SOUND SYSTEM DESIGN FOR INDOOR ARENAS

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1. INTRODUCTION

The subject of systems design for sound reinforcement in indoor arenas will be explored. The four primary design approaches commonly used in arenas will be presented and the merits of each approach discussed.

The intent of this paper is to provide a basic primer to some of the design issues involved in the design of sound systems for arenas. Complete discussion of all design issues is beyond the scope of this paper.

2. PROGRAMMING

Before any decisions can be made regarding the appropriate design approach for a given arena, the intended usage of the facility must be fully understood. Typical usage for many arenas includes:

Concerts for touring popular music groups. This will include a wide variety of music styles from rock groups to classical performances.

Sporting/ competition events. These sports may include ice hockey, indoor soccer, gymnastics, basketball, badminton, boxing, ballroom dancing, figure skating etc.

Conferences and trade shows.

Each of these events represents widely divergent (and often conflicting) requirements for sound reinforcement. It is beyond the scope of this paper to fully address the programming issues required for designing a sound system for a specific venue. Suffice to say that there is no single correct approach to system design for arenas. The best choice of performance compromises can only be made after a full evaluation of facility usage is completed.

3. PERFORMANCE CRITERIA

To a certain extent, the required sound system performance criteria will vary from facility to facility. However, a few common performance requirements are presented.

3.1 Loudness.

The system must be capable of an average SPL output which is sufficiently high to overcome the ambient noise levels of the facility. During sporting events, crowd loudness can easily exceed 110 dBA. It is generally considered unrealistic to design a system which will override the peak SPL output of the crowd and many designers consider peak levels of 105-110 dBA measured in the seating area to be adequate for most facilities. In the event that the sound system serves as an emergency evacuation system, it should be noted that some countries are in the process of establishing required maximum SPL regulations for this purpose.

3.2 Bandwidth.

The required frequency bandwidth for the system will vary widely according to usage. We will consider possible requirements for "speech only" and "music" systems. High quality speech only systems typically require a bandwidth of 100 Hz (-3dB) to 8 kHz (with a roll off

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of 3 dB/oct above 3 kHz). Systems which also are used to reinforce music typically require a bandwidth of 50 Hz (-3dB) to 15 kHz (with a roll off of 3 dB/oct above 3 kHz).

3.3 Sound Coverage.

The sound coverage consistency throughout the seating area should be no greater than +/- 2dBA. Variations greater than this are likely to result in low direct to reverberant ratios and hence poor speech intelligibility.

3.4 Speech Intelligibility.

The design should provide for no more than 10% articulation loss of consonants at any seat in the facility. This should be measured with 50% of the seats occupied by spectators.

4. DESIGN APPROACHES

Four arena sound system design approaches are presented and the benefits and compromises of each design approach are discussed.

4.1 Central Cluster.

The central cluster, or single point, system is simple in concept and relatively easy to accommodate. The cluster is composed of a single array of loudspeaker components, usually located in the center or at one end of the arena. A large number of speaker components is required in order to provide acceptably loud levels to the entire arena. Coupled with the need for high quality sound, this approach can result in a large and heavy cluster. (See Fig 1)

4.1.1 Benefits

- Single structural location. This provides for relatively simple maintenance and installation.
- Provides sound to both floor and seating areas.
- Single point source with no source echo problems.
- Relatively simple and hence inexpensive.

4.1.2 Compromises

- Excessive high frequency attenuation at distant seats due to air absorption.
- Minimal capability for muting of sound to seating zones. In particular, sound to the main floor cannot be muted successfully.
- Poor audio synchronization (lip synch) with video screens due to significantly varying sound arrival times at different seating locations.
- Substantial reverberant field excitation due to the high source SPL required to project sound to distant seats.
- Generates substantial specular reflections from side walls and roof structure. These late arriving echoes will significantly compromise speech intelligibility in certain seating zones.
- Large size and load. The size of cluster may obscure signage or a scoreboard. The single point source load may present structural loading problems.
- Significant tonal changes with listener location. This is due to the high frequency attenuation at distant seats and excessive low frequency energy in locations nearby the central cluster (such as immediately below).

