734	0.707	0.719	0.857	0.950	
1.25	0.785	0.679	0.666	0.666	0.834	0.938	
1.60	0.766	0.613	0.636	0.624	0.817	0.924	
2.00	0.756	0.558	0.637	0.612	0.811	0.915	
2.50	0.737	0.520	0.653	0.623	0.811	0.909	
3.15	0.705	0.529	0.671	0.641	0.804	0.901	
4.00	0.678	0.535	0.653	0.641	0.783	0.888	
5.00	0.644	0.522	0.604	0.586	0.764	0.870	
6.30	0.604	0.436	0.592	0.565	0.749	0.843	
8.00	0.523	0.355	0.570	0.555	0.714	0.813	
10.00	0.550	0.266	0.599	0.473	0.676	0.766	
12.50	0.533	0.211	0.539	0.445	0.649	0.701	
octave TI	0.633	0.527	0.592	0.578	0.700	0.820	

STI value= 0.563 (0.676 modified) ALcons= 8.1% Rating= FAIR

FRONT STALLS CENTRE

MLSSA: ST

MTF Matrix (Uncalibrated)

Frequency-Hz	125	250	500	1000	2000	4000	8000
level dB-SPL	89.0	90.2	93.6	95.9	94.4	93.9	
m-correction	1.000	1.000	1.000	1.000	1.000	1.000	
0.63	0.817	0.816	0.829	0.840	0.854	0.924	
0.80	0.761	0.763	0.782	0.791	0.809	0.894	
1.00	0.702	0.713	0.735	0.743	0.762	0.858	
1.25	0.639	0.667	0.693	0.700	0.714	0.814	
1.60	0.549	0.616	0.652	0.655	0.653	0.753	
2.00	0.443	0.557	0.603	0.597	0.570	0.681	
2.50	0.334	0.459	0.502	0.505	0.448	0.584	
3.15	0.202	0.297	0.360	0.375	0.328	0.464	
4.00	0.051	0.158	0.220	0.215	0.238	0.346	
5.00	0.126	0.109	0.071	0.085	0.244	0.292	
6.30	0.269	0.227	0.131	0.196	0.300	0.324	
8.00	0.177	0.276	0.244	0.302	0.304	0.334	
10.00	0.132	0.169	0.226	0.252	0.213	0.216	
12.50	0.221	0.062	0.165	0.205	0.144	0.191	
octave TI	0.412	0.434	0.453	0.470	0.481	0.544	

STI value= 0.405 (0.487 modified) ALcons= 19.0% Rating= POOR

OUTER STALLS

MLSSA: ST

MTF Matrix (Uncalibrated)

