Proceedings of the Institute of Acoustics

INVESTIGATION OF INTELLIGIBILITY AT THE NATIONAL EXHIBITION CENTRE, BIRMINGHAM

A.S.Munro

Munro Associates, Electro-Acoustic Consultants

INTRODUCTION

In response to a brief from the NEC, steps were taken to appraise the system requirements for Halls 1, 3 and 5.

By pre-selecting, at the choice of the NEC, the spherical radiating Soundsphere System it has been possible to calculate the total number of speakers and power requirement for various degrees of coverage.

It can be shown that there is a trade off between speaker height and intelligibility for any given system and this will be the subject of detailed analysis when reverberation data for the halls has been verified.

The prime objective is to achieve the highest articulation over the entire area of each hall, even under adverse ambient noise conditions.

It should be noted that the direct to reverberant ratio is adversely affected by the number of speakers not radiating directly to the listener. In other words the fewer speakers within the coverage angle of each unit the better the intelligibility at that point. The spacing of the speakers depends on height of mounting and the table gives two examples;

Height 11m

Spacing	15.5m for	0dB variation in direct soundfield.
	23.5m for	1 dB variation in direct soundfield.
	32.0m for	2dB variation in direct soundfield.

SPL required at 1 m for 90dB at floor = 111 dB
Power required for PA is 27Watts RMS
Power required for music is 60Watts RMS

Height 18m

Spacing	25.5m for	0dB variation in direct soundfield.
	39.0m for	1dB variation in direct soundfield.
	49.0m for	2dB variation in direct soundfield.

Power required for PA is 60Watts RMS
Power required for music is 140Watts RMS

NB. These calculations are based on direct ratiation in free field conditions. The final power requirement will be reduced by the reverberant energy of the halls.

It can be seen that the speaker requirement in Hall 5 for example could vary from 28 to 80 depending on the final spacing and height requirement. As the grid layout of the halls is set at 30m it is logical to design the system with a spacing of 30m. This corresponds almost exactly with the preferred height of 15.5m and, allowing for the average height of visitors, will result in the ideal design aim of 1dB variation in the direct sound field pressure if the speaker is 14m above the person's head.

The most difficult thing to achieve in any highly reverberant space is good intelligibility. Good articulation is achieved by maximising the direct to reverberant energy ratio. This is improved by;

Minimum distance from listener to loudspeaker or coherent group of speakers.
Reduction in reverberant energy.
Reduction in the number of loudspeakers relative to those feeding the direct sound field.
Increase in room size for a given reverberation time.
Increase in loudspeaker directivity, provided coverage angle is maintained.

Several factors are mutually reciprocating in that higher directivity means more speakers and also greater variation in sound quality. A perfect system would deliver all its radiated energy within only the desired coverage angle to a perfectly absorbing floor surface! The intelligibility would be 100% provided the ambient noise was 25dB below the system level and bandwidth plus distortion were 10kHz and 1% respectively.

We have the following known parameters;

Wanted vertical coverage angle: 94°, actual angle 180°
Wanted RT60: 2-3s, actual RT60: 5-9s (see Chart 1)
Wanted Critical Distance: +14m, actual: 8m for N=7*

* N at any one point is the ratio between the number of direct radiating speakers and total number of identical speakers in the whole system. The value varies with the position of the listener as follows;

Hall 5. 28 speakers installed, one per bay

(Hall empty)

	N	D	%ALcons
Directly under speaker	28	14	39
Between 4 loudspeakers	7	25.4	31
Between 2 loudspeakers	14	20.5	42

N=Direct speakers/total speakers D=Distance to nearest speaker

The Articulation Losses (%ALcons.) can be seen to exceed the normally accepted limit of 15%, even without taking into account the high ambient noise levels encountered in the halls. This will be discussed in the summary.

It can be shown that the Sound sphere has an extremely wide coverage 'footprint' which means that many units overlap. Any one inside speaker is covered by 8 others, each delivering 7dB less direct sound than the one inside unit. The 8 units will give a combined, averaged level of 2dB more than the inside one, giving a theoretical decrease of 'N' to 3.5.

This could be the reason why the Soundsphere appears to give better performance in large halls than is theoretically predicted. If each unit is optimally placed to maximise the overlap of direct energy then the apparent lack of directivity will be compensated.

SIGNAL TO NOISE RATIO

The noise level in each hall has been measured under all normal conditions and found to vary from 72 to 80dB(A).

To maintain the same level of intelligibility as without background noise will require levels from the system, at the listener of 97 to 105dB(A).

LOUDSPEAKER OUTPUT

The power required of each speaker unit to give the required level of 105dB(A) will be determined by both N and the acoustical parameters of the hall.

The combined level is given by the Modified Hopkin-Stryker Equation.

This predicts an acoustic gain of 2dB for Hall 5 which with the addition of direct sound due to overlap (previously calculated at 2dB giving a combined level increase of 2.2dB) means the total increase of sound level at any point will be in the region of 4.2dB.

The maximum rated output of the speaker is 120dB for 200W electrical input. This will give a direct level of 103dB at 14m. Adding the total acoustic gain we get 107.2dB which means the power input can be reduced to 100W to achieve 104.2dB throughout the floor area.

It can be seen that 100Watt RMS power per unit will be required to satisfy maximum intelligibility requirements, even with no headroom.

TEST RESULTS

The RASTI figures for systems such as hall 5 are not reliable in the sense that noise and position of reflections can give inaccurate readings. A full STI is more meaningful as anomalies are averaged out of the overall matrix.

The averaged STI value for hall 5 when occupied is just below the 0.5 recommendation but the weighted value and the RASTI value are .651 and .665 which rates a 'good'. This value could not be obtained in every bay and several points came to light;

1. The high bay speakers do suffer from the extra initial distance which

reduces the direct to reverberant ratio.
2. At the edge of each bay the sound is less distinct due to interference and the increased initial time delay.
3. The roof and ventilation units cause reflections and stray energy radiation which decreases the direct energy ratio.

The pronounced comb filter effect shown in the frequency plots is evidence of the effect of early reflections as marked on the time domain plots.

This could be reduced by controlling the upward diffraction of the bass driver as the problem does not occur with the high frequency units.

Acoustic treatment of the area local to each soundsphere is strongly recommended.

The system, as a whole, performed according to expectations and the acoustic data obtained does correlate with the initial predictions.

The advantage of the distributed sound system over the existing, local line source array arrangement is immediately apparent once the halls are occupied as there is virtually no masking of the direct sound whereas the indirect reverberant energy is reduced dramatically.

The most important factor will always be the direct to reverberant sound ratio which can be improved by controlled directivity and reduced initial time delay (reducing height of speakers). Control of reverberation will also work but is only cost effective at the design stage of a building. Ambient sound level can be overcome by increasing system level and this is how the setting have been made. The level may seem high under show conditions but this is considered necessary given the marginal STI values.

PRINTOUTS

1. A detailed calculation spread sheet used for the prediction and calculation of sound level Lp and % ALcons
2. The double impulse from one unit which causes a comb filter effect.
3. RASTI for hall 5 empty.
3a. RT60 hall 5. 500Hz. 7 seconds. Note reverberation reduces at some lower frequencies due to panel resonance in the roof decking.
4. Frequency plot of one speaker combined with roof reflection. See main report for comment.
5. RT of 9.3 seconds at 1kHz in hall 5 empty.
6. Hall 5 occupied, no visitors RT at 1kHz now 3.3 seconds.
7. On axis RASTI for previous test. Result GOOD.
8. Full STI for hall 5. STI= .65 which is acceptable. Actual vocal tests were carried out at this point which were also acceptable.
9. Windowed direct response of loudspeaker shows mis-alignment of bass and HF

drivers. To be discussed with manufacturer.

