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D, H AND C: A NEW LOOK AT THE DEFINING PARAMETERS OF A CURVED LINE ARRAY

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1. INTRODUCTION

Optimising a straight line array for an audience area is an impossible task, due to the far-reaching and frequency dependent crossover between near field and far field. The effects of curving in real world line arrays don't seem to be well understood. While novices are enjoying mythical 3dB happiness and experienced practitioners are sweating through the various simulation tools, a clear engineering methodology for setting up and optimising line arrays still seems to be missing. Our research into the simulation of line arrays has led us to a new understanding of the relationship between the defining parameters distance, height and curving, and the resulting quantities such as max SPL, vertical dispersion, ripple in frequency response etc. We will visualize some of the key results, in order to make it more obvious how the complexity of the matter can be reduced to a few rules of thumb and a handful of do's and don'ts. This will leave us with a very practical methodology for setting up and optimising real line array systems. We will show a spreadsheet-based tool to demonstrate the approach.

2. DEFINITIONS

The key characteristics of a line array are:

- Maximum sound pressure level SPL_{max}
- HF loss corner frequency f.near.eqv
- Vertical dispersion angle alpha.v (f)
- Corner frequency fc.α , defined by alpha.v (f) ~ constant for all f $\geq$ fc.α
- Frequency response ripple Δ above f.near.eqv

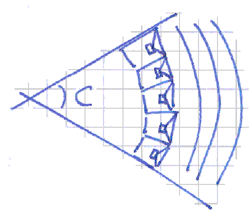

Figure 1. Curved array with curving angle C

These characteristics depend on the following parameters:

- Distance D, listening distance in m
- Curving C, the nominal vertical opening angle of the array [Fig. 1]
- Height H of the (straight) array in m

D and H are self explanatory. However, it might be relevant to note that all key characteristics actually do change with distance. C describes the curvature of the array and is defined as the (vertical) angle between the 0° axis of the lower and upper loudspeaker. In order to reduce the complexity we will initially only look at circular shapes of the curvature.

All results have been calculated with a point source model of a line array.

In our examples we have used a weighting function to drive the point source model in order to achieve an optimal linear frequency response (unless otherwise noted). This way we can better show the basic principles we want to demonstrate. However, it should be clear that a finite length straight line array will by definition exhibit strong ripple in the near field frequency response if all point sources are transmitting identical signals. This can not be equalized with a conventional equalizer, as the peaks and troughs vary with listening distance – an equalizer would therefore always be correct only for one distance.

