Proceedings of the Institute of Acoustics

DO ALL MID-RANGE HORN LOUDSPEAKERS HAVE A RECOGNISABLE CHARACTERISTIC SOUND?

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Loudspeaker systems utilizing compression driver/horn combinations for mid-range and high frequency reproduction have been bones of contention for many years in terms of their sonic characteristics vis-a-vis direct radiators. Each and every monitor system seems to have both its partisan followers and vociferous critics. In order to gain some more definitive insight into both measured and perceived performance, Keith Holland undertook, on my behalf, a three year research programme on horn parameters and their relationship to sonic performance.

It is probably true to say that by far the majority of studio monitor loudspeakers using horns in the mid-range, have borrowed or only slightly modified the technology from the world of sound reinforcement. Without in any way wishing to imply that the sound reinforcement industry operates to lower standards than the recording industry, it is true to say that their priorities lie in different areas. Maximum SPL delivery and directivity control usually take precedence over some of the more subjectively subtle requirements of studio monitoring. Indeed, many such subtleties would be lost in the environment of an auditorium, so it would be foolish to concentrate too much effort into areas of little consequence. Unfortunately, when much of this technology is transplanted into studio systems, the required subtleties cannot just be "bolted on" as afterthoughts, they must be considered at the very outset of the design process.

It is largely for the above reasons that horns have to a very great degree, all been tarred with the same brush in many subjective assessments of their sound. It was evident that in order to investigate the full potential for mid-range horns in studio applications, development from first principles would most probably be the only viable path. In the late summer of 1987, Keith Holland began thorough library searches at the commencement of intensive research. Finite element modelling followed, with single parameter models being evaluated against measurements from the testing of a wide range of actual horns, many of which were relatively common in studio usage. Both linear and non-linear performance data were measured and analysed prior to the first attempts to correlate the subjective and objective measurements.

In the process of this research, a system was devised for both the rapid and accurate measurement of the throat impedance of horns, a paper on which was presented (1) at the Reproduced Sound 5 conference in November 1989. The use of this system has continued to produce excellent data on many aspects of the manipulation of horn geometry, giving rapid correlation with effects on throat impedance, and the implied pressure amplitude response when connected to real world drive units.

At the beginning of the third year of research, an extensive series of listening tests were carried out in the large (10m x 12m x 8m) anechoic chamber at the Institute of Sound and Vibration Research in Southampton University. In brief, the procedure involved the setting-up of five mid-range loudspeaker units, positioned in an arc, equidistant from a listening position. The listening position was on the axis of all the five loudspeakers, which were hidden from view by means of a visually opaque calico screen. The screen showed no significant sign of attenuation up to 8kHz, but in any case, the object of the exercise was to compare like with like, so any effects of the screen would be equal for all devices. The metal grids of the floor were removed from between the loudspeakers and the listening position, rendering the sound at the listening position to be to all intents and purposes, the axial responses of the drivers under test.

From left to right, the 5 loudspeaker positions were identified as A, B, Sample, C and D, with the sample being directly in front of the listener and the arc from A to D subtending an angle at the listening position in the order of 60°. "A" was an electrostatic loudspeaker, "B", a widely used 6" mid-range cone driver of European manufacture, "C" was a compression driver/ rectangular horn combination deemed to be typical of such systems, being carefully chosen to be representative of a majority of widely used horns, whilst "D" was the mid/high section of a dual concentric loudspeaker using the bass cone as the axisymmetric horn of the mid/high frequency driver. Sixteen other mid-range units were rotated through the sample position in a manner ensuring that no two listeners received the same sequence of loudspeaker samples.

The test signals consisted of nine sounds, digitally recorded via measurement microphones. The signals were chosen to cover the range from highly transient to relatively steady state sounds, the information content of which was minimal in order to try to prevent the listeners from being drawn into the sounds, or showing preferences should one loudspeaker "enhance" a particularly favourite sound. The only two sounds having any musical content were an anechoically recorded single guitar chord, and two notes on a lightly blown flute.

