Rear Loudspeaker Transducer Measurements

Loudspeaker's frequency response was measured in-room, using windowed MLS techniques. The 0.5m set-up and results are presented on the pictures below.

Tweeter frequency/phase response

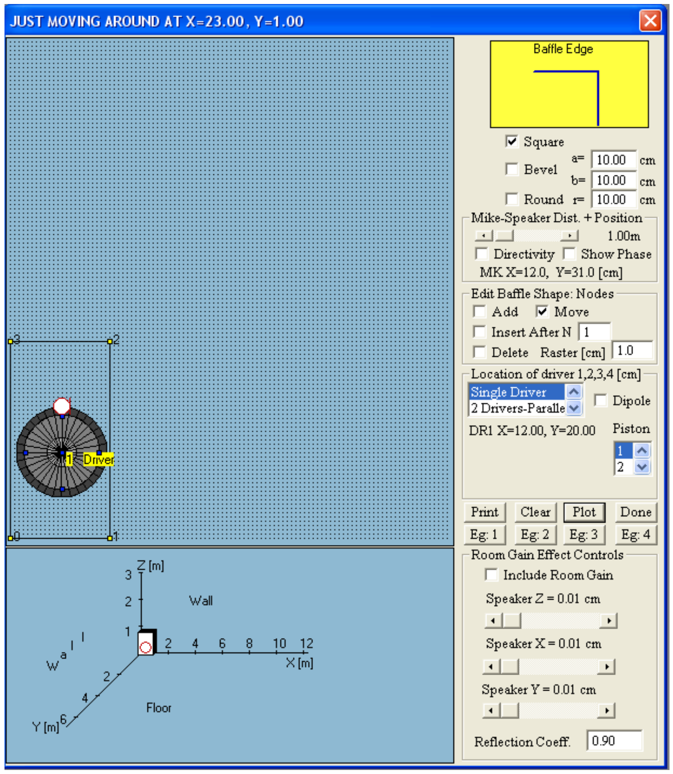
Woofer frequency/phase response

Tweeter's frequency response is fully usable for the design purposes, however, woofer's frequency response lacks information in the low-end and is really unsuitable for developing equalization.

Consequently, woofer's frequency response was measured in-room, using close-mike technique. The way it works, is that you need to measure driver's frequency response, then port's frequency response, and add them together. Port response has to be scaled down by several decibels, due to the difference in effective diameter between port and driver: **20*log(Driver_Radius / Port_Radius)**

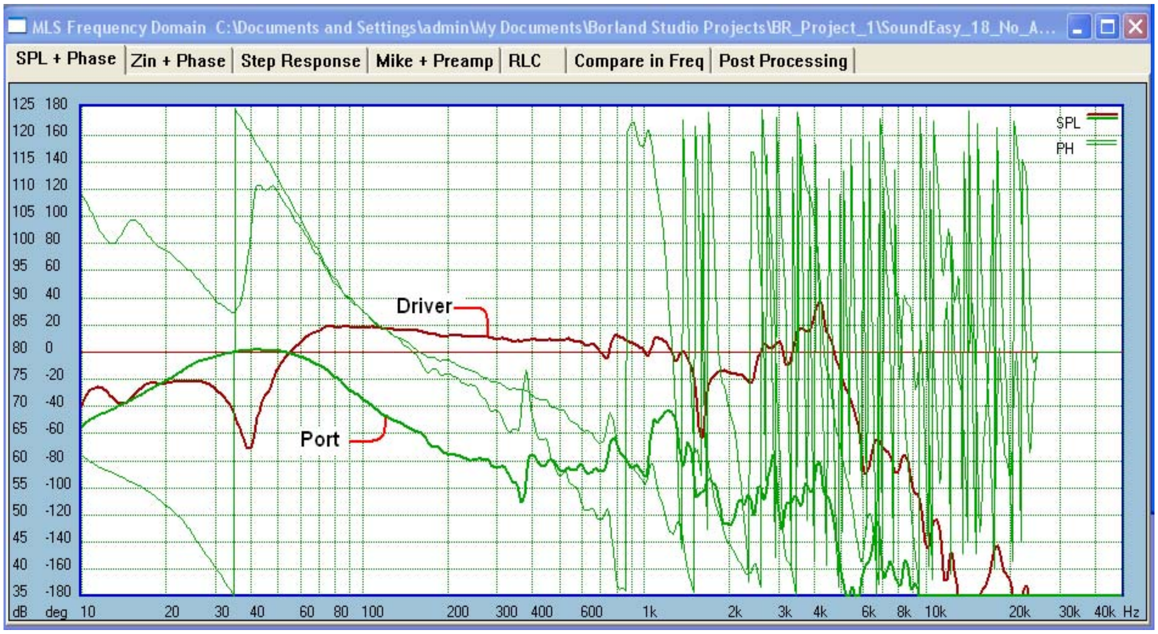
In my case, the port SPL was shifted down by -10dB. On the top of this, you need to add pre-calculated diffraction for this box. The technique was also described in details in UE3 User's Manual, http://www.bodziosoftware.com.au/UE%20V3%20Manual.zip

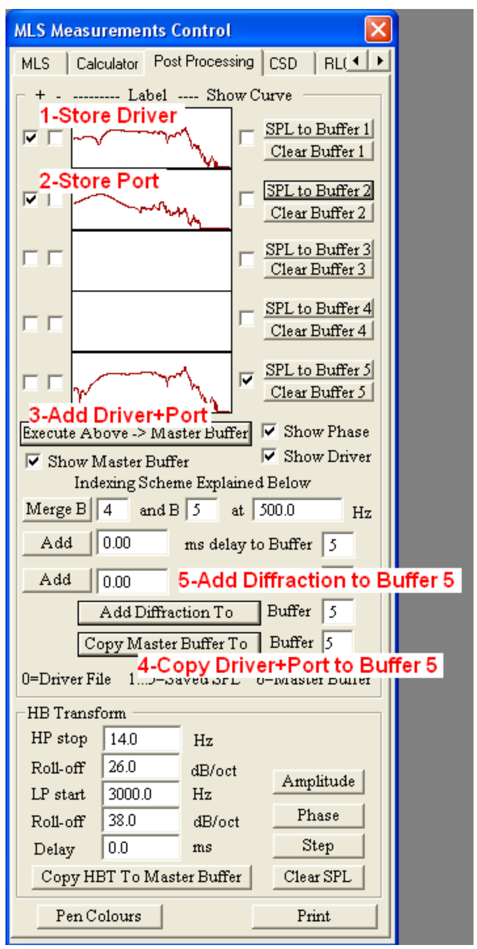
All operations and measurements were performed using SoundEasy V18. As a starting point, I calculated diffraction of the front panel. Dimensions are 23cm x 46cm.



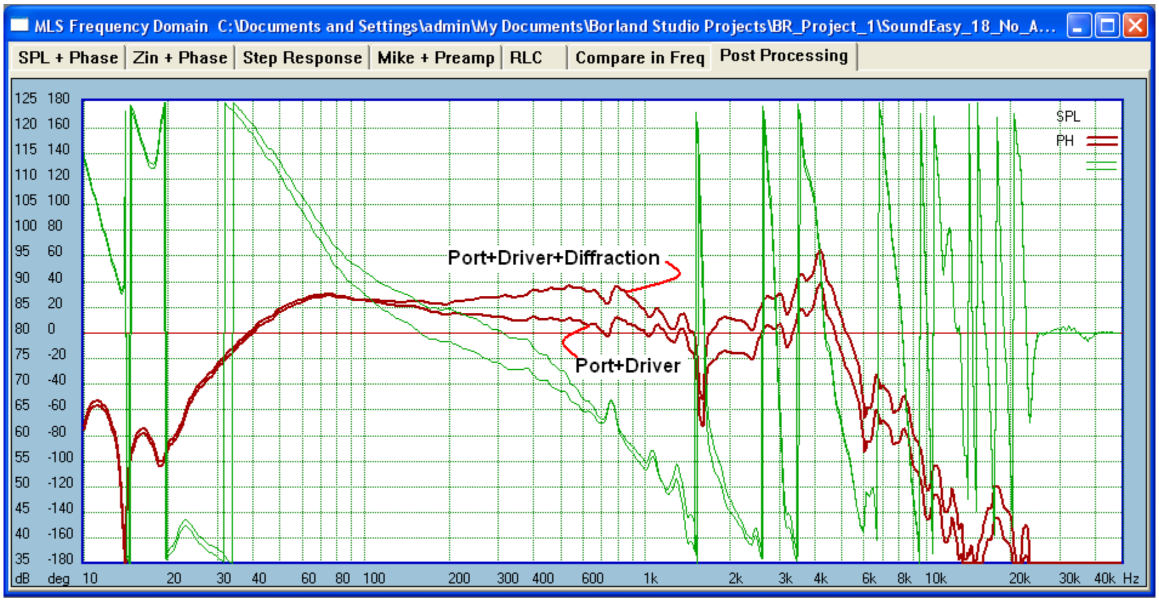
Diffraction plot is shown below.