3. PARAMETERS

3.1. Parameter D

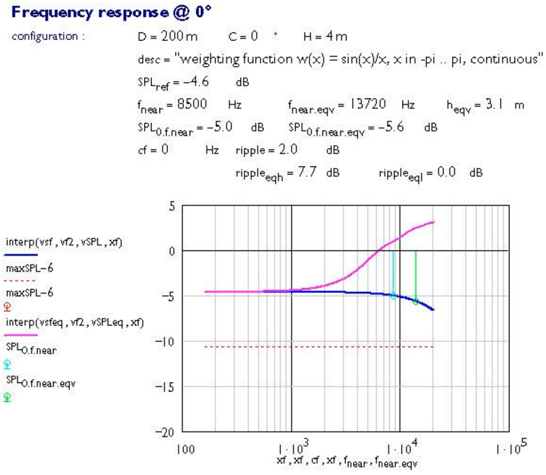

Figure 2. D 200m C 0° H 4m W3
f.near = 8.5kHz, SPL.max = -4.6dB

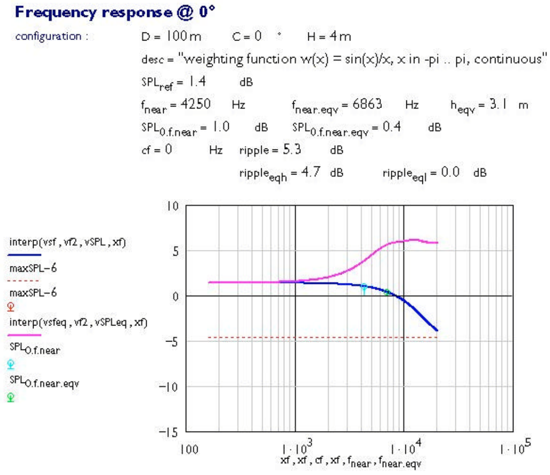

Figure 3. D 100m C 0° H 4m W3
f.near = 4.25kHz, SPL.max = 1.4dB

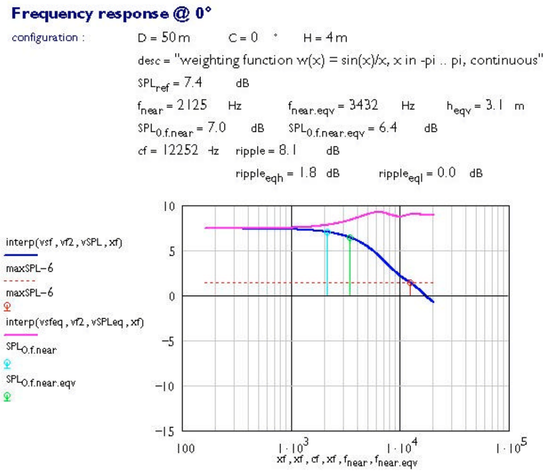

Figure 4. D 50m C 0° H 4m W3
f.near = 2.12kHz, SPL.max = 7.4dB

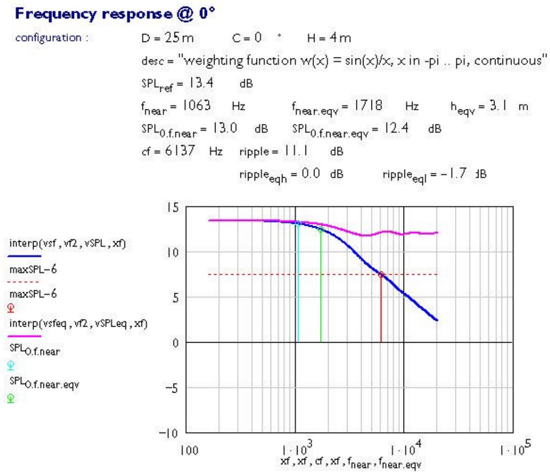

Figure 5. D 25m C 0° H 4m W3
f.near = 1.1kHz, SPL.max = 13.4dB

D describes the distance from the array. In the examples above the blue curve is the frequency response at 0° vertical without EQ. The pink curve is the frequency response with an optimal EQ. Optimal in this example means an EQ that is set for linear response in 35m distance.

The light blue line shows f.near, the crossover point between near- and far-field according to the well known formula cited in every line array article. The green line f.near.eqv is an empirical, calculated value for the crossover point between near- and far-field. It denotes the –1dB point in the frequency response. The –1dB value is quite arbitrary, and in actual fact is chosen so that in the case of a *straight* array it is nearly identical to f.near. It is well worth remembering that at this distance you are in the far field for all frequencies lower than f.near.eqv, and in the near field for all higher frequencies. However the ‘near-field effects’ become really visible (and audible) only at about twice f.near.eqv.

From 200m to 25m distance we can clearly see the 6dB increase per halving of distance, at and below f.near.eqv. Above this frequency the level increase is definitely less than +6dB, in the example you can see a level increase of only +3dB at 10kHz at 100m, 50m and 25m.

That's the whole secret of the "3dB loss per distance doubling" – by parts of the industry still presented as *the* advantage of line arrays: it's just another way of saying that the losses in the near field are greater than in the far field, so that a 6dB increase cannot be achieved for half the distance. The near field effect is simply a *lower* efficiency compared to the far field situation.