By means of switching, in a sequence:- Sample,..A,..Sample,.. B,..Sample,..C,..Sample,..D,..Sample,..A.....the listeners were asked to mark a questionnaire as to which of the references A to D, they considered the sample to sound most similar. A "none" column was also provided for use in the event that they could not say that the sample was similar to any of the fixed references A to D. Just what constituted "similar" was left to the discretion of each listener, though amongst the 16 sample drivers, one was identical to reference B, whilst another was a unit not ideally suited to the frequency range under test. These two units provided an "up" control and a "down" control in terms of similarity. The test signals were 24dB/octave band limited from 1kHz to 6kHz, the remainder of electronics in the reproduction system responding from DC to 100kHz, or 20kHz in the case of the digital tape machine.

A large selection of listeners were utilised, but only one listener at a time took part in the tests. The listeners consisted of record producers, magazine editors, academics, acoustics engineers, lay persons, musicians, and sound reinforcement engineers. The majority of the listeners were "professionals" in the musical/acoustics domain. Due to the magnitude of the task of listening to nine sounds through each of sixteen sample loudspeakers, each cross referenced to four fixed units (a minimum of 9 x 9 x 16 = 1296 operations), the listeners were given frequent breaks for tea, coffee, lunch or whatever. In some instances, several people were used to complete one questionnaire. The tests continued for a period of four months until sufficient data had been collected to enable meaningful analysis. After the tests had been concluded, the authors each analysed the results without reference to the other, only conferring once again when their results had been tabulated and assessed.

The statistical analysis conducted by Keith Holland on a basis of Similarity Confidence Limits gave total 100% similarity for sample No 6 which was identical to reference B, when compared to "B". The "down", non-similar control produced by far the worst similarity confidence limits of any of the samples used, producing four 100% in the "none" column out of the nine signals available. The "unambiguous ticks" approach adopted by Philip Newell for his analysis of the data led to equally strong correlation of the "similar" and "non-similar" control reference drivers. Overall confidence in the test results were greatly enhanced by the excellent results from the "similar" and "non-similar" control drivers.

Of the driver samples, 3 were direct radiators and 13 were compression driver/horn combinations. Two similar compression drivers were used to facilitate rapid changeover of the samples. The compression drivers were chosen for response uniformity and relatively low distortion, in order that the horn differences would predominate, rather than the listeners being subjected to driver irregularities. The one exception to this was sample 16 which was a horn/driver combination representing the latest product of a very well known American manufacturer.

RESULTS

Electrostatics

None of the 16 test samples were deemed to sound similar to the electrostatic, reference A. Only on certain sounds on a few sample drivers by a few people were any suggestions of audible similarity indicated. We did begin to wonder if there was something wrong or being overlooked, so after the completion of the listening tests at the end of the four month period, we set up a secondary test. In this test, we substituted an electrostatic loudspeaker of a different type to the reference A for one of the samples, then asked a small number of listeners to perform the test. The results were not included in the data for the main test analysis, but lo and behold, the electrostatic sample was immediately and almost unanimously chosen as being similar to our reference electrostatic, A. Given the fact that there appeared to be nothing unique about the pressure amplitude responses of the electrostatics, the fact that they were the only units capable of reproducing anything approaching an accurate impulse, square wave, or step function, indicated that the uniqueness of their sound lay in the time domain.

Direct Radiators

Of the three direct radiators included in the test samples, the two "serious" contenders were clearly chosen as being similar to the direct radiator reference driver B. As previously discussed, one of the test sample was an identical unit to B, the results giving 100% confirmation of similarity. Even the third direct radiator sample, the "non-similar" control reference, showed a tendency towards the direct radiator "B" in what little similarity did exist. The disparity in both size and design of the three direct radiators samples ensured that undue commonality with the reference sample was avoided.

Horns

Of the remaining thirteen samples, all were horns, nine of which were of proprietary manufacture and in general use. Of the other four, one was a wooden horn from a 1920's gramophone, which conveniently terminated in a throat of about 1 inch. Another was identical to one of the other nine samples except that the radial "lips" had been removed from the mouth; thus maintaining the same throat and flare rate characteristics but disturbing the mouth termination into the room. The other two samples were specially made for these listening tests, one intended to be an example of a "bad" horn with very irregular throat impedance, the other being an attempt to combine the knowledge of the previous research into a horn with the best throat impedance characteristics which could be achieved.