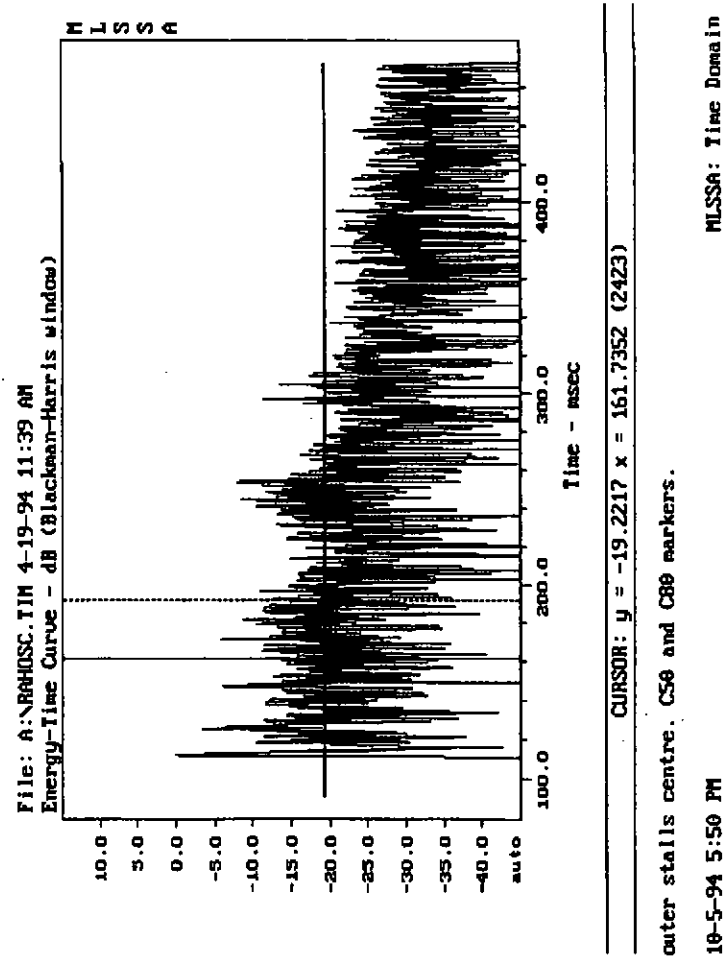
Frequency-Hz	125	250	500	1000	2000	4000	8000
level dB-SPL	93.1	92.4	94.8	96.2	98.2	96.7	
m-correction	1.000	1.000	1.000	1.000	1.000	1.000	
0.63	0.855	0.795	0.787	0.787	0.891	0.936	
0.80	0.806	0.735	0.719	0.719	0.857	0.911	
1.00	0.753	0.680	0.646	0.648	0.822	0.882	
1.25	0.697	0.631	0.571	0.577	0.786	0.850	
1.60	0.626	0.583	0.489	0.494	0.745	0.809	
2.00	0.553	0.537	0.406	0.404	0.700	0.769	
2.50	0.473	0.487	0.306	0.291	0.657	0.730	
3.15	0.363	0.448	0.191	0.203	0.638	0.700	
4.00	0.256	0.439	0.090	0.184	0.640	0.685	
5.00	0.216	0.455	0.125	0.179	0.650	0.677	
6.30	0.300	0.348	0.151	0.201	0.642	0.657	
8.00	0.217	0.349	0.078	0.079	0.588	0.608	
10.00	0.205	0.373	0.065	0.128	0.571	0.602	
12.50	0.318	0.437	0.087	0.162	0.587	0.597	
octave TI	0.486	0.515	0.365	0.397	0.631	0.672	

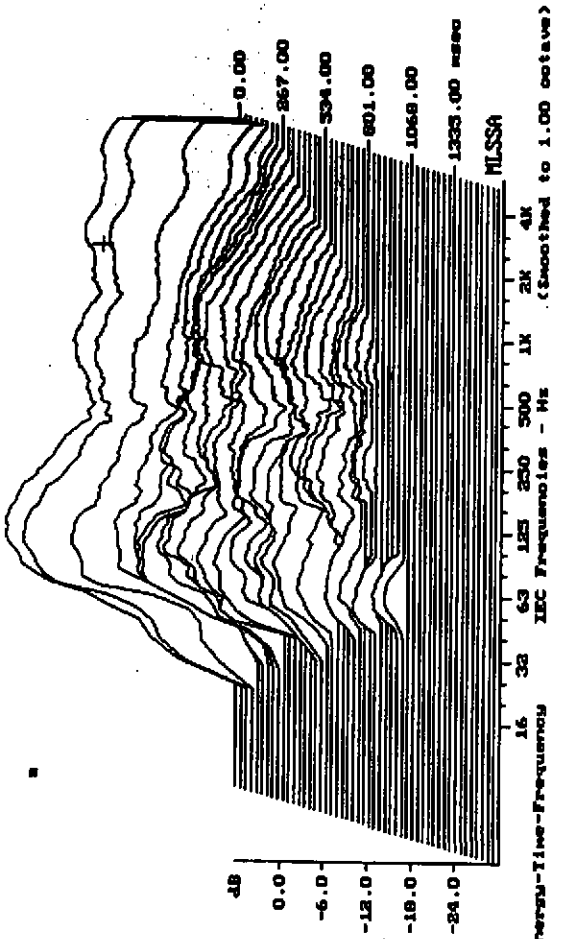
STI value= 0.457 (0.547 modified) ALcons= 14.3% Rating= FAIR

