Meindert's HPD315 project

History

Thirty years ago I bought a pair of HPD 315 speaker and build them into the Devon cabinet, one of the enclosures in the construction guide of Tannoy. Ten years later I measured the TS-parameters and build, using the original Small AES-paper, a 100 liter cabinet, a heavy triangular column 100 cm high. But, after a while I changed to two B&W801 F's, I sold a few years later because they didn't sound good at all (too much distortion in mid and high, and a thick bass). After I build the SEAS Odin MK3 (quite good), it was due to get my Tannoy's from the attic, repair the roll surround (see elsewhere) and build a new cabinet using the modern measurement and simulation techniques the computer offers today.

The Plan

My personal design criteria are:

- Active filtering: now easily done digitally with for example miniDSP
- Small size, since my listening room is small (lowest fundamental 40Hz)
- Simple, light but sturdy construction, to make it easily to build and to transport

The design procedure was as follows:

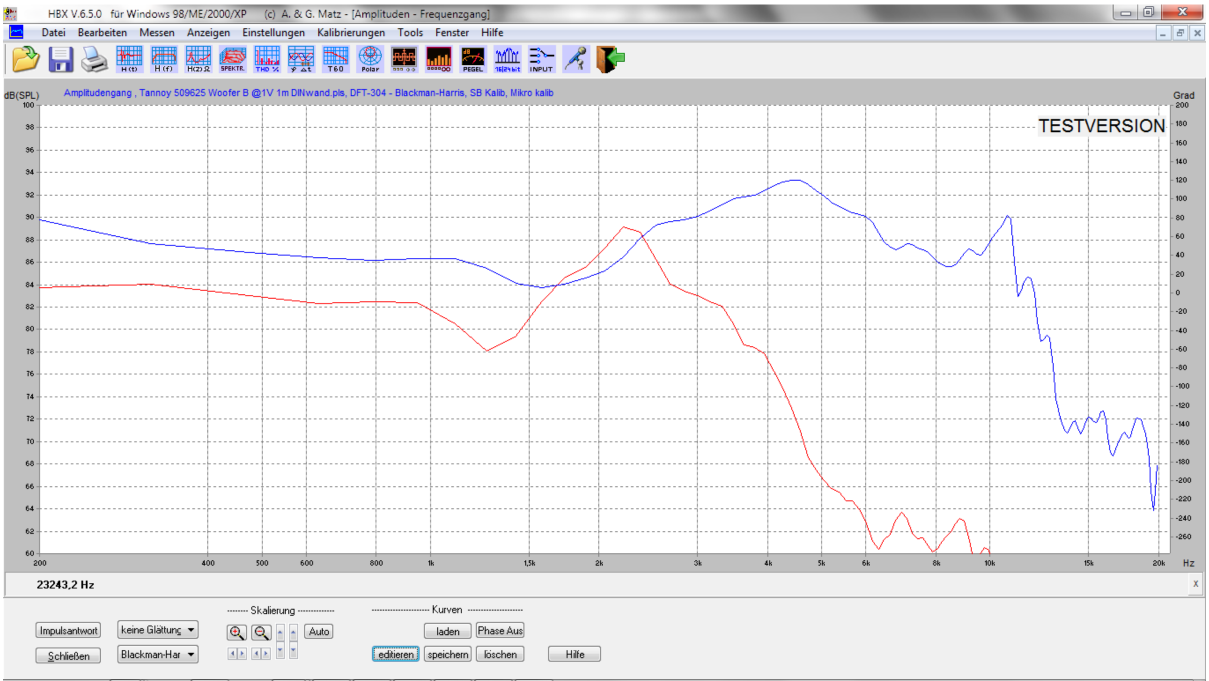
- Measurement of the frequency & phase response of the sound pressure
- Simulation of the speaker
- Designing of the speaker
- Tuning of the active filter
- Measurement of difference between passive and active filter

Measurement of the frequency & phase response of the sound pressure

I used the HobboyBox HBX V.6.5 measuring software with a iSEMcon EMM-8 calibrated microphone on my DELL Studio laptop with good internal soundcard (24 bits, 48000kHz, THD<-70dB). The measurements were done on a self made DIN 45575 standard baffle (165 x 135, speaker at 65 & 55 cm) on which I placed the speaker in a 100 liter closed and moderate damped box.

Figure 1 Measuring a Tannoy HPD 315 on a DIN baffle with calibrated microphone using MLS & time windowing

I used the standard MLS-technique of the measurement software with a 1V noise signal and a 5 msec measurement time window in order to make possible a semi-free field measurement under a low ceiling (2,6 meter) and a cramped space. The microphone was placed on axis at 1 meter measured from the baffle. The results in a diagram in HBX V.6.5.0:



The woofer shows an interesting response: there is a dip between 1000 and 2000 Hz and has a steep peak at 2200 Hz. The response is only useful till 1000Hz. The waterfall spectrum shows like this:

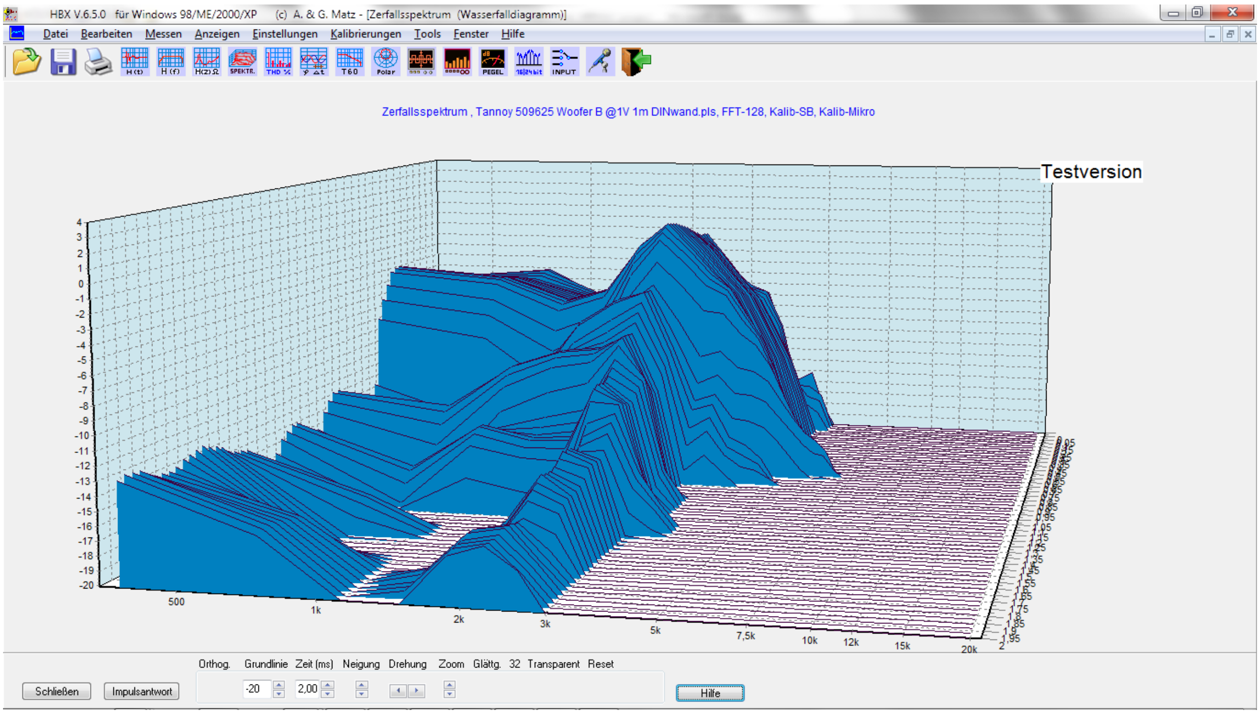
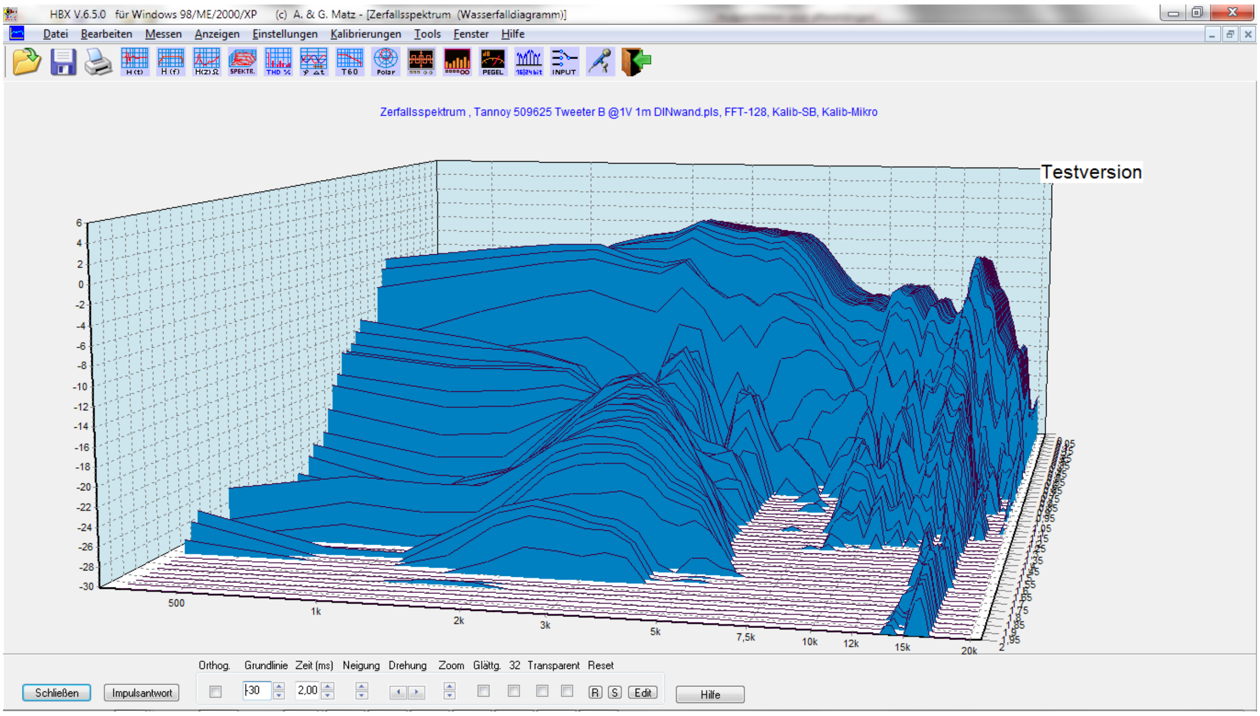


Figure 3 A waterfall spectrum of a Tannoy HPD 315 Woofer on a DIN-baffle

Note the ringing of the woofer at a frequency around 2kHz. Even more interesting is the typical horn tweeter response:

Figure 4 Amplitude (red) and phase (blue) of a HPD 315 Horn Tweeter on a DIN45575-baffle at 1 meter & 1V RMS



Figuur 5 A waterfall spectrum of a Tannoy HPD 315 Tweeter on a DIN-baffle

With HBX you can export with it measurement points to be used as a input for the simulation on the BOXSIM simulation program from Visaton. The data is set in steps of 150 Hz is:

Frequency Hz	Amplitude Woofer dB	Absolute Phase° woofer	Amplitude Tweeter dB	Absolute Phase°
150	84,0317	89,0833	56,5833	99,5905
300	85,0143	51,7021	69,6169	-46,0829
450	83,7141	44,821	79,8983	-83,0904
600	82,6962	39,1852	85,5849	-85,077
750	82,5677	35,2524	87,7585	-81,2497
900	82,591	35,5834	89,8359	-79,5615
1050	81,3322	36,9232	91,7805	-77,0611
1200	78,6538	29,4548	93,4815	-73,5094
1350	78,3203	12,2942	95,208	-68,4004
1500	81,8756	1,9884	96,7101	-60,5908
1650	84,2227	4,0812	97,2044	-52,2396
1800	85,837	10,9202	97,586	-45,0317
1950	86,1785	16,729	97,4913	-38,8633
2100	88,5742	25,4718	96,9107	-36,2472
2250	89,7168	43,0225	97,0453	-37,0036
2400	88,7109	61,9113	98,317	-35,972
2550	85,7669	72,6124	99,5719	-29,9004
2700	83,9098	73,9087	99,9861	-20,7375