As already discussed, none of the sample units were deemed to be similar to the electrostatic unit. Only one was deemed similar to the axisymmetric dual concentric horn sample "D". The remainder were spread in their similarity between "B", the direct radiator, and "C" our "typical" horn. Essentially, the samples divided between B and C in accordance with their length. Reference C, the typical horn, had a length of around 24 inches from the diaphragm of the driver to the mouth of the horn. ("B", the direct radiator, is in fact a special extreme case of a conical horn with 180 degrees of flare and zero length.) Samples with less than 12 inches between the diaphragm and the mouth were deemed more or less similar to "B", whilst those with greater than 12 inches between diaphragm and mouth were deemed more or less similar to "C".

In terms of audible similarity, we could find no evidence of any correlation with non-linear distortions. Indeed, certain samples with non-linearity differences of over 20dB were deemed to be remarkably similar on a wide range of sounds. Likewise, linear distortions in terms of amplitude (see Fig 1), except where they were grossly different, did not appear to be the controlling factor. In a statistical comparison of the measured pressure amplitude responses of the loudspeaker samples, only a 60% confidence correlation with the listening test similarity results could be established. Rate of flare/cut-off frequency, geometrical method of achieving flare, nor material of construction appeared to have little correlation with audible similarity, although it should be pointed out that certain transient signals did excite some timbral anomalies in some of the units auditioned. A plastic, wooden, or metallic characteristic could be detected in some horns on some signals, according to their material of construction: the metallic sound generally being deemed to be the most objectionable.

Work being carried out in parallel with these listening tests revealed disturbing audible characteristics when listening at a normal to any abrupt irregularity in the horn geometry, such as an irregularity on a side wall or even an angle where the side wall meets the top or bottom of the flare. The implication of this extended to sharp angles at the junction of dividers and waveguides, and also to any pillars and posts which may be present in the throat area for the purpose of resonance damping in the structure of the horn.

The length of the horn would appear to be important in terms of the distance, and hence time delay, over which the mouth reflexions must travel. Obviously, were the horn long enough, a distinct echo would be heard. The longer the horn, the larger the mouth would need to be in order to smoothly terminate to the air in the room in order to avoid abrupt cross sectional changes. The "bad" horn specifically designed for these listening tests had a very abrupt mouth termination and hence large throat impedance/pressure amplitude (frequency) response irregularities. However, being very short, around 9", this horn was deemed similar to the direct radiator B with almost 100% similarity confidence. It is also worth nothing that it was axisymmetric and had neither any obstructions in the flare, nor any abrupt angles in its geometry. It would appear to be not so much the amplitude of any irregularities which contribute to any characteristic horn sound, but the length of time which those undesirable irregularities have in which to superimpose themselves on the desired signal. This is entirely consistent with the findings of any characteristic electrostatic loudspeaker sound (or lack of it) being time domain dependent rather than functions of specifically amplitude, phase, or non-linear distortion characteristics.

The previously mentioned single sample which strongly correlated with reference D, the axisymmetric dual concentric horn, was itself an axisymmetric horn of remarkably similar geometry, yet entirely different in terms of material of construction, compression driver design, and mounting arrangement.

These horns were not in any respect deemed to be typically "horn-like". It is probable that it is for reasons of meeting the criteria of axial symmetry, absence of abrupt angles in the geometry and short distance from the diaphragm to the mouth, that the Tannoy dual concentrics have enjoyed such a long working life in both classical and rock circles without being sonically "lumped in" with other horn loudspeakers, which above 1kHz, they most definitely are. Neither have they been generally grouped with other similarly sized co-axial units having discrete horns mounted in the apex of the bass cone.

Ultimately, if frequencies above 7 or 8kHz are not required in a mid-range only driver, dispensation with the phasing plug of the compression driver and/or general reductions in compression ratios can reduce non-linearities to levels generally commensurate with direct radiators. However, even with compression ratios which still afford relatively high sensitivity and good H.F. response (via the phasing plug) non-linearities do not appear to be controlling factors in any "hornlike" sound. The specific characteristics of any "Tannoy" sound, are probably also functions of crossover and drive unit design, but it is undoubtedly the overall size and geometry which has largely prevented "horn-like" criticisms being lodged against them.

