Proceedings of the Institute of Acoustics

ACOUSTIC MEASUREMENTS & LOUDSPEAKER EVALUATION TESTING FOR THE NEW HOUSE OF COMMONS SPEECH REINFORCEMENT & BROADCAST SYSTEM

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1. INTRODUCTION

This paper is supplementary to that by David Errock of BBC Radio Projects and is confined to two specific aspects of the project:-

i) Testing of the original Tannoy system in the House of Commons Chamber carried out in 1991 January.

ii) Loudspeaker drive unit evaluation carried out at GEC Hirst Research, Wembley, to identify a drive unit which would be capable of meeting the SPL and amplitude response criteria in the existing seat-back enclosures of just 76mm diameter and 0.2ltr internal volume.

The paper will describe the procedures adopted, present the results obtained and discuss the conclusions reached.

2. ORIGINAL SYSTEM OVERVIEW

The system was installed in 1951 to co-incide with the re-opening of the Chamber following World War 2 and was updated in 1972. It comprised approximately 40 Tannoy ribbon cardioid microphones suspended by roof lines over the benches with AKG D202 dynamic microphones at the Despatch Boxes, controlled by a simple switch selection panel and an overall volume control. The signal processing equipment included a Tannoy "Standing Wave Eliminator" - which turned out to be a 5Hz/8Hz frequency shifter - and a type C3200 Room Equaliser providing +/- 12dB adjustment at 13 frequencies between 125Hz and 8KHZ plus high-pass and low-pass shelving filters. This fed approximately 250 loudspeaker units recessed into the seatbacks of the famous "Benches" and a similar number in the upper galleries. Loudspeaker distribution was at 100V line level to group transformers located under the bench seats. By the time the evaluation was carried out the BBC had already been experimenting with microphone types and had replaced some of the original ribbons with AKG CK1s capsules.

3. OBJECTS

There were three primary objects to this element of the project:-

i) To ascertain the SPL and spectral response of the existing system under typical operating conditions.

ii) To establish the SPL and spectral response at maximum gain and determine the point of onset of howlround.

iii) To determin the limiting factors.

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4. INSTRUMENTATION

The instrumentation comprised an Ivie IE-30A combined real time spectrum analyser and SPLM with an IE-2B measuring microphone at the center of the Chamber, 2m forward of the Despatch Box table and 2M above floor level. Hard copy plots were produced using an IE-17A ancillary processor with a Hewlet Packard type 7010B XY recorder and Urei type 2020 DC amplifier module. The system was calibrated using a Cirrus Research CRL-5.11B calibrator.

The excitation source for the RT60 measurements comprised an Ivie IE-20B precision pink noise generator feeding a pair of Bose 802 wide dispersion full range loudspeakers lying back-to-back on the floor of the Chamber and angled upwards at approximately 15° to form a half-space source.

5. ROOM ACOUSTICS

The two primary factors of interest were background noise and RT60. Fig 1A shows the 1/3rd octave RTA of the empty chamber with and without the air conditioning system operating. The broadband SPL is 40.1dB(A) in either case. This is an exceptionally quiet air conditioning system. Fig 1B shows this same data, converted to octave band values and plotted against the NR curve family. It can be seen that below 125Hz NR20 is achieved, whilst NR35 would probably reflect a more representative subjective impression.

Fig 1C shows the family of RT60 measurements at 125Hz thru 4KHz. Note that the longer RT60s are occurring at the higher frequency bands - ie quite the opposite of most room characteristics. This was attributed to the extensive timber panelling used in the House of Commons Chamber. When occupied however there would be an appreciable increase in the mid and high frequency absorption but little change at lower frequencies, thus redressing the balance and reducing the RT60 figures significantly.

It was concluded that whilst there would be no problems with background noise, a means of changing the room equalisation according to occupancy, in order to compensate for the reverse weighted RT60 conditions in the empty House would be desirable.

6. EVALUATION OF EXISTING SYSTEM

Speech Tests

For these tests a practiced male speaker was used at the despatch box microphones and at various Members bench positions. Although no STI measurements were carried out, intelligibility and general quality were adjudged surprisingly good by all concerned, having regard to the small size of the loudspeaker devices, the sheer numbers involved and the antiquity of the electronics.

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Fig 2A shows the result of a "normal speaking voice" test, using the Government Side Despatch Box D222, with the system gain set to "ringing tails" but not quite at howlround. It can be seen that the maximum level is only 57dB in the 500Hz 1/3rd octave band and the broadband level is typically 60dB(A).

Fig 2B shows a similar test, this time with the speaker standing under and in front of, microphone #5, middle row, Government side, being one of the original Tannoy ribbon microphones, and speaking in a raised voice. The analyser "freeze hold" facility was activated on the "air" syllable of the word "there". This time the maximum level is 70dB in the 400Hz 1/3rd octave band and the broadband SPL, 68dB(A).

Fig 2C shows the result of a similar test but from microphone #5, front row, Opposition Side, which was one of the experimental CK1s capsules. This showed a 2dB increase in the broadband measurement of 70dB(A). Both "raised voice" tests produced significant vowel distortion of a kind normally associated with loudspeaker cone break-up.

By a series of incremental level tests starting at 60dB(A) it was established that 65dB(A) was the maximum broadband capability of the system before the distortion problem became intrusive.

Fig 2D shows a level normalised overlay between plots 2B and 2C, which shows the surprisingly small differences over the frequency band of interest, between the original Tannoy ribbon and the new CK1S microphones.

