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PROBLEMS IN DESIGNING SMALL CONTROL ROOMS FOR MONITORING TELEVISION STEREO SOUND

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1. INTRODUCTION

About twelve months ago it was realised that with the introduction of stereophonic sound on the ITV Network, it would be necessary to re-consider the whole aspect of control and monitoring of the sound signal.

The best that stereophonic sound can do for television with the currently small picture size is to provide a credible illusion that between the pair of loud speakers there exists a realistic acoustic environment within which the artists are performing. In order to provide a transparent channel from the studio floor to the sound controller's ears, all elements of the path must be analysed. The problems arise when it becomes necessary to relate system measurements to subjective listening tests and agree an overall performance rating for the channel.

Measurements indicated that the electrical path from microphone to the monitoring loudspeaker system input was quantifiable and of high quality and it was decided that three complex systems namely - The Control Room, The Loudspeaker System and The Ears would determine the final system performance.

It would now be necessary to find a relationship between the objective measurements of parameters and the subjective listening qualities dictated by the so called 'Golden Ears'.

Granada Television decided it would have to up-date its control rooms for stereophonic monitoring and engaged Andy Munro as a Consultant and Designer. Previous work commissioned by the ITCA in 1977 at the University of Bradford had addressed the problem of the acoustic requirements for small monophonic control rooms. Although the outcome of this work had been useful it was by no means conclusive and did not consider the second dimension of stereo sound imaging. Having studied scores of technical papers written on the subjects of Room Reflections, Reverberation Time, Imaging and Sound Quality, it became clear that we would be entering a scientific field that had existed for many years, was still developing, and heavily dependent on subjective analysis.

The objective of this paper is to report on the project and to outline the difficulties that were faced. It is understood that the approach is one of many but the main aim was to attempt to achieve a better correlation of measured results with an acceptable monitoring environment.

2. BACKGROUND

2.1 Acoustics

The BSI Glossary of Acoustical Terms states that acoustics is the science of sound and that the acoustics of a room or auditorium are those factors that determine its character with respect to the quality of the received sound.

Several investigators have looked into the perceptual effects produced by early reflections in concert halls and more recently there is concern about reflections within small control rooms. The emphasis on large rooms has meant there are limited data relating to the shorter time delays found in broadcasters' control rooms [1].

As mentioned previously, the Technical Acoustics Group of the University of Bradford, who were investigating the application of digital techniques to the measurements of loudspeakers [2] at the time, were commissioned by the ITV Association to determine the acoustical properties of control rooms and listening rooms for monophonic television sound.

Their experimental work was to use test signals such as White Noise and orchestral music recorded in a large anechoic chamber and to replay them through different control rooms around the ITV Network using a standard monitoring loudspeaker. A dummy head was used to record the sound at the normal Sound Controller's position and then reproduced for subjective tests using electrostatic headphones. The object was to attempt to identify the acoustic signatures of the various control rooms.

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It was established that each room had its own signature and this was more apparent using White Noise even though Sound Controllers found it more natural to identify the colouration of the music. The outcome was that all control rooms appeared to be heavily acoustically treated, and had very short reverberation time of 0.2 seconds or less which varied to some extent with frequency. The only conclusions that could be drawn on this occasion was that the effect of short early reflections and the problems of reproducing low frequencies in small control rooms with an RT time of 0.2 seconds must be further investigated.

2.2 Loudspeakers

In the late 40's, the standard loudspeaker used by the BBC Television Service was a single unit hanging over the picture monitors mounted on a four-foot open baffle. Today, multiple units are employed with potentially phase distorting cross over networks, suffice it to say that the loudspeaker system is a key element in the chain and characteristics such as dispersion and phase become more important in stereo reproduction. Simulation of cross-over filters using digital techniques is yielding valuable information on characteristics which may contribute to colouration of the sound signal [3].

Impulse and step response testing of loudspeakers in the time domain would appear to yield valuable information as to the initial response of such systems.

2.3 Listening Tests

One fundamental pre-requisite for achieving comparable results in listening tests to be carried out in different rooms is the use of identical test material. To this end the compact disc produced by the EBU was used extensively throughout the Granada project for sound quality assessment. Many attempts have been made to identify and control the factors contributing to personal opinions expressed in listening tests. Scientifically controlled tests on loudspeakers are lengthy, costly and complicated. For example, the IEC report entitled 'Guide for Listening Tests on Loudspeakers' is a 35-page document. More recently published work has taken years to complete [4].

