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REPORT

Design of the high-level studio
monitoring loudspeaker type LS 5/8

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DESIGN OF THE HIGH-LEVEL MONITORING LOUDSPEAKER TYPE LS 5/8

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Summary

A new studio monitor is described which can provide high-quality sound at sufficiently high levels to fulfil the complete range of monitoring requirements from pop to serious music. The design principles and criteria are outlined, and the performance of the prototypes is assessed both subjectively and objectively.

Issued under the authority of



Head of Research Department

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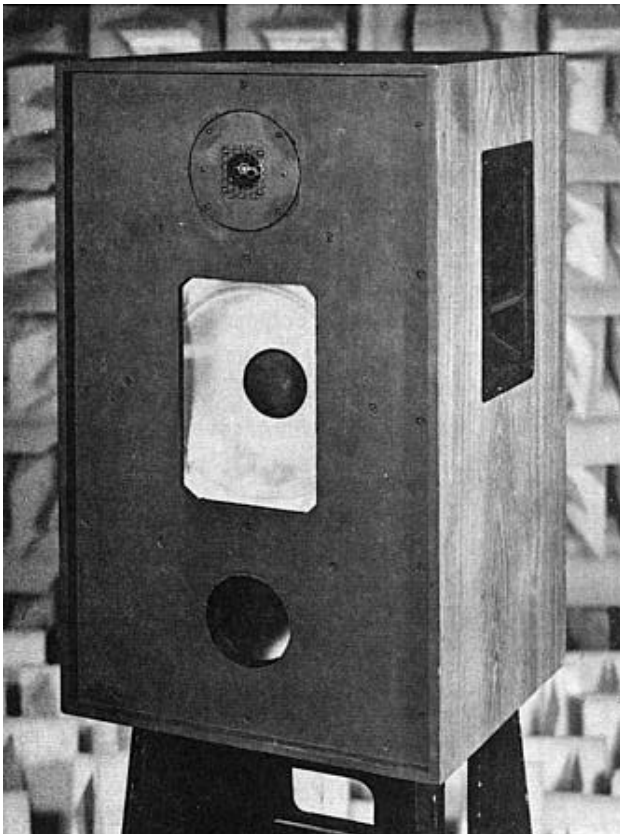
C.D. Mathers, M.Sc., M.I.E.E.

1. Introduction

Of late, the need has arisen in the BBC for new studio monitoring loudspeakers in two distinct fields of application. One is the balancing of pop and light music, for which high sound levels are required; the other is the balancing of serious music, in which the main requirement is for clean uncoloured sound quality.

The introduction by a British manufacturer of a new type of low-frequency drive unit led to a loudspeaker design that could fulfil both of the BBC's requirements. Designated the LS 5/8,* and shown in Fig. 1, the new monitor has undergone field trials in a number of studios and has so far elicited a very favourable response from the majority of users.

* The original LS 5/8 design, from which no fundamental departures have been made, was by H.D. Harwood, who recently retired from BBC Research Department.



*Fig. 1 - Prototype LS 5/8
(with front grille removed)*

This Report describes the most important features of the LS 5/8 design, and emphasises the fact that listening rather than measurement has been the criterion for final optimisation.

2. General design considerations

The starting point of this loudspeaker design was defined by the following essential requirements:

1. The ability to generate high sound pressure levels (at least 110 dB(A) at 1m distance).
2. Low coloration,* particularly at mid-frequencies to enable the monitor to be used for balancing serious music.
3. The ability to produce a sharply defined stereo image.

A desirable, but not essential, objective was that, if possible, the required frequency range (40 Hz to 16 kHz) should be achieved using only two drive units. Addition of a third unit to cover the mid-frequencies (as in the previous design, the LS 5/5) greatly increases the complexity of the crossover circuitry,² and adds considerably to the weight, cost and initial setting-up time of the completed assembly.