Spectral Response Tests

For these tests the Ivie IE-20B pink noise generator was set to -58dBm level, and connected via a balancing transformer, to the Opposition Side Despatch Box microphone channel. The "Standing Wave Eliminator" was by-passed.

Fig 3A shows the spectral response of the system. It can be seen that the nominal pass-band is 160Hz - 8KHz with a tendency to peak at 400Hz and 2.5KHz/3.15KHz. This characteristic is not reflected in the setting of the room equaliser or in the RT60 plots. The broad-band SPL was 69.2dB(A) suggesting that the system was on the verge of distortion. A series of further measurements were carried out with the measuring microphone placed at typical seated Member ear positions, 40cm from the individual loudspeaker devices, at 30 locations on both sides of the House and on all four sides at Gallery level. Only small variations in the spectral response was noted, with a range of 69/71dB(A) in the Benches and 71/72dB(A) at Gallery level.

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Fig 3B shows a similar test to that shown at Fig 3A except that the IE-30A was set to its dBV operating mode and the microphone replaced with a calibrated measurement probe connected directly to the 100V distribution line. It can be seen that the pass-band is now 80Hz to 20KHz. Fig 3C is an overlay of plots 3A and 3B to show the difference between the electrical and acoustic responses of the system. It can also be seen that at onset of distortion the system is operating 7dB below the nominal line voltage: ie less than 25% utilisation of the available amplifier power.

Conclusions

i) As a concept the system is providing excellent uniformity of coverage and good intelligibility.

ii) The maximum SPL capability of the system was limited to 65dB(A) broadband or 70dB in any 1/3rd octave band.

iii) The first limiting factor is howlround when a speaker addresses the House in a normal speaking voice, but this may be less of a problem when the House is occupied.

iv) The 2nd limiting factor is distortion. Given the fact that the system was distorting at 7dB below the available line voltage level it was concluded that the loudspeaker drive units themselves were the limiting factor, but that in any event, there could be only 6dB of additional headroom available using the existing electronics.

v) The distortion could be attributable to the loudspeaker devices being presented with significant levels of out-of-band energy, due to the absence of pass-band filtering in the signal processing chain, rather than a limitation in the devices themselves.

vi) Whilst 65dB(A) - ie normal speech level - was found adequate in the empty Chamber, it was estimated that something between 72dB(A) and 78dB(A) would be required with a full House and as much as 90dB when in uproar. Thus the system was falling some 13dB(A) short of a realistic SPL and 25dB short of that necessary to enable a call for Order from the Speaker's Chair to be heard.

vii) It was concluded that further tests were required to establish the performance parameters of the existing loudspeaker drive units and to investigate the availability of possible replacements.

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7. LOUDSPEAKER EVALUATION TESTING PROCEDURES

Tests were carried out using the anechoic chamber facility at GEC Hirst Research, Wembley using a B&K ½" air condenser microphone type 4147 with preamplifier type 2639, connected to a B&K type 2010 Hetrodyne Analyser/Measuring Amplifier, driving a B&K type 2304 Level Recorder. A B&K type 3922 Turntable was used for the polar response measurements. The system was calibrated using an NPL certificated B&K type 4230 Sound Level Calibrator.

Each device was mounted in a replica of the HOC seatback housing on a 500 x 500 x 15mm MDF baffle. The housing was 76mm diameter x 45mm deep, thus providing an enclosure volume of 0.2ltr.

Tests were conducted to show the free air and enclosed impedance and resonance characteristics and the 1W/1m axial EFC. Polar measurements were restricted to the four IEC octave bands of interest - ie: 500Hz, 1KHz, 2KHz & 4KHz - and to selected units. In the absence of time to perform harmonic distortion tests, the maximum SPL vs power handling capability of each device was determined by listening for the 2nd harmonic component always present when a transducer is in its cone break-up mode or when its piston excursion limits are being exceeded.

Devices Tested

Samples were selected for testing on the basis of a realistic power and sensitivity rating and whether or not they could be accommodated within the existing seat-back enclosures and within the dimensions of the existing, ornately cast grilles. Following an in-depth market survey the following were identified:

Manufacturer	Type Number	Origin
Tannoy Ltd	Existing HoC Unit	UK
Westra GMBH	BF-66-214	Germany
Westra GMBH	BF-66-202	Germany
Westra GMBH	SF-77-318	Germany
Eurotec	SR-2747	Taiwan
Bose Corporation	AW-5	USA
Elac	Model 65	UK
Secomak Vitavox	CN-350	UK
Bandor	51112 Mk II	UK
E J Jordan	J-51	UK

Tannoy HoC Device Results

These are in essence, an early version of a typical hi-fi mid-range dome radiator, but with a shallow paper composition dome. In the absence of a manufacturer's specification, two of these devices were tested in order to be sure that the results were representative. Fig 4A shows the composite impedance curve, Fig 4B the 1W/1m EFC and Fig 4B the polar response plot. It can be

seen from Fig 4A that the nominal impedance is 8 ohms and that the enclosure loading is almost a perfect Theil-Small match, with the fundamental resonance nulled and the F1 and F2 points of equal amplitude and equi-spaced. Fig 4B shows the amplitude response to be somewhat erratic, a possible explanation for which is shown at Fig 5 (1). The pass-band is 220Hz - 7KHz at the -6dB points, and nominal sensitivity 86dB. The polar response is surprisingly uniform and entirely suited to the application.

