

KEF KEFTOPICS

A technical bulletin covering aspects of development, design and use of loudspeakers.

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REFERENCE SERIES MODEL 105

Model 105 is the newest addition to the well-known Reference Series based on KEF's experience in the production of high-grade monitoring loudspeakers for sound and television broadcasting organisations. Its design is the result of a long-term development aimed primarily at avoiding the restrictions — particularly in stereo reproduction — imposed by the directional characteristics of conventional loudspeakers.

Although the project involved some advanced mathematical theory, the design objective was a very practical one, namely, that the high standard of sound quality and stereo realism to be achieved should not be confined to some preferred listening position, but should be maintained constant over a defined area large enough to accommodate a group of listeners.

Judging by the outward appearance of Model 105 in Figure 1, the most striking feature is the arrangement of the three drive units, two of which are mounted in a separate housing of somewhat unconventional shape. But this is only one aspect of a comprehensive development, in which drive units, filter networks, enclosures and spatial acoustics were all considered as part of an overall system-engineering plan.

This issue of KEFTOPICS describes the background to the Model 105 development and discusses some of the ideas on which the novel features of the loudspeaker system are based. The natural starting point for this discussion is the distribution of sound in the listening room, and its effect on various aspects of sound reproduction.

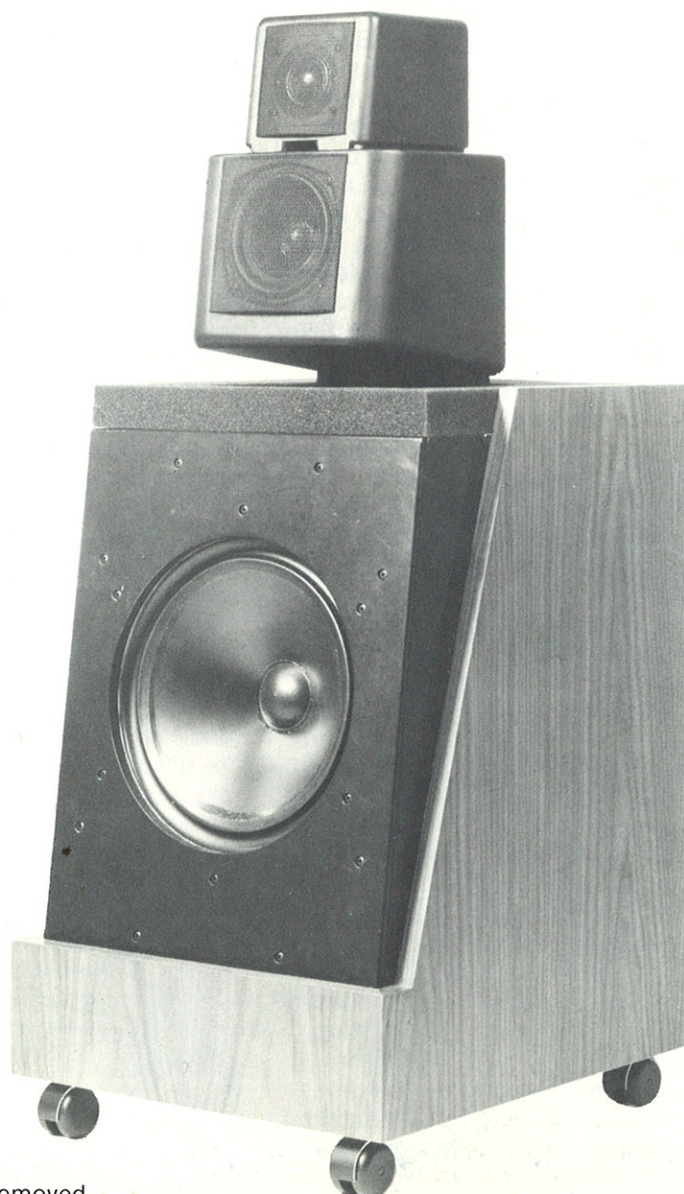


Fig 1 Model 105, grille cover removed

Direct Sound

The tonal quality and clarity of the reproduction, and above all, the sharpness of the stereo image, are determined by the sound that reaches the listener directly, without reflection from walls, floor or ceiling. Ideally, therefore, the frequency response of the loudspeaker, and hence the spectral content of the programme, should be constant over an area covering all the listeners.