Next, close-mike measurements are performed on driver and port. Port is scaled down by -10dB. Driver's SPL is stored in Buffer 1 and port is stored in Buffer 2 - see below.

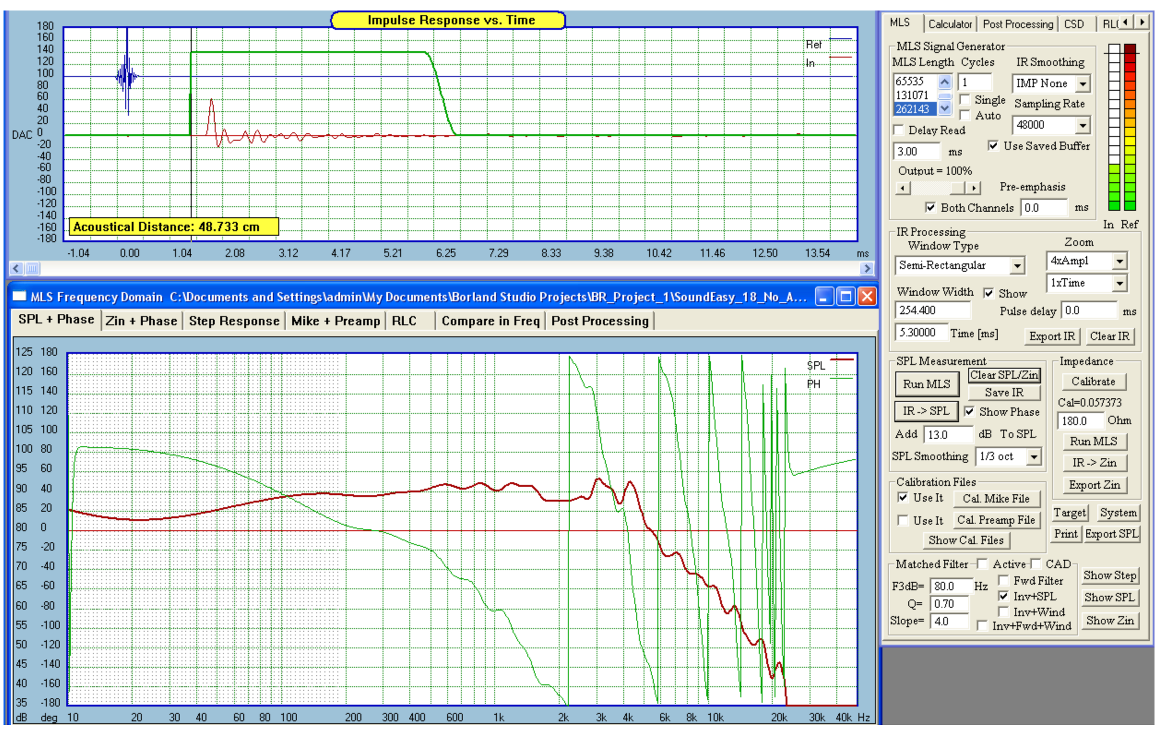




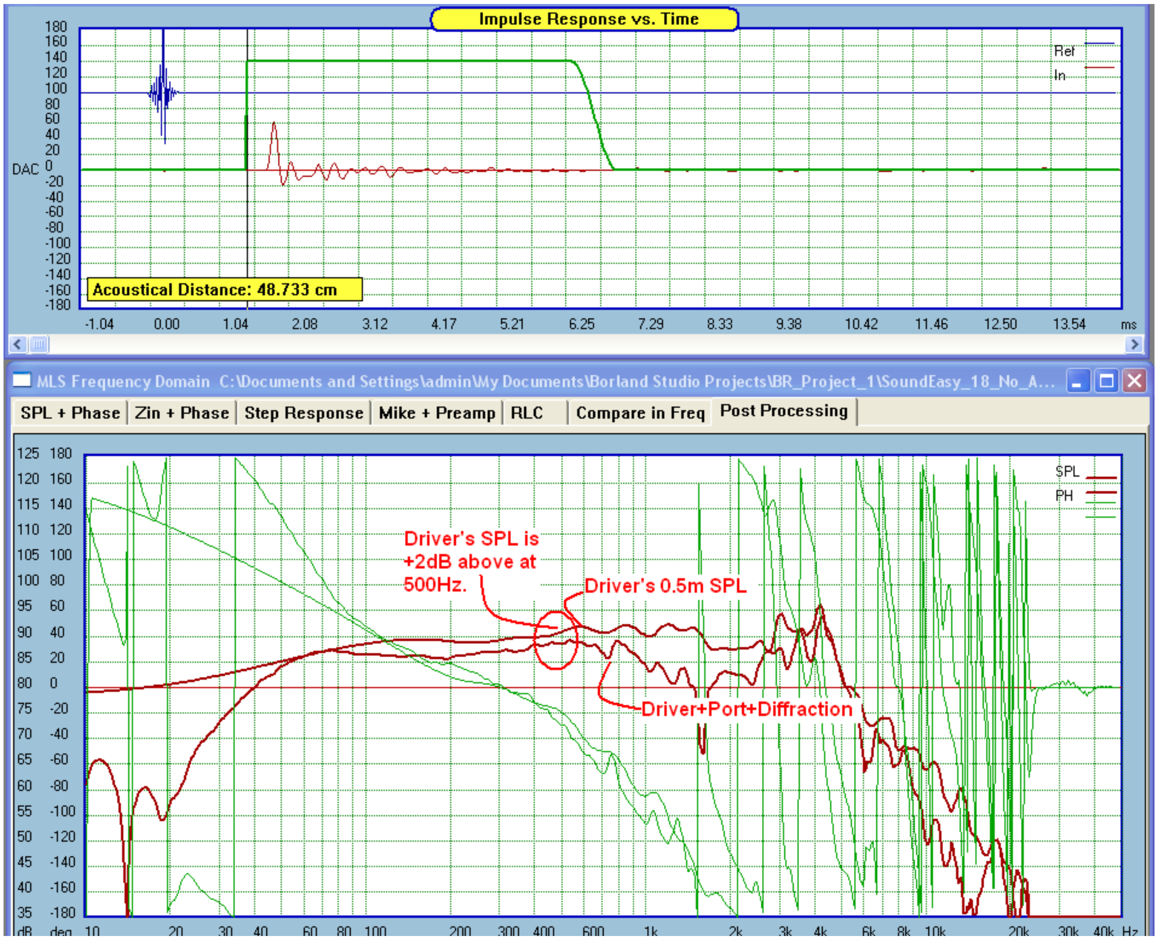
Next, port and driver SPL are summed in Master Buffer and the Master Buffer is copied to Buffer 5. Then, I added pre-calculated diffraction to Buffer 5 – see step 5 above.



Next, I moved the microphone to 0.5m distance and measured "far field" SPL. This is to make sure I capture diffraction effects. The result is shown below.



The "far field" SPL is stored in Buffer 3, and will be used to represent driver's Transfer Function above 500Hz.

