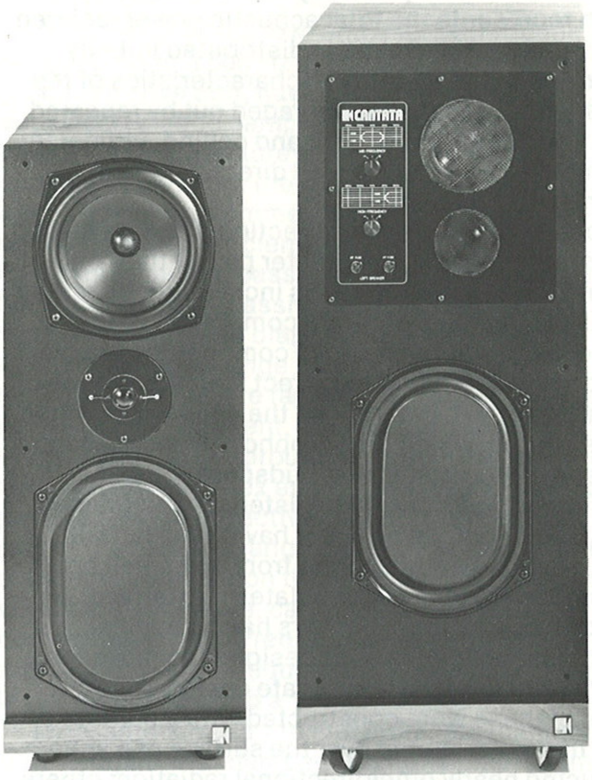
KEF KEFTOPICS

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

Volume 3 No 2



THE CALINDA AND CANTATA LOUDSPEAKERS

The Calinda and Cantata three-way loudspeakers are among the first KEF models to benefit from the technological innovations introduced by the Company during the last few years — in particular, the application of computer-based test methods* in both design and quantity production and the use of the Target Function concept** in the synthesis of crossover networks. These advances have made it possible to produce loudspeakers in the domestic size and price range with a standard of performance hitherto associated with professional equipment.

Like most modern loudspeakers, Calinda and Cantata have been designed to meet aesthetic requirements imposed on them as articles of furniture, and as a result, the outward appearance shows no sign of their special technical features. However, with the grille covers removed, as shown above, certain differences in the type and positioning of the drive units in the two models are apparent, and it will also be noticed that in both models the conventional placing of the mid-range and high-frequency units is reversed. These features, the reason for which may not be immediately clear, are in fact part of an overall system-engineering approach, in which the various components of each model — drive units, enclosures and filter networks — are developed together and optimised to fulfil a particular need; both designs are based on practical considerations of performance and cost-effectiveness, avoiding the kind of over-specification that may look impressive on paper but is irrelevant to the listener's requirements.

This issue of KEFTOPICS deals with the background and design philosophy of the Calinda and Cantata development, with particular reference to the individual technical features of each model.

*BERMAN, J. M. and FINCHAM, L. R.
(KEF Electronics Ltd.),
The Application of Digital Techniques to the Measurement of Loudspeakers
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*

Listening in Three Dimensions

The performance of a loudspeaker under practical conditions depends very much on the directional distribution of the radiated sound, and on the way in which this sound is modified by the listening room. The significance of these factors, which for a long time were ignored or misunderstood, can be appreciated by considering the different routes by which sound reaches the listener.

The first sounds to arrive are those which come direct from the diaphragms of the drive units, closely followed by reflections from near objects such as the floor, rear wall and side wall. The picture is then completed by the reverberant sound, which represents the total acoustic power radiated into the room; this sound is distributed initially according to the directional characteristics of the loudspeaker, but is then averaged out by repeated reflections from walls, floor and ceiling, ultimately reaching the listener from all directions with roughly equal intensity.

Most loudspeakers are directional except at the lowest frequencies; the greater part of their output is concentrated in front, thus increasing the ratio of the direct to the reverberant component of the sound. Even when these two components are of comparable intensity, the direct sound, because of its earlier arrival, determines the apparent position of the source, which in monophonic reproduction is therefore located in the loudspeaker itself. In the pre-stereophonic era, when listeners complained about the unnatural effect of having the output from a full orchestra coming from one small box, attempts were made to simulate an extended source by using loudspeakers having special directional characteristics designed to make the reverberant sound predominate over the direct. Some of these were constructed with a number of drive units distributed over the surface of a sphere, producing nearly omnidirectional radiation; others had units pointing at the walls or ceiling instead of towards the listeners. Unfortunately, the resulting reproduction lacked clarity, and its spectral content was critically dependent on the acoustics of the environment; moreover, the artificial spreading of the sound was quite inappropriate for small sources, such as the voice or solo instruments.