In a multi-unit loudspeaker, the polar characteristics, i.e. the variation in response with the direction of radiation, depend on the size, shape and positioning of the drive units and of their enclosures, together with the crossover filters. Attention to all these factors in the design of the Model 105 has produced the striking result shown in Figure 2; the variation in frequency response with direction has been held, up to very high frequencies, within ± 2 dB for angles up to 20° on either side of the "design axis" shown in Figure 3, and within ± 1 dB for angles up to 5° above and below it. The design axis is tilted up by 4° from the horizontal, and is arranged to pass through a point 1.2 m (4') above floor level (a typical height for the ears of a seated listener) and 3 m (10') in front of the loudspeaker; the area enclosed by the $\pm 20^\circ$ horizontal and $\pm 5^\circ$ vertical limits constitutes a "listening window" which, even at 3 m distance, is 2 m (6'6") wide and 0.52 m (20") high — sufficient to provide optimum conditions for a small group.

To make the system still more flexible, the separate head assembly, which houses the middle- and high-frequency drive units, is designed to be rotated by $\pm 30^\circ$ horizontally and tilted by $\pm 7^\circ$ vertically, so that the listening window illustrated in Figure 3 can be placed to suit the convenience of the listeners without altering the position or outward appearance of the loudspeaker as a whole. The orientation of the head assembly is indicated by a light-emitting diode (LED) energised by the audio signal fed to the loudspeaker. The LED is masked so that the glow, which can be seen through the cloth cover, is

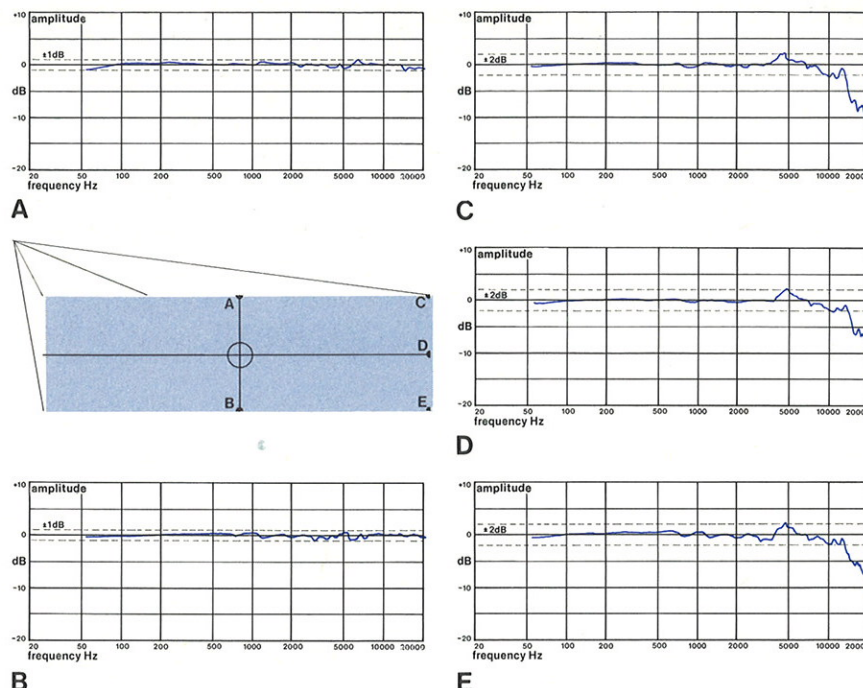


Fig 2 Curves showing the variations in frequency response at the extremes of the "listening window" expressed as deviations from the frequency response measured at 2m on the "design axis".

visible only within the optimum listening area. As long as every listener can see both lights of a stereo pair, there will be no blurring or instability of the images through differences in response of the left- and right-hand loudspeakers.

Indirect Sound

A significant factor in the overall quality of reproduction is the amount of sound that reaches the listener indirectly, after a short time delay, by reflection from walls, floor or ceiling; this should be sufficient to add warmth and ambience without, however, interfering with the sharp location of stereo images produced by the earlier direct sound. With most three-unit

loudspeakers, the proportion of indirect sound from the middle- and high-frequency units is restricted by the presence of the large enclosure required to give adequate bass response. In the Model 105, however, the head assembly is designed to provide the optimum form of baffle for each unit in its working frequency range, and the comparatively small frontal area allows more sound to reach the sides and rear of the loudspeaker than in systems of more conventional geometry. This improves the quality of the ambient sound and enhances the impression of depth without detriment to the stereo effect; in addition, it gives a more natural reproduction