3. Drive units

3.1. Low-frequency unit

The bass unit is of the conventional moving-coil type with a 300mm vacuum-formed thermoplastic diaphragm and surround. However, it does incorporate several novel features. Chief of these is the choice of diaphragm material, polypropylene instead of the more usual rubberised polystyrene ('Bextrene'). The new material is light (s.g. 0.9)

* The term 'colorations' is used in this Report to describe tonal effects which, although clearly audible, do not usually show up in steady-state measurements. They are believed to be due to mechanical resonances in the drive units.¹

and is mechanically much more lossy than Bextrene, so that no additional mass of damping material is required: the greatly reduced moving mass provides an increase in sensitivity of about 4 dB over that of comparable Bextrene units like LS 2/1.³

To maintain a low LF resonant frequency (about 30 Hz) with so light a diaphragm, the surround and spider must be very compliant; a very light surround material (thin plasticised PVC) provides both a high compliance and a lossy termination to waves propagated radially outwards from the centre of the diaphragm.

A further factor contributing to the high sensitivity is the use of a high-flux magnet and, to maximise the power-handling capability, high-temperature materials are used in constructing the voice coil.

3.2. High-frequency unit

The first LS 5/8 prototypes incorporated a 25mm soft-dome tweeter of French manufacture, which provided a reasonably flat (within ± 3 dB) and largely uncoloured response from 2 kHz to 20 kHz. Unfortunately, the power rating and sensitivity of this unit were insufficient to match those of the low-frequency driver, and a series of field trials using high output levels resulted in the burnout of several tweeters.

The introduction by the same manufacturer of a 30mm soft-dome unit with a high-flux magnet provided the solution to the problem. The larger dome provides about 3 dB increase in sensitivity, and the stronger magnet a further 2 dB; the larger voice coil permits about 1 dB increase in power input. The total obtainable increase in acoustic output is therefore about 6 dB which has been shown by field trials to be just adequate.

In subjective terms, the performance of the larger tweeter is slightly inferior. It introduces a slight coloration at around 3 kHz, but this is perceptible only in very careful comparative listening tests. Also, its output falls off somewhat above 15 kHz, but for the purposes of broadcast monitoring this is of no significance.^{4,5}

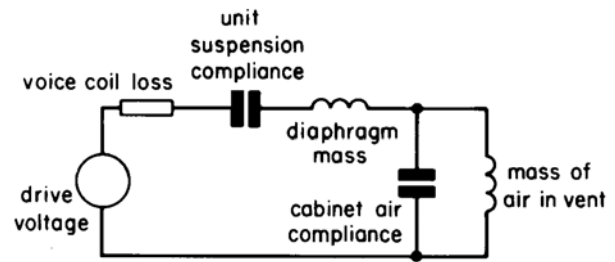


Fig.2 - Low-frequency analogue of bass unit in vented cabinet

4. Cabinet design

4.1. Interior

The chief difficulty in generating high sound pressure levels occurs at low frequencies, where large movements of the transducer diaphragm are required. This problem may be eased somewhat by the use of a vented cabinet (Fig. 1), which behaves as a Helmholtz resonator driven by the back of the diaphragm. The amplitude of the air movement in the vent is unrestricted, provided that the air velocity is not so high as to cause turbulence.⁶ A simplified electrical analogy of the LS 5/8 cabinet and bass unit is shown in Fig. 2, and in Fig. 3 the required amplitude of movement of the diaphragm is plotted as a function of frequency for both a vented and a closed cabinet.⁷

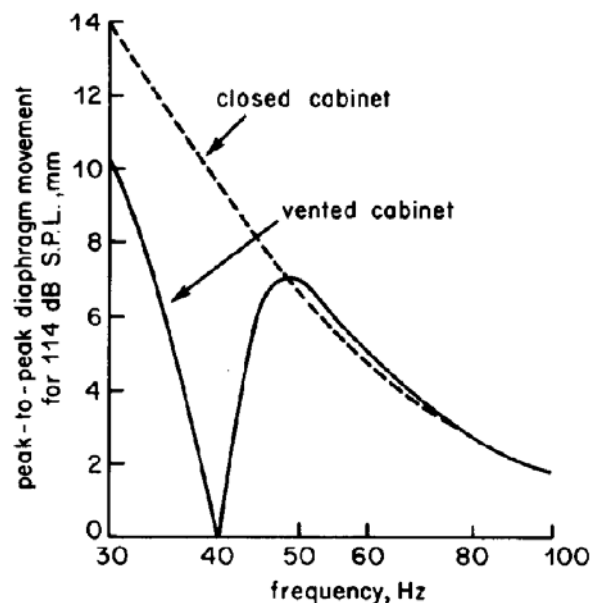


Fig.3 - Calculated amplitude of movement of bass unit in vented and non-vented cabinets

