Introduction

A popular line array model is the infinite line source that is approximated physically by a floor to ceiling array multiplied by floor and ceiling reflections and reflections of those reflections. Such an array has a frequency response that falls at -3db per octave and an intensity that drops 3db with each doubling of distance. The arrays that we build and listen to are both finite and discrete. They approximate the infinite line source in room at the low end of the spectrum but depart from it to an increasing degree as frequency rises. Simulation of line arrays in Vituix allows one to quantify these departures and to reduce them through shading.

Point Source Array Response

Its helpful to examine the responses of arrays of point sources first before bringing in the complications of a physical driver's frequency response and directivity. Figure 1 below shows responses of 3 approximately 2.5m tall arrays in free space with increasing point density of 1, 2 and 4 points per 100 mm. In the limit as the point density and line length increase, we get the infinite line source model's response. The frequency responses show ripple around the -3db per octave roll off predicted for an infinite, continuous line source. In addition, near the frequency where the spacing is a wavelength, the ripple transitions to a more combining like response and at the same frequency, the vertical polar map shows vertical sidebands and loss of vertical directivity. With the 25 mm spacing, this transition occurs above 20 khz but most of the arrays we build with full range drivers are intermediate in spacing between that of the first two rows of the figure.

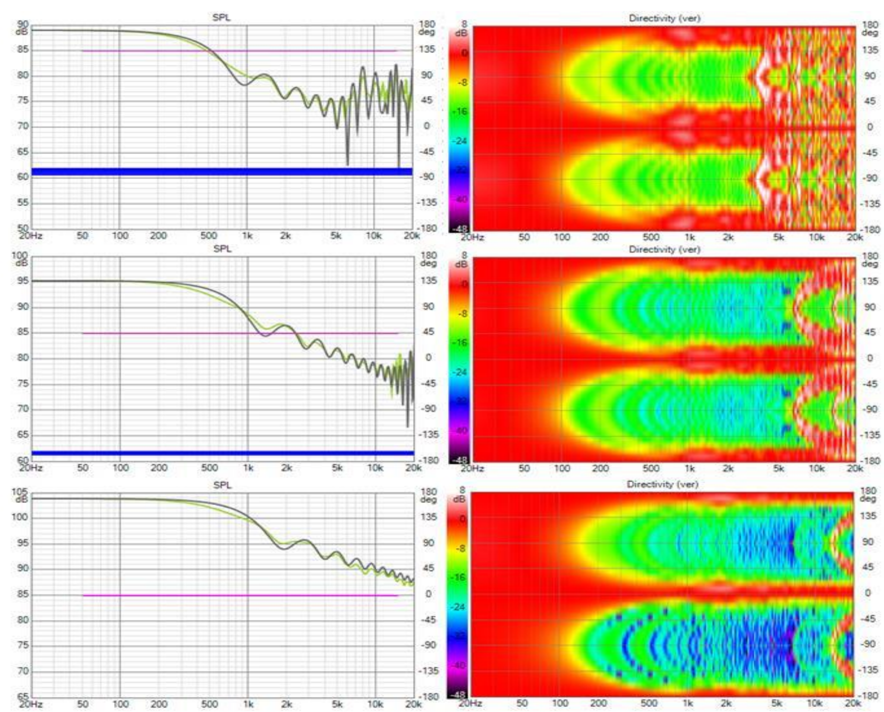


FIGURE 1 ARRAY RESPONSES WITH INCREASING POINT DENSITY

Figures 2 and 3 show that the array frequency response ripple varies with both listening distance and height. Thus, equalization of the ripple will be position dependent. By reduction of the ripple via shading we hope to reduce the positional dependency and to eliminate or reduce the combing and loss of vertical directivity in the top two octaves.