As a matter of interest, this work concluded that loudspeakers with obvious flaws in monophonic listening received substantially higher sound quality ratings on stereophonic presentations. This would seem to indicate that there is still a missing link between the measurements and their subjective relationships.

3. CURRENT RESEARCH

It is useful to consider the outcome of the latest research into fields which would appear to have a bearing on the problems of designing small control rooms.

3.1 The Ear

Whilst it is not possible to go into detail it is interesting to note that the inner ear cell is considered to have one hundred or so hairs which are arranged like organ pipes. Researchers claim to have stimulated individual hairs and measured their electrical response. This equates to knowledge at the molecular level and responses to movements of one thousandth of a millionth of a metre [5]. Current acoustical measurement techniques on which the room measurements are based do not have that apparent degree of resolution.

3.2 The Dummy Head

In 1984 Prof. Schroeder used the Dummy Head to study the acoustic quality of 20 Halls with RT times of less than two seconds [6]. This work showed that listeners preferred Halls with a significant amount of lateral reflected energy.

Researchers are becoming more interested in reflections and reverberation time is just one of several parameters. The work of Wrighton and Berger in 1986 [7] which established that the addition of high amplitude contralateral or rear reflections to the direct sound results in a less accurate perception of the image. Depending on the type of signal, there could be an increase in width of as much as four times as shown in Fig. 1.

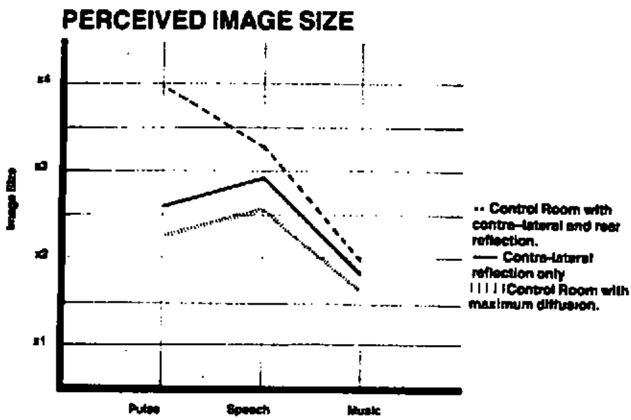

Fig. 1

So far current work shows that room reflections are of great importance and that it is necessary to control them in order to obtain a neutral listening environment.

4. IDENTIFYING THE MAIN PROBLEMS

It was decided there were two main areas of subjective analysis that would have to be controlled to obtain the desired neutral monitoring result namely:

1) Stereo imaging quality
2) Sound quality colouration

Having established that, in the signal path, the room acoustics, loudspeaker system and ears dominate the above and assuming 'Perfect' ears, it is important to relate the objective parameters that influence these factors.

These parameters are summarised in the following table:

SUBJECTIVE EFFECT	ROOM MEASUREMENT	LOUDSPEAKER SYSTEM MEASUREMENT
STEREO IMAGING QUALITY	LEVEL OF EARLY REFLECTIONS	BALANCE AMPLITUDE/ FREQUENCY/PHASE TIME DELAY & DISPERSION
SOUND QUALITY COLOURATION	LEVEL OF REFLECTIONS SOUND DECAY TIME	BALANCE AMPLITUDE/ FREQUENCY/ PHASE TIME DELAY & DISPERSION

The control of the above parameters forms the basis of the design goal when designing small control rooms for television. This is summarised as follows:

a) For stereophonic monitoring the elimination of early reflections and control of the symmetry of late arrivals is essential.

b) The loudspeaker system design and positioning must give a uniform balanced sound field at the controller's position.

c) The reverberation time must be controlled to enable source material to remain unaffected yet provide a neutral and comfortable listening environment.

d) Correct correlation between room measurements and actual aural performance must be established.

Before proceeding further, it is useful to consider the previous work which considered the audibility of reflections in a recording environment.

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5. THE AUDIBILITY OF EARLY REFLECTIONS

As stated before, there is a twofold effect to consider since early reflections, which add to the direct sound, influence both quality and image placement.

5.1 Sound Quality Colouration

An energy time curve, as shown below, shows a density and amplitude that is reasonably uniform with no strong reflections.

