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The design of the miniature monitoring loudspeaker type LS3/5A

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Research Department, Engineering Division
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Summary

This report describes the design of a miniature two-unit loudspeaker of adequate sound quality and loudness to serve as a monitor in conditions where larger existing designs would be unusable.

Details are given of the construction and performance of the loudspeaker which is shown to be equally suitable for monophonic, stereophonic or quadraphonic purposes.

* **Designs Department**

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1. Introduction

There is a need to monitor sound programme quality in circumstances where space is at a premium and where headphones are not considered satisfactory. Such circumstances include the production-control section of a television mobile control-room, where the producer responsible for the overall production of the programme needs to monitor the output from the sound mixer but at levels lower than those used for mixing. Thus a small monitoring loudspeaker is required and, as no adequate commercial device was available, one was designed by BBC Research Department. The design is based on an experimental loudspeaker developed during the preliminary work on acoustic scaling described elsewhere[1] in which a small loudspeaker was needed to cover the frequency range from 400 Hz to about 20 kHz. When the characteristics of the loudspeaker were measured it was found that, despite the small size cabinet, the axial response/frequency characteristic was substantially uniform down to 100 Hz and that excellent sound quality was obtained with programme input. Subsequently, a number of loudspeakers to this design, known as type LS3/5, were made, and used in television mobile control-rooms where they gave very satisfactory service. When a further batch of loudspeakers was required it was found that the manufacturers of the low- and high-frequency units had made significant modifications and a re-design was therefore necessary. This was carried out in conjunction with BBC Designs Department and this report describes this later design, known as the LS3/5A. The Loudspeaker is now in production both by the BBC Equipment Department and also by three commercial licencees.

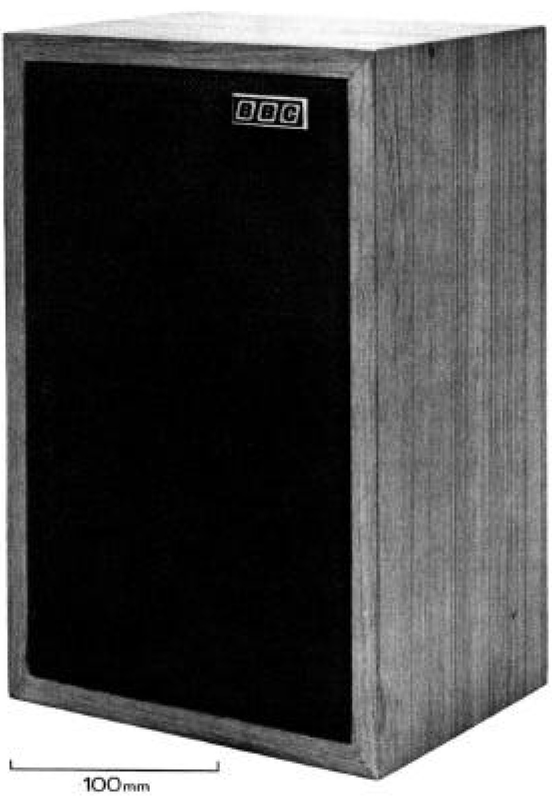

Fig. 1 - Appearance of loudspeaker

2. Description

(a) General

Fig. 1 shows the general appearance of the loud-speaker. The external dimensions are 31x19x16 cms (12x7½x6½ in) and the weight is approximately 5.3kg (11.6 lb). Its input impedance is nominally 15 ohms and it will accept the output of a 50 watt amplifier for programme signals and then gives a peak output level of +98 dB with reference to 2×10^{-5} N/m^2, measured at 1.5m in a room with 0.4 sec reverberation time. The loudspeaker is of the two unit type using a 127 mm (5 in) low-frequency unit and a high-frequency unit with a 20 mm (0.75 in) dome type radiator. The cross-over frequency is about 3 kHz.

(b) Cabinet

It has been indicated above that one of the objects of the design was to produce as small a loudspeaker as possible consistent with an adequate axial response/frequency characteristic. The cabinet has a free volume of a little under 5 litres (0.17 cuft.) and is of the closed type, as the use of a vent would not be helpful with such a small enclosure.