Frequency Hz	Amplitude Woofer dB	Absolute Phase° woofer	Amplitude Tweeter dB	Absolute Phase°
2850	83,6772	74,3308	99,4905	-12,0265
3000	83,6293	78,2233	98,1774	-7,5593
3150	83,1959	83,8544	97,3375	-8,0581
3300	82,9866	91,5064	97,4184	-9,8615
3450	81,6866	100,1659	98,2589	-8,6886
3600	79,3604	103,5801	98,6546	-3,8065
3750	78,5478	103,5123	98,1696	0,941
3900	78,4081	107,4856	97,5518	2,9738
4050	76,9164	113,3141	97,3372	3,3799
4200	75,1397	116,3832	97,4868	4,1138
4350	73,497	117,4537	97,9334	6,9148
4500	71,7648	117,1228	97,9711	11,5734
4650	69,9131	114,4115	97,6858	16,2764
4800	68,6014	110,2524	97,384	21,0257
4950	67,2475	105,6449	96,671	25,4272
5100	65,8238	98,8228	95,8736	28,5836
5250	65,3872	91,4816	95,1496	31,2656
5400	65,0991	86,1708	94,1273	33,3324
5550	64,7069	81,8588	92,9533	33,6477
5700	64,57	78,8253	91,8748	32,1066
5850	64,1134	77,3318	91,0827	29,792
6000	63,2007	75,7445	90,2017	27,0211
6150	61,4966	70,496	89,1392	22,0637
6300	60,1679	58,7908	88,746	15,2792
6450	61,2898	47,8735	89,0452	9,817
6600	62,2416	42,9421	89,3748	6,8913
6750	63,1211	41,7587	89,5371	5,7363
6900	63,511	43,3633	89,2637	4,7462
7050	63,193	45,4201	88,8589	2,4195
7200	62,2987	45,1834	88,6412	-0,9815
7350	61,5247	41,7033	88,5732	-4,7768
7500	61,4996	37,7074	88,6789	-8,7625
7650	61,422	34,9812	89,245	-11,5652
7800	61,0398	31,5345	89,8831	-11,3363
7950	61,07	26,8961	89,6327	-9,9938
8100	61,7614	23,8659	88,6199	-12,4838
8250	62,4246	24,2376	88,3717	-19,2505
8400	62,1968	24,8381	89,201	-25,9045
8550	62,4358	24,4393	90,8146	-28,2798

Frequency Hz	Amplitude Woofer dB	Absolute Phase° woofer	Amplitude Tweeter dB	Absolute Phase°
8700	62,9202	25,725	92,2415	-24,9576
8850	63,4012	29,9761	92,5775	-19,2216
9000	63,1877	36,4102	92,414	-14,4329
9150	61,9637	41,3318	91,9796	-11,3131
9300	60,3804	41,4255	91,6343	-9,2865
9450	59,6126	38,0243	90,9515	-8,8574
9600	59,8219	35,9939	90,8422	-9,3225
9750	59,9772	37,2331	90,8318	-8,1994
9900	60,0041	40,9569	90,2467	-6,7537
10050	59,7117	46,907	89,4423	-6,8963
10200	58,6952	53,3921	88,3485	-9,995
10350	57,4516	59,3571	87,7367	-16,1047
10500	55,9586	65,746	87,5072	-24,4849
10650	53,9236	73,3452	88,9309	-30,9339
10800	50,3682	80,7612	90,6001	-30,5642
10950	42,3233	70,8506	91,4012	-25,3115
11100	35,5503	24,9625	91,2003	-19,3412
11250	44,7593	-6,8303	90,2428	-16,1428
11400	46,7577	-2,1598	89,4341	-16,2344
11550	46,3594	4,0792	88,9312	-17,4402
11700	44,6822	7,5581	88,0909	-20,2849
11850	41,8909	6,4703	87,7554	-25,2415
12000	36,3406	-11,5804	88,0941	-29,4492
12150	35,2147	-47,6217	88,6642	-30,5283
12300	42,3031	-65,4388	88,4854	-29,911
12450	45,562	-52,6158	87,5989	-31,8224
12600	43,5266	-34,0435	86,8543	-38,4268
12750	36,488	-33,0963	87,5667	-45,6444
12900	27,2124	-75,7796	88,6492	-48,7717
13050	35,9228	-113,798	89,1827	-49,1183
13200	36,2942	-121,506	89,106	-50,2542
13350	35,1647	-140,452	88,9721	-54,372
13500	37,4901	-164,525	89,504	-60,7211
13650	42,0076	-178,031	91,2849	-64,9382
13800	45,7887	-178,197	93,4239	-63,1184
13950	47,4365	-172,794	94,9317	-56,2123
14100	47,5004	-170,445	95,8609	-46,2272
14250	47,4554	-174,358	95,5687	-36,1687
14400	48,7308	-180,491	94,8037	-28,8348

Frequency Hz	Amplitude Woofer dB	Absolute Phase° woofer	Amplitude Tweeter dB	Absolute Phase°
14550	51,0721	-181,792	93,6115	-25,4296
14700	52,856	-176,412	92,9931	-25,0477
14850	53,1332	-169,545	92,3822	-26,9891
15000	53,1251	-164,175	93,5463	-26,3774
15150	52,4328	-160,746	93,4416	-22,0638
15300	51,4511	-161,182	93,3942	-18,2872
15450	50,7956	-165,469	93,5688	-12,5537
15600	51,486	-168,576	92,5868	-6,8813
15750	51,7379	-167,479	91,7708	-3,6601
15900	51,0207	-165,945	91,3651	0,6074
16050	49,7099	-167,005	89,6558	3,6587
16200	47,4755	-174,687	88,3303	2,5826
16350	46,0291	-191,345	87,8146	1,8458
16500	47,1259	-209,876	86,6559	2,0391
16650	49,5191	-222,521	84,9422	-1,1274
16800	52,5591	-226,231	83,881	-7,9472
16950	54,6811	-221,946	83,5684	-15,3615
17100	55,3162	-215,55	83,9219	-20,7377
17250	55,3876	-210,854	84,5737	-21,812
17400	55,361	-207,48	84,427	-19,6742
17550	55,1549	-204,758	83,4042	-17,9311
17700	54,6821	-203,543	80,6201	-25,5337
17850	55,0625	-200,794	81,6984	-37,2335
18000	54,3642	-195,629	83,594	-39,0459
18150	52,9153	-192,186	83,9358	-35,0158
18300	51,1073	-191,356	83,9898	-29,3323
18450	48,3348	-195,733	82,4636	-25,2588
18600	44,9677	-212,813	80,6198	-28,3458
18750	46,9287	-229,999	80,8457	-33,2493
18900	48,5063	-232,711	82,4939	-27,2686
19050	47,0648	-233,546	79,7701	-18,0867
19200	45,7229	-240,601	75,1173	-26,9577
19350	45,0465	-249,758	77,428	-35,4932
19500	43,7318	-263,022	75,558	-35,7624
19650	45,5384	-274,673	74,2924	-44,4212
19800	48,0363	-271,381	78,4803	-38,4685
19950	47,3961	-256,198	77,0377	-11,4954