Fig. 2

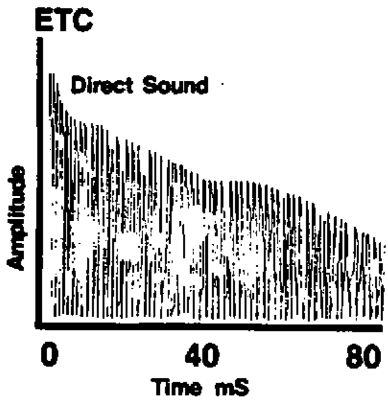
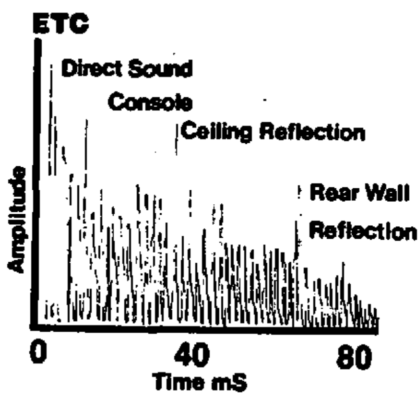


Fig. 3 shows the sound field generated at a control room listening position with a high level of discrete reflections.

Fig. 3



Olive and Toole [1] drew a comparison of their work on absolute thresholds of audibility of reflections with that of other investigators, this is shown below:

Fig. 4

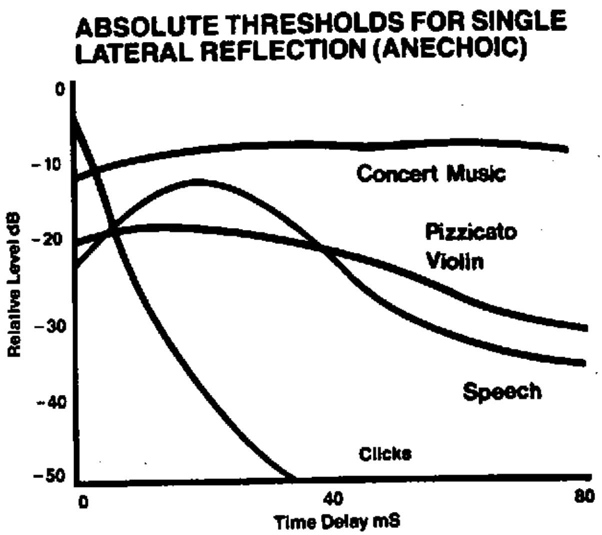


Fig. 4 shows that in an anechoic environment, thresholds vary considerably with the type of sound source. Most sensitive to early reflections are the short term transient type sounds. This raises the question of reflections which modify or cancel the leading edge of instrumental sounds.

Strawn [8] showed that a change of pitch from one note to another takes place in only a few periods of the waveform and during the transition from one note to another the pitch change perception is usually associated with the actual time of the second note.

5.2 Change of Imaging

Work by Wrighton [7] has shown that strong lateral reflections have a significant effect on perceived image width. This was indicated earlier in Fig. 1 and shows how the effect of lateral reflections increases the image width especially for pulse and speech source material. Again the importance of short term transient sound reproduction is indicated.

Toole [1] carried out further experiments whereby the listeners were required to identify the now familiar absolute threshold (where any change is registered) as well as an image width threshold. With speech signals, the image spreading was detected at time delays of less than 10 mSec, the direct sound source being pulled towards the lateral reflection. From 10 ms to 40 mSec an increasing sense of spaciousness was observed and for longer delays the reflection became identifiable as an echo.

The conclusion was that listeners were inclined to respond to the directional spatial effects rather than changes in sound quality or colouration.

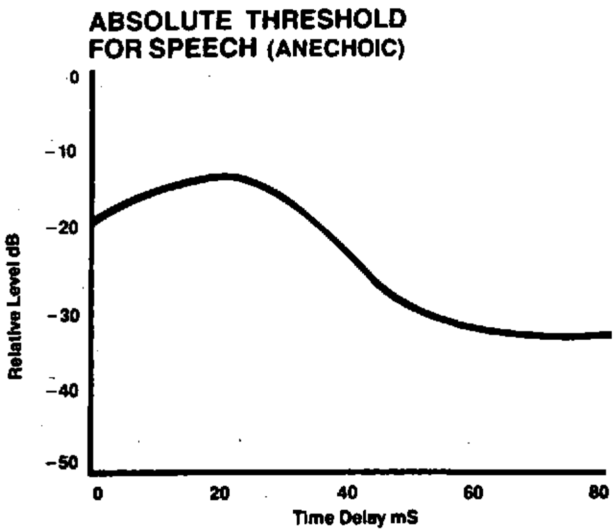
This appears to suggest there are two thresholds for reflections, one for quality and one for imaging.