In the absence of any specification the power rating was determined by incrementing the input power and observing the results. At 1w RMS there was no sign of stress over the working range above 220Hz. At 4w RMS, mild buzzing due to dome break-up was observed below 240Hz, but otherwise with no sign of stress. At 8w RMS the device was clearly under stress with pronounced buzzing below 240Hz, with harmonically related distortion occurring between 420Hz and 480Hz, and further narrow band resonances above about 1.5KHz. At 4w, the SPL was measured at 91dB and at 8w, at 94dB, suggesting that the device was otherwise still working in the linear part of its working range at 8w RMS. To stay clear of the buzzing modes it seems that the maximum input power should not exceed 2w below 240Hz or 4w above 240Hz. This would limit the broadband SPL to 91dB if a 240Hz 12dB/oct high-pass filter was employed - which is considerably more than the level recorded in the House of Commons Chamber.

All the new devices are of a conventional moving coil loudspeaker design and a similar testing routine was applied to all nine units. Due to space limitations however the results cannot all be reproduced here. The following Table provides a summary.

TABLE 1: Summary Results - All Devices

Device	Z ohm	Fs Hz	F.encl Hz	Sens dB	-6dB Hz	P.in W	SPL dB
Tannoy	8	200	200	86	220/7K	4	91
BF-66-214	4	280	390	89	240/19K	6	96
BF-66-202	4	290	390	89	210/16K	6	95
SF-77-318	8	140	310	89	220/17K	10	94
Eurotec	8	310	410	87	250/12K	4	92
Bose	4	300	410	90	250/21K	6	97
Elac	6	590	590	86	360/7K	1	86
Vitavox	8	610	690	85	500/10K	4	91
Bandor	8	100	200	83	160/20K	8	91
Jordan	6	150	300	77	200/30K	8	86

NOTE: P.in and SPL are based on the linear portion of the working range & without break-up. In many instances this is a small proportion of the manufacturer's rated power specification but is considered the only valid basis for comparison.

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One problem which does not come out of the tabulated results is that all contender samples exhibited a pronounced response peak centered between 400Hz and 600Hz according to model. This was attributed to underdamping due to inadequate motor BI factor in such a small enclosure space. What is also not apparent is that some of these samples were rated at up to 30W RMS, yet were found to exhibit severe cone break-up problems at less than one quarter of that figure in practice.

8. SELECTION

The selection criteria is for maximum SPL before cone break-up, best LF extension without cone break-up, and the best achievable uniformity of response, in that order of priority. It was considered that the underdamping problem identified is likely to be present in any unit working in so small an enclosure volume and that the resultant LF overshoot - which was present in all units tested - was capable of being normalised by equalisation. This aspect was not therefore a primary consideration in arriving at a selection. Considering first the SPL vs power requirement the top three contenders from Table 1 are as follows:-

Bose AW5:	97dB for 6w
Westra BF-66-214:	96dB for 6w
Westra BF-66-202:	95dB for 6w

Considering now the LF extension gives the following:-

Westra BF-66-202	210Hz
Westra BF-66-214:	240Hz
Bose AW5:	250Hz

Considering the 3rd criteria - uniformity of frequency response, gives exactly the same order as for LF extension vs power.

It was found during testing that the two Westra BF-66 devices were the only units tested which did not exhibit cone break-up nodes at its full rated power. However at twice the rated power the BF-66-202 remained clean whilst the BF-66-214 showed ringing modes between 700Hz and 900Hz. The Bose unit, whilst showing significant cone break-up below 390Hz, was only tested at its full 25w power rating. Given that its linear range appears to be restricted to 6w, this too may well be clean at that operating level and should perhaps be re-assessed on that basis.

Another consideration is that the Westra units will require less equalisation to correct the LF overshoot problem, probably because of the reduced displacement volume of the unit itself, thus leaving an effectively larger enclosure volume.

Taking these further factors into account the Westra BF-66-202 emerged as first choice. It's impedance and EFC plots are shown at Fig 6. To summarise the qualification:-

i) Best LF extension.

ii) Only device tested with total freedom from cone break-up modes over 1st octave of working range.

iii) Within 1dB of best sensitivity and 2dB of best SPL.

iv) Best uniformity of frequency response.

v) Requires minimum EQ to correct LF overshoot due to underdamped BI factor/enclosure volume conditions.

vi) Chassis relatively easy to crop in order to be accommodated behind the existing HoC grilles.

It was considered that because of its reduced LF extension and increased tendency towards cone break-up, the Westra BF-66-214 comes a close second, with the Bose AW5 as third runner. Although the Bose has the best sensitivity and the best SPL of all units tested, it was considered that the excessive LF correction necessary, its erratic frequency response characteristic and the uncertainty regarding its cone break-up characteristics over the linear part of its working range, combine to make it a less attractive proposition than the two Westra devices.

9. CONCLUSION

This study originated because of the need to quantify the observed performance shortcomings in the House of Commons speech reinforcement system and as a direct result of broadcasting requirements. The investigation showed the principle limitation to lie with the loudspeaker devices used and led to a laboratory study of miniature loudspeaker drive units. Conclusive results were obtained in both elements of the work.

This paper has shown that given proper understanding of the appropriate criteria, relatively basic measurement procedures can be used to provide valuable objective data regarding sound system performance and how first impressions need not necessarily produce the right answers.

