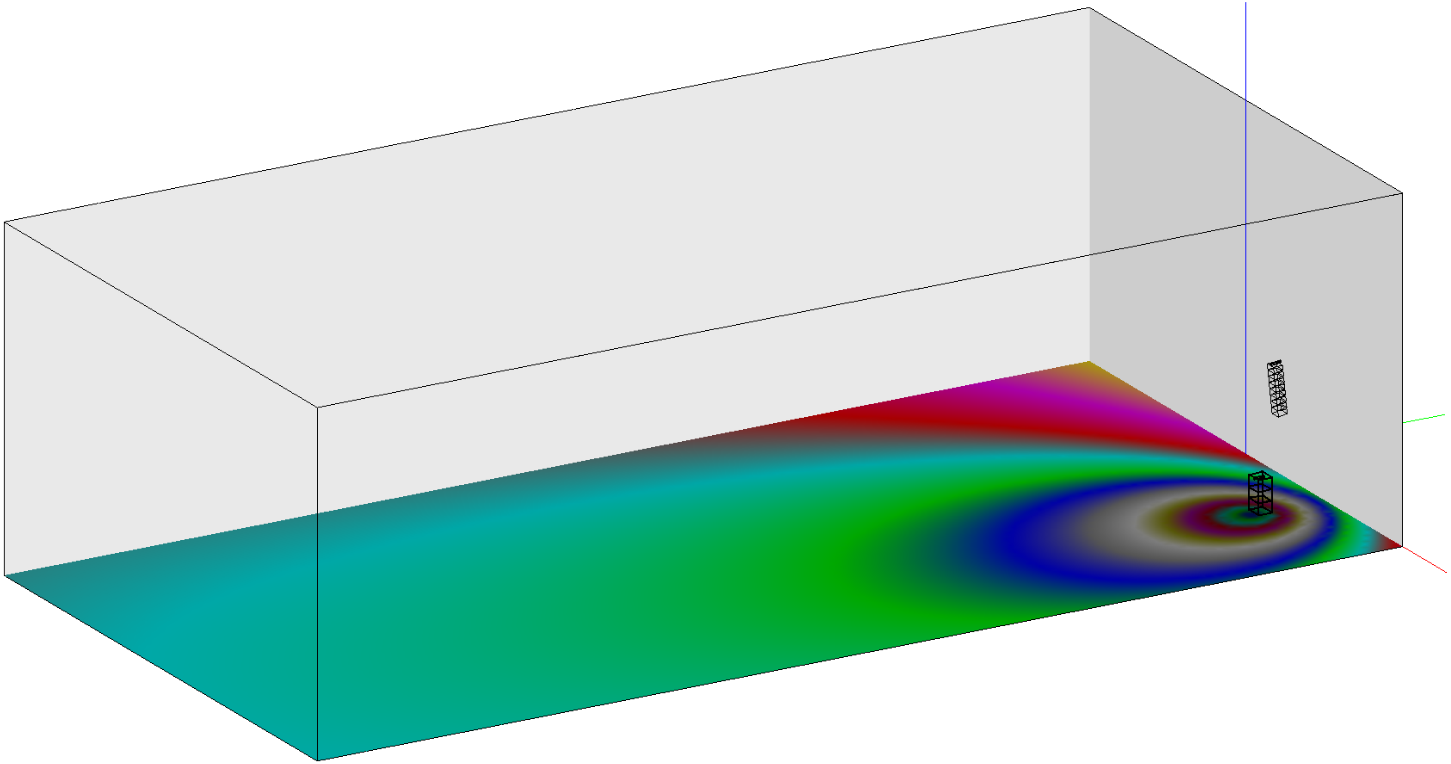
Subwoofer & Full-Range Alignment



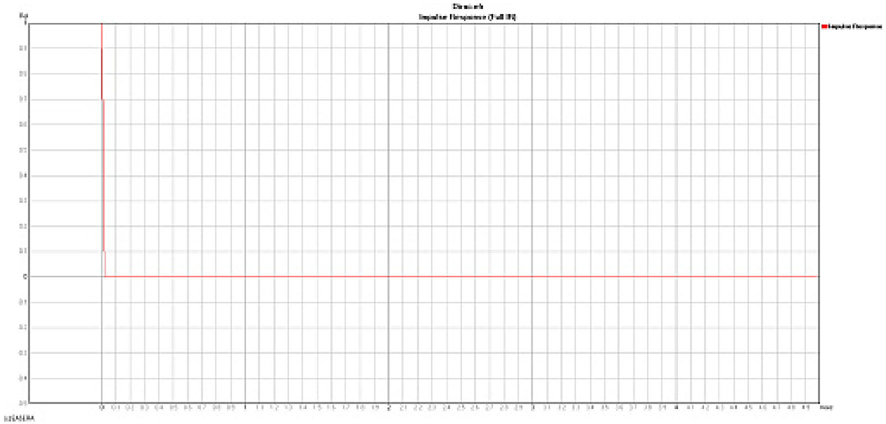
Topics

1) Impulse response of high passed & low passed devices
2) Alignment & misalignment of IRs
3) Arrival time differences
4) Where to put the measurement mic
5) Minimizing response variation through the crossover region at different locations

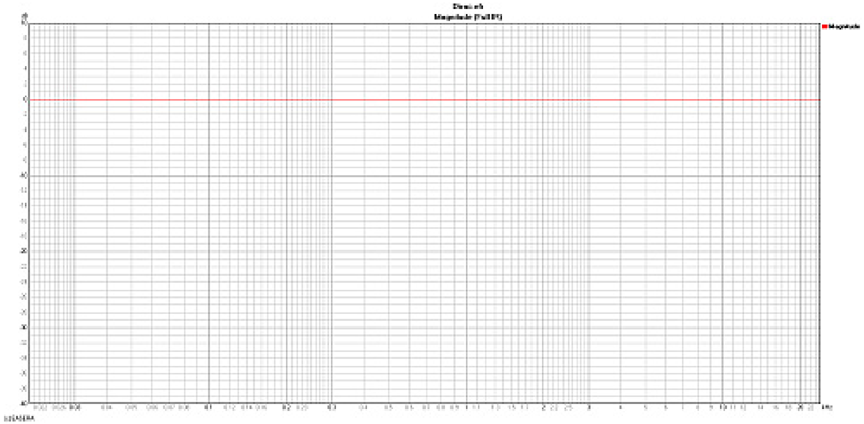
What to Look for in the Impulse Response

Perfect impulse at time t=0

Impulse Response



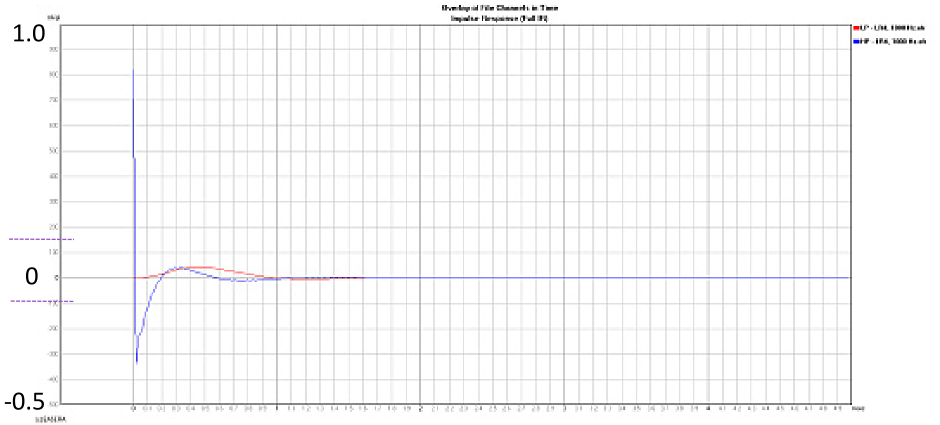
Magnitude Response (Frequency)



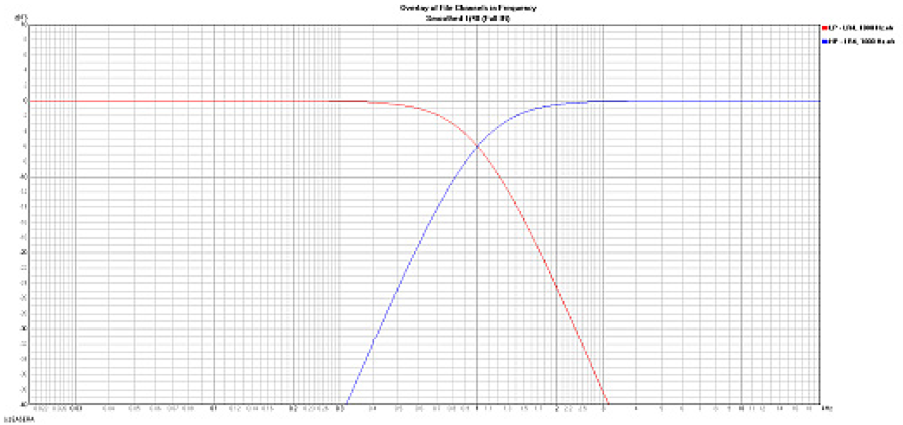
What to Look for in the Impulse Response

Linkwitz-Riley LP & HP Filters – 4^{th} Order, 1 kHz

Impulse Response



Magnitude Response (Frequency)

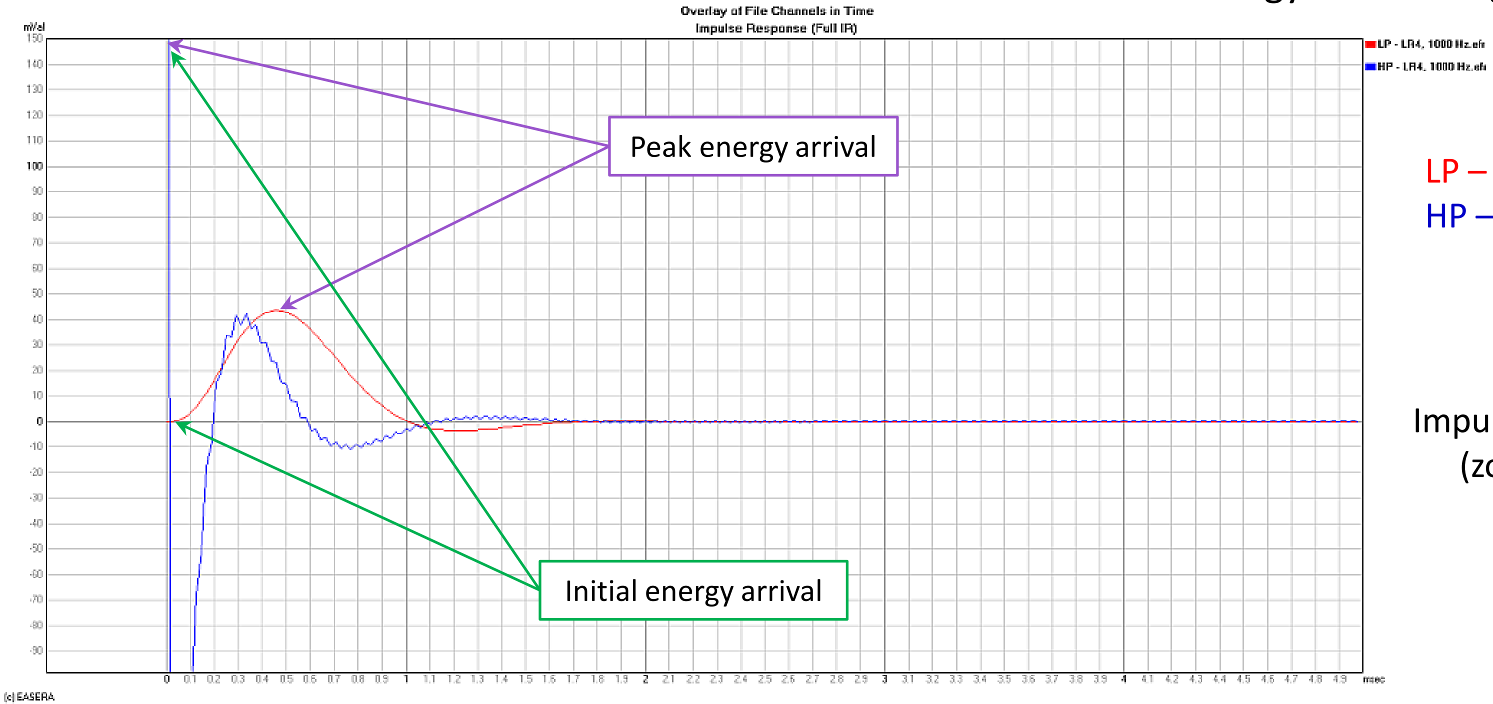


LP – Red; HP – Blue

What to Look for in the Impulse Response

Linkwitz-Riley LP & HP Filters – 4th Order, 1 kHz

Initial energy arrivals aligned



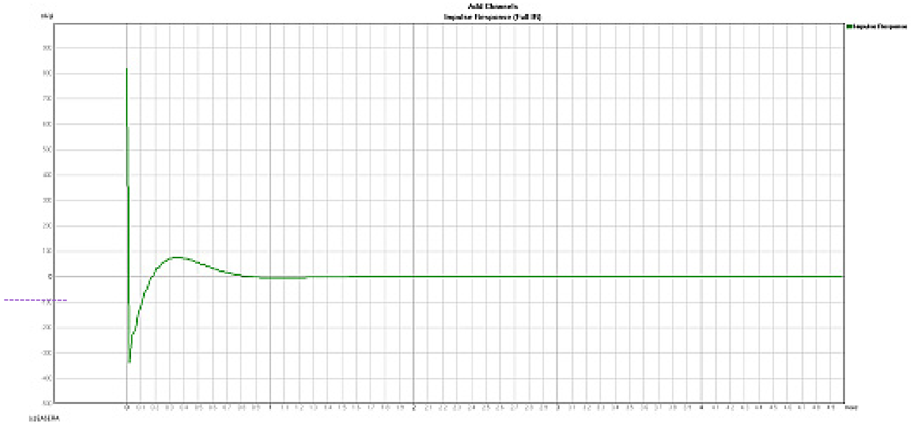
LP – Red
HP – Blue

Impulse Response (zoomed in)