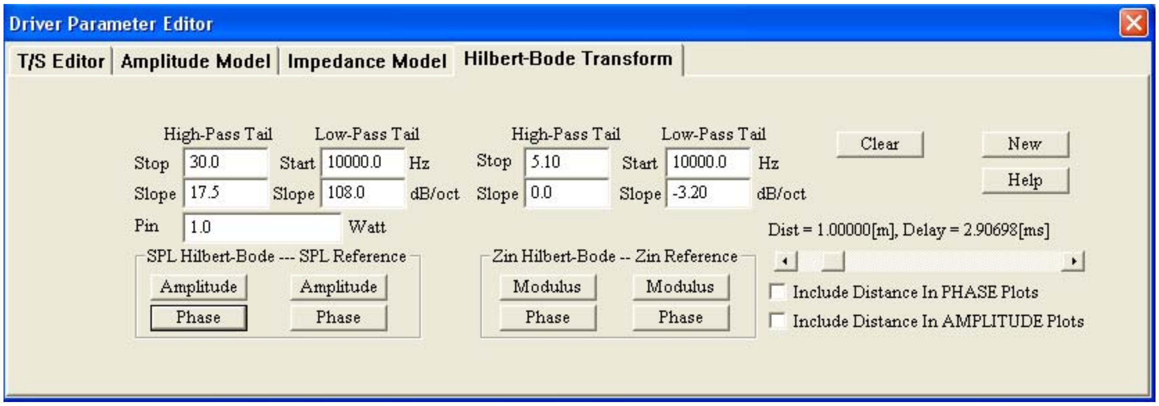


Driver's 0.5m SPL is stored in Buffer 3 and close-mike measurements (Driver+Port+Diffraction) are stored in Buffer 5. As Buffer 5 is 2dB below Buffer 5 at 500Hz (our merging frequency), we need to add +2dB to Buffer 5.

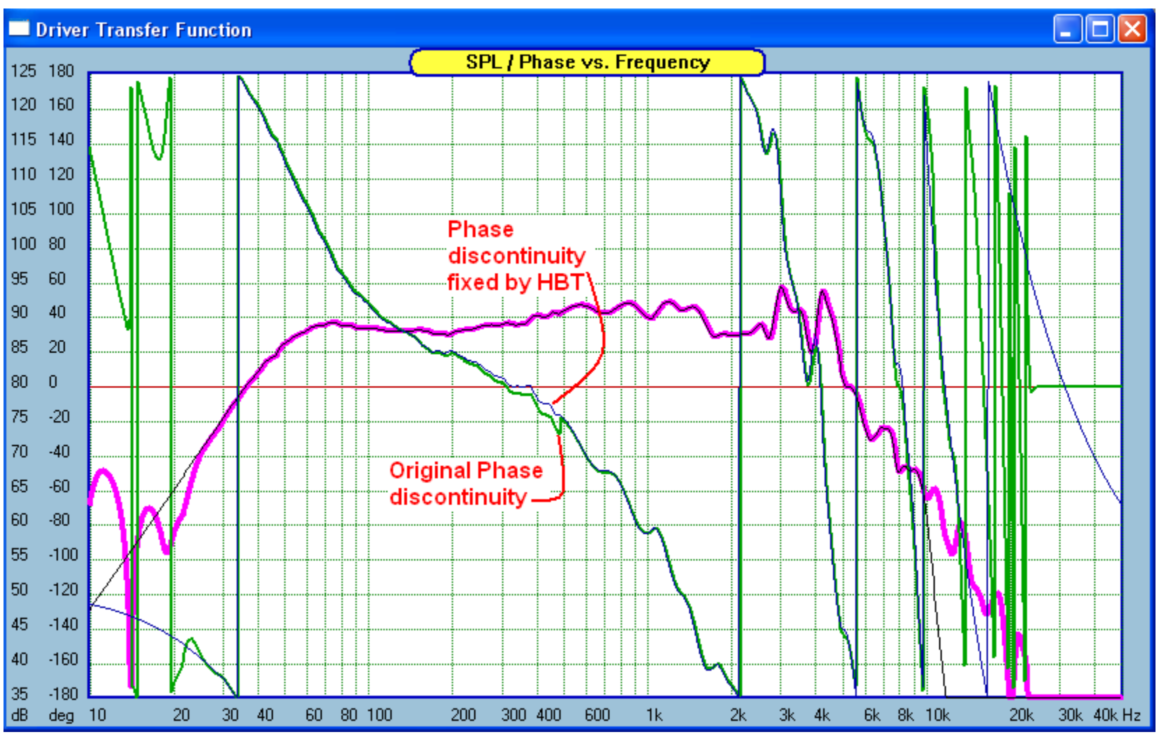
Next, Buffer 5 (lower-end of the SPL) is merged with Buffer 3 (higher end of the SPL) at 500Hz. The result will be automatically stored in Master Buffer (Buffer 6).

Finally, I transferred Master Buffer to Buffer 0 (Driver Editor Screen). And this completes curve arithmetic operations.

I can now move my activities to Driver Editor screen for developing proper Transfer Function of this driver.

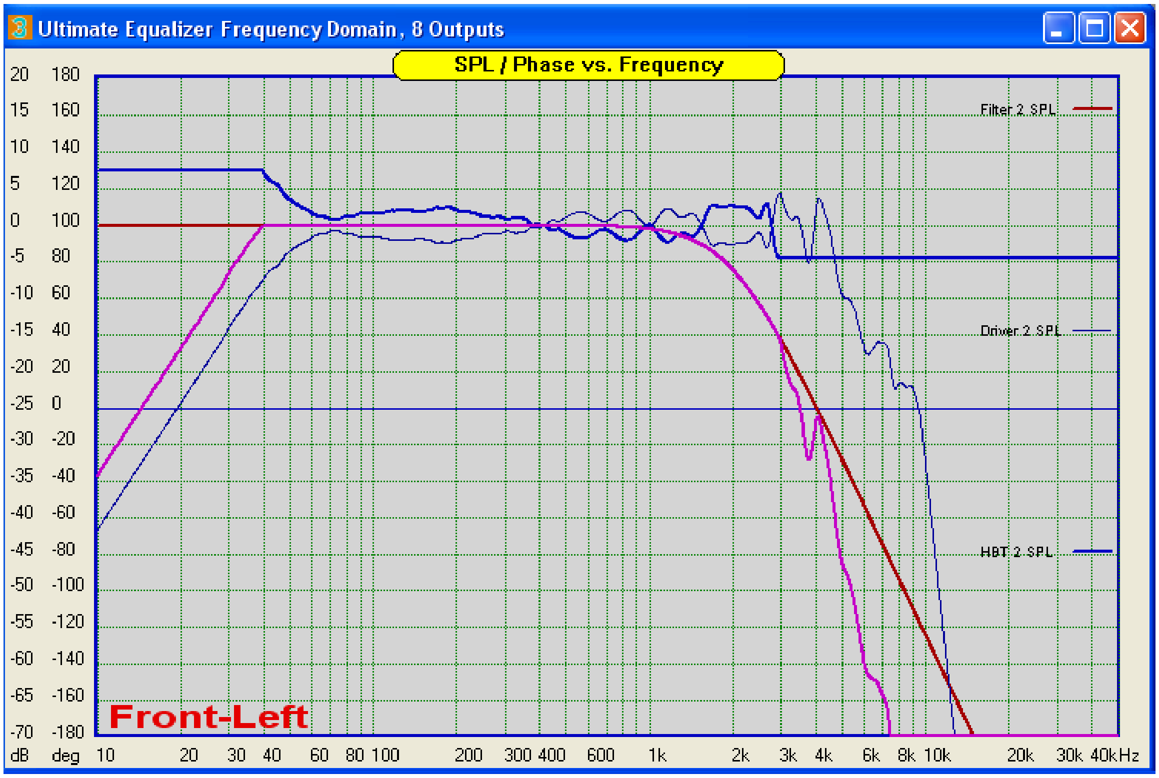


The above HBT parameters secure perfect agreement between measured SPL and HBT-generated Transfer Function from 24Hz to 11kHz. This is much better than we need. In addition, curve arithmetic performed in the MLS section resulted in slight phase discontinuity the “merge” frequency of 500Hz – see the green line on the Figure below. This phase discontinuity was automatically fixed by HBT as well.



