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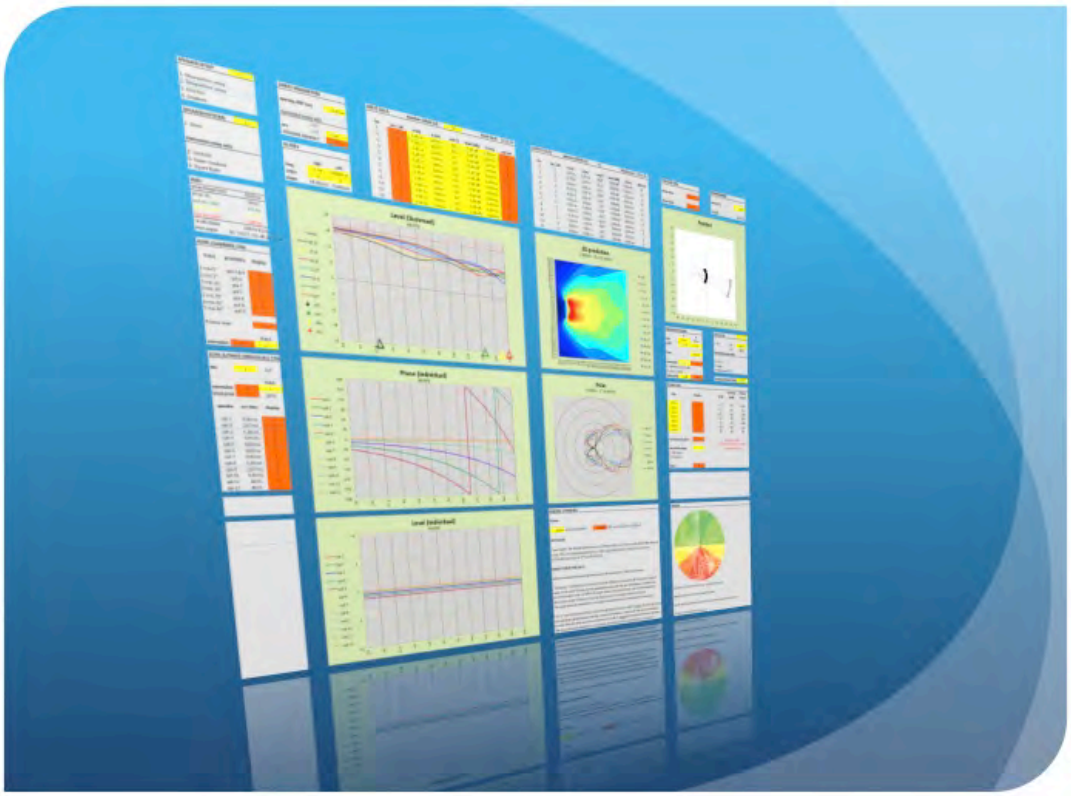
S.A.D. (Subwoofer Array Designer)

manual



This calculator is inspired and endorsed by

Mauricio “Magu” Ramirez

&

Bob “6o6” McCarthy

Thanks for your support and input!

DISCLAIMER

Source dimensions:

The sources used in this spreadsheet are infinitely small without any physical dimensions. Real speakers are enclosures containing one or more drivers. Their physical dimensions may obstruct the line of sound and affect path lengths, ergo delay, depending on wavelength and the type of speaker configuration.

Speaker patterns:

The speaker patterns used in this spreadsheet are mathematical constructs, which approximate real speaker patterns. Real speakers patterns are determined by the dimensions of the enclosure, baffle size, the size, amount and arrangement of drivers, etc..

Boundary conditions:

This spreadsheet does not take into account the effect caused by the proximity of surfaces (floors, walls, ceilings, stage deck, etc.) or the combined baffle size of coupled line sources.

Especially cardioid configurations are prone to the destructive effects of stage decks and such. Don't place them under the stage. Try to maintain a minimum clearance of 60 cm in all directions.

Relative levels:

Subwoofer configurations rely on differences in phase (time). This will unavoidably render part of the frequency spectrum unusable due to cancelation. Subwoofer levels (no weighting) that deviate considerably from the mains, will emphasize these unusable frequencies and degrade overall system performance.

High-pass filters:

The high-pass filters in this calculator predominantly serve an illustrational purpose. Most subwoofers exhibit a high-pass filter by design and/or electronic means. Few cases will require the application of an actual high-pass filter.

DISCLAIMER (CONTINUED)

Measure to verify and adapt:

The values obtained from this spreadsheet should serve as a starting point and not to be used blindly. Use a dual-channel FFT analyzer or equivalent solution to measure, verify and adapt. This spreadsheet is optimized for low frequency content. In order to avoid the effect from floor bounce, ground floor measurements are best suited for the job.

Where to measure:

I recommend measuring at a distance where you are still able to tell phase (time) with confidence.

Further away is better, but reflections and late arrivals from other sources might make it harder to read phase. Particularly indoors.

At greater distance the unintentional “errors” in level and timing caused by the physical dimensions of the enclosures and displacement become insignificantly small.

The tables below show the effects of differences in level and timing for cancelation and summation respectively.

Δ level	cancelation
0,0 dB	-∞ dB
0,1 dB	-39 dB
0,2 dB	-33 dB
0,3 dB	-29 dB
0,4 dB	-27 dB
0,5 dB	-25 dB
0,6 dB	-24 dB
0,7 dB	-22 dB
0,8 dB	-21 dB
0,9 dB	-20 dB
1,0 dB	-19 dB
1,1 dB	-18 dB
1,2 dB	-18 dB
1,3 dB	-17 dB
1,4 dB	-17 dB
1,5 dB	-16 dB
1,6 dB	-15 dB
1,7 dB	-15 dB
1,8 dB	-15 dB
1,9 dB	-14 dB
2,0 dB	-14 dB

Δ path		32 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz
0,0 ms	0 cm	6,0	6,0	6,0	6,0	6,0	6,0	6,0
0,1 ms	3 cm	6,0	6,0	6,0	6,0	6,0	6,0	6,0
0,2 ms	7 cm	6,0	6,0	6,0	6,0	6,0	6,0	6,0
0,3 ms	10 cm	6,0	6,0	6,0	6,0	6,0	6,0	6,0
0,4 ms	14 cm	6,0	6,0	6,0	6,0	6,0	6,0	5,9
0,5 ms	17 cm	6,0	6,0	6,0	6,0	6,0	5,9	5,8
0,6 ms	20 cm	6,0	6,0	6,0	6,0	5,9	5,9	5,8
0,7 ms	24 cm	6,0	6,0	6,0	5,9	5,9	5,8	5,7
0,8 ms	27 cm	6,0	6,0	6,0	5,9	5,8	5,7	5,6
0,9 ms	31 cm	6,0	6,0	5,9	5,9	5,8	5,7	5,5
1,0 ms	34 cm	6,0	6,0	5,9	5,8	5,7	5,6	5,3
1,1 ms	37 cm	6,0	5,9	5,9	5,8	5,7	5,5	5,2
1,2 ms	41 cm	6,0	5,9	5,9	5,8	5,6	5,4	5,0
1,3 ms	44 cm	5,9	5,9	5,8	5,7	5,6	5,3	4,8
1,4 ms	48 cm	5,9	5,9	5,8	5,7	5,5	5,1	4,6
1,5 ms	51 cm	5,9	5,9	5,8	5,6	5,4	5,0	4,4
1,6 ms	54 cm	5,9	5,8	5,7	5,6	5,3	4,9	4,1
1,7 ms	58 cm	5,9	5,8	5,7	5,5	5,2	4,7	3,9
1,8 ms	61 cm	5,9	5,8	5,7	5,5	5,1	4,5	3,6
1,9 ms	65 cm	5,9	5,8	5,6	5,4	5,0	4,4	3,3
2,0 ms	68 cm	5,8	5,7	5,6	5,3	4,9	4,2	2,9

temp = 14° C

IN REAL LIFE APPLICATIONS
ALWAYS MEASURE TO VERIFY AND ADAPT !!!

General comments:

Yellow cells may contain any numerical value

Orange cells may only contain 1 or 0 (on/off)

block level: Is the theoretical maximum achievable level of summation depending on the number of speakers. The term “block” refers to a “block” of closely grouped speakers with minimal displacement to achieve maximum coupling.

speakers	1	2	3	4	5	6	7	8	9	10	11	12
block level	0 dB	6 dB	10 dB	12 dB	14 dB	16 dB	17 dB	18 dB	19 dB	20 dB	21 dB	22 dB

Environment settings:

ENVIRONMENT	
temp (°C)	14 °C
c (m/s)	340 m/s

Temperature is a global setting and determines the speed of sound for the entire spreadsheet.

Speaker setup selection:

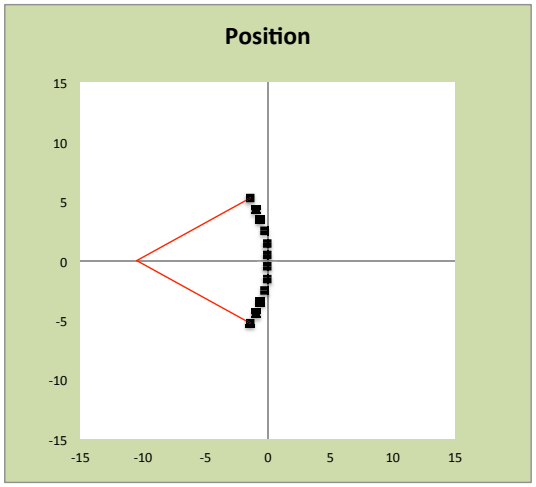
SPEAKER SETUP	1

1. Physical hor. array
2. Delayed hor. array
3. End-Fire
4. Gradient

Enter one of the following numbers to select the corresponding setup:

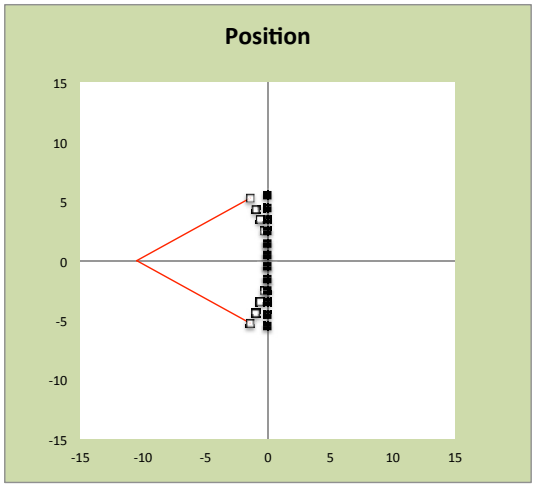
1. Physical horizontal array (min. 6 speakers, 8 speakers or more recommended)

   The speakers will be physically positioned at regular intervals in an arc with a fixed radius determined by the “arc” parameter.

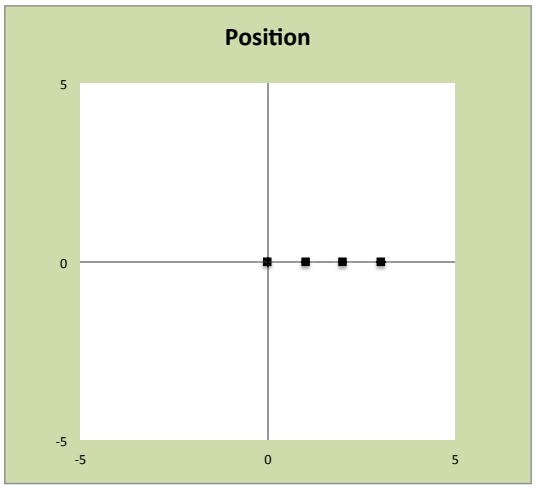


2. Delayed horizontal array (min. 6 speakers, 8 speakers or more recommended)

   The speakers will be physically positioned at regular intervals in a straight line. Delay will be added automatically as if the speakers where positioned in an arc. The amount of delay for each speaker is determined by the “arc” parameter.

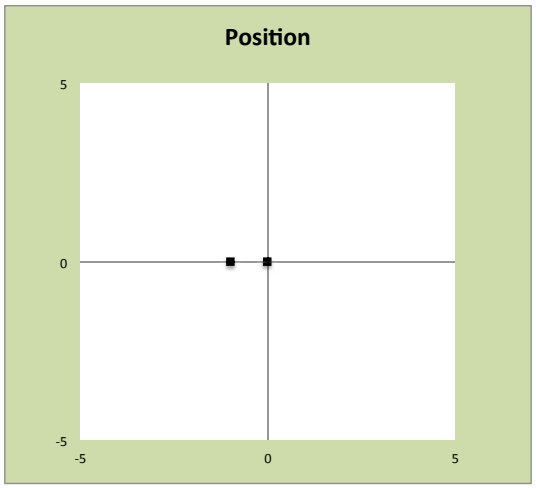


3. End-Fire
(min. 2 speakers, diminishing returns with more than 4 speakers)



Two or more speakers will be placed in front of each other at regular intervals determined by the “spacing” parameter. Delay will be added automatically in order that all signals add in front of the array. The amount of delay is determined by the “spacing” parameter. Behind the array one or more nulls will appear depending on the amount of speakers.

4. Gradient
(2 speakers only)



Two speakers will be placed behind each other at a distance determined by the “spacing” parameter. Delay will be added automatically to the rear speaker. The amount of delay is determined by the “spacing” parameter. Polarity of the rear speaker is inverted to cancel the signals behind the array. In front of the array there will be partial summation depending on the spacing.

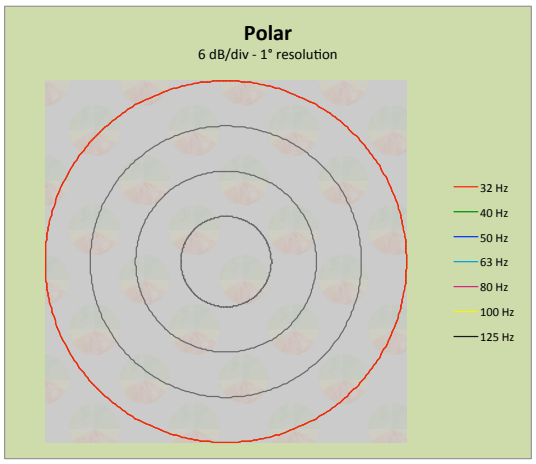
(Speaker amount recommendations are limited to the horizontal plane only, if more power is required in practice, add more speakers by stacking them vertically)

Speaker pattern selection:

SPEAKER PATTERN	1
1. Omni	
horizontal array only	
2. Cardioid	
3. Super-Cardioid	
4. Figure Eight	

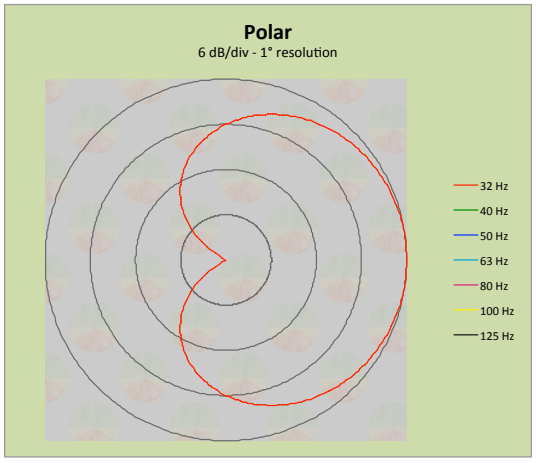
Enter one of the following numbers to select the corresponding pattern:

1. Omnidirectional



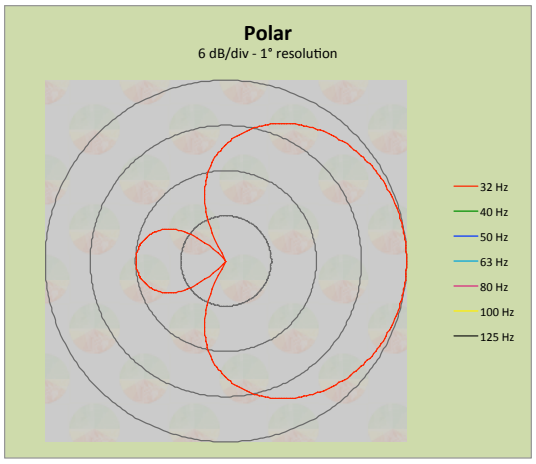
2. Cardioid

   Best substitution for gradient configurations in more complex designs.

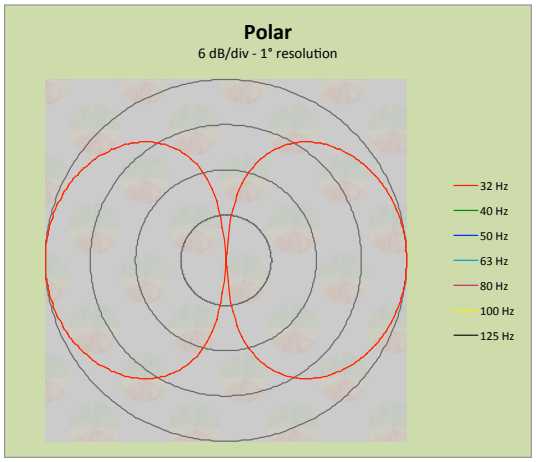


3. Super-Cardioid

   Best substitution for end-fired configurations in more complex designs.



4. Figure eight



Microphone setup selection:

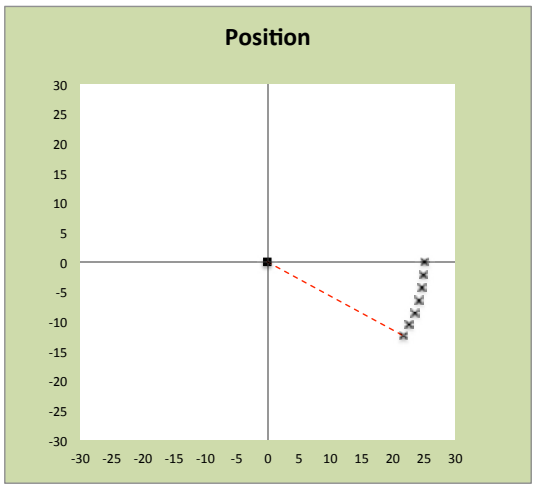
MIC SETUP		1
1. Arc	FAR	30,0°
	2,00	(60°)
horizontal array only		
2. Array		
3. Edge		
4. Exponential 72°		

Enter one of the following numbers to select the corresponding setup:

1. Arc

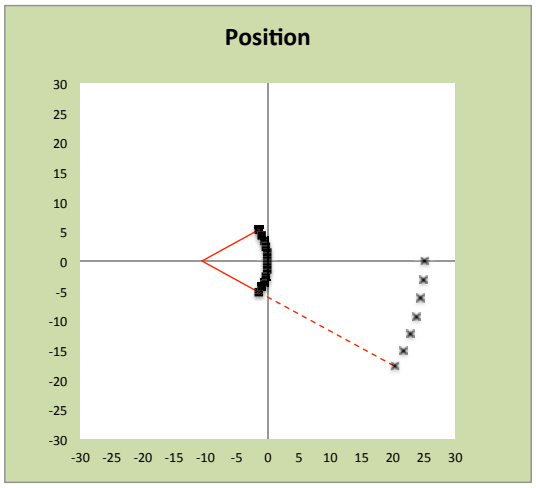
   The microphones are distributed equidistant at regular intervals in an arc around origin 0,0. The angle of the arc is determined by the “arc” parameter under “mic setup”.