REAR STALLS RIGHT MLSSA: ST

RAH%ALCO.XLS

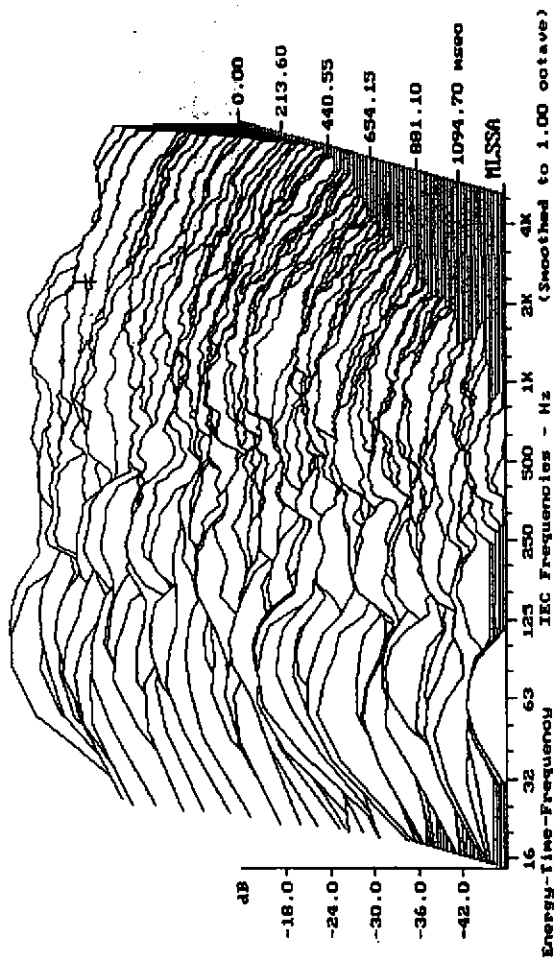
NO. OF	%ALCON	CRIT	SND	SND	DIR	DIST	ROOM	SURF	HALL	AVE	REV'B
IND SPK		DIST	LEVL	POWE	INDX	POINT	CONST	AREA	VOLUME	ABS	TIME
mod n	mod n $					very					
		Dc	Lp	Lw	Q	D2	R	S	V	Aave	T60
1	0.01	15.24	92.04	100	2	1	5924.24	11500	87000	0.34	2.93
1	0.04	15.24	86.07	100	2	2	5924.24	11500	87000	0.34	2.93
1	0.16	15.24	80.26	100	2	4	5924.24	11500	87000	0.34	2.93
1	0.63	15.24	75.00	100	2	8	5924.24	11500	87000	0.34	2.93
1	1.42	15.24	72.51	100	2	12	5924.24	11500	87000	0.34	2.93
1	1.94	15.24	71.72	100	2	14	5924.24	11500	87000	0.34	2.93
1	2.22	15.24	71.41	100	2	15	5924.24	11500	87000	0.34	2.93
1	3.95	15.24	70.31	100	2	20	5924.24	11500	87000	0.34	2.93
1	6.17	15.24	69.68	100	2	25	5924.24	11500	87000	0.34	2.93
1	8.89	15.24	69.30	100	2	30	5924.24	11500	87000	0.34	2.93
1	20.00	15.24	68.77	100	2	45	5924.24	11500	87000	0.34	2.93
1	24.69	15.24	68.69	100	2	50.00	5924.24	11500	87000	0.34	2.93
										very	
	%alcons	Dc	Lp	Lw	Q	D2	R	S	V	Aave	T60
1	61.44	7.08	75.48	100	2.00	20.00	1277.78	11500	87000	0.10	11.56
1	13.70	10.62	72.53	100	2.00	20.00	2875.00	11500	87000	0.20	5.46
1	5.36	13.90	70.83	100	2.00	20.00	4928.57	11500	87000	0.30	3.41
1	2.61	17.34	69.64	100	2.00	20.00	7666.67	11500	87000	0.40	2.38
1	1.42	21.23	68.73	100	2.00	20.00	11500.00	11500	87000	0.50	1.76
1	0.81	26.00	67.99	100	2.00	20.00	17250.00	11500	87000	0.60	1.33
1	0.47	32.43	67.38	100	2.00	20.00	26833.33	11500	87000	0.70	1.01
1	0.26	42.46	66.86	100	2.00	20.00	46000.00	11500	87000	0.80	0.76
1	0.13	63.70	66.40	100	2.00	20.00	########	11500	87000	0.90	0.53
					very						
MOD N	%ALcons	Dc	Lp	Lw	Q	D2	R	S	V	Aave	T60
1	12.93	12.52	67.98	100	1.00	25.00	7991.53	11500	87000	0.41	3.00
1	6.47	17.70	68.78	100	2.00	25.00	7991.53	11500	87000	0.41	3.00
1	4.31	21.68	69.46	100	3.00	25.00	7991.53	11500	87000	0.41	3.00
1	3.23	25.03	70.04	100	4.00	25.00	7991.53	11500	87000	0.41	3.00
1	2.59	27.99	70.56	100	5.00	25.00	7991.53	11500	87000	0.41	3.00
											variable
										Aave	T60
1	6.47	17.55	68.83	100	2.00	25.00	7860.27	11500	87000	0.41	3.00
1	4.49	20.70	67.93	100	2.00	25.00	10925.90	11500	87000	0.49	2.50
1	2.87	26.50	66.79	100	2.00	25.00	17911.76	11500	87000	0.61	2.00
1	1.62	44.13	65.25	100	2.00	25.00	49670.21	11500	87000	0.61	1.50
1	8.80	15.51	69.57	100	2.00	25.00	6138.04	11500	87000	0.35	3.50
1	11.49	14.05	70.21	100	2.00	25.00	5034.87	11500	87000	0.30	4.00
1	14.55	12.93	70.76	100	2.00	25.00	4267.82	11500	87000	0.27	4.50
ROYAL ALBERT HALL											
ACOUSTIC PERFORMANCE CRITERIA											
ARTICULATION PREDICTIONS											


