THE COVENTRY RECIPROCATING ROOM ALIGNMENT DELAY

A Microphone & Loudspeaker Alignment Solution arising from the new Speech Reinforcement System for Coventry Cathedral.

K Dibble, Project Consultant, Ken Dibble Acoustics, Rugby.

1. INTRODUCTION

This paper will present an account of the 30 year search to provide Coventry Cathedral with an effective speech reinforcement system. The problem of interfacing an aesthetically acceptable loudspeaker system with the hostile acoustic environment of the building interior is discussed and the solution described. A new alignment technique appropriate to a distributed loudspeaker and multi-microphone installation in large acoustic space, arising from the Coventry project, is presented and the conclusion drawn that but for lack of technology it would probably have worked first time around, 30 years ago.

2. BACKGROUND

Coventry's Cathedral was destroyed by the Luftwaffe during the night of 1940 November 14. Sir Basil Spence's revolutionary design for a new cathedral was selected from an international competition in 1949. The new building was constructed during the 1950s and was consecrated in the presence of Her Majesty Queen Elizabeth II on 1962 May 25. The Cathedral Church of St. Michael has been widely acclaimed as a celebration of 20th century British architecture and artistic achievement, attracting visitors from all over the world.

Not least amongst Coventry's attractions is the magnificent 4 manual 73 stop organ by Harrison's of Durham, whose pipe ranks rise in tiers to the roof on both sides of the nave. Whilst the latter can be heard resounding and reverberating throughout the building with marvellous power and sonority, the same cannot be said of speech, which, unless armed with pre-knowledge of the text or a gift for lip reading, has been virtually inaudible in this building since its consecration.

3. THE BUILDING

The general layout can be seen from Fig 14. The interior comprises one vast open-plan space encompassing the Nave,

THE COVENTRY RECIPROCATING ROOM ALIGNMENT DELAY

Baptistry, Chancel, Sanctuary, Lady Chapel and the Hallowing Places as one and measuring some 94m end to end, an average of 28m across with an acoustically transparent slatted timber canopy ceiling at 21m and a structural roof soffit at approximately 24m above the Nave floor. The internal volume calculates out at 63,000 cu.m.. The floor is marble, the walls vermiculite coated stone faced concrete and the roof is of concrete slab carried on massive steel reinforced cast concrete joists. The "west" end is almost entirely of glass flanked by stone, whilst the Baptistry Window, along with the acute return angles to the ten Hallowing Places to the side aisles are leaded stained glass in masonry casements rising the entire floor to ceiling height of the building.

4. ACOUSTICS

There are two concessions in this otherwise unforgiving acoustic environment: One is the Sutherland Tapestry which covers the entire "east" end of the building behind the Lady Chapel, the other a scheme of acoustic treatment applied to the roof soffit and which, surprisingly, was found to have been carried out in exact conformity with the original Basil Spence drawing detail found in the Cathedral's archives. This comprises panels of 25mm cork over a 25mm air space, alternated with panels of chipboard. Given the absorption coefficient of such materials the relatively small surface area treated and the considerable distance from the Nave floor, this treatment does not make a great contribution to the overall quality of the acoustic environment.

Using an Ivie IE-30A RTA with the IE-17A processor and an HP/Urei System 200 plotter, the RT60 was measured at 4.5 seconds at 1KHz and 6.1 seconds at 500Hz. Due to lack of available headroom from the existing speech reinforcement system it was not possible to measure the low frequency RT, although a simple hand clap and a pair of ears suggested a figure in the region of 7 or 8 seconds! Figure #1 shows the R[illegible]0 curves with a 250Hz measurement running into noise after about 35dB of decay. Figure #2 shows a 1/3rd octave analysis of the typical daytime background noise within the building, measured at 43dB(A).

Arrival time measurements, again using the IE-30A/IE-17A set-up, showed 1st reflections arriving at approximately 15mS, multiple merged reflections at significant amplitude - ie only a few dB below the stimulus - up to 50mS with late arrivals after 150mS still only 6/8dB below the stimulus and perceived as echoes.

THE COVENTRY RECIPROCATING ROOM ALIGNMENT DELAY

A series of listening tests were also carried out, comparing the unaided voice with the existing system, and with low-Q near field alternatives. Speaking from the pulpit it was found that the unaided voice is virtually unintelligible in the Nave after the first six or seven rows of seating and totally inaudible in the Chancel. The existing system produced only a marginal increase in level with marginally better articulation but with a thin and distant, almost ethereal, quality. Experiments with low-Q near field alternatives provided much better performance altogether and it was ascertained that provided a 250Hz high-pass filter and appropriate system EQ was used, a throw of up to 15m could be obtained with surprisingly good intelligibility, even in an empty building. Anything below 250Hz was masked by reverberation.

Also there is a problem in the Chancel as there is nothing to provide those natural early reflections so essential to give a sense of ensemble and fullness of tone amongst the Cathedral choir or to reinforce solo recital or spoken text.

5. THE EARLY ATTEMPTS

An archived electrical installation drawing circa 1955 shows conduit provision for some 20 loudspeaker positions distributed around the perimeter of the building, although what type of system was envisaged is not stated and enquiries have led to none able to recall the original intentions. This system however never materialised and in the event the contract went to Pamphonic Reproducers - a leading UK manufacturer of the day and whose Managing Director - Paul Taylor is the acknowledged father of the line source array in the UK and whose 1964 paper <1>, in which the Coventry Cathedral line arrays are illustrated and described in some detail, remains to this day a principal reference work on this subject. It seems that the original installation comprised a 3.3m line array above the Pulpit and Great Lectern facing forward down the Nave, two 2.6m line arrays in the same positions but directed rearwards into the Chancel and Sanctuary and two further 2.6m columns on wheeled dollies part way down the Nave.

These very large line arrays were apparently a 2-way design comprising 17 x 165mm midrange drive units covering 250Hz/1KHz and 9 x 75mm HF drivers covering 1KHz to 4 KHz, both using Taylor's Truncated Binomial Power Tapering technique (Pamphonic patent) <1> as a means of extinguishing unwanted side lobes whilst maintaining axial beam geometry, and employing appropriate passive crossover and band stop filtering between the two arrays.

The entire assembly was encased in a cylindrical tube of natural hardwood and brass to complement the aesthetics of the building.

The system employed a complex arrangement of cue lights and microphone switching so that when any particular microphone was "live" any loudspeaker in the vicinity was automatically muted. It also employed a multi-channel electro-magnetic time delay system using a revolving magnetic drum with multiple heads on an adjustable bed. This it seems, was a complex and sophisticated device providing different delays according to the particular microphone and loudspeaker combination in use. Despite its advanced conceptual design however, no technical paper can be traced, leaving us today with only a sketchy picture of the actual system composition.

Unfortunately, (according to Brittain <2><3>) the system never worked satisfactorily; the delay unit would not last the duration of one service without mechanical failure, delay times were unpredictable, the mechanism was excessively noisy, the switching unreliable and the system generally plagued by howlround.

Within six months of the consecration Hugh Brittain, head of Acoustics at the GEC-Hirst Research Laboratories at Wembley, was called in to assess the problem <2><3>. Much of the Pamphonic system, including the delay and switching systems, was condemned and the entire system replaced with a conventional mixer/ amplifier combination feeding the loudspeaker cluster shown in Fig. #3. This comprised smaller line source arrays in a cruciform configuration and a single Vitavox multicell horn - high up in the roof above the Chancel Steps <4>.

Hugh carried out a series of acoustical measurements and arrived at the theory that by beaming sound from a critical height above the Chancel Steps, the sound waves would hit the Nave floor, be reflected back towards the West Window and thence up into the roof void where it would be absorbed by the acoustic treatment to the roof soffit as shown in Fig #4. Although founded on what would today be considered simplistic acoustic principles and providing poor intelligibility at best, as a system it has proved reliable, with the original Vortexion tube amplifiers and mixers remaining in service for some 28 years until the system was replaced in 1990.