Reference:

(1) Colloms M, "High Performance Loudspeakers" Pentech Press, Plymouth, 1978, ISBN 0 7273 0802 5.

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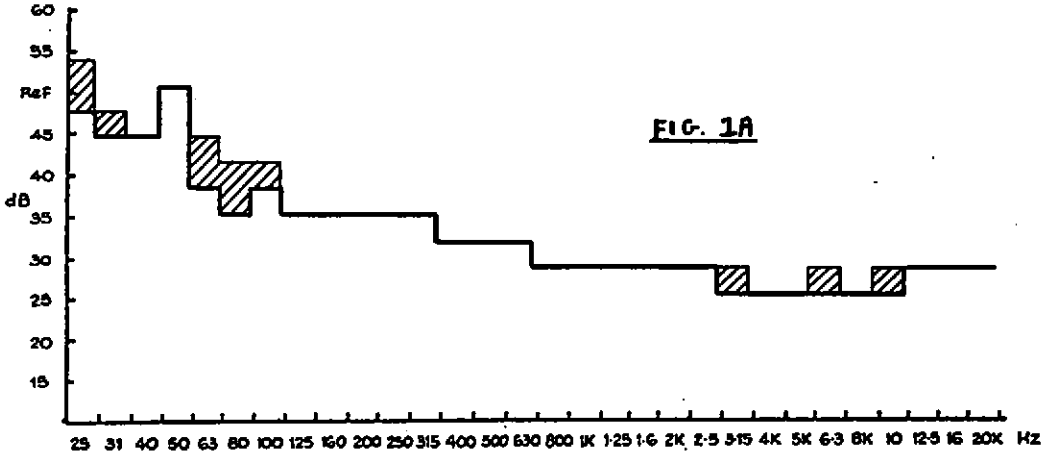

FIG. 1A

Data: NOISE FLOOR (BLACK) HVAC OFF (RED) HVAC FULL Date: 21/01/19 Ref: CF57
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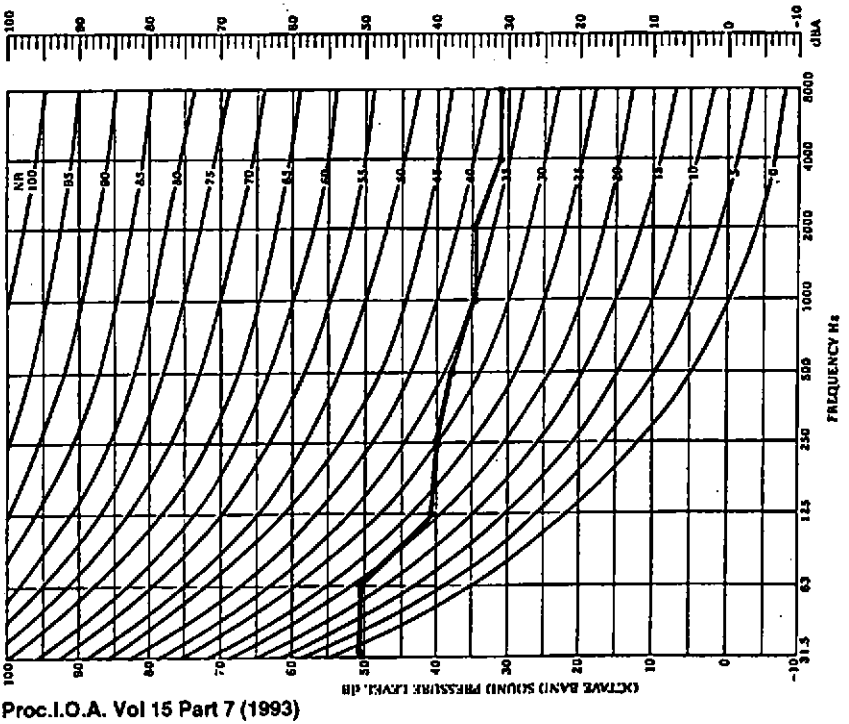
Ref Lvl: 50 dB Sens: 5 dB SPL: 40+1 dB Wtg: A Resp: SLW Sig: TD