10. Energy time curve shows above mis-alignment at 2ms (approx.).

11. Final equalisation for hall 5. Smooth peak free curve with gentle rise to 2kHz. Best subjective result with this setting.

12. Overlay of bass and tweeter ETC shows that reflections are cause by bass driver only. To be discussed with manufacturer.

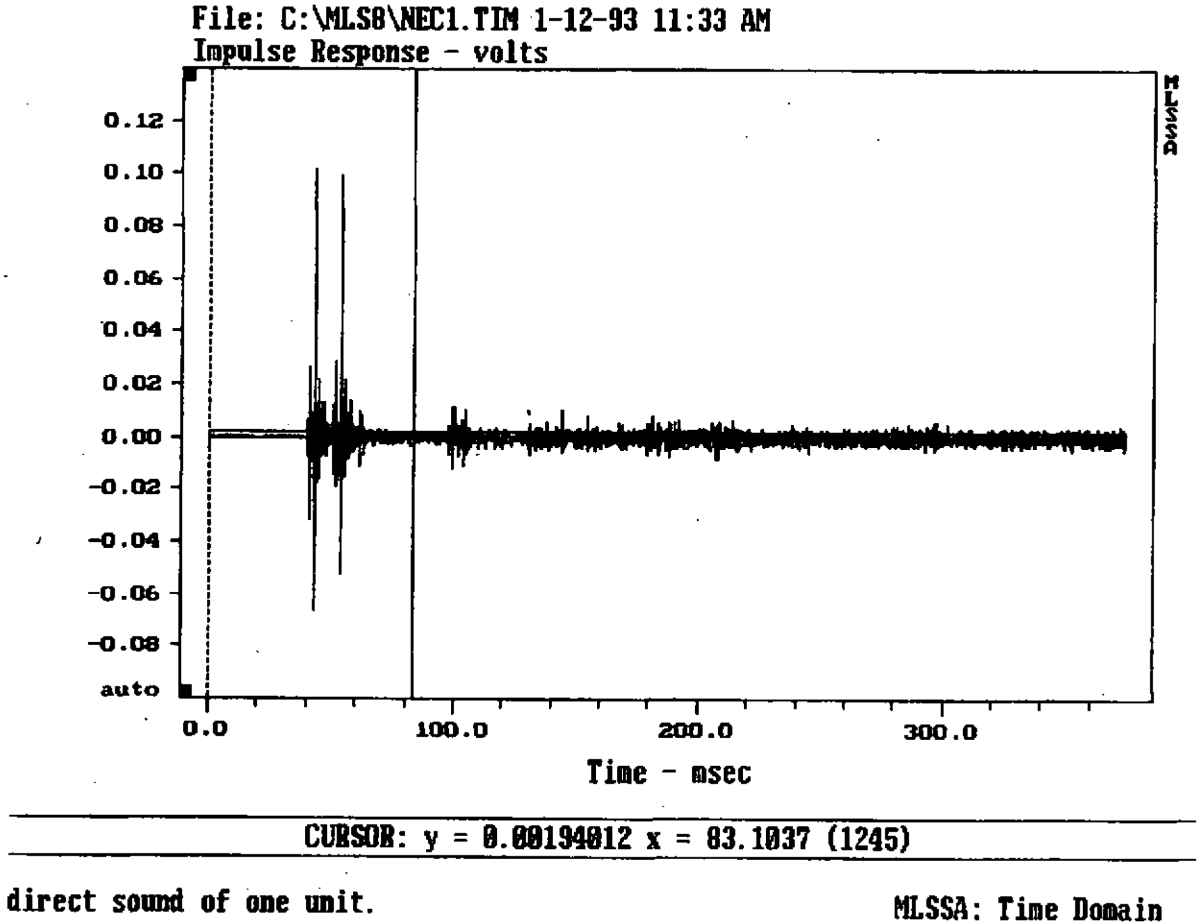
13-19. Various backup measurements showing hall 1 also, which, as it was mainly empty, did not give valid conditions for full STI.

The results are in fact better that hall 5 empty, so there should be no problem with hall 1, occupied, and the system has been equalised as for hall 5, occupied.

NEC%ALCO.XLS

NO. OF IND SPK	%ALCON	CRIT DIST	SND LEVL	SND POW	DIR INDX	DIST POINT	ROOM CONST	SURF AREA	HALL VOLUME	AVE ABS	REVRB TIME	
mod n	mod m $					vary						
	2	Dc	Lp	Lw	Q	D2	R	S	V	Aave	T60	
14	0.04	26.4	82.0	90	2	1	17750	71000	520000	0.2	5.28	
14	0.15	26.4	76.0	90	2	2	17750	71000	520000	0.2	5.28	
14	0.60	26.4	70.1	90	2	4	17750	71000	520000	0.2	5.28	
14	2.41	26.4	64.3	90	2	8	17750	71000	520000	0.2	5.28	
14	5.41	26.4	61.2	90	2	12	17750	71000	520000	0.2	5.28	
14	7.37	26.4	60.2	90	2	14	17750	71000	520000	0.2	5.28	
14	8.46	26.4	59.7	90	2	15	17750	71000	520000	0.2	5.28	
14	9.62	26.4	59.3	90	2	16	17750	71000	520000	0.2	5.28	
14	10.86	26.4	58.9	90	2	17	17750	71000	520000	0.2	5.28	
14	15.04	26.4	57.9	90	2	20	17750	71000	520000	0.2	5.28	
14	23.49	26.4	56.8	90	2	25	17750	71000	520000	0.2	5.28	
14	33.83	26.4	56.0	90	2	30.00	17750	71000	520000	0.2	5.28	
										vary		
	%alcons	Dc	Lp	Lw	Q	D2	R	S	V	Aave	T60	
14	67.44	17.6	59.6	90	2.00	20.00	7889	71000	520000	0.10	11.19	
14	15.04	26.4	57.9	90	2.00	20.00	17750	71000	520000	0.20	5.28	
14	5.89	34.5	57.2	90	2.00	20.00	30429	71000	520000	0.30	3.31	
14	2.87	43.1	56.8	90	2.00	20.00	47333	71000	520000	0.40	2.31	
14	1.56	52.8	56.6	90	2.00	20.00	71000	71000	520000	0.50	1.70	
14	0.89	64.6	56.4	90	2.00	20.00	106500	71000	520000	0.60	1.29	
14	0.52	80.6	56.3	90	2.00	20.00	165667	71000	520000	0.70	0.98	
14	0.29	105.5	56.1	90	2.00	20.00	284000	71000	520000	0.80	0.73	
14	0.14	158.3	56.1	90	2.00	20.00	639000	71000	520000	0.90	0.51	
					vary							
MOD N	%ALcons	Dc	Lp	Lw	Q	D2	R	S	V	Aave	T60	
14	18.39	24.4	54.1	90	1.00	25.00	30429	71000	620000	0.30	3.31	
14	9.20	34.5	55.9	90	2.00	25.00	30429	71000	620000	0.30	3.31	
14	4.60	48.8	58.1	90	4.00	25.00	30429	71000	520000	0.30	3.31	
14	2.30	69.1	60.6	90	8.00	25.00	30429	71000	520000	0.30	3.31	
14	1.15	97.7	63.4	90	16.00	25.00	30429	71000	520000	0.30	3.31	
											variable	
										Aave	T60	
14	3.03	67.1	58.6	90	5.00	25.00	45979	71000	520000	0.39	3.00	
14	5.38	53.9	58.9	90	5.00	25.00	29879	71000	520000	0.29	4.00	
14	12.12	41.3	59.4	90	5.00	25.00	17368	71000	520000	0.20	6.00	
14	21.54	34.7	59.8	90	5.00	25.00	12274	71000	520000	0.15	8.00	
14	33.65	30.5	60.2	90	5.00	25.00	9491	71000	520000	0.12	10.00	
14	48.46	27.5	60.6	90	5.00	25.00	7737	71000	520000	0.10	12.00	
14	65.98	25.3	61.0	90	5.00	25.00	6530	71000	520000	0.08	14.00	
NATIONAL EXHIBITION CENTRE HALL 5.												
SOUNDSPHERE INSTALLATION 28 UNITS												
INSTALLATION OF ABSORPTION PREDICTIONS												

