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DESIGNING LOUDSPEAKERS WITH THREE WALLS

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1. INTRODUCTION

The effect the presence of boundaries have on the low frequency output of loudspeakers is well known [1-4]. Many methods of ameliorating these effects have been proposed, ranging from careful positioning to special speaker designs which try to remove the effect of the boundaries.

However, in most practical applications the loudspeaker designer is faced with the fact that the speakers will be used in an unspecified room, with six boundaries, and a limited space in which to position them.

The purpose of this paper is to present a method of designing loudspeakers in which the presence of the nearest three boundaries are taken into account in the design of the low frequency speaker. The paper will first review the effects of the three boundaries. It will then discuss how these effects might be compensated for. The paper will then examine the low frequency behaviour of loudspeaker drive units, and make suggestions for new alignments which take account of the boundaries. It will conclude with some simulation examples.

2. HOW BOUNDARIES AFFECT LOUDSPEAKER OUTPUT

Waterhouse [2] extended work by Rayleigh [3] and confirmed experimentally that the power output of a source in the presence of three boundaries (mutually perpendicular) is given by:

$$\frac{W}{W_f} = 1 + \frac{\sin(4\pi\frac{x}{\lambda})}{4\pi\frac{x}{\lambda}} + \frac{\sin(4\pi\frac{y}{\lambda})}{4\pi\frac{y}{\lambda}} + \frac{\sin(4\pi\frac{z}{\lambda})}{4\pi\frac{z}{\lambda}} +$$

$$\frac{\sin(4\pi\frac{(x^2+y^2)^{\frac{1}{2}}}{\lambda})}{4\pi\frac{(x^2+y^2)^{\frac{1}{2}}}{\lambda}} + \frac{\sin(4\pi\frac{(y^2+z^2)^{\frac{1}{2}}}{\lambda})}{4\pi\frac{(y^2+z^2)^{\frac{1}{2}}}{\lambda}} + \frac{\sin(4\pi\frac{(z^2+x^2)^{\frac{1}{2}}}{\lambda})}{4\pi\frac{(z^2+x^2)^{\frac{1}{2}}}{\lambda}} +$$

$$\frac{\sin(4\pi\frac{(x^2+y^2+z^2)^{\frac{1}{2}}}{\lambda})}{4\pi\frac{(x^2+y^2+z^2)^{\frac{1}{2}}}{\lambda}} \tag{1}$$

where: $\frac{x}{\lambda}, \frac{y}{\lambda}, \frac{z}{\lambda}$ are the distances to the boundaries and

$\frac{W}{W_f}$ is the power output relative to the free field output

Equation 1 gives the output for three boundaries the outputs for one or two boundaries can be obtained by setting the appropriate distances from the boundaries to infinity. The effect of this

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Figure 1 Loudspeaker Boundary Interaction "Non-Optimum" Placement