The electrical analogy of Fig. 2 holds good only at low frequencies below the first internal standing-wave mode. Such modes may be damped by covering the internal surfaces of the cabinet with a layer of porous material; it is well known that for a porous layer backed by a hard surface, the absorption coefficient increases with frequency. By using a 30mm layer of low-density mineral wool, almost no damping is obtained at the cabinet resonant frequency (40 Hz), whereas the first mode (213 Hz) is heavily damped. To prevent the escape of loose fibres, the mineral wool is contained in 100-gauge polyethylene bags, which do not significantly effect the absorption coefficient over the, required frequency range (40 Hz to 3 kHz). In practice, one internal surface may be left untreated, because at least two reflecting surfaces are required to support standing waves. For easy installation and replacement of units, it is convenient to leave the baffle untreated.

One final aspect of cabinet behaviour must be considered, namely that of panel resonance. The six panels of which the cabinet is made can resonate mechanically in a number of modes, both individually and collectively. The LS 5/8 cabinet is made of relatively light (12mm) birch ply of which all panels except the front baffle may be effectively damped by adding self-adhesive bitumen-based damping pads to a thickness approximately equal to that of the wood itself.⁸ The baffle presents a different problem; its compliance, in conjunction with the considerable mass of the drive units, forms a system that resonates at about 60 Hz, with a Q factor of about 10.

Experiment has shown that the addition of two horizontal hardwood battens, fixed above and below the low frequency unit, effectively removes the resonance, which had previously been so pronounced as to be clearly visible on a response/ frequency plot. Drawings of the cabinet and baffle are shown in Fig. 4.