Experience with these "pseudo-stereophonic" devices, together with the advent of genuine stereophony, led eventually to a better understanding of the roles played by the direct and reverberant sound, and of the optimum relationship between the two. It is now generally recognised that the tonal quality of the reproduction and the sharp location of stereo images depend primarily on the direct sound, so that if these are not to vary unduly with the listener's location in the room, the response characteristic of the loudspeaker should be constant over an area covering all practical listening positions. With careful design, this ideal can be closely approached by dividing the audio-frequency range betwen two or three forward-facing drive units, each having a wide angle of radiation in its working band. The reverberant sound, on the other hand, provides a backing to the programme, adding warmth, ambience and depth, but should not be allowed to interfere with the quality or spatial distribution of the stereo images. Directional characteristics which meet these requirements can usually be achieved by attention to the geometry of the loudspeaker enclosure and the positioning of the units.

The first reflection from the rear or side wall of the listening room can lead to colouration if it arrives too soon after the direct sound. Loudspeakers should not, therefore, be placed too close to either wall; for the Calinda and Cantata, the minimum spacing is 0.5 m from the rear wall and 1.0 m from the side wall. The first reflection from the floor can also produce deleterious effects; this factor is however taken into account, as described later, in the design of the enclosure and the location of the drive units.

Measurement of Frequency Response

In the design and manufacture of a loudspeaker, a variety of objective tests, covering different aspects of the performance, are necessary. For comparison between different types, however, a matter of concern to the prospective customer, interest is usually centred in the first instance on the frequency response as the most important single criterion; not surprisingly, therefore, the method of measuring this characteristic,and the interpretation of the test results in terms of quality judged subjectively under practical working conditions,have been the subject of much discussion.

A loudspeaker, operating as it does in a three-dimensional space, has in fact an infinite number of frequency characteristics, each one corresponding to a different direction of radiation; some of these characteristics relate to the direct sound reaching various parts of the listening area, while all contribute to the quality of the reverberant sound. From time to time, it has been suggested that the frequency response of a loudspeaker measured in a "live" room would represent the combined effect of direct and reverberant sound as heard by a listener. Tests of this kind have been made in a variety of ways, for example, with multi-microphone arrangements intended to average the results over a number of different listening positions, or with microphones used in pairs in the hope of simulating binaural hearing. The fundamental defects of all such methods is that instead of the natural hearing mechanism, which involves both ear and brain, they substitute an arbitrary summation process in which information of practical importance is lost; in the final result, the smoothness or otherwise of the frequency response is obscured by the multiple resonances of the room, and it is impossible to tell how much this response varies over the listening area. The listener's hearing mechanism, on the other hand, takes advantage of the fact that the direct and reverberant components of the sound arrive at different times and from different directions, and is able to detect them separately; the overall auditory impression is derived by complex psycho-physical processes which cannot as yet be simulated in the laboratory.

In the present state of the art, therefore, the most realistic objective assessments of loudspeaker performance under practical conditions are those based on the time-honoured method of free-field testing. Measurements are made either with continuous signals in a non-reflecting environment or, taking advantage of modern digital technology, by computer analysis of impulse tests in which the required information is collected and stored before any reflections arrive. For most purposes, it is sufficient to indicate the quality of the direct sound by presenting a series of frequency response curves taken at a number of angles, in both horizontal and vertical planes, covering the designated listening area. Additional response measurements can be made at angles outside this area, but there is no simple way in which these can be used to assess the quality of the reverberant sound heard by the listener, which in any case depends on the unknown acoustics of the room. In the development of a new design, therefore, the overall effect needs to be checked subjectively in a number of representative listening environments.

Enclosures

The starting point in most loudspeaker designs is the enclosure volume, since this determines how far downwards the low-frequency response can be extended while keeping the electrical/acoustical conversion efficiency high enough to avoid making unreasonable demands on amplifier power. In addition to such technical factors, however, the decision has to take into account the amount of space the user can spare and the fact that a well-designed enclosure will represent an appreciable fraction of the total cost. From these considerations, the volume of the Calinda was fixed at 45 litres, and that of the Cantata at 60 litres.

For a given volume, the optimum ratio between width, depth and height is determined by a combination of technical, aesthetic and practical requirements. For good sound distribution, a narrow enclosure is preferable; in addition, the mid-range and high-frequency units should be placed well away from the floor, reflections from which can produce pronounced colouration in the voice-frequency range (a phenomenon that can be easily demonstrated by getting someone to kneel and speak from a point some 300 mm above the carpet). To meet these two requirements, the Calinda and Cantata enclosures are designed to give, in each case, the maximum height and minimum width consistent with acceptable appearance and complete mechanical stability.

In spite of all the inorganic materials and associated moulding techniques now available, most loudspeaker enclosures are still constructed — and with good reason — of wood or wood products, and have a straightforward rectangular form that has survived the ephemeral changes of fashion. Wood is the natural material for an article of furniture, and the rectangular structure avoids unnecessary cabinet work. For all its outward simplicity, however, a well-designed enclosure must incorporate a number of refinements in construction to prevent it from being a source of colouration. The enclosure walls, for example, if allowed to vibrate freely, would act as sound sources having an area greater than the diaphragms of the drive units. In the Calinda and Cantata, wall resonance is inhibited by internal bracing at strategic points, and by the damping effect of a laminated bituminous lining; air cavity resonance is also damped by an additional lining of plastic foam.

Division of Frequency Range

The choice of different drive units for the Calinda and Cantata and the division of the audio-frequency range between the units are determined, directly or indirectly, by the dimensions of the enclosures in each case.