4.2 Central Cluster with Satellite Speakers.

This design approach utilizes a large central cluster for sound coverage of most of the seating areas and a ring of signal delayed speakers providing sound coverage to the furthermost seats. (See Fig 3)

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4.2.1 Benefits

- The size and mass of the central cluster is slightly reduced as compared to a single central cluster.
- Slightly less reverberant field excitation due to the reduced need for the central cluster to provide sound to the furthermost seats.
- Reduced specular reflections from the side walls and roof.
- Slightly improved tonal consistency at various seating locations.
- Provides sound coverage of field area.

4.2.2 Compromises

- In most cases the general compromises are similar in nature to a single central cluster.
- It is difficult to signal align the satellite speakers with the central cluster unless the seating is symmetrical around the cluster.

4.3 Satellite Clusters

The satellite cluster system usually consists of a number of identical clusters which are distributed around the edge of the main floor, firing into the seating stands. (See Fig 5)

4.3.1 Benefits

- The satellite speakers are reasonably close to the listeners and thus are not susceptible to high frequency loss due to air absorption. This results in improved sound quality.
- Reduced reverberant field excitation compared to a central cluster due to the lower source SPL required to project sound to distant seats.
- Speakers are aimed primarily at spectators thus resulting in reduced specular reflections from side walls and roof. However, in cases where the cluster height is similar to the rearmost seats, considerable specular reflections can result from the side walls unless acoustical treatment is implemented. (Fig. 6 indicates a late arriving reflection generated from the untreated side walls of the arena).
- There is some muting capability of sound coverage to selected seating zones.
- The satellite clusters present a reduced single point structural load.
- There is improved (but still noticeable) audio synchronization (lip synch) with video screens. This synchronization is commonly on the order of 80-120 msec. This synchronization can be improved with video delay.

4.3.2 Compromises

- Sound is not directed to the field and thus supplementary systems are required to cover the field. It is not possible to simply use rear firing speakers from the satellite speakers as the cross arena sound arrivals will compromise intelligibility.
- Careful design is required to reduce late arriving sound from adjacent clusters in the coverage overlap zones. This late arriving sound can compromise intelligibility considerably.

4.4 Distributed Loudspeaker System

The distributed system, while commonly used in convention centers, is not often used in arenas. The system consists of multiple loudspeakers mounted in the roof structure and aimed downwards. These speakers are distributed around the room. (See Fig 7)

4.4.1 Benefits

- There is reasonably good audio synchronization (lip synch) with video screens. This synchronization is commonly on the order of 40-80 msec. This synchronization can be improved with video delay.
- The use of individual cabinets presents small structural loads.
- The sound quality and tonal consistency in all parts of the room (including the main floor) can be very good.

- The cabinets present minimal sightline obstructions to scoreboards etc.
- There is minimal reverberant field excitation due to the low source SPL.
- Very few specular reflections are generated as a result of the speakers being aimed directly at the seating areas.
- There is excellent muting capability of sound coverage to selected seating zones.

4.4.2 Compromises

- The sound arrives directly from overhead and thus there is little localization of sound to the center of the arena.
- Loudspeakers of reasonably high directivity must be used to minimise late arrival of sound from distant speakers.
- The system must be set up extremely carefully with respect to speaker loudness levels. Misajustment results in severely compromised speech intelligibility.

5. DESIGN EXAMPLES

The Sheffield Events Centre in Sheffield England is used as a basis for presenting the four different design approaches. The arena dimensions are 120 meters long, 90 meters wide and 27 meters high.

Computer predicted Energy/Time arrival graphs are presented for each design approach in Fig 2, Fig 4, Fig 6 and Fig 8. These graphs indicate the substantial difference in early reflections character between the various design approaches.