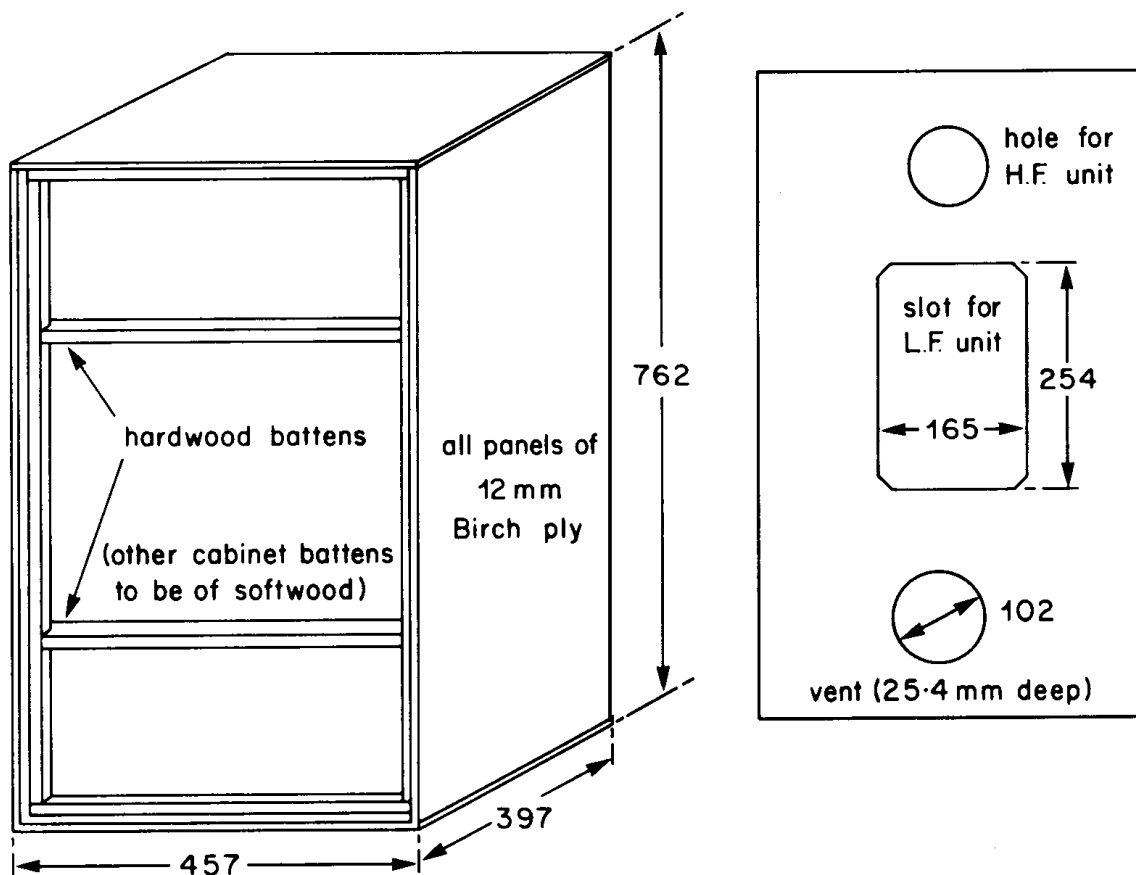


Fig. 4 - LS 5/8 - cabinet and baffle

(a) cabinet

(b) baffle

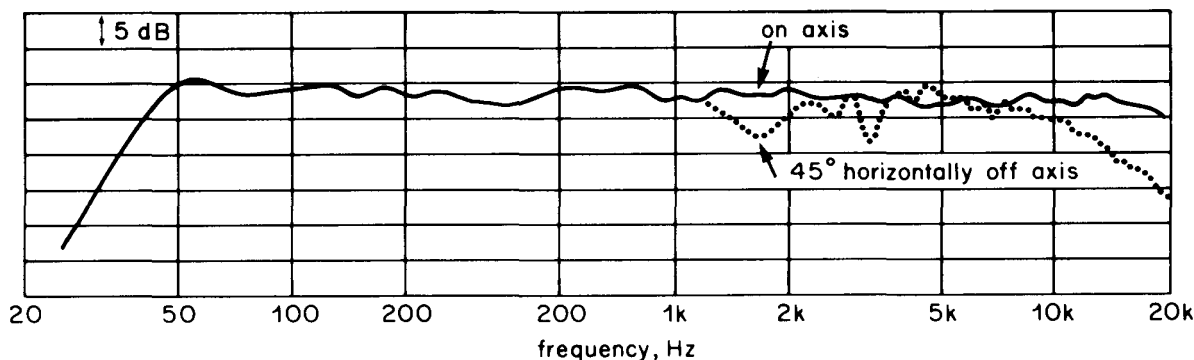


Fig. 5 – Response/frequency plot of typical LS 5/8, measured in the Free Field Room at 1.5m

4.2. Exterior

The external dimensions of the cabinet, and the disposition of the drive units on the baffle, combine with the properties of the units themselves to determine the directional characteristics of the completed loudspeaker.

The precise nature of the relationship between stereo image sharpness and directional radiation pattern is not known. However, experience has shown that excessively directional loudspeakers produce well-defined stereo images in only a very small listening zone, whereas those whose radiation is nearly omni-directional are excessively influenced by their surroundings.

In a control room, it is important that a sharp stereo image is available, not only to the person at the control desk, but also to the producer, who may from time to time stand alongside or behind him. This suggests that the radiated energy should be distributed over a wide angle, whereas the acoustically inhospitable nature of the surroundings (which usually include reflecting surfaces such as

windows and equipment bays) indicates that the sound energy should be contained in as narrow a beam as possible. The usual compromise adopted is to maintain a flat frequency response as far as possible for angles up to 45° off the main axis.

It is to be expected that a 300mm drive unit should become very directional above about 400 Hz, (the frequency at which the wave number is unity). This does indeed occur, but because the diaphragm moves progressively less like a piston as the frequency is increased, the directionality increases less rapidly with frequency than might be supposed. Nevertheless, it has been found useful to place a slot in front of the bass unit (Fig. 1), thereby slightly widening the horizontal radiation angle at frequencies above 1 kHz.² A narrower slot would permit further widening of the radiation pattern, but problems arise with narrow slots because the mass of air in the slot can combine with the volume of air behind it to form a resonant system which can ‘colour’ the radiated sound.