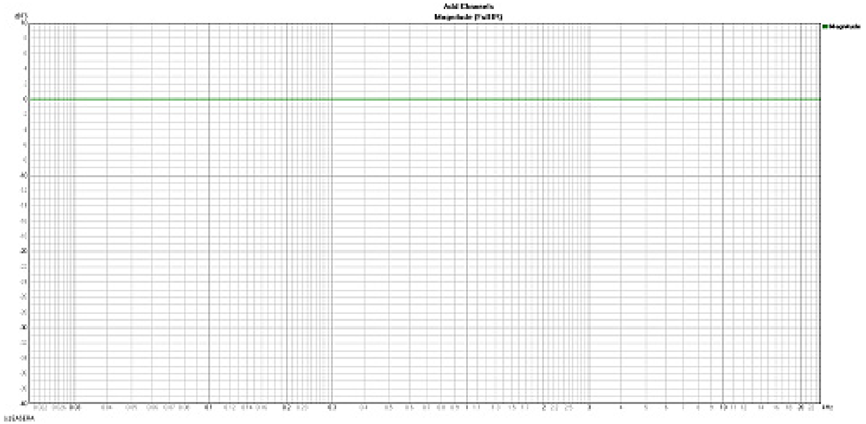
What to Look for in the Impulse Response

Summation of Linkwitz-Riley LP & HP Filters – 4th Order, 1 kHz

Impulse Response



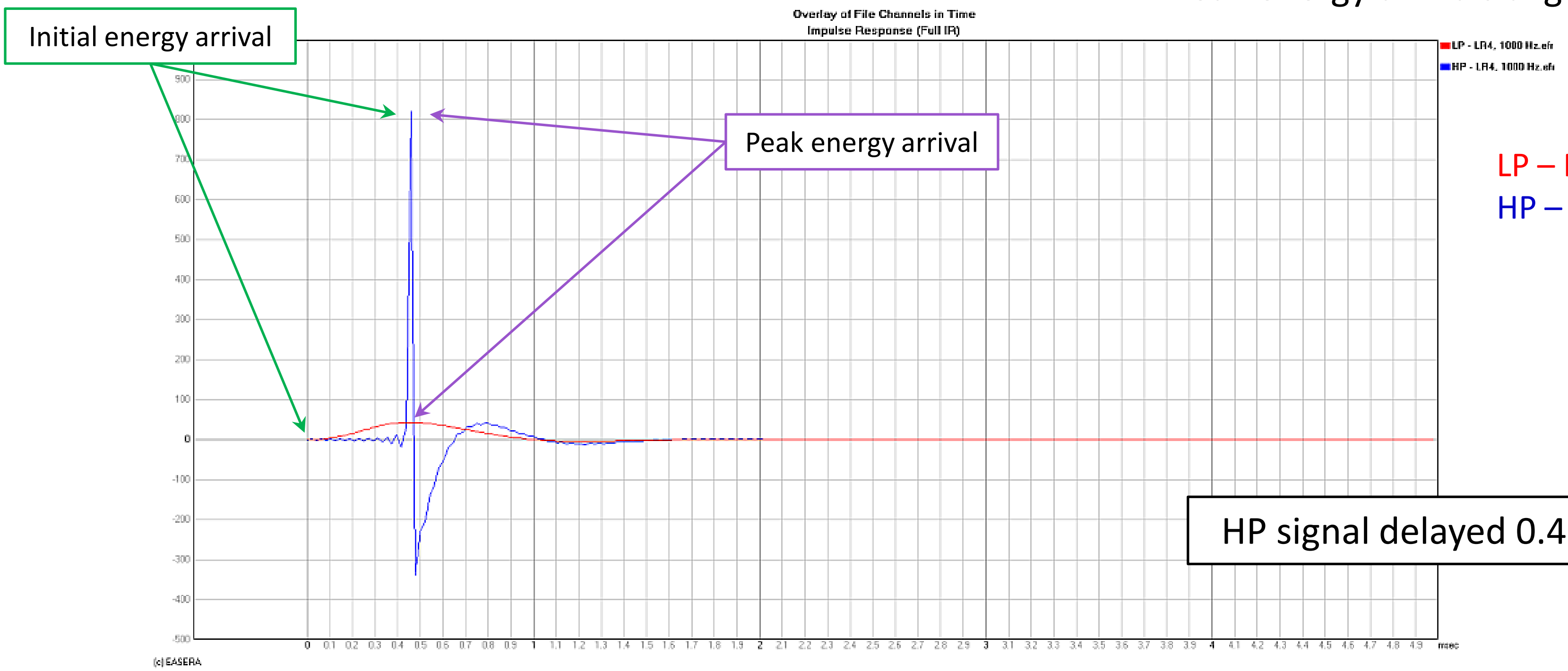
Magnitude Response (Frequency)



What to Look for in the Impulse Response

Linkwitz-Riley LP & HP Filters – 4th Order, 1 kHz

Peak energy arrivals aligned



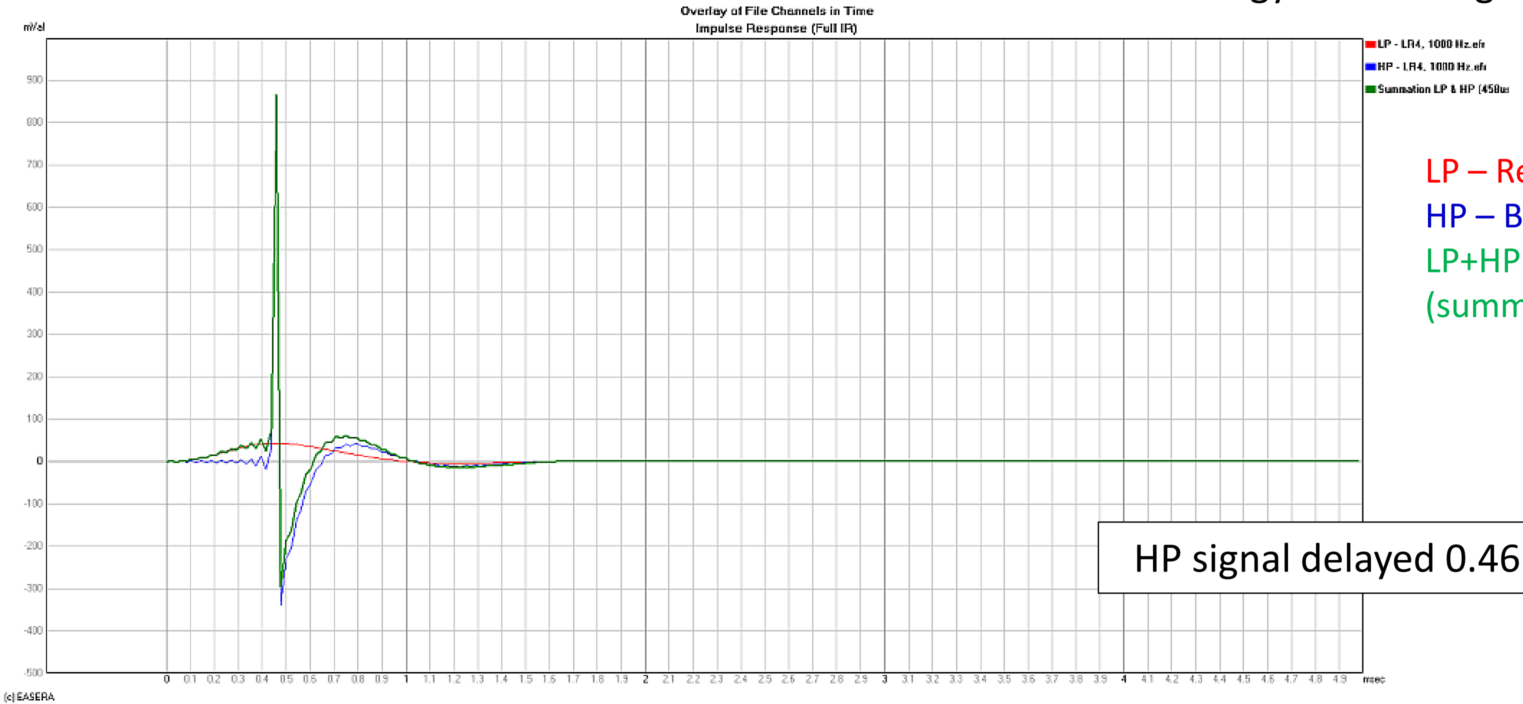
LP – Red
HP – Blue

HP signal delayed 0.46 ms

What to Look for in the Impulse Response

Linkwitz-Riley LP & HP Filters – 4th Order, 1 kHz

Peak energy arrivals aligned



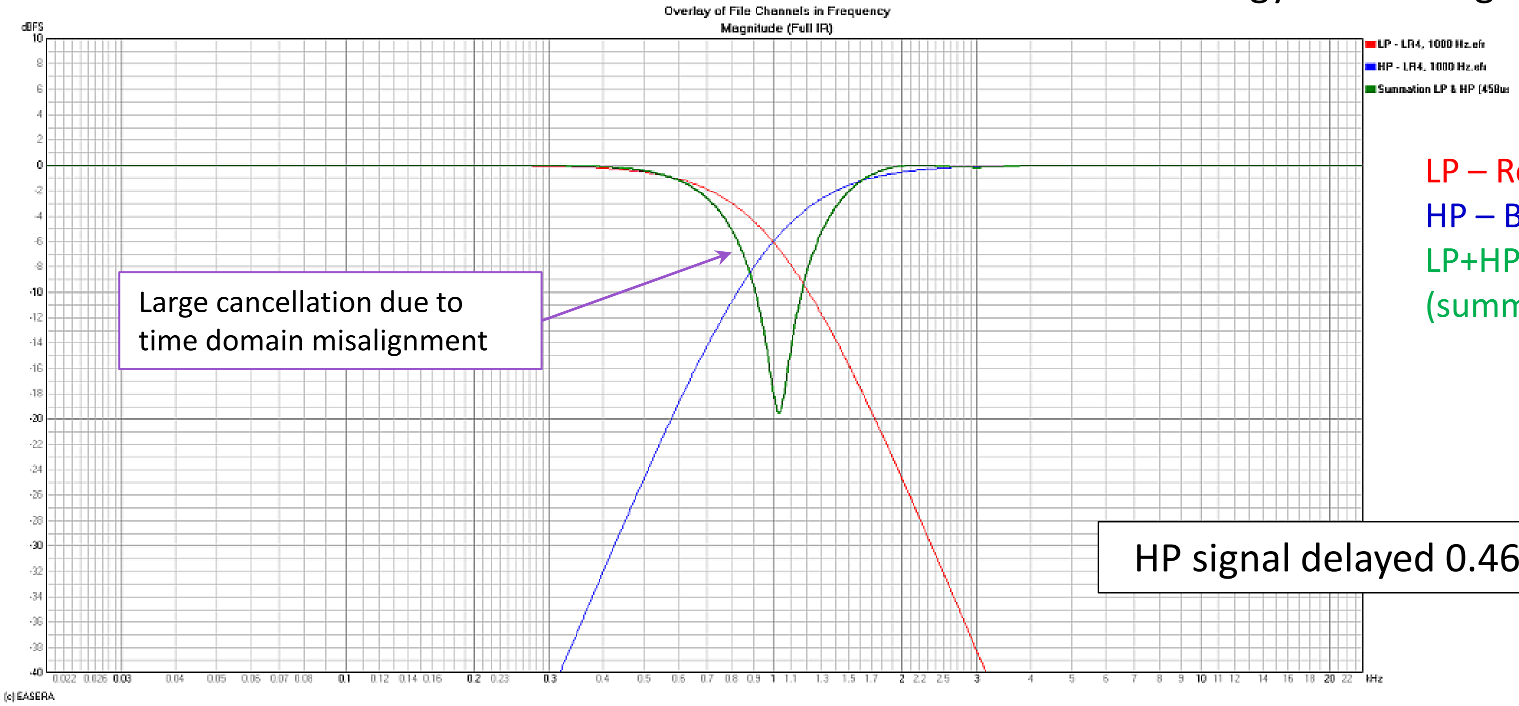
LP – Red
HP – Blue
LP+HP – Green (summation)

