Proceedings of the Institute of Acoustics

SOUND POWER – THE FORGOTTEN LOUDSPEAKER PARAMETER

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1. ABSTRACT

The sound power radiation characteristic of a loudspeaker is shown to be an essential but forgotten parameter in sound system design and loudspeaker characterisation. A study has been made of the Sound Power radiation characteristics of a wide range of devices including the new class of device the Distributed Mode Loudspeaker. Data is presented which suggests that in most commercial / industrial and professional applications, it is the sound power response that dominates the measured in-room frequency response and perceived frequency balance. The parameter is shown to directly relate to speech intelligibility and it is concluded that this useful parameter should be included in manufacturers data sheets & information.

2. INTRODUCTION

Although in building and physical acoustics, sound power radiation is a common and basic parameter used to calculate resultant sound pressure levels in a wide range of applications, in electro-acoustics it is a virtually forgotten parameter. Few if any manufacturers provide sound power data for their products. This paper shows that in most distributed sound systems and many other loudspeaker systems operating in reverberant or reflective spaces, that it is the sound power radiation of the loudspeaker that dominates the situation and has a considerable impact in determining the potential intelligibility of the system.

The paper reviews the methods of measurement and their ease of implementation. The results of a series of measurements made on a wide range of commercial products and devices are then presented. Comparisons are made with traditional frequency response measurements and in-situ responses. This is a unique collection of data, that allows a number of trends to be immediately seen and conclusions drawn relating to the acoustic power and frequency responses of commercial sound products.

The role of sound power in determining the overall perceived frequency response is discussed as are the mechanisms whereby it affects and indeed is shown to often determine the overall intelligibility of a system.

3. FREQUENCY RESPONSE VERSUS POWER RESPONSE

Although we are all familiar with the loudspeaker frequency response graphs and measurements that we see on manufacturer's specification sheets, such measurements do not really signify how a particular loudspeaker is going to sound in a given environment – unless that happens to be an anechoic chamber. However, it is hypothesised that sound power, which describes the total radiated acoustic output of a loudspeaker, can in many circumstances can give us a much better idea of this and particularly for reverberant spaces.

Imagine a loudspeaker operating in a reflective or reverberant space. Normally, we are concerned with the sound that it radiates either on or just off axis in a forwards direction. (i.e. 'the bit we want to point at the audience or listeners'). This is the sound that the conventional axial frequency response describes, particularly if supported by off-axis curves as well. What is often forgotten however, is that loudspeakers also radiate in other directions as well – and in many cases will actually radiate more combined acoustic energy outside the nominal coverage angle than within it (Assuming the usual –6dB coverage angle convention). Now in a reverberant or reflective space, this side and rear sound radiation will also reach the listener and will affect the spectral balance of what we hear. As can be imagined, this unwanted sound radiation is generally highly coloured and will usually have a radically different spectral response to that generated and perceived on axis.

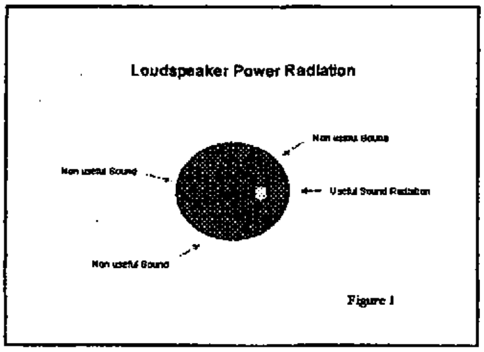


Figure 1

Figure 1 shows the basic concept where the 'light grey sound' is the useful or wanted component whereas the 'dark grey sound' is the non-useful component. Rather interestingly, with most loudspeakers it turns out, there is usually a greater area of non-useful sound than useful sound - but only by integrating over the prescribed areas and taking account of the extent of the relative radiation components can this be quantified – the answer of course being found in the sound power.

Ideally, a loudspeaker with an even or flat sound power characteristic (Lw) would seem like a good idea, in that the off axis radiation (way off axis that is) would then have a nominally similar characteristic to the on axis – assuming that the loudspeaker has a flat axial frequency (Lp) response – which after all is the inherent aim of most loudspeakers. In other words, the sound energy feeding the reverberant field would have a similar response to the direct sound. As will be shown later, this has a number of interesting applications and implications.