Fig. 5 shows the response/frequency plot

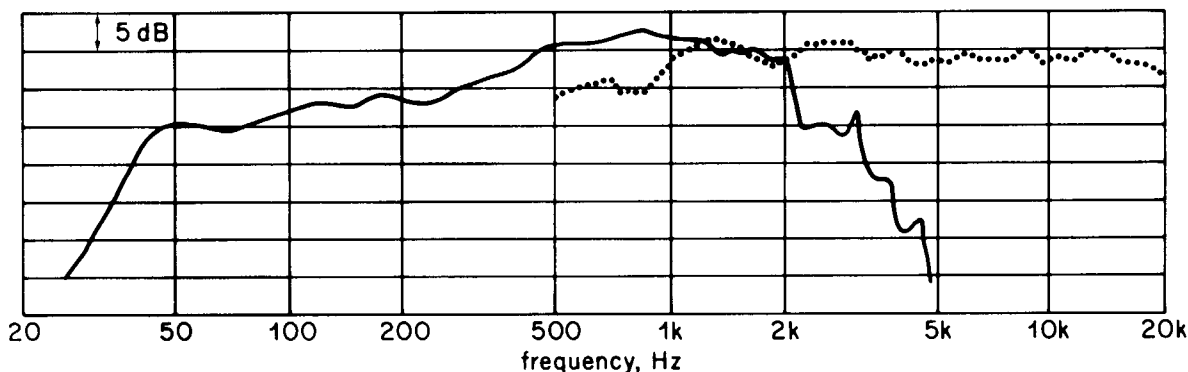


Fig. 6 – Response/frequency plot of drive units in LS 5/8 cabinet, units driven at constant voltage

for a typical LS 5/8, measured in free field at 0° and 45° to the main axis in the horizontal plane.

5. Frequency splitting and equalisation

Until 5 years ago, it was customary to use only passive filters for frequency-splitting and

equalisation. However, as solid-state power amplifiers have become cheaper and specially wound inductors more expensive, increasing use is being made of active inductorless filters followed by a separate power amplifier for each drive unit. For a two-unit loudspeaker this system is particularly convenient as most

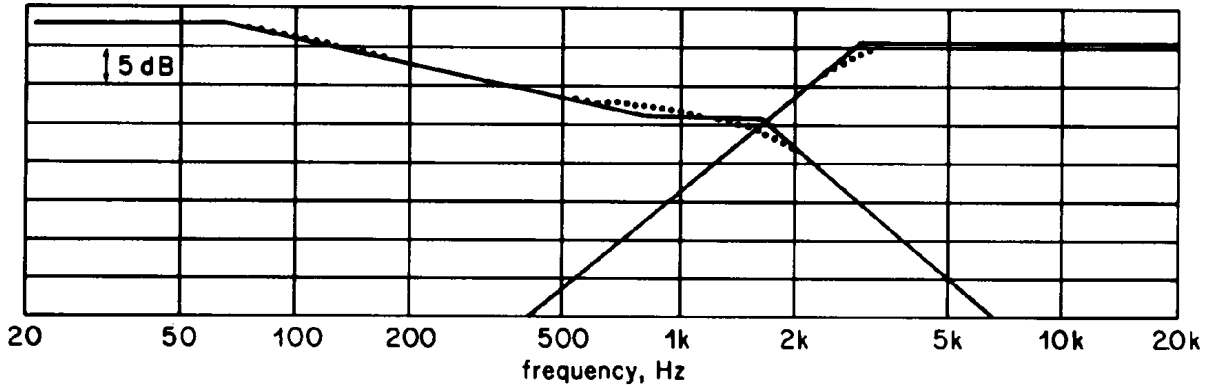


Fig. 7 – Idealised response (full lines) and actual response of LS 5/8 crossover and equaliser