6. MEASURED RESULTS - SHEFFIELD EVENTS CENTRE

A distributed loudspeaker system was designed for Sheffield Events Centre and installed in 1991. This system comprised of 40 full range speaker cabinets (Community RS220) used in conjunction with 8 sub-bass speaker cabinets (Community VB212). The full range speaker cabinets are comprised of an all horn loaded three way speaker system. The nominal (-6dB) coverage pattern of these speakers is 60 degrees horizontal by 40 degrees vertical.

Measurements were made of the arena reverberation time (See Fig. 10). This measurement was made in an empty room.

The speech intelligibility of the sound system was measured using the MLSSA TDS system. Fig. 12 shows the results of a full modulation transfer matrix. The results indicate that the system provides 2.2% AL_{cons} (STI=0.8) which is considered excellent.

A subjective assessment of speech intelligibility was made using phonetically-balanced word lists. Each list comprised of 50 words and were input into the system from a DAT recording. Four subjects and six lists were used. (See Fig. 13)

An impulse response measurement was taken. Fig. 11 shows the energy-time curve (ETC) of the system. The direct to reverberant ratio is approximatley 7dB. Please note the drop in energy following the direct sound impulse. This measured result can be compared to the computer predicted result in Fig. 8.

7. ACKNOWLEDGEMENTS

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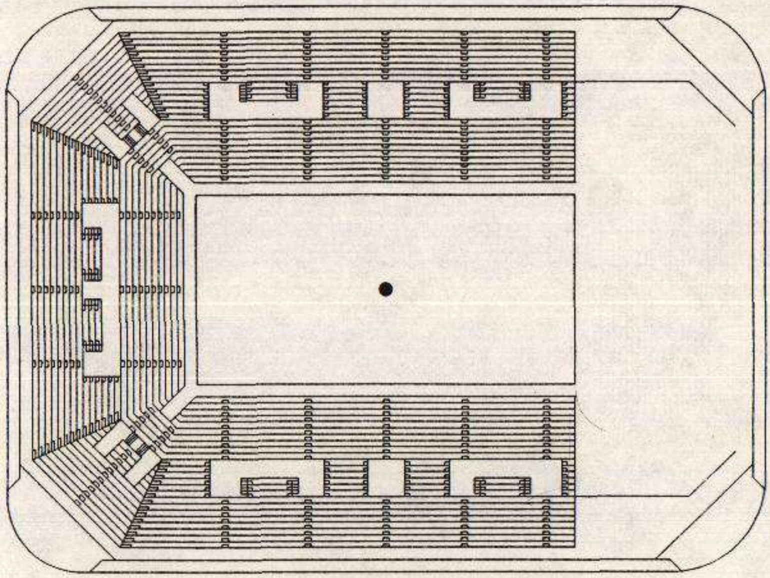