   For proper analysis of end-fired and gradient setups, the angle should be set to 180° degrees.



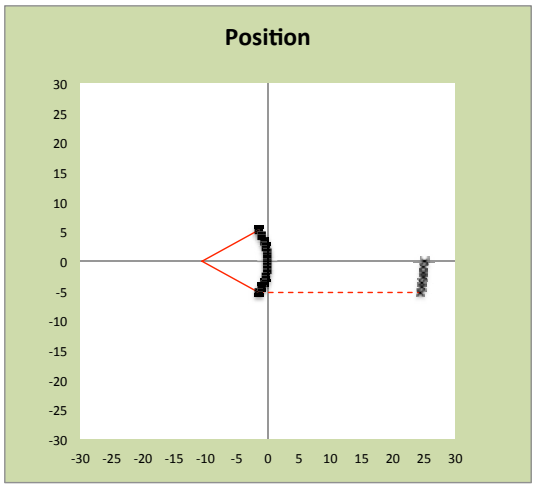
2. Array

   The microphones are distributed equidistant at regular intervals in an arc around the virtual point of origin of horizontal arrays. The angle of the arc is determined by the “arc” parameter under “array parameters”.



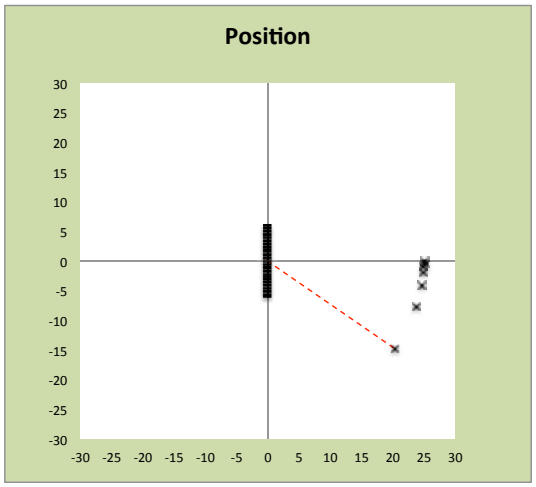
3. Edge

   The microphones are distributed equidistant at regular intervals in arc ranging from the center of the array to the edge of the array.



4. Exponential 72°

   The microphones are distributed at fixed intervals to illustrate straight line array behavior according to Harry F. Olson.



Microphone 1 is always at the center of the array. Microphone 7 is always the outermost microphone.

Global radius:

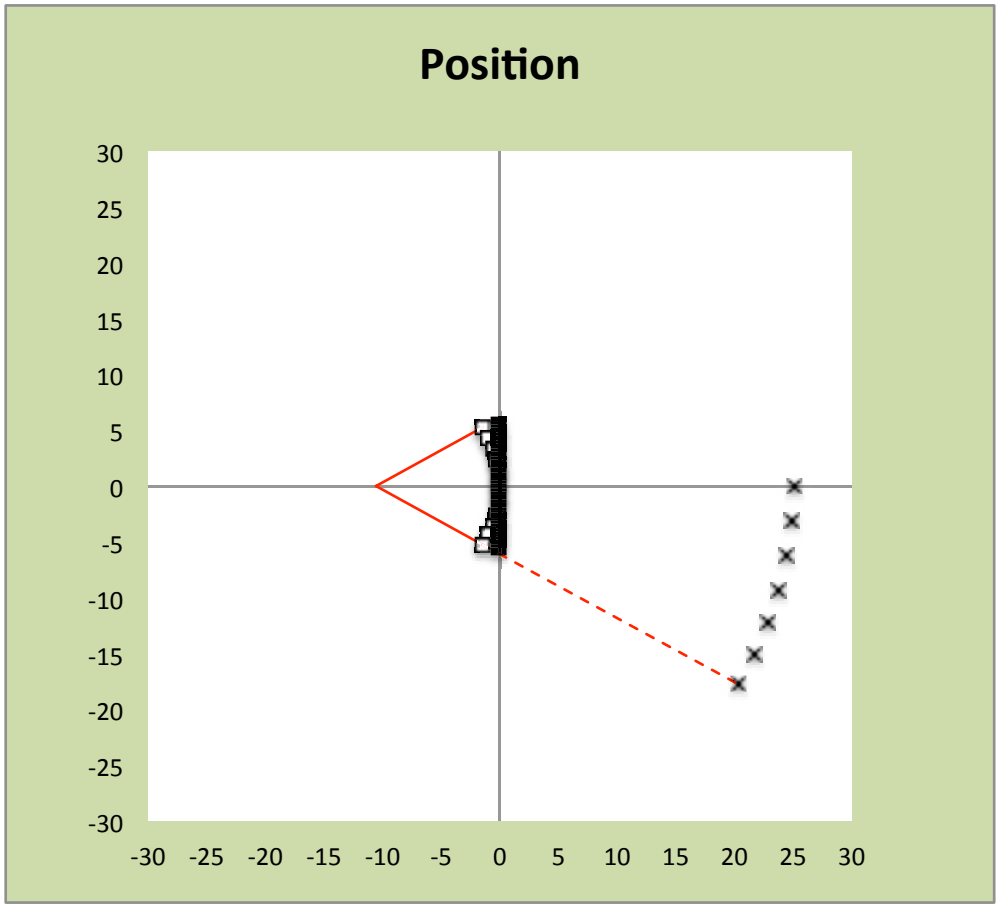
GLOBAL RADIUS (FOH)	25 m

Global radius is a global setting for the entire spreadsheet. It is the point of observation for microphones, SPL and polar plots.

The distance is best to be set equal to the F.O.H. position or halfway across the venue for optimum results.

Position plot:

POSITION CTRL	
show mics	1
show lines	1



show mics: Allows you to display the 7 microphones, marked by “X”.

show lines: Allows you to display the guides that illustrate the arcs.

black boxes: Are physical speaker positions.

white boxes: Are virtual speaker positions.

Input data:

INPUT DATA		speakers (MAX 12)		12		block level	21,58 dB
no.	on / off	x (m)	y (m)	rot (°)	level (dB)	t (ms)	pol inv
1	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
2	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
3	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
4	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
5	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
6	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
7	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
8	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
9	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
10	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
11	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
12	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0

Input data is where you select the number of speakers. In the top right corner the “block level” is displayed depending on the number of speakers. It allows you to set various parameters per speaker like on/off, position, rotation, level, delay and polarity.

Output data:

OUTPUT DATA		speakers (MAX 12)		12		block level	21,58 dB
no.	on / off	x (m)	y (m)	rot (°)	level (dB)	t (ms)	pol inv
1	1	-1,41 m	5,25 m	30,0°	0,00 dB	0,00 ms	0
2	1	-0,95 m	4,36 m	24,5°	0,00 dB	0,00 ms	0
3	1	-0,58 m	3,44 m	19,1°	0,00 dB	0,00 ms	0
4	1	-0,30 m	2,48 m	13,6°	0,00 dB	0,00 ms	0
5	1	-0,11 m	1,49 m	8,2°	0,00 dB	0,00 ms	0
6	1	-0,01 m	0,50 m	2,7°	0,00 dB	0,00 ms	0
7	1	-0,01 m	-0,50 m	-2,7°	0,00 dB	0,00 ms	0
8	1	-0,11 m	-1,49 m	-8,2°	0,00 dB	0,00 ms	0
9	1	-0,30 m	-2,48 m	-13,6°	0,00 dB	0,00 ms	0
10	1	-0,58 m	-3,44 m	-19,1°	0,00 dB	0,00 ms	0
11	1	-0,95 m	-4,36 m	-24,5°	0,00 dB	0,00 ms	0
12	1	-1,41 m	-5,25 m	-30,0°	0,00 dB	0,00 ms	0

Output data displays the actual values being used by the spreadsheet. Most values will be set automaticity. Certain values may be overridden depending on the speaker setup in order to produce correct results.

Array parameters:

ARRAY PARAMETERS		
spacing 180° (m)		1,00 m
horizontal array only		
	FAR	
arc	2,00	60°
orientate speakers		0

spacing: Sets the distance between speakers depending on the speaker setup.

½ wavelength for horizontal arrays

¼ wavelength for end-fire and gradient

arc: Sets the angle of the arc section between the outermost speakers and affects horizontal arrays only.

FAR: Displays the equivalent Forward Aspect Ratio of the arc angle.

orientate speakers: Allows you to orientate the speakers in a straight delayed horizontal array like they would be in a physical array.

Level & Phase (Individual):

LEVEL & PHASE (INDIVIDUAL) CTRL		
mic	1	0,0°
		trace
normalize	1	1
tracking	1	2
1. Nearest (spk 1)		
2. Earliest (spk 1)		
speaker	**arr time**	**display**
spk 1	0,00 ms	1
spk 2	0,00 ms	1
spk 3	0,00 ms	1
spk 4	0,00 ms	1
spk 5	0,00 ms	1
spk 6	0,00 ms	1
spk 7	0,00 ms	1
spk 8	0,00 ms	1
spk 9	0,00 ms	1
spk 10	0,00 ms	1
spk 11	0,00 ms	1
spk 12	0,00 ms	1
avg		0

mic: Selects the microphone for which the individual level and phase of each speaker are displayed.

normalize: Enables normalization to the selected trace (speaker).

tracking: Overrides the selected trace (speaker) for normalization with option:

1. nearest trace (speaker)
2. earliest trace (speaker)

in relation to the selected microphone. The speaker is displayed between parentheses.

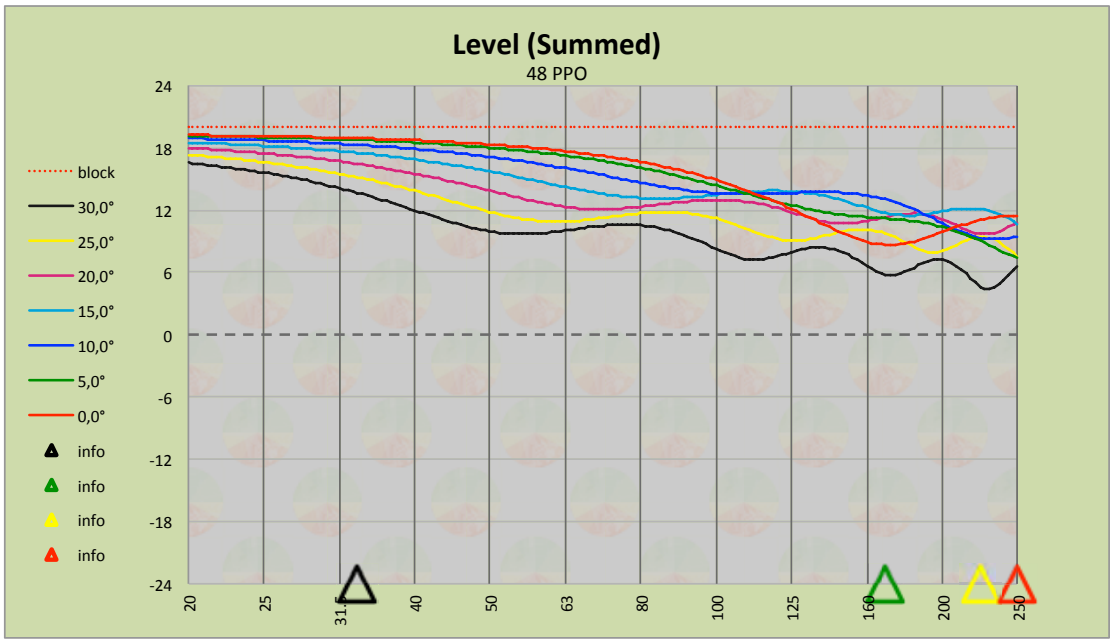
avg: The average phase of all active speakers.

display: Allows you to display or hide traces.

Obsolete traces of unused speakers are hidden automatically.

Level, phase and arrival times are absolute at the position of the selected microphone with normalization turned off and relative with normalization turned on.

Level (Summed):



LEVEL (SUMMED) CTRL		
trace	**proximity**	**display**
1 mic 0°	spk 5 & 6	1
2 mic 5°	spk 6	1
3 mic 10°	spk 7	1
4 mic 15°	spk 8	1
5 mic 20°	spk 8	1
6 mic 25°	spk 9	1
7 mic 30°	spk 10	1
8 block level		1
		trace
normalize	0	1

proximity: Displays the nearest speaker for each microphone.

display: Allows you to display or hide traces.

normalize: Enables you to normalize to the selected trace (microphone) including trace 8 “block level”.

For information on the markers residing on the x-axis please refer to the info panel.

2D prediction (SPL plot):

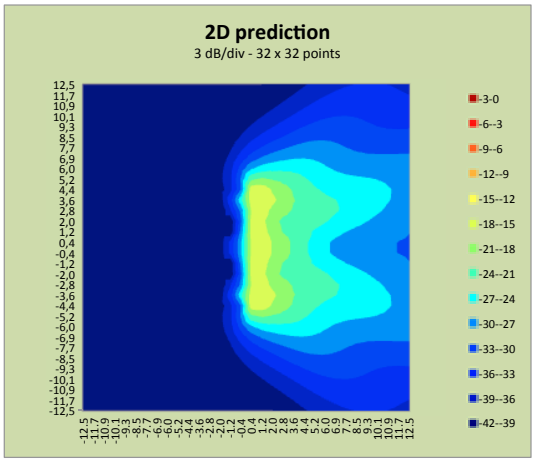
PREDICTION PLANE	x	y
size	50 m	50 m
shift	0 m	0 m
freq		100 Hz
normalize	1	1
1. Speaker(s) (1,1 dB)		
2. Mic 1 (0 dB)		
offset (dB)	0	0 dB

size: The plot is square by default. Only the x value is required.

shift: Moves the prediction plane along the x- or y-axis.

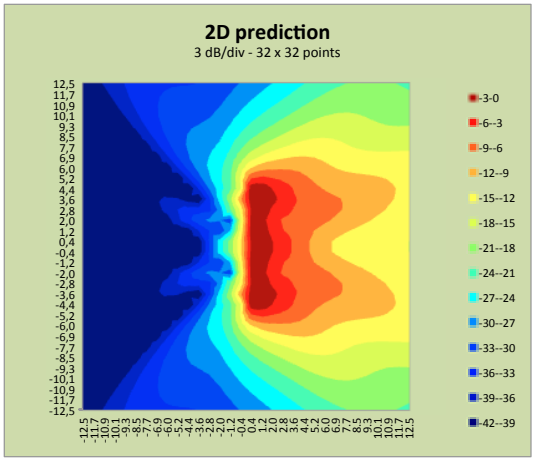
freq: Sets the frequency for the SPL plot.

normalization:



normalization turned off:

This setting displays absolute values on a scale from -42 dB to 0 dB “block level” (full scale).

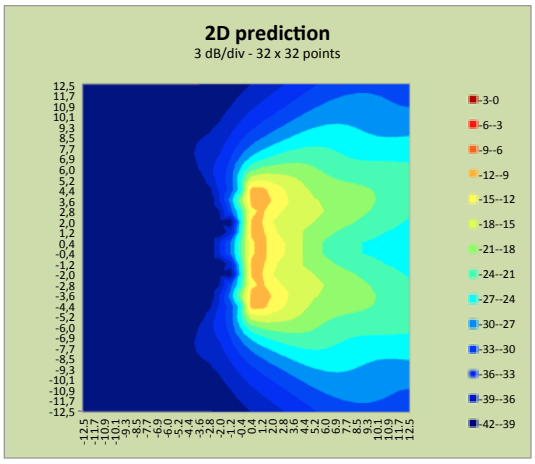


normalization turned on
option 1 (source):

This setting looks for the loudest value in the plot, usually at the source, and compares is to 0 dB “block level” (full scale).

The difference is used to offset the plot. The value is shown between parentheses.

This behavior is similar to Meyer Sound MAPP Online Pro.



normalization turned on
option 2 (receiver):

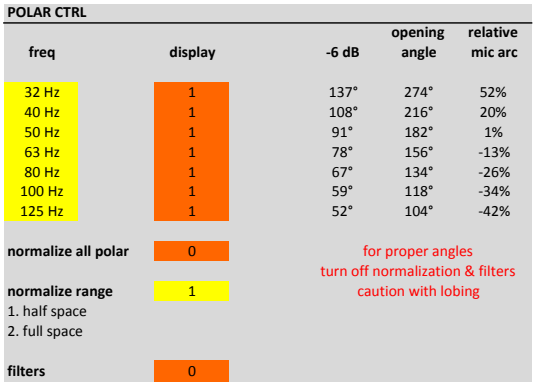
This setting compares the level at microphone No. 1 to 0 dB “block level” (full scale) minus the loss of level over distance (inverse square law).

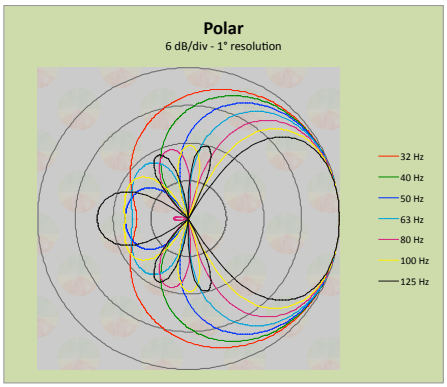
$$offset = \frac{level\ microphone\ 1}{0\ dB\ \text{"block level"} - \text{distance}}$$

The difference is used to offset the plot. The value is shown between parentheses.

manual offset: You can enable manual offset and enter a specific value. Be aware that the manual offset is in series with the other normalization options.