In the Calinda, the low- and middle-frequency range 45 Hz to 3 500 Hz is covered by a 200 mm (nominal) drive unit, having a Bextrene diaphragm with visco-elastic damping for low colouration, and a high-temperature voice coil assembly capable of handling the output of a 100 watt amplifier on programme. To achieve maximum band-width and efficiency with the chosen enclosure volume, bass loading is provided by a 300 mm x 210 mm passive radiator unit with a flat-fronted polystyrene diaphragm, which extends the useful frequency range downwards to 23 Hz (–10 dB). The passive radiator or "drone" operates rather like a reflex vent, but has the advantage of eliminating the air turbulence distortion that often occurs in small reflex enclosures. In addition, it provides a more effective barrier to sound from the rear of the low/mid-range unit; this sound, which is subject to colouration through residual reflections within the enclosure, can escape freely from a conventional vent. Frequencies above 3 500 Hz are radiated by a high-frequency unit with a 27 mm Mylar diaphragm and a 19 mm voice coil.

The Cantata has a 110 mm (nominal) mid-range unit — again with damped Bextrene diaphragm and high-temperature voice coil assembly — covering the range 250 Hz to 3 000 Hz. For the frequency range below 250 Hz, a 300 mm x 210 mm unit having a flat-fronted diaphragm of aluminium-reinforced polystyrene is used as an active driver with "infinite baffle" loading; the useful low-frequency response extends down to 28 Hz (–10 dB) with ample power-handling capacity on programme without risk of distortion or damage resulting from subsonic signals. The frequency range above 3 000 Hz is covered by a unit with a 52 mm Mylar diaphragm and 39 mm voice coil, designed to match the high efficiency and programme power rating — 150 watts — obtained with the 60 litre enclosure in the middle and low-frequency ranges.

Crossover Filters

In designing crossover filters, allowance has to be made for the fact that drive units have in practice neither a flat frequency response nor a purely resistive impedance. Both these factors are taken into account by basing each filter design on a "Target Function", which represents the overall response that the filter/drive unit combination must have in order to give a smooth transition at crossover and an adequate degree of attenuation in the cut-off region. This function — which in the case of the Calinda and Cantata takes the form of a

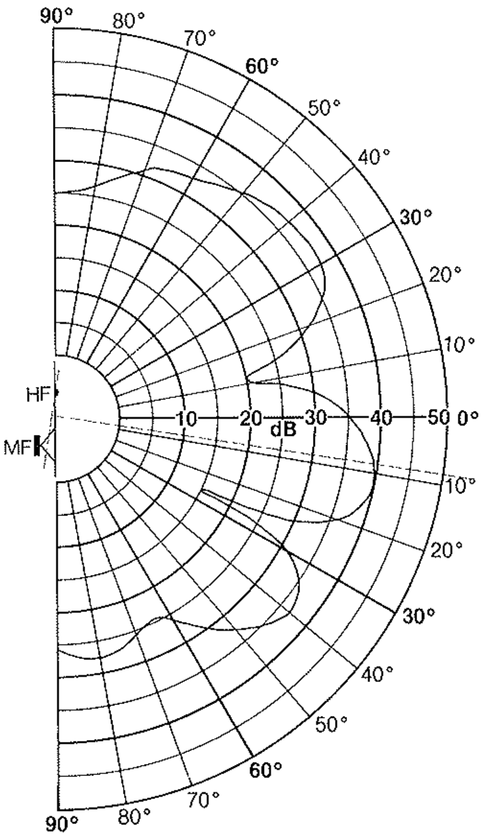


Fig. 1. *Vertical-plane polar characteristics at crossover, high-frequency unit mounted above mid-range unit.*
— — — Axis of zero inter-unit time delay.

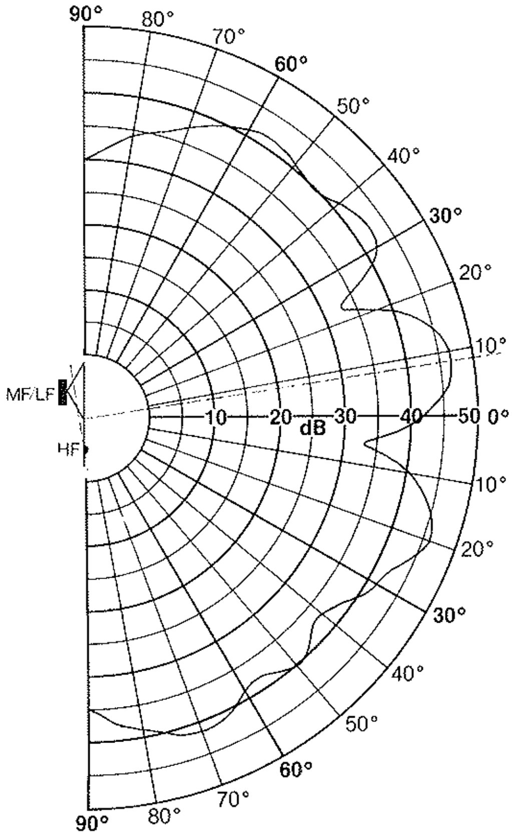


Fig. 2. *Vertical-plane polar characteristics at crossover, mid-range unit mounted above high-frequency unit (Calinda).*
— -- — Axis of zero inter-unit time delay.

third-order Butterworth filter response with 18 dB/octave cut-off slope — is then compared with the measured response of the drive unit alone, and a network is designed which, when loaded with the impedance of the unit, has the exact characteristic required to make up the difference. In synthesising this network, additional restrictions are imposed to ensure that the input to the loudspeaker system as a whole will present an acceptable impedance to the amplifier — a matter that will be considered further in a later section.