It is important to note that Toole's work was originally carried out under anechoic conditions (Room A) and in two listening rooms, one with an RT time of 0.4 seconds (Room B) and the other with a reduced RT time (Room C) produced by using sound absorbent material which reduced the early reflections from adjacent boundaries. The ETC's for the three conditions are shown in Figs. 6-8.

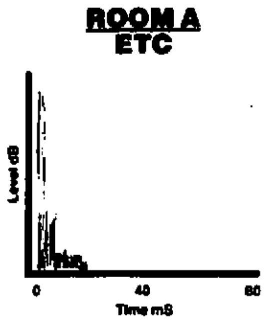
Emphasising the importance of attack time, Professor Taylor of the Institution of Sound and Vibration Research at the University of Southampton demonstrated that when leading edges are removed from violins and oboes, the sounds produced are almost indistinguishable from each other.

It would appear, therefore, that there is general agreement on the thresholds for single lateral reflections (anechoic) using various signals and that for speech, an important source for television, the threshold is approximately -15 dB for reflections from 0 - 20 ms as shown below:-

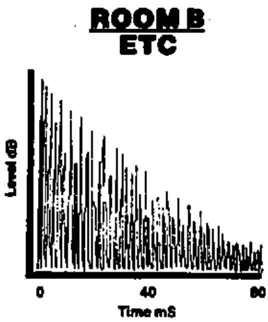
Fig. 5



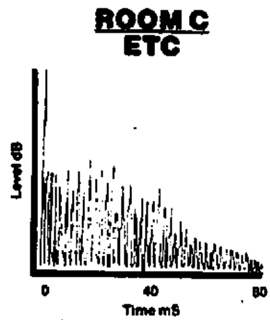
Of course, real listening rooms are not anechoic neither is there likely to be only one significant reflection. Hence Toole further examined the audibility of a 'Target' reflection in the presence of increasing amounts of room reflections.



A
Fig. 6



B
Fig. 7

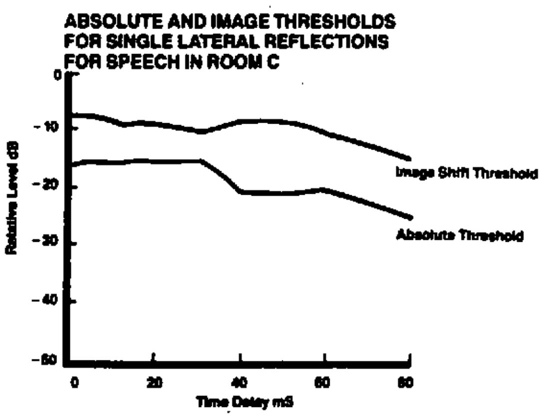


C
Fig. 8

Fig. 6 - ROOM A Represents the anechoic room.
Fig. 7 - ROOM B Shows the complex array of reflections typical of an unprepared domestic living room.
Fig. 8 - ROOM C Shows a cleaner display with all reflections at least 15 dB below the direct sound and a relatively smooth and dense reverberant tail.

Fig. 9 - below shows the relationship between absolute and image thresholds for Room C, where strong early room reflections have been eliminated.

Fig. 9



It is important to note that, in general, the imaging threshold is some 8-10dB above the absolute threshold.

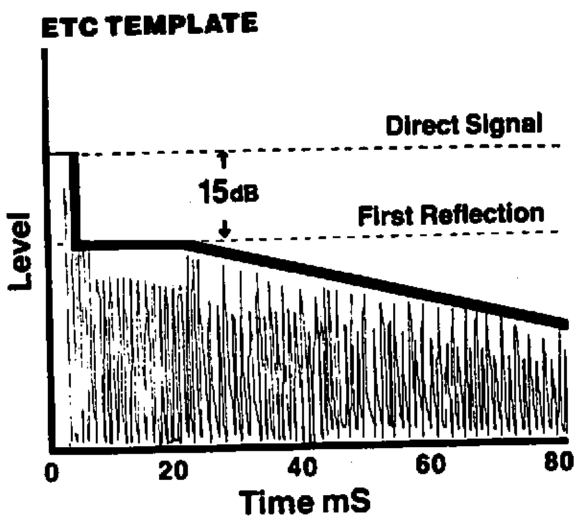
An important discovery was that up to a time delay of 30 mSec, the thresholds changed relatively little between the Anechoic and Reflection Free Zone Room C and went up by no more than 6 dB in the moderately reverberant Room B with an RT of 0.4 seconds.

