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AXI-SYMMETRIC HORNS FOR STUDIO MONITOR SYSTEMS

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1. INTRODUCTION

The occasional need for many studio monitoring systems to produce high sound pressure levels in large, acoustically dead, rooms, usually requires the use of horn loudspeakers to cover the upper-mid and high frequency ranges. The horns traditionally used by monitor designers have usually been 'borrowed' from the vast range of public address units available. These horns have been designed with absolute sound quality taking second place to directivity control in the list of priorities, and thus almost always have a rectangular cross-sectional shape. For studio monitoring applications, the main requirement for directivity control is that a relatively narrow area (compared to public address applications) in the vicinity of the mixing console receives the on-axis sound, and that all of the off-axis radiation varies 'smoothly' with frequency. Horns possessing a circular, axi-symmetric cross-sectional shape have been found to satisfy these directivity requirements, and offer significant improvements over rectangular designs in terms of sound fidelity.

2. RECTANGULAR DESIGNS

2.1 An Historical Review.

For centuries, horns of some form or another have been used to amplify the human voice and the sound of musical instruments. Until the beginning of this century, these horns were designed from experience and trial and error. The theoretical analysis of the sound field within horns began with Rayleigh [1] and Webster [2], who presented independent derivations of the so-called 'Webster Horn Equation'. Since then, most horns have been designed using this equation, analytical solutions of which exist for only a small number of horn flare shapes (or 'area profiles', see [3]). The simplest of these area profiles, and the best for most loudspeaker applications, is the exponential, so most designs have been based on this shape.

The simplest cross-sectional shape for an exponential horn is circular, and most of the earliest horns were of this type, for example the 'His Masters Voice' phonographs. It soon became clear, with the development of the moving coil drive-unit, that as well as offering a high electro-acoustic efficiency, horns had much more clearly defined and controllable directivity properties than conventional loudspeakers, allowing the sound to be 'pointed' only where it was needed.

2.2 Directivity Control.

For public address applications, where the majority of horns find use, it is often desirable to have different horizontal and vertical directivity patterns. This has been achieved in a number of ways: a number of horns can be arranged in a cluster; an axi-symmetric horn can be 'squashed' into an ellipse; the cross-sectional shape of the horn can be made rectangular with different flares in the horizontal and vertical axes. The first technique, by attaching the cluster to a single drive-unit via a manifold, can be seen in the classic 'multicellular' designs, notably from Altec. The second technique is uncommon, due mostly to manufacturing problems. The latter technique has been most widely used due to the resultant high degree of control over the directivity and ease of manufacture.

2.3 The Limitations of Rectangular Horns.
If two of the sides of a rectangular horn are shaped to give the desired directivity properties along one axis, in order to maintain the required (usually exponential) area profile, the shape of the other two sides is pre-determined. This often leads to a compromise in the directivity properties along the other axis. Figures 1 to 4 show the directivity properties for a rectangular horn used in current studio monitor systems, along four different axes. It can be seen that the performance is very good in the horizontal plane, but deteriorates as the axis is rotated until an unacceptably poor performance is seen along the vertical axis. It should be noted here that this horn is generally accepted as being of high quality. Recently, to overcome this problem, horns known as 'constant directivity' designs have appeared. These consist of a number of short, straight sided sections with alternating rapid and slow flare in the two axes, giving optimum directivity properties at the expense of an accurate area profile. This approach can lead to a loss of efficiency at low frequencies and/or an uneven on-axis frequency response.

Even if these problems could be overcome with careful design, another limitation exists. A major cause of frequency response problems in horns is the reflection of sound waves back down the horn due to any discontinuities in the flare. If a horn is designed with smoothly changing contours, this problem can be avoided within the flare; however, avoiding a discontinuity at the mouth of the horn is more difficult. Many rectangular horns have a rapid, wide flare along the horizontal axis to give a broad directivity pattern, and a slow, narrow flare in the vertical axis. This narrow vertical dimension presents a discontinuity which results in reflection of a propagating wave. The effect that these reflections can have on the performance of a horn can be seen in figures 5 and 6, which show the throat impedance (see [3]) and on-axis frequency response of the rectangular horn above. A 'comb filtering' effect, similar to that found in the radiation from a pipe of comparable length, due to the interference between direct and reflected waves can clearly be seen. The smooth propagation of a wave from the throat to the mouth of a horn and out into the far field is essential if frequency response errors and hence sound colouration are to be avoided. Achieving this aim with a rectangular cross-sectional shape is very difficult, although some attempts have been made to help the situation by attaching elaborate 'lips' to the mouth of the horn.