Avoiding Interference

In both the Calinda and Cantata loudspeakers, the drive units are positioned to optimise the overall response as measured on a "design axis" passing through a typical listening location — 1.2 m above floor level at 3 m distance — and to maintain the same response within close limits over an area large enough for most practical purposes.

In a multi-unit loudspeaker, all the sound sources should ideally be at the same distance from the listener (at least to within a small fraction of a wavelength) to avoid interference in the crossover region through inter-unit time delay; this requirement is particularly important in relation to mid-range and high-frequency drive units, for which the wavelength at crossover is of the order of 100 mm. For maximum horizontal distribution of sound without interference effects, the units should therefore be mounted one above the other. Because of the unavoidable separation between units, the vertical angle, above and below the design axis, within which the overall response can be maintained substantially constant, is limited by the interference which occurs when the listener is no longer equidistant from the different sound sources; however, this angle can be made large enough for practical purposes provided that the design axis is properly located in the first place.

The acoustic centre of a high-frequency drive unit, i.e. the point at which the sound appears to originate, lies approximately in the plane of the panel on which the unit is mounted, while that of a mid-range unit is located further back, a short distance in front of the voice coil (the exact position can be determined by computer analysis of the impulse response). When the high-frequency unit is mounted, in the conventional way, above the mid-range unit, the axis of zero inter-unit time delay is therefore tilted downwards as in Figure 1. which refers to an otherwise well-designed two-way system. If the acoustic outputs from the two units in the crossover region were in phase, the main lobe of the vertical-plane polar characteristic would coincide with the axis of zero inter-unit time delay; in practice, however, there is usually a phase difference (90° at crossover in the case of a third-order filter), and as a result, the main lobe is tilted downwards even further, as shown in the figure. Sound is thus directed away from the listening area and towards the floor, producing unwanted reflections; moreover, a typical listening position, instead of lying within the main lobe, may coincide with the much narrower subsidiary lobe above it or — worse still — with the minimum between the two, so that a small vertical displacement produces

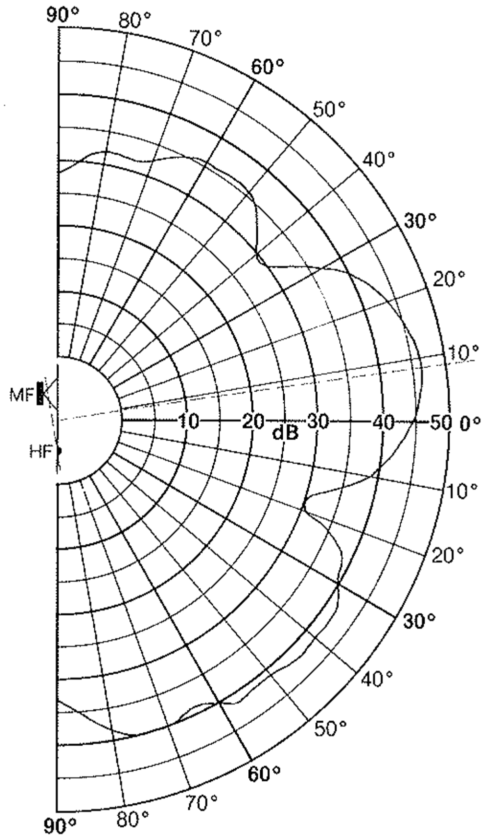


Fig. 3. *Vertical-plane polar diagram of Cantata at crossover, with mid-range unit mounted above high-frequency unit.*
— — — *Axis of zero inter-unit time delay.*

a large change in response in the crossover region, and hence in the spectrum of the direct sound.

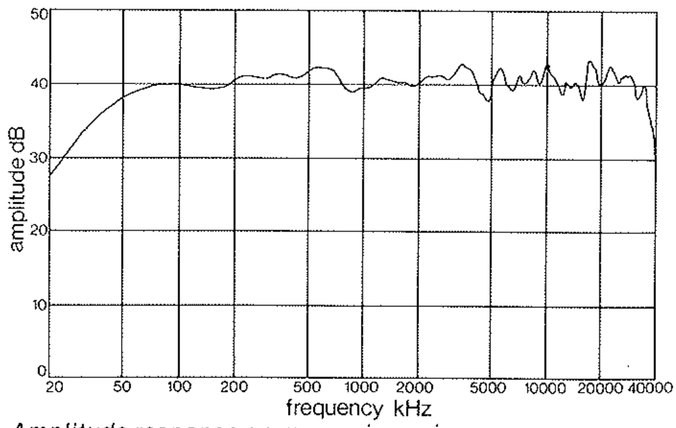
In the Calinda and Cantata loudspeakers, these difficulties are overcome by mounting the mid-range unit above the high frequency unit, as in Figures 2 and 3 so that the axis of zero inter-unit time delay is directed upwards into the listening area and by modifying the design of the crossover network so that the outputs from the two drive units in the crossover region are approximately in phase, thus avoiding displacement of the polar lobe.