Simulation of the speaker

In order to use the simulator properly, the simulation with Boxsim had to be calibrated first: the simulation of the speaker build into the DIN-baffle had to give the same result as the measurement. The calibration failed because of a few reasons (my informed guess): the actual passive filter I used was not the same as the simplified filter I build into the simulator, and/or the acoustical centers of the speaker where not right (I did not measure them). I experimented with different distances between the acoustical centers and I filter I found on Hilberinks site, but I did not succeed in simulating the actual passive filtered speaker response.

So I took another route: I wanted to know the simulated effect of the enclosure on the response and than choose the one with the smallest effect. Hence I loaded Boxsim with measuring points of an ideal speaker woofer and tweeter with the bandwidth from 50 to 12000Hz. I filtered them actively at 1000 Hz and got the best results with baffle of 80 x 50, the speaker placed 20 from the top and the baffle ends tapered.

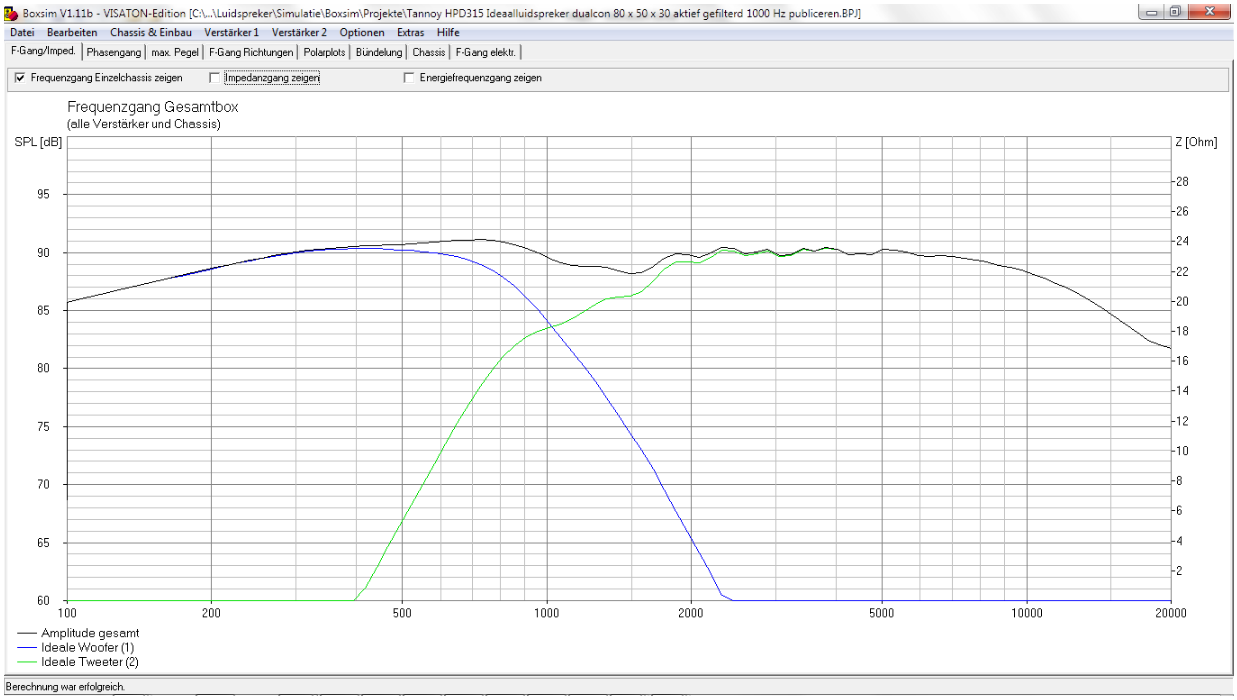
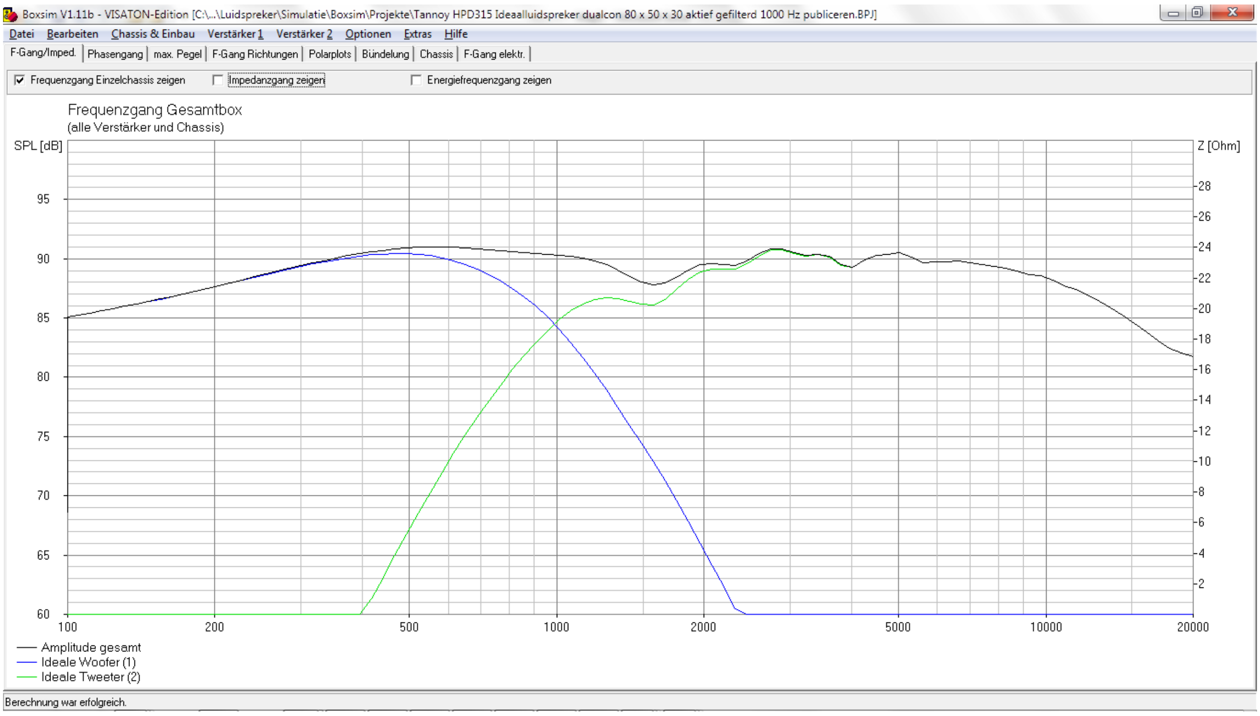