3. THE BENEFITS OF AXIAL SYMMETRY

The axi-symmetric form is probably the oldest and most well known of any horn shape, but its use in loudspeaker applications has diminished slowly with time. Nowadays, only a small number of axi-symmetric loudspeaker horns are in use; and most of these are high frequency units. The reason for this is unclear but it appears to be a classic case of a forgotten art. Because for many years, the vast majority of horns have been designed and built for public address systems, where the properties exhibited by rectangular horns are desirable, it has become excepted that loudspeaker horns should be rectangular in shape. In an outdoor situation or in a large auditorium, the bad vertical directivity exhibited by rectangular horns is not a problem. However, for reproduction in rooms, much of the off-axis radiation of a loudspeaker is heard as reflections and reverberation and if this radiation does not behave smoothly with frequency, gross colouration of the perceived sound could result. The possibility that for high quality applications, axial symmetry may offer superior performance, appears to have been either passed by or forgotten. Indeed, it may well be the use of rectangular horns in high quality loudspeaker systems that has resulted in horns of any shape acquiring a bad name.

3.1 The Radiated Field.

A fundamental property of an axi-symmetric horn is the axial symmetry of the radiated field. This symmetry means that the directivity of the horn will be the same in the vertical plane as it is in the horizontal (and any plane in between), hence the vertical compromise problem above is eliminated. An axi-symmetric system does not allow as much 'juggling' of the directivity properties by designers as a rectangular system, however, for many high quality loudspeaker systems, the horizontal angle that it is necessary to 'cover' with the on-axis radiation is small compared to the requirements for public address systems, being usually of the order of about 60 degrees inclusive. The designer of an axi-symmetric horn for such a system can therefore relax the horizontal coverage angle constraints imposed on public address horn design, in favour of good overall off-axis behaviour. If an acceptable directivity pattern can be achieved in the horizontal plane, the rest of the off-axis radiation will follow suit. Figure 7 shows the directivity for a first generation prototype axi-symmetric horn designed by the author specifically for use in a studio monitor system. The directivity pattern shown is comparable with the performance of the rectangular horn along its horizontal axis, although a little narrower (see fig. 1), but is vastly superior to the performance of the rectangular horn along its vertical axis (see fig. 4). Clearly, when used in anything other than anechoic conditions, the sound quality of the axi-symmetric horn should be superior to the rectangular, all else being equal.

3.2 Mouth Reflections.

As mentioned above, the free propagation of a sound wave from the throat of a horn to the mouth and out into the far field is essential to avoid colouration of the sound. Any discontinuities, either within the flare or at the mouth, will cause reflections back down the flare which interfere with the forward wave and cause comb filtering. Such discontinuities can be avoided within the flare of both rectangular and axi-symmetric horns, but a smooth transition from flare to baffle is very difficult to achieve with rectangular horns. Provided the flare of an axi-symmetric horn is allowed to continue to a shallow enough angle, this discontinuity at the mouth can virtually be eliminated. Figures 8 and 9 show the throat impedance and on-axis frequency response for the axi-symmetric horn. The absence of mouth reflections is evident from the very smooth impedance / frequency characteristics. The ripple in the on-axis response of about ±2dB is due to a diffraction problem at the edge of the mouth which could be eliminated in later prototypes (lack of time precluded this prior to writing this paper). This diffraction can also be seen in the directivity plots as a ripple at all angles other than those on or near axis. An approximation to the on-axis response of the horn when the diffraction has been removed, can be seen in figure 10 which shows the response 10 degrees off-axis.

All of the above measurements (except throat impedance) were taken in the large anechoic chamber at the ISVR, Southampton University, with the horns mounted on a baffle of approximately 48 inches by 27 inches, which was thought representative of a large monitor cabinet. The same driver was used for both horns.