Finally, the mid-range and high-frequency drive units in the Calinda and Cantata are positioned to obtain the smoothest possible frequency response by minimising the effects of diffraction, i.e. the formation of secondary sound sources, at the top and side edges of the front panel of the enclosure. For the Cantata enclosure, the optimum performance is obtained with the two units mounted off centre; to preserve symmetry in stereo reproduction, this model is therefore manufactured in mirror-image pairs.

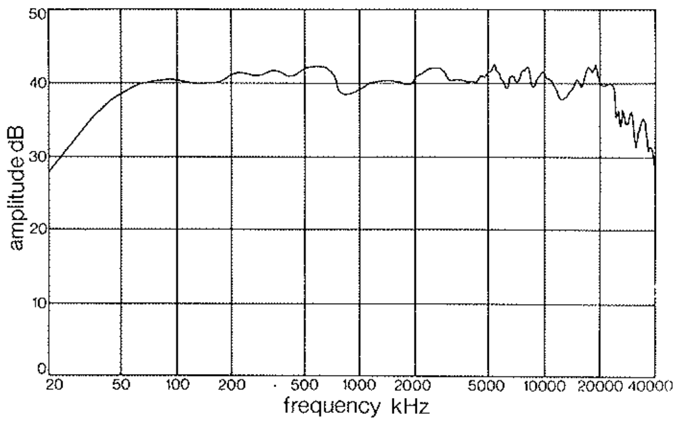
Frequency Response and Phase Response

The end product of the various design features outlined above is illustrated in Figures 4 and 5, which shows the frequency characteristics of the Calinda and Cantata, measured at a distance of 2 m* at different angles to the design axis. These results were obtained by computer analysis of the impulse response, a process which gives not only

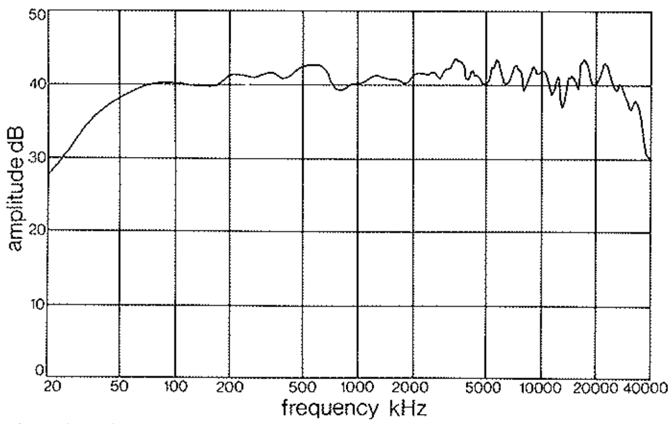
*Two metres is the closest range for which the frequency response is independent of distance.



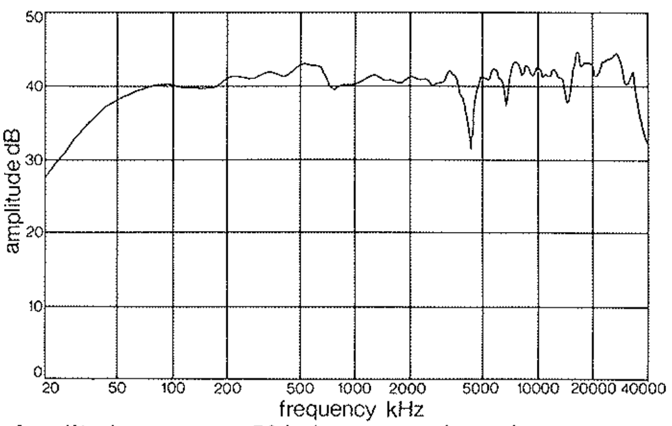
Amplitude response on measuring axis.



Amplitude response 20° off measuring axis horizontally.

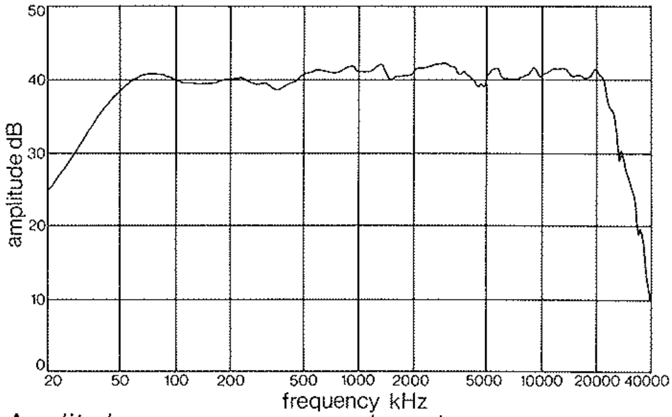


Amplitude response, 5° above measuring axis.