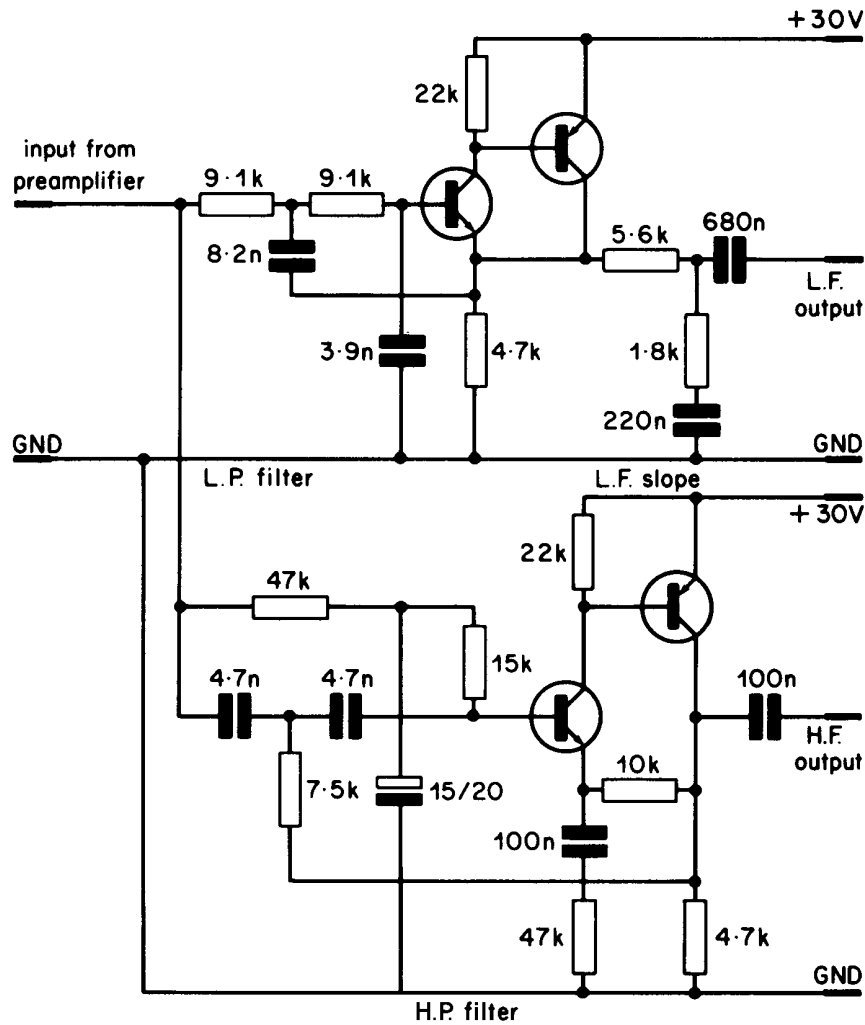


Fig. 8 – Schematic of filter circuit

commercial power amplifiers are packaged in pairs intended for stereophony. Low level filters are especially suitable for development work because they can be quickly adjusted, and their behaviour is easily calculable because no account need be taken of the complex impedance of the drive units.

Fig. 6 shows the free field response/frequency characteristics of the LS 5/8 drive units in their cabinet, driven at constant voltage. To obtain the best from both units, it is clear that the crossover frequency should be set between 1 and 2 kHz; it is also evident that the low-frequency fall off of the bass unit can be approximately corrected by a simple R - C step circuit. In simplified form the required filter characteristics are shown in Fig. 7; these are readily obtained using the circuit of Fig. 8. Complementary pairs of transistors are used rather than simple emitter followers for two reasons: first, their input impedance is so high that for practical purposes it can be considered infinite; secondly, much less distortion is generated, so that an indefinite number of stages may be cascaded without audible effect. The response/frequency plot of the filter circuit (measured or calculated) is shown as a pair of dashed lines in Fig. 7.

6. Appraisal of the initial design

The following tests, both objective and subjective, were made to assess whether the three design criteria of Section 2 had been adequately met; as a result of one test, a small modification was made to the filter circuitry.

6.1. Maximum sound pressure level

The peak SPL was measured in third-octave bands at a distance of 1m on axis, in a room of volume 70m³ and reverberation time 0.35 sec.

Between 100 Hz and 1 kHz, the LS 5/8 is capable of generating a peak SPL of at least 114 dB(A). In all cases the limiting factor was the peak power output of the amplifier (100W nominal).