One may conclude that for speech, the audibility of a specific lateral reflection at threshold is the same in most types of room.

It is now possible to propose a design target template for the ETC of a suitable stereo control room for television.

Up to a time of about 20 ms after the direct sound, reflections should be below 15dB relative to it. Reflections arriving after this time should be diffused and only contribute to the general room ambience and RT measurement. The period up to 20 ms appears to be related to the so-called Haas or precedence effect.

Fig. 10



As stated before, in order to quantify the parameters to be measured in a control room, it is necessary to use techniques which will correlate with the subjective effects and can be reliably repeated within the limitations set by the measuring technique.

6. MEASUREMENT TECHNOLOGY

Two approaches were used in the design and measurement of the control rooms:

1) Time Delay Spectrometry (TDS)
2) Maximum Length Sequence System Analyser (MLSSA)

These techniques will be described in more detail in the accompanying paper by A Munro. Briefly, TDS utilises a frequency sweep and tracking filter which enables analysis of the direct sound in the presence of reflections. FFT analysis is used to transform from the frequency to the time domain to generate Energy Time Curves (ETC's) and impluse responses. Waterfall curves of frequency response against time are also available.

MLS methods use a pseudo random number source which correlates to the ideal impulse response. Again FFT processing allows transformation between time and frequency domains. Reflections are gated in time from the total response to enable analysis of the direct sound.

A comparison of the two systems [9] concludes that the resolution of MLS is superior to that of TDS. However, both approaches were used on the project. Care must be taken in recognising the limitations of these techniques when attempting to measure low frequency signals in small control rooms.

7. DESIGN APPROACH

It was initially decided to collect TDS data from a purpose built Audio Dubbing Suite and a Studio Sound Control Room which had been refurbished to previously accepted acoustic standards, both rooms using the Rogers LS5/8 free-standing loudspeakers.

The conclusions drawn were that the Audio Dubbing suite was a workable monophonic monitoring environment, but had short comings in low frequency reverberation and left to right balance. The number of early reflections made imaging difficult.

The Studio Sound Control Room produced poor results and was used to test the correlation between measurement and subjective results.

7.1

Layout of New Control Room

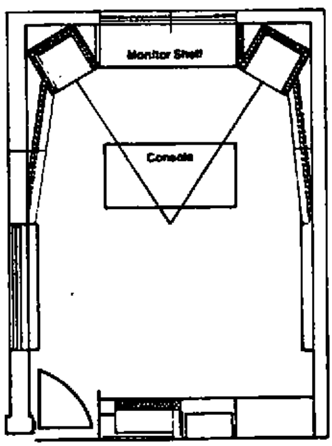


Fig. 11

Having decided to use the Rogers LS5/8 in the new control room they were flush mounted in the knowledge that this may not be the optimum arrangement. However, it was thought necessary at the time to use the same speakers in an effort to match the sound sources for comparison and evaluation.

Briefly the acoustic design approach was to achieve a reflection free zone (RFZ) around the console and to use rear end diffusers to produce reflected energy which contributes only to the effective RT time of the room.

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The following results show the problems that were encountered and the step-by-step approach used to achieve the end result. The description applies to the newly designed control room in Studio 8.

8. PHASE 1 NEW DESIGN USING ROGERS LS5/8

The results of TDS measurements indicated the following:

8.1 Loudspeakers

1. A low frequency boundary problem was found that called for equalisation.

2. A dip in response at 161 Hz caused by a reflection from the ceiling.

3. A dip in the response around the cross-over frequency and an HF peak on one of the loudspeakers.

The final transfer characteristics in the critical band 0-500 Hz looked acceptable after appropriate electrical equalisation and small adjustment of the vertical position of the loudspeakers.

Fig. 12

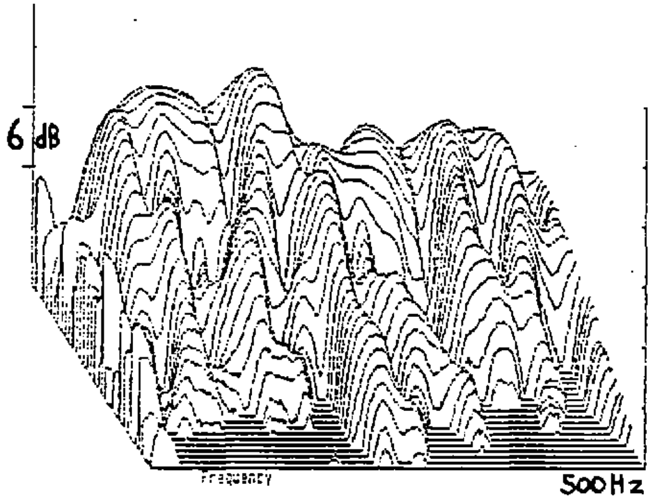

Fig. 12 The TEF Waterfall Curve indicates that the 161Hz dip has moved to 250 Hz and shows the 'filling in' of the low frequency energy 0-250 Hz.