HP signal delayed 0.46 ms

What to Look for in the Impulse Response

Linkwitz-Riley LP & HP Filters – 4th Order, 1 kHz

Peak energy arrivals aligned



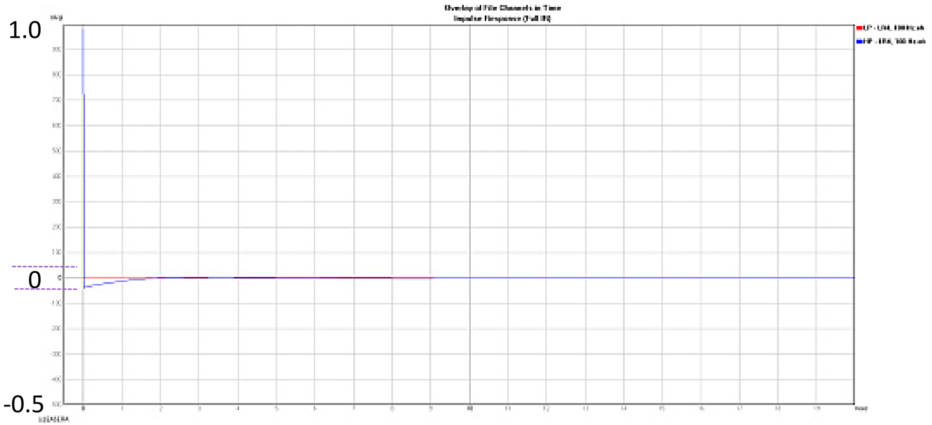
LP – Red
HP – Blue
LP+HP – Green (summation)

HP signal delayed 0.46 ms

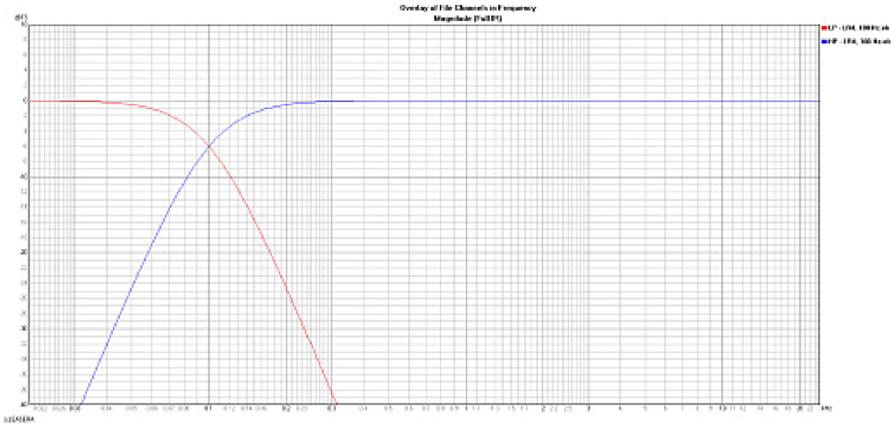
What to Look for in the Impulse Response

Linkwitz-Riley LP & HP Filters – 4^{th} Order, 100 Hz

Impulse Response



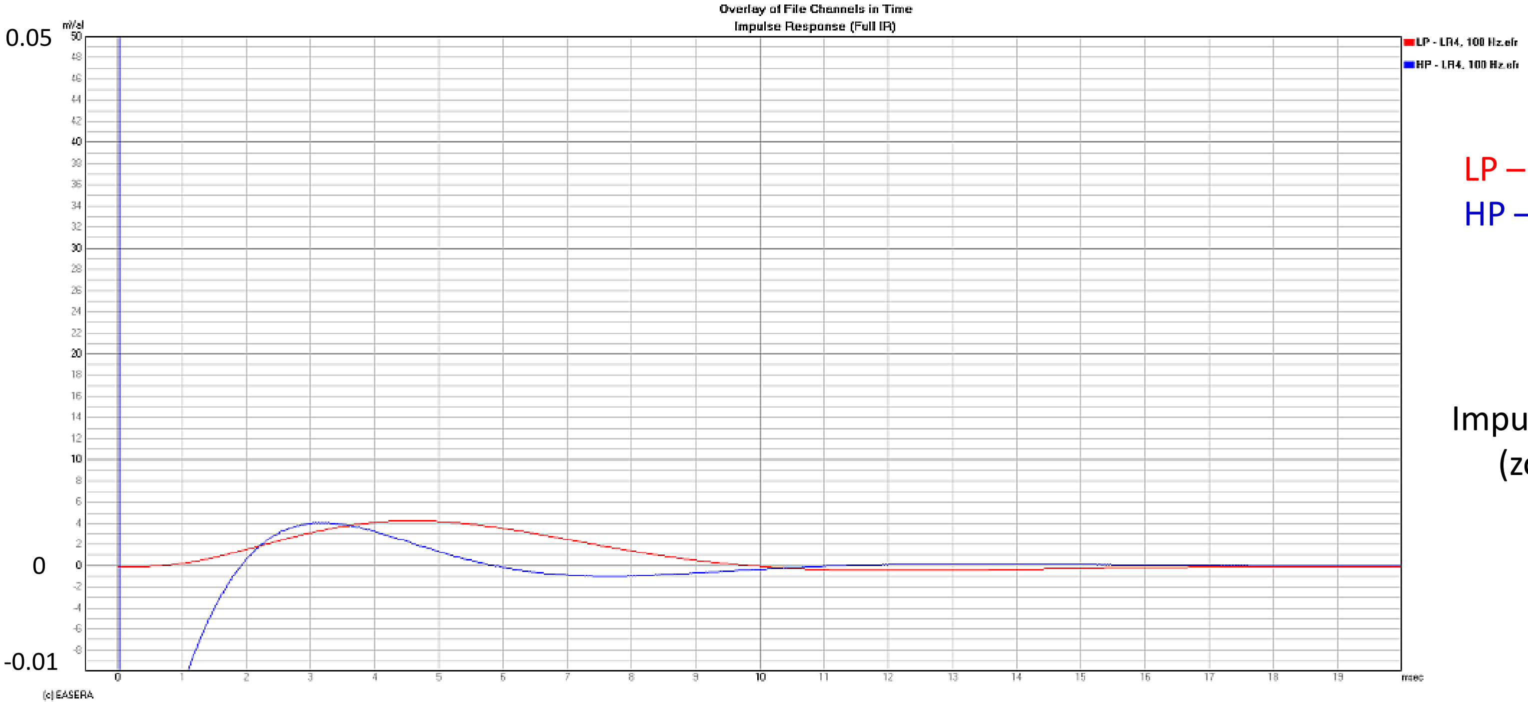
Magnitude Response (Frequency)



LP – Red; HP – Blue

What to Look for in the Impulse Response

Linkwitz-Riley LP & HP Filters – 4th Order, 100 Hz



LP – Red

HP – Blue

Impulse Response (zoomed in)

Measurement & Determining Arrival Time

It can help to allow as much HF energy output from the subwoofer as possible

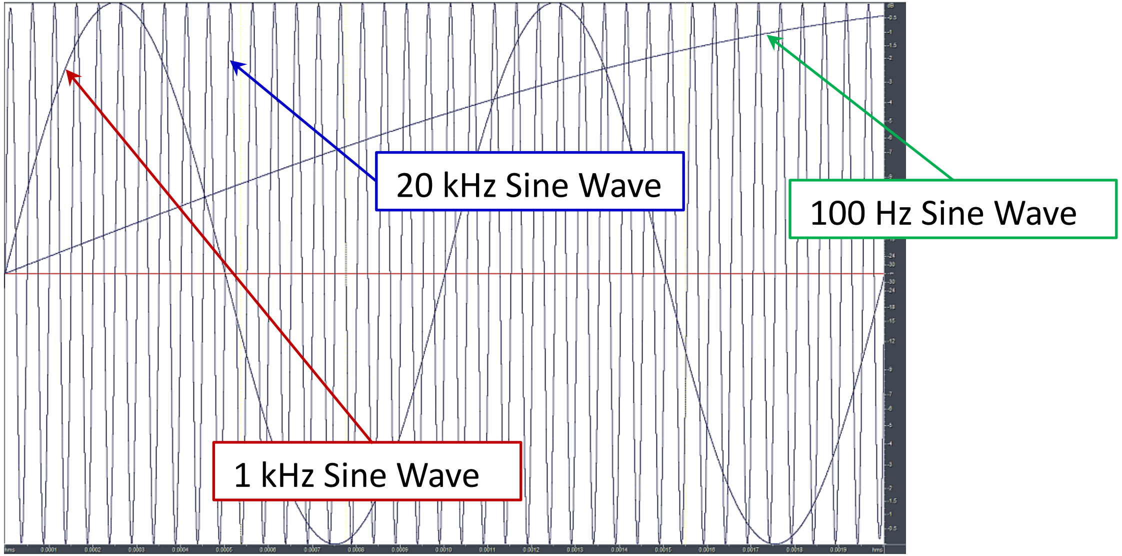
- Disengage LP filter or raise it to a very high frequency
- More HF energy in the signal from a device increases our ability to resolve smaller time increments, $\Delta t = 1/\Delta f$

Period = 1/frequency

P_{20kHz} = 0.05 ms

P_{1kHz} = 1.0 ms

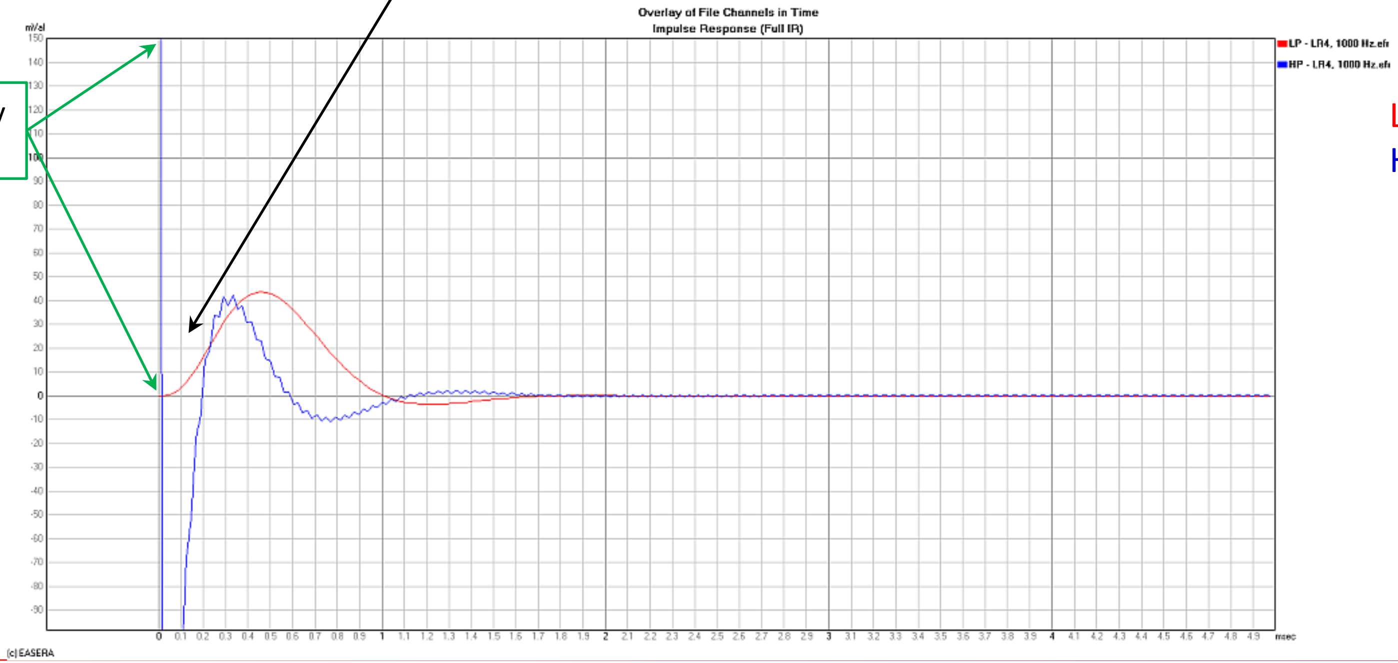
P_{100Hz} = 10 ms



Measurement & Determining Arrival Time

Apparent time gap in the LP response is not due to a pure, broadband delay but rather a lack of high frequency energy content and the necessary phase shift of the low frequency energy content

Initial energy arrival

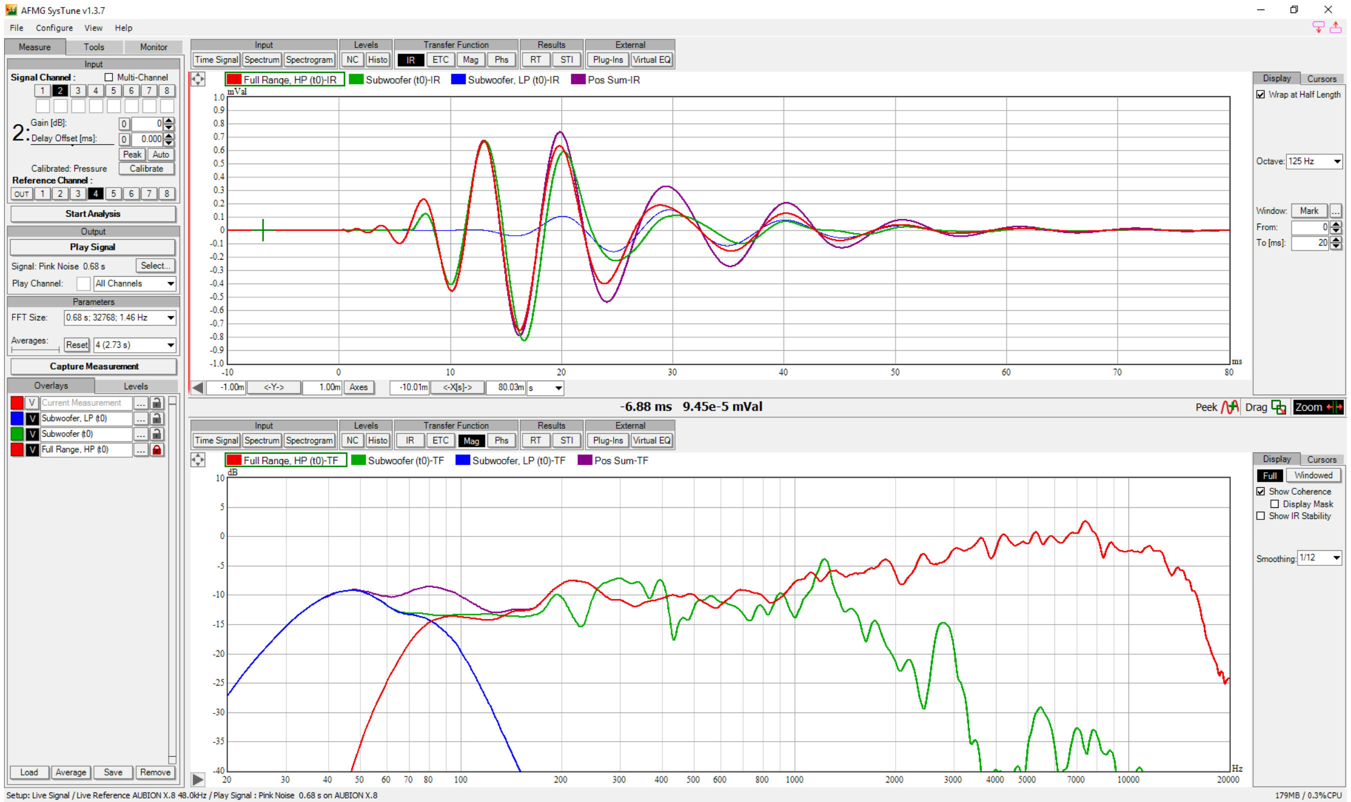


LP – Red

HP – Blue

Measurement & Determining Arrival Time

Time Alignment in SysTune



Goals for Arrival Time

Energy from adjacent pass bands (Subs & Full-Range) need to arrive at the listener at the same time