Polar plot:





freq: Enter up to 7 frequencies.

display: Display and hide polar plots.

-6 dB: Displays the off-axis angle for the -6 dB point.

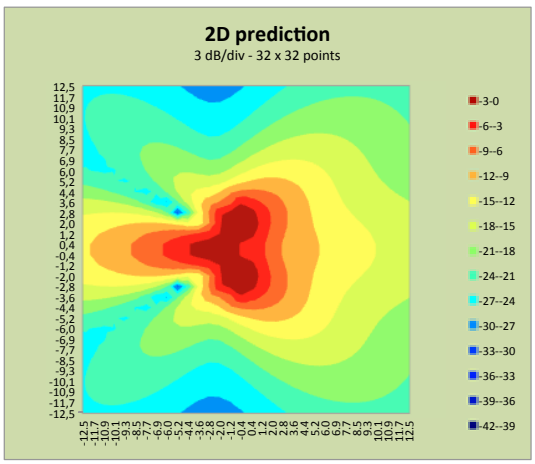
opening angle: Displays the opening angle for a specific frequency.

relative mic. arc: Displays the difference to the microphone arc (mic setup No. 1).

norm. all polar: Normalizes all plots to the plot with the highest on-axis value.

norm. range: Half-space limits the range of values used for normalization to 180°, the front of the array.

Full-space uses all 360° of values for normalization.

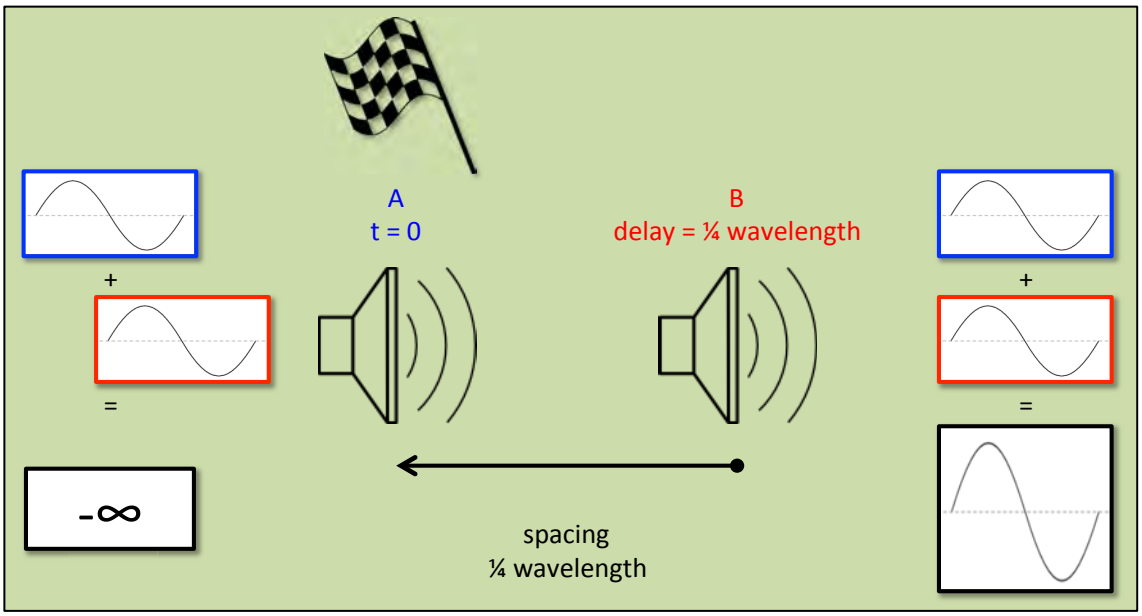


In some speaker setups e.g. a physical horizontal array with omni sources, a focal point appears behind the array that contains more energy in comparison to the front of the array. With full-space normalization this would lead to attenuated polar plots in front of the array and consequently incorrect -6 dB values.

filters: Includes attenuation by filters into the normalization process.

Always scrutinize the conceivability of the -6 dB points and consequentially the opening angle. Due to the calculation method, severe lobing, “normalize all polars” and the inclusion of filters might provide incorrect values.

End-fire theory:



The illustration above shows the principle of end-fired configurations.

Two speakers facing forward are spaced ¼ wavelength apart. Speaker B is delayed by ¼ wavelength.

front: Due to the delay applied to speaker B equal to the spacing. Both signals arrive in phase and add up for all frequencies.

rear: The signal from speaker B arrives ½ wavelength later than speaker A. This causes the signals to cancel each other out for a limited bandwidth.

The ½ wavelength delay is the combination of:

¼ wavelength acoustical time-of-flight
¼ wavelength electrical delay

The result is a singe null behind the configuration. The frequency of the null is determined by the corresponding wavelength.

Depending on the application a suitable wavelength can be chosen for optimum effect.

Tutorial 1: end-fire 2 speakers

Goals: 1.) null at 75 Hz (wavelength 4.53 m. at 14° C)
2.) upper bandwidth limit 100 Hz

Step 1 - select end-fire speaker setup

SPEAKER SETUP	3
1. Physical hor. array	
2. Delayed hor. array	
3. End-Fire	
4. Gradient	

Step 2 - select omni speaker pattern

SPEAKER PATTERN	1
1. Omni	
horizontal array only	
2. Cardioid	
3. Super-Cardioid	
4. Figure Eight	

Step 3 – select 2 speakers

INPUT DATA		speakers (MAX 12)		2		block level	6,02 dB
no.	on / off	x (m)	y (m)	rot (°)	level (dB)	t (ms)	pol inv
1	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
2	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
3	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
4	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
5	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
6	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
7	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
8	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
9	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
10	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
11	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
12	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0

Step 4 – set spacing (1,13 m. is ¼ wavelength 75 Hz at 14° C)

ARRAY PARAMETERS		
spacing 90° (m)		1,13 m
horizontal array only		
	FAR	
arc	1,41	90°
orientate speakers		0
ARC DISABLED		

Step 5 – inspect output data

OUTPUT DATA	speakers (MAX 12)	2			block level	6,02 dB
no.	**on / off**	**x (m)**	**y (m)**	**rot (°)**	**level (dB)**	**t (ms)**	**pol inv**
1	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
2	1	1,13 m	0,00 m	0,0°	0,00 dB	3,32 ms	0
3	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
4	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
5	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
6	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
7	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
8	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
9	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
10	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
11	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
12	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0

Speaker 2 is automatically positioned at 1,13 m. and has 3,32 ms of delay.

Step 6 – select microphone setup 1 “arc” at 180° degrees

MIC SETUP		1
1. Arc	FAR	180,0°
	########	(360°)
horizontal array only		
2. Array		
3. Edge		
4. Exponential 72°		

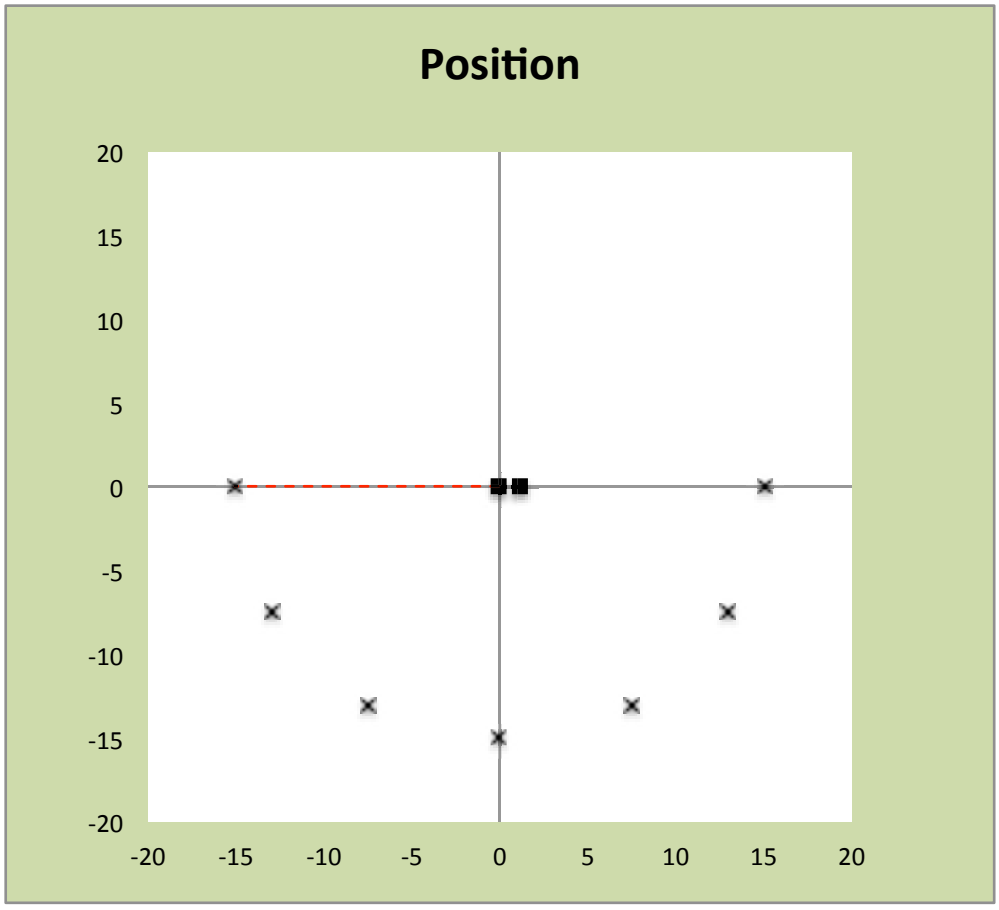
Microphones on either side of the configuration are needed, hence 180° deg.

Step 7 – set global radius

GLOBAL RADIUS (FOH)	15 m

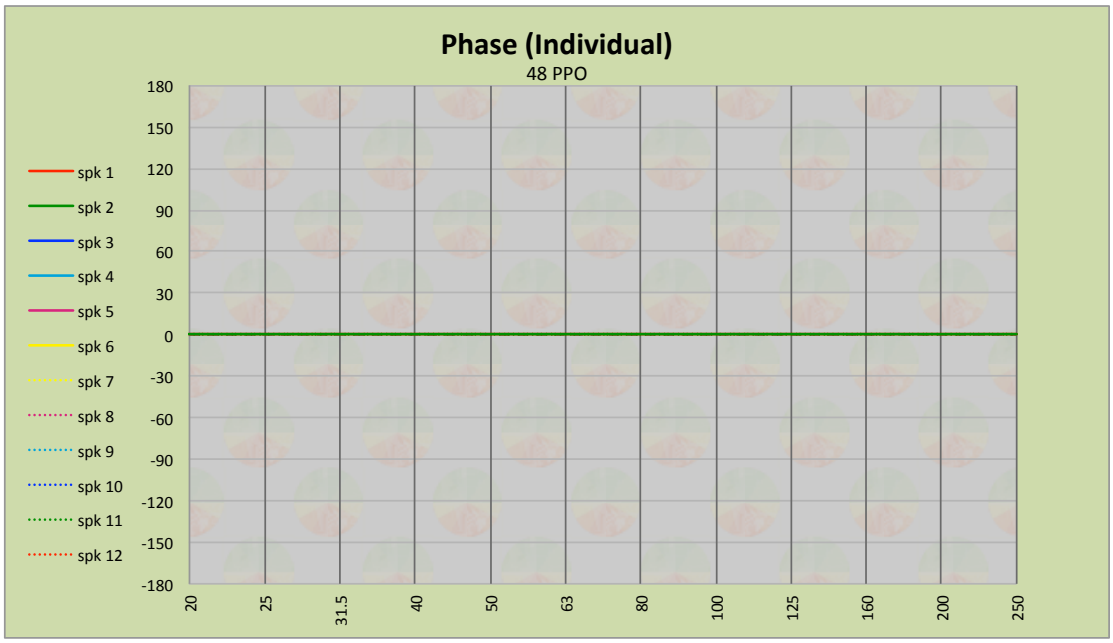
The point of observation is less crucial for end-fired setups in the absence of physical dimensions of the enclosures. For the purpose of illustration I have chosen 15 m. The default value of 25 m. will suffice for most situations.

Step 8 – position overview



Both speakers can be seen as well as the 7 microphones positioned in a half circle at a distance of 15 m. The red dotted line indicates the microphone arc and always ends at the last microphone (No. 7).

Step 9 – phase in front



LEVEL & PHASE (INDIVIDUAL) CTRL		
mic	1	0,0°
		trace
normalize	1	1
track prox	0	spk 1
speaker	arr time	display
spk 1	0,00 ms	1
spk 2	0,00 ms	1
spk 3	#N/A	1
spk 4	#N/A	1
spk 5	#N/A	1
spk 6	#N/A	1
spk 7	#N/A	1
spk 8	#N/A	1
spk 9	#N/A	1
spk 10	#N/A	1
spk 11	#N/A	1
spk 12	#N/A	1

Mic 1 (front) is selected. Normalization is turned on, relative to trace 1 (speaker 1).

The relative arrival time of both speakers is identical and the phase traces overlap perfectly.

Based on this data, summation of both signals is expected for all frequencies.

Step 10 – phase in rear

LEVEL & PHASE (INDIVIDUAL) CTRL		
mic	7	180,0°
		trace
normalize	1	1
track prox	0	spk 1
speaker	arr time	display
spk 1	0,00 ms	1
spk 2	6,65 ms	1
spk 3	#N/A	1
spk 4	#N/A	1
spk 5	#N/A	1
spk 6	#N/A	1
spk 7	#N/A	1
spk 8	#N/A	1
spk 9	#N/A	1
spk 10	#N/A	1
spk 11	#N/A	1
spk 12	#N/A	1

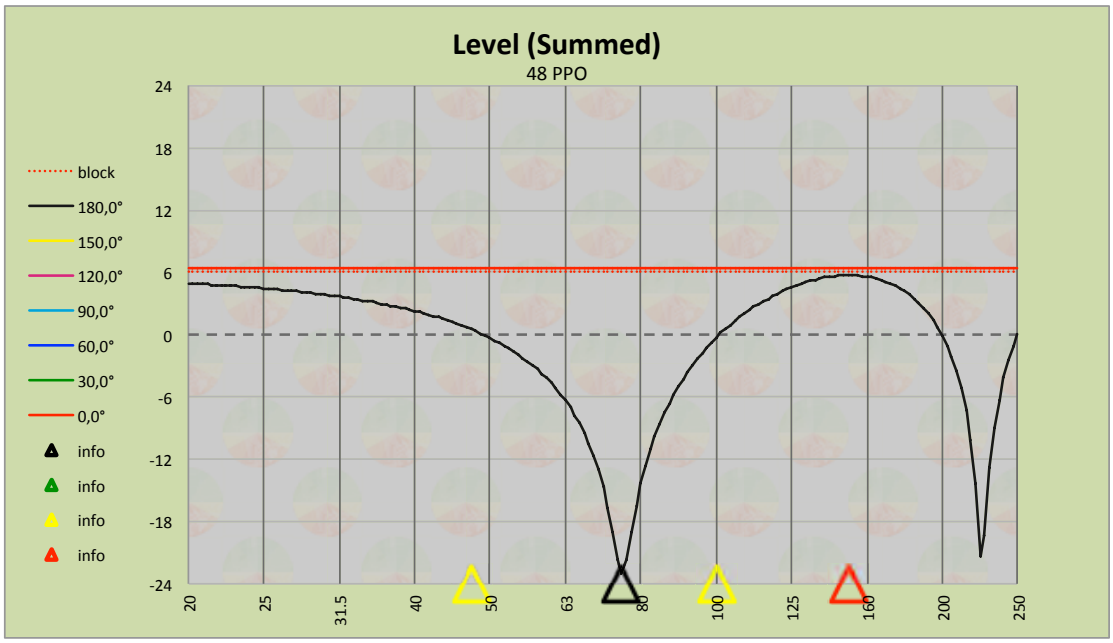
Mic 7 (rear) is selected. Normalization is left on, relative to trace 1 (speaker 1).

Speaker 2 arrives 6,65 ms. (½ wavelength) later relative to speaker 1. As frequency increases the relative phase of speaker 2 starts to deviate and is 180° degrees out of phase at 75 Hz. By the time 150 Hz is reached the phase of speaker 2 has come around full circle, in phase but one complete cycle of 75 Hz apart.

Based on this data, summation will change into cancelation as frequency increases, reaching a maximum at 75 Hz. Continuing towards 150 Hz cancelation will decrease and change into summation.

This progression will repeat itself creating the familiar comb filter.

Step 11 – level (summed)



LEVEL (SUMMED) CTRL		
trace	**proximity**	**display**
1 mic 0°	spk 2	1
2 mic 30°	spk 2	0
3 mic 60°	spk 2	0
4 mic 90°	spk 1	0
5 mic 120°	spk 1	0
6 mic 150°	spk 1	0
7 mic 180°	spk 1	1
8 block level		1
		trace
normalize	0	1

For clarity microphones 2 through 6 have been hidden.

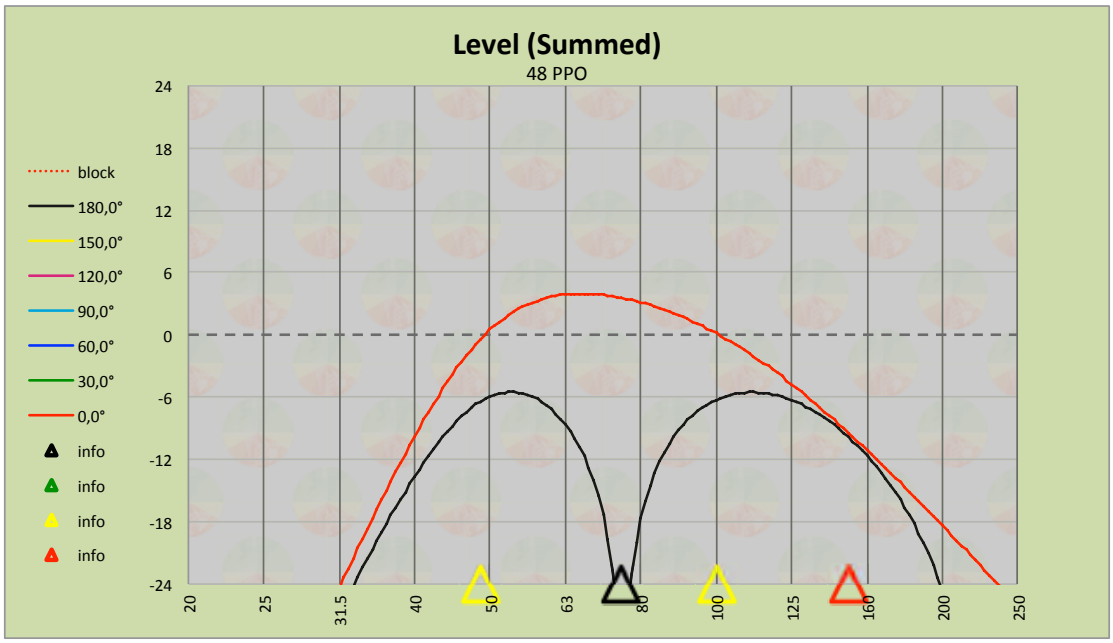
The red trace (microphone 1 - front) shows summation for all frequencies.