3.2. Parameter H

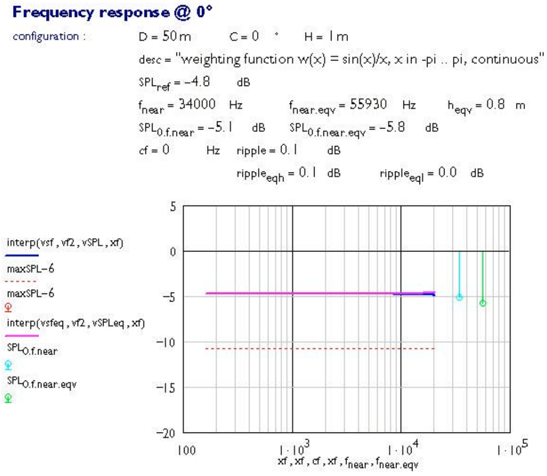

Figure 6. D 50m C 0° H 1m W3
f.near = 34kHz, SPL.max = -4.8dB

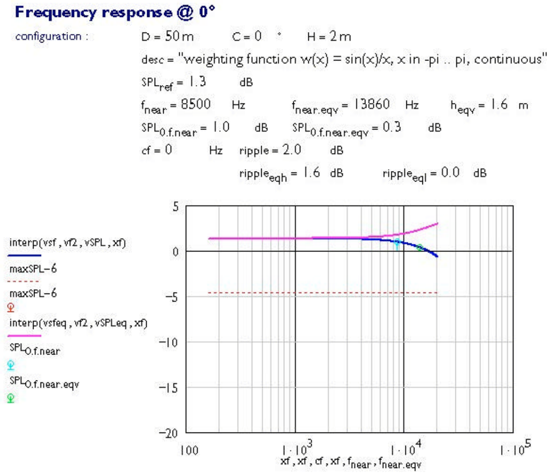

Figure 7. D 50m C 0° H 2m W3
f.near = 8.5kHz, SPL.max = 1.3dB

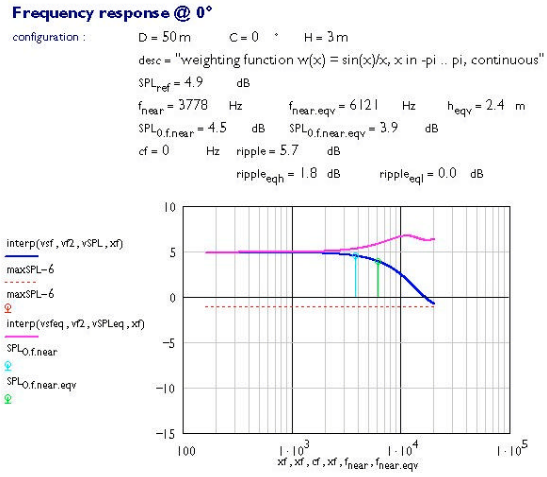

Figure 8. D 50m C 0° H 3m W3
f.near = 3.8kHz, SPL.max = 4.9dB

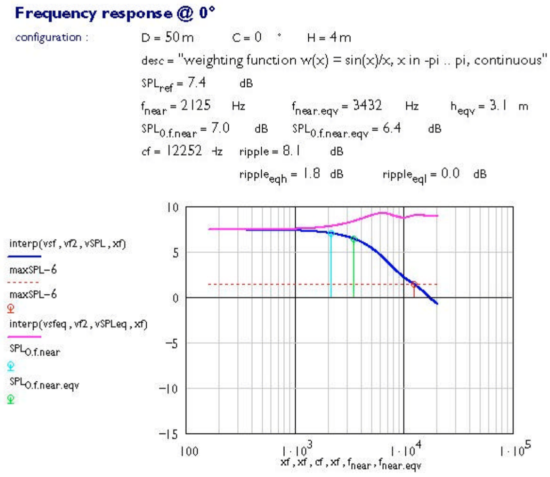

Figure 9. D 50m C 0° H 4m W3
f.near = 2.1kHz, SPL.max = 7.4dB

An increase in the height of the array is simply achieved by lining up more boxes. Obviously a higher sound pressure level can be achieved. At frequencies where coherent coupling between cabinets is achieved the level increases by 6dB in the far field when doubling the number of cabinets. In the near field, or – at a given distance – for frequencies above f.near.eqv only an increase closer to 3dB is achieved. f.near.eqv changes with $1/h^2$: twice the height reduces f.near.eqv to a quarter.