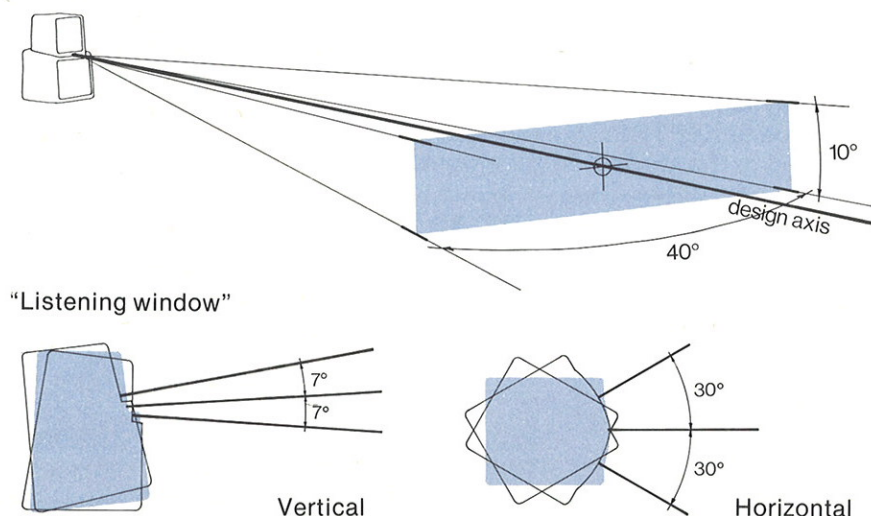


Fig 3 Range of adjustments of "listening window"

of small sound sources such as the human voice. To obtain the maximum advantage from the sound distribution of the Model 105, the loudspeaker should be placed at least 0.5 m (20") from the rear wall of the listening room.

Division of Frequency Range

To achieve the required directional characteristics, the audio-frequency range is divided, in the Model 105, between three drive units, each giving wide-angle radiation within its working band. A 300 mm (12") diameter cone drive unit operates up to 400 Hz, a 110 mm (5") diameter cone unit covers the range from 400 Hz to 2500 Hz, while a 50 mm (2") diameter unit with a domed diaphragm radiates frequencies above 2500 Hz.

Avoiding Interference

Ideally, all the sound sources in a multi-unit loudspeaker should be at the same distance from the listener; failure to meet this requirement leads to colouration of the sound through interference between different sources in the crossover regions. To achieve the maximum horizontal distribution of sound without interference effects, the drive units of the Model 105 are therefore mounted one above the other and so positioned that any point on the design axis is equidistant from all three sources.

Another potential cause of interference is the diffraction, i.e. the formation of secondary sources, which occurs when sound waves, spreading out at right angles to the driver unit axis, encounter an abrupt discontinuity at the edge of a box or baffle; the resulting colouration is particularly noticeable at off-axis listening positions. In the Model 105, these effects are reduced to negligible proportions by rounding off the front edges of the head assembly.

Because of the vertical separation between the different drive units (which is usually comparable with the wavelength of sound in the crossover regions), a listener located above or below the design axis cannot be exactly equidistant from all the sources. However, the vertical angle within

which the loudspeaker response is free from interference effects is large enough for practical purposes provided that the main lobe of the polar characteristic is symmetrical above and below the design axis; this latter requirement involves the characteristics of the crossover filters, which are discussed in the next section.

For the accurate location of the sound sources in a multi-unit loudspeaker, the position of the acoustic centre of each drive unit, i.e. the point at which the sound appears to originate, must be known. In designing the Model 105, this information was obtained by computer analysis of the sound produced by applying a short electrical impulse to the input of the unit concerned.* This analysis allows the results of the impulse test to be expressed in terms of frequency response and phase response. It also separates the phase shift associated with the frequency response of the unit (minimum phase shift) from the multiple phase rotations associated with the time taken for the sound to reach the measuring microphone; from this time delay, the position of the apparent sound source can then be calculated.

Crossover Filters

The design of crossover filters is complicated by the fact that drive units have in practice neither a flat frequency response nor a purely resistive impedance. The associated filter networks must therefore provide some degree of equalisation and, in addition, must function correctly while loaded with a complex impedance. Both these requirements are embraced by the concept of the "Target Function"**, which specifies the desired overall frequency response and phase response of the filter/unit combination, in the pass-band and in the cut-off region. By comparing the Target Function with the measured response of the unit alone, the response of the network required to make up the difference is determined; the final stage in the design is then to synthesise a filter which has the appropriate characteristics and which, in addition, presents an acceptable impedance to the

amplifier — a matter that will be considered later.