CENTRAL CLUSTER

Fig 1

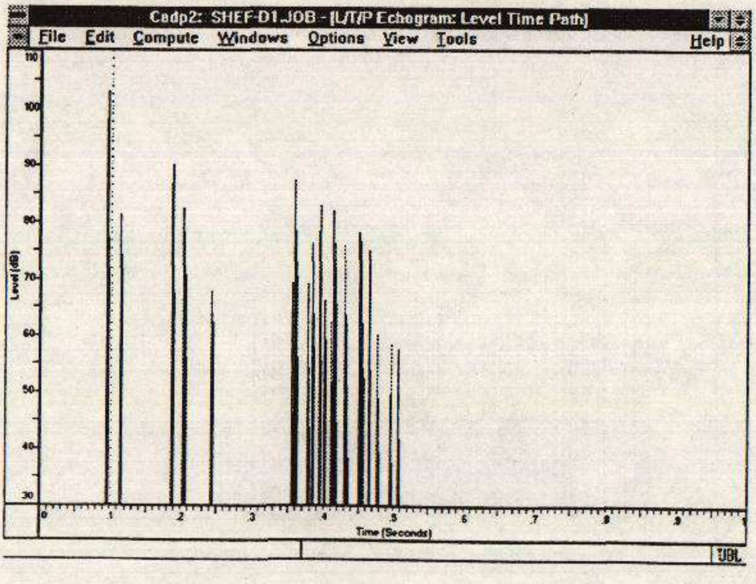
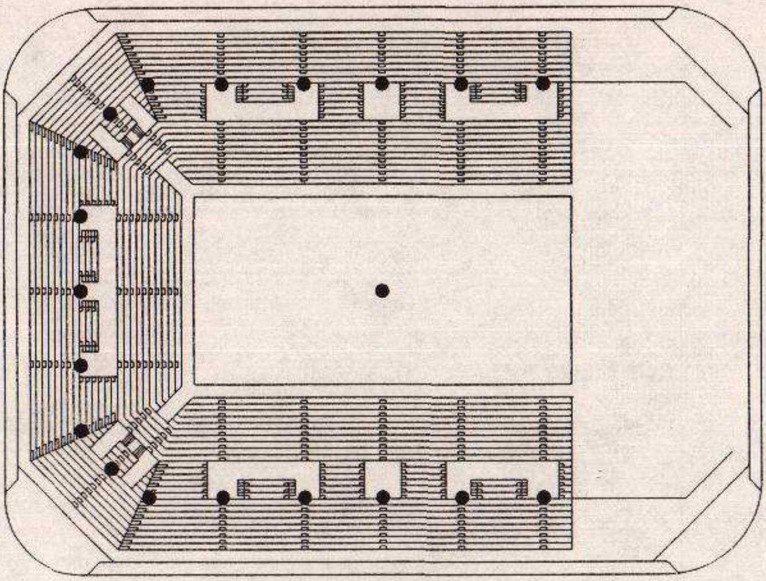


Fig 2



CENTRAL CLUSTER
WITH
SATELLITE RING

Fig 3

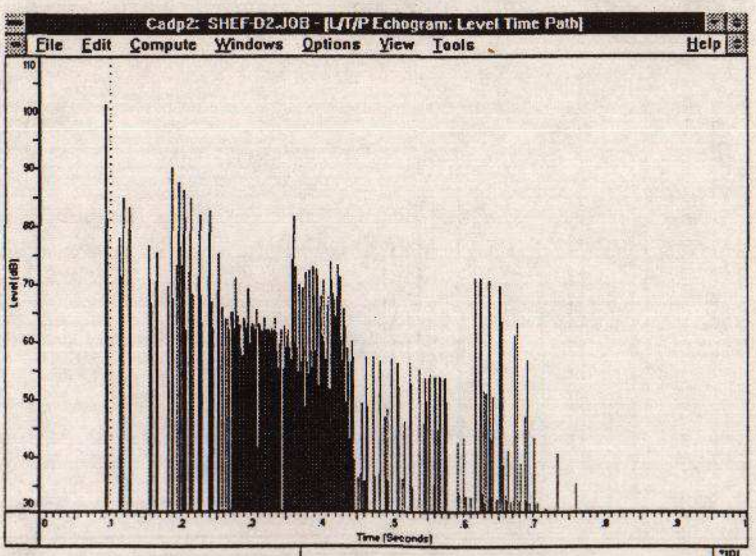
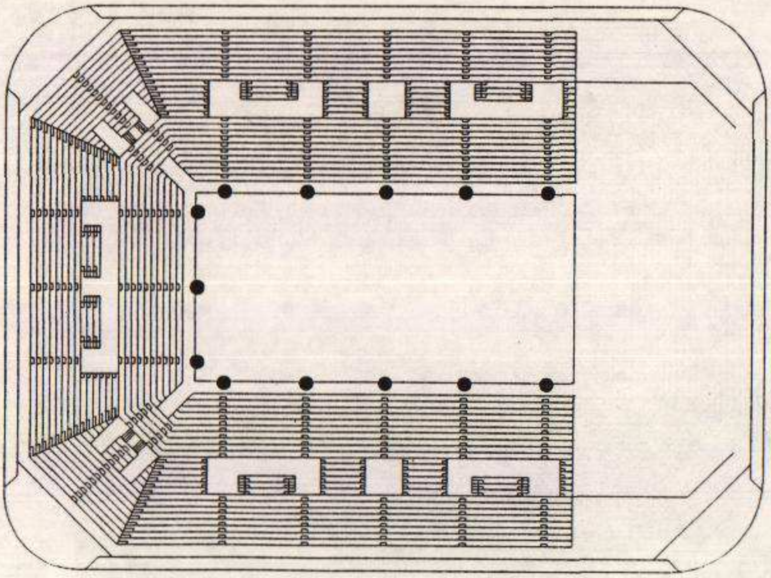