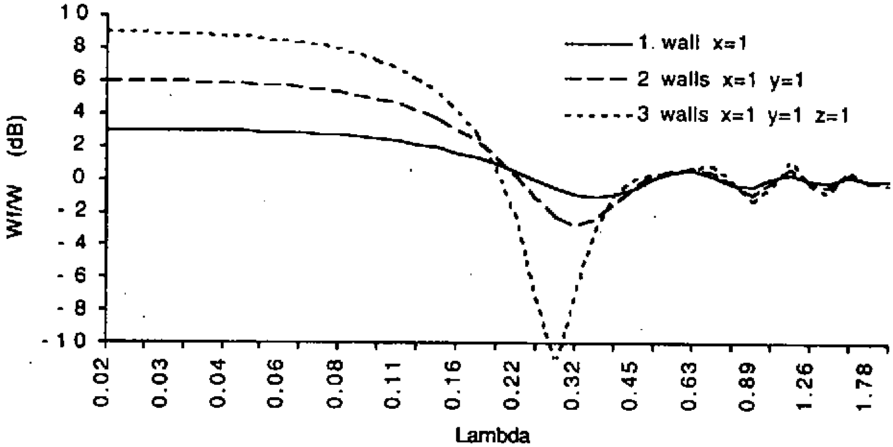
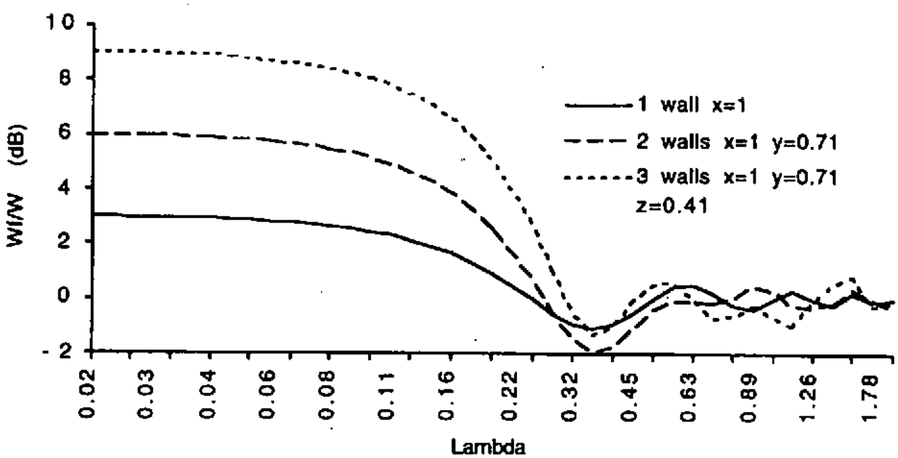


Figure 2 Loudspeaker Boundary Interaction "Optimum" Placement



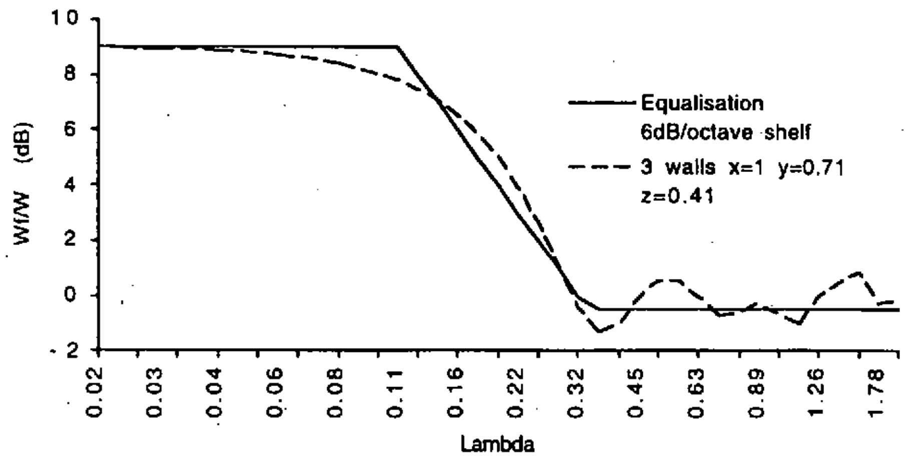
is plotted in figures 1 and 2 for two different boundary conditions. In one case all the dimensions are the same (figure 1), in the other they are different so as to minimise the effects (figure 2). From these graphs we can see two main things:

1. If the dimensions are the same then one has a low frequency response which rises to 9dB above the mid-band response and which has significant variation over the frequency range.

2 By placing the speaker carefully with respect to the boundaries one can eliminate some of the variation in the response but one still has a 9dB rise in response at low frequencies.

The above is well known and the 9dB rise at low frequencies is inherent in operating in an environment with three boundaries.