File: A:\RAHOSC.TIM 4-19-94 11:39 AM
Energy-Time Curve - dB (Blackman-Harris window)
M L S S A
10.0
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
auto
100.0
200.0
300.0
400.0
Time - msec
CURSOR: y = -19.2217 x = 161.7352 (2423)
outer stalls centre. C50 and C80 markers.
10-5-94 5:50 PM
MLSSA: Time Domain



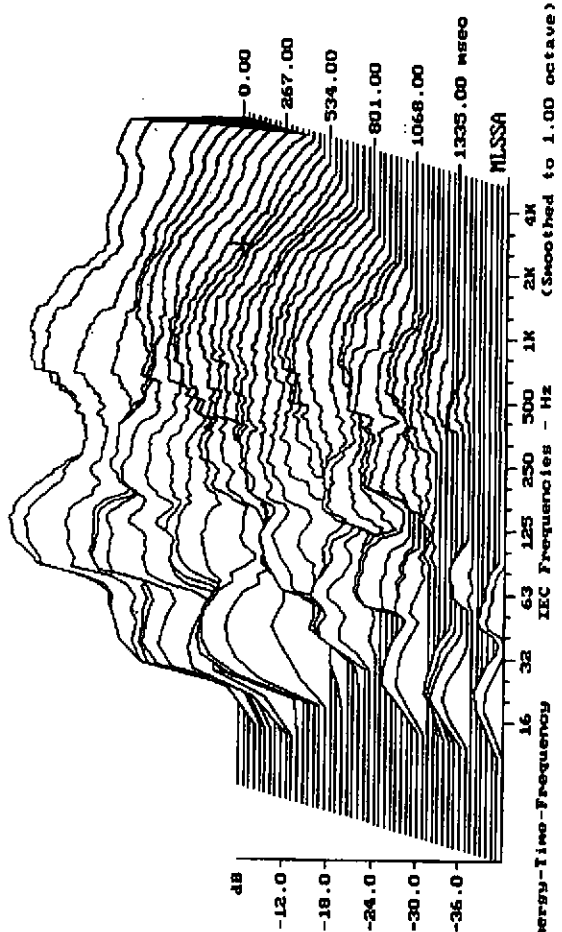
-11.67 dB, 1251 Hz (342), 0.000 msec (0)