4. REVERBERANT ROOM GAIN

It could be anticipated that that the Reverberation Time frequency characteristic of the space in which a loudspeaker or loudspeaker system is operating would have a significant influence on the spectral balance of the reverberant sound field. However, in practice this turns out not to such a dominant influence as at first thought. Analysis of many spaces shows that over the main speech range of 250 Hz – 4 kHz for example, the reverberation time will only result in a 2-3 dB variation. This is small in comparison to many loudspeaker acoustic power output response curve fluctuations. The concept of a 'flat' power response would therefore seem to hold – certainly for the speech frequency range.

5. MEASURING AND USING SOUND POWER Lw

Whereas the direct sound field component of a loudspeaker can readily be calculated from a knowledge of the 1 w / 1m sensitivity value by use of the inverse square law, it is not immediately obvious how one calculates the reverberant component – except from a knowledge of the loudspeaker's sound power characteristic. Once this is known the reverberant sound level within a given space is calculable and when this is known it becomes immediately possible to calculate the Direct to Reverberant ratio of either a single loudspeaker or of a system. This in turn enables the potential intelligibility to be estimated and also an idea of the overall frequency response to be gained.

Using one of the most basic of acoustic equations

$$Lp = Lw + 10 \log (Q/4\pi r^2 + R/4) \text{ .... Eq 1}$$

enables the direct and reverberant sound levels in a room to be calculated but of course Lw needs to be known. Essentially there are three methods of determining Lw. These are based around (a) Reverberation room, (b) Anechoic chamber or (c) Sound Intensity techniques. In practice either the reverberation chamber or anechoic measurement methods tend to be used. Where a reverberation chamber is available the sound power can be calculated from a knowledge of the diffuse sound pressure level (Lp), the reverberation time and the volume of the room. Lw can then be calculated from the expression $Lw = Lp_{rev} + 10 \log V - 10 \log T - 14$ (Where Lp_{rev} is the spatially averaged reverberant or diffuse sound level, V is the volume of the chamber and T is the RT60). If the nominal electrical (audio) power taken by the loudspeaker is known (from a knowledge of the applied voltage and impedance (or current)) then Lw can be found and referred back to the reference power level of 10^{-12} watts. In the anechoic chamber method (which also includes reflection free, time gated measurements), Lw can be derived from calibrated polar measurements and the computed directional Q or Di value of the loudspeaker eg $Lw = Lp - 10 \log Q + 20 \log r + 10.8$ dB. Again assuming that the nominal audio signal input power is known.

6. SOUND POWER DATA

Very few manufacturers provide sound power data. A rare exception is an old 1985 data sheet from EV shown in figure 2 – bottom curve. The data is for a 2 way device with integral, wide dispersion horn CD flare. This is a good power characteristic and fairly typical for such a device. More recently JBL have begun to publish power response information for their high quality studio monitor loudspeakers and a graph of this is shown in figure 3. These devices however are hardly typical of the units generally used for PA and Voice Alarm systems. A number of typical devices were therefore taken into the laboratory and measured. (Unfortunately as the measurement techniques developed, the data presentation techniques also changed, so that some care needs to be taken when reading the following succession of graphs – however it is the general shape of the curves that is the important aspect to remember).

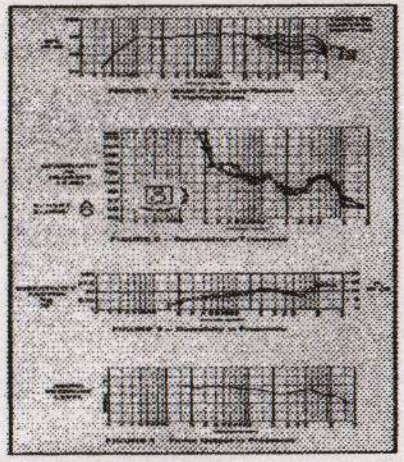


Figure 2 EV Data Sheet (1985)

Figure 3
Frequency Response Curves For High Quality Monitor Ls - Note Off Axis & Power Curves