3.3. Parameter C

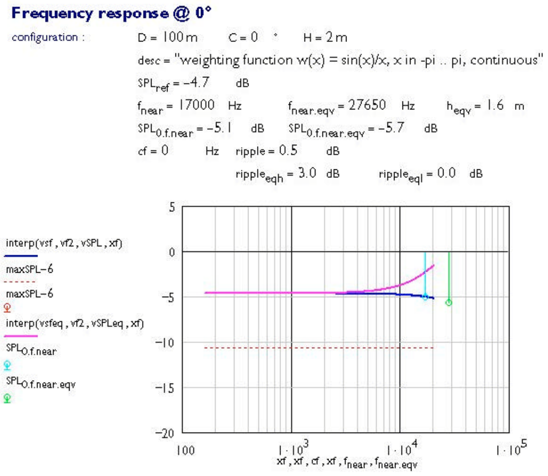

Figure 10. D 100m C 0° H 2m W3
f.near.eqv = 27.6kHz, SPL.max = -4.7dB

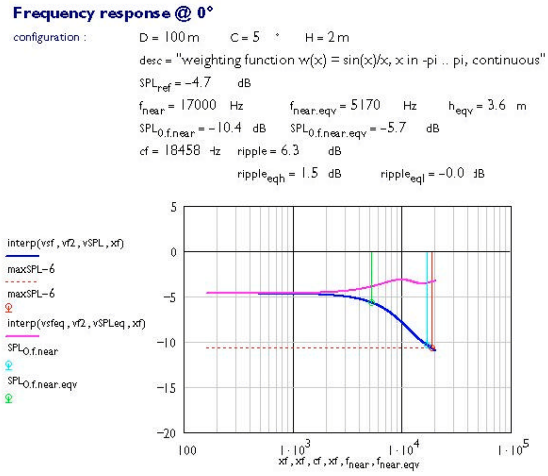

Figure 11. 1 D 100m C 5° H 2m W3
f.near.eqv = 5.2kHz, SPL.max = -4.7dB

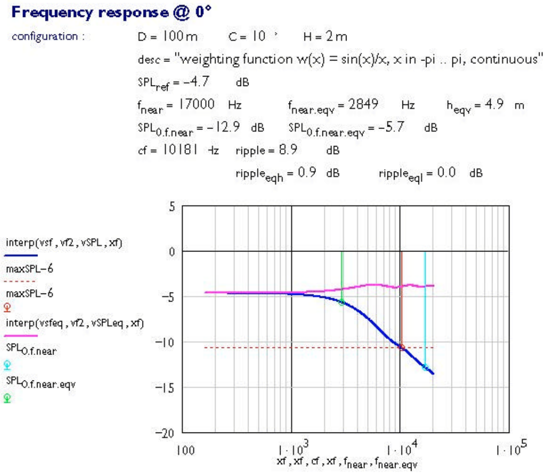

Figure 12. D 100m C 10° H 2m W3
f.near.eqv = 2.85kHz, SPL.max = -4.7dB

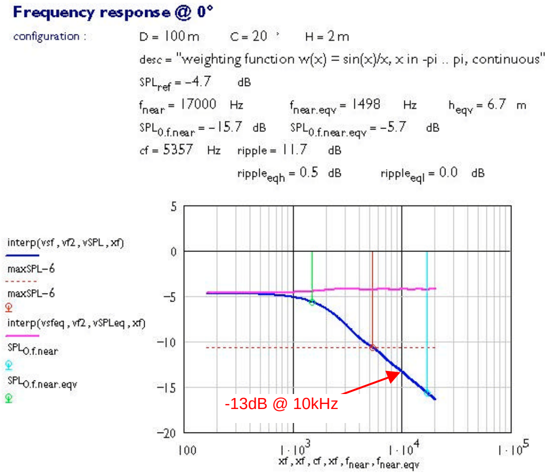

Figure 13. D 100m C 20° H 2m W3
f.near.eqv = 1.50kHz, SPL.max = -4.7dB

We are using circular curving in order not to complicate matters, and to show the effects in principle. As can be seen in the examples above the effect of increasing curving is an HF loss, with appr. –3dB/octave and a corner frequency appr. inversely proportional to the opening angle (f.near.eqv ~ 1/C above 5° in the example).