In 1984 Bill Stevens of AIRO carried out a study of the Brittain system. The resulting report concentrates heavily on the poor condition of the cabling, earthing problems and the obsolescence of the mixing and amplification equipment, with little or no

THE COVENTRY RECIPROCATING ROOM ALIGNMENT DELAY

reference to the uncompromising acoustics of the building interior. In the one small paragraph making any reference to the loudspeaker system, this was found to be "...almost beyond reproach...providing excellent coverage over most of the seating areas in the Nave..." and suggesting that "...a.simple acoustic check to confirm the exact positioning of the individual loudspeaker assemblies." was all that was required <5>. This is clearly an altogether different scenario to that found by the author 5 years later.

In 1986 Artec Consultants of New York City studied the problem <6>, recommending that in the short term close miking techniques be adopted, that a mixer with individual tone controls be used and that the low frequency response of the existing loudspeaker system be extended, with a view to increasing the amount of absorption in the building at a later date. Given that - as has been shown - the problem is not one of insufficient gain but of excessive reverberation, with the 125Hz RT60 figure running out to 8 seconds, these recommendations hardly seemed to provide an appropriate solution and were therefore not taken up.

6. CAD TO THE RESCUE

There has probably been more progress in electro-acoustics in the period since 1962 than in the whole of Hugh Brittain's long and distinguished career and many conclusions reached and assumptions made then may no longer be valid in 1990. So how were we to convince the Cathedral that things had changed and that maybe a cruciform cluster of line arrays and a single small horn some 20m up in the air might not be the answer?!

With an intuitive feel for a likely solution already in mind, Bose Modeler was used to model the building on screen, look at some room acoustic predictions and try some possible loudspeaker configurations. Modeler was chosen partly because it was just about the only open menu software then available in the UK and partly because of its comparatively advanced room acoustics algorithms.

Fig #5 shows the room model and Fig #6 the RT60 predictions - which were felt to be sufficiently close to the measured data to enable the model to be useful as a predictive tool in this situation. Fig #7 shows the predicted direct sound coverage from a replacement central array at the Brittain cluster location, using just two Community M4 co-axial horns.

Fig #8 shows the D+R prediction for a distributed system around the perimeter walls which is not dissimilar to that shown on the archive electrical layout plan. If the central cluster were to be dispensed with this would be the option preferred by the Cathedral authorities on aesthetic grounds. Loudspeakers C & D, and K & L straddle the line of the Pulpit and Great Lectern, with A, B, C, L, M & H directed down the Nave towards the "West End", D, E, J and K covering the Chancel, F and I the Sanctuary and G and H the Lady Chapel behind the High Altar. Appropriate time alignment was input into the model between each pair. Comparing Fig #8 with the direct field plot shown in Fig #9 shows that much of the central Nave coverage is due to the reverberant field, with most of the loudspeaker output energising the wide marble floored side aisles where no useful purpose is served and unwanted reverberant energy is the result. Fig #10 shows a set of three time response predictions.

Fig #11 shows the direct plus reverberant prediction in respect of a distributed system with the loudspeakers mounted directly to the structural columns at approximately 3m above the Nave floor. Note that in this instance the principle areas of coverage are just where they are wanted - ie the seated sections of the Nave, Chancel and Sanctuary which will provide near field absorption whilst the side aisles and main entrance areas, with their highly reflective floors and walls, remain relatively "dark". A further bonus is the band of relative shadow in the vicinity of the Pulpit, Great Lectern, Provost and Precentor's Stalls and Chancel Steps reading lectern - this being the area from where most of the services are conducted and where most microphone positions will be required. Fig #12 shows the loudspeaker aiming plan for this arrangement and shows three sample "listening" locations. Fig #13 shows a pingraph arrival and intelligibility prediction for each location.

7. SITE TRIALS

The computer predictions having gone some way towards convincing the authorities that there may be some substance in the arguments being put forward it was agreed that a trial system would be installed for the 1989 Christmas season. So with the co-operation of a number of manufacturers a temporary installation was duly provided and tests carried out to assess the three options, each with appropriate alignment delays, a 250Hz high-pass filter and equalised for a flat spectrum response between 250Hz and 8KHz. The computer predictions were immediately validated, with all concerned in agreement that the column mounted distributed system provided noticeably the best performance in terms of uniformity of coverage, subjective intelligibility and source imaging. So this system was left in situ for the annual carol broadcast, for Midnight Mass on Christmas Eve and for Christmas Day services.

8. SYSTEM ARCHITECTURE

Having satisfied the client that the proposed system would indeed be capable of providing the quality of speech reinforcement they had long hoped for the next stage was to finalise the engineering of the system and prepare budgets. Although the outcome was by no means conventional, and considerable engineering effort was necessary to bring the system through to completion, it is not the object of this paper to become embroiled in the whys and wherefores of hardware selection or the nuts and bolts of the installation itself. That aspect is adequately covered in an American magazine article <7>. Suffice it to say that because of an overriding requirement that the system should be capable of being operated by non technical persons and should preferably not require an operator at all for a simple evensong or prayer meeting, some 28 channels of automatic microphone mixing with automatic level sensing were provided, along with twelve separately equalised and individually selectable loudspeaker zones and a host of other facilities to meet the users requirements. It turned out however that having resolved the loudspeaker problem the critical element was the time alignment requirement, and it is this which is the main thrust of this paper.

9. TIME ALIGNMENT

In order to conceive what is happening within so large a space it is necessary to view the building as if it were dimensioned in "sound seconds", in which case the floor plan is 273mS long x 80mS wide and the building is 70mS high to the soffit slab. Fig #14 shows a plan of the Cathedral with all the loudspeakers and microphones in place and showing the alignment delay requirements at each location. Because most of the action takes place at the Pulpit, Great Lectern, Provosts or Precentor's Stalls or at a reading lectern at the top of the Chancel Steps, this line has been adopted as a "zero time datum" with delays running forwards down the Nave and backwards into the Lady Chapel.

The problem however is what to do about the other microphone points? Imagine speaking into the Baptistry or Chapel of Unity

THE COVENTRY RECIPROCATING ROOM ALIGNMENT DELAY

Steps microphones against a time delay of 120mS, or at the West Door against 155mS! What about the Bishop at the High Altar battling with a 70mS delay? The delivery will become slower and slower with each syllable uttered until it degenerates into a sea of verbal soup with the entire building acting like a giant echo chamber. The problem is compounded by the fact that for the annual Christmas Carol broadcast and for the Graduation Ceremonies of the University of Warwick and Coventry Polytechnic the Cathedral is turned around so that the congregation face the West End and all activity is centered on temporary staging against the glass screen. Imagine the acoustic mayhem!

What is needed is a feed-forward speech accelerator to enable an address being given at the Baptistry to reach the zero time datum loudspeaker group 120mS before it is uttered. That would solve the problem nicely! But even with today's electronics it is no more likely to be achieved than Dr Brown's DeLorean will reach 1955! <8>.

The answer is the Coventry Reciprocating Room Alignment Delay. It is a complex and expensive solution, but it works. In order to preserve signal quality it is necessary to employ at least a 14 bit digital delay with good noise performance and at least a 12KHz pass band. For each stage a separate 1-in x 1-out delay card is required, with its own A-to-D and D-to-A converter. These are cascaded to form a multi-tapped delay chain extending the entire length of the loudspeaker floor plan, in this case starting with an input at the Lady Chapel and finishing at the Nave 4 loudspeaker location, each loudspeaker feed being tapped off at the appropriate point. Next a second line is formed running the other way - ie starting at the West Door microphone point and running down to the Lady Chapel loudspeakers, this time with each microphone sub-mix fed in at the appropriate point.

Finally a somewhat complex system of buffering is used to cross connect the corresponding stage of each line so that signal can be fed into, and taken out of, either line at any point and the ends of the two lines are looped around in such a way that phase response and gain structure is preserved throughout the chain and such that the system cannot self oscillate. So in effect we are looking at a bi-directional multi-tapped delay line with inputs and outputs at each tapping. Fig #15 shows the basic schematic, although in practice, the buffering is somewhat more involved than is shown here.