Figure 3 Loudspeaker Boundary Interaction "Optimum" Placement plus Equalisation Curve



Given that the problem is inherent can one design the low frequency output of the loudspeaker to allow for this effect? In order to answer this we need to consider whether the curves shown can be compensated by any known equalisation network. Figure 3 shows the "optimum" three boundary case overlaid with a simple 6dB per octave shelf. From this graph we can see that a simple 6dB per octave shelving type equaliser can do a creditable job of equalising the gross response at low frequencies providing one accepts that there will be some variation from flatness. However, the ideal would be to build the equalisation into the loudspeaker alignment so that extra equalisation components are not required. Such alignments may also offer advantages in the size of loudspeaker enclosure. Unfortunately loudspeakers have frequency responses which have slopes in excess of 6 dB per octave. Therefore, to see if see if such alignments might be possible, we need to look in more detail at the response of the moving coil loudspeaker drive unit at low frequencies.

3. THE LOW FREQUENCY RESPONSE OF DRIVE UNITS

The low frequency output of a moving coil drive unit in an infinite baffle can be given by (from Small [5]):

$$G(s) = \frac{s^2T_c^2}{s^2T_c^2 + s\frac{sT_c}{Q_{TC}} + 1}$$

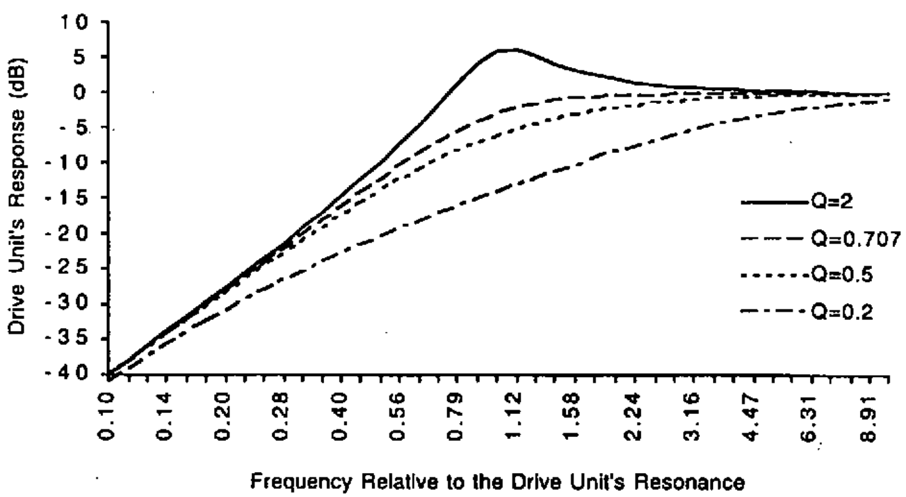
Where: T_c is the drive unit time constant given by: (2)

$$T_c = \frac{1}{2\pi f_o} \text{ where } f_o \text{ is the unit's resonance frequency}$$

and Q_{TC} is the total system Q

This gives us the familiar second order response in which the shape of the curve is controlled by the Q to give responses which vary from peaked to heavily damped as shown in figure 4.

Figure 4 Drive Unit Response for Varying Qt



The curve for Q=0.2 seems to have a slope which is less than 12dB per octave and could provide what we require. Therefore let us consider the frequency response of a drive unit whose Q is less than 0.5, that is, heavily damped.

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Equation (2) can be re written as:

$$G(s) = \frac{\frac{s^2}{\omega_o^2}}{s^2 + s\frac{\omega_o}{Q_{TC}} + \omega_o^2} \qquad (3)$$

The denominator of (3) can be rewritten in the form of:

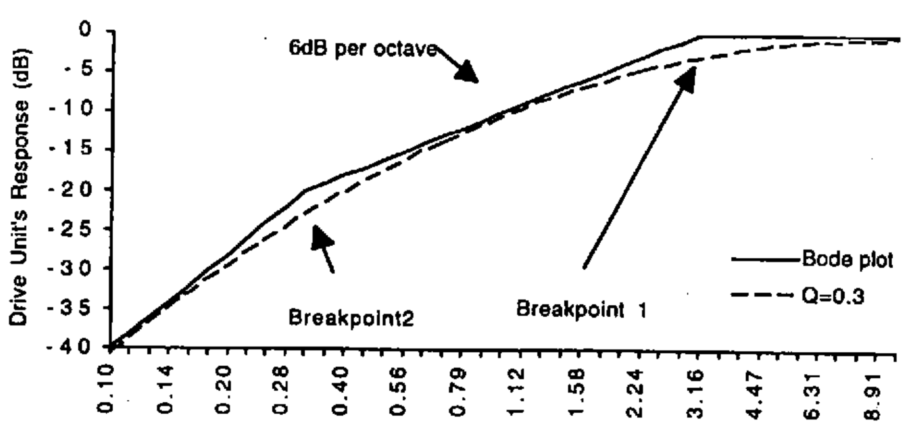
$$D(s) = (s + \alpha + \beta)(s + \alpha - \beta)$$

$$Where:\ \alpha = \frac{\omega_o}{2Q} \qquad (4)$$

$$and:\ \beta = \omega_o\sqrt{\frac{1}{4Q^2} - 1}$$

Equation (4) clearly shows the two roots of the second order equation. If Q is greater than 0.5 then β is imaginary and we have the familiar conjugate root of a second order system. However if Q is less than 0.5 then β is real and we have two real roots in the system, one at a break frequency which is greater than the drive units resonance and one which is below. In fact the resonance will be at the geometric mean of these two break points. Because each break point is real the frequency response will only change by 6dB per octave at each one. This means that the frequency response will contain a section between the breakpoints, around the resonance, which has a slope of 6dB per octave. This is shown in figure 5.

Figure 5 Drive Unit Response for Small Qt



Equation (3) can therefore be written as:

$$G(s) = \frac{\frac{s^2}{\omega_o^2}}{\left(s + \frac{\omega_o}{2Q} + \omega_o\sqrt{\frac{1}{4Q^2} - 1}\right)\left(s + \frac{\omega_o}{2Q} - \omega_o\sqrt{\frac{1}{4Q^2} - 1}\right)} \tag{5}$$

Both figure 5 and equation 5 show that one can achieve a 6dB per octave slope in a drive unit around its resonance frequency by choosing an appropriately low Q for the drive unit.

4. APPLICATION

For closed box loudspeakers one can apply the above equation without modification. One just has to adjust the drive unit's Q_t and resonance in the box such that when it is placed in the room the bass lift due to the boundaries is compensated by the 6dB per octave section in the loudspeakers response. This section needs to extend over about one and a half octaves to compensate for the 9dB lift introduced by the boundaries. This could be achieved by a total system Q_t of about 0.4 to 0.5.

For vented box loudspeakers the problem is a little harder. However if one looks at Small's [6] results for mis-tuned enclosures one finds that enclosures, which have low Q drivers and are mis-tuned such that the port resonance is lower than the drive unit's, can also exhibit a region of slope which is 6dB per octave. Therefore they can also be designed to compensate for the room boundaries.

5 RESULTS AND FURTHER WORK

Figures 6 and 7 show these ideas applied to a sealed and vented box loudspeaker. They are based on the parameters of real drive unit with a Q_{ts} of 0.31 and a resonant frequency of 65Hz. The results clearly show that it is possible to compensate for the bass lift due to the boundaries. However the ripples could probably be optimised further and more work needs to be done in this area. The results are also dependent on the position of the speaker in the room. In these calculations the speaker was placed such that its back would be near the wall, a typical bookshelf mounting. However, although the results get poorer as the speaker is moved away from the wall, the results vary smoothly towards the free-field result as on moves away from the boundaries. Figure 8 shows the effect of moving two of the boundaries further away by 50% and one can see the effect is a, well behaved, slight reduction of low frequency output.

6. CONCLUSION

The effect of the three nearest boundaries on a loudspeaker can be broadly compensated for with a 6dB per octave shelf. Loudspeaker drive units with a low Q exhibit a region of 6dB per octave roll off in their frequency responses which can be used to provide this compensation. Thus by designing with such units in conjunction with the effect of the room boundaries it should be possible to achieve better low frequency performance in real domestic environments.

