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SYSTEM DESIGN FOR GERMAN FEDERAL HISTORIC GOVERNMENT BUILDING, PAULSKIRCHE, FRANKFURT

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INTRODUCTION

The Paulskirche (St. Paul's Church), Frankfurt am Main is an oval sandstone building constructed in the years 1798-1833 as a Protestant city church. May 1848 saw the building taken over for one year for use by the first German National Parliament before returning to being a place of worship, until the last service held on 12th March 1944. After its complete destruction by bombing during the War and the rebuilding during the hard post-war years, the Paulskirche was re-opened on 18th May 1948.

During the post-war years the building has seen use primarily as a meeting place where the City of Frankfurt honours worthy literary figures and to which numerous Heads of State are invited to speak, including such persons as President Kennedy and President Mitterand. The style of the building as created in 1948 has been kept by this latest renovation, which has benefitted by much changed and improved acoustics to suit its present use.

PAULSKIRCHE ACOUSTICS

Prior to this latest renovation, the reverberation time was long in the mid frequencies making it totally unsuitable for speech (now its prime use). The interior was treated with acoustic plaster which has dramatically reduced the mid-frequency reverberation time. Fig. 1 showsthe original reverberation time together with measurements made at various stages of the restoration.

EVALUATION OF DESIGN

The initial design called for a speech reinforcement system to supplement the existing. The existing system comprised a number of cardioid speech columns located around the perimeter of the space. The existing equipment gave indifferent audio quality, poor gain-prior-to-feedback and poor directional information. Our initial proposed design involved a centrally-placed array of constant-directivity units located in the assumed redundant organ loft. The design calculations predicted a gain-prior-to-feedback in the region of -10 dB and an intelligibility rating in the range 5-10% Alcons.

Over a period of approximately one year the design underwent a process of metamorphosis; the organ gradually assuming more importance until finally the organ and its associated grilles became a 'no go' area.

Mindful of the architect's desire to preserve the architectural integrity of the building, after much discussion the final design was approved. To maintain the aesthetic theme of the interior it was determined that the loudspeakers should be suspended in two linear arrays situated forward and to each side of the organ. Such an arrangement was consistent with the vertical lines of the interior and in sympathy with the lighting fittings.

SYSTEM DESIGN FOR GERMAN FEDERAL HISTORIC GOVERNMENT BUILDING, PAULSKIRCHE, FRANKFURT

FINAL DESIGN CONSIDERATIONS

The new proposed arrangement not only involved a compromise over the central array option, but also introduced a number of electro-acoustic problems. Calculations revealed that there would be a deterioration in both articulation and gain-prior-to-feedback.

In the case of the intelligibility, a small probably unavoidable degradation was predicted. In the case of the gain-prior-to-feedback the effect was both dramatic and undesirable.

In addition to the above, there existed the problem of array alignment.

Array of this kind can give rise to considerable lobing and on-axis phase cancellation. Such effects manifest themselves not only in poor sound quality which is unredeemable even with gross equalisation, but also since the polar response of the units is affected, undue excitation of the reverberent field can ensue invalidating the calculations and predictions.

The solution is to 'time-align the array' - in effect ensure that the wave front is as far as is practically possible in phase.

We also decided that the entire array should be electronically tilted to maximise the available absorption and to ensure that the wave front was as far as was practically possible planar.

Recalculation of the system performance indicated that if we maximised the effect of the available absorption, a further 3-4 dB advantage could be expected on the gain-prior-to-feedback.

SYSTEM DESCRIPTION

The system was configured as shown in fig. 2 and is largely self-explanatory. Each loudspeaker was driven from a separate power amplifier and sourced via individual signal delays. The loudspeakers were arranged as shown in fig. 3. The drive units were, as far as possible, physically aligned although fine tuning would be possible using the signal delay units.

The loudspeakers were selected on the basis of directivity pattern with due regard to the areas to be covered.

The Table below provides the results of the calculations to determine the acoustic output power of each of the devices to provide 80 dB(A) at the listener.