There are however one or two considerations which need to be borne in mind. One is that there is no point in the system from which a time coherent summed signal can be derived for recording or for feeding an inductive loop etc. It is therefore necessary to provide a pre-set summing mix to overcome this problem. Another is that each pair of delays must be set to the same delay setting or phase cancellations of varying severity according to the amount of displacement will occur at each output. Therefore some compromises in the ideal microphone alignment are sometimes necessary. In the case of Coventry, the time displacement to the Baptistry microphone for example should be 120mS, but in practice this sub-mix group must enter the delay chain at the Nave 4 delay point - ie 90mS.

The system at Coventry also has provision for a bank of six cross -fired rifle mics to be used to reinforce the choir. These are fed via a separate 6/1 pre-set mix into the zero time datum point using a manually operated fader controlling VCAs so that as the choir mix is opened so the chancel loudspeaker system is ducked. There is a similar provision for music replay.

10. COMMERCIAL REALISATION

At the time of writing there is no commercial realisation of the reciprocating delay device. The system for Coventry Cathedral was realised using IRP System 41 modular processing rack using type DJ4132-1 delay cards with custom buffering built into DJ4125 custom circuit modules. At least one other means of realising the system was identified during the design process. The concept is a registered design and is copyrighted 1989 by the author.

All the automatic mixing, level sensing, auxiliary system mixing, VCA control and interfacing functions were also achieved using System 41, which proved to be a cost effective, compact and very convenient way of assembling what would otherwise have been a far more complex and cumbersome installation. The complete system schematic is shown in Fig #16.

11. THE BONUS

Coventry Cathedral has a wide central aisle used extensively as a processional route using omnidirectional lapel radio microphones to relay the proceedings. Fig 17A shows the spectral response of the commissioned system - which was found to be fairly uniform throughout the Nave - taken from an end of row seat adjacent to the central aisle between the Nave 2 and Nave 3 loudspeaker location. Fig 17B shows the spectral response taken at the centre of the main aisle itself - a distance of no more than 1.5m from the first. Note the huge phase cancellation effects between the pair of loudspeakers, occurring just in the right place to allow the procession unrestricted used of the radio microphones without howlround problems! Because of the symmetry of the loudspeaker system and building we had wondered if there might be some nulling in the central Nave area, but would not go so far as to claim it was designed in.

12. CONCLUSIONS

Coventry Cathedral's new speech reinforcement system was commissioned during early November 1990. Its first public performance was the Armistice Day Service of Remembrance broadcast on November 11 with the principal address given by the Rt Reverend Robert Runcie, Archbishop of Canterbury. And as the Archbishop said to the Provost:-

"...I've preached a number of times here John, but this is the first time I've been heard..."

It's second outing was on November 14 on the occasion of the Service of Remembrance and Reconciliation, with Her Majesty Queen Elizabeth the Queen Mother and His Excellency Richard von Weizsacker, President of the Federal Republic of Germany in attendance. This service was part of the City of Coventry's commemoration of her destruction exactly 50 years previously and was televised nationally within the UK and to much of Europe. On both occasions most of the broadcast feeds were taken from the new system.

It is interesting to reflect that what we have ended up with bears significant resemblance to the original Pamphonic system conceived by Paul Taylor over 30 years ago. Clearly that original system was conceptually years ahead of the technology available to implement it in the late 1950s. We now have that technology and it is for this reason that we may have succeeded where Pamphonic did not. As with Pamphonic, the heart of the system is the delay rack. All signal sources are fed into it and all outputs are derived from it. It controls the entire system. We just hope it will prove a little more reliable than its forebear!

Acknowledgements.

Special personal and corporate thanks for their help and support during the realisation of this project are extended as follows:-

THE COVENTRY RECIPROCATING ROOM ALIGNMENT DELAY

John Dodson, Bose UK Ltd
Ken Jacobs, Bose Inc, Framingham MA.
Steve Smith, The Sound Department, London.
Roger M Carroll, IRP, Elk Grove Village Il.
Peter Kinder, Evode Speciality Adhesives Ltd (UK)
Rane Corporation (thru Music Lab, London)
AKG Acoustics (UK) Ltd
David K Mead, Cathedral Bursar
Martin R Williams LL.B, Chairman, Coventry Cathedral Public Address Working Group, without whose total dedication it is unlikely the project would ever have been realised.

References.

<1> Taylor P H "The Line Source Loudspeaker and its Applications" British Kinematography (BKSTS) Vol 44, No 3, 1964 March, pp 64 thru 83.

<2> Brittain F H "Coventry Cathedral - A Preliminary Study" Unpublished report by GEC-Hirst Research Acoustics Laboratory, 1962 October.

<3> Brittain F H "Original Sound System" - Unpublished report by GEC-Hirst Research Acoustics Laboratory, 1963 June 26.

<4> Brittain F H "Reinforcing the Spoken Word - Solution for Coventry Cathedral" GEC Journal Vol 32, No 3, 1965, pp 135 thru 140.

<5> Stevens W R, Letter-form report to Cathedral Architect (in succession) from AIRO Ltd, Airo reference WRS/JH/26/C dated 1984 September 14, unpublished.

<6> Edwards N, Garrity P & Orbach S "Coventry Cathedral - Acoustics for the Spoken Word" Unpublished report by Artec Consultants New York, 1986 October.

<7> Dibble K, "Full Circle - The Cathedral Church of St Michael, Coventry", Sound & Video Contractor, Intertec Publishing, Kansas, USA, 1991 May and October issues.

<8> Speilberg S, "Back to the Future", 20th Century Fox, 1987.

This paper is based on an earlier work entitled "The Cathedral Church of St Michael, Coventry - A Sound System 30 Years On" delivered at the AES 90th Convention, Paris, 1991 February 19/22.