Figure 6 Effect of the cabinet dimensions on a ideal loudspeaker response at the optimal box dimensions of about 80 x 50 cm

As you can see, the box dimensions and the active filter result into a lift between 500 and 1000 Hz, a dip between 1000 and 2000Hz and a ripple beyond 2000Hz. The dip is especially nasty since the speaker itself has an dip in this region, as you will see below. I will discuss this problem later on when I show the active filter tuning. In the end I chose a cabinet of 63 x 41 x 32, for various reasons a explain in a minute, that gives the following simulated response of figure if equipped with ideal speakers:



Figuur 7 Effect of the cabinet dimensions on a ideal loudspeaker response with baffle dimensions of 63 x 41 cm

Shaping the box

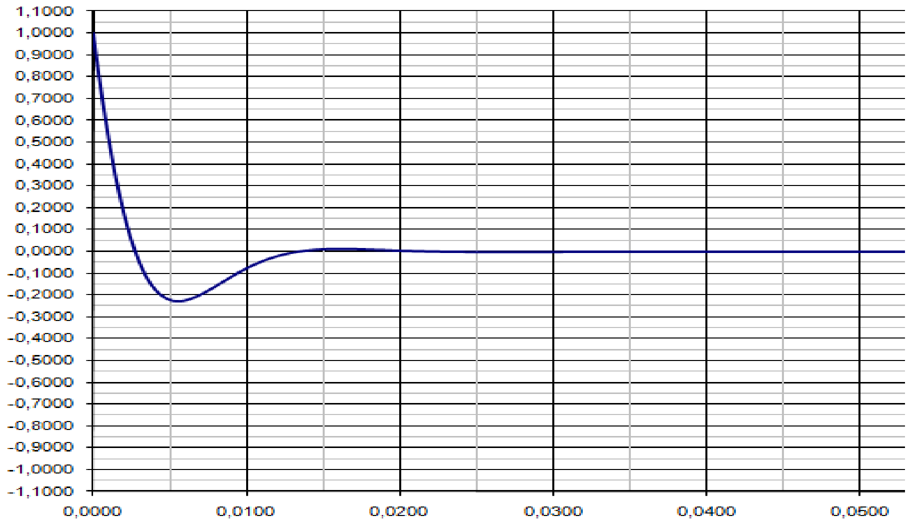
In choosing the exact dimensions I took in to account the following:

- The tweeter should be at ear height, that is 90 cm, so a small box on a standard or a big stand alone box should work
- The cut off frequency of the speaker should be 40 Hz or higher, since the fundamental frequency of my listening room is 40 Hz. Choosing a lower frequency is useless. If I want a speaker with 'slam' I don't need deeper basses, but a optimal timing between woofer and tweeter, so to produce shock waves in my room.

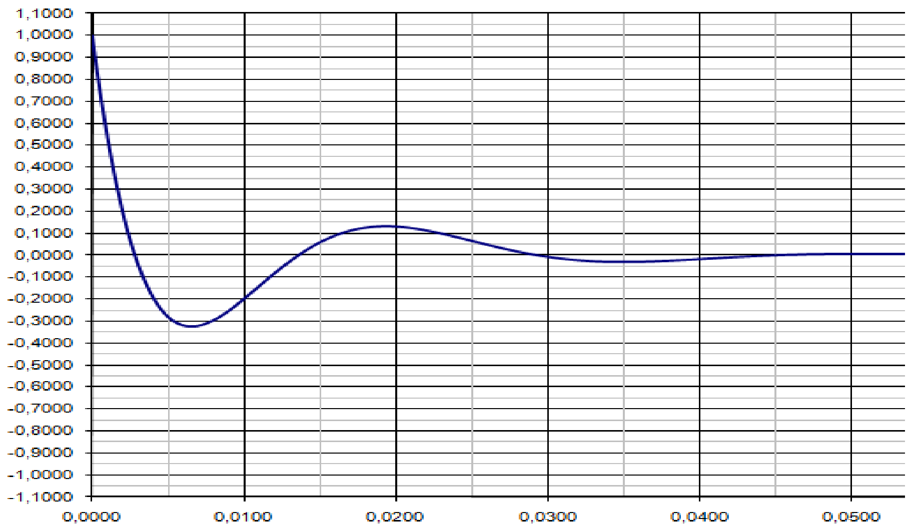
The next two design criteria need some extra explanation:

A fast or a deep bass tuning?