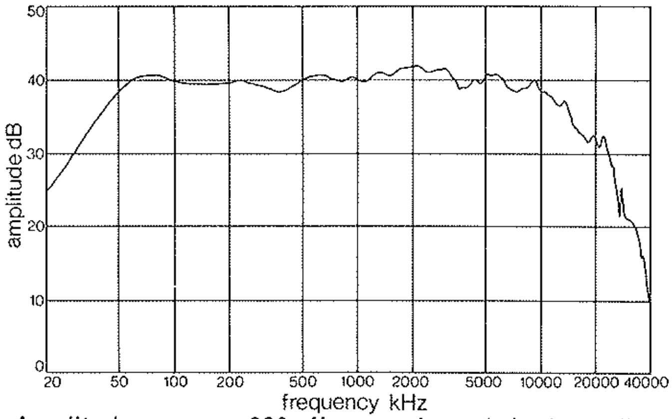


Amplitude response, 5° below measuring axis.

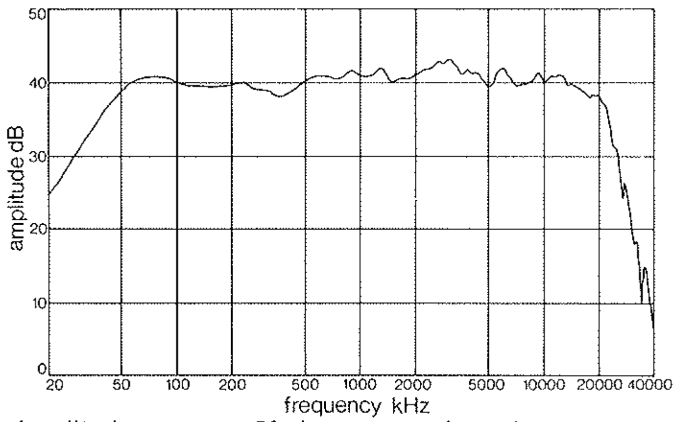
Fig. 4. *Effective free-field response of Calinda measured at 2 m* at various angles in the horizontal and vertical planes, using digital processing techniques.*



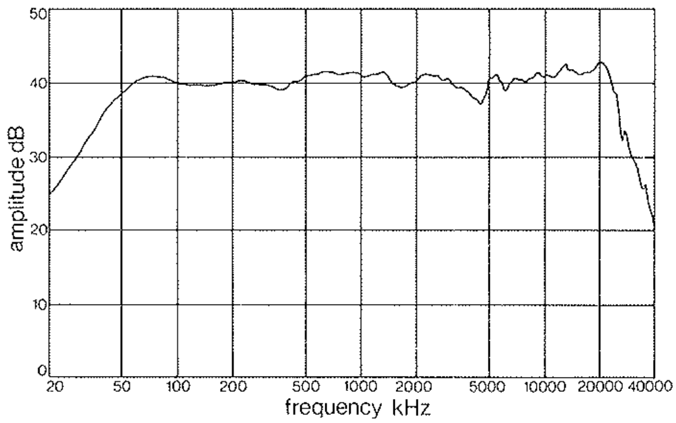
Amplitude response, on measuring axis. Both controls at 'ref'.



Amplitude response 20° off measuring axis horizontally. Both controls at 'ref'.



Amplitude response, 5° above measuring axis. Both controls at 'ref'.



Amplitude response, 5° below measuring axis. Both controls at 'ref'.

Fig. 5. *Effective free-field response of Cantata measured at 2 m* at various angles in the horizontal and vertical planes, using digital processing techniques.*

the effective free-field amplitude/frequency characteristic but also the associated smoothly-varying phase/frequency characteristic shown in Figure 6. It will be seen that the frequency response of both models, and hence the spectral content of the reproduced programme, is maintained constant within close limits over an area sufficient for most practical listening conditions.

Acoustic Balance Control

In normal circumstances, the tonal quality obtained from a loudspeaker is mainly determined, as already pointed out, by the direct sound reaching the listener, the reverberant sound providing a background which in general is beneficial. Unfortunately, however, the acoustics of some domestic environments are abnormal to the extent of imparting to the reverberant sound a degree of colouration that cannot be ignored. To mitigate the effects of such abnormalities, the Cantata loudspeaker is provided with acoustic balance controls (accessible by removing the grille cover), which allow independent adjustment of response in the frequency ranges from 300 Hz to 3 000 Hz and from 3 000 Hz upward by ± 2 dB — the maximum change that can be made without unduly affecting the quality of the direct sound. The curves in Figure 4 (b) were taken with the acoustic balance controls set for level response; Figure 7 shows the degree of variation obtainable at different settings.

Amplifier/Loudspeaker Compatibility

For the realistic reproduction of programme material having a wide dynamic range, it is essential to provide amplifiers capable of delivering enough power to handle the highest peaks without overloading. The Calinda is designed for operation with amplifiers up to 100 watts rating; with the Cantata, amplifiers rated up to 150 watts may be used.