HOUSE OF COMMONS CHAMBER NOISE FLOOR

FIG. 1B

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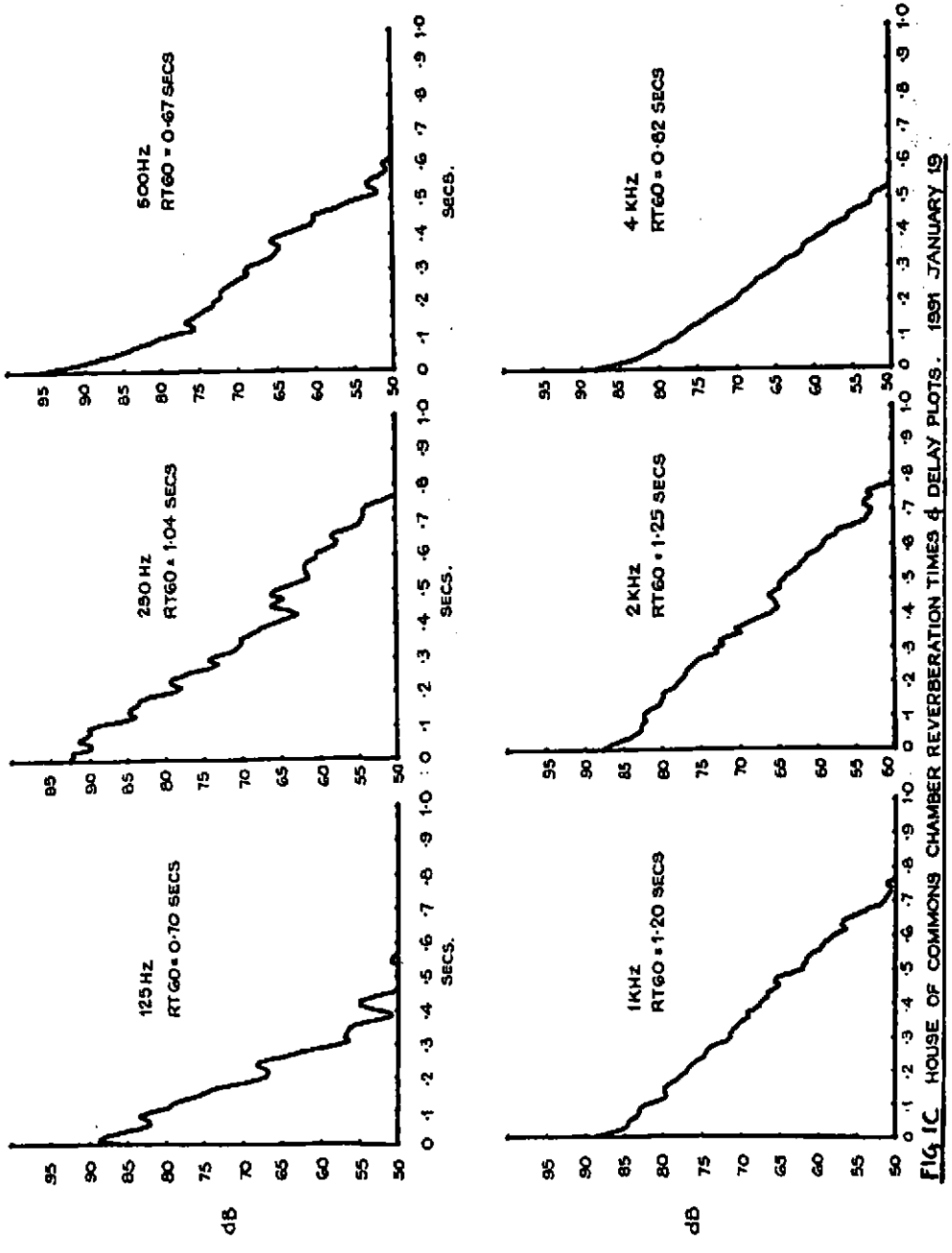

FIG 1C HOUSE OF COMMONS CHAMBER REVERBERATION TIMES & DELAY PLOTS. 1991 JANUARY 19

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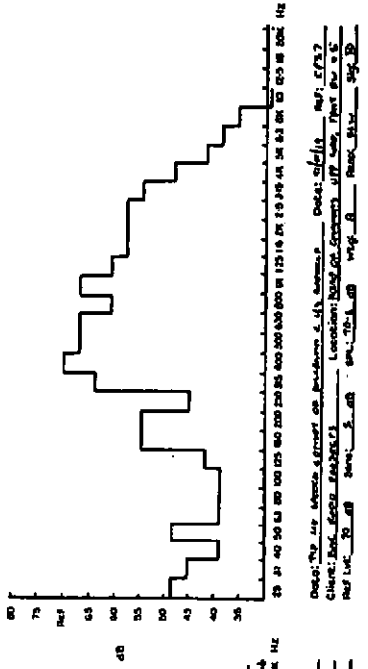