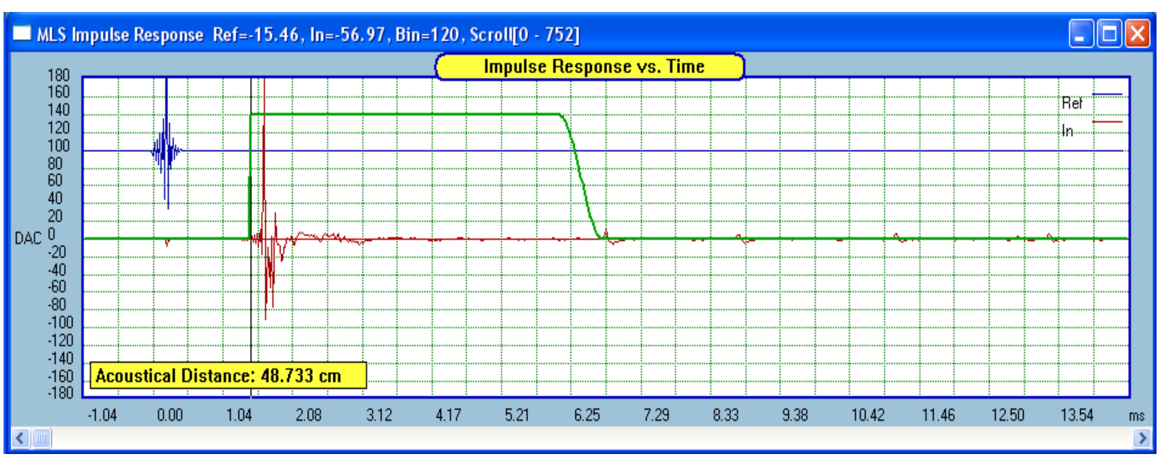
I can now save woofer driver file for use with Ultimate Equalizer.

Here are the equalization curves developed in UE3 for the woofer driver. I aim at -24dB/oct Linkwitz filter at 2000Hz. HBT range selected in UE3 is 40Hz-3000Hz.

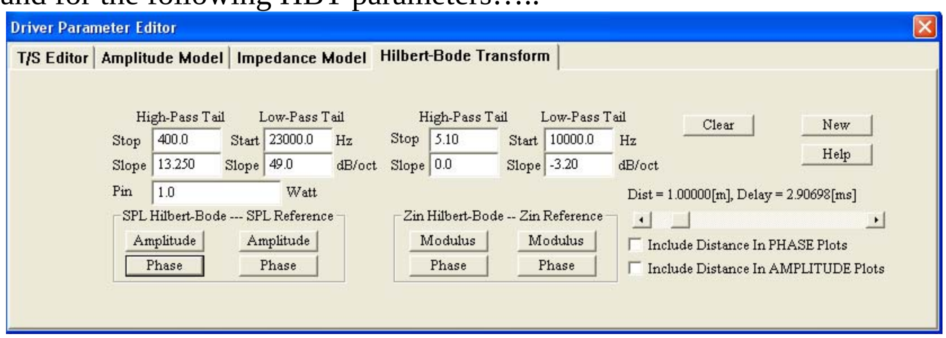


Thin blue curve – woofer measured SPL
Thick Blue curve – woofer's HBT equalization
Red curve – filter's template.
Pink curve – final woofer response

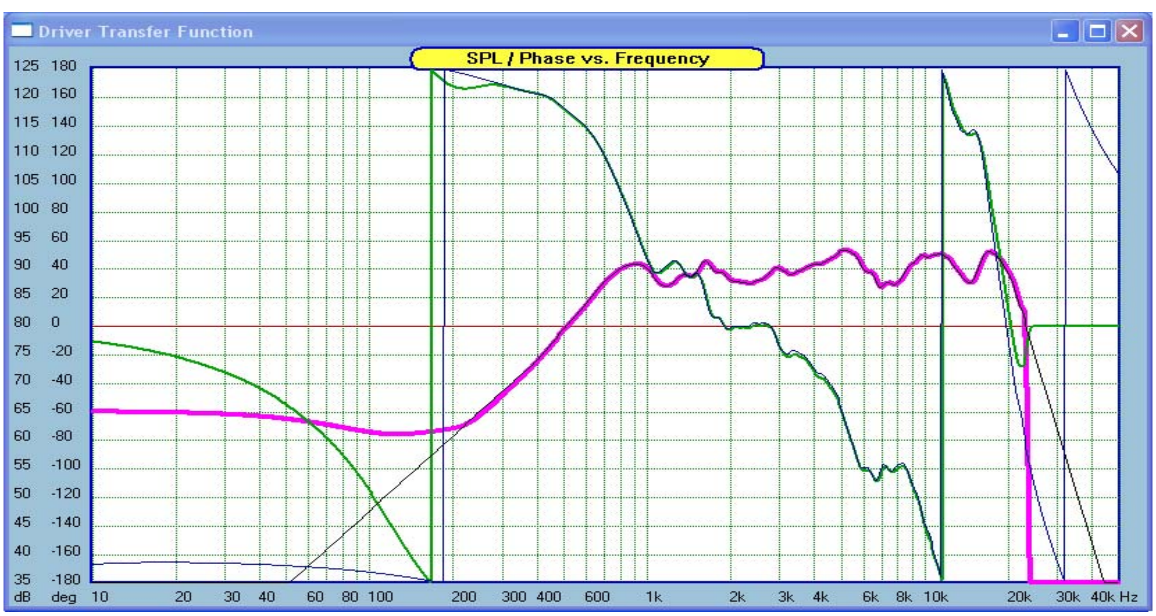
For the tweeter, I intended to capture diffraction effects, therefore for this small box, I measured the tweeter at 0.5m distance, and had to window room reflection – as shown below. I have also removed "flight time" from the impulse response, by shifting the starting point of the FFT window. Secondly, you will notice a plastic "phase shield" in front of the tweeter dome. Using the close mike technique on such driver leads to less accurate frequency response, which was not the same as the 0.5m distant SPL, even with diffraction accounted for.



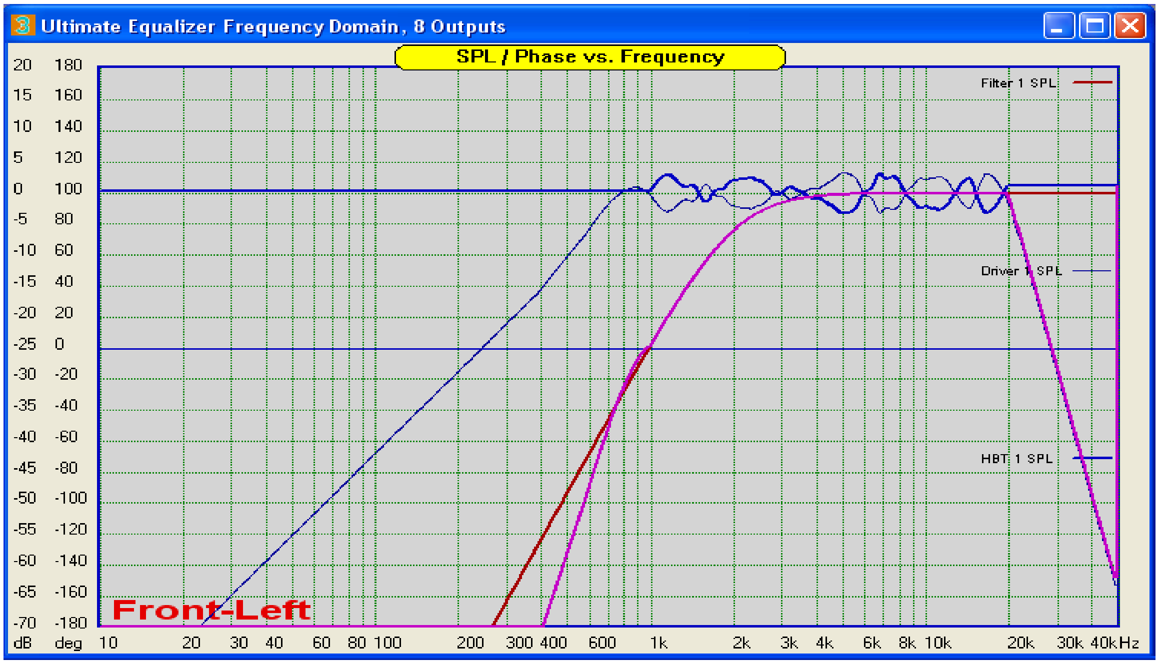
There are no curve arithmetic issues here, so I can now move to Driver Editor screen, and for the following HBT parameters…..