1. A detailed calculation spread sheet used for the prediction and calculation of sound level Lp and % ALcons



1-25-93 5:53 PM

2. The double impulse from one unit which causes a comb filter effect.

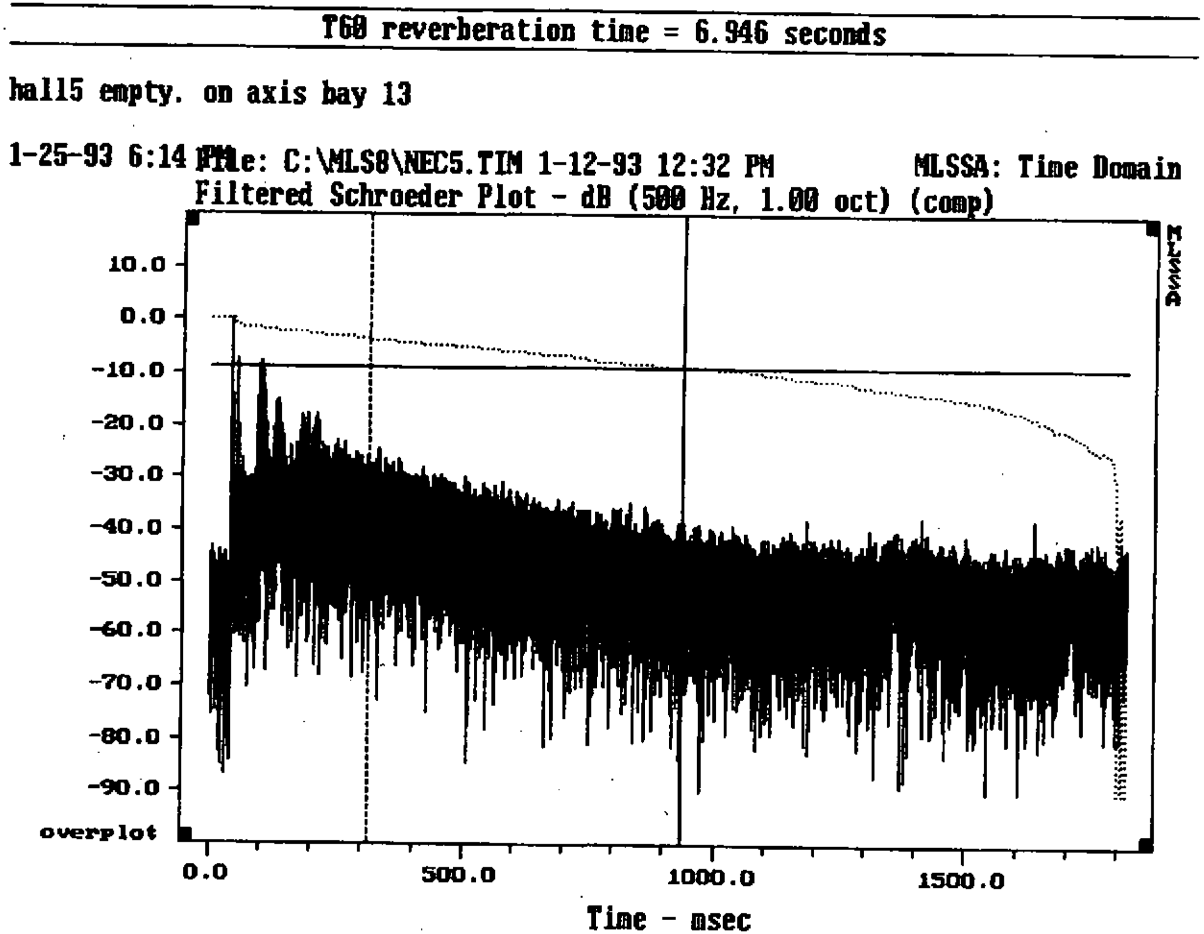
MTF Matrix (Calibrated)

Frequency-Hz	125	250	500	1000	2000	4000	8000
level dB-SPL			78.5		83.7		
0.71					0.502		
1.00			0.313				
1.41					0.388		
2.00			0.284				
2.80					0.287		
4.00			0.237				
5.60					0.281		
8.00			0.209				
11.20					0.264		

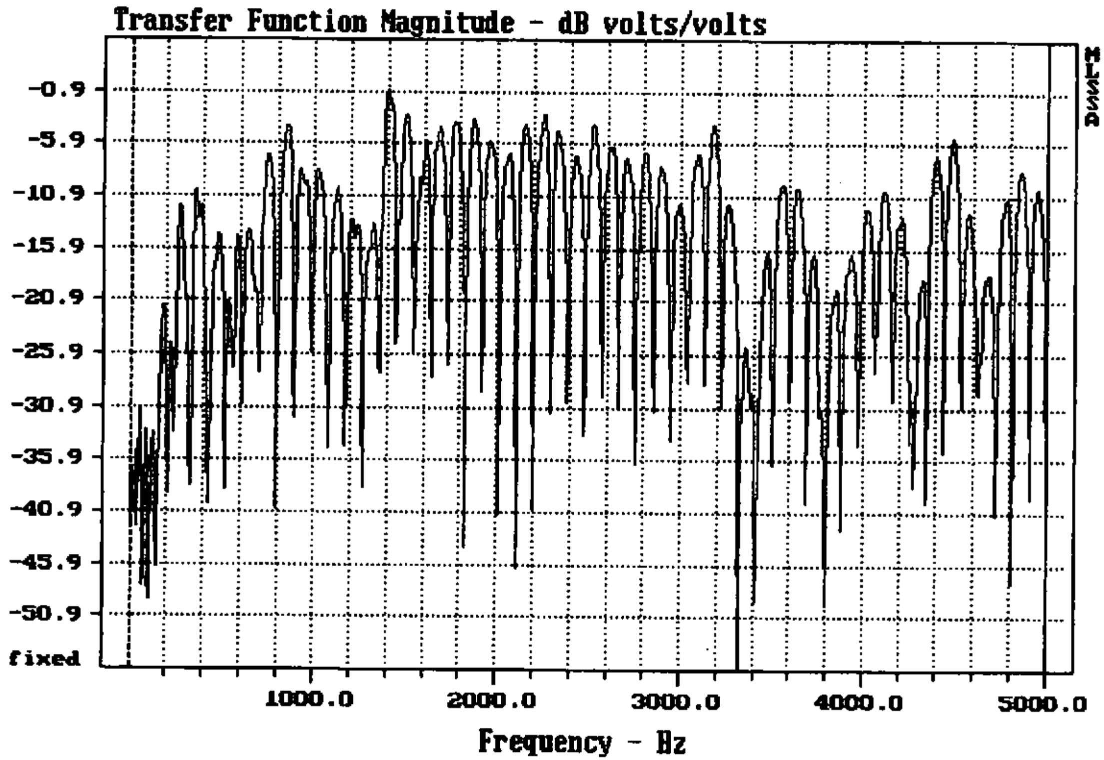
RASTI value= 0.379 ALcons= 21.9% Rating= POOR

File: C:\MLS8\NEC5.TIM 1-12-93 12:32 PM MLSSA: RASTI

3. RASTI for hall 5 empty.



3a. RT60 hall 5. 500Hz. 7 seconds. Note reverberation reduces at some lower frequencies due to panel resonance in the roof decking.