The construction is of 12 mm (½ in) birch plywood with fillets of beech. Although no difficulty was found with this construction for the original design (LS3/5), it was found that, for the LS3/5A, it was necessary to specify the wood more carefully than was originally thought necessary. The use of any type of hard wood such as Parana Pine for the fillets was found to be unacceptable as a clearly audible colouration was produced by a resonance of the l.f. unit on its chassis, and these fillets had insufficient mechanical impedance to reduce it; this matter is reported in more detail elsewhere.[2] In order to ensure that this resonance would not give rise to any further difficulties the side panels are damped with a layer of damping material and the top and bottom panels with two layers; in addition, a p.v.c. edging is

*Designs Department

applied to the chassis of the low-frequency unit so as to decouple it somewhat from the front panel. In order to damp the air modes of resonance inside the cabinet all internal surfaces except the front panel are lined with polyurethane foam; this has a thickness of 25 mm (1 in) on the top and bottom of the cabinet and 16 mm (¾") on the sides and back. The cabinet is sealed so as to prevent air leaks which could give rise to extraneous noises resulting from the high sound pressures produced inside the cabinet; even screw holes are made air tight.

(c) Units

The low-frequency unit is a KEF type B110 unit specially selected to BBC specification; the nominal impedance is 8 ohms and the free-air resonance frequency is 35 Hz (with a statistical spread having 95% confidence limits at 33 and 40 Hz).

The high-frequency unit is a KEF tweeter type T27 with a nominal impedance of 8 ohms and a nominal resonance frequency of 1200 Hz (95% confidence limits of 1000 and 1450 Hz). As the diaphragm of this unit is exposed and could therefore be easily damaged in use, it has been protected by a domed perforated metal cover. This has a small effect on the frequency response of the T27, which is wholly beneficial as it raises the output somewhat at high frequencies. The radiating surface of the T27 is small and the radiator is therefore nearly omnidirectional; in order to prevent the acoustic discontinuity presented by the edge of the cabinet from setting up an interference pattern, the tweeter is surrounded by a thick felt strip mounted on the baffle front surface.

(d) Equaliser/crossover network

The circuit diagram of the network used for this purpose is shown in Fig. 2. The inductance L_1 and the resistor R_1 are employed to equalise the generally rising axial response/frequency characteristic of the bass unit; the group C_5, L_2, R_2, compensates for a hump in this characteristic and the crossover frequency to the high-frequency unit is at about 3 kHz. For the high-frequency unit, inductor L_3 serves simultaneously as a shunt inductor for the crossover network, and as an auto transformer to allow different relative sensitivities of individual l.f. and h.f. units to be matched. When used for this purpose, capacitor C_2 is adjusted to keep the crossover frequency constant. This convenient form of network was first used in the design of the LS5/1 loudspeaker[3] and has proved to be very useful. R_3 serves as a damping resistor to prevent ringing, whilst R_4, and C_6 serve to adjust the frequency response at the upper end of the band.

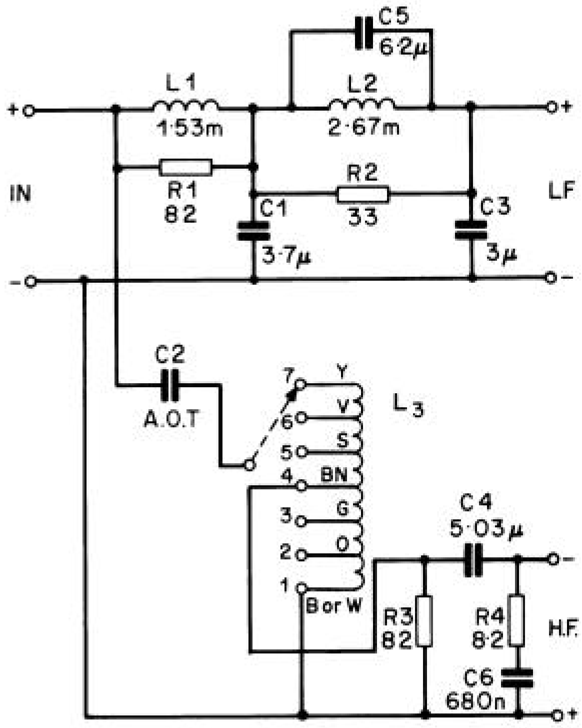

Fig. 3 - Circuit diagram of equaliser/crossover network

Physically the circuit board is mounted just behind the T27 unit and is prevented from resonating mechanically by means of a thick felt pad, placed between the board and the unit.

(e) Impedance

The modulus of the impedance is shown in Fig. 3. The nominal value is 12 ohms.