I have obtained HBT generated Transfer Function from 250Hz to 20kHz – see below.

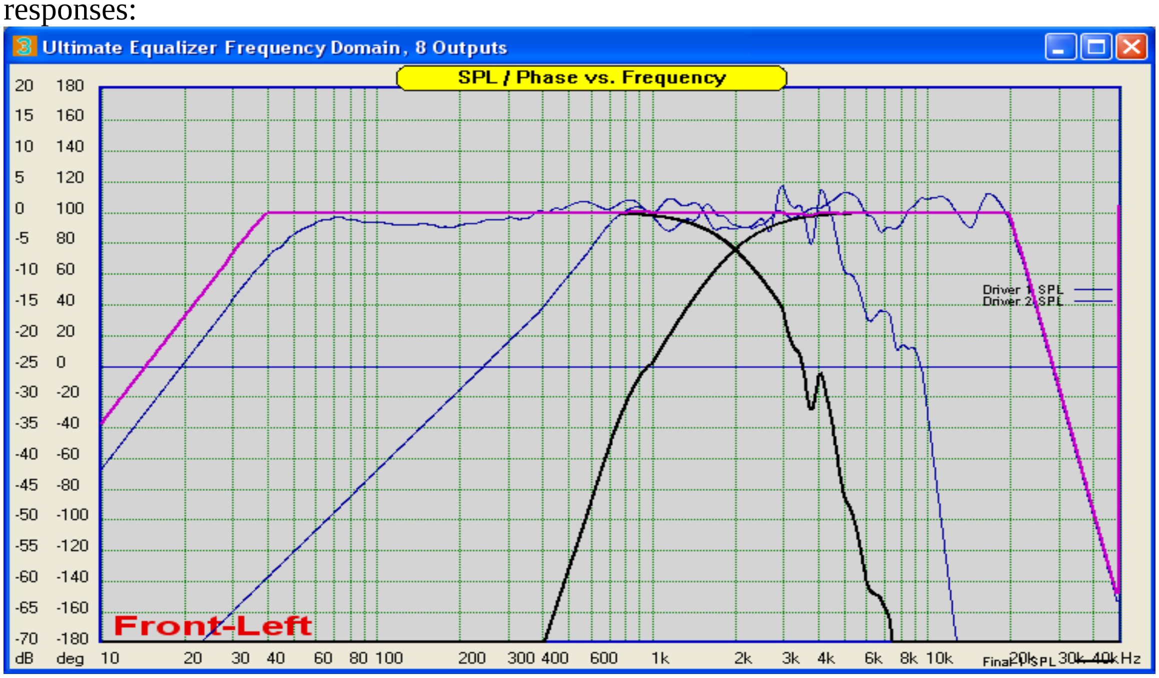


I can now save tweeter driver file. In order to protect tweeter driver more effectively, I decided to use 24dB/oct LR crossover, at 2000Hz. If the system is run in linear-phase mode, the crossover slope does not matter, as the phase will always be flat in this mode. In the next step, I developed equalization curves for the tweeter using UE3.



Thin blue curve – tweeter measured SPL
Thick blue curve – tweeter's HBT equalization
Red curve – Filter's template.
Pink curve – final tweeter response

Putting the two drivers together, creates the following set of UE3 modeled responses:

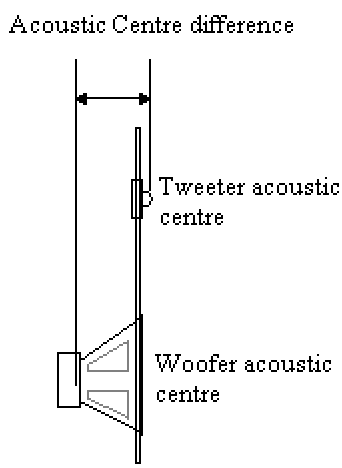


Thin blue curves – woofer and tweeter measured SPL
Black curves – woofer and tweeter equalized SPL (they are partially overlapped by the pink curves)
Pink curve – Final System SPL response
Blue curve – Final System Phase response (flat, linear curve in the middle of the screen).

It is observable, that final system amplitude response extends flat from 40Hz – 20000Hz. The 3dB low-frequency extension down to 35Hz is provided by 6.5dB HBT boost in this frequency range. If only 2.5dB of amplifier headroom is available, then the HBT boost must be reduced to 2.5dB, resulting in 45Hz cut-off frequency. This was the exact goal of this design. Un-equalized cut-off frequency was 50Hz. As I anticipated, diffraction effects (broad hump from 200Hz -600Hz) were correctly equalized and also tweeter SPL irregularities are gone.

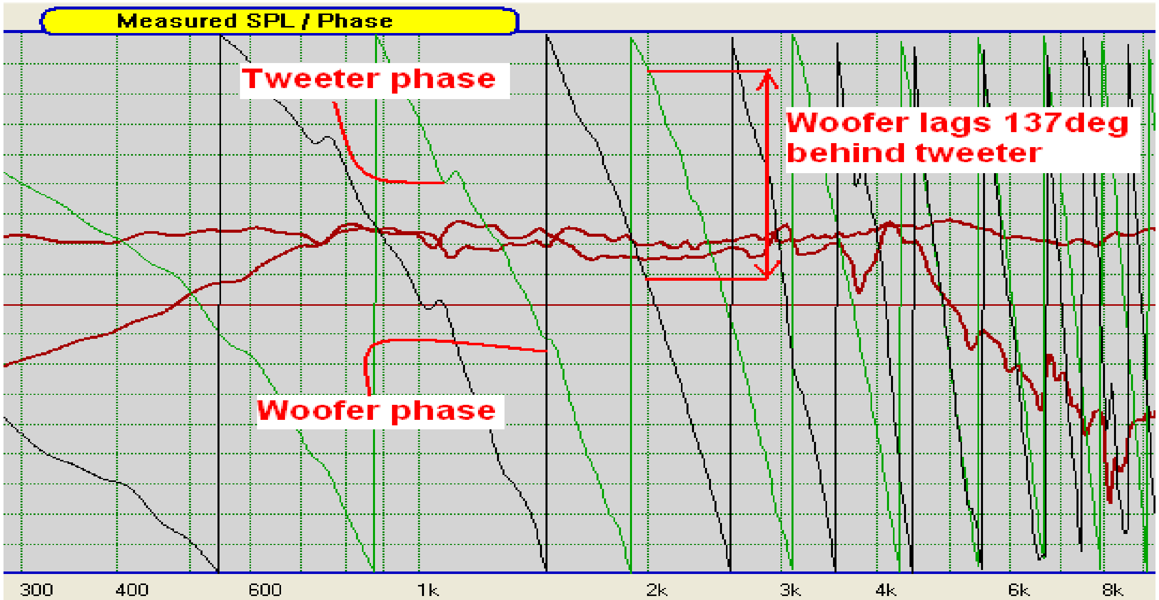
Time Alignment Of The Drivers

Due to quite simple mounting configuration on a flat, front baffle, acoustic centers of both drivers are likely to be offset against each other. This problem is explained on the diagram below, and will manifest itself during the MLS measurements as woofer phase response lagging behind tweeter's phase response.