FIG. 1C

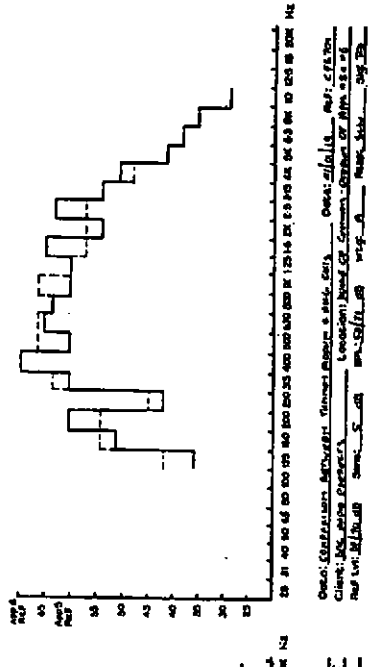


FIG. 1D

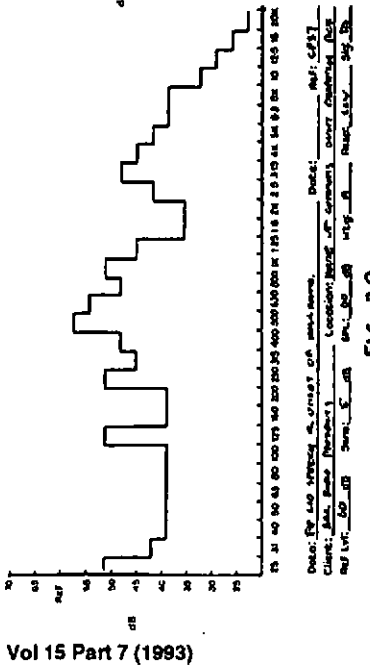


FIG. 2A

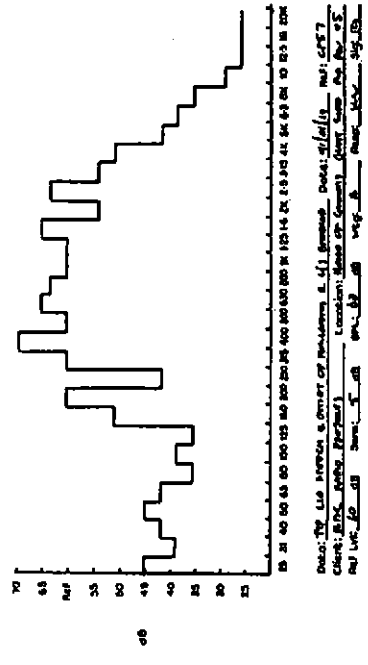
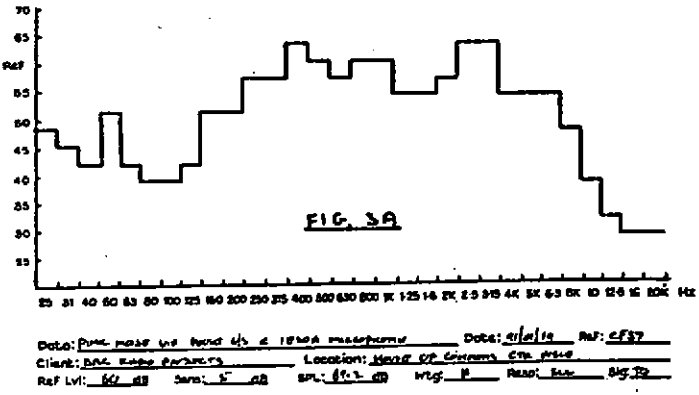
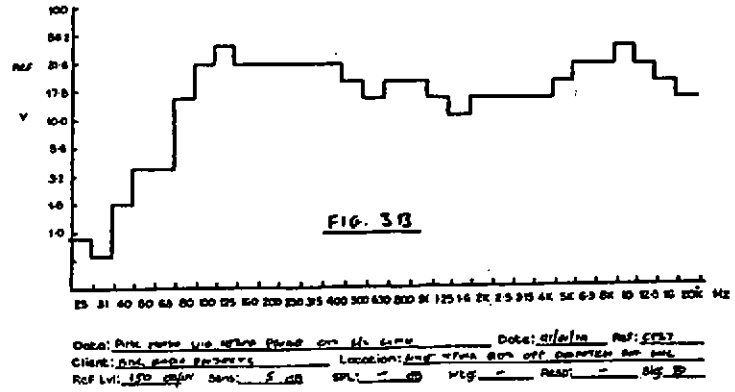
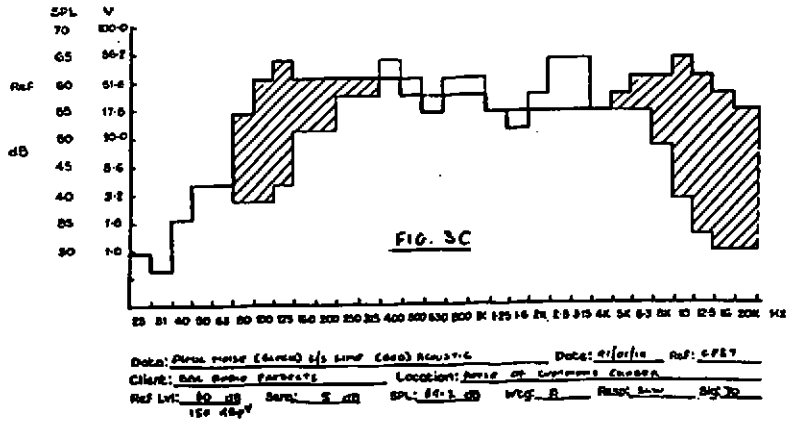


FIG. 2B

ACOUSTIC MEASUREMENTS & LOUDSPEAKER EVALUATION TESTING FOR THE NEW HOUSE OF COMMONS SPEECH REINFORCEMENT & BROADCAST SYSTEM







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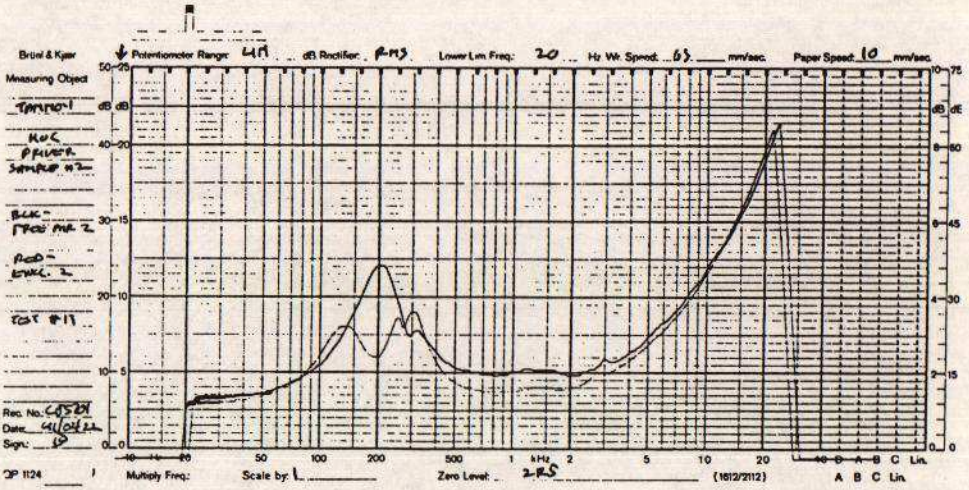