In principle, the overall response represented by the Target Function can be achieved only at a single position — that of the measuring microphone. In practice, with drive units such as those used in Model 105, the response is substantially constant over a sufficiently wide angle in the horizontal plane. In the vertical plane, however, the interference effects that arise in the crossover regions from the physical separation of the drive units are aggravated by any phase difference between the acoustic outputs. In a typical situation, the output of the high-frequency unit leads in phase over that of the middle-frequency unit mounted below it. In these circumstances, the maximum response — and hence the main lobe of the polar characteristic — occurs at some angle, below the design axis, at which the difference in distance from the two units is such as to bring their outputs into phase. In the region just above the axis, on the other hand, the two outputs are further out of phase, and at some angle must cancel each other at the crossover frequency. The net result of all this is that a small vertical displacement of the listening position from the design axis of the loudspeaker produces a large change in the spectrum of the direct sound, with peaks or dips at crossover.

Although various compromise measures may be adopted to minimise these effects, the only radical solution is to keep the acoustic outputs from the different drive units in phase at all frequencies. In the Model 105, this end is achieved by adopting

*"The Application of Digital Techniques to the Measurement of Loudspeakers", by J. M. Berman and L. R. Fincham (KEF Electronics Ltd.), *Journal of the Audio Engineering Society*, Vol. 25, No. 6, June 1977.

**"A Target Function Approach to the Design of Filters", *KEFTOPICS*, Vol. 2, No. 1.

***"Active Crossover Networks for Noncoincident Drivers", by Siegfried H. Linkwitz, *Journal of the Audio Engineering Society*, Vol. 24, No. 1, January/February 1976.

a Target Function having the response of a fourth-order Linkwitz-Riley filter***, equivalent to two second-order Butterworth filters in cascade and giving a cut-off slope of 24 dB/octave. With this Target Function, the main lobe of the polar characteristic coincides with the design axis of the loudspeaker at all frequencies.

Bass Loading

The method of achieving efficient transfer of power from the amplifier to the low-frequency drive unit of the Model 105 is a further example of the KEF system-engineering approach, in which the units, enclosures and electrical networks are all developed together. A new bass loading technique, involving the interaction between the electrical, mechanical and acoustic characteristics of the system, has been devised.

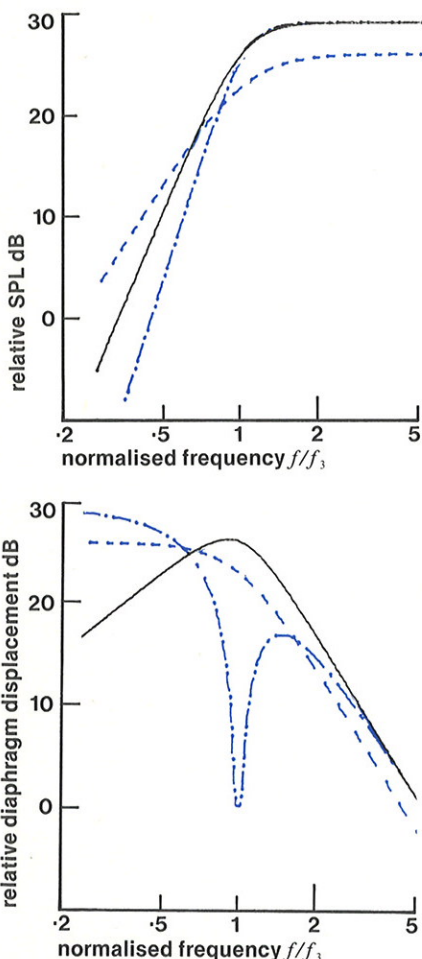


Fig 4 Comparative performance curves for three enclosures of identical internal volume and lower cut-off frequency (-3 dB at f_3).