The black trace (microphone 7 - rear) shows cancelation, reaching a maximum at 75 Hz.

This is the first “tooth” of the “comb filter” that is caused by a delay of 6,65 ms.

The traces of microphone 1 and “block level” are identical because the maximum amount of summation with 2 speakers, 6 dB, has been achieved.

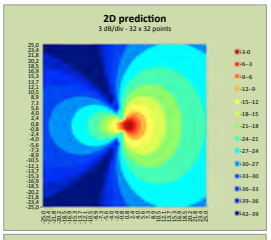
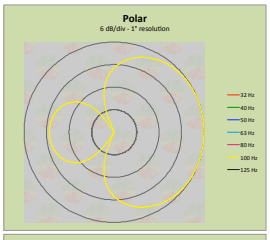
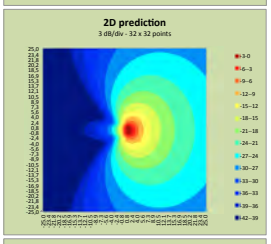
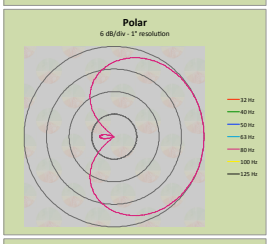
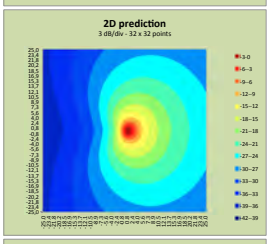
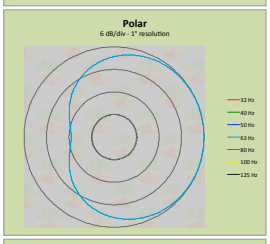
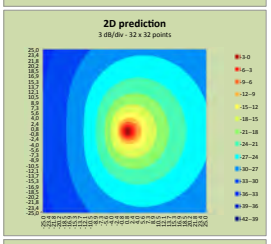
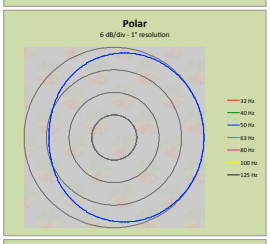
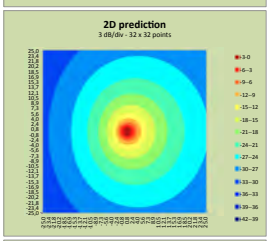
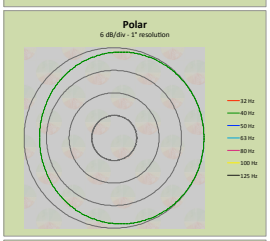
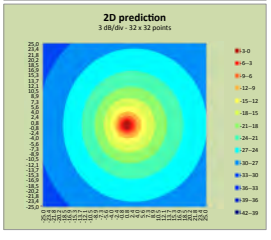
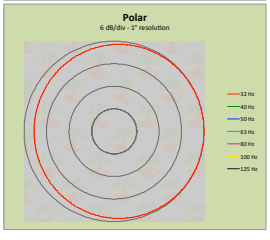
Step 12 – info panel



INFO	
array length (m)	2,26 m
1st cancel	75 Hz
pref filters @ min BL	49 / 100 Hz
crit freq	150 Hz
BW min BL / F2B	1,04 oct. / 10,4

array length:	The total length of the array (speakers x spacing).
1st cancel:	The frequency of the first cancelation indicated by the black marker.
pref filters:	The recommended frequencies for high- and low-pass filters indicated by the yellow makers.
crit frequency:	The critical frequency where summation behind the array equals summation in front of the array indicated by the red marker.
BW / F2B	The bandwidth and front-2-back ratio between the yellow markers.

* For the purpose of illustration filters have been added.

frequency	SPL	polar
100 Hz		
80 Hz		
63 Hz		
50 Hz		
40 Hz		
32 Hz		

Tutorial 2: end-fire 4 speakers

Goals: 1.) upper bandwidth limit 100 Hz

Most parameters are identical to the previous tutorial only the changes will be handled.

Step 3 – select 4 speakers

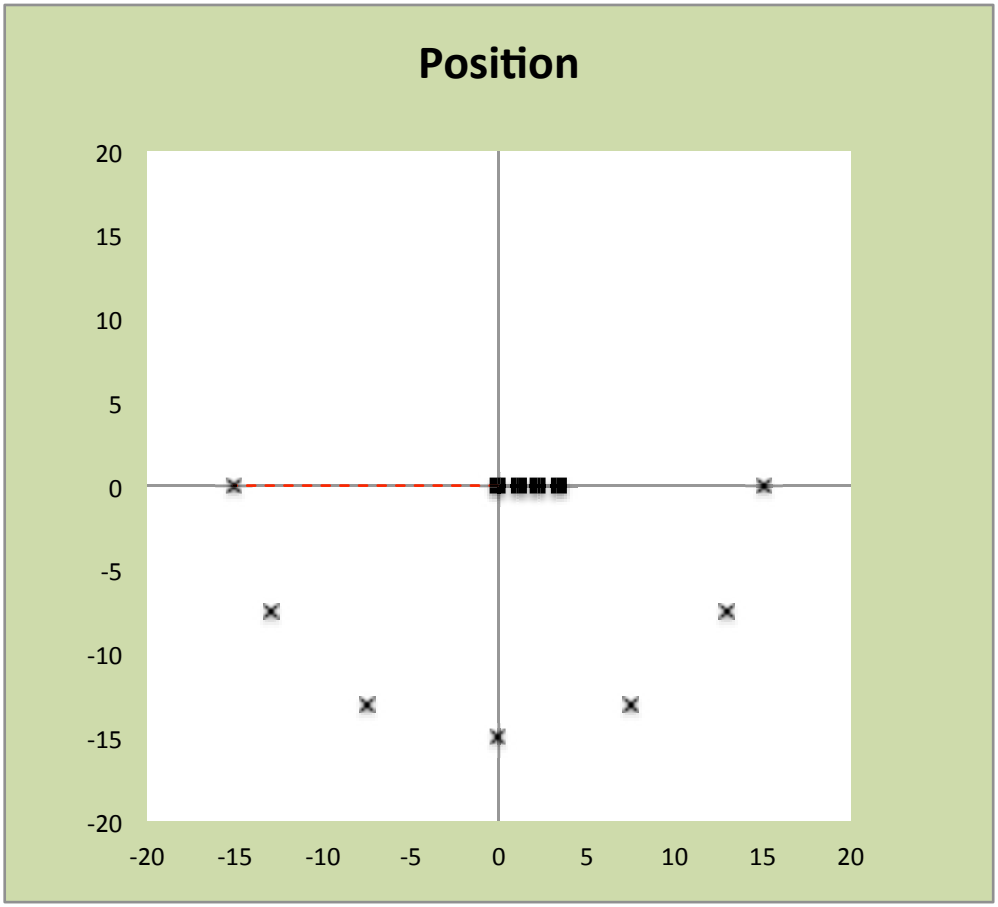
INPUT DATA		speakers (MAX 12)		4		block level	12,04 dB
no.	on / off	x (m)	y (m)	rot (°)	level (dB)	t (ms)	pol inv
1	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
2	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
3	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
4	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
5	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
6	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
7	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
8	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
9	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
10	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
11	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
12	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0

Step 5 – inspect output data

OUTPUT DATA		speakers (MAX 12)		4		block level	12,04 dB
no.	on / off	x (m)	y (m)	rot (°)	level (dB)	t (ms)	pol inv
1	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
2	1	1,13 m	0,00 m	0,0°	0,00 dB	3,32 ms	0
3	1	2,26 m	0,00 m	0,0°	0,00 dB	6,65 ms	0
4	1	3,39 m	0,00 m	0,0°	0,00 dB	9,97 ms	0
5	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
6	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
7	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
8	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
9	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
10	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
11	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
12	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0

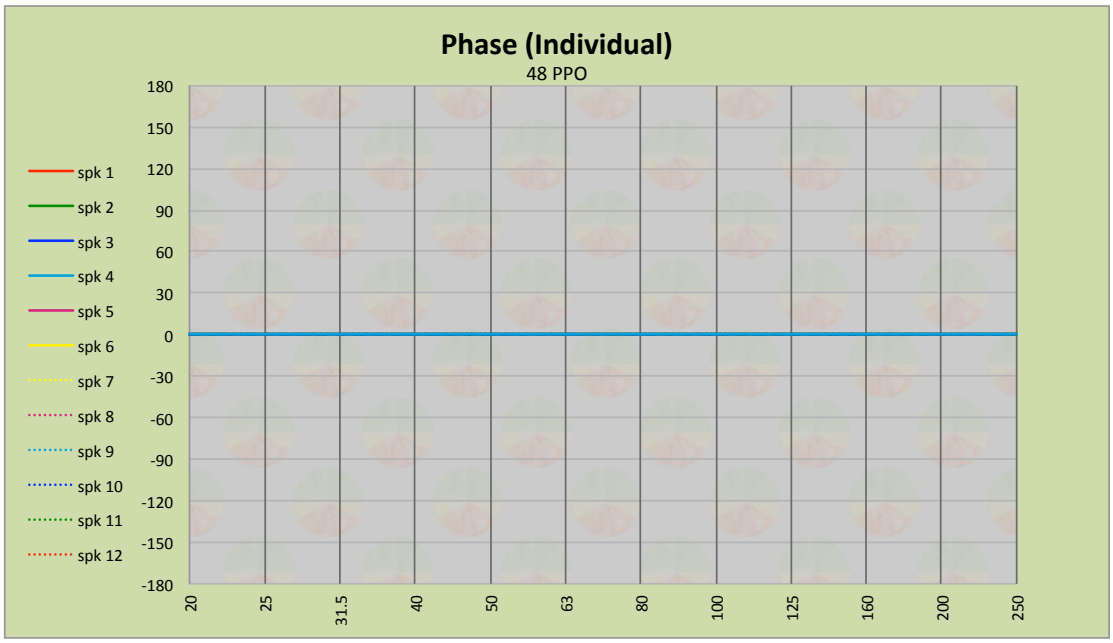
Speaker 1 through 4 are automatically positioned at 1,13 m. intervals and have increments of 3,32 ms of delay.

Step 8 – position overview



Four speakers can be seen as well as the 7 microphones positioned in a half circle at a distance of 15 m. The red dotted line indicates the microphone arc and always ends at the last microphone.

Step 9 – phase in front



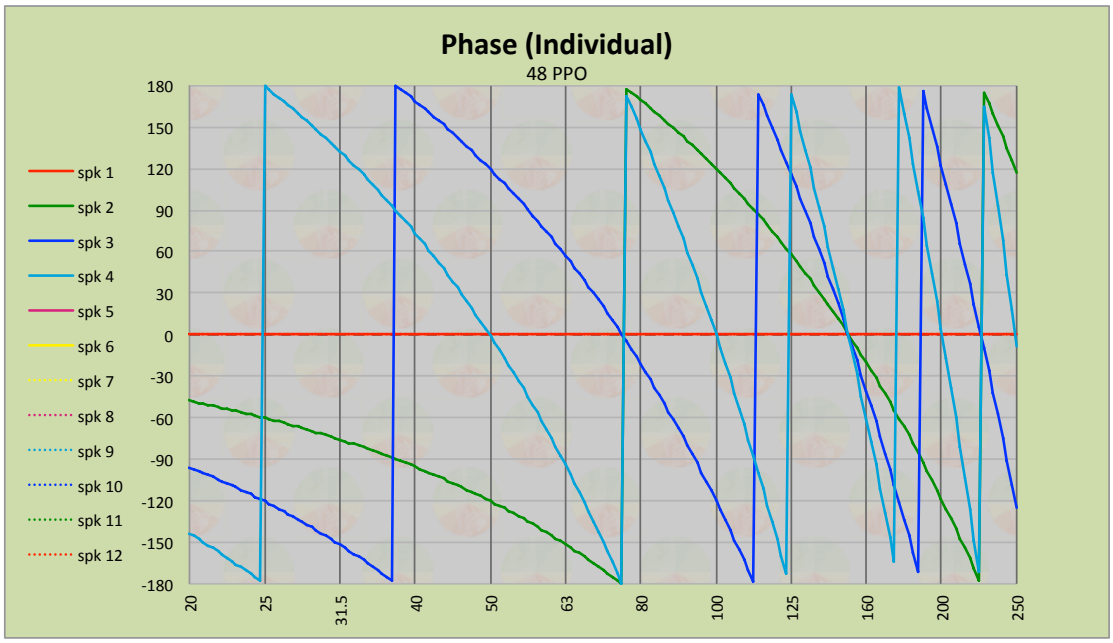
LEVEL & PHASE (INDIVIDUAL) CTRL		
mic	1	0,0°
		trace
normalize	1	1
track prox	0	spk 1
speaker	arr time	display
spk 1	0,00 ms	1
spk 2	0,00 ms	1
spk 3	0,00 ms	1
spk 4	0,00 ms	1
spk 5	#N/A	1
spk 6	#N/A	1
spk 7	#N/A	1
spk 8	#N/A	1
spk 9	#N/A	1
spk 10	#N/A	1
spk 11	#N/A	1
spk 12	#N/A	1

Mic 1 (front) is selected. Normalization is turned on, relative to trace 1 (speaker 1).

The relative arrival time of all speakers is identical and the phase traces overlap perfectly.

Based on this data, summation of all signals is expected for all frequencies.

Step 10 – phase in rear



LEVEL & PHASE (INDIVIDUAL) CTRL		
mic	7	180,0°
		trace
normalize	1	1
track prox	0	spk 1
speaker	arr time	display
spk 1	0,00 ms	1
spk 2	6,65 ms	1
spk 3	13,30 ms	1
spk 4	19,95 ms	1
spk 5	#N/A	1
spk 6	#N/A	1
spk 7	#N/A	1
spk 8	#N/A	1
spk 9	#N/A	1
spk 10	#N/A	1
spk 11	#N/A	1
spk 12	#N/A	1

Mic 7 (rear) is selected. Normalization is left on, relative to trace 1 (speaker 1).

Due to the late arrivals of speakers 2 through 4, several frequencies occur where the signals are out of phase.

Based on this data, more than one null is to be expected behind the array. Three nulls to be precise. The amount of speakers minus one.

Note that at the “critical frequency” equal to one wavelength (150 Hz in this example), all signals arrive in phase. Resulting in summation equal to the front of the array. This is why this region should be avoided.

Step 11 – level (summed)

LEVEL (SUMMED) CTRL		
trace	**proximity**	**display**
1 mic 0°	spk 2	1
2 mic 30°	spk 2	0
3 mic 60°	spk 2	0
4 mic 90°	spk 1	0
5 mic 120°	spk 1	0
6 mic 150°	spk 1	0
7 mic 180°	spk 1	1
8 block level		1
		trace
normalize	0	1

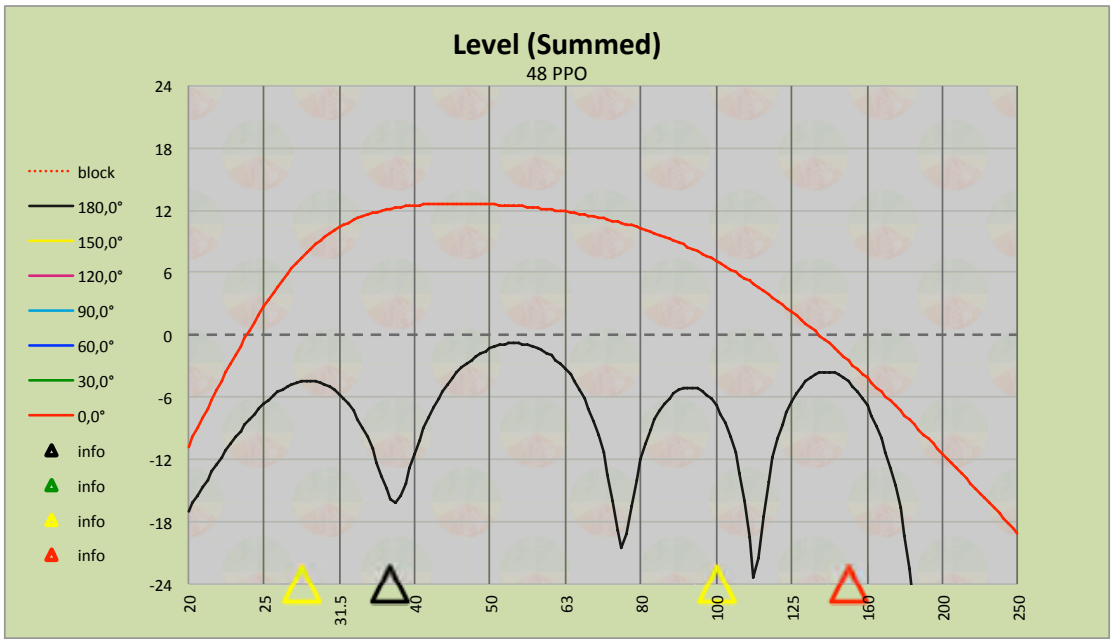
For clarity microphones 2 through 6 have been hidden.

The red trace (microphone 1 - front) shows summation for all frequencies.

The black trace (microphone 7 - rear) shows three nulls. Besides the null at 75 Hz from the previous tutorial there are nulls at ½ and 1½ times that frequency.

The nulls past “critical frequency” are of no concern. They occur outside the region of interest.

Step 12 – info panel



INFO	
array length (m)	4,52 m
1st cancel	38 Hz
pref filters @ min BL	28 / 100 Hz
crit freq	150 Hz
BW min BL / F2B	1,83 oct. / 16 d

array length: The total length of the array (speakers x spacing).