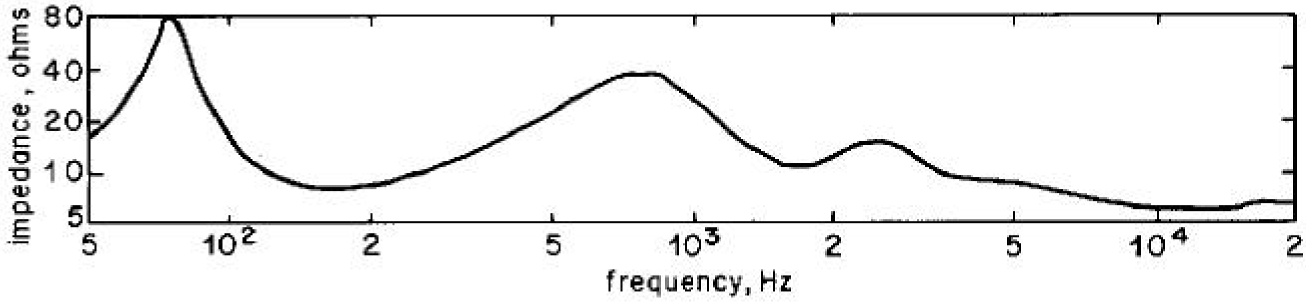

Fig. 2 - Modulus of impedance

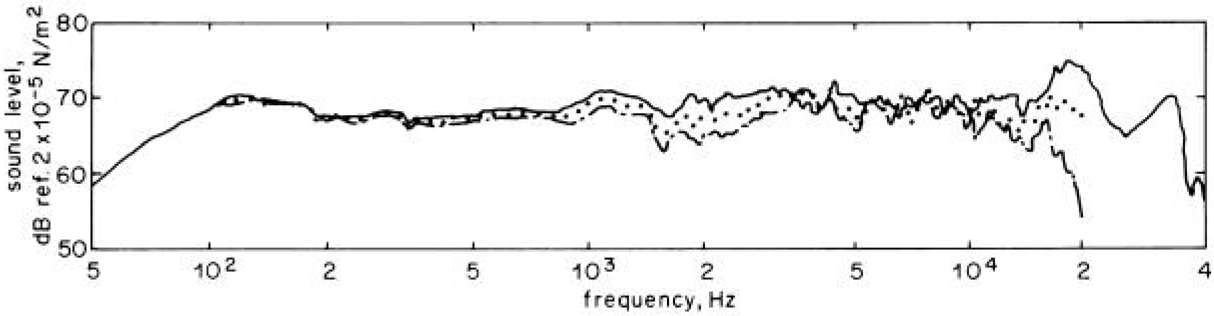

Fig. 4 - Response/frequency characteristics at1.5 m for various angles in the horizontal plane. 1V input.

————— 0º •••••• 30º –•–•–• 45º

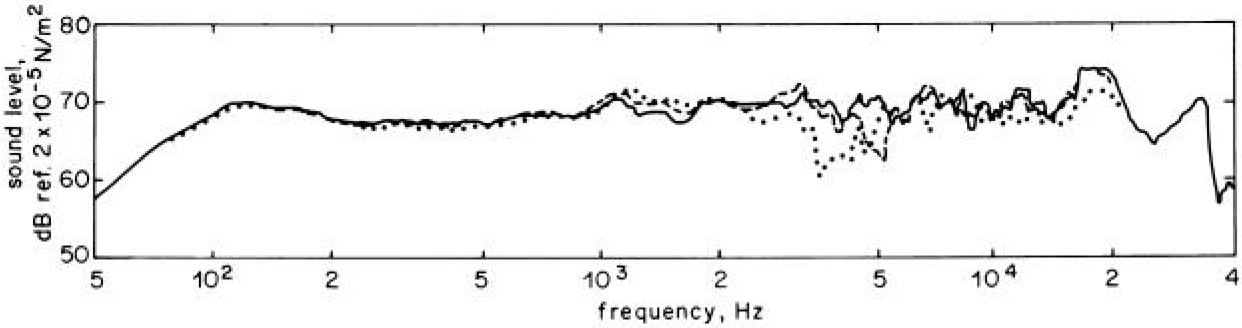

Fig. 5 - Response/frequency characteristics at1.5 m for various angles in the vertical plane. 1V input.