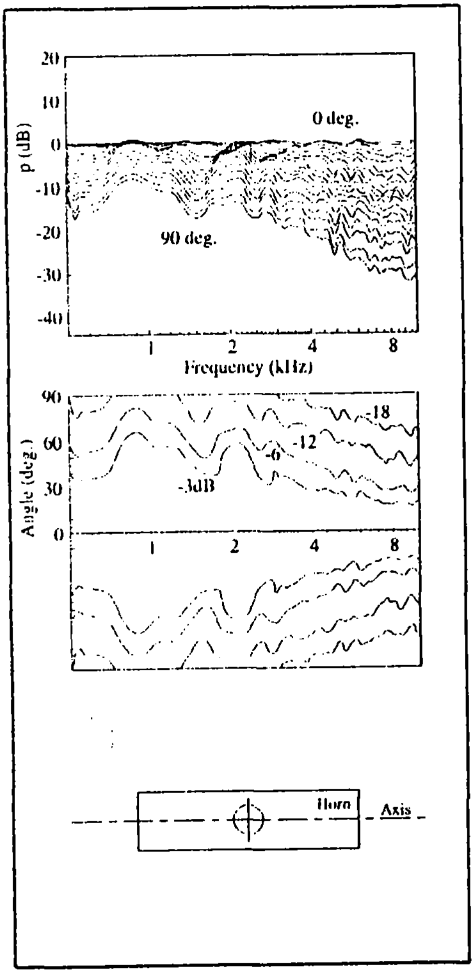

Figure 1 Directivity of Rectangular Horn along the Horizontal Axis.

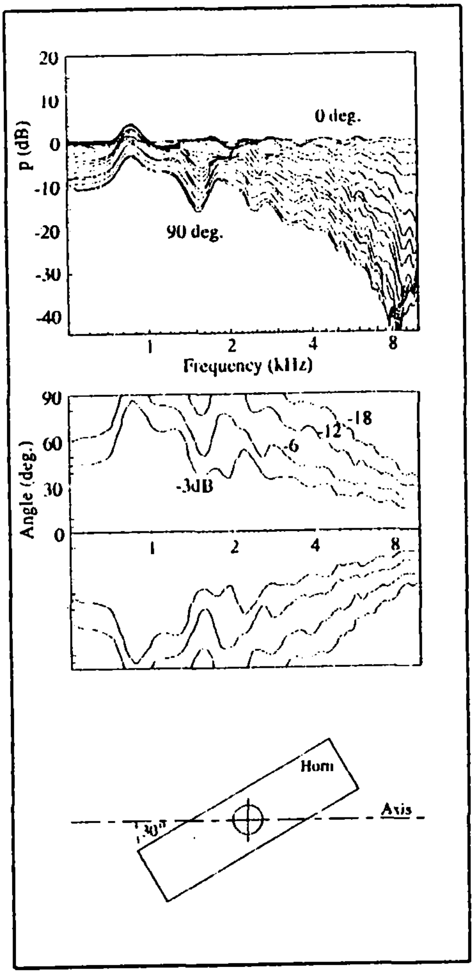

Figure 2 Directivity of Rectangular Horn *at 30 degrees to the Horizontal Axis.*

AXI-SYMMETRIC HORNS

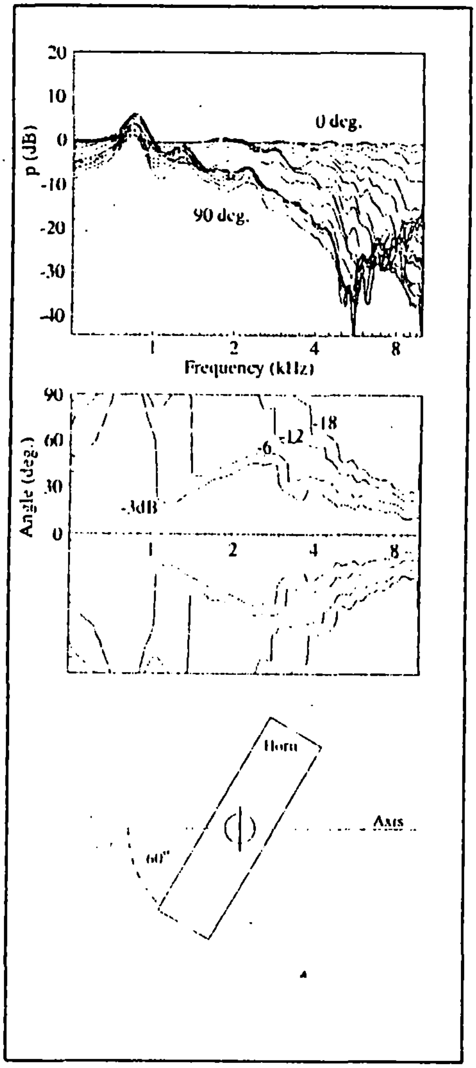

Figure 3 Directivity of Rectangular Horn at 60 degrees to the Horizontal Axis.