SYSTEM DESIGN FOR GERMAN FEDERAL HISTORIC GOVERNMENT BUILDING, PAULSKIRCHE, FRANKFURT

Horn No.	Type	Directivity Q	Distance to target (m)	Required Spl (dB)	Calculated Pwl (dB)
1	HP4020	50	18	80	98
2	HP4020	50	20	80	99
3	HP6040	25	14	80	99
4	HP6040	25	14	80	99
5	HP9040	12	10	80	99

From the calculated Pwl of each horn loudspeaker it is possible to predict both intelligibility and gain-prior-to-feedback.

Horn No.	Type	Calculated Pwl (dB)	Absorption Coefficient Audience + 50% Spillage	Reflection Coefficient	Pwl to Rev. Field	NE*
1	HP4020	98	0.4	0.6	96	0.5
2	HP4020	99	0.4	0.6	97	ref.
3	HP6040	99	0.4	0.6	97	0.6
4	HP6040	99	0.4	0.6	97	0.6
5	HP9040	99	0.4	0.6	97	0.6

*NE is the equivalent output to the reverberent field referenced to the output of the longest throw horn loudspeaker.

From the above Table the predicted intelligibility was in the region of 5-10% Alcons.

SYSTEM COMMISSIONING

The system was commissioned over a two-day period. Firstly, the signal levels through the processing chain were optimised to reduce the possibility of overload and to ensure the best possible signal-to-noise ratio. The output of each horn element was adjusted to give equal target levels.

SYSTEM DESIGN FOR GERMAN FEDERAL HISTORIC GOVERNMENT BUILDING, PAULSKIRCHE, FRANKFURT

Next, a single horn was equalised, the results are shown in fig. 4. The measurement was repeated with the adjacent horn active. These results are shown in fig. 5. It can be seen that the equalisation curve has been severely modified as a result of phase cancellation.

With the aid of a portable storage oscilloscope the signal delay was applied to one of the horns until the arrival time was synchronized. The frequency response of the system was again measured, see fig. 6.

It can be seen that there was a considerable improvement over fig. 5.

The process was repeated for all of the horn elements.

Finally, an additional 10ms was added to each element to preserve the Haas effect and with the bass unit also active the system was finally equalised.

The final system equalisation is shown in fig. 7. The gain-prior-to-feedback was also measured and found to be in the region of 15 dB. The increase over the predicted was almost certainly due to the directional properties of the microphone.

Figs. 8 and 9 show the system gain and coverage obtained respectively.

CONCLUSIONS

The final audio quality of the system was excellent with little or no problems from reflective surfaces. The effectiveness of this approach may be readily understood from the reverberation time traces shown in fig. 10. The curves shown are representative of those taken throughout the space. It can be seen that there is an initial drop of some 5-10 dB demonstrating the effectiveness of the directional properties of the array.

The importance of time aligning such arrays may be seen from the degradation in equalisation caused by introducing additional loudspeakers. What is not shown is the detrimental effect on the polar response. Such arrays, if not time-aligned lose most of their directional properties thereby increasing the reverberent field.

Finally, we believe this project demonstrates the need for close co-operation between the interior designers and audio consultants to ensure that neither audio quality or aesthetics are compromised.