It should be remembered that amplifier power ratings refer to the output that can be delivered to a pure resistance load, and give no indication of what may happen when the load is a loudspeaker having a complex impedance. Modern amplifiers are often provided with current-limiting devices to protect the output transistors against overheating. If at some frequency the loudspeaker impedance is predominantly reactive, with only a small resistance component, then for signals at that frequency, the danger point is reached, and current-limiting distortion sets in, at a level well below the rated amplifier output. To avoid this situation, it is necessary, when designing a loudspeaker with its crossover networks, to consider both the resistance and reactance components of the impedance, and to ensure that the resistance never falls too low. By the same token, published curves of loudspeaker impedance versus frequency should preferably give both components, and not just the modulus (magnitude). Figure 8 (a) and (b) shows the complex impedance of the Calinda and Cantata respectively; in neither case does the resistance component fall below 65% of the nominal loudspeaker impedance of 8 ohms.

Both the Calinda and Cantata can handle their maximum rated amplifier outputs under normal programme conditions without risk of damage. For

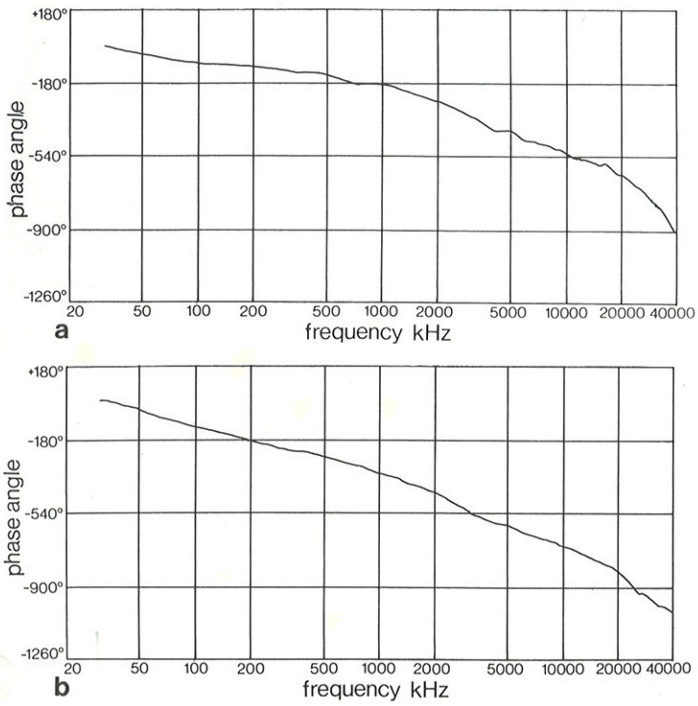


Fig. 6. *Effective free-field phase response of (a) Calinda, (b) Cantata, measured at 2 m* on design axis, using digital processing techniques.*

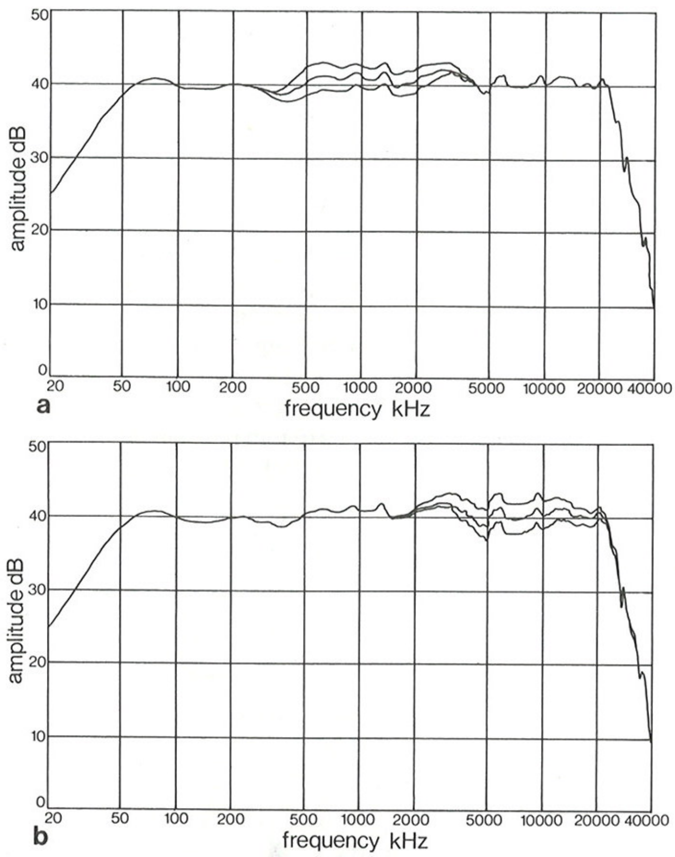


Fig. 7. *Effect of Acoustic Balance Controls (a) on mid-frequency response and (b) on high-frequency response of Cantata.*

protection against accidental overloading, for example, through rapid spooling of tape recordings the mid-range and high-frequency drive units of the Cantata are fitted with fuses having appropriate thermal time constants; these fuses are unaffected by signal peaks too short in duration to produce significant heating, but operate quickly if the voice coil temperature approaches the safe limit.