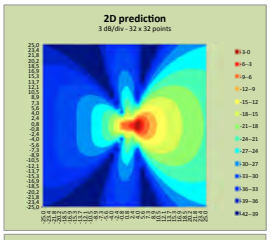
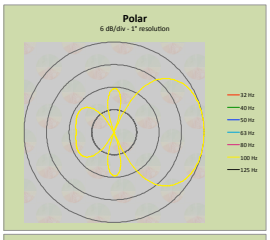
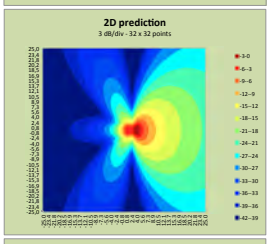
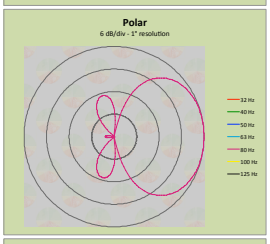
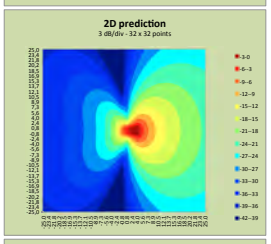
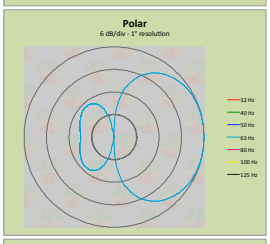
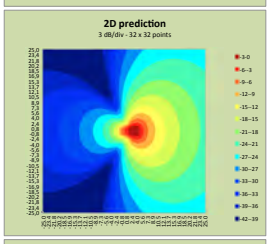
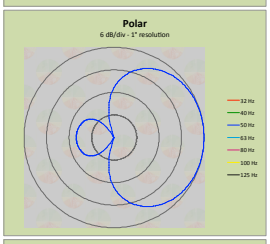
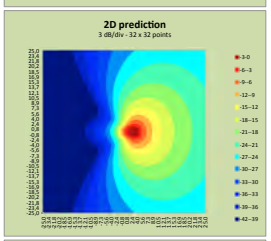
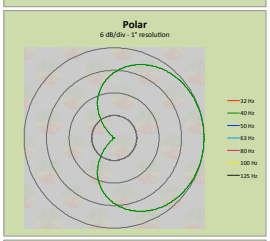
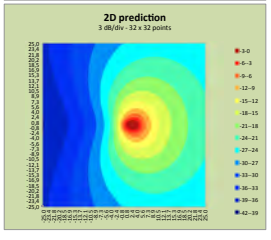
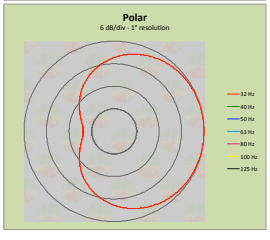
1st cancel: The frequency of the first cancelation indicated by the black marker.

pref filters: The recommended frequencies for high- and low-pass filters indicated by the yellow makers.

crit frequency: The critical frequency where summation behind the array equals summation in front of the array indicated by the red marker.

BW / F2B The bandwidth and front-2-back ratio between the yellow markers.

* For the purpose of illustration filters have been added.

frequency	SPL	polar
100 Hz		
80 Hz		
63 Hz		
50 Hz		
40 Hz		
32 Hz		

End-fire closing words:

The previous tutorials demonstrated 3 trends, more subwoofers increases both bandwidth, front-2-back ratio and forward directivity.

speakers	2	3	4	5	6	7	8
f-low	50 Hz	37 Hz	30 Hz	25 Hz	21 Hz	< 20 Hz	< 20 Hz
f-high	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz
F2B ratio	10 dB	13 dB	15 dB	16 dB	17 dB	> 17 dB	> 17 dB

spacing 1,13 m / temp 14° C

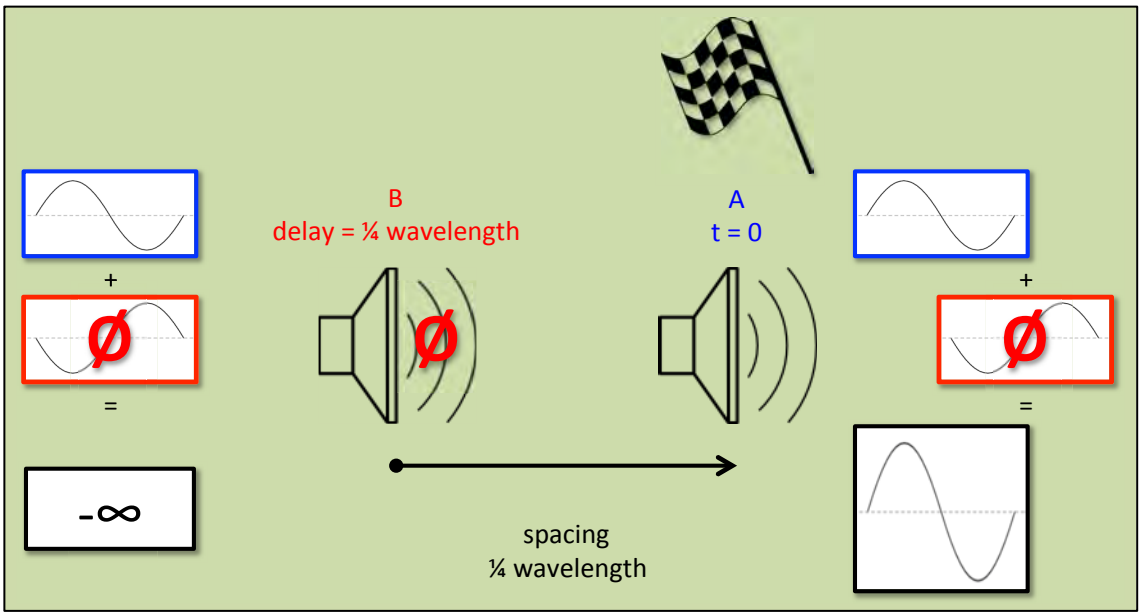
Five or more subwoofers will arguably deliver diminishing returns. The added bandwidth has little or no practical application and those few extra dB's of cancelation hardly justify the disproportional amount of extra speakers needed. With limited resources those speakers could be put to use more efficiently. Not to mention the physical dimensions of the entire array and consequentially the spatial requirements.

The frequency for the upper bandwidth limit is 2/3 of the "critical frequency". At this frequency all signals behind the array arrive 120° apart. Nothing is gained and nothing is lost. With fixed spacing the limit holds regardless of the amount of speakers.

Of all cardioid configurations, end-fire yields the most output.

The trade-off is regions of narrowband cancelation behind the array and an inconsistent coverage angle over frequency in front of the array.

Gradient theory:



The illustration above shows the principle of the gradient configuration.

Two speakers facing forward are spaced ¼ wavelength apart. Speaker B is delayed by ¼ wavelength and polarity inverted.

rear: Due to the delay applied to speaker B equal to the spacing, both signals arrive in phase. But the polarity inversion of speaker B will cause all frequencies to cancel.

front: The signal of speaker B arrives ½ wavelength later than speaker A, out of phase. But the polarity inversion of speaker B causes the signals to add up for a limited bandwidth.

The ½ wavelength delay is the combination of:

¼ wavelength acoustical time-of-flight
¼ wavelength electrical delay

The result is a singe peak in front of the configuration. The frequency of the peak is determined by the corresponding wavelength.

Depending on the application a suitable wavelength can be chosen for optimum effect.

Tutorial 3: gradient

Goals: 1.) peak at 68 Hz (wavelength 5 m. at 14° C)
2.) upper bandwidth limit 100 Hz

Step 1 - select gradient speaker setup

SPEAKER SETUP	4
1. Physical hor. array	
2. Delayed hor. array	
3. End-Fire	
4. Gradient	

Step 2 - select omni speaker pattern

SPEAKER PATTERN	1
1. Omni	
horizontal array only	
2. Cardioid	
3. Super-Cardioid	
4. Figure Eight	

Step 3 – speakers will be automatically set to 2

INPUT DATA		speakers (MAX 12)		1	DISABLED	block level	0,00 dB
no.	on / off	x (m)	y (m)	rot (°)	level (dB)	t (ms)	pol inv
1	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
2	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
3	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
4	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
5	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
6	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
7	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
8	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
9	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
10	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
11	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
12	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0

Step 4 – set spacing (1,25 m. is ¼ wavelength 68 Hz at 14° C)

ARRAY PARAMETERS		
spacing 90° (m)		1,25 m
horizontal array only		
	FAR	
arc	2,00	60°
orientate speakers		0

Step 5 – inspect output data

OUTPUT DATA	speakers (MAX 12)	2		block level	6,02 dB	
no.	**on / off**	**x (m)**	**y (m)**	**rot (°)**	**level (dB)**	**t (ms)**	**pol inv**
1	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
2	1	-1,25 m	0,00 m	0,0°	0,00 dB	3,68 ms	1
3	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
4	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
5	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
6	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
7	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
8	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
9	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
10	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
11	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
12	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0

Speaker 2 is automatically positioned at -1,25 m. and has 3,68 ms of delay.

Step 6 – select microphone setup 1 “arc” at 180° degrees

MIC SETUP		1
1. Arc	FAR	180,0°
	########	(360°)
horizontal array only		
2. Array		
3. Edge		
4. Exponential 72°		

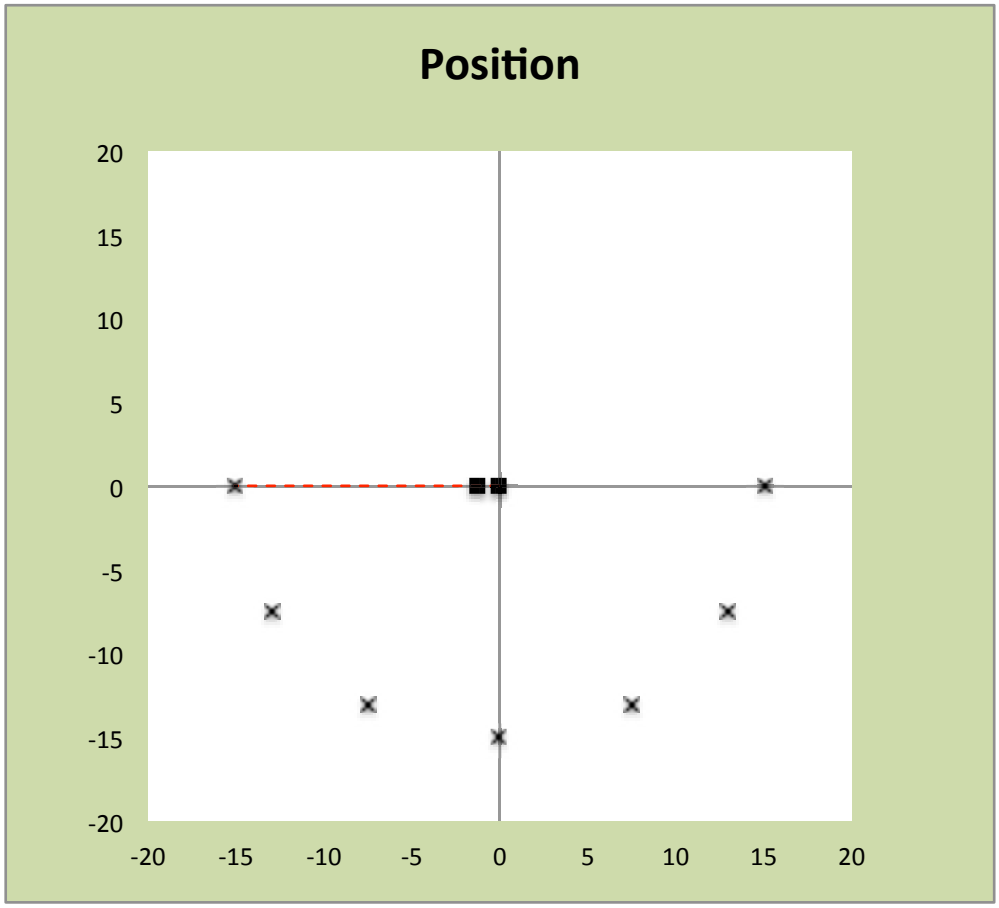
Microphones on either side of the configuration are needed, hence 180° deg.

Step 7 – set global radius

GLOBAL RADIUS (FOH)	15 m

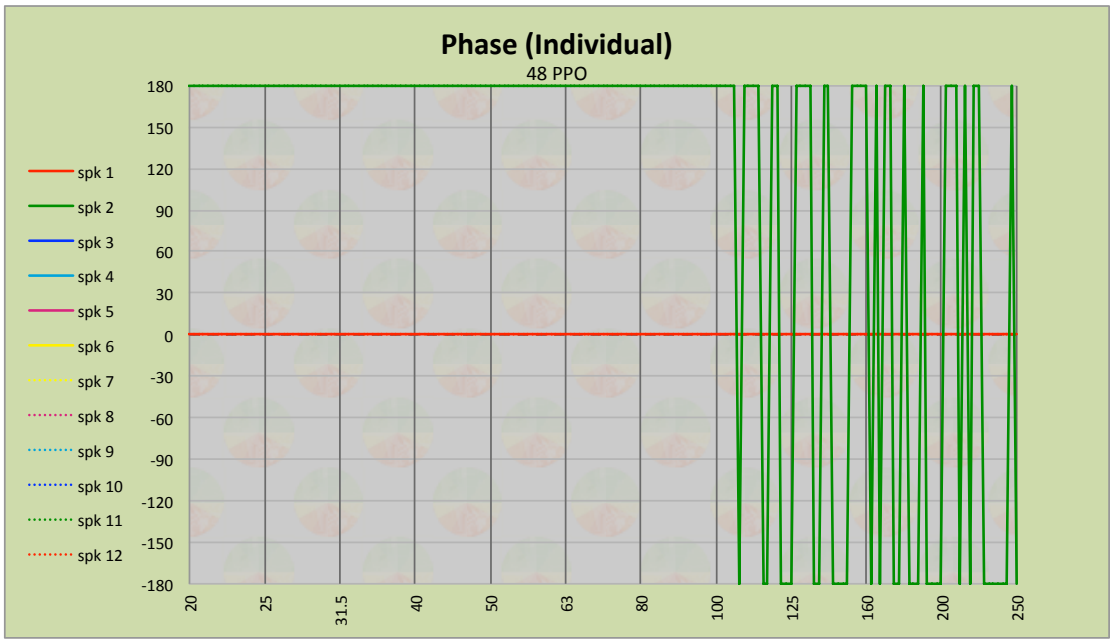
For the purpose of illustration I have chosen 15 m. The default value of 25 m. will suffice for most situations.

Step 8 – position overview



Both speakers can be seen as well as the 7 microphones positioned in a half circle at a distance of 15 m. The red dotted line indicates the microphone arc and always ends at the last microphone.

Step 9 – phase in rear



LEVEL & PHASE (INDIVIDUAL) CTRL		
mic	7	180,0°
		trace
normalize	1	1
track prox	0	spk 1
speaker	arr time	display
spk 1	0,00 ms	1
spk 2	0,00 ms	1
spk 3	#N/A	1
spk 4	#N/A	1
spk 5	#N/A	1
spk 6	#N/A	1
spk 7	#N/A	1
spk 8	#N/A	1
spk 9	#N/A	1
spk 10	#N/A	1
spk 11	#N/A	1
spk 12	#N/A	1

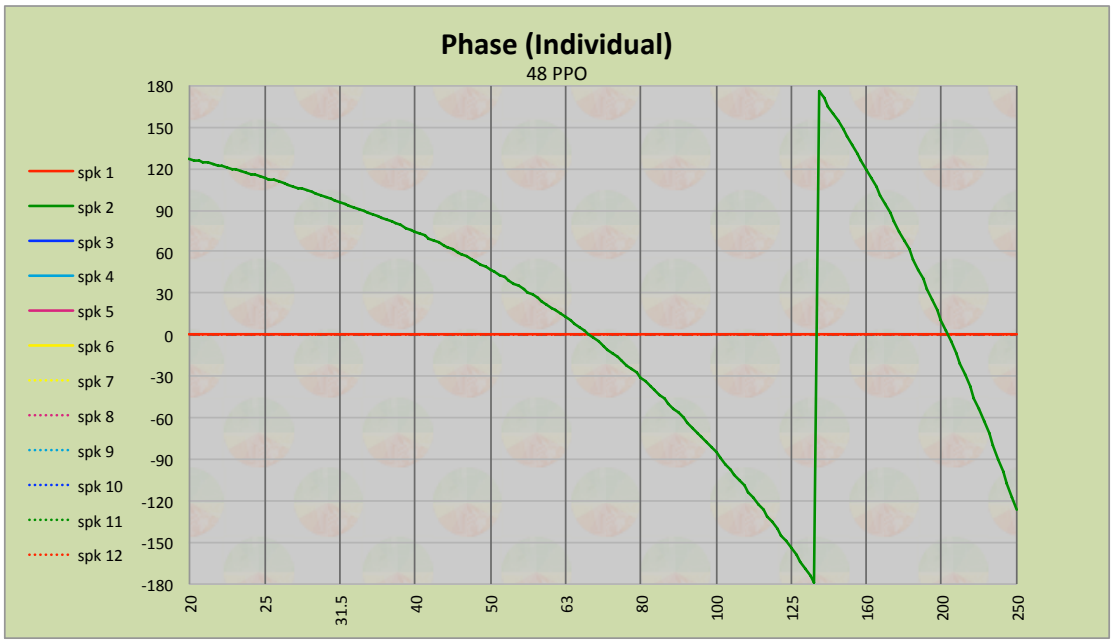
Mic 7 (rear) is selected. Normalization is turned on, relative to trace 1 (speaker 1).

The relative arrival time of both speakers is identical and the phase traces are 180° apart due to the polarity inversion of speaker 2 (B).

Based on this data, cancelation is expected for all frequencies.

(The jumping of the phase trace can be disregarded, this is caused by values close to the wraparound value of ±180°).