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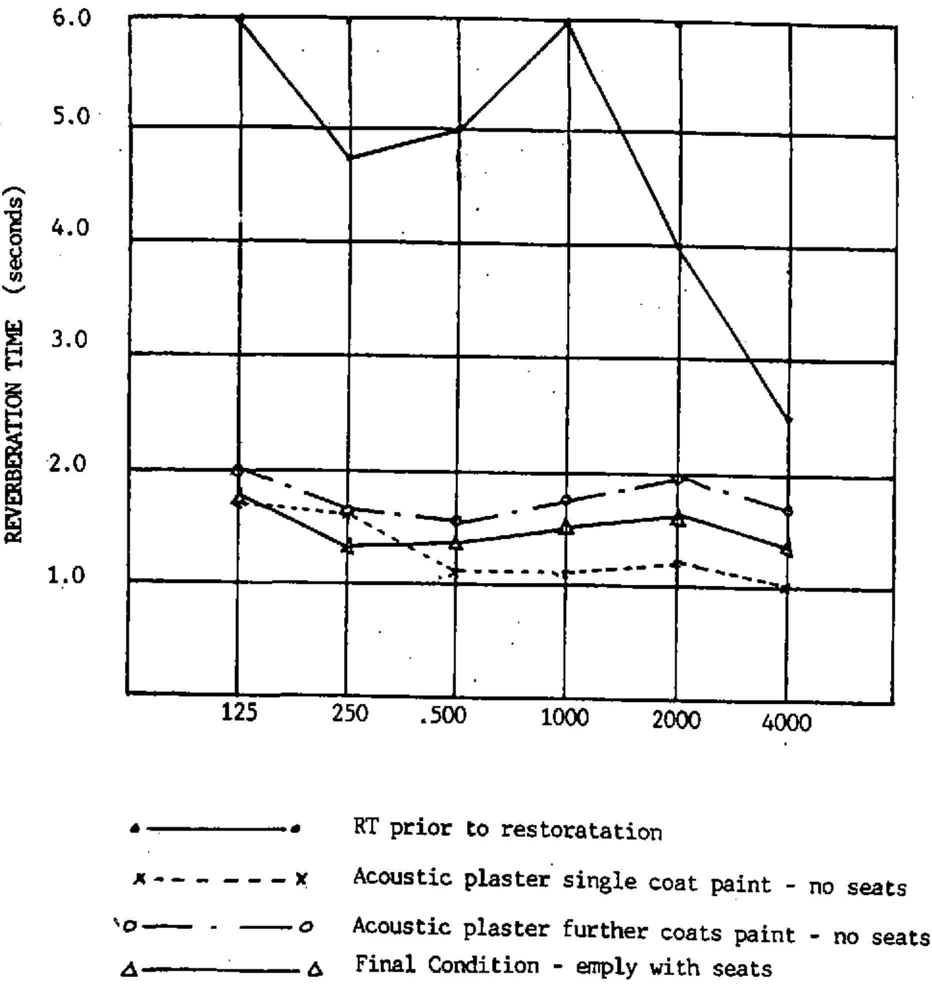
PAULSKIRCHE, FRANKFURT



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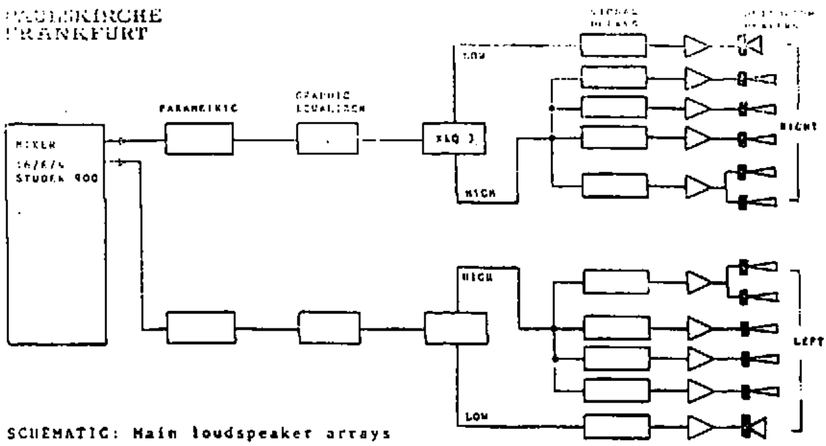