Fig 4



SATELLITE CLUSTERS

Fig 5

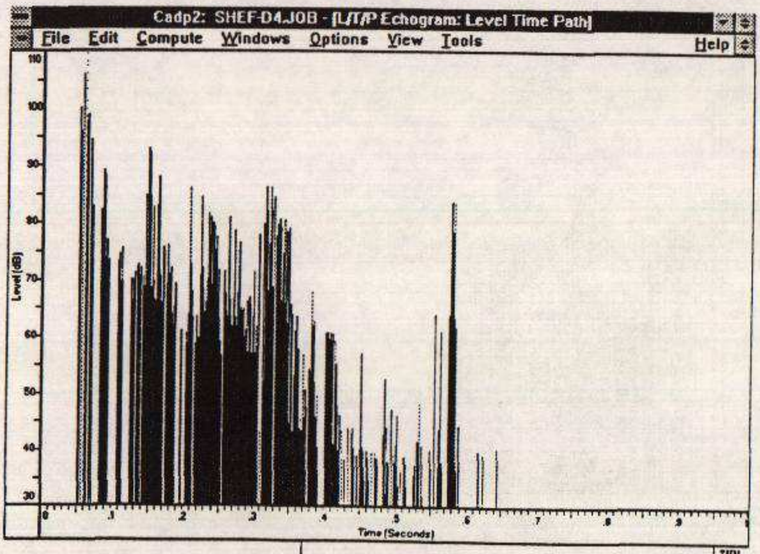
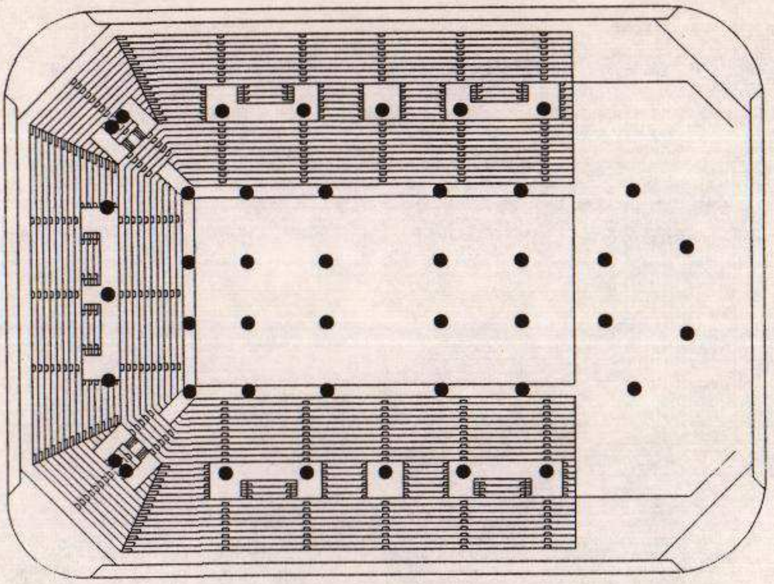