Step 10 – phase in front



LEVEL & PHASE (INDIVIDUAL) CTRL		
mic	1	0,0°
		trace
normalize	1	1
track prox	0	spk 1
speaker	arr time	display
spk 1	0,00 ms	1
spk 2	7,36 ms	1
spk 3	#N/A	1
spk 4	#N/A	1
spk 5	#N/A	1
spk 6	#N/A	1
spk 7	#N/A	1
spk 8	#N/A	1
spk 9	#N/A	1
spk 10	#N/A	1
spk 11	#N/A	1
spk 12	#N/A	1

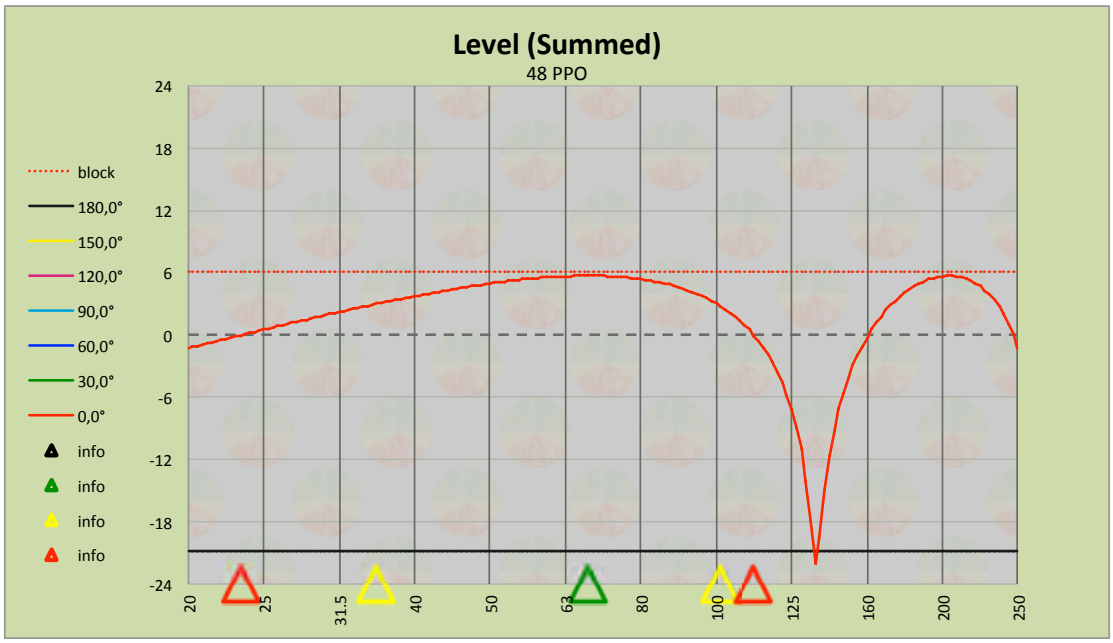
Mic 1 (front) is selected. Normalization is left on, relative to trace 1 (speaker 1).

Speaker 2 arrives 7,36 ms (½ wavelength) later relative to speaker 1, partially in phase due to the polarity inversion of speaker 2 (B). As frequency increases the relative phase of speaker 2 starts to approach the phase of speaker 1. By the time 68 Hz is reached both signals are in phase. Beyond 68 Hz the phase traces start to deviate again.

Based on this data, cancelation will change into summation as frequency increases, reaching a maximum at 68 Hz. Continuing towards 136 Hz summation will decrease and change into cancelation.

This progression will repeat itself creating the familiar comb filter.

Step 11 – level (summed)



LEVEL (SUMMED) CTRL		
trace	**proximity**	**display**
1 mic 0°	spk 2	1
2 mic 30°	spk 2	0
3 mic 60°	spk 2	0
4 mic 90°	spk 1	0
5 mic 120°	spk 1	0
6 mic 150°	spk 1	0
7 mic 180°	spk 1	1
8 block level		1
		trace
normalize	0	1

For clarity microphones 2 through 6 have been hidden.

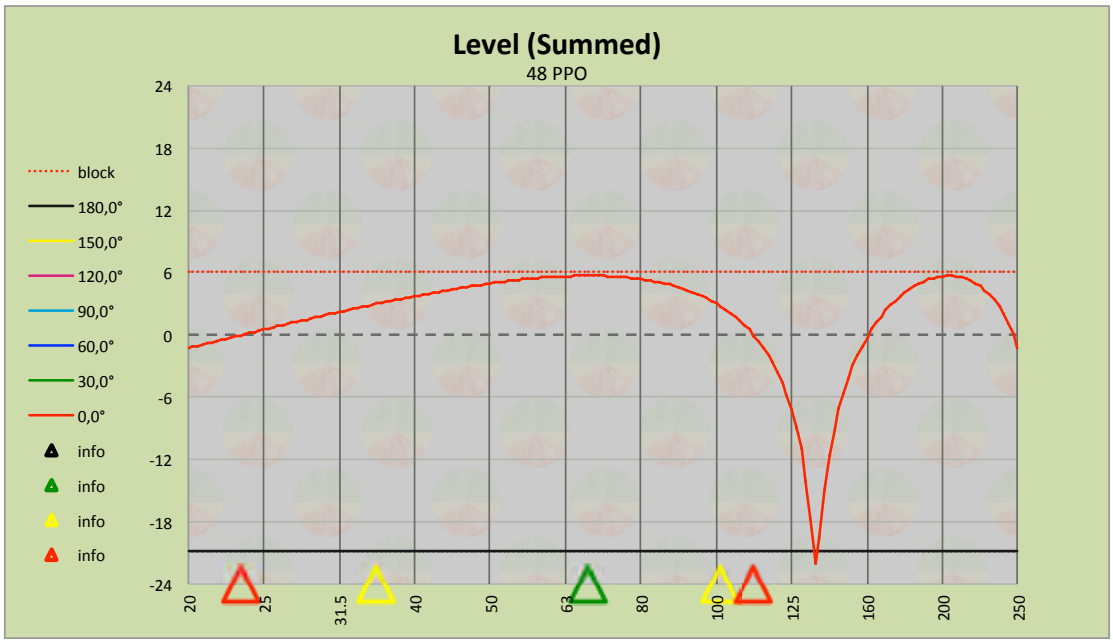
The red trace (microphone 1 - front) shows partial summation, reaching a maximum at 68 Hz.

This is the first “dip” of the “comb filter” that is caused by a delay of 7,36 ms but, the polarity inversion turns cancelation into summation and vice versa.

The black trace (microphone 7 - rear) shows cancelation for all frequencies.

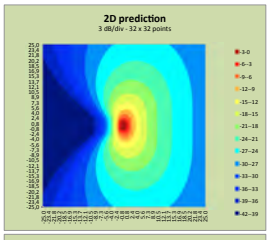
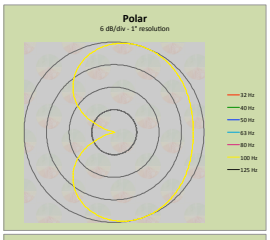
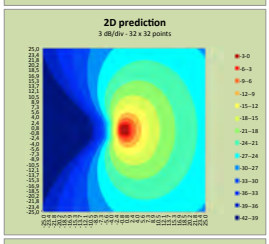
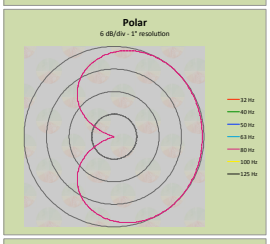
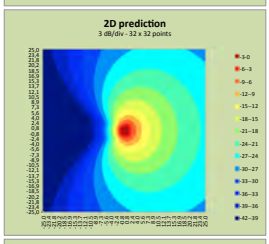
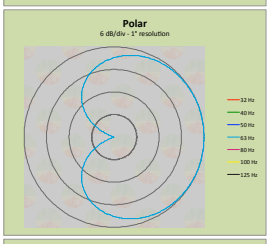
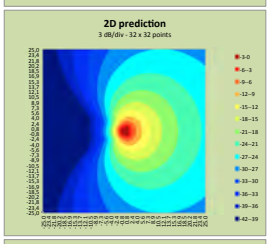
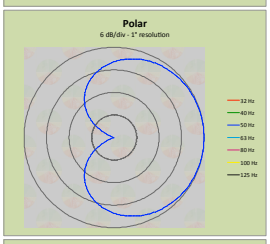
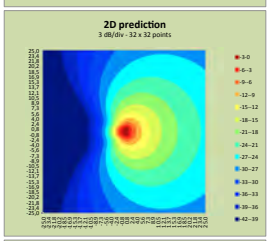
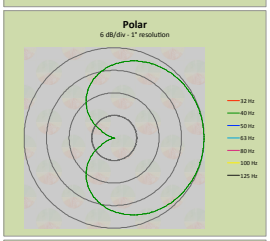
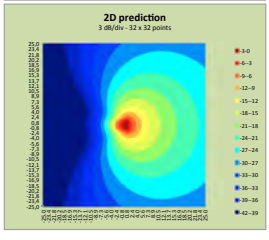
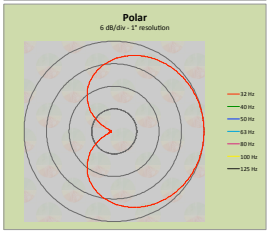
Due to phase relationship the maximum amount of summation or “block level” with 2 speakers, 6 dB, hasn’t been achieved for all frequencies.

Step 13 – info panel



INFO	
array length (m)	
max sum	68 Hz
pref filter @ - 3dB	36 / 100 Hz
max filter @ -6 dB	23 / 111 Hz
BW -3 dB / F2B	1,49 oct. / 25,6
BW -6 dB / F2B	2,24 oct. / 24,8

max sum:	The frequency where maximum summation occurs.
pref filters: -3 dB	The recommended frequencies for high- and low-pass filters indicated by the yellow makers.
max filters: -6 dB	The limit frequencies for high- and low-pass filters indicated by the red makers.
BW / F2B: -3 dB	The bandwidth and front-2-back ratio between the yellow markers.
BW / F2B: -6 dB	The bandwidth and front-2-back ratio between the red markers.

frequency	SPL	polar
100 Hz		
80 Hz		
63 Hz		
50 Hz		
40 Hz		
32 Hz		

Gradient closing words:

The previous tutorial demonstrated effective broadband attenuation behind the array and consistent coverage over frequency in front of the array.

The trade-off is a partial increase in output of only +6 dB, due to the two element restriction, and arguably time-smearing in front of the array over an 60° through 300° phase span.

Up to the final step of polarity inversion of the rear speaker and with the exception of speaker orientation, gradient arrays are the mirror image of the 2-element end-fire arrays.

Line array theory:

Line array (coupled and uncoupled) directivity starts at the frequency whose wavelength equals the line length and stops at ⅔ of the frequency whose wavelength equals the source spacing. Beyond the latter, lateral summation outside the array will occur.

Physical arced arrays exhibit a coverage angle equal to the segment of the arc segment of virtual circle whose origin lies behind the array.

The on-axis frequency at global radius (FOH) where summation drops 6 dB, is the upper frequency limit of the horizontal configuration.

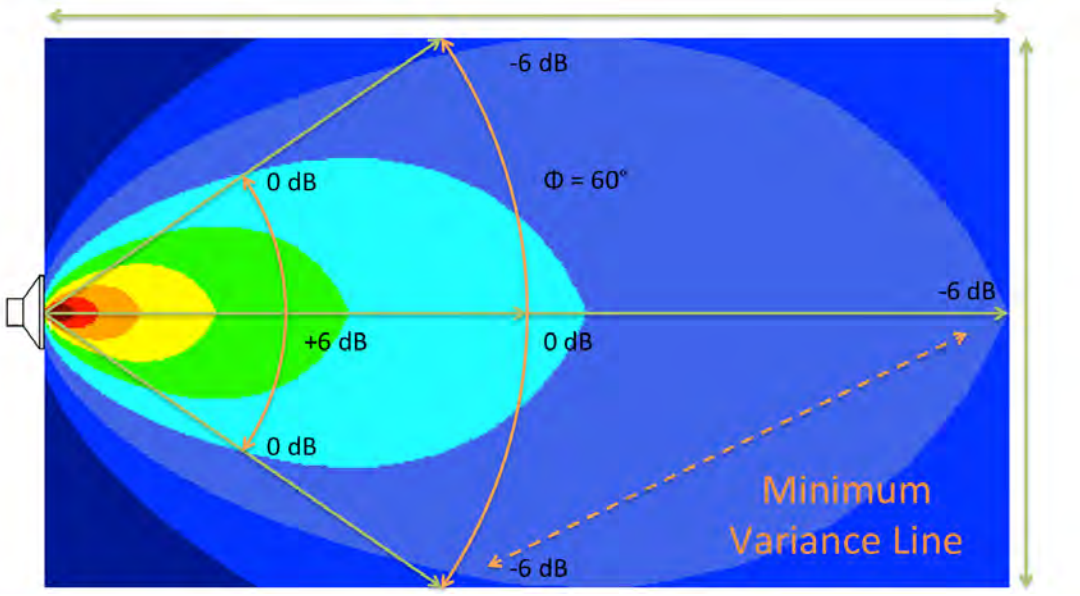
The usable coverage angle, where tonal variation is limited to 6 dB, is ⅔ of the arc angle.

Physical arrays made of omnidirectional sources will exhibit a focal node behind the array at the origin of the virtual circle.

Electronic delayed horizontal arrays, as if the speakers where placed in an arc, require less real estate but behave virtually identical.

Delayed arrays made of omnidirectional sources, in contrast to physical arrays, are inherently symmetrically.

Forward Aspect Ratio[1]:



Forward Aspect Ratio or FAR is the ratio between the depth and width of a given speaker or array based on its coverage angle.

$$FAR = \frac{1}{\sin\left(\frac{c_\angle}{2}\right)} \quad \Leftrightarrow \quad c_\angle = 2 \cdot \operatorname{asin}\left(\frac{1}{FAR}\right)$$

The resulting shape makes it easy to find areas of minimum variance in level.

[1] Sound Systems: Design and Optimization by Bob McCarthy

Tutorial 4: physical horizontal array

Goals: 1.) even coverage of a 25 by 50 meter audience area (FAR=2 $c_{\angle}$=60°) using 10 speakers
2.) upper bandwidth limit 100 Hz

Step 1 - select Physical hor. array speaker setup

SPEAKER SETUP	1
1. Physical hor. array	
2. Delayed hor. array	
3. End-Fire	
4. Gradient	

Step 2 - select omni speaker pattern

SPEAKER PATTERN	1
1. Omni	
horizontal array only	
2. Cardioid	
3. Super-Cardioid	
4. Figure Eight	

Step 3 – select 10 speakers

INPUT DATA		speakers (MAX 12)		10		block level	20,00 dB
no.	**on / off**	**x (m)**	**y (m)**	**rot (°)**	**level (dB)**	**t (ms)**	**pol inv**
1	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
2	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
3	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
4	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
5	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
6	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
7	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
8	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
9	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
10	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
11	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
12	1	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0

Step 4 – select microphone setup 1 “arc” at 30° degrees

MIC SETUP		1
1. Arc	FAR	30,0°
	2,00	(60°)
horizontal array only		
2. Array		
3. Edge		
4. Exponential 72°		

Notice that FAR indicates 2,00 the ratio between the width and depth of the venue.

Step 5 – twiddle the parameters spacing and arc until the max angle value between parentheses reads 60° and -6 dB ONAX reads 100 Hz in the info panel.

ARRAY PARAMETERS		
spacing 180° (m)		0,99 m
horizontal array only		
	FAR	
arc	1,74	70°
orientate speakers		0

INFO	
array length (m)	9,90 m
array 1λ	34 Hz
spk dist 180°	172 Hz
spk dist 240°	229 Hz
spk dist 360°	343 Hz
-6 dB ONAX	100 Hz 2,9 λ
max angle	47 ° (60 °) -6,1 dB @ 60 Hz

The max angle value without parentheses is ⅔ of the arc angle under array parameters as seen from the virtual point of origin behind the array. The value between parentheses is the equivalent angle for microphone setup No. 1 (arc) as seen from the physical origin of the array at xy-coordinates 0,0.

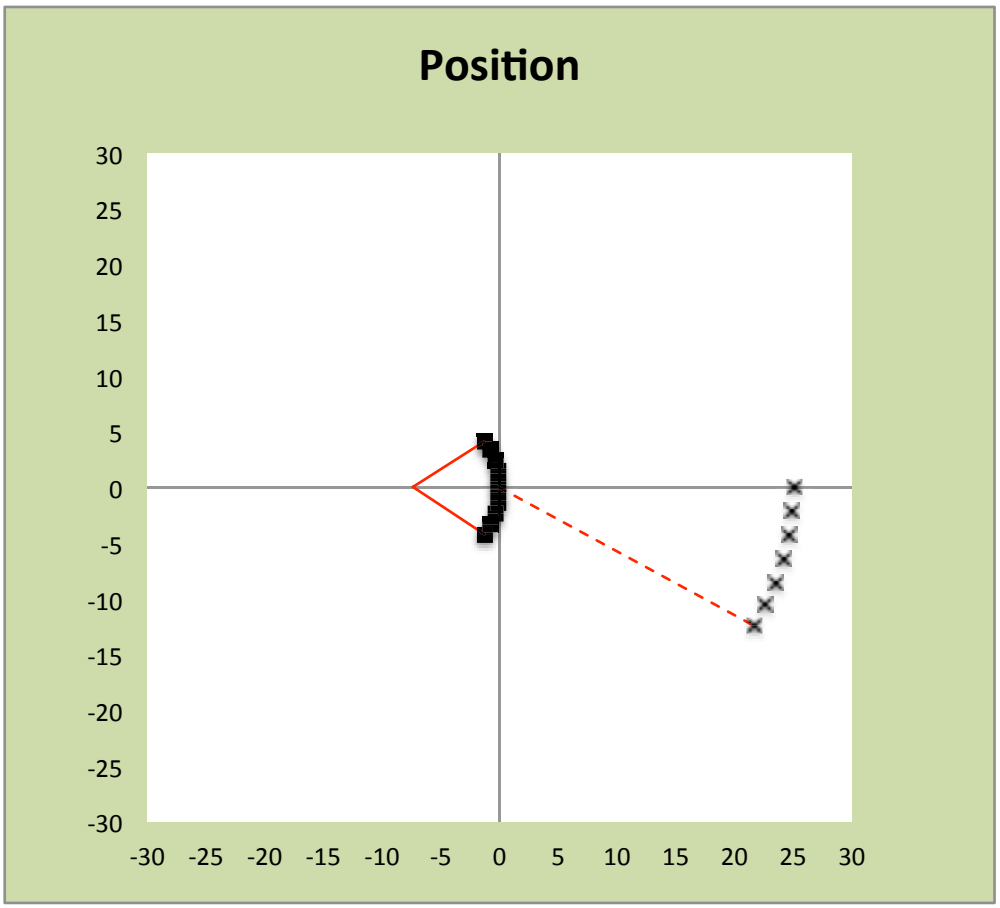
The maximum tonal variation reaches -6,1 dB at 60 Hz.