- New KEF bass loading technique
- - - Reflex enclosure
- ... Closed box (IB)

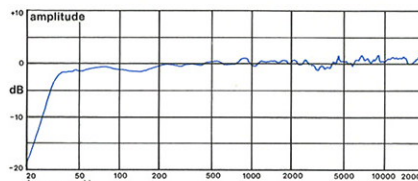
Normally, the rise in electrical impedance in the region of the low-frequency resonance reduces the current drawn by the drive unit from the amplifier, and as a result, the inherently high efficiency of the unit cannot be realised in this part of the frequency range. By re-matching the drive unit via a special electrical network, a better transfer of power has been achieved. This technique makes it possible to use a closed box (infinite baffle) without the loss of efficiency usually associated with this type of enclosure, and to extend the frequency response down to 38 Hz — with ample power-handling capacity on programme — while avoiding subsonic disturbances arising, for example, from record warp or amplifier d.c. offset. Figure 4 shows quantitatively the advantages of the new bass loading technique over the conventional closed box and reflex enclosures.

Drive Units

If the advanced design concepts outlined in the preceding sections are to be realised in practice, the characteristics of all the drive units must be accurately reproducible in commercial production, and must be stable over long periods of time. In the Model 105, these requirements are met by making the diaphragms and surrounds of modern plastic materials which are physically predictable and much less subject to change with temperature, humidity and ageing than the old-fashioned paper. The high-frequency drive unit has a domed Mylar diaphragm with an integral damped surround, while the middle- and low-frequency units have visco-elastic damped Bextrene diaphragms with PVC surrounds. Because of the high degree of internal damping, mechanical resonance is minimised, and the diaphragms act as a barrier to residual acoustic reflections from within their enclosures. The combination of these factors makes possible the unusually smooth overall axial frequency response of the Model 105, which is shown in Figure 5 together with its associated smoothly varying phase-frequency characteristic.

Enclosures

In designing the enclosures for the Model 105, special precautions were taken against colouration of the sound by mechanical resonance of the walls or acoustic resonance in the interior. The walls are internally braced and damped by laminated bituminous linings, while acoustic damping of the enclosed air space is provided by a further lining of cellular foam.



Effective free field response from 20 Hz-20 kHz, obtained using digital processing techniques

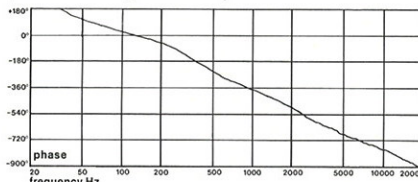


Fig 5 Frequency response of Model 105, measured at 2m on the "design axis" showing both the amplitude and phase characteristics.

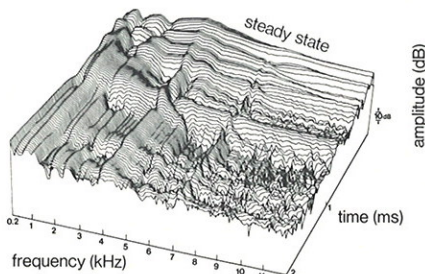


Fig 6 The use of cumulative decay spectra for investigating internal reflections inside enclosures.

In the development of these enclosures, the impulse test was again applied to good effect; this technique gives a sensitive indication of reflections or resonances and allows their origin to be quickly pinpointed. As an illustration of the method, Figure 6 shows a family of cumulative decay spectra, relating amplitude, frequency and time, obtained by computer analysis of impulse tests on an experimental loudspeaker. This three-dimensional figure may be regarded as the result of a set of tone-burst tests made at all frequencies simultaneously under ideal acoustic conditions. The ridge running parallel with the frequency axis at about

$t = 1$ ms represents a reflection from the rear wall of the enclosure.

Amplifier/Loudspeaker Compatibility

Modern high-quality loudspeakers are designed to reproduce programme material covering a wide dynamic range, and unless the associated amplifier is capable of delivering a peak power far in excess of the long-term average, wave-form clipping will occur from time to time. This happens more often than is generally realised, the resulting distortion being wrongly attributed to the loudspeaker. For the distortionless reproduction of programme at realistic sound levels, it is therefore necessary to provide amplifiers of adequate power rating in relation to the sensitivity of the loudspeaker. But amplifier power ratings relate to the performance with a purely resistive load, and give no guarantee of satisfactory operation when the load is a loudspeaker, the impedance of which may at some frequencies be largely reactive.