Ideally, locate the Subs and the Full-Range units very close to each other to minimize arrival time differences

1) **All Ground Stacked**

   In many situations this is not desirable for audience coverage and other reasons

2) **All Flown**

   While possible, and can yield very good results, it may not always be practical due to size and weight constraints

→ 3) **Flown Full-Range and Ground Stacked Subs** ←

   Very commonly seen configuration
   Worse case for timing differences

Goals for Arrival Time

Energy from adjacent pass bands (Subs & Full-Range) need to arrive at the listener at the same time

Physically separated Subs and Full-Range

Less than 1 dB variation

Adjacent pass bands must not be out-of-phase by more than 55°

At 100 Hz this is 1.53 ms

→ **Less than 2 dB variation** ←

Adjacent pass bands must not be out-of-phase by more than 75°

At 100 Hz this is 2.08 ms *At 112 Hz this is 1.86 ms*

Less than 3 dB variation

Adjacent pass bands must not be out-of-phase by more than 90°

At 100 Hz this is 2.50 ms

Note: Above the crossover frequency the outputs from the filters are within 10 dB of each other and the wavelengths/periods are shorter. Arrival time constraints must be based on slightly higher frequency. For the Linkwitz-Riley 4th order response in our example this will be approximately 1/6 octave.

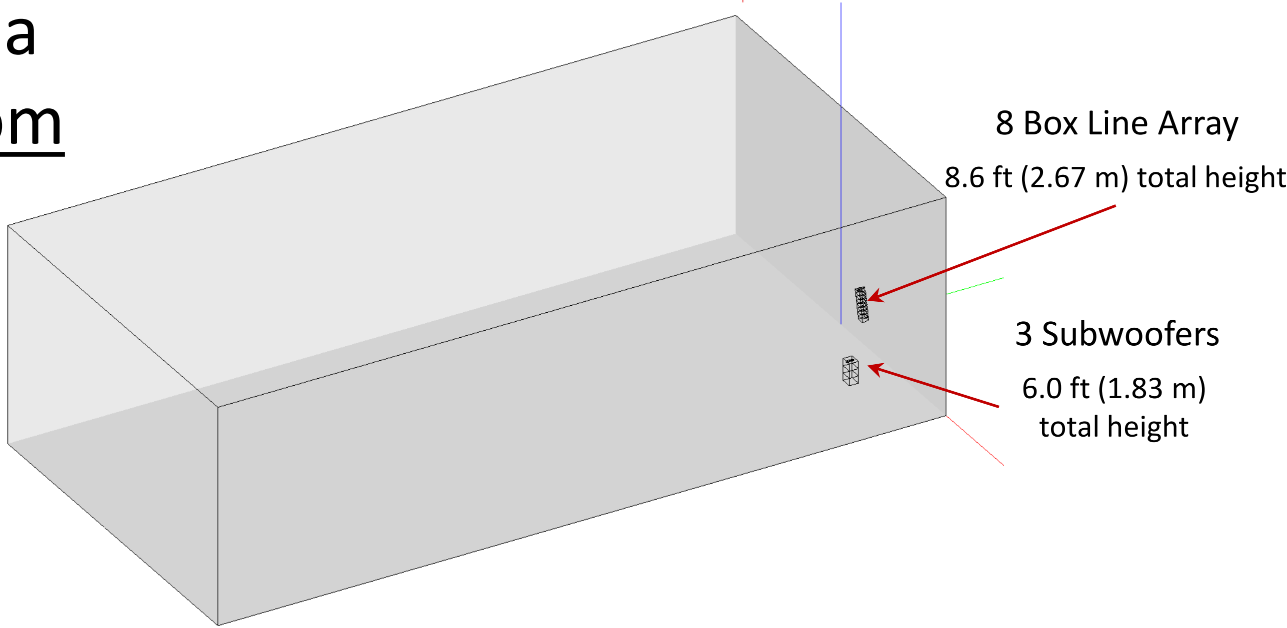
Recap & Putting It All Together

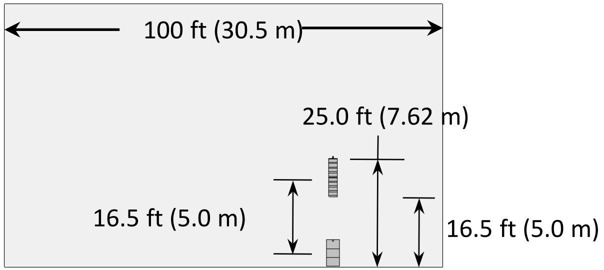
1) We know that to properly align devices we must align the initial energy arrivals, not the peak energy arrivals.

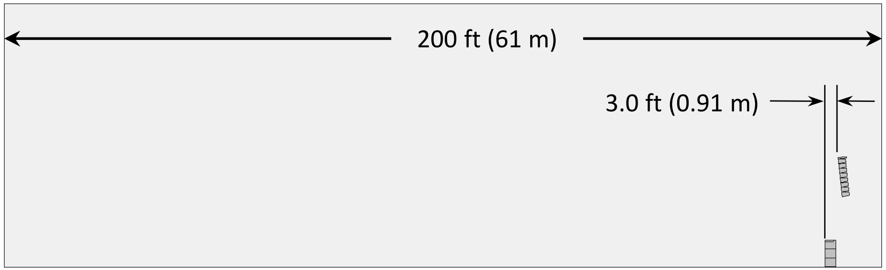
2) We know what to look for to determine the initial energy arrival time from full-range and low frequency band-limited loudspeakers.

3) We have a criterion for maximum arrival time variation (time domain) from separated sources in order to keep the overall response variation (frequency domain) below a selected level.

Example System in a Non-Reflective Room

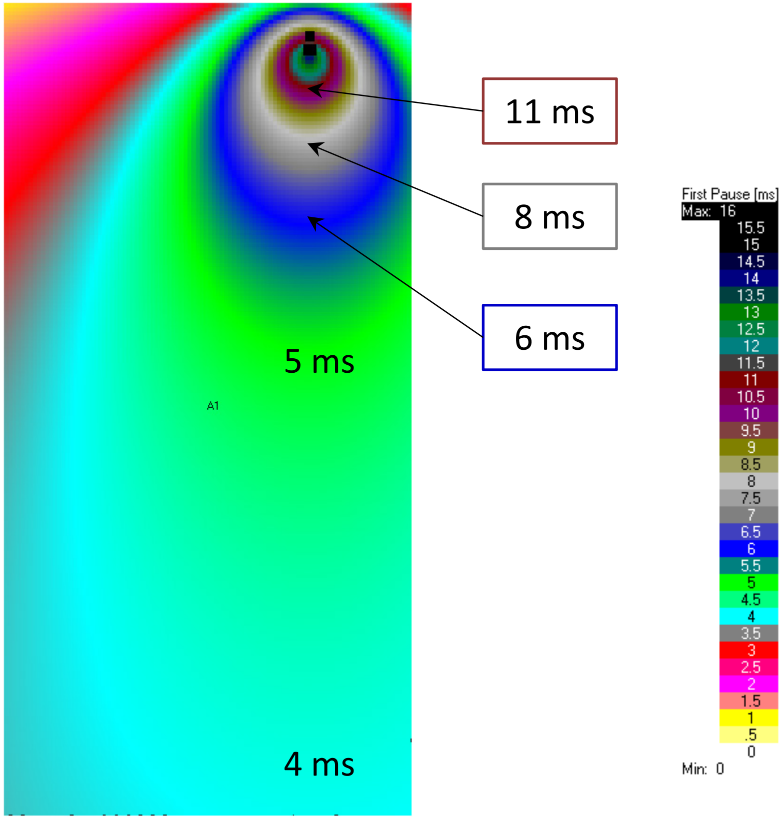






Arrival Time Difference Map

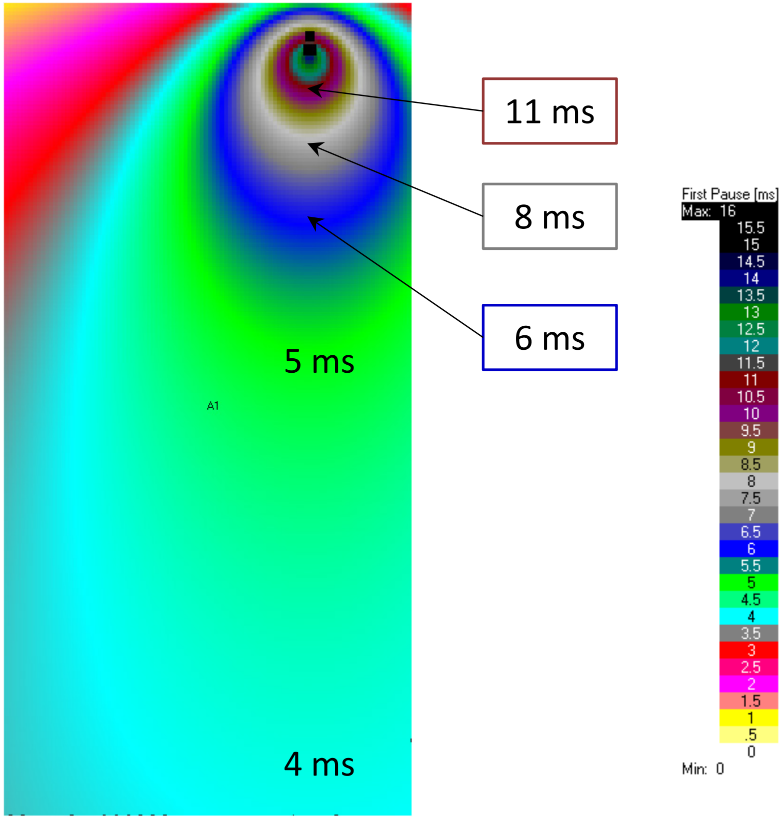
For the majority of the audience area the arrival time difference ranges from 4 to 10 ms (> 90% of house-right)



For 2 dB Summation Uniformity

For this example, the smallest arrival time difference is in the back of the room.

1) Look at the area(s) of smallest arrival time difference
2) Delay the first signal arrival by this time plus 2 ms (approx. 6 ms)
3) Examine new arrival time differences

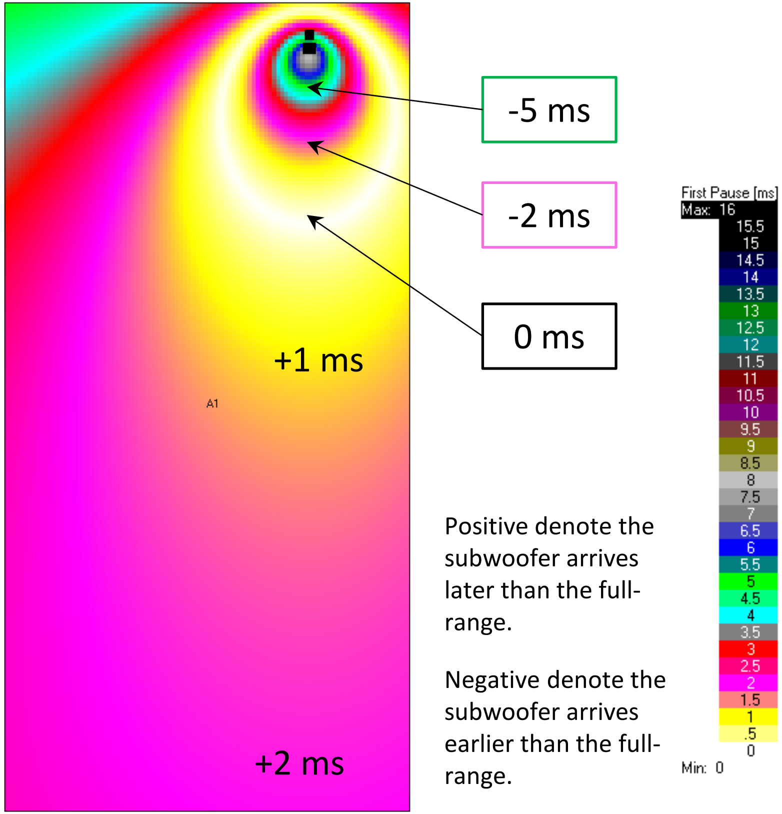


For 2 dB Summation Uniformity

Subs Delayed 6 ms

For this example, the smallest arrival time difference is in the back of the room.