Fig. 2

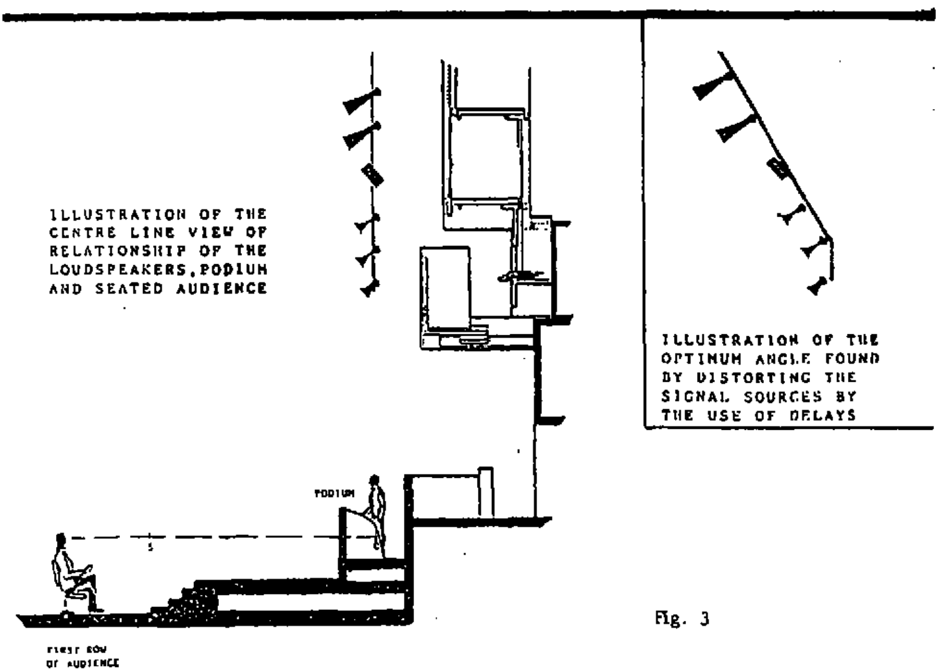

Fig. 3

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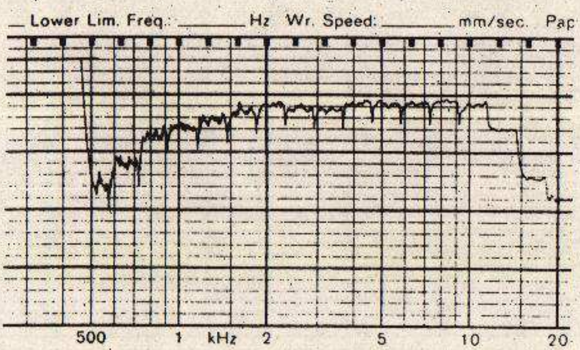
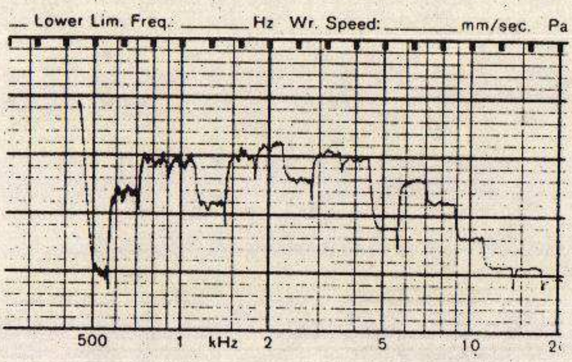
PAULSKIRCHE, FRANKFURT