THE COVENTRY RECIPROCATING ROOM ALIGNMENT DELAY

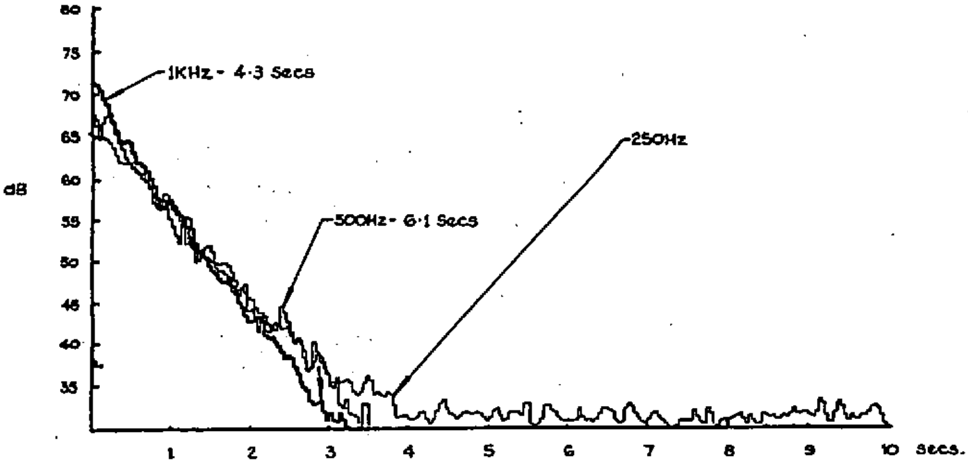


Fig.1 COVENTRY CATHEDRAL NAVE REVERBERATION CURVES USING EXISTING CENTRAL LOUDSPEAKER ARRAY. 89-04-03

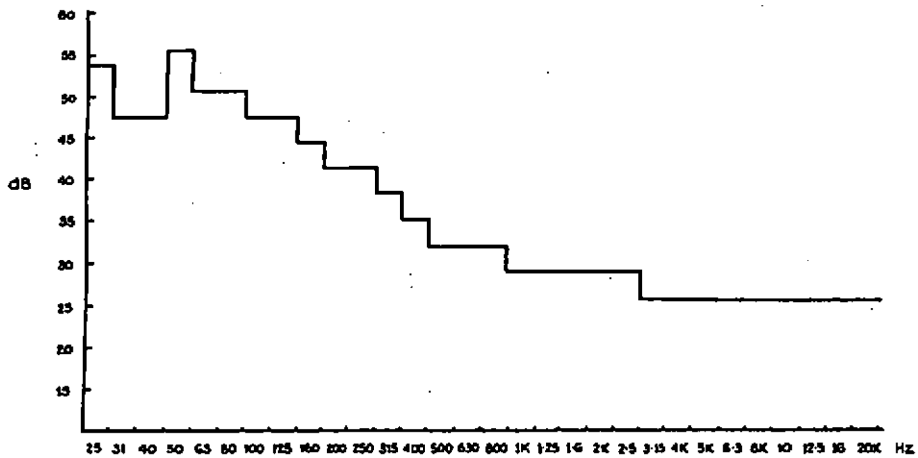


Fig. 2 COVENTRY CATHEDRAL NAVE NOISE FLOOR. 1400HRS. 89-04-03

THE COVENTRY RECIPROCATING ROOM ALIGNMENT DELAY

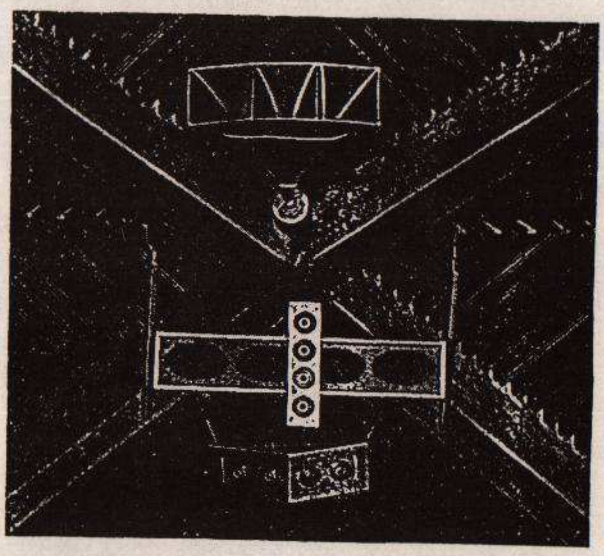