1) Look at the area(s) of smallest arrival time difference
2) Delay the first signal arrival by this time plus 2 ms (approx. 6 ms)
3) Examine new arrival time differences
   a) Areas greater than 1.9 ms (75°) will vary by more than 2 dB
   b) Areas greater than 2.3 ms (90°) will vary by more than 3 dB

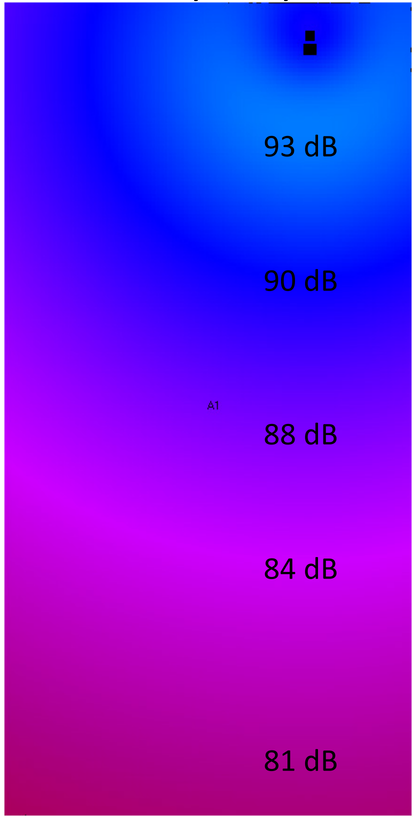


Positive denote the subwoofer arrives later than the full-range.

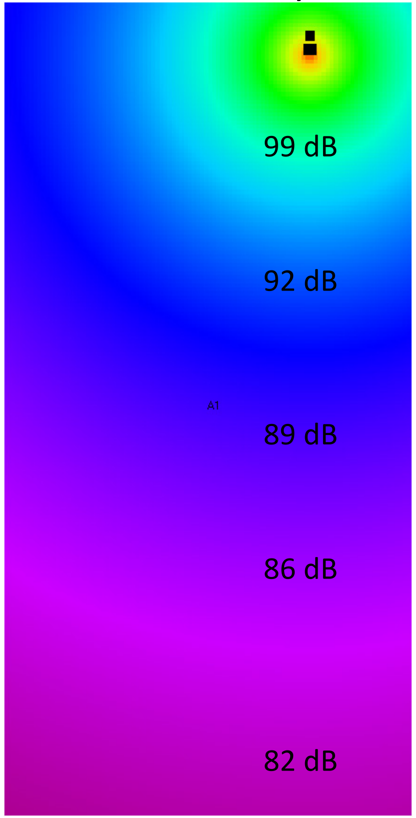
Negative denote the subwoofer arrives earlier than the full-range.

SPL Map – 100 Hz

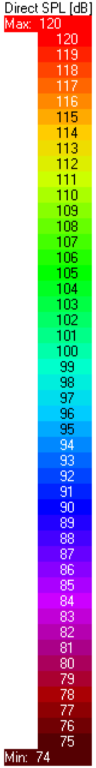
Array Only



Subs Only

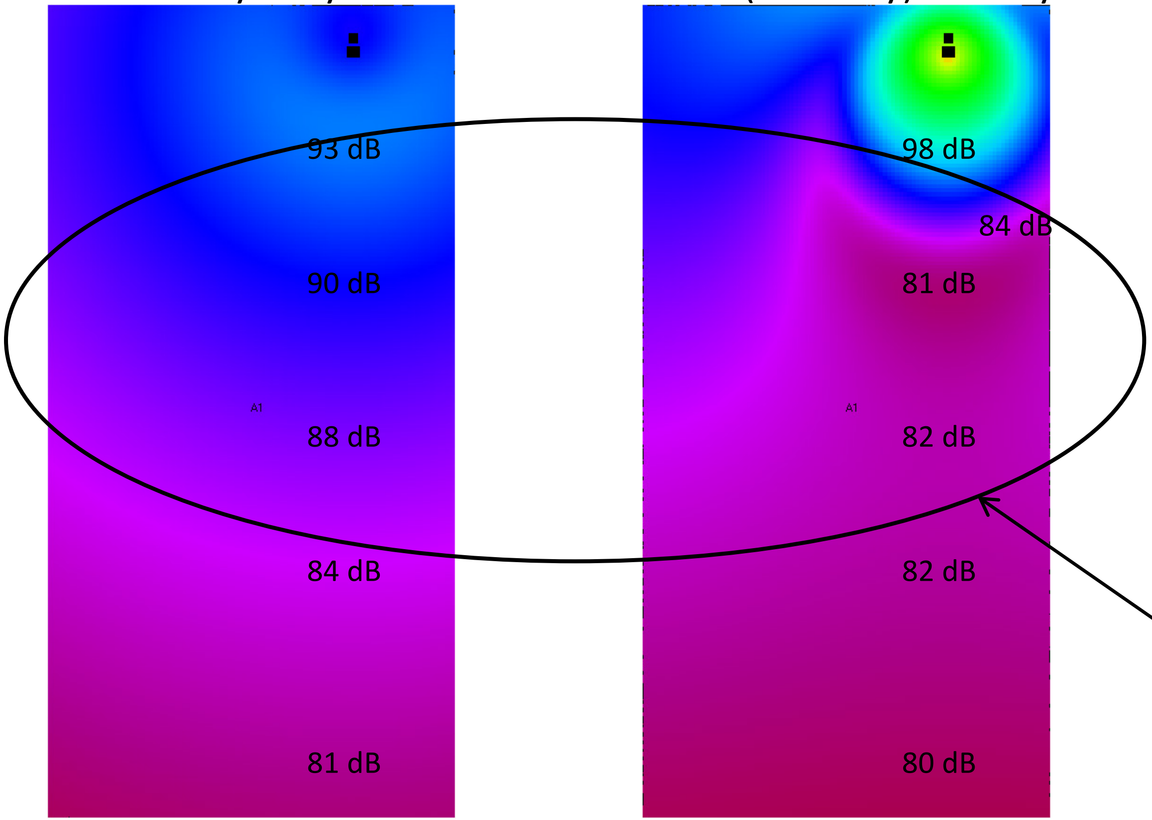


No LP or HP filters applied



SPL Map – 100 Hz

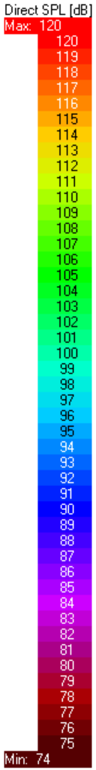
Array Only | Subs (no delay) & Array*



*Using 100 Hz Linkwitz-Riley filters, no delay on Subs

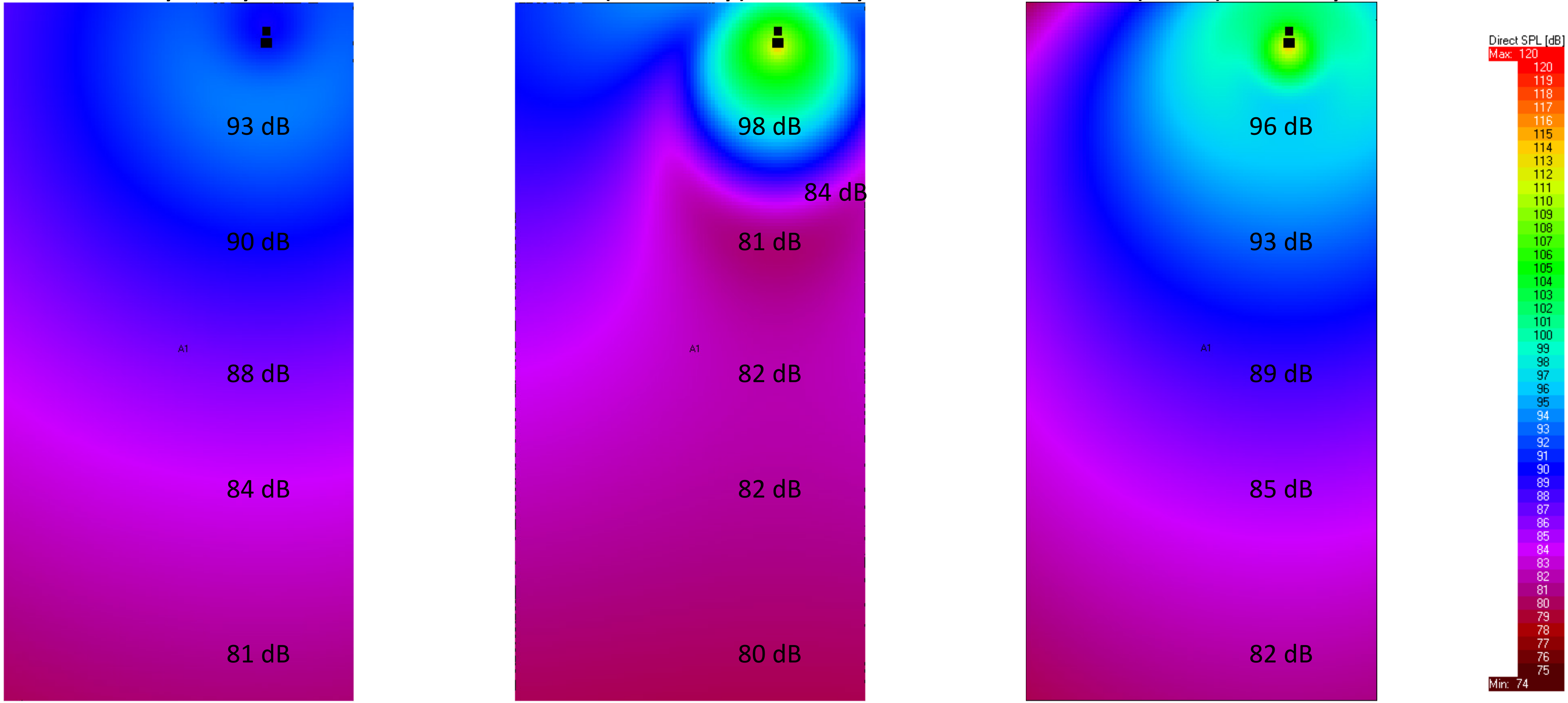
This would be very similar to aligning the peak arrivals of the loudspeakers and applying 4th order Linkwitz-Riley filters to them without taking their inherent response into account

Cancellations of 6 – 11 dB over a large area

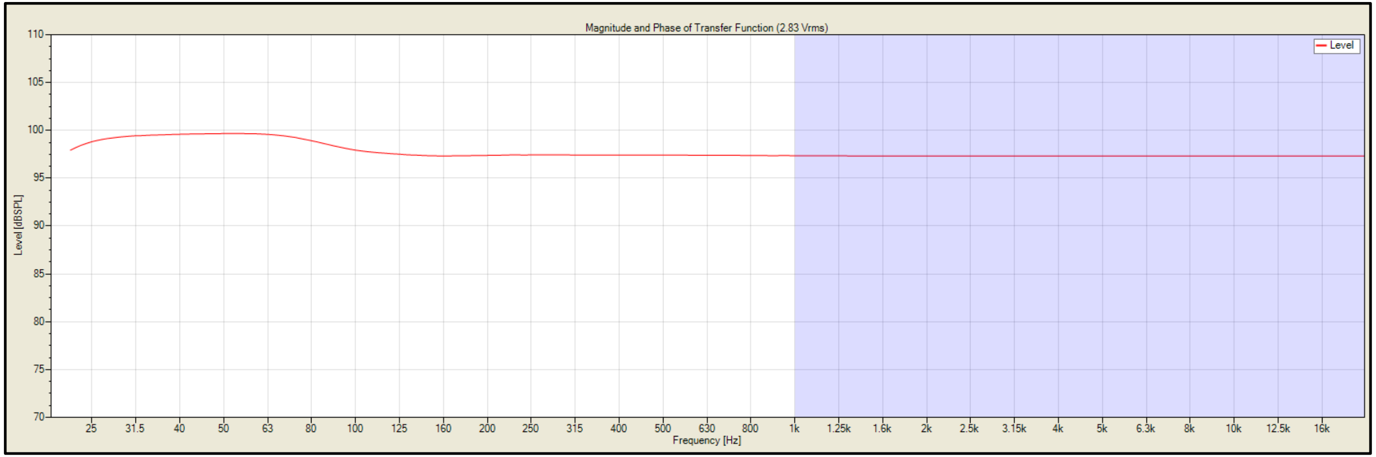


SPL Map – 100 Hz

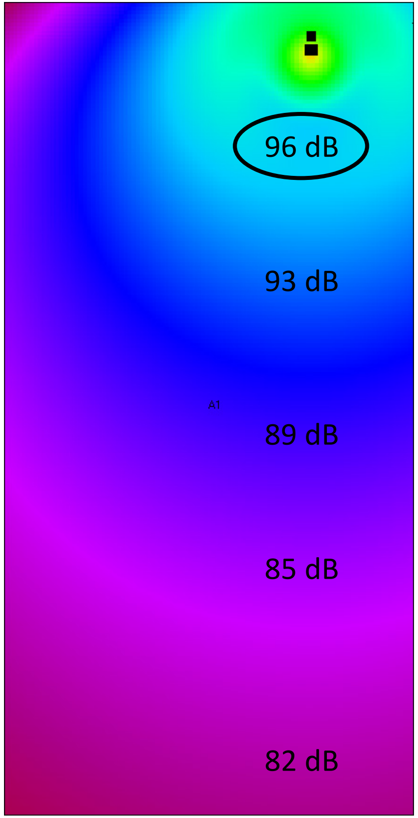
Array Only | Subs (no delay) & Array* | Alignment Method Subs (6 ms) & Array