————— 0º ––––––15º •••••• 30º

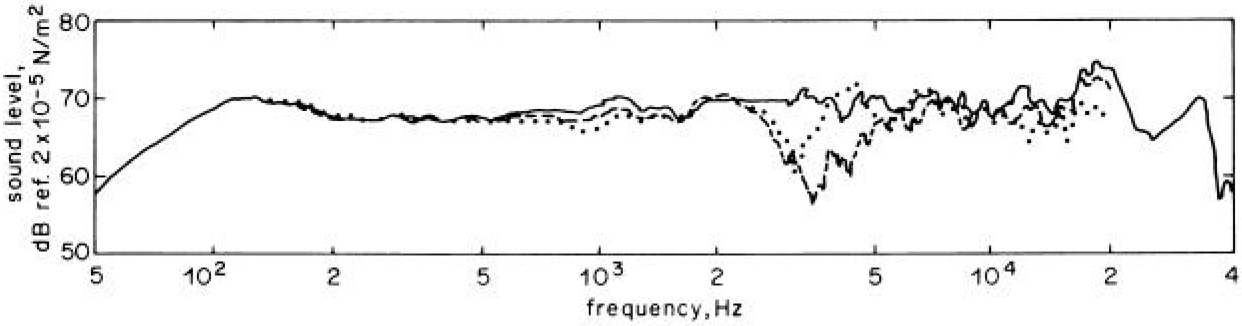

Fig. 6 - Response/frequency characteristics at1.5 m for various angles in the vertical plane below the axis. 1V input.

————— 0º ––––––15º •••••• 30º

3. Performance

The free-field response/frequency characteristics for a constant-voltage input are shown in Fig. 4 for various angular displacements in the horizontal plane; the measurement distance was 1.5 m. Figs. 5 and 6 show corresponding curves for the vertical plane, measured above and below the axis respectively, at the same distance from the loudspeaker.

Fig. 7 shows the results of sound measurements made on the cabinet itself. The axial response of the low-frequency unit at a distance of 25 mm (1 in) and the sound radiated from one side and from the rear of the cabinet at a similar distance are shown, using an uncalibrated microphone with a figure-of-eight characteristic. The audibility criterion is laid down elsewhere;[2] the radiation from the cabinet is below this criterion at almost all frequencies and is inaudible.

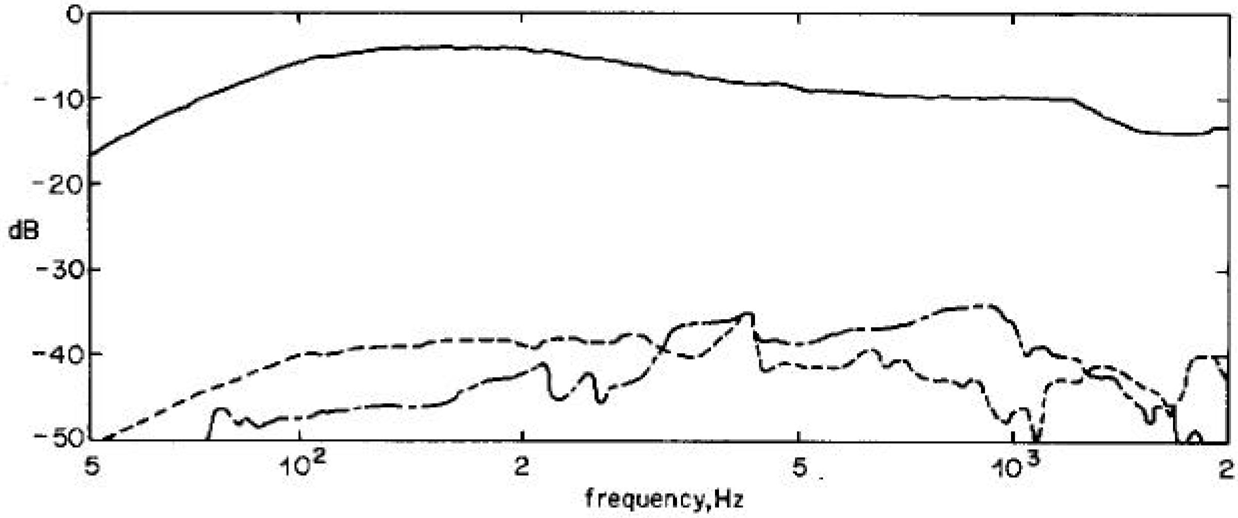

Fig. 7 - Response/frequency characteristics at 25 mm for l.f.unit and for centre of side and rear panels of cabinet.