It is important to note, however, that the HF loss above f.near.eqv is *not* the same as in the near field HF loss in [fig. 2 … 9]. [Fig. 13] and [Fig. 14] show the same array at distances 100m and 25m resp.: the level increase at 10kHz is 11dB, close to the theoretical 12dB in the far field.

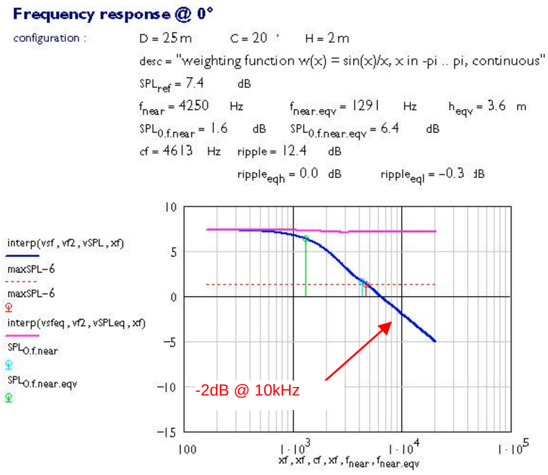

Figure 14. D 25m C 20° H 2m W3
f.near.eqv = 1.30kHz, SPL.max = 7.4dB

The biggest benefit of this situation can be seen in the pink curves: this type of HF loss can easily be compensated with an equaliser, as it does not change with distance. The optimal EQ for 35m distance is also optimal for 100m distance.

In larger arrays, with a lower f.near, curving and near field effects overlay each other. In actual examples it can be shown that curving still very much helps in “linearising” a frequency response, in the sense that the frequency response of the array doesn’t change as much with distance any more.

Of course, the real reason to use curving is the fact that the very small vertical dispersion angles that are achieved with straight line arrays are very seldom really desirable. A sub 5° vertical dispersion is easily blown away by the smallest air movement. Typical coverage angles required are more in the region of 15° - 80° for typical applications, depending on the distance of the speakers from the first rows of the audience.

3.4. Parameter W

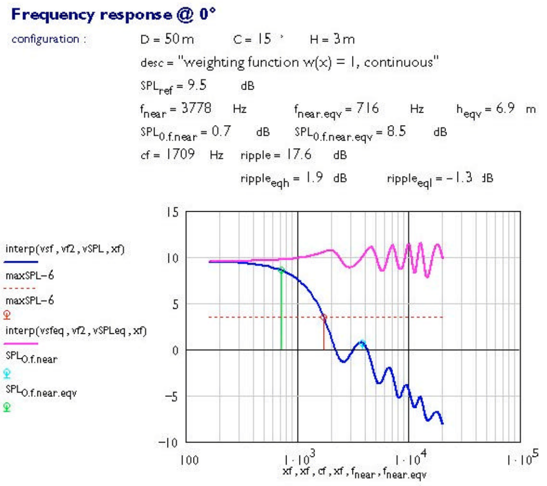

Figure 15. D 50m C 15° H 3m W1
SPL.max = 9.5dB, ripple.eq = 3.2dB

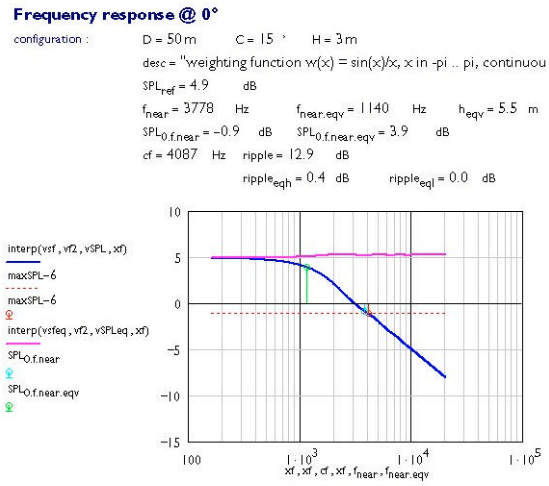

Figure 16. D 50m C 15° H 3m W3
SPL.max = 4.9dB, ripple.eq = 0.4dB

(Level) weighting of the sound sources in the array is not really the topic of this paper, however, one short comment, as weighting has been used in all of the graphics. The reasons for doing this were simply to show the principles without cluttering the picture with the frequency response ripple one would see without weighting (W1, [Fig. 15]). sin(x)/x weighting is used unless otherwise noted, which gives a very smooth response (W3, [Fig. 16]). However, due to the level loss of about 4.5dB, this type of weighting is not practical for real life applications. In real life situations $\cos^2(x)$ weighting is a good compromise with a level loss of appr. 2 dB and sufficiently good smoothing characteristics.