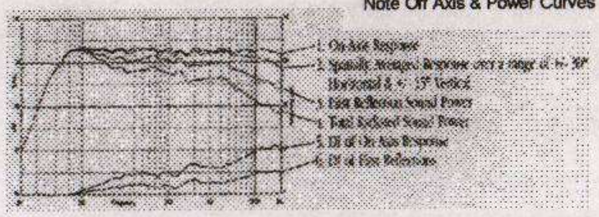


Figure 4 shows the power response for a 5 inch cone loudspeaker. This is very typical for a device which either has a collapsing coverage angle or progressively gets more directional. The point to note is the collapsing power response (steep gradient from low to high frequencies). Figure 5 shows a typical power response for a CD horn. The device does not have effective pattern control until around 1 kHz and above. As can be seen from the power response curve, from there on up, the acoustic power output is pretty constant as well, maintaining a variation within just 3 dB. Figure 6 shows the power response of a short column loudspeaker with an HF crossover just above 2 kHz. Again the collapsing response can be seen at low to mid frequencies but is overcome at high frequencies by the HF device.

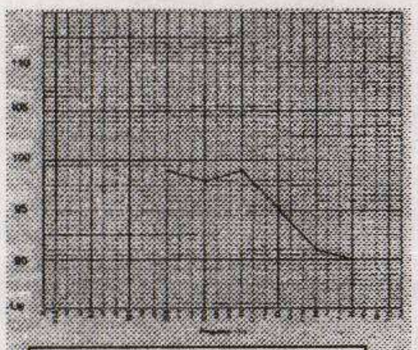


Figure 4 Sound Power Response of typical 5 inch Driver

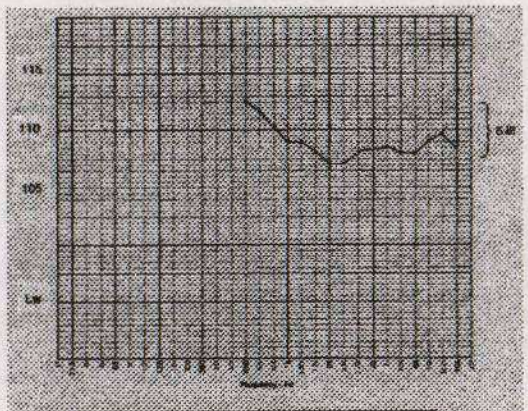


Figure 5 Sound Power Response of typical CD Horn

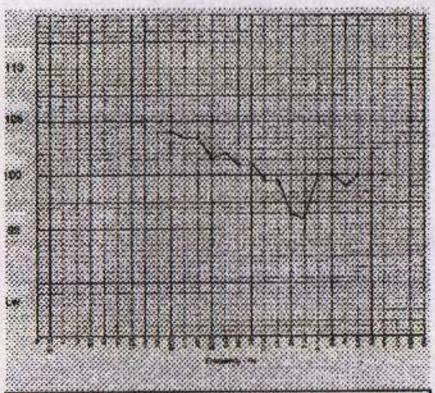


Figure 6 Sound Power Response of Column LS (with cross-over)

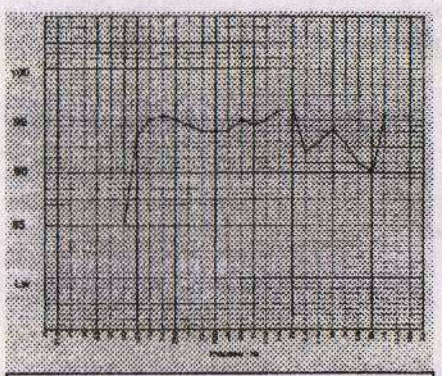


Figure 7 Sound Power Response of Ceiling Loudspeaker

By contrast, figure 7 shows the response for a typical ceiling speaker - measured in half space to more closely mimic its real performance when in use. The device exhibits a reasonably well controlled characteristic up to around 2 kHz when the dispersion collapses in a fairly typical manner and the power output falls. By contrast figure 8 shows the power response for a Distributed Mode Loudspeaker (DML). This bares out the theoretical prediction that such devices, when correctly designed, should exhibit a nominally flat power response.