SPL Map (100 Hz & Frequency Response)

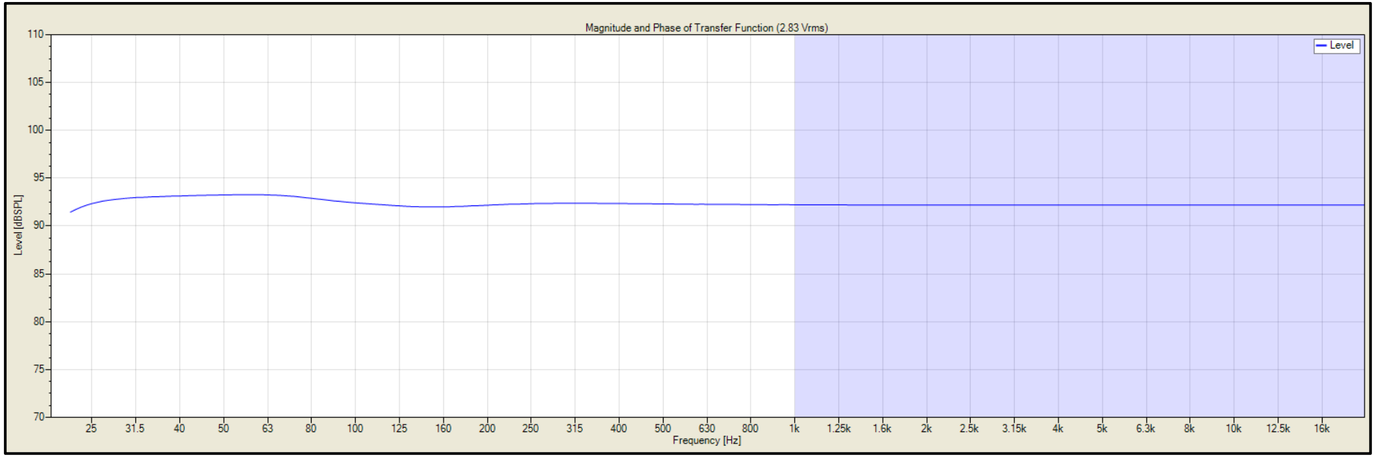


Frequency Response at Location 1

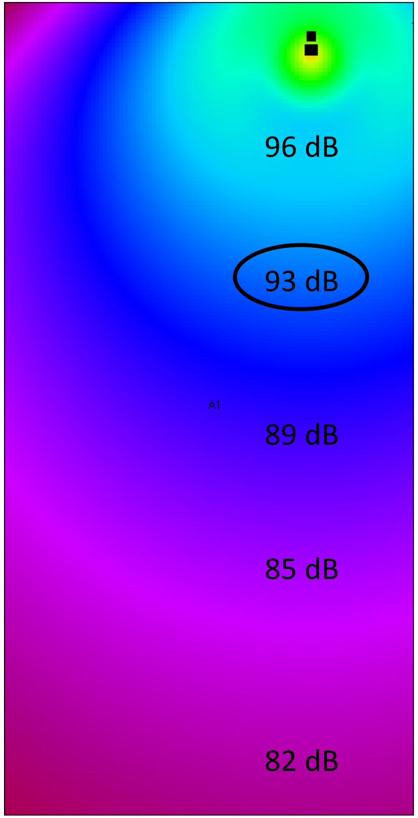


Note increased SPL below 125 Hz due to being much closer to ground-stacked subs than flown array

SPL Map (100 Hz & Frequency Response)

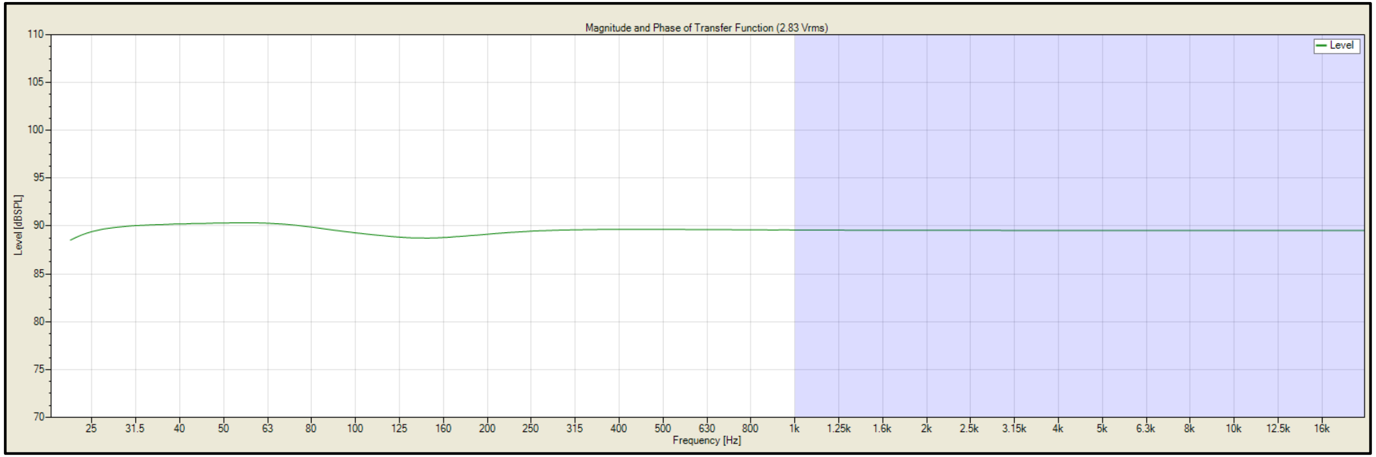


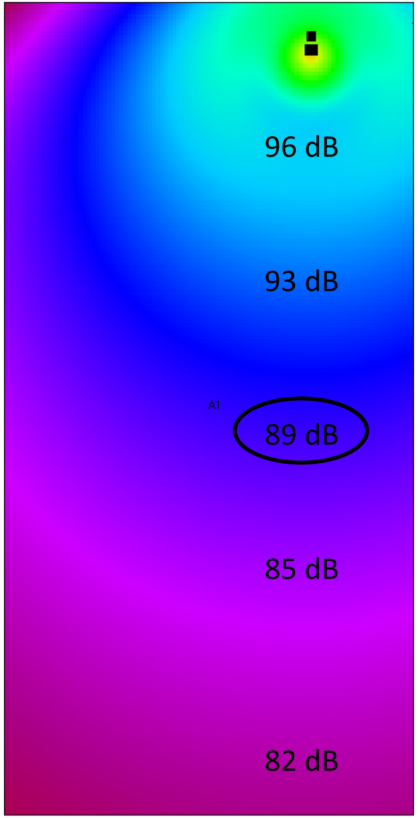
Frequency Response at Location 2



Slightly increased SPL below 100 Hz due to being closer to ground-stacked subs than flown array

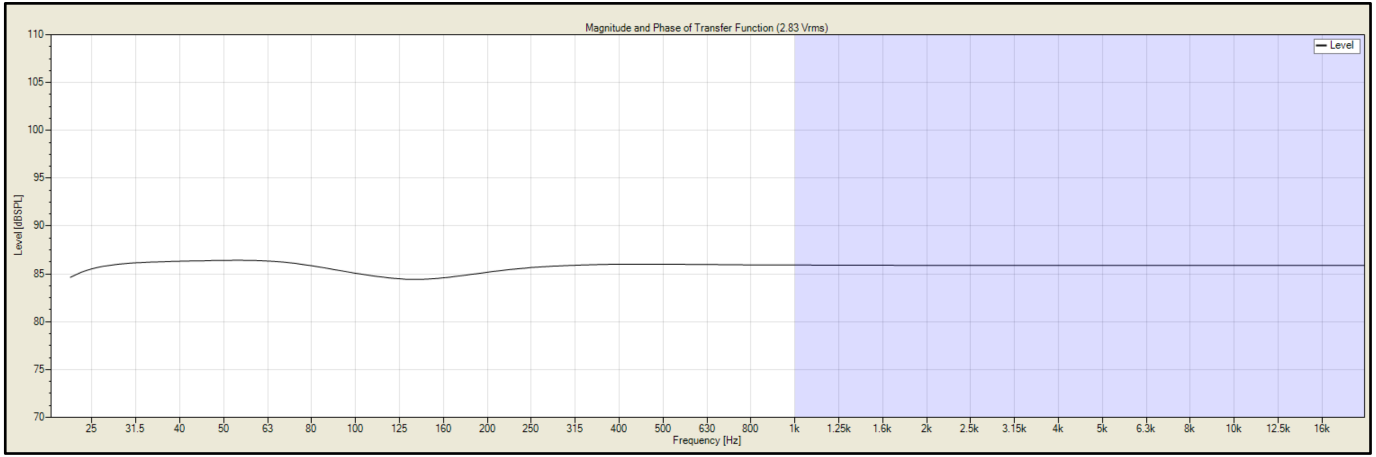
SPL Map (100 Hz & Frequency Response)



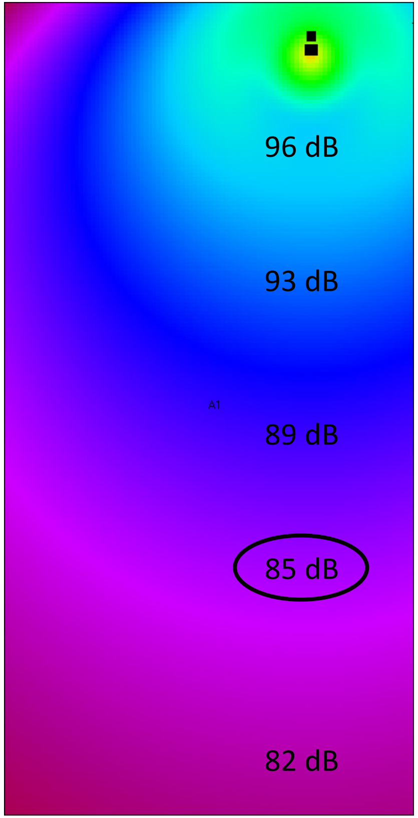


Frequency Response at Location 3

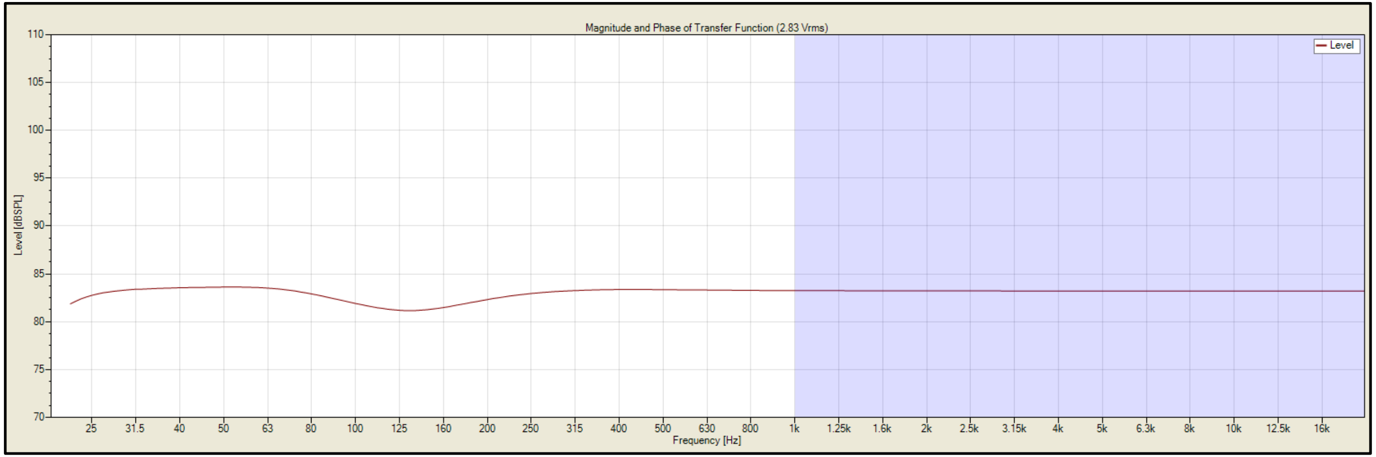
SPL Map (100 Hz & Frequency Response)