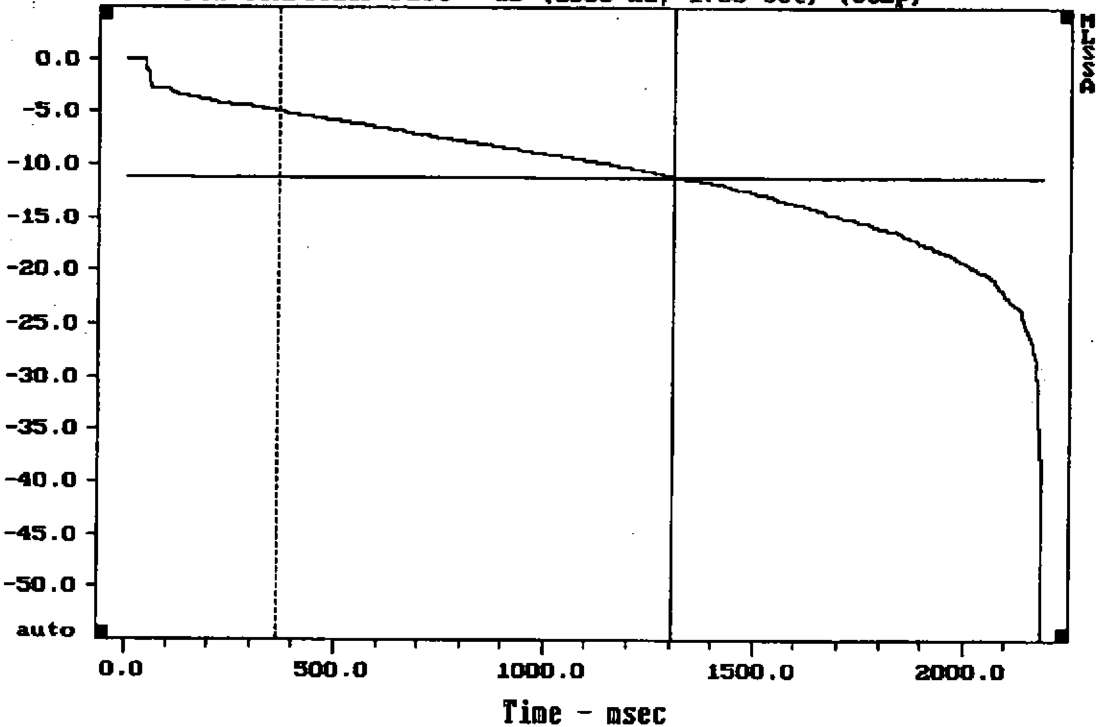
direct sound of one unit.

1-25-93 5:59 PM

MLSSA: Frequency Domain

4. Frequency plot of one speaker combined with roof reflection. See main report for comment.

File: C:\MLS8\NEC1.TIM 1-12-93 11:33 AM
Filtered Schroeder Plot - dB (1000 Hz, 1.00 oct) (comp)



T60 reverberation time = 9.399 seconds

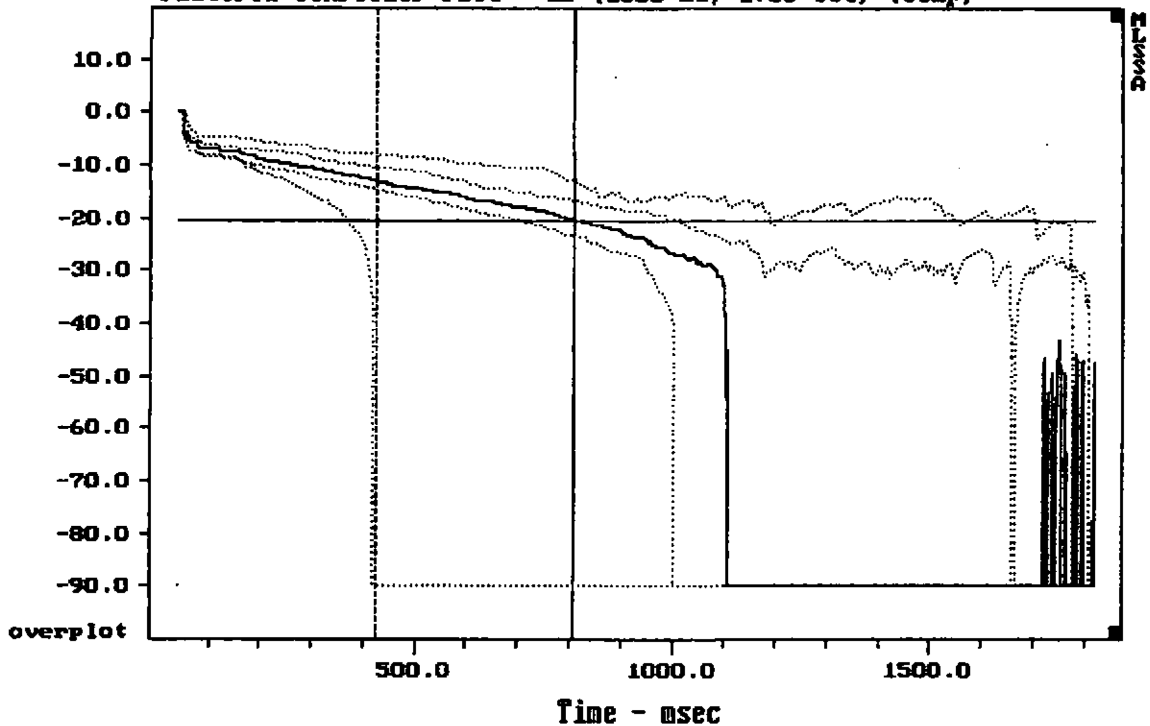
hall5 empty, initial system test

MLSSA: Time Domain

1-25-93 5:40 PM

5. RT of 9.3 seconds at 1kHz in hall 5 empty.

File: C:\MLS8\NEC23.TIM 1-22-93 11:29 AM
Filtered Schroeder Plot - dB (1000 Hz, 1.00 oct) (comp)



T60 reverberation time = 3.296 seconds

mid band T60, hall5, occupied, no visitors.

1-25-93 5:36 PM MLSSA: Time Domain

6. Hall 5 occupied, no visitors RT at 1kHz now 3.3 seconds.

MTF Matrix (Calibrated)

Frequency-Hz	125	250	500	1000	2000	4000	8000
level dB-SPL 0.71 1.00 1.41 2.00 2.80 4.00 5.60 8.00 11.20			69.6 0.673 0.651 0.683 0.626		63.5 0.892 0.831 0.788 0.789 0.756		