Step 6 – inspect output data

OUTPUT DATA		speakers (MAX 12)		10		block level	20,00 dB
no.	**on / off**	**x (m)**	**y (m)**	**rot (°)**	**level (dB)**	**t (ms)**	**pol inv**
1	1	-1,32 m	4,18 m	35,0°	0,00 dB	0,00 ms	0
2	1	-0,81 m	3,34 m	27,2°	0,00 dB	0,00 ms	0
3	1	-0,42 m	2,43 m	19,4°	0,00 dB	0,00 ms	0
4	1	-0,15 m	1,47 m	11,7°	0,00 dB	0,00 ms	0
5	1	-0,02 m	0,49 m	3,9°	0,00 dB	0,00 ms	0
6	1	-0,02 m	-0,49 m	-3,9°	0,00 dB	0,00 ms	0
7	1	-0,15 m	-1,47 m	-11,7°	0,00 dB	0,00 ms	0
8	1	-0,42 m	-2,43 m	-19,4°	0,00 dB	0,00 ms	0
9	1	-0,81 m	-3,34 m	-27,2°	0,00 dB	0,00 ms	0
10	1	-1,32 m	-4,18 m	-35,0°	0,00 dB	0,00 ms	0
11	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
12	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0

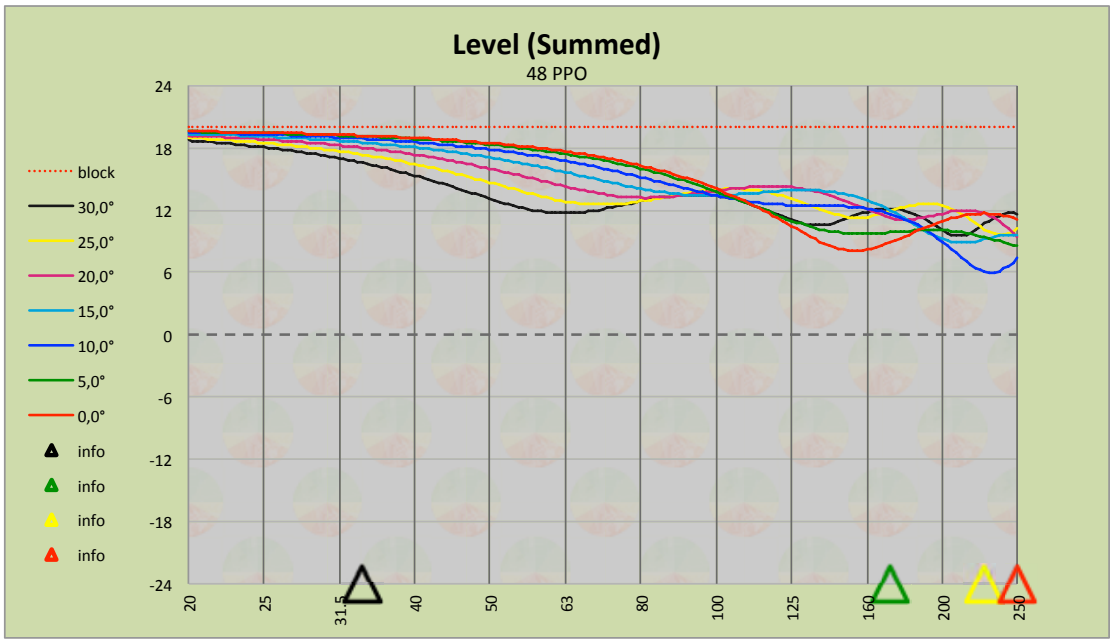
All 10 speakers have been physically placed on a 70° arc and are rotated accordingly.

Step 7 – position overview



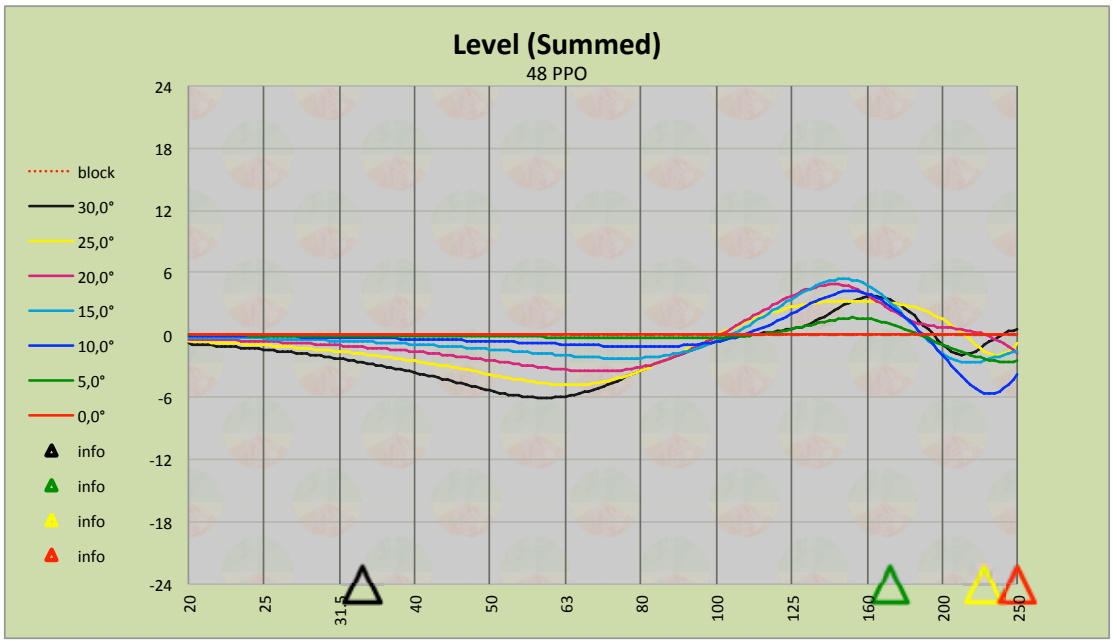
The 10 speakers and the 70° virtual arc angle can be seen. The 7 microphones are distributed equidistant over a 30° angle at 25 meters (global radius).

Step 8 – level (summed)

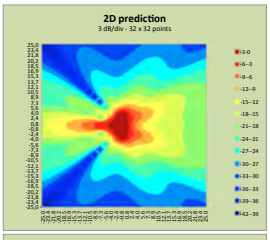
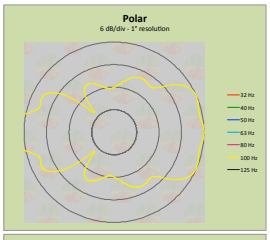
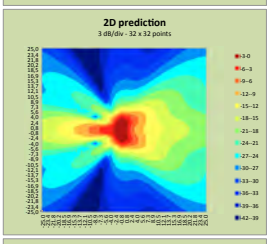
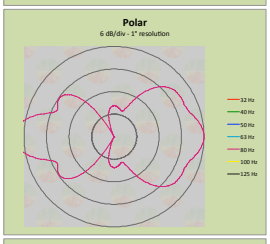
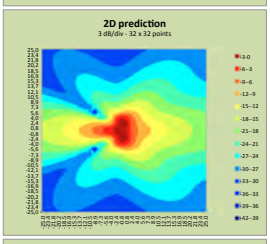
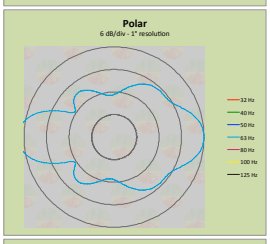
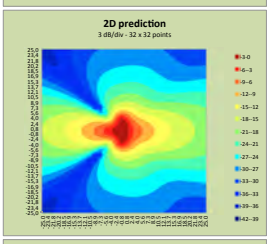
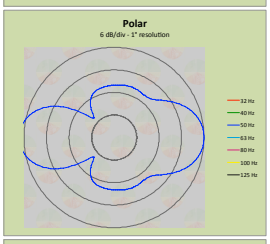
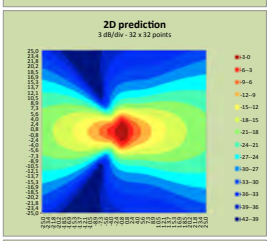
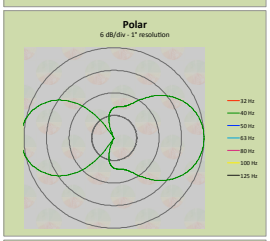
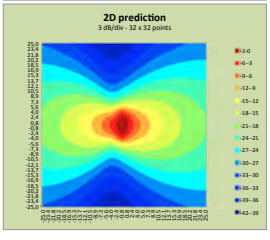
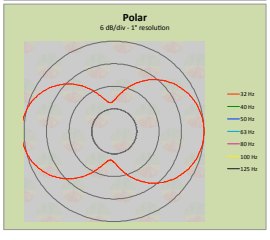


INFO	
array length (m)	9,90 m
array 1λ	34 Hz
spk dist 180°	172 Hz
spk dist 240°	229 Hz
spk dist 360°	343 Hz
-6 dB ONAX	100 Hz 2,9 λ
max angle	47 ° (60 °) -6,1 dB @ 60 Hz

The ONAX level (microphone No. 1) gradually drops down to -6 dB in relation to “block level” at 100 Hz, the intended upper frequency limit. 2,9 Wavelengths in relation to the array length of 9,90 meters.

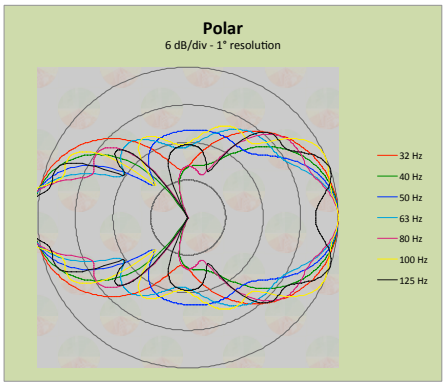


The same plot from the previous page but normalized to microphone No. 1 clearly shows that all tonal variation within the intended bandwidth falls within 6 dB.

frequency	SPL	polar
100 Hz		
80 Hz		
63 Hz		
50 Hz		
40 Hz		
32 Hz		

Both SPL and polar plots clearly show the focal node with greater output behind the array.

Step 9 – polar



POLAR CTRL

freq	display	-6 dB	opening angle	relative mic arc
32 Hz	1	49°	98°	63%
40 Hz	1	38°	76°	27%
50 Hz	1	32°	64°	7%
63 Hz	1	30°	60°	0%
80 Hz	1	47°	94°	57%
100 Hz	1	42°	84°	40%
125 Hz	1	49°	98°	63%

normalize all polar 0

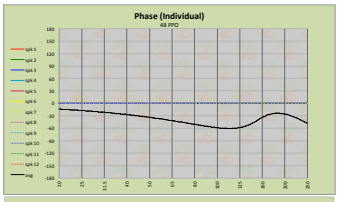
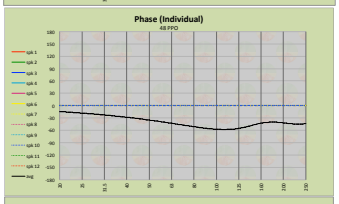
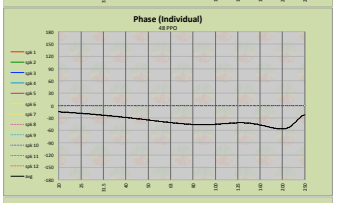
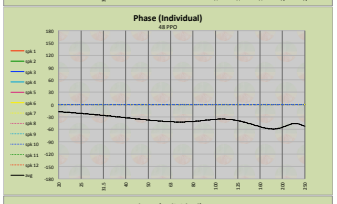
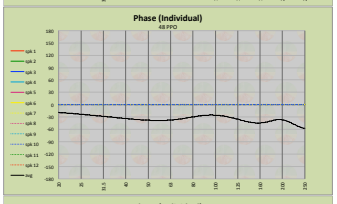
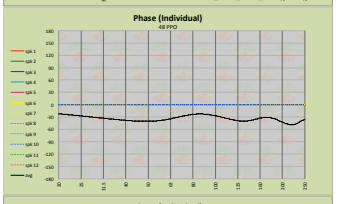
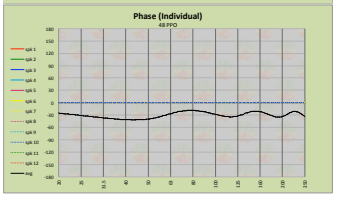
for proper angles
turn off normalization & filters
caution with lobing

normalize range 1
1. half space
2. full space

filters 0

The panel shows a nominal coverage of 60° +63%.

The polar for 125 Hz, past our intended bandwidth, shows the onset of pattern breakup indicated by lobing.

microphone	average phase
1	
2	
3	
4	
5	
6	
7	

Notice the consistent average phase ±15° for microphones 1 through 7 within the intended bandwidth. Past -6 dB ONAX at 100 Hz pattern breakup causes increasingly irregular average phase.

The next tutorial will try to achieve similar results with a delayed horizontal array using omnidirectional sources.

Tutorial 5: delayed horizontal array

Goals: 1.) even coverage of a 25 by 50 meter audience area (FAR=2 $c_{\angle}$=60°) using 10 speakers
2.) upper bandwidth limit 100 Hz

Most parameters are identical to the previous tutorial only the changes will be handled.

Step 1 - select Delayed hor. array speaker setup

SPEAKER SETUP	2
1. Physical hor. array	
2. Delayed hor. array	
3. End-Fire	
4. Gradient	

Step 5 – twiddle the parameters spacing and arc until the max angle value between parentheses reads 60° and -6 dB ONAX reads 100 Hz in the info panel.

ARRAY PARAMETERS		
spacing 180° (m)		0,94 m
horizontal array only		
	FAR	
arc	1,72	71°
orientate speakers		0

INFO	
array length (m)	9,40 m
array 1λ	36 Hz
spk dist 180°	181 Hz
spk dist 240°	241 Hz
spk dist 360°	362 Hz
-6 dB ONAX	100 Hz 2,8 λ
max angle	47 ° (60 °) -5,6 dB @ 56 Hz

The max angle value without parentheses is ⅔ of the arc angle under array parameters as seen from the virtual point of origin behind the array. The value between parentheses is the equivalent angle for microphone setup No. 1 (arc) as seen from the physical origin of the array at xy-coordinates 0,0.

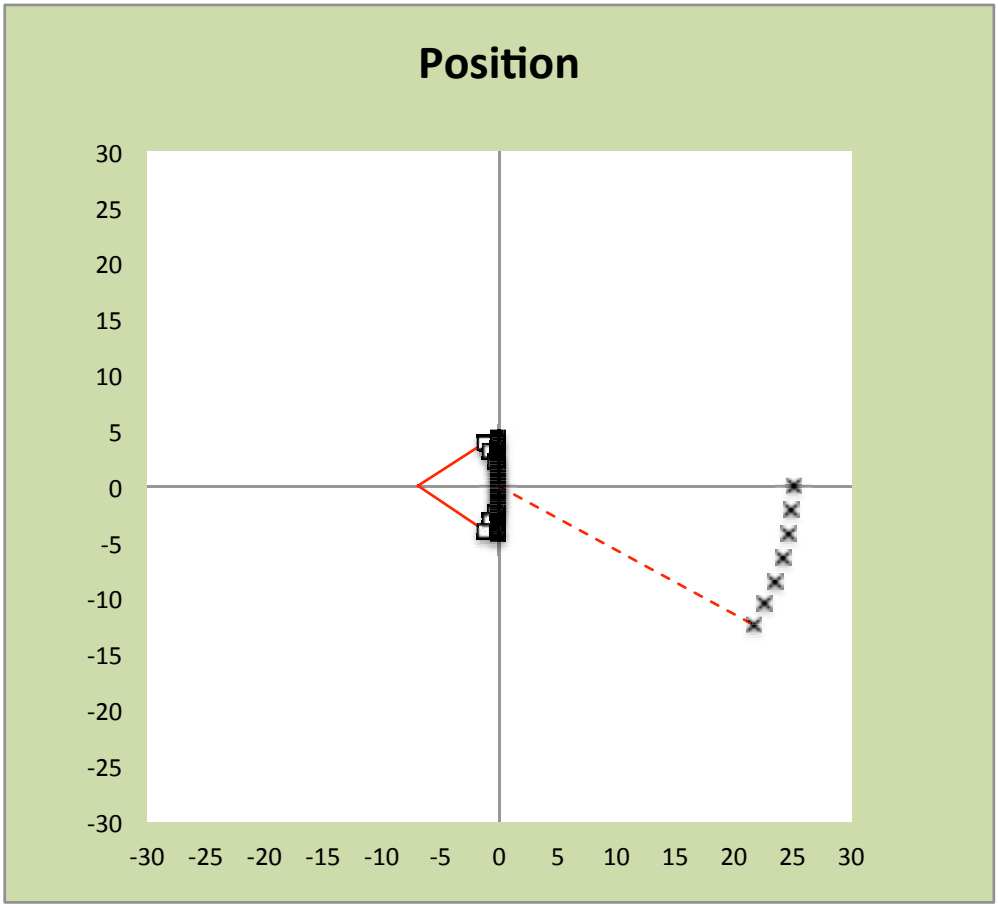
The maximum tonal variation reaches -5,6 dB at 56 Hz.

Step 6 – inspect output data

OUTPUT DATA		speakers (MAX 12)		10		block level	20,00 dB
no.	**on / off**	**x (m)**	**y (m)**	**rot (°)**	**level (dB)**	**t (ms)**	**pol inv**
1	1	0,00 m	4,23 m	0,0°	0,00 dB	3,77 ms	0
2	1	0,00 m	3,29 m	0,0°	0,00 dB	2,27 ms	0
3	1	0,00 m	2,35 m	0,0°	0,00 dB	1,14 ms	0
4	1	0,00 m	1,41 m	0,0°	0,00 dB	0,38 ms	0
5	1	0,00 m	0,47 m	0,0°	0,00 dB	0,00 ms	0
6	1	0,00 m	-0,47 m	0,0°	0,00 dB	0,00 ms	0
7	1	0,00 m	-1,41 m	0,0°	0,00 dB	0,38 ms	0
8	1	0,00 m	-2,35 m	0,0°	0,00 dB	1,14 ms	0
9	1	0,00 m	-3,29 m	0,0°	0,00 dB	2,27 ms	0
10	1	0,00 m	-4,23 m	0,0°	0,00 dB	3,77 ms	0
11	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0
12	0	0,00 m	0,00 m	0,0°	0,00 dB	0,00 ms	0

All 10 speakers have been physically placed on a straight line and are delayed automatically.