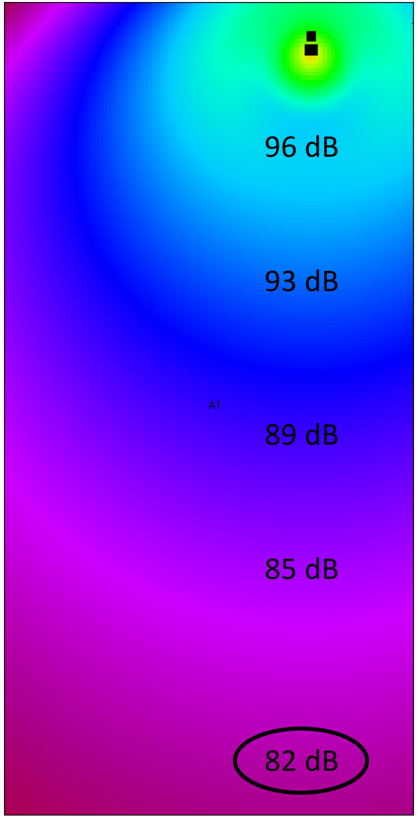
Frequency Response at Location 4



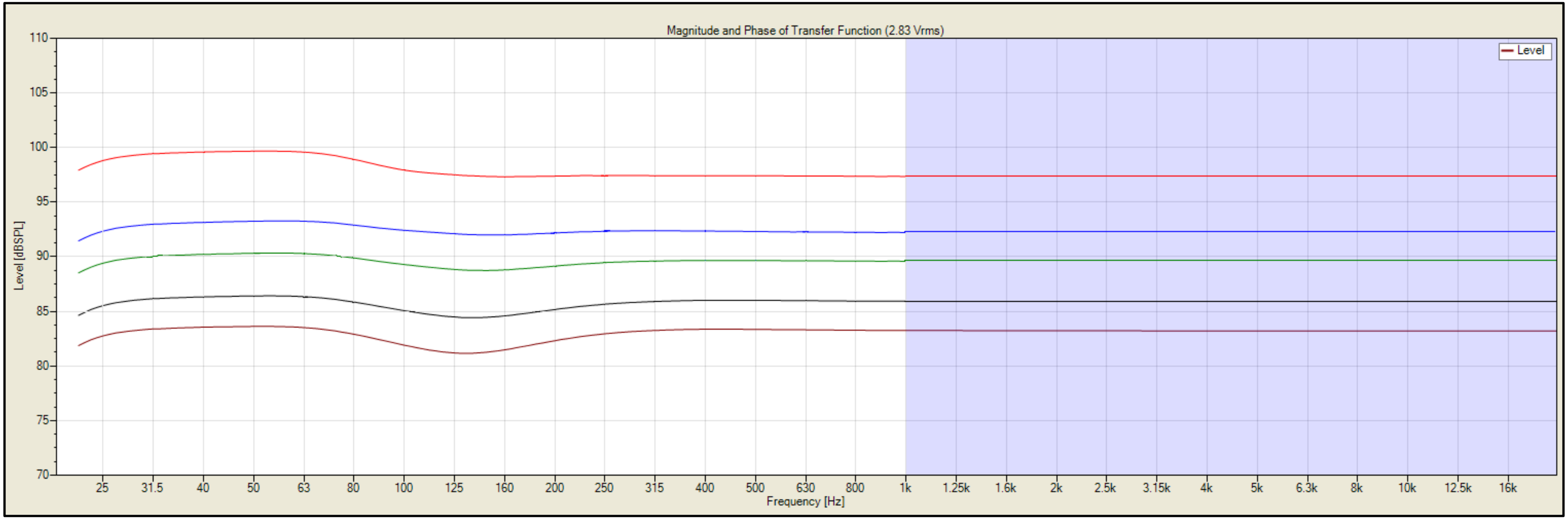
SPL Map (100 Hz & Frequency Response)



Frequency Response at Location 5



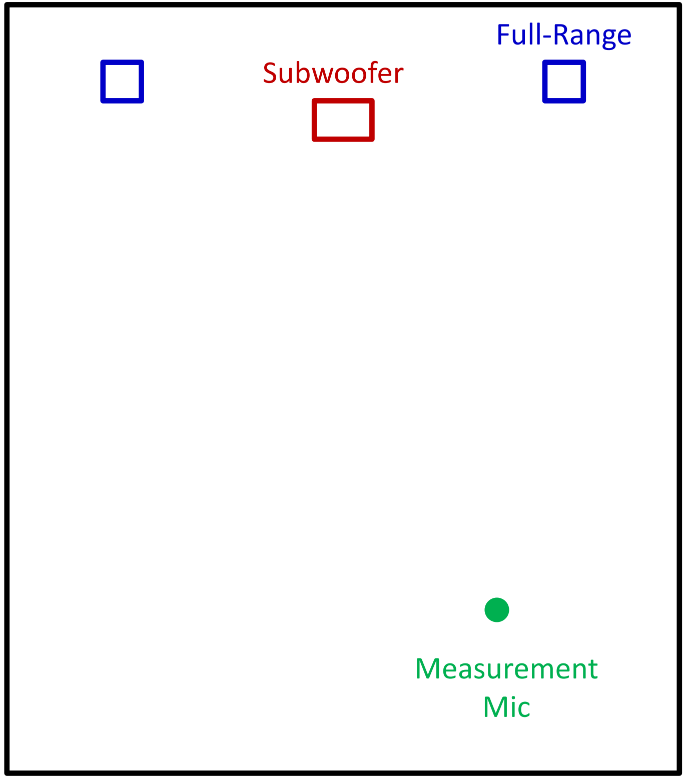
Frequency Response



Very even coverage and response with no more than 2 dB deviation in the crossover region

Increased SPL below 125 Hz at Location 1 is due to being much closer to ground-stacked subs than flown array

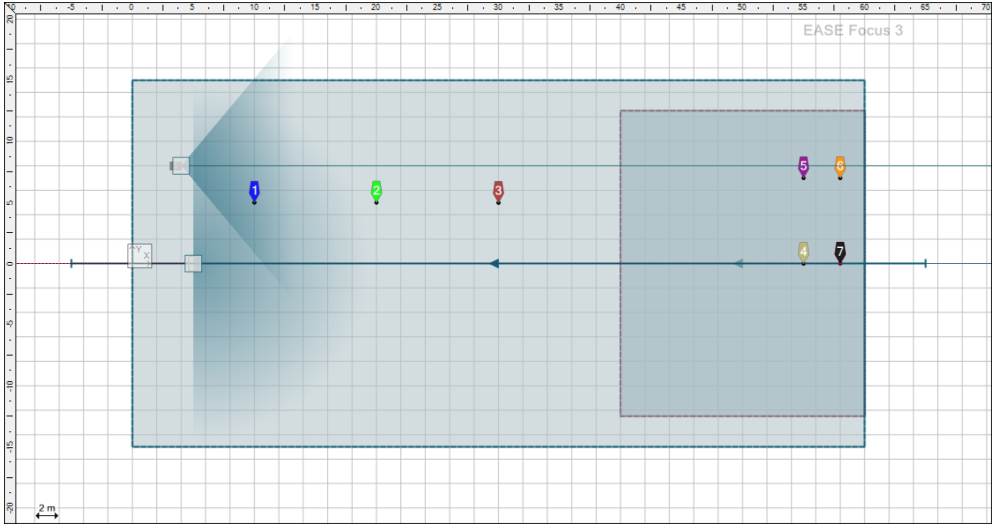
Horizontal Offset Between Devices

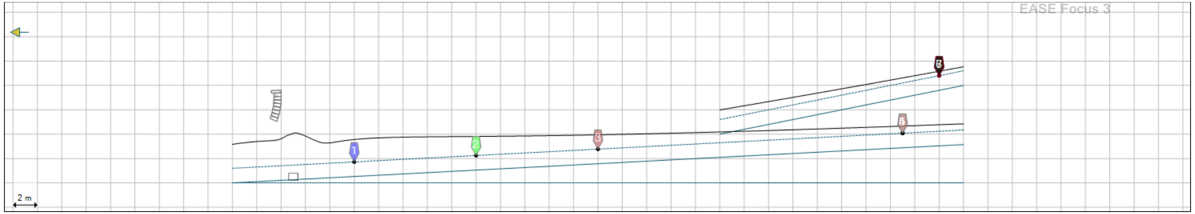


We learned from the example of vertically offset loudspeakers that the measurement mic needs to be where the difference in the arrival time has the smallest value.

Apply the same principal to the horizontal location of the measurement mic.

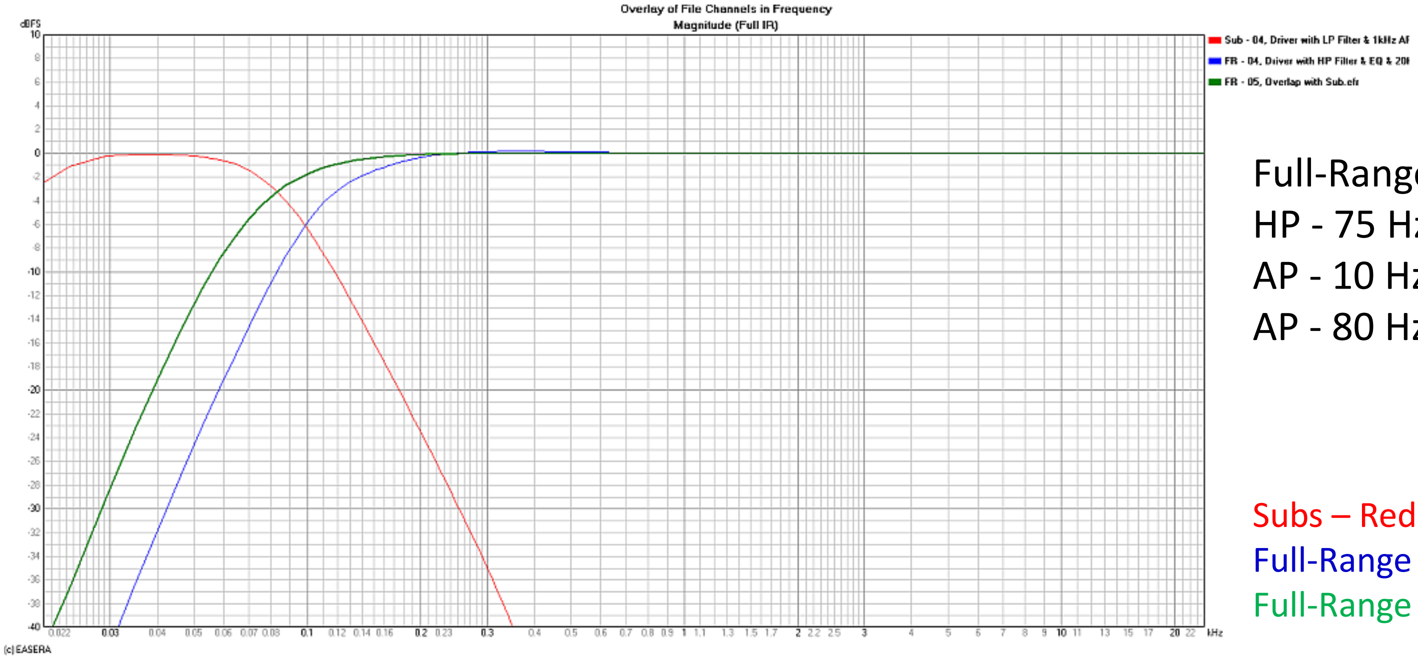
Modeling & Investigation with Focus 3





Full-Range Overlapping Subs

Extending LF output of full-range array to overlap the output from the subs



Full-Range new filtering:

HP - 75 Hz, 2nd order Butterworth

AP - 10 Hz, 1st order

AP - 80 Hz, 1st order

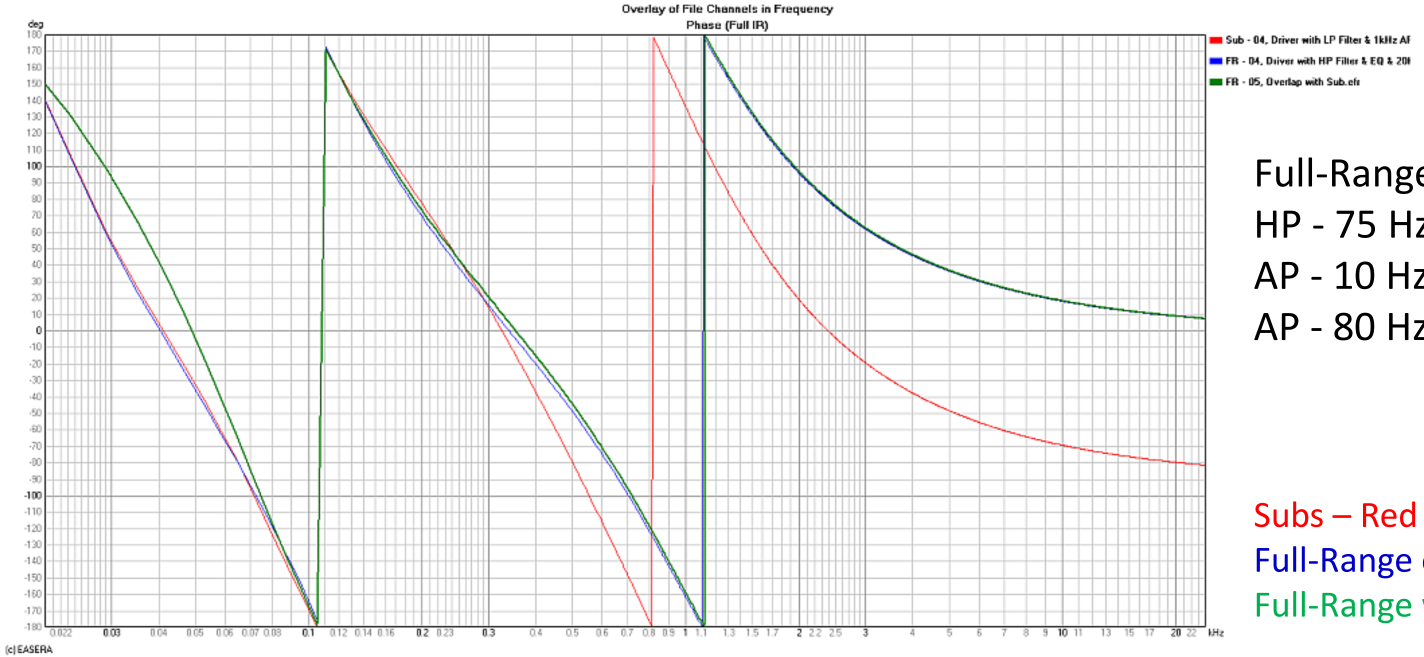
Subs – Red

Full-Range original filtering– Blue

Full-Range with new filtering– Green

Full-Range Overlapping Subs

We must still maintain matching phase response of the subs & the full-range system through the crossover region