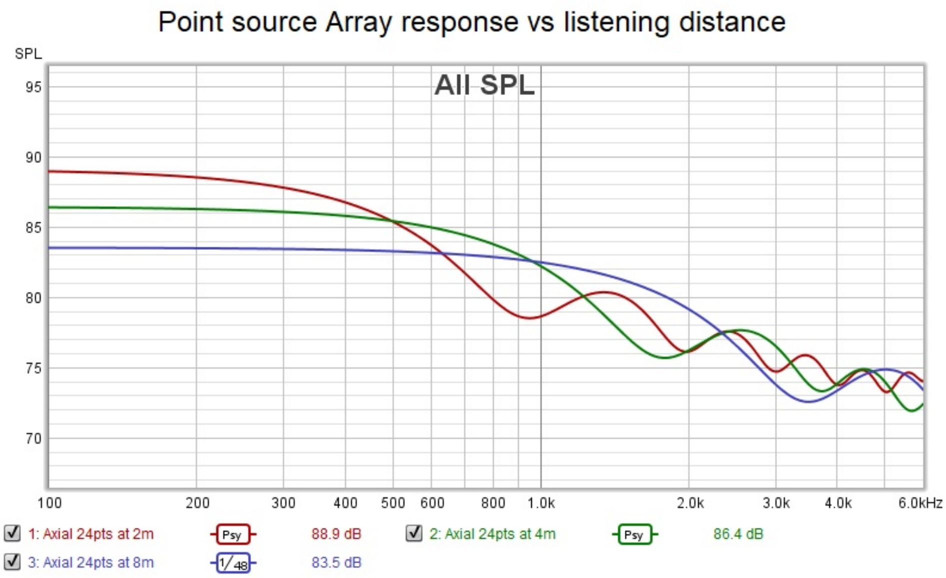


FIGURE 2 POINT SOURCE ARRAYS: RESPONSES VS DISTANCE

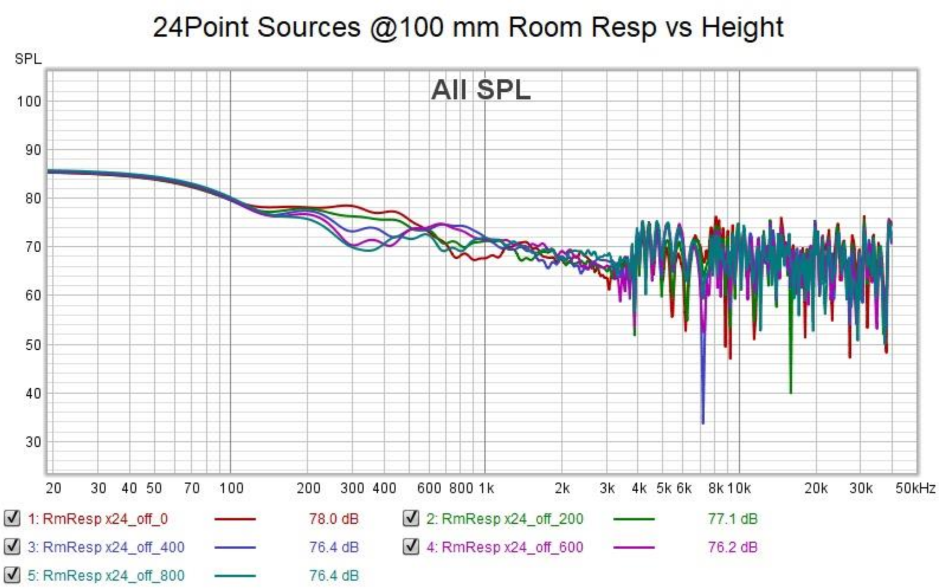


FIGURE 3 POINT SOURCE ARRAYS: RESPONSES VS VERTICAL OFFSET FROM ARRAY CENTER

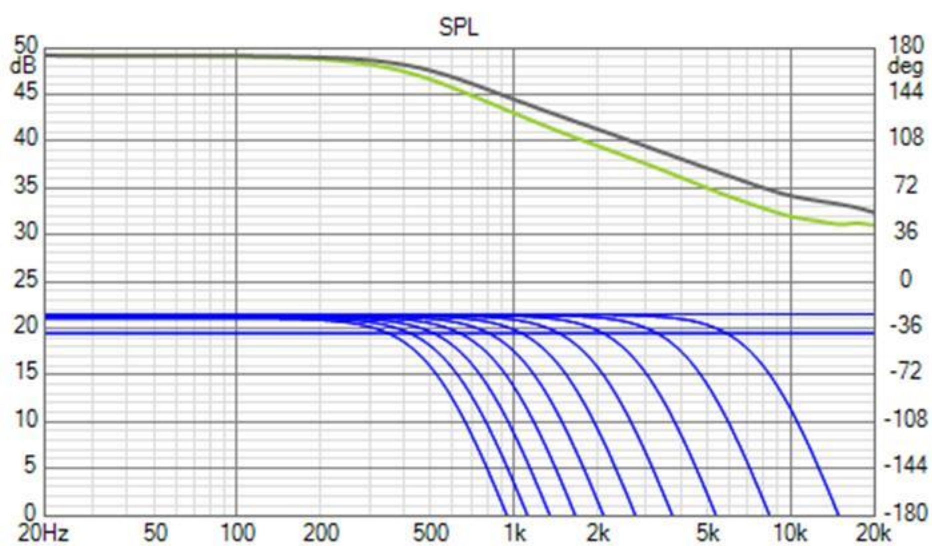
Fine Frequency Shading

What is the cause of this frequency response ripple? The response of a finite discrete array in free space is calculated by summing the response from each individual driver, taking into account the phase shift and attenuation with distance to the microphone and that due to the driver's directivity. The easiest way to do this calculation is to model the array in VituixCAD, without which I could not have done this paper.

It should be clear that the ripple can only be caused when the difference in path length for some drivers exceeds 90^0, resulting in subtractive combination. This delta path length dependent phase shift between each driver and that at the level of the microphone increases with frequency, progressing from mild frequency response ripple through severe combing. With this understanding one can implement shading to reduce or even eliminate this response ripple and combing.

Perhaps the best way to demonstrate that frequency response ripple and combing are caused by delta path length phase shifts greater than 90^0 is to implement shading in which each driver pair symmetrically located around the array center is low pass filtered to cut off its response where the delta path length phase shift would equal 90^0. I call this a fine frequency shaded array. The response of such an array with drivers spaced 84 mm, compatible with the popular TC9FD is shown in Figure 4. The blue traces in the same graph show the filter characteristics and number of channels used in the shading. The filters used where linear phase LR4; linear phase because the phase turn of a high order IIR filter at its corner frequency is problematic.

Combing and ripple have been eliminated from the frequency response. Subsequent figures show that the response shape is uniform over a wide range of listening positions but that the usable vertical listening window has been narrowed. We see a loss of treble as the mic moves up or down relative to array center. At 100mm offset and 3m listening distance, the response is down only 3 db, making this shading an excellent albeit expensive solution for seated only listening.



.