Fig 3

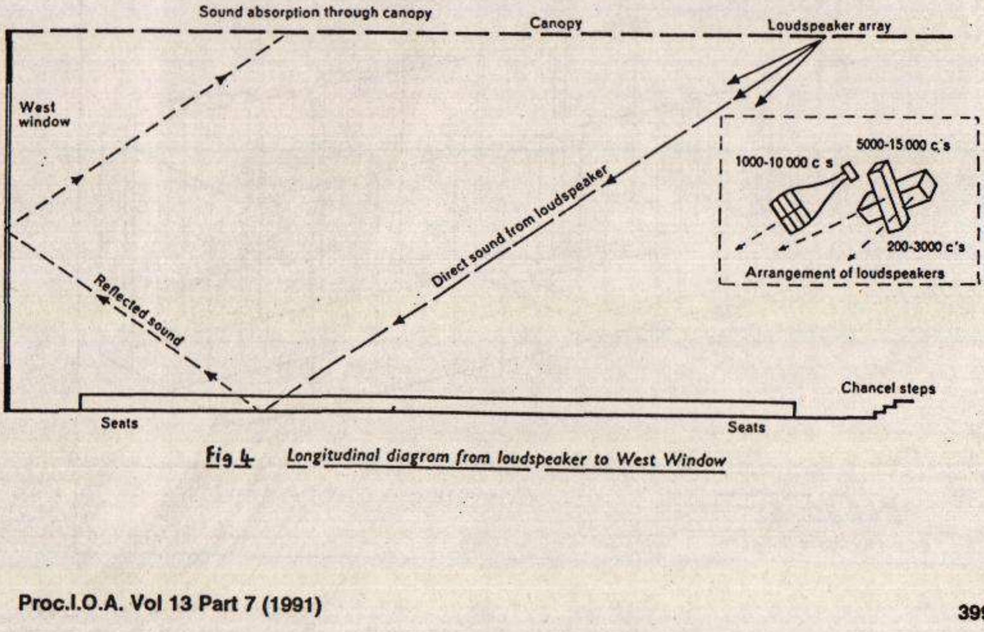


Fig 4 Longitudinal diagram from loudspeaker to West Window

THE COVENTRY RECIPROCATING ROOM ALIGNMENT DELAY

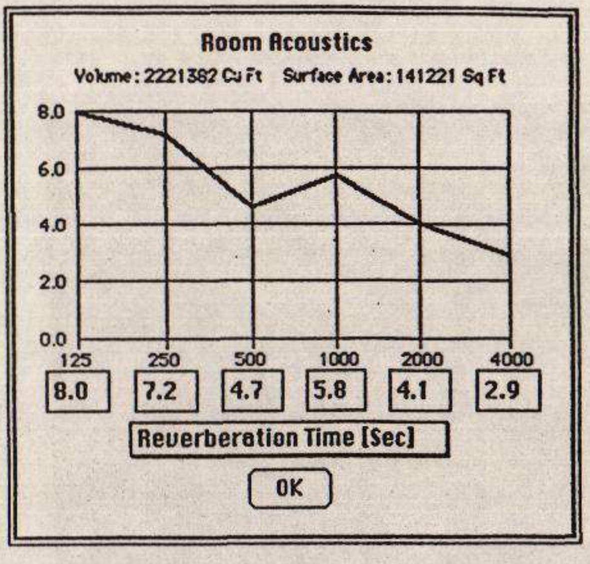


Fig 6

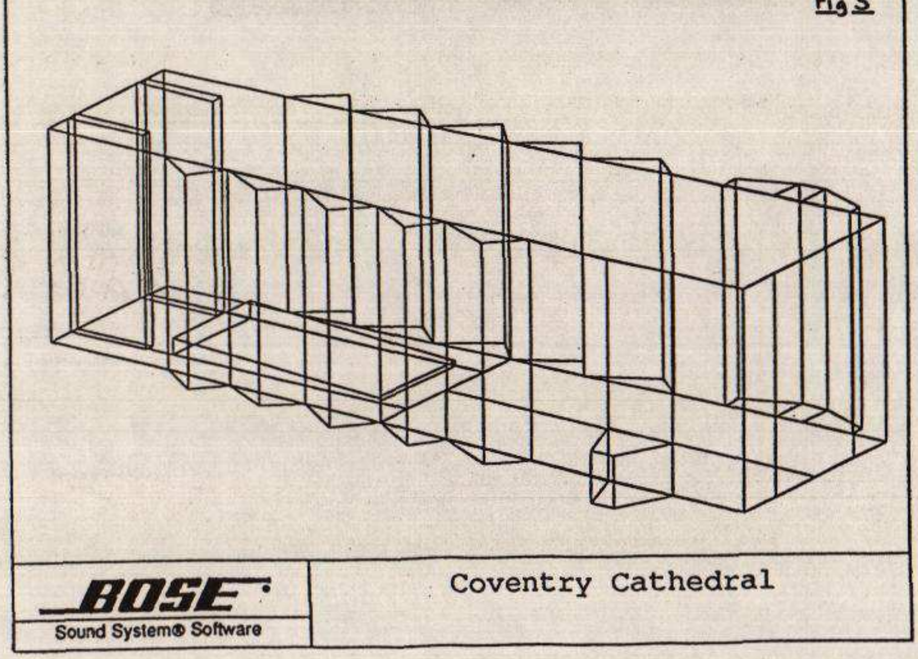


Fig 5

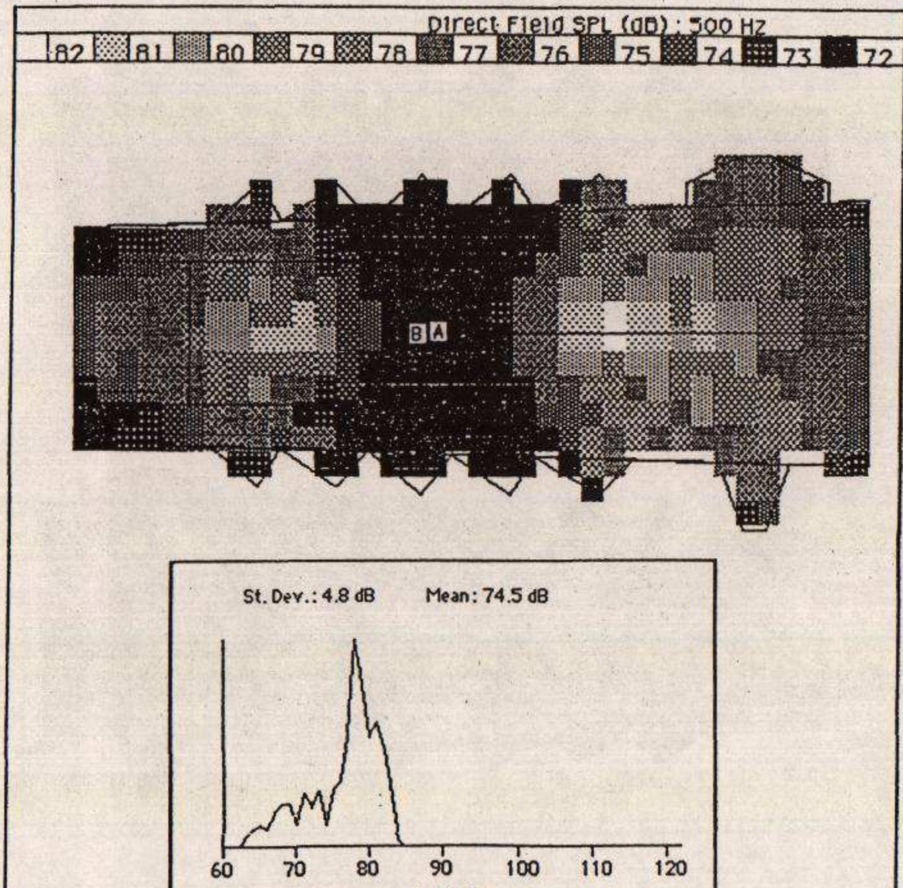
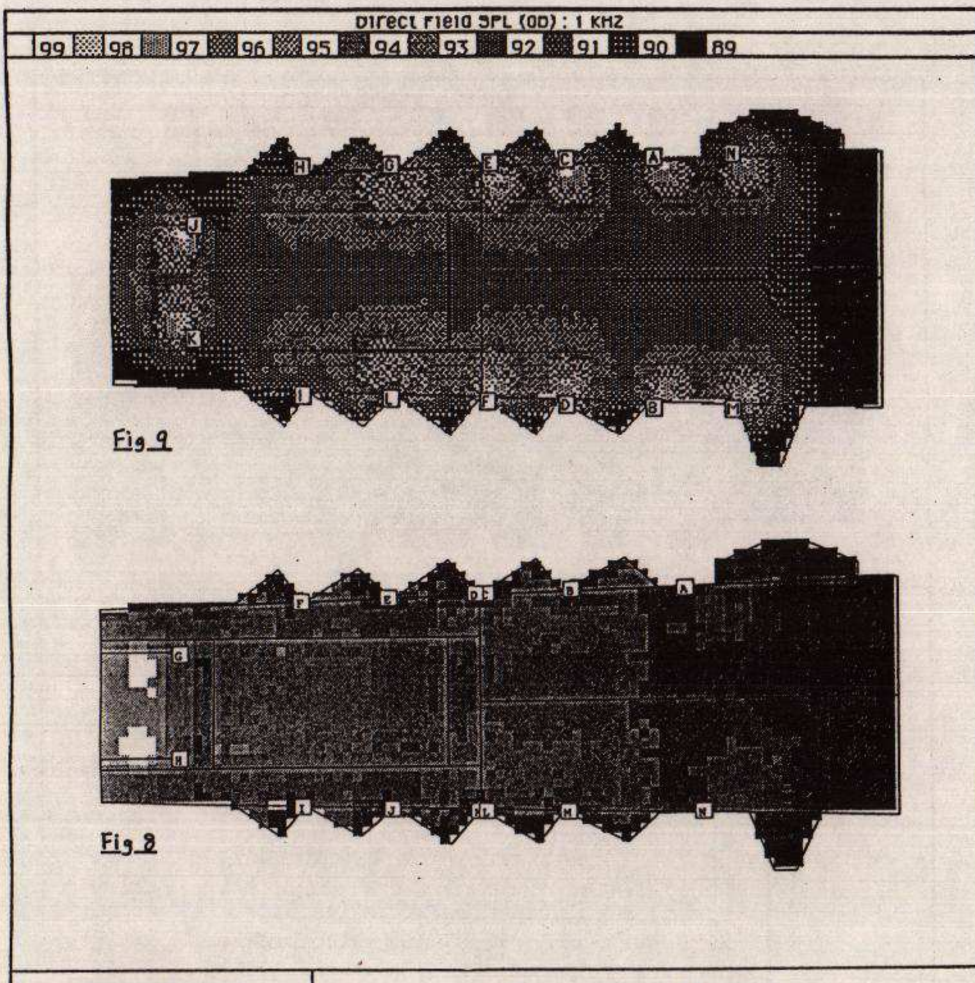
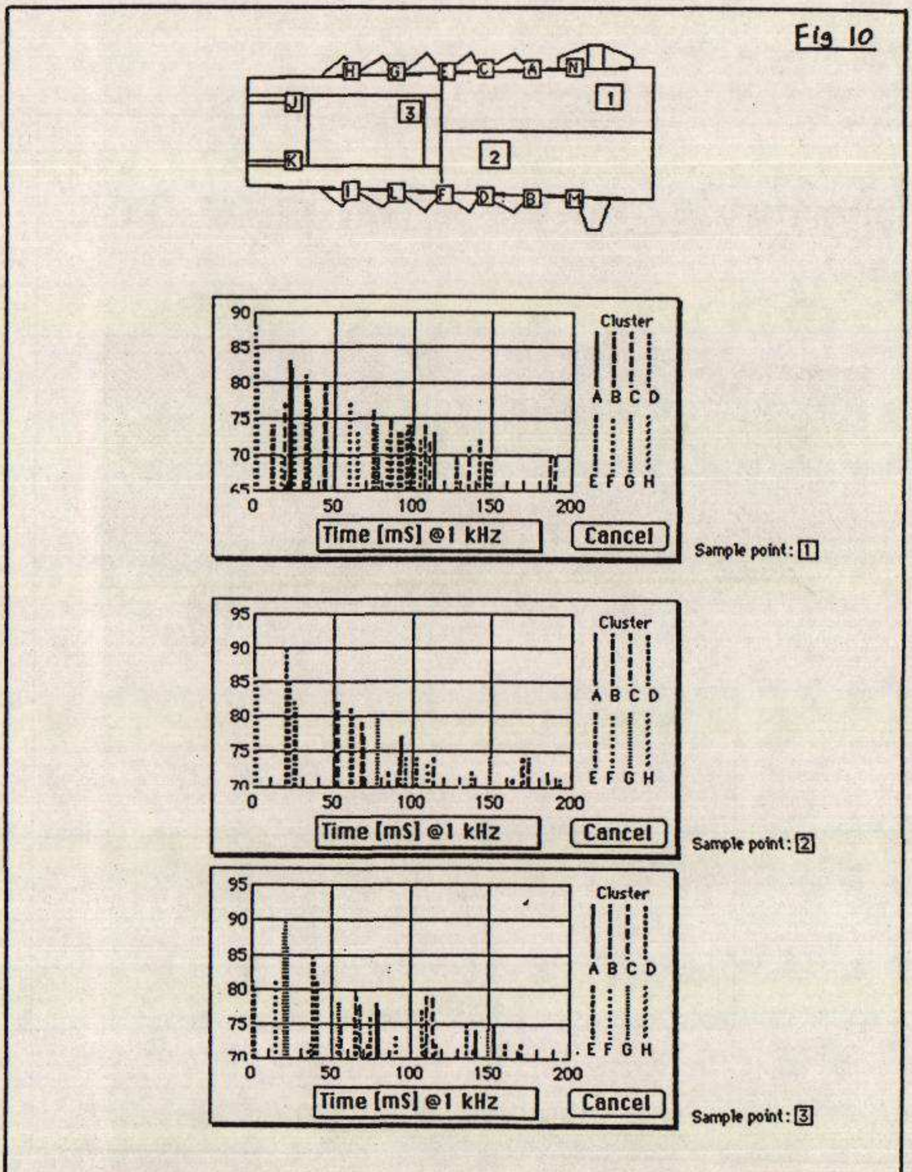