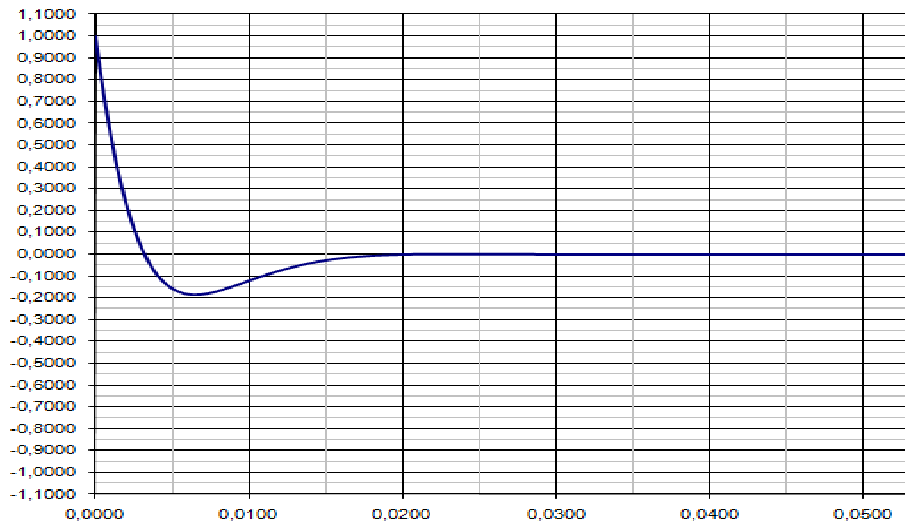
Normally a Tannoy is build within a bass reflex box. This gives more bass in the frequency domain, but is costs speed in the time domain, since a bass reflex box is in principle a box with a low frequency gong build into it. A closed box design of 40 liter reacts fast (with Unified Box Model 408):



A optimal Butterworth bass reflex design of 100 liter reacts slower:



I still chose a bass reflex design of 70 liter with a cut off frequency of 40 Hz. If I wanted it to sound faster I could simply fill the ports, giving the following approximated 70 liter closed box response:



Non-resonant internal dimensions

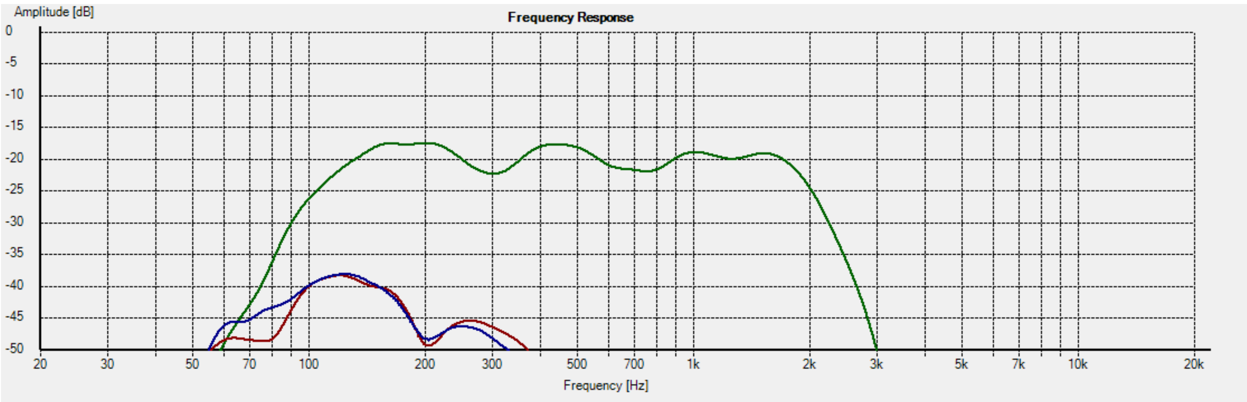
But what exact internal dimensions should the box have? There should be as little as possible standing waves inside the box. So I calculated half the length of an standing wave of all the notes of western music. The internal dimensions should be somewhere between these lengths:

Frequency	247	262	279	294	311	330	349	370	392	415	440	466	494	523	558
Half wave length	0,695	0,656	0,615	0,584	0,552	0,521	0,491	0,464	0,438	0,413	0,390	0,368	0,347	0,328	0,307
Optimal dimension	0,675	0,635	0,599	0,568	0,536	0,506	0,478	0,451	0,425	0,402	0,379	0,358	0,338	0,318	0,300

The internal dimensions chosen are 63,5 x 38 x 33,8 cm. At these dimensions also checked the higher order resonances of the longer dimension at frequencies other than the western tuning, would not coincide with the resonances in a shorter dimension. In the end the cabinet panels appeared remarkably silent.

Chipboard or MDF?

Normally you would take thick MDF to build a box. This would get very heavy, too heavy. A better choice is a lighter but stronger cabinet using a internal board reinforcement, making the front baffle acoustically practically dead. I choose 16 mm chipboard panels for a calculated weight of 18kg (with speaker) and one internal board reinforce just below the speaker, damping of every bending waves coming from it and . Chipboard? Yes, chipboard is better. I tested the vibration sound of both a chipboard and a MDF 12 mm 80 x 50 cm panel in an closed box with a small speaker inside(green line). The result, chipboard (red) won:



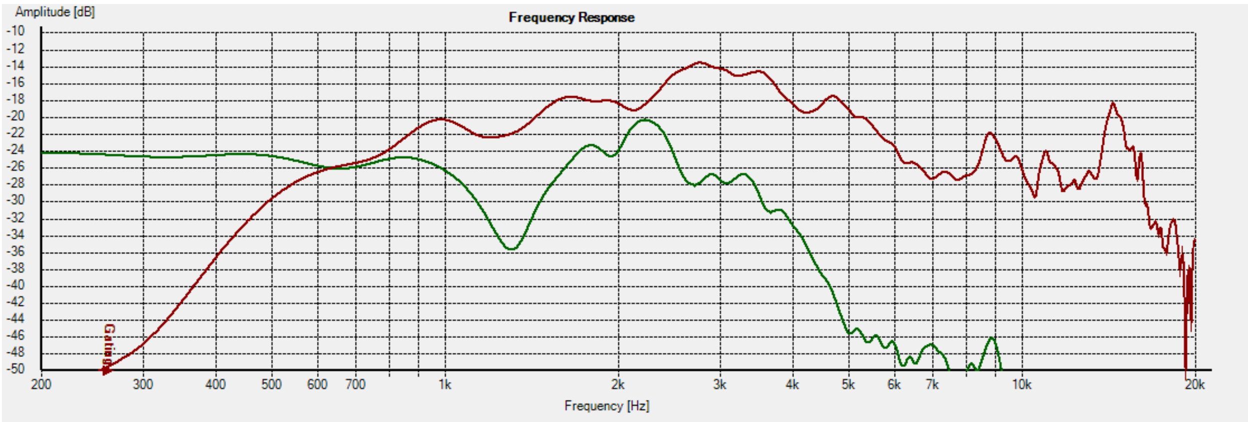
Figuur 8 Sound pressure 50 cm from 12 mm MDF (blue) and chipborard (red) panel

Tuning the active filter

After assembling the cabinet with the speaker and placing it in a measurement setting, I started tuning the active filter via the USB link to a miniDSP active filter. Using a interfacing and communication software the ‘TWO WAY CROSSOVER PEQ’ can be tuned as required:

For this tuning some knowledge of filtering techniques is required, since filters interact on mysterious ways if you haven't got the knowledge. This time I use HOLMImpuls software to measure the results.