Figure 8 Power Response PRD 1 DML.

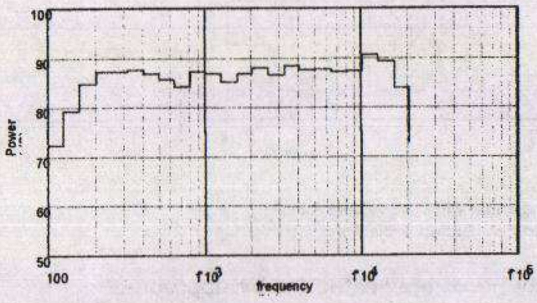
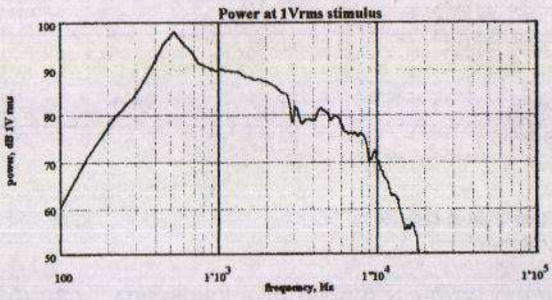


Figure 9 Sound Power Response of 750 mm Column LS



Two further interesting power response examples are given in Figures 9 & 10. Figure 9 shows the response for a 750 mm column loudspeaker. This is pretty typical for such a device with a well pronounced high frequency roll off in power output, but in this case with a 6 dB peak at around 500 Hz as well. The normal (axial) frequency response for the unit however, is respectably flat and therefore at odds with the sound power output. Figure 10(a) shows the power response for a compact directional sound projector. This also exhibits a peak at around 500 Hz but then maintains a reasonably flat response up to 4 kHz and then collapses. By contrast, figure 10(b) shows the corresponding axial frequency response, which although exhibiting a hint of the peak at 500 Hz does not give any indication of the power response characteristic of the unit. The response of the projector when measured in situ in a reverberant concourse is shown in figure 11. Unfortunately due to the different instrumentation employed, the graphs do not have the same scales but, it can be seen that it is the power response rather than the axial frequency response that determines the resulting measured and very audible effect.

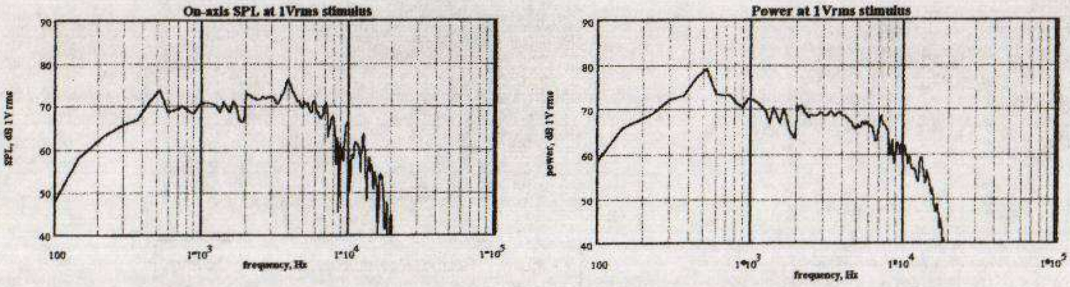


Figure 10 Frequency Response & Sound Power for Directional Sound Projector

This is also demonstrated in figure 12, which shows an in situ response measurement of the column loudspeaker shown in figure 9, again indicates that it is the power response predominantly at work rather than the axial frequency response with a combination of the two giving rise to resulting audible response.