RASTI value= 0.663 ALcons= 4.7% Rating= GOOD

File: C:\MLS8\NEC23.TIM 1-22-93 11:29 AM MLSSA: RASTI

7. On axis RASTI for previous test. Result GOOD.

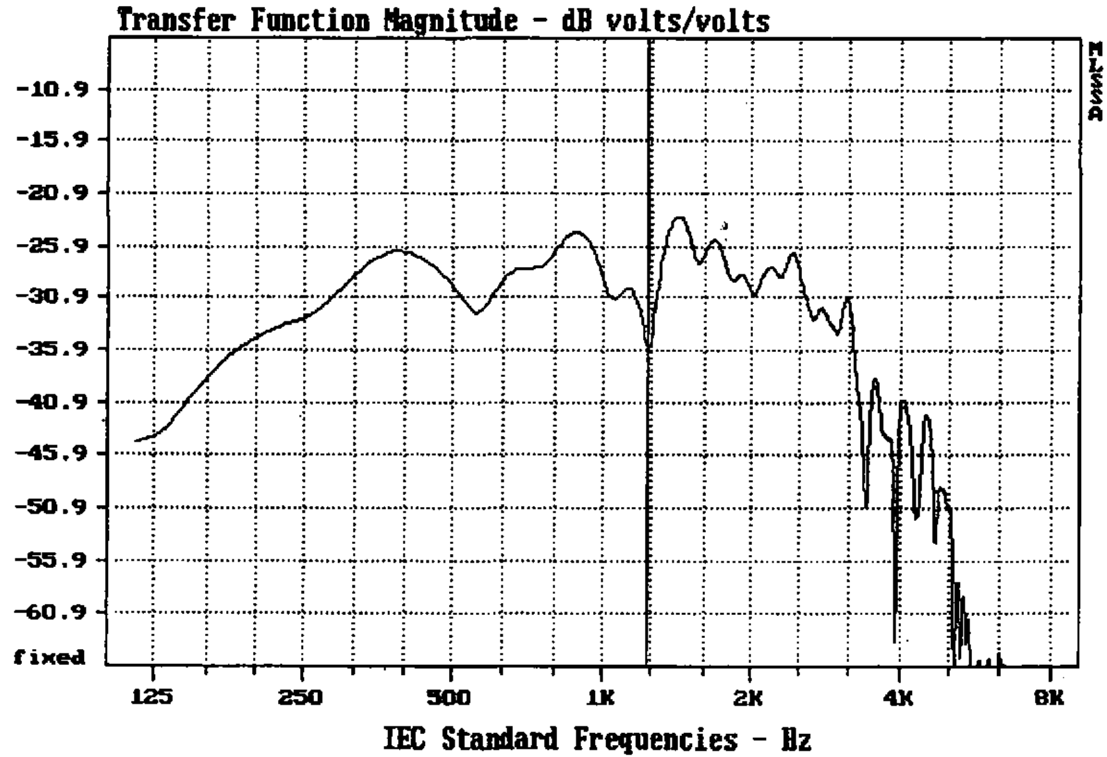
MTF Matrix (Calibrated)

Frequency-Hz	125	250	500	1000	2000	4000	8000
level dB-SPL	65.5	69.8	69.6	66.9	63.6	50.3	34.2
m-correction	1.000	1.000	1.000	0.999	0.999	0.994	0.988
0.63	0.070	0.451	0.753	0.869	0.916	0.916	0.356
0.80	0.070	0.451	0.753	0.869	0.916	0.916	0.356
1.00	0.043	0.400	0.659	0.796	0.857	0.830	0.272
1.25	0.043	0.400	0.659	0.796	0.857	0.830	0.272
1.60	0.096	0.381	0.633	0.757	0.827	0.773	0.125
2.00	0.141	0.319	0.630	0.737	0.804	0.736	0.126
2.50	0.177	0.404	0.610	0.725	0.785	0.720	0.073
3.15	0.092	0.304	0.620	0.711	0.777	0.713	0.087
4.00	0.031	0.351	0.652	0.704	0.776	0.706	0.064
5.00	0.095	0.310	0.616	0.713	0.775	0.693	0.050
6.30	0.043	0.313	0.569	0.719	0.787	0.697	0.055
8.00	0.111	0.342	0.582	0.723	0.800	0.682	0.003
10.00	0.054	0.297	0.540	0.680	0.767	0.640	0.058
12.50	0.087	0.232	0.515	0.613	0.748	0.545	0.149
octave TI	0.134	0.411	0.578	0.660	0.721	0.666	0.207

STI value= 0.497 (0.651 modified) ALcons= 11.6% Rating= FAIR

File: C:\MLS8\NEC23.TIM 1-22-93 11:29 AM MLSSA: STI

8. Full STI for hall 5. STI= .65 which is acceptable. Actual vocal tests were carried out at this point which were also acceptable.



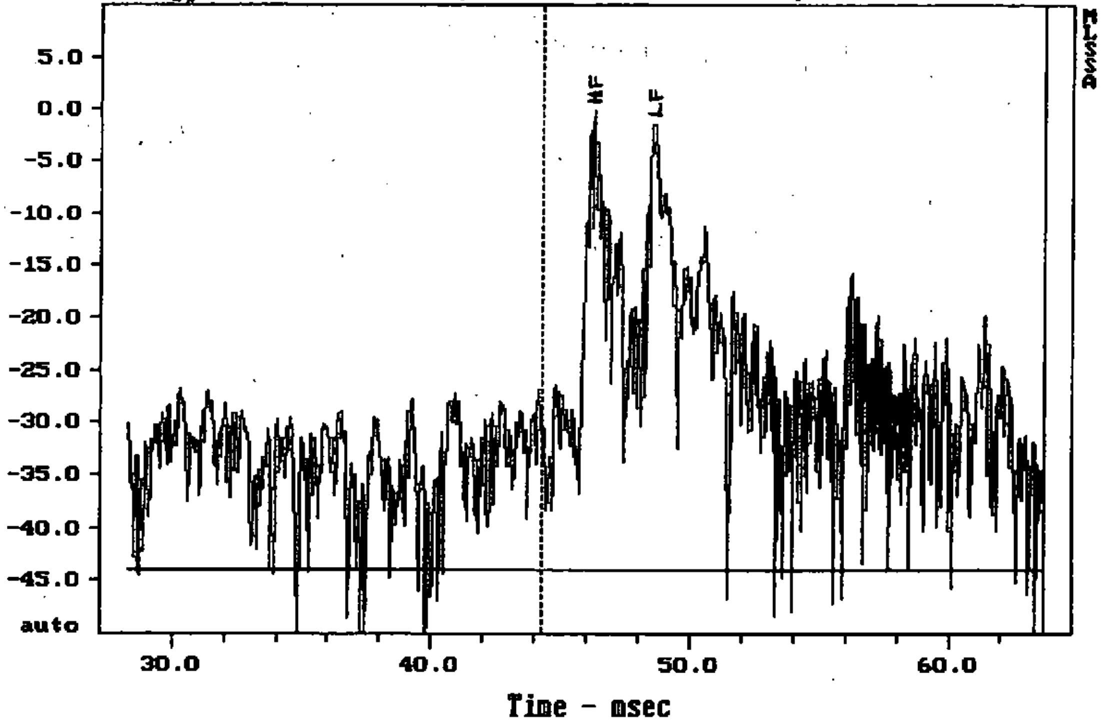
CURSOR: y = -35.5481 x = 1231.7005 (140)

windowed soundsphere response showing dip at 1.2k

1-25-93 5:02 PM MLSSA: Frequency Domain

9. Windowed direct response of loudspeaker shows mis-alignment of bass and HF drivers. To be discussed with manufacturer.