The problem

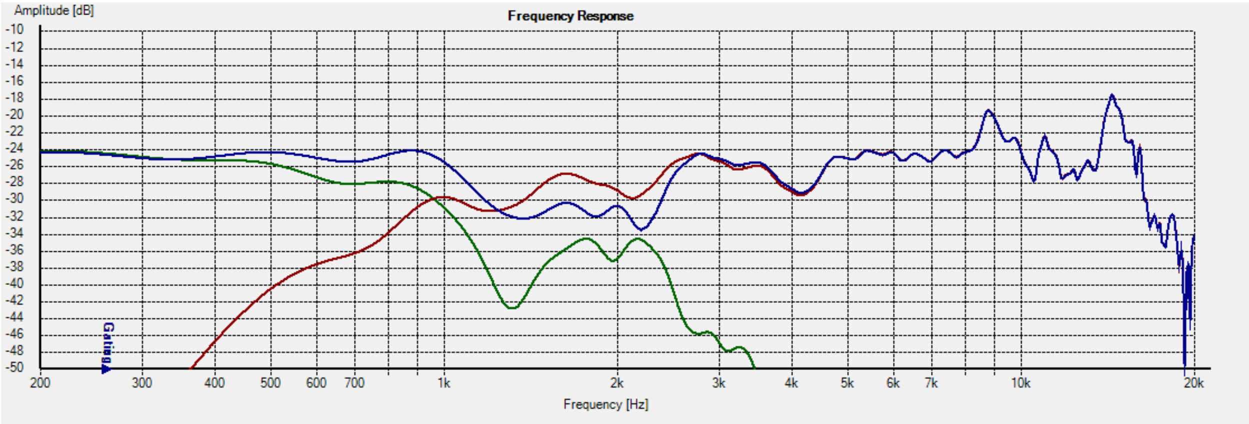


This response is not easily to be filtered. The woofer rolls of at 1000Hz, the cut off frequency set by Tannoy's passive filter, but after 1300 goes up and down again with a peak at 2200Hz, leaving us with a gap to fill with .. sound from the tweeter. The tweeter has a typical horn response to be made flat. What to do?

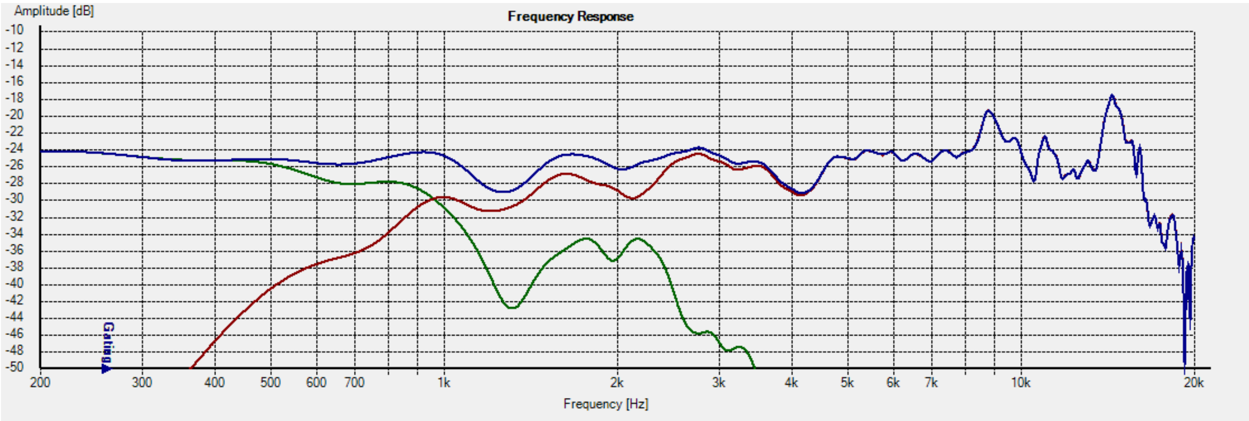
The solutions

I adopted a principle in filtering: Ockham's razor, or: less is more. Then, first the simplest part: the tweeter rolls off at low frequency even without any filtering added. So I added only a real life capacitor of 30 uF (2x15) only to protect the tweeter and giving it a 1st order high pass filter set at 500 Hz, the resonance filter of the tweeter (it has resonance frequencies at about 2000, 8000 and 14500Hz ...).

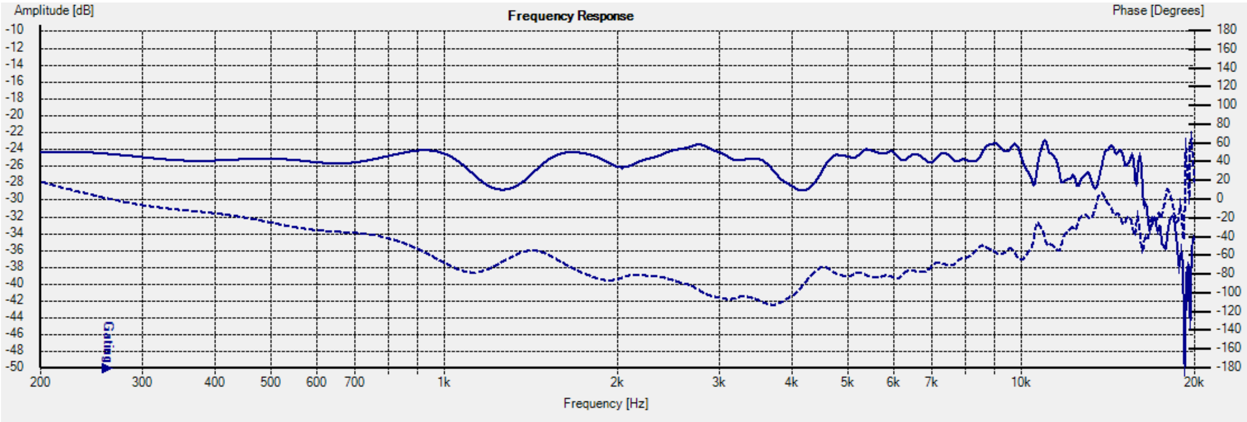
Second, I gave the woofer a second order low pass Bessel filter at 1000Hz. Bessel is a very moderate filter, resembling a 2nd order Linkwitz Riley Filter (the LW rolls off faster, too fast here). More filter options are possible, but I chose Bessel because of its moderate nature in the time domain. In the next step the tweeter response is flattened out with a step filter: -9 dB flat from 5300Hz downwards (Q=3). The result:



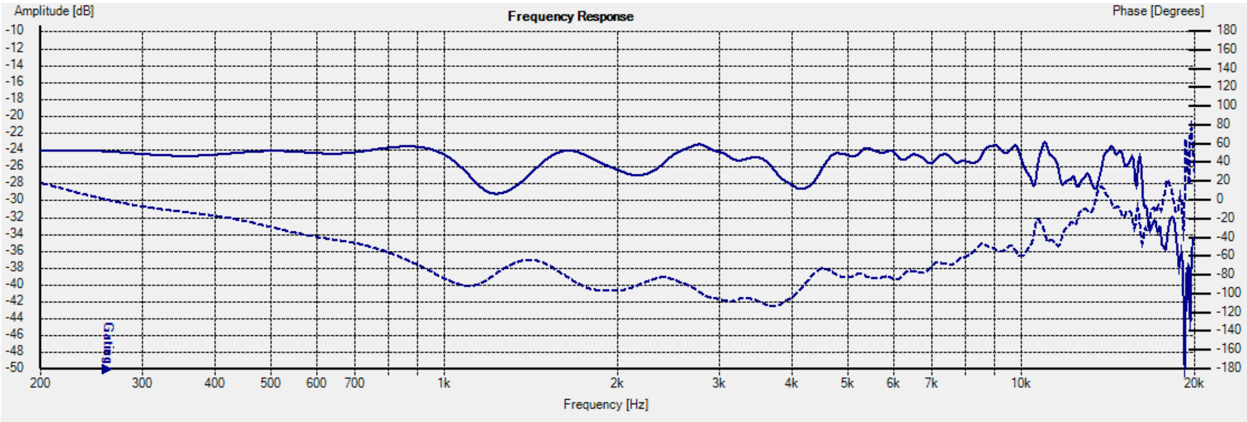
In the high frequencies there are a few resonance peaks to dealt with later, but first the deep dip between 1000 and 2600Hz. There are a lot of options, two simple ones: lifting this regions with the parametric EQualiser or fiddling with a forgotten parameter: time delay, either of the tweeter, or the woofer. The time delay needed depends on the physical dimensions of the woofer/tweeter combination and the phase of both woofer and tweeter driven with a certain filter in the cross over region, so trial and error is the easiest way to optimize the results. Delaying the woofer (not the tweeter) between 0,2 – 0,3 msec (7 – 10 cm; depending on the type of woofer filtering used) did the trick (blue line).



Last but not least: supressing the (resonance) peaks and checking the phase (dotted line):



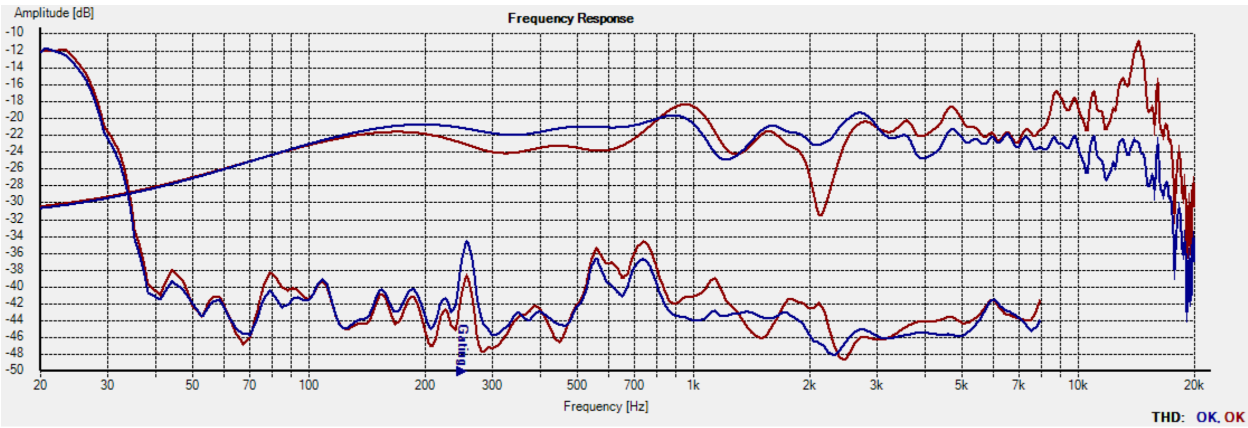
An alternative solution with 3de order Butterworth filtering looks quite similar:



The response bellows up and down between 1 and 5 kHz. I couldn't hear the difference between Bessel and Butterworth filtering, yet. A could manage to get it flat with the parameticequaliser, but I choose not to: less is more.

Is active filtering better?

I did a comparison of the original passive filter with a slithly different active filter tuning:



The top red line is the original filter, the top blue line the active filter: the active filtered is less uneven. Below a indication of the distortion of the speaker: the active filtered speaker is a bit better: approximately -46 dB (0,5%) THD between 2 and 5kHz, less than 1% above 800Hz. Not bad for a 30 year old speaker. The results could get better if my measuring conditions would have been better (the distortion measurements does not use time windowing, so panel vibrations from my room could influence the measurements).

What's up next?

After this project I would like to try and check a few things:

- Simulate the speaker using LSPcad from Ijdata, like all big speaker builders do
- Measure the psycho-acoustic differences between different filter settings
- Test the psycho-acoustic effect of a bigger baffle (50 x 80) (need a bigger house first)
- using a automatic filter optimalisation routine I would like to tune the digital filter so to get a Linkwitz-Riley response on both the woofer and tweeter measured sound pressure

Meindert Scholma, Amsterdam, 2011