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Figure 6 Frequency Response of a Closed Box Loudspeaker Design Including the Boundaries

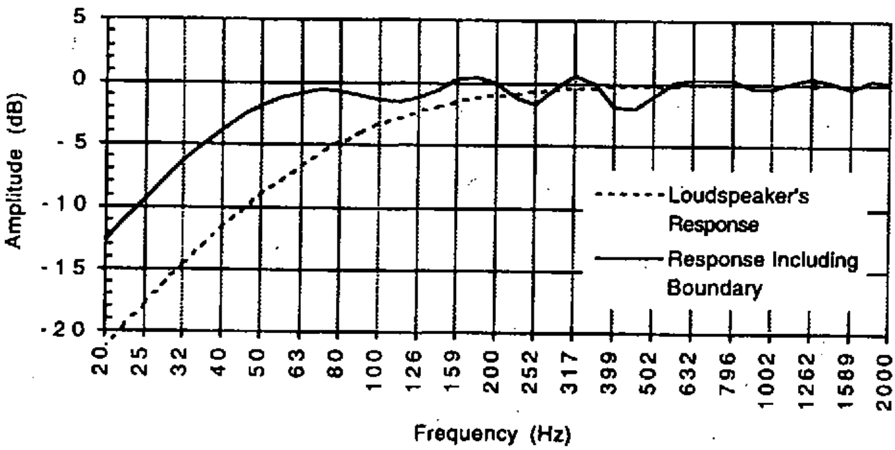

Figure 7 Frequency Response of a Vented Box Loudspeaker Design Including the Boundaries

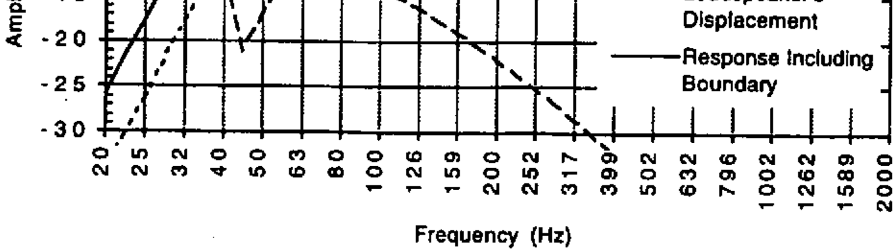

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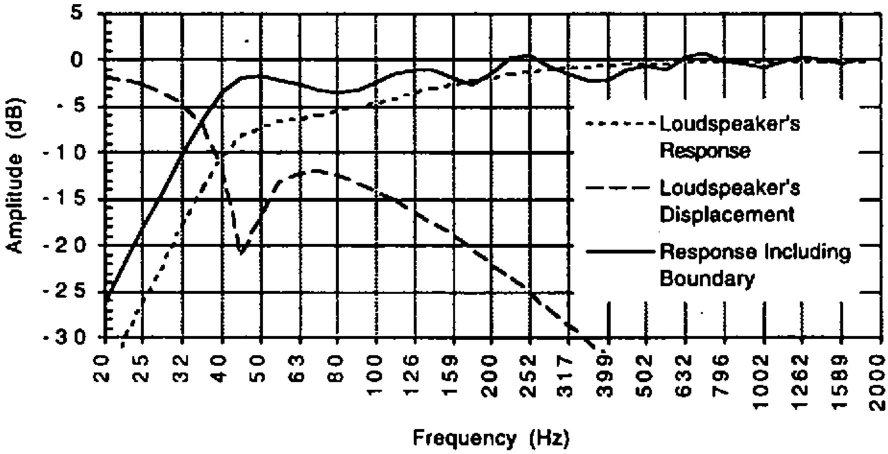
Figure 8 Frequency Response of a Vented Box Loudspeaker Design with the Boundaries Further Away



7. REFERENCES

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