Step 7 – position overview

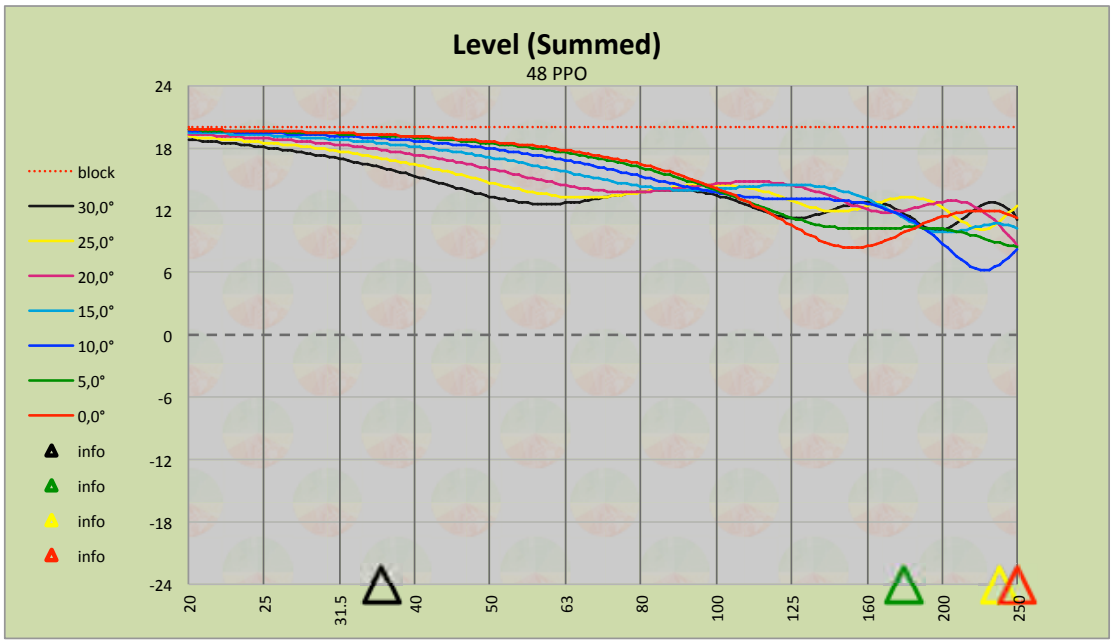


The 10 speakers and the 70° virtual arc angle can be seen. The 7 microphones are distributed equidistant over a 30° angle at 25 meters (global radius).

The black boxes represent the actual physical positions of the speakers. The white boxes represent the virtual positions.

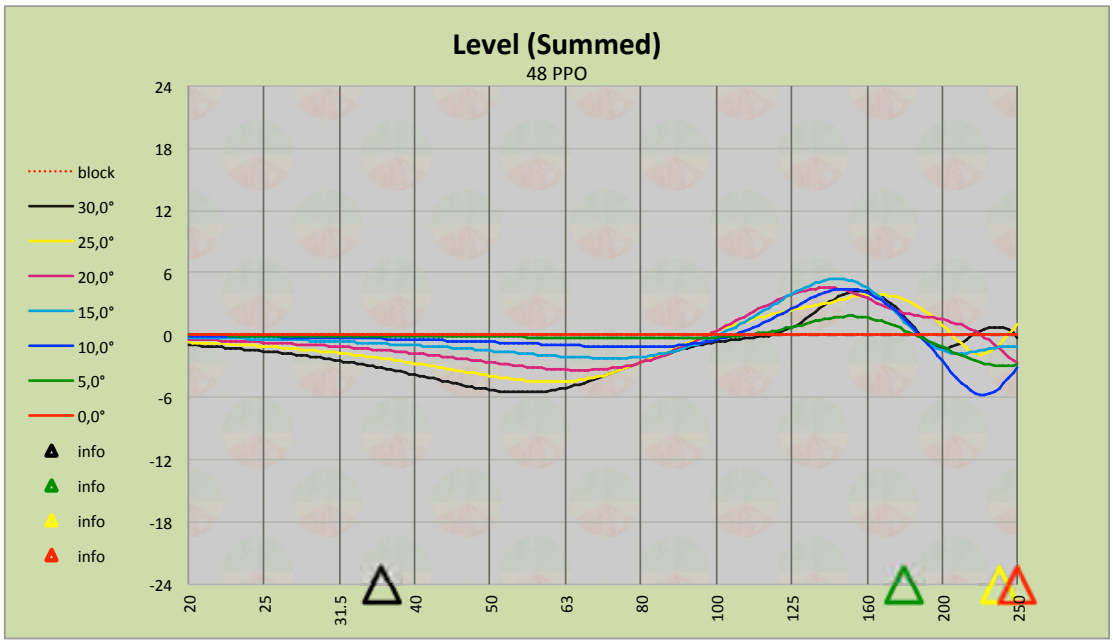
The difference in position is applied as electronic delay.

Step 8 – level (summed)

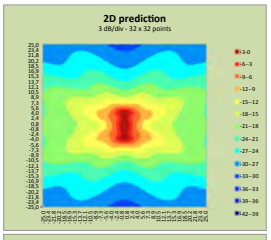
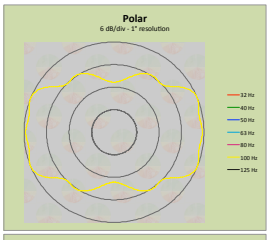
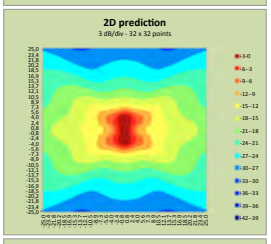
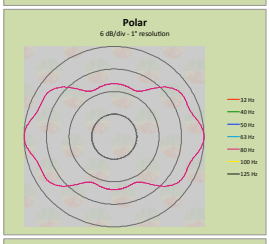
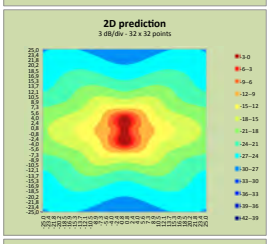
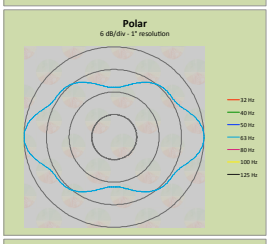
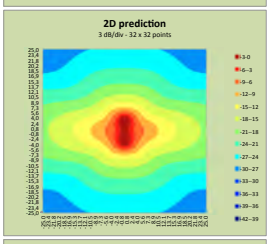
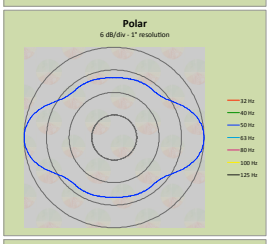
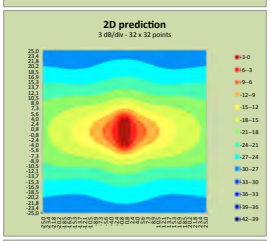
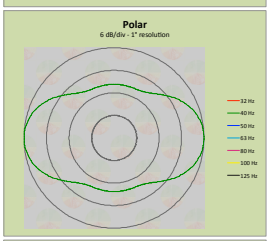
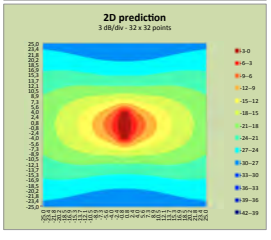
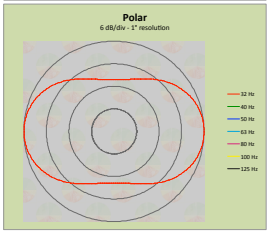


INFO	
array length (m)	9,40 m
array 1λ	36 Hz
spk dist 180°	181 Hz
spk dist 240°	241 Hz
spk dist 360°	362 Hz
-6 dB ONAX	100 Hz 2,8 λ
max angle	47 ° (60 °) -5,6 dB @ 56 Hz

The ONAX level (microphone No. 1) gradually drops down to -6 dB in relation to “block level” at 100 Hz, the intended upper frequency limit. 2,8 Wavelengths in relation to the array length of 9,40 meters.

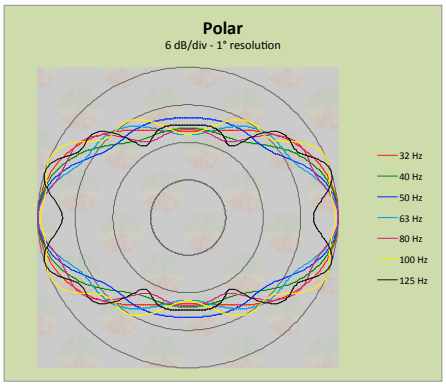


The same plot from the previous page but normalized to microphone No. 1 clearly shows that all tonal variation within the intended bandwidth falls within 6 dB.

frequency	SPL	polar
100 Hz		
80 Hz		
63 Hz		
50 Hz		
40 Hz		
32 Hz		

Notice the inherent symmetrical “Rorschach” behavior of delayed straight arrays in both SPL and polar plots.

Step 9 – polar



POLAR CTRL

freq	display	-6 dB	opening angle	relative mic arc
32 Hz	1	49°	98°	63%
40 Hz	1	38°	76°	27%
50 Hz	1	32°	64°	7%
63 Hz	1	51°	102°	70%
80 Hz	1	46°	92°	53%
100 Hz	1	44°	88°	47%
125 Hz	1	48°	96°	60%

normalize all polar 0

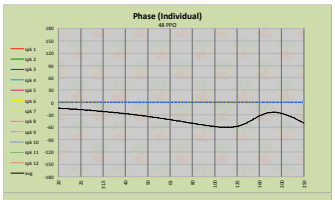
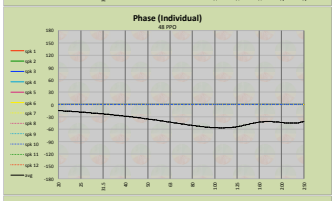
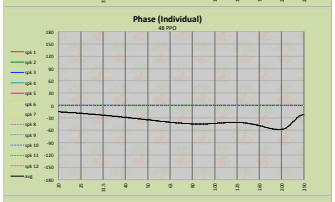
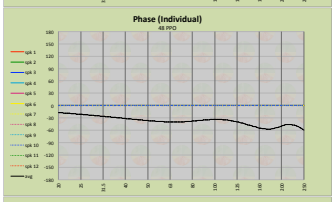
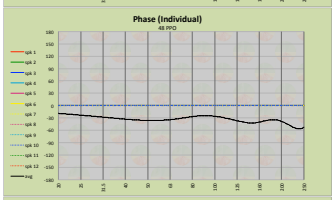
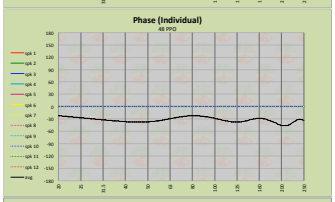
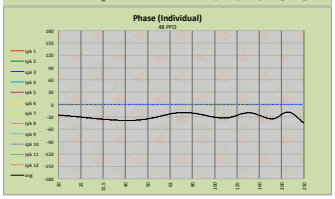
for proper angles
turn off normalization & filters
caution with lobing

normalize range 1
1. half space
2. full space

filters 0

The panel shows a nominal coverage of 64° +70%.

The polar for 125 Hz, past our intended bandwidth, shows the onset of pattern breakup indicated by lobing.

microphone	average phase
1	
2	
3	
4	
5	
6	
7	

Notice the consistent, virtual identical to the previous tutorial, average phase ±15° for microphones 1 through 7 within the intended bandwidth. Past -6 dB ONAX at 100 Hz pattern breakup causes increasingly irregular average phase.

The next tutorial will try to achieve similar results with cardioid sources.

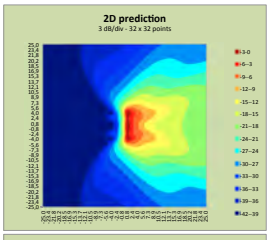
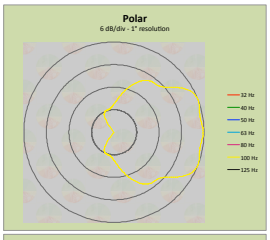
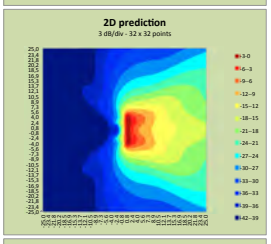
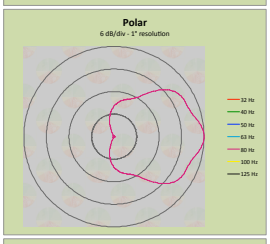
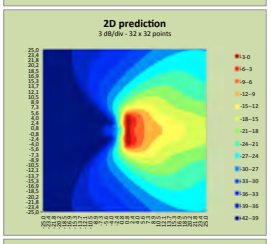
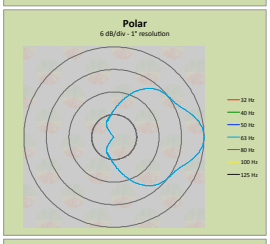
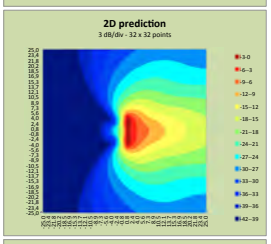
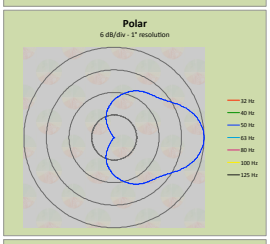
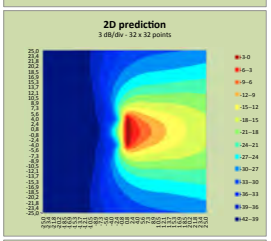
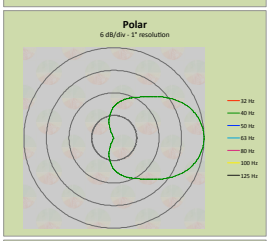
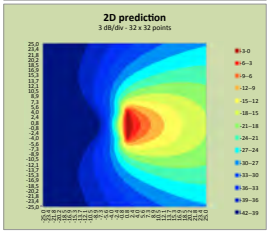
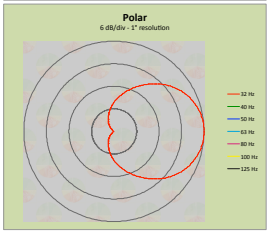
Tutorial 6: delayed horizontal array with cardioid sources

Goals: 1.) even coverage of a 25 by 50 meter audience area (FAR=2 $c_{\angle}$=60°) using 10 cardioid speakers
2.) upper bandwidth limit 100 Hz

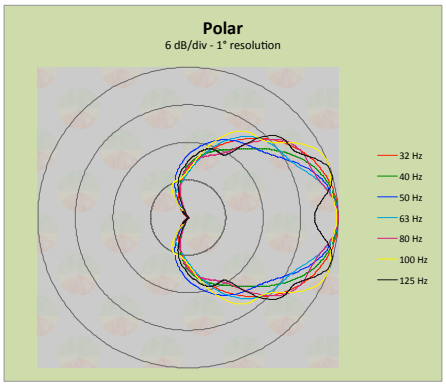
Most parameters are identical to the previous tutorial only the changes will be handled.

Step 2 - select cardioid speaker pattern

SPEAKER PATTERN	2
1. Omni	
horizontal array only	
2. Cardioid	
3. Super-Cardioid	
4. Figure Eight	

frequency	SPL	polar
100 Hz		
80 Hz		
63 Hz		
50 Hz		
40 Hz		
32 Hz		

Step 9 – polar



POLAR CTRL

freq	display	-6 dB	opening angle	relative mic arc
32 Hz	1	44°	88°	47%
40 Hz	1	36°	72°	20%
50 Hz	1	31°	62°	3%
63 Hz	1	38°	76°	27%
80 Hz	1	43°	86°	43%
100 Hz	1	41°	82°	37%
125 Hz	1	46°	92°	53%

normalize all polar	0	for proper angles turn off normalization & filters
normalize range 1. half space 2. full space	1	caution with lobing
filters	0	

The panel shows a consistent coverage of 62° +53%.

The polar for 125 Hz, past our intended bandwidth, shows the onset of pattern breakup indicated by lobing.

Horizontal array closing words:

Two mechanisms govern horizontal arrays with 6 dB or less tonal variation.

- line length, regardless of the amount of speakers
- arc angle

Both parameters affect the -6 dB ONAX point.

One trend however, unsurprisingly, clearly stands out.

> Narrow coverage angles require relatively long line lengths and vice versa.

In other words coverage angle is inversely proportional to line length.

The amount of speakers greatly influences the pattern breakup behavior past the -6 dB ONAX point. A few speakers introduce more extreme behavior than many speakers, provided they physically fit within the line length.

Based on observation the absolute minimum recommended amount of speakers for horizontal arrays is 6, preferably 8 or more.

When dealing with relatively extreme broad coverage angles and in turn short line lengths ergo few speakers, overall power can be restored by stacking abundant speakers vertically. This has the added advantage of increasing vertical directivity.

Reference:

Physical straight arrays

Book:	Elements of Acoustical Engineering, p. 24
Author:	Harry F. Olson, E.E., Ph.D.
Publisher:	D. van Nostrand Company, Inc.
Year:	1940

Physical curved arrays

Book:	Elements of Acoustical Engineering, p. 25
Author:	Harry F. Olson, E.E., Ph.D.
Publisher:	D. van Nostrand Company, Inc.
Year:	1940

Delayed straight arrays

Book:	Acoustical Engineering, p. 36
Author:	Harry F. Olson, Ph.D.
Publisher:	D. van Nostrand Company, Inc.
Year:	1957

End-fired arrays

Book:	Acoustical Engineering, p. 38
Author:	Harry F. Olson, Ph.D.
Publisher:	D. van Nostrand Company, Inc.
Year:	1957

Gradient arrays

AES paper:	Gradient Loudspeakers
Author:	Harry F. Olson
Year:	1972, 43rd AES Convention NY