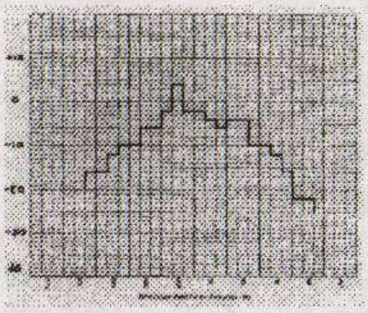


Figure 11 Response of Directional Sound Projector

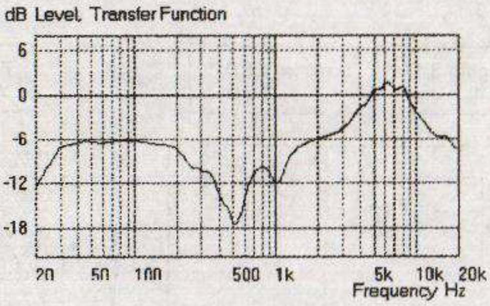


Figure 13 Equalisation Filter Response for Directional Sound Projector

Whereas the power response of a loudspeaker can readily be compensated for by appropriate equalisation, such filtering will of course also unavoidably affect the axial (direct) response, which makes system equalisation when using such devices a painstaking and often frustrating process. An example of the radical filtering that sometimes needs to be applied is shown in figure 13. That the reflected and reverberant fields can dominate the system response yet still provide adequate intelligibility can come as a surprise. For example, in a space with a 2 second Reverberation Time and employing a distributed sound system, the direct to reverberant ratio can be quite negative e.g. –9 dB for a resultant intelligibility of 0.50 STI (10 % Alcons) or –5 dB D/R for 0.65 STI (5 % Alcons). The corresponding C50 may also be quite negative under such circumstances as exemplified by figure 14.

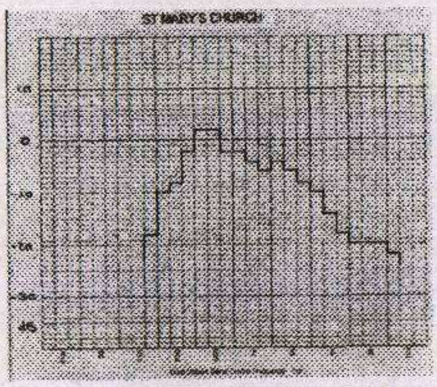


Figure 12 Column Ls Response in 2 Sec Rt

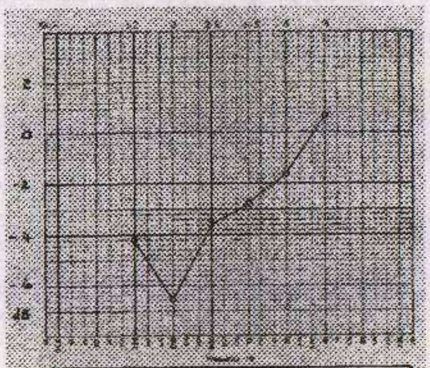


Figure 14 C50 vs Frequency for an STI of 0.5 in 2 sec RT space.

7. SOME THOUGHTS AND CONCLUSIONS

Based on many measurements and systems evaluated by the author, it is clear that in reverberant / highly reflective spaces, the sound power response of the loudspeaker often dominates – even when observed using time windowed responses. Subjectively, a combination of both the direct and reflected fields is heard and in many cases when equalising a system, a compromise has to be reached between the often conflicting requirements of these individual responses. Loudspeakers that exhibit a sound power response that is radically different to their axial frequency response, generally do not equalise as easily as those devices which more nearly track each other and offer a smooth or nominally power flat response. Constant Directivity horns and similar devices seem to provide this latter characteristic as can well designed DMLs. The current generation of high quality monitor loudspeakers can also get extremely close this ideal.

The sound power response of a loudspeaker is an extremely useful parameter, which in many situations and particularly in reverberant spaces, can act as a superior indicator of potential loudspeaker performance and furthermore allows an indication of potential speech intelligibility to also be calculated. As we have seen, it is relatively simple to measure or compute the sound power response of a loudspeaker. Many sound system loudspeakers are now being measured with 1/3 octave and 10 or 5 degree angular resolutions for CAD programme device libraries. The opportunity to provide this really useful parameter should be taken, as all that is required is a small computational manipulation of the data. Ironically, perhaps, it is the lower cost device end of the market where this information would probably be most useful in practice. However, it would also find considerable application at the upper end as well – particularly as an additional tool for loudspeaker designers and specifiers, after all, if you have the polar and Q data (which no self respecting spec sheet these days should be without) it only takes a couple of clicks of a mouse and a spread sheet modification to provide it !