Fig 7 Replacement Central Cluster Option

THE COVENTRY RECIPROCATING ROOM ALIGNMENT DELAY



The Perimeter Distributed System Option



Sound System® Software

Coventry Cathedral

Time Response

THE COVENTRY RECIPROCATING ROOM ALIGNMENT DELAY

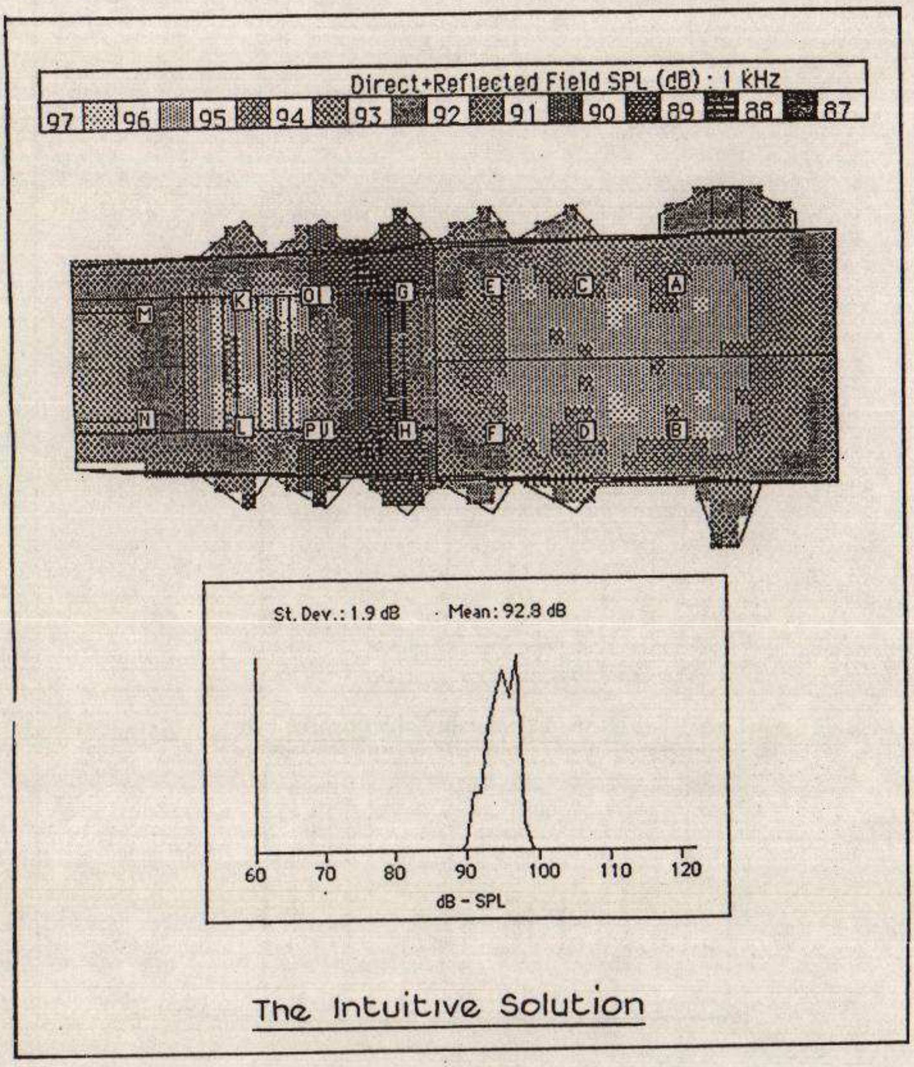


Fig. 11

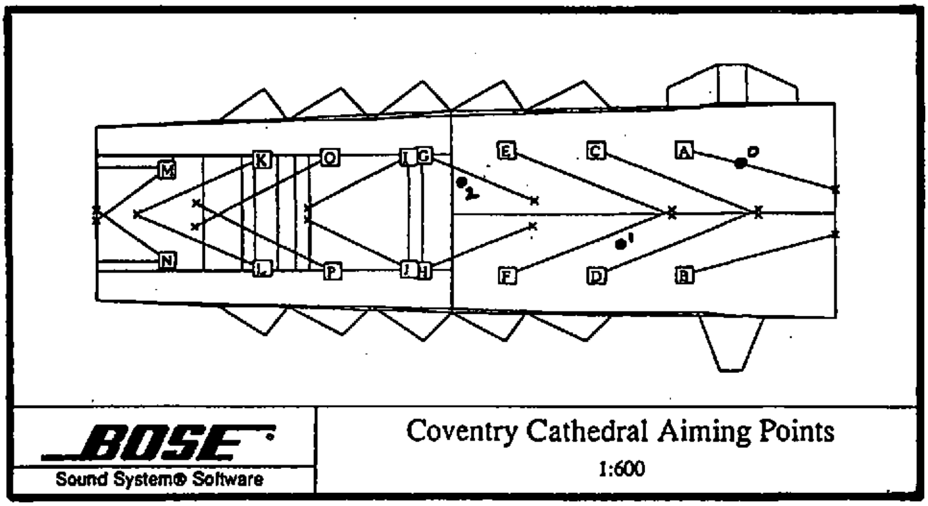
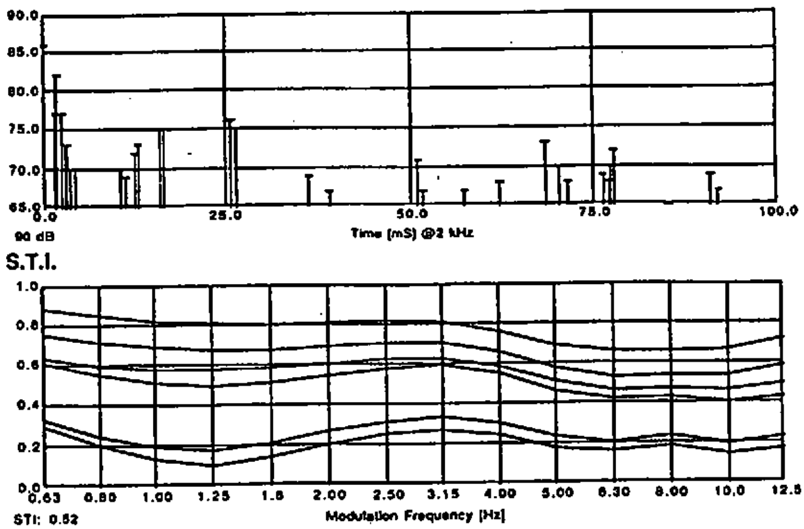


Fig 12

Listener Location "0"

Time Arrivals:



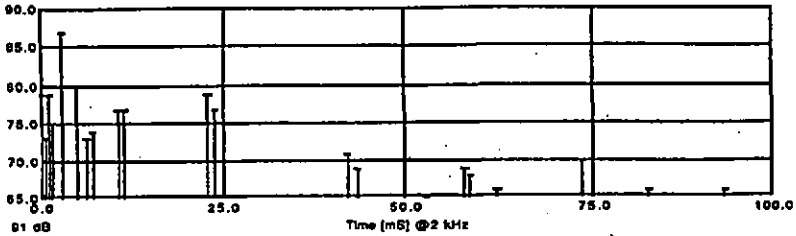
STI: 0.52

% Slansi: 84% %ALcons: 10 Descriptor: Fair/Good

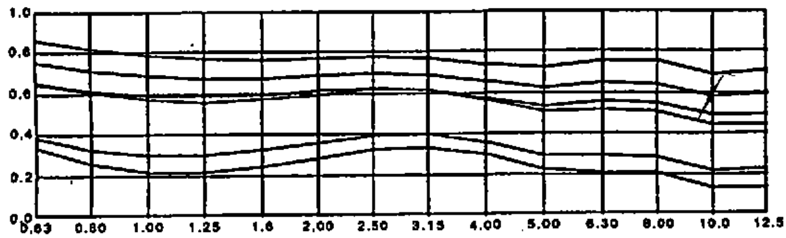
Fig 13A

Listener Location "1"

Time Arrivals:



S.T.I.