FIG. 4A

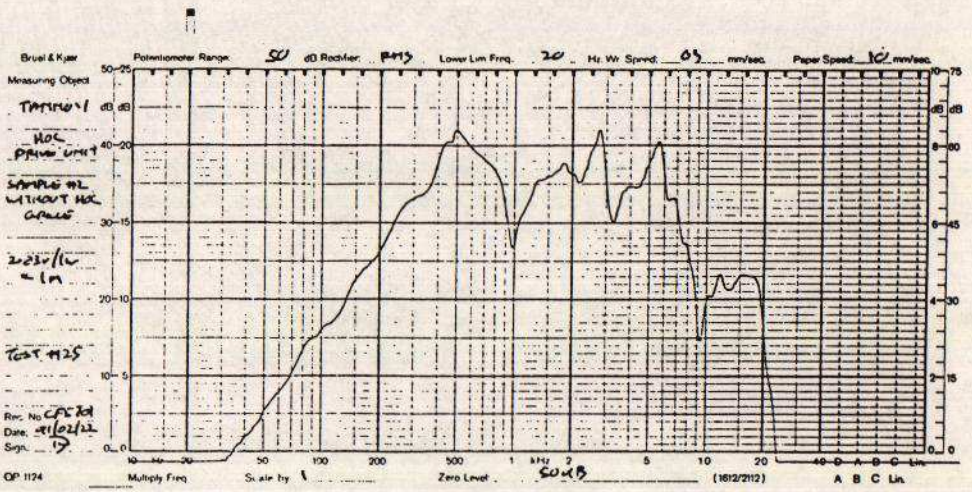

FIG. 4B

ACOUSTIC MEASUREMENTS & LOUDSPEAKER EVALUATION TESTING FOR THE NEW HOUSE OF COMMONS SPEECH REINFORCEMENT & BROADCAST SYSTEM