Full-Range new filtering:

HP - 75 Hz, 2nd order Butterworth

AP - 10 Hz, 1st order

AP - 80 Hz, 1st order

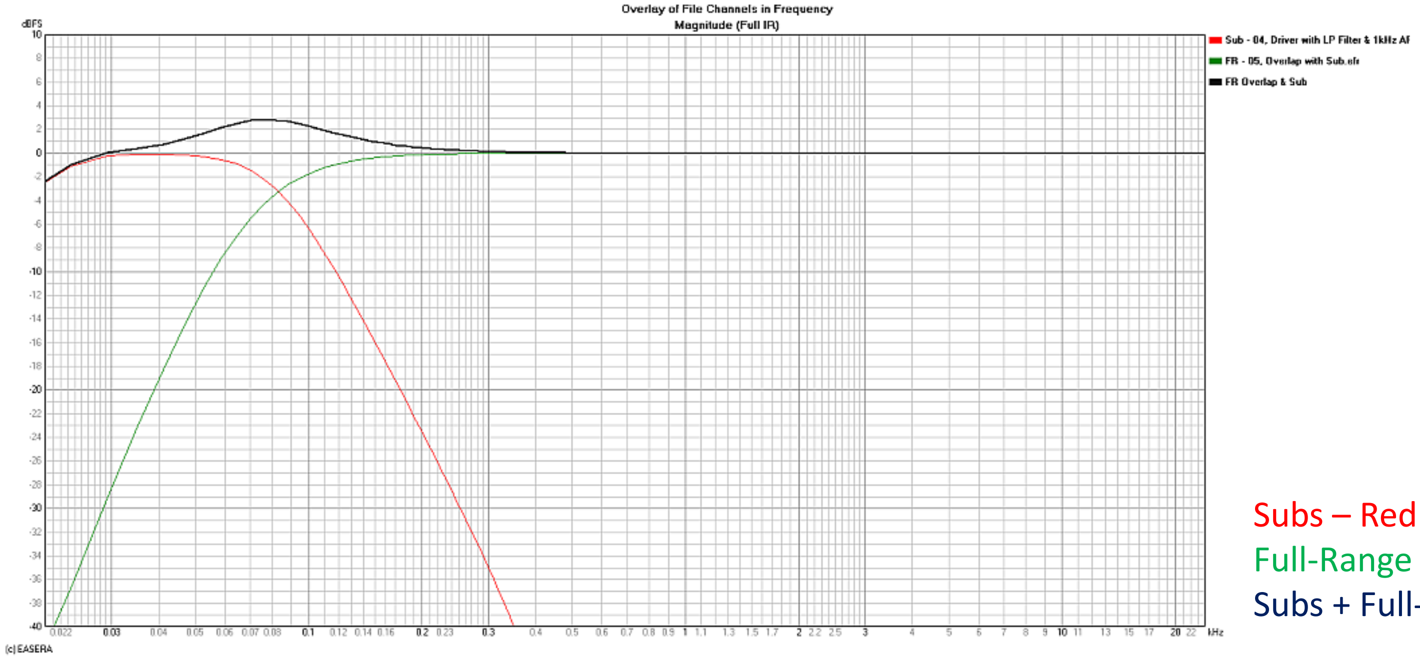
Subs – Red

Full-Range original filtering– Blue

Full-Range with new filtering– Green

Full-Range Overlapping Subs

The overlapping response of the full-range array with the subwoofers results in a +3 dB bump in the combined system response.



Subs – Red

Full-Range with new filtering– Green

Subs + Full-Range - Black

SPL Map – 100 Hz

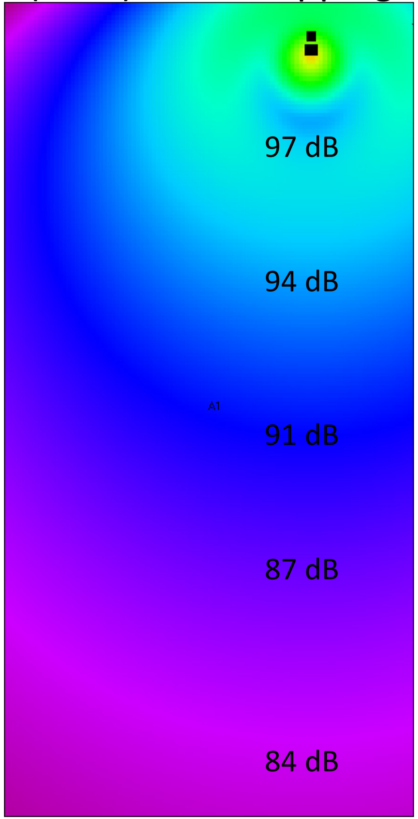
The summation is still very good throughout the area.

The overlapping neither significantly helps nor hurts the coverage.

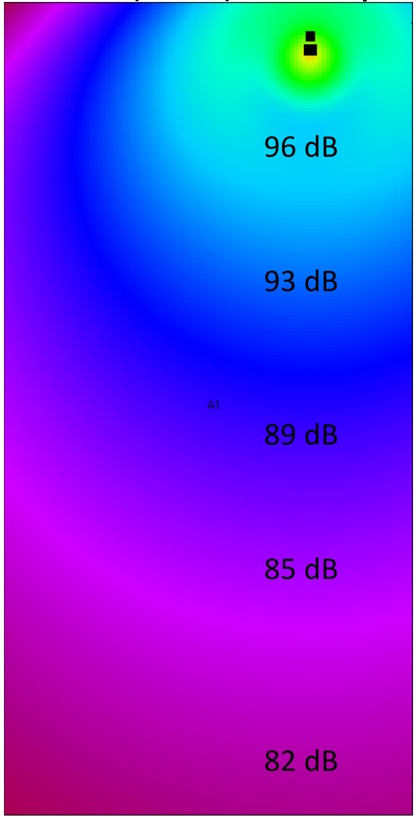
It just increases the overall level a bit, but only in the crossover region.

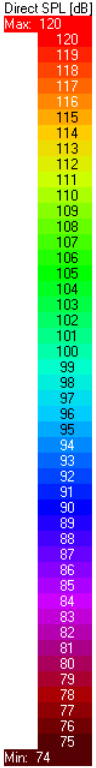
This could have easily been achieved with system EQ.

Subs (6 ms) & Overlapping Array

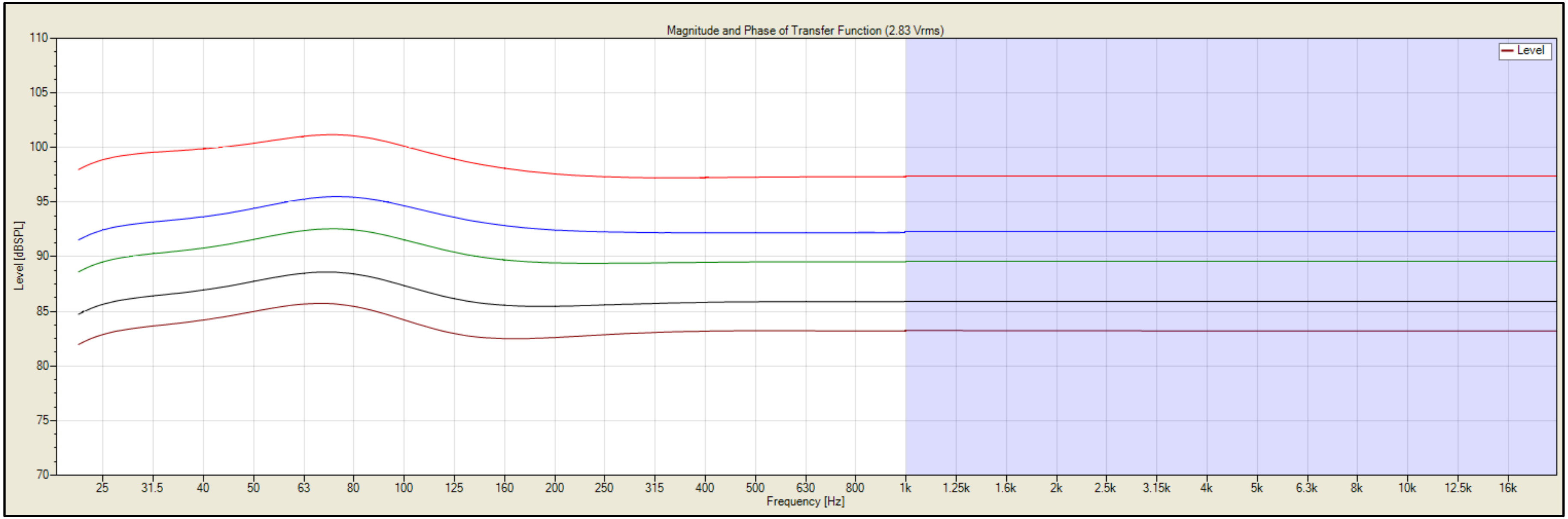


Alignment Method
Subs (6 ms) & Array





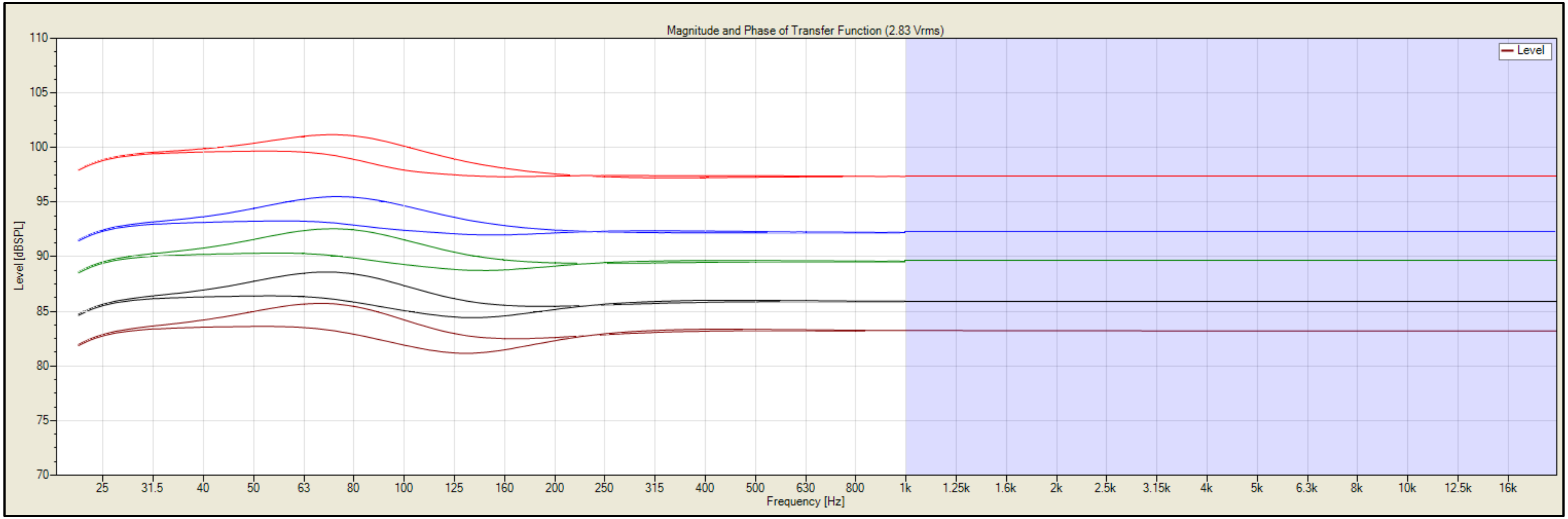
Frequency Response



Subs (6 ms delay) & Overlapping Array

Similar response to original filtering but with increased SPL in the 50 – 150 Hz region

Frequency Response



Comparison of the loudspeakers at the same locations with the original filtering and with the full-range array overlapping the sub

Conclusions

For the most consistent response over a relatively large area:

When one device always arrives early throughout the audience areas

1) Chose a measurement location where the difference in arrival time from the subs & the full-range system should be the smallest.

2) Determine the difference in initial energy arrival times for the subwoofer and the full-range loudspeakers at this location.

3) Add 2 ms to the measured arrival time difference & apply that delay time to the device with the earlier arrival.

4) When time aligning loudspeakers, work in the ***time domain***.

Conclusions

For the most consistent response over a relatively large area:

If one device arrives early in some audience areas, but the other device arrives early in other audience areas (i.e. arrival time switch)

1) Chose a measurement location where the arrival times have switched (typically farther back in the venue) and the difference in arrival time from the subs & the full-range system is the largest.

2) Determine the difference in initial energy arrival times for the subwoofer and the full-range loudspeakers at this location.

3) If the difference is arrival times is less than 2 ms, add the required delay so that the later arriving device is 2 ms after the earlier device at that location.

4) If the difference in arrival times is already more than 2 ms, there is nothing more that can be done.

5) When time aligning loudspeakers, work in the ***time domain***.