3.5. Vertical dispersion angle alpha.v.

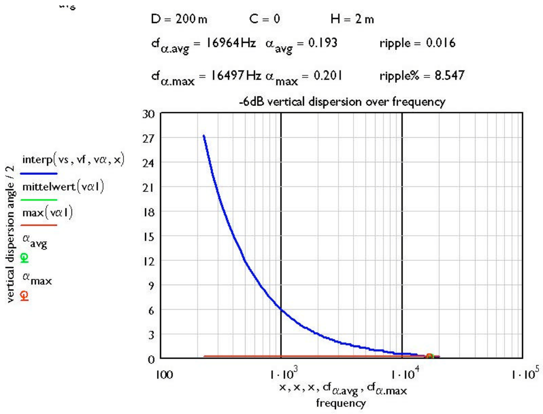

Figure 17. D 200m C 0° H 2m W1
fc.α.avg = 17kHz, α.avg = 0.4°, ripple = 8.5%

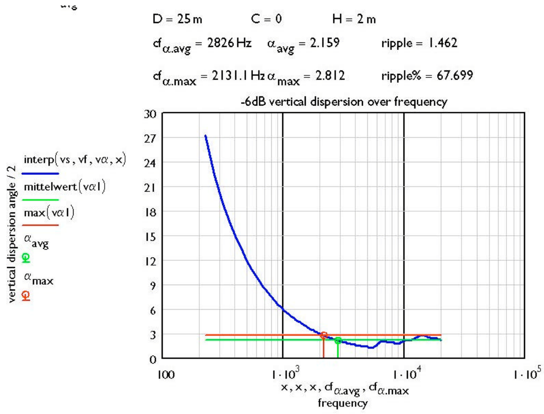

Figure 18. D 25m C 0° H 2m W1
fc.α.avg = 2.8kHz, α.avg = 4.3°, ripple = 68%

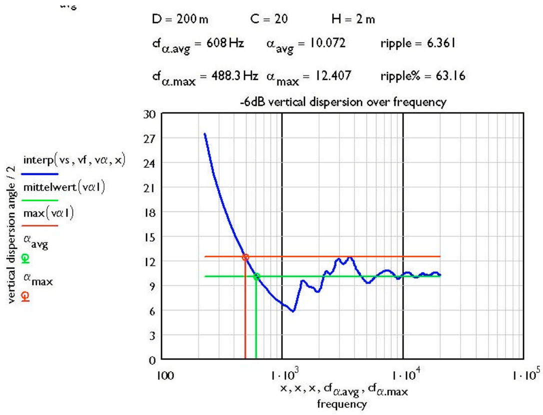

Figure 19. D 200m C 20° H 2m W1
fc.α.avg = 610Hz, α.avg = 20°, ripple = 63%

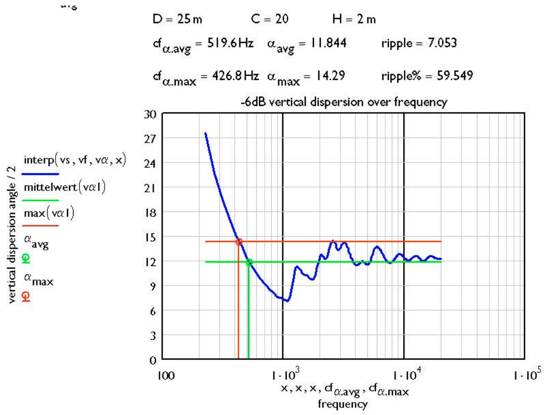

Figure 20. D 25m C 20° H 2m W1
fc.α.avg = 520Hz, α.avg = 24°, ripple = 60%

[Fig. 17 … 22] display the vertical dispersion of an array, the blue line denotes the –6dB point of ½ of the vertical dispersion angle (only one side shown). In [Fig. 17] and [Fig. 18] one can see the differences of a straight line array at 200m and 25m distance. While at 200m distance the line array exhibits something like a proportional directivity, vertical directivity is relatively constant at 25m distance for frequencies above a certain corner frequency.

