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THE DESIGN OF LOUDSPEAKERS FOR ACOUSTIC SCALE MODELS

C.D. MATHERS

BRITISH BROADCASTING CORPORATION

INTRODUCTION

Acoustic scale modelling techniques have been in use within the BBC for about thirteen years and during all of this time the emphasis has been on achieving adequate quality of reproduction through the system to enable skilled listeners to make valid subjective judgements.

All of our work has been based on a scale factor of eight to one, and we have set as our ideal the frequency range from 400Hz to 100kHz, whose real equivalent of 50Hz to 12.5kHz falls just short of broadcast bandwidth. In modelling, as in the real world, the loudspeaker is by far the weakest link in the audio chain. The model speakers in use at present were designed about ten years ago; although they are still the best we know of, they suffer from some serious shortcomings. We therefore set out about six months ago to find out whether recent advances in transducer technology might enable us to design better ones. At present the project is not quite complete, but already the new loudspeakers provide such an improvement in quality that we consider the main features of their design to be worth putting on record.

PERFORMANCE REQUIREMENTS

In acoustic scale modelling, one important parameter does not scale: namely, the acoustic power output required of the loudspeakers. The very small capacitor microphones that we have used in modelling have an extremely high noise floor and to achieve a reasonable signal-to-noise ratio through the system, sound levels well in excess of 100dB are required. There are two reasons for the high noise floor: amplifier mismatch at high or low frequencies, and Brownian air motion at high frequencies.

The high output power of the model speakers must be combined with reasonable tonal quality to make possible the subjective judgements mentioned earlier. In other words, the free-field frequency response must be reasonably flat on axis, the directionality must not be very different from that of a full-size monitoring loudspeaker, and audible colorations must be kept to a minimum.

To summarise, the model loudspeaker should be a scaled version of a studio monitor in all respects except output power.

CHOICE OF HIGH-FREQUENCY UNIT

In the original BBC model loudspeaker, the high-frequency end of the spectrum posed most problems. The solution that was finally adopted can be seen in Fig. 1, namely, a hemispherical array of electrostatic units. The use of this array served two purposes: to avoid excessive directionality at the top end of the band and to generate a reasonably high sound level at the low end where the units are severely displacement-limited.

After some searching amongst commercial ultra-tweeters and a little investigation of our own into piezoelectric plastics, we were able to test two models of leaf tweeter made by Matsushita. Both of these produced usable outputs from about 3kHz to 100kHz with acceptable horizontal directionality. In the vertical plane they were both rather more directional than might ideally have been wished, but apart from this they appeared very promising as far as measurements alone could show.

Accordingly, an experimental assembly was put together using a small low-frequency unit together with the smaller of the leaf tweeters (the larger one, although 3dB more sensitive, is physically very large indeed). The prototype assembly was set up in an anechoic chamber with a microphone. After initial testing and equalisation, a test tape was played through the system at eight times normal speed, re-recorded and then replayed at normal speed. The subjective quality was immensely better than had ever been achieved with the array of electrostatic units; furthermore, the available level was much greater and the frequency range was sufficiently wide to make possible the design of a two-unit loudspeaker. This latter possibility represents a step forward indeed, because the loudspeaker shown in Fig. 1 is effectively five metres high, whereas with two units only it is possible to model a studio monitor (admittedly a very large one).

DESIGN OF LOW-FREQUENCY UNIT AND CABINET

It is already apparent that our projected loudspeaker is far from being a detailed model of a studio monitor. The tweeter effectively extends in range down to about 500Hz, and would weigh half a tonne.

It would be similarly impracticable to make a scale model of a low-frequency unit. An equivalent 300mm woofer would have an overall diameter of 38mm and a voice coil diameter of about 5½mm. The efficiency would be unchanged by scaling. However, as we still need a power output comparable with that of a full-size unit, we would have to design for a voice-coil temperature of 11,000° C.

A possible solution might be to look for a small commercial low-frequency or midrange unit of about 100mm diameter. In view, however, of the considerable acoustic output needed and our wish to house the complete assembly in as small a box as possible, we decided to base the model woofer on the magnet and voice-coil of a 200mm polypropylene unit that we have recently designed for a full-size monitor. The maximum diameter of the magnet is about 100mm, so there is clearly no space to be saved by making the diaphragm much smaller than this.