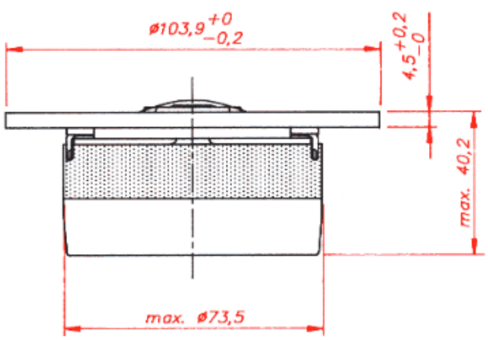
Fortunately, UE3 allows for easy manipulation of the "location" of the acoustic center. This is accomplished by introducing a small delay to the "forward" driver – in this case the tweeter.

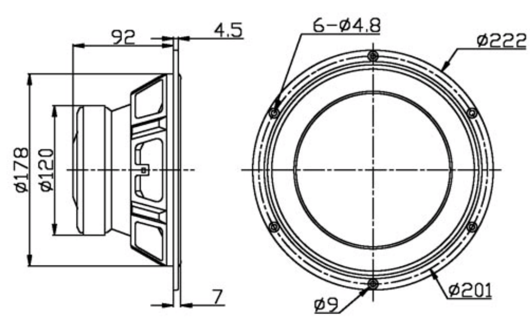
The amount of delay can be calculated by comparing woofer and tweeter phase responses measured with the microphone located approximately half-way between woofer and tweeter center axis of rotation. I have located the microphone 26.5 cam from the front baffle in such location, and measured both drivers without changing the measurement setup. The result is shown on the picture below.



Delay = (phase difference) *1000 /(360 x Fc) = 137 x 1000 / (360 x 2000) = 0.19msec. This value is entered in UE3 as the tweeter's "Delay" parameter.

The 190usec is equal to 64.7mm of acoustic centres offset. Given, that tweeter's dome is about 5mm in front of the baffle, this leaves us with the acoustic centre of the woofer, located about 59.7mm behind the front baffle. This conclusion is quite reasonable, as the "esoteric" acoustic centre is usually located behind the dust cup, and just above the voice coil. I have included simple mechanical details of both drivers, so one can picture this issue with some reference to the physical dimension of the drivers.





Minimum-phase system delay adjustment is explained in the UE3 User's Manual, http://www.bodziosoftware.com.au/UE%20V3%20Manual.zip in the "Non-Linear Phase System" chapter and will not be repeated here.

There is perhaps a simpler method for assuring the driver's AC offsets are accounted for. I used 1.0m distance measurements for both drivers, and removed the same amount of time-of-flight from both drivers. What was left, the was phase response with the AC distance embedded in both cases. Now, if I use UE3 to phase-linearize driver's file created such way, the phase will be linearized, including the path differences.

In summary, the most involving and time consuming part of designing loudspeakers in this project seems to be the acoustical measurement itself. This issue is present in other loudspeaker design projects too, so no point procrastinating about it. Without anechoic chamber, the substitute techniques work reasonably, with an occasional hick-up. UE3 has reduced all other design and performance issues to a trivial button presses, or simple selections, with the exception of enclosure design – still performed using SoundEasy V18.

After all this hard work, now comes the enjoyable part - my loudspeaker is ready for listening tests, so that I can adjust voicing to my taste.

Listening tests

Nothing elaborate here. I listened to single loudspeaker only, so I had no chance of evaluating any linear-phase improvements related to spatial sound reproduction. This will come later, when the whole system is auditioned.

For now, I only wanted to understand tonal balance, dynamic range and overall quality of the sound provided by the loudspeaker powered by UE3. I have adjusted UE3 volume for maximum undistorted output, and then set the analogue gain of the woofer channel on the woofer amplifier to maximum undistorted level. Then, I adjusted the analogue gain of the tweeter amplifier to the same as woofer, minus 2dB. The 2dB drop was due to higher efficiency of the tweeter. So, now my 2-way loudspeaker is in full tonal balance over the whole volume range of UE3, with no possibility of overdriving or distortion.

I played CDs using an external CD-player (44.1kHz/16bit), so I had 3 A/D converters in the audio chain. This was possibly the worst case scenario for evaluating the dynamic range of the system. With the UE3 volume set to very loud, I listened to the loudspeaker when there were breaks between songs. I wanted to subjectively evaluate the electronic "noise floor" coming from the PC. The only faint noise I could hear, was when I stacked my ear right into the driver, and all this was at loud volume setting. Obviously, I could not play music with my ear so close to the cone. The faint noise becomes inaudible 10-20cm from the cone.

Conclusion – the published Dynamic Range of Delta1010LT sound card (Input = 99.6dB, Output = 101.5dB A-weighted) seems more than adequate for normal-to-loud listening levels.

As far as tonal balance is concerned, the 2dB drop in tweeter level is quite necessary. HBT equalization extends the bass, removes diffraction distortions, and transforms the overall frequency response into a flat line. Now, the sound is balanced, and I was surprised at the amount of solid, low-end output that the 8" speaker produced. High frequencies could be described as "smooth".

Overall sonic quality was better than I expected from this small loudspeaker. This system, which is intended as rear surround speaker, could easily pass as front LR speakers in a smaller stereo or HT system. To my own surprise, I decided to leave the voicing flat for the time being.

References

Woofer's data

Woofer	W-220PII
SPECIFICATIONS	
Size	8
Nominal Diameter	200
RMS Power	100 W
Maximal Power	200 W
Rated Impedance	8 Ω
Sensitivity	89 dB
Frequency Range	fo-5k Hz
Basket Material	steel
Gasket Material	
Cone Material	coating with PP paper
Surround Material	rubber
Magnet Material	ferrite
Magnet Weight/Overall size	33 oz/φ126
Voice Coil Diameter	1.53" (38.8)
Former Material	aluminium
Wire	copper
Layers	two
Spider Material	cotton
Terminals Type	plug
Shorting Ring	
Magnet Structure	
Highest Recommend Crossover	≤2.5k

PARAMETERS	
Re	6 Ohm
F0	28 Hz
Qms	1.58
Qes	0.43
Qts	0.33
Zmax	27 Ohm
Sd	0.022698 m^2
Mms	26.95 g
Mmd	24.98 g
BL	8.19 T m
Xmax	6.8 mm
Cms	1187u M/N
Vas	86.87 L
SIMULATION DESIGN	
Cabinet Type	vented enclosure
Recommended Enclosure Volume	30 L
Recommended PORT of Cabinet Dimension	φ65×200
fb	37 Hz

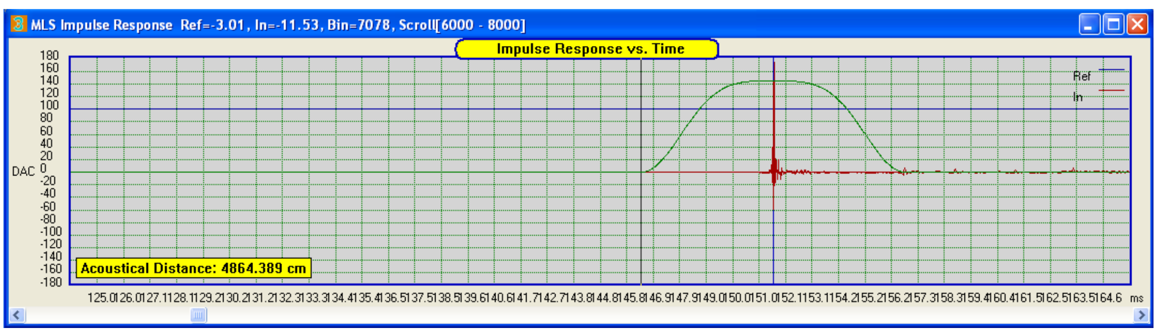
Tweeter's data

NOMINAL IMPEDANCE	6	Ω
NOMINAL POWER (IEC 268–5)	100	W
FREQUENCY RANGE	1,5–35	kHz
SENSITIVITY (1W, 1m)	89	dB
EFFECTIVE DIAPHRAGM AREA	7,1	cm²
VOICE COIL RESISTANCE	4,6	Ω
OPERATING POWER	5	W
VOICE COIL DIAMETER	25	mm
VOICE COIL HEIGHT	1,6	mm
AIR GAP HEIGHT	2	mm
FREE AIR RESONANCE	850	Hz
MOVING MASS (incl. air)	0,3	g
FORCE FACTOR, B x l	3,3	Txm
MAGNET WEIGHT (8,5 oz)	240	g