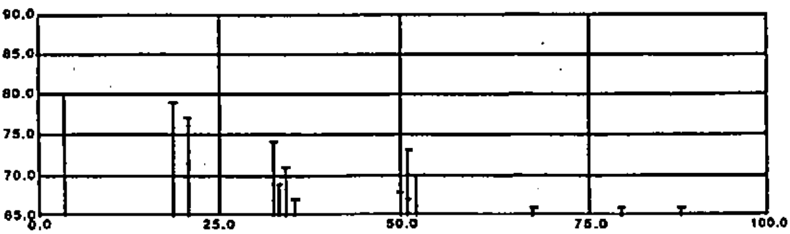
STI: 0.54

% Slansl: 86% % ALcons: 9 Descriptor: Fair/Good

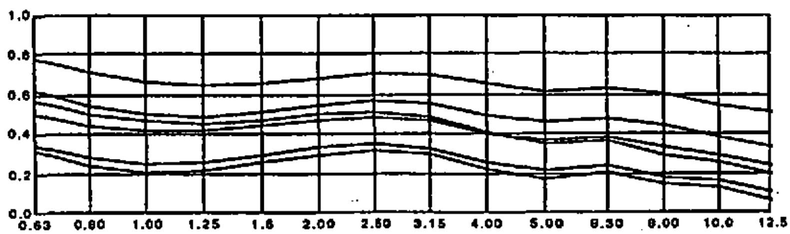
Fig 13B

Listener Location "2"

Time Arrivals:



S.T.I.

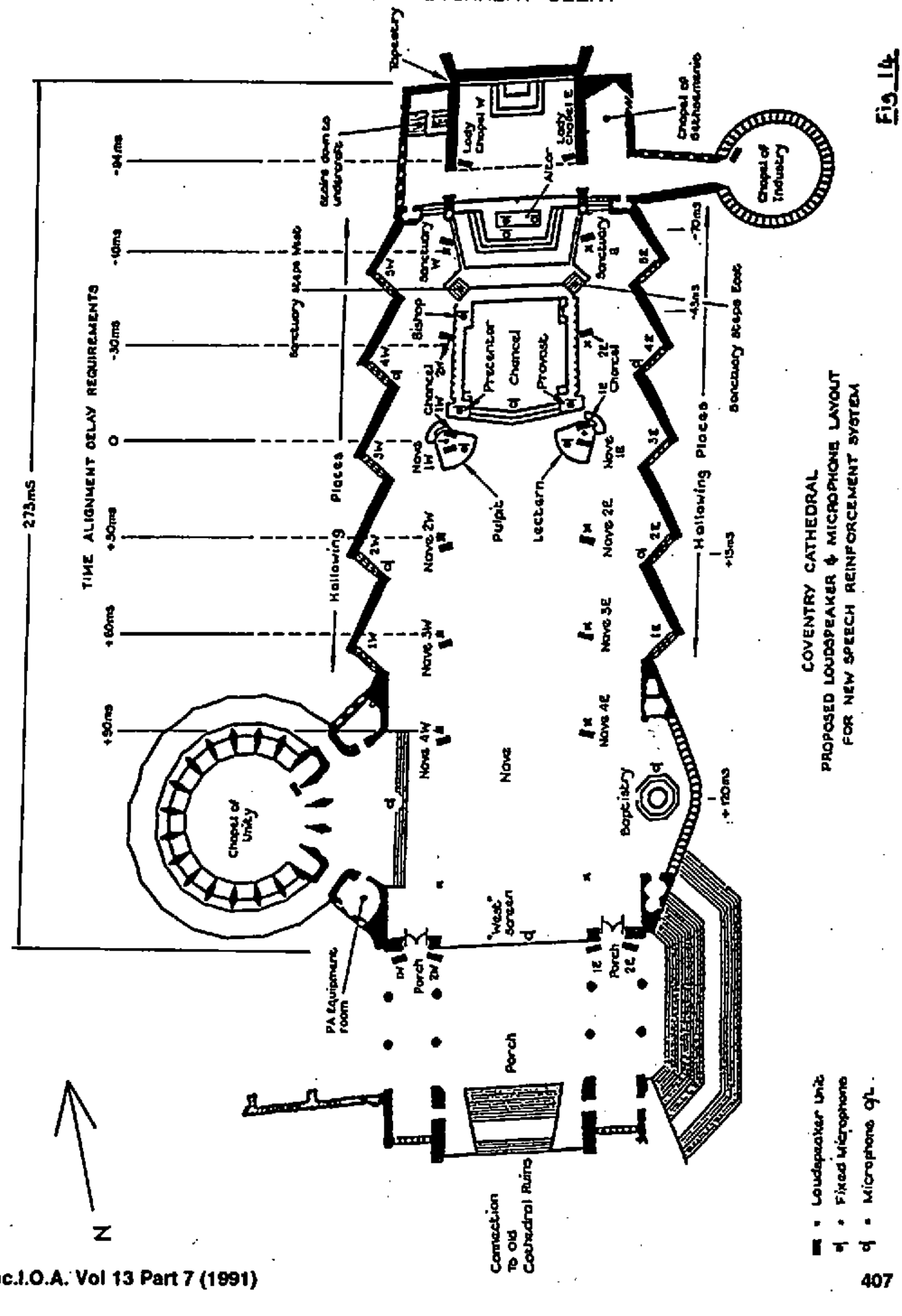


STI: 0.47

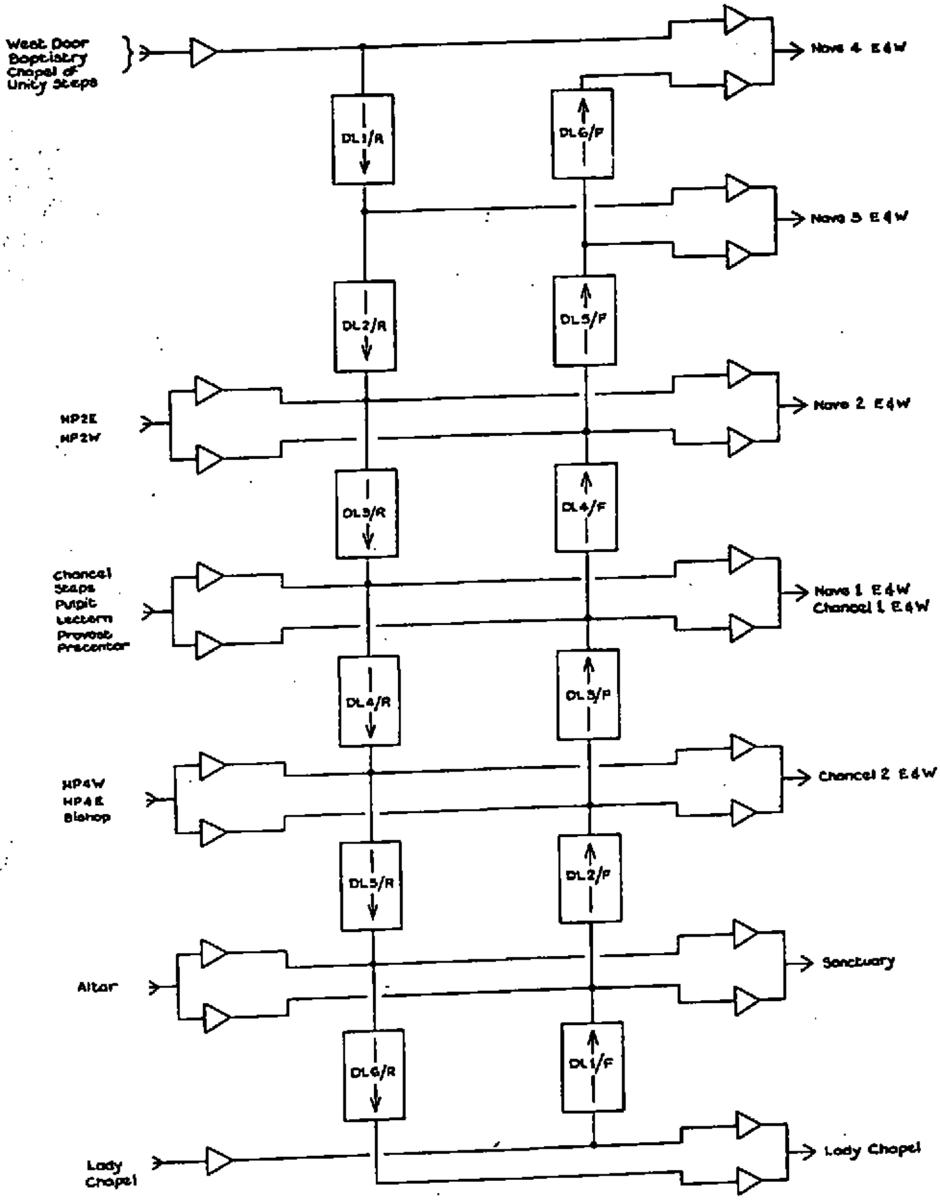
% Slansl: 76% %ALcons: 13 Descriptor: Fair