front stalls centre



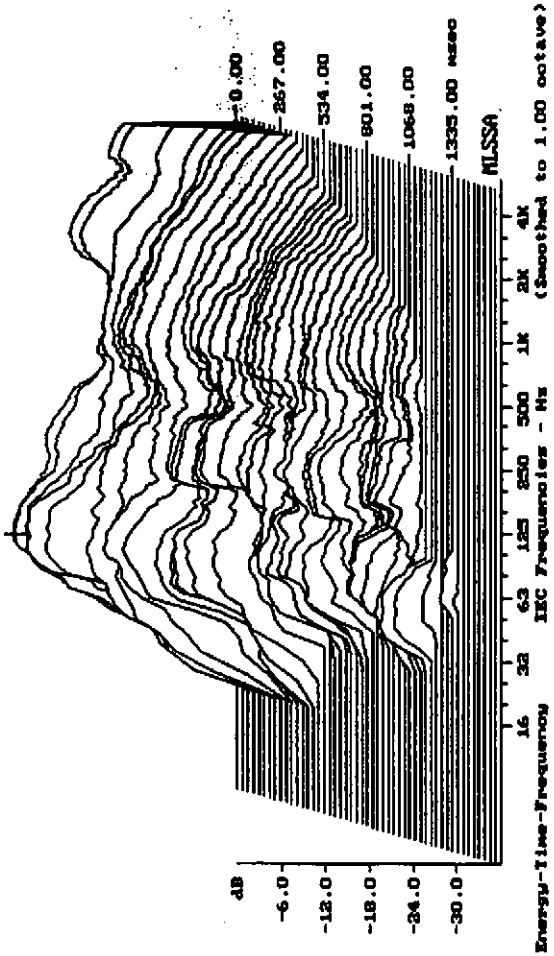
-26.98 dB, 1258 Hz (86), 0.000 msec (0)

rear of hall, level 4.



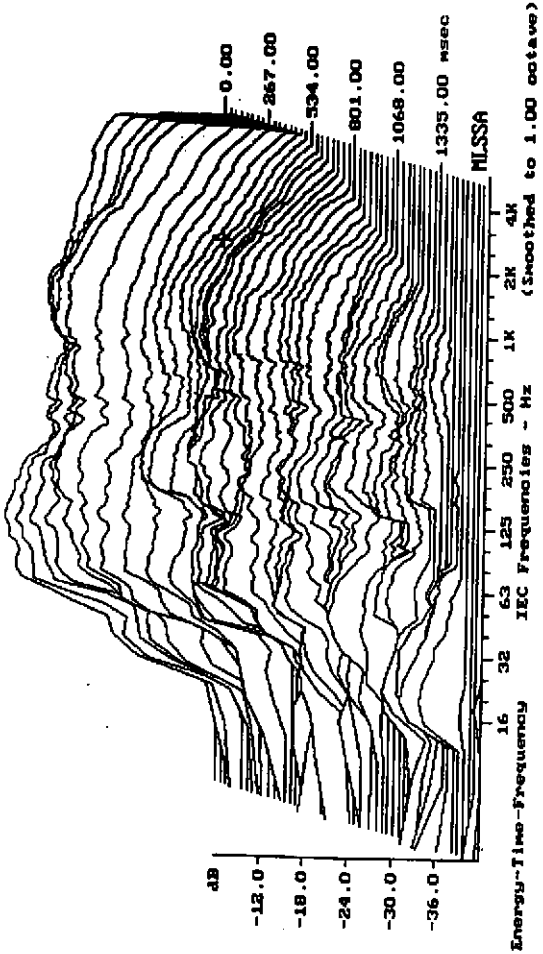
-42.00 dB, 1251 Hz (342), 0.000 msec (0)

level 1 left.



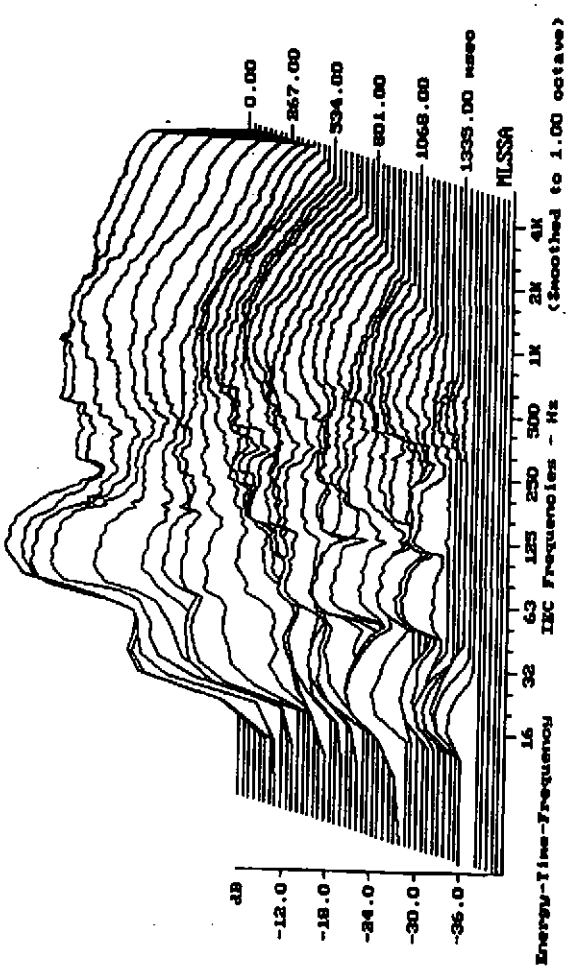
-3.58 dB, 59 Hz (16), 100.125 msec (3)