Fig. 13

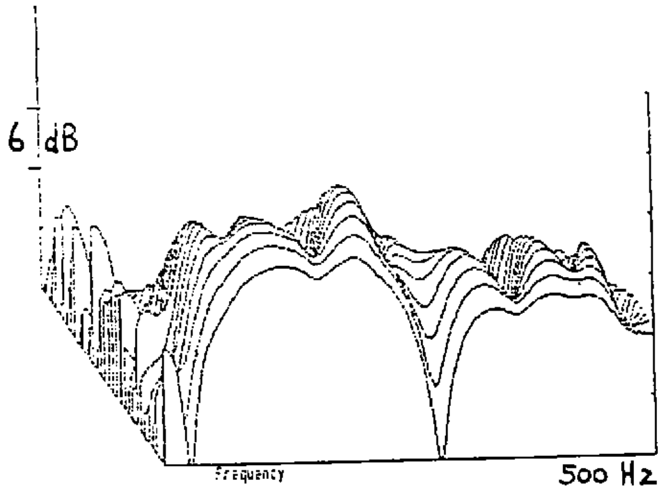

Fig. 13 is a time reversal of Fig. 12 and clearly displays the dip at 250 Hz.

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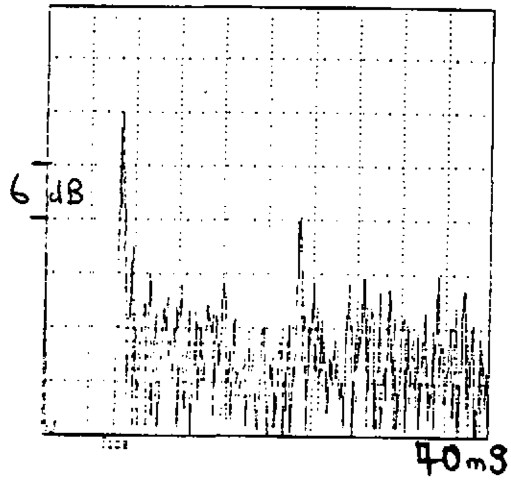
Fig. 14



The ETC of Fig. 14 shows a 12 dB headroom between the direct sound and the first reflection with a mass of specular reflections creating an even decay of the sound field. The RT time was around 0.2 seconds.

It was decided to hand over the room for listening tests on the basis that the results were considered to be reasonable.

8.2 Listening Tests

Although the RT time was measured at 0.2 seconds and 95% of programme content was speech, sound engineers were unanimous in declaring the room too lively (Reverberant). This immediately indicated that the measured RT time may not be showing the source of liveliness.

There was a disturbing change of quality as one moved throughout the normal listening area, especially when moving the head forwards and backwards. Variations in high frequencies were particularly noticeable on speech provided by the EBU compact disc.

Although the stereo imaging was agreed to be excellent, the quality of the loudspeakers was judged to be poor and was said to compare unfavourably with some engineers' home Hi-Fi systems.

It was clear that measurements had not shown up the poor subjective results and that the ear was clearly winning