Practicability of Design

Initially, we were worried that in order to achieve a rate of flare allowing for a smooth mouth termination, together with a short diaphragm to mouth distance, we would be looking at a flare rate with a relatively high cut-off frequency. Cut-off frequency is a function of flare rate and it has long been held unwise to approach too far below one octave above cut-off if the response irregularities associated with cut-off were to be avoided. In the case of the axisymmetric horn referred to above, the development of which is the subject of a separate paper [(2)], the cut-off region was so benign in behaviour that utilisation almost down to the point of cut-off was sonically, entirely feasible.

The above tests are fully documented, eminently repeatable, and open to inspection. Short horns <u>can</u> be produced having high efficiency, wide frequency range <u>and</u> benign distortion levels, which are <u>not</u> sonically horn-like but can be grouped as audibly similar to typical direct radiators. The audible similarity of drive units would appear to be in their time histories, and where a mouth reflexion effect of a horn is in the same order of any inherent resonances in direct radiator units, then general audible similarity is to be expected. Long horns produce longer reflexion delays and do group together, whilst electrostatics group due to their rapid and accurate transient (impulse/step/ square wave) response. We therefore submit that the general audible similarity of ALL loudspeaker drive units of similar frequency range and general overall quality, irrespective of generic type, lies not in the non-linearities, nor solely in the pressure amplitude response, but in the time domain response as specified by the linear distortions of the convolution of the amplitude and phase response.

One further point worthy of note was our investigations into old but frequently held beliefs that horns tend to "get harder as you wind them up". We recorded a range of seven test signals through a selection of horn/compression driver combinations and also direct radiators. The recordings were made via a B+K measuring microphone with a pre-amplifier having attenuation facilities in 10dB steps. The recordings were repeated at levels of 70dB, 80dB, 90dB, 100dB, 110dB, 115dB, 120dB and 130dB at 3 metres, on axis in an anechoic chamber. Each time that the level was increased by 10dB, the pre-amplifier was attenuated by the same amount to provide a constant level on the digital tape. When the recordings were subsequently played back, either via good quality loudspeakers or headphones, the timbral differences even between the 70dB and 115dB levels were all but insignificant. At a level in the order of 125dB @ 1m, the horns rather suddenly produced unpleasant distortions, which we are attributing to air overload. At these levels however, the direct radiators had dropped out of the ratings due to thermal or mechanical failure. Although the horns could not be deemed "hi-fi" at these levels, it is doubtful that "hi-fi" per se exists at such levels. The main relevant point was that at these levels, the horn/driver combinations were still not at risk from either thermal or mechanical failure. There was absolutely no evidence whatsoever of mid-range horn loudspeakers showing any tendency towards timbral hardening until well past a point where conventional radiators could no longer sustain such an output.

REFERENCES

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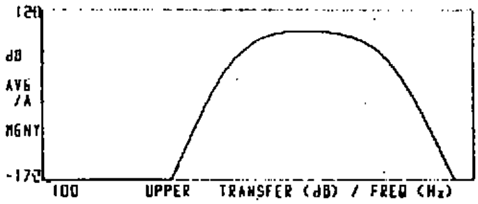
Pressure amplitude response comparisons of the 16 sample loudspeakers, as compared to the 4 reference "archetypes" and the electrical response of the filter through which all signals were passed.



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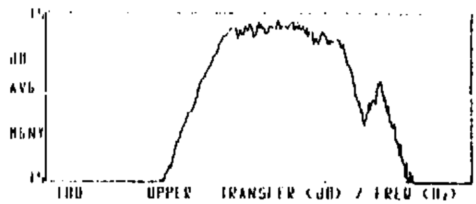

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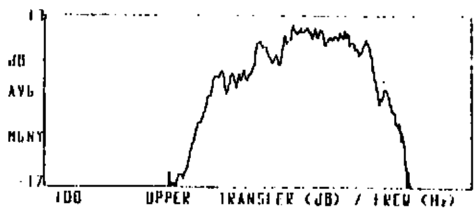

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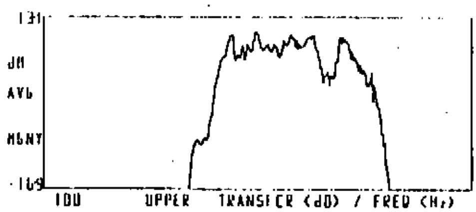