FIGURE 4 FINE FREQUENCY SHADED POINT SOURCE ARRAY

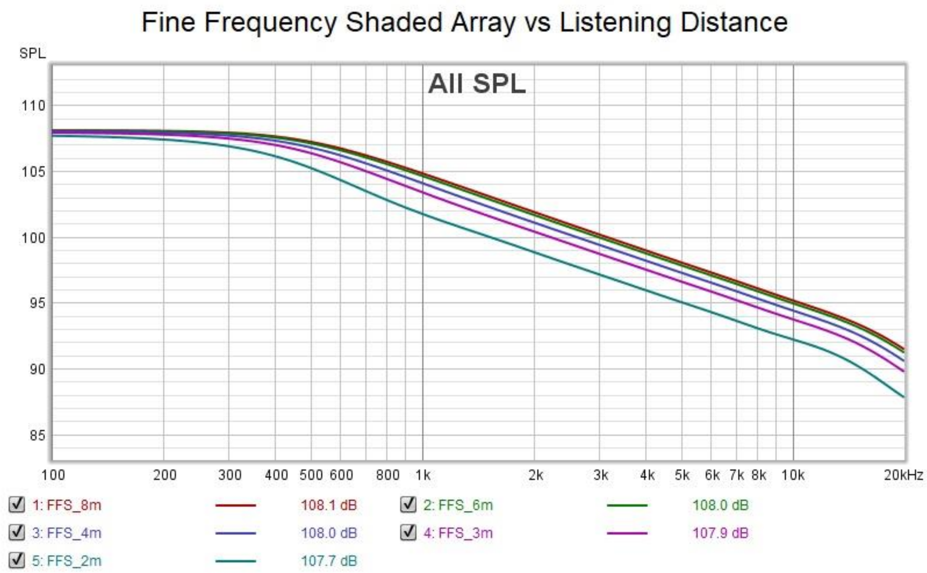


FIGURE 5 FINE FREQUENCY SHADED ARRAY RESPONSE VS LISTENING DISTANCE

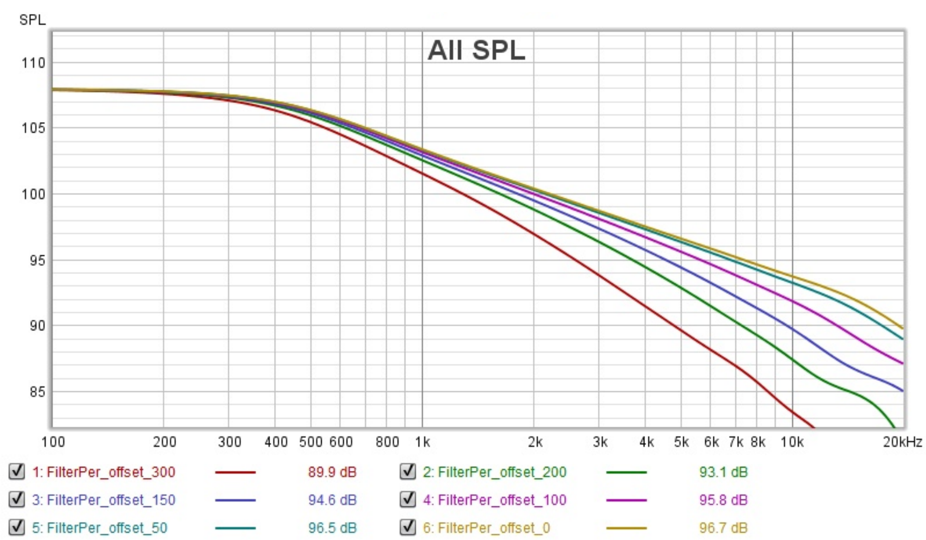


FIGURE 6 FINE FREQUENCY SHADED ARRAY RESPONSE VS VERTICAL OFFSET FROM ARRAY CENTER AT 3M

Response In-room

When this point source array is brought into a room and floor and ceiling reflections are included in the response combing appears above 5 khz. The path lengths for floor and ceiling reflections are longer than for direct response and so some subtractive combining does occur. There is also some response variation in the midbass that is a byproduct of the fact that fewer drivers operate in this region due to the shading. Ostensibly, the combing due to floor and ceiling reflections could be eliminated with thin layers of absorption on those surfaces as it occurs only at high frequencies.