In the foregoing discussion, some of the less obvious factors in loudspeaker operation have been considered. The Calinda and Cantata are examples of the way in which a knowledge of these factors, coupled with a sound functional design approach, can lead in each case to an exceptional combination of performance and cost-effectiveness.

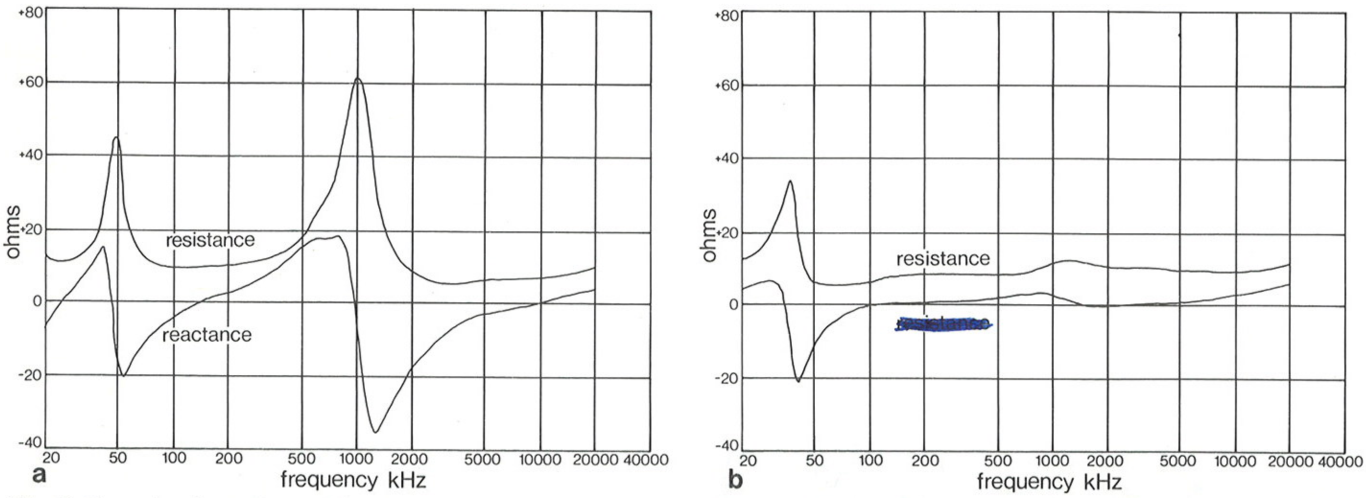


Fig. 8. *Complex impedance of (a) Calinda, (b) Cantata.*

Calinda

Dimensions	700 x 280 x 350 mm
Weight	19.1 kg
Drive Units	200 mm low-frequency unit with 33 mm high temperature voice coil. Visco-elastic damped Bextrene diaphragm with PVC surround. 27 mm high-frequency unit with 20 mm voice coil. Mylar domed diaphragm with integral damped roll surround. 300 mm x 210 mm passive radiator with flat fronted polystyrene diaphragm.
Enclosure	Passive radiator tuned mechanical reflex system, 45 litres volume. System resonance 23 Hz.
Dividing Frequencies	45 Hz and 3 500 Hz
Nominal Impedance	8 ohms
Programme Rating	100 watts
Frequency Response	40 Hz to 30 000 Hz ± 2 dB at 2 metres on axis
Characteristic Sensitivity	83 dB spl at 1 metre on axis for 1 watt (band-limited pink noise, anechoic conditions)
Maximum Continuous Sinusoidal Input	28 V rms, 100 Hz to 3 500 Hz 8 V rms, 3 500 Hz to 20 000 Hz
Maximum Output	102 dB spl at 1 metre on programme peaks under typical listening conditions

Cantata

Dimensions	815 x 340 x 392 mm
Weight	31.7 kg
Drive Units	300 mm x 210 mm low-frequency unit with 50 mm high temperature voice coil. Aluminium-reinforced polystyrene diaphragm with synthetic rubber surround. 110 mm mid-frequency unit with 25 mm high temperature voice coil. Visco-elastic damped Bextrene diaphragm with PVC roll surround. 52 mm high-frequency unit with 39 mm voice coil. Mylar domed diaphragm with integral damped roll surround.
Enclosure	Low-frequency enclosure, 60 litres system resonance 36 Hz. Q = 0.7
Dividing Frequencies	250 Hz and 3 000 Hz
Nominal Impedance	8 ohms
Programme Rating	150 watts
Frequency Response	35 Hz to 20 000 Hz ± 3 dB at 2 metres on axis
Characteristic Sensitivity	84 dB spl at 1 metre on axis for 1 watt (band limited pink noise, anechoic conditions)
Maximum Continuous Sinusoidal input	20 V rms, 100 to 250 Hz 28 V rms, 200 to 3 000 Hz 10 V rms, 3 000 to 20 000 Hz
Maximum Output	106 dB spl on programme peaks under typical listening conditions

KEF Electronics Limited Tovil Maidstone ME15 6QP Kent ☎ 0622 672261
Registered in England No 702392

Printed in England and Published by KEF Electronics Limited

Part No.KT3.2E1078