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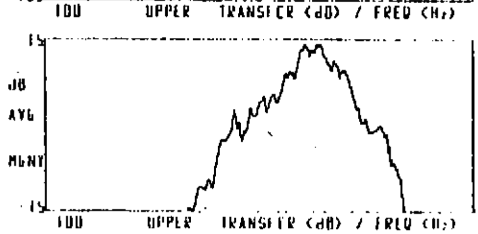

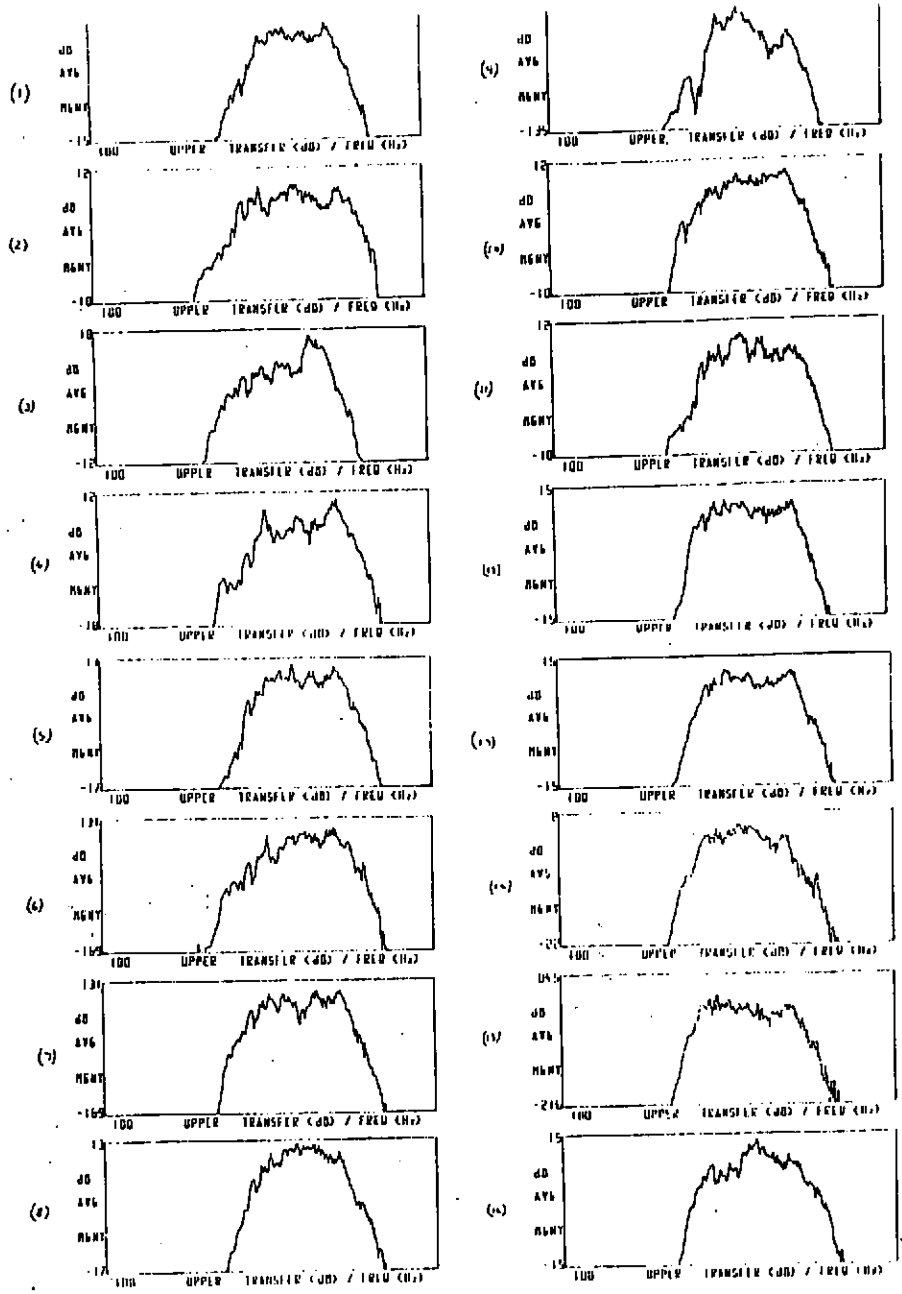
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ISBN 1 873082 10 X