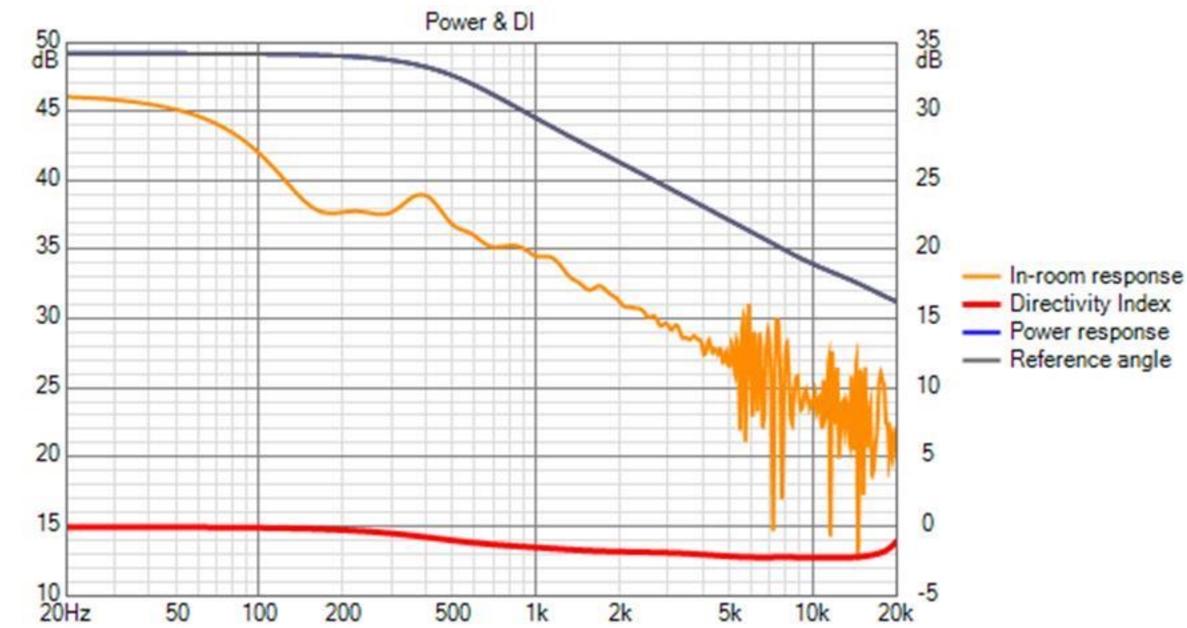


FIGURE 7 IN-ROOM RESPONSE OF THE ARRAY

Although reduced in magnitude compared to the unshaded array, vertical sidelobes remain visible in the polar map of Figure 8.

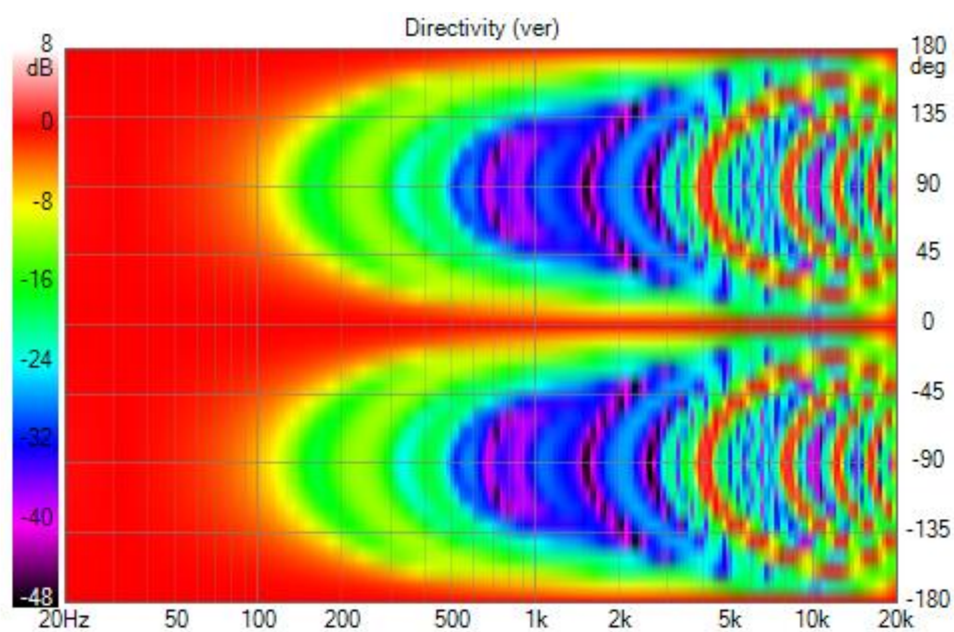


FIGURE 8 VERTICAL POLAR MAP OF THE UN-EQUALIZED SHADED ARRAY

Figure 9 shows the axial and in-room responses when the point sources are replaced with TC9FD models in the simulation and then equalized. High frequency combing due to floor and ceiling reflections is reduced because this driver beams at high frequencies thus directing less energy at floor and ceiling. The absence of sidelobes in the treble region of the vertical polar map is correlated with the reduction of combing in the same frequency range.

Its interesting to compare the directivity indexes of the un-equalized shaded array (red trace in Figure 7) to that of the equalized shaded array (Figure 9). Un-equalized the vertical directivity is virtually flat; equalized, directivity increases with frequency with increased slope in the top two octaves.