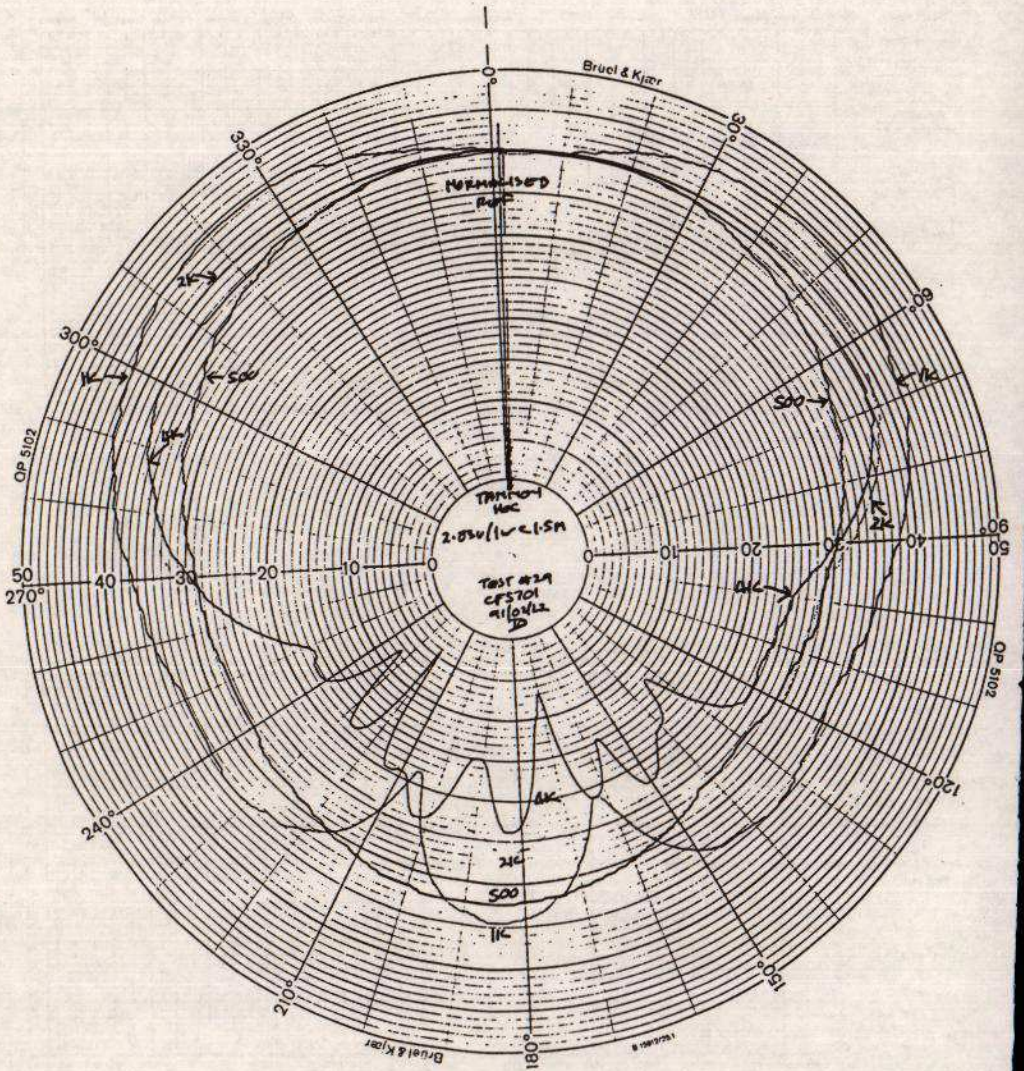

FIG. 4C

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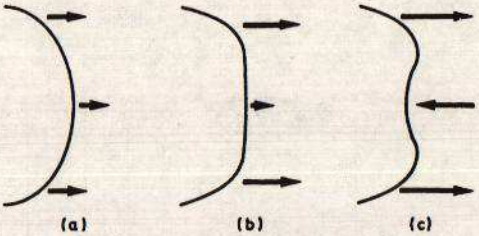
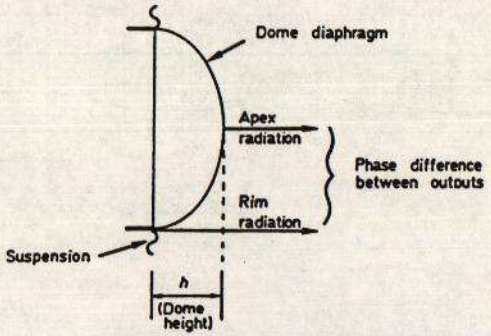
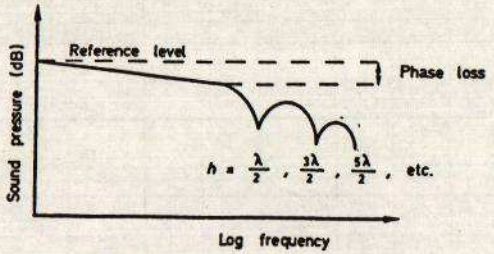


Dome behaviour leading to first breakup (a) piston operation at low frequencies; (b) at mid-frequencies, breakup beginning; (c) at resonance, centre out of phase with rim



Dome geometry and phase loss (first dip when $\lambda = 2h$)



Typical dome response dominated by phase loss

FIG. 5 Nodal Behavior of Typical Dome Radiator

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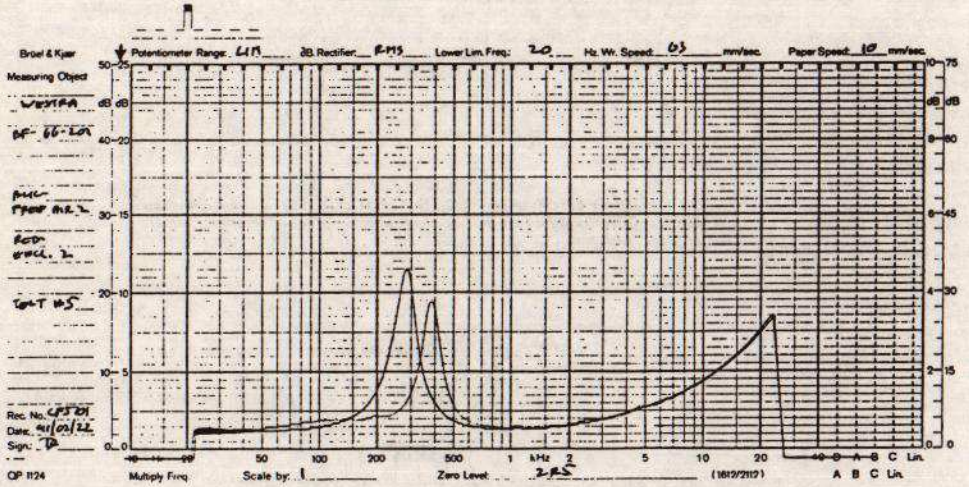

FIG. 6A

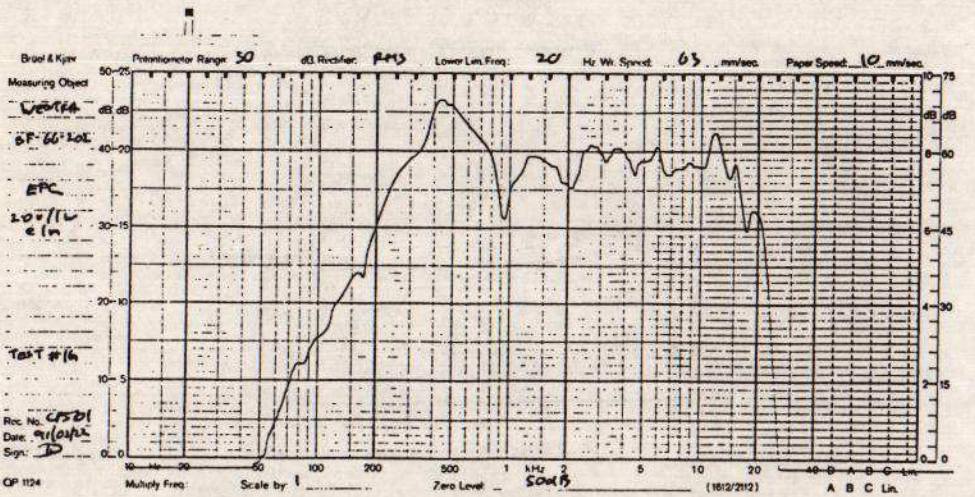

FIG. 6B