rear stalls right



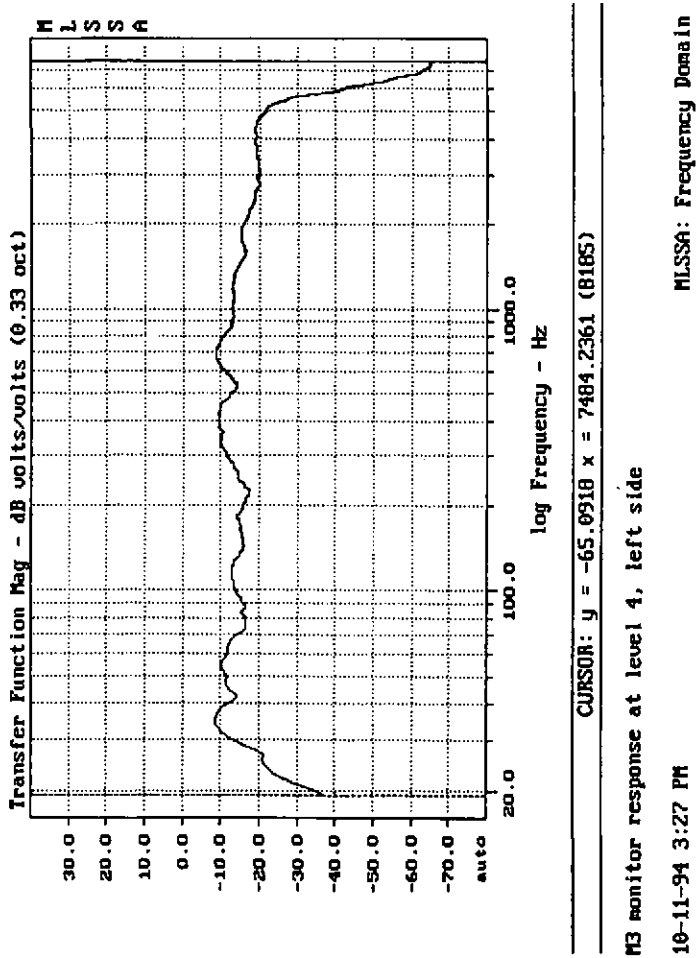
-42.00 dB, 1251 Hz (342), 0.000 msec (0)

outer stalls centre.



-42.00 dB, 1251 Hz (342), 0.000 msec (0)

level 1. centre back.


MLSSA
Transfer Function Mag - dB volts/volts (0.33 oct)
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
auto
20.0
100.0
1000.0
log Frequency - Hz
CURSOR: y = -65.0918 x = 7484.2361 (BIBS)
M3 monitor response at level 4, left side
10-11-94 3:27 PM
MLSSA: Frequency Domain

Acquisition
 mode: Cross-correlation
 length: 65535 samples (4374 msec)
 sample rate: 15 kHz (66.7 µsecs)
 Concurrent pre-average cycles: 4
 Autorange: enabled
Antialiasing filter
 type: Chebyshev
 bandwidth: 5 kHz
 gain: 0.5 (± 10 volts range)
Trigger
 type: Stimulus trigger
 delay: 0 samples (0 msec)
Units
 acquisition: 1 volts/volt
 stimulus: 1 volts/volt
Tracking
 filename: A:\RAHL4L.TIM
 precursor: acquisition
 acquisition date: 4-19-94 12:02 PM
 dynamic range: 35%
 (unequalized) ref: NONE
 comment: level 4 circle left

Stimulus
 Burst MLS
 amplitude: ± 5.229 volts
 rep-rate: 0.2286 Hz
 period: 65535 samples
 4374 msec
Microphone
 Make: IVIE
 model: IE2P
 serial#: 0563
 sensitivity: 36.62 mV/Pascal
 preamp gain: 20.0 dB
 calibration date: 11-11-92
 0 dB ref: 7.476387E-006 volts

RAH MEASUREMENT SET UP.

MLSSA: Main Inf