———— cone – – – – – –side – • – • – • back

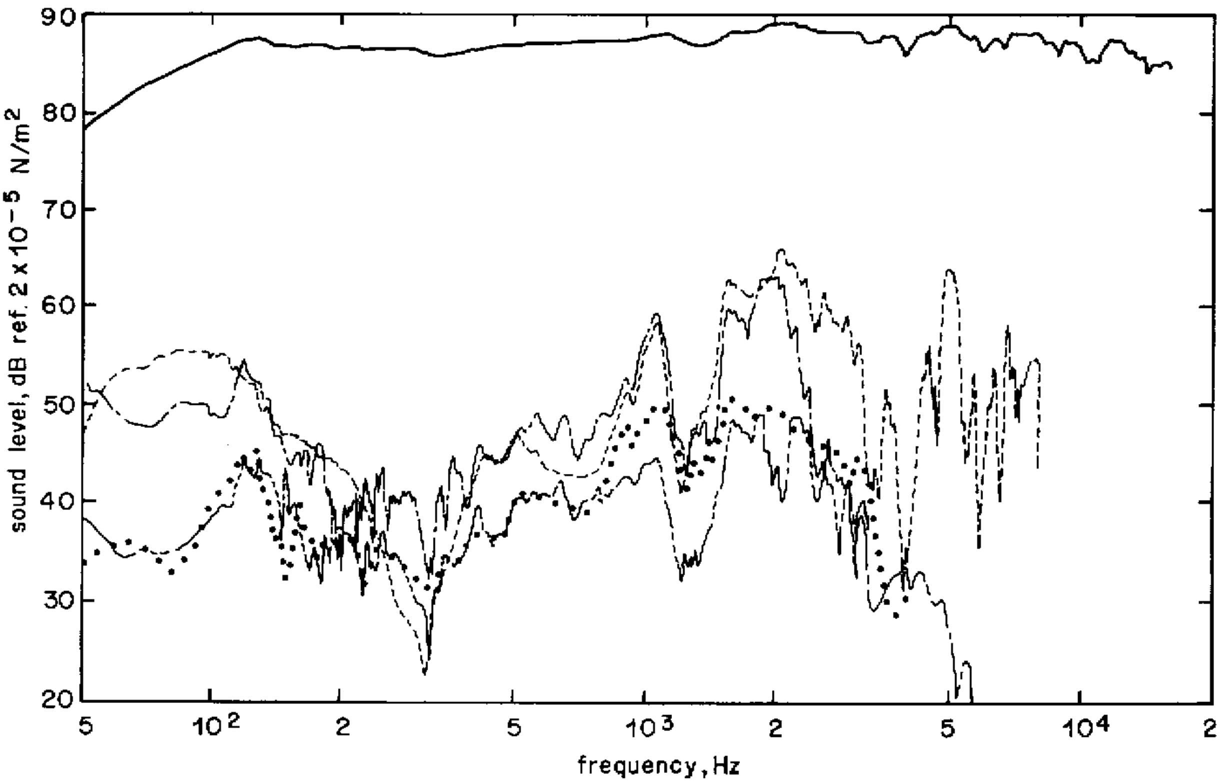

Fig. 8 - - Response/frequency characteristics at 1.5 m for fundamental and harmonics, on axis; for mean sound level of +88 dB w.r.t. 2 x 10^{-5} N/m^2.

———— Fundamental – – – – – – 2nd Harmonic – • – • – • 3rd Harmonic

• • • • • • • • • 4th Harmonic – •• – •• – •• 5th Harmonic

Fig. 8 shows the axial non-linearity distortion curves for various harmonics, as a function of frequency, the mean sound level was +88 dB w.r.t. 2×10^{-5} N/m^2 on the axis at 1.5 m, the highest safe steady state level for the h.f. unit. Fig. 9 shows the axial non-linearity distortion curves for various intermodulation products as function of frequency for the same sound level on the axis at 1.5 m from 1 kHz upwards; the two tones employed were 121 Hz apart[4] at equal levels. For both harmonic and inter-modulation tests the distortion is seen to be low.