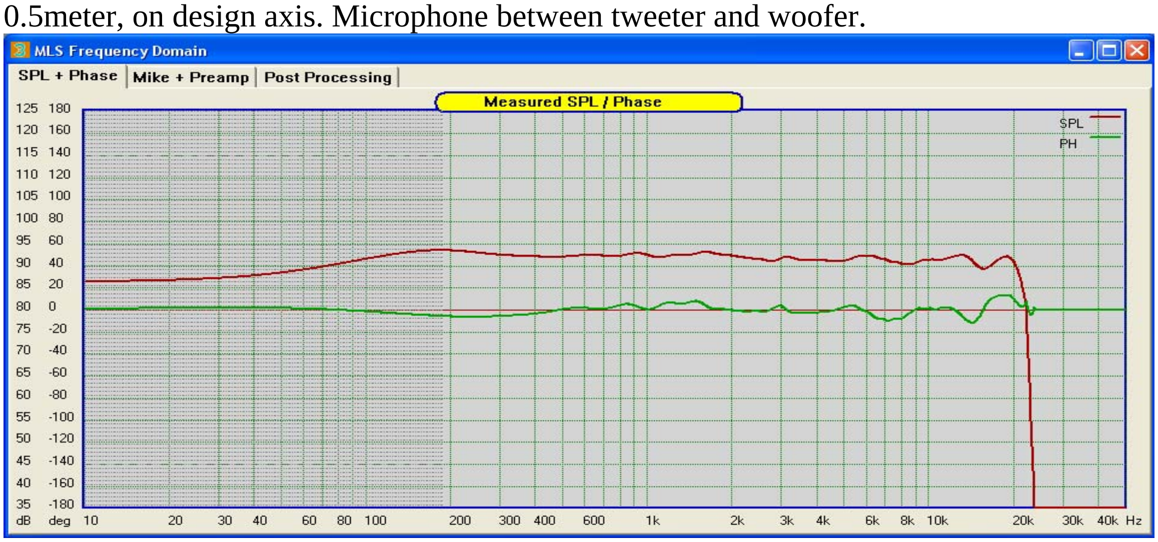
UE3 Acoustical Measurements

Acoustical measurements of UE3 system were performed using SoundEasy V18 in my AV room. Due to the size of FFT window (5.2ms on both sides of IR), the lowest reliable SPL/Phase frequency is 190Hz and the region below 190Hz is shaded on the figures below.

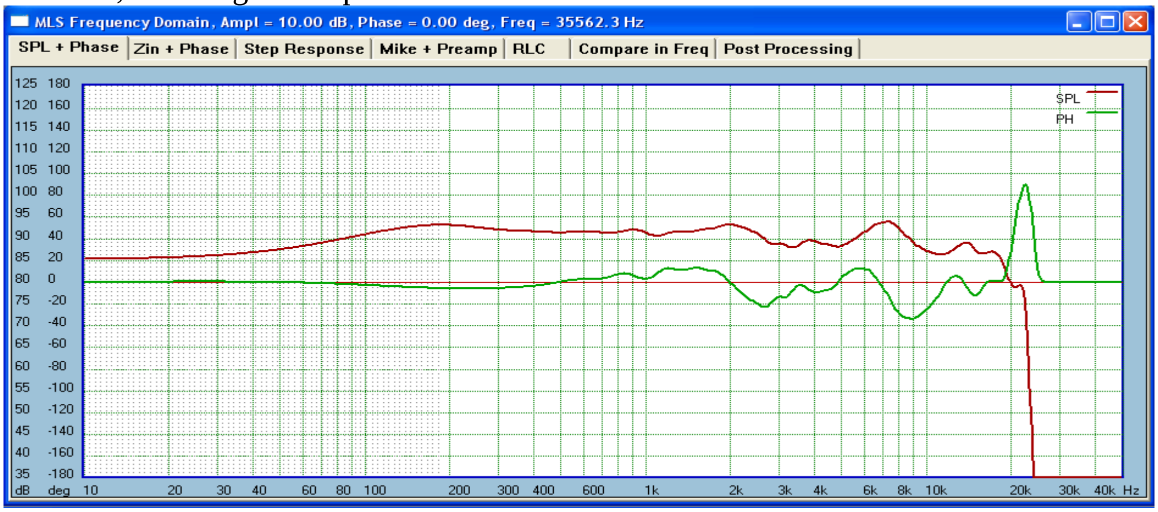
Acoustical measurements were performed with new, symmetrical FFT windows in MLS system – see figure below. Red = Magnitude response, Green = Phase response.



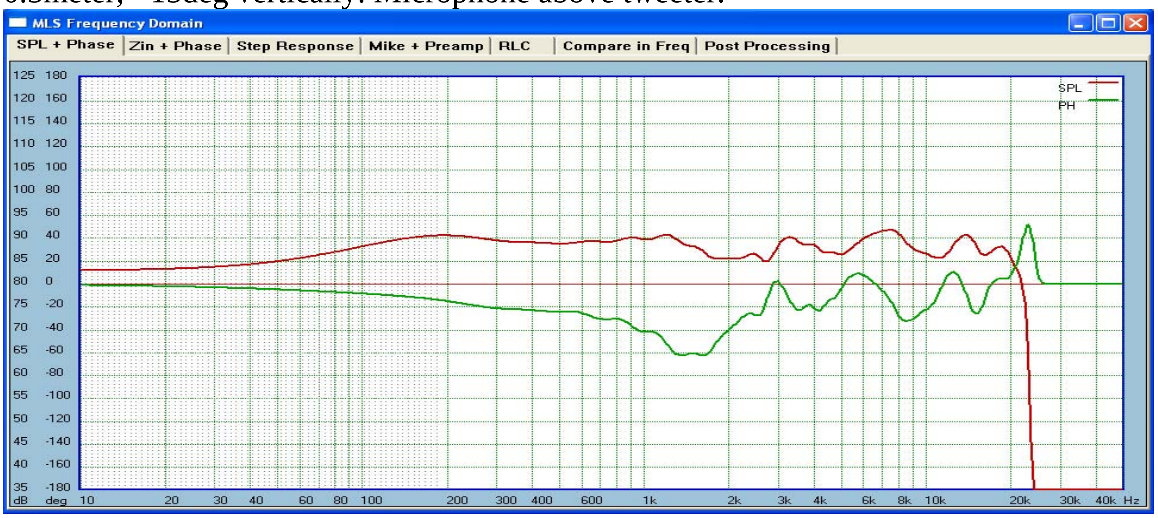
0.5meter, on design axis. Microphone between tweeter and woofer.



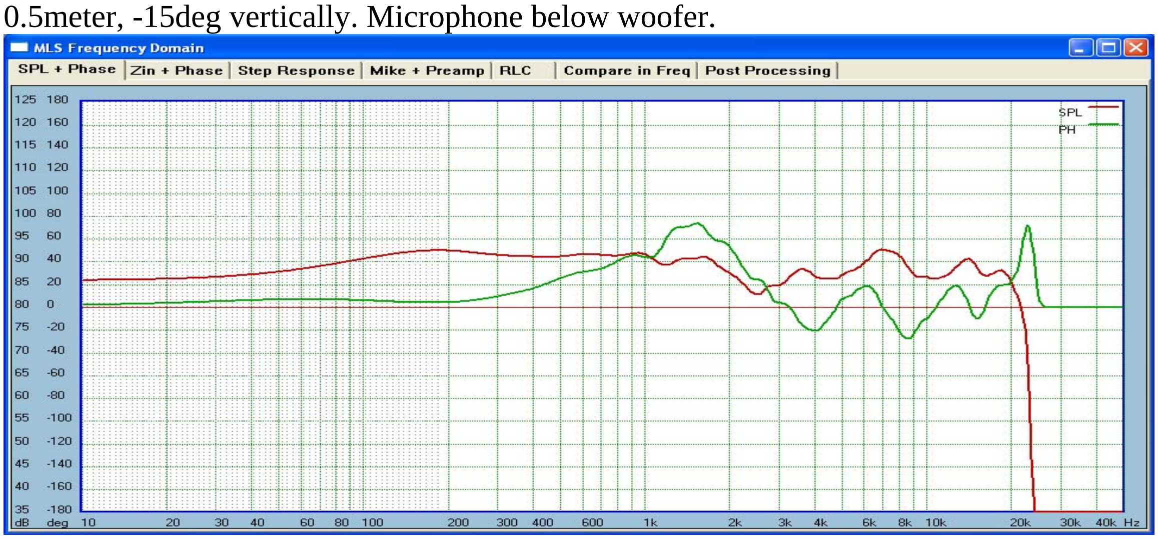
0.5meter, +/-30deg. Microphone between tweeter and woofer.