For a 100mm unit operating at or above 400Hz, the design of the box becomes completely trivial. Nothing would be gained by the use of a vent, which could in any case present practical difficulties because of the small box and high air velocities. A box size was therefore chosen which would just accommodate both drive units; the box is made of 3mm plywood lined with a single layer of bitumenous damping compound. Air damping is provided by a 1cm layer of mineral wool.

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Let us now return to completing the design of the low-frequency unit. The voice coil is wound on a polyimide former with polyimide-insulated wire; the former diameter is 25mm. Because the peak throw required is less than that of the full-size unit from which the coil was borrowed, the winding has been shortened considerably. This reduces its resistance to 2.5ohms, which is inconveniently low for matching to most standard transistor amplifiers. To reduce the mass of copper would reduce the efficiency of the unit, but there are three other possibilities; the design of a suitable amplifier, the design and winding of a four-layer coil, or the design and winding of a transformer. The transformer provided by far the quickest and simplest solution.

In model work the power dissipation density in the coil would be about twice that of the original full-size unit with its longer coil; the best solution seems to be the use of a ferromagnetic fluid in the coil gap. In accordance with calculations, the use of a fairly thin fluid has no measurable effect on acoustic performance while according to literature on the subject, the rate of heat transfer to the magnet should be increased about five-fold. Burnout tests have not yet been carried out.

There is no simple way that we know of to calculate the required diaphragm profile of a low-frequency driver. A convenient starting point therefore was to use the centre part of a 200mm polypropylene diaphragm with a specially moulded PVC surround. In fact, the smooth response curve of the prototype unit suggested that the diaphragm was fairly well behaved and this was confirmed by examination with a laser interferometer.

At present we are considering possible modifications to the diaphragm to extend the upper frequency response of the unit if possible to 5kHz, to allow adequate overlap with the leaf tweeter.

ACHIEVED PERFORMANCE TO DATE

The complete prototype assembly is shown in Fig. 2. Its height is somewhat less than half that of its predecessor and the other dimensions are comparable with those of a large studio monitor. The loudspeaker is driven by a pair of amplifiers fed from an active crossover; this system is very quick to design and is especially suitable for development prototypes.

The frequency response of the assembly is shown in Fig. 3. The subjective quality of reproduction is not as good as that of a studio monitor such as the LS 5/8, but represents an appreciable step forward and is expected to make subjective judgement of model acoustics significantly easier.

ACKNOWLEDGEMENT

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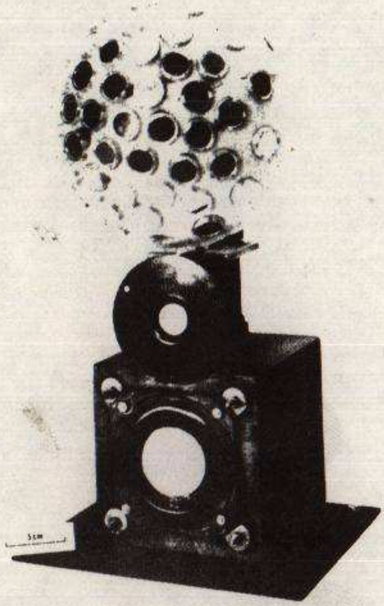

Fig. 1 - Model loudspeaker in current use

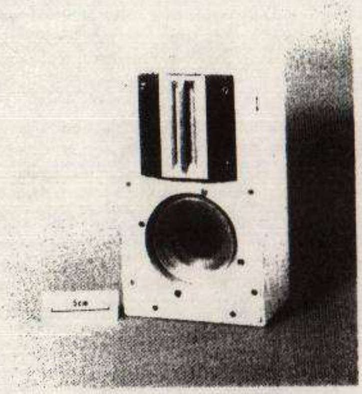

Fig. 2 - New prototype model loudspeaker

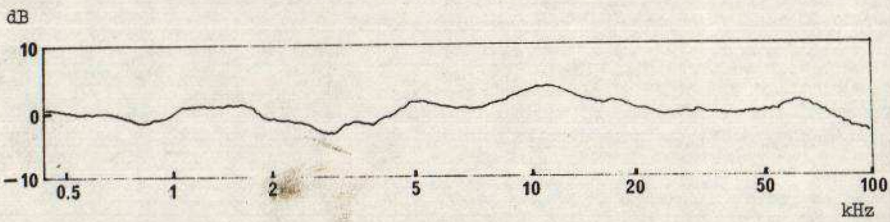

Fig. 3 - Free-field response of new model loudspeaker