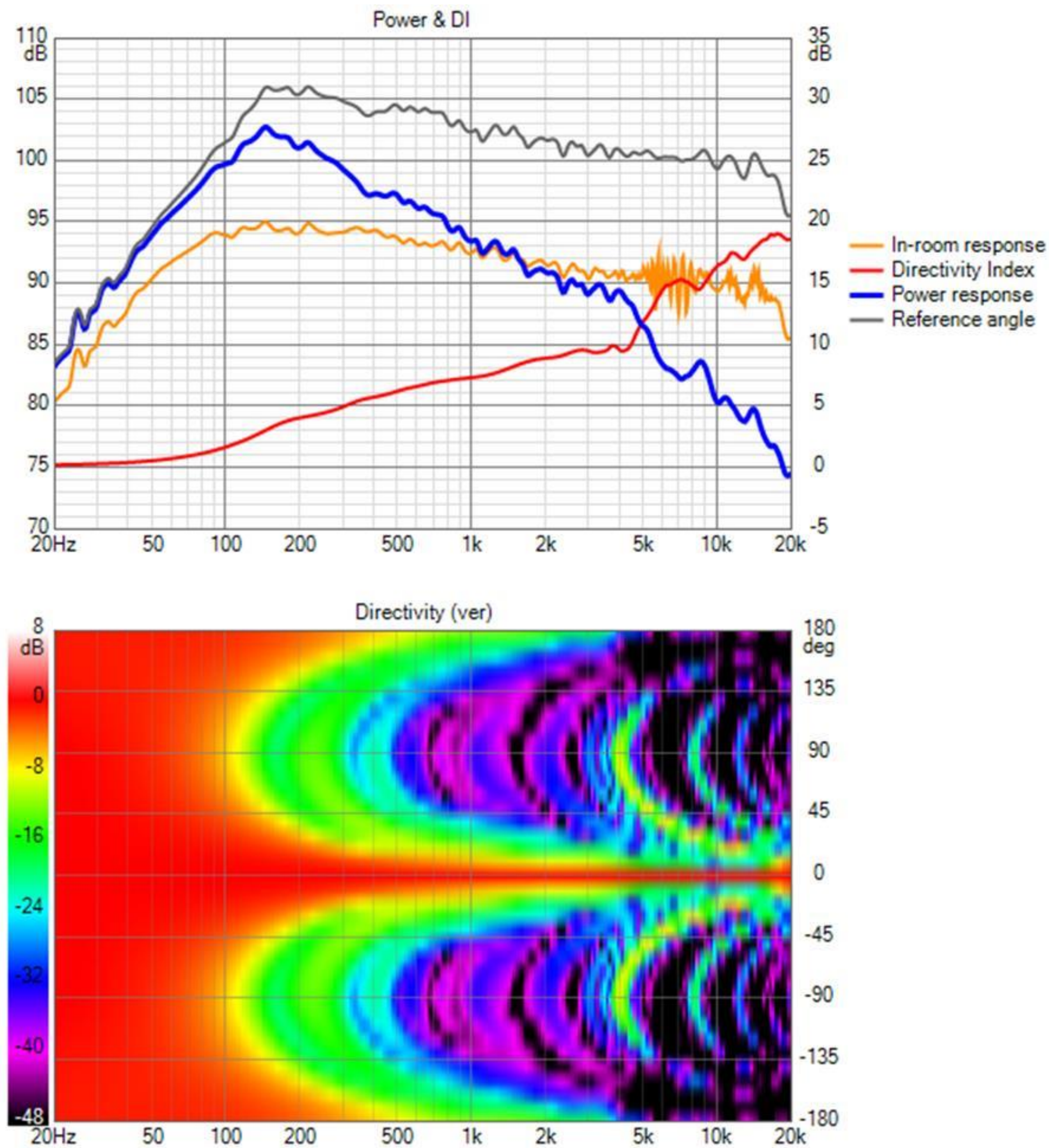


FIGURE 9 EQUALIZED ARRAY RESPONSE AND VERTICAL DIRECTIVITY

Fine frequency shading is presented here as a proof of concept. Strictly implementing the rule to cut off each driver pair at the frequency where its delta path length phase shift would equal 90 degrees leads to an expensive or extravagant implementation. In the next section, a more practical implementation with a wider vertical listening window will be described.