The maximum sound level for programme material such as heavily limited pop music depends on the duration of the peaks. For a one second burst of pure tone at 150 Hz, a maximum input of 25 volts is permitted corresponding to a peak sound level of +97 dB w.r.t. 2×10^{-5} N/m^2 at 1.5 m. For a steady signal with a duration of 30 min the r.m.s. signal level causing the rated temperature of the voice coil to be reached is equivalent to a nominal input power of 30 watts, i.e. a sound level of +90.5 dB w.r.t. 2×10^{-5} N/m^2 at 1.5 m allowing for the increased resistance of the voice coil due to the high temperature. For heavily limited pop music these limits correspond to a maximum sound level of +98 dB w.r.t. 2×10^{-5} N/m^2.

The stereo performance was measured by assessing the width of a central stereo image, the tests were carried out in a listening room with a reverberation time of 0.35 s using speech as the input signal. The average image width for a team of 5 observers listening to full bandwidth speech was 6.6º* with a standard error of 1.3º. Tests were also carried out using octave bands of speech signal and the corresponding results are given in Table 1 together with the mean position of the image centre, the relative displacement of which would give rise to chromatic aberration.†

* For a centrally placed observer at the apex at a 60º triangle, the base being formed by the loudspeaker.

† As in the corresponding optical case, a condition where a nominally white image has a varying spectral density across its width.

4. Discussion

The axial response/frequency characteristic is extensive for such a small loudspeaker. It should be evident from the shape of the curve in the bass that the low-frequency unit is overdamped**; therefore the bass response could be still further extended either by reducing the sensitivity or by the equivalent of feeding it, not from a constant voltage source, but from a source with an impedance of about seven ohms, and redesigning the equaliser/crossover network for the bass unit. The penalty in either case would be a significant loss of efficiency. The sound distribution is seen to be quite wide in terms of angle of radiation and to vary smoothly with angle. Listeners off axis should therefore still receive good sound quality.

The cabinet does not contribute significant colouration, and the non-linearity distortion is low over the whole frequency range.

Finally, the subjective evaluation of the sound quality is very favourable, the stereo performance is shown to be excellent and the chromatic aberration of the image is, according to published data,[5] undetectable. This implies that the loudspeaker should be equally suitable for quadraphony, and it has already been used for experimental work in this area.

5. Conclusions

This report describes a small loudspeaker containing two units. The performance both for monophonic and stereophonic use is excellent and the sound level is adequate for many purposes. It is being used in applications additional to that for which it was originally designed, and it has been licensed for outside manufacture in quantity production.

** The resonance frequency of the bass unit in the cabinet is seen from Fig. 3 to be about 75 Hz.

Table 1 - Stereo performance

Octave band centre frequency, Hz	125	250	500	1K	2K	4K	8K
Central image width, degrees	8.2	8.0	6.8	6.2	5.6	6.4	5.0
Standard error, degrees	0.8	0	0.8	0.7	0.4	0.7	0.6
Image centre displacement, degrees	-0.2	-0.8	-0.5	0	+0.4	0	+0.3
Standard error, degrees	0.5	0.3	0.4	0	0.5	0.2	0.5

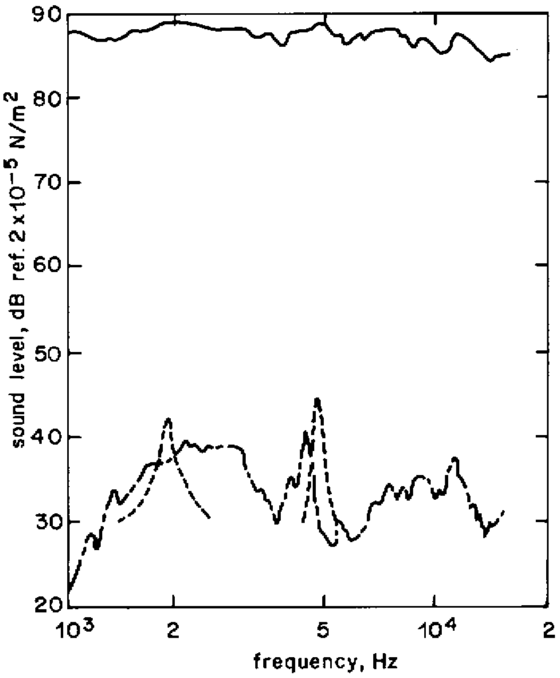

Fig. 9 - Response/frequency characteristics at 1.5 m for fundamental and intermodulation products, on axis; for mean sound level of +88 dB w.r.t. 2 x 10^{-5} N/m^2.

—————Fundamental

– – – – – 2nd Order Intermodulation

– • – • – • 3rd Order Intermodulation

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