A straight line array as in [Fig. 17] and [Fig. 18] not only changes frequency response with distance but also exhibits a rather difficult to use dispersion angle. With only a 2m array the vertical dispersion at 200m distance could euphemistically be described as proportional directivity, and at 25m it's still only 4° - rarely a really useable number. 20° curving as in [Fig. 19] and [Fig. 20] results in much less change of vertical dispersion between 200m and 25m. However, without weighting the result is not very smooth over frequency. Applying cos²(x) weighting to the line arrays of [Fig. 19] and [Fig. 20} results in dispersion patterns as in [Fig. 21] and [Fig. 22], quite obviously an improvement.

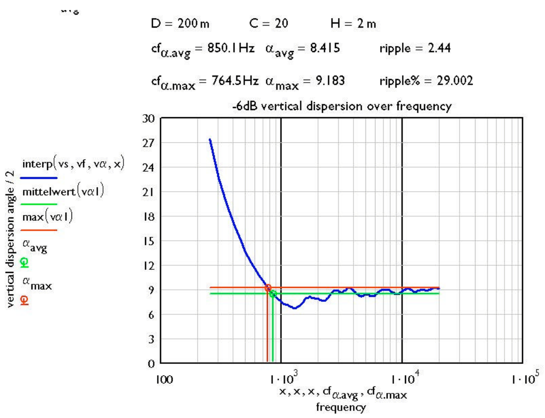

Figure 21. D 200m C 20° H 2m W2
fc.α.avg = 850Hz, alpha.v.avg = 17°, ripple = 29%

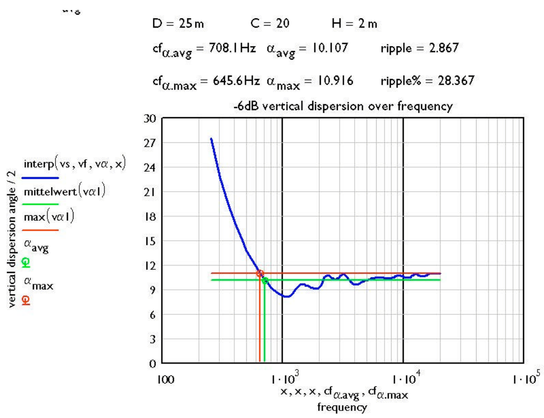

Figure 22. D 25m C 20° H 2m W2
fc.α.avg = 710Hz, alpha.v.avg = 20°, ripple = 28%

When comparing the examples for 0° and 20° curving one can easily see, that the relative difference in vertical dispersion between 200m and 25m distance is much less *with* curving than without (alpha.v.avg between 20° and 24° with curving, compared to 0.4° and 4.3° without). Relative ripple is the same, with or without curving there is a pronounced narrowing appr. 20% above f.near.eqv.

[Fig. 21] and [Fig. 22] show how weighting can reduce the ripple in the vertical dispersion. In the examples above we have used $\cos^2(x)$ weighting, which reduces the ripple from appr. 60% to less than 30%. Sin(x)/x weighting, by the way, would only reduce the dispersion ripple to appr. 40%.

4. CONCLUSION

Line array technology has resulted in systems that exhibit plane wave fronts up to quite high frequencies. So far, most systems were optimised for flat wave fronts. We have shown in this paper, that curved wave fronts exhibit smoother response characteristics that appear to be a more useable solution to covering large audience areas. In addition, common set ups actually do require vertical coverage angles larger than those achieved by straight line arrays and flat wave fronts. As a result, we believe that systems which allow for well defined *curved* wave fronts seem to be a more interesting development path to future sound reinforcement systems.