6.2. Audible coloration of reproduced programme

Initial comparative listening tests, using varied programme material,* suggested that

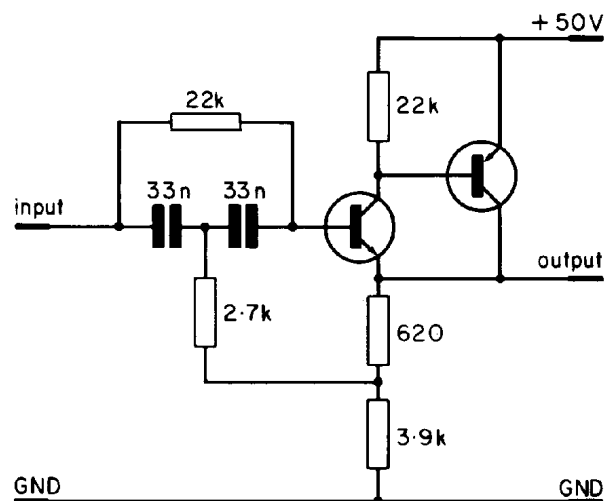


Fig. 9 - 600 Hz dip circuit ($Q \approx 1$)

the reproduced sound was less coloured by the LS 5/8 than by any other loudspeaker so far tested at Research Department. Nevertheless, audible colorations are present, and the most noticeable of these is at about 600 Hz. A low-Q notch filter at this frequency was therefore inserted and it was found that a 2 dB dip produced a marked subjective improvement without noticeably affecting the tonal balance. A circuit for this purpose (Fig. 9) has now been incorporated into the low-frequency part of the filter network.

6.3. Stereo image width

A series of subjective tests was set up in which participants were asked to measure the apparent width of a central image produced by replaying a monophonic recording of male speech over a pair of loudspeakers. This was done by electrically moving the image with a differential attenuator until either boundary appeared to impinge upon the line represented by a vertical string suspended midway between the loudspeakers. The test programme was replayed both at full bandwidth and in a series of filtered octave bands.

The tests were first performed in a listening room at BBC Research Department, and then repeated in the control room of BBC's Studio 1 at Maida Vale. The listening room represents an attempt to create an ideal listening environment whereas the studio control room has a rather adverse acoustic; as well as the usual control desk, equipment bays

* This included serious music (solo instrumental, orchestral and choral) as well as light music and speech.

and asymmetrically placed window, it has a sloped ceiling.

In all tests, the subjective image width was of the same order as that of the loudspeaker cabinets (about 450mm), and its apparent position did not vary significantly with frequency. Subsequent field trials carried out in a variety of listening environments, attest further to the satisfactory stereo performance of the LS 5/8.

7. Conclusions

Using two commercially available drive units, it has proved feasible to design a high level, high quality monitoring loudspeaker suitable for balancing a wide range of material including both light and serious music. That this monitor should be superior in all respects (including simplicity) to its predecessors is a tribute to the industry's progress in the design and manufacture of drive units during the past decade.

8. References

1. Loudspeaker transient response: its measurement and graphical representation. *BBC Quarterly* **1**, 3, p.121, 1946.
2. HARWOOD, H.D. *and* HUGHES, S.A. 1967. The design of studio monitoring loudspeakers types LS 5/5 and LS 5/6. BBC Research Department Report No. PH-13, Serial No. 1967/57.
3. HARWOOD, H.D. 1966. The design of a low frequency unit for monitoring loudspeakers. BBC Research Department Report No. L-050, Serial No. 1966/28.
4. SHORTER, D.E.L., MANSON, W.I. *and* WIGAN, E.R. Private internal communication, 1957.
5. Which bandwidth is necessary for optimal sound transmission? *Aud. Eng. Soc. Convention* 62, pre-print No. 1449, 1979.
6. HARWOOD, H.D. 1972. Loudspeaker distortion associated with low frequency signals. BBC Research Department Report No. 1972/25.
7. NOVAK, J.F. Performance of enclosures for low resonance high compliance loudspeakers. *IRE Trans. Aud.*, p.5, Jan - Feb. 1959.
8. HARWOOD, H.D. *and* MATHEWS, R. 1976. Factors in the design of loudspeaker cabinets. BBC Research Department Report No. 1977/ 3.