Fig 6



DISTRIBUTED SYSTEM

Fig 7

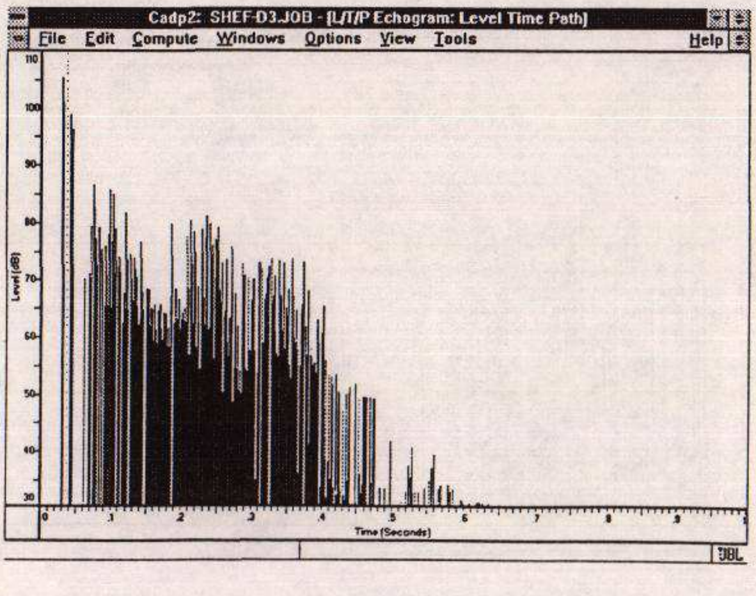


Fig 8

GENERALIZED SOUND SYSTEM CONFIGURATION COMPARISON

		Central Cluster	Central Cluster w/ Satellites	Satellite Cluster	Distributed Speakers
1	Speech Clarity	Fair	Fair	Good	Excellant
2	Sound Quality	Fair	Good	Excellant	Excellant
3	System Cost	Low	Moderate	Moderate	High
4	Coverage of Main Floor	Good	Good	Additional System Req'd	Good
5	Flexibility of Configuration	Poor	Poor	Moderate	Excellant
6	Audio Sych. with Video Board	Poor	Poor	Adequate	Adequate
7	Spectator Sightline Blockage	Some Possible	Some Possible	None	None
8	Audible Late Signal Arrivals From Speaker Systems	None	Some	Slight	Slight
9	High Level of Specular Reflections	Considerable	Moderate	Moderate	Very Little
10	Structural Point Source Loading	High	High	Moderate	Low
11	Tonal Consistency From Seat to Seat	Poor	Poor	Good	Excellant

Figure 9

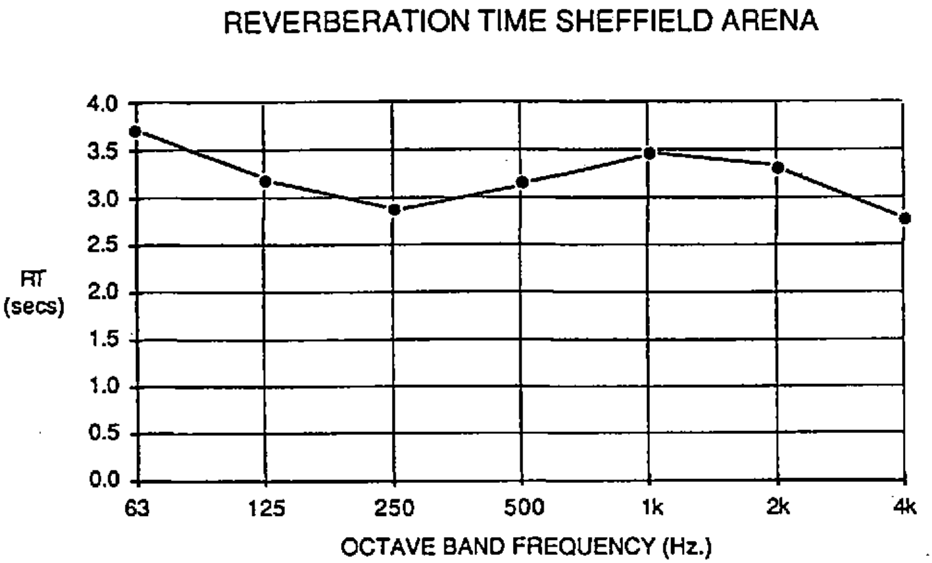

REVERBERATION TIME SHEFFIELD ARENA
RT (secs)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
63
125
250
500
1k
2k
4k
OCTAVE BAND FREQUENCY (Hz.)