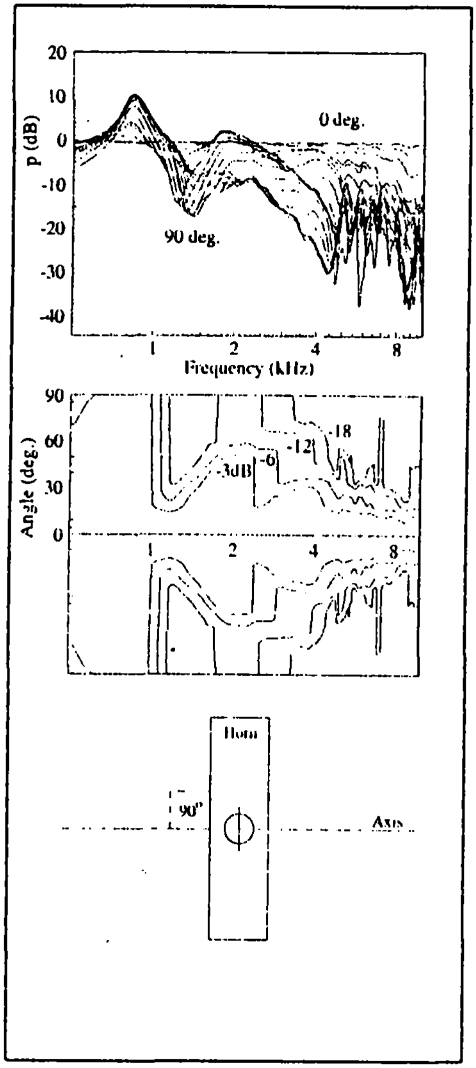

Figure 4 Directivity of Rectangular Horn along the Vertical Axis.

AXI-SYMMETRIC HORNS

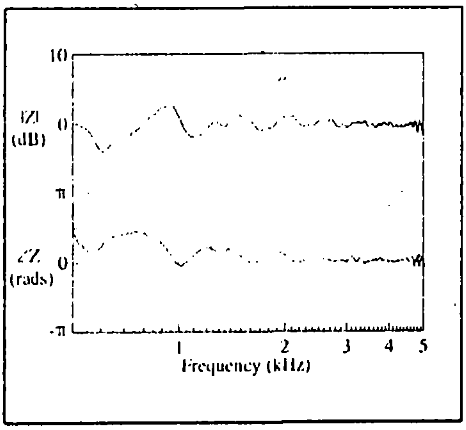

Figure 5 Throat Impedance of Rectangular Horn.

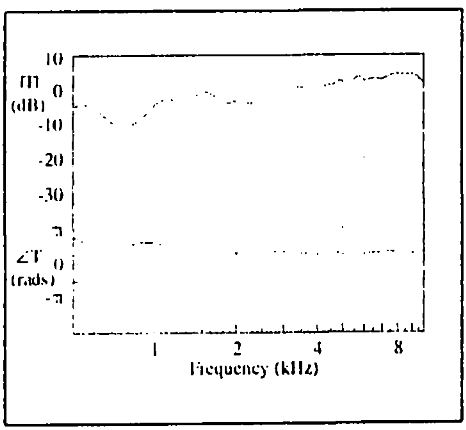

Figure 6 On-axis Frequency Response of Rectangular Horn.