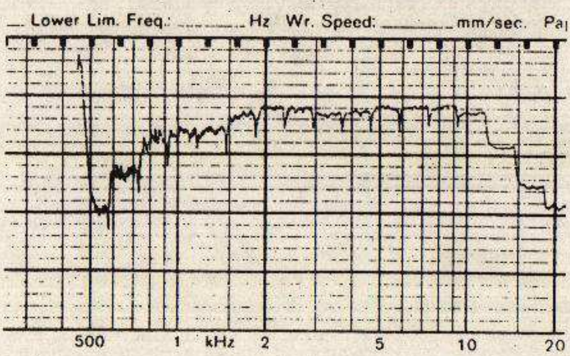
Single Horn Equalisation

Fig. 4



Adjacent Horns Active - No Alignment

Fig. 5



Adjacent Horns Active after Alignment

Fig. 6

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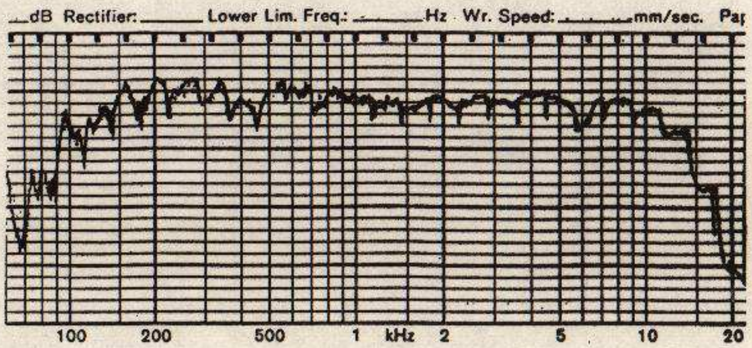
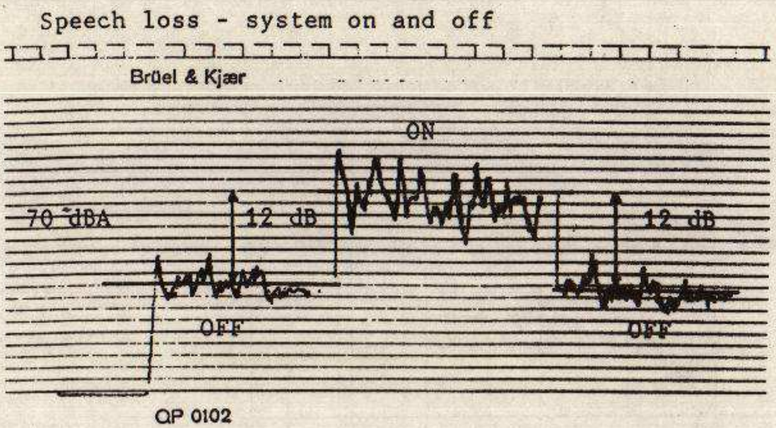
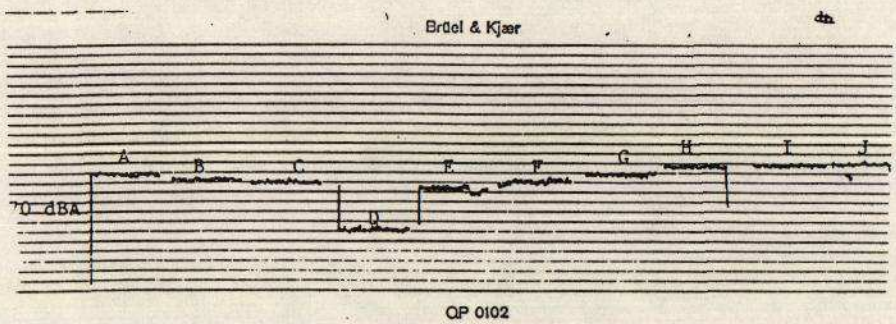


Final System Equalisation Fig. 7



System Gain Fig. 8



Measurement Positions

A. Right Aisle Front
B. Centre Front.
C. Right Front.
D. Podium.
E. Front Platform.
F. Far Right Centre.
G. Right Rear.
H. Centre Rear.
I. Rear Left.
J. Front Left.

System Coverage Fig. 9

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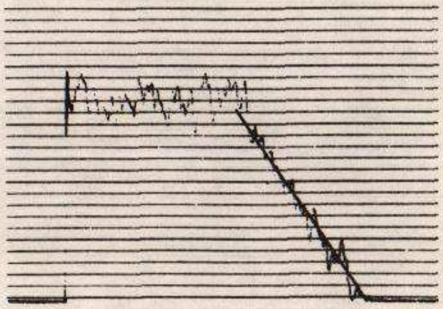
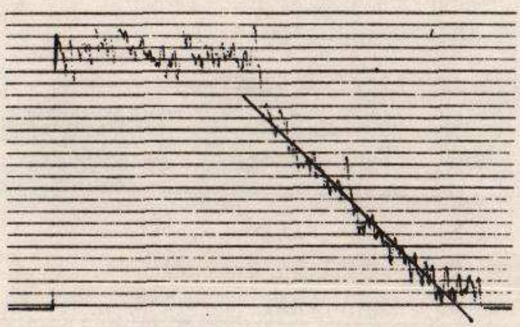
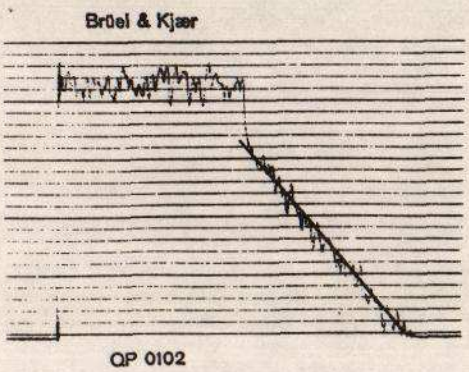
RT's measured using system as source (Note initial decay drop)



500 Hz



1000 Hz



2000 Hz

Fig. 10