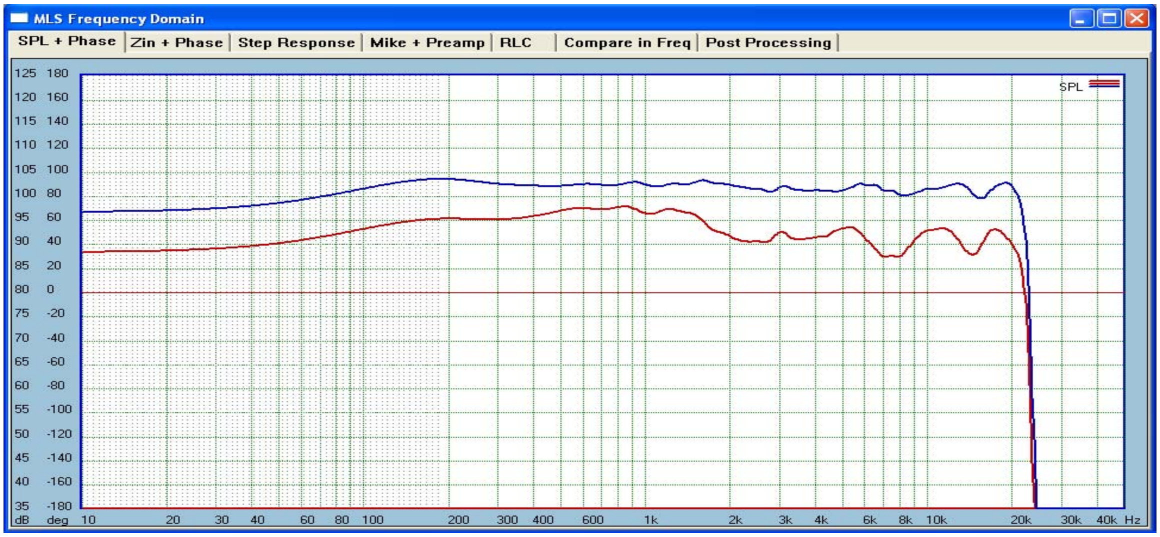
0.5meter, +15deg vertically. Microphone above tweeter.



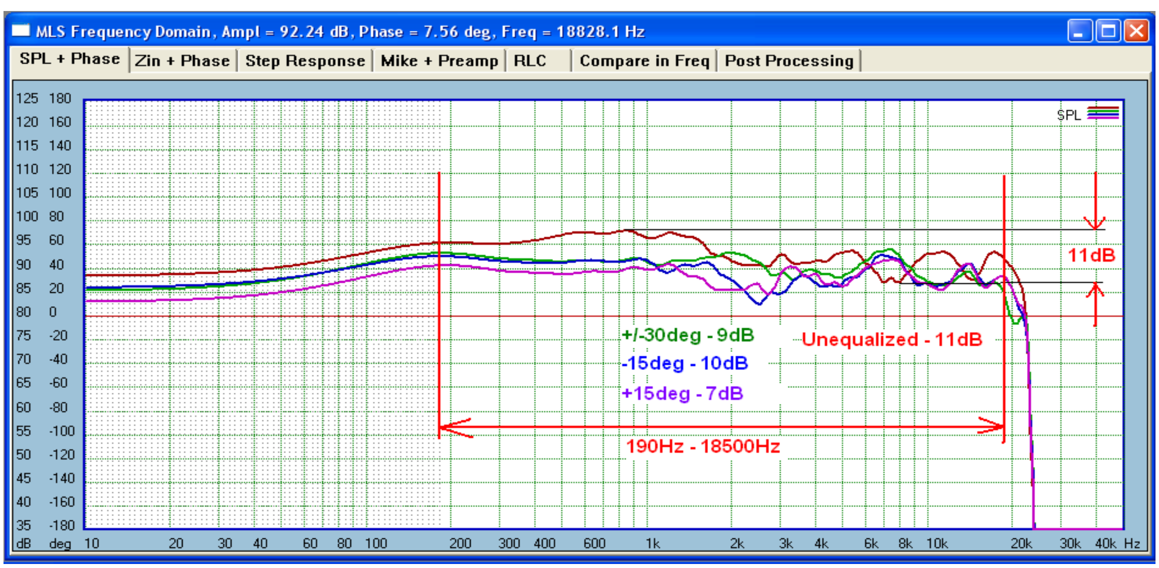
0.5meter, -15deg vertically. Microphone below woofer.



On the next figure, the blue curve depicts acoustical response of equalized loudspeaker and red curve depicts loudspeaker with no correction applied. HBT equalization resulted in SPL variation of +/-1.5dB across 190Hz-22000Hz bandwidth vs. +/-5.5dB variations for raw loudspeaker.



Even more interesting is the comparison below. It shows SPL level variations of un-equalized loudspeaker vs. off-axis SPL level variations of equalized loudspeaker. It is observable, that ***all off-axis SPL curves show less variation than raw loudspeaker on axis***. Concluding from all the above figures, this is an important observation, as it confirms, that you can still get benefits of HBT and linear-phase equalization, even at significant off-axis location. Obviously, off-axis location deteriorates SPL and phase linearity, but it does not destroy it. For instance, +/-30deg off-axis locations exhibit phase variations of +/-22deg over 190Hz-22000Hz, but it's still a linear-phase loudspeaker with acceptable tonal balance. In addition, the +/-30deg horizontal off-axis performance is virtually unchanged below 1000Hz, and changes very little between 1kHz and 2kHz



For testing purposes, I have specifically selected off-axis locations far exceeding real locations in my AV room. In my case, the horizontal off-axis locations will not exceed +/-20deg. And vertical off-axis locations will not exceed +/-10deg for all listeners. Therefore, users of my system will experience significantly less SPL and phase variations than those reported above. And this may as well be a typical situation in average AV room in your home.

Comments on Measurement Accuracy

Drivers' frequency response generation is not a simple process. Woofer's transfer function was measured and "glued" together, using four elements: (1) close-mike measurement of port's SPL, (2) close-mike measurement of driver's SPL, (3) modeled diffraction, (4) 0.5m distance SPL measurement – let's call it far-field. Then, tweeter's SPL response, measured at 0.5m was incorporated.

The above method is only a substitute for a proper 1m/1W anechoic chamber measurements, and as such, one would expect, that this less accurate method will result in some deterioration in flatness of both: SPL and phase. Then there is the issue of microphone's phase response – for which data is not available. Phase response above 15kHz is basically a wild guess. Calibration file for microphone was pretty much estimated from the available information.

The amount of SPL octave smoothing used when generating driver's SPL curves should be minimized. This is because overly smooth curves, with shallow dips and valleys will not be sufficient to equalize raw driver.

With 48kHz sampling frequency, any data above 22kHz is basically an artifact of digital processing. You may expect wild SPL/Phase irregularities in your measurements there, and these should be discarded.

Considering all the above, I regard the measured on-axis and +/-30deg off-axis performance very good indeed. It's just two drivers and some wires in a square box, but performance-wise (thanks to the UE3 Technology), the rear speaker is a very well performing, small-size and inexpensive loudspeaker.