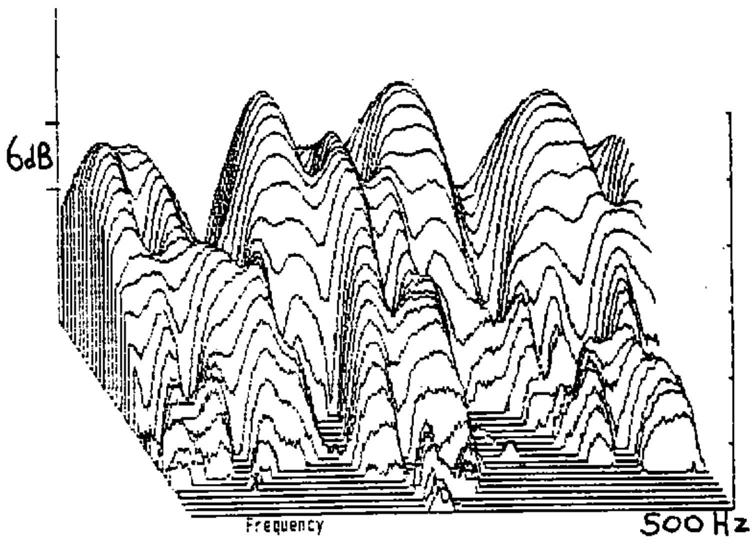
9. PHASE 2 REPLACEMENT LOUDSPEAKERS

It was decided to install another design of commercial loudspeaker and to repeat the measurements.

Initially, the question of phasiness and liveliness were addressed. ETCs were made with and without vision monitors which may have caused reflections in the operating area. Also the glass window between the control room and studio in front of the control position was covered by sound absorbing material.

It was interesting to note that the liveliness was clearly apparent when speaking normally in the control room and that this was definitely reduced by the foam on the window. The new ETC curves showed no perceptible change in reflections at the listening position.

Fig. 15



Although the EFC measurements at higher frequencies looked good there was considerable lumpiness in the Waterfall display between 50 Hz and 500 Hz as shown in Fig. 15.

Again the direct sound measured at the listening position showed no significant difference between the Rogers LS5/8 and the commercial loudspeaker.

At this stage an impulse response of the two systems was made which showed significant differences.

The Reflection Free Zone (RFZ) had not changed, however, there was a new spectral reflection at 25 ms which was not present with the Rogers LS5/8.

9.1 Listening Tests

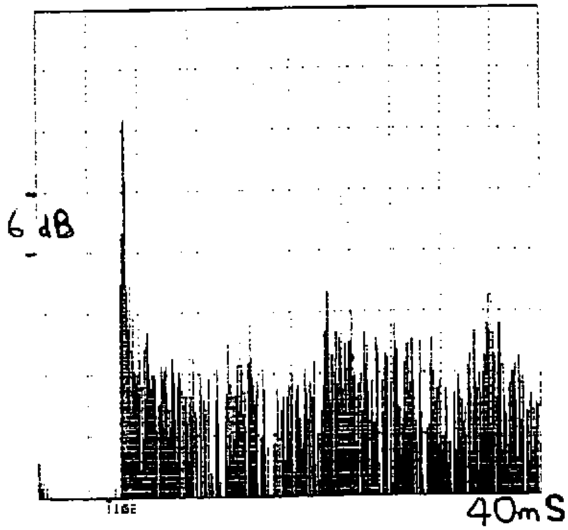
These only took five minutes and although the room was still considered to be too lively, the quality of the loudspeaker was ruled to be unacceptable. Words like megaphone were perhaps the kindest comments from the sound engineers. Again subjective assessment completely overruled the measured results.

10. PHASE 3 LOUDSPEAKER DESIGN BY A MUNRO

In view of the complete dominance of the loudspeaker quality over the situation, it was decided to use a system recommended by A Munro.

In addition, as well as acoustic absorbent over the window, additional small amounts of absorbent were applied to critical points on the rear wall directly in line with the direct sound from the loudspeakers. This again surprisingly did not affect the RT measurement and an excellent ETC response was achieved (see Fig. 16). The frequency response and balance between the new loudspeakers were considered to be good.

Fig. 16



10.1 Listening Tests

The acoustic characteristics of the room were agreed to be good with no sign of liveliness. In addition, the new speakers provided a much more uniform sound field over the controller's operating position. Stereo imaging is excellent with high spatial resolution. Although several engineers have been involved in listening tests, the quality of sound from the speakers has not been considered to be totally acceptable. It was realised that we were now entering a field of extreme subjective judgement. Nevertheless we believe the room acoustics are entirely acceptable.

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It was felt that the instrumentation was not able to show up the obvious differences in the loudspeaker systems and it was decided to use MLS impulse and step response techniques to investigate the loudspeaker further. One theory was that the transient response of the speakers was giving the difference coupled with hitherto unexamined phase and group delay characteristics.

11. LOUDSPEAKER RESPONSE

Three loudspeaker systems had been evaluated and, although they all produced anechoic and room frequency response curves that were basically similar, there was general agreement that they all sounded different and one was completely unacceptable.

Work at Southampton University [10] aimed at understanding mid-range horns concluded that frequency response was definitely not the main parameter determining the perceived sonic characteristics. Fincham [11] however, concluded that frequency response variations of as little as 1dB were capable of being heard and frequency response provided the most important clue to the likely subjective performance.