File: C:\MLS8\NEC25.TIM 1-22-93 11:41 AM
Energy-Time Curve - dB (Blackman-Harris window)

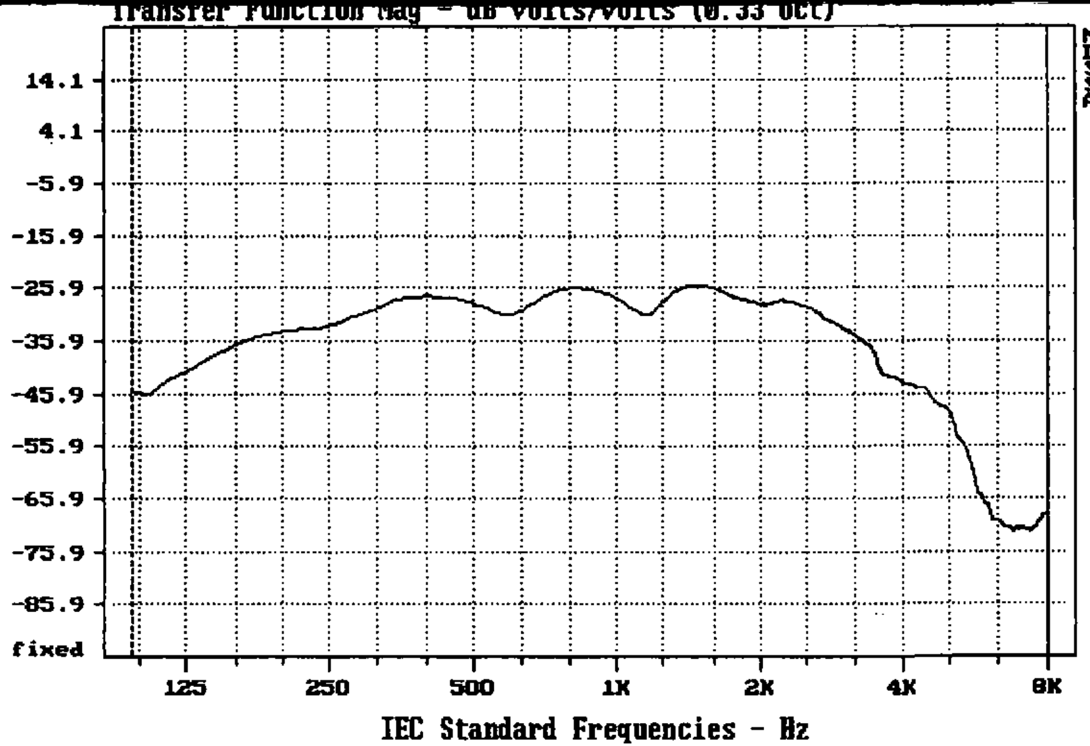


CURSOR: y = -43.9593 x = 63.6862 (2295)

soundsphere etc showing 2ms mis-alignment

1-25-93 4:56 PM MLSSA: Time Domain

10. Energy time curve shows above mis-alignment at 2ms (approx.).

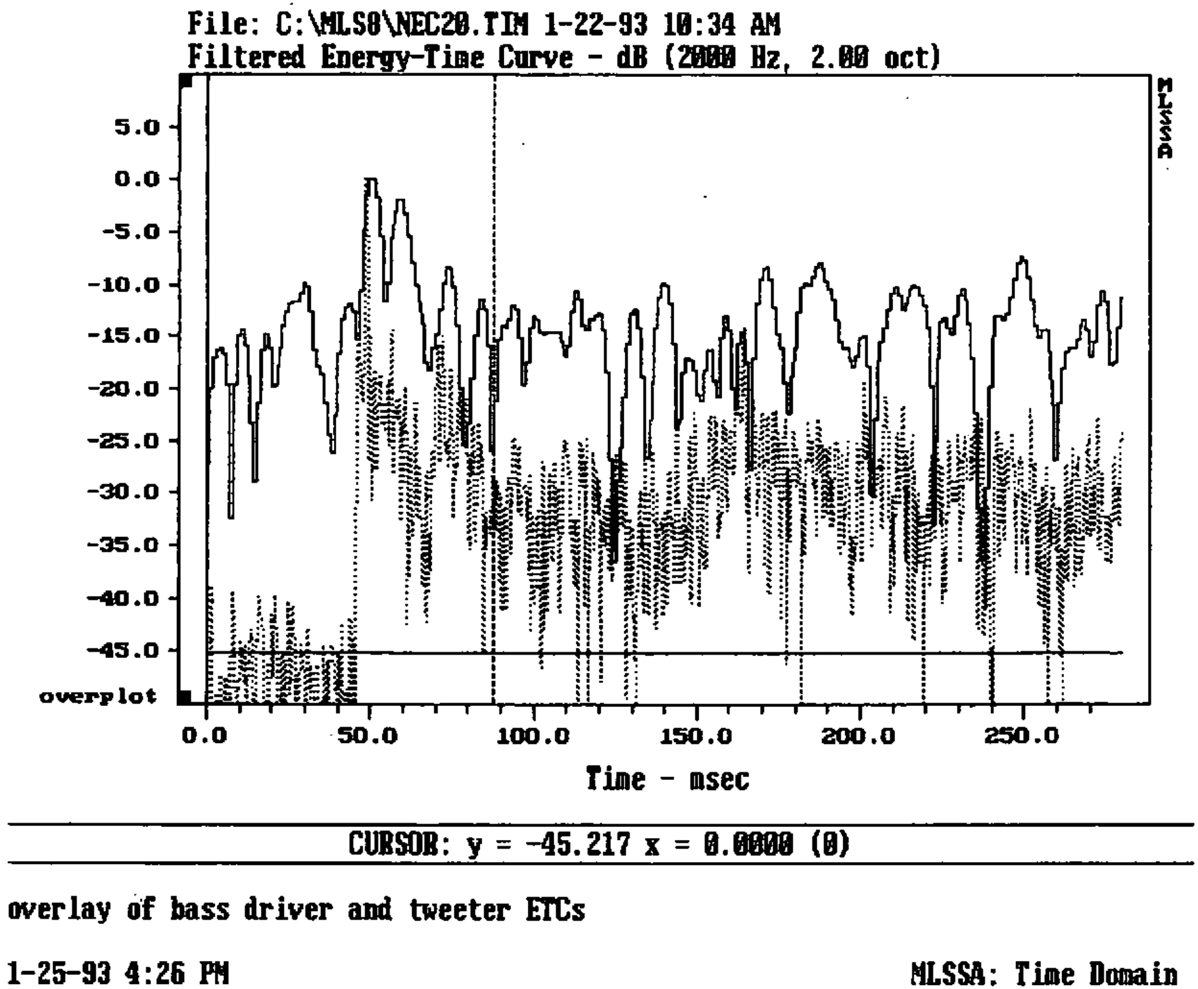


final eq. for spkr system in hall5.

1-25-93 4:49 PM

MLSSA: Frequency Domain

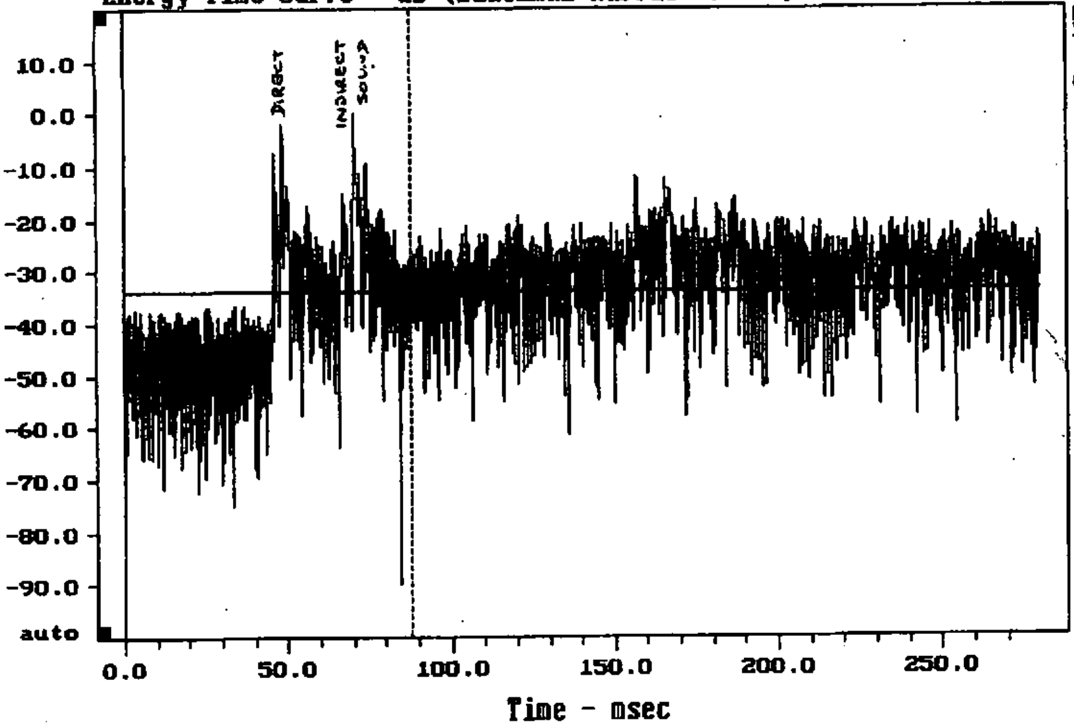
11. Final equalisation for hall 5. Smooth peak free curve with gentle rise to 2kHz. Best subjective result with this setting.