Fig 10

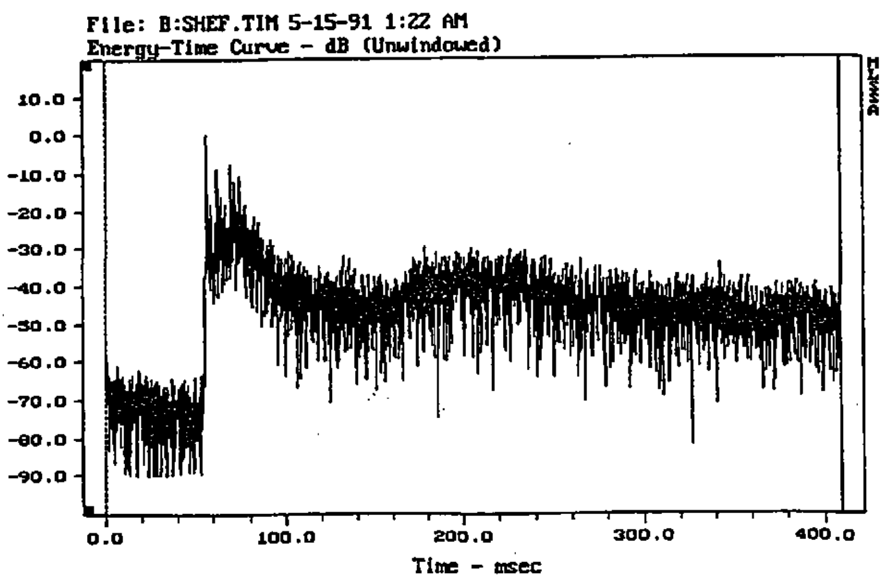

File: B:SHEF.TIM 5-15-91 1:22 AM
Energy-Time Curve - dB (Unwindowed)
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
0.0
100.0
200.0
300.0
400.0
Time - msec

Fig 11

Modulation Transfer Function Matrix

Frequency Hertz	1 125	2 250	3 500	4 1000	5 2000	6 4000	7 8000
0.63	0.917	0.930	0.955	0.955	0.968	0.979	0.993
0.80	0.892	0.908	0.941	0.940	0.957	0.971	0.989
1.00	0.870	0.890	0.930	0.927	0.946	0.961	0.985
1.25	0.844	0.872	0.918	0.913	0.934	0.950	0.979
1.60	0.802	0.851	0.901	0.895	0.918	0.936	0.971
2.00	0.767	0.833	0.884	0.882	0.904	0.923	0.962
2.50	0.746	0.819	0.870	0.871	0.893	0.911	0.953
3.15	0.741	0.812	0.861	0.867	0.885	0.902	0.945
4.00	0.723	0.806	0.858	0.868	0.882	0.899	0.940
5.00	0.737	0.808	0.853	0.868	0.888	0.903	0.937
6.30	0.752	0.786	0.836	0.859	0.887	0.897	0.930
8.00	0.745	0.739	0.796	0.815	0.851	0.855	0.900
10.00	0.675	0.714	0.743	0.771	0.799	0.801	0.855
12.50	0.626	0.676	0.684	0.721	0.747	0.749	0.802
Channel TI	0.689	0.728	0.781	0.788	0.822	0.847	0.911

STI value= 0.800 (0.808 modified)   ALcons= 2.2%   Rating= EXCELLENT

-91 9:56 AM   MLSSA: S

Fig 12

SUBJECT	LIST 1	LIST 2	LIST 3	LIST 4	LIST 5	LIST 6	AV	SD
A	92	92	96	96	96	94	94.3	1.97
B	100	96	96	96	100	96	97.3	2.07
C	100	100	98	100	100	98	99.3	1.03
D	96	96	100	98	100	100	98.3	1.97
AV	97.0	96.0	97.5	97.5	99.0	97.0	97	
SD	3.83	3.27	1.91	1.91	2.00	2.58	2.16	

Fig 13