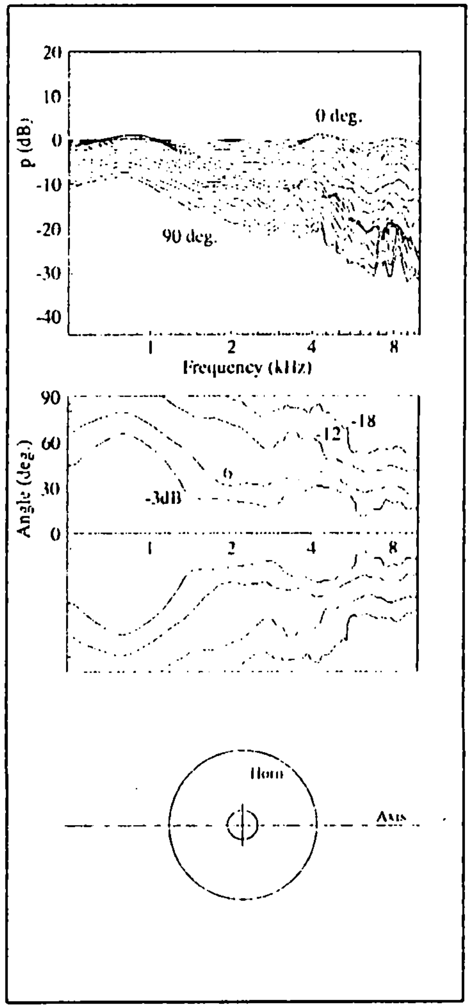

Figure 7 Directivity of Axi-symmetric Horn.

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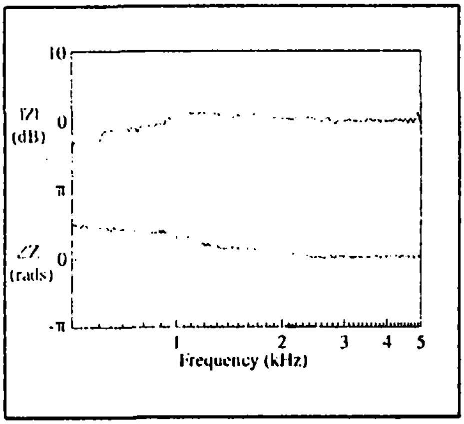

Figure 8 Throat Impedance of Axi-symmetric Horn.

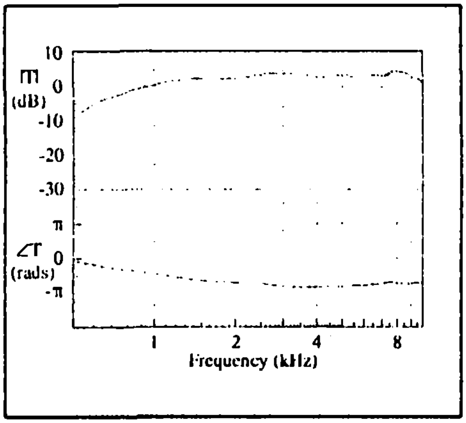

Figure 10 Frequency Response of Axi-symmetric Horn at 10 degrees off axis.

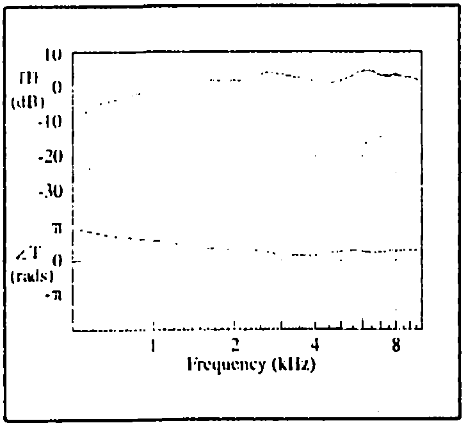

Figure 9 On-axis Frequency Response of Axi-symmetric Horn.

4. CONCLUSIONS

The requirements for the sound radiation properties of mid-range horn loudspeakers intended for use in studio monitors are different to those for public address applications. Most of the designs for horns found in current studio monitors have been 'borrowed' from the field of public address and thus possess properties which, although often desirable for their originally intended use, are undesirable for high quality sound reproduction. These properties are; a compromised vertical directivity pattern, and an uneven on-axis frequency response, which are a direct result of the adoption of a rectangular cross-sectional shape. An axi-symmetric horn is proposed as offering better performance in studio monitor systems than a rectangular design.

The results of measurements of throat impedance, on-axis frequency response and directivity are presented for a rectangular horn in current use in studio monitors, and a first generation prototype axi-symmetric horn. Comparison between the results for the two horns shows the axi-symmetric horn to be superior in performance.

The authors are indebted to Tonni Johansen and friends at Norges Tekniske Hogskole, Trondheim, Norway for the seeds of thoughts on axial symmetry.

5. REFERENCES

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[3] K. R. HOLLAND, F J. FAHY, C. L. MORFEY, P. R. NEWELL, "The Prediction and Measurement of the Throat Impedance of Horns", Proc. I.O.A. 11 (7), (1989).