12. Overlay of bass and tweeter ETC shows that reflections are cause by bass driver only. To be discussed with manufacturer.

File: C:\MLS8\NEC20.TIM 1-22-93 10:34 AM

Energy-Time Curve - dB (Blackman-Harris window)



CURSOR: y = -33.9330 x = 0.0000 (0)

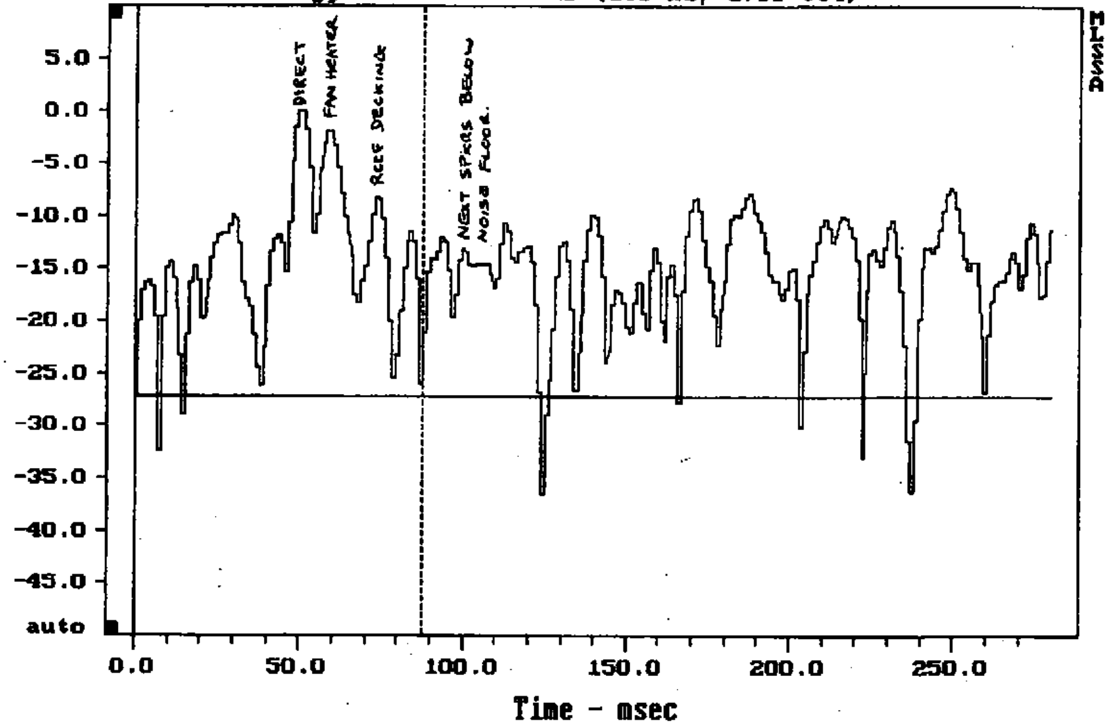
hall15 ETC, slightly off axis of bay centre.

1-25-93 4:05 PM MLSSA: Time Domain

13-19. Various backup measurements showing hall 1 also, which, as it was mainly empty, did not give valid conditions for full STI.

File: C:\MLS8\NEC20.TIM 1-22-93 10:34 AM

Filtered Energy-Time Curve - dB (250 Hz, 2.00 oct)



CURSOR: y = -27.1384 x = 0.0000 (0)

bass driver only showing early reflections. hall5

1-25-93 4:15 PM

MLSSA: Time Domain

MTF Matrix (Calibrated)

Frequency-Hz	125	250	500	1000	2000	4000	8000
level dB-SPL	65.8	76.6	79.4	81.5	81.5	74.0	59.6
m-correction	1.000	1.000	1.000	1.000	1.000	0.998	0.992
0.63	0.148	0.404	0.456	0.611	0.741	0.830	0.781
0.80	0.148	0.404	0.456	0.611	0.741	0.830	0.781
1.00	0.027	0.131	0.299	0.476	0.645	0.679	0.648
1.25	0.027	0.131	0.299	0.476	0.645	0.679	0.648
1.60	0.023	0.137	0.281	0.430	0.623	0.608	0.555
2.00	0.038	0.179	0.227	0.403	0.603	0.572	0.507
2.50	0.100	0.171	0.268	0.405	0.610	0.555	0.503
3.15	0.050	0.154	0.303	0.395	0.619	0.555	0.474
4.00	0.058	0.173	0.282	0.402	0.622	0.563	0.464
5.00	0.015	0.185	0.206	0.398	0.618	0.543	0.442
6.30	0.060	0.157	0.218	0.396	0.634	0.512	0.369
8.00	0.059	0.119	0.242	0.397	0.639	0.450	0.225
10.00	0.048	0.155	0.225	0.369	0.587	0.375	0.159
12.50	0.050	0.132	0.227	0.386	0.632	0.374	0.043
octave TI	0.087	0.278	0.363	0.465	0.584	0.553	0.469

STI value= 0.417 (0.497 modified)   ALcons= 17.8%   Rating= POOR

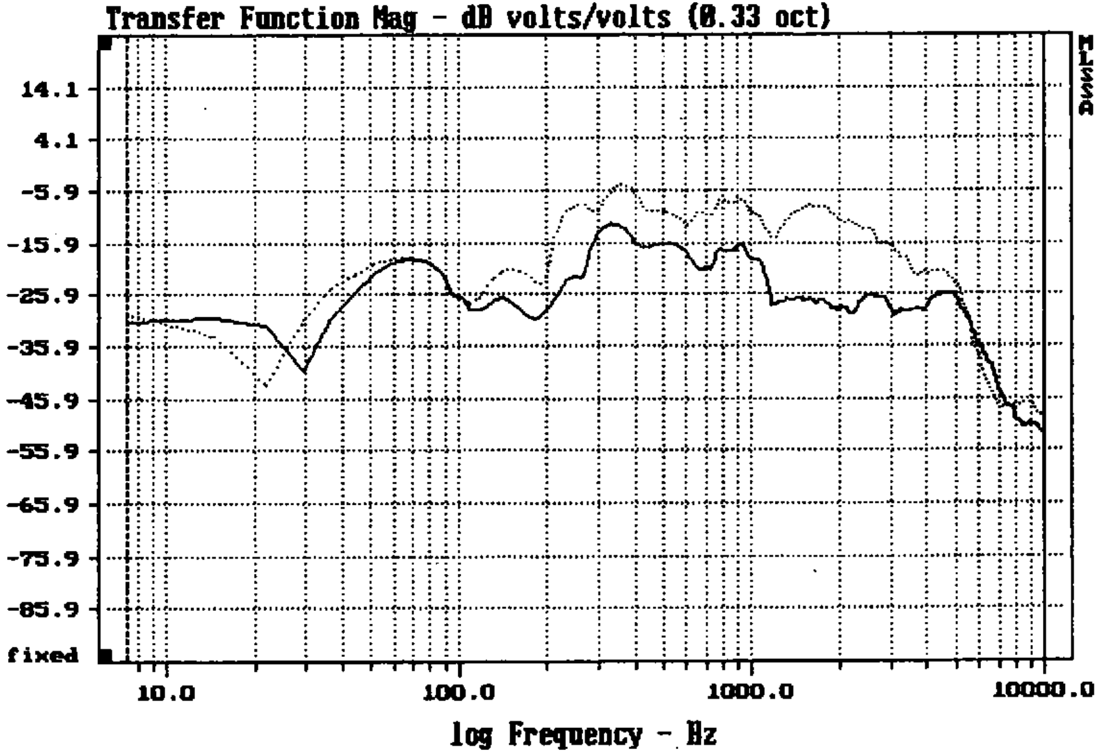
File: C:\MLS8\NEC34.TIM 1-22-93 1:07 PM   MLSSA: STI