It is common in modern solid-state amplifiers to provide voltage-dependent current-limiting circuits to protect the output transistors from excessive power dissipation. The circuits detect the peak voltage across these transistors as well as the peak current passing through them, and are arranged to limit at progressively lower currents as the voltage increases. With a pure resistance load, the output transistors deliver their maximum current at the instant when the voltage across them is passing through its minimum. But if the load is almost entirely reactive, with only a small resistive component, the voltage across the transistors at the time of maximum current flow is much higher, so that more power is dissipated; the protective current-limiting circuit must therefore come into operation — producing waveform distortion — at a lower signal level than with a pure resistance load of the same magnitude.

Curves showing loudspeaker impedance against frequency usually give only the modulus or

magnitude, i.e. the ratio of voltage to current without regard to the phase angle between them. From this data, it is impossible to tell whether at any frequency the resistive component of an apparently adequate impedance is too low for satisfactory operation with certain amplifiers, and it is therefore preferable to plot the resistive and reactive components separately. Figure 7 shows the impedance of the Model 105 plotted in this way; it will be seen that the resistive component is never less than 70% of the nominal figure of 8 ohms.

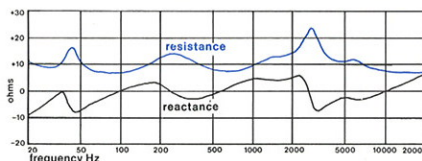


Fig 7 Impedance characteristics of Model 105

Whatever amplifier is used, it is necessary to set the signal level carefully so that even momentary overloading is avoided. To facilitate this operation, the LED provided in the Model 105 to indicate the orientation of the head assembly is made to serve also as a peak level indicator, which can be adjusted, by a pre-set switch graduated from 40 W to 200 W, to glow whenever the peak input voltage exceeds a value corresponding to the power rating of the particular amplifier in use.

Provided that peak overloading does not occur, the average power dissipated in the loudspeaker on programme will not cause any damage, even with a 200 W amplifier. However, to guard against accidents — for example, the rapid spooling of tape with the replay head in contact — the middle- and high-frequency drive units are each protected by a fuse having a thermal time-constant matched to that of the unit. These fuses are unaffected by short-duration programme peaks, which have negligible heating effect, but operate quickly if the voice coil temperature approaches the safe limit

The KEF Reference Series has now been extended by the addition of the Model 105, which represents the most advanced state of the art. In the design of this loudspeaker, the long-standing problem of obtaining the optimum spatial distribution of sound under practical conditions has been solved by a complete breakaway from conventional loudspeaker geometry — without detriment to the outward appearance — plus other technical refinements, including a new type of filter network having unusual phase characteristics.

The resulting natural quality of reproduction and the sharpness of the stereo images have been confirmed by many experienced and critical listeners. The success of this design provides yet another illustration of the way in which the traditional mysteries associated with high-quality sound can yield to the combination of advanced mathematical theory and good engineering practice.



Specification	Dimensions	965 x 415 x 455 mm (38 x 16.3 x 17.9 in.)
	Weight	36 kg (80 lb)
	Drive units	300 mm (12") low-frequency unit with 50 mm (2") high-temperature voice coil. Visco-elastic damped Bextrene diaphragm with PVC surround. 110 mm (5") middle-frequency unit with 25 mm (1") high-temperature voice coil. Visco-elastic damped Bextrene diaphragm with PVC roll surround. 50 mm (2") high-frequency unit with 38 mm (1½") voice coil. Mylar domed diaphragm with integral damped roll surround
	Enclosures	Low-frequency enclosure, 70 litres (4 270 cu. in.) Middle-frequency enclosure, 7 litres (427 cu. in.)
	Crossover frequencies	400 Hz and 2500 Hz
	Nominal impedance	8 ohms
	Programme rating	200 watts
	Characteristic sensitivity	86 dB spl at 1 m on axis for 1 watt (anechoic conditions)
	Maximum continuous sinusoidal input	35 V rms, 100 Hz to 400 Hz 28 V rms, 400 Hz to 2500 Hz 11 V rms, 2500 to 20 000 Hz
	Maximum output	107 dB spl on programme peaks under typical listening conditions
	Frequency response	38 Hz to 22 000 Hz ± 2 dB at 2 m on axis
	Directional characteristics	Horizontal: within ± 2 dB of axial response up to 13 000 Hz for $\pm 20^\circ$. Vertical: within ± 1 dB of axial response up to 20 000 Hz for $\pm 5^\circ$
	Peak level indicator	Switchable (a) to indicate power levels of 40, 50, 60, 80, 100, 125, 150 and 200 watts (b) to operate at low power levels while orientation of head assembly is being adjusted