Fig 13C

THE COVENTRY RECIPROCATING ROOM ALIGNMENT DELAY



THE COVENTRY RECIPROCATING ROOM ALIGNMENT DELAY



THE COVENTRY RECIPROCATING ALIGNMENT DELAY –
SYSTEM SCHEMATIC

Fig. 15

THE COVENTRY RECIPROCATING ROOM ALIGNMENT DELAY

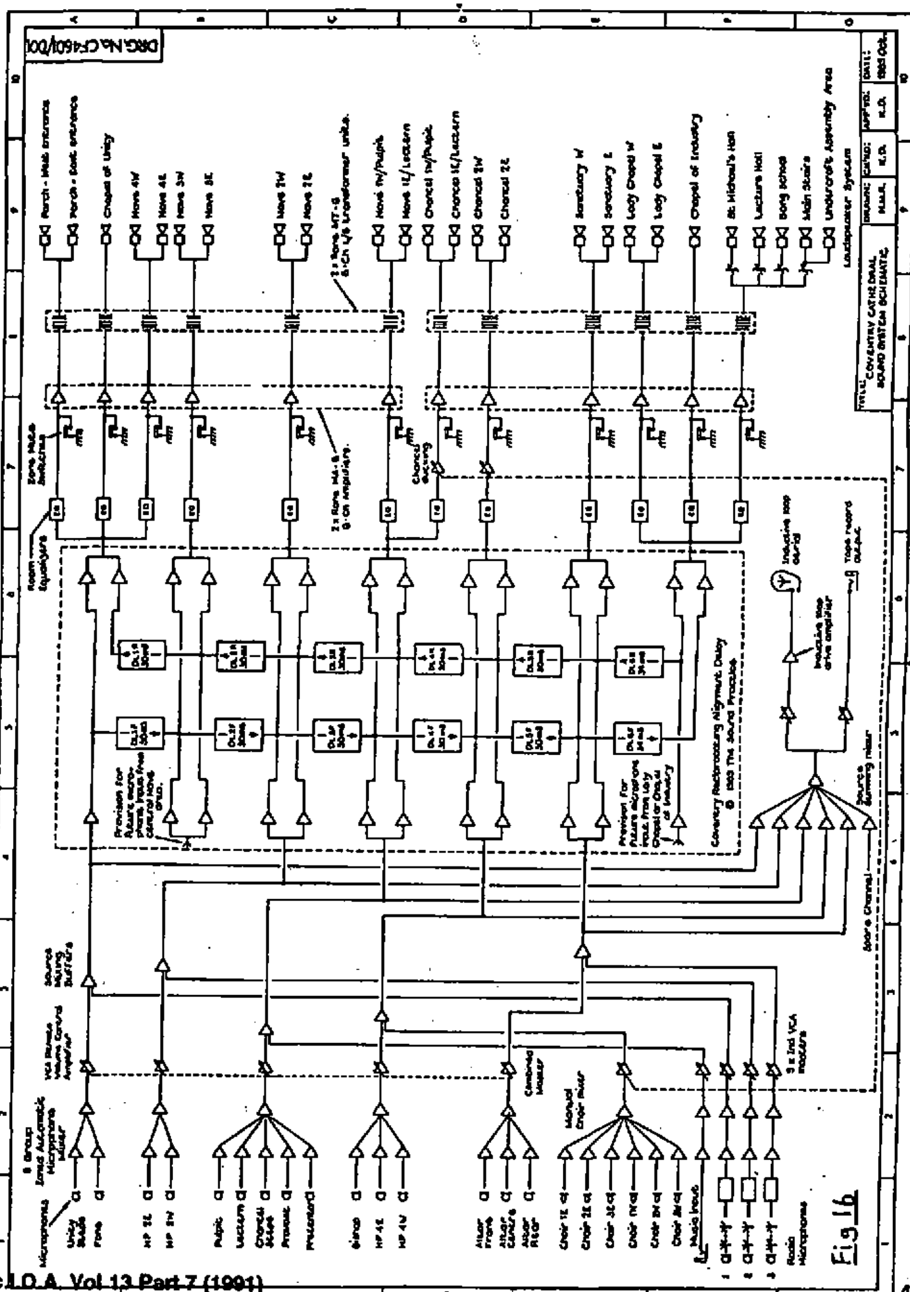


Fig 1b

THE COVENTRY RECIPROCATING ROOM ALIGNMENT DELAY

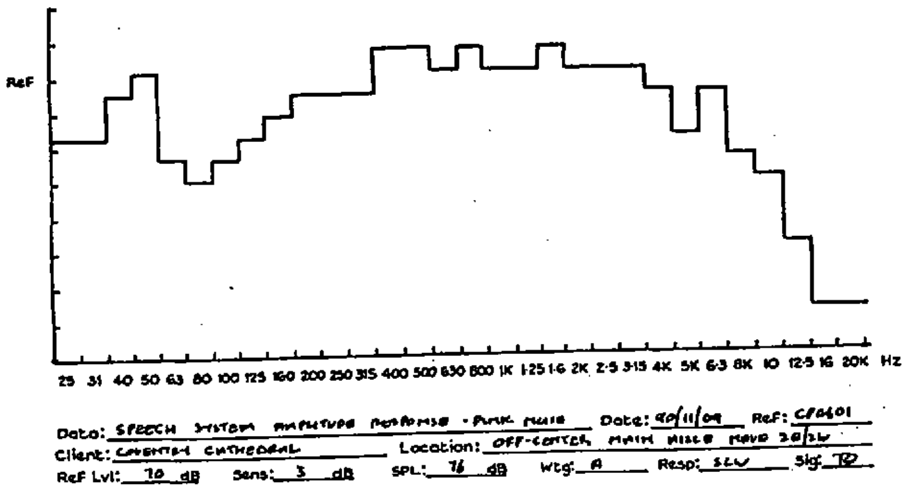


Fig 17A

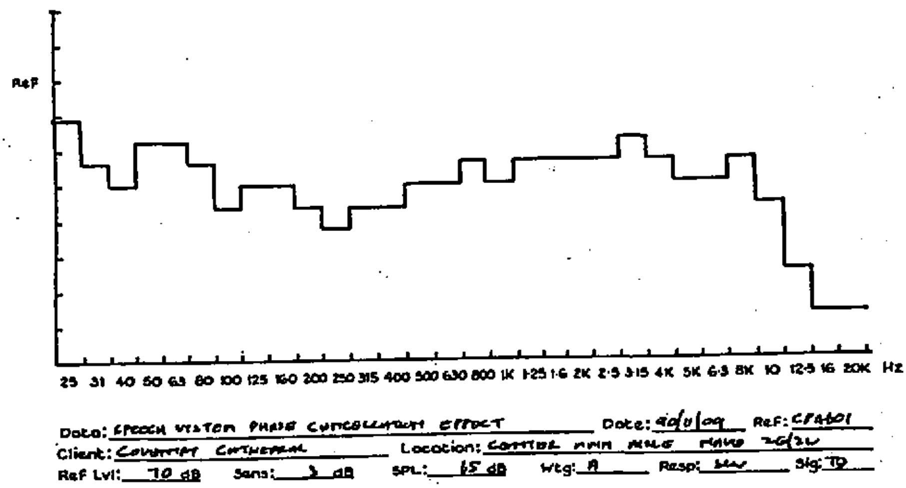


Fig 17B

ISBN 1 873082 27 4 (pp 167 - 410)
ISBN 1 873082 28 2 (Set of two)