MTF Matrix (Calibrated)

Frequency-Hz	125	250	500	1000	2000	4000	8000
level dB-SPL			72.2		79.6		
0.71					0.790		
1.00			0.275				
1.41					0.665		
2.00			0.249				
2.80					0.586		
4.00			0.192				
5.60					0.605		
8.00			0.194				
11.20					0.558		

RASTI value= 0.469 ALcons= 13.4% Rating= FAIR

File: C:\MLS8\NEC20.TIM 1-22-93 10:34 AM MLSSA: RASTI



CURSOR: dy = 2.93096 x = 10000.5873 (1362)

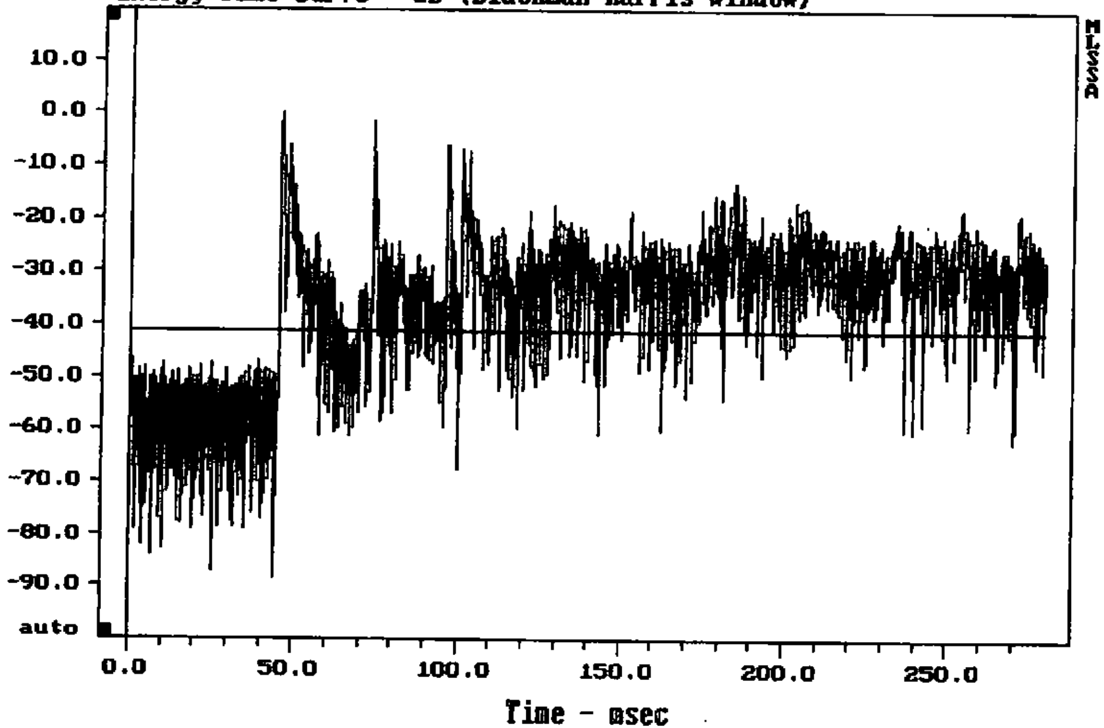
on axis dots, next cluster solid, hall1

1-25-93 3:56 PM

MLSSA: Frequency Domain

File: C:\MLS8\NEC30.TIM 1-22-93 12:40 PM

Energy-Time Curve - dB (Blackman-Harris window)

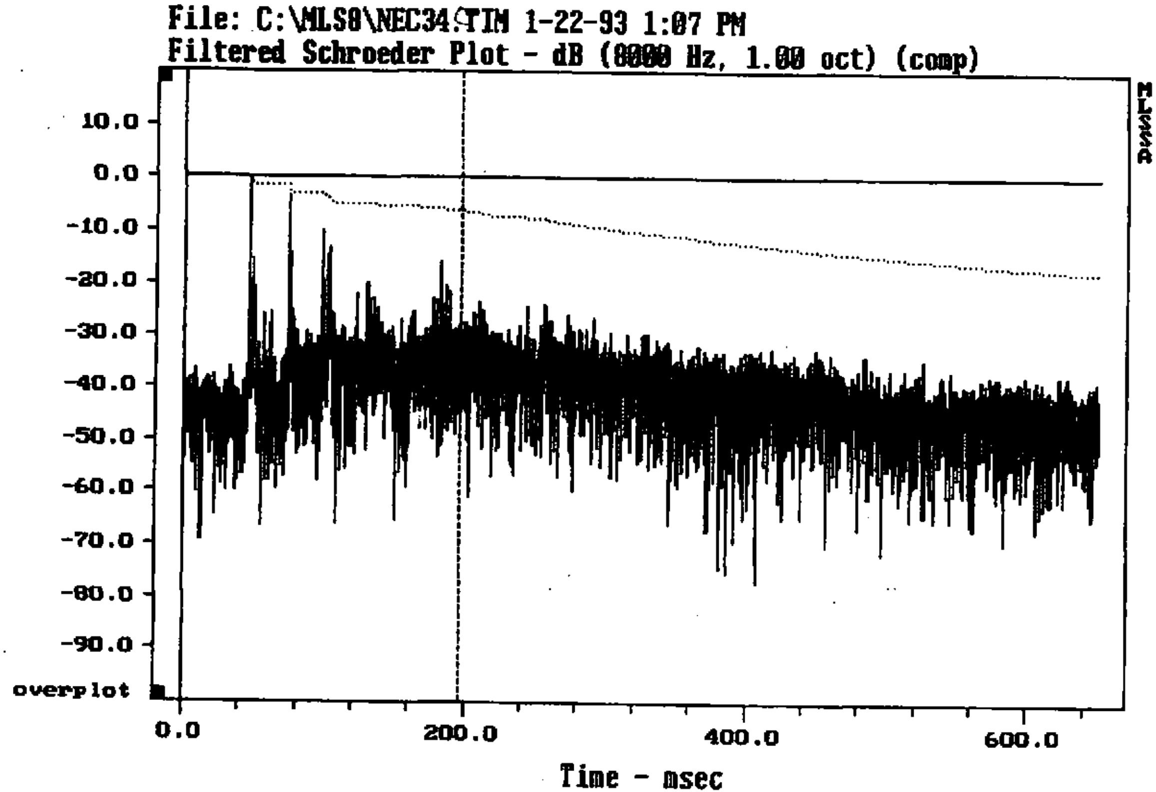


CURSOR: y = -41.0211 x = 0.0000 (0)

on axis etc. bay centre hall1, empty.

1-25-93 3:18 PM

MLSSA: Time Domain



CURSOR: y = 0 x = 0.0000 (0)

etc at 8k showing relative distance of soundspheres

1-25-93 1:27 PM

MLSSA: Time Domain