During the work on phase 3 of the project, impulse response measurements were taken on the Rogers LS5/8 and the new speaker system. Although the impulse response contains valuable information, it is not naturally easy to interpret as is the frequency response. Whilst the steady state phase performance had been considered in previous works, the question of phase distortion was raised.

11.1 Phase Response

In 1969 Richard Heyser [12] studied the effects of phase distortion. In a Minimum Phase Response System, if the amplitude response is flat then the phase shift will be zero. Heyser concluded that if a loudspeaker falls into the minimum phase category, the amplitude response may be improved without regard to the phase response. However, if this is not so, the same procedure could have destructive results on the transient response.

Lipshitz, Pocock and Vanderkooy [13] studied the audibility of Midrange Phase Distortion in Audio Systems and concluded the phase distortion was audible on transients and that as listening rooms became more anechoic these effects would be more noticeable. For linear systems the group delay will be constant with freqency and it is this aspect which controls the ability of the system to reproduce transients. It was, therefore, decided to study the transient response of the loudspeaker system using a step function. The resulting waveforms are more easy to interpret than the impulse response and led to some interesting discoveries about the characteristics of the loudspeaker system.

11.2 Step Function Testing of the Loudspeaker System

Using the MLS system to drive the speakers and measuring the response in the control room, it was clear that the leading edge of the step was suffering group delay and possibly phase distortion. Tests were carried out on each driver element separately and it became clear that the base driver output was delayed about 1 mSec on the mid and high drives.

Listening tests on the system when driven by the step function produced two clearly audible responses. Namely the H.F. and mid-range click followed by the base response.

Further analysis of the amplifier system showed clearly that it was producing the delay effect that had been detected in the room by the MLS system.

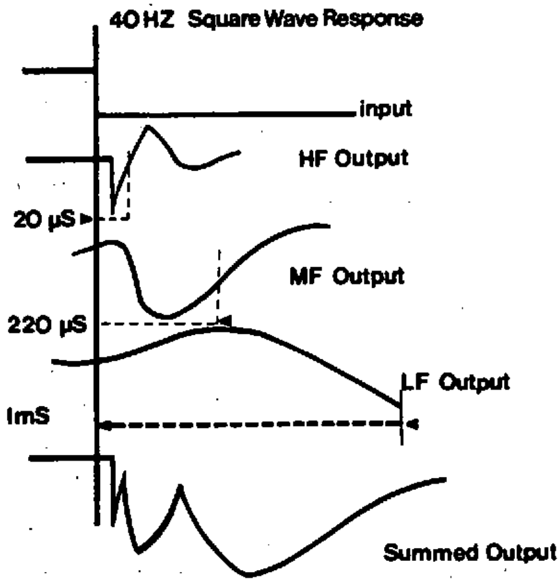
40 HZ Square Wave Response
input
HF Output
20 µS
MF Output
220 µS
LF Output
lmS
Summed Output

Fig. 17

12. CONCLUSIONS

A more detailed explanation of TDS and MLSSA measurement systems together with indepth analysis of the measured results of Studio 8 control room are reported in the second part this paper by Andy Munro entitled 'The Comparative Acoustic Measurements of a Television Studio Sound Control Room using Time Delay Spectrometry and Maximum Length Sequence System Analysis'.

This project has shown that by careful control of acoustic absorbers the region around the console can be made free of early reflections which resulted in an excellent stereo image performance. Rear and side wall diffusions produced an acceptable listening environment with an RT time of about 0.2 sec essentially flat over the useful frequency range. Measured results correlated well with these results.

The ETC showed an RFZ of about 17 mS which was very close to the target template of 20 mS.

However, the quality of sound under the above conditions was now entirely dominated by the loudspeaker system performance and the subjective impressions of sound engineers. Whilst measured frequency responses appeared acceptable the transient response was definitely not with clear time delays between the three outputs. Apart from this being audible on step waveforms it is yet to be proven whether these time delays are affecting the subjective acceptance of source material such as speech and transient sounds. Further tests will be carried out after time equalisation of the three drivers and it is expected that this will result in detectable improvements but will it produce the ideal sound?

A television control room for stereo sound must faithfully reproduce what is taking place on the studio floor especially where speech is concerned. With music personal preferences are likely to dominate and so the pursuit of the ideal sound still continues with that intriguing instrument, the ear, still apparently having the last word.

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