Practical Implementation of Fine Frequency Shading

For a practical implementation of FFS we want to reduce the number of amplifier channels and FIR DSP channels required and, if possible without compromising the response at the preferred listening height, to widen the usable vertical listening window.

Figure 10 is a delta path length table. The rightmost column shows the frequency by which the driver on that row must be cut off to avoid subtractive combining. A strict implementation of FFS calls for an amplifier and DSP channel per driver. Drivers can be combined into groups with little loss in response smoothness.

2	Listening distance				3000	mm	speed of sound	343	m/s	mic height	1153
3	Driver #	Image	Driver height	Cum Ht"	Cum. Height	elev from Mic	distance to mic	delta distance (m)	delta delay (ms)	4xΔdelay	90^0 freq
4	1	26	84	85.08	2161	1008	3164.82	0.1648	0.4791	1.9165	522
5	2	27	84	81.8	2077	924	3139.07	0.1391	0.4043	1.6171	618
6	3	28	84	78.5	1993	840	3115.38	0.1154	0.3354	1.3416	745
7	4	29	84	75.2	1909	756	3093.79	0.0938	0.2726	1.0906	917
8	5	30	84	71.9	1825	672	3074.34	0.0743	0.2161	0.8645	1157
9	6	31	84	68.5	1741	588	3057.08	0.0571	0.1659	0.6637	1507
10	7	32	84	65.2	1657	504	3042.04	0.0420	0.1222	0.4889	2046
11	8	33	84	61.9	1573	420	3029.26	0.0293	0.0851	0.3402	2939
12	9	34	84	58.6	1489	336	3018.76	0.0188	0.0545	0.2181	4585
13	10	35	84	55.3	1405	252	3010.57	0.0106	0.0307	0.1229	8140
14	11	36	84	52.0	1321	168	3004.70	0.0047	0.0137	0.0547	18297
15	12	37	84	48.7	1237	84	3001.18	0.0012	0.0034	0.0137	73144
16	13	38	84	45.4	1153	0	3000.00	0.0000	0.0000	0.0000	#DIV/0!
17	14	39	84	42.1	1069	-84	3001.18	0.0012	0.0034	0.0137	73144
18	15	40	84	38.8	985	-168	3004.70	0.0047	0.0137	0.0547	18297
19	16	41	84	35.5	901	-252	3010.57	0.0106	0.0307	0.1229	8140
20	17	42	84	32.2	817	-336	3018.76	0.0188	0.0545	0.2181	4585
21	18	43	84	28.9	733	-420	3029.26	0.0293	0.0851	0.3402	2939
22	19	44	84	25.6	649	-504	3042.04	0.0420	0.1222	0.4889	2046
23	20	45	84	22.2	565	-588	3057.08	0.0571	0.1659	0.6637	1507
24	21	46	84	18.9	481	-672	3074.34	0.0743	0.2161	0.8645	1157
25	22	47	84	15.6	397	-756	3093.79	0.0938	0.2726	1.0906	917
26	23	48	84	12.3	313	-840	3115.38	0.1154	0.3354	1.3416	745
27	24	49	84	9.0	229	-924	3139.07	0.1391	0.4043	1.6171	618
28	25	50	84	5.7	145	-1008	3164.82	0.1648	0.4791	1.9165	522
29			103		space to first driver = half driver height plus cabinet floor and feet space						

FIGURE 10 DELTA PATH LENGTH TABLE FOR TC9 ARRAY

At the low end of the spectrum, it apparently makes little difference in response to combine driver pairs into groups of 4. This grouping can't be carried too far up the spectrum without widening vertical directivity in the midbass. Widened direcivity there leads to response dips and one must make a judgment as to how much of this can be tolerated. At the top end of the spectrum, one can increase the number of drivers that aren't low pass filtered. The delta path length spreadsheet calls for 3 unfiltered drivers with an 18 khz low pass filter on the next outermost driver pair. Combining the 5 most central driver pair into a single group not only saves amplifier pairs but widens the usable vertical listening window. Doing a small amount of amplitude shading on those 5 drivers improved it incrementally